Water and Environment

MALLEE CMA GROUNDWATER MODEL (EM3) - TRANSIENT CALIBRATION DEVELOPMENT REPORT DEVELOPMENT REPORT

Prepared for	Department of Sustainability and Environment
Date of Issue	9 June 2010
Our Reference	A53B/B2/R004b

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	Date	Revision Description
Revision A	22/04/10	Draft issued for client and independent review
Revision B	09/06/10	Final report

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EXECUTIVE SUMMARY

The Mallee Catchment Management Area (CMA) groundwater flow model (referred to as the EM3 model), constructed in MODFLOW, was developed for the Department of Sustainability and Environment (DSE) ecoMarkets initiative. It represents part of a state-wide program to develop groundwater models for each CMA in Victoria. The models developed through this program will be used, in conjunction with a recharge and evapotranspiration model of each CMA developed separately by the DSE, to assess the impacts of land use change on groundwater regime and stream-aquifer interaction. The project was completed in two key stages structured along the development of the steady state and transient model.

The Mallee CMA hydrogeological structure is represented by a four-layer system that is used to represent key aquifers (generally from top to bottom): an alluvial floodplain along the River Murray, Parilla Sand aquifer (includes the Shepparton Formation), Murray Group Limestone and Renmark Group. Low permeability units that include Blanchetown Clay (on top of Parilla Sand), Bookpurnong Beds, Winambool Formation / Geera Clay (generally below Parilla Sand) and Ettrick Formation (between Murray Group Limestone and Renmark Group) function as aquitards. The River Murray is an important part of the general hydrology and runs along the northern boundary of the Mallee CMA and its flow is regulated by weirs. There are numerous smaller floodplain water features which hold water intermittently. Surface water features are approximated in the model using River, Evapotranspiration and Recharge packages (Modflow modules). River Murray levels are modelled as constant and vary from lock to lock, however flooding events were not considered. A distributed recharge and evapotranspiration rate coverage has been tailored to the Mallee CMA area using the Ensym model (by DSE) and applied to the groundwater flow model.

The model performance has been enhanced through history matching over 1990 to 2005 after the initial calibration of the steady state model (year 2000 was selected to represent steady state conditions). Parameters adjusted during the history matching process were used to update the steady state model to make sure the both models are consistent. The outcome of parameter and boundary condition adjustment has been a general improvement in calibration performance (the achieved calibration statistic SRMS for the transient model is below 5%). The hydrographs for 1990 to 2005 show a good match for both level and trend.

There are areas of the model where its performance could be improved: (1) Irrigation mounds generally around Mildura region, and (2) Recharge rates in the southern part of the model are considered high, especially in areas where water levels are set deep, i.e. below 50 m below surface. We believe that currently adopted (prescribed) recharge rates under-represent the impact of irrigation resulting in under-predicted water levels in the monitoring bores in or near irrigation mounds in the north near the River Murray. In the southern areas the model generally over-predicts groundwater levels when using the prescribed recharge rates, which are considered to be at the high end of a plausible range. To further improve the match in those areas would require general increase in horizontal conductivity values that may not be consistent with perceived or measured values applicable to lithological materials. DSE may also consider adopting a revised recharge model in areas with deep-seated water levels that may specify either significantly reduced or even zero recharge rates, and/or the application of significant time lags on recharge fluxes (egg. many decades).

Model water balance figures indicate that at the end of the calibration period the largest contributor to the groundwater is the river (62% of the total incoming flux), while the most significant losses are attributed to evapotranspiration (77% of the total outgoing flux). The lateral inflow from the south is relatively small, less than 47 GL/yr or less than 6% of the total incoming flux and this is consistent with northern outflow from the neighbouring Wimmera model to the south.

The magnitude of river losing flux volumes, and the extent of river losing reaches is considered to be higher than physically realistic, and further model calibration is warranted by further decreasing the river bed conductance, although this will require some adjustments to other parameters, and most likely also to the evapotranspiration parameters to improve calibration.

The Mallee CMA numerical groundwater model catchment is considered to be fit for the purpose of assessment of groundwater regime changes due to broad land use impacts, as well as the potential use by other stakeholders such as water utilities to assist with groundwater resource management. While the overall calibration statistic is favourable and well within the required limit, there are areas, as with any model, where additional improvement could be achieved to better represent the regional groundwater system and recommendations include:

- Reconsider updating the recharge model especially in irrigated areas, but also in dryland areas with deep water levels, and possibly include recharge lag times for areas with deep water tables;
- Incorporate updated pumping rate information for the borefields on the western boundary;
- Update the long-term pumping rate estimates from Grampian Wimmera Mallee Water;
- Refine surface elevations at regional discharge points (egg. Lake Tyrrell);
- Reduce the river bed conductance parameter (to reduce river losing flux volumes) and make adjustments to other parameters and the ET parameters to adjust calibration;
- Refine the ET parameterisation where warranted, more specifically in the floodplain and apply time varied ET rates and extinction depth;
- Incorporate floodplain inundation recharge processes.

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1 INTRODUCTION

1.1 BACKGROUND

1.1.1 ECOMARKETS PROJECT BACKGROUND

This report has been prepared for the Department of Sustainability and Environment Victoria (DSE) by Aquaterra. It describes the current status on the groundwater model development for the Mallee Catchment Management Area (CMA) (Figure 1.1).

The Mallee study represents part of a state-wide program to develop groundwater models for each CMA in Victoria and follows completion of a pilot groundwater modelling study of the Corangamite CMA. The models developed through this program will be used, in conjunction with a recharge model of each CMA developed separately by the DSE, to assess the impacts of land use change on groundwater regime and stream-aquifer interaction. Specifications for the modelling work are summarised from the contract documents in Section 1.1.2.

The modelling study and results will be used as part of the DSE 'ecoMarkets' initiative, a new system of market based approaches designed to reward landholders for environmental improvements on their properties (www.dse.vic.gov.au/dse/). One of the approaches under the 'ecoMarkets' initiative is known as 'ecoTender'. This scheme is currently being demonstrated in the Corangamite CMA and the DSE uses it as one of the tools compare the relative merits of different bids aimed at improving native vegetation management and revegetation in selected parts of the CMA. It is intended that the groundwater models produced could also be used in the future by other stakeholders such as water utilities to assist with groundwater resource management.

In common with the modelling studies for each CMA under the ecoMarkets initiative, a staged approach is adopted for the modelling work for the Mallee CMA:

- **Phase 1** involves conceptualisation and development of a steady state multi-layered groundwater model of the aquifer system present within the Mallee CMA, and subsequent independent review, in two stages:
  - Stage 1: Calibration of the steady state model using catchment average recharge conditions.
  - Stage 2: Validation assessment of the steady state model based on current recharge conditions.
- **Phase 2** involves the refinement and expansion of Phase 1 Mallee CMA steady state multi-layered model platform, building upon the conceptualisation and data sets developed and collated, and transient calibration over a minimum 10-year period.

This report specifically focuses on the results of the Phase 2, with detailed results of the Phase 1 described in Aquaterra (2010).

1.1.2 MODEL SPECIFICATIONS

Specifications for the Mallee CMA modelling study (further referred to as 'study') as stipulated in the contract for the work are:

- Modflow numerical groundwater modelling platform to be used;
- Model domain represents the entire extent of the catchment management area;
- The steady-state and transient groundwater recharge layers developed and provided by the DSE on a 200 metre grid are to be incorporated unaltered into each model unless demonstrated to be erroneous;
- Finite difference gridding at a maximum 200 metre cell size (to accommodate the recharge data developed by DSE on a 200 metre grid);
- Multi-layer groundwater model (representing major geological units – see further discussion at Section 1.1.3) consistent with conceptual hydrogeological model, and designed mainly to simulate water table levels and stream-aquifer interaction, and

response times to changed land and water use and/or climate change, for the ecoMarkets initiative (primary purpose);

- Secondary model purpose is for subsequent use/refinement by CMA for resource management purposes;
- Common boundary conditions and consistent aquifer parameters with adjacent models, as arising from the state-wide groundwater modelling workshop outlined below;
- A normalised (scaled) RMS of less than 5% for the Phase 1 steady state model based on matching mapped depth to water table as of 1st January 2000 (± three months);
- A normalised (scaled) RMS of less than 10% for the transient model based on matching mapped depth to water table at representative year(s) to be specified, sub-catchment baseflow and groundwater hydrograph responses for selected and agreed groundwater monitoring bores;
- A transient calibration period of no less than 10 years;
- A sensitivity analysis to assess the variability of modelled outputs to variations in key model input parameters;
- Catchment groundwater balance errors of less than 2%;
- Key catchment water balance features to be considered and reported;
- The source and statement of quality of all input data sets to be reported;
- At least 500 groundwater monitoring observation bores used for calibration of water table maps (if more than 500 are present).

All modelling work is to be carried out and reported in accordance with the Murray Darling Basin groundwater modelling guidelines (MDBC, 2001), which is the Australian best practice guideline for groundwater flow modelling, including review and appraisal.

1.1.3 EXTERNAL REVIEWS AND WORKSHOPS

Independent external review of the key project outputs forms an integral part of the project. **Dr Juliette Woods** (Australian Water Environments) has been appointed as the independent reviewer for the Mallee CMA model.

External review is to be achieved via a series of workshops, held at key stages during the project, combined with regular informal communication and review by the appointed reviewers. The following workshops are planned:

- Informal review workshop. Carried out following collation of all relevant data sets and development of preliminary aquifer conceptualisation;
- State-wide groundwater modelling workshop. Carried out following preliminary conceptualisation of each model area to ensure consistency between model areas;
- Formal Phase 1 model review workshop. Formal presentation of final aquifer conceptualisation and a calibrated multi-layer, steady state groundwater model for review (i.e. a formal review based on this report);
- Final model workshop. Formal presentation of a calibrated multi-layer transient groundwater model and report for review; and
- Final audit workshop. Formal audit of the final groundwater model including handover and review of the model input and output data files.

In principle, to achieve the state-wide aspirations for the project and ensure consistency with models of the other CMAs the following geological units should be represented in the Mallee CMA:

- Quaternary and Volcanics (i.e. Post Tertiary age strata);
- Pliocene (i.e. Late Tertiary age strata; in the eastern Mallee: Parilla Sand and Bookpurnong Beds);
- Early Tertiary age strata (Renmark Group in the eastern Mallee);
- Pre-Cainozoic (i.e. Pre-Tertiary age basement strata).

It is noted that previous investigations and modelling by Aquaterra (2007, 2008) has demonstrated that the Bookpurnong Beds and laterally contiguous Geera Clay units form an effective hydraulic basement to the late Tertiary and Quaternary aquifer units, and it is not necessary to include the early Tertiary (Renmark Group) or pre-Cainozoic basement to develop a well-calibrated model for shallow water table simulation and surface-groundwater interactions.

However, once the modelling platform is developed for the DSE, the CMA would likely wish to use the model for a range of water management purposes, which may require representation and inclusion of the deeper confined aquifer layers in the model. At the State-wide workshop in mid-2009, it was decided that the Mallee model needed to have a layer structure that is consistent with the adjoining models (Wimmera and North Central) and a more complex layer structure has been implemented.

1.2 OTHER EASTERN MALLEE GROUNDWATER MODELLING INITIATIVES

The extent of the EM3 model in relation to other Eastern Mallee models is presented in Figure 1.1. The coverage, purpose and owner of each of the Eastern Mallee models are summarised in Table 1.1.

Table 1.1: Eastern Mallee Models: Coverage, Ownership and Purpose

Model	Coverage	Owner	Purpose
EM1	Nyah to SA Border	MDBA	Register B 'Legacy of History; salinity impacts from dryland clearing and irrigation development
EM2	Sunraysia (Colignan to Lock 10)	G-MW (MCMA, NOW, MDBA)	Register A assessments of salt interception and RISI
EM3	Entire Mallee CMA	DSE (MCMA)	To support the ecoMarkets initiative for land and water management on private land
EM4	Lindsay-Wallpolla floodplain	MCMA (LMD CMA)	The Living Murray environmental watering flow and salinity effects

A regional scale groundwater model has previously been developed (covering the northern part of the Mallee CMA area) by Aquaterra (2007) for the Murray-Darling Basin Commission (MDBC). The purpose of the model was to assess salinity impacts in the Mallee Zone of New South Wales and Victoria. The Eastern Mallee Version 1 (**EM1**) model was used as the initial basis for this project, by extending it to the south to cover the entire Mallee CMA region, and with additional layers to represent deeper, pre-Tertiary confined aquifers. The EM1 model layer elevations were completely revised for this EM3 project, based on a review and analysis of drill logs, but most of the hydrological process features were incorporated into the EM3 model, based on features in the EM1 model, and other models in the area.

The original aim of the **EM1** model was to develop a groundwater model to assess past, present future salinity impacts in the Eastern Mallee zone from Swan Hill to the SA border, based on current hydrogeological knowledge. The outcome was a modelling platform that was intended for further refinements in ongoing work programs to more accurately simulate all actions and/or to upgrade as new information about relevant hydrogeological and hydrological processes becomes available. The model was independently reviewed in regard to its 'fitness for purpose' for 'B' Register assessments.

The **EM1** model was based on the most up to date data currently available on geology, soil profiles and hydrogeology and incorporated key physically recorded stresses such as irrigation application rates, salt interception scheme (SIS) pumping regime and historical land and water use change where possible. The model has been used to predict future salt loads entering the River Murray in the Eastern Mallee Zone under different land-use scenarios.

Aquaterra developed another model on a sub-regional scale in the Mildura region for Goulburn-Murray Water and the MDBA, to inform the evaluation of irrigation-related effects and the design and optimisation of salt interception schemes in the Sunraysia (Aquaterra, 2009b). The Eastern Mallee 2 (**EM2**) sub-regional groundwater model is also used to inform the Mallee CMA (EM3) model development, notably in regard to shallow floodplain processes and layer properties.

The Mallee CMA engaged Aquaterra in extending and refining the **EM1** model to examine floodplain processes and the impacts of environmental watering in the area from downstream of Lock 10 to the South Australian border (Aquaterra, 2008). This model is referred to as **EM4**.

1.3 THIS REPORT

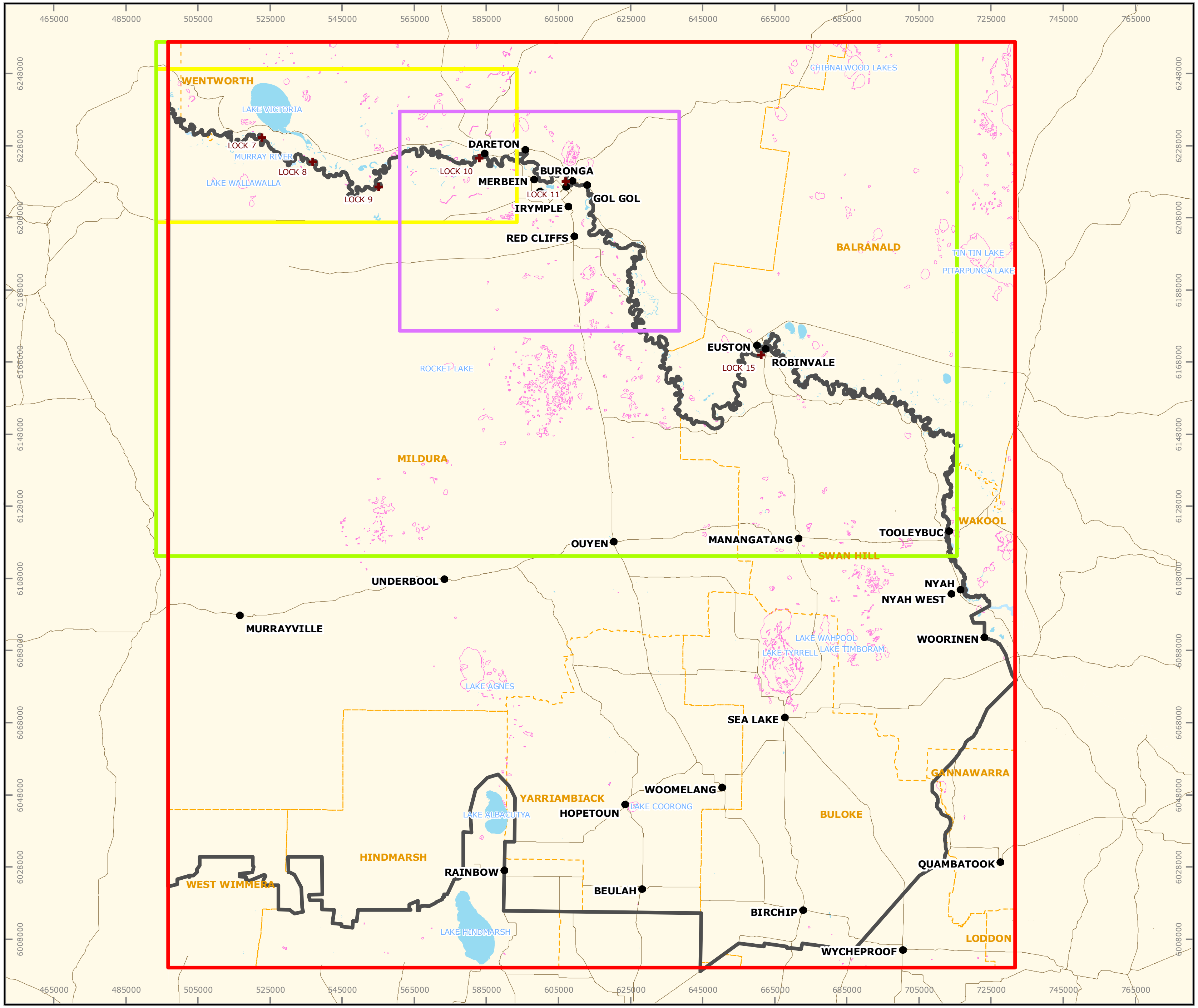
This report comprises five principal chapters. Chapter 1 outlines the aims of the study and provides background and history of the key recent groundwater model development initiatives related to Mallee CMA.

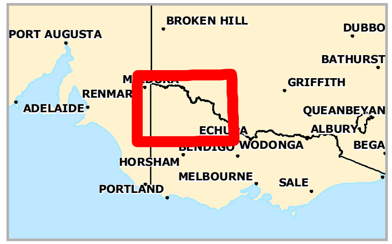
Chapter 2 describes the hydrogeological conceptualisation, the principal aquifer and aquitard units and surface processes that influence recharge to and discharge from groundwater. It provides the basis for the numerical model development.

Chapter 3 outlines the current implementation of the transient numerical groundwater flow model. It describes the approach that has been taken to represent the complex geological setting, currently adopted hydrogeological parameters used to describe the flow properties and representation of processes governing the surface water groundwater interaction. The geometry of aquifer and aquitard units and hydrogeological parameterisation is illustrated through a set of maps and model outputs provided in Appendices A and C.

Chapters 4 cover the overall calibration and sensitivity results and provide the principal information on the performance of the steady state and transient model.

Chapter 5 discusses the model capability, identified issues and recommendations for modelling works going forward.





LEGEND

- Locks
- Localities
- Main Roads
- River Murray
- LGAs
- EM3 Model Boundary
- EM1 Model Boundary
- EM2 Model Boundary
- EM4 Model Boundary
- Mallee CMA Boundary

Suface Water Bodies

- Perennial
- Non-perennial

N

0 5 10 20

Kilometres

SCALE 1:1,500,000 @ A4

GDA 1994 MGA Zone 54

DATA SOURCES

MCMA: Irrigated Areas
GA: Localities, Lakes, Locks, Roads, LGAs
AQT: EM3 Model

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FIGURE 1.1

Mallee CMA Study Area

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2 HYDROGEOLOGICAL SETTING

2.1 STUDY AREA

The Mallee CMA study area comprises an area of approximately 50,400 km^2, extending eastwards from the South Australian border to about Swan Hill, and extending north from Lake Hindmarsh and Birchip/Wycheproof to the River Murray (Figure 1.1). It is proposed that the northern boundary of the Mallee CMA model should extend north of the River into NSW (i.e. consistent with the EM1 model boundaries), to ensure that the groundwater flow system influences from the north and east are adequately represented (e.g. there are irrigation mounds and salt interception schemes in NSW adjacent to the River Murray that have influences on the groundwater flow systems in Victoria).

2.2 CLIMATE

The Mallee CMA region is located within an arid to semi-arid climate with hot dry summers and dry mild winters. The mean annual rainfall recorded at Mildura (combined data from Mildura Airport and Mildura Post Office meteorological stations, station numbers 076031 and 076077) based on data from 1889-2008 is 275.6 mm/year. The mean annual rainfall recorded at Ouyen (station number 076047), based on data from 1911 to 2008 is 330.5 mm/year. The long-term average annual rainfall across the Mallee CMA is provided in Figure 2.1.

Pan evaporation at Mildura Airport and Ouyen is significantly higher than rainfall at 2,190 mm/year (1965 to 2008) and 1,423.5 mm/year (1972 to 1987), respectively.

Average monthly rainfall is relatively consistent over the year, although rainfall can be sporadically intense with long periods of near dry conditions intervening. Pan evaporation is highest in summer, and mean pan evaporation exceeds rainfall in every month. The greatest potential for rainfall infiltration occurs during intense storm events when rainfall exceeds evaporation over short periods.

Accumulated residual rainfall indicates that there were drier periods from 1993 to 2006 and during the early 1940s, the late 1920s and the late 1890s to early 1900s, consistent with periods when the Interdecadal Pacific Oscillation (IPO) index was positive (i.e. when the normally above average rainfall La Nina events would be weak, which would be expected to combine with intervening dry El Nino periods, and overall drier periods would not be unusual). Wetter periods occurred from 1988 to 1993 and during the early 1970s and the late 1950s, when the IPO was negative or near zero.

2.3 TOPOGRAPHY AND VEGETATION

The northern Mallee CMA area is characterised by a "highland" region outside the River Murray floodplain comprising ground elevations above 50 m AHD, and the River Murray floodplain below those elevations between 35 and 45 m AHD – the Murray Trench (see Figure 2.2). The Murray Trench is an erosional feature where the Murray River has cut through the older sediments, in response to changing recent sea levels, to form a floodplain. The transition between both landscapes can be abrupt, with cliffs marking the edge of floodplains in some areas.

The highlands are characterised by elevated areas due to differential settlement, and some uplift, of the Tertiary and younger sediments over an undulating pre-Tertiary basement. Some of these highs, such as the Neckarboo Ridge in the north-east of the study area, reach elevations of 120 m AHD, rising over 60 m above the surrounding plain. Other underlying structural features are also expressed in the surface topography to varying extents, including the Danyo and Wargan faults.

The topography in the southern half of the Mallee CMA area exhibits a gradational surface from the highlands of central Victoria and the Grampians, with the highest elevations (reaching 180 m AHD) observed in the south-west corner of the CMA. The highlands are punctuated by low elevations around Lake Tyrrell on the eastern margin of the Mallee Zone. Lake Hindmarsh, to the immediate south of the Mallee CMA area, is incorporated into the numerical model and also represents an area of low elevation in the highlands.

Native vegetation has been cleared almost entirely from Victoria within the study area, except for the major national parks (Sunset, Little Desert and Big Desert), the River Murray floodplain, and small/isolated pockets such as that south-west of Mildura. The area of NSW is largely uncleared, with pockets of cleared areas on Neckarboo Ridge, at the NSW irrigation areas and other isolated pockets of cleared land.

Floodplain vegetation predominantly comprises of Red Gum communities in proximity to the river or fresh water bodies and Black Box forests elsewhere. Uncleared highland vegetation is dominated by Mallee scrub, and lignum scrub in some areas.

2.4 LANDUSE AND IRRIGATION

Current land use within the Mallee CMA is presented in Figure 2.3. The main land uses within the Study Area can be summarised as:

- Dryland farming within cleared areas;
- Conservation for most uncleared native vegetation;
- Urban development within townships, in particular Mildura, Merbein, Ouyen, Redcliffs, Irymple and Buronga; and
- Irrigated horticulture in the Sunraysia.

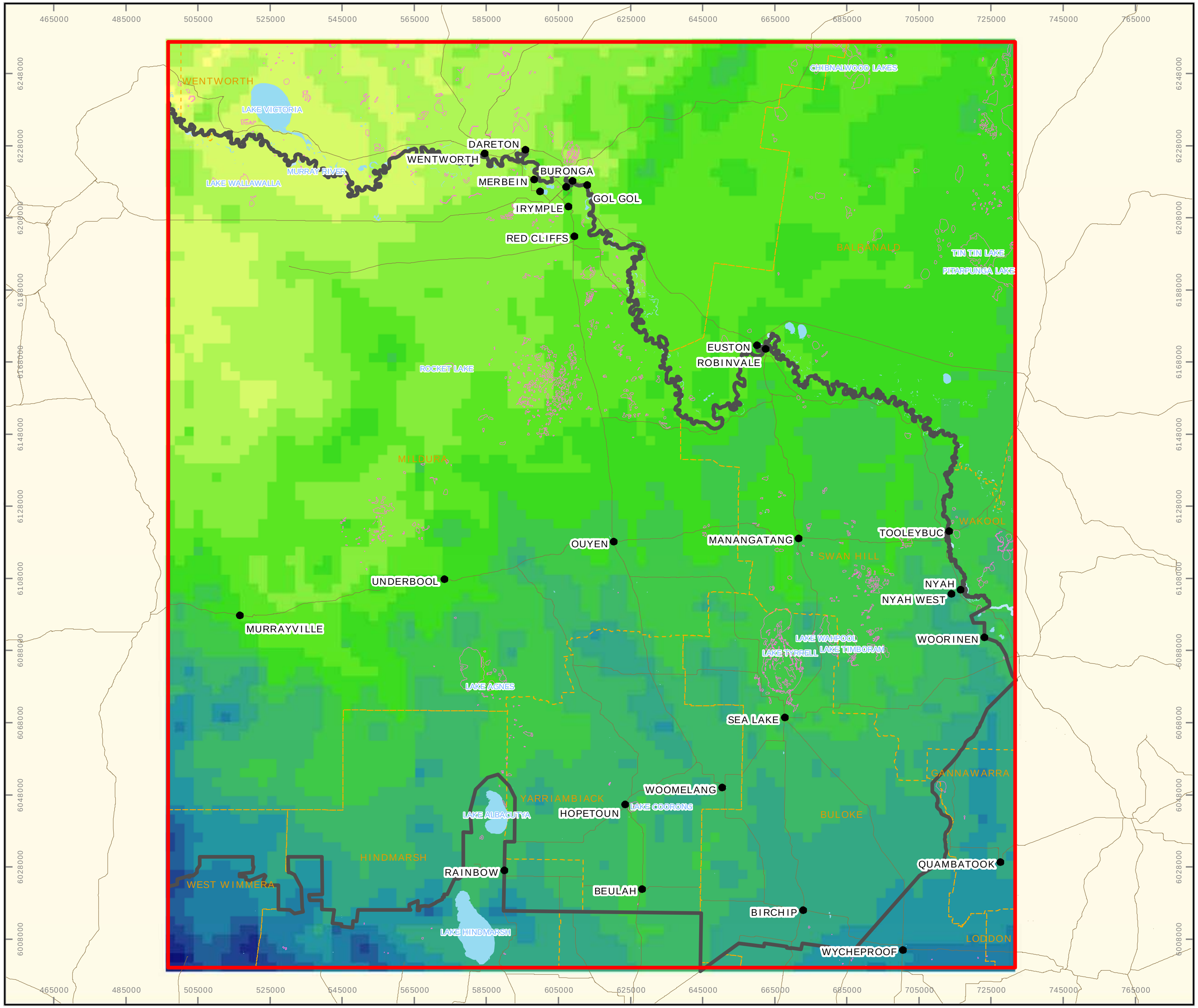
Irrigation has a major impact on water table levels, and on groundwater flows to the River Murray, and needs to be accounted for specifically in the model. Irrigation occurs on both sides of the River Murray (see Figure 2.4). In NSW, there are the irrigation districts of Buronga (including Gol Gol), Coomealla (including Mourquong), Curlwaa, Monak, Paringi and Trentham Cliffs. In Victoria, the irrigation districts include the First Mildura Irrigation Trust (FMIT), Merbein, Nangiloc-Colignan (part) and Red Cliffs. Many of the major irrigation districts are serviced by drainage infrastructure, and there is a network of water supply pipelines (previously channels) for stock and domestic supplies in the northern Mallee (sourced from the River Murray) and southern Mallee (sourced from the Wimmera River and dams in the Grampians).

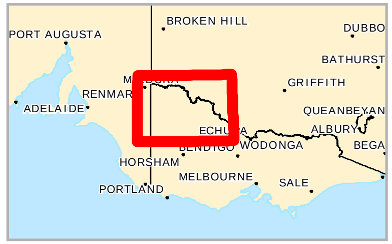
Drainage infrastructure has been installed to reduce water clogging of irrigated soils and salinisation due to local perched water tables under irrigation developments in the Sunraysia. Perched water tables can develop due to a marked permeability contrast between the Blanchetown Clay and Woorinen formation (Thorne *et al.,* 1989). A subsurface drainage system exists in the Victorian irrigation districts, whilst in NSW there are both surface and subsurface drains established (SKM and AWE, 2003). Average drainage rates are available from previous reports (SKM AND AWE, 2003; and MRCC, 2001) for the irrigation districts of Merbein, Redcliffs, FMIT, Nangiloc-Colignan, Coomealla, Curlwaa and Buronga. There is a 5% to 15% difference between MDBC (2003) and MRCC (2001) for the estimated drainage flows for the drainage districts of Merbein, Redcliffs and FMIT, and less than 4% difference between the total estimate drainage flows of all of these districts, both at 2000.

No data is available of the actual depth of drains, but is generally understood to be within 2 to 4 m of the surface and/or above the Woorinen/Blanchetown Clay interface. Also, there was no data on the actual implementation date of drainage schemes. Drained areas are generally of similar size to the actual irrigated areas.

To the south and south-west, the Mallee CMA contains all of the Murrayville Water Security Protection Area (WSPA) as well as part of the Telopea Downs WSPA and Kaniva TCSA (Tertiary confined sand aquifer) GMA. Groundwater use in 2006/07 almost doubled in the Murrayville WSPA compared with 2005/06; however extractions in the Telopea Downs WSPA almost halved over the same period. There has been no licensed groundwater use in the Kaniva TCSA GMA over both the 2005/06 and 2006/07 period.

The Murrayville WSPA freshwater aquifer is an important resource for domestic and irrigation purposes in the west of the Mallee CMA region. It is used for irrigation of potatoes and olives, as well as urban supplies for Murrayville and Cowangie townships. The Tertiary Limestone Aquifer is shared with the SA Mallee Prescribed Wells Area and the SA/Vic Border Zones.





LEGEND

- Localities
- River Murray
- Main Roads
- Mallee CMA Boundary
- EM3 Model Boundary
- LGAs

Suface Water Bodies

- Perennial
- Non-perennial

Average Rainfall (mm)

240 - 255	315 - 330	390 - 405
255 - 270	330 - 345	405 - 420
270 - 285	345 - 360	420 - 435
285 - 300	360 - 375	435 - 450
300 - 315	375 - 390	450 - 465

N

0 5 10 20
Kilometres

SCALE 1:1,500,000 @ A4

GDA 1994 MGA Zone 54

DATA SOURCES

GA: Localities, Lakes, Rainfall, Roads, LGAs
AQT: EM3 Model

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FIGURE 2.1

Long Term Average Annual Rainfall 1961- 1990

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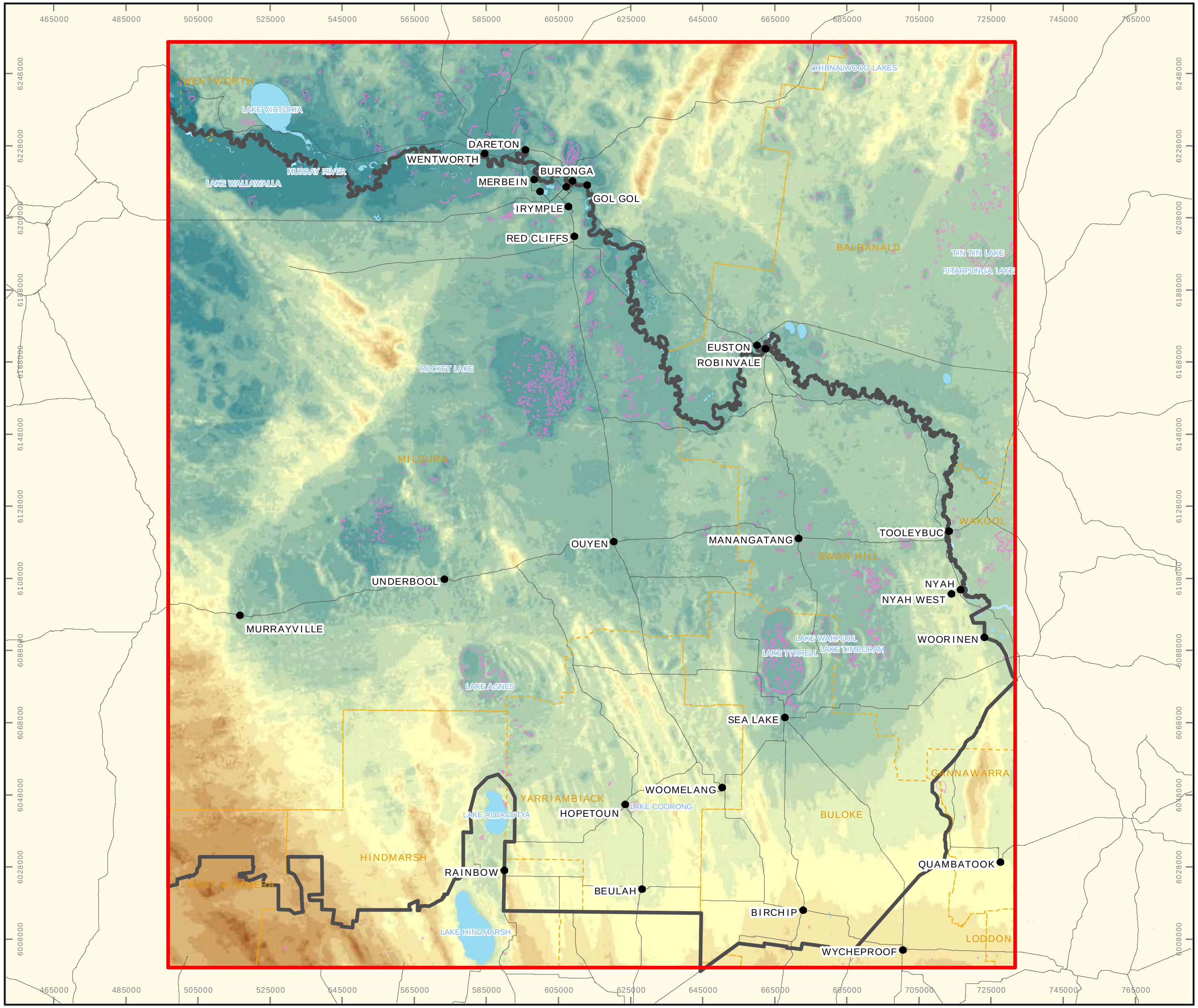

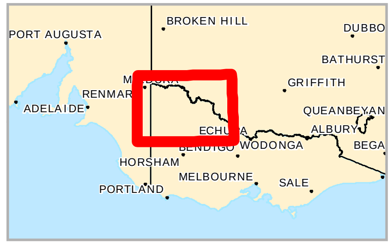

LEGEND

- Localities
- LGAs
- River Murray
- EM3 Model Boundary
- Main Roads
- Mallee CMA Boundary

Suface Water Bodies

- Perennial
- Non-perennial

Elevation (mAHD)

< 20	70 - 80	130 - 140
20 - 30	80 - 90	140 - 150
30 - 40	90 - 100	150 - 160
40 - 50	100 - 110	160 - 170
50 - 60	110 - 120	170 - 180
60 - 70	120 - 130	

N

0 5 10 20

Kilometres

SCALE 1:1,500,000 @ A4

GDA 1994 MGA Zone 54

DATA SOURCES

GA: Localities, Lakes,, Roads, LGAs

AQT: EM3 Model, DEM

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FIGURE 2.2

Topography - DEM

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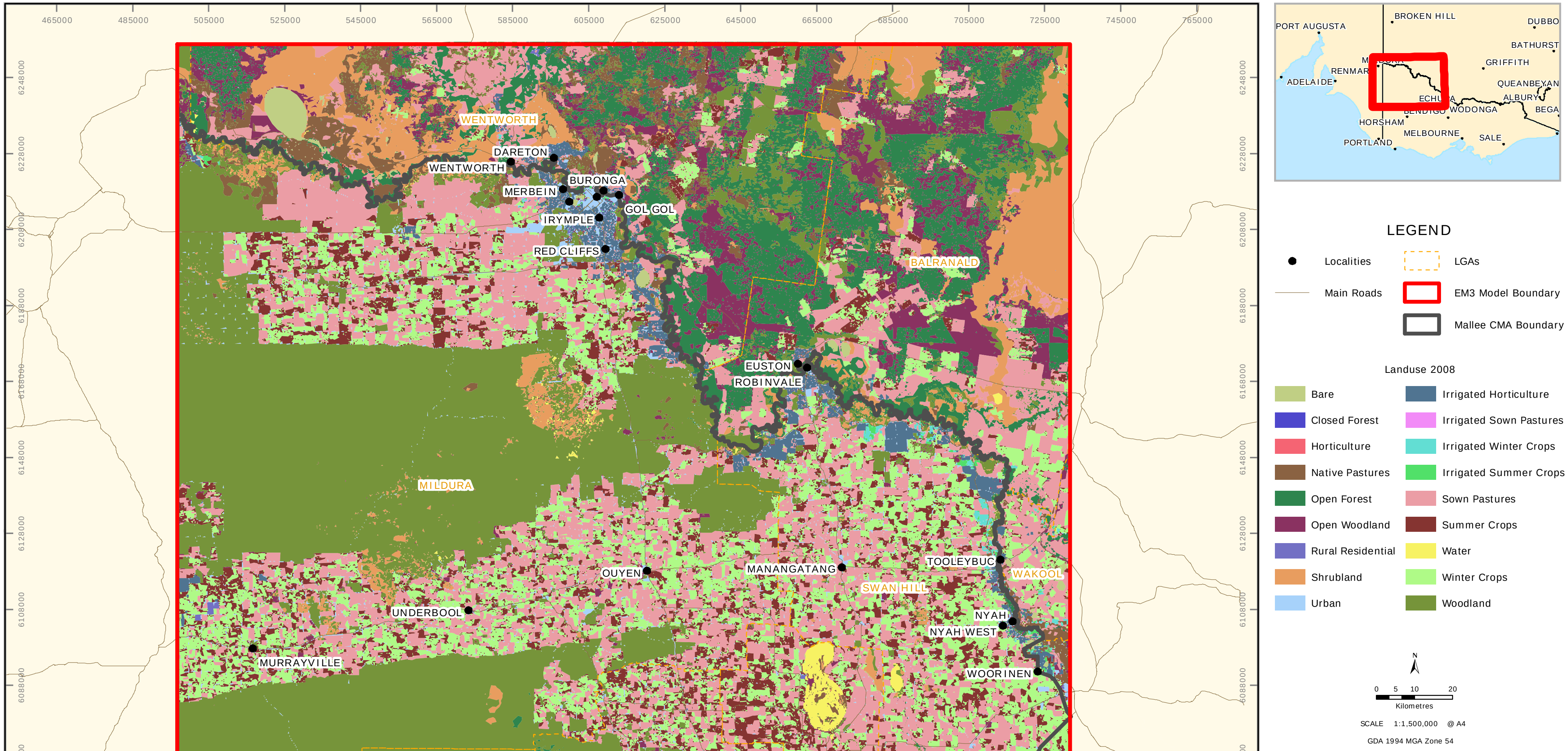

DATA SOURCES

GA: Localities, Lakes, Rainfall, Roads, LGAs
AQT: EM3 Model

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FIGURE 2.3

Landuse in the Mallee CMA

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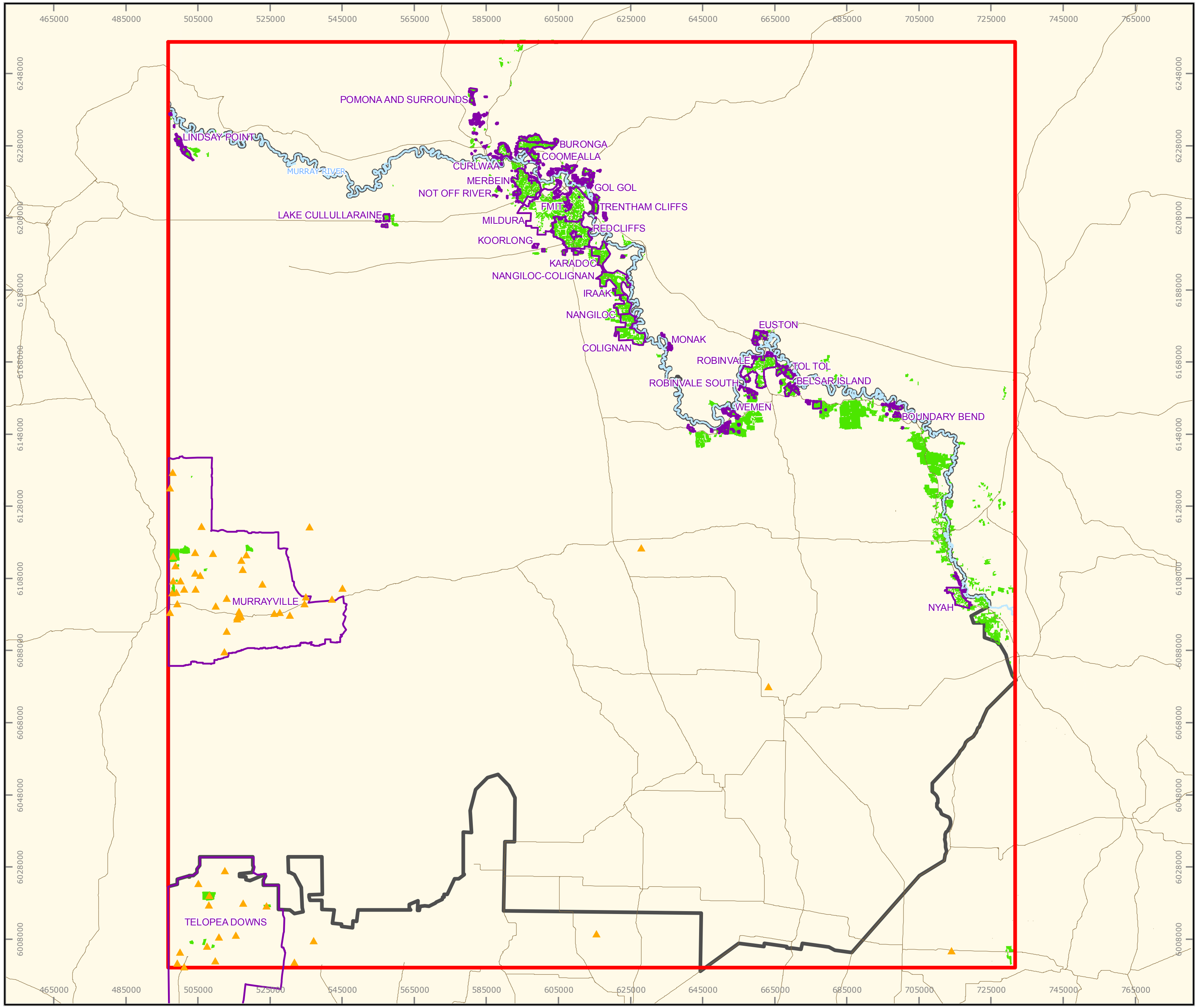

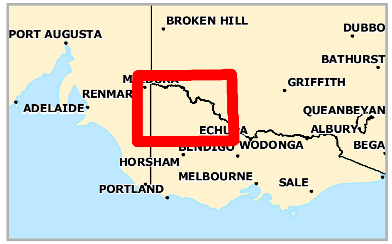

DATA SOURCES

GA: Localities, Lakes, Roads
AQT: EM3 Model, Bores

Disclaimer: While all reasonable care has been taken to ensure the information contained on this map is up to date and accurate, no guarantee is given that the information portrayed is free from error or omission. Please verify the accuracy of all information prior to use.

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FIGURE 2.4

Irrigation in the Mallee CMA

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2.5 HYDROLOGY

2.5.1 RIVER MURRAY

The Murray-Darling Basin is Australia's largest river system and is fed mainly by runoff from the Great Dividing Range, up-catchment of the study area. The River Murray runs along the northern boundary of the Mallee CMA in a south-east to north-west direction from Swan Hill, meeting the Darling River at Wentworth, and then continuing on westwards to the SA border (see Figure 2.5).

In the unaltered, natural system, the flows in the River Murray were highly variable, cycling between baseflow and flooding events. River regulation in the 1920s to provide for river navigation and reliable water supplies for potable and irrigation uses significantly reduced the frequency and magnitude of the flooding events (Jolly, 1996).

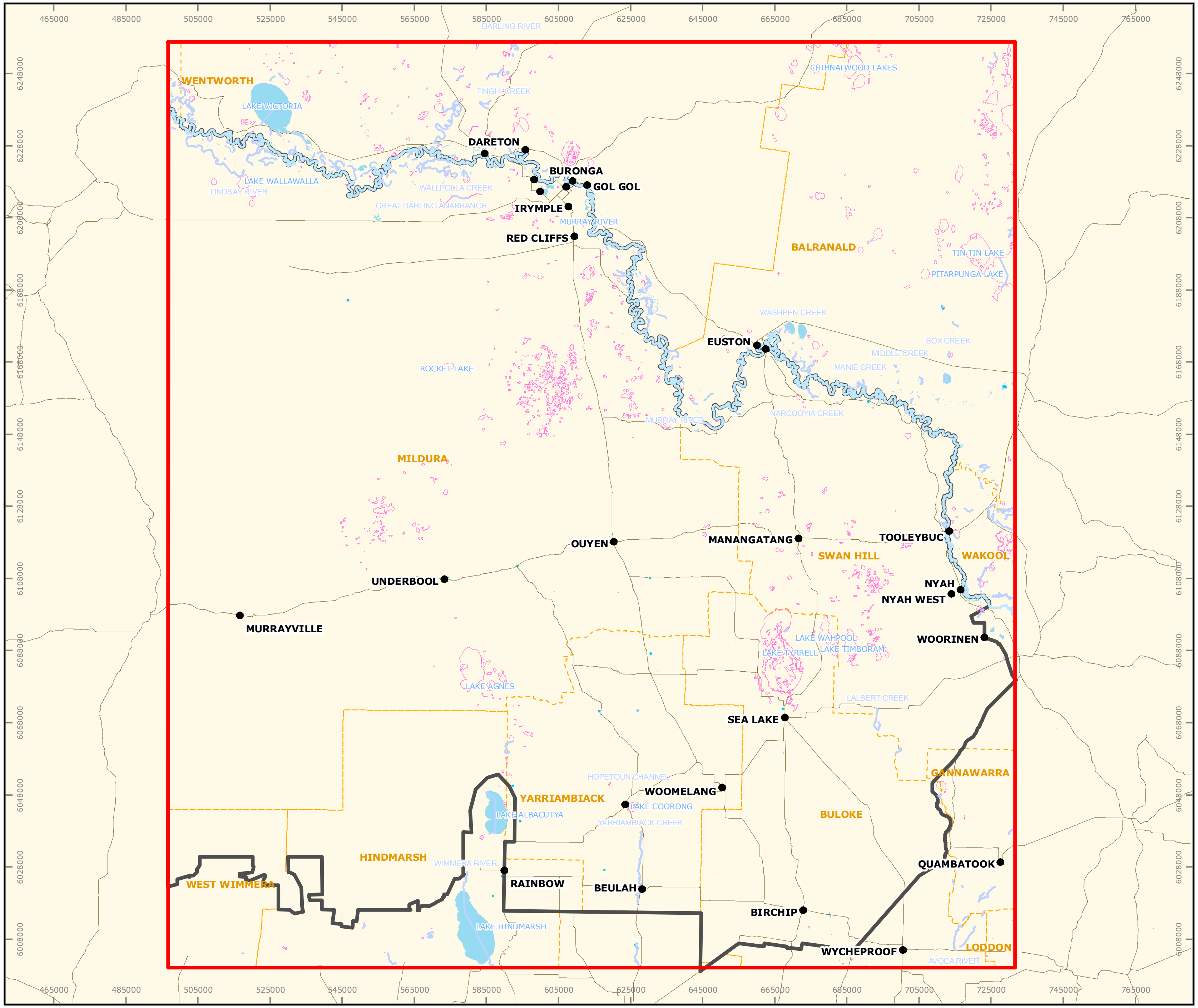
Flows are regulated by the Locks between the SA border (Lock 6 at Chowilla in SA), through to Lock 10 at Wentworth and Lock 11 at Mildura, with a long reach to Lock 15 at Euston. The variation in water level observed at flow stations immediately upstream and downstream of the Lock 11 and upstream of Lock 10 is shown on Figure 2.6, along with some short term monitoring data upstream of Lock 11 at Psyche Bend and Mallee Cliffs. Annual average river levels are shown on Figure 2.7.

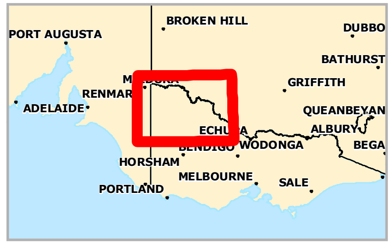
This data (which falls within the EM2 model domain) has been used along with the centreline river bathymetry estimated from water depth provided by NanoTEM reduced to m AHD levels using relevant pool level, and is expected to be accurate to within 1 to 2 m. This data indicates that the river bathymetry typically varies between 25 and 29 m AHD downstream of Mildura Weir, and 27 and 34 m AHD upstream. There is evidence of sediment build-up behind Mildura Weir for up to 6 km. The data has been extrapolated in other areas, constrained by measurements of river level where available, as discussed in more detail in Section 3.4.

2.5.2 WIMMERA RIVER AND ASSOCIATED LAKES

The Wimmera River is the longest river in Victoria that does not flow into the ocean. The river and its tributaries flow from Mt Cole and Pyrenees Ranges in the south-east and the Grampians in the south to terminal lakes including Lakes Hindmarsh and Lake Albacutya (see Figure 2.5).

Lake Albacutya is listed as a wetland of international significance (Ramsar site) under the international Convention on Wetlands. However, changes in land and water use over many decades mean Lake Hindmarsh and Lake Albacutya are now usually dry. Also in many years flows do not reach these terminal lakes and the river contracts to a series of pools of varying sizes. The health of Wimmera River is expected to improve under the Wimmera Mallee Pipeline project, outlined in Section 2.5.3.





LEGEND

- ● Localities
- Watercourses
- River Murray
- Main Roads
- LGAs
- EM3 Model Boundary
- Mallee CMA Boundary
- Surface Water Features

Suface Water Bodies

- Perennial
- Non-perennial

N

0 5 10 20
Kilometres

SCALE 1:1,500,000 @ A4

GDA 1994 MGA Zone 54

DATA SOURCES
GA: Localities, Lakes, Rainfall, Roads, LGAs
AQT: EM3 Model

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FIGURE 2.5

Hydrological Features

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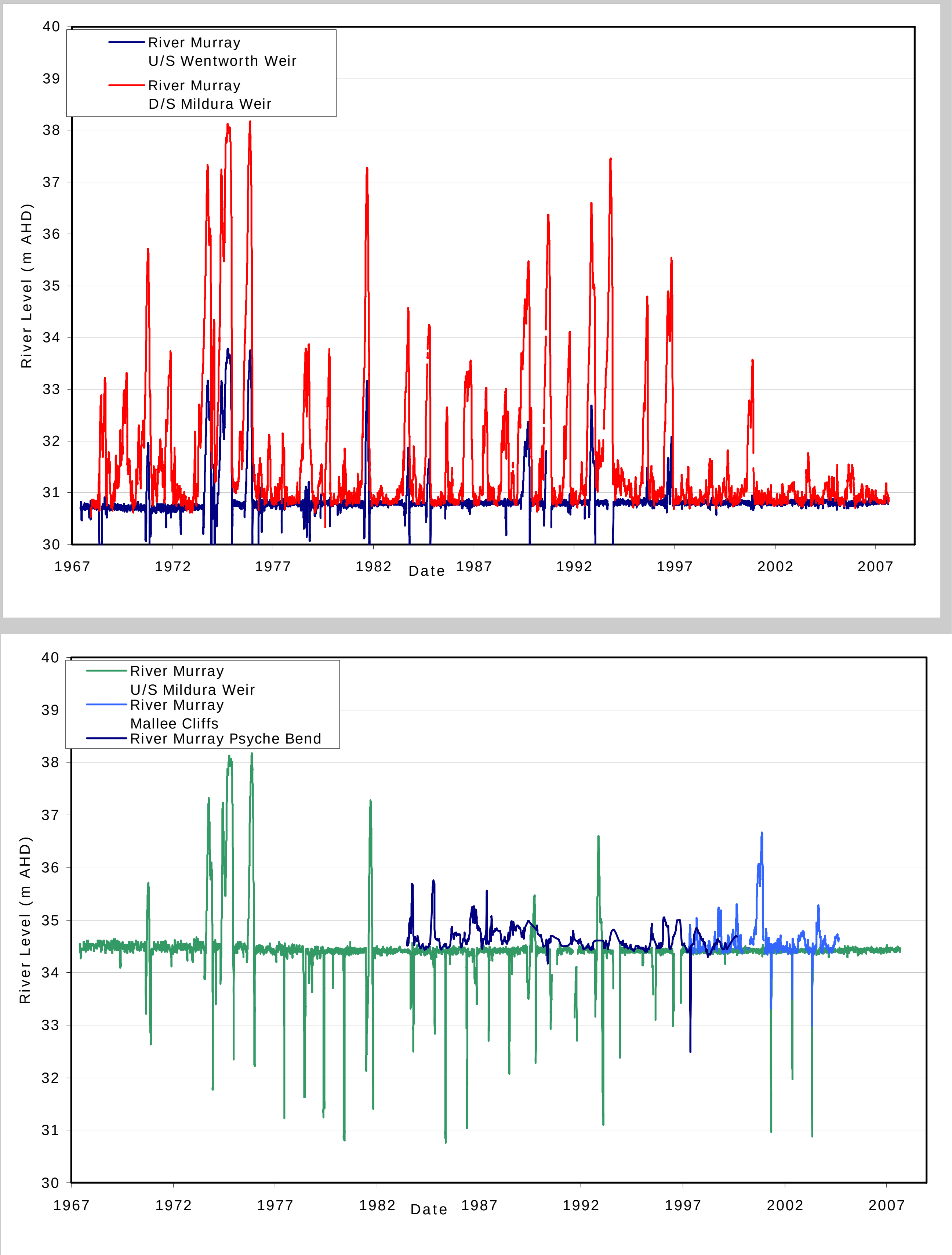

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HISTORICAL RIVER LEVELS FIGURE 2.6

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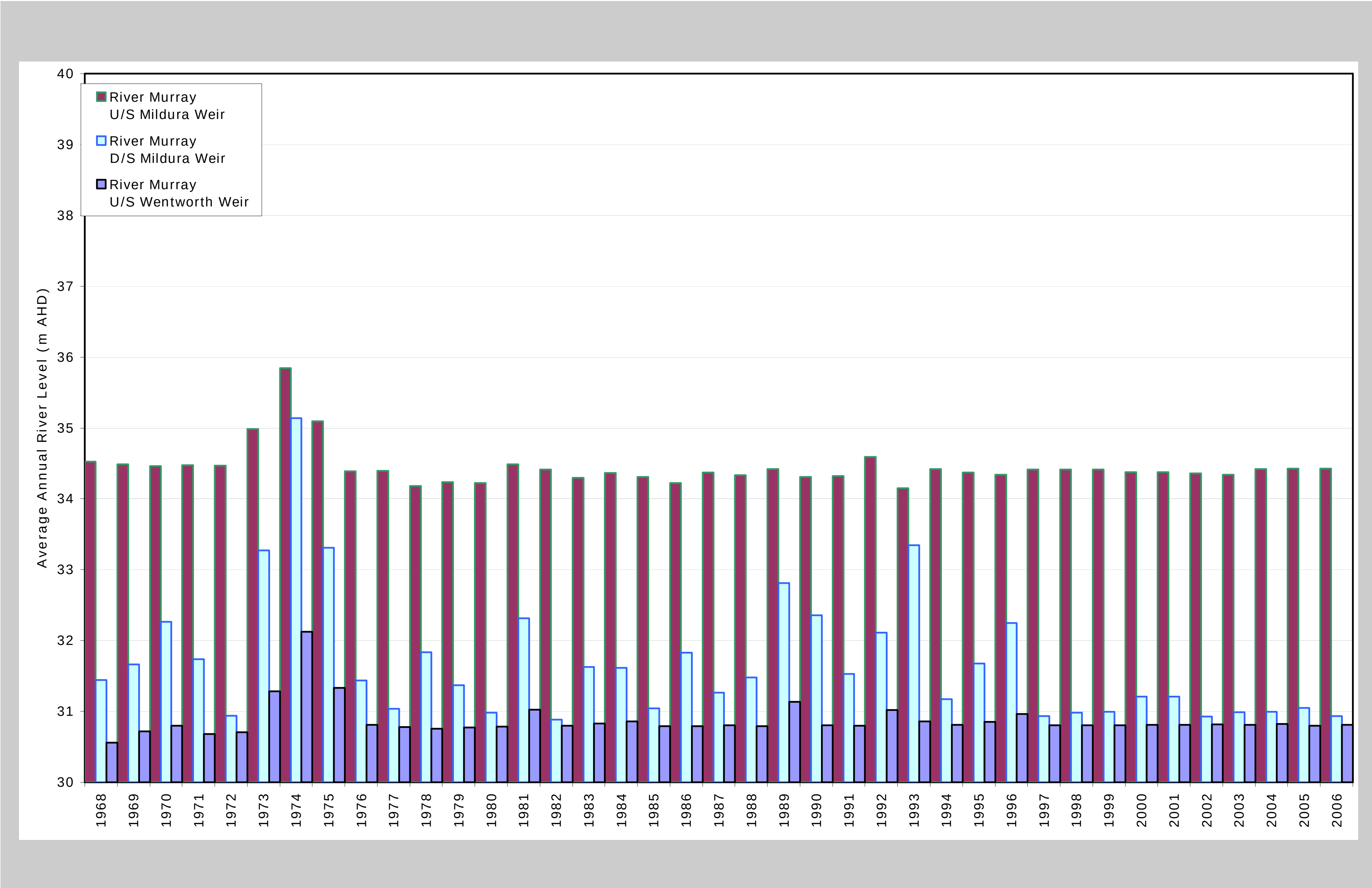

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ANNUAL AVERAGE RIVER LEVELS FIGURE 2.7

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2.5.3 WATER SUPPLY CHANNELS AND PIPES

The Northern Mallee Pipeline Project, which started in 1992 with construction of a pipeline system services 650,000 hectares from Swan Hill to Sea Lake, to Ouyen, Underbool and Manangatang. More recently, this system was extended to include Patchewollock and Speed then to the Cannie Ridge area north of Quambatook, bringing the total piped area to 820,500 hectares. These areas draw water from the River Murray.

The Wimmera-Mallee (open) channel system that currently services the southern sections of the region is unsustainable, with 85% of water in the system wasted through seepage and evaporation. Over 16,000 kilometres of open channels provide stock and domestic requirements in the region.

The Wimmera Mallee Pipeline involves the construction of almost 9,000 kilometres of reticulated pipeline which will replace the open channel system. The project will supply stock and domestic water to approximately 6,000 rural customers and 36 towns across the Mallee-Wimmera region. The project is estimated to be completed by 2010.

The main source of water for the Wimmera Mallee Pipeline system will be Bellfield Reservoir near Halls Gap in the Grampians. Water from Taylors Lake will supplement the system as required, whilst the River Murray will be the source of water for the Berriwillock-Culgoa area.

There are seven Supply Systems within the Pipeline network, five of which have some portions within the Mallee CMA region. The current state of these (as of 27 January 2009) Supply Systems are outlined below:

- Supply System 1 – construction of this section of the pipeline is complete. GWM Water operations group are now managing this section of the pipeline, with supply of Lake Bellfield water to townships including Rainbow and Yaapeet (both located within the Mallee CMA);
- Supply System 2 – Construction is complete, with full supply to farms available. Supply is secured to towns including Brim, Beulah, Hopetoun, Lascelles and Woomelang (all located within the Mallee CMA);
- Supply Systems 3 and 4 – construction commenced in May 2008 for Supply System 3 (Birchip) and Supply System 4 (Wycheproof);
- Supply System 5 – the total length of pipe has now been installed. GWM Water operations group are now managing this section of the pipeline, with supply of River Murray water to Nullawil, Berriwillock and Culgoa and farms within the supply zone.

2.6 GEOLOGY

2.6.1 GEOLOGICAL STRUCTURE

Airborne geophysical surveys carried out in the past of the Mallee CMA have identified the presence of the north-south trending faults in the pre-Permian basement rocks. Faults have generally the potential to either provide preferential flowpaths or compartmentalise groundwater flow if they are less permeable than the surrounding environment.

The pre-Permian faults identified from the geophysical surveys are assumed to have very limited impact on groundwater flow in the overlying Cainozoic sedimentary cover with few notable exceptions.

2.6.2 SEDIMENTARY STRATIGRAPHY

At the regional scale, the pre-Tertiary basement is overlain by basal sediments of the Renmark Group, overlain in turn by a complex sequence of Oligo-Miocene marine sediments comprising Ettrick Formation, Geera Clay and Winnambool Formation. This Oligo-Miocene package of sediments is in turn overlain by sediments deposited during a Pliocene transgressive phase.

The Renmark Group sediments form a near-continuous sheet across the model area, and are comprised of sands, silts, carbonaceous clays and lignite's (Brown and Stevenson, 1991). The basal parts of the sequence are much sandier. The Renmark Group is overlain by the transgressive sediments of the Murray Group. The initial sedimentation of the Group is the

Ettrick Formation, a clay layer of up to 20 metres in thickness. This formation is found in the western parts of the model area. Further to the east, the onset of marine sedimentation in the Murray Group is marked by deposition of Geera Clay. The marine transgression did not cover the entire model area, so that the Oligo-Miocene shoreline occurred towards the eastern margin. In these parts, the Renmark Group (Olney Formation) continued to be deposited on the landward side of the shoreline.

In the west, the Ettrick Formation is overlain by the Murray Group Limestone (comprised of layers of limestone, marl and calcarenite). The limestone grades into marls of the Winnambool Formation further east, and this in turn grades into the Geera Clay, representing sedimentation moving from open water deposits in the west, to restricted marine estuarine conditions in the east. The Oligo-Miocene sequence on the landward side of the shoreline is comprised of contiguous Renmark Group sedimentation.

The Pliocene sediments comprise the relatively impermeable clays of the Bookpurnong Formation, which in turn are overlain by the major aquifer unit of the Parilla Sands. The Bookpurnong Formation overlies directly the Murray Group Limestone (where it occurs in the western part of the model area). The Bookpurnong Formation also overlies sediments of the Winnambool Formation and the Geera Clay. In the case of the latter association (that is, Bookpurnong Formation overlying Geera Clay), it is difficult to definitively assign fine grained sediments to either of the two units based on drillers' logs. The Bookpurnong Formation does not extend across the entire model area and is confined to the central and western parts. This means that the Parilla Sands directly overlies Geera Clay in the central eastern parts of the model area, and directly overlies Renmark Group in the most easterly parts.

The Pliocene Parilla Sands form a reasonably continuous sheet across the study area. They comprise a complex sequence of interbedded sands, silts and clays deposited in a beach ridge and swale environment that trends roughly north-west to south east, in large arcuate trends (Brown and Stevenson, 1991). The elevation difference between the swale and the ridge crest can be substantial, and the Parilla Sands vary in thickness between 10m and 60m. The isopach of the Parilla Sands is shown in Appendix A.

In the eastern part of the EM3 model domain, fluvial and lacustrine sediments of the Pliocene Shepparton Formation exist above, or can be intercalated with either the lateral equivalents of the Pliocene Parilla Sands (i.e. locally the Wandella Sandstone, Tragowell Member or Kerang Sand Member), or with sediments recognised as the Calivil formation. Brown and Stephenson (1991) report the lithology of the Shepparton Formation as being unconsolidated to poorly consolidated clay, silt, silty clay with some developed lenses of fine to coarse sand with some gravel.

The majority of the Study Area was covered by a lake that was formed during Early Pleistocene. The sediments that were deposited in Lake Bungunnia are collectively called the Blanchetown Clay. These clays cap the Parilla Sands below elevations of about 65 m AHD.

A period of weathering prior to the development of Lake Bungunnia resulted in deep weathering on the top of the Parilla Sands. This weathering has produced a clay-rich layer in places. The overall thickness of clay comprising the Blanchetown Clay and the weathered Parilla Sands can be up to 50 metres, but is highly variable.

Lake Bungunnia dried at about 600,000 yrs BP, and the ancestral River Murray subsequently carved a trench through the old lake floor. This trench has been successively eroded and back-filled over time in response to the cyclical wetting and drying of the landscape. The final depositional phase has left a coarser sand layer buried at the base of the trench (the Monoman Formation, also referred to as the Channel Sands), with a finer grained overlying layer (the Coonambidgal Formation), which is generally only partially saturated. In some places the erosion prior to the deposition of the trench sediments resulted in the removal of the Blanchetown Clay and exposure of the Parilla Sands prior to the deposition of the Monoman Formation.

As the ancestral Lake Bungunnia dried, and in response to the cyclical wetting and drying of the climate, groundwater discharge features became established in the low points of the landscape

in areas away from the Murray River. These features led to the deposition of gypseous lake deposits collectively identified as Yamba Formation.

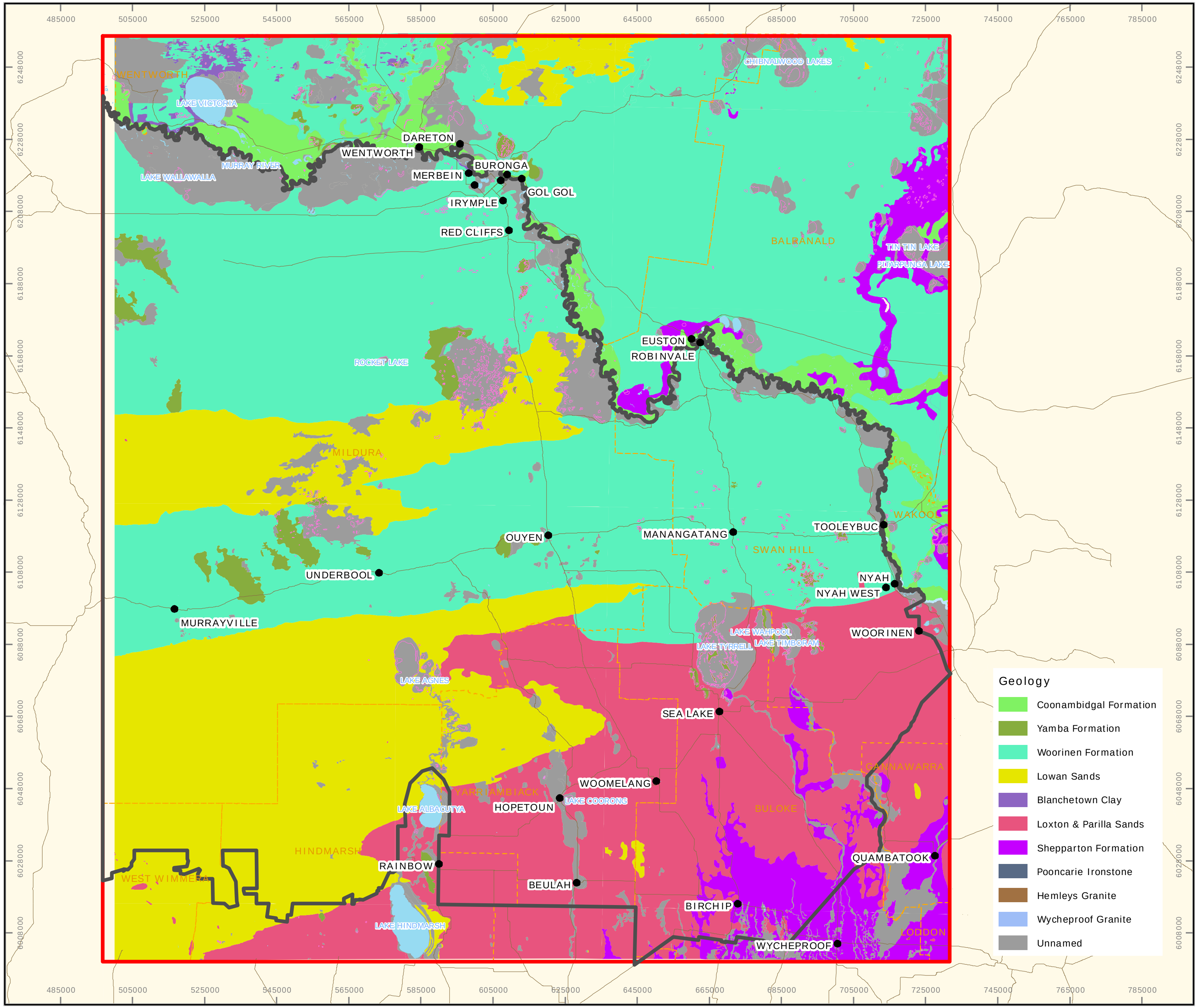
The Parilla Sands was reworked into a series of linear dunes over drier periods of recent climate. These sands are known as the Woorinen Formation and give the region its current landscape character. The dune systems can be up to 10 metres thick and tend to blanket most of the landscape.

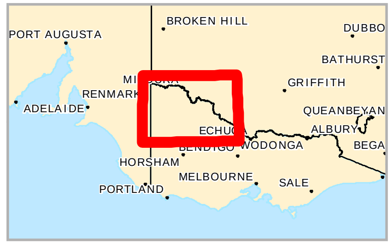
The surface geology map showing the extent of Quaternary deposits and outcropping Pliocene sediments is presented in Figure 2.8.

