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National Centre for Groundwater Management, UTS

Groundwater Knowledge and Gaps in the Queensland Murray Darling Committee Inc Management Area

Border Rivers, Moonie and Lower Balonne catchments

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Queensland Murray Darling Committee Inc.

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Executive Summary

This report covers the Border Rivers, Moonie and Lower Balonne catchments in the Queensland Murray Darling Committee, Inc., (QMDC) management area with the focus of determining priority groundwater projects. There are three major alluvial groundwater management issues in the QMDC management area. In the east the Dumaresq River is highly connected to the alluvial aquifers which are used for groundwater extraction by the irrigation sector. The groundwater model that covers these alluvial aquifers, and which was used as part of informing the water allocations between NSW and QLD, needs to be updated. There is new information in the form of longer hydrograph records, better understanding of river aquifer interactions, longer river flow records and new approaches to catchment water balance modelling that can all be integrated to give a better catchment water balance model for input into groundwater management decisions. The main issue for the cotton/irrigation industry is that over use of groundwater from the Dumaresq River alluvia may influence river flows, including water released for downstream users.

In the west of the catchment from Goondiwindi to Mungindi, the irrigation districts overlie highly saline water at reasonably shallow depth. While the river irrigation water is of very good quality the shallow underlying aquifers are highly saline (approaching sea water salinity levels) and sometimes acid. Very little is known about how the deep drainage under the irrigated crops is affecting the shallow water table. Areas upslope of the alluvia, where red soils are used for dryland cropping, are also a potential source of groundwater discharge into the alluvia. There is considerable potential for the mobilisation of the saline groundwater if the deep drainage is not controlled.

In the far west of the QMDC management area the Lower Balonne region has been extensively investigated in recent years by the Cooperative Research Centre for Landscape Environments and Mineral Exploration (CRC LEME) and the Queensland Department of Natural Resources and Water (NRW). These projects have recorded extensive hydrogeological, geophysical and water quality data which now needs to be coordinated in an interactive 3D geological property model (for example GoCAD or EarthVision). Coordinating these data in a 3D environment would allow for improved understanding of the hydrogeology and the interconnection between surface and ground water. An enhanced understanding of the water dynamics of the area would yield insights that would help with the management of the water resources and environment of the region.

Given the recent extensive work in the Lower Balonne, it is suggested that the focus should shift to other regions and similar scales of investigation to that done in the Lower Balonne be undertaken in order to generate similar quality baseline hydrogeological data.

Listed below are recommended projects that will advance our scientific understanding of the Dumaresq River catchment water balance.

- Update the Dumaresq River catchment water balance model.

  Current groundwater models which are used as part of the sustainable groundwater yield estimates are created using MODFLOW (MODular Groundwater Flow Model). This software does not model surface water inputs comprehensively. IQQM (Integrated Quantity Quality Models), which is used for surface water estimates, does not model groundwater contributions sufficiently. The two modelling approaches also use different time scales and have different grid/node resolution over the regions of interest, thus the outputs from one package do not link seamlessly with the other.

  Given the highly coupled nature of the river and aquifers in the Dumaresq River catchment it is recommended that one of the newer fully coupled surface and ground water modelling environments be applied in this region. Queensland NRW has already applied a more comprehensive coupled surface and ground water modelling approach using MODHMS in coastal regions. This style of modelling needs to be applied in the Dumaresq River catchment.

- Compare cumulative rainfall departure data with NRW monitoring bore hydrographs.

  A comprehensive statistical analysis is needed comparing rainfall trends to groundwater behaviour. This is needed to isolate natural fluctuation from anthropogenic influences.

- Record deep drainage at the shallow water table using data loggers.

  Better estimates of deep drainage (both under irrigation and in native vegetation areas) are needed and deep drainage needs to be incorporated into regional surface and ground water models. We need to know how much water reaches the shallow groundwater systems and how much then reaches the deeper aquifers that are used for irrigation.

- Incorporate the recent Bureau of Rural Science (BRS) Border Rivers surface and ground water interaction survey results into the regional water balance models.

  The results of the BRS river aquifer interconnected investigation being undertaken by Baskaran, Ransley and Brodie will shortly be published. This research aims to improve our understanding of the interaction between rivers and the underlying aquifers and to quantify the success of various methods for monitoring the coupling between rivers and aquifers. Once released, this information needs to be integrated into future catchment management research.

- Measure the water chemistry, both major ions and isotopes, to explore the interaction between the Great Artesian Basin (GAB) and alluvial aquifers.

  Additional monitoring wells are needed near the Marburg Sandstone to help improve the understanding of the alluvial aquifer interaction with the GAB. This would improve the water balance modelling in this region as the link with the GAB had limited control in the present groundwater model.

- Incorporate farmer recorded rainfall data into water balance models.

  The rainfall gauging network used by the Bureau of Meteorology for recording rain is too coarse, resulting in substantial uncertainty in the rainfall contribution to catchment scale water balance modelling. Incorporating reliable farmer recorded rainfall data into regional water balance models would reduce this uncertainty.

For the Border Rivers-Moonie catchments, in order to better model the impacts of deep drainage under irrigated crops and the potential for the mobilisation of shallow saline groundwater the following suggestions are given:

- Increase the number of groundwater monitoring wells.

  There are too few monitoring wells to accurately understand where and how the groundwater systems are recharged and where the water is migrating. There needs to be a series of monitoring wells placed in transects near the Barwon and Weir Rivers. Transects of monitoring wells are also needed near irrigated crops (ideally some monitoring boreholes should be placed in the centre of irrigated fields). Data loggers which record daily water level and quality information are needed in these monitoring wells.

- Measure the major ion chemistry and relevant isotopes in all monitoring wells.

  The chemistry is needed to understand the migration and interaction of the groundwater with other water systems. It is also required to quantify the scale of any impacts if the saline water is mobilised.

- Undertake land geophysical surveying using a combination of frequency domain EM38, EM31 and EM34 or time domain TEM surveys.

  The geophysical surveys are important because the area to be investigated is vast, so it is difficult to know how representative the borehole locations are with respect to soil conditions and water quality. Calibrated geophysical surveys would allow the groundwater conditions to be monitored between the boreholes.

- Incorporate farmer recorded rainfall data into water balance models.

  The rainfall gauging network used by the Bureau of Meteorology for recording rain is too coarse, resulting in substantial uncertainty in the rainfall contribution in catchment scale water balance modelling, and especially deep drainage recharge over the wider catchment area. Incorporating reliable farmer recorded rainfall data into regional water balance models would reduce this uncertainty.

- Compare cumulative rainfall departure data with NRW monitoring bore hydrographs.

  A comprehensive statistical analysis is needed comparing rainfall trends to groundwater behaviour. From this analysis index maps can be developed to determine where aquifer behaviour is in or out of sync with respect to prevailing climatic conditions.

- Couple the groundwater chemistry to the groundwater flow modelling.

  To better understand the migration of zones of saline groundwater towards the fresh water zones the water chemistry needs to be coupled to the groundwater flow models.

- Improved surveying of the land surface, stream incision and the monitoring bores is needed.

  In order to model the influence of the groundwater on the land surface and the streams, the landscape, rivers, weirs and boreholes all need to be accurately surveyed. The lack of high resolution survey data was a major limitation encountered by Whiting (2007) when trying to build a MODFLOW model of the region.

- Incorporate the recent BRS Border Rivers surface and ground water interaction survey results into the regional water balance models.

  In the west of the catchment the Barwon/MacIntrye River is largely disconnected from the aquifer but there are some intervals that are connected. Understanding where the groundwater is discharging into the rivers is critical for understanding if the mobilisation of the saline groundwater will influence the river water quality to any significant extent.

- Explore the reuse of deep drainage water.

  In areas where the shallow groundwater is rising due to deep drainage, the re-use of the water could be explored. This assumes the shallow water is not too saline and the quantities are economically viable. This is a low priority.

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1. Introduction

This scoping study reviews our current knowledge of groundwater quality and quantity in the Border Rivers, Moonie and Lower Balonne catchments that form part of the Queensland Murray Darling Committee management area (QMDC). The focus of the report is on the alluvial aquifers and their interactions with rivers. The Great Artesian Basin (GAB) bores are not discussed as GAB water is generally not suitable for irrigated crops, and all GAB bores are covered by research associated with the GAB bore capping program. The report is also focused on the irrigation districts surrounding the Dumaresq River, where alluvial groundwater is used, and in the flood plain between Goondiwindi, Talwood and south west to Mungindi, where river water is used.