A subtle influence on the land surface can be seen from the underlying basement structure beneath the Tertiary sediments. This influence is manifest as areas of differential subsidence and uplift, forming small depocentres where the sedimentary sequence thickens over areas of subsidence and thins over areas of uplift. In some uplifted areas (on the Neckarboo Ridge in NSW), there has been ongoing uplift into the Late Cainozoic, causing the shallow Blanchetown Clay to be elevated higher than elsewhere and absent at higher elevations.

The digital elevation model highlights the some major geological structures, including the major uplift feature of the Neckarboo Ridge in NSW (Figure 2.2). More subtle differential movement at the local scale has resulted in the relative thickening of units in the down thrown parts of the landscape.

The result of this tectonic activity has been the thickening of the Parilla Sands over the depocentres from about 50 to 60 m. Similarly, the Parilla Sands can be seen to thin over the structural high areas, with the unit less than 10 m thick in these areas. The major depocentres also correlate with the maximum thickness of up to 50 m of Blanchetown Clay. The areas of uplift correlate with regions where Blanchetown Clay is thin or non-existent.





LEGEND

- Localities
- Main Roads
- LGAs
- Mallee CMA Boundary
- EM3 Model Boundary

Suface Water Bodies

- Non-perennial
- Perennial

SCALE 1:1,500,000 @ A4

GDA 1994 MGA Zone 54

DATA SOURCES

GA: Localities, Lakes, Rainfall, Roads, LGAs
AQT: EM3 Model

Disclaimer: While all reasonable care has been taken to ensure the information contained on this map is up to date and accurate, no guarantee is given that the information portrayed is free from error or omission. Please verify the accuracy of all information prior to use.

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FIGURE 2.8

Surface Geology of the Mallee CMA

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2.7 HYDROGEOLOGY

2.7.1 AQUIFER AND AQUITARD UNITS

There are three major regional aquifers: the deep, confined Renmark Group, the Murray Group Limestone in the western portion and the shallow, unconfined Parilla Sands (Figure 2.9). The sands of the Monoman and Coonambidgal Formation form a less extensive assemblage of laterally discontinuous aquifer units that underlies the Murray Trench and is therefore limited to the Trench alignment.

In the western parts of the study area, the Murray Group Limestone aquifer overlies the Renmark Group aquifer, and in turn is overlain by the Parilla Sands aquifer. In the central-eastern parts the deeper Renmark Group is separated from the Parilla Sands by between 100 to 180 m of Oligo-Miocene and Pliocene clays (Ettrick, Geera, Winnambool and Bookpurnong Formations). Further east, the Parilla Sands and Renmark Group aquifers are contiguous (i.e. absence of intervening aquitards, including Ettrick Marl). **The base of the Parilla Sand aquifer is considered to be the base of the shallow aquifer system for the purposes of this study (i.e. the system that hosts the shallow water table and stream-aquifer interaction processes that are important to quantify for the ecoMarkets initiative).**

The Blanchetown Clay acts as a semi-confining layer on top of the Parilla Sands, but in some places the water table lies below the base of the clay. The Parilla Sands is predominantly confined, but also unconfined, specifically at two locations, part of the Redcliffs and Merbein irrigation districts (pers. comm. Andrew Telfer, 2007). The Blanchetown Clay is absent within the Murray Trench between Dareton and Mallee Cliffs, on the Neckarboo Ridge and several other isolated locations.

At the local scale within the Murray Trench, there is a complex relationship between the Monoman Formation underlying the floodplain and the broader Blanchetown Clay - Parilla Sands sequence. At locations where the Blanchetown Clay is absent from the Murray Trench due to tectonic raising and lowering, the Monoman Formation is in direct contact with the Parilla Sands. Outside these locations the Blanchetown Clay underlies and separates the Monoman Formation from the Parilla Sands.

Within the floodplain, the silts and clays of the Coonambidgal Formation act as a semi-confining layer to the Monoman Formation, such that the aquifer has a confined response over short pumping timeframes, and an unconfined response over longer timeframes (pers. comm. Andrew Telfer, 2007).

The Renmark Group aquifer in the model area is part of a larger regional aquifer system where flow originates outside of the model area and continues on through the model area. Likewise, the Murray Group Limestone aquifer is generally recharged outside the model area and except for areas of evaporation from the shallow water table (for instance, in the Pink Lakes area near Murrayville), it discharges laterally across the model area boundary. The Renmark Group is confined by the overlying sediments of the Oligo-Miocene sequence, and the Murray Group Limestone aquifer is confined by the overlying Bookpurnong Formation.

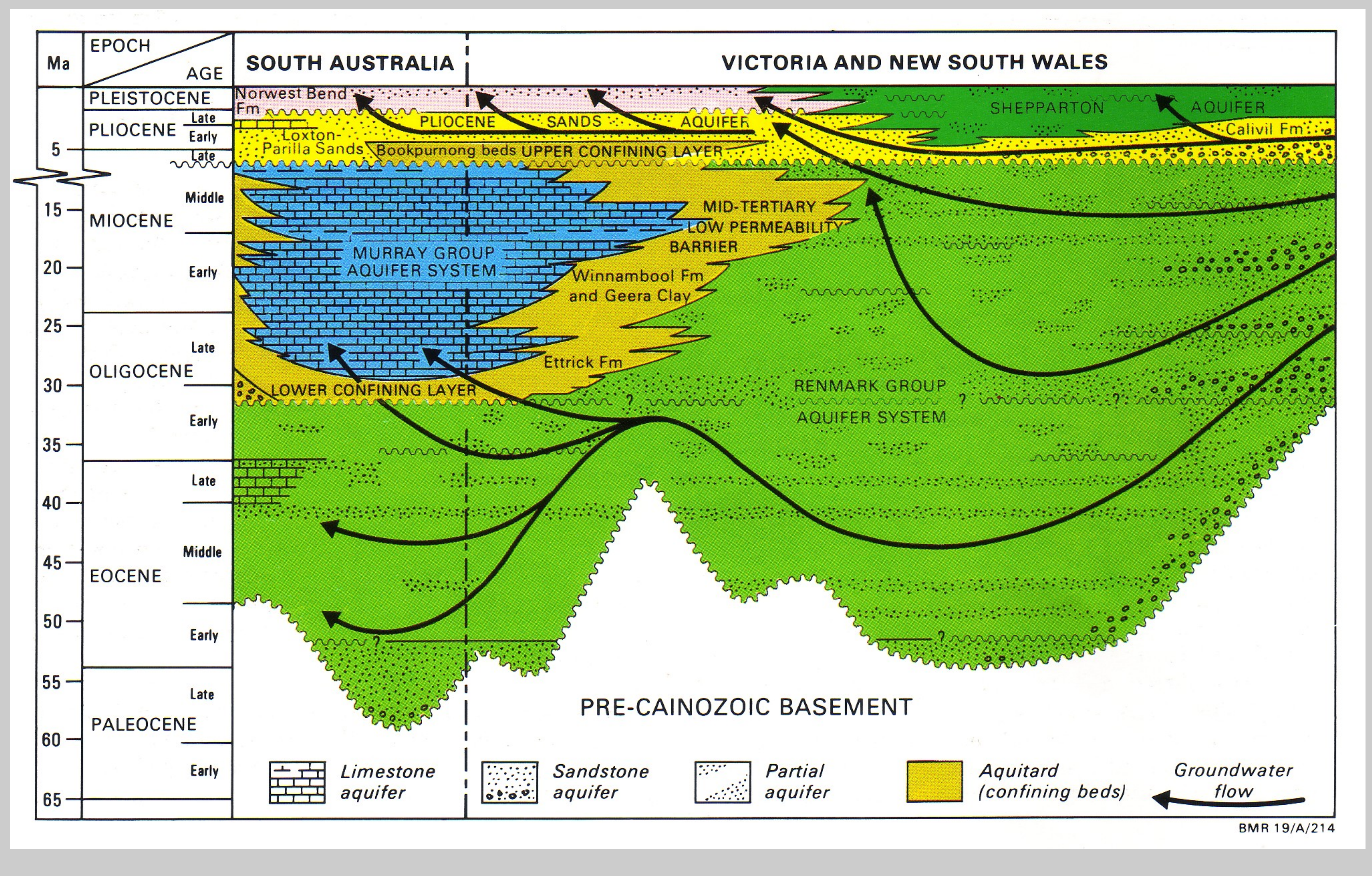
Groundwater generally flows vertically upwards from the Renmark Group to the Murray Group Limestone aquifer across the Ettrick Formation.

2.7.2 GROUNDWATER FLOW AND LEVELS

Regional groundwater flow within the major aquifer units of the Parilla Sands is generally from east to west and southeast to northwest.

Groundwater mounding occurs within the Parilla Sands under irrigation areas in Victoria and NSW, with the largest mound occurring beneath Mildura/Redcliffs/Merbein. These mounds give rise to groundwater gradients towards the floodplains and river.

The structural highs and lows imposed by the tectonism in the area have also caused modification to the pattern of groundwater flow, as does the influence of the Lake Tyrrell discharge complex. In some places, such as the Neckarboo Ridge in the northeast, the elevation of the base of the Parilla Sands alters the flow paths of the regional groundwater flow system, pushing fluxes towards Mallee Cliffs and away from the higher elevations.



REGIONAL AQUIFER SYSTEMS OF THE MURAAY BASIN (SOURCE: BROWN AND STEVENSON 1991) FIGURE 2.9

In the Lake Tyrrell area, groundwater flow patterns are influenced by the uplift across the Tyrrell Fault. There has been substantial movement on the fault over time, with the western side of the fault uplifted relative to the east. The size of the uplift has meant that groundwater flow in the Parilla Sand aquifer has been disrupted. This has been coupled with the shallow water levels in the area to the east of the fault to produce a large region of active discharge via evapotranspiration, centred in Lake Tyrrell. At the lake itself, the evaporative process has been so dominant for such a long period of time that it has produced a brine pool within the Parilla Sand aquifer under the lake. The disruption to groundwater flow caused by the evaporation process has turned this feature into a terminal groundwater flow system, with a segment of the Parilla Sand aquifer flow now terminating at the Lake.

The absence of the Blanchetown Clay within the Murray Trench through the majority of the Study Area, apart from small areas around Robinvale, results in the Parilla Sands being hydraulically connected to the Monoman Formation. Groundwater flow within the Monoman Formation generally reflects flow within the Parilla Sands with local hydraulic gradients towards the river downstream of the Locks and weirs, within a regional groundwater flow system of flow generally from south and east to the north and west. The raised weir pool level upstream of the Locks causes local gradients to be generally away from the river at these locations.

2.7.3 AQUIFER PARAMETERS

A number of studies have been undertaken to examine the hydraulic properties of the Parilla Sands and Monoman Formation at various locations along the river. These studies include pumping tests, SIS bore shut down tests, particle size analysis of boreholes and calibrated groundwater models. Few studies have been undertaken to determine hydraulic properties in the lower lithological units. The available studies for the units of interest are summarised in Table 2.1.

Table 2.1: Summary of Hydrogeological Parameters from Previous Studies

Reference	Method	Target Geological Unit	Transmissivity (m^2/day)	Hydraulic Conductivity (m/day)	Storage
Merrick & Middlemis (1988)	Calibrated Model	Monoman Formation	150		0.1
Middlemis (1990) & Merrick *et al.* (1999)	Calibrated Models	Monoman Formation	45-270		0.1-0.01 (S)
Thorne *et al.* (1989)	Pumping tests	Monoman Formation	150-220		0.001
SKM (2005a)	Literature review	Monoman Formation	70 – 400	K_H = 10 – 40	0.05 – 0.3 (storage Coefficient)
SKM (2005b)	Calibrated Model	Monoman Formation		K_H = 3.0 – 20.0 K_v = 0.01 – 20.0	
Hodgkin *et al.* (2007)	Calibrated Model	Monoman Formation		K_H = 15 K_v = 1.5	0.1 (Sy)
AWE (2007)	Shut down tests	Parilla Sands + Monoman Formation	61-980		--
AWE (2007)	Particle size analysis (low reliability)	Parilla Sands + Monoman Formation	130-1,300		--
Ghassemi *et al.*	Calibrated	Parilla Sands	100-300		0.02

Reference	**Method**	**Target Geological Unit**	**Transmissivity (m^2/day)**	**Hydraulic Conductivity (m/day)**	**Storage**
(1987)	Model	+ Monoman Formation			
Ghassemi *et al.* (1987)	Pumping tests	Parilla Sands + Monoman Formation	30-350		0.001-0.05
AWE (2007)	Particle size analysis (low reliability)	Parilla Sands + Monoman Formation	0.02-14		--
AWE (2007)	Shut down tests	Parilla Sands + Monoman Formation	290-2,100		0.0007-0.01 (S)
AWE (2007)	Particle size analysis (low reliability)	Parilla Sands + Monoman Formation	540-5,100		--
Thorne *et al.* (1989)		Blanchetown Clay		K_H = 0.0017 – 0.035	
SKM (2005a)	Literature review	Blanchetown Clay	0.0348 > 1.74 [sic]	K_H = 0.0348	0.05 – 0.3 (S)
SKM (2005b)	Calibrated Model	Blanchetown Clay		K_H = 0.035 [sic] K_v = 0.35 [sic]	
AWE (2009)	Pumping tests at Red Cliffs	Parilla Sands	655-2,400		0.1
Williams & Erny (2001)	Pumping tests	Parilla Sands	145-270		0.0003 to 0.02
Merrick & Middlemis (1988)	Calibrated Model	Parilla Sands	500		0.0001
Middlemis (1990) & Merrick *et al.* (1999)	Calibrated Models	Parilla Sands	120-500		0.0005-0.01 (S)
Aquaterra (2009c)	Pumping tests at Lake Gol Gol	Parilla Sands	129-449		0.0002-0.007 (S) 0.05-0.24 (Sy)
SKM (2005a)	Literature review	Parilla Sands	60 – 218	K_H = 1 – 4	1 – 7×10^{-4} (storage Coefficient)
SKM (2005b)	Calibrated Model	Parilla Sands		K_H = 1.0 – 5.0 K_v = 0.01 – 5.0	
Barnett and Osei-bonsu (2006)	Aquifer tests	Parilla Sands		K_H = 3 - 15	
Barnett & Osei-bonsu (2006)		Parilla Sands			0.1 (Sy)
Hocking & Dyson (2006)		Parilla Sands	100 – 200	K_H = 2 – 4	
Evans & Kellett	Literature	Parilla Sands		K_H = 0.1 – 10	

Reference	Method	Target Geological Unit	Transmissivity (m^2/day)	Hydraulic Conductivity (m/day)	Storage
(1989)	review				
Thorne *et al.* (1989)	Pumping tests	Parilla Sands	115-1,460		0.0001-0.001
SKM (2008a)	Literature review	Parilla Sands		K_H = 0.1 – 2.0	0.002 – 0.3 (S)
Cook *et al.* (2001)	Calibrated model	Parilla Sands		K_H = 3	
Evans & Kellett (1989)	Literature review	Shepparton Formation		K_H = 2 – 3 (regional) K_H = 25 – 100 (sandy lens)	
Evans & Kellett (1989)	Literature review	Calivil Formation		K_H (Upper end) = 230	
Barnett & Osei-bonsu (2006)		Bookpurnong Beds			10^{-5} (Ss)
SKM (2008a)	Laboratory tests	Bookpurnong Beds		K_v = $2x10^{-5}$ – $9x10^{-3}$	
SKM (2008a)	Pumping tests	Bookpurnong Beds		K_v = 0.0002	
Nolan-ITU (2004)	Calibrated model	Bookpurnong Beds		K_v = $1x10^{-5}$	
SKM (2008a)	Literature review	Bookpurnong Beds		K_v = $1x10^{-9}$ – $2x10^{-4}$	
Evans & Kellett (1989)	Literature review	Bookpurnong Beds		K_v = $1x10^{-4}$ – $5x10^{-4}$	
SKM (2008a)	Literature review	Bookpurnong Beds		K_H = $2x10^{-5}$ – $8x10^{-3}$	
Hodgkin *et al.* (2007)	Calibrated Model	Bookpurnong Beds, Lower Loxton Clay and Shells		K_H = $1x10^{-4}$ K_v = $1x10^{-4}$	0.001 (Sy) $1x10^{-6}$ (Ss)
Barnett & Osei-bonsu (2006)	Aquifer tests	Murray Group Limestone		K_H Mean = 3.8 K_H Range = 0.7 – 7.3	Average = $3.5x10^{-3}$ Range = $4.0x10^{-4}$ – $1.4x10^{-2}$ (S)
Barnett & Osei-bonsu (2006)		Murray Group Limestone			0.15 (Sy)
SKM (2008b)	Pumping tests	Murray Group Limestone	1.4 – 200		
Evans & Kellett (1989)	Literature review	Murray Group Limestone		K_H = 1 – 2 (north) K_H = 3 (south)	
Robinson (1992)	Pumping tests	Murray Group Limestone		K_v = 0.2	
SKM (1998a)	Pumping tests	Murray Group Limestone	5-580	K_H = 0.3 – 47.2	$1.2x10^{-4}$ – 2.9 x 10^{-2} (S)
SKM (1998b)	Calibrated model	Murray Group Limestone	455		

Reference	Method	Target Geological Unit	Transmissivity (m^2/day)	Hydraulic Conductivity (m/day)	Storage
SKM (2008a)	Literature review	Murray Group Limestone	500 - 1000	K_H = 4.0 – 8.0	0.1 – 0.15 (S)
SKM (2008a)	Literature review	Murray Group Limestone	700 - 1000	K_H = 2 – 15	$1x10^{-4}$(S)
SKM (2008a)	Literature review	Murray Group Limestone	1300 - 4200		0.1 (S)
CSIRO (2001)	Calibrated model	Murray Group Limestone		K_H = 0.5 – 7.5	
Hodgkin *et al.* (2007)	Calibrated Model	Murray Group Limestone		K_H = 0.5 – 1 K_v = 0.05 – 0.1	0.05 (Sy) $1x10^{-6}$ (Ss)
Evans & Kellett (1989)	Literature review	Geera Clay/ Winnambool Formation		K_H = $4x10^{-4}$ K_v = $2x10^{-5}$	
SKM (2008a)	Calibrated model	Geera Clay		K_v = $9x10^{-6}$	
SKM (2008a)	Laboratory tests	Ettrick Formation		K_v = $9x10^{-6}$	
SKM (2008a)	Pumping tests	Ettrick Formation		K_v = 0.0002 – 0.03	
Nolan-ITU (2004)	Calibrated model	Ettrick Formation		K_v = $2x10^{-5}$ – $1x10^{-6}$	
SKM (2008a)	Literature review	Ettrick Formation		K_v = $1x10^{-8}$ – $1x10^{-4}$	
Evans & Kellett (1989)	Literature review	Ettrick Formation		K_H = $4x10^{-4}$ K_v = $2x10^{-5}$	
Hodgkin *et al.* (2007)	Calibrated Model	Ettrick Formation		$1x10^{-6}$ (vertical leakance)	
Barnett & Osei-bonsu (2006)		Renmark Group			10^{-4} – 10^{-5} (Ss)
SKM (2008b)	Pumping tests	Renmark Group	640 - 810		
CSIRO (2001)	Calibrated model	Renmark Group		K_H = $4x10^{-4}$	
Hodgkin *et al.* (2007)	Calibrated Model	Upper Renmark Group		K_H = 1 K_v = 0.1	$1x10^{-6}$ (Ss)
Hodgkin *et al.* (2007)	Calibrated Model	Lower Renmark Group		K_H = 5 K_v = 0.5	$1x10^{-6}$ (Ss)
Evans & Kellett (1989)	Literature review	Renmark Group		K_H (Mean) = 2 K_H (Upper end) = 100 K_H:K_V ratio = 10:1 – 100:1	

2.8 SURFACE WATER AND GROUNDWATER INTERACTIONS

A range of surface processes interact with groundwater, causing aquifer systems to be recharged (inflow) or for groundwater to be discharged (outflow). The representation of these

processes in the model will depend on available knowledge with regard to the relationship of the feature to the water table (i.e. whether they act as areas of groundwater recharge or discharge).

Surface processes can recharge the groundwater system via:

- Diffuse recharge from rainfall;
- Deep drainage from irrigation;
- Disposal basins for stormwater, irrigation drainage water and/or SIS pumping (usually sited in natural depressions in the landscape);
- River recharge either from bank storage processes or over-bank flows on the floodplain;
- Interaction with surface water bodies, particularly the complex flow processes around the Lake Tyrrell system, and potential leakage from channel systems.

Groundwater can be discharged to the surface and be lost to the aquifer system via:

- Evapotranspiration from shallow water tables in low-lying parts of the landscape through direct evaporation, such as around salinas in dryland regions (notably Lake Tyrrell), in other low-lying parts of the landscape such as around Hattah Lakes, and the Noora complex and the Lindsay River anabranch system on the western margins, and/or through transpiration of vegetation, particularly on the floodplain;
- Groundwater pumping, such as irrigation and salt interception schemes (SIS);
- Groundwater discharge to the river, notably adjacent to irrigation mounds in the Sunraysia;
- Interaction with surface water bodies and/or disposal basins.

Each of these recharge and discharge processes are discussed below.

2.8.1 RAINFALL RECHARGE

The DSE provided the recharge data sets (from the ENSYM model) on a 100 metre grid.

Appendix B presents details on the findings from previous modelling investigations undertaken by Aquaterra in the Sunraysia (northern Mallee CMA) region. The details provide a description of the recharge processes and the issue of the time lags for land and water management change action at the land surface to reach the water table as effective recharge, which may be relevant to the further development of the Mallee CMA model.

2.8.2 FLUXES TO RIVER

Groundwater fluxes to the river (also called "baseflows") occur when the river and groundwater system is connected and there is sufficient groundwater flow gradient towards the river, i.e. river is gaining. Groundwater inflows into the river have been reduced by introduction of SIS schemes designed to limit the transfer of salinity loads from saline groundwater to the river.

The River Murray would be expected to lose rather than gain water to the groundwater systems through a significant portion of its course in the study area, based on information from the NanoTEM and Airborne EM surveys. The losing rather than gaining character of the river aquifer interaction has been confirmed by the recent work on EM4 in the Lindsay-Walpolla area.

2.8.3 EVAPOTRANSPIRATION

Evapotranspiration (ET) is the removal of water from soils as water vapour via a combination of direct evaporation and plant transpiration, and is affected by climate, availability of water and vegetation type (Bureau of Meteorology, 2001). The depth to which ET is typically assumed to have an effect is up to 8 m, depending on soil and vegetation type. The effect of evapotranspiration is typically assumed to reduce with depth from a maximum rate at the surface, to zero at the maximum depth (referred to as the 'extinction depth').

At locations where the water table is shallow (typically less than 3 m), ET has a direct influence on the water table. Areas of shallow water table exist within some areas of the floodplain and salinas or boinkas, notably Lake Tyrrell. As demonstrated during the development of EM1

(Aquaterra, 2007), ET is critical to proper simulation of floodplain processes, having a significant (interception) effect on ambient groundwater fluxes to the River Murray.

When the water table is deep (typically greater than 5 m), ET is removed from the shallow unsaturated soils and not directly from the water table. As this groundwater flow model is concerned with the saturated zone, ET from the unsaturated zone has been taken into account in the recharge functions, identified above. Recharge in this sense is the net deep (RZD) drainage to the aquifer resulting from rainfall plus irrigation, reduced by ET, runoff and drainage infrastructure.

Based on the Climatic Atlas of Australia (Bureau of Meteorology, 2001) which uses Morton's (1983) complementary relationship, the average actual ET in Mildura and Ouyen is 300 and 350 mm/year respectively. This is the actual ET that would take place in an area where there is limited water supply, i.e. limited by rainfall and a deep water table. In areas where there is a shallow water table, and hence a (relatively) unlimited water supply, ET may be much greater and could be as high as the average potential ET of 1,100 mm/year (Bureau of Meteorology, 2001).

Studies by CSIRO at Chowilla, SA, indicate that transpiration by river red gum is limited by salinity and soil properties, typically to around 1 to 2 mm/day (365 to 730 mm/year) (Thorburn *et al.,* 1993). Transpiration by Black Box is typically ten times lower at less than 0.1 to 0.3 mm/day (37 to 110 mm/year) (Thorburn *et al.,* 1993). In these studies, both species were identified as removing water from a depth of between 0.1 and 3.3 m. The effect of increasing ET rates, and varying extinction depths, will be explored during model calibration.

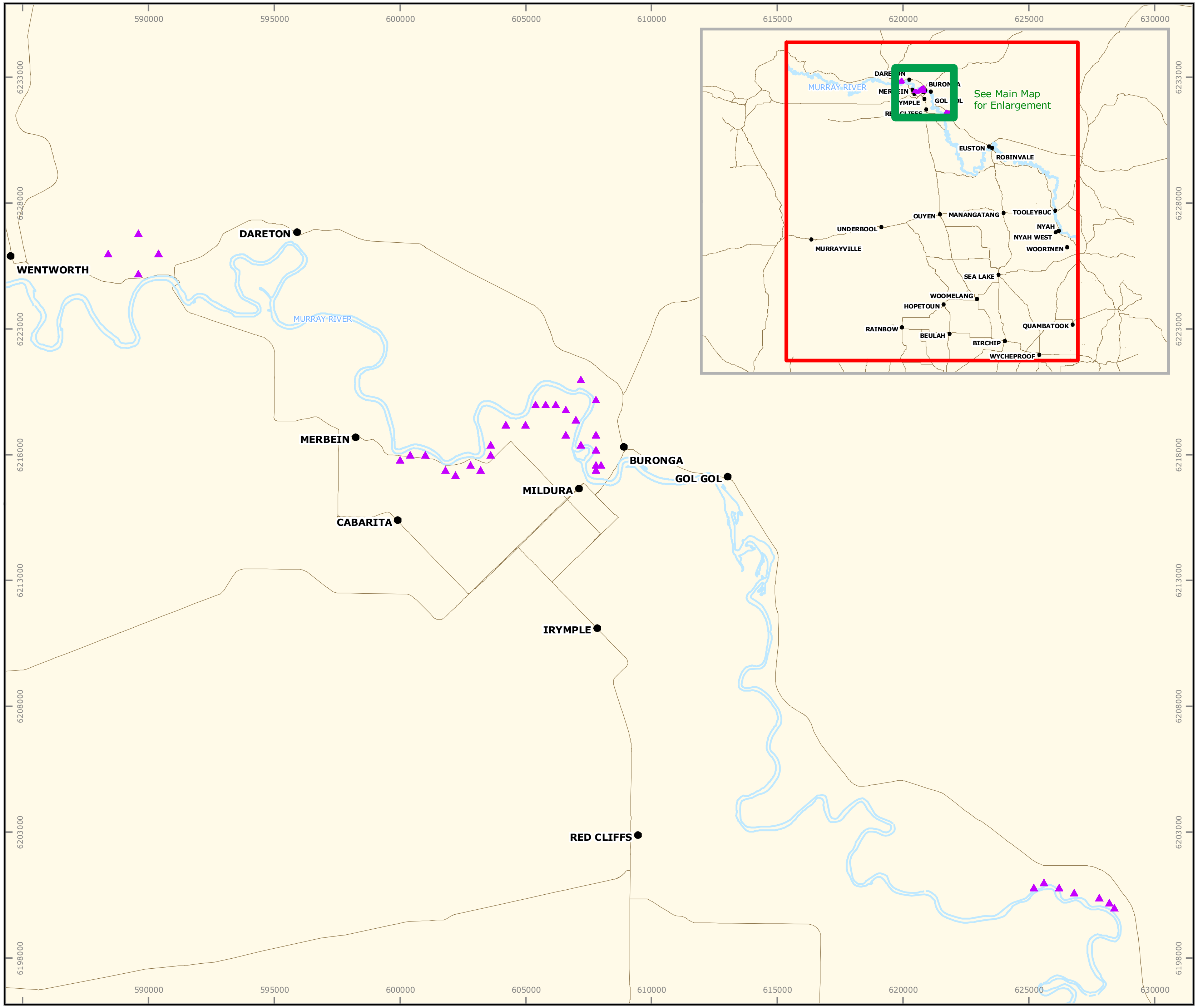
As an initial assumption, an extinction depth of 3 m was specified generally across the study area, with a maximum rate of 900 mm/year. This was subsequently changed during the transient calibration process, with adoption of 4 metres as a global extinction depth, and the maximum evapotranspiration rate being long term average ENSYM potential rate minus the actual ENSYM rate (to avoid double-counting of evapotranspiration between ENSYM and Modflow).

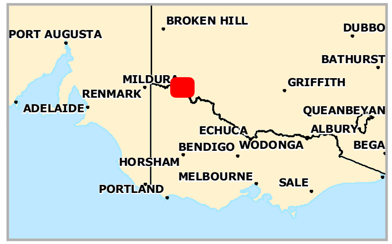
2.8.4 SIS SCHEMES

There are five pumped Salt Interception Schemes (SISs) that operate within the Study Area; Mildura-Merbein, Buronga, Curlwaa, Mallee Cliffs and Rufus River (see Figure 2.10). The schemes consist of a series of bores designed to intercept groundwater and salt fluxes to the River Murray within the Parilla Sands and/or Monoman Formation. A summary of the schemes is provided in Table 2.2:

Table 2.2: Existing SIS within Study Area

SIS Name	Number of Bores	Commencement Date
Mildura Merbein	19 in total (13 currently operating)	17 bores in 1980 1 new and 1 replacement bore in 1992
Buronga	8 in total (all currently operating)	5 bores in 1980 1 bore in 1991 2 bores in 2007
Curlwaa	5 in total (all currently operating)	1 bore in 1973 3 bores in 1975 1 bore in 1985
Mallee Cliffs	7 in total (all currently operating)	All bores in 2000-2001
Rufus River	4 wellpoint lines (each connected to about 40 wellpoints)	Commissioned in 1983





LEGEND

- SIS Bores
- Localities
- Main Roads
- EM3 Model Boundary

N

0 1 2 4
Kilometres

SCALE 1:215,000 @ A4

GDA 1994 MGA Zone 54

DATA SOURCES
GA: Localities, Lakes, Roads
AQT: EM3 Model, Bores

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FIGURE 2.10

Salt Interception Scheme (SIS) Locations - Layer 2

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DATE	18/03/10	JOB NO.	A53 018

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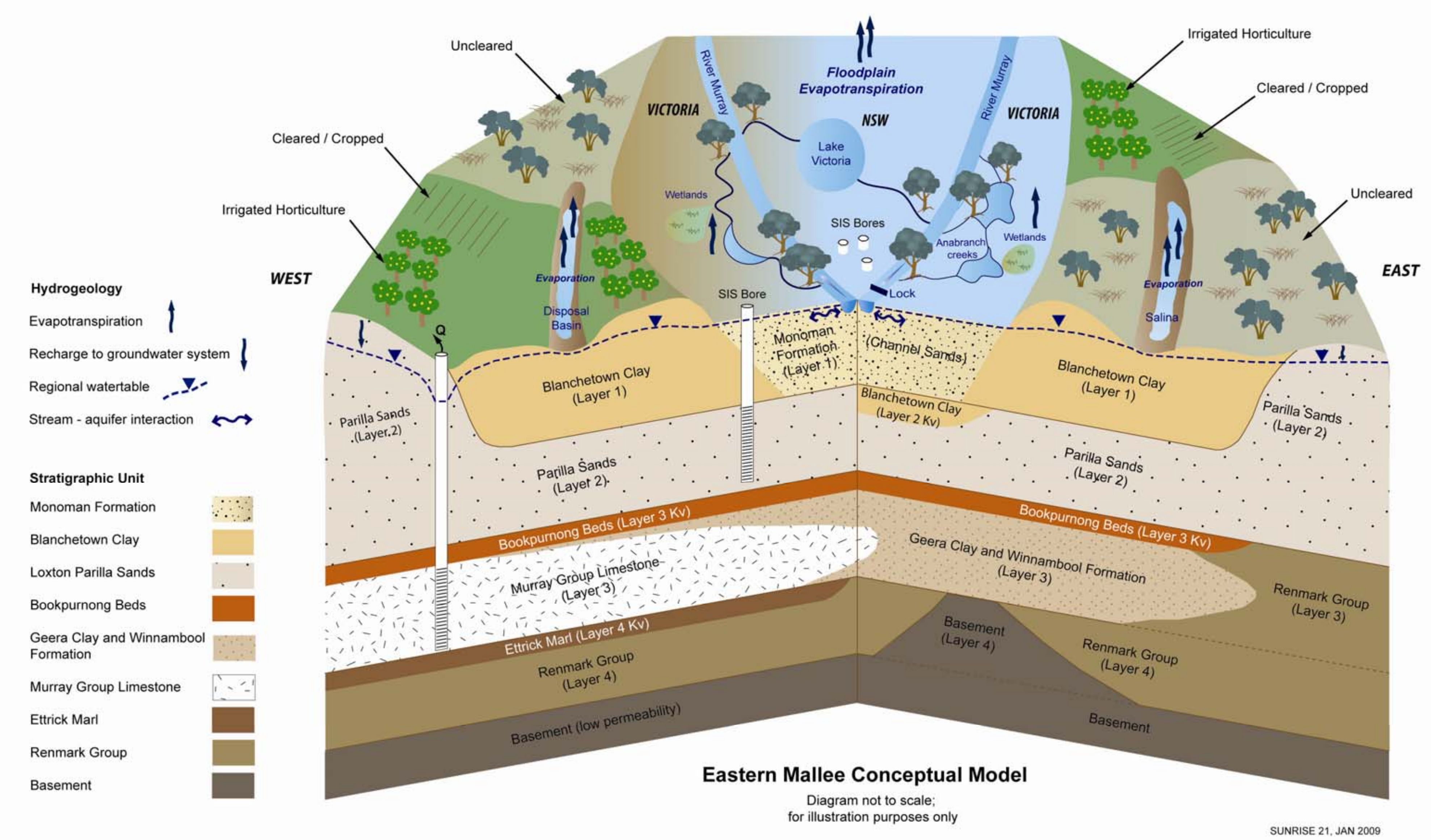
2.8.5 INTERACTION WITH LAKES

Lake Tyrrell is the largest of three salt lakes in the Tyrrell Basin with an area of 185km^2, located within the Mallee CMA (see Figure 2.5). The two remaining salt lakes are Lake Wahpool and Lake Timboran. Direct rainfall in the winter months provides most of the surface water currently entering the lakes, with the lakes remaining water-covered for up to 3 months a year in the winter and early spring. The lakebeds are underlain by Parilla Sands, with the Parilla aquifer system contributing most of the salt load in the lake. "As upwelling regional groundwater reaches the Lake Tyrrell depression, it evaporates and concentrates and so becomes denser". It then sinks to mix with the regional groundwater crossflow atop the Geera Clay aquiclude" (Warren, 2006).

2.9 CONCEPTUAL MODEL

A conceptual block diagram summarising the conceptual model for the Mallee CMA is presented in Figure 2.11. The key features represented by the conceptual diagram are:

- The low permeability Bookpurnong Beds (not modelled as a specific layer) underlie the Parilla Sands, and effectively constrain any upwards vertical groundwater flow into the model domain;
- The Parilla Sands is the major regional aquifer; it can be unconfined and semi-confined, and it can be either in contact with the Monoman Formation or separated from it by the Blanchetown Clay;
- Overlying the Parilla Sands, the very low permeability Blanchetown Clay acts as a semi-confining unit, and can have saturated thicknesses of up to 50 metres; in some areas it is absent, either due to erosion processes (within the Murray trench) or due to non-deposition;
- Recharge occurs via rainfall, and groundwater throughflow from the south (plus a little from the east), irrigation, leakage from surface water features, and river flow infiltration (noting that the River Murray is largely losing in this area);
- Dryland recharge is complicated by the history of land clearing, the depth to the water table and the clay content of the unsaturated zone, which may introduce time lags into time- and space-variable recharge rates, especially where there is a thick and clay-rich unsaturated zone; conversely, there is data to indicate that time lags may not be significant in some areas, especially under irrigation areas;
- Groundwater discharge to the River Murray and/or floodplain is governed by the complex relationship between the groundwater head in the Parilla Sands and the Monoman Formation aquifers, evapotranspiration on the floodplain, and the dynamic river stage elevation;
- Discharge occurs through evapotranspiration in low-lying areas such as dryland salinas or the floodplain environment, with complex salt storage and release processes operating on the floodplain. Discharge also occurs within the Parilla Sands aquifer through the western boundary of the study area;
- Discharge also occurs as groundwater throughflow to the west, in the area north and south of the River Murray;
- There is no substantial groundwater pumping except that associated with salt interception schemes and within the Murray Group Limestone on the western and southwestern margin of the model.



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MALLEE CMA REGIONAL GROUNDWATER FLOW CONCEPTUAL MODEL FIGURE 2.11

3 NUMERICAL MODEL DESIGN

3.1 GROUNDWATER MODELLING SOFTWARE

The MODFLOW modelling platform is used for this work, operating under the Groundwater Vistas Graphical User Interface (ESI Ltd, 2005). MODFLOW has industry-leading modules for simulating surface water and groundwater interaction. There have also been recent advances in the development of other modules (e.g. Banta, 2000; Harbaugh *et al.*, 2000), and likely further development in the future, which are expected to provide major benefit when applied to this project to simulate hydrological stresses and floodplain processes.

There continues to be major new developments in practical modelling approaches (rather than research-oriented approaches) based mainly on research outside Australia, but also on some within these shores. This is resulting in a range of integrated surface water and groundwater modelling packages becoming available, and it is expected that comprehensive and fully integrated surface water and groundwater models will be in standard use within five years, rather than the groundwater-focused or surface water-focused "integrated" models in current usage.

Notable Modflow and non-Modflow based platforms are:

- MODFLOW-based packages include ModHMS, an integrated catchment model, and MODFLOW-Surfact which includes more rigorous treatment of rewetting issues and unsaturated flow (a known shortcoming of the classical MODFLOW design);
- Mike-SHE is an integrated modelling package that is not based on MODFLOW and is known for its early reputation as having onerous data/budget/resourcing requirements and being suitable only for highly complex systems. Mike-SHE has been recently upgraded, and is receiving some of the most intensive code development worldwide. While Mike-SHE is not based on MODFLOW, it now provides an interface to it, and it also provides a comprehensive set of integrated surface and/or groundwater modules that range from very simple to highly complex, including unsaturated flow, such that it can model the entire hydrological cycle in a catchment;
- FeFlow (DHI Wasy) is a finite element modelling platform that provides advantages to modelling surface water-groundwater interactions in that the location and shape of water bodies can be more accurately modelled. However, this advantage is often outweighed by the difficulties in generating accurate water fluxes from the FeFlow software, which is a key model data output requirement for calculating salt loads;
- An object-oriented ZOOMQ3D is under development by the British Geological Survey and may provide future options for detailed regional scale and local scale modelling within the one package;
- A linkage between the surface water model IQQM and MODFLOW is an example of a development within Australia, designed to interactively model both surface and groundwater resources. The Integrated Quantity Quality Model (IQQM) is one of the adopted standard surface water management model for the Murray Darling Basin. However, only initial trials have been completed of the IQQM-MODFLOW link, and further development and testing is needed before the tool can be generally applied. This is being recommended to the MDBC on other projects.

In summary, while there is ongoing development of groundwater and integrated modelling codes, many of these developments involve MODFLOW or provide a transfer capability. Thus, it is virtually assured that further development of a MODFLOW-based model for any project will provide ongoing future utility.

3.2 MODEL EXTENT, FINITE DIFFERENCE GRID AND BOUNDARY CONDITIONS

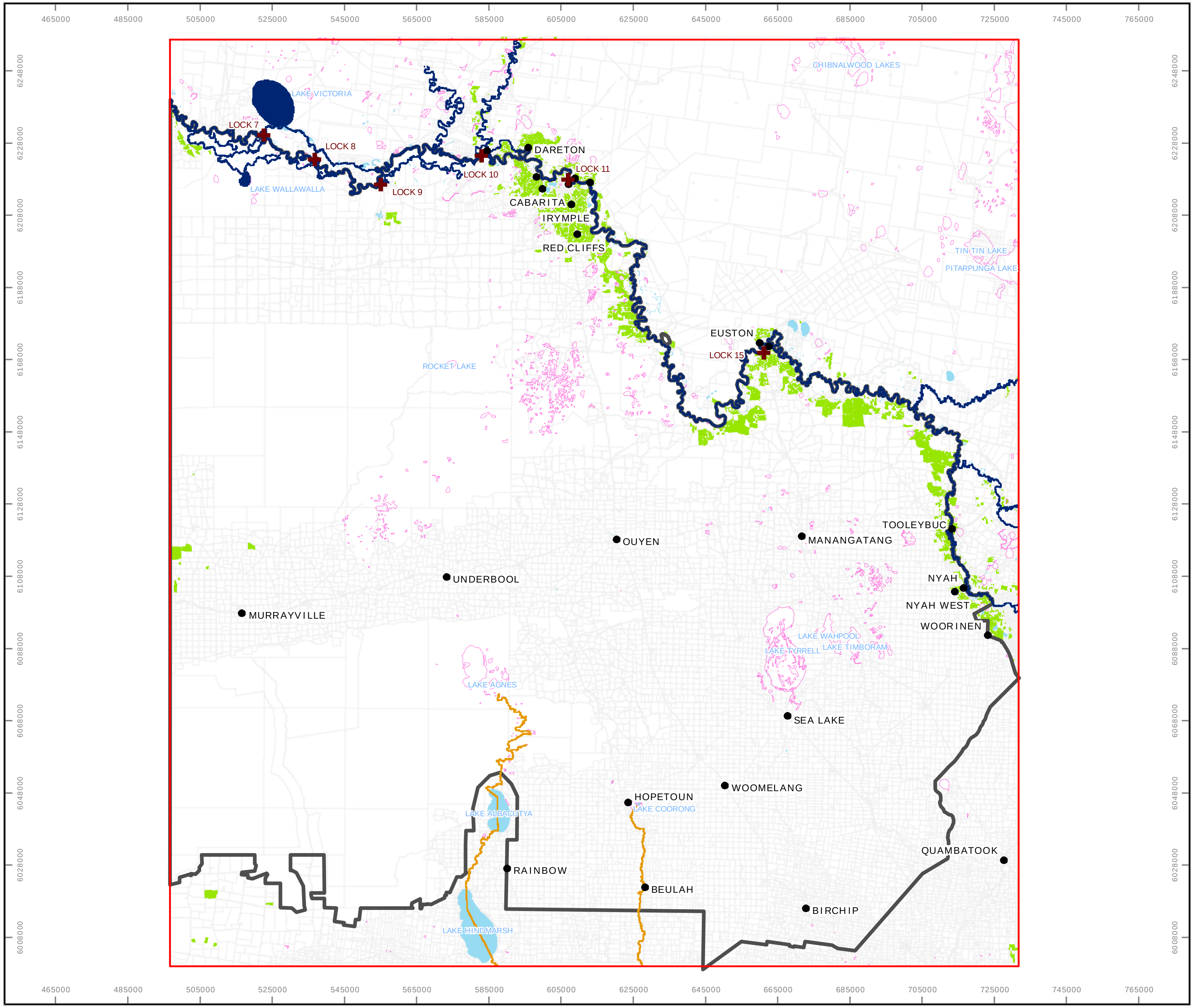
The previous EM1 model and its extensions, EM2 and EM4 were developed assuming that the principal aquifer unit was the Parilla Sands aquifer which is generally separated from the deeper units by the Bookpurnong Beds and Geera Clay. Since there was a need to represent the deeper

units to meet the secondary model purpose, the EM3 model includes aquifer and aquitard units extending to the Basement.

The extent of the model domain, along with the boundary conditions, is summarised as follows:

- Model domain covers the entire Mallee CMA area (plus extensions into NSW, and also south into the Wimmera CMA area). The EM3 model area extends to the SA border from immediately west of Swan Hill, and from south of Lake Hindmarsh to north of Lake Victoria in NSW;
- The model has 1,283 rows and 1,175 columns, thus making 1,507,525 cells per layer, and 6,030,100 cells total (a very large Modflow model by any standard);
- The northern boundary, most of the western boundary and a mid-section of the eastern boundary, is specified as no-flow based on the regional water table contours being aligned orthogonal to the boundary.
- All the model boundaries in layer 1 are specified as no-flow;
- The southern boundary is a specified flux boundary (total flux consistent with the neighbouring Wimmera CMA model);
- The southern part of the eastern boundary is a specified head boundary (consistent with the neighbouring North Central CMA model), with spatially variable head levels specified (ranging from 70 m AHD in the north to 90 m AHD in the south in layers 2 and 3, and ranging from 78 m AHD in the north to 90 m AHD in the south in layer 4), consistent with the water levels provided on the hydrogeological map sheets;
- The northern part of the eastern boundary is a specified head boundary, with spatially variable head levels specified (ranging from 53 m AHD in the north to 65 m AHD in the south in layer 2, and ranging from 53 m AHD in the north to 55 m AHD in the south in layers 3 and 4), consistent with the water levels provided on the hydrogeological map sheets;
- The northern part of the western boundary is a general head boundary in layers 2 and 4, with prescribed head levels specified in layer 2 (18 m AHD) and specified at a constant 32 m AHD in layer 4, consistent with the water levels provided on the hydrogeological map sheets;
- The central part of the western boundary (Murrayville area) is assigned prescribed outflow of 10 ML/d, to account for groundwater pumping across the state boundary (in South Australia). The prescribed flux is the best estimate available and was adopted during calibration.

Figures 3.1 – 3.4 presents the boundary condition arrangement, as well as the river and drain boundaries.



LEGEND

- Locks
- Localities
- Irrigated Areas
- Mallee CMA Boundary

Suface Water Bodies

- Non-perennial
- Perennial

MODEL FEATURES

- EM3 Model Boundary
- Non Perennial Rivers - DRN cells (Bed at 2m below Topography)
- Rivers - RIV Cells (Detailed BC data in Appendix)

N

0 10 20 30 40
Kilometres

SCALE 1:1,500,000 @ A3

GDA 1994 MGA Zone 54

DATA SOURCES

MCMA: Cultivated Areas
GA: Localities, Lakes, Locks
AQT: EM3 Model

FIGURE 3.1

Modelled Boundary Conditions - Layer 1

AUTHOR	AL	REPORT NO	N/A
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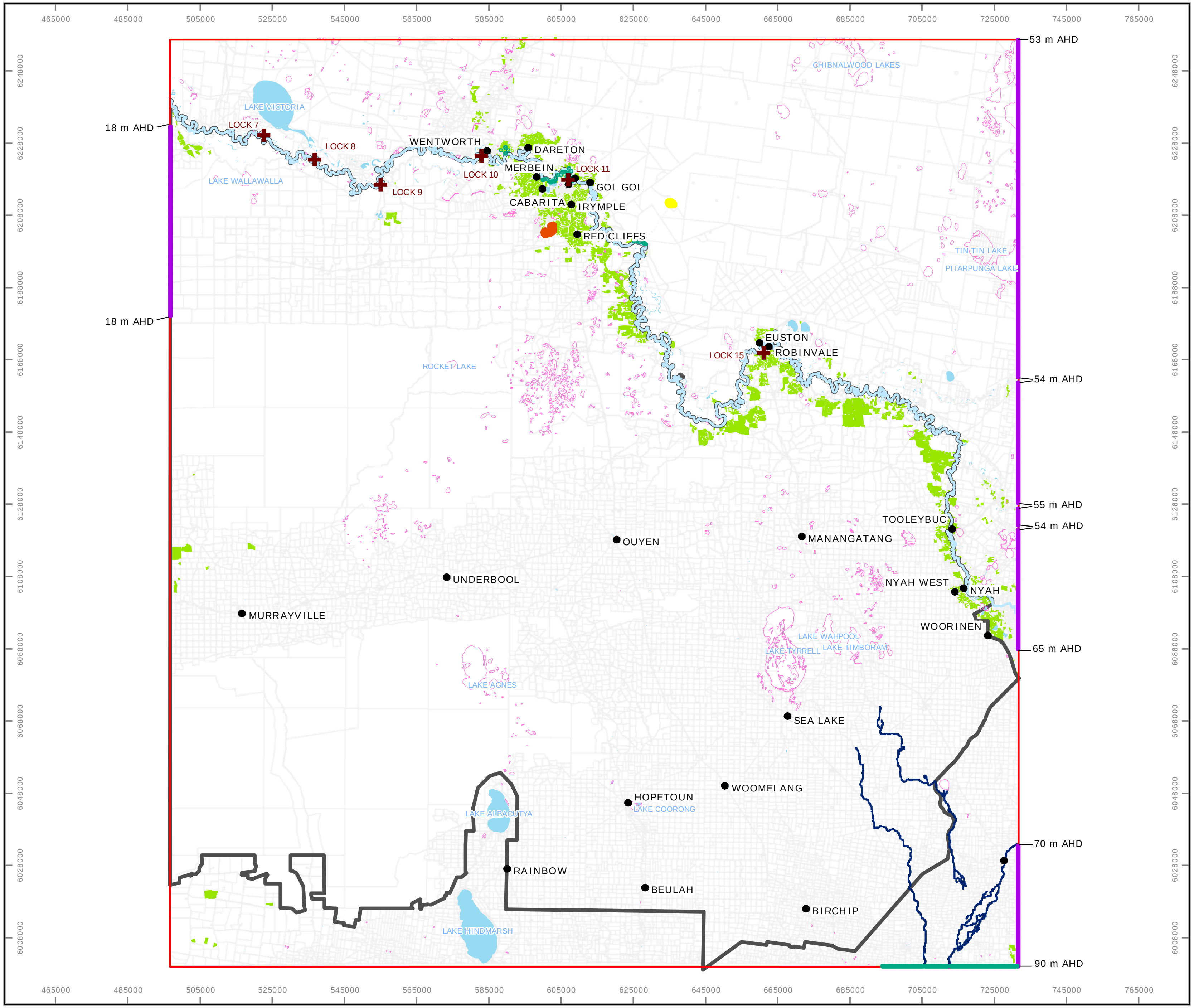

LEGEND

- Locks
- Localities
- River Murray

Suface Water Bodies

- Non-perennial
- Perennial
- Mallee CMA Boundary
- Irrigated Areas

MODEL FEATURES

- Cardross Lakes - Well Cells
- Mallee Cliffs Basin - Well Cells
- Rivers - RIV Cells (Detailed BC data in Appendix)
- Inflow/Outflow - GHB cells (Specified head range)
- Prescribed Flux
- EM3 Model Boundary

0 10 20 30 40
Kilometres

SCALE 1:1,500,000 @ A3

GDA 1994 MGA Zone 54

DATA SOURCES

MCMA: Cultivated Areas
GA: Localities, Lakes, Locks
AQT: EM3 Model

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FIGURE 3.2

Modelled Boundary Conditions - Layer 2

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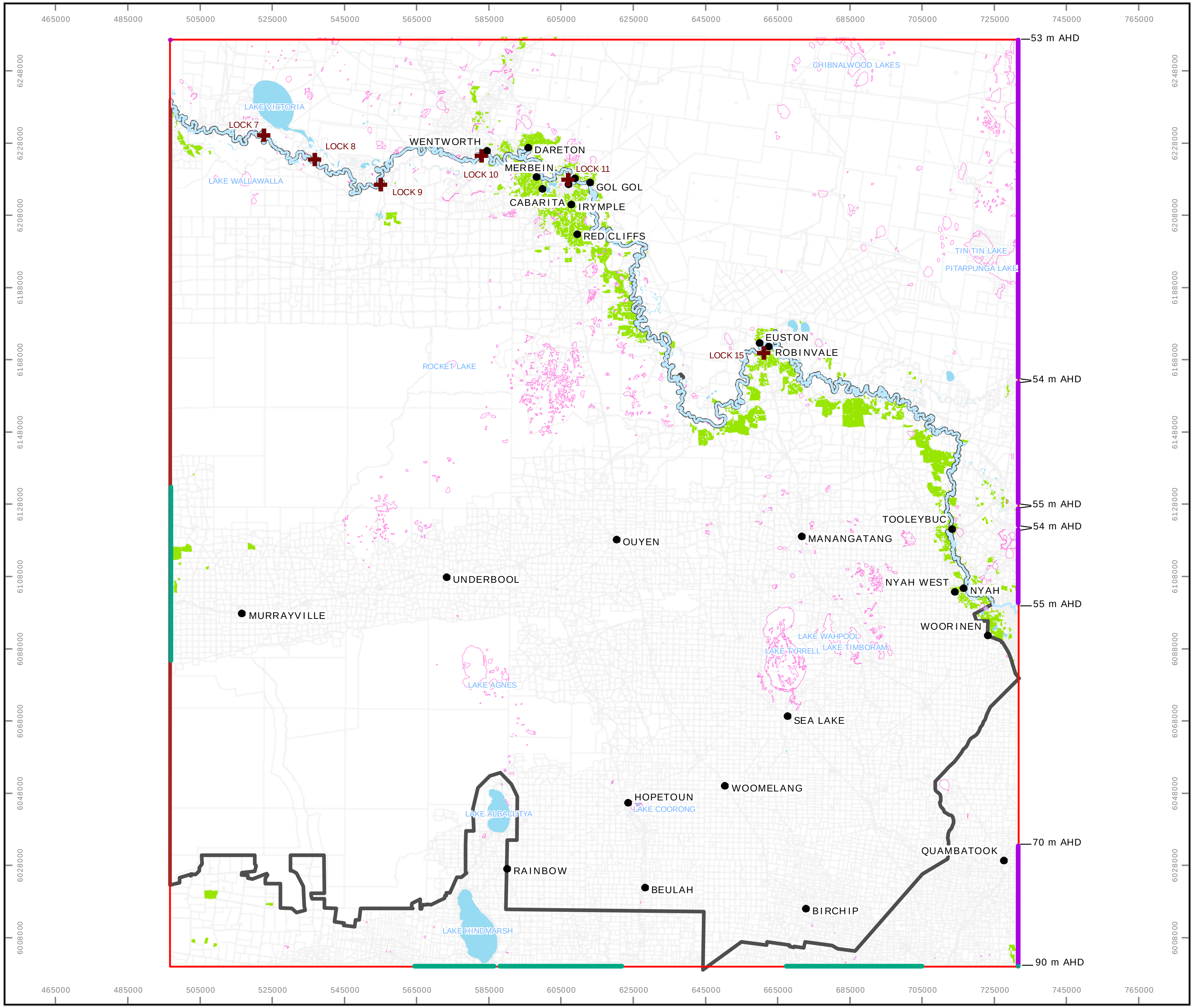

LEGEND

- Locks
- Localities
- River Murray
- Irrigated Areas
- Mallee CMA Boundary

Suface Water Bodies

- Perennial
- Non-perennial

MODEL FEATURES

- Prescribed Flux
- Inflow/Outflow - GHB cells (Specified head range)
- EM3 Model Boundary

N

0 10 20 30 40

Kilometres

SCALE 1:1,500,000 @ A3

GDA 1994 MGA Zone 54

DATA SOURCES

MCMA: Cultivated Areas
GA: Localities, Lakes, Locks
AQT: EM3 Model

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FIGURE 3.3

Modelled Boundary Conditions - Layer 3

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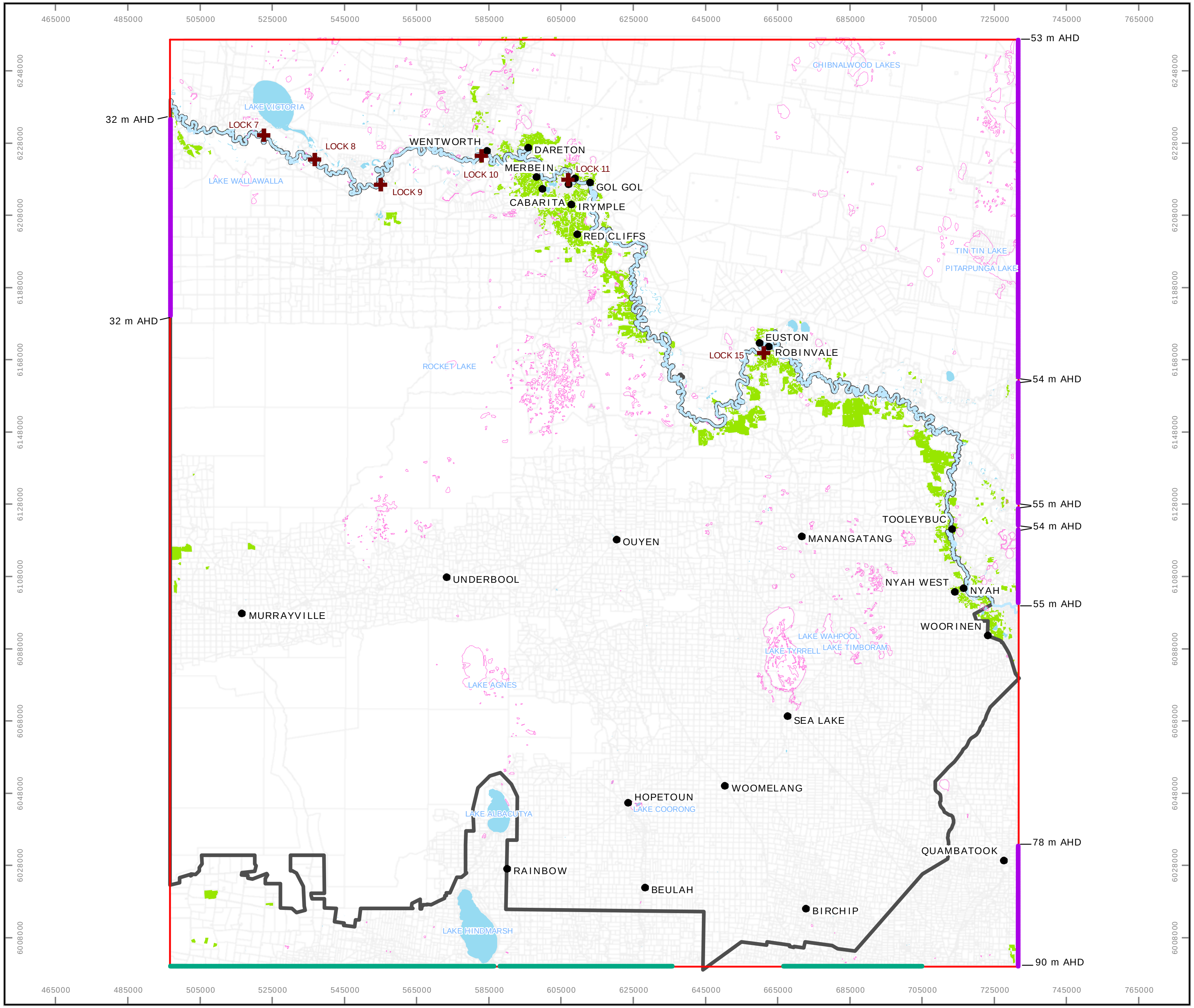

LEGEND

- Locks
- Localities
- River Murray
- Irrigated Areas
- Mallee CMA Boundary

Suface Water Bodies

- Perennial
- Non-perennial

MODEL FEATURES

- Prescribed Flux
- Inflow/Outflow - GHB cells (Specified head range)
- EM3 Model Boundary

N

0 10 20 30 40

Kilometres

SCALE 1:1,500,000 @ A3

GDA 1994 MGA Zone 54

DATA SOURCES

MCMA: Cultivated Areas
GA: Localities, Lakes, Locks
AQT: EM3 Model

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FIGURE 3.4

Modelled Boundary Conditions - Layer 4

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3.3 MODEL LAYERS

3.3.1 SPATIAL EXTENT

The geology of the study area, and associated hydrogeological systems are described in detail in Sections 2.6 and 2.7. A summary of the aquifers/aquitards considered in the Mallee CMA is provided in the conceptual block diagram presented in Figure 2.11 as well as Table 3.1.

Table 3.1: Aquifers and Aquitards of Interest in the Study Area

Aquifer/ Aquitard Unit	Model Layer	Characteristics
Coonambidgal Formation	(not represented in EM3)	Low permeability unit overlying Monoman formation, producing short term semi-confined conditions.
Woorinen Formation	(not represented in EM3)	Low permeability unit overlying Blanchetown Clay, and mostly unsaturated across the study area.
Monoman Formation (Channel Sands)	Layer 1 within floodplain	High permeability unit within Murray Trench only, hydraulically connected to river channels.
Blanchetown Clay	Layer 1 outside floodplain, and Layer 2 (Kv) in areas where Monoman Formation overlies Blanchetown Clay within floodplain	Low permeability unit. Generally present outside the Murray Trench, and absent under the Murray Trench.
Parilla Sands	Layer 2, and Layer 1 in areas where Blanchetown Clay absent outside floodplain	Relatively high permeability unit present across entire Study Area, underlying the Channel Sands and Blanchetown Clay where present.
Bookpurnong Beds	Layer 3 (Kv)	Thin low permeability unit overlying the Murray Group Limestone, Geera Clay and Winnambool Formation.
Murray Group Limestone	Layer 3 (western part)	High permeability unit located in the western area of the Mallee CMA.
Geera Clay	Layer 3 (central part)	Low permeability unit. Predominantly overlies Renmark Group.
Winnambool Formation	Layer 3 (central part)	Low permeability unit. Predominantly overlies Murray Group Limestone.
Ettrick Marl	Layer 4 (Kv)	Relatively thin low permeability unit underlying the Murray Group Limestone. Separates the Renmark Group aquifer system from the Murray Group aquifer system.
Renmark Group	Layer 4, and Layer 3 where Parilla Sands directly overlies Renmark Group in east	High permeability unit present across majority of the study area.
Basement	Layer 4	Low permeability unit outcropping into the Renmark Group.

3.3.2 LAYER ELEVATIONS

At the time of EM1 model development, the most accurate digital elevation model (DEM) available for the topographical surface was the NASA SRTM DEM. For this project, a LIDAR topographical surface for the floodplain and a 20m grid spacing DEM for Victoria (Vicmap DEM) are available. The LIDAR surface is limited to the Murray floodplain, and was inserted into the

Vicmap DEM (study area in Victoria) and the regional SRTM DEM (study area in NSW). The composite DEM was used as the upper reference surface for the EM3 model layer structure.

The use of the LIDAR DEM on the floodplain addresses a potential model limitation in regard to modelling shallow flow processes on the floodplain, as evapotranspiration from shallow water tables and stream-aquifer interaction processes are very dependent on accurate topographical information.

The current model development included a geological structure analysis of available bore logs from the EM1 model area, as well as the Victorian GMS, GEDIS and DPI databases accessed on 18 November 2008. The initial data, provided as "depth to" in metres, was converted to metres AHD based on the composite DEM. The converted bore log data was then extrapolated and smoothed using kriging to produce top and bottom elevation surfaces and isopach thicknesses for the Monoman Formation, Blanchetown Clay, Parilla Sand, Murray Group Limestone, Geera Clay, Winnambool Formation and Renmark Group units. Plots of layer isopachs are presented in Appendix A, they also show the localities of bores used for the stratigraphical analysis.

The base of layer 1 is defined by assuming a minimum thickness of three metres for this layer generally. Where Monoman Formation and Blanchetown Clay are present, the bottom elevations for these units were applied to the base of layer 1 (while maintaining a minimum thickness of three metres). This was subsequently refined (during the transient calibration process), to ensure that, under the River Murray, the base of layer 2 was not higher than the bed of the River.

The base of layer 2 is defined by the Parilla Sand base elevations, or the base of the equivalent Pliocene sand unit locally.

The base of layer 3 is defined by the Renmark Group top elevations. Ettrick Marl lies above the Renmark Group, however due to the thinness of the unit and the limited bore log data available, its thickness is assumed to be incorporated into layer 4. Renmark Group extends up into Layer 3 in areas to the east. Renmark Group top elevations are still applicable in these areas to represent base of layer 3 as the extrapolated layer surface grid provides a reasonable isopach thickness for layer 3 in these areas.

The base of layer 4 is defined by the top of basement elevations.

3.3.3 HYDROGEOLOGICAL PARAMETERISATION

Aquifer property values applied to the model layers have been constrained to physically realistic values, consistent with the range of values for parameters obtained from lithological and pumping test analysis undertaken on these units across the region and from a range of values used in EM series of models (values summarised in Table 2.1).

The values have been distributed spatially to the hydrogeological units. The hydraulic conductivity and storage aquifer parameter distribution for each model layer is presented in plots in Appendix C and summarised in Table 3.2.

Table 3.2: EM3 Hydrogeological Parameterisation (after History Matching Calibration)

Layer(s)	Formation(s)	Kh (m/day)	Kv (m/day)	S	Sy
1	Monoman Formation	15	1.5	0.0001	0.1
1	Blanchetown Clay	0.0027	0.00027	0.0001	0.1
1 and 2	Parilla Sands	15	5	0.0001	0.1
2	Parilla Sands (with Blanchetown Clay influencing vertical leakage)	4	0.008	0.0001	0.1
3	Murray Group Limestone (with Bookpurnong Beds influencing vertical leakage)	5 (north) 20 (south)	0.005 (N) 0.005 (S)	0.0001	0.02
3	Murray Group Limestone (with Geera Clay/ Winnambool Formation and/or Bookpurnong Beds influencing vertical leakage)	2 (north) 6 (south)	0.005 (N) 0.005 (S)	0.0001	0.02
3	Geera Clay/ Winnambool Formation and Bookpurnong Beds	0.1 (north) 2 (south)	0.01 (N) 0.01 (S)	0.0001	0.02
3 and 4	Renmark Group	25	0.1 0.5 (L3 S)	0.0001	0.05
4	Renmark Group (with Ettrick Marl influencing vertical leakage)	25	0.00001	0.0001	0.05
4	Basement	0.03	0.01	0.0001	0.005

3.4 MODEL FEATURES FOR SURFACE WATER BODIES

3.4.1 RIVER MURRAY AND ASSOCIATED FEATURES

The numerical model uses MODFLOW River (RIV module) cells to represent the River Murray as well as major anabranch rivers, creeks and associated major lakes (notably Lake Victoria) downstream of Lock 10/Wentworth (refer Figures 3.1). The MODFLOW RIV package requires data on stage elevation, stream bed elevation and bed conductance.

The following assumptions have been applied to represent the River Murray:

- River stage levels are set to annual average river levels that are constant with time;
- Stage elevation data for each river cell was interpolated linearly from River Murray gauge height data obtained from the MDBA Live River Data website (accessed 24 February 2010). It should be noted that the key data requirement is the River stage level, as it is this relationship between the stage level and the modelled groundwater level that governs the hydraulic loss/gain character of these major surface water bodies;
- Stream bed elevation data was based on river bathymetry which has been approximated from the water depth given by the NanoTEM survey (Telfer *et al.* 2006) reduced from the long term average pool level (stage elevation);
- For each reach in the model, the bed level is uniform (but the levels vary between reaches);
- Water depths indicate that the river is likely to be connected to the Monoman Formation. As the Monoman Formation is implemented in Layer 1, it is also appropriate for the river and associated features to be located in this layer;
- River bed conductance has been set to 150 m^2/day based on previous modelling work by Aquaterra (2009) in the region. This parameter value was tested for sensitivity, and there is scope to apply spatial distribution, e.g. to reduce this value for the floodplain anabranch creeks, and for further change to reduce the volume leaking from the River into the floodplain (for subsequent discharge by evapotranspiration).

River reach details, including reach locality, stage and bed levels, are provided in Appendix D.

3.4.2 FLOODPLAIN WETLANDS

The representation of other significant surface bodies throughout the study area is summarised in Table 3.3.

Surface water bodies that have water level monitoring data and display a relatively low variation in water level (nominally selected as a standard deviation of 0.3 m or less) are assigned average water levels as a MODFLOW River feature. There are many of these basins, including the major ones of Lake Hawthorn, Lake Ranfurly, Basin 12/Psyche Bend Lagoon, Lambert's Swamp and Kings Billabong. The River Package allows for leakage to or from the water table, depending on the relative groundwater level.

There is no readily available water level data for Cardross Lakes and Mallee Cliffs Basin, however there is water balance data (SKM and AWE, 2003). These water bodies are represented in the model as recharge features using the MODFLOW Well Package, as per EM1 (Aquaterra, 2007).

Table 3.3: Lakes, Wetlands and Groundwater Discharge Zone Features in EM3 Model (Excluding Lindsay-Wallpolla)

Surface Water Body	Representation in Model	Recorded Values	Source of Data	Adopted Head or Rate
Lake Victoria	River package	~22 – 27 mAHD	MDBA	25.0 m AHD
Lake Wallawalla	River package	Dry since 1996 flood	Mallee CMA website	21.88 m AHD
Mourquong Basin	Evaporative feature	--	SKM and AWE (2003)	Model to determine value (evaporation from shallow water table)
Lake Hawthorn	River package	34.4 to 35.8 m AHD (July 1988-May 2006) Average: 35.0 m AHD	Provided by Mallee CMA	35.0 m AHD
Lake Ranfurly	River package	33.6 to 34.4 m AHD (2004-06) Average: 34.0 m AHD (for Ranfurly East and West combined)	Provided by Mallee CMA	34.0 m AHD
Basin 12 and Psyche Bend	River package	--	Ecological Associates (2007)	36.0 m AHD
Fletcher's Lake	Evaporative feature	No data available	No data available	Model to determine value (evaporation from shallow water table)
Koorlong Basins	Nil	No data available	No data available	No data available, but located on the landward side of irrigation mound thus exclusion is unlikely to affect predictions
Wargan Basins	Nil	--	SKM and AWE (2003)	No groundwater interaction
Cardross Lakes	Recharge feature using Well package	--	SKM and AWE (2003)	164 ML/year recharge

Surface Water Body	Representation in Model	Recorded Values	Source of Data	Adopted Head or Rate
Lamberts Swamp	River package	32.2 to 33.0 m AHD (July 1983-Dec 2004) Average: 32.5 m AHD	DSE (2007)	32.5 m AHD
Mallee Cliffs Basin	Recharge feature using Well package	--	SKM and AWE (2003)	822 ML/year recharge
Rifle Butts Swamp	Nil	No data available	No data available	Relatively minor feature, exclusion is unlikely to affect predictions
Apex Park Lagoon	River package	Approx. 36 m AHD	Provided by G-MW	36.0 m AHD
Kings Billabong	River package	Maintained at 37 m AHD	SKM (2002)	37.0 m AHD
Gol Gol lake and swamp	Evaporative feature	--	Aquaterra (2007a)	Model to determine value (evaporation from shallow water table)
Bullock Swamp/Lake Iraak	Evaporative feature	--	Mallee CMA (2000)	Model to determine value (evaporation from shallow water table)
Karadoc Swamp	Evaporative feature	--	SKM (2002a)	Model to determine value (evaporation from shallow water table)
Rifle Butts Swamp	Nil	No data available	No data available	Relatively minor feature, exclusion is unlikely to affect predictions
Lake Tyrrell	Evaporative feature	TBC		Model to determine value (evaporation from shallow water table)
Lakes Wahpool and Timboram	Evaporative feature	TBC		Model to determine value (evaporation from shallow water table)
Lakes Albacutya and Hindmarsh	Evaporative feature	TBC		Model to determine value (evaporation from shallow water table)

All surface water features represented using the River package have an assumed bed conductance of 150 m^2/day, and this parameter value was tested for sensitivity.