No high priority concerns were found in the literature for the Moonie River catchment, but if surface water irrigation is developed in the region the effect of deep drainage on the shallow saline aquifers will need to be monitored.

Limited discussion is given on the Lower Balonne because of the recent extensive work in that region by the Cooperative Research Centre for Landscape Environments and Mineral Exploration (CRC LEME) and the Queensland Department of Natural Resources and Water (NRW), although suggestions for further work will be presented in Section 6.

There have been five recent investigations in the QMDC area that are highly relevant to this review of groundwater conditions: Please et al (2000), Skelt et al. (2004), Tolmie and Silburn (2003), Biggs et al. (2005) and Power et al. (2005). **In particular the report by Biggs et al. (2005) covers all the background geology, hydrogeology and water chemistry and that report must be read in conjunction with this scoping study.**

The biggest problem confronting understanding the science behind the water management issues in the QMDC area is the lack of data. There are too few boreholes (with monitoring bores placed tens to hundreds of kilometres apart), a lack of survey details, no bores with data loggers monitoring recharge at the shallow water table, too few river flow gauging stations (also spaced tens to hundreds of kilometres apart) and too few rainfall gauging stations.

The review of the literature revealed two priority areas that require further research. In the east of the QMDC area the Dumaresq River groundwater MODFLOW model needs updating, or upgrading to a coupled river aquifer water balance modelling environment like MODHMS or GSFLOW. In the west (Goondiwindi to Mungindi) more data are needed to understand the potential impacts of irrigation deep drainage on mobilising the shallow saline groundwater and the potential for salinisation of agricultural lands and deterioration of river water quality in the Weir and Barwon rivers.

2. The Implications of Past Climatic Rainfall Trends

Rainfall at the Texas Post Office has been collected continuously since 1887. It is clear from the records that the latter half of last century was wetter than average. The data also indicate that dry runs of below average rainfall can last 30 years or more. The wet and dry runs become evident by graphing the data in a Cumulative Rainfall Departure graph (CRD). CRD graphs are also called residual mass graphs. To generate a CRD graph:

1. Subtract the average rainfall from the yearly total to give a residual (the average is determined from complete rainfall record range)
2. Keep a running tally of the residuals.

The cumulative rainfall departure graph for the Texas Post Office is shown in Figure 1. From 1910 through 1946 there was a run of below average rainfall. This pattern of dry runs in the first half of last century and wets runs in the later half of last century is consistent throughout the QLD and NSW portions of the Murray Darling Basin. If the irrigation industry were to be faced with such a trend again there would be significant pressure on water use efficiency and financial implications for all irrigation districts.

It should be possible to link the trends displayed in cumulative rainfall departure graphs to other climatic variables (for example Pacific Ocean oscillation index data), so that a long range forecasting tool could be established. These trends could also be linked to aquifer response. This would allow water management authorities and irrigators to assess future risks.

In areas of no pumping, or in balance pumping, there is a strong link between the cumulative rainfall departure and groundwater levels in the shallow aquifers. In areas of excess pumping, or excessive deep drainage, there is no correlation. These trends are shown in Figure 2.

The systematic analysis of statistics of the hydrographs has not been undertaken throughout the QMDC area. Via a statistical analysis of the borehole hydrographs it should be possible to generate index maps of where groundwater extractions are in balance with climatic trends and where extractions are out of balance with climatic trends.

The potential for water stress to occur in the QMDC area supports the need to upgrade the Dumaresq River groundwater MODFLOW model which will be discussed below. This also has implications for the salinity issues in the west of the QMDC because during prolonged runs of below average rainfall there will be less flooding and flushing of salts in the vicinity of the rivers.

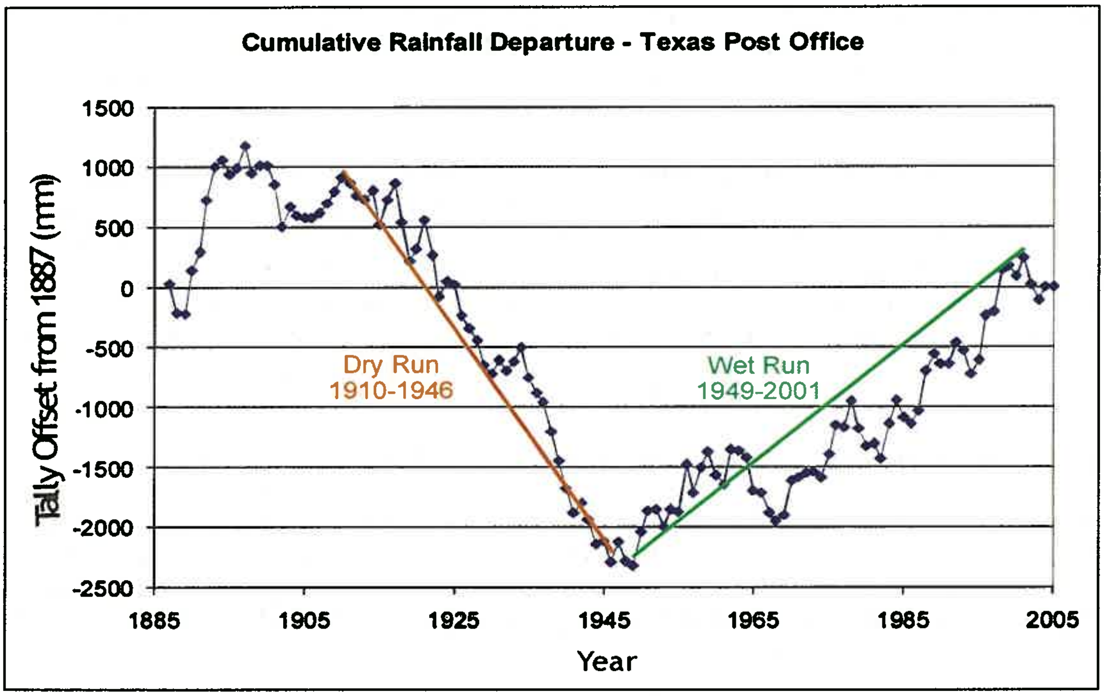

Figure 1. Cumulative rainfall departure at the Texas post office, showing that the first half of last century was much drier than the second half.

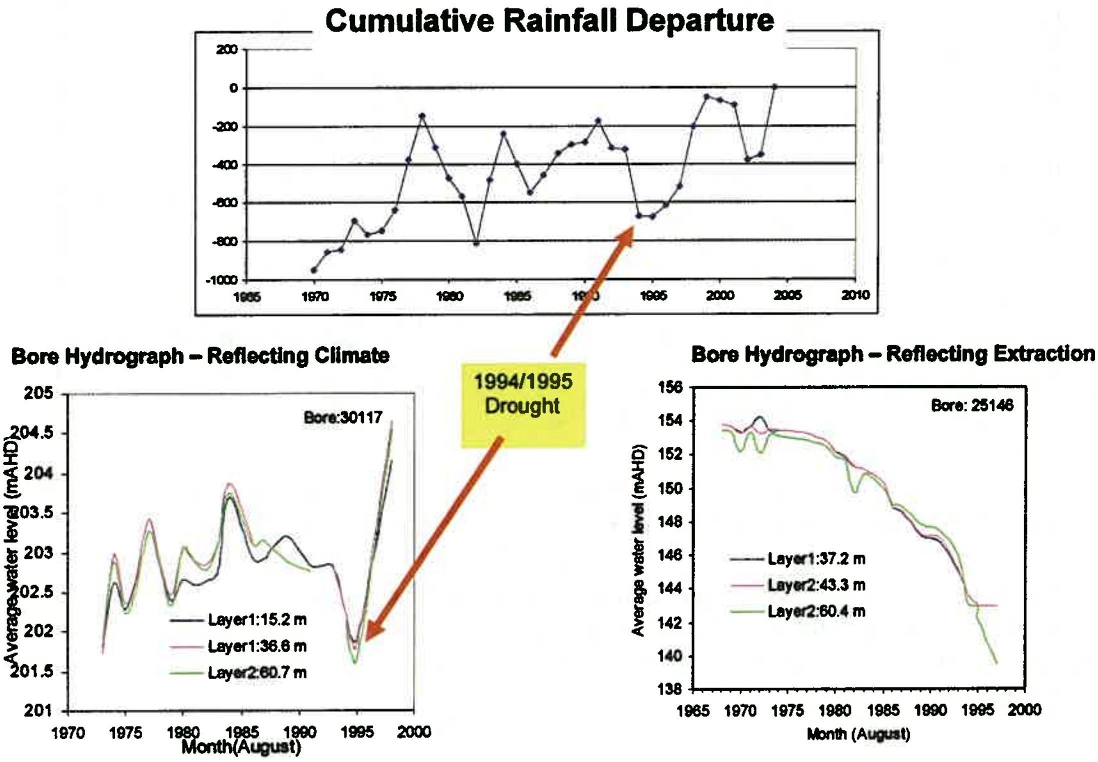

Figure 2. Representative groundwater monitoring hydrographs in the Namoi catchment compared to cumulative rainfall departure (CRD). The hydrograph on the left is in balance with the CRD curve, while the hydrograph on the right shows excess extraction.

3. Border River and Moonie

Irrigation Deep Drainage Mobilisation of Shallow Saline Groundwater

3.1. Information Supporting the Concerns

West of Goondiwindi, in the flood plains associated with the Macintyre/Barwon and Weir rivers irrigation agriculture production has expanded rapidly over the last 20 years. Although the river water that is used for irrigation is very fresh (200 µS/cm to 500 µS/cm) the underlying shallow groundwater is highly saline with salinity levels approaching sea water (Biggs et al., 2005).

3.1.1. Geological setting

The lower Weir River and lower Macintyre River alluvia both sit on top of Griman Creek Formation, Cretaceous fine-grained sandstones which occur west of the Goondiwindi fault and outcrop to the north of the alluvia. The Griman Creek Formation tends to be deeply weathered, forming the red soils typically found north of the Weir River. The alluvia generally are made up of clay overlying sand. Figure 3 gives a simplified cross-section through the area. However, it is not known whether the sand layers are spatially continuous.

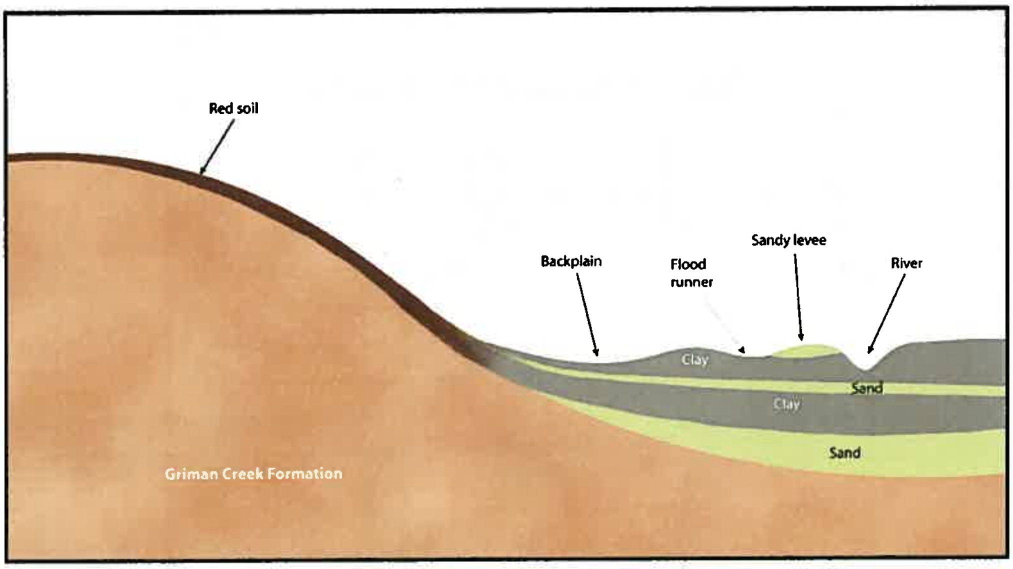

Figure 3. Conceptual cross section of the western Macintyre alluvia (A Biggs, NRW, pers. comm.)

The red soils may have low water holding capacities and are potentially prone to a high rate of deep drainage under dryland annual-fallow cropping. If this is the case, an extra layer of risk is added to the situation in the alluvia, as groundwater from the red soils/Griman Creek would move down slope.

3.1.2. Groundwater

Depth to basement is typically 20-30 m in the east of the area and 10-20 m in the west. This is reasonably shallow compared with, for instance, the Lower Balonne (Chamberlain and Wilkinson, 2004). The depth to the Griman Creek formation is progressively deeper to the south.

An indication of the extent of the saline groundwater is shown in Figure 4. The majority of bores in the western half of the QMDC area have water conductivity readings greater than 5000 µS/cm, with many greater than 30,000 µS/cm. The shallow water table is only 10 metres below the ground surface (Whiting, 2007), and the water table has risen 0.5 to 2m meters over the last 6 years in the few monitoring bores located near irrigation (Biggs et al., 2005; Whiting, 2007). West of Goondiwindi there are fewer than 20 monitoring bores surrounding the Macintyre/Barwon and Weir river available to investigate groundwater quality. Despite the limited monitoring there is a consistent pattern of highly saline shallow groundwater. New monitoring wells are planned (Mark Silburn, personal communication), and this report supports the necessity to expand the monitoring network.

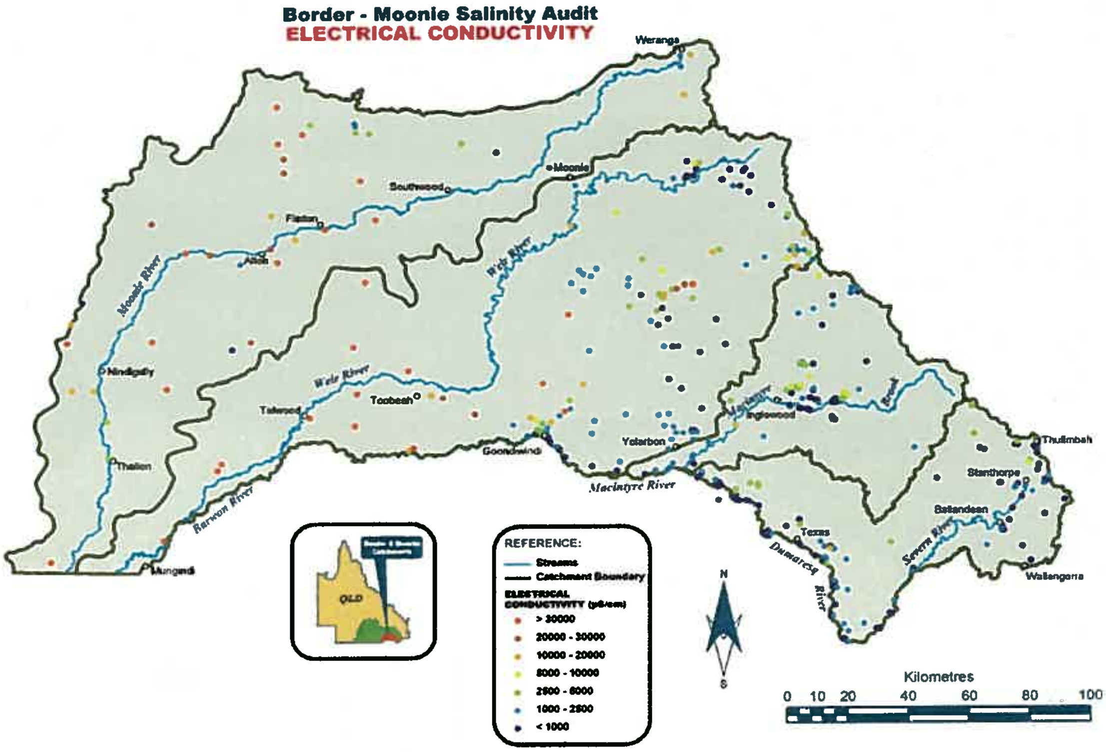

Figure 4. Groundwater salinity (measured via electrical conductivity) in the QMDC management area (from Biggs et al., 2005).

3.1.3. Land use and deep drainage

The extent of irrigation agriculture in the alluvial plain of the QMDC area is shown in Figure 5. Because irrigation agriculture covers such a large area, there is significant potential for impacts on the water balance and large changes in the water movement.