All low-lying areas (including the river itself) are subject to evapotranspiration (ET) in the model. Thus all natural depressions, whether or not they are on the floodplain, and whether or not they receive small quantities of drainage water and/or floodwaters from the River, are represented in the model as potential evaporative (discharge) features, using the MODFLOW ET package. This provides the opportunity, where warranted, to apply site-specific parameters to the ET package to represent detailed water balance processes for any specific landscape feature. If there is data available on recharge to the water table from these features, then that can also be incorporated into the model.

No data is available for Fletcher's Lake and Koorlong Basins, and as they are on the landward side of irrigation mounds, and as groundwater levels are shallow at these locations (natural depressions), the MODFLOW ET package should ensure that these locations act as evaporative (discharge) features with little influence on fluxes to the River. This is also the situation for Mourquong Basin and Wargan Basins, which have previously been shown to have minimal

interaction with groundwater in terms of leakage (SKM and AWE, 2003) and no specific representation in the model is implemented other than as an evaporative feature, which allows for quantification of discharge volumes.

While there is no data for Rifle Butt Swamp, given the small size of this water body, it is unlikely to have an appreciable influence on fluxes to the River, and is not specifically included in the model.

Recharge to the irrigated treelots and pastures of the Apex Park wastewater treatment facility (north-west of Mildura), and the lagoon is treated as a River feature.

3.4.3 STREAMS AND LAKES IN THE SOUTHERN PART OF THE MALLEE CMA

The numerical model uses MODFLOW DRAIN cells in layer 1 to represent the following major surface bodies that are located mostly within the southern part of the Study Area (refer Figure 3.2):

- Wimmera River;
- Outlet Creek;
- Yarriambiack Creek.

The MODFLOW Drain package works in a similar way to the River package, although it only allows for groundwater inflow to the drain (not leakage from the drain to the aquifer). The Drain package requires data on the drain bed level and bed conductance. The following assumptions were applied to represent the aforementioned major surface bodies:

- Drain bed is taken as two metres below surface elevation, determined from the composite DEM;
- Drain bed conductance has been set to 150 m^2/day.

The numerical model uses MODFLOW RIVER cells in layer 2 (the highest active layer) to represent the following major surface bodies that are located mostly within the south-eastern part of the Study Area (refer Figure 3.2), and are considered to be potential sources of leakage to the aquifer:

- Tyrrell Creek;
- Lalbert Creek;
- Avoca River;
- Mosquito Creek.

The following assumptions have been applied to represent these major surface bodies in the River package:

- River stage elevation is taken as 1.5 metres below surface elevation, determined from the composite DEM;
- River bed elevation is taken as two metres below surface elevation, determined from the composite DEM;
- River bed conductance has been set to 150 m^2/day.

3.5 EVAPOTRANSPIRATION

Evapotranspiration (ET) is applied using the MODFLOW Evapotranspiration package which requires data on the topography, the maximum ET rate, and the extinction depth (where ET reduces to zero).

The maximum ET rate applied in the model is constant with time and calculated based on potential evapotranspiration less any actual evapotranspiration already accounted for in the ENSYM modelling, both datasets being provided by DSE. The maximum ET rate was produced on a long-term average annual basis over the period 1957 to 2005. Appendix E presents the spatial distribution of maximum ET rates across the model, uniform for each stress period.

Across the entire model the aforementioned steady-state maximum ET rate has been applied at the surface of the model diminishing to zero at the extinction depth of four metres. For the current assumption of an extinction depth of four metres, ET is active in the EM3 model only in those areas where the water table is quite close to the surface (e.g. Lake Tyrell and parts of the floodplain). In these areas, there is effectively an unlimited supply of water available for evapo(transpi)ration. In which case, ET discharge from the water table in the model is appropriate, whether or not ET from the unsaturated zone has already been calculated as part of the ENSYM model recharge estimation procedure.

3.6 DSE SUPPLIED RECHARGE

Dryland rainfall and irrigation recharge is applied to the model using the MODFLOW Recharge Package. This package applies recharge directly to the top of the water table and thus represents deep drainage past the root zone of plants. DSE provided the recharge data sets (incorporating irrigation recharge) on an annual average basis over the transient calibration period (1990 to 2005) calculated from ENSYM modelling (refer to section 3.6.1). Zero time lag has been assumed as a simple assumption at this stage of model development. There is scope to consider invoking a time lag effect in areas with a deep water table (i.e. in excess of 20 metres), as the modelled recharge data generates some variability in modelled levels in many areas with deep-seated water level where there is no variation in measured levels.

Appendix E presents the spatial distribution of recharge rates across the model.

3.6.1 ENSYM

EnSym (Environmental Systems Modelling Platform) is a computer program designed by the Victorian Government to provide:

- simple and intuitive access to complex science that helps prioritise natural resource investment
- an understanding of the environmental benefits delivered by actions undertaken in the landscape; and
- a framework for scientists and researchers to test and apply empirical and process based scientific models.

Ensym employs scientific models to improve understanding about the impacts that actions such as revegetation, weed control and riparian management, have on the landscape. Users can visualise, test and interpret results of changes in climate, land use and land management practices through a single interface. Models are grouped into 5 toolboxes that relate to different sections of the landscape and analytical capabilities. The toolbox that simulates surface water dynamics and thus provides the recharge values is known as Biosym.

Biosym

Biosym (biophysical systems toolbox) is the name given the biophysical modelling toolbox within the Ensym model. BioSym originated from the Catchment Analysis Tool, also known as CAT1D (Beverley, 2007) which was jointly developed by DSE and DPI. From December 2008 onward, DSE and DPI followed different paths in further developments and modifications of the CAT1D module, thus to distinguish and to reflect the divergence of the simulation codes, BioSym was the name adopted as the computer program for biophysical modelling within the Ensym model.

BioSym solves for physical processes conceptually by using simplified analytical solutions and empirical equations. The code for BioSym was written with the objective of simulating all major hydrologic components as simply and realistically as possible, and to use inputs readily available over large spatial scales to enhance the likelihood that the model would become routinely used in planning and water resource decision making.

The model components of BioSym can be placed into eight major categories - hydrology, weather, sedimentation, soil temperature, crop growth, nutrients, agricultural management, and pesticides.

Water entering the soil profile is initially determined by subtracting the calculated surface runoff from the total daily precipitation and irrigation. Once in the soil profile, water can be removed by evapotranspiration, lateral flow, and downward movement if soil capacity is exceeded. Water fills up lower soil layers until it exits the soil profile and becomes drainage. Drainage is then partitioned into sub surface lateral flow and recharge.

The Biosym modelling approach, results in several limitations in regards to recharge calculations, the most major of which are:

- no recharge time lags are taken account of, thus it is assumed that water partitioned for recharge instantly hits the water table. This limitation is of most concern in areas of deeper water tables and of little concern in shallow water table areas.
- surface runoff does not cascade from upstream modelling cells to downstream modelling cells, thus no pooling can be modelled or accumulation of water in low lying areas. This may result in the underestimation of recharge is low lying areas.
- similarly floods are not modelled thus recharge events caused by flood waters will be missed. Obviously recharge still tends to peak during flood events as a result of high rainfall however recharge will be underestimated in areas where flood waters contribute to recharge.
- all biophysical processes are simulated on a daily timestep thus processes that occur on a smaller timestep may be poorly accounted for, such as short high intensity storm events.
- any influence that underlying geology has on impeding or aiding recharge is not taken into account, for example in some areas of upland Victoria the deeper regolith is suspected to throttle recharge depending on it's water content.
- the soil mapping used is the best currently available across the state however it is primarily a landsystem map thus large variations in soil types can exist within each of the Biosym soil units.
- Biosym assumes no temporal changes in land use, thus for example, recharge changes from afforestation are not modelled during the groundwater model time period.
- Biosym does not take into account areas where the soil profile is saturated due to groundwater discharge.

It is important that these recharge modelling limitations are taken into account when assessing the overall limitations of a groundwater model using Biosym recharge values.

For further detail on the Biosym toolbox please refer to the CAT1D technical manual (Beverley, 2007) and to the Programmer's Guide for BioSym (Ha, in preparation)

3.7 IRRIGATION AND SALT INTERCEPTION PUMPING

3.7.1 IRRIGATION PUMPING

Abstraction data was provided for the Grampians Wimmera Mallee Water regions, in the form of annual average metered abstraction volumes taken over five years (historical time period not specified) for irrigation, urban and intensive bores.

A total of 57 irrigation bores pumping at a constant (annual average) rate over the transient model period were incorporated into the EM3 model using the MODFLOW Well Package. They are situated in the Murray Group Limestone aquifer (layer 3 of the model), mostly in the south-west corner. Steady state abstraction rates vary from 5 to 4685 m^3/day, however it may be necessary to refine these rates as they are based on averaged volumes over an unknown period of time (rather than metered values).

Appendix F presents the GWMW irrigation pumping rates (constant over all modelled stress periods).

3.7.2 SALT INTERCEPTION SCHEMES

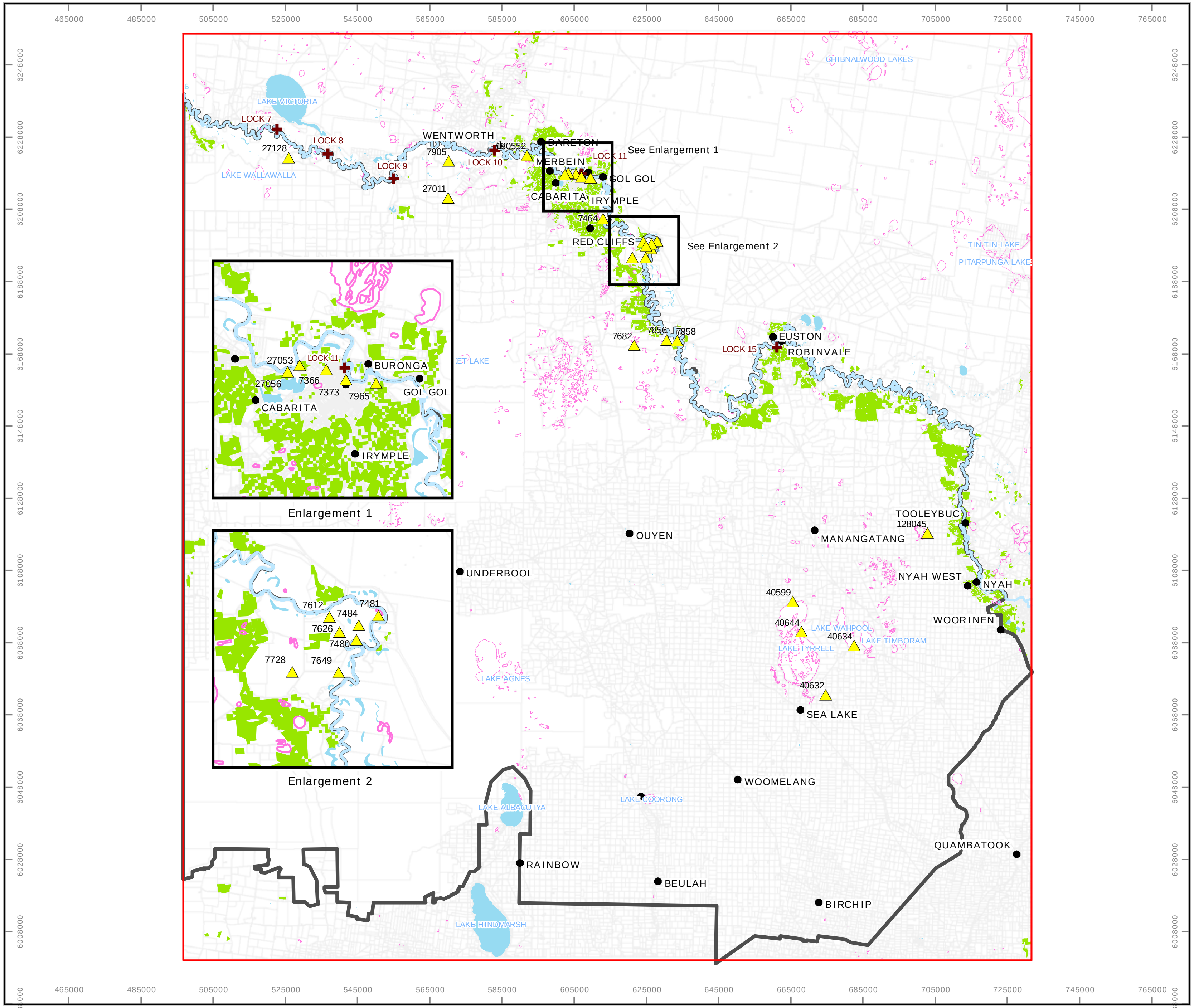
Four of the five Salt Interception Schemes (SIS) operating in the study area have been incorporated into the EM3 model using the MODFLOW Wells Package. Historical pumping by the

Rufus River SIS (in NSW) has not been incorporated into the model as limited data was available (from 2004 to 2008), and the data that was available was regarded as unreliable.

Details of the pump rates used in the schemes incorporated into the model are provided in Appendix G. All pump rates over the transient calibration period (1990 to 2005) are yearly averages, and draw from the Parilla Sands in layer 2.

3.8 TRANSIENT OBSERVATION WATER LEVELS

The transient period for which the historical calibration match has been conducted was selected as January 1990 to December 2005. 150 bores were selected throughout the model domain (some outside the Mallee CMA) to provide observation data in which to provide a match to and was chosen based on data availability and reliability as well as spatial variability (see Figures 3.5 – 3.9). All model layers and major aquifer units are represented by the selected observation bores, and a range of bores in NSW have also been incorporated.



LEGEND

- Bores
- Locks
- Localities
- River Murray
- Irrigated Areas
- EM3 Model Boundary
- Mallee CMA Boundary

Suface Water Bodies

- Perennial
- Non-perennial

N

0 10 20 30 40
Kilometres

SCALE 1:1,500,000 @ A3

GDA 1994 MGA Zone 54

DATA SOURCES

MCMA: Bores
GA: Localities, Lakes, Locks
AQT: EM3 Model

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FIGURE 3.5

Groundwater Level Observation Bores - Layer 1

AUTHOR	AL	REPORT NO	N/A
DRAWN	AL	REVISION	1
DATE	14/01/10	JOB NO.	A53B1 004

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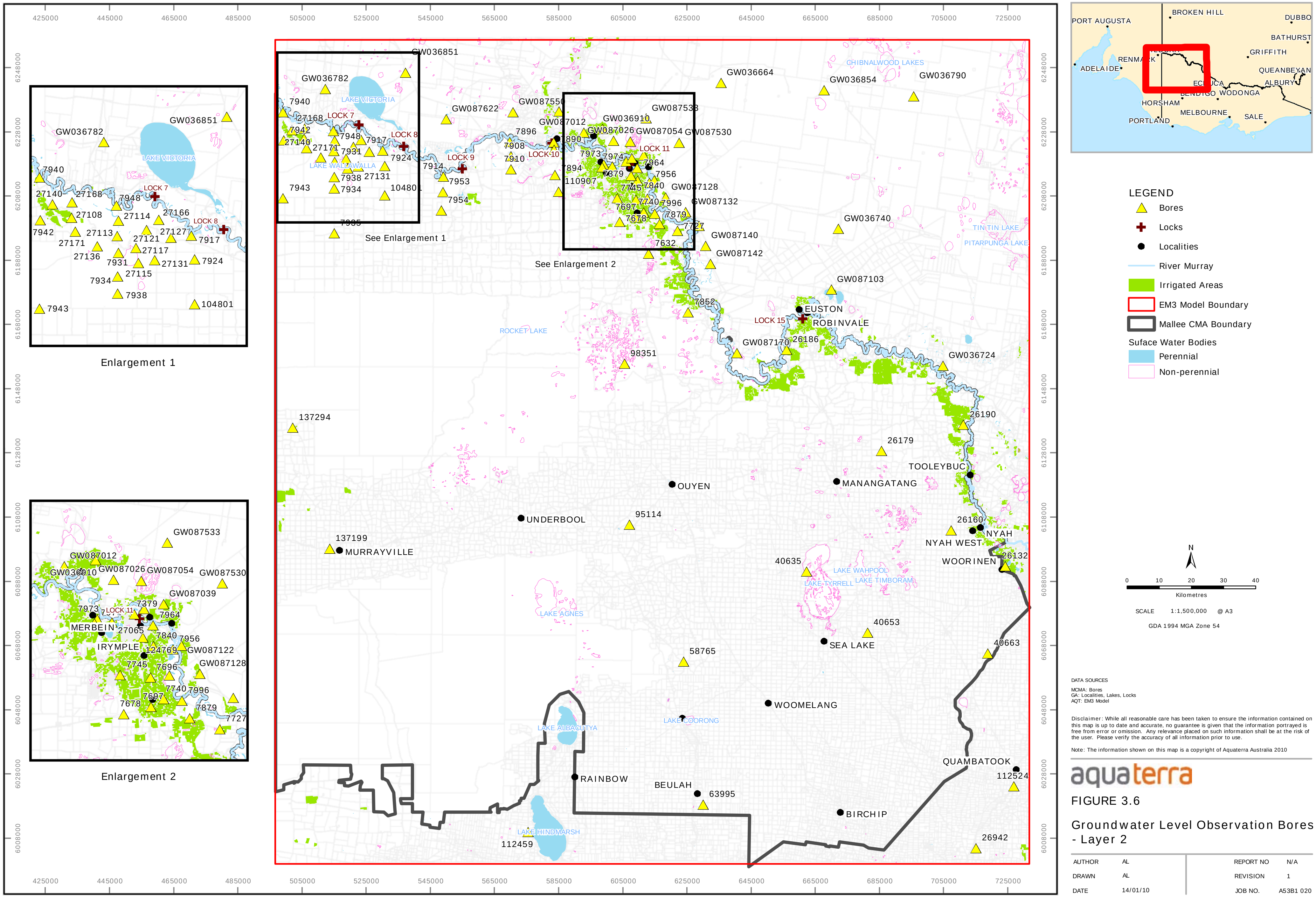
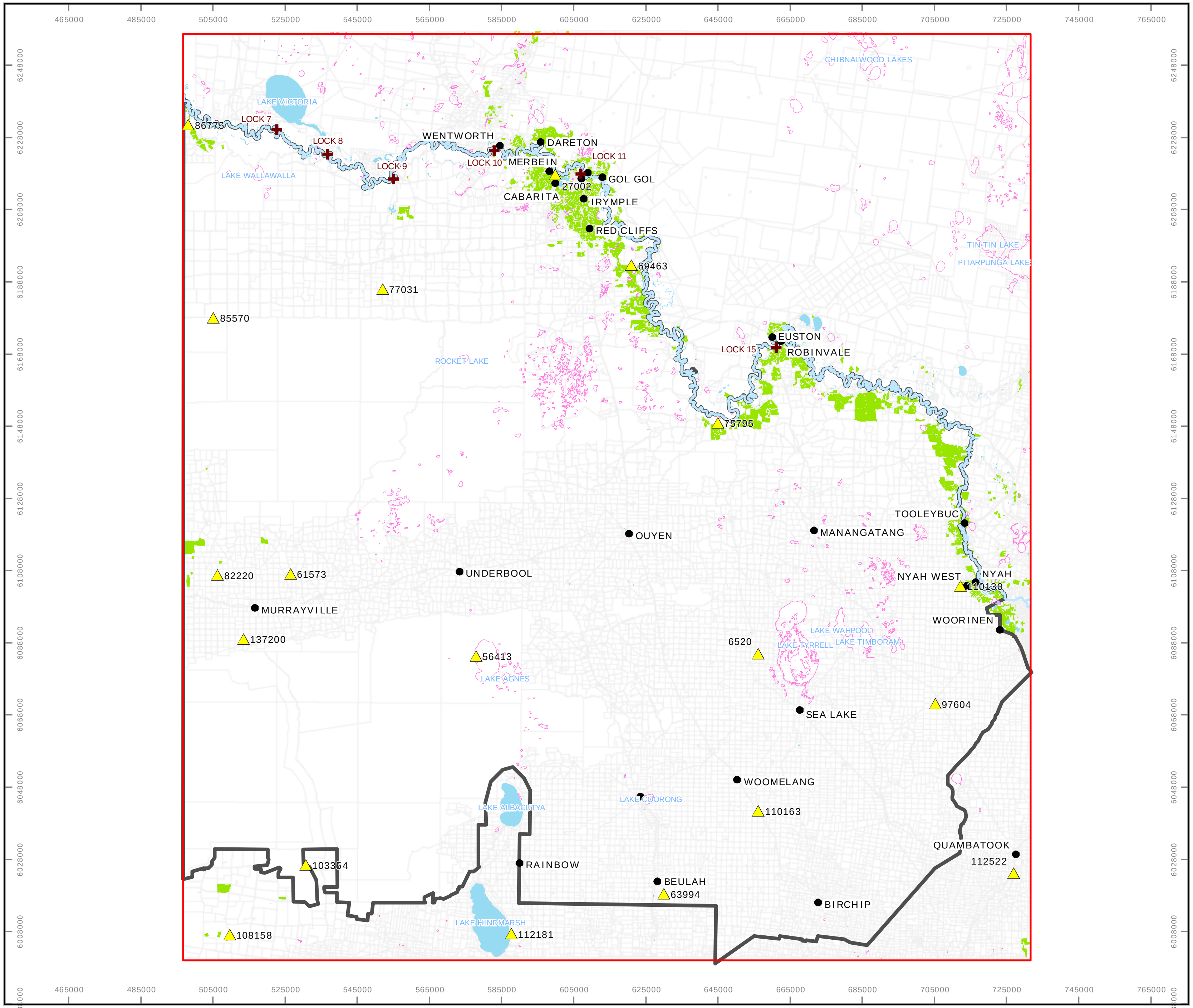
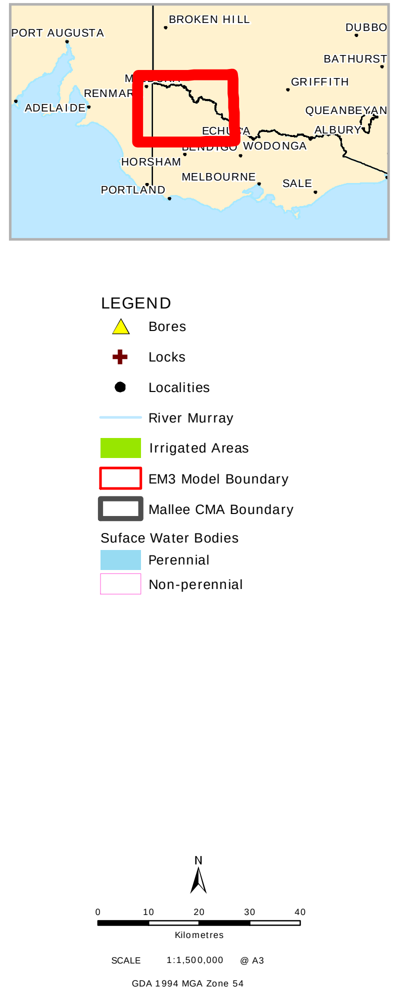


FIGURE 3.6

Groundwater Level Observation Bores - Layer 2





DATA SOURCES
MCMA: Bores
GA: Localities, Lakes, Locks
AQT: EM3 Model

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FIGURE 3.7

Groundwater Level Observation Bores - Layer 3

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DATE	14/01/10	JOB NO.	A53B1 021

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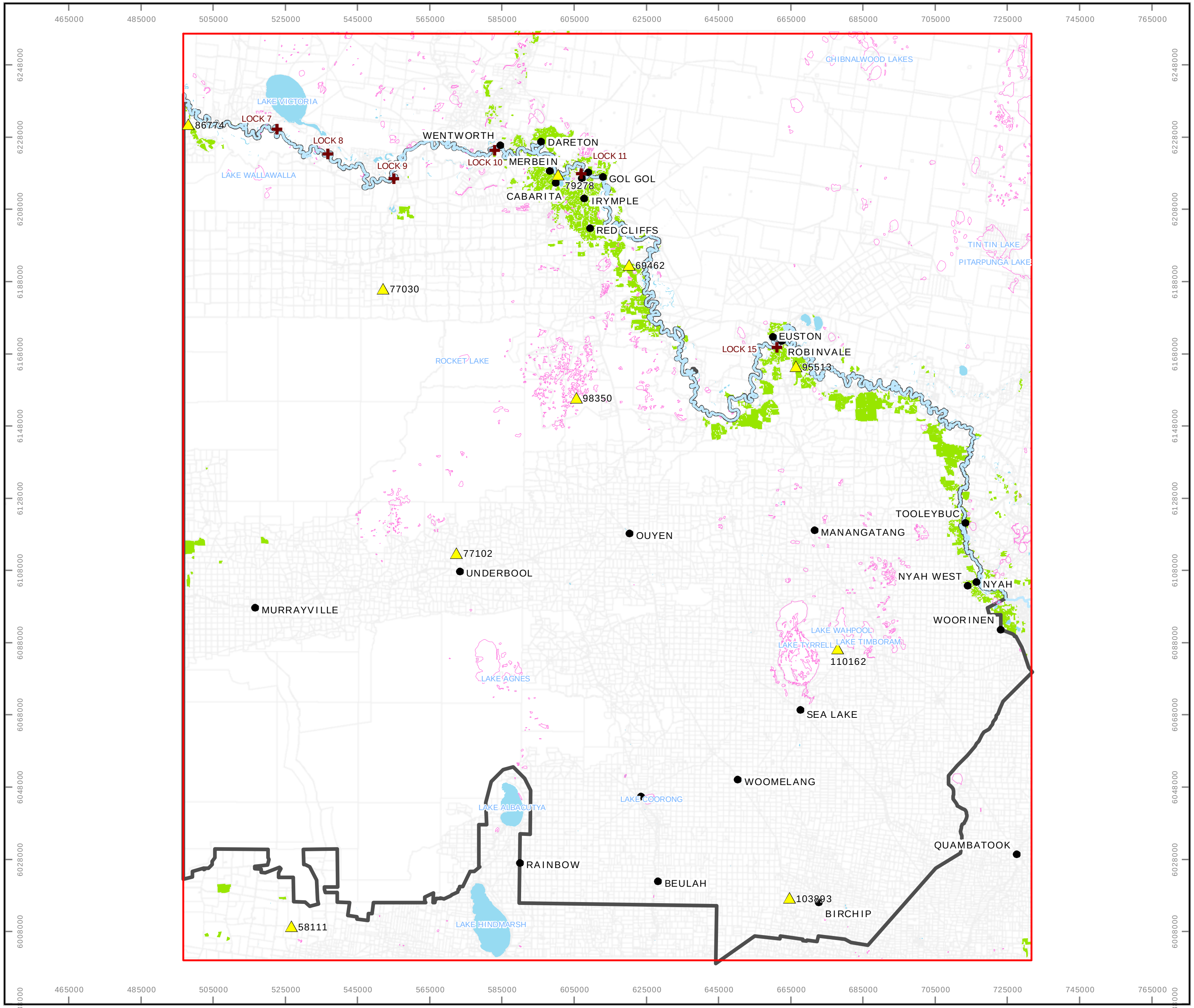

LEGEND

- Bores
- Locks
- Localities
- River Murray
- Irrigated Areas
- EM3 Model Boundary
- Mallee CMA Boundary

Suface Water Bodies

- Perennial
- Non-perennial

N

0 10 20 30 40

Kilometres

SCALE 1:1,500,000 @ A3

GDA 1994 MGA Zone 54

DATA SOURCES

MCMA: Bores
GA: Localities, Lakes, Locks
AQT: EM3 Model

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FIGURE 3.8

Groundwater Level Observation Bores - Layer 4

AUTHOR	AL	REPORT NO	N/A
DRAWN	AL	REVISION	1
DATE	14/01/10	JOB NO.	A53B1 022

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4 MODEL CALIBRATION

4.1 CALIBRATION APPROACH

To make valid predictions in future, the model has been calibrated (i.e. history-matched) to monitoring data covering a range of observed climatic and hydrological stresses such as pumping, recharge and drought-related recession.

As a precursory process to transient calibration, a benchmarking steady-state model was run at year 2000 conditions, during a period of near flat hydrographs (i.e. close to equilibrium) to determine the appropriate hydraulic conductivity distribution for the DSE provided recharge dataset. Then a historical model scenario was run, covering the period from 1990 to 2005. At each step of the modelling process, model calibration performance was checked against a range of calibration targets, discussed in section 4.3 below.

4.2 ADDRESSING NON-UNIQUENESS

An important component of developing a well-calibrated model is addressing 'non-uniqueness'. Non-uniqueness arises because many different possible sets of model inputs can produce similar history match performance. As per the MDBC Groundwater Flow Modelling Guideline (Middlemis, 2001), the main methods employed in calibration to reduce the non-uniqueness problem were:

- Calibrating the model using hydraulic conductivity (and other) parameters that are, where possible, consistent with the measured values (i.e. "unique" to that aquifer) in published literature;
- Calibrating to multiple distinct hydrological conditions with that parameter set. For EM3, involved calibration to changes to hydrological conditions and pumping of existing SIS bores;
- Calibrating to measured groundwater flow rates to restrict the water budget values. For EM3, this involved calibration to patterns of losing and gaining sections of the River Murray.

4.3 CALIBRATION TARGETS

During the modelling process, model calibration performance was checked in quantitative (head value matches) and qualitative (pattern-matching) terms against a range of targets, in accordance with the model guidelines (Middlemis, 2001), including:

- Groundwater level based targets:
  - modelled versus measured head during the chosen history match period
  - contour plans of measured head
  - time-series hydrographs of modelled/measured heads at selected monitoring bores
- River flux (patterns of gaining/losing sections of the river);
- Expected lateral flux from the south (Wimmera);
- Other water balance components over time, including the pattern of evapotranspiration.

This calibration approach is more rigorous than is usually applied to groundwater models, which are typically only matched against measured water table levels, and are not further constrained by a required match to flux estimates/measurements.

The main **quantitative model performance indicator** is the scaled RMS value (the RMS error term divided by the range of heads across the catchment). 5% and 10% scaled RMS values were set in the project specifications as appropriate upper range targets for steady state and transient aquifer water levels respectively. This approach is consistent with the Australian best practice groundwater modelling guidelines (MDBC, 2001).

Calibration was somewhat constrained by the prescribed recharge dataset which was supplied by the DSE. Recharge values in this dataset differ from the results in some areas obtained with other models. The following strategy was applied to deal with this apparent discrepancy:

- Hydraulic conductivity values (both horizontal and vertical) were varied to achieve matches to observed water level measurements in areas not covered by previous modelling work;
- The head assignment in GHB boundary conditions was subject to some uncertainty due to outdated data (hydrogeological maps used to inform the setting are generally old) or poor data cover and in some cases a trial and error technique was applied to setting boundary head values for individual layers;
- Only limited calibration work was attempted for areas such as Sunraysia where we believe the DSE recharge values set for irrigated areas are not consistent with (i.e. much lower than) widely adopted/accepted irrigation figures; this mainly affects the steady state model recharge data set, although the transient recharge data set also appears to show much greater variability in annual recharge under irrigation areas compared to recharge rates derived from District scale water balance derived on the projects (egg. EM2 and EM1 models; Aquaterra, 2009). The DSE recharge dataset specifies comparable rates through few stress periods, for larger part of the calibration period (approximately 70%) the prescribed rates are within 20 to 50 mm/yr band which is considered inadequate;
- As there were limits to what could be achieved by varying hydraulic parameters other than recharge within reasonable range of values, the residuals between modelled and observed values in some areas were provisionally accepted, although these could be improved with changes to the recharge dataset, especially under irrigation areas and in areas with deep water levels (i.e. deeper than 50 m).

In addition to the above calibration targets we used our experience with well calibrated models (such as EM2 developed for Sunraysia and EM4 for the NW part of the model domain), where parameter values are constrained by previously computed and calibrated salt fluxes to the River Murray (Aquaterra, 2009b, 2008).

4.4 STEADY STATE CALIBRATION

Steady state calibration represents long term average groundwater conditions that do not include or account for any change in aquifer storage (i.e. no long term trend in piezometric levels). The results presented here are for the final run of the steady state model with the parameters as adopted for the final transient model calibration (i.e. not the initial steady state run).

During the calibration process a number of different parameters were adjusted in an effort to provide an adequate calibration performance. Horizontal and vertical hydraulic conductivity, inflow and outflows, recharge and general head boundaries (GHB) were all investigated, especially for the transient model calibration, and the sensitivities of these elements to the model's performance is provided.

4.4.1 HEAD-DEPENDENT FLOW BOUNDARIES

Hydraulic conductivity adjustment was in some cases not sufficient to account for differences between modelled and observed water levels, particularly in the southern and western sections of the model domain. As an additional measure we refined the Head-Dependent Flow boundaries (using the Modflow GHB package) in these areas, in particular the southern boundary. Modification of the GHBs generally did have a noticeable effect on model performance.

However, whilst overall there appears to be an improvement in model performance and this is certainly the case for water levels nearby the boundaries, there is a diminishing effect further away from the boundaries. As expected the water levels in the central region of the model do not appear to be sensitive to changes in boundary conditions.

The work on calibration with boundary conditions also suggests the presence of varying groundwater pressures with depth in individual lithological or aquifer units. This led to specification of non-uniform head levels in individual layers along some stretches of the boundaries, e.g. in the northern section of the western boundary as indicated in Section 2.2.1. The level difference there is 14 m, with significant upward pressure component. This is in

agreement with published hydrogeological maps and the Mallee vertical leakage study undertaken by SKM (2008).

4.4.2 RECHARGE

The recharge values prescribed per model cell have been developed independently by DSE and were not subject to calibration (other than sensitivity testing in some cases). Our experience with calibration of this model and other modelling work carried in areas covered by the model domain indicates that the prescribed recharge implemented in the model may be too high for some parts of this catchment, and/or there should perhaps be a time lag applied, particularly in the south and/or where there is great depth to water table. Large sections of the model domain in the south have prescribed values in excess of 5 mm/yr or even 15 mm/yr which is thought to be unrealistic, and is not consistent with the significant body of research in this area (egg. Cook *et al.* 2004).

The notable exception is the Sunraysia irrigation region near the River Murray, where the prescribed steady state recharge under irrigation areas is considered insufficient when compared against the detailed EM2 recharge dataset which is based on measurements (and some estimates) of river diversion volumes, diversion losses, irrigation areas, water use efficiencies and drainage rates (Aquaterra, 2009b).

During the initial steady state model calibration, the degree to which recharge may be responsible for the mounding effects in the south was explored with several exploratory runs in which recharge was adjusted to lower values (i.e., reductions down to 3 to 10 mm/yr). Considering the degree to which the rates were decreased, there was only a small variation in the SRMS and changes in modelled water levels, which suggests that recharge in those runs was not a particularly sensitive parameter. It is however possible that even those values were too high and therefore the resulting changes in the water level configuration were inadequate.

4.4.3 RIVER AND GHB CONDUCTANCE

Murray River bed conductance was adopted at 150 m^2/day. Spatial variation in river bed conductance was not considered during the steady state model calibration.

GHB conductance was varied during the initial steady state calibration process. During transient calibration, GHB conductance varied spatially as it was calculated using K values corresponding with parameter zone and true saturated thickness. Depending on these site-specific factors the values generally are in the order of tens or hundreds, and less often thousands of m^2/day.

4.5 STEADY STATE CALIBRATION RESULTS

4.5.1 SOLVER CRITERIA

The PCG2 (pre-conditioned conjugate gradient) solver (Hill 2003) was used as the MODFLOW solver. PCG2 is commonly used with MODFLOW to simulate linear or nonlinear flow conditions by solving the hydraulic head equations produced by the model.

Convergence of the solver is determined using both head-change and residual criteria. The solver criteria set for the EM3 steady state and transient models are presented in Table 4.1

Table 4.1: EM3 Steady State Solver Criteria

Maximum outer iteration	Maximum inner iteration	Head change criterion	Residual criterion for convergence	Relaxation parameter	Damping factor
100	500	0.3 m	20 m^3/day	0.97	0.97

4.5.2 CALIBRATION STATISTICS

The steady state calibration statistics are summarised in Table 4.2 and the scatter plot of measured versus modelled head is shown in Appendix H. A scaled RMS value of 4.91% which is within the 5% target, and a coefficient of determination of 0.99 (the target value is 1.00) is

achieved, both consistent with the Groundwater Flow Modelling Guidelines (MDBC, 2001). However, calibration performance indicators and the scatter plot in Appendix H show some notable differences between modelled and measured levels in certain areas, indicating potential uncertainty for predictive purposes.

Appendix H presents details on the calibration performance, including the bore coordinates, model layer assignment for the screened interval, observed head and modelled head. The completion aquifer for each bore has been based on data provided by the Victorian DSE Groundwater Management System (GMS) database, as well as lithological elevation data.

Table 4.2: Calibration Performance Indicators of Mallee CMA Steady State Model

Calibration Parameters		Value
Root Mean Square	RMS	4.29 m
Scaled RMS	SRMS	4.91 %
Coefficient of Determination	CD	0.99

The scatter plot in Appendix H indicates that a number of the modelled heads are close to the measured heads, with the majority of the modelled heads systematically lower, with differences ranging up to 18.36 m (average 2.94 m). Modelled heads observed to be higher than the measured heads had a smaller difference range, from 0.01 to 13.99 m (average 2.11 m).

4.5.3 WATER LEVEL CONTOUR PLOTS

Figures H.2 to H.5 in Appendix H present the modelled steady state water level contours incorporating residual plots. Dry cells pattern can be observed to occur in layers 1 and 2. The general groundwater flow pattern for all four layers is from the south-east to the north-west, which is in agreement with the known/mapped groundwater flow pattern.

It can be seen that the dry cell pattern dominates in layer 1 and the residuals around Lake Tyrell indicate that modelled heads are lower than observed. Modelled heads are generally good in the floodplain, with the possible exception around Mildura which exhibits slightly lower modelled heads. This is due to inadequate recharge assigned to irrigation zones.

Water level contour plots for layer 2 (Figure 3.3) show an area of dry cells along the southern half of the western boundary as well as within the centre of Lake Tyrell indicating that measured and modelled water levels both lie close to the layer 2 interface. The residuals indicate that the irrigation areas in the Sunraysia region along the River Murray generally exhibit modelled water levels that are lower than the measured spot values, whilst those areas in the Parilla across the remainder of the model predominantly indicate modelled water levels higher than measured values. This suggests that the irrigation area recharge rates are too low, and perhaps the dryland area recharge rates may be too high. The one exception to this is around the Avoca River in the south-eastern corner of the model (outside of Mallee CMA) where modelled levels are lower than measured. It is likely that a combination of local low permeability alluvium conditions combined with leakage from Avoca River is a driver for higher than predicted local water levels. Hydraulic conductivity assigned to the regional aquifer is fairly high and not likely to reflect alluvial conditions and to match local observation bores additional parameter zoning would have to be applied.

Residuals in layer 3 and 4 both indicate that modelled water levels in the north are lower than measured spot values, whilst the opposite is observed in the south (aside from where southern drain and river features that are influencing the flow in layer 3, as well as layer 2). Layer 3 also shows some discrepancies between the modelled and measured water levels around the Murrayville and Telopea WSPA areas to the west and south-west, indicating that there is an issue with the level of accuracy in terms of the pumping data implemented in this region.

4.5.4 MODELLED WATER BALANCE

Table 4.3 shows the steady-state modelled water balance for the entire catchment. The largest component of flow into the catchment is from river leakage; while evapotranspiration makes up the major catchment outflows.

The modelled water balance indicates that the rivers are generally a losing system at the catchment scale; however the numerical model indicates that there are a few short reaches along the Murray River that are gaining as shown in Figure 4.4. This losing and gaining reach pattern is broadly (but not wholly) not consistent with the results of recent AEM and nanoTEM surveys that identify losing and gaining reaches or river (Telfer *et al.* 2006); essentially this model is considered to over-estimate the losing nature of the River.

It can also be seen that evapotranspiration is a more dominating process when compared to recharge in terms of the volumes of flow. This is consistent with the Mallee providing large groundwater discharge outlets such as saline lakes.

Table 4.3: EM3 Mallee Model Steady State Water Balance

Component	Inflow (m^3/day)	Outflow (m^3/day)
Wells	129,110	65,721
Drains	0.0	3708
Recharge	429,490	0.0
Evapotranspiration	0.0	1,489,000
River Leakage	1,220,000	111,790
Head Dependent Boundaries	86,908	141,630
Total	1,865,508	1,811,849
Discrepancy (%)	2.92	

4.6 STEADY STATE SENSITIVITY ANALYSIS

Sensitivity analysis in the modelling context is an evaluation of the effect that variations in input parameters have on the model output, to examine which parameters are likely to influence the accuracy of the model if their input values are inaccurate. Note that sensitivity analysis has been carried out prior transient calibration and the steady state model itself was updated during the transient calibration stage. The results presented in Table 4.4 relate to the original steady state calibration, the report for which is provided in Appendix I.

Key results of the steady state sensitivity analysis are summarised in Table 4.4:

Table 4.4: Key Sensitivity Analysis Results

Parameter	Initial steady state Calibrated value (base case)	Perturbation	SRMS (%)
Calibrated model (original steady state)			3.95
Kh: Parilla Sands (north)	20 m/d	40 m/d	3.84
Kh: Parilla Sands (south)	50 m/d	25 m/d	4.01
Kh: MGL & Bookpurnong Beds (south)	20 m/d	10 m/d	3.89
Kh: Renmark Group	25 m/d	12.5 m/d	4.00
Kv: Geera Clay/Winnambool Formation & Bookpurnong Beds	0.01 m/d	0.1 m/d	3.93
Kv: Renmark Group and Ettrick Marl	0.001 m/d	0.01 m/d	3.97
Recharge: Maximum recharge 3 mm/yr	variable	max 3 mm/yr	3.73

The effects of parameter perturbations on the base case shown in examples (Table 4.3) suggest that the horizontal hydraulic conductivity has a significant effect on the calibration performance of the steady state model. There is a scope for better SRMS results, if, for example, hydraulic conductivity of the Parilla Sand aquifer in the north is doubled to 40 m/d. Such increases would have to be backed up by field evidence (egg. pumping tests), as the accepted range of physically realistic values does not extend this high. Note that in the southern part of the model the hydraulic conductivity of the Parilla Sand aquifer (base case) is 50 m/d, a value is regarded as very much at the upper limit of the realistic range.

Sensitivity analysis also suggests some scope for improvement by raising hydraulic conductivity in the two deeper aquifers, the Renmark Group and Murray Group Limestone.

The effects of the vertical hydraulic conductivity are relatively small, despite the order of magnitude perturbations examined. It is concluded that higher values of vertical hydraulic conductivity has lesser impacts on the calibration performance of the steady state model, but it may become more important during the transient calibration when lower values of Kv could be tested.

Recharge perturbation had quite a significant impact – as would be expected. In the case shown in Table 4.4 all recharge values in the DSE dataset above 3 mm/yr was constrained to not exceed 3 mm/yr. This had the effects of removing recharge values that were up to one or two orders of magnitude higher. Such a variation resulted in the most significant reduction of the SRMS statistic and demonstrates the high sensitivity to recharge of the steady state model.

The sensitivity analysis identified several key parameters that are critical for improved model performance:

- Irrigation recharge – this was not changed during this study but it is known from work on other projects such as EM2 that it has a great impact on the accuracy of matching the water table mounding effects, and subsequent river/aquifer interaction and hydrological balances. It is suggested that the steady state model results and sensitivity assessment demonstrates that the irrigation area recharge values provided by DSE are too low and not realistic, and an alternative recharge dataset should be developed and applied as the basis for an alternative model calibration;
- Hydraulic conductivity of the Parilla Sands aquifer - this is the most important aquifer in this region and is most prone to any impacts resulting from land use changes, so accurate calibration in this unit is important for model capability;
- Hydraulic conductivity of the Murray Group Limestone and Renmark Group - both represent deeper units of the aquifer system and have the potential to be commercially utilised for water supply and irrigation.

4.7 TRANSIENT (HISTORY MATCH) MODEL

The transient groundwater model was set up using the steady state model as a basis (with an updated recharge dataset from the DSE), and using the steady state results as the initial conditions of the transient model. The transient model runs over the period 1990 to 2005.

The transient model implements a number of time varying features, namely:

- Recharge;
- Evapotranspiration;
- SIS pumping.

During the calibration procedure, model parameters were changed from their initial values and configuration. Aquifer parameters were originally consistent between the steady state and transient models, it was however necessary to adjust aquifer parameters during transient modelling. Aquifer parameters that were changed during the transient calibration procedure were recycled into the steady state model, with the steady state model being re-run to generate a new set of initial water levels.

The series of figures in Appendix E show spatial recharge distribution applied per stress period (one year each). Figure E17 in Appendix E shows the evapotranspiration rate applied uniformly for each stress period, i.e. there is no annual variation in ET rates. ET rates are based on ENSYM generated dataset (potential minus actual) provided by DSE. A uniform extinction depth of 4 m was applied across the whole model domain. An annually varied ET rate was also applied as a sensitivity run.

The simulated groundwater levels from the history match run were compared against observed water level data. Hydrographs and calibration statistics are used to show the calibration performance. The calibration statistics was calculated from all measurements available from selected monitoring bores.

4.7.1 STRESS PERIOD SETUP

The model consisted of 16 stress periods, each a constant length of 365 days (366 days each leap year). The stress period duration was predominantly based upon computational power (e.g. size of files were becoming large) however available calibration data and project objectives (e.g. determined by DSE) were also taken into consideration. The first year of the model run featured 10 time steps, with each subsequent year containing five time steps. The model incorporated a time step multiplier of 1.07.

4.7.2 SOLVER CRITERIA

The PCG2 (pre-conditioned conjugate gradient) solver (Hill 2003) was used as the MODFLOW solver. PCG2 is commonly used with MODFLOW to simulate linear or nonlinear flow conditions by solving the hydraulic head equations produced by the model.

Convergence of the solver is determined using both head-change and residual criteria. The solver criteria set for the EM3 steady state and transient models are presented in Table 4.5

Table 4.5: EM3 Transient Solver Criteria

Maximum outer iteration	Maximum inner iteration	Head change criterion	Residual criterion for convergence	Relaxation parameter	Damping factor
100	500	0.01 m	10 m^3/day	0.97	0.97

4.7.3 COMPARISON OF GROUNDWATER LEVELS

Hydrographs for calibration were available from the GMS database for Victoria and from NOW in NSW. Hydrographs have been selected for transient model calibration on the basis of record length and their location. Figures 3.5 to 3.8 shows the bores selected for calibration, and Appendix J presents the hydrographs of computed vs observed levels.

4.7.4 CALIBRATION STATISTICS

The calibration statistics are based on comparison of observed water level records from selected monitoring bores (150 in total) and computed water levels. The statistics are calculated on the whole dataset, i.e. not on any specific time snapshot.

Table 4.6 shows the calibration statistics for the history matching effort, reflecting the comparison between the 150 measured and calculated heads over the whole modelled period.

Table 4.6: Model Calibration Statistics

Statistic	History match performance
Residual mean (RM)	0.38
Residual sum of squares (RSS)	2.61×10^5
Absolute residual mean (ARM)	2.64 m

Statistic	History match performance
Residual standard deviation divided by target range (RMS error)	3.82
Scaled mean sum of residuals (SMSR)	1.61%
Root mean square (RMS)	2.60
Scaled root mean square (SRMS)	2.27%
Coefficient of determination (CD)	0.75

RM is computed by dividing the sum of residuals by the number of residuals. This value should be close to zero for good calibration. The value of 0.38 is slightly positive, suggesting that on average the model marginally under-predicts computed heads. RSS is important only for comparing individual runs, with the aim to minimise the RSS value. The ARM is a measure of the average error in the model, suggesting than on average our computed heads are about 2.6 m off the observed ones. We suggest that this is likely to be affected by errors in adopted topographical elevations (the SRTM dataset has known error issues).

RMS error indicates how the errors relate to the overall gradient across the model. For good calibration this value should be less than 0.05 (i.e. 5%), and the EM3 model achieved 3.82%. RMS is an absolute measure that is thought to be the best error measure, if errors are normally distributed. Its value is 2.60 m in our current calibration. SRMS statistic is accepted to be below 5% for good calibration, our model achieved 2.27%. CD value of 1 or close to 1 is suggestive of very good calibration, however our model achieved 0.75.

4.7.5 WATER LEVEL CONTOURS

A qualitative evaluation of the history matching results was undertaken by comparing contours of the modelled groundwater levels with the contours available from the Basin in the Box. The latter source only offers what could be regarded as watertable elevation and it is assumed that it largely represents the water levels in the Parilla Sand aquifer. There is a generally good match between the Basin in the Box and modelled contours from Layer 2 (see Figure 4.1). The levels in the south-eastern corner of the model are slightly higher (up to several metres) and also show the draining effect of the creek system associated with Avoca River and Tyrrell Creek, which is not shown in the Basin in the Box map.

Groundwater level contours from the deeper units represented by layers 3 and 4 (see Figures 4.2 and 4.3) were compared to contours shown on a set of Murray Basin Hydrogeological Map Series 1:250,000 maps. The model shows acceptable match given the fact the water level contours presented on those maps were generally compiled for early 1990s. The area of slight potential variation is in the northwest corner of the model where water levels in the model are lower and the overall gradient is flatter that what is suggested by the Murray Basin Mildura Sheet. Attempts to maintain water level contour of about 25 m in this area resulted in general inflow rather than outflow from the model, which was subsequently corrected to ensure that the western boundary is an outflow feature.

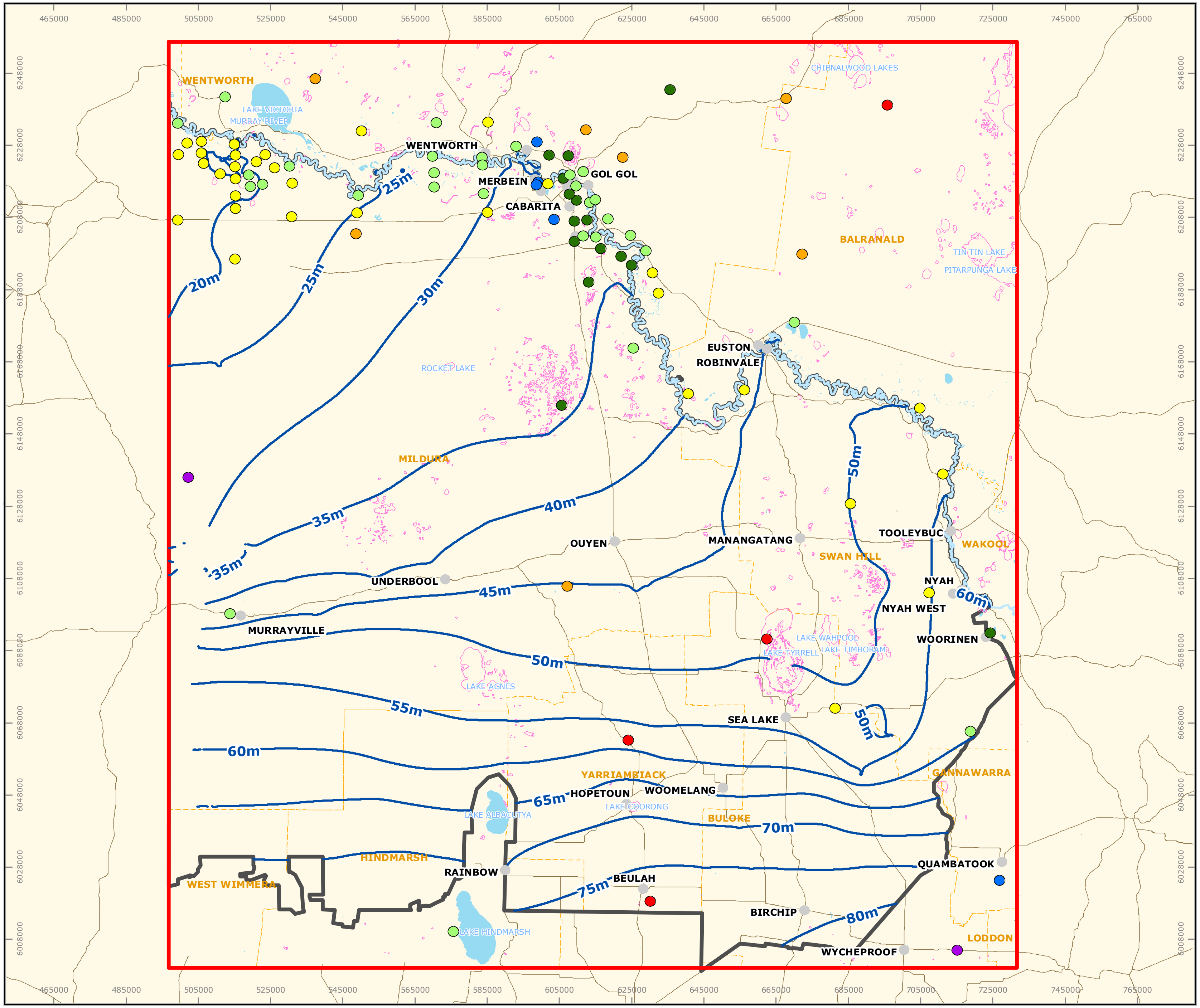
Water levels along the River Murray are controlled by river levels and are adequately reproduced by the model. The model may not correctly reproduce the irrigation mounds around Mildura, i.e. the computed water levels are lower than observed. The reason is that the recharge rate applied in those areas is not sufficient to reflect the irrigation practices, especially for the steady state run (due to very low recharge rates), and thus the water table at the start of the 1990-2005 run does not adequately reflect the irrigation mound development to this time.

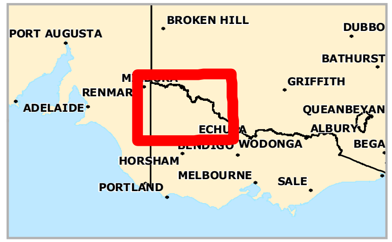
4.7.6 DEPTH TO WATERTABLE

Depth to watertable plots are presented in Figures 4.4 to 4.6 and provide the following insights:

- Geological structural features and zonations are distinguishable across the plots;
- Steady state model depth to watertable (2000) – generally greater than five metres across the entire model, aside from floodplain areas;

- Transient model depth to watertable (2000 and 2005) – predominantly greater than 10 metres across the model, aside from select areas within the floodplain, as well as groundwater discharge zones (i.e. Lake Tyrell).





LEGEND

- Localities
- River Murray
- Main Roads
- Water Level Contours (mAHD)
- LGAs
- EM3 Model Boundary
- Mallee CMA Boundary
- Suface Water Bodies
  - Perennial
  - Non-perennial

Residuals

- less than -5
- -5 to -2
- -2 to 0
- 0 to 2
- 2 to 5
- 5 to 10
- greater than 10

N

0 5 10 20
Kilometres

SCALE 1:1,500,000 @ A4

GDA 1994 MGA Zone 54

DATA SOURCES
GA: Localities, Lakes,, Roads, LGAs
AQT: EM3 Model, DEM

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FIGURE 4.1

Modelled Water Levels with Residuals - Layer 2

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DRAWN	AL	REVISION	1
DATE	21/04/10	JOB NO.	A53 057

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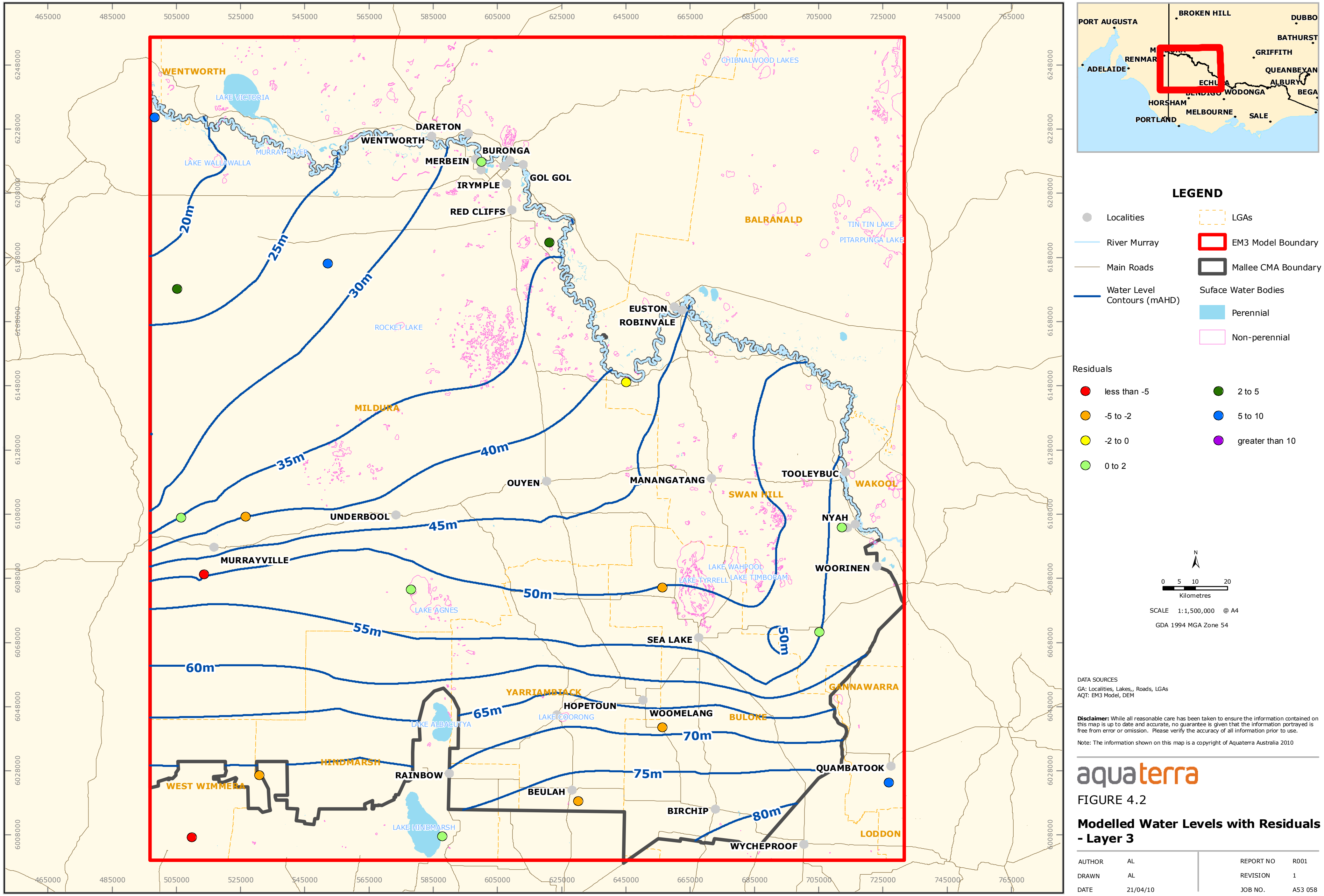

DATA SOURCES
GA: Localities, Lakes,, Roads, LGAs
AQT: EM3 Model, DEM

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FIGURE 4.2

Modelled Water Levels with Residuals - Layer 3

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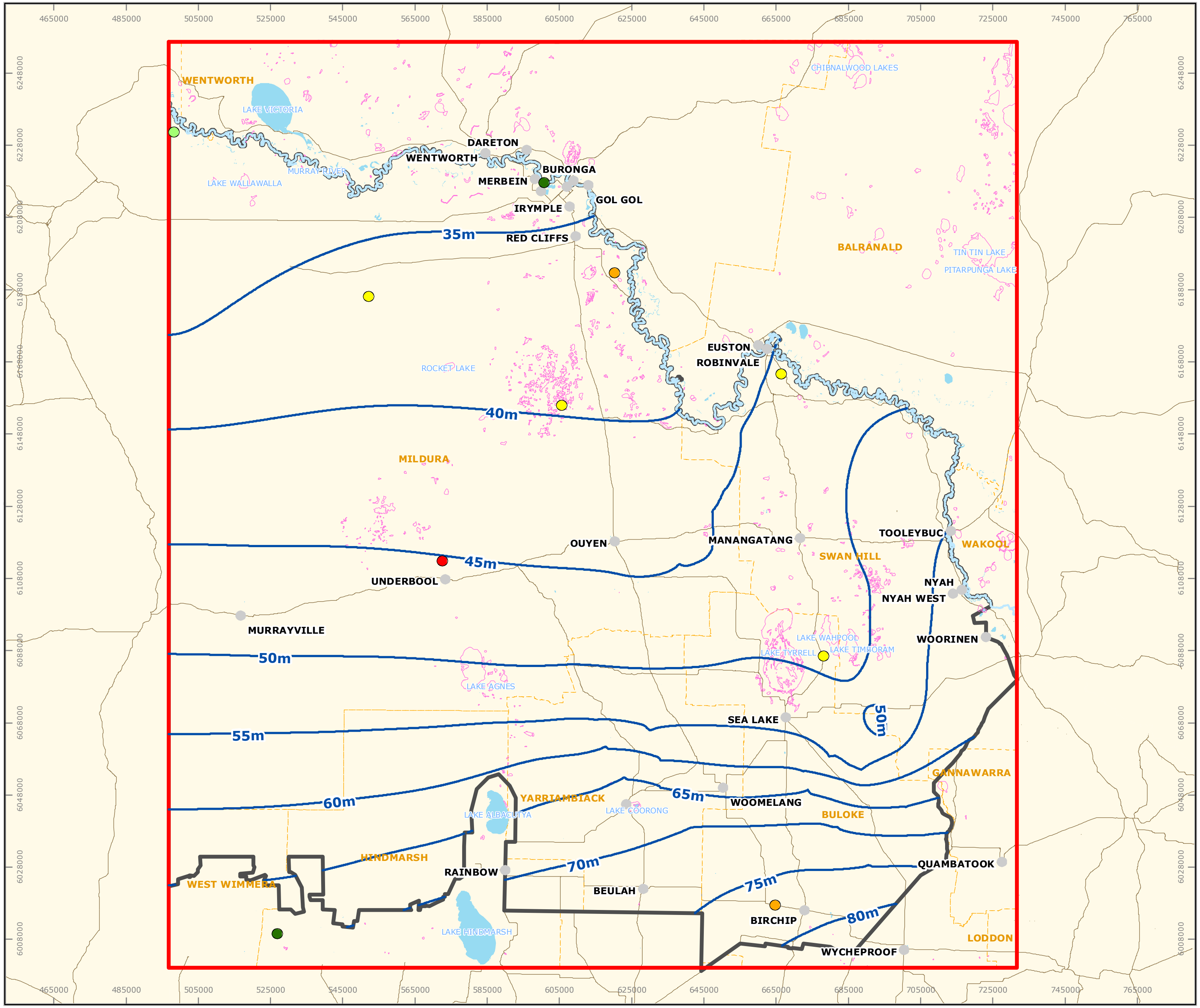

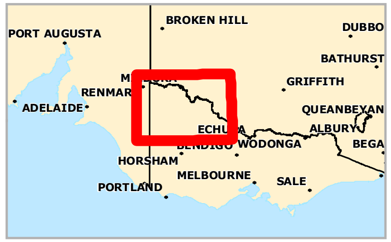

LEGEND

- Localities
- River Murray
- Main Roads
- Water Level Contours (mAHD)
- LGAs
- EM3 Model Boundary
- Mallee CMA Boundary
- Suface Water Bodies
  - Perennial
  - Non-perennial

Residuals

- less than -5
- -5 to -2
- -2 to 0
- 0 to 2
- 2 to 5
- 5 to 10
- greater than 10

N

0 5 10 20

Kilometres

SCALE 1:1,500,000 @ A4

GDA 1994 MGA Zone 54

DATA SOURCES

GA: Localities, Lakes,, Roads, LGAs

AQT: EM3 Model, DEM

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FIGURE 4.3

Modelled Water Levels with Residuals - Layer 4

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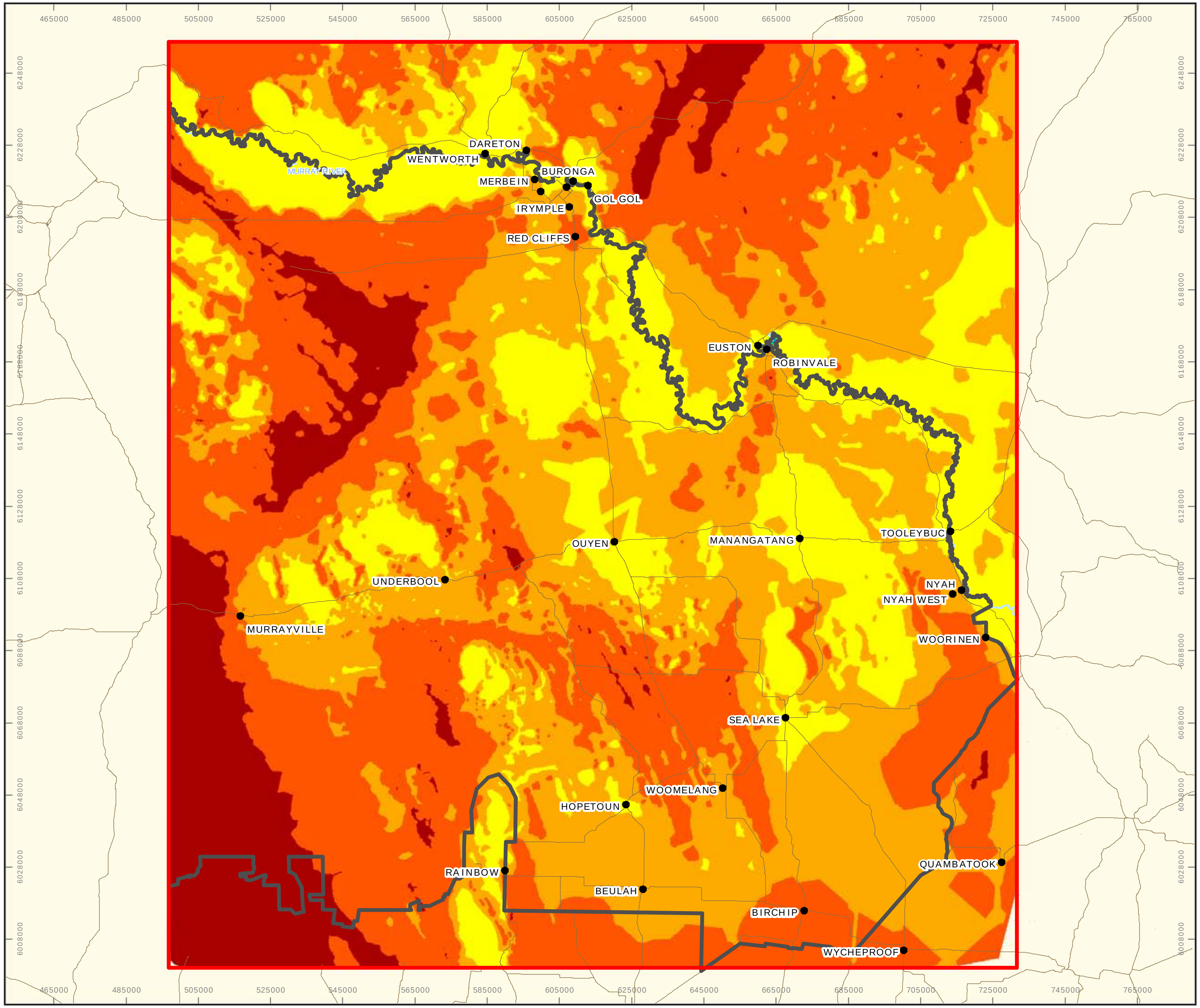

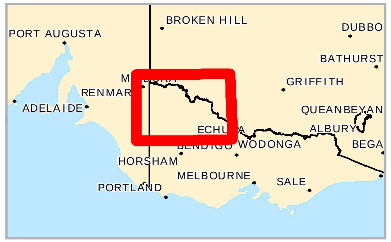

LEGEND

- ● Localities
- River Murray
- Main Roads
- EM3 Model Boundary
- Mallee CMA Boundary

Depth To Groundwater (m)

- < 0
- 0 - 2
- 2 - 5
- 5 - 10
- 10 - 20
- 20 - 50
- 50 - 100

N

0 5 10 20
Kilometres

SCALE 1:1,500,000 @ A4

GDA 1994 MGA Zone 54

DATA SOURCES

GA: Localities, Lakes,, Roads, LGAs
AQT: EM3 Model, DEM, DTW

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FIGURE 4.4

Modelled Steady State Depth To Groundwater (2000)

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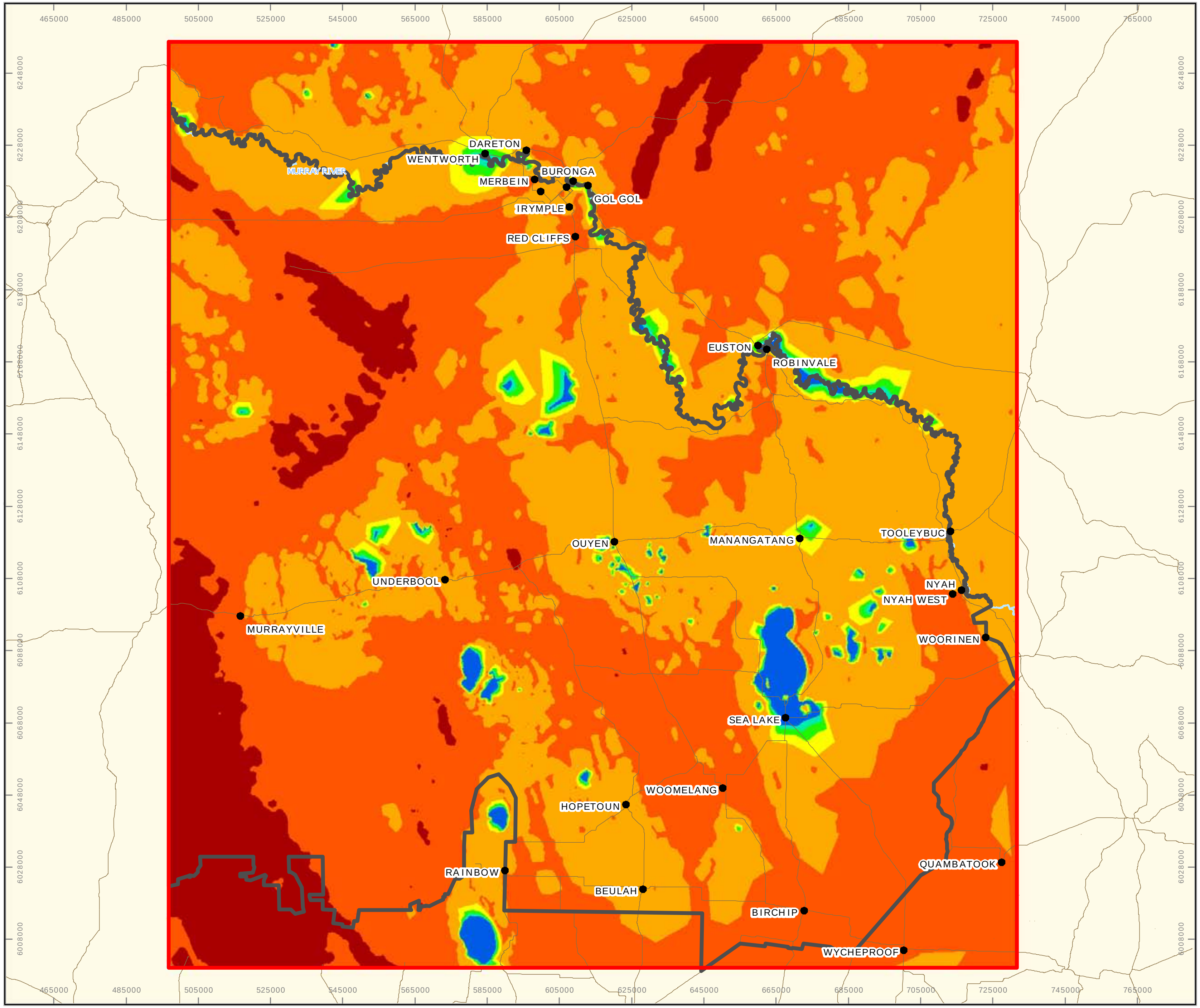

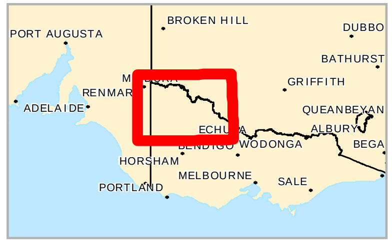

LEGEND

- Localities
- River Murray
- Main Roads
- EM3 Model Boundary
- Mallee CMA Boundary

Depth To Groundwater (m)

- < 0
- 0 - 2
- 2 - 5
- 5 - 10
- 10 - 20
- 20 - 50
- 50 - 100

N

0 5 10 20

Kilometres

SCALE 1:1,500,000 @ A4

GDA 1994 MGA Zone 54

DATA SOURCES

GA: Localities, Lakes,, Roads, LGAs
AQT: EM3 Model, DEM, DTW

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FIGURE 4.5

Modelled Transient
Depth To Groundwater (2000)

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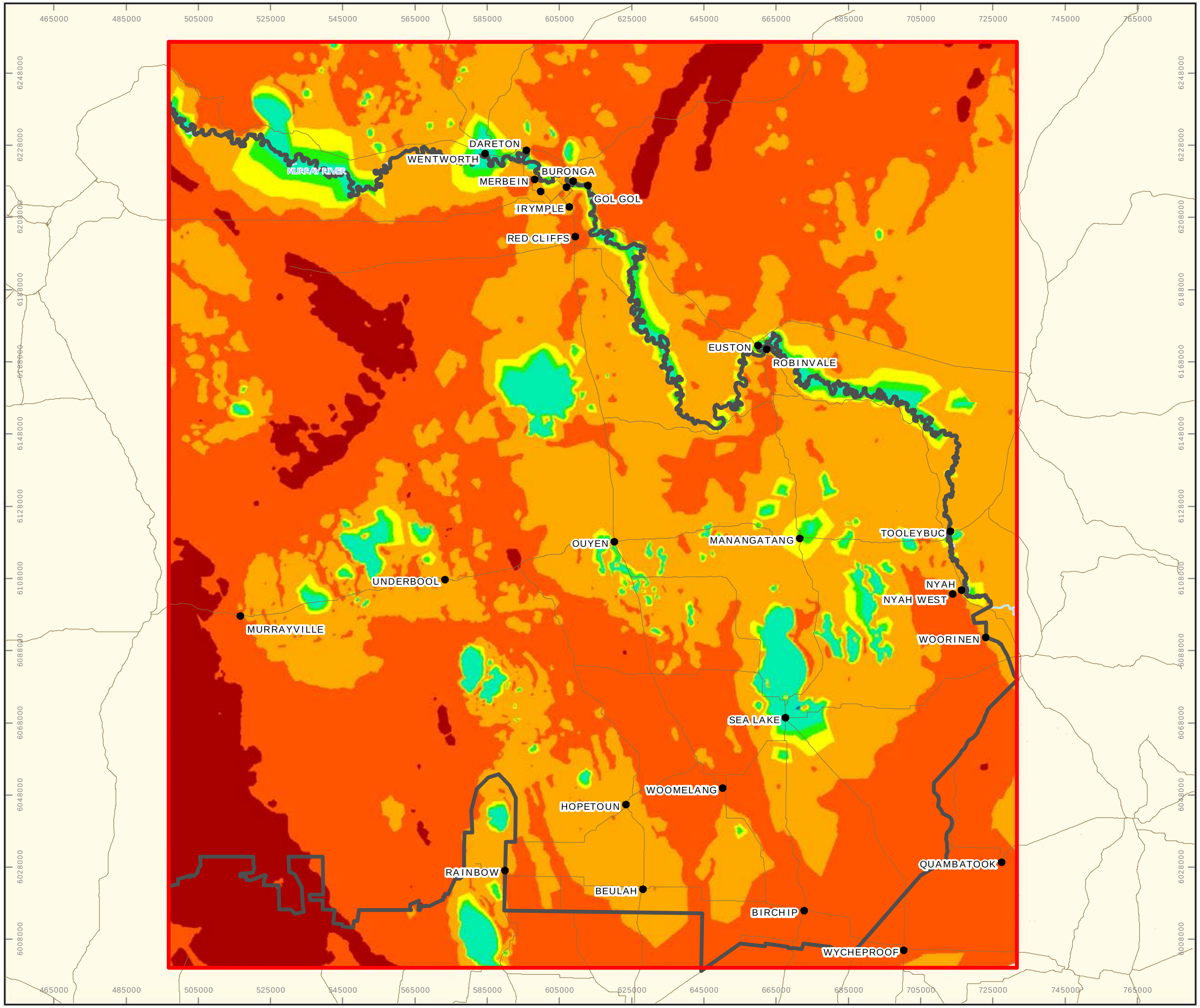

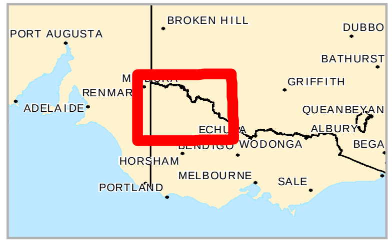

LEGEND

- Localities
- River Murray
- Main Roads
- EM3 Model Boundary
- Mallee CMA Boundary

Depth To Groundwater (m)

- < 0
- 0 - 2
- 2 - 5
- 5 - 10
- 10 - 20
- 20 - 50
- 50 - 100

N

0 5 10 20

Kilometres

SCALE 1:1,500,000 @ A4

GDA 1994 MGA Zone 54

DATA SOURCES

GA: Localities, Lakes,, Roads, LGAs

AQT: EM3 Model, DEM, DTW

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FIGURE 4.6

Modelled Transient Depth To Groundwater (2005)

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DATE	21/04/10	JOB NO.	A53 056

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4.7.7 BASEFLOW

The comparison between contributions to river baseflow in modelled versus measured data is considered an important part of the model calibration for Ecomarkets due to the outlined objectives of the project. It was however not possible to quantify and analyse baseflow in the Mallee CMA due to:

1) The stretch of the River Murray within the CMA is highly regulated, with a number of locks present, which prevents the baseflow process being realistically represented in measured and/or modelled datasets
2) Lack of flow data available for the river systems to the south of the CMA. A search of the Victorian Water Resources Data Warehouse on the 19 April 2010 yielded no flow measurement data within the Mallee CMA catchment off the floodplain.