There is very little hard data on deep drainage (refer Tolmie and Silburn, 2004; McGarry et al. 2005) so it is critical that in the new and existing monitoring wells data loggers be installed to monitor the water level and water quality on a daily basis. McGarry monitors deep drainage at one site in the area, in Queensland, using drainage lysimeters. Results from the current research indicate that approximately 10% of the irrigation drains beneath the root zone. A quick calculation for the area of irrigated cotton shows that this is a large volume of water on a regional scale. Cotton Australia (2005) report that 41000 hectares of cotton were grown in the Macintyre region and 22000 hectares of cotton in the Mungindi district. If each hectare of cotton was irrigated using 7 ML/hectare and 10% of this water went to deep drainage then 44100 ML of water is heading down towards the shallow aquifers. We do not have a good understanding of how much of this water reaches the shallow water table, how much moves laterally to shallow drainage areas, or heads towards the rivers.

Deep drainage in the red soils to the north of the Weir River, and its impact on groundwater, also needs to be considered.

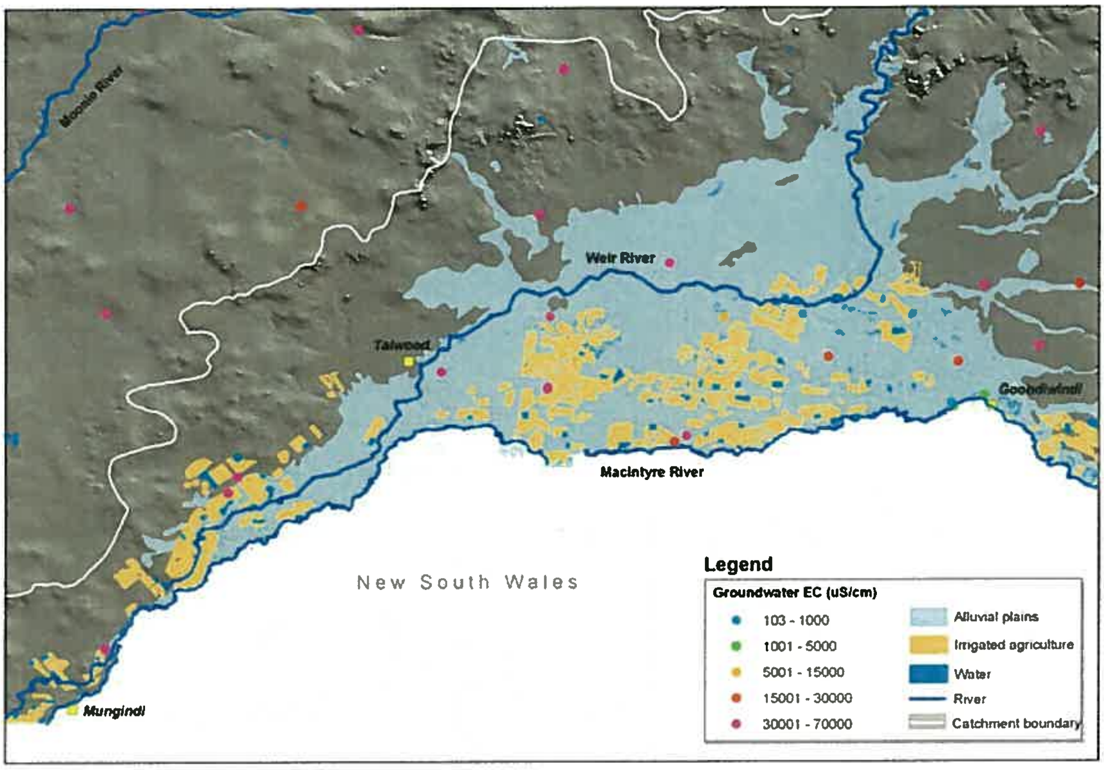

Figure 5. Map showing the extent of irrigation in the alluvial plains adjacent to the Barwon/Macintyre and Weir rivers in the QMDC management area (from Biggs et al., 2005).

3.1.4. Groundwater modelling

In order to better understand the problem, Whiting (2007) built a MODFLOW groundwater model to estimate the influence of irrigation deep drainage on the groundwater levels and whether this deep drainage water would mobilise the saline groundwater.

When gathering the necessary data to build the MODFLOW model the extent of the gaps in the current hydrogeological data sets became apparent. This made it extremely difficult to build an accurate model (Whiting, 2007). However, this exercise was valuable because it highlighted the data gaps and has resulted in a number of suggestions for further monitoring and research. Presented in the next sections are the recommendations by Whiting (2007).

Results from the MODFLOW modelling indicated near surface groundwater mounding and surface groundwater emergence occurred in areas with a combination of a) crop irrigation and b) shallow depth from surface to starting groundwater heads. These areas were generally in the south to southwestern part of the project area near the Barwon River where starting groundwater heads were shallower. Shallow groundwater mounding and breakthrough at the surface were most sensitive to hydraulic conductivity and surface recharge rate applications.

3.2. Deficiencies in the Existing Groundwater Monitoring Data

As an exercise to understand the potential scale and impacts of irrigation deep drainage on the shallow aquifers and adjacent rivers, Whiting (2007) built a conceptual MODFLOW model to investigate the link. He focused his model on the irrigation districts near Talwood. In the process of gathering data to build this model a number of deficiencies in the current data sets were discovered.

These data gaps are discussed in more detail under the following recommendations by Whiting (2007).

1) ***Field Investigations***

   Areas identified by modelling as susceptible to shallow groundwater mounding and salinisation should be targeted for field investigations, including the possibility of applying ground geophysics truthing to identify any rising saline watertable.

2) ***Topographical Elevation Data of the Region and River Reaches***

   A more detailed elevation survey should be conducted using modern techniques, perhaps modern airborne laser backscattering methods, however the survey may be limited by costs. The surveys may be conducted in areas identified as high risk for potential saline groundwater outbreaks. A detailed survey (0.1m or less accuracy) of stage elevations along the reach of major rivers, including Callandoon Creek, would assist in identifying groundwater levels relative to surface flow in the rivers and potential groundwater emergence areas at surface.

3) ***Interaction of Major Rivers with the Groundwater System***

   There is a requirement for alluvial groundwater monitoring bores to be located adjacent to the river at strategic locations to assess this interaction. The stage elevation of the river adjacent to monitoring bores would need to be surveyed.

4) ***Groundwater Monitoring Information***

   More monitoring bores should be installed to reduce spatial coarseness of data.

   Several lines of bores should be installed in an approximately north-south direction across the floodplain from Queensland into NSW. The line of bores should dissect the Weir and Macintyre Rivers. Infill monitoring bores may be installed along lines between current bores in QLD and NSW (example infill bores along the Bungunya Line, and possibly extend the line into NSW). The stratigraphic information would be used to improve characterisation of geology and hydrogeological units.

   Along the lines of bores there should be several monitoring bores installed in the Griman Creek Formation adjacent to alluvial monitoring bores (nested monitoring stations) to compare hydraulic heads and salinities and direction of groundwater leakage between the units. The nested monitoring stations should be located in salinisation risk areas near irrigated areas and streams to assess their hydraulic relationship.

   Several strategically located bores should be fitted with automatic water level loggers for monitoring high frequency water level fluctuations from short pulse recharge events, such as heavy storms or irrigation drainage.

   Multilevel piezometers should be installed in strategic locations where mounding is occurring or potentially may occur so as to monitor a) water salinity within stratigraphic column at several different elevation and b) groundwater levels. A deep piezometer should be located within the underlying bedrock to establish water chemistry and the hydraulic relationship with overlying alluvium.

More paired (control and irrigated) monitoring bore stations should be installed to assess groundwater mounding adjacent irrigated areas, particularly in the areas identified with significant groundwater mounding or surface outbreak in modelled scenarios.

Irrigation rates of farms adjacent to observation bores should be monitored and changes in water application noted.

5) ***Hydraulic Properties of the Alluvium Aquifer and Underlying Bedrock (Griman Creek Formation)***

Pumping tests or at least single borehole testing should be conducted in established or proposed bore sites (may include privately owned bores located in alluvium). The pumping bore will need to be of a suitable diameter to fit a 4 to 6 inch pump and be within sand/gravel beds in the alluvium to allow effective longterm pumping.

Core samples of the Griman Creek Formation should be collected for laboratory testing of hydraulic conductivity. The hydraulic conductivity values from field and lab testing and hydraulic head data within both geological units in nested monitoring bores are used to calculate leakage rate estimates between alluvium and Griman Creek Formation.

Source hydrological/geological information of alluvium bores on private land.

6) ***Lateral and Vertical Variation in Geology***

Several lines of boreholes should be drilled across the floodplain and completed as monitoring bores as discussed in the above point under "Groundwater Monitoring Information" above.

4. Dumaresq River Groundwater Model

To aid groundwater management and allocation decisions Chen (2002) built a MODFLOW model of the Dumaresq River alluvial aquifers between the Glenlyon Dam and the Peel fault offset. A comprehensive review of this model against the Murray-Darling Basin Groundwater Modelling guidelines is presented in Section 5. Figure 6 shows the approximate extent of the cotton area along the Dumaresq River, with respect to official groundwater model extents at 2002. It can be seen that the cotton area lies mostly downstream of the Dumaresq River groundwater model (#9) along the MacIntyre River. An IQQM model for the entire Border Rivers has been developed.

Due to data constraints there are a number of limitations with the model that could be improved with additional supporting information:

- the water levels in the QLD NRW and NSW DNR monitoring wells are recorded manually approximately four times per year. The calibration of the MODFLOW model would be improved if data loggers were installed throughout the monitoring network.

- Only 4 active river flow stations existed at the time of modelling. This introduced a large degree of uncertainty into the model and gave little information on where the river was gaining or losing water. Chen also used a non-standard approach to calibrate monthly river flow versus monthly rainfall. This is discussed further in Section 5. This aspect of the calibration could be improved using the larger river flow gauging data sets now available.

- Chen (2002) acknowledged that there was poor control of the GAB-alluvial interaction so the model may have overestimated the groundwater resource. A more thorough investigation is required near the Marburg Sandstone outcrop to further quantify the GAB interaction. Detailed major ion and isotope water chemistry may help with quantifying the GAB influence on the alluvial aquifers.

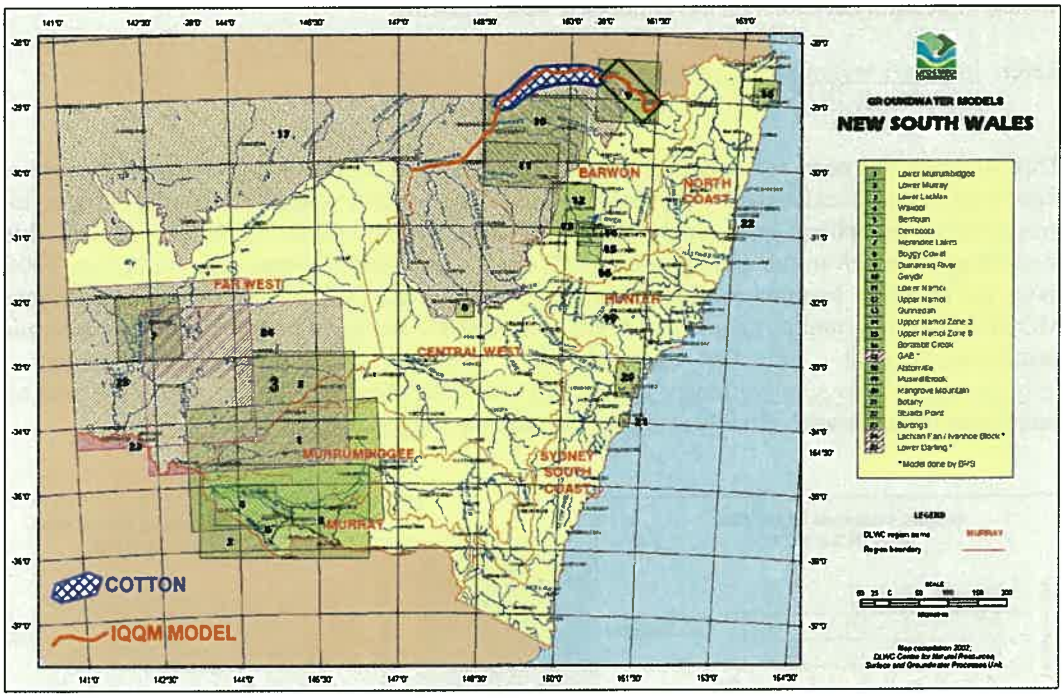

Figure 6. Extent of river and groundwater models relevant to the Border Rivers cotton area.

In Chen's model when the extractions exceeded 50% of the allocations then the river acts as a major recharge source. This is likely to happen during a drought period as is currently being experienced. At the time of Chen's modelling the long term trend in the aquifers was stable, but recent graphing of the hydrographs by Sales (2006) shows that in the shallow aquifer (depths not given in the report) the groundwater level is declining in the lower reaches of the Dumaresq River (Figure 7), and that in the deeper aquifers (again depth not given in the report) there has been 5 to 20 metres of groundwater level decline since 1985 (Figure 8). Under natural conditions the aquifer feeds the river, but under current extractions the river is recharging the aquifers. What needs to be determined is if this rate of decline is in excess of the long term sustainable yield and if the level of river recharge to the aquifer is acceptable.

Systematic graphing of all the monitoring wells in the region is required along with the statistical analysis of the climatic influences versus anthropogenic influence on the aquifer behaviour- for example, examining the correlation between rainfall cumulative departure graphs (residual mass) and groundwater response. This is an alternative approach to the groundwater MODFLOW modelling, which would also separate the causes of the decline.

Given that the groundwater levels have declined, especially in the last 5 years, this has significant implications for water releases from Glenlyon Dam. A portion of the release would be topping up losses from the aquifer and not reaching its target further down the catchment. Chen (2002) estimated that if extractions equalled 100% of allocation then the river flow would be reduced by up to 9%.

At both federal and state levels there is a move to treat the river and ground waters as connected and to base allocation decisions on the connected water systems.

Refer: http://www.connectedwater.gov.au/
http://www.nht.gov.au/ncc/ground-surface-water.html

This supports the need for updating the water balance modelling in the Dumaresq River region. Recent advances in catchment water balance modelling make it possible to couple surface flow and groundwater modelling in a single numerical environment. QLD NRW has applied this new modelling approach in the coastal regions (Werner et al. 2005, Werner and Gallagher, 2006), but have yet to apply coupled modelling in the QMDC area. Two of the available approaches are MODHMS (www.modhms.com) and GSFLOW. CSIRO has been commissioned to determine the sustainable yield of the groundwater systems in the Murray-Darling Basin (http://www.pm.gov.au/government/water.cfm). However they will not be generating new coupled catchment water balance models using the approaches suggested.