If flow data was to become available, it is recommended that this is compared to baseflow from the model.

4.7.8 TIME SERIES GROUNDWATER HYDROGRAPHS

In general terms the hydrographs display a good fit between modelled and observed values in terms of absolute magnitude and general trends. The following discussion relates to the model performance in cases where modelled values deviate from the observed ones:

- The adopted extinction depth for the ET function in this model is four metres, i.e. it is assumed that the impact of ET can potentially apply to the whole area if the local water table is shallow enough. This has a particular effect on bores with shallow water levels where the water level is within a few metres from the surface. In some cases the ET function can draw the modelled water level deeper that it should, especially if the DEM value of the cell in which the observation is made is also inaccurate. However this extinction depth was adopted as a compromise since ET would be typically limited to the floodplain areas – where extinction depth can be even deeper for some vegetation classes - and to regional discharge areas such as Lake Tyrrell. In majority of the model domain water levels are beyond the reach of the ET function. To study the potential impact of the extinction depth we plotted the elevation of the model cell adopted from the DEM in the bore hydrographs in Appendix J. This allows for examination of whether the extinction depth has a potential effect on the model level in an individual observation bore. Such an effect is likely to be demonstrated by bores 40644, 40634, 7896, 7883. The ET extinction depth effect is less noticeable when the bore is close enough to the river for it to override the ET effect and maintain the water level in the observation bore.
- The adopted transient recharge rates are believed to be low in areas where irrigation mounds have developed (especially in NSW). Consequently, the model generally under-predicts water levels in bores situated in or near irrigation mounds and the difference can be up to several metres. Our experience in the NSW parts of the Sunraysia area, with developing the accredited groundwater model there is that recharge to irrigation mounds should be high. For example, the calibration of the accredited EM1.2 model considered up to 144 mm of recharge applied in year 2000 to the Buronga area, but values were even higher in 1960s and 1970s (over 300 mm/yr). Such high rates are not taken into account in DSE recharge model, and therefore computed water level, in affected bores are under-predicted. As discussed above, the steady state recharge rates are also very low under irrigation areas in Victoria, so the initial conditions for the transient run are under-predicted. This effect carries through into the transient model, with irrigation mounds under-predicted; examples of such bores include 7740, 7678, 7696, 7745, 7973 and others.
- The recharge model assumes instantaneous recharge in all parts of the model domain, irrespective of the depth to groundwater level. It is generally acceptable and hydrogeologically plausible that response to recharge events in areas with deep-seated watertable can be significantly delayed or the recharge pulse does not actually reach groundwater level and is still moving through the unsaturated zone. There is no evidence to allow for definitive assumptions to be made in regard to time lags. In this model domain there are large areas where watertable is more than 50 m deep and may be

partially disconnected from recharge events. Those areas usually presented some challenges with calibration under currently prescribed recharge. Such areas are widespread in the southern, western and also NSW parts of the model. The southern sections have relatively high recharge rates although technically some of this recharge would be rejected on the depth to water level argument. The bores in the south have often over-predicted water levels despite raising hydraulic conductivity to the upper range of expected values.

- The two groundwater pumping schemes in the southwest and west section of the model with high prescribed recharge coincide with areas of generally deep water levels. The early calibration attempts led to over-predicting of water levels. It is possible that a combination of inaccurate pumping figures and higher recharge (without a time lag) can contribute to those discrepancies. We also need to invoke the effect of pumping on the SA side of the model boundary in the Murrayville area, by setting a prescribed flux boundary to discharge 10 ML/d. This change led to significant improvement of calibration in this area. An example is bores 137200, 82220, 61573 in the Murrayville area. A similar situation is present in the southwest corner of the model, outside of the Mallee CMA, where the water levels are over-predicted for the same reason. No prescribed flux simulating the effect of cross-boundary pumping was introduced there because it is outside the study area. Although only two hydrographs were selected there (108158 and 103354) the area was studied during the steady state calibration runs more extensively with greater observation coverage.
- Several bores in the central and central south area show over-predicted levels by several metres. The area is generally underlain by Geera Clay / Winnambool Formation. Despite fairly high hydraulic conductivity in this area (2 m/d) we cannot achieve sufficient reduction in water levels. The area receives comparatively higher rainfall than other parts of the model but it is thought that due to lithological characteristics (clayey nature) significant part of the recharge would be rejected. Example hydrographs are 58765 and 63995 (nominally in Parilla Sand but underlain by Geera Clay), and 63994.
- Density driven effects have been disregarded in this modelling study but it has to be noted that they can account to a difference of up to several metres between corrected and uncorrected values. They could also change the pattern of flow, for example Hodgkin and others (2007) concluded in their report on Noora Basin that "in the region surrounding Noora Basin, groundwater levels in the MGL aquifer are typically several metres higher than the Loxton Sands Aquifer, which indicates a potential for upward leakage…the formation of dense saline water in the watertable aquifer from evaporation has created potential for downwards leakage in the immediate Noora Basin area and led to a formation of a saline groundwater plume within the MGL aquifer over thousands of years by localised density flow". This mechanism can be applicable not only to Noora Basin (partly in the northwest section of the model domain), but also to other areas since the observed salinities can reach multiples of seawater.
- Hydrographs in some observation bores show recession becoming noticeable especially after 1998 to 2000, which may not be well matched by modelled results in some cases despite the overall decrease in recharge. A sensitivity run undertaken by applying annually varying ET rates. The annual variation was implemented by applying multiplication factors in which year 2000 was given a factor of 1. Multiplication factors were derived from the total evapotranspiration rate calculated for the Mallee CMA for each year and sourced from DSE. Application of time varied ET rates led to better alignment with observed trends in bores that are likely to be affected by evapotranspiration (i.e. floodplain and shallow discharge basins). This proved the potential for further model improvement that can be enhanced even further by spatial variation and similar approach to extinction depths (these, too, could vary with time, especially in response to prolonged drought periods).

A summary table of the time series model performance was prepared from a semi-quantitative analysis of the match between observed and modelled values in terms of levels and temporal trends. The results of this analysis are shown in Table 4.7.

Table 4.7: Trend and Magnitude Comparison between Observed and Modelled Values

Level Deviation	Compliant Targets	Trend Alignment	Compliant Targets
Less than 2 m	54%	Good	47%
2 to 5 m	37%	Fair	43%
5 to 10 m	7%	Poor	3%
More than 10 m	<1%	Poor (early/late match)	7%
Total: worst two classes	<8%		10%

The trend and magnitude analysis indicates that the model matches both water level magnitude and trends well, with the proportion of bores in the worst two classes (i.e. water level deviation of more than 5 m and poor trend match) being 10% or less.

The overall conclusion based on the calibration statistics is that the model is fit for the purpose for future predictive simulations. The calibration is not of high quality in all areas and in all layers, and care should be exercised when evaluating the fitness for a particular purpose of the model in a particular location/aquifer.

4.8 GROUNDWATER – RIVER INTERACTIONS

Rivers and streams, mainly the River Murray, are the main contributors of water into the groundwater system as our analysis suggests in the next section. Large sections of the River Murray supply water into the floodplain aquifers where it is to a large degree used by vegetation and evaporation processes. The river bed conductance was identified as a potentially sensitive parameter in this regards, and a transient sensitivity run was undertaken accordingly, with a much lower river bed conductance (by a factor of 3). This run resulted in significant reduction of leakage from the river, by 40% and caused slight drop in modelled water levels in observation hydrographs while still complying with SRMS requirement. The important conceptual conclusion is than there is definite relationship between river leakage and evapotranspiration in that the latter balances out the input of the former.

4.9 WATER BALANCE COMPONENTS

The modelled water balance at the end of the calibration period for two alternative runs is presented in Table 4.8. The base case was run with river conductance set 150 m^2/day, while we also included a sensitivity run in which the conductance value was decreased to 50 m^2/day.

Water balance figures for the base indicate that at the end of the calibration period the largest contributor to the groundwater is the river (62% of the total incoming flux), while the most of losses are attributed to evapotranspiration (77% of the total outgoing flux). The lateral inflow from the south is relatively small, less than 47 GL/yr or less than 6% of the total incoming flux, although quite consistent with outflow from the neighbouring Wimmera model to the south.

The alternative case in which river conductance was lowered by a factor of 3 (to 50 m^2/day) produced similar calibration outcomes in terms of matching measured groundwater levels with similar and acceptable calibration statistics. The total amount of water in the system is significantly smaller (by 25%) due to the lower river bed conductance, but proportional contributions by individual balance items change less except for the river contribution which decreases by a third. These results indicate that further reductions in the river bed conductance would further reduce the river losing volumes, and increase the potential for river gaining reaches (Figures 4.7 and 4.8), which may produce a more consistent match with the findings of the AEM and NanoTEM surveys.

Table 4.8: Model Water Balance Components

	Base Case Transient Calibration (River Conductance 150 m^2/day)				**Sensitivity** (River Conductance 50 m^2/day)			
Flux feature	**In (GL/yr)**	**In (%)**	**Out (GL/yr)**	**Out (%)**	**In (GL/yr)**	**In (%)**	**Out (GL/yr)**	**Out (%)**
Storage in (i.e. removed from aquifer storage)	86	10.3	71	8.8	91	14	67	10
Wells (also includes inflow from south)	47	5.7	23	2.8	47	7	23	4
Drains			<1	<1			<1	<1
Recharge	157	18.8			157	25		
General head boundary	30	3.6	56	6.7	37	6	51	8
River	515	61.7	40	4.5	303	48	40	6
Evapotranspiration			645	77.2			455	72
Total	835		835		636		636	

4.10 CALIBRATION CONCLUSIONS

The Mallee CMA model (EM3) has been run over the calibration period of 1990 to 2005. Parameters adjusted during the history matching effort were used to update the steady state model to make sure the both models are consistent. The outcome of parameter and boundary condition adjustment has been a general improvement in calibration performance. Calibration statistic SRMS is below 5%. The hydrographs for the period 1990 to 2005 show a good match for both level and trend. There are areas of the model where its performance could be improved and they include:

- Irrigation mounds generally around Mildura region. We believe that currently adopted (prescribed) recharge rates under-represent the impact of irrigation resulting in under-predicted water levels in the monitoring bores in or near irrigation mounds.
- Recharge rates in the southern part of the model are considered high, especially in areas where water levels are set deep, i.e. below 50 m below surface. In these areas the model generally over-predicts groundwater level when using the prescribed recharge rates. To further reduce the mismatch in those areas would require general increase in horizontal conductivity values that may not be consistent with perceived or measured values applicable to lithological material. DSE may consider adopting a revised recharge model in areas with deep-seated water level that may specify either significantly reduced or even zero recharge rates.
- The magnitude of river losing flux volumes, and the extent of river losing reaches is considered to be in excess of previously reported figures, and further model calibration is warranted by further decreasing the river bed conductance, although this will require some adjustments to other parameters, and most likely also to the evapotranspiration parameters to improve calibration.

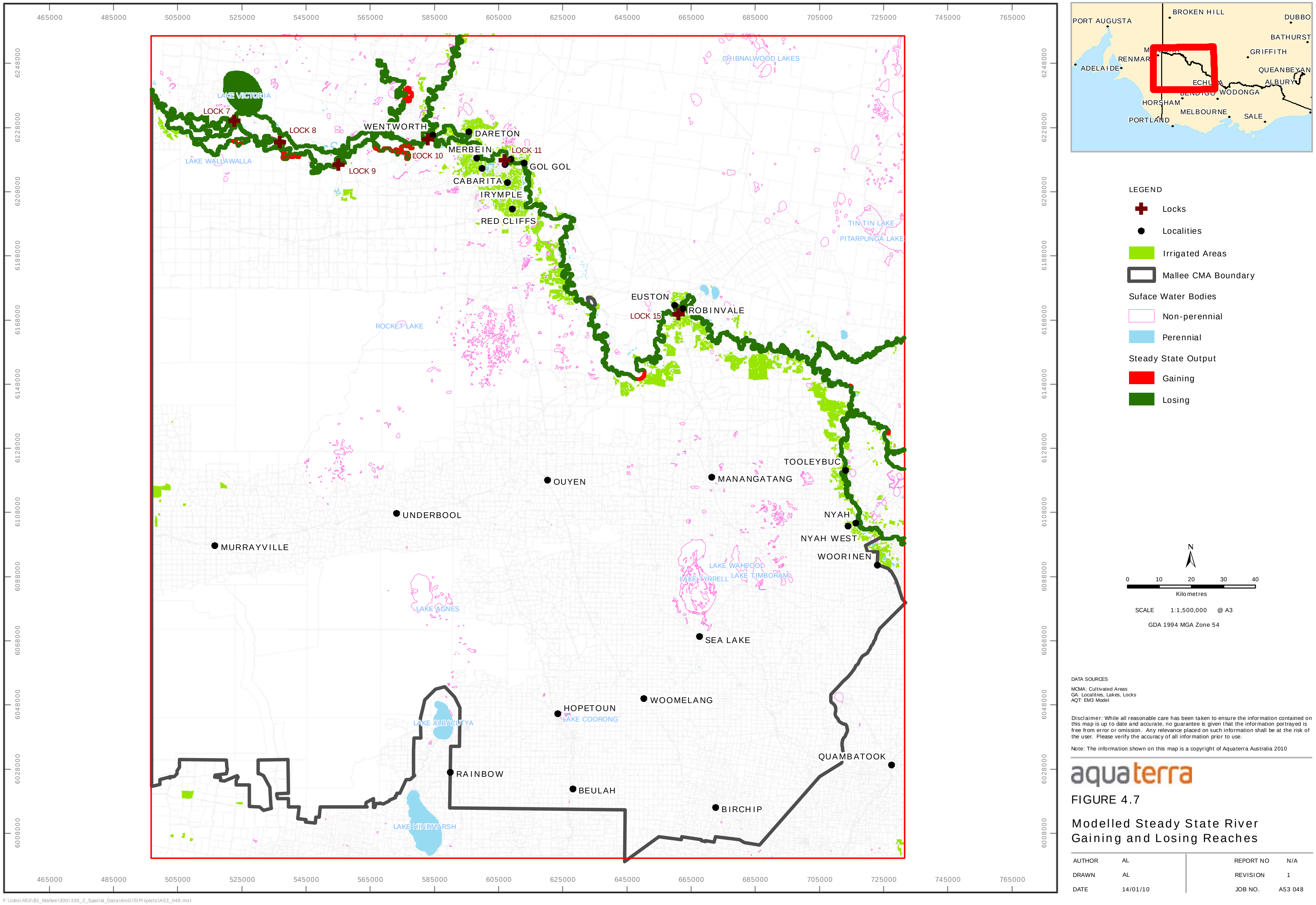
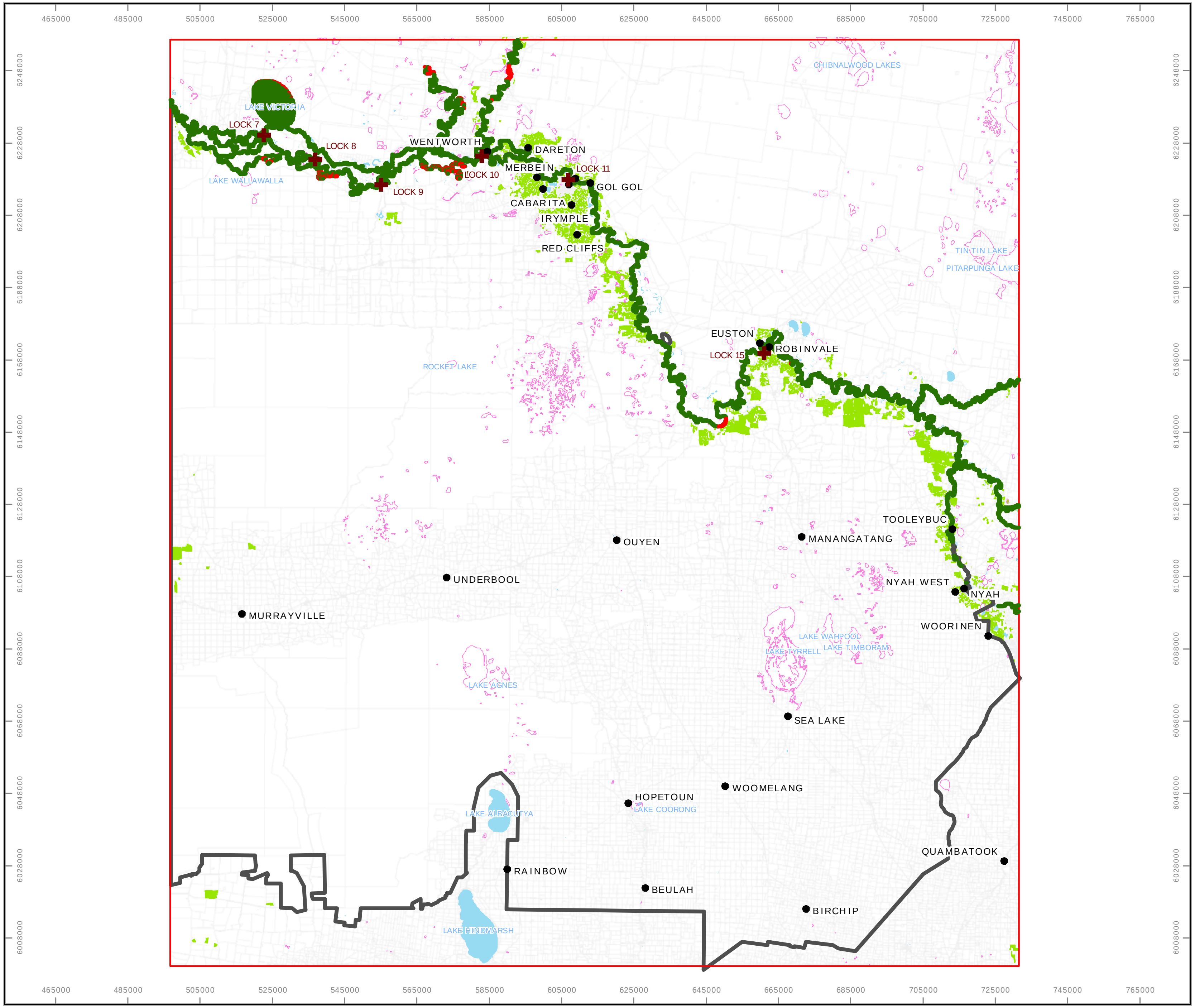
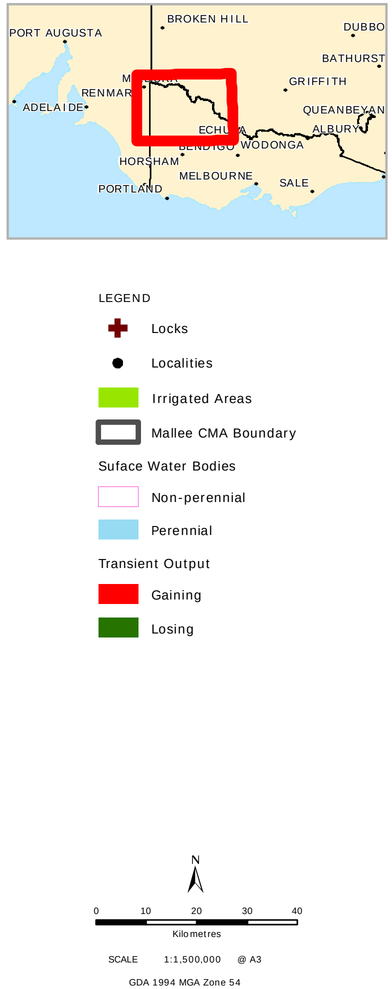


FIGURE 4.7

Modelled Steady State River Gaining and Losing Reaches





DATA SOURCES
MCMA: Cultivated Areas
GA: Localities, Lakes, Locks
AQT: EM3 Model

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FIGURE 4.8
Modelled Transient River Gaining and Losing Reaches (Year 2000; river conductance 50m^2/day

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5 MODEL CAPABILITY

5.1 MODEL CAPABILITY

The aim of this project is to develop catchment models that will be used to assess the impacts of land use change on groundwater regime and stream-aquifer interaction as part of the DSE 'ecoMarkets' initiative. The Mallee CMA Region Groundwater Flow Phase 2 model (EM3) is a transient (history match) model which was developed and calibrated as part of this project. The update also included the upgrade of the steady sate model.

A key purpose of this work is to demonstrate that the model can be developed further, with readily available data, and to use the model results to help identify where data deficiencies critically constrain the use of the model as a management tool.

This report documents that a sound steady state and history matched model platform has been established for the Mallee catchment which is fit for the purpose of assessment of groundwater regime changes due to broad land use impacts, as well as the potential use by other stakeholders such as water utilities to assist with groundwater resource management.

5.2 ISSUES LOG

There are several knowledge/data gaps that can influence the confidence in the results produced by the model and could be addressed in further refinement of the model.

The sensitivity analysis and trial and error calibration process showed that key parameters that influence model outcomes are recharge and hydraulic conductivity, but also parameters that are associated with evapotranspiration and possibly floodplain processes.

The main knowledge/data gaps and/or uncertainties within the study area that affect the conceptual model are summarised in Table 5.1.

5.3 RECOMMENDATIONS

While the overall calibration statistic is favourable and well within the required limit there are areas where additional improvement could be achieved to better represent the regional groundwater system of the Mallee CMA. Further work is recommended in the following areas:

- Reconsider updating the recharge model especially in irrigated areas, but also in dryland areas with deep water levels, and possibly reduce recharge or include recharge lag times for areas with deep water tables;
- Incorporate updated pumping rate information for the borefields on the western boundary;
- Update the long-term pumping rate estimates from Grampian Wimmera Mallee Water ;
- Refine surface elevations at regional discharge points (e.g. Lake Tyrrell);
- Reduce the river bed conductance and make adjustments to other parameters to adjust calibration;
- Remove ET from river and drain cells (will have no effect on modelled water levels but will affect water balance results);
- Refine the ET parameterisation where warranted, i.e. predominantly in the floodplain and apply time varied ET rates and extinction depth;
- Incorporate floodplain inundation recharge processes.

Table 5.1: Key Model Issues

Feature	Limitation	Measure required
Groundwater levels in Parilla Sands	The model generally over predicts groundwater levels in the Parilla Sand aquifer in the southern section of the model	Consider refinement of recharge model, and/or interaction between recharge, hydraulic conductivity and boundary conditions
Groundwater levels in irrigation areas in northern Mallee near River Murray	The model generally under predicts water level in the irrigated areas	Refine irrigation recharge model
Floodplain processes	There is scope for refinement of the ET feature, and there will likely be a need to incorporate floodplain inundation recharge features to areas of wide floodplain (egg Lindsay-Walpolla). It is questionable whether the DSE recharge model can provide this level of detail.	Keep these issues under review during the transient calibration process.
River Murray losing reaches and fluxes	The river losing flux volumes and the extent of river losing reaches is considered to be in excess of what was previously reported in other models (EM1, EM2).	Reduce the river bed conductance parameter and make adjustments to other parameters and the ET parameters to achieve calibration
ET processes, topo accuracy	The DEM is accurate on the floodplain (Lidar), but not outside the floodplain (approximately +/- 10 metres). This may be a significant issue in close proximity to low-lying areas with shallow water tables such as around Lake Tyrell, and saline evaporative features in the study area (egg. Hattah, Noora, near Underbool).	Implement more accurate topo information in areas of regional groundwater discharge
ET processes	Evapotranspiration is currently set up using the steady state with areally distributed parameters across all stress periods. An extinction depth of 4 m is applied uniformly across the modelled area	Apply areally distributed mode ET rates for each individual stress periods. Consider refining extinction depths to better represent root system and floodplain processes
Groundwater levels in irrigation areas in western Mallee in the MGL aquifer	The model generally over predicts groundwater levels in the irrigated areas	Obtain more accurate pumping data from Grampian Wimmera Mallee Water and reconsider applied recharge rates

6 REFERENCES

Aquaterra (2010) Mallee CMA Region Groundwater Flow Model (EM3) – Steady State Calibration. Prepared for the Department of Sustainability and Environment (Vic). Dated 15 January 2010.

Aquaterra (2009a) Mallee CMA Region Groundwater Flow Model (EM3) – Design. Prepared for the Department of Sustainability and Environment (Vic). Dated 11 March 2009.

Aquaterra (2009b) Sunraysia Sub-Regional Groundwater Flow Model (EM2.3) Final Report. Prepared for Goulburn-Murray Water and Murray Darling Basin Authority. Dated 16 October 2009.

Aquaterra (2009c) Lake Gol Gol Hydrogeological Investigations. Report prepared for Lower Murray Darling CMA, August 2009.

Aquaterra (2008). Lock 10 to SA Border Groundwater model (EM4). Prepared for SKM. Dated 8 December 2008.

Aquaterra (2007). Mallee Zone 5-year Rolling Salinity Review – Hydrogeological Modelling for Victoria and NSW, B-Register 'Legacy of History' Assessments, Eastern Mallee Model version 1 (EM1). Prepared for the Murray-Darling Basin Commission.

AWE (2007). Sunraysia Salt Interception Hydrogeology and Engineering Design Inputs. Australian Water Environments report 45682i.

AWE (2009). Sunraysia Salt Interception Red Cliffs Aquifer Test. Prepared for Goulburn Murray Water, September 2009.

Banta ER (2000). MODFLOW-2000, the U.S. Geological Survey modular ground-water model - Documentation of packages for simulating evapotranspiration with a segmented function (ETS1) and drains with return flow (DRT1). U.S. Geological Survey Open-File Report 00-466, 127 pp.

Barnett SR, Osei-bonsu K (2006). Mallee PWA – Murrayville WSPA Groundwater Model. South Australia Department of Water, Land and Biodiversity Conservation. DWLBC Report 2006/27

Beverly, C., 2007. Technical Manual - Models of the Catchment Analysis Tool. Victoria Department of Sustainability and Environment.

Brodie, R. (AGSO) (1992). Anabranch Hydrogeological Map (1:250,000 scale). Australian Geological Survey Organisation, Canberra, Australia.

Brown CM, Stephenson AE (1991). Bulletin 235 Geology of the Murray Basin South Eastern Australia. Bureau of Mineral Resources, Geology & Geophysics. Department of Primary Industries & Energy. Commonwealth of Australia.

Bureau of Meteorology (2001). Climatic Atlas of Australia – Evapotranspiration.

Cook PG, Leaney FW, Miles M (2004). Groundwater Recharge in the Northeast Mallee Region, South Australia. CSIRO Land and Water Technical Report 24/05.

Cook PG, Leaney FW, Jolly ID (2001) Groundwater recharge in the Mallee Region, and salinity implications for the Murray River. CSIRO land and Water Technical Report 45/01

Dudding, M. *et al.* Rural Water Corporation, Victoria (1993). St Arnaud Hydrogeological Map (1:250,000 scale). Australian Geological Survey Organisation, Canberra, Australia.

Environmental Simulations International (ESI) Limited (2005). URL for Groundwater Vistas: http://www.groundwatermodels.com/Software.php

Ghassemi F, Jakeman AJ, Thomas GA (1987) Groundwater modelling and simulation of salinity management options in the Sunraysia region of Victoria. Report to the River Murray Commission. Centre for Resource and Environmental Studies, Australian National University Canberra.

Ha, J., in preparation. A Programmer's Guide for BioSym – the Biophysical Modelling Toolbox of EnSym. Victoria Department of Sustainability and Environment.

Harbaugh AW, Banta ER, Hill MC, McDonald MG (2000). MODFLOW-2000, the U.S. Geological Survey modular ground-water model - User guide to modularization concepts and the Ground-Water Flow Process. U.S. Geological Survey Open-File Report 00-92, 121 pp.

Hill, M. (2003) Preconditioned Conjugate-Gradient 2 (PCG2), a computer program for solving ground-water flow equations. *Water-Resources Investigations Report 90-4048*. U.S. Geological Survey.

Hocking, M. and Dyson, P. (2006) Mallee water balance – the role of evaporation on salinity area in the Victorian Mallee dryland. *Proceedings of the Royal Society of Victoria* 118(2): 211-227. ISSN 0035-9211.

Jolly ID (1996). The effects of river management on the hydrogeology and hydroecology of arid and semi-arid floodplains. Floodplain Processes. Anderson MG, Walling DE, Bates PD (eds). pp.577-609.

Kellet, J.R. (AGSO) (1994). Balranald Hydrogeological Map (1:250,000 scale). Australian Geological Survey Organisation, Canberra, Australia.

McAuley, C. *et al.* Rural Water Corporation, Victoria (1992). Horsham Hydrogeological Map (1:250,000 scale). Australian Geological Survey Organisation, Canberra, Australia.

Merrick NP and Middlemis H. (1988) Buronga salt Interception Scheme; Optimisation of Groundwater Pumping. NSW Department of Water Resources Technical Services Report No. TS88.003, Sydney.

Merrick NP, Middlemis H, Rozlapa K, Williams RM (1999) Buronga Salt Interception Scheme Review. Department of Land & Water Conservation. Centre for Natural Resources. CNR99.034

Middlemis (1990) Buronga salt interception scheme numerical model. M. Eng. Sc. Project Report. University of New South Wales, School of Civil Engineering.

Mildura Rural City Council (2001). Sunraysia Drainage Strategy 2000 Stage 1. Final Report. April 2001.

Murray-Darling Basin Commission (2001). Groundwater Flow Modelling Guideline. Prepared for the Murray-Darling Basin Commission by Aquaterra. Dated 16 January 2001.

Nolan-ITU (2004) Murrayville WSPA Five Year Technical Review, November 2004.

O'Rorke, M.E. *et al.* Victorian Rural Water Commission (1992). Swan Hill Hydrogeological Map (1:250,000 scale). Bureau of Mineral Resources, Geology and Geophysics, Canberra, Australia.

REM-SKM. 2009. River Murray Floodplain Salinity .Assessment. Report to Lower Murray-Darling CMA. 17 March 2009.

Robinson, M. *et al.* Victorian Rural Water Commission (1992a). Ouyen Hydrogeological Map (1:250,000 scale). Bureau of Mineral Resources, Geology and Geophysics, Canberra, Australia.

Robinson, MA (1992b) Calculation of vertical hydraulic conductivity and vertical discharge in the Victorian Mallee, South-Eastern Australia. Rural Water Commission

Rural Water Commission (1991). Mildura Hydrogeological Map (1:250,000 scale). Bureau of Mineral Resources, Geology and Geophysics, Canberra, Australia.

SKM (1998a) Review of transmissivity and storage co-efficient values from pumping test data for the Victorian proportion of the Border Designated Area. Final report to Department of Natural Resources and Environment. Dated November 1998.

SKM (1998b) Predictions of potentiometric surface drawdown in the Murrayville area for the 1998/99 irrigation season. Final report to Wimmera Mallee Water.

SKM and AWE (2003). Integration and Optimisation of Salt Interception in the Sunraysia region. Final Report to Department of Land and Water Conservation.

SKM (2005a) *Mallee CMA Numerical Water Trade Models – Hydrogeological Conceptualisation (Draft B).* Prepared for the Mallee CMA. Dated 3 February 2005.

SKM (2005b) *Mallee CMA Numerical Water Trade Models – Model Calibration Report (Draft).* Prepared for the Mallee CMA. Dated 4 February 2005.

SKM (2008a) *Mallee Drilling Program – Volume 2: Vertical Leakage Estimates*. Prepared for the Mallee CMA. Dated 1 April 2008.

SKM (2008b) *Mallee Drilling Program – Volume 1: Hydrogeological and Geophysical Factual Report*. Prepared for the Mallee CMA. Dated 19 February 2008.

Telfer AL, Hatch MA, and PA Shintodewi (2006). Atlas of Instream NanoTEM 2006. Australian Water Environments report 45755bb.

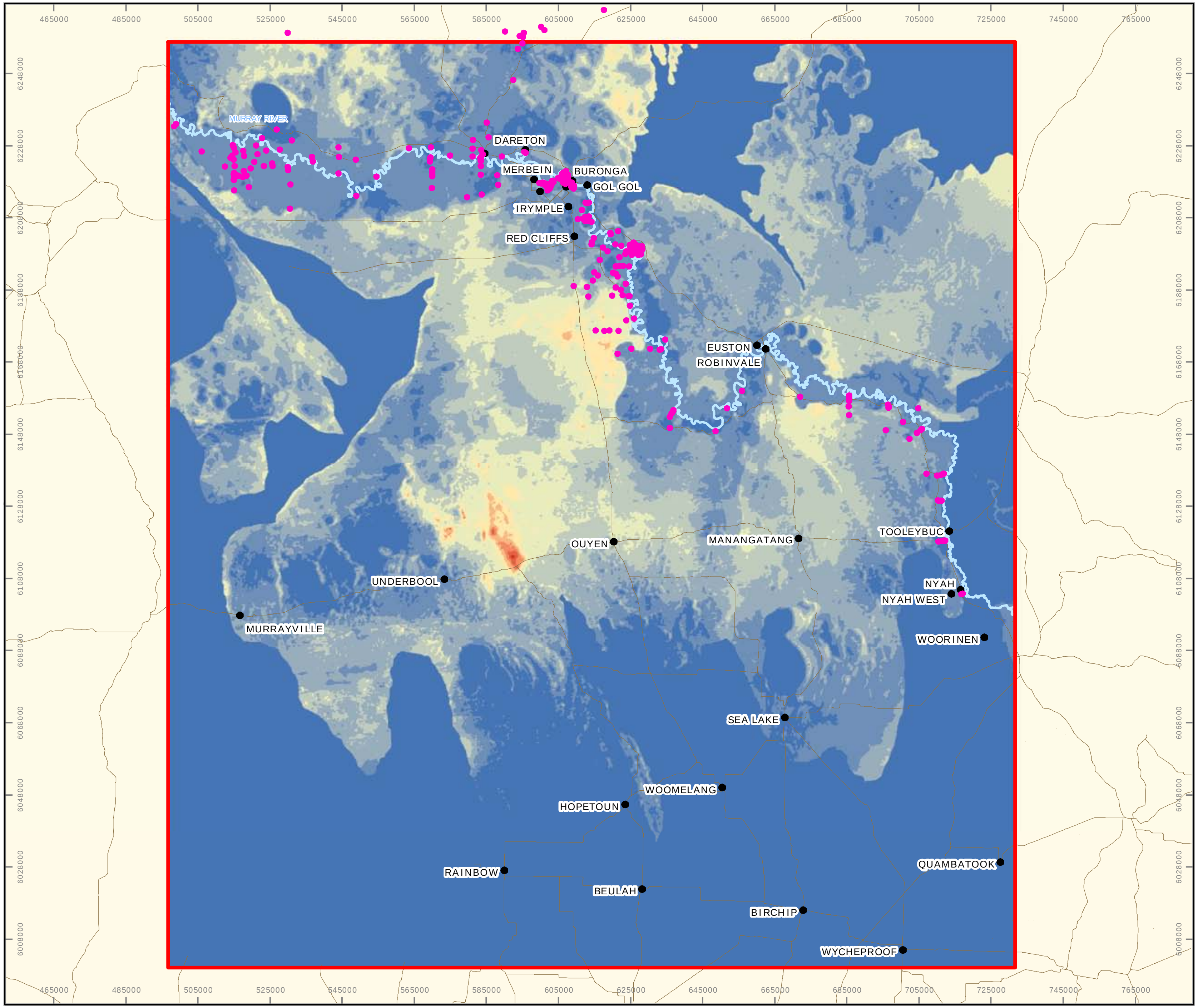
Thorburn PJ, Hatton TJ, Walker GR (1993). Combining measurements of transpiration and stable isotopes of water to determine groundwater discharge from forests. Journal of Hydrology, 150: 563-587.

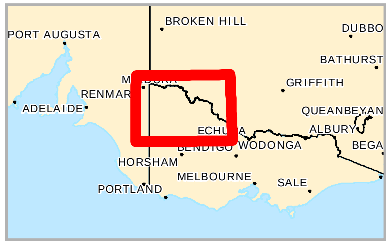
Thorne R, Hoxley G, Chaplin H (1989). Draft Nyah to the South Australian Border Hydrogeological Study Volume 1 Report. Investigations Branch Report 1988/5, Investigations Branch, Rural Water Commission of Victoria.

Warren, J.K (2006). Evaporites: Sediments, Resources and Hydrocarbons. Birkhäuser Publishing Ltd, 1035 pp.

Williams RM, Erny M (2001) Buronga Salt Interception Scheme Redesign Implications of Pumping Tests. CNR2001.035.

APPENDIX A EM3 MODEL LAYER STRUCTURE





LEGEND

- Strat Picks
- Localities
- River Murray
- Main Roads
- EM3 Model Boundary
- Mallee CMA Boundary

Isopachs (m)

- 1.5 - 10
- 10 - 20
- 20 - 30
- 30 - 40
- 40 - 50
- 50 - 60
- 60 - 70
- 70 - 80
- 80 - 90
- 90 - 100

N

0 5 10 20
Kilometres

SCALE 1:1,500,000 @ A4

GDA 1994 MGA Zone 54

DATA SOURCES
GA: Localities, Lakes, Roads
AQT: EM3 Model, Strat Picks

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FIGURE A1

Isopachs and Strat Picks - Layer 1

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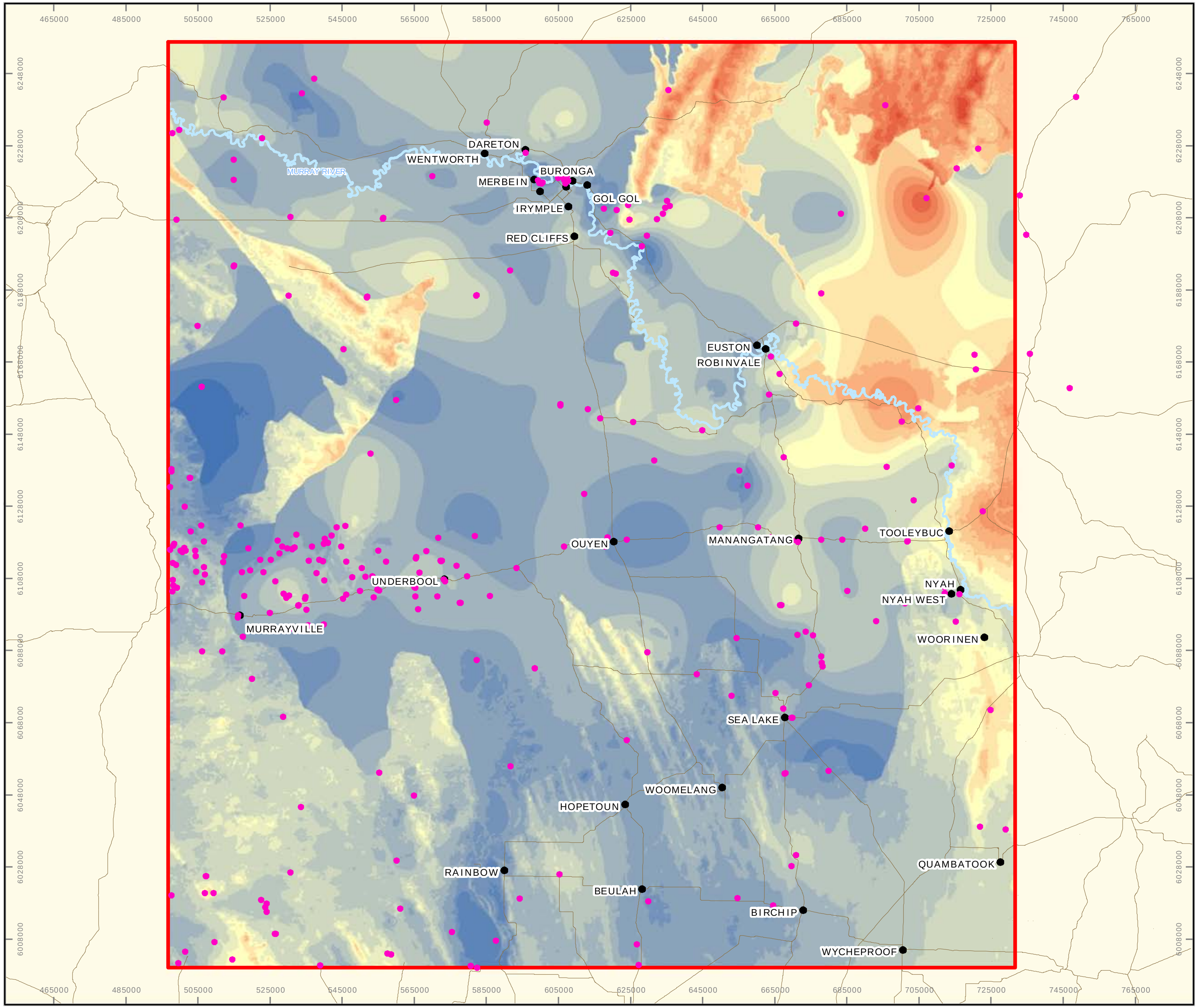

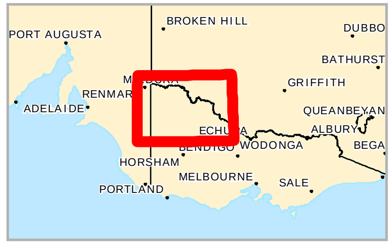

LEGEND

- Strat Picks
- Localities
- River Murray
- Main Roads
- Mallee CMA Boundary
- EM3 Model Boundary

Isopachs (m)

4 - 10	90 - 100
10 - 20	100 - 110
20 - 30	110 - 120
30 - 40	120 - 130
40 - 50	130 - 140
50 - 60	140 - 150
60 - 70	150 - 160
70 - 80	160 - 170
80 - 90	

N

0 5 10 20
Kilometres

SCALE 1:1,500,000 @ A4

GDA 1994 MGA Zone 54

DATA SOURCES

GA: Localities, Lakes, Roads
AQT: EM3 Model, Strat Picks

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FIGURE A2

Isopachs and Strat Picks - Layer 2

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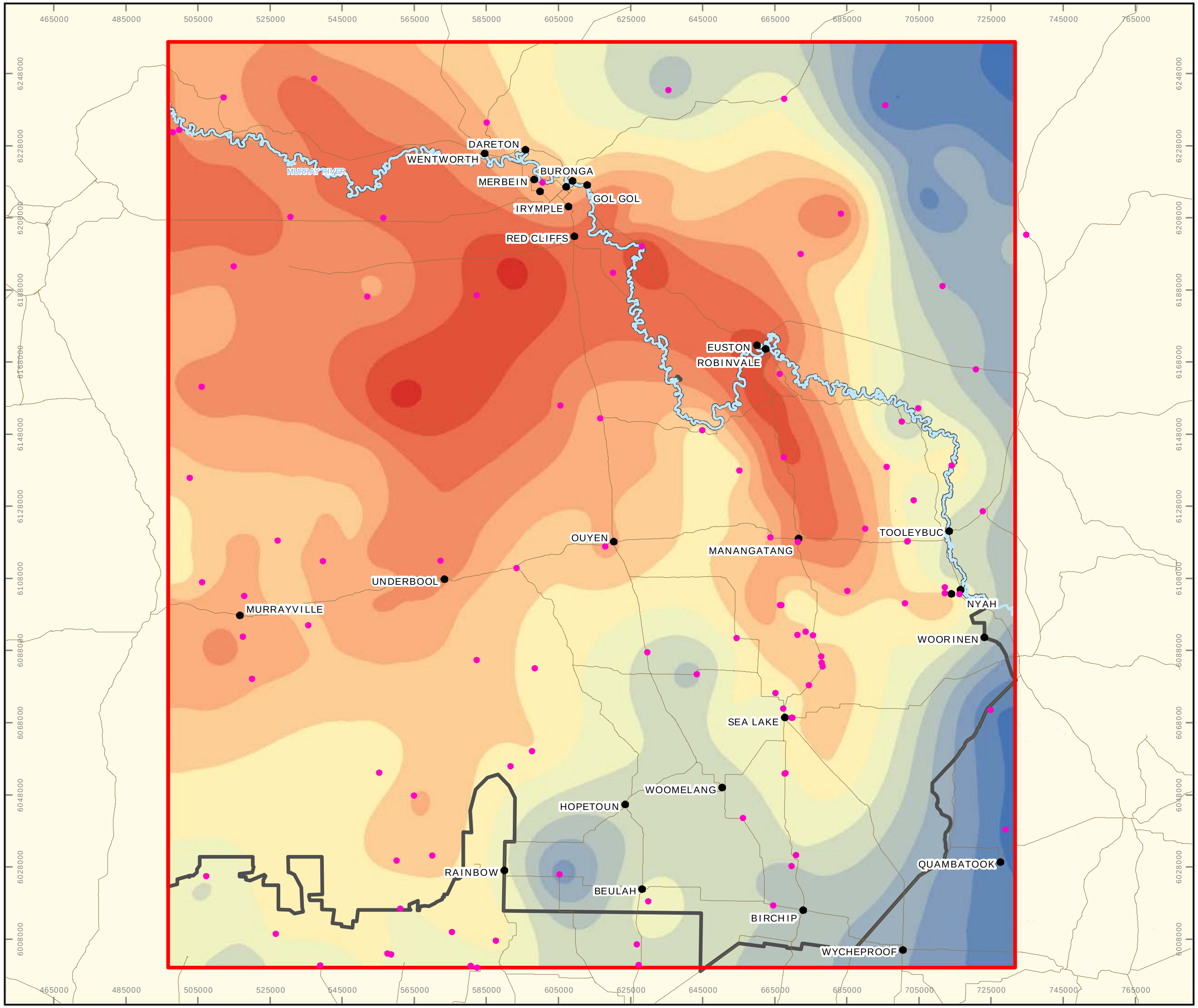

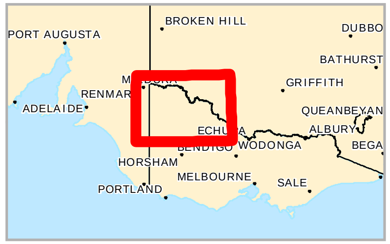

LEGEND

- Strat Picks
- Main Roads
- Localities
- EM3 Model Boundary
- River Murray
- Mallee CMA Boundary

Isopachs (m)

- 12 - 20
- 20 - 40
- 40 - 60
- 60 - 80
- 80 - 100
- 100 - 120
- 120 - 140
- 140 - 160
- 160 - 180
- 180 - 200
- 200 - 220
- 220 - 240
- 240 - 260
- 260 - 280

N

0 5 10 20

Kilometres

SCALE 1:1,500,000 @ A4

GDA 1994 MGA Zone 54

DATA SOURCES

GA: Localities, Lakes, Roads
AQT: EM3 Model, Strat Picks

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FIGURE A3

Isopachs and Strat Picks - Layer 3

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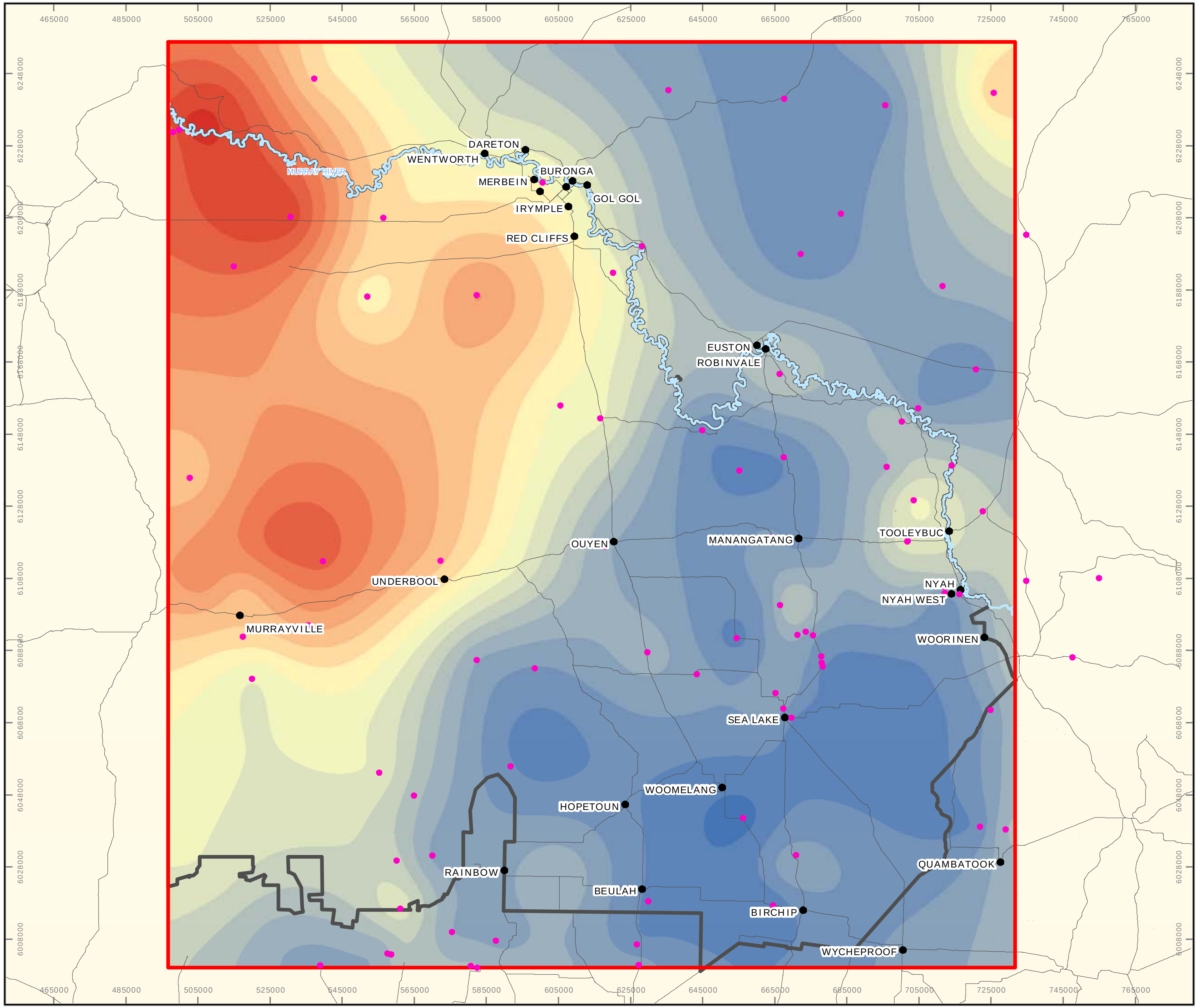

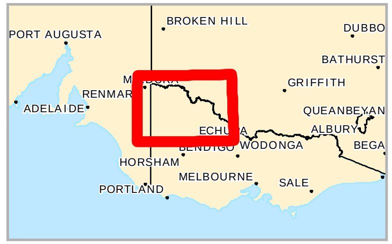

LEGEND

- Strat Picks
- Localities
- River Murray
- Main Roads
- EM3 Model Boundary
- Mallee CMA Boundary

Isopachs (m)

12 - 20	180 - 200
20 - 40	200 - 220
40 - 60	220 - 240
60 - 80	240 - 260
80 - 100	260 - 280
100 - 120	280 - 300
120 - 140	300 - 320
140 - 160	320 - 340
160 - 180	340 - 360

N

0 5 10 20
Kilometres

SCALE 1:1,500,000 @ A4

GDA 1994 MGA Zone 54

DATA SOURCES

GA: Localities, Lakes, Roads
AQT: EM3 Model, Strat Picks

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FIGURE A4

Isopachs and Strat Picks - Layer 4

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APPENDIX B PREVIOUS RECHARGE MODELLING IN EASTERN MALLEE

Uncleared Dryland

In areas that retain native vegetation, conventional wisdom assumes that the rainfall recharge rate is estimated to be a constant 0.1 mm/yr (Aquaterra, 2007).

Cleared Dryland Recharge and Time Lags

The basic conceptual model of dryland recharge is that rainfall percolating through the unsaturated zone is either intercepted/transpired by vegetation or evaporates from the soil, or it continues to percolate through the root zone to enter the water table as groundwater recharge. It is generally accepted that recharge within areas that have been cleared is typically greater than areas of native vegetation due to the reduction in evapotranspiration as a result of replacing deep-rooted vegetation with shallower rooted species. It is also generally accepted that there is a time lag between increased root zone drainage due to clearance and when the wetted front enters the water table as recharge.

In cleared areas, EM1 used dryland recharge rates and time lags which were estimated using the SIMRAT model by URS et al. (2005), which was based in part on Cook et al. (2004). This approach requires an annual rainfall, a soil texture (to 2 m depth) and cleared agriculture land use coverage as input. The SIMRAT model estimates that the recharge rate increases with time from the uncleared dryland rate to a maximum rate of around 10 mm/yr for the majority of areas, but reaches up to 30 mm/yr in areas of higher rainfall combined with sandy soils.

Time lags for the wetted front from vegetation clearance recharge to reach the water table were estimated by the SIMRAT model at between 10 and 250 years. Analysis of hydrograph data by Aquaterra for this study suggests that the initial time lags have passed in areas where there are no bores showing increasing head over the recent monitoring period, suggesting initial time lags are less than 70 years (i.e. the time between clearance around 1900 and the beginning of broad scale groundwater monitoring around the mid 1970s). The alternative suggestion is that no recharge has occurred and hence the effect is yet to be observed, and this is likely to be a variable effect across the study area. In addition, it is noted that SIMRAT assumes that the Blanchetown Clay is "heavy clay" based on investigations in the Riverland region of SA and unsaturated flow parameters have been assigned accordingly. Observations in the field indicate that the Blanchetown Clay can vary from a sandy silt to a high plasticity clay. Time lags are sensitive to these unsaturated flow parameters and SIMRAT may therefore be over estimating time lags.

Once the initial time lag has occurred and the wetted front has passed, the time lag between any changes to the surface application of rainfall due to changes to climatic conditions (such as drought) and the response in the water table is significantly reduced. This reduction occurs because the post-wetted-front soil profile has a higher moisture content and hence vertical unsaturated flow is much more rapid (as hydraulic conductivity is related to moisture content in an unsaturated flow context). The time lags estimated by SIMRAT are based on the initial wetting front propagation and therefore, are not necessarily applicable once the wetted front has passed. Analysis by Aquaterra suggests that time lags may in fact be much less than the time lags from the wetted front propagation predicted by SIMRAT.

In some areas, water levels have responded almost immediately to changes in the climatic trend, particularly during the transition from a wetter period to a drier period around the mid 1990s in the cleared and uncleared areas. This suggests that cleared dryland recharge time lags are less than one year in some areas, and, for the purposes of this study, can be assumed to be zero in terms of years for those areas. That is not to say that the cleared dryland time lags are, in fact, zero, as the analysis indicates that time lags are of the order of months (but not multiple years). In simple terms, it is not possible to achieve a calibration to monitoring bore hydrographs that show a response to the last 10 years of drought if a time lag of more than 10 years is believed to apply (i.e. as suggested by SIMRAT).

It is possible that some of the cleared dryland monitoring bores are close enough to the irrigation areas (where it is generally accepted that time lags are effectively zero in terms of years) that they are showing a response to decays in the water table mounds under irrigation areas. However, there are some bores in cleared dryland areas that are remote from irrigation areas that also show a decreasing water table during the recent drought period.

In other areas, where is no response to the recent drought evident in the monitoring records, scenario and/or sensitivity modelling will be undertaken to determine the most appropriate time lag to apply to recharge to achieve a match to monitoring bore levels.

As was found for the time lag phenomena, the water level change due to changes in climatic conditions is generally somewhat similar for both cleared and uncleared areas, apart from some specific location close to Lake Tyrrell, where observed levels show a continuing rising trend.

A greater water level variation, however, is observed for the area in proximity to Neckarboo Ridge, suggesting a greater amount of recharge, possibly due to the absence or thinning of Blanchetown Clays at this location.

Irrigated Areas

Recharge rates in irrigated areas are generally higher than the post-clearing dryland recharge rates, due to deep drainage from excess irrigation water. The recharge to the water table is termed "root zone drainage" (RZD), and it depends mainly on the application volume, irrigation efficiency, soil type and whether drainage schemes are present.

At present, there is considerable scientific debate about irrigation efficiencies and RZD, mainly because there is little specific information that can be used to be definitive about irrigation efficiency changes with time. For the purposes of this project, rather than engage in that debate about irrigation efficiency, the irrigation recharge assumptions described below are discussed in terms of effective recharge to the water table.

The SIMRAT model (URS et al, 2005) assumes 85% water use efficiency based on the amount of water applied and the quantity taken up by plants. Of the remaining 15%, approximately 5% is allowed for losses such as surface runoff, evaporation and removal via subsurface drains, leaving 10% to be recharged to the water table as RZD (URS *et al*, 2005). Analysis of drainage monitoring data by Aquaterra during development of EM1 (Aquaterra, 2007) indicates that the volume removed by drainage in the irrigated areas of the Eastern Mallee is approximately 7.5% of the water applied, greater than that assumed by SIMRAT (5% minus surface runoff and evaporation losses). For EM1, 7.5% was applied as the basic (RZD) recharge rate to the water table, assuming surface runoff and evaporation losses to be minimal, which resulted in recharge to the aquifer of between 51 and 144 mm/year, across the irrigation regions in 2000. This basic rate was further refined during model calibration, as discussed in Sections 3 and 4, and there is scope to further refine assumptions around the RZD rate for periods prior to 1988.

Based on measurements made during 2002/2003, water use efficiency at Red Cliffs, FMIT, Buronga and Coomealla irrigation districts was estimated to be between 88% and 90% (Sunrise 21, 2006), whereas the estimate for Red Cliffs during 1996/1997 was 72% (SunRISE 21, 2006). This suggests that there is some variation in the water use efficiency with time (generally towards more efficient use), which is a refinement that was not implemented to the previous EM1 model, and has been used to guide assumptions about reductions with time in irrigation recharge rates for the EM2 model (Aquaterra, 2008).

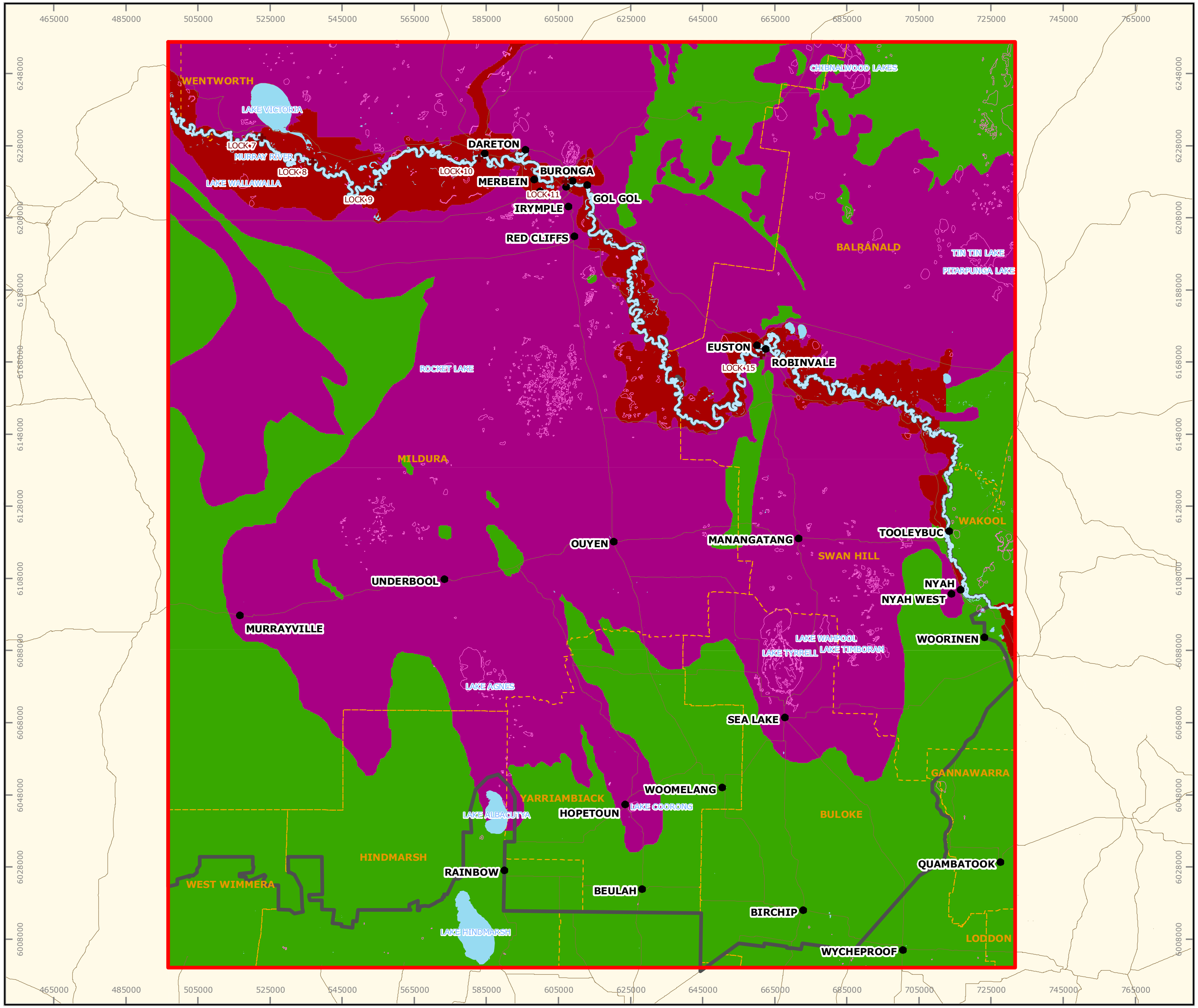
Time lags that represent the delay between the initial surface application of irrigation and when the increased recharge due to irrigation propagates to the water table were estimated for EM1 (Aquaterra, 2007) based on the SIMRAT model vertical flux algorithm. Estimates of time lags under irrigation areas were between 10 and 40 years (as provided by DEH from the SIMRAT model, assuming 120 mm/year RZD; Aquaterra, 2007; and URS *et al.*, 2005). However, the EM1 model assumed that the time lags also applied once the wetted front has been received at the water table and produced rising water level trends within the Mildura/Merbein/Redcliffs irrigated areas which are not reflected in the bore hydrographs (e.g. bore 7840, Aquaterra, 2007). In fact, these hydrographs generally show a slight downward trend in measured levels since the mid 1980s (SKM and AWE, 2003), which can be attributed to one or a combination of factors such as improved irrigation practice, local variations in rainfall recharge, and reduced annual average river levels (i.e. the drought).