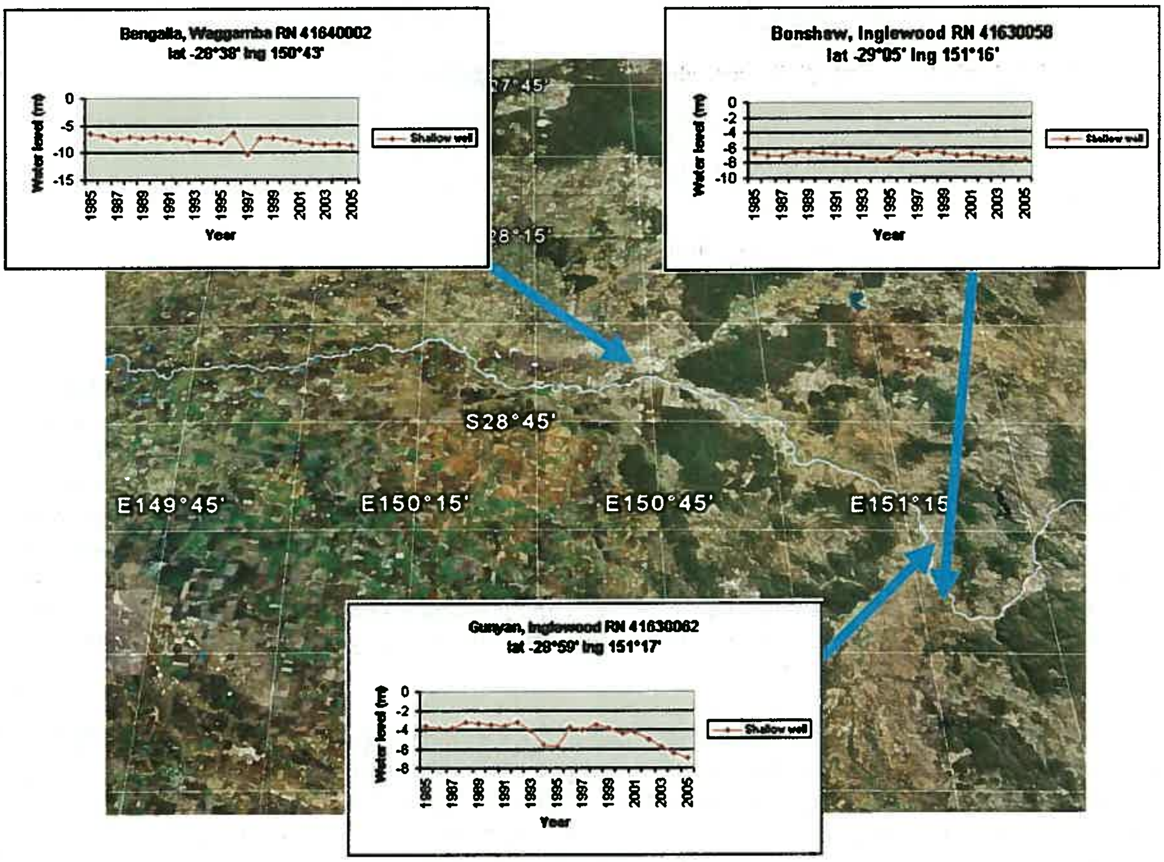

Figure 7. Decline in the shallow aquifer water levels since 1985 (Sales, 2006).

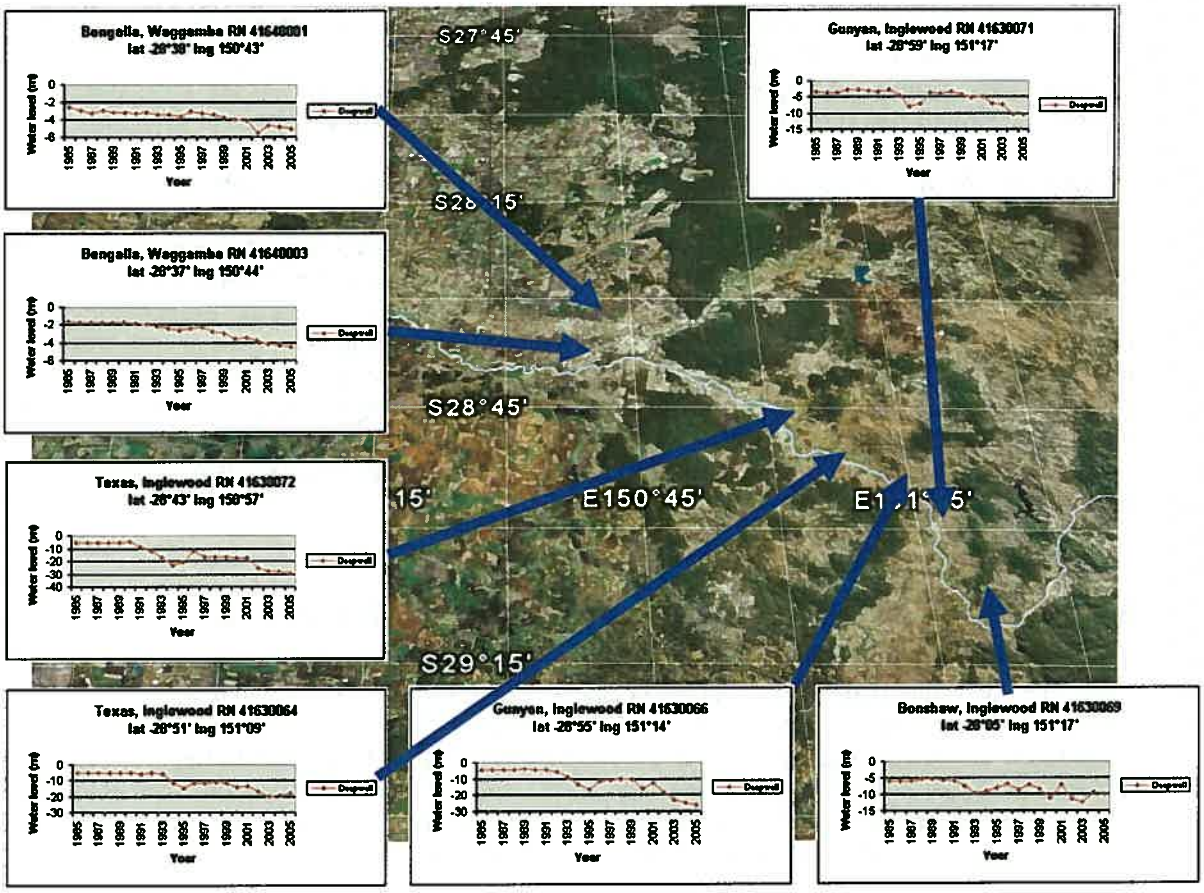

Figure 8. Decline of the deeper aquifer water levels since 1985 (Sales, 2006).

5. Murray Darling Basin Modelling Guideline Review

5.1. Modelling Overview

A model is a physical or mathematical replica of something in the real world. A mathematical model aims to capture the essence of the real world, but deliberately omits non-essential processes or details. Environmental modelling is the science and the art of simulating environmental phenomena. Often, modelling is the only way to answer "what happened" questions, by reconstructing an environmental event to establish cause and effect. Modelling certainly is the only way to answer "what if" questions, to predict the consequences of a decision or action. For water resources in particular, we could say that water modelling is a computer-based analysis of processes in the water cycle and controls imposed on water systems, for the purpose of evaluating the effects of climate and management policy/actions.

In New South Wales and Queensland, government agency river models are standardised on IQQM software and groundwater models are standardised on MODFLOW software.

IQQM (Integrated Quantity Quality Model) was developed by the NSW Department of Natural Resources (NRW) to investigate the impacts of water resource management policy on stakeholders.

A river is represented in the model as a series of nodes that have attached inflows, outflows and storages. The nodes are connected by links that represent water flows and routing processes. IQQM usually operates on a daily time scale, can be applied to regulated or unregulated rivers, and can simulate water salinity. In ungauged tributaries or where stream flow data are incomplete, the Sacramento rainfall-runoff model is used to infer stream flow from climate data and land use.

MODFLOW (MODular Groundwater FLOW Model) was developed in the 1980s by the United States Geological Survey as a generic simulator of groundwater flow processes in saturated aquifers (McDonald & Harbaugh, 1988). It represents an aquifer system as a three-dimensional mesh of rectangles stacked in multiple layers. It simulates rainfall recharge and evapotranspiration from a water table, but does not simulate infiltration through unsaturated soil or evaporation from vegetation or surface water bodies. A river is represented in the model as a series of cells that may or may not be connected. The "river" package requires specification of water level in the river, whereas the "stream" package routes flow along a channel. Discharge to wells, bores and drains is simulated. MODFLOW usually operates on a monthly time scale for catchment models. It does not simulate groundwater salinity but a companion product (MT3D) can simulate generic solute transport.

5.2. Review of the Dumaresq – Border Rivers Groundwater Model

The Dumaresq River groundwater model was developed by the Queensland Department of Natural Resources and Mines (Chen, 2002) for the Dumaresq Barwon Border Rivers Commission. It covers an area of 106 km northwest-southeast by 44 km northeast-southwest, as shown in Figure 9, using a grid rotated 45 degrees. The model has two layers known locally as Unit C for the upper unconfined aquifer, and Unit B for the underlying aquifer. A nominal aquitard (clay) of 10 m thickness separates the aquifers. The model has 700 rows and 200 columns, with rectangular cell sizes of 100-400 m. It was developed using MODFLOW96, in part using the PMWIN graphic user interface, but with heavy reliance on non-public pre-processing and post-processing software. The model has undergone both automated steady-state calibration (using PEST-ASP) and manual transient calibration for the period 1960-1999. A large number (86) of hydrographs was available for transient calibration.

The development of this model exhibits a monumental effort. Most of the techniques used are "leading edge". In fact, a set of three models has been built, each calibrated to different assumptions for rainfall recharge in the range 1-6 % of rainfall. This approach is rare in Australia, but is being promoted in the United States through multi-model averaging as a means of accounting for inherent uncertainties in groundwater flow modelling. A major limitation in models is that, given hydraulic data alone, rain recharge and top layer permeability are coupled as a ratio, and only that ratio can be calculated. Groundwater fluxes, water chemistry, and plausible physical property ranges are needed to separate the two components of the ratio.

Automatic calibration was applied only to the steady state model, as application to the transient simulation would have required runtimes in the order of a week for each run. Steady-state replication is extremely good, with an average residual of only 10 cm in a field of heads that vary by 100 m. On the whole, with transient calibration, replication of the dynamics shown in bore hydrographs is quite good. There are some cases with elevation offsets around 1 m, and there is often an inability to reproduce the substantial drawdowns caused by groundwater pumping.

There is one feature of the model that requires improvement. The modeller elected to calculate river stages through a relationship with rainfall, rather than direct use and interpolation of real data. The reasoning for this is puzzling, particularly since the relation between river flow and rainfall has a very low coefficient of determination (0.17). This practice places a huge uncertainty on river-aquifer interactions, and this is probably the main driver of the water system. The finding of this model is that the river is mostly a gaining stream, with the river taking about one-third of natural groundwater discharge. On the contradictory, Baskaran, Ransley and Brodie (personal communication) have found that the river is mostly a losing stream. Until this interaction is resolved, the findings of the model must be treated with caution.

Another finding of the model is that the salt scald at Yelarbon can be explained by evaporation from a high water table, rather than upflow from the Great Artesian Basin as proposed by Knight et al. (1989). The chemical signature of the water should resolve which conceptualisation is correct.

Model scenario analysis provides useful indicators of how the aquifer is likely to respond to increased groundwater pumping, or climate change. For example, the model finds that the river switches from a predominantly gaining stream to a losing stream when groundwater pumping reaches about half of the allocation limit of 30,000 ML/year. Up to the year 2000, usage was approximately 5,700 ML/year.

An appraisal of this model according to MDBC guidelines is presented in Table 1.

The model provides a range of water balance information, subject to uncertainty, but fails to recommend a likely sustainable yield for the aquifer system.

The existing model provides a very good foundation for ongoing development. What needs to be done is replacement of river stages by measured and interpolated levels, some re-calibration, then validation using the 2000-2005 data set. One limitation of the modelling that can't readily be addressed is that groundwater pumping data per bore is available only annually, whereas monthly volumes are required for proper calibration. It is imperative that bore pumping be monitored at a monthly time scale.

As the main cotton-growing area lies farther to the west, the model area should be extended in this direction, or a separate model should be developed along the MacIntyre River. The model developed by Whiting (2007) is a step in this direction.

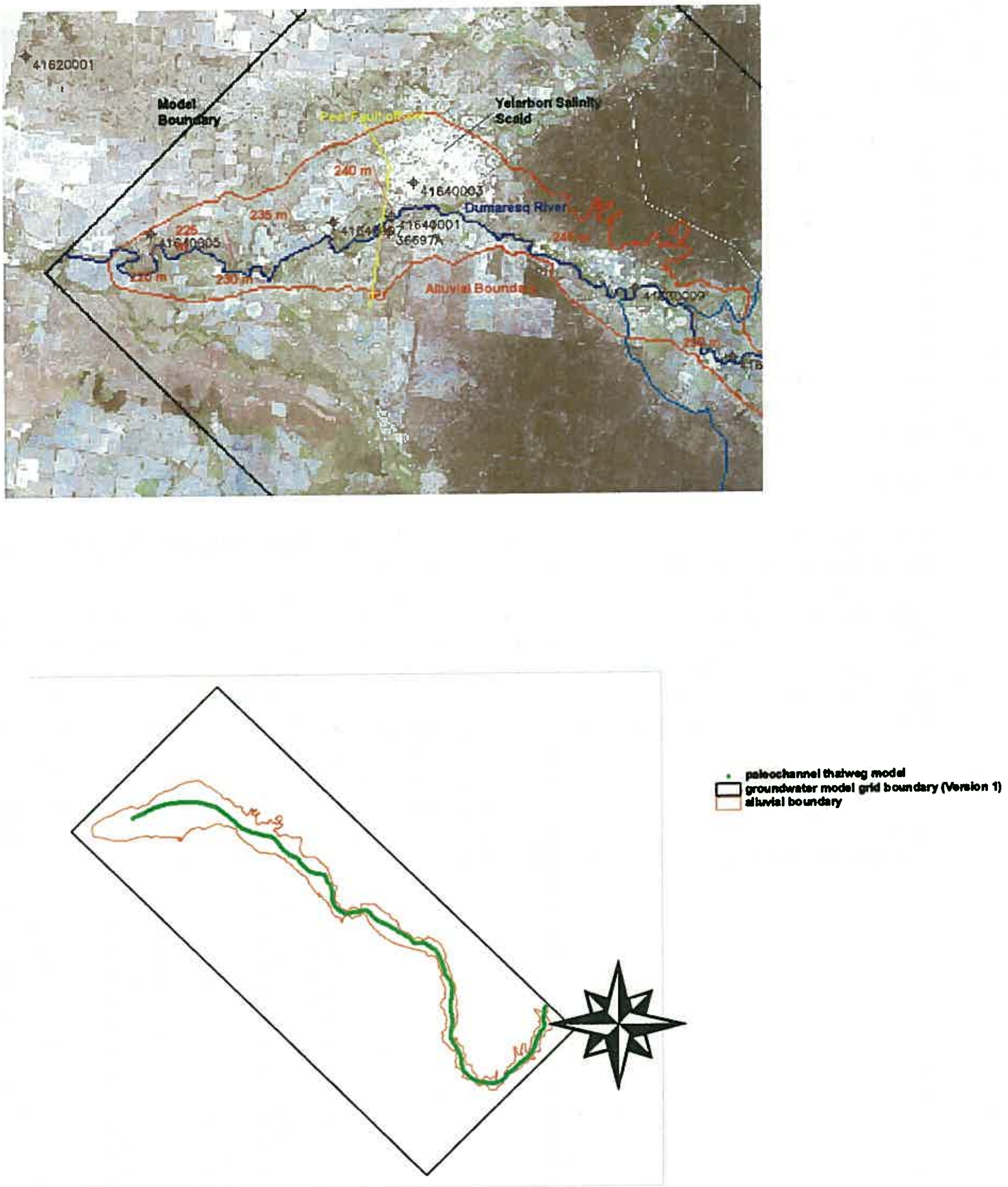

Figure 9. Extent of the Dumaresq model (from Chen, 2002).

Table 1-a. Model Appraisal: Dumaresq Model 2002 (Part 1 of 2).

	QUESTION	Not Applicable or Unknown	Score 0	Score 1	Score 3	Score 5	Score	Max. Score (0, 3, 5)	COMMENT
1.0	THE REPORT								
1.1	Is there a clear statement of project objectives in the modelling report?		Missing	Deficient	Adequate	Very Good			Pages 1-12 & 1-13
1.2	Is the level of model complexity clear or acknowledged?		Missing	No	Yes				High complexity (not stated)
1.3	Is a water or mass balance reported?		Missing	Deficient	Adequate	Very Good			Preliminary estimates and model values
1.4	Has the modelling study satisfied project objectives?		Missing	Deficient	Adequate	Very Good			No clear statement on sustainable yield
1.5	Are the model results of any practical use?			No	Maybe	Yes			
2.0	DATA ANALYSIS								
2.1	Has hydrogeology data been collected and analysed?		Missing	Deficient	Adequate	Very Good			
2.2	Are groundwater contours or flow directions presented??		Missing	Deficient	Adequate	Very Good			
2.3	Have all potential recharge data been collected and analysed? (rainfall, streamflow, irrigation, floods, etc.)		Missing	Deficient	Adequate	Very Good			Streamflow not used directly. Residual mass examined. No rain probability distribution. River stage said to be lower than water table (not shown).
2.4	Have all potential discharge data been collected and analysed? (abstraction, evapotranspiration, drainage, springflow, etc.)		Missing	Deficient	Adequate	Very Good			River & aquifer pumping annual only (need monthly)
2.5	Have the recharge and discharge datasets been analysed for their groundwater response?		Missing	Deficient	Adequate	Very Good			Poor correlation with residual mass (implying minor role for rain). Better with rain less evaporation.
2.6	Are groundwater hydrographs used for calibration?			No	Maybe	Yes			Total 86
2.7	Have consistent data units and standard geometrical datums been used?			No	Yes				
3.0	CONCEPTUALISATION								
3.1	Is the conceptual model consistent with project objectives and the required model complexity?		Unknown	No	Maybe	Yes			
3.2	Is there a clear description of the conceptual model?		Missing	Deficient	Adequate	Very Good			
3.3	Is there a graphical representation of the modeller's conceptualisation?		Missing	Deficient	Adequate	Very Good			Appears later in scenario analysis.
3.4	Is the conceptual model unnecessarily simple or unnecessarily complex?			Yes	No				River believed to be mostly gaining (contentious). Examined GAB upflow at Yelarbon. No rain recharge in high ET months (weakness).
4.0	5.2.1. MODEL DESIGN								
4.1	Is the spatial extent of the model appropriate?			No	Maybe	Yes			Excludes main cotton growing area downstream.
4.2	Are the applied boundary conditions plausible and unrestrictive?		Missing	Deficient	Adequate	Very Good			Should use real river stages, not estimates derived from rain.
4.3	Is the software appropriate for the objectives of the study?			No	Maybe	Yes			PMWIN V5 & Modflow96; PEST-ASP; private processing programs (not public).