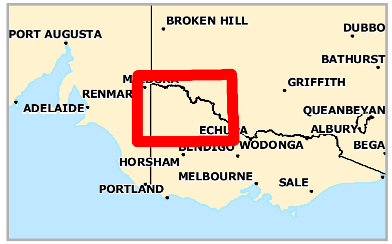
Based on review by Aquaterra of data from the one available nested bore in the Mildura/Redcliffs/Merbein irrigations districts, it is noted that whilst a declining trend is apparent, the head difference above and below the Blanchetown Clay aquitard is relatively constant over the period of review (mid 1980s to 2002), which indicates that vertical flow through the aquitard (i.e. recharge to Parilla Sands) is also relatively constant over the period.

Constant recharge suggests that the aquifers are in equilibrium and that time lag do not influence the irrigation recharge process on a semi-regional scale.

As discussed above, SIMRAT predicts time lags for the wetted front from increased recharge due to irrigation commencing (or vegetation clearance) and the response in the water table. This time lag is not applicable once the wetted front has passed. Once passed, the time lag between changes to irrigation practices and responses in the water table are significantly reduced as the moisture content of the soil is higher and hence vertical unsaturated flow is much more rapid (as hydraulic conductivity is related to moisture content in an unsaturated flow context). In addition, SIMRAT assumes zero initial saturation and a constant unsaturated thickness over time (i.e. it is based on algorithms that were initially derived for dryland areas). Further, application of these lag times to EM1 produced a delayed response to recharge that is not consistent with monitoring bore levels and trends. The timing of irrigation inputs to the EM2 model have been reviewed to provide a reasonable representation of the spatial and temporal trends in recharge, notably including observed drops in measured water levels during the current drought, which would not be possible to achieve with time lags of more than 10 years.

APPENDIX C MODELLED HYDROGEOLOGICAL PARAMETERISATION DISTRIBUTION





LEGEND

- Locks
- Localities
- River Murray
- Main Roads
- LGAs
- EM3 Model Boundary
- Mallee CMA Boundary
- Suface Water Bodies
  - Perennial
  - Non-perennial

Hydrogeological Parameterisation Distribution

Zone	K_H	K_V	S	S_Y
1	15	5	0.0001	0.1
2	0.0027	0.00027	0.0001	0.1
3	15	1.5	0.0001	0.1

N

0 5 10 20
Kilometres

SCALE 1:1,500,000 @ A4

GDA 1994 MGA Zone 54

DATA SOURCES
MCMA: Irrigated Areas
GA: Localities, Lakes, Locks, Roads, LGAs
AQT: EM3 Model

Disclaimer: While all reasonable care has been taken to ensure the information contained on this map is up to date and accurate, no guarantee is given that the information portrayed is free from error or omission. Please verify the accuracy of all information prior to use.

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FIGURE C1

Modelled Hydrogeological Parameterisation Distribution - Layer 1

AUTHOR	AL	REPORT NO	R001
DRAWN	AL	REVISION	1
DATE	18/03/10	JOB NO.	A53 023

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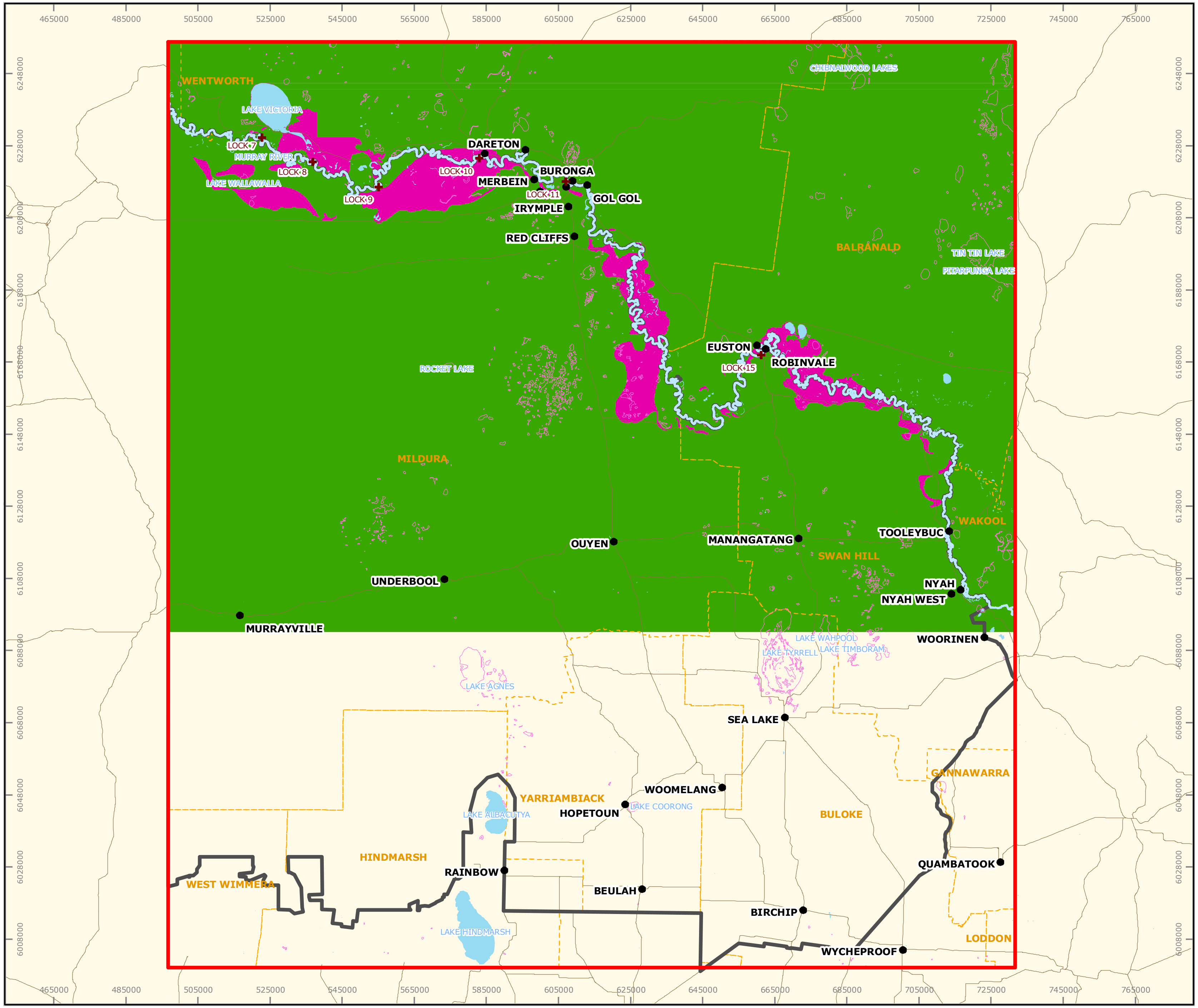

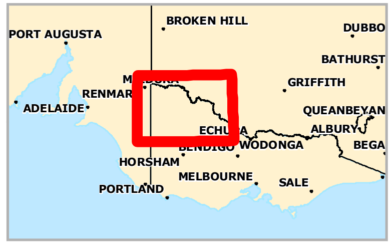

LEGEND

- Locks
- Localities
- River Murray
- Main Roads
- LGAs
- EM3 Model Boundary
- Mallee CMA Boundary
- Suface Water Bodies
  - Perennial
  - Non-perennial

Hydrogeological Parameterisation Distribution

Zone		K_H	K_V	S	S_Y
(green)	1	15	5	0.0001	0.1
(magenta)	4	4	0.008	0.0001	0.1

N

0 5 10 20

Kilometres

SCALE 1:1,500,000 @ A4

GDA 1994 MGA Zone 54

DATA SOURCES

MCMA: Irrigated Areas
GA: Localities, Lakes, Locks, Roads, LGAs
AQT: EM3 Model

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FIGURE C2

Modelled Hydrogeological Parameterisation Distribution - Layer 2

AUTHOR	AL	REPORT NO	R001
DRAWN	AL	REVISION	1
DATE	18/03/10	JOB NO.	A53 024

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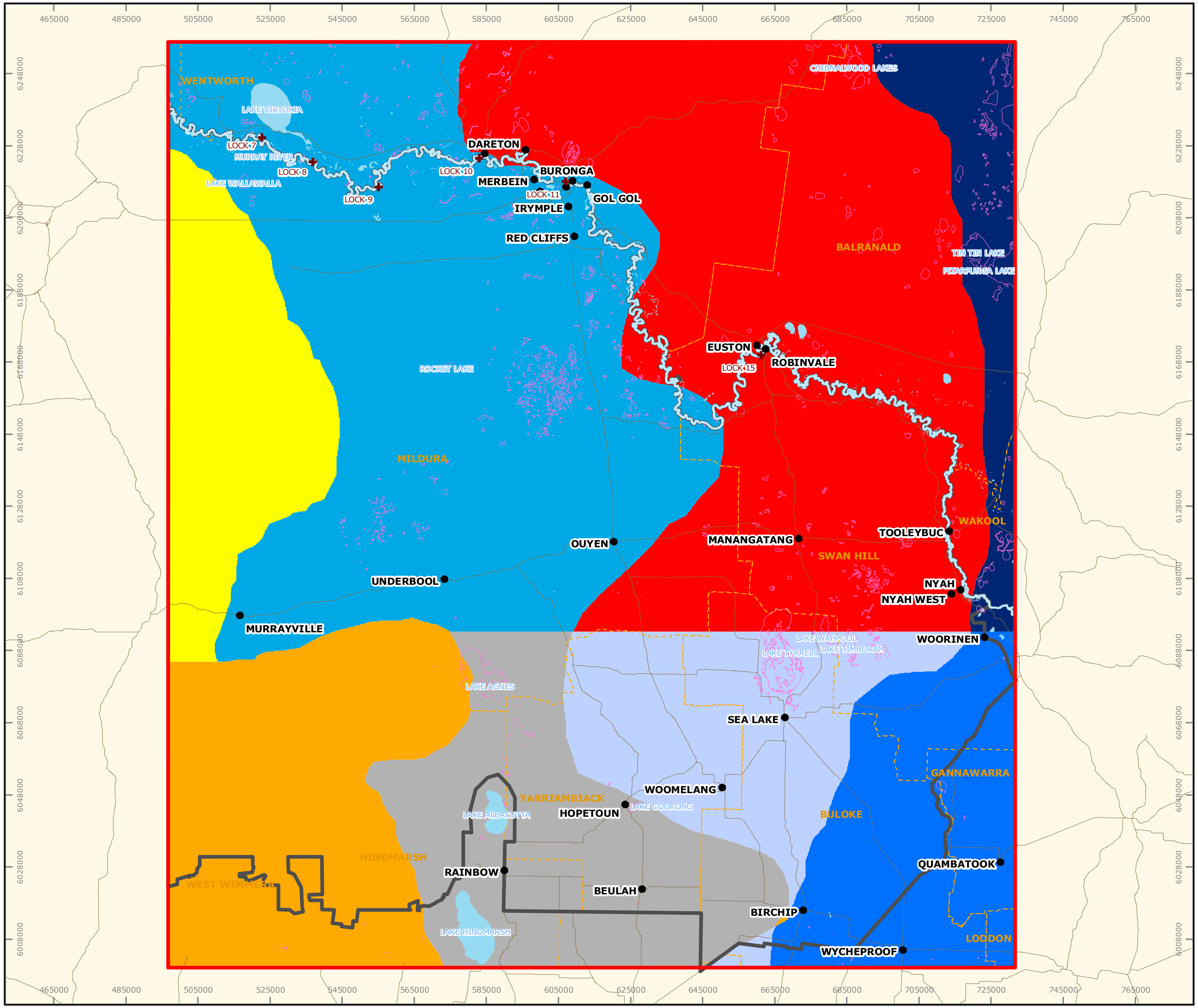

LEGEND

- Locks
- Localities
- River Murray
- Main Roads
- LGAs
- EM3 Model Boundary
- Mallee CMA Boundary
- Suface Water Bodies
  - Perennial
  - Non-perennial

Hydrogeological Parameterisation Distribution

Zone	K_H	K_V	S	S_Y
5	5	0.005	0.0001	0.1
6	0.1	0.01	0.0001	0.02
7	2	0.005	0.0001	0.02
8	25	0.1	0.0001	0.05
11	20	0.005	0.0001	0.02
12	6	0.005	0.0001	0.02
13	2	0.01	0.0001	0.02
14	25	0.01	0.0001	0.05

N

0 5 10 20

Kilometres

SCALE 1:1,500,000 @ A4

GDA 1994 MGA Zone 54

DATA SOURCES

MCMA: Irrigated Areas
GA: Localities, Lakes, Locks, Roads, LGAs
AQT: EM3 Model

Disclaimer: While all reasonable care has been taken to ensure the information contained on this map is up to date and accurate, no guarantee is given that the information portrayed is free from error or omission. Please verify the accuracy of all information prior to use.

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FIGURE C3

Modelled Hydrogeological Parameterisation Distribution - Layer 3

AUTHOR	AL	REPORT NO	R001
DRAWN	AL	REVISION	1
DATE	18/03/10	JOB NO.	A53 024

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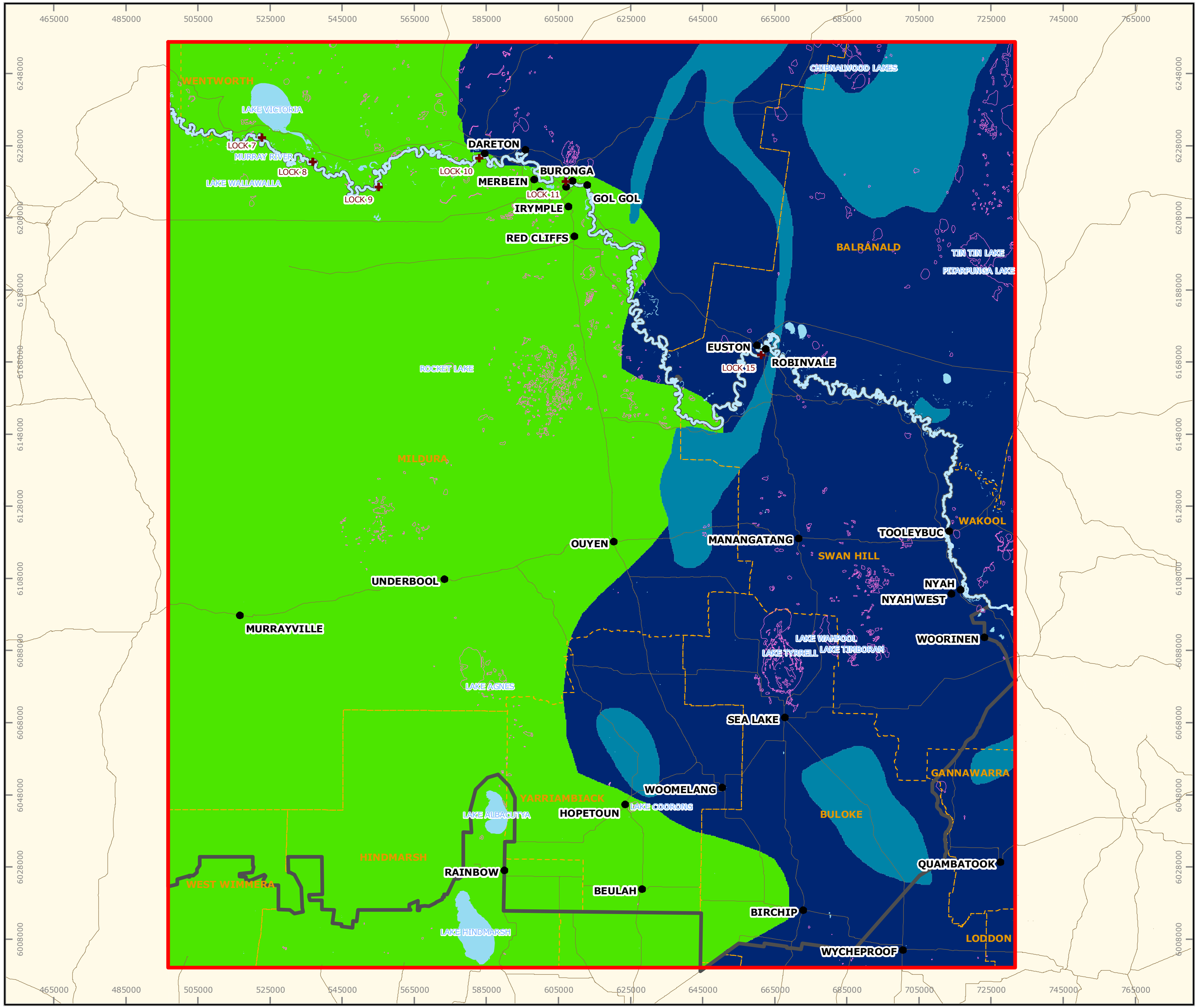

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LEGEND

- Locks
- Localities
- River Murray
- Main Roads
- LGAs
- EM3 Model Boundary
- Mallee CMA Boundary
- Suface Water Bodies
  - Perennial
  - Non-perennial

Hydrogeological Parameterisation Distribution

Zone	K_H	K_V	S	S_Y
8	25	0.1	0.0001	0.05
9	25	0.00001	0.0001	0.05
10	0.03	0.01	0.0001	0.005

N

0 5 10 20
Kilometres

SCALE 1:1,500,000 @ A4

GDA 1994 MGA Zone 54

DATA SOURCES
MCMA: Irrigated Areas
GA: Localities, Lakes, Locks, Roads, LGAs
AQT: EM3 Model

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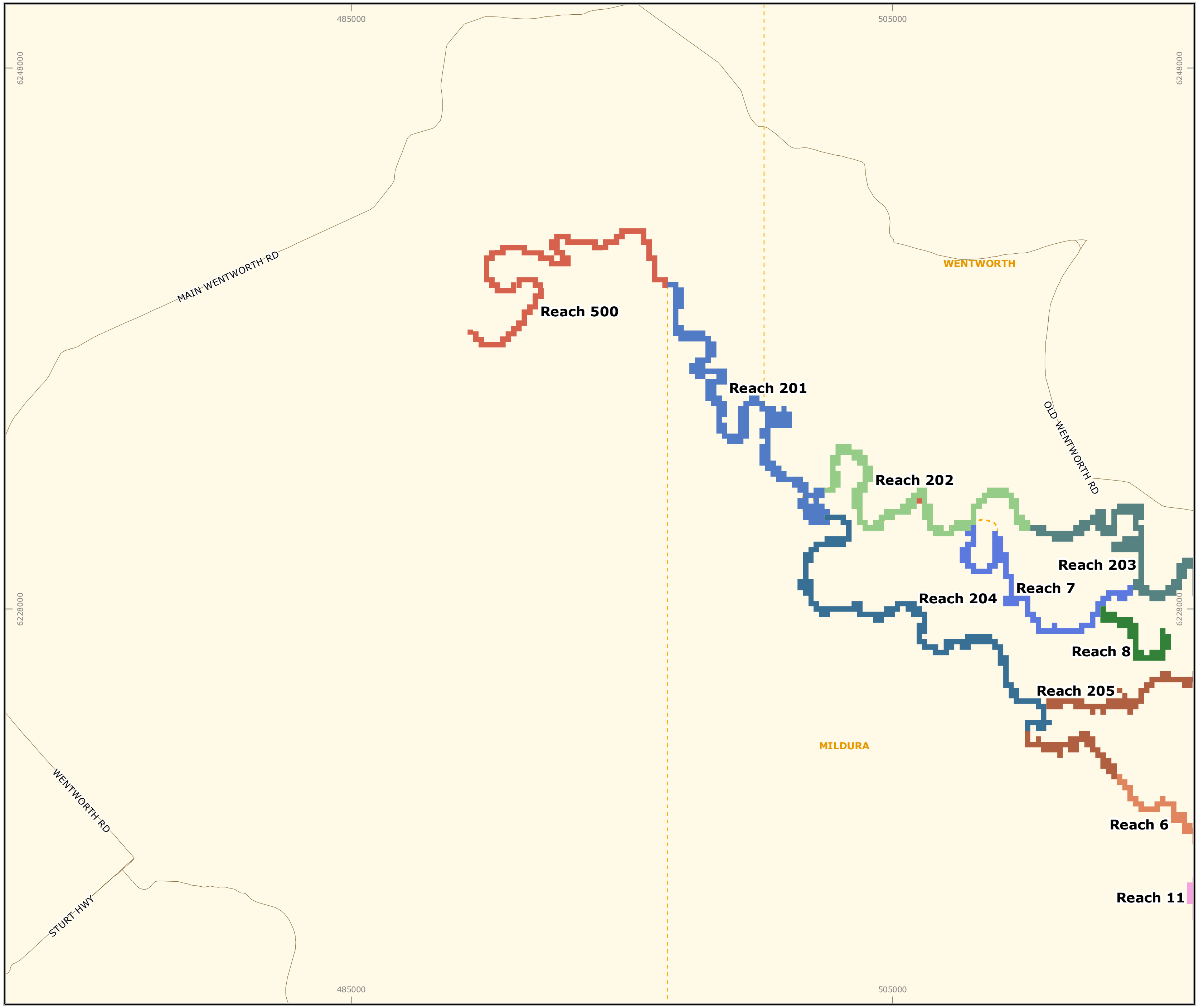
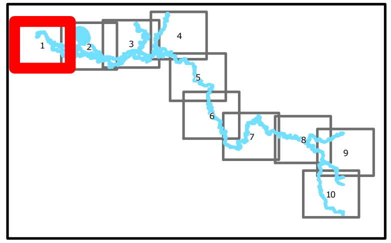
FIGURE C4

Modelled Hydrogeological Parameterisation Distribution - Layer 4

AUTHOR	AL	REPORT NO	R001
DRAWN	AL	REVISION	1
DATE	18/03/10	JOB NO.	A53 026

APPENDIX D RIVER MURRAY AND ASSOCIATED FEATURES – RIVER REACH DETAILS

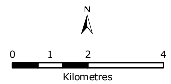




Mapsheet 1 of 10

LEGEND

✚	Locks	——	Main Roads
●	Localities	- - -	LGAs



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GDA 1994 MGA Zone 54

DATA SOURCES

MCMA: Irrigated Areas
GA: Localities, Lakes, Locks, Roads, LGAs
AQT: EM3 Model

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FIGURE D1

River Murray & Associated Features -River Reach

AUTHOR	AL	REPORT NO	R001
DRAWN	AL	REVISION	1
DATE	18/03/10	JOB NO.	A53 027

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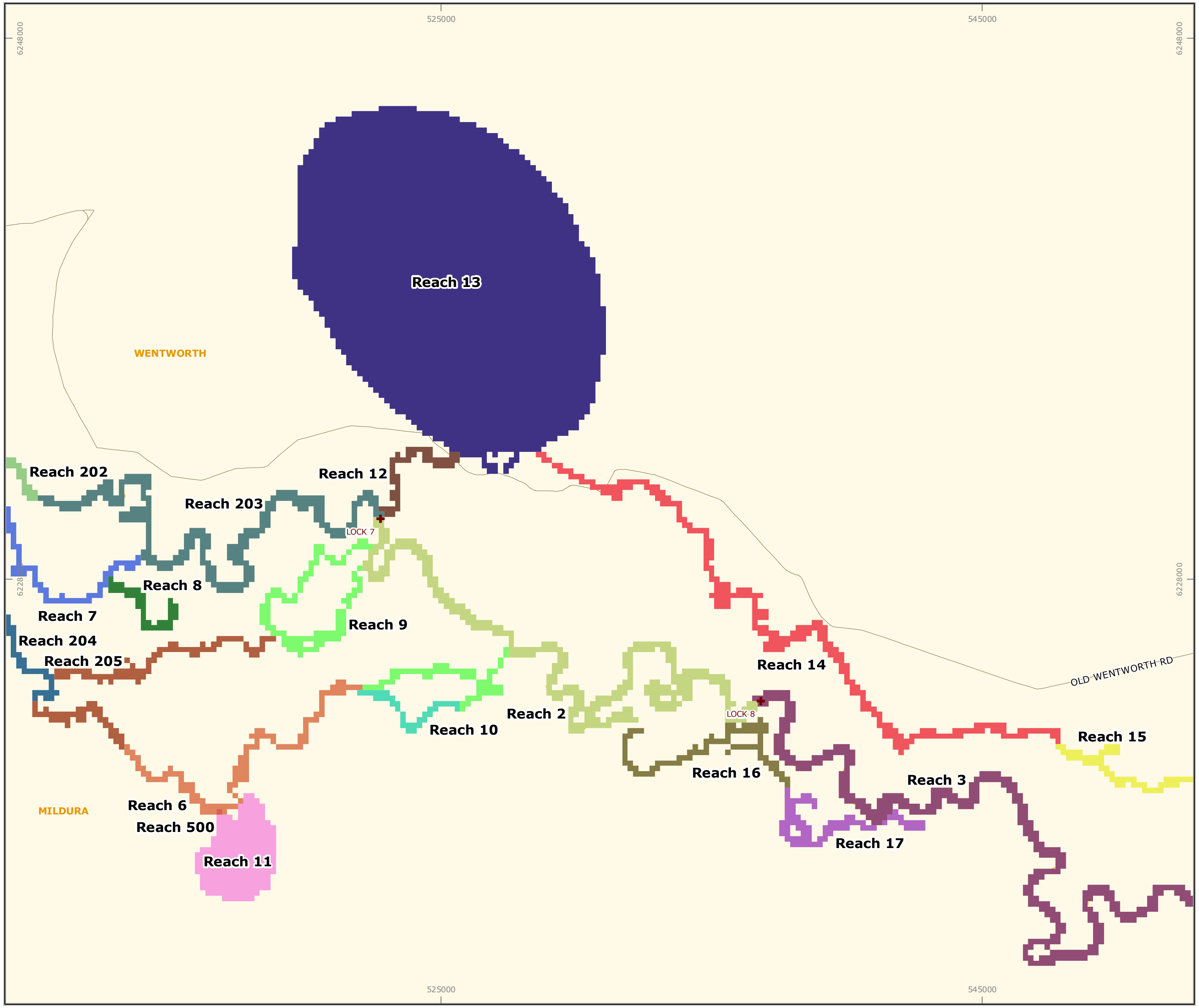

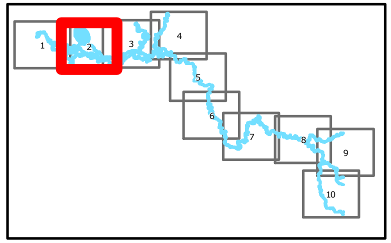

Mapsheet 2 of 10

LEGEND

✚	Locks		Main Roads
●	Localities		LGAs

N

0 1 2 4

Kilometres

SCALE 1:200,000 @ A4

GDA 1994 MGA Zone 54

DATA SOURCES

MCMA: Irrigated Areas
GA: Localities, Lakes, Locks, Roads, LGAs
AQT: EM3 Model

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FIGURE D1

River Murray & Associated Features -River Reach

AUTHOR	AL	REPORT NO	R001
DRAWN	AL	REVISION	1
DATE	18/03/10	JOB NO.	A53 027

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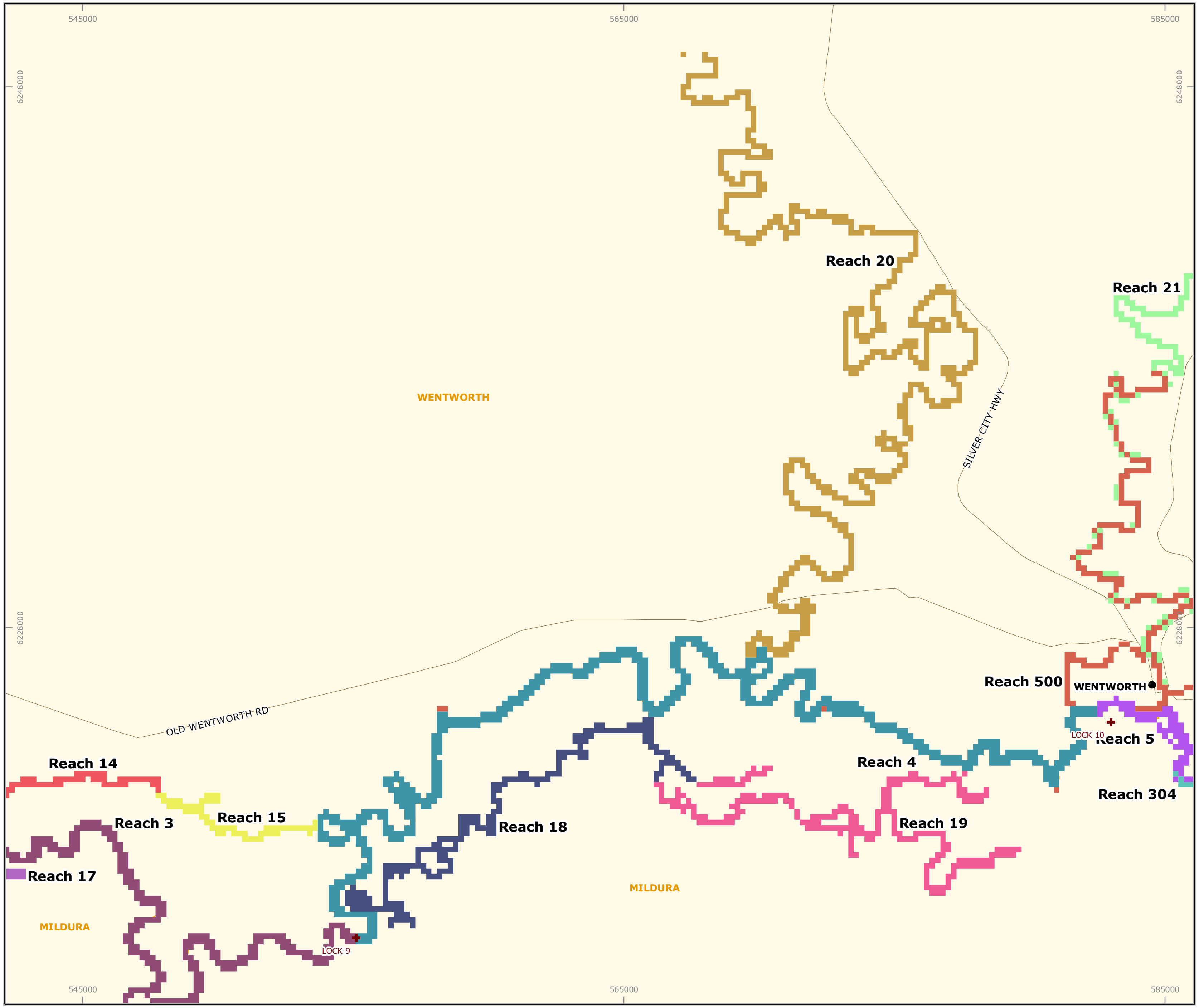

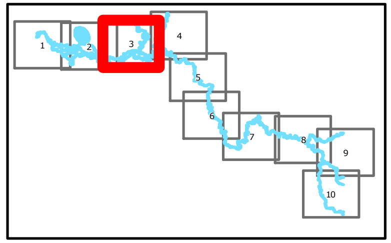

Mapsheet 3 of 10

LEGEND

- Locks
- Localities
- Main Roads
- LGAs

N

0 1 2 4

Kilometres

SCALE 1:200,000 @ A4

GDA 1994 MGA Zone 54

DATA SOURCES

MCMA: Irrigated Areas
GA: Localities, Lakes, Locks, Roads, LGAs
AQT: EM3 Model

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FIGURE D1

River Murray & Associated Features -River Reach

AUTHOR	AL	REPORT NO	R001
DRAWN	AL	REVISION	1
DATE	18/03/10	JOB NO.	A53 027

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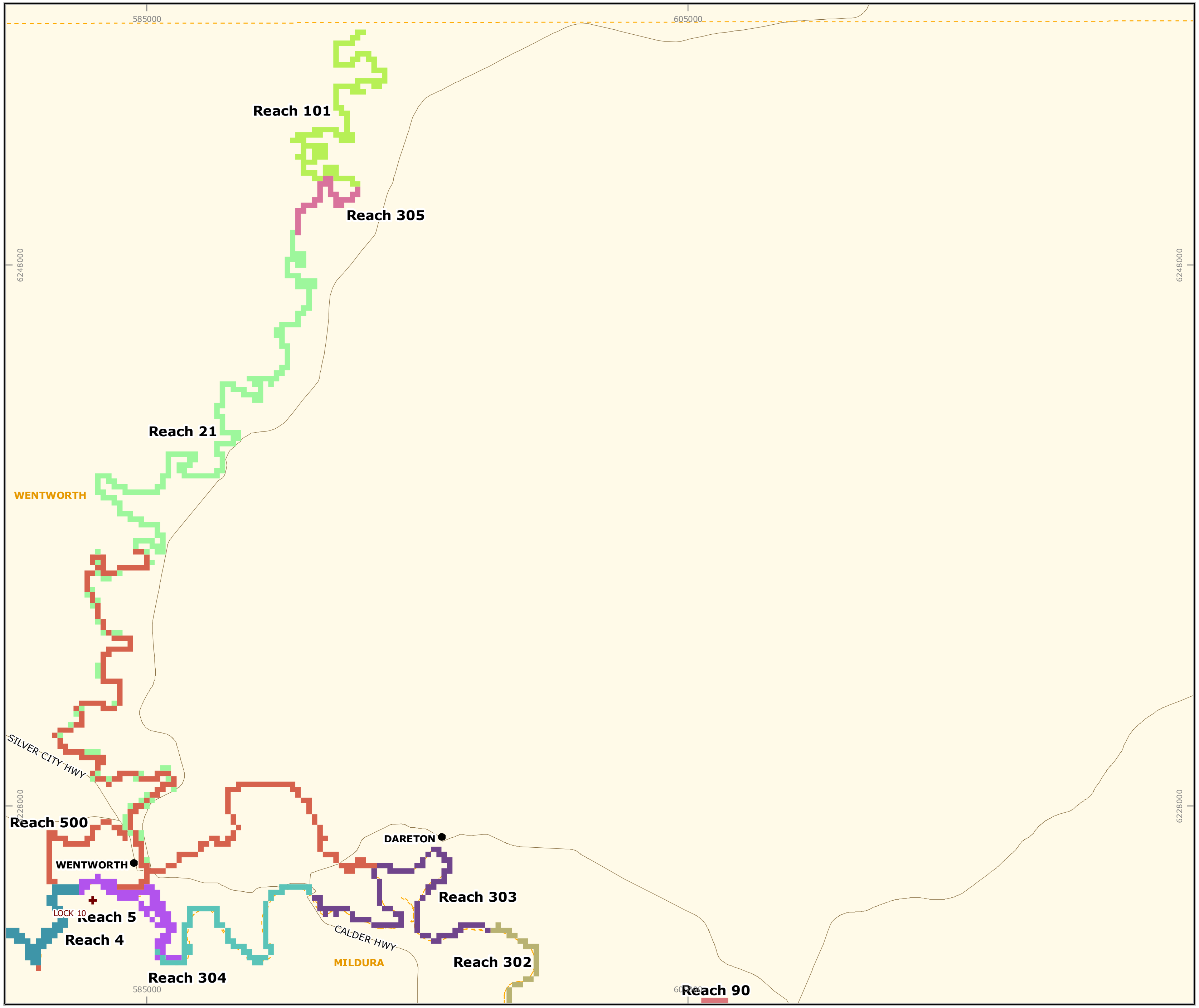

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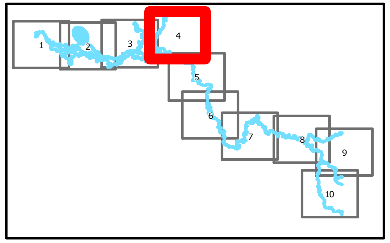

Mapsheet 4 of 10

LEGEND

Locks — Main Roads

Localities — LGAs

N

0 1 2 4

Kilometres

SCALE 1:200,000 @ A4

GDA 1994 MGA Zone 54

DATA SOURCES

MCMA: Irrigated Areas

GA: Localities, Lakes, Locks, Roads, LGAs

AQT: EM3 Model

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FIGURE D1

River Murray & Associated Features -River Reach

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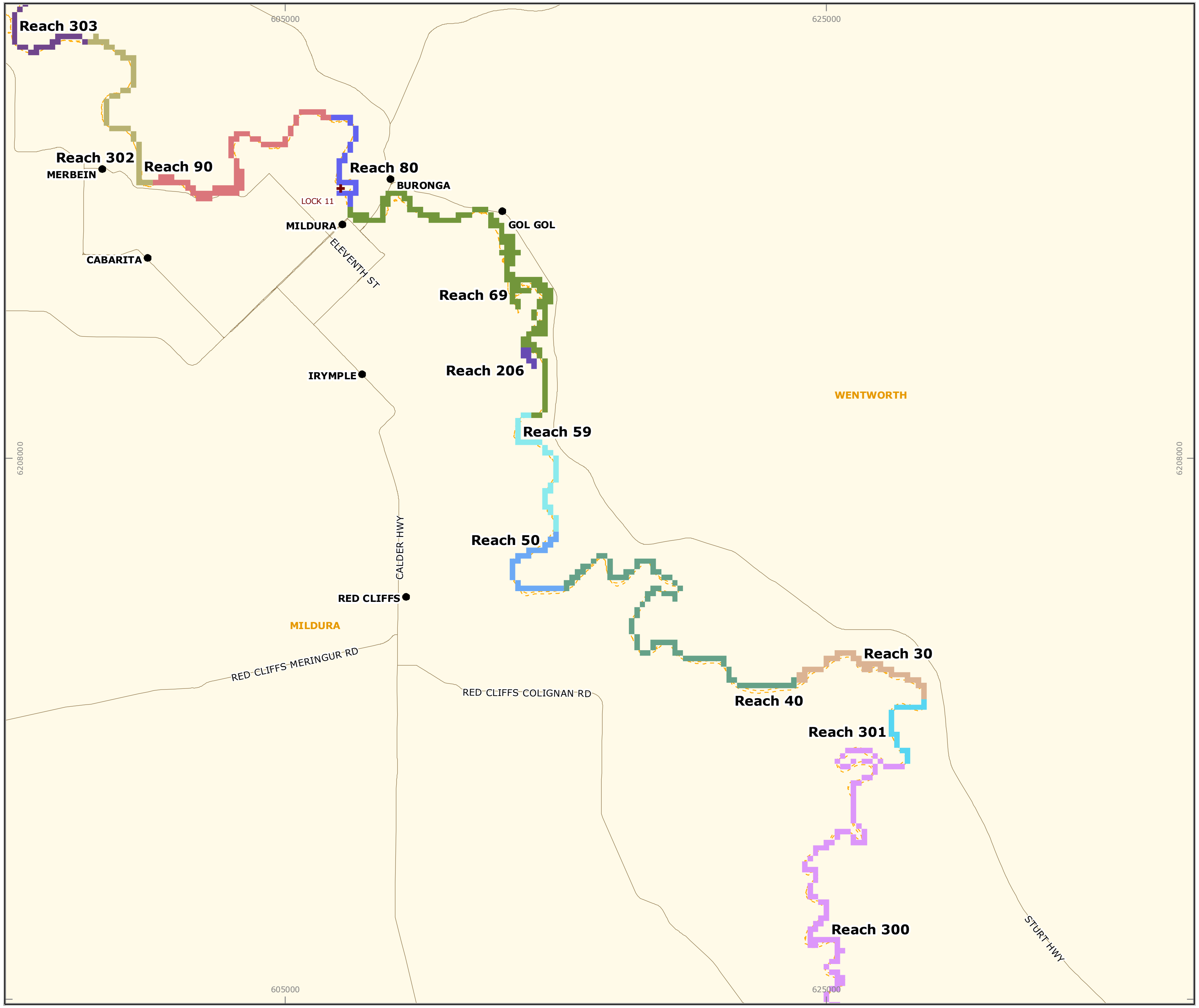
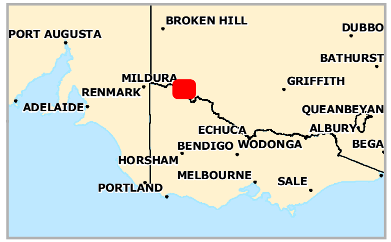
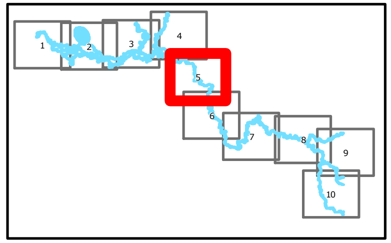
DATE	18/03/10	JOB NO.	A53 027







Mapsheet 5 of 10

LEGEND

✚	Locks	—	Main Roads
●	Localities	▭	LGAs

N

0 1 2 4
Kilometres

SCALE 1:200,000 @ A4

GDA 1994 MGA Zone 54

DATA SOURCES

MCMA: Irrigated Areas
GA: Localities, Lakes, Locks, Roads, LGAs
AQT: EM3 Model

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FIGURE D1

River Murray & Associated Features -River Reach

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DRAWN	AL	REVISION	1
DATE	18/03/10	JOB NO.	A53 027

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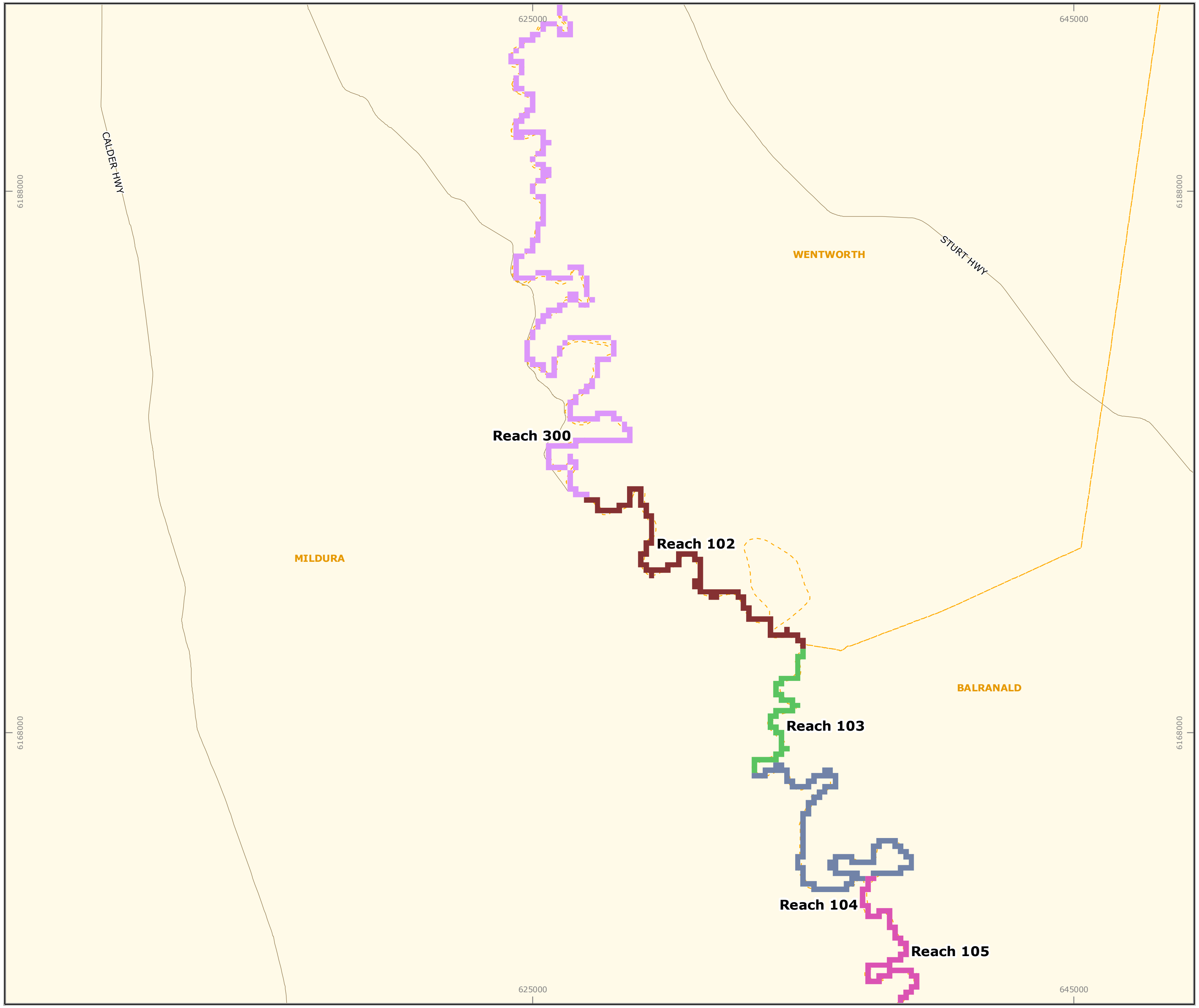

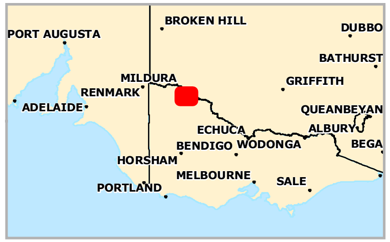

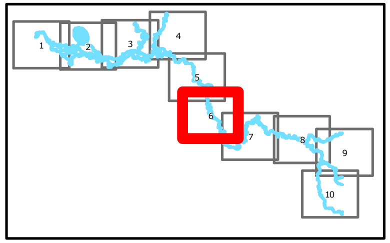

Mapsheet 6 of 10

LEGEND

Locks	Main Roads
Localities	LGAs

0 1 2 4
Kilometres

SCALE 1:200,000 @ A4

GDA 1994 MGA Zone 54

DATA SOURCES

MCMA: Irrigated Areas
GA: Localities, Lakes, Locks, Roads, LGAs
AQT: EM3 Model

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FIGURE D1

River Murray & Associated Features -River Reach

AUTHOR	AL	REPORT NO	R001
DRAWN	AL	REVISION	1
DATE	18/03/10	JOB NO.	A53 027

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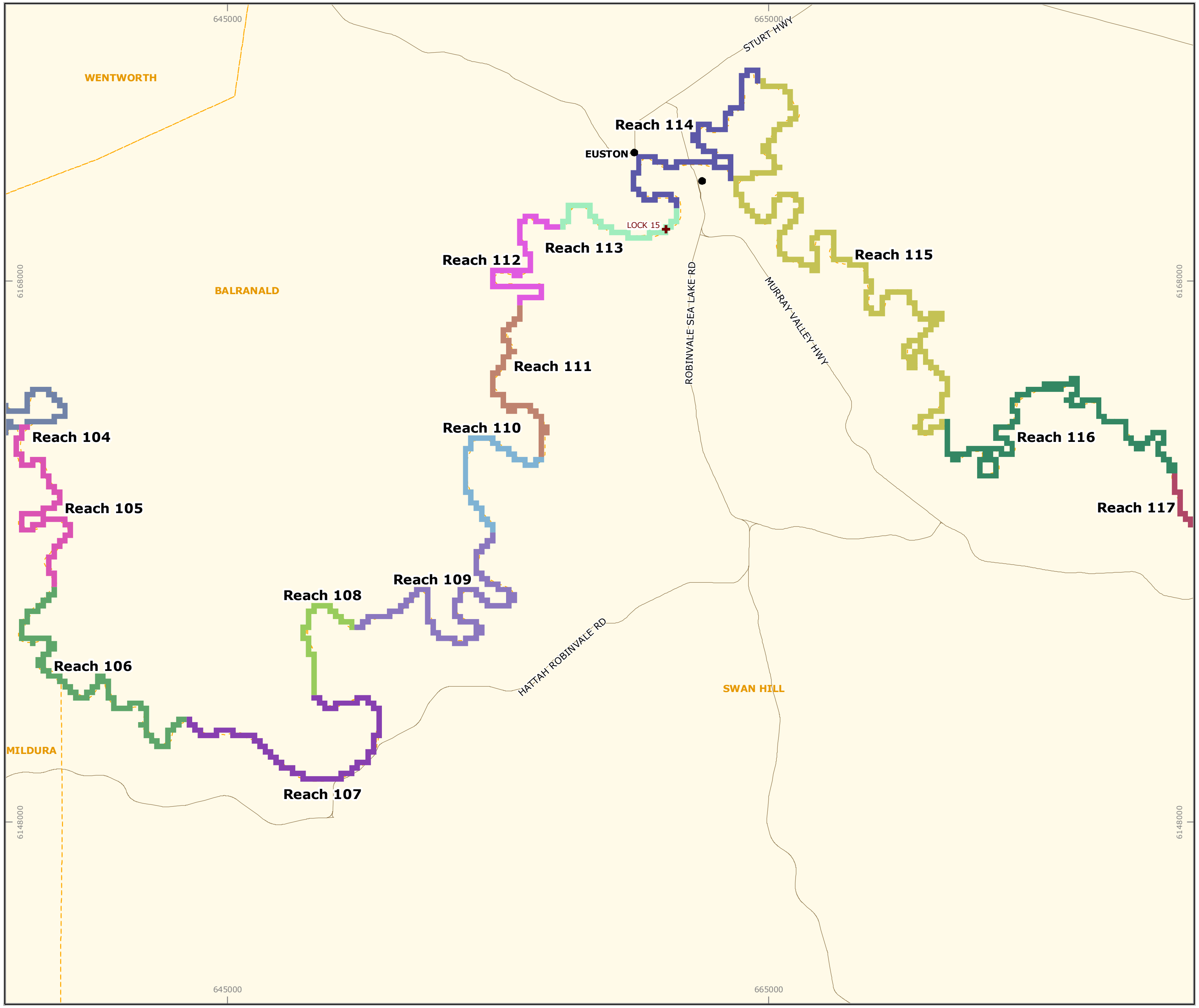
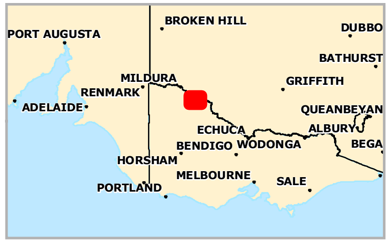
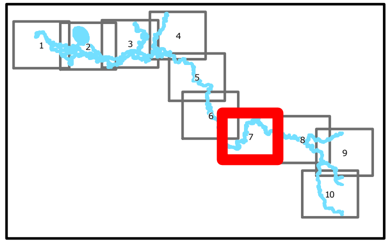


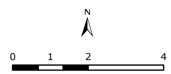




Mapsheet 7 of 10

LEGEND

- Locks
- Main Roads
- Localities
- LGAs



SCALE 1:200,000 @ A4

GDA 1994 MGA Zone 54

DATA SOURCES

MCMA: Irrigated Areas
GA: Localities, Lakes, Locks, Roads, LGAs
AQT: EM3 Model

Disclaimer: While all reasonable care has been taken to ensure the information contained on this map is up to date and accurate, no guarantee is given that the information portrayed is free from error or omission. Please verify the accuracy of all information prior to use.

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FIGURE D1

River Murray & Associated Features -River Reach

AUTHOR	AL	REPORT NO	R001
DRAWN	AL	REVISION	1
DATE	18/03/10	JOB NO.	A53 027

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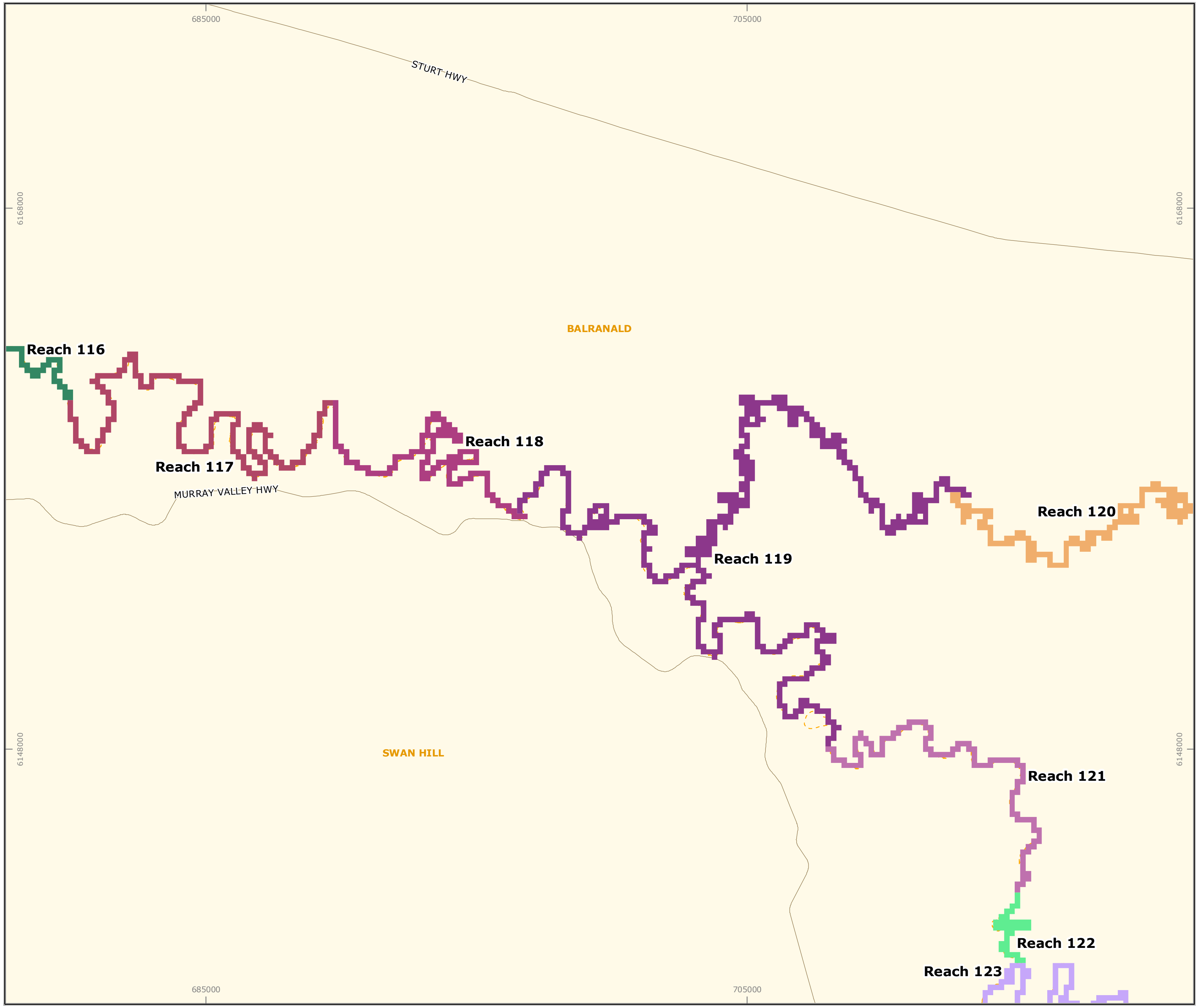
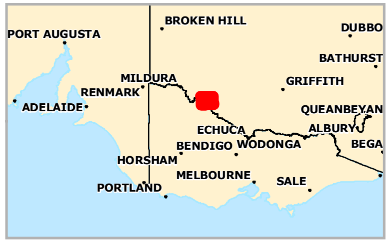
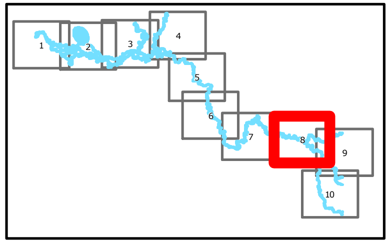


C:\JOBS\A53D\ArcGIS\Projects\A53_027.mxd





Mapsheet 8 of 10

LEGEND

Locks	Main Roads
Localities	LGAs

N

0 1 2 4
Kilometres

SCALE 1:200,000 @ A4

GDA 1994 MGA Zone 54

DATA SOURCES

MCMA: Irrigated Areas
GA: Localities, Lakes, Locks, Roads, LGAs
AQT: EM3 Model

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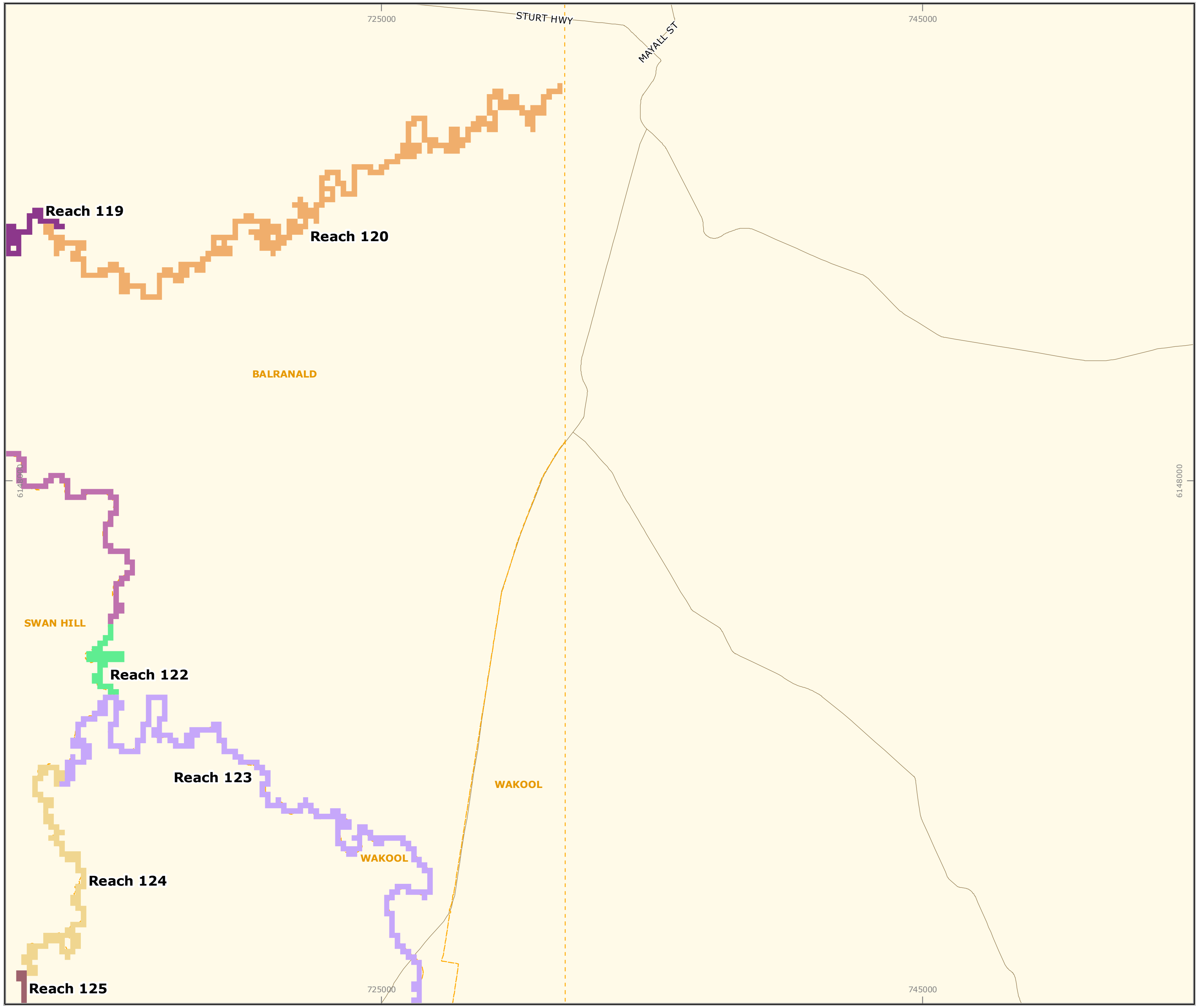
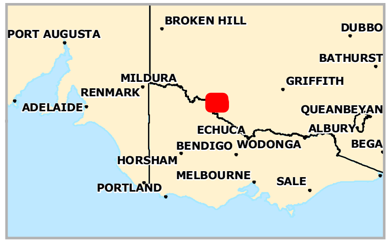
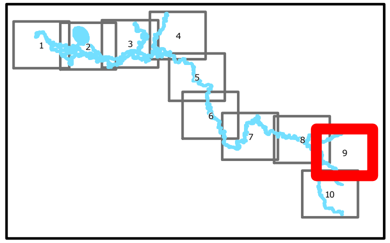
FIGURE D1

River Murray & Associated Features -River Reach

AUTHOR	AL	REPORT NO	R001
DRAWN	AL	REVISION	1
DATE	18/03/10	JOB NO.	A53 027



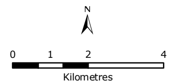




Mapsheet 9 of 10

LEGEND

- Locks
- Main Roads
- Localities
- LGAs



SCALE 1:200,000 @ A4

GDA 1994 MGA Zone 54

DATA SOURCES

MCMA: Irrigated Areas
GA: Localities, Lakes, Locks, Roads, LGAs
AQT: EM3 Model

Disclaimer: While all reasonable care has been taken to ensure the information contained on this map is up to date and accurate, no guarantee is given that the information portrayed is free from error or omission. Please verify the accuracy of all information prior to use.

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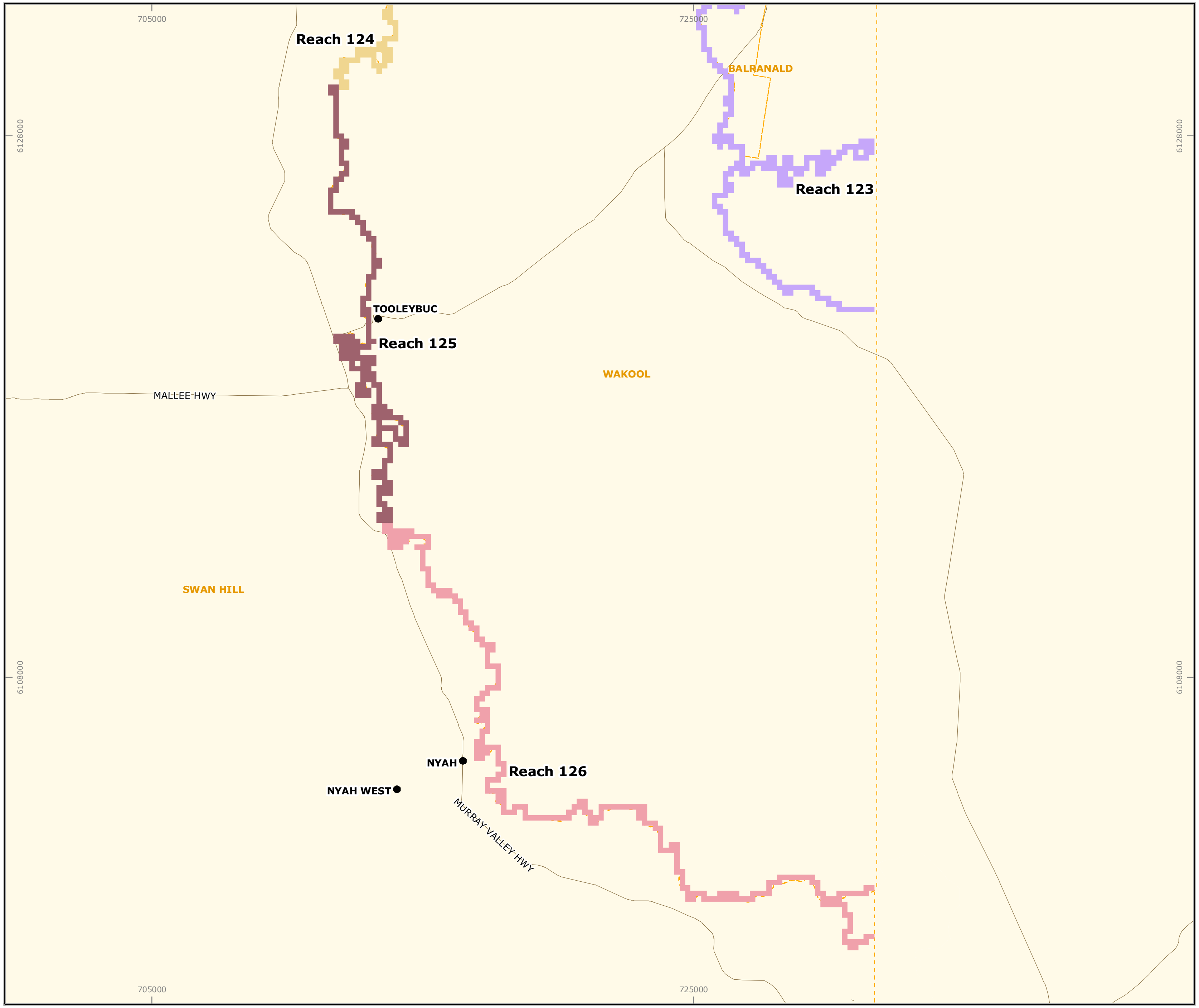
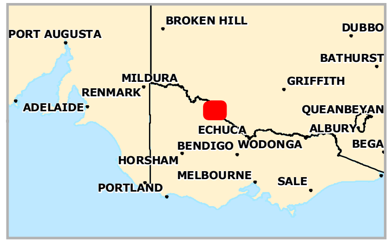
FIGURE D1

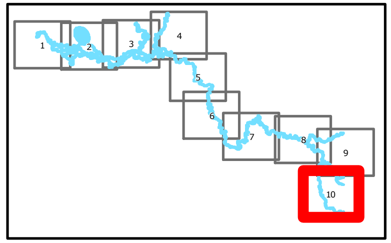
River Murray & Associated Features -River Reach

AUTHOR	AL	REPORT NO	R001
DRAWN	AL	REVISION	1
DATE	18/03/10	JOB NO.	A53 027

C:\JOBS\A53D\ArcGIS\Projects\A53_027.mxd







Mapsheet 10 of 10

LEGEND

Locks — Main Roads
Localities — LGAs

N

0 1 2 4
Kilometres

SCALE 1:200,000 @ A4

GDA 1994 MGA Zone 54

DATA SOURCES
MCMA: Irrigated Areas
GA: Localities, Lakes, Locks, Roads, LGAs
AQT: EM3 Model

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Note: The information shown on this map is a copyright of Aquaterra Australia 2010

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FIGURE D1

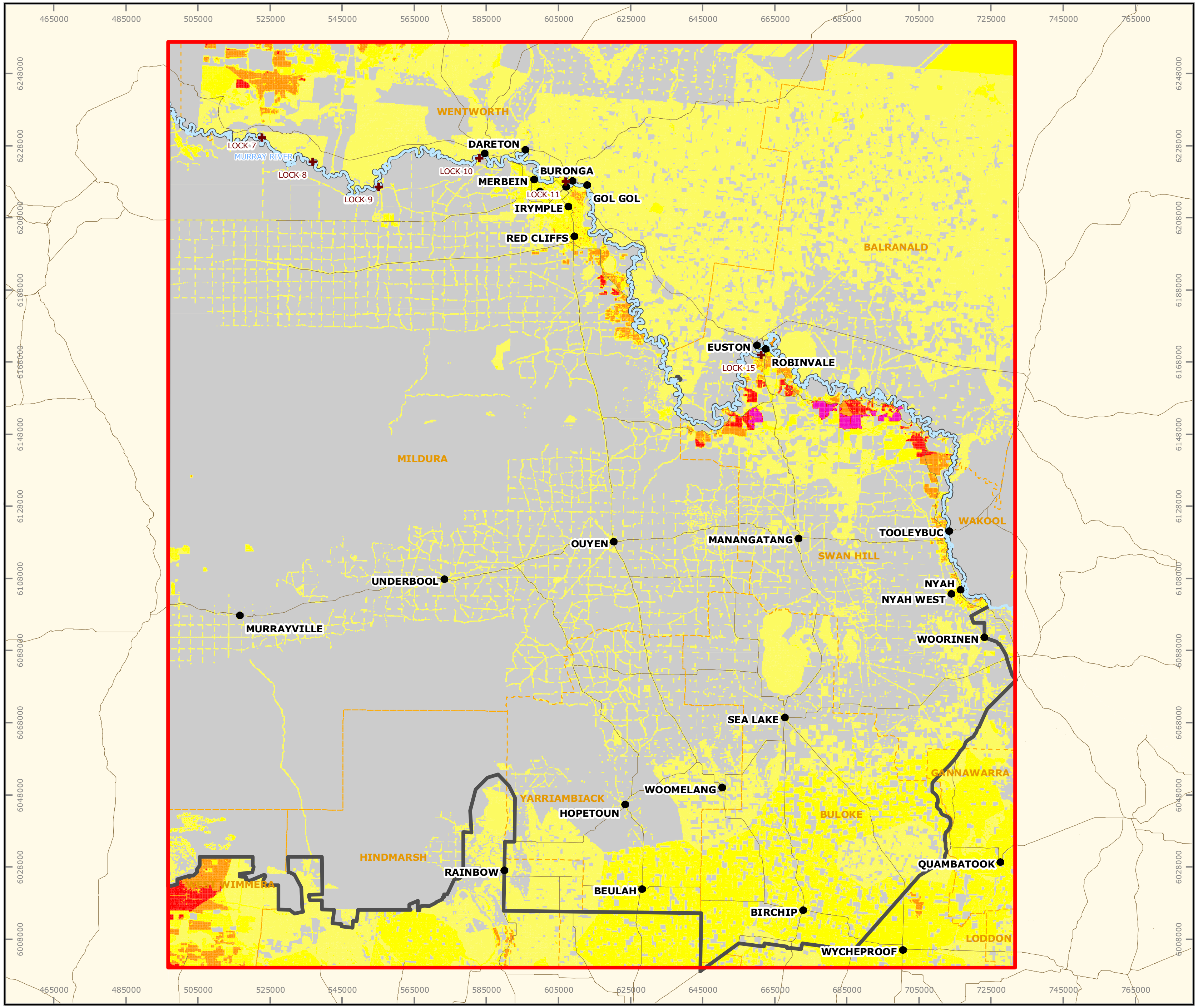
River Murray & Associated Features -River Reach

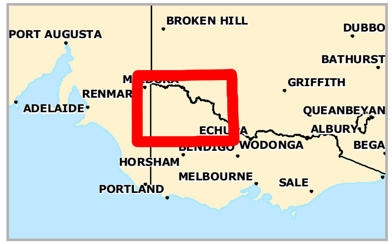
AUTHOR	AL	REPORT NO	R001
DRAWN	AL	REVISION	1
DATE	18/03/10	JOB NO.	A53 027

C:\JOBS\A53D\ArcGIS\Projects\A53_027.mxd

Reach	Long term average Stage (AHD)		Bed Level (mAHD)			Reach	Long term average Stage (AHD)		Bed Level (mAHD)	
	Minimum	Maximum	Minimum	Maximum			Minimum	Maximum	Minimum	Maximum
2	22.49	22.93	18.49	18.93		107	40.94	41.62	39.44	40.12
3	22.87	25.15	18.87	21.15		108	41.63	41.89	39.63	39.89
4	27.51	28.36	23.51	24.36		109	41.90	42.68	39.90	40.68
5	28.36	30.96	24.36	26.96		110	42.69	43.05	40.69	41.05
6	21.61	22.33	19.61	20.33		111	43.06	43.47	41.06	41.47
7	20.21	20.55	19.71	20.05		112	43.48	43.90	41.48	41.90
8	20.49	20.58	19.99	20.08		113	43.90	47.80	41.90	45.80
9	22.01	22.63	21.01	21.63		114	47.80	48.12	42.80	43.12
10	22.34	22.51	22.34	22.51		115	48.12	48.88	44.12	44.88
11	21.88	21.88	21.88	21.88		116	48.89	49.34	44.89	45.34
12	20.83	25.00	20.33	24.50		117	49.35	49.98	46.35	46.98
13	25.00	25.00	21.00	21.00		118	49.98	50.43	47.98	48.43
14	25.00	27.11	23.00	25.11		119	50.43	53.11	47.43	50.11
15	27.11	27.62	25.11	25.62		120	53.12	55.96	51.12	53.96
16	22.94	23.97	22.44	23.47		121	52.00	52.78	49.00	49.78
17	23.98	24.84	23.98	24.84		122	52.78	53.40	49.28	49.90
18	27.53	27.86	27.03	27.36		123	53.42	55.55	49.92	52.05
19	27.84	28.16	27.84	28.16		124	54.18	56.02	51.18	53.02
20	28.03	32.31	26.03	30.31		125	56.04	59.58	54.04	57.58
21	30.91	32.30	28.91	30.30		126	59.59	64.50	57.59	62.50
30	34.45	34.46	27.55	27.56		201	19.58	19.99	15.58	15.99
40	34.43	34.45	30.30	30.32		202	20.00	20.28	17.00	17.28
50	34.43	34.43	29.75	29.75		203	20.29	20.83	18.29	18.83
59	34.42	34.43	30.30	30.31		204	19.97	21.32	15.97	17.32
69	34.39	34.42	28.51	28.54		205	21.28	22.00	18.28	19.00
80	31.44	34.39	27.29	30.24		206	34.17	34.42	29.54	29.79
90	31.32	31.43	26.99	27.10		300	34.69	37.51	32.12	34.94
101	32.41	32.84	30.41	30.84		301	34.47	34.67	29.54	29.74
102	37.52	38.29	36.02	36.79		302	31.24	31.31	26.17	26.24
103	38.30	38.66	36.80	37.16		303	31.08	31.23	26.20	26.35
104	38.67	39.60	37.17	38.10		304	30.94	31.07	24.58	24.71
105	39.61	40.17	37.61	38.17		305	32.30	32.46	30.30	30.46
106	40.18	40.93	38.68	39.43		500	27.79	31.60	24.37	28.18

APPENDIX E MODELLED TRANSIENT EVAPOTRANSPIRATION AND RECHARGE DISTRIBUTION





LEGEND

- Locks
- Localities
- River Murray
- Main Roads
- LGAs
- EM3 Model Boundary
- Mallee CMA Boundary

ENSYM Recharge (mm/year)

- 0
- 0 - 25
- 25 - 50
- 50 - 75
- 75 - 100
- 100 - 125
- 125 - 150
- 150 - 175
- 175 - 200

N

0 5 10 20
Kilometres

SCALE 1:1,500,000 @ A4

GDA 1994 MGA Zone 54

DATA SOURCES
MCMA: Irrigated Areas
GA: Localities, Lakes, Locks, Roads, LGAs
AQT: EM3 Model

Disclaimer: While all reasonable care has been taken to ensure the information contained on this map is up to date and accurate, no guarantee is given that the information portrayed is free from error or omission. Please verify the accuracy of all information prior to use.

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FIGURE E1

ENSYM Recharge - Stress Period 1

AUTHOR	AL	REPORT NO	R001
DRAWN	AL	REVISION	1
DATE	18/03/10	JOB NO.	A53 028

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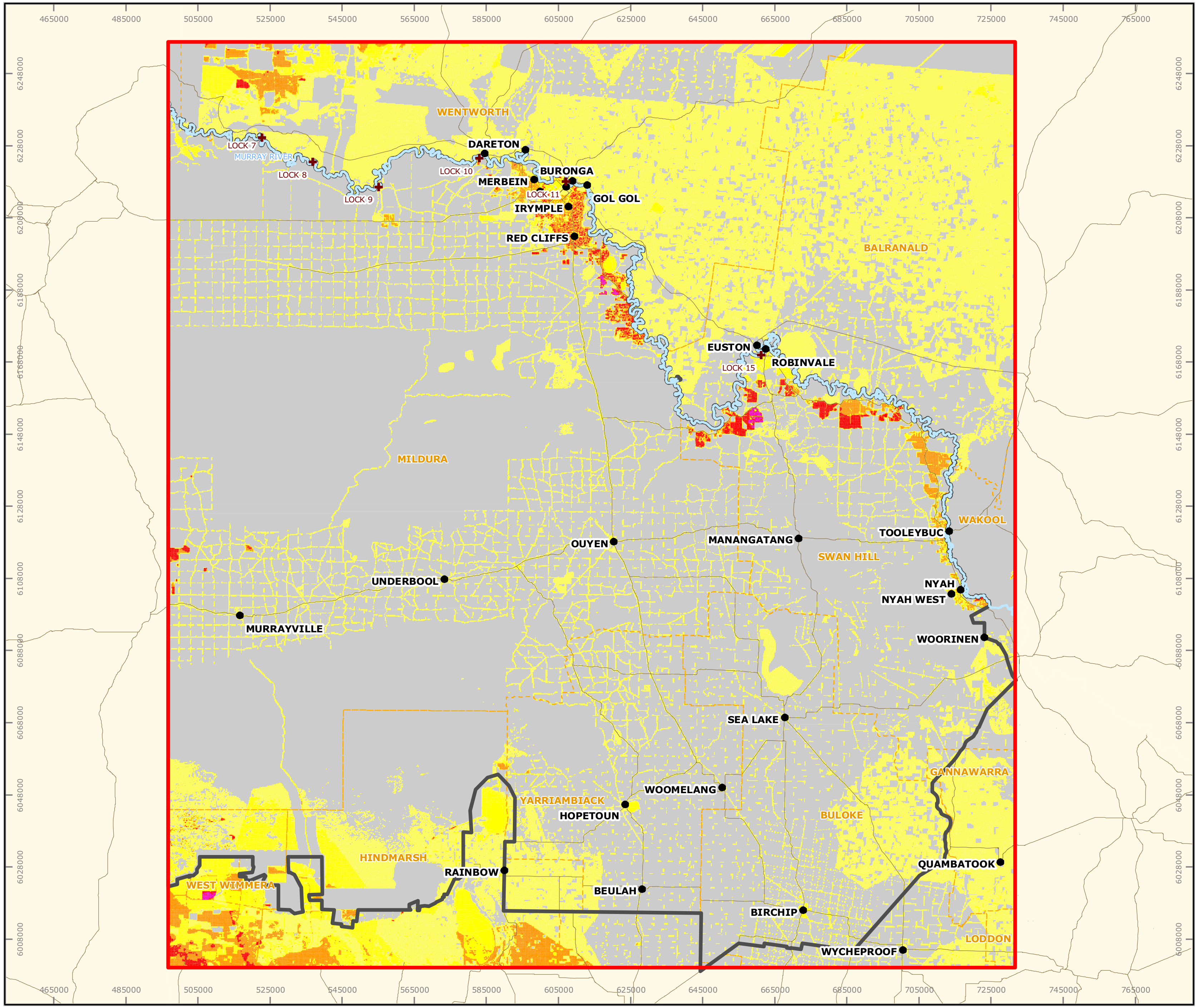

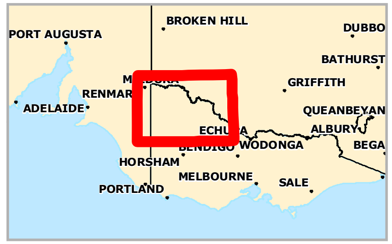

LEGEND

- Locks
- LGAs
- Localities
- EM3 Model Boundary
- River Murray
- Mallee CMA Boundary
- Main Roads

ENSYM Recharge (mm/year)

- 0
- 0 - 25
- 25 - 50
- 50 - 75
- 75 - 100
- 100 - 125
- 125 - 150
- 150 - 175
- 175 - 200

N

0 5 10 20

Kilometres

SCALE 1:1,500,000 @ A4

GDA 1994 MGA Zone 54

DATA SOURCES

MCMA: Irrigated Areas
GA: Localities, Lakes, Locks, Roads, LGAs
AQT: EM3 Model

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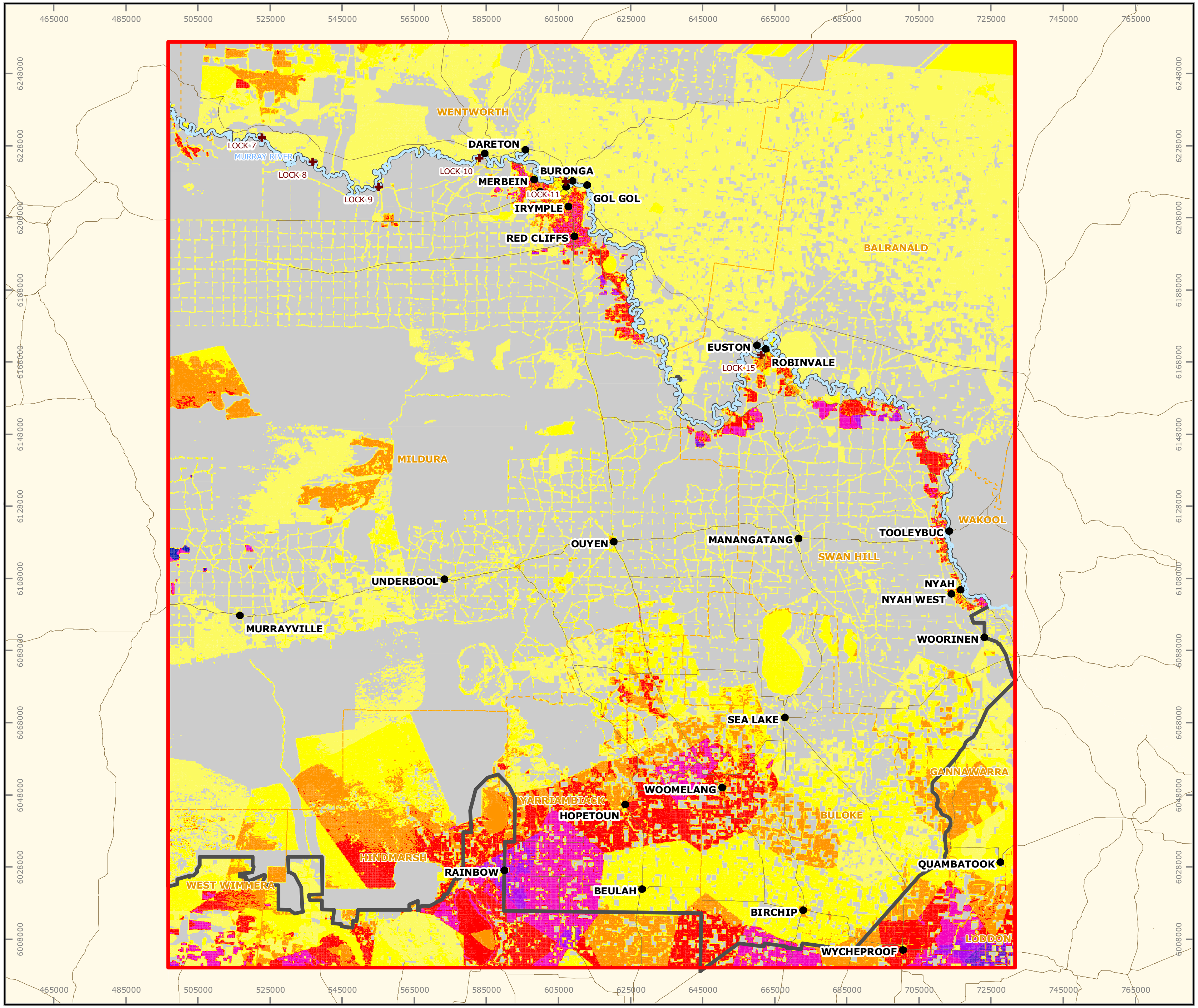
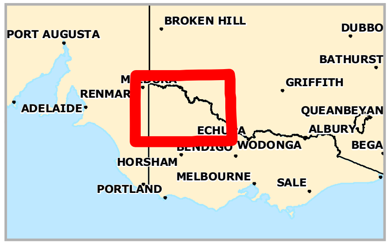
FIGURE E2

ENSYM Recharge - Stress Period 2

AUTHOR	AL	REPORT NO	R001
DRAWN	AL	REVISION	1
DATE	18/03/10	JOB NO.	A53 029

C:\JOBS\A53D\ArcGIS\Projects\A53_029.mxd





LEGEND

- Locks
- Localities
- River Murray
- Main Roads
- LGAs
- EM3 Model Boundary
- Mallee CMA Boundary

ENSYM Recharge (mm/year)

- 0
- 0 - 25
- 25 - 50
- 50 - 75
- 75 - 100
- 100 - 125
- 125 - 150
- 150 - 175
- 175 - 200

N

0 5 10 20
Kilometres

SCALE 1:1,500,000 @ A4

GDA 1994 MGA Zone 54

DATA SOURCES

MCMA: Irrigated Areas
GA: Localities, Lakes, Locks, Roads, LGAs
AQT: EM3 Model

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FIGURE E3

ENSYM Recharge - Stress Period 3

AUTHOR	AL	REPORT NO	R001
DRAWN	AL	REVISION	1
DATE	18/03/10	JOB NO.	A53 030

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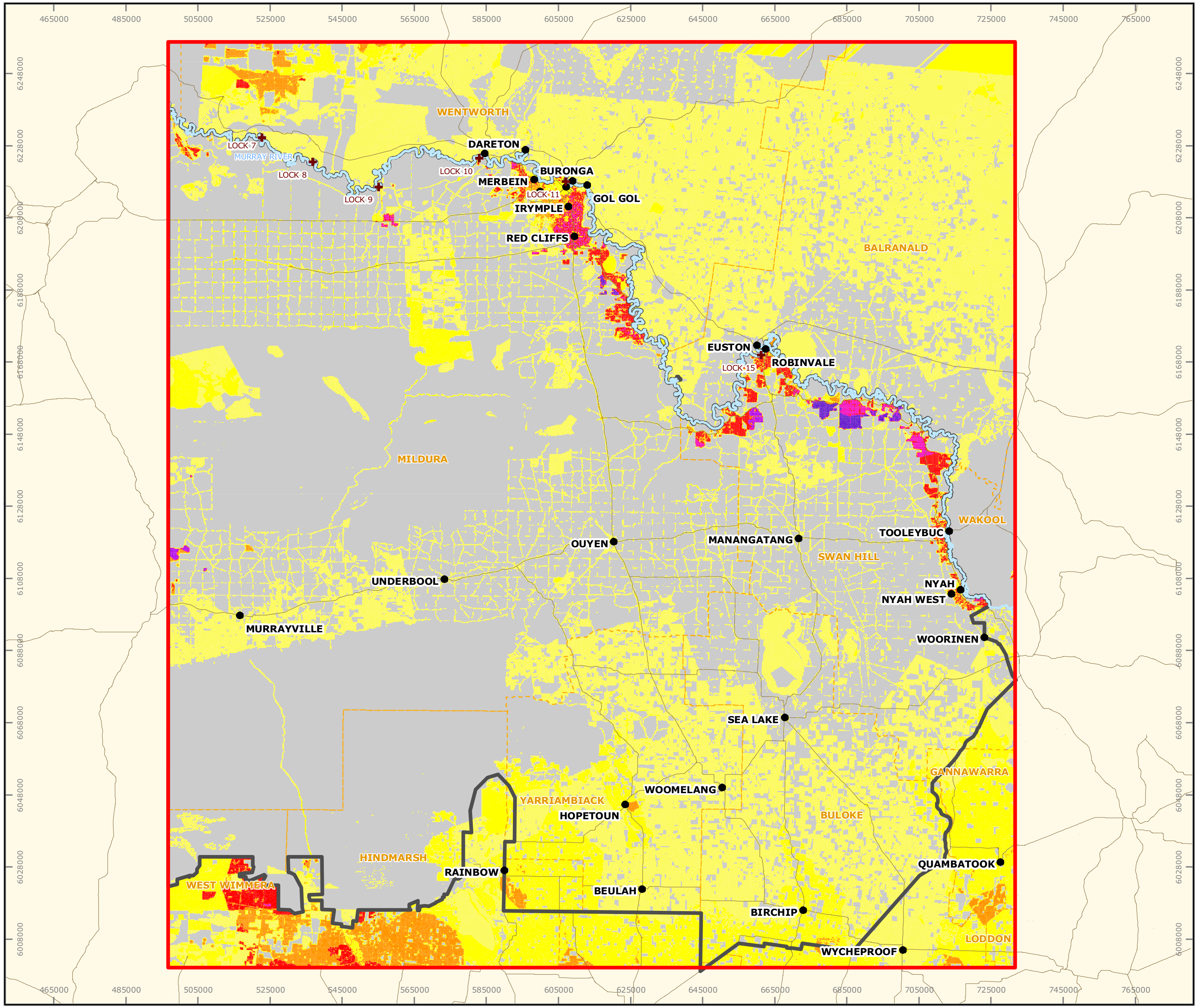

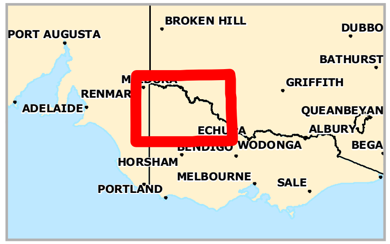

LEGEND

- Locks
- Localities
- River Murray
- Main Roads
- LGAs
- EM3 Model Boundary
- Mallee CMA Boundary

ENSYM Recharge (mm/year)

0	100 - 125
0 - 25	125 - 150
25 - 50	150 - 175
50 - 75	175 - 200
75 - 100	

N

0 5 10 20
Kilometres

SCALE 1:1,500,000 @ A4

GDA 1994 MGA Zone 54

DATA SOURCES

MCMA: Irrigated Areas
GA: Localities, Lakes, Locks, Roads, LGAs
AQT: EM3 Model

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FIGURE E4

ENSYM Recharge - Stress Period 4

AUTHOR	AL	REPORT NO	R001
DRAWN	AL	REVISION	1
DATE	18/03/10	JOB NO.	A53 031

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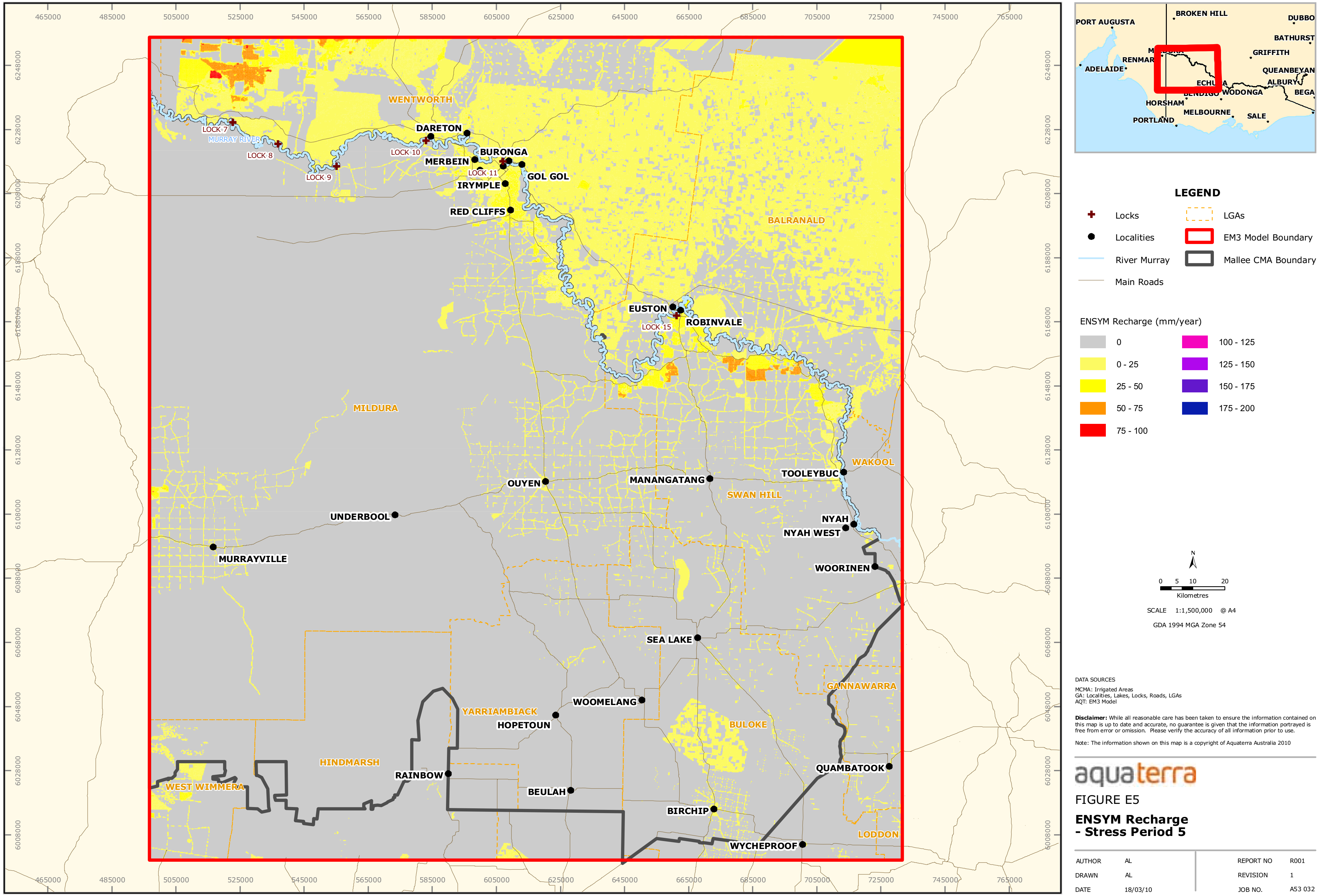

FIGURE E5
ENSYM Recharge - Stress Period 5

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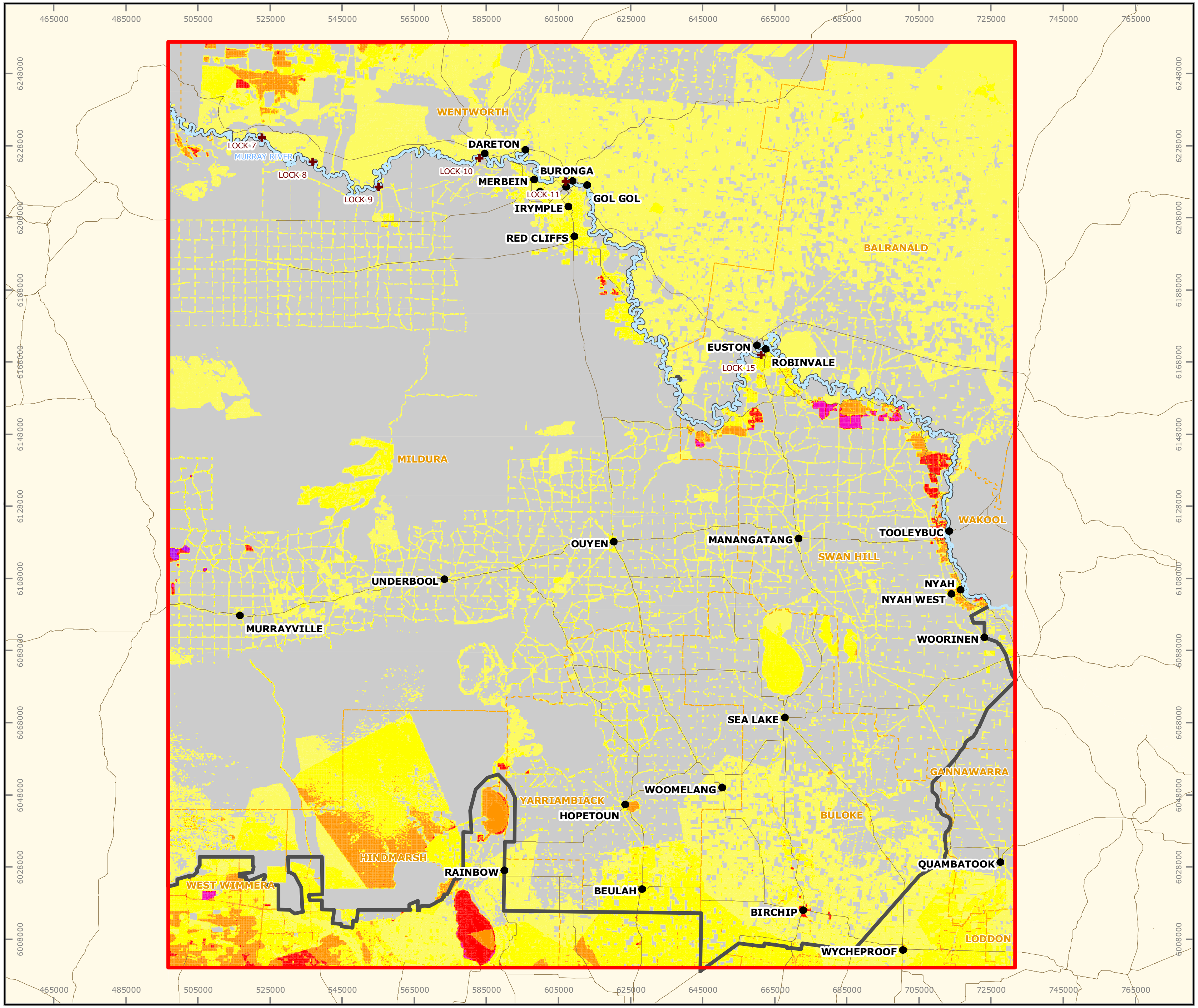
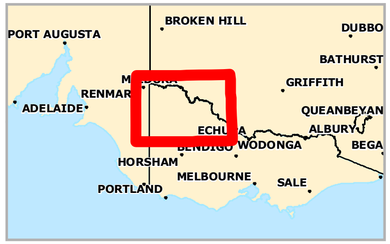


C:\JOBS\A53D\ArcGIS\Projects\A53_033.mxd



LEGEND

- Locks
- Localities
- River Murray
- Main Roads
- LGAs
- EM3 Model Boundary
- Mallee CMA Boundary

ENSYM Recharge (mm/year)

- 0
- 0 - 25
- 25 - 50
- 50 - 75
- 75 - 100
- 100 - 125
- 125 - 150
- 150 - 175
- 175 - 200

N

0 5 10 20

Kilometres

SCALE 1:1,500,000 @ A4

GDA 1994 MGA Zone 54

DATA SOURCES

MCMA: Irrigated Areas
GA: Localities, Lakes, Locks, Roads, LGAs
AQT: EM3 Model

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FIGURE E6

ENSYM Recharge - Stress Period 6

AUTHOR	AL	REPORT NO	R001
DRAWN	AL	REVISION	1
DATE	18/03/10	JOB NO.	A53 033

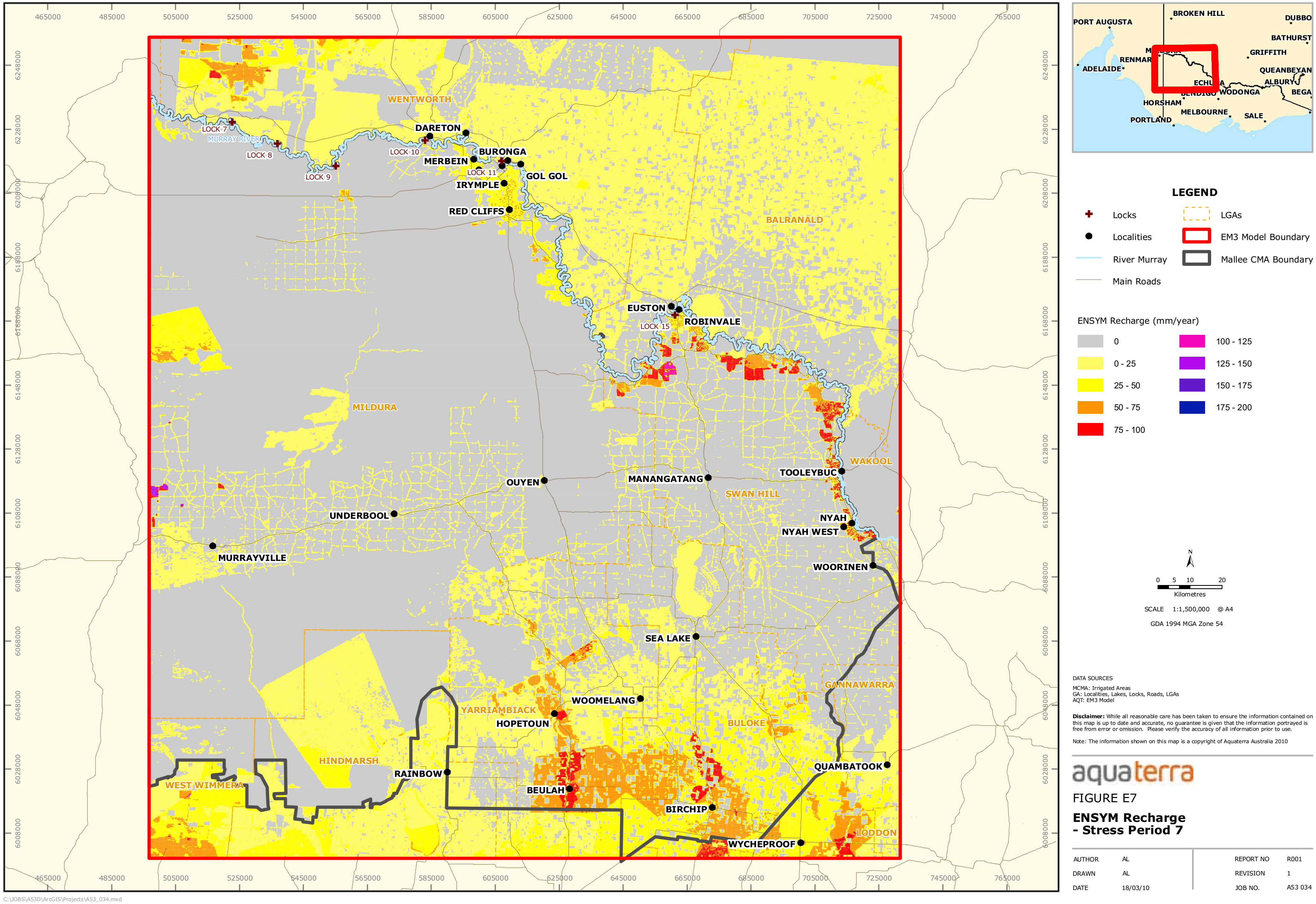


FIGURE E7

ENSYM Recharge - Stress Period 7

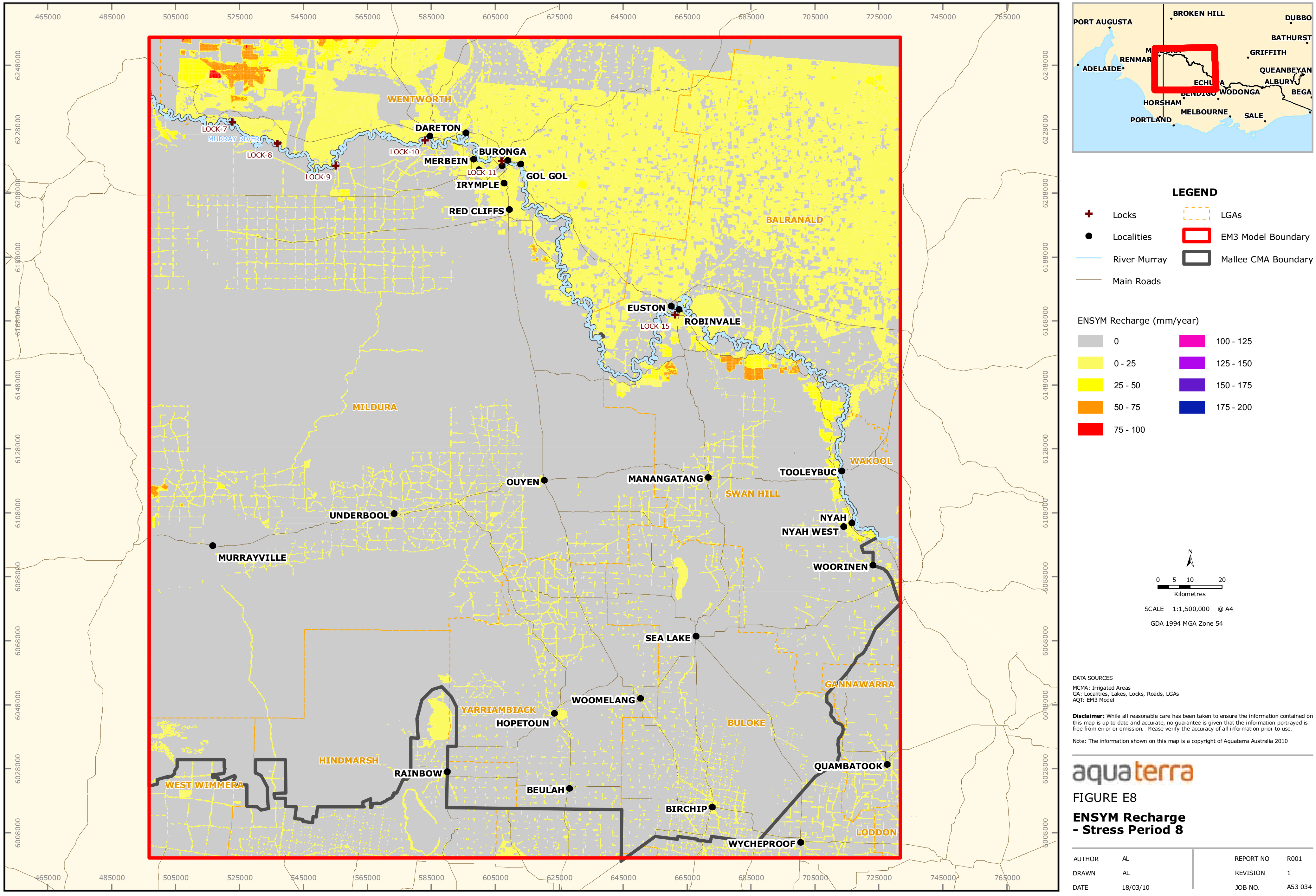
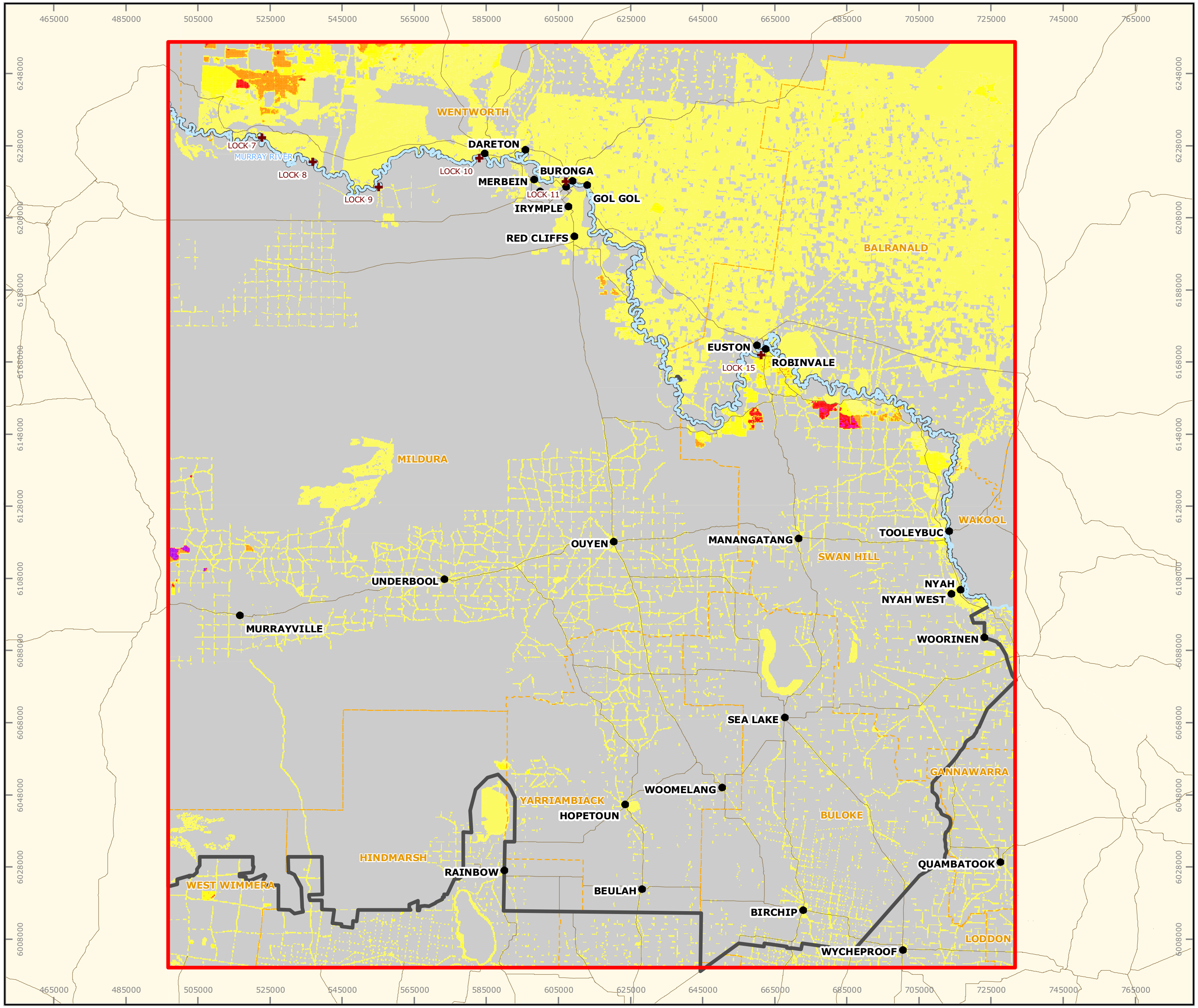
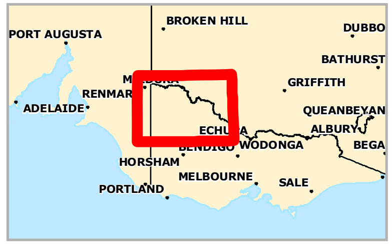


FIGURE E8

ENSYM Recharge - Stress Period 8





LEGEND

- Locks
- Localities
- River Murray
- Main Roads
- LGAs
- EM3 Model Boundary
- Mallee CMA Boundary

ENSYM Recharge (mm/year)

- 0
- 0 - 25
- 25 - 50
- 50 - 75
- 75 - 100
- 100 - 125
- 125 - 150
- 150 - 175
- 175 - 200

0 5 10 20
Kilometres

SCALE 1:1,500,000 @ A4

GDA 1994 MGA Zone 54

DATA SOURCES
MCMA: Irrigated Areas
GA: Localities, Lakes, Locks, Roads, LGAs
AQT: EM3 Model

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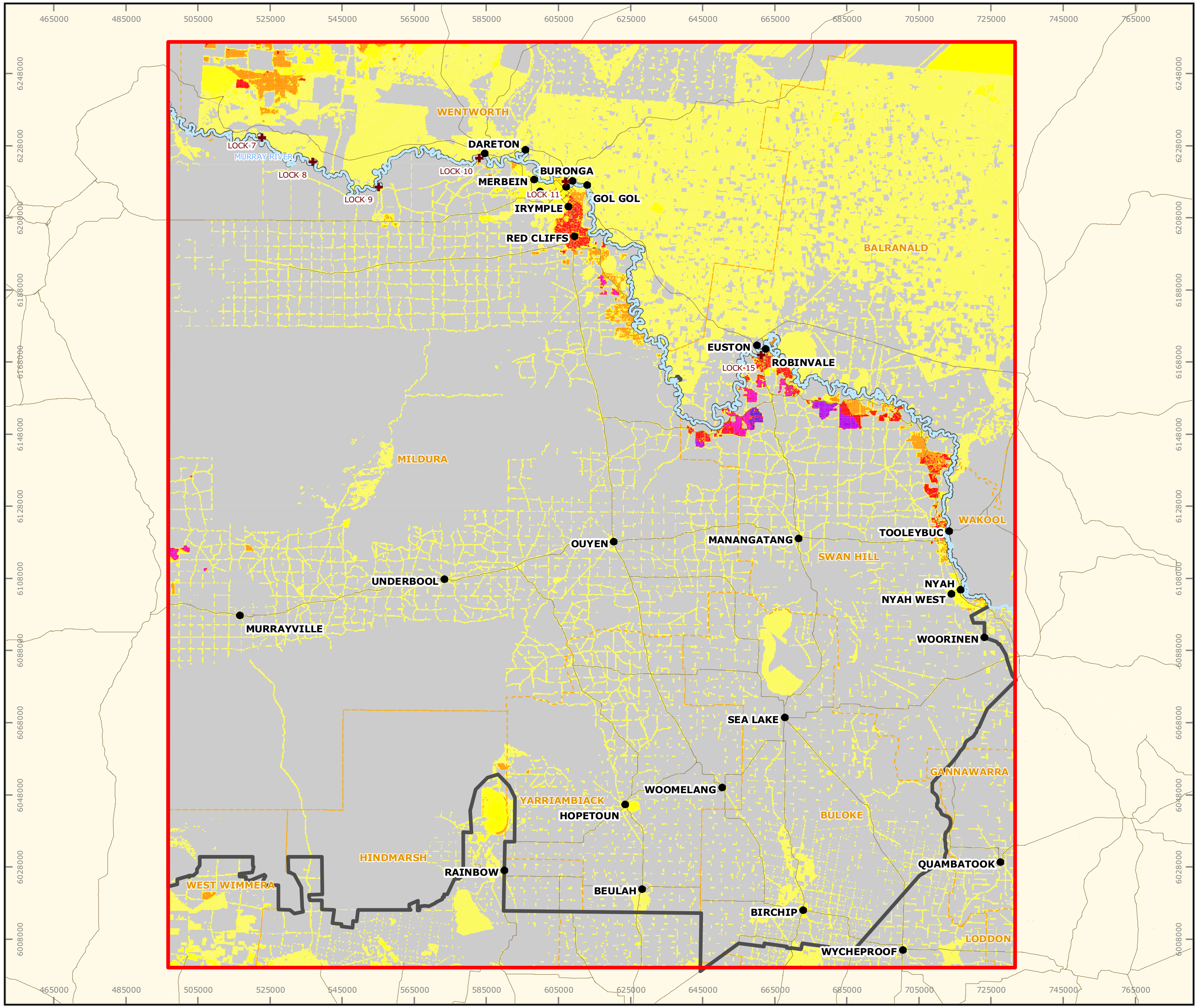
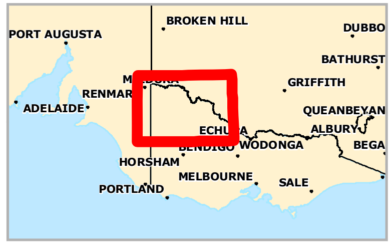
FIGURE E9

ENSYM Recharge - Stress Period 9

AUTHOR	AL	REPORT NO	R001
DRAWN	AL	REVISION	1
DATE	18/03/10	JOB NO.	A53 036

C:\JOBS\A53D\ArcGIS\Projects\A53_036.mxd





LEGEND

Locks	LGAs
Localities	EM3 Model Boundary
River Murray	Mallee CMA Boundary
Main Roads	

ENSYM Recharge (mm/year)

0	100 - 125
0 - 25	125 - 150
25 - 50	150 - 175
50 - 75	175 - 200
75 - 100	

N

0 5 10 20
Kilometres

SCALE 1:1,500,000 @ A4

GDA 1994 MGA Zone 54

DATA SOURCES

MCMA: Irrigated Areas
GA: Localities, Lakes, Locks, Roads, LGAs
AQT: EM3 Model

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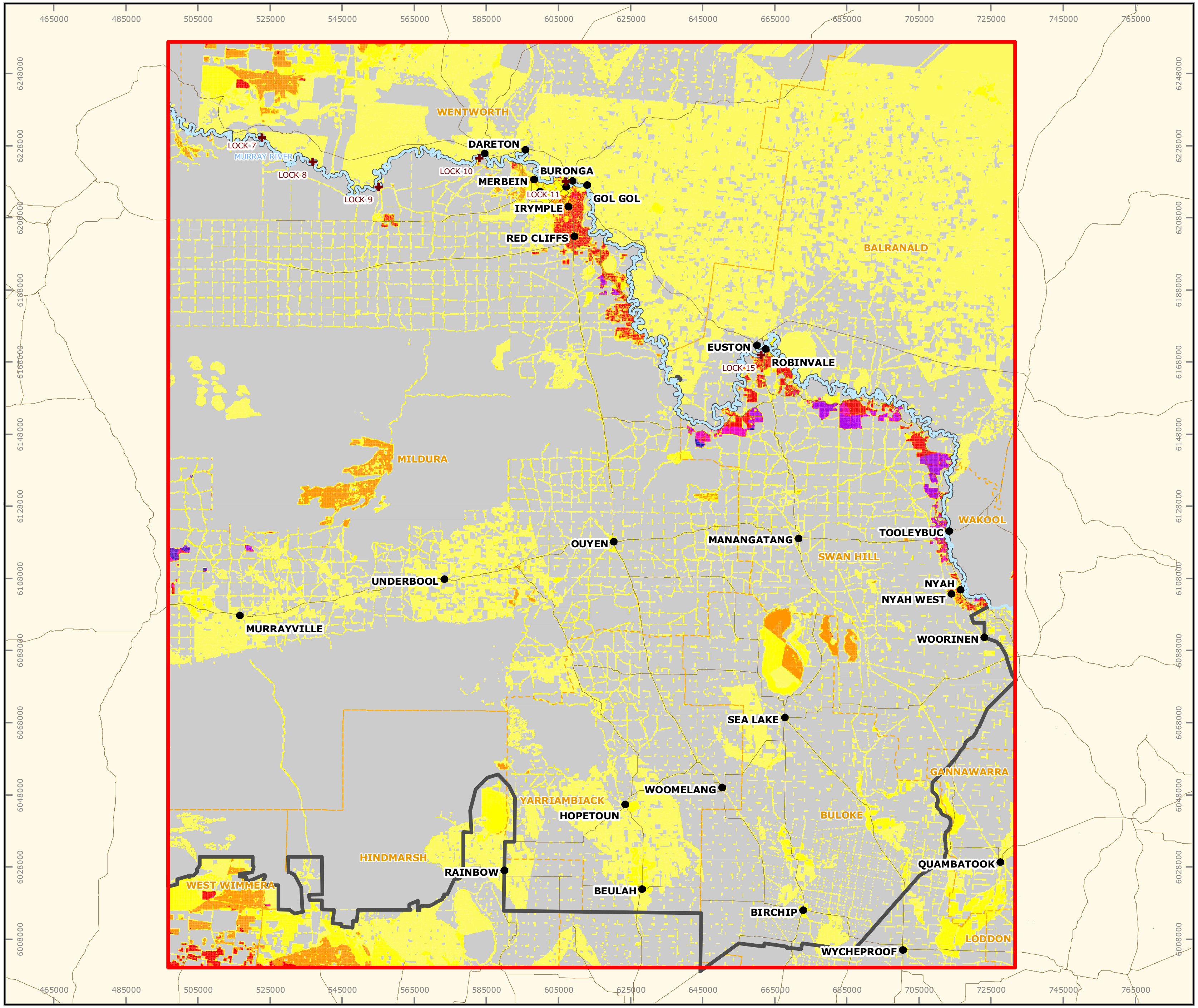
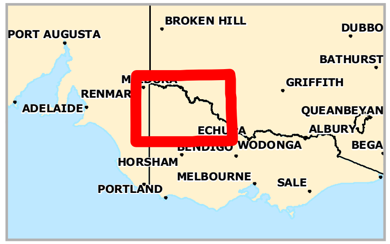
FIGURE E10

ENSYM Recharge - Stress Period 10

AUTHOR	AL	REPORT NO	R001
DRAWN	AL	REVISION	1
DATE	18/03/10	JOB NO.	A53 037

C:\JOBS\A53D\ArcGIS\Projects\A53_037.mxd





LEGEND

- Locks
- Localities
- River Murray
- Main Roads
- LGAs
- EM3 Model Boundary
- Mallee CMA Boundary

ENSYM Recharge (mm/year)

- 0
- 0 - 25
- 25 - 50
- 50 - 75
- 75 - 100
- 100 - 125
- 125 - 150
- 150 - 175
- 175 - 200

N

0 5 10 20
Kilometres

SCALE 1:1,500,000 @ A4

GDA 1994 MGA Zone 54

DATA SOURCES

MCMA: Irrigated Areas
GA: Localities, Lakes, Locks, Roads, LGAs
AQT: EM3 Model

Disclaimer: While all reasonable care has been taken to ensure the information contained on this map is up to date and accurate, no guarantee is given that the information portrayed is free from error or omission. Please verify the accuracy of all information prior to use.

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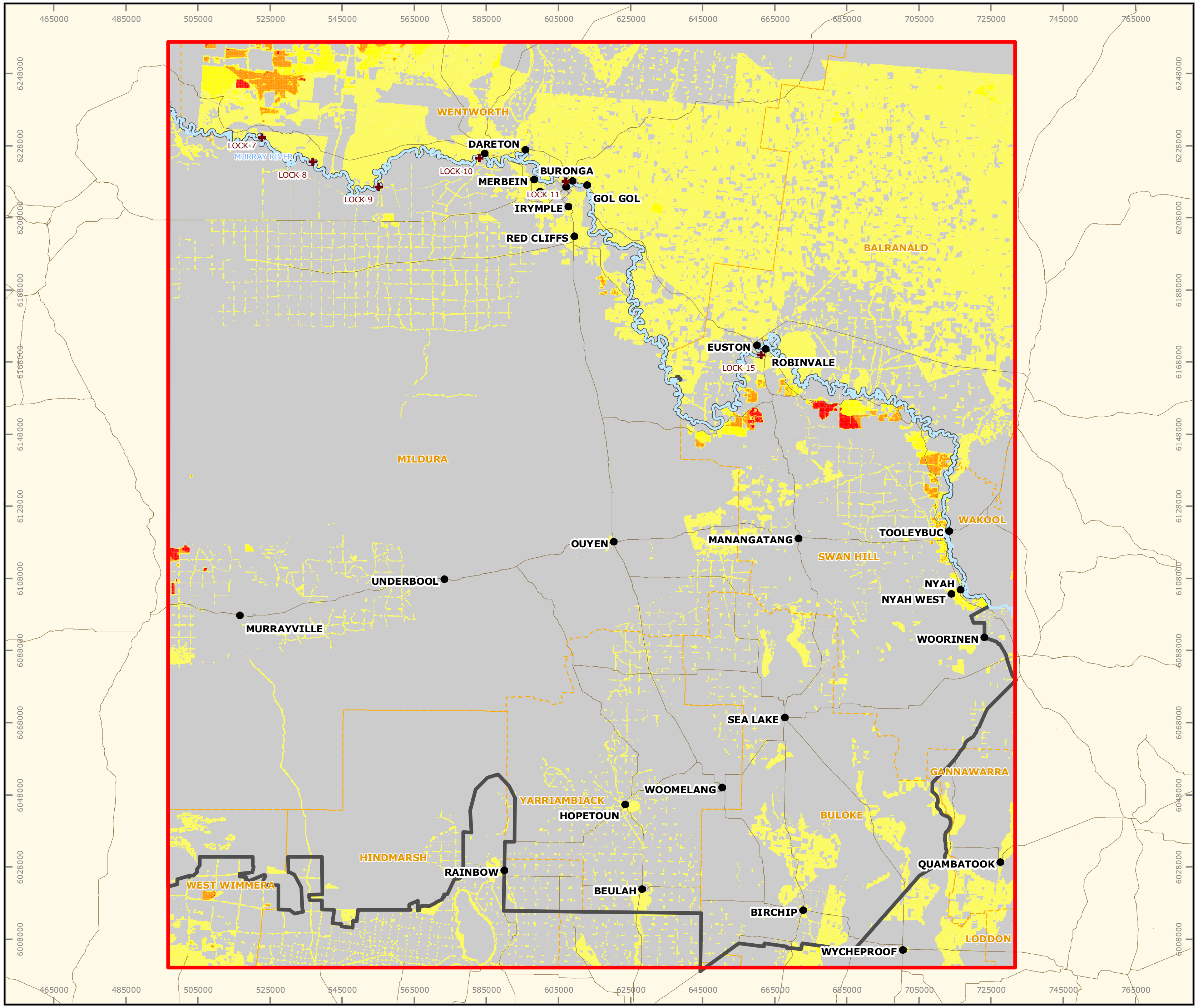
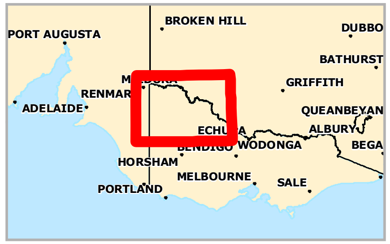
FIGURE E11

ENSYM Recharge - Stress Period 11

AUTHOR	AL	REPORT NO	R001
DRAWN	AL	REVISION	1
DATE	18/03/10	JOB NO.	A53 038

C:\JOBS\A53D\ArcGIS\Projects\A53_038.mxd





LEGEND

- Locks
- Localities
- River Murray
- Main Roads
- LGAs
- EM3 Model Boundary
- Mallee CMA Boundary

ENSYM Recharge (mm/year)

- 0
- 0 - 25
- 25 - 50
- 50 - 75
- 75 - 100
- 100 - 125
- 125 - 150
- 150 - 175
- 175 - 200

N

0 5 10 20
Kilometres

SCALE 1:1,500,000 @ A4

GDA 1994 MGA Zone 54

DATA SOURCES

MCMA: Irrigated Areas
GA: Localities, Lakes, Locks, Roads, LGAs
AQT: EM3 Model

Disclaimer: While all reasonable care has been taken to ensure the information contained on this map is up to date and accurate, no guarantee is given that the information portrayed is free from error or omission. Please verify the accuracy of all information prior to use.

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FIGURE E12

ENSYM Recharge - Stress Period 12

AUTHOR	AL	REPORT NO	R001
DRAWN	AL	REVISION	1
DATE	18/03/10	JOB NO.	A53 039

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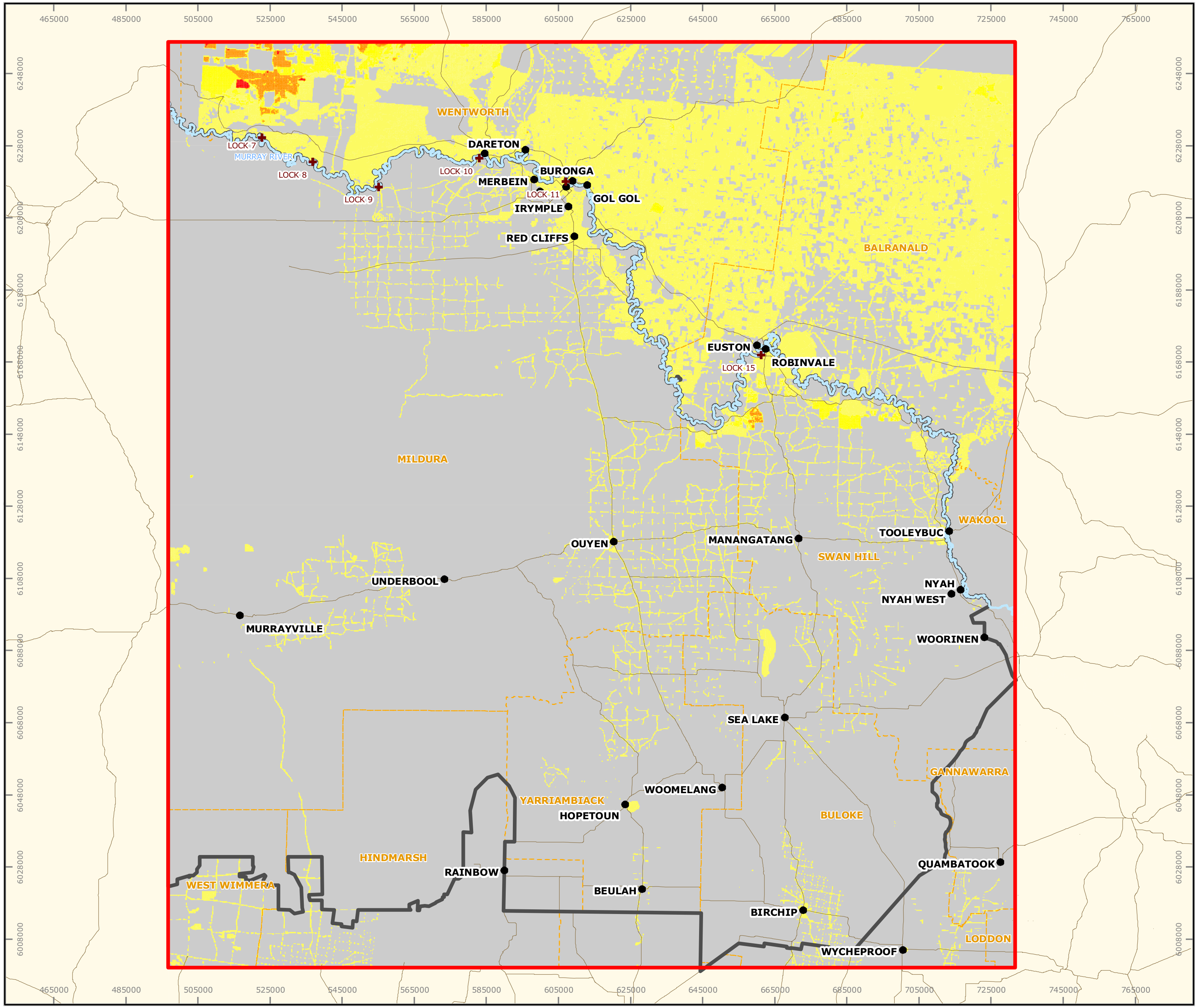

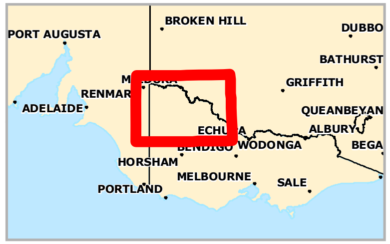

LEGEND

- Locks
- Localities
- River Murray
- Main Roads
- LGAs
- EM3 Model Boundary
- Mallee CMA Boundary

ENSYM Recharge (mm/year)

- 0
- 0 - 25
- 25 - 50
- 50 - 75
- 75 - 100
- 100 - 125
- 125 - 150
- 150 - 175
- 175 - 200

0 5 10 20
Kilometres

SCALE 1:1,500,000 @ A4

GDA 1994 MGA Zone 54

DATA SOURCES
MCMA: Irrigated Areas
GA: Localities, Lakes, Locks, Roads, LGAs
AQT: EM3 Model

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FIGURE E13

ENSYM Recharge - Stress Period 13

AUTHOR	AL	REPORT NO	R001
DRAWN	AL	REVISION	1
DATE	18/03/10	JOB NO.	A53 040

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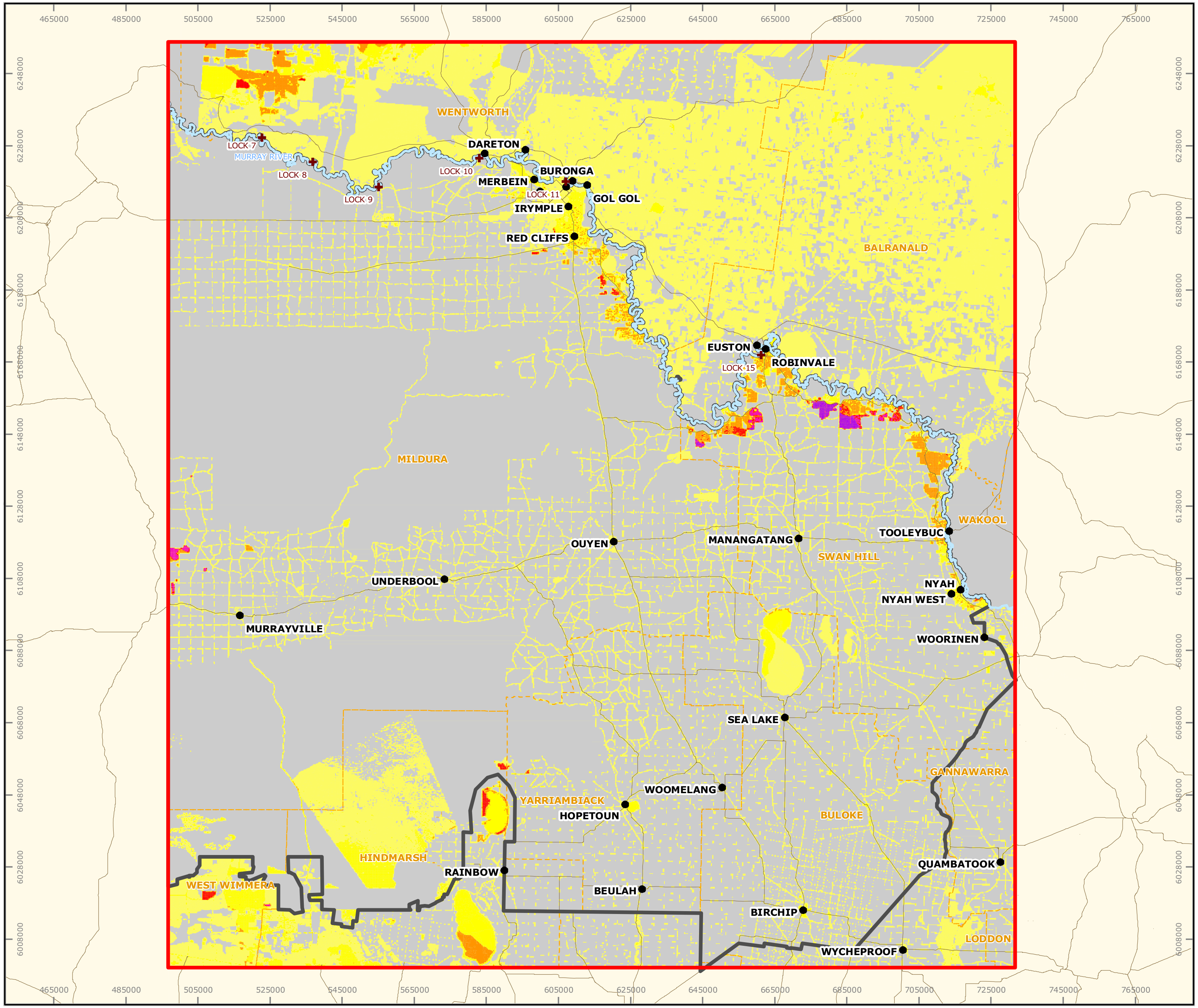

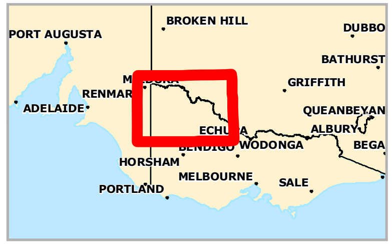

LEGEND

- Locks
- Localities
- River Murray
- Main Roads
- LGAs
- EM3 Model Boundary
- Mallee CMA Boundary

ENSYM Recharge (mm/year)

0	100 - 125
0 - 25	125 - 150
25 - 50	150 - 175
50 - 75	175 - 200
75 - 100	

N

0 5 10 20
Kilometres

SCALE 1:1,500,000 @ A4

GDA 1994 MGA Zone 54

DATA SOURCES
MCMA: Irrigated Areas
GA: Localities, Lakes, Locks, Roads, LGAs
AQT: EM3 Model

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FIGURE E14

ENSYM Recharge - Stress Period 14

AUTHOR	AL	REPORT NO	R001
DRAWN	AL	REVISION	1
DATE	18/03/10	JOB NO.	A53 041

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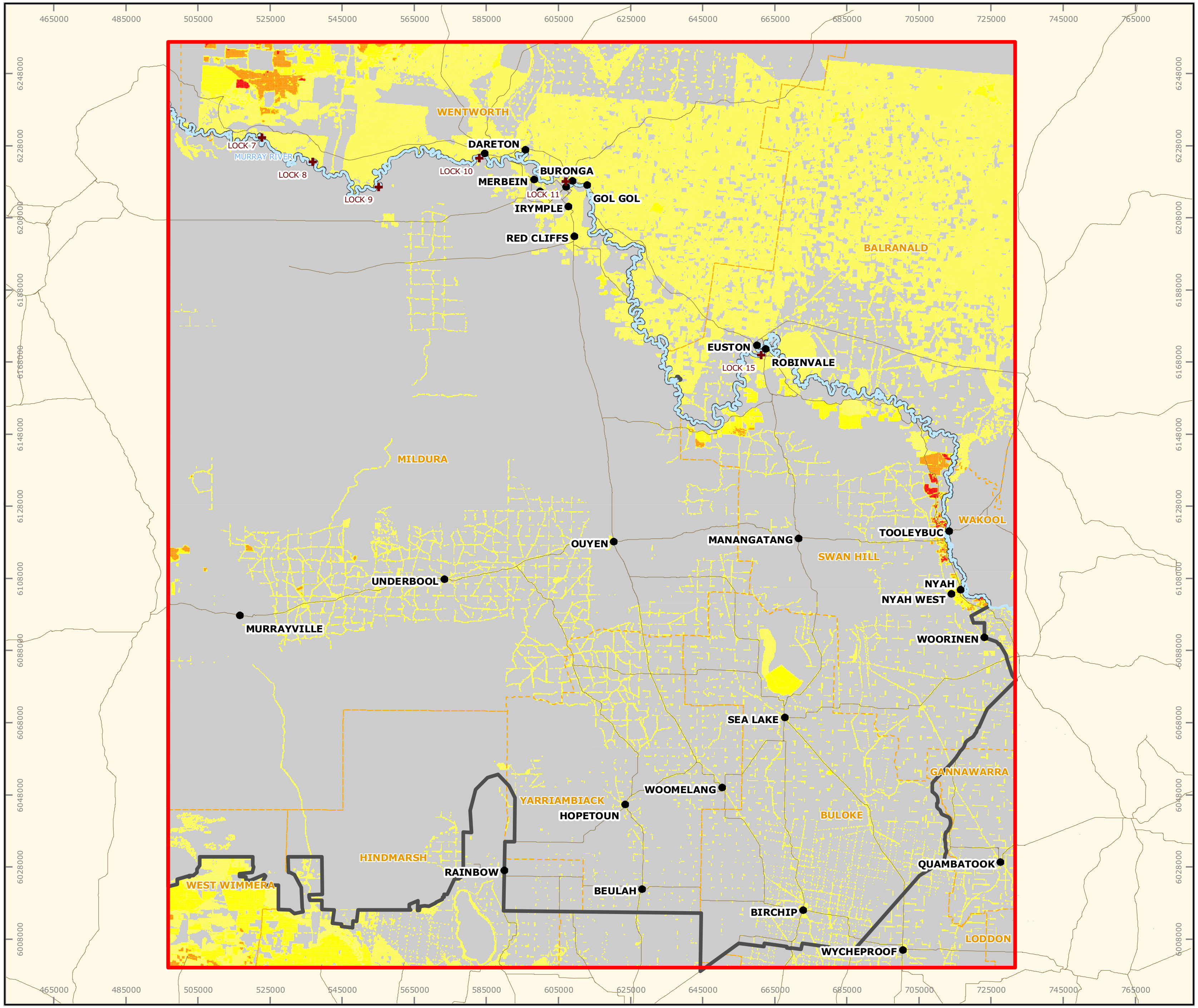

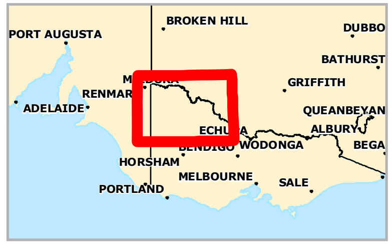

LEGEND

- Locks
- Localities
- River Murray
- Main Roads
- LGAs
- EM3 Model Boundary
- Mallee CMA Boundary

ENSYM Recharge (mm/year)

- 0
- 0 - 25
- 25 - 50
- 50 - 75
- 75 - 100
- 100 - 125
- 125 - 150
- 150 - 175
- 175 - 200

N

0 5 10 20
Kilometres

SCALE 1:1,500,000 @ A4

GDA 1994 MGA Zone 54

DATA SOURCES

MCMA: Irrigated Areas
GA: Localities, Lakes, Locks, Roads, LGAs
AQT: EM3 Model

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FIGURE E15

ENSYM Recharge - Stress Period 15

AUTHOR	AL	REPORT NO	R001
DRAWN	AL	REVISION	1
DATE	18/03/10	JOB NO.	A53 042

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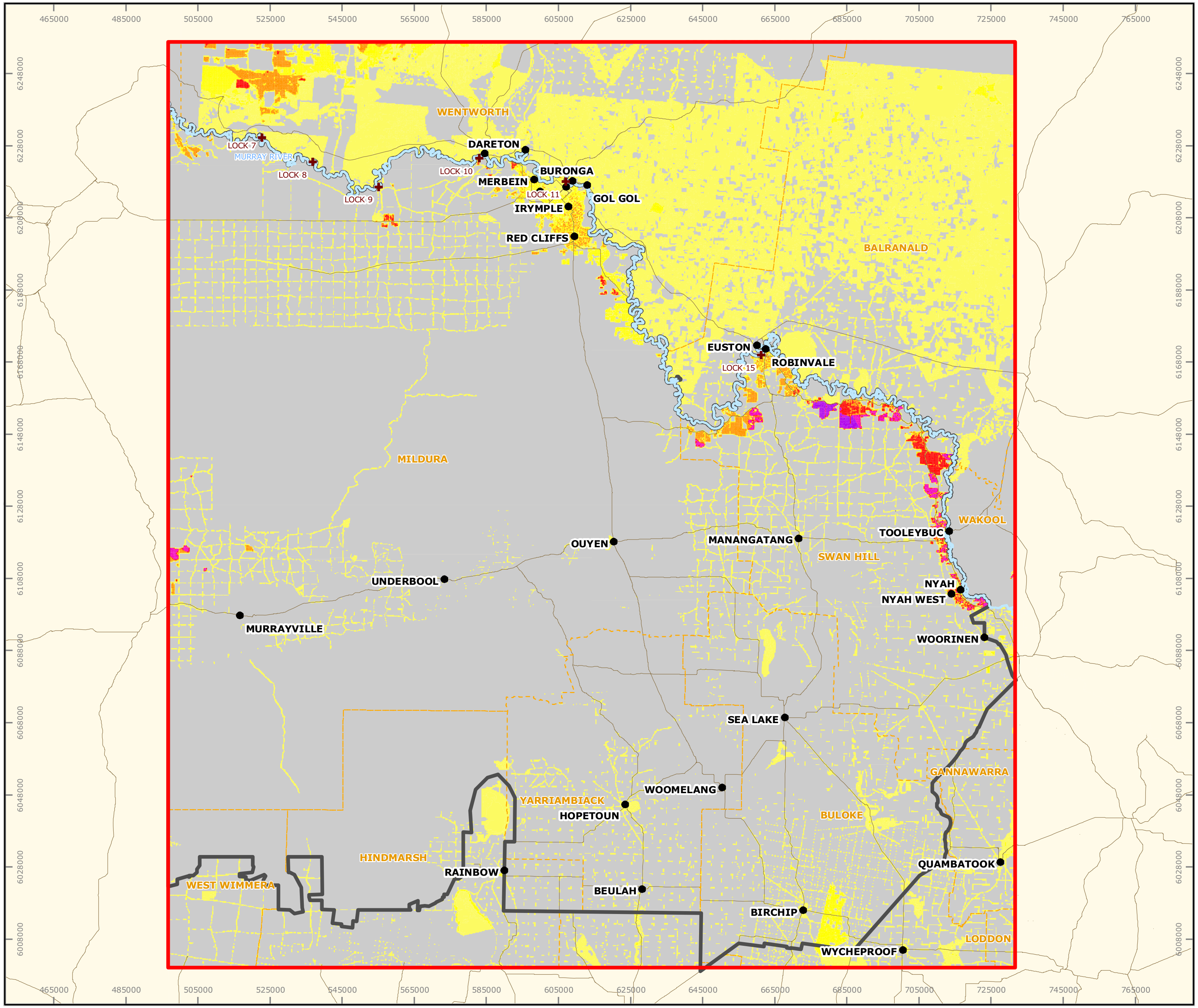

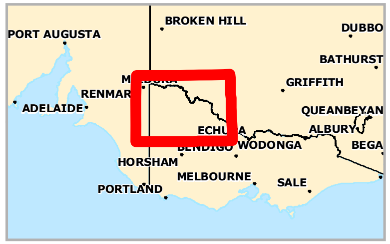

LEGEND

- Locks
- Localities
- River Murray
- Main Roads
- LGAs
- EM3 Model Boundary
- Mallee CMA Boundary

ENSYM Recharge (mm/year)

- 0
- 0 - 25
- 25 - 50
- 50 - 75
- 75 - 100
- 100 - 125
- 125 - 150
- 150 - 175
- 175 - 200

N

0 5 10 20
Kilometres

SCALE 1:1,500,000 @ A4

GDA 1994 MGA Zone 54

DATA SOURCES

MCMA: Irrigated Areas
GA: Localities, Lakes, Locks, Roads, LGAs
AQT: EM3 Model

Disclaimer: While all reasonable care has been taken to ensure the information contained on this map is up to date and accurate, no guarantee is given that the information portrayed is free from error or omission. Please verify the accuracy of all information prior to use.