Table 1-b. Model Apprasial: Dumaresq Model 2002 (Part 2 of 2).

Q.	QUESTION	Not Applicable or Unknown	Score 0	Score 1	Score 3	Score 5	Score	Max. Score (0, 3, 5)	COMMENT
5.0	**CALIBRATION**								
5.1	Is there sufficient evidence provided for model calibration?		Missing	Deficient	Adequate	Very Good			
5.2	Is the model sufficiently calibrated against spatial observations?		Missing	Deficient	Adequate	Very Good			
5.3	Is the model sufficiently calibrated against temporal observations?		Missing	Deficient	Adequate	Very Good			Generally good 1960-1999, within 1m. Some difficulty matching pumping drawdowns.
5.4	Are calibrated parameter distributions and ranges plausible?		Missing	No	Maybe	Yes			
5.5	Does the calibration statistic satisfy agreed performance criteria?		Missing	Deficient	Adequate	Very Good			Excellent steady state: Mean residual 10cm. Adequate transient (no stats.).
5.6	Are there good reasons for not meeting agreed performance criteria?	N/A	Missing	Deficient	Adequate	Very Good			
6.0	**VERIFICATION**								
6.1	Is there sufficient evidence provided for model verification?	N/A	Missing	Deficient	Adequate	Very Good			Recommended to be done in 2005 on 2000-2005 data. Overdue.
6.2	Does the reserved dataset include stresses consistent with the prediction scenarios?	N/A	Unknown	No	Maybe	Yes			
6.3	Are there good reasons for an unsatisfactory verification?	N/A	Missing	Deficient	Adequate	Very Good			
7.0	**PREDICTION**								
7.1	Have multiple scenarios been run for climate variability?		Missing	Deficient	Adequate	Very Good			8 scenarios x 3 models
7.2	Have multiple scenarios been run for operational /management alternatives?		Missing	Deficient	Adequate	Very Good			8 scenarios x 3 models
7.3	Is the time horizon for prediction comparable with the length of the calibration / verification period?		Missing	No	Maybe	Yes			40 years
7.4	Are the model predictions plausible?			No	Maybe	Yes			
8.0	**SENSITIVITY ANALYSIS**								
8.1	Is the sensitivity analysis sufficiently intensive for key parameters?		Missing	Deficient	Adequate	Very Good			River conductance across 5 orders. Storage parameters by 10% (not wide enough)
8.2	Are sensitivity results used to qualify the reliability of model calibration?		Missing	Deficient	Adequate	Very Good			Except for rain/K ratio.
8.3	Are sensitivity results used to qualify the accuracy of model prediction?		Missing	Deficient	Adequate	Very Good			
9.0	**UNCERTAINTY ANALYSIS**								
9.1	If required by the project brief, is uncertainty quantified in any way?		Missing	No	Maybe	Yes			Chloride informs recharge rate: 0.6% - 6% rain. 3 separate models built.
	TOTAL SCORE								**PERFORMANCE:** %

6. Lower Balonne

In recent years the Lower Balonne has been extensively investigated with respect to geomorphology, hydrogeology, geochemistry, geophysical properties, groundwater ages, palynostratigraphy , surface hydrology and ecology (McAlister, 2002; Chamberlain and Wilkinson, 2004; Clarke and Reisz, 2004; Herczeg, 2004; Kernich et al., 2004; Lane et al., 2004; Macphail, 2004; Payenberg and Reilly, 2004; Kernich et al., 2005; SMEC, 2006). As a result of these investigations the Lower Balonne area is now one of the better characterised aquifers in the Darling Basin.

A new MODFLOW model of the region is being calibrated by the NRW. At the time of discussions with NRW staff this was only a steady state model due to the lack of available time-series hydrogeological data. As the appropriate time-series calibration data sets become available transient calibration will be undertaken. Ideally the groundwater modelling also needs to be extended to take advantage of recent advances in coupled surface and ground water modelling using packages like MODHMS or GSFLOW.

McAlister (2001) recommended that improvements should be made in the amount of groundwater level data being collected. It is not known if these recommendations were adopted, as the monitoring network currently being used has not been made available for review. Based on what has been reviewed in the existing reports the recommendations of McAlister are supported. The groundwater hydrographs presented in the reports indicate that the groundwater levels have not been recorded at a high enough frequency. Given the intermittent nature of surface flows through the region it is recommended that water level and atmospheric pressure data loggers be installed throughout the monitoring network in order to improve the understanding of the connection between surface and ground water. This is particularly important given that many of the larger river and over-bank flows through the region are pulse events.

The extensive data sets collected in the recent investigations need to be combined in an interactive 3D geological property model (for example GoCAD or EarthVision), which would help with quality assurance of the information and correct spatial referencing of the information. Once the data are in a 3D environment it would enable better understanding of the groundwater processes, which would result in enhanced management decisions. It would also allow easier communication of surface and ground water processes to a wider audience.

7. Conclusions

Compared to other irrigation districts in the Murray-Darling Basin the irrigation districts in the central and western regions of the QMDC Border Rivers-Moonie management area are young. As a result of this there are limited groundwater monitoring data in the districts. However, there are enough data to raise concerns that there is the potential to mobilise the saline water in the shallow aquifers. Given that this shallow aquifer water has salinity levels approaching sea water then any mobilisation of this water could have significant detrimental impacts on soil, crop, and river water health. This review supports the need for extending the groundwater monitoring network, installing data loggers and undertaking water chemistry surveys (both major ions and isotopes).

Based on the conceptual MODFLOW modelling undertaken by Whiting (2007) the following recommendations for further work to improve the modelling of groundwater salinisation outbreak potential in the region include:

a) targeting field drilling and groundwater monitoring in areas identified through this modelling as susceptible to shallow groundwater mounding and surface outbreak;

b) improve the hydrogeological conceptual model of the region by conducting drilling investigations to characterise layering within the alluvium and hydraulic interaction between underlying Griman Creek Formation and the alluvium;

c) conducting more detailed elevation surveys, particularly along the major rivers reaches;

d) groundwater investigations to asses river interaction with the groundwater system;

e) improve groundwater spatial and temporal data resolution across the region by installing more observation bores and monitoring more frequently;

f) introduce more paired control and irrigated monitoring groundwater stations; and

g) characterise saturated alluvium hydraulic properties by conducting single borehole testing or pumping tests on established bores or strategically placed bore sites.

Water catchment modelling techniques are evolving rapidly. Given that there are better approaches for catchment water balance models available, and the fact that data sets have now been recorded over a longer period of time over different climatic extremes and pumping rates then this is the ideal time to upgrade the Dumaresq River groundwater model, preferably to a coupled river aquifer catchment water balancing modelling environment. The model could also be improved by installing data loggers throughout the borehole monitoring network, particularly in the bores monitoring the shallow aquifer, undertaking a water chemistry survey (both major ion chemistry and isotopes) to determine the extent of the GAB-alluvial interaction, and possibly some additional investigation boreholes near the Marburg Sandstone are required. Chen's (2002) MODFLOW model indicates that the Marburg Sandstone may be a recharge bed for the GAB, but there is a lack of data to make definitive statements. This interaction of the alluvial aquifer with the GAB has significant implications for the sustainable yield of the aquifer.

A vast amount of data has been collected in the Lower Balonne area. Value could be added to this information by building an interactive 3D geological property model of the region. Collating all the information in 3D would have many benefits including: quality assurance of the data, improved understanding of the hydrogeological processes, easy visualisation of the connections between the surface and ground water, and better spatial communication of the information in a public forum for all stakeholders involved in water resource and environmental management.

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