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FIGURE E16

ENSYM Recharge - Stress Period 16

AUTHOR	AL	REPORT NO	R001
DRAWN	AL	REVISION	1
DATE	18/03/10	JOB NO.	A53 043

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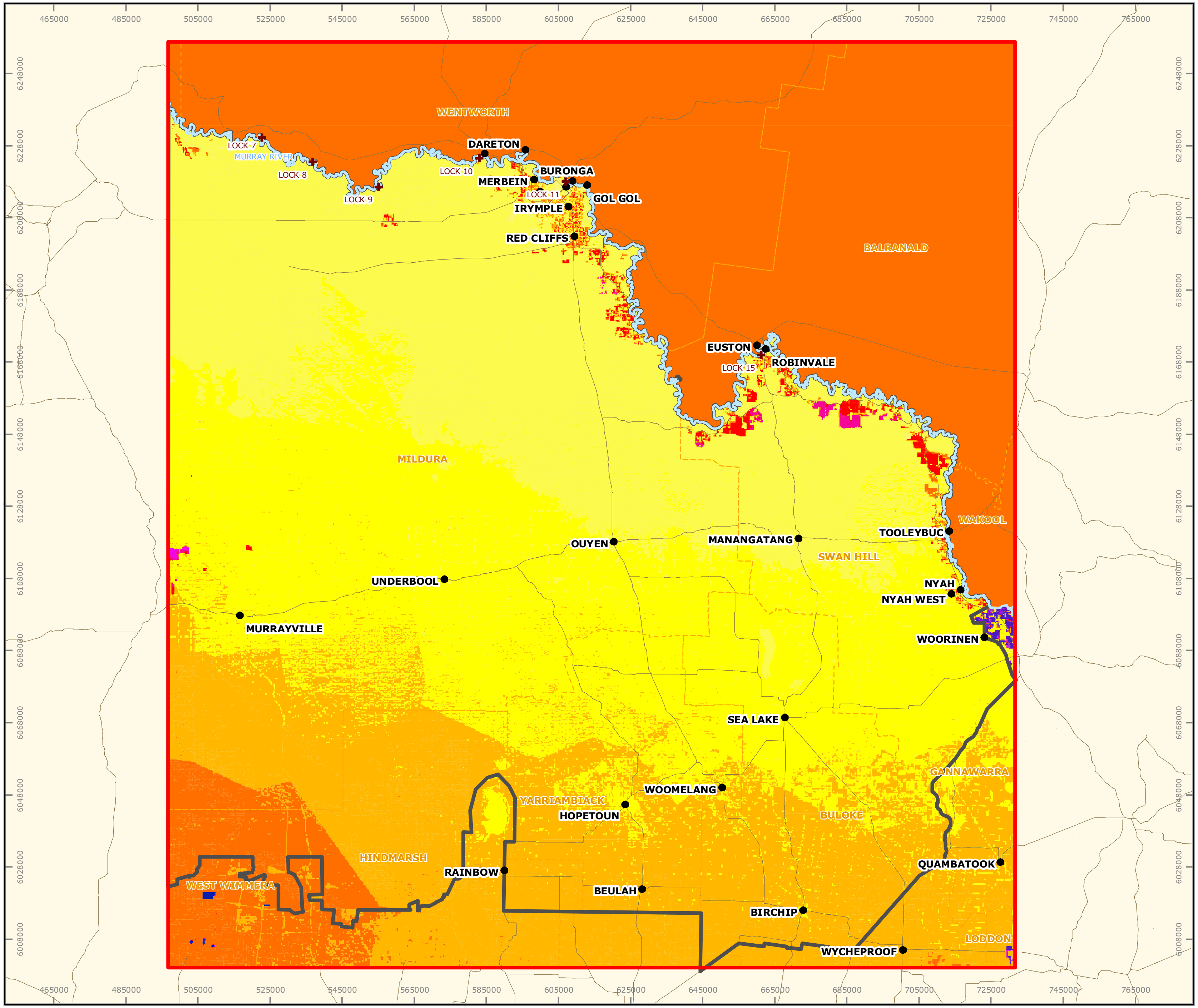

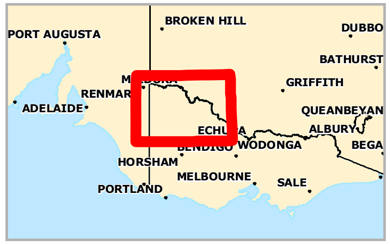

LEGEND

- Locks
- Localities
- River Murray
- Main Roads
- LGAs
- EM3 Model Boundary
- Mallee CMA Boundary

Evapotranspiration (mm/day)

- < 300
- 300 - 400
- 400 - 500
- 500 - 600
- 600 - 700
- 700 - 800
- 800 - 900
- 900 - 1000
- 1000 - 1100
- 1100 - 1200
- 1200 - 1300
- 1300 - 1400
- > 14000

N

0 5 10 20
Kilometres

SCALE 1:1,500,000 @ A4

GDA 1994 MGA Zone 54

DATA SOURCES

MCMA: Irrigated Areas
GA: Localities, Lakes, Locks, Roads, LGAs
AQT: EM3 Model

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FIGURE E17

Evapotranspiration

AUTHOR	AL	REPORT NO	R001
DRAWN	AL	REVISION	1
DATE	18/03/10	JOB NO.	A53 044

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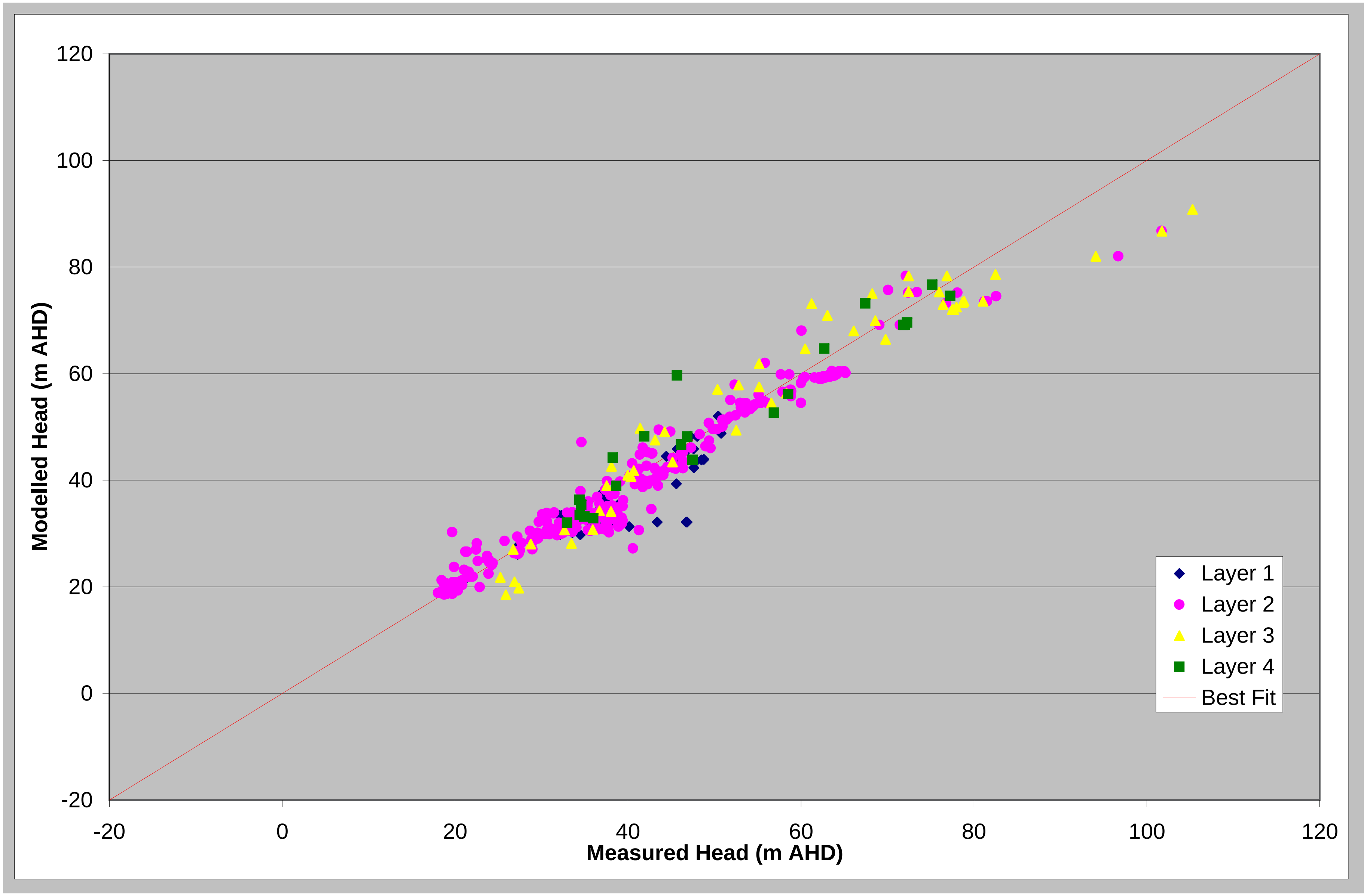
APPENDIX F GWMW IRRIGATION PUMPING RATES

Bore ID	Easting	Northing	Constant pumping rate (ML/yr)	Layer		Bore ID	Easting	Northing	Constant pumping rate (ML/yr)	Layer
864684	517450	6110600	230	3		8002367	518500	6114600	150	3
867128	515520	6009180	5	3		8002387	499250	6101000	10	3
889377	524000	6017300	380	3		8002470	512500	6027000	1350	3
892475	526180	6098390	5	3		8002612	628000	6116500	10	3
896152	509830	6002100	5	3		8002661	508200	6020200	690	3
897671	512960	6093420	2	3		8002663	516900	6097600	260	3
897787	542180	6102320	5	3		8002731	497200	6133100	540	3
898503	527700	6098680	5	3		8003455	509960	6100390	2	3
904597	534600	6101000	25	3		3016226A	498800	6111590	670	3
910783	534890	6102870	5	3		3016226B	497950	6104100	420	3
925314	663250	6078095	50	3		8002364A	517000	6113100	300	3
928984	537100	6007660	2	3		8002364B	504200	6115200	300	3
929433	499300	6001350	320	3		8002364C	498000	6137500	290	3
930741	516600	6097300	360	3		8002364D	504200	6109500	250	3
3014142	515920	6096810	40	3		8002364E	497300	6098600	250	3
3014150	515920	6097310	125	3		GWMW1	500090	6004482	5	3
3016218	512300	6087730	600	3		GWMW10	545100	6105300	2	3
3016242	499000	6104200	120	3		GWMW11	615500	6009500	10	3
3016242	498100	6114200	640	3		GWMW12	714000	6004820	25	3
3018814	530515	6097840	5	3		GWMW13	508100	6017500	2	3
3020088	517520	6018000	5	3		GWMW2	500150	6107320	150	3
3021572	507500	6006100	1710	3		GWMW3	501150	6000370	5	3
8001534	498200	6107430	180	3		GWMW4	504370	6105100	120	3
8001668	505650	6108920	455	3		GWMW5	505100	6023500	5	3
8001853	506000	6122500	155	3		GWMW6	510805	6008676	270	3
8001922	509200	6115000	425	3		GWMW7	522900	6106500	35	3
8002233	516400	6098900	2	3		GWMW8	531760	6001690	4	3
8002361	501200	6105120	12	3		GWMW9	535900	6122350	2	3
8002362	513050	6102550	15	3						

APPENDIX G SIS PUMPING RATES

				Stress Period															
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Bore ID	**Easting**	**Northing**	**Layer**	**Pumping Rate (ML/day)**															
MMIS - pump1	599925.0	6217862.0	2	84.0	172.2	107.1	103.4	217.1	177.4	110.8	121.3	151.1	145.9	101.8	172.3	94.1	48.7	135.2	114.7
MMIS - pump2	600398.0	6218033.0	2	96.2	126.5	63.3	46.5	71.8	85.3	75.6	143.9	139.0	146.3	91.5	114.7	84.1	124.9	134.1	106.8
MMIS - pump3	600934.0	6218030.0	2	186.0	278.0	180.8	132.1	180.2	167.9	79.0	252.6	233.2	205.1	145.1	187.6	157.3	174.0	195.9	170.6
MMIS - pump4	601775.0	6217333.0	2	55.0	454.0	230.1	113.9	365.9	310.2	56.4	549.0	643.8	700.7	584.1	541.2	302.3	308.5	414.8	291.1
MMIS - pump5	602181.0	6217237.0	2	28.6	286.6	21.0	129.1	170.9	128.1	122.0	10.2	246.0	264.6	187.5	166.6	86.8	83.7	70.9	85.1
MMIS - pump6a	602813.0	6217633.0	2	38.4	95.4	31.6	109.6	234.7	225.3	164.5	303.7	275.3	277.1	262.2	303.2	169.1	203.7	311.8	274.3
MMIS - pump8	603473.0	6217965.0	2	60.7	200.4	137.1	96.4	164.2	181.9	101.3	163.2	174.0	224.7	136.9	179.1	109.8	222.1	195.2	66.4
MMIS - pump9	603448.0	6218435.0	2	15.8	38.6	18.7	14.8	89.2	61.4	50.2	79.4	72.1	52.9	40.4	76.0	52.3	74.3	84.7	82.9
MMIS - pump10	604174.0	6219226.0	2	34.0	29.5	35.1	16.9	38.1	44.0	20.3	53.4	63.4	56.7	42.4	61.7	38.5	35.3	13.4	9.9
MMIS - pump11	604999.0	6219270.0	2	0.0	20.3	54.7	28.9	46.8	0.7	0.2	0.2	0.2	0.2	0.2	0.2	0.2	1.6	0.2	0.2
MMIS - pump12	605374.0	6219880.0	2	35.8	63.1	54.3	54.4	75.5	55.6	48.6	89.4	130.6	112.0	67.9	95.3	57.7	92.2	78.0	90.9
MMIS - pump13	605794.0	6220018.0	2	129.8	200.1	124.3	64.8	129.2	64.3	81.7	191.2	326.9	167.8	119.2	163.8	67.8	152.5	106.2	143.5
MMIS - pump14	606199.0	6220074.0	2	122.2	171.3	185.2	0.0	131.8	169.2	148.4	228.7	404.0	356.1	313.0	335.2	193.1	289.8	312.0	318.5
MMIS - pump15	606652.0	6219779.0	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MMIS - pump16	607047.0	6219444.0	2	123.6	93.1	49.1	116.6	368.6	212.2	105.0	42.9	212.6	259.7	118.6	98.2	8.8	0.0	0.0	0.0
MMIS - pump17	606537.5	6218717.9	2	102.1	161.0	111.3	69.6	142.3	6.9	0.0	0.0	0.0	107.2	108.5	121.1	56.1	67.5	0.0	0.0
GW 039483	608076.1	6217520.0	2	40.4	30.9	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GW 087304	607798.1	6218730.0	2	192.3	358.9	14.0	154.8	274.7	315.0	225.6	1248.2	344.8	278.2	216.3	192.2	244.1	109.8	11.9	97.2
GW 088470	607878.1	6220163.0	2	120.9	492.2	66.5	322.1	388.1	513.2	609.9	748.0	595.4	487.2	30.5	48.5	49.8	155.1	62.5	51.5
GW 087305	607250.1	6221031.0	2	503.8	1534.0	574.3	1084.4	272.4	609.3	455.5	529.1	530.6	232.8	0.0	427.1	530.0	116.9	0.4	126.1
GW 087314	607865.1	6217456.0	2	589.6	662.8	586.1	330.2	591.3	390.4	433.4	678.6	647.2	668.7	412.2	1565.0	551.9	602.4	701.7	237.1
GW 087317	607711.1	6217681.0	2	213.4	209.7	296.9	183.5	292.5	308.5	189.6	186.4	244.1	163.2	275.2	299.7	312.9	306.0	284.5	26.4
GW 040895	607159.1	6218397.0	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	241.8
GW 088469	607527.1	6218216.8	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	299.8
Curlwaa - pump1	589685.0	6226840.0	2	179.8	219.6	191.7	138.7	111.7	127.4	120.4	163.2	55.3	51.0	63.5	97.0	96.2	71.9	59.1	70.1
Curlwaa - pump2	588458.0	6226038.0	2	140.5	88.1	32.9	113.7	53.7	44.5	50.2	55.5	73.3	65.5	95.5	82.7	67.2	47.6	66.5	70.0
Curlwaa - pump3	589607.0	6225292.0	2	99.6	73.7	170.2	87.9	62.2	158.7	105.9	58.5	55.3	60.0	83.7	67.4	76.9	59.4	52.5	28.2
Curlwaa - pump4	590304.0	6225921.0	2	96.7	136.0	64.6	83.1	114.4	99.7	93.4	43.5	69.5	60.7	46.7	60.2	80.0	88.7	55.1	50.8
GW 036864	626264.21	6200749.1	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	148.5	348.9	54.4	275.1	317.5	317.2	226.8
GW 036861	626828.21	6200527.1	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	97.7	295.9	803.4	260.8	255.2	299.4	236.1
GW 036980	627737.21	6200331.1	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	19.6	261.6	693.3	662.6	430.0	609.7
GW 036622	625225.21	6200750.1	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	105.8	224.7	199.4	172.9	324.9	259.7	105.9
GW 036923	625537.21	6200885.1	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	46.4	265.7	212.2	857.5	111.7	266.2	0.2
GW 036936	628115.21	6200117.1	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	220.0	71.3	1654.0	3148.0	636.2
GW 036924	628399.21	6199974.1	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	19.3	143.1	143.6	133.8

APPENDIX H STEADY STATE CALIBRATION RESULTS



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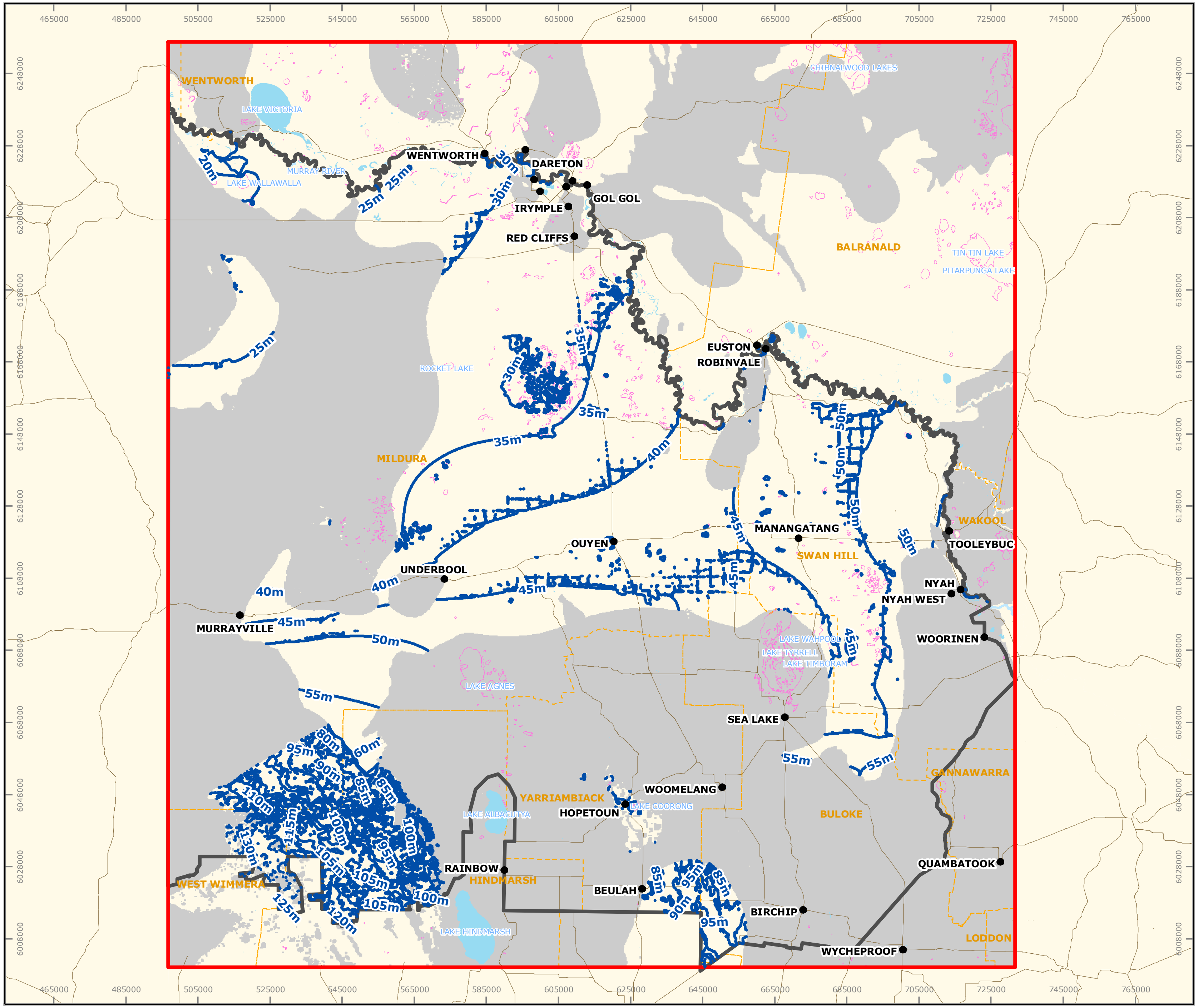
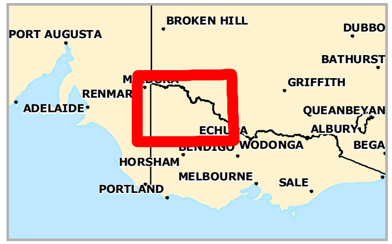
STEADY STATE SCATTER PLOT OF MEASURED VS MODELLED HEADS FIGURE H.1

F:\Jobs\A53\B1_Mallee\600\602_Calib\HIST\Appendices\Appendix_H\[Figure_H1.xls]Scatterplot





LEGEND

- Localities
- River Murray
- Main Roads
- Water Level Contours (mAHD)
- Dry Cells
- LGAs
- EM3 Model Boundary
- Mallee CMA Boundary

Suface Water Bodies

- Perennial
- Non-perennial

N

0 5 10 20
Kilometres

SCALE 1:1,500,000 @ A4

GDA 1994 MGA Zone 54

DATA SOURCES
GA: Localities, Lakes,, Roads, LGAs
AQT: EM3 Model, DEM

Disclaimer: While all reasonable care has been taken to ensure the information contained on this map is up to date and accurate, no guarantee is given that the information portrayed is free from error or omission. Please verify the accuracy of all information prior to use.

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FIGURE H2

Steady State Modelled Water Levels - Layer 1

AUTHOR	AL	REPORT NO	R001
DRAWN	AL	REVISION	1
DATE	21/04/10	JOB NO.	A53 050

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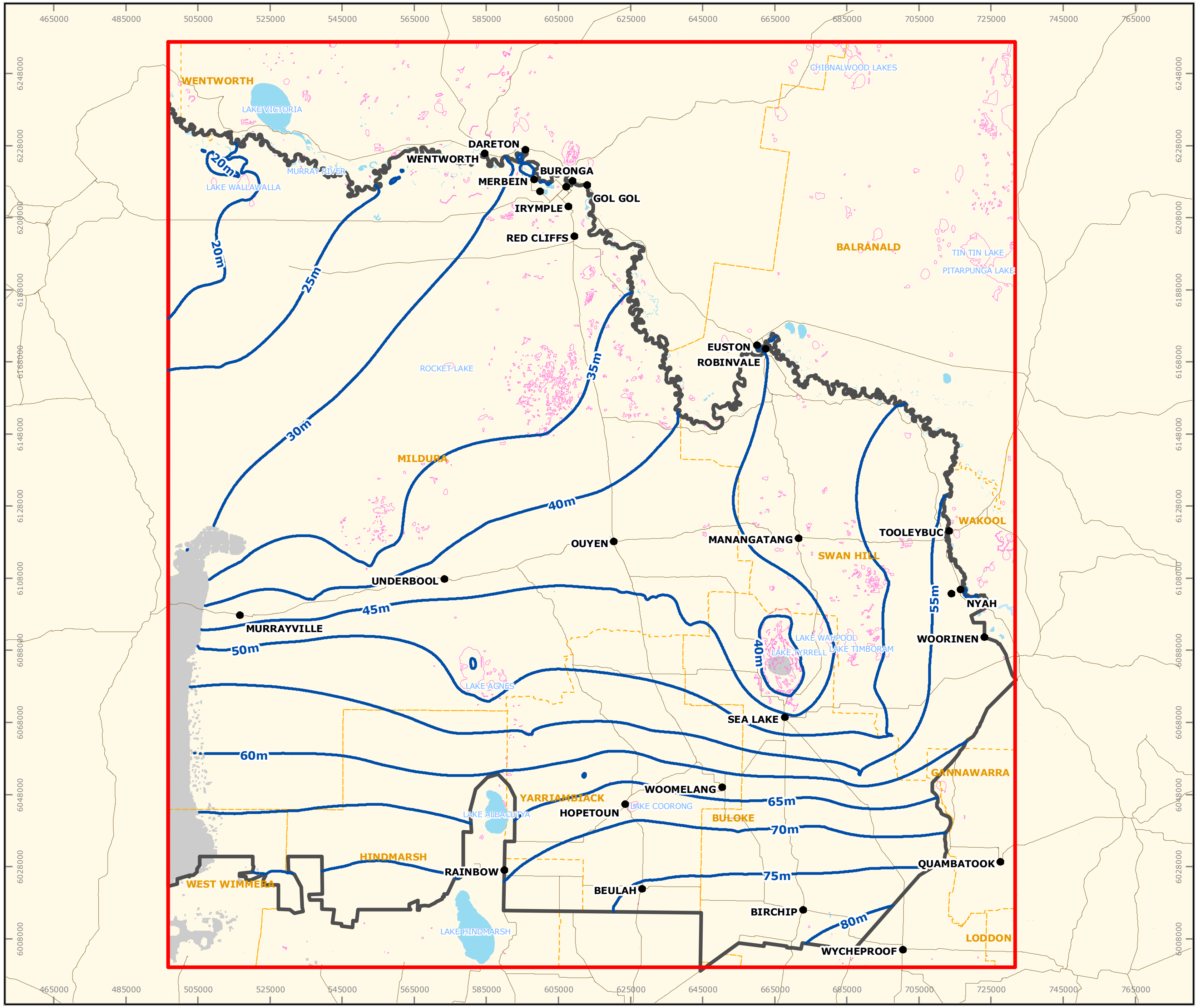

LEGEND

- Localities
- River Murray
- Main Roads
- Water Level Contours (mAHD)
- Dry Cells
- LGAs
- EM3 Model Boundary
- Mallee CMA Boundary

Suface Water Bodies

- Perennial
- Non-perennial

0 5 10 20 Kilometres

SCALE 1:1,500,000 @ A4

GDA 1994 MGA Zone 54

DATA SOURCES

GA: Localities, Lakes,, Roads, LGAs
AQT: EM3 Model, DEM

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FIGURE H3

Steady State Modelled Water Levels - Layer 2

AUTHOR	AL	REPORT NO	R001
DRAWN	AL	REVISION	1
DATE	21/04/10	JOB NO.	A53 051

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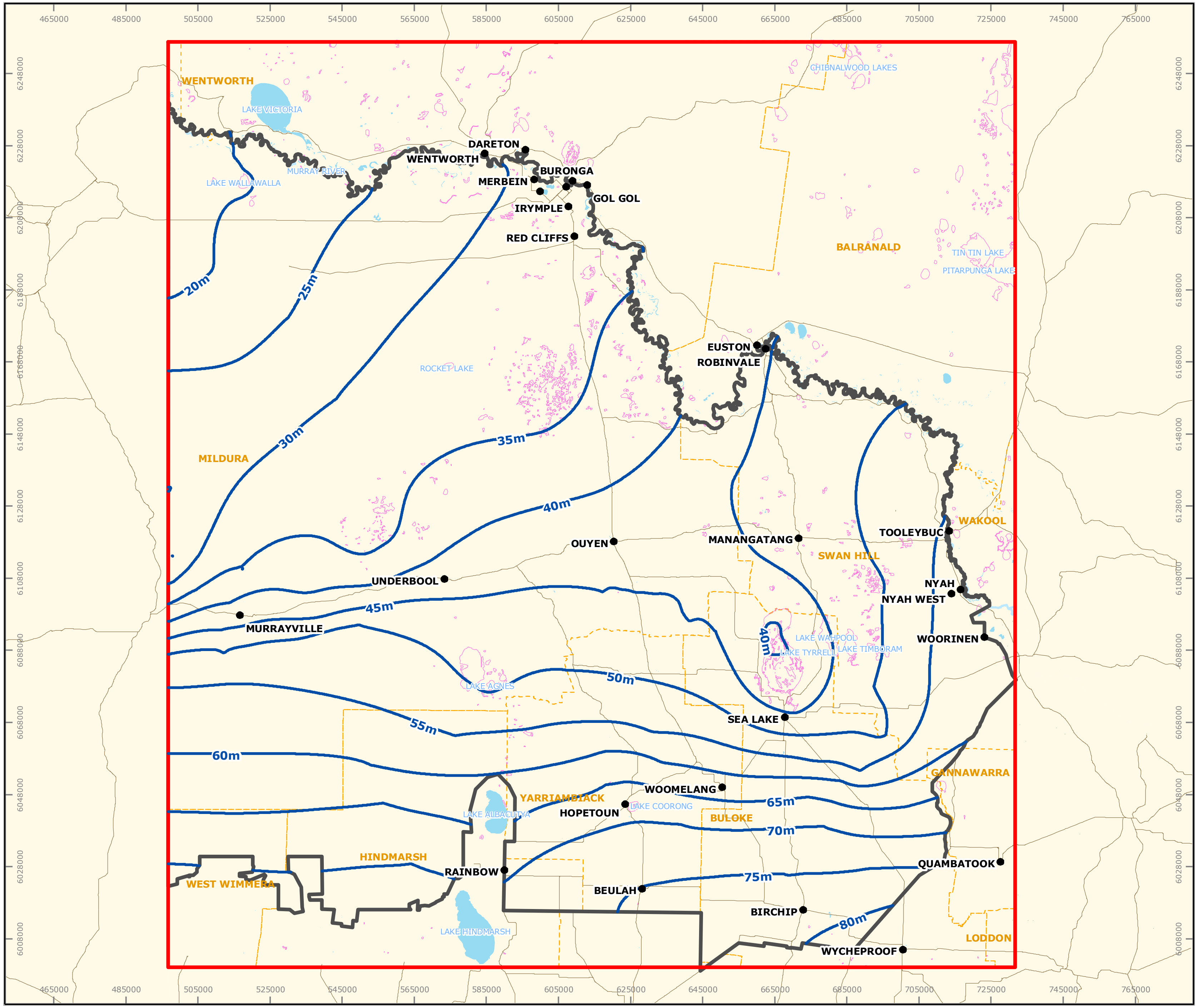

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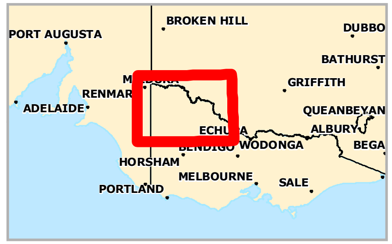

LEGEND

- ● Localities
- River Murray
- Main Roads
- Water Level Contours (mAHD)
- LGAs
- EM3 Model Boundary
- Mallee CMA Boundary

Suface Water Bodies

- Perennial
- Non-perennial

N

0 5 10 20

Kilometres

SCALE 1:1,500,000 @ A4

GDA 1994 MGA Zone 54

DATA SOURCES

GA: Localities, Lakes,, Roads, LGAs

AQT: EM3 Model, DEM

Disclaimer: While all reasonable care has been taken to ensure the information contained on this map is up to date and accurate, no guarantee is given that the information portrayed is free from error or omission. Please verify the accuracy of all information prior to use.

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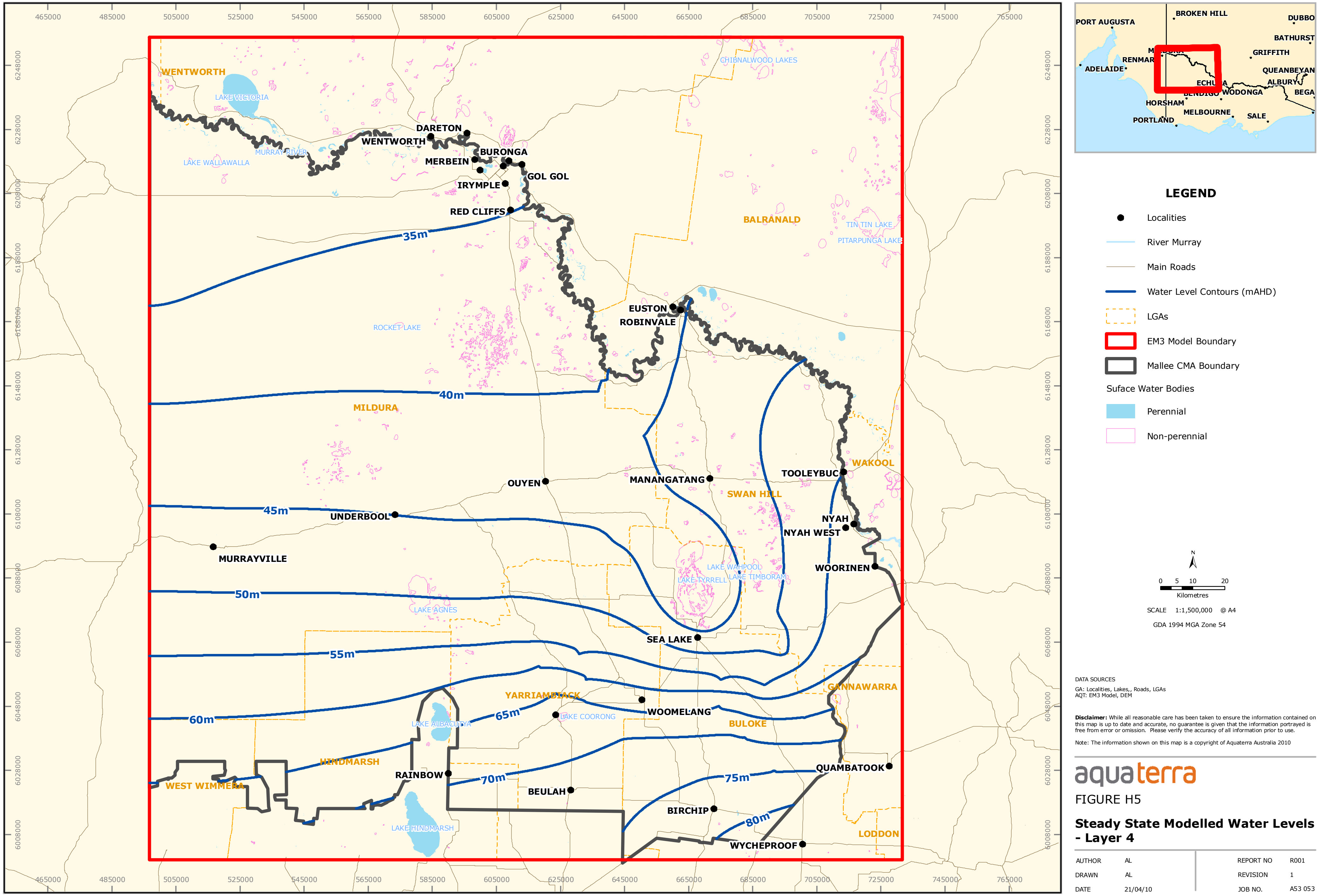
FIGURE H4

Steady State Modelled Water Levels - Layer 3

AUTHOR	AL	REPORT NO	R001
DRAWN	AL	REVISION	1
DATE	21/04/10	JOB NO.	A53 052



DATA SOURCES
GA: Localities, Lakes,, Roads, LGAs
AQT: EM3 Model, DEM

Disclaimer: While all reasonable care has been taken to ensure the information contained on this map is up to date and accurate, no guarantee is given that the information portrayed is free from error or omission. Please verify the accuracy of all information prior to use.

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FIGURE H5

Steady State Modelled Water Levels - Layer 4

AUTHOR	AL	REPORT NO	R001
DRAWN	AL	REVISION	1
DATE	21/04/10	JOB NO.	A53 053

C:\JOBS\A53D\ArcGIS\Projects\A53_053.mxd

Bore	Easting	Northing	Layer	Measured	Computed	Weight	Residual
7366	605545.2	6217868.4	1	36.90	31.03	1	5.87
7370	603229.2	6213860.4	1	35.91	31.78	1	4.13
7373	607105.2	6217050.4	1	34.07	31.92	1	2.15
7464	613058.2	6205496.4	1	36.78	33.38	1	3.40
7480	626276.2	6197348.4	1	34.45	34.18	1	0.27
7481	628020.2	6199312.4	1	34.38	34.01	1	0.37
7484	626461.2	6198537.4	1	37.57	33.96	1	3.61
7489	609489.2	6189234.4	1	33.69	33.88	1	-0.19
7493	613102.2	6194344.4	1	34.33	33.53	1	0.80
7494	613052.2	6189057.4	1	36.23	33.92	1	2.31
7526	613113.2	6194899.4	1	35.68	33.46	1	2.22
7527	613110.2	6194580.4	1	32.30	33.44	1	-1.14
7538	613199.2	6199360.4	1	33.48	33.45	1	0.03
7566	613083.2	6190845.4	1	35.00	33.49	1	1.51
7612	624127.2	6199188.4	1	34.43	33.72	1	0.71
7626	624926.2	6197991.4	1	35.20	33.89	1	1.31
7649	624843.2	6194781.4	1	34.95	34.24	1	0.71
7657	609202.2	6192291.4	1	34.80	33.59	1	1.21
7659	611014.2	6194829.4	1	36.06	33.36	1	2.70
7660	613155.2	6196971.4	1	34.05	33.61	1	0.44
7661	613171.2	6196977.4	1	36.26	33.62	1	2.64
7682	621603.2	6170509.4	1	37.34	36.34	1	1.00
7728	621135.2	6194788.4	1	32.08	33.37	1	-1.29
7729	621104.2	6188936.4	1	38.11	34.68	1	3.43
7856	630621.2	6171877.4	1	36.94	37.55	1	-0.61
7858	633621.2	6171777.4	1	37.30	37.44	1	-0.14
7905	570221.1	6221477.4	1	27.23	26.09	1	1.14
7965	609532.2	6216782.4	1	34.27	32.69	1	1.58
26148	728221.4	6093527.3	1	63.75	59.94	1	3.81
27003	589621.1	6214347.4	1	33.55	30.16	1	3.39
27010	583921.1	6212677.4	1	29.28	29.21	1	0.07
27011	570121.1	6211277.4	1	27.16	27.54	1	-0.38
27012	603671.2	6213377.4	1	38.06	31.92	1	6.14
27053	603404.2	6218188.4	1	30.89	30.59	1	0.30
27056	602473.2	6217705.4	1	30.88	30.36	1	0.52
27128	525921.1	6222477.4	1	20.88	20.98	1	-0.10
27141	597471.2	6205777.4	1	36.01	31.90	1	4.11
27144	597421.2	6205777.4	1	35.65	31.88	1	3.77
27152	596021.2	6210177.4	1	40.13	31.32	1	8.81
27160	602818.2	6214337.4	1	37.18	31.63	1	5.55
27175	622734.2	6184177.4	1	35.26	35.00	1	0.26
27176	622734.2	6184177.4	1	38.23	35.00	1	3.23
27178	623102.2	6184160.4	1	38.11	35.20	1	2.91
27183	622841.2	6185097.4	1	38.83	35.39	1	3.44
27189	620321.2	6188947.4	1	38.30	35.16	1	3.14
40599	665521.3	6099577.3	1	44.36	41.92	1	2.44
40603	685921.4	6084977.3	1	46.78	45.52	1	1.26
40620	669021.3	6102577.3	1	47.92	43.65	1	4.27
40621	672471.3	6091527.3	1	47.60	42.37	1	5.23
40625	682321.4	6094077.3	1	47.57	45.89	1	1.68
40626	679021.3	6090377.3	1	44.43	44.49	1	-0.06
40627	682371.4	6091577.3	1	45.68	45.91	1	-0.23
40628	688821.4	6089777.3	1	47.20	48.25	1	-1.05
40629	690121.4	6089677.3	1	48.00	48.22	1	-0.22

Bore	Easting	Northing	Layer	Measured	Computed	Weight	Residual
40630	673471.3	6098427.3	1	48.78	43.90	1	4.88
40634	682521.4	6087377.3	1	46.01	44.01	1	2.00
40643	668421.3	6099177.3	1	45.59	39.33	1	6.26
40649	658821.3	6104027.3	1	48.50	43.85	1	4.65
124770	604772.2	6214410.4	1	46.84	32.16	1	14.68
124771	604770.2	6214409.4	1	46.73	32.16	1	14.57
124772	604769.2	6214408.4	1	43.36	32.17	1	11.19
128042	699838.4	6118337.3	1	50.42	52.05	1	-1.63
128045	702845.4	6118471.3	1	50.75	48.80	1	1.95
130546	591828.1	6222954.4	1	34.48	29.80	1	4.68
130547	591828.1	6222953.4	1	32.09	29.80	1	2.29
130549	591788.1	6223052.4	1	31.98	29.82	1	2.16
130551	591755.1	6223133.4	1	31.89	29.84	1	2.05
7300	606952.2	6218959.4	2	31.92	30.81	1	1.11
7301	606922.2	6219161.4	2	32.33	30.71	1	1.62
7303	607129.2	6219402.4	2	31.11	30.63	1	0.48
7304	606825.2	6219584.4	2	31.44	30.52	1	0.92
7306	606436.2	6219945.4	2	31.66	30.36	1	1.30
7308	606815.2	6220175.4	2	30.99	30.48	1	0.51
7310	607361.2	6219981.4	2	31.22	30.57	1	0.65
7321	599557.2	6218033.4	2	35.60	30.49	1	5.11
7340	600841.2	6217903.4	2	30.92	30.06	1	0.86
7355	603350.2	6217975.4	2	31.33	30.59	1	0.74
7357	603509.2	6218026.4	2	31.96	30.50	1	1.46
7361	603377.2	6218368.4	2	30.88	30.63	1	0.25
7363	603533.2	6218605.4	2	30.61	30.59	1	0.02
7367	603442.2	6217744.4	2	31.78	30.50	1	1.28
7376	606857.2	6218765.4	2	31.74	30.85	1	0.89
7379	606041.2	6218871.4	2	33.30	30.71	1	2.59
7460	607161.2	6217855.4	2	32.84	31.19	1	1.65
7463	610637.2	6207820.4	2	37.69	33.10	1	4.59
7474	606909.2	6218747.4	2	31.62	30.87	1	0.75
7475	605101.2	6219624.4	2	32.45	30.49	1	1.96
7476	605123.2	6219611.4	2	33.12	30.48	1	2.64
7491	613041.2	6192274.4	2	36.56	33.43	1	3.13
7516	613112.2	6193442.4	2	35.63	33.43	1	2.20
7517	613112.2	6193441.4	2	36.80	33.43	1	3.37
7536	613069.2	6190544.4	2	35.15	33.53	1	1.62
7591	626044.2	6199326.4	2	30.59	33.85	1	-3.26
7593	626837.2	6199197.4	2	31.45	33.94	1	-2.49
7609	624154.2	6199383.4	2	34.85	33.70	1	1.15
7613	624107.2	6199131.4	2	34.64	33.73	1	0.91
7614	624037.2	6198953.4	2	35.07	33.74	1	1.33
7618	624923.2	6198701.4	2	35.02	33.81	1	1.21
7620	624793.2	6198629.4	2	35.13	33.81	1	1.32
7622	625278.2	6197906.4	2	34.90	33.93	1	0.97
7625	625145.2	6197927.4	2	34.84	33.92	1	0.92
7632	613067.2	6190131.4	2	36.52	33.57	1	2.95
7651	621621.2	6192829.4	2	37.95	34.01	1	3.94
7662	614655.2	6197111.4	2	33.57	33.47	1	0.10
7664	613066.2	6191450.4	2	36.83	33.43	1	3.40
7666	611115.2	6192284.4	2	33.93	33.40	1	0.53
7671	624844.2	6199440.4	2	31.38	33.76	1	-2.38
7673	614760.2	6190754.4	2	37.05	33.63	1	3.42

Bore	Easting	Northing	Layer	Measured	Computed	Weight	Residual
7678	604027.2	6200126.4	2	37.81	32.85	1	4.96
7684	613015.2	6207687.4	2	35.70	32.99	1	2.71
7686	613623.2	6206342.4	2	35.86	33.26	1	2.60
7688	613007.2	6206587.4	2	36.50	33.20	1	3.30
7690	612616.2	6207345.4	2	36.45	33.11	1	3.34
7694	611037.2	6205036.4	2	37.04	33.32	1	3.72
7695	609207.2	6204446.4	2	38.66	33.20	1	5.46
7696	609066.2	6206981.4	2	39.14	33.05	1	6.09
7697	609131.2	6201457.4	2	37.76	33.26	1	4.50
7698	612016.2	6200980.4	2	36.51	33.42	1	3.09
7700	613784.2	6201715.4	2	36.22	33.47	1	2.75
7701	600566.2	6217870.4	2	30.95	30.06	1	0.89
7702	601683.2	6217613.4	2	30.76	30.28	1	0.48
7703	602070.2	6217606.4	2	30.93	30.37	1	0.56
7704	602120.2	6217486.4	2	37.79	30.23	1	7.56
7706	603343.2	6217899.4	2	31.29	30.57	1	0.72
7707	603914.2	6218075.4	2	32.88	30.59	1	2.29
7708	604161.2	6219183.4	2	31.97	30.60	1	1.37
7709	604229.2	6219254.4	2	31.79	30.60	1	1.19
7710	604301.2	6219324.4	2	31.58	30.60	1	0.98
7711	605900.2	6220030.4	2	32.37	30.02	1	2.35
7712	607226.2	6219544.4	2	31.18	30.64	1	0.54
7726	626467.2	6198539.4	2	34.53	33.96	1	0.57
7727	622069.2	6197293.4	2	35.62	33.68	1	1.94
7732	606816.2	6218998.4	2	32.14	30.76	1	1.38
7734	612729.2	6207565.4	2	36.05	33.06	1	2.99
7740	611477.2	6202929.4	2	36.74	33.42	1	3.32
7743	603736.2	6203707.4	2	38.89	32.74	1	6.15
7744	606489.2	6203944.4	2	39.21	32.97	1	6.24
7745	603343.2	6207462.4	2	39.37	32.43	1	6.94
7747	607472.2	6205748.4	2	39.27	32.97	1	6.30
7788	601594.2	6217721.4	2	30.53	30.34	1	0.19
7831	530721.1	6202077.4	2	21.04	23.20	1	-2.16
7832	548921.1	6193077.4	2	22.43	27.00	1	-4.57
7833	570221.1	6219777.4	2	26.82	26.31	1	0.51
7837	530721.1	6210677.4	2	21.54	22.69	1	-1.15
7839	570321.1	6196277.4	2	27.19	29.42	1	-2.23
7840	609621.2	6212877.4	2	38.18	32.75	1	5.43
7842	593821.2	6209877.4	2	37.69	31.07	1	6.62
7843	584121.1	6196877.4	2	31.08	30.71	1	0.37
7844	584121.1	6196877.4	2	31.36	30.71	1	0.65
7850	612321.2	6171027.4	2	37.00	34.47	1	2.53
7852	625421.2	6171877.4	2	37.98	37.18	1	0.80
7863	618821.2	6198877.4	2	36.52	33.45	1	3.07
7865	633621.2	6171777.4	2	38.42	37.40	1	1.02
7866	630621.2	6171877.4	2	38.43	37.57	1	0.86
7867	624971.2	6186427.4	2	37.59	35.14	1	2.45
7870	623021.2	6186677.4	2	38.15	34.89	1	3.26
7875	613521.2	6186377.4	2	36.90	33.91	1	2.99
7879	616421.2	6199377.4	2	34.12	33.51	1	0.61
7880	601021.2	6199477.4	2	33.82	32.55	1	1.27
7883	583521.1	6224777.4	2	29.60	29.06	1	0.54
7886	583621.1	6224477.4	2	29.46	29.06	1	0.40
7888	583621.1	6223977.4	2	29.17	28.96	1	0.21

Bore	Easting	Northing	Layer	Measured	Computed	Weight	Residual
7890	583621.1	6222577.4	2	28.82	28.83	1	-0.01
7892	583721.1	6220077.4	2	28.76	28.67	1	0.09
7894	583921.1	6214677.4	2	28.96	28.37	1	0.59
7896	569721.1	6224977.4	2	27.50	26.87	1	0.63
7898	569621.1	6224577.4	2	27.41	26.64	1	0.77
7900	569621.1	6223777.4	2	27.39	26.31	1	1.08
7902	570221.1	6221577.4	2	27.28	26.14	1	1.14
7906	570221.1	6221077.4	2	27.18	26.17	1	1.01
7908	570221.1	6220477.4	2	27.16	26.23	1	0.93
7909	570221.1	6219777.4	2	27.10	26.31	1	0.79
7910	570121.1	6216477.4	2	27.02	26.64	1	0.38
7914	549148.1	6214214.4	2	24.25	24.13	1	0.12
7915	530221.1	6221877.4	2	21.96	21.91	1	0.05
7917	530121.1	6222277.4	2	21.58	21.90	1	-0.32
7920	530221.1	6221377.4	2	22.05	21.92	1	0.13
7924	530821.1	6217477.4	2	21.78	22.11	1	-0.33
7926	515221.0	6220577.4	2	19.10	20.10	1	-1.00
7927	515221.0	6220177.4	2	19.47	20.14	1	-0.67
7928	515121.0	6224277.4	2	18.92	19.76	1	-0.84
7929	515221.0	6219677.4	2	19.18	20.03	1	-0.85
7930	515221.0	6218777.4	2	19.13	19.65	1	-0.52
7931	515221.0	6218777.4	2	19.21	19.65	1	-0.44
7932	515221.0	6215777.4	2	19.37	19.36	1	0.01
7934	515121.0	6213977.4	2	19.58	19.78	1	-0.20
7935	515071.0	6196577.4	2	18.96	20.67	1	-1.71
7936	498621.0	6233577.4	2	18.98	18.66	1	0.32
7938	515121.0	6210477.4	2	19.06	20.16	1	-1.10
7940	499121.0	6234177.4	2	18.59	18.71	1	-0.12
7941	498921.0	6231677.4	2	19.03	18.65	1	0.38
7942	499321.0	6225477.4	2	18.91	18.89	1	0.02
7943	499121.0	6207377.4	2	18.03	18.88	1	-0.85
7944	530621.1	6194577.4	2	19.87	23.73	1	-3.86
7945	549399.1	6213795.4	2	24.30	24.31	1	-0.01
7948	514881.0	6228407.4	2	19.14	19.90	1	-0.76
7949	515061.0	6228037.4	2	18.90	19.78	1	-0.88
7950	515321.0	6227477.4	2	18.86	19.82	1	-0.96
7951	549345.1	6213308.4	2	24.33	24.47	1	-0.14
7952	549238.1	6212332.4	2	23.93	24.67	1	-0.74
7953	548919.1	6209377.4	2	23.90	25.12	1	-1.22
7954	548521.1	6203577.4	2	23.69	25.81	1	-2.12
7955	613661.2	6212317.4	2	34.15	33.29	1	0.86
7956	613261.2	6212247.4	2	33.97	33.08	1	0.89
7957	612701.2	6212327.4	2	34.28	33.06	1	1.22
7961	611821.2	6212177.4	2	35.30	33.03	1	2.27
7962	609477.2	6217198.4	2	33.89	32.72	1	1.17
7964	609533.2	6216782.4	2	34.03	32.69	1	1.34
7966	609481.2	6216272.4	2	34.46	32.65	1	1.81
7967	609370.2	6215332.4	2	35.51	32.62	1	2.89
7968	625586.2	6199107.4	2	34.44	33.83	1	0.61
7969	628021.2	6199313.4	2	33.56	34.02	1	-0.46
7972	599293.2	6218320.4	2	35.70	30.55	1	5.15
7973	599037.2	6217919.4	2	37.72	30.55	1	7.17
7974	598529.2	6217128.4	2	41.26	30.62	1	10.64
7976	611971.2	6207927.4	2	36.75	33.11	1	3.64

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Modelled steady state vs modelled calibration bore details and performance FIGURE H9

Bore	Easting	Northing	Layer	Measured	Computed	Weight	Residual
7978	611921.2	6208877.4	2	36.68	33.07	1	3.61
7980	612571.2	6208377.4	2	36.02	33.02	1	3.00
7982	613571.2	6207327.4	2	35.49	32.97	1	2.52
7984	614421.2	6207077.4	2	34.68	33.13	1	1.55
7986	612821.2	6208377.4	2	35.50	32.96	1	2.54
7990	613221.2	6208077.4	2	35.10	32.90	1	2.20
7992	614321.2	6200777.4	2	36.48	33.49	1	2.99
7994	614571.2	6201427.4	2	36.13	33.45	1	2.68
7996	614971.2	6202627.4	2	35.24	33.29	1	1.95
26105	730421.4	6093677.3	2	64.87	60.41	1	4.46
26106	730471.4	6094227.3	2	65.02	60.43	1	4.59
26107	730521.4	6095577.3	2	64.42	60.43	1	3.99
26110	725771.4	6098327.3	2	63.59	59.78	1	3.81
26116	725771.4	6099177.3	2	63.41	59.98	1	3.43
26117	725771.4	6099177.3	2	63.95	59.98	1	3.97
26118	728221.4	6098677.3	2	63.67	60.08	1	3.59
26119	730021.4	6098077.3	2	63.58	60.50	1	3.08
26120	728921.4	6099677.3	2	64.01	60.26	1	3.75
26125	727221.4	6090377.3	2	63.54	59.63	1	3.91
26126	727221.4	6090377.3	2	63.90	59.63	1	4.27
26127	727221.4	6090377.3	2	63.66	59.63	1	4.03
26128	721671.4	6096977.3	2	62.13	59.04	1	3.09
26129	721671.4	6096977.3	2	62.40	59.04	1	3.36
26130	725071.4	6095577.3	2	62.92	59.50	1	3.42
26131	725071.4	6095577.3	2	63.15	59.50	1	3.65
26132	724221.4	6092877.3	2	61.56	59.27	1	2.29
26133	724221.4	6092877.3	2	62.33	59.27	1	3.06
26134	724221.4	6092877.3	2	62.06	59.27	1	2.79
26135	725871.4	6092877.3	2	62.63	59.52	1	3.11
26136	726071.4	6091627.3	2	63.40	59.50	1	3.90
26138	724921.4	6097577.3	2	63.44	59.57	1	3.87
26139	724221.4	6098077.3	2	63.51	59.48	1	4.03
26140	724221.4	6097377.3	2	63.40	59.44	1	3.96
26142	722321.4	6095877.3	2	62.50	59.10	1	3.40
26144	724921.4	6096527.3	2	63.34	59.51	1	3.83
26146	723321.4	6096677.3	2	62.87	59.27	1	3.60
26147	723721.4	6094727.3	2	62.76	59.27	1	3.49
26151	729671.4	6090377.3	2	65.15	60.12	1	5.03
26152	728521.4	6090527.3	2	64.16	59.88	1	4.28
26155	717269.4	6103947.3	2	58.66	59.85	1	-1.19
26157	716371.4	6103833.3	2	60.23	58.99	1	1.24
26158	715331.4	6103857.3	2	60.01	58.25	1	1.76
26159	712234.4	6103910.3	2	57.88	56.56	1	1.32
26160	707334.4	6104005.3	2	53.61	54.48	1	-0.87
26161	692857.4	6105427.3	2	48.31	48.64	1	-0.33
26162	712462.4	6118664.4	2	58.81	56.96	1	1.85
26163	712055.4	6118710.4	2	58.88	56.67	1	2.21
26164	711590.4	6118642.4	2	58.63	56.38	1	2.25
26165	710528.4	6118474.4	2	58.85	55.79	1	3.06
26166	707791.4	6118444.4	2	55.39	54.51	1	0.88
26168	688013.3	6118818.3	2	49.81	49.66	1	0.15
26169	711521.4	6129777.4	2	51.84	55.04	1	-3.20
26170	711121.4	6129777.4	2	55.72	54.83	1	0.89
26171	710621.4	6129777.4	2	56.03	54.58	1	1.45

Modelled steady state vs modelled calibration bore details and performance FIGURE H10

Bore	Easting	Northing	Layer	Measured	Computed	Weight	Residual
26172	710421.4	6129877.4	2	53.65	54.47	1	-0.82
26173	710021.4	6129977.4	2	54.75	54.30	1	0.45
26174	709521.4	6130027.4	2	54.64	54.15	1	0.49
26175	708521.4	6130177.4	2	54.48	53.83	1	0.65
26176	705421.4	6130277.4	2	53.53	53.04	1	0.49
26177	700621.4	6130077.4	2	52.44	52.19	1	0.25
26178	695221.3	6129377.4	2	50.89	51.30	1	-0.41
26179	685621.3	6128777.4	2	49.82	49.64	1	0.18
26182	717270.4	6103946.3	2	57.68	59.85	1	-2.17
26186	656121.3	6160177.4	2	42.15	42.69	1	-0.54
26188	712121.4	6137277.4	2	53.43	53.78	1	-0.35
26189	711921.4	6137277.4	2	53.41	53.74	1	-0.33
26190	711221.4	6136877.4	2	53.07	53.62	1	-0.55
26191	710221.4	6136777.4	2	54.15	53.36	1	0.79
26192	707321.4	6137277.4	2	53.52	52.72	1	0.80
26193	702521.4	6137977.4	2	51.78	51.92	1	-0.14
26195	685821.3	6140077.4	2	50.29	49.58	1	0.71
26196	708221.4	6135227.4	2	53.42	53.26	1	0.16
26198	706021.3	6149677.4	2	51.00	51.38	1	-0.38
26199	705621.3	6149277.4	2	51.43	51.37	1	0.06
26942	715121.5	6004977.1	2	101.73	86.76	1	14.97
26948	726421.5	6022577.2	2	82.58	74.53	1	8.05
27001	599480.2	6218638.4	2	32.99	30.52	1	2.47
27023	609021.2	6191077.4	2	36.46	33.35	1	3.11
27031	603221.2	6217097.4	2	33.58	30.34	1	3.24
27032	602421.2	6217077.4	2	32.51	30.16	1	2.35
27033	601721.2	6217077.4	2	31.91	30.15	1	1.76
27034	602621.2	6217327.4	2	32.18	30.17	1	2.01
27035	602721.2	6217577.4	2	31.83	30.05	1	1.78
27051	606182.2	6220060.4	2	31.52	30.30	1	1.22
27054	602908.2	6217622.4	2	30.69	30.14	1	0.55
27057	602517.2	6217698.4	2	30.81	30.34	1	0.47
27058	602116.2	6217403.4	2	30.78	30.12	1	0.66
27061	602211.2	6217386.4	2	29.56	30.12	1	-0.56
27065	601776.2	6217333.4	2	30.44	29.92	1	0.52
27067	601742.2	6217234.4	2	30.50	30.05	1	0.45
27069	601798.2	6217419.4	2	30.92	29.86	1	1.06
27073	601358.2	6217546.4	2	30.70	30.22	1	0.48
27074	601476.2	6217515.4	2	30.88	30.21	1	0.67
27075	601503.2	6217647.4	2	19.66	30.27	1	-10.61
27077	601613.2	6217413.4	2	30.90	30.10	1	0.80
27079	602790.2	6217636.4	2	29.26	30.03	1	-0.77
27102	591821.1	6210077.4	2	36.63	30.83	1	5.80
27108	505721.0	6225977.4	2	19.66	19.82	1	-0.16
27109	506221.0	6226577.4	2	19.47	20.02	1	-0.55
27110	509721.0	6222777.4	2	19.02	20.32	1	-1.30
27111	510021.0	6223077.4	2	18.99	20.47	1	-1.48
27112	515121.0	6221077.4	2	19.10	19.95	1	-0.85
27113	514971.0	6222177.4	2	18.99	19.60	1	-0.61
27114	515221.0	6225377.4	2	18.91	20.39	1	-1.48
27115	519321.1	6216677.4	2	19.68	18.67	1	1.01
27117	518821.1	6219777.4	2	19.67	19.24	1	0.43
27118	517921.1	6221077.4	2	19.81	20.20	1	-0.39
27121	521021.1	6223477.4	2	19.8	20.860748	1	-1.06

Bore	Easting	Northing	Layer	Measured	Computed	Weight	Residual
27122	520821.1	6223677.4	2	20.05	20.90	1	-0.85
27124	520621.1	6224697.4	2	19.70	20.47	1	-0.77
27125	520121.1	6225277.4	2	19.63	20.62	1	-0.99
27126	521221.1	6224177.4	2	19.73	20.87	1	-1.14
27127	526021.1	6221877.4	2	20.81	20.97	1	-0.16
27131	522621.1	6217277.4	2	20.28	20.22	1	0.06
27132	519821.1	6221877.4	2	19.76	20.57	1	-0.81
27134	512721.0	6222377.4	2	19.08	20.47	1	-1.39
27136	510921.0	6220077.4	2	18.91	20.01	1	-1.10
27138	509121.0	6225377.4	2	18.95	20.21	1	-1.26
27140	501821.0	6228677.4	2	19.26	19.41	1	-0.15
27142	597421.2	6205777.4	2	37.47	31.87	1	5.60
27145	597321.2	6205777.4	2	37.47	31.86	1	5.61
27147	596121.2	6209977.4	2	38.85	31.33	1	7.52
27150	596121.2	6210077.4	2	38.90	31.32	1	7.58
27155	602221.2	6215827.4	2	35.37	30.64	1	4.73
27162	523471.1	6222577.4	2	20.81	20.36	1	0.45
27164	521721.1	6225827.4	2	20.13	20.44	1	-0.31
27166	523471.1	6225527.4	2	20.30	20.55	1	-0.25
27167	525841.1	6223277.4	2	20.79	21.20	1	-0.41
27168	505761.0	6229097.4	2	18.42	19.12	1	-0.70
27170	515421.0	6222497.4	2	19.04	19.51	1	-0.47
27171	506421.0	6223077.4	2	19.21	19.78	1	-0.57
27172	506271.0	6226527.4	2	19.08	20.01	1	-0.93
27177	623102.2	6184160.4	2	38.19	35.23	1	2.96
27179	622571.2	6184497.4	2	39.38	35.11	1	4.27
27182	622841.2	6185097.4	2	38.28	35.07	1	3.21
27184	622131.2	6186477.4	2	37.91	34.80	1	3.11
27186	622261.2	6186717.4	2	38.69	34.78	1	3.91
27188	620321.2	6188947.4	2	37.63	34.34	1	3.29
27190	619921.2	6188927.4	2	38.38	34.30	1	4.08
40600	679271.3	6097727.3	2	46.38	45.22	1	1.16
40609	660221.3	6084977.3	2	43.92	40.99	1	2.93
40610	660221.3	6084877.3	2	44.08	41.00	1	3.08
40614	666321.3	6074327.2	2	41.27	42.13	1	-0.86
40615	666021.3	6074327.2	2	46.36	42.24	1	4.12
40616	666321.3	6074327.2	2	43.11	42.13	1	0.98
40617	669221.3	6075477.2	2	42.59	39.92	1	2.67
40618	656321.3	6080277.2	2	45.18	44.17	1	1.01
40619	656221.3	6091327.3	2	45.34	42.76	1	2.58
40624	673921.3	6077927.3	2	45.53	42.17	1	3.36
40631	682821.4	6078677.3	2	48.97	46.40	1	2.57
40633	676571.4	6071577.2	2	47.30	46.10	1	1.20
40635	662321.3	6091177.3	2	41.71	38.69	1	3.02
40637	662321.3	6081077.3	2	42.30	39.25	1	3.05
40640	657821.3	6085177.3	2	44.56	42.49	1	2.07
40641	668421.3	6099177.3	2	44.21	41.86	1	2.35
40646	667921.3	6091177.3	2	43.48	38.97	1	4.51
40647	665521.3	6076427.2	2	41.97	39.87	1	2.10
40648	659121.3	6097977.3	2	45.27	42.30	1	2.97
40650	664121.3	6104077.3	2	46.33	43.59	1	2.74
40653	681321.4	6072077.2	2	49.38	47.40	1	1.98
40658	695621.4	6071977.3	2	50.92	50.06	1	0.86
40661	707321.4	6066877.3	2	55.10	56.06	1	-0.96

Bore	Easting	Northing	Layer	Measured	Computed	Weight	Residual
40663	718821.4	6065677.3	2	60.45	59.36	1	1.09
49987	660281.3	6084884.3	2	44.00	40.95	1	3.05
49989	660521.3	6091227.3	2	41.42	40.31	1	1.11
49990	660521.3	6091327.3	2	43.22	40.29	1	2.93
49991	660496.3	6091477.3	2	43.18	40.29	1	2.89
50073	602571.2	6155627.3	2	34.55	33.29	1	1.26
50074	596171.2	6156077.3	2	33.58	32.63	1	0.95
50075	593071.2	6155377.3	2	34.07	32.86	1	1.21
51347	665471.3	6076627.2	2	41.07	39.58	1	1.49
51348	665471.3	6076877.2	2	40.78	39.25	1	1.53
51350	665021.3	6076327.2	2	41.41	40.32	1	1.09
58765	624021.3	6063177.2	2	52.33	57.92	1	-5.59
63995	630021.3	6018577.1	2	70.10	75.68	1	-5.58
64361	505521.0	6159877.3	2	21.18	26.58	1	-5.40
64362	505521.0	6159877.3	2	21.37	26.58	1	-5.21
65736	587121.2	6159027.3	2	35.15	32.63	1	2.52
65738	575971.1	6167577.4	2	32.02	32.03	1	-0.01
69464	621051.2	6192677.4	2	36.84	33.95	1	2.89
75796	644971.3	6149077.4	2	40.19	40.81	1	-0.62
77032	552071.1	6186117.4	2	22.50	28.16	1	-5.66
79619	545571.1	6171777.4	2	25.72	28.63	1	-2.91
81834	515121.0	6194777.4	2	18.68	20.68	1	-2.00
85568	505121.0	6178177.4	2	18.44	21.27	1	-2.83
85933	716521.5	6012977.2	2	96.71	82.02	1	14.69
86776	498171.0	6231677.4	2	18.74	18.58	1	0.16
95114	607121.2	6105777.3	2	42.82	45.03	1	-2.21
95116	606821.2	6105877.3	2	42.77	45.01	1	-2.24
95530	666421.3	6164677.4	2	49.53	46.03	1	3.50
97332	646621.3	6082877.2	2	34.61	47.16	1	-12.55
97603	705221.4	6071277.3	2	60.00	54.50	1	5.50
97605	705221.4	6071277.3	2	52.97	54.50	1	-1.53
98347	605621.2	6155927.3	2	37.04	33.86	1	3.18
98348	605621.2	6155927.3	2	33.30	33.86	1	-0.56
98349	605621.2	6155927.3	2	36.83	33.86	1	2.97
98351	605621.2	6155907.3	2	36.20	33.86	1	2.34
98363	594721.2	6112677.3	2	40.48	43.16	1	-2.68
103161	582461.1	6186667.4	2	34.04	31.13	1	2.91
104801	530771.1	6208277.4	2	21.58	22.83	1	-1.25
104804	515121.0	6218777.4	2	19.34	19.66	1	-0.32
109463	636321.3	6053627.2	2	55.83	62.01	1	-6.18
110116	701931.4	6021917.2	2	72.15	78.33	1	-6.18
110128	656221.3	6041577.2	2	60.08	68.08	1	-8.00
110129	712234.4	6103910.3	2	58.36	56.56	1	1.80
110186	729131.5	6038527.2	2	69.07	69.16	1	-0.09
110871	714071.5	6026827.2	2	72.42	75.20	1	-2.78
110872	714071.5	6026827.2	2	78.09	75.20	1	2.89
110873	720441.5	6024607.2	2	73.41	75.31	1	-1.90
110907	585051.1	6209437.4	2	30.23	29.92	1	0.31
112459	575513.3	6010074.0	2	76.80	73.22	1	3.58
112523	726921.5	6024327.2	2	81.53	73.57	1	7.96
112524	726921.5	6024327.2	2	81.23	73.57	1	7.66
112525	729131.5	6038527.2	2	71.46	69.16	1	2.30
115238	604521.2	6215477.4	2	36.27	31.49	1	4.78
115241	604921.2	6214977.4	2	39.26	31.81	1	7.45

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Modelled steady state vs modelled calibration bore details and performance

FIGURE H13

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Bore	Easting	Northing	Layer	Measured	Computed	Weight	Residual
119369	501941.0	6226727.4	2	20.33	19.30	1	1.03
121826	504171.0	6224327.4	2	19.45	19.49	1	-0.04
124769	607636.2	6214459.4	2	37.61	32.34	1	5.27
130553	591904.1	6223090.4	2	32.35	30.06	1	2.29
137190	506806.0	6118427.3	2	30.79	31.25	1	-0.46
137191	511811.0	6117487.3	2	34.13	33.61	1	0.52
137196	501566.0	6128078.3	2	28.94	27.06	1	1.88
137199	513655.1	6098281.2	2	43.06	42.30	1	0.76
137201	513489.1	6089222.2	2	44.88	49.12	1	-4.24
137294	502131.0	6135977.3	2	40.58	27.23	1	13.35
141391	625064.2	6183838.4	2	36.70	35.60	1	1.10
141392	620543.2	6183527.4	2	39.02	34.94	1	4.08
141393	616641.2	6181867.4	2	42.70	34.56	1	8.14
141394	612488.2	6183994.4	2	36.82	33.95	1	2.87
141395	618094.2	6177423.4	2	35.31	35.13	1	0.18
GW036646	683440.0	6209100.0	2	41.70	46.13	1	-4.43
GW036664	635620.0	6243392.0	2	39.44	36.25	1	3.19
GW036724	704810.0	6155230.0	2	49.35	50.75	1	-1.40
GW036740	672200.0	6197930.0	2	42.22	45.27	1	-3.05
GW036782	512270.0	6241400.0	2	22.85	19.93	1	2.92
GW036784	585145.0	6234440.0	2	28.67	30.49	1	-1.82
GW036790	695700.0	6239190.0	2	43.57	49.48	1	-5.91
GW036809	595150.0	6256310.0	2	30.36	32.41	1	-2.05
GW036851	537350.0	6246550.0	2	22.61	24.84	1	-2.23
GW036854	667750.0	6241050.0	2	41.37	44.83	1	-3.46
GW036858	635175.0	6212750.0	2	34.51	37.94	1	-3.43
GW036878	631075.0	6198700.0	2	34.53	36.04	1	-1.51
GW036910	598740.0	6229000.0	2	37.24	30.80	1	6.44
GW040351	596000.0	6254520.0	2	30.60	32.32	1	-1.72
GW087012	592892.0	6227823.0	2	31.65	30.40	1	1.25
GW087026	602096.0	6225347.0	2	33.81	30.99	1	2.82
GW087039	611510.0	6220739.0	2	32.86	31.54	1	1.32
GW087045	607830.0	6219810.0	2	31.23	30.58	1	0.65
GW087054	607332.0	6225123.0	2	31.82	29.67	1	2.15
GW087103	669980.0	6179019.0	2	46.13	44.91	1	1.22
GW087122	614874.0	6212953.0	2	34.63	33.31	1	1.32
GW087128	618330.0	6207710.0	2	34.12	33.65	1	0.47
GW087131	623527.0	6202506.0	2	34.56	34.00	1	0.56
GW087132	624552.0	6203139.0	2	34.73	34.29	1	0.44
GW087133	625796.0	6204370.0	2	34.94	34.79	1	0.15
GW087134	628811.0	6198843.0	2	34.88	34.66	1	0.22
GW087135	630417.0	6198918.0	2	35.16	35.73	1	-0.57
GW087140	630765.0	6192634.0	2	35.43	36.04	1	-0.61
GW087142	632375.0	6187056.0	2	36.43	36.89	1	-0.46
GW087146	645415.0	6176508.0	2	37.58	39.85	1	-2.27
GW087150	636168.0	6176589.0	2	37.36	38.23	1	-0.87
GW087170	640604.0	6159204.0	2	39.07	39.73	1	-0.66
GW087238	627600.0	6199875.0	2	32.96	33.92	1	-0.96
GW087331	607691.0	6222292.0	2	32.53	30.68	1	1.85
GW087335	607799.0	6217979.0	2	32.36	30.79	1	1.57
GW087530	622519.0	6224658.0	2	30.07	33.61	1	-3.54
GW087533	612235.0	6232273.0	2	29.68	32.21	1	-2.53
GW087550	570841.0	6234267.0	2	27.70	28.24	1	-0.54
GW087580	518518.0	6242940.0	2	23.88	22.48	1	1.40

Bore	Easting	Northing	Layer	Measured	Computed	Weight	Residual
GW087622	550010.0	6232016.0	2	23.66	25.19	1	-1.53
6520	656221.3	6085077.3	3	45.13	43.43	1	1.70
27002	599952.2	6217852.4	3	32.66	30.69	1	1.97
36210	715121.5	6004977.1	3	101.76	86.74	1	15.02
49950	528721.1	6069677.2	3	50.36	57.06	1	-6.70
49951	533721.1	6044677.1	3	60.49	64.66	1	-4.17
50349	680021.4	6054677.2	3	55.17	57.53	1	-2.36
56413	577921.2	6084477.2	3	52.50	49.40	1	3.10
58764	624021.3	6063177.2	3	52.79	57.87	1	-5.08
61573	526521.1	6107227.2	3	37.53	38.99	1	-1.46
63994	630021.3	6018577.1	3	72.46	75.42	1	-2.96
65270	713821.5	6001277.1	3	105.30	90.82	1	14.48
66477	517531.1	6091867.2	3	43.12	47.57	1	-4.45
69463	621051.2	6192677.4	3	38.02	34.11	1	3.91
75795	644971.3	6149077.4	3	39.97	40.97	1	-1.00
77031	552071.1	6186117.4	3	33.44	28.16	1	5.28
77110	572521.2	6112877.3	3	40.36	40.69	1	-0.33
77304	730721.5	6008127.2	3	82.50	78.63	1	3.87
79279	600571.2	6217727.4	3	35.92	30.73	1	5.19
81833	515121.0	6194777.4	3	26.86	20.92	1	5.94
82220	506271.0	6106937.2	3	36.70	34.28	1	2.42
85570	505121.0	6178177.4	3	25.23	21.81	1	3.42
85932	716521.5	6012977.2	3	94.10	82.01	1	12.09
86775	498171.0	6231677.4	3	25.85	18.53	1	7.32
86885	618221.2	6117077.3	3	38.09	42.61	1	-4.52
92807	728571.5	6048977.2	3	69.80	66.47	1	3.33
96445	720411.5	6024577.2	3	75.98	75.33	1	0.65
97604	705221.4	6071277.3	3	56.59	54.50	1	2.09
98254	507321.0	6025527.1	3	63.05	70.92	1	-7.87
98297	497821.0	6020177.1	3	61.22	73.13	1	-11.91
103354	530721.1	6026577.1	3	68.60	69.97	1	-1.37
104803	515121.0	6218777.4	3	27.36	19.76	1	7.60
108158	509721.0	6007277.1	3	68.24	75.03	1	-6.79
109464	636321.3	6053627.2	3	55.16	61.88	1	-6.72
110130	712234.4	6103909.3	3	58.31	56.36	1	1.95
110163	656221.3	6041577.2	3	66.10	68.02	1	-1.92
110164	598521.2	6083077.2	3	41.40	49.74	1	-8.34
110179	701931.4	6021917.2	3	72.46	78.33	1	-5.87
110180	701931.4	6021917.2	3	76.87	78.33	1	-1.46
112180	578764.3	6007568.0	3	77.99	72.49	1	5.50
112181	587765.3	6007565.0	3	77.48	72.01	1	5.47
112182	587766.3	6007561.0	3	77.65	72.01	1	5.64
112183	578311.2	6003265.0	3	78.67	73.38	1	5.29
112186	575514.3	6010070.0	3	76.44	72.97	1	3.47
112521	726921.5	6024327.2	3	78.88	73.57	1	5.31
112522	726921.5	6024327.2	3	81.06	73.57	1	7.49
137194	503141.0	6121291.3	3	28.75	28.04	1	0.71
137195	501566.0	6127982.3	3	26.72	27.05	1	-0.33
137198	513658.1	6098283.2	3	40.64	41.80	1	-1.16
137200	513493.1	6089222.2	3	44.23	49.07	1	-4.84
52367	729141.5	6038477.2	4	71.83	69.16	1	2.67
52368	729146.5	6038477.2	4	72.00	69.16	1	2.84
58111	526721.1	6009577.1	4	72.28	69.60	1	2.68
66476	517531.1	6091867.2	4	41.88	48.22	1	-6.34

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Modelled steady state vs modelled calibration bore details and performance

FIGURE H15

Bore	Easting	Northing	Layer	Measured	Computed	Weight	Residual
69462	620221.2	6192777.4	4	34.40	36.35	1	-1.95
77030	552121.1	6186127.4	4	34.59	35.39	1	-0.80
77102	572421.2	6112927.3	4	38.25	44.25	1	-6.00
79278	600621.2	6217727.4	4	35.96	32.89	1	3.07
81832	515121.0	6194777.4	4	34.41	33.46	1	0.95
86774	498171.0	6231677.4	4	32.94	32.04	1	0.90
88000	701821.4	6118327.3	4	56.88	52.66	1	4.22
95513	666421.3	6164677.4	4	46.15	46.68	1	-0.53
98290	507371.0	6025477.1	4	62.70	64.69	1	-1.99
98350	605621.2	6155927.3	4	38.63	38.93	1	-0.30
103893	664621.4	6017427.1	4	75.18	76.68	1	-1.50
104800	530721.1	6208277.4	4	34.96	33.21	1	1.75
105664	591821.2	6055977.2	4	45.66	59.65	1	-13.99
110161	643421.3	6081477.2	4	46.86	48.18	1	-1.32
110162	678021.4	6086477.3	4	47.47	43.82	1	3.65
112179	587763.3	6007570.0	4	77.27	74.60	1	2.67
112185	575514.3	6010066.0	4	67.44	73.19	1	-5.75
112492	712233.4	6103910.3	4	58.53	56.16	1	2.37

APPENDIX I INITIAL STEADY STATE CALIBRATION REPORT – REFER TO CD

Department of
Sustainability and
Environment

ecoMarkets
VALUING OUR ENVIRONMENT

Mallee CMA Groundwater Model

Interim steady state model development report

A Victorian
Government
initiative

Victoria
The Place To Be

Produced by Aquaterra on behalf of the Victorian Government Department of Sustainability and Environment Melbourne December, 2009.

Authorised by the Victorian Government, 8 Nicholson Street, East Melbourne.

www.dse.vic.gov.au/ecomarkets

MALLEE CMA REGION GROUNDWATER FLOW MODEL (EM3) - STEADY STATE CALIBRATION

Prepared for	Department of Sustainability and Environment
Date of Issue	15 January 2010
Our Reference	A53/B1/R003b

MALLEE CMA REGION GROUNDWATER FLOW MODEL (EM3) - STEADY STATE CALIBRATION

	Date	Revision Description
Revision A	13/11/09	Draft issued for client and independent review
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	Name	Position	Signature	Date
Originator	Milo Simonic Katharine Bond	Principal Hydrogeologist Environmental Scientist / Modeller		15/01/10
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EXECUTIVE SUMMARY

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1 INTRODUCTION

1.1 BACKGROUND

1.1.1 ECOMARKETS PROJECT BACKGROUND

This report has been prepared for the Department of Sustainability and Environment Victoria (DSE) by Aquaterra. It describes the current status on the groundwater model development for the Mallee Catchment Management Area (CMA) (Figure 1.1). The hydrogeological conceptualisation and initial model design for the Mallee CMA are described in Aquaterra (2009a).

The Mallee study represents part of a state-wide program to develop groundwater models for each CMA in Victoria and follows completion of a pilot groundwater modelling study of the Corangamite CMA. The models developed through this program will be used, in conjunction with a recharge model of each CMA developed separately by the DSE, to assess the impacts of land use change on groundwater regime and stream-aquifer interaction. Specifications for the modelling work are summarised from the contract documents in Section 1.1.2.

The modelling study and results will be used as part of the DSE 'ecoMarkets' initiative, a new system of market based approaches designed to reward landholders for environmental improvements on their properties (www.dse.vic.gov.au/dse/). One of the approaches under the 'ecoMarkets' initiative is known as 'ecoTender'. This scheme is currently being demonstrated in the Corangamite CMA and the DSE uses it as one of the tools compare the relative merits of different bids aimed at improving native vegetation management and revegetation in selected parts of the CMA. It is intended that the groundwater models produced could also be used in the future by other stakeholders such as water utilities to assist with groundwater resource management.

In common with the modelling studies for each CMA under the ecoMarkets initiative, a staged approach is adopted for the modelling work for the Mallee CMA:

- Phase 1 involves conceptualisation and development of a steady state multi-layered groundwater model of the aquifer system present within the Mallee CMA, and subsequent independent review, in two stages:
  - Stage 1: Calibration of the steady state model using catchment average recharge conditions.
  - Stage 2: Validation assessment of the steady state model based on current recharge conditions.
- Phase 2 involves the refinement and expansion of Phase 1 Mallee CMA steady state multi-layered model platform, building upon the conceptualisation and data sets developed and collated, and transient calibration over a minimum 10-year period.

This report specifically focuses on the results of the Phase 1.

1.1.2 MODEL SPECIFICATIONS

Specifications for the Mallee CMA modelling study (further referred to as 'study') as stipulated in the contract for the work are:

- Modflow numerical groundwater modelling platform to be used;
- Model domain represents the entire extent of the catchment management area;
- The steady-state and transient groundwater recharge layers developed and provided by the DSE on a 200 metre grid are to be incorporated unaltered into each model unless demonstrated to be erroneous;
- Finite difference gridding at a maximum 200 metre cell size (to accommodate the recharge data developed by DSE on a 200 metre grid);
- Multi-layer groundwater model (representing major geological units – see further discussion at Section 1.1.3) consistent with conceptual hydrogeological model, and designed mainly to simulate water table levels and stream-aquifer interaction, and

response times to changed land and water use and/or climate change, for the ecoMarkets initiative (primary purpose);

- Secondary model purpose is for subsequent use/refinement by CMA for resource management purposes;
- Common boundary conditions and consistent aquifer parameters with adjacent models, as arising from the state-side groundwater modelling workshop outlined below;
- A normalised (scaled) RMS of less than 5% for the Phase 1 steady state model based on matching mapped depth to water table as of 1st January 2000 (± three months);
- A normalised (scaled) RMS of less than 10% for the transient model based on matching mapped depth to water table at representative year(s) to be specified, sub-catchment baseflow and groundwater hydrograph responses for selected and agreed groundwater monitoring bores;
- A transient calibration period of no less than 10 years;
- A sensitivity analysis to assess the variability of modelled outputs to variations in key model input parameters;
- Catchment groundwater balance errors of less than 2%;
- Key catchment water balance features to be considered and reported;
- The source and statement of quality of all input data sets to be reported;
- At least 500 groundwater monitoring observation bores used for calibration of water table maps (if more than 500 are present).

All modelling work is to be carried out and reported in accordance with the Murray Darling Basin groundwater modelling guidelines (MDBC, 2001), which is the Australian best practice guideline for groundwater flow modelling, including review and appraisal.

1.1.3 EXTERNAL REVIEWS AND WORKSHOPS

Independent external review of the key project outputs forms an integral part of the project. Dr Juliette Woods (Australian Water Environments) has been appointed as the independent reviewer for the Mallee CMA model.

External review is to be achieved via a series of workshops, held at key stages during the project, combined with regular informal communication and review by the appointed reviewers. The following workshops are planned:

- Informal review workshop. Carried out following collation of all relevant data sets and development of preliminary aquifer conceptualisation;
- State-wide groundwater modelling workshop. Carried out following preliminary conceptualisation of each model area to ensure consistency between model areas;
- Formal Phase 1 model review workshop. Formal presentation of final aquifer conceptualisation and a calibrated multi-layer, steady state groundwater model for review (i.e. a formal review based on this report);
- Final model workshop. Formal presentation of a calibrated multi-layer transient groundwater model and report for review; and
- Final audit workshop. Formal audit of the final groundwater model including handover and review of the model input and output data files.

In principle, to achieve the state-wide aspirations for the project and ensure consistency with models of the other CMAs the following geological units should be represented in the Mallee CMA:

- Quaternary and Volcanics (i.e. Post Tertiary age strata);
- Pliocene (i.e. Late Tertiary age strata; in the eastern Mallee: Parilla Sand and Bookpurnong Beds);
- Early Tertiary age strata (Renmark Group in the eastern Mallee);
- Pre-Cainozoic (i.e. Pre-Tertiary age basement strata).

It is noted that previous investigations and modelling by Aquaterra (2007, 2008) has demonstrated that the Bookpurnong Beds and laterally contiguous Geera Clay units form an effective hydraulic basement to the late Tertiary and Quaternary aquifer units, and it is not necessary to include the early Tertiary (Renmark Group) or pre-Cainozoic basement to develop a well-calibrated model for shallow water table simulation and surface-groundwater interactions.

However, once the modelling platform is developed for the DSE, the CMA would likely wish to use the model for a range of water management purposes, which may require representation and inclusion of the deeper confined aquifer layers in the model. At the Statewide workshop in mid-2009, it was decided that the Mallee model needed to have a layer structure that is consistent with the adjoining models (Wimmera and North Central) and a more complex layer structure has been implemented.

1.2 OTHER EASTERN MALLEE GROUNDWATER MODELLING INITIATIVES

A regional scale groundwater model has previously been developed (covering the northern part of the Mallee CMA area) by Aquaterra (2007) for the Murray-Darling Basin Commission (MDBC). The purpose of the model was to assess salinity impacts in the Mallee Zone of New South Wales and Victoria. The Eastern Mallee Version 1 (EM1) model was used as the initial basis for this project, by extending it to the south to cover the entire Mallee CMA region, and with additional layers to represent deeper, pre-Tertiary confined aquifers. The EM1 model layer elevations were completely revised for this EM3 project, based on a review and analysis of drill logs, but most of the hydrological process features were incorporated into the EM3 model, based on features in the EM1 model, and other models in the area.

The original aim of the EM1 model was to develop a groundwater model to assess past, present future salinity impacts in the Eastern Mallee zone from Swan Hill to the SA border, based on current hydrogeological knowledge. The outcome was a modelling platform that was intended for further refinements in ongoing work programs to more accurately simulate all actions and/or to upgrade as new information about relevant hydrogeological and hydrological processes becomes available. The model was independently reviewed in regard to its ‘fitness for purpose’ for ‘B’ Register assessments.

The EM1 model was based on the most up to date data currently available on geology, soil profiles and hydrogeology and incorporated key physically recorded stresses such as irrigation application rates, salt interception scheme (SIS) pumping regime and historical land and water use change where possible. The model has been used to predict future salt loads entering the River Murray in the Eastern Mallee Zone under different land-use scenarios.

Aquaterra developed another model on a sub-regional scale in the Mildura region for Goulburn-Murray Water and the MDBA, to inform the evaluation of irrigation-related effects and the design and optimisation of salt interception schemes in the Sunraysia (Aquaterra, 2009b). The Eastern Mallee 2 (EM2) sub-regional groundwater model is also used to inform the Mallee CMA (EM3) model development, notably in regard to shallow floodplain processes and layer properties.

The Mallee CMA engaged Aquaterra in extending and refining the EM1 model to include floodplain processes in the area from downstream of Lock 10 to the South Australian border (Aquaterra, 2008). This model is referred to as EM4.

The extents of the Eastern Mallee models are presented in Figure 1.1.

1.3 THIS REPORT

This report comprises six principal chapters. Chapter 1 outlines the aims of the study and provides background and history of the key recent groundwater model development initiatives related to Mallee CMA.

Chapter 2 describes the hydrogeological conceptualisation, the principal aquifer and aquitard units and surface processes that influence recharge to and discharge from groundwater. It provides the basis for the numerical model development.

Chapter 3 outlines the current implementation of the numerical groundwater flow model. It describes the approach that has been taken to represent the complex geological setting, currently adopted hydrogeological parameters used to describe the flow properties and representation of processes governing the surface water groundwater interaction. The geometry of aquifer and aquitard units and hydrogeological parameterisation is illustrated through a set of maps and model outputs provided in Appendices A and C.

Chapters 4 and 5 cover the overall calibration and sensitivity results and provide the principal information on the performance of the steady state model. The key parameters that influence the modelling outcomes of the steady state model are outlined for potential use in the next phase of the transient development and calibration.

Chapter 6 discusses the model capability, issues and forward work recommended for the next phase.

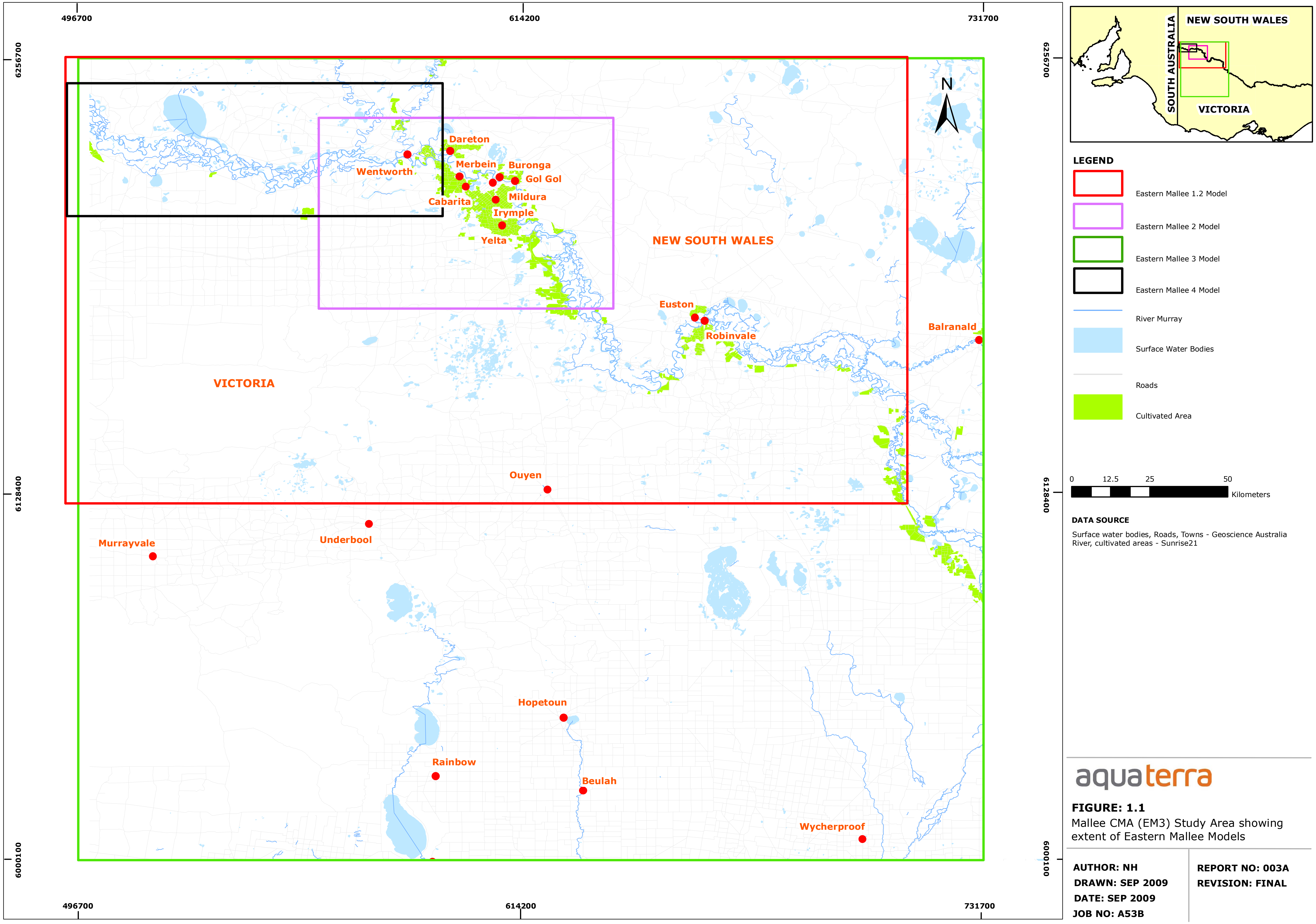

FIGURE: 1.1

Mallee CMA (EM3) Study Area showing extent of Eastern Mallee Models

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DRAWN: SEP 2009
DATE: SEP 2009
JOB NO: A53B

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2 HYDROGEOLOGICAL SETTING

2.1 STUDY AREA

The Mallee CMA study area comprises an area of approximately 50,400 km^2, extending eastwards from the South Australian border to about Swan Hill, and extending north from Lake Hindmarsh and Birchip/Wycheproof to the River Murray (Figure 1.1). It is proposed that the northern boundary of the Mallee CMA model should extend north of the River into NSW (i.e. consistent with the EM1 model boundaries), to ensure that the groundwater flow system influences from the north and east are adequately represented (e.g. there are irrigation mounds and salt interception schemes in NSW adjacent to the River Murray that have influences on the groundwater flow systems in Victoria).

2.2 CLIMATE

The Mallee CMA region is located within an arid to semi-arid climate with hot dry summers and dry mild winters. The mean annual rainfall recorded at Mildura (combined data from Mildura Airport and Mildura Post Office meteorological stations, station numbers 076031 and 076077) based on data from 1889-2008 is 275.6 mm/year. The mean annual rainfall recorded at Ouyen (station number 076047), based on data from 1911 to 2008 is 330.5 mm/year. Pan evaporation at Mildura Airport and Ouyen is significantly higher at 2,190 mm/year (1965 to 2008) and 1,423.5 mm/year (1972 to 1987), respectively.

Average monthly rainfall is relatively consistent over the year, although rainfall can be sporadically intense with long periods of near dry conditions intervening. Pan evaporation is highest in summer, and mean pan evaporation exceeds rainfall in every month. The greatest potential for rainfall infiltration occurs during intense storm events when rainfall exceeds evaporation over short periods.

Accumulated residual rainfall indicates that there were drier periods from 1993 to 2006 and during the early 1940s, the late 1920s and the late 1890s to early 1900s, consistent with periods when the Interdecadal Pacific Oscillation (IPO) index was positive (i.e. when the normally above average rainfall La Nina events would be weak, which would be expected to combine with intervening dry El Nino periods, and overall drier periods would not be unusual). Wetter periods occurred from 1988 to 1993 and during the early 1970s and the late 1950s, when the IPO was negative or near zero.

2.3 TOPOGRAPHY AND VEGETATION

The northern Mallee CMA area is characterised by a “highland” region outside the River Murray floodplain comprising ground elevations above 50 m AHD, and the River Murray floodplain below those elevations between 35 and 45 m AHD – the Murray Trench. The Murray Trench is an erosional feature where the Murray River has cut through the older sediments, in response to changing recent sea levels, to form a floodplain. The transition between both landscapes can be abrupt, with cliffs marking the edge of floodplains in some areas.

The highlands are characterised by elevated areas due to differential settlement, and some uplift, of the Tertiary and younger sediments over an undulating pre-Tertiary basement. Some of these highs, such as the Neckarboo Ridge in the north-east of the study area, reach elevations of 120 m AHD, rising over 60 m above the surrounding plain. Other underlying structural features are also expressed in the surface topography to varying extents, including the Danyo and Wargan faults.

The topography in the southern half of the Mallee CMA area exhibits a gradational surface from the highlands of central Victoria and the Grampians, with the highest elevations (reaching 180 m AHD) observed in the south-west corner of the CMA. The highlands are punctuated by low elevations around Lake Tyrrell on the eastern margin of the Mallee Zone. Lake Hindmarsh, to the immediate south of the Mallee CMA area, is incorporated into the numerical model and also represents an area of low elevation in the highlands.

Native vegetation has been cleared almost entirely from Victoria within the study area, except for the major national parks (Sunset, Little Desert and Big Desert), the River Murray floodplain,

and small/isolated pockets such as that south-west of Mildura. The area of NSW is largely uncleared, with pockets of cleared areas on Neckarboo Ridge, at the NSW irrigation areas and other isolated pockets of cleared land.

Floodplain vegetation predominantly comprises of Red Gum communities in proximity to the river or fresh water bodies and Black Box forests elsewhere. Uncleared highland vegetation is dominated by Mallee scrub, and lignum scrub in some areas.

2.4 LANDUSE AND IRRIGATION

The main land uses within the Study Area can be summarised as:

- Dryland farming within cleared areas
- Conservation for most uncleared native vegetation
- Urban development within townships, in particular Mildura, Merbein, Redcliffs, Irymple and Buronga
- Irrigated horticulture in the Sunraysia.

Irrigation has a major impact on water table levels, and on groundwater flows to the River Murray, and needs to be accounted for specifically in the model. Irrigation occurs on both sides of the River Murray. In NSW, there are the irrigation districts of Buronga (including Gol Gol), Coomealla (including Mourquong), Curlwaa, Monak, Paringi and Trentham Cliffs. In Victoria, the irrigation districts include the First Mildura Irrigation Trust (FMIT), Merbein, Nangiloc-Colignan (part) and Red Cliffs. Many of the major irrigation districts are serviced by drainage infrastructure, and there is a network of water supply pipelines (previously channels) for stock and domestic supplies in the northern Mallee (sourced from the River Murray) and southern Mallee (sourced from the Wimmera River and dams in the Grampians).

Drainage infrastructure has been installed to reduce water clogging of irrigated soils and salinisation due to local perched water tables under irrigation developments in the Sunraysia. Perched water tables can develop due to a marked permeability contrast between the Blanchetown Clay and Woorinen formation (Thorne *et al.,* 1989). A subsurface drainage system exists in the Victorian irrigation districts, whilst in NSW there are both surface and subsurface drains established (SKM and AWE, 2003). Average drainage rates are available from previous reports (SKM AND AWE, 2003; and MRCC, 2001) for the irrigation districts of Merbein, Redcliffs, FMIT, Nangiloc-Colignan, Coomealla, Curlwaa and Buronga. There is a 5% to 15% difference between MDBC (2003) and MRCC (2001) for the estimated drainage flows for the drainage districts of Merbein, Redcliffs and FMIT, and less than 4% difference between the total estimate drainage flows of all of these districts, both at 2000.

No data is available of the actual depth of drains, but is generally understood to be within 2 to 4 m of the surface and/or above the Woorinen/Blanchetown Clay interface. Also, there was no data on the actual implementation date of drainage schemes. Drained areas are generally of similar size to the actual irrigated areas.

The Mallee CMA contains all of the Murrayville Water Security Protection Area (WSPA) as well as part of the Telopea Downs WSPA and Kaniva TCSA (Tertiary confined sand aquifer) GMA. Groundwater use in 2006/07 almost doubled in the Murrayville WSPA compared with 2005/06; however extractions in the Telopea Downs WSPA almost halved over the same period. There has been no licensed groundwater use in the Kaniva TCSA GMA over both the 2005/06 and 2006/07 period.

The Murrayville WSPA freshwater aquifer is an important resource for domestic and irrigation purposes in the west of the Mallee CMA region. It is used for irrigation of potatoes and olives, as well as urban supplies for Murrayville and Cowangie townships. The Tertiary Limestone Aquifer is shared with the SA Mallee Prescribed Wells Area and the SA/Vic Border Zones.

2.5 HYDROLOGY

2.5.1 RIVER MURRAY

The Murray-Darling Basin is Australia's largest river system and is fed mainly by runoff from the Great Dividing Range, up-catchment of the study area. The River Murray runs along the northern boundary of the Mallee CMA in a south-east to north-west direction from Swan Hill, meeting the Darling River at Wentworth, and then continuing on westwards to the SA border.

In the unaltered, natural system, the flows in the River Murray were highly variable, cycling between baseflow and flooding events. River regulation in the 1920s to provide for river navigation and reliable water supplies for potable and irrigation uses significantly reduced the frequency and magnitude of the flooding events (Jolly, 1996).

Flows are regulated by the Locks between the SA border (Lock 6 at Chowilla in SA), through to Lock 10 at Wentworth and Lock 11 at Mildura, with a long reach to Lock 15 at Euston.

Within the EM2 model domain centreline river bathymetry has been estimated from water depth provided by NanoTEM reduced to m AHD levels using pool level, and is expected to be accurate to within 1 to 2 m. This data indicates that the river bathymetry typically varies between 25 and 29 m AHD downstream of Mildura Weir, and 27 and 34 m AHD upstream. There is evidence of sediment build-up behind Mildura Weir for up to 6 km.

2.5.2 WIMMERA RIVER AND ASSOCIATED LAKES

The Wimmera River is the longest river in Victoria that does not flow into the ocean. The river and its tributaries flow from Mt Cole and Pyrenees Ranges in the south-east and the Grampians in the south to terminal lakes including Lakes Hindmarsh and Lake Albacutya.

Lake Albacutya is listed as a wetland of international significance (Ramsar site) under the international Convention on Wetlands. However, changes in land and water use over many decades mean Lake Hindmarsh and Lake Albacutya are now usually dry. Also in many years flows do not reach these terminal lakes and the river contracts to a series of pools of varying sizes. The health of Wimmera River is expected to improve under the Wimmera Mallee Pipeline project, outlined in Section 2.5.3.

2.5.3 WATER SUPPLY CHANNELS AND PIPES

The Northern Mallee Pipeline Project, which started in 1992 with construction of a pipeline system services 650,000 hectares from Swan Hill to Sea Lake, to Ouyen, Underbool and Manangatang. More recently, this system was extended to include Patchewollock and Speed then to the Cannie Ridge area north of Quambatook, bringing the total piped area to 820,500 hectares. These areas draw water from the River Murray.

The Wimmera-Mallee (open) channel system that currently services the southern sections of the region is unsustainable, with 85% of water in the system wasted through seepage and evaporation. Over 16,000 kilometres of open channels provide stock and domestic requirements in the region.

The Wimmera Mallee Pipeline involves the construction of almost 9,000 kilometres of reticulated pipeline which will replace the open channel system. The project will supply stock and domestic water to approximately 6,000 rural customers and 36 towns across the Mallee-Wimmera region. The project is estimated to be completed by 2010.

The main source of water for the Wimmera Mallee Pipeline system will be Bellfield Reservoir near Halls Gap in the Grampians. Water from Taylors Lake will supplement the system as required, whilst the River Murray will be the source of water for the Berriwillock-Culgoa area.

There are seven Supply Systems within the Pipeline network, five of which have some portions within the Mallee CMA region. The current state of these (as of 27 January 2009) Supply Systems are outlined below:

- Supply System 1 – construction of this section of the pipeline is complete. GWM Water operations group are now managing this section of the pipeline, with supply of Lake Bellfield water to townships including Rainbow and Yaapeet (both located within the Mallee CMA);

- Supply System 2 – Construction is complete, with full supply to farms available. Supply is secured to towns including Brim, Beulah, Hopetoun, Lascelles and Woomelang (all located within the Mallee CMA);
- Supply Systems 3 and 4 – construction commenced in May 2008 for Supply System 3 (Birchip) and Supply System 4 (Wycheproof);
- Supply System 5 – the total length of pipe has now been installed. GWM Water operations group are now managing this section of the pipeline, with supply of River Murray water to Nullawil, Berriwillock and Culgoa and farms within the supply zone.

2.6 GEOLOGY

2.6.1 GEOLOGICAL STRUCTURE

Airborne geophysical surveys carried out in the past of the Mallee CMA have identified the presence of the north-south trending faults in the pre-Permian basement rocks. Faults have generally the potential to either provide preferential flowpaths or compartmentalise groundwater flow if they are less permeable than the surrounding environment.

The pre-Permian faults identified from the geophysical surveys are assumed to have very limited impact on groundwater flow in the overlying Cainozoic sedimentary cover with few notable exceptions.

2.6.2 SEDIMENTARY STRATIGRAPHY

At the regional scale, the pre-Tertiary basement is overlain by basal sediments of the Renmark Group, overlain in turn by a complex sequence of Oligo-Miocene marine sediments comprising Ettrick Formation, Geera Clay and Winnambool Formation. This Oligo-Miocene package of sediments is in turn overlain by sediments deposited during a Pliocene transgressive phase.

The Renmark Group sediments form a continuous sheet across the model area, and are comprised of sands, silts, carbonaceous clays and lignites (Brown and Stevenson, 1991). The basal parts of the sequence are much sandier. The Renmark Group is overlain by the transgressive sediments of the Murray Group. The initial sedimentation of the Group is the Ettrick Formation, a clay layer of up to 20 metres in thickness. This formation is found in the western parts of the model area. Further to the east, the onset of marine sedimentation in the Murray Group is marked by deposition of Geera Clay. The marine transgression did not cover the entire model area, so that the Oligo-Miocene shoreline occurred towards the eastern margin. In these parts, the Renmark Group (Olney Formation) continued to be deposited on the landward side of the shoreline.

In the west, the Ettrick Formation is overlain by the Murray Group Limestone (comprised of layers of limestone, marl and calcarenite). The limestone grades into marls of the Winnambool Formation further east, and this in turn grades into the Geera Clay, representing sedimentation moving from open water deposits in the west, to restricted marine estuarine conditions in the east. The Oligo-Miocene sequence on the landward side of the shoreline is comprised of contiguous Renmark Group sedimentation.

The Pliocene sediments comprise the relatively impermeable clays of the Bookpurnong Formation, which in turn are overlain by the major aquifer unit of the Parilla Sands. The Bookpurnong Formation overlies directly the Murray Group Limestone (where it occurs in the western part of the model area). The Bookpurnong Formation also overlies sediments of the Winnambool Formation and the Geera Clay. In the case of the latter association (that is, Bookpurnong Formation overlying Geera Clay), it is difficult to definitively assign fine grained sediments to either of the two units based on drillers' logs. The Bookpurnong Formation does not extend across the entire model area and is confined to the central and western parts. This means that the Parilla Sands directly overlies Geera Clay in the central eastern parts of the model area, and directly overlies Renmark Group in the most easterly parts.

The Pliocene Parilla Sands form a reasonably continuous sheet across the study area. They comprise a complex sequence of interbedded sands, silts and clays deposited in a beach ridge and swale environment that trends roughly north-west to south east, in large arcuate trends (Brown and Stevenson, 1991). The elevation difference between the swale and the ridge crest

can be substantial, and the Parilla Sands vary in thickness between 10m and 60m. The top and bottom elevations of the Parilla Sands are shown in Appendix A.

In the eastern part of the EM3 model domain, fluvial and lacustrine sediments of the Pliocene Shepparton Formation exist above, or can be intercalated with either the lateral equivalents of the Pliocene Parilla Sands (ie locally the Wandella Sandstone, Tragowell Member or Kerang Sand Member), or with sediments recognised as the Calivil formation. Brown and Stephenson (1991) report the lithology of the Shepparton Formation as being unconsolidated to poorly consolidated clay, silt, silty clay with some developed lenses of fine to coarse sand with some gravel.

The majority of the Study Area was covered by a lake that was formed during Early Pleistocene. The sediments that were deposited in Lake Bungunnia are collectively called the Blanchetown Clay. These clays cap the Parilla Sands below elevations of about 65 m AHD.

A period of weathering prior to the development of Lake Bungunnia resulted in deep weathering on the top of the Parilla Sands. This weathering has produced a clay-rich layer in places. The overall thickness of clay comprising the Blanchetown Clay and the weathered Parilla Sands can be up to 50 metres, but is highly variable.

Lake Bungunnia dried at about 600,000 yrs BP, and the ancestral River Murray subsequently carved a trench through the old lake floor. This trench has been successively eroded and back-filled over time in response to the cyclical wetting and drying of the landscape. The final depositional phase has left a coarser sand layer buried at the base of the trench (the Monoman Formation, also referred to as the Channel Sands), with a finer grained overlying layer (the Coonambidgal Formation), which is generally only partially saturated. In some places the erosion prior to the deposition of the trench sediments resulted in the removal of the Blanchetown Clay and exposure of the Parilla Sands prior to the deposition of the Monoman Formation.

As the ancestral Lake Bungunnia dried, and in response to the cyclical wetting and drying of the climate, groundwater discharge features became established in the low points of the landscape in areas away from the Murray River. These features led to the deposition of gypseous lake deposits collectively identified as Yamba Formation.

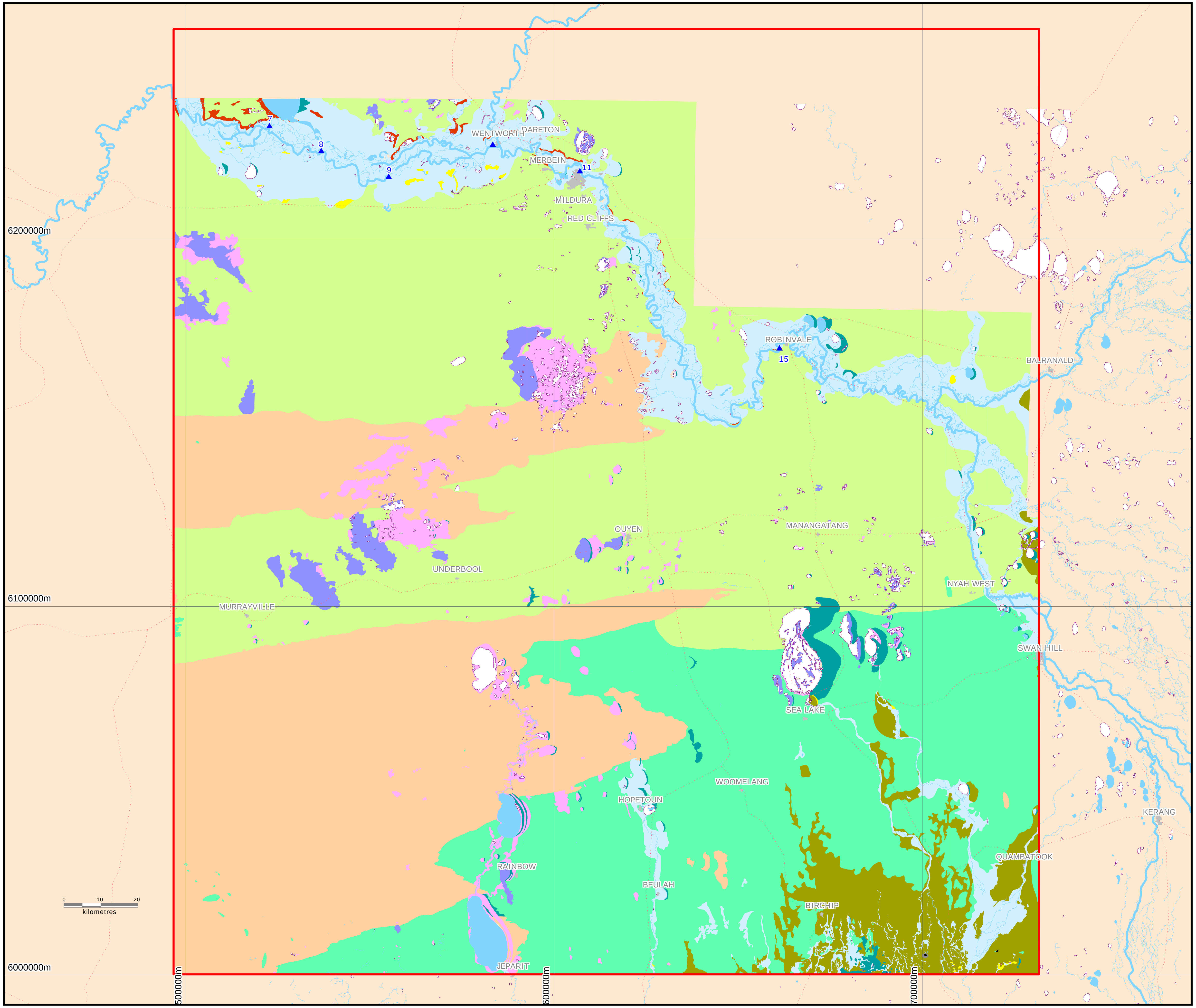
The Parilla Sands was reworked into a series of linear dunes over drier periods of recent climate. These sands are known as the Woorinen Formation and give the region its current landscape character. The dune systems can be up to 10 metres thick and tend to blanket most of the landscape.

The surface geology map showing the extent of Quaternary deposits and outcropping Pliocene sediments is presented in Figure 2.1

A subtle influence on the land surface can be seen from the underlying basement structure beneath the Tertiary sediments. This influence is manifest as areas of differential subsidence and uplift, forming small depocentres where the sedimentary sequence thickens over areas of subsidence and thins over areas of uplift. In some uplifted areas (on the Neckarboo Ridge in NSW), there has been ongoing uplift into the Late Cainozoic, causing the shallow Blanchetown Clay to be elevated higher than elsewhere and absent at higher elevations.

The digital elevation model highlights the some major geological structures, including the major uplift feature of the Neckarboo Ridge in NSW (Appendix A). More subtle differential movement at the local scale has resulted in the relative thickening of units in the down thrown parts of the landscape.

The result of this tectonic activity has been the thickening of the Parilla Sands over the depocentres from about 50 to 60 m. Similarly, the Parilla Sands can be seen to thin over the structural high areas, with the unit less than 10 m thick in these areas. The major depocentres also correlate with the maximum thickness of up to 50 m of Blanchetown Clay. The areas of uplift correlate with regions where Blanchetown Clay is thin or non-existent.



LOCATION MAP

LEGEND

road
river
EM3 model boundary

non-perennial lake
perennial lake

town
lock

Geology

alluvium
colluvium
inland dunes deposits
lunette deposits
swamp and lake deposits
Lowan Sand
Woorinen Formation
Yamba Formation
Blanchetown Clay
Shepparton Formation
Parilla Sand
Palaeozoic Basement

DATA SOURCE

Geoscience Australia, 2008, 2009, licence 117730

aquaterra

FIGURE 2.1
SURFACE GEOLOGY OF MALLEE CMA

AUTHOR:	MS	REPORT NO:	R001
DRAWN:	MS	REVISION:	A
DATE:	Jan 09	SCALE:	1:1000,000
JOB NO:	A53B		

Location: A53B1/330

2.7 HYDROGEOLOGY

2.7.1 AQUIFER AND AQUITARD UNITS

There are three major regional aquifers: the deep, confined Renmark Group, the Murray Group Limestone in the western portion and the shallow, unconfined Parilla Sands (Figure 2.2). The sands of the Monoman and Coonambidgal Formation form a less extensive assemblage of laterally discontinuous aquifer units that underlies the Murray Trench and is therefore limited to the Trench alignment.

In the western parts of the study area, the Murray Group Limestone aquifer overlies the Renmark Group aquifer, and in turn is overlain by the Parilla Sands aquifer. In the central-eastern parts the deeper Renmark Group is separated from the Parilla Sands by between 100 to 180 m of Oligo-Miocene and Pliocene clays (Ettrick, Geera, Winnambool and Bookpurnong Formations). Further east, the Parilla Sands and Renmark Group aquifers are contiguous (ie. absence of intervening aquitards, including Ettrick Marl). The base of the Parilla Sand aquifer is considered to be the base of the shallow aquifer system for the purposes of this study (i.e. the system that hosts the shallow water table and stream-aquifer interaction processes that are important to quantify for the ecoMarkets initiative).

The Blanchetown Clay acts as a semi-confining layer on top of the Parilla Sands, but in some places the water table lies below the base of the clay. The Parilla Sands is predominantly confined, but also unconfined, specifically at two locations, part of the Redcliffs and Merbein irrigation districts (pers. comm. Andrew Telfer, 2007). The Blanchetown Clay is absent within the Murray Trench between Dareton and Mallee Cliffs, on the Neckarboo Ridge and several other isolated locations.

At the local scale within the Murray Trench, there is a complex relationship between the Monoman Formation underlying the floodplain and the broader Blanchetown Clay - Parilla Sands sequence. At locations where the Blanchetown Clay is absent from the Murray Trench due to tectonic raising and lowering, the Monoman Formation is in direct contact with the Parilla Sands. Outside these locations the Blanchetown Clay underlies and separates the Monoman Formation from the Parilla Sands.

Within the floodplain, the silts and clays of the Coonambidgal Formation act as a semi-confining layer to the Monoman Formation, such that the aquifer has a confined response over short pumping timeframes, and an unconfined response over longer timeframes (pers. comm. Andrew Telfer, 2007).

The Renmark Group aquifer in the model area is part of a larger regional aquifer system where flow originates outside of the model area and continues on through the model area. Likewise, the Murray Group Limestone aquifer is generally recharged outside the model area and except for areas of evaporation from the shallow water table (for instance, in the Pink Lakes area near Murrayville), it discharges laterally across the model area boundary. The Renmark Group is confined by the overlying sediments of the Oligo-Miocene sequence, and the Murray Group Limestone aquifer is confined by the overlying Bookpurnong Formation.

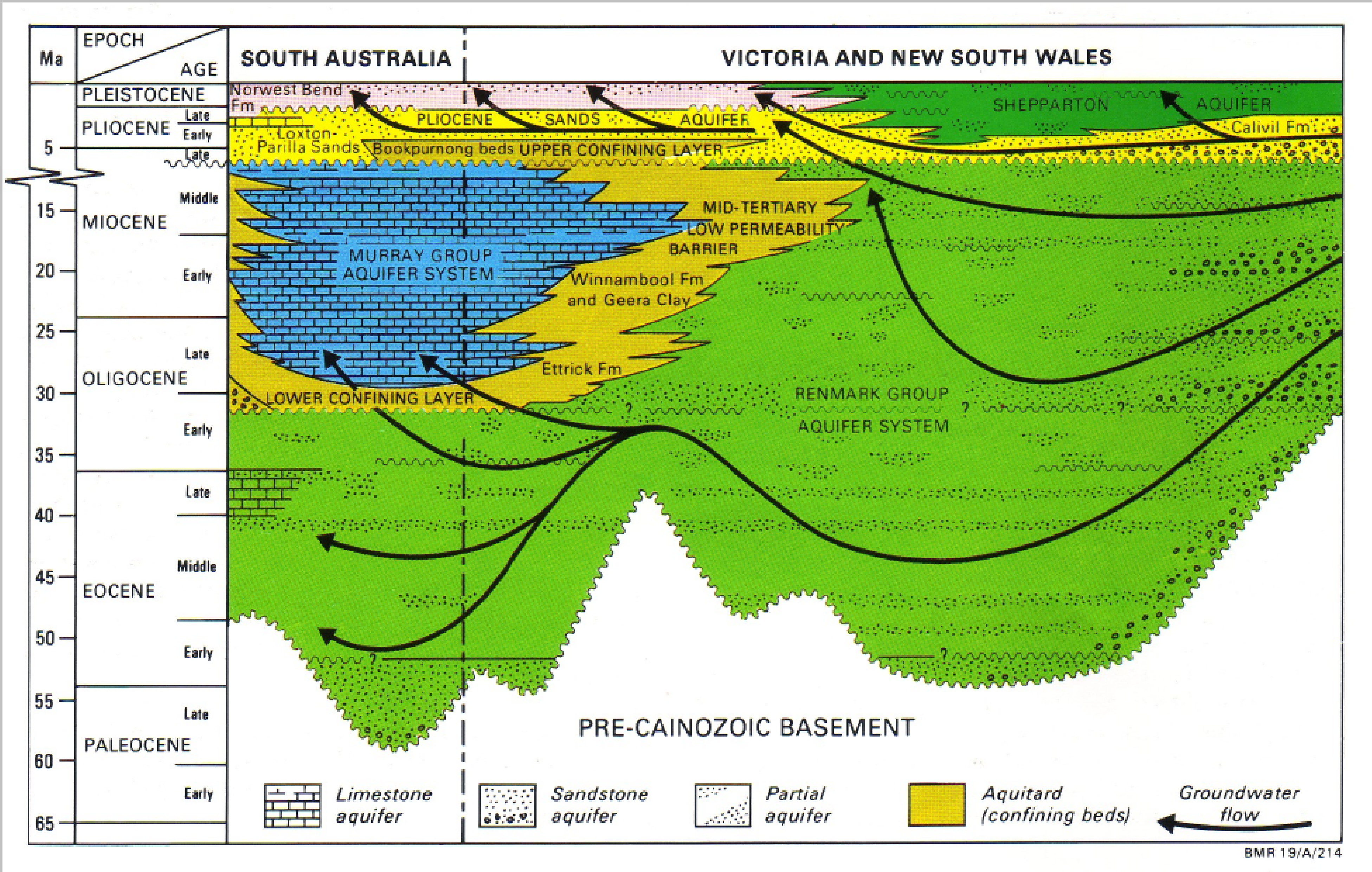
Groundwater generally flows vertically upwards from the Renmark Group to the Murray Group Limestone aquifer across the Ettrick Formation.

2.7.2 GROUNDWATER FLOW AND LEVELS

Regional groundwater flow within the major aquifer units of the Parilla Sands is generally from east to west and southeast to northwest.

Groundwater mounding occurs within the Parilla Sands under irrigation areas in Victoria and NSW, with the largest mound occurring beneath Mildura/Redcliffs/Merbein. These mounds give rise to groundwater gradients towards the floodplains and river.

The structural highs and lows imposed by the tectonism in the area have also caused modification to the pattern of groundwater flow, as does the influence of the Lake Tyrrell discharge complex. In some places, such as the Neckarboo Ridge in the northeast, the elevation of the base of the Parilla Sands alters the flow paths of the regional groundwater flow system, pushing fluxes towards Mallee Cliffs and away from the higher elevations.



Regional aquifer systems of the Murray Basin (Source: Brown and Stevenson 1991) FIGURE 2.3

In the Lake Tyrrell area, groundwater flow patterns are influenced by the uplift across the Tyrrell Fault. There has been substantial movement on the fault over time, with the western side of the fault uplifted relative to the east. The size of the uplift has meant that groundwater flow in the Parilla Sand aquifer has been disrupted. This has been coupled with the shallow water levels in the area to the east of the fault to produce a large region of active discharge via evapotranspiration, centred in Lake Tyrrell. At the lake itself, the evaporative process has been so dominant for such a long period of time that it has produced a brine pool within the Parilla Sand aquifer under the lake. The disruption to groundwater flow caused by the evaporation process has turned this feature into a terminal groundwater flow system, with a segment of the Parilla Sand aquifer flow now terminating at the Lake.

The absence of the Blanchetown Clay within the Murray Trench through the majority of the Study Area, apart from small areas around Robinvale, results in the Parilla Sands being hydraulically connected to the Monoman Formation. Groundwater flow within the Monoman Formation generally reflects flow within the Parilla Sands with local hydraulic gradients towards the river downstream of the Locks and weirs, within a regional groundwater flow system of flow generally from south and east to the north and west. The raised weir pool level upstream of the Locks causes local gradients to be generally away from the river at these locations.

2.7.3 AQUIFER PARAMETERS

A number of studies have been undertaken to examine the hydraulic properties of the Parilla Sands and Monoman Formation at various locations along the river. These studies include pumping tests, SIS bore shut down tests, particle size analysis of boreholes and calibrated groundwater models. Few studies have been undertaken to determine hydraulic properties in the lower lithological units. The available studies for the units of interest are summarised in Table 2.1.

Table 2.1: Summary of Hydrogeological parameters from previous studies.

Reference	Method	Target Geological Unit	Transmissivity (m^2/day)	Hydraulic Conductivity (m/day)	Storage
Merrick & Middlemis (1988)	Calibrated Model	Monoman Formation	150		0.1
Middlemis (1990) & Merrick *et al.* (1999)	Calibrated Models	Monoman Formation	45-270		0.1-0.01 (S)
Thorne *et al.* (1989)	Pumping tests	Monoman Formation	150-220		0.001
SKM (2005a)	Literature review	Monoman Formation	70 – 400	K_H = 10 – 40	0.05 – 0.3 (storage Coefficient)
SKM (2005b)	Calibrated Model	Monoman Formation		K_H = 3.0 – 20.0 K_v = 0.01 – 20.0	
AWE (2007)	Shut down tests	Parilla Sands + Monoman Formation	61-980		--
AWE (2007)	Particle size analysis (low reliability)	Parilla Sands + Monoman Formation	130-1,300		--
Ghassemi *et al.* (1987)	Calibrated Model	Parilla Sands + Monoman Formation	100-300		0.02

Reference	Method	Target Geological Unit	Transmissivity (m^2/day)	Hydraulic Conductivity (m/day)	Storage
Ghassemi *et al.* (1987)	Pumping tests	Parilla Sands + Monoman Formation	30-350		0.001-0.05
AWE (2007)	Particle size analysis (low reliability)	Parilla Sands + Monoman Formation	0.02-14		--
AWE (2007)	Shut down tests	Parilla Sands + Monoman Formation	290-2,100		0.0007-0.01 (S)
AWE (2007)	Particle size analysis (low reliability)	Parilla Sands + Monoman Formation	540-5,100		--
Thorne *et al.* (1989)		Blanchetown Clay		K_H = 0.0017 – 0.035	
SKM (2005a)	Literature review	Blanchetown Clay	0.0348 > 1.74 [sic]	K_H = 0.0348	0.05 – 0.3 (S)
SKM (2005b)	Calibrated Model	Blanchetown Clay		K_H = 0.035 [sic] K_v = 0.35 [sic]	
AWE (2009)	Pumping tests at Red Cliffs	Parilla Sands	655-2,400		0.1
Williams & Erny (2001)	Pumping tests	Parilla Sands	145-270		0.0003 to 0.02
Merrick & Middlemis (1988)	Calibrated Model	Parilla Sands	500		0.0001
Middlemis (1990) & Merrick *et al.* (1999)	Calibrated Models	Parilla Sands	120-500		0.0005-0.01 (S)
Aquaterra (2009c)	Pumping tests at Lake Gol Gol	Parilla Sands	129-449		0.0002-0.007 (S) 0.05-0.24 (Sy)
SKM (2005a)	Literature review	Parilla Sands	60 – 218	K_H = 1 – 4	1 – $7x10^{-4}$ (storage Coefficient)
SKM (2005b)	Calibrated Model	Parilla Sands		K_H = 1.0 – 5.0 K_v = 0.01 – 5.0	
Barnett and Osei-bonsu (2006)	Aquifer tests	Parilla Sands		K_H = 3 - 15	
Barnett & Osei-bonsu (2006)		Parilla Sands			0.1 (Sy)
Hocking & Dyson (2006)		Parilla Sands	100 – 200	K_H = 2 – 4	
Evans & Kellett (1989)	Literature review	Parilla Sands		K_H = 0.1 – 10	
Thorne *et al.* (1989)	Pumping tests	Parilla Sands	115-1,460		0.0001-0.001

Reference	Method	Target Geological Unit	Transmissivity (m^2/day)	Hydraulic Conductivity (m/day)	Storage
Evans & Kellett (1989)	Literature review	Shepparton Formation		K_H = 2 – 3 (regional) K_H = 25 – 100 (sandy lens)	
Evans & Kellett (1989)	Literature review	Calivil Formation		K_H (Upper end) = 230	
Barnett & Osei-bonsu (2006)		Bookpurnong Beds			10^{-5} (Ss)
SKM (2008a)	Laboratory tests	Bookpurnong Beds		K_v = $2x10^{-5}$ – $9x10^{-3}$	
SKM (2008a)	Pumping tests	Bookpurnong Beds		K_v = 0.0002	
Evans & Kellett (1989)	Literature review	Bookpurnong Beds		K_v = $1x10^{-4}$ – $5x10^{-4}$	
Barnett & Osei-bonsu (2006)	Aquifer tests	Murray Group Limestone		K_H Mean = 3.8 K_H Range = 0.7 – 7.3	Average = $3.5x10^{-3}$ Range = $4.0x10^{-4}$ – $1.4x10^{-2}$ (S)
Barnett & Osei-bonsu (2006)		Murray Group Limestone			0.15 (Sy)
SKM (2008b)	Pumping tests	Murray Group Limestone	1.4 – 200		
Evans & Kellett (1989)	Literature review	Murray Group Limestone		K_H 1 – 2 (north) K_H 3 (south)	
Evans & Kellett (1989)	Literature review	Geera Clay/ Winnambool Formation		K_H = $4x10^{-4}$ K_v = $2x10^{-5}$	
SKM (2008a)	Laboratory tests	Ettrick Formation		K_v = $9x10^{-6}$	
SKM (2008a)	Pumping tests	Ettrick Formation		K_v = 0.0002 – 0.03	
Evans & Kellett (1989)	Literature review	Ettrick Formation		K_H = $4x10^{-4}$ K_v = $2x10^{-5}$	
Barnett & Osei-bonsu (2006)		Renmark Group			10^{-4} – 10^{-5} (Ss)
SKM (2008b)	Pumping tests	Renmark Group	640 - 810		
Evans & Kellett (1989)	Literature review	Renmark Group		K_H (Mean) = 2 K_H (Upper end) = 100 K_H:K_V ratio = 10:1 – 100:1	

2.8 SURFACE WATER AND GROUNDWATER INTERACTIONS

A range of surface processes interact with groundwater, causing aquifer systems to be recharged (inflow) or for groundwater to be discharged (outflow). The representation of these processes in the model will depend on available knowledge with regard to the relationship of the feature to the water table (i.e. whether they act as areas of groundwater recharge or discharge).

Surface processes can recharge the groundwater system via:

- Diffuse recharge from rainfall;
- Deep drainage from irrigation;
- Disposal basins for stormwater, irrigation drainage water and/or SIS pumping (usually sited in natural depressions in the landscape);
- River recharge either from bank storage processes or over-bank flows on the floodplain;
- Interaction with surface water bodies, particularly the complex flow processes around the Lake Tyrrell system, and potential leakage from channel systems.

Groundwater can be discharged to the surface and be lost to the aquifer system via:

- Evapotranspiration from shallow water tables in low-lying parts of the landscape through direct evaporation, such as around salinas in dryland regions (notably Lake Tyrrell), in other low-lying parts of the landscape such as around Hattah Lakes, and the Noora complex and the Lindsay River anabranch system on the western margins, and/or through transpiration of vegetation, particularly on the floodplain;
- Groundwater pumping, such as irrigation and salt interception schemes (SIS);
- Groundwater discharge to the river, notably adjacent to irrigation mounds in the Sunraysia;
- Interaction with surface water bodies and/or disposal basins.

Each of these recharge and discharge processes are discussed below.

2.8.1 RAINFALL RECHARGE

The DSE will provide the recharge data sets (from the ENSYM model) on a 200 metre grid.

Appendix B presents details on the findings from previous modelling investigations undertaken by Aquaterra in the Sunraysia (northern Mallee CMA) region. The details provide a description of the recharge processes and the issue of the time lags for land and water management change action at the land surface to reach the water table as effective recharge, which may be relevant to the further development of the Mallee CMA model.

2.8.2 FLUXES TO RIVER

Groundwater fluxes to the river (also called “baseflows”) occur when the river and groundwater system is connected and there is sufficient groundwater flow gradient towards the river, i.e. river is gaining. Groundwater inflows into the river have been reduced by introduction of SIS schemes designed to limit the transfer of salinity loads from saline groundwater to the river.

The river would be expected to lose rather than gain water to the groundwater systems through a significant portion of its course in the study area. The losing rather than gaining character of the river aquifer interaction has been confirmed by the recent work on EM4.

2.8.3 EVAPOTRANSPIRATION

Evapotranspiration (ET) is the removal of water from soils as water vapour via a combination of direct evaporation and plant transpiration, and is affected by climate, availability of water and vegetation type (Bureau of Meteorology, 2001). The depth to which ET is typically assumed to have an effect is up to 8 m, depending on soil and vegetation type. The effect of evapotranspiration is typically assumed to reduce with depth from a maximum rate at the surface, to zero at the maximum depth (referred to as the ‘extinction depth’).

At locations where the water table is shallow (typically less than 3 m), ET has a direct influence on the water table. Areas of shallow water table exist within some areas of the floodplain and salinas or boinkas, notably Lake Tyrrell. As demonstrated during the development of EM1 (Aquaterra, 2007), ET is critical to proper simulation of floodplain processes, having a significant (interception) effect on ambient groundwater fluxes to the River Murray.

When the water table is deep (typically greater than 5 m), ET is removed from the shallow unsaturated soils and not directly from the water table. As this groundwater flow model is concerned with the saturated zone, ET from the unsaturated zone has been taken into account

in the recharge functions, identified above. Recharge in this sense is the net deep (RZD) drainage to the aquifer resulting from rainfall plus irrigation, reduced by ET, runoff and drainage infrastructure.

Based on the Climatic Atlas of Australia (Bureau of Meteorology, 2001) which uses Morton's (1983) complementary relationship, the average actual ET in Mildura and Ouyen is 300 and 350 mm/year respectively. This is the actual ET that would take place in an area where there is limited water supply, i.e. limited by rainfall and a deep water table. In areas where there is a shallow water table, and hence a (relatively) unlimited water supply, ET may be much greater and could be as high as the average potential ET of 1,100 mm/year (Bureau of Meteorology, 2001).

Studies by CSIRO at Chowilla, SA, indicate that transpiration by river red gum is limited by salinity and soil properties, typically to around 1 to 2 mm/day (365 to 730 mm/year) (Thorburn *et al.,* 1993). Transpiration by Black Box is typically ten times lower at less than 0.1 to 0.3 mm/day (37 to 110 mm/year) (Thorburn *et al.,* 1993). In these studies, both species were identified as removing water from a depth of between 0.1 and 3.3 m. The effect of increasing ET rates, and varying extinction depths, will be explored during model calibration.

As an initial assumption, an extinction depth of 3 m will be specified generally across the study area.

2.8.4 SIS SCHEMES

There are five pumped Salt Interception Schemes (SISs) that operate within the Study Area; Mildura-Merbein, Buronga, Curlwaa, Mallee Cliffs and Rufus River. The schemes consist of a series of bores designed to intercept groundwater and salt fluxes to the River Murray within the Parilla Sands and/or Monoman Formation. A summary of the schemes is provided in Table 2.:

Table 2.2: Existing SIS within Study Area

SIS Name	Number of Bores	Commencement Date
Mildura Merbein	19 in total (13 currently operating)	17 bores in 1980 1 new and 1 replacement bore in 1992
Buronga	8 in total (all currently operating)	5 bores in 1980 1 bore in 1991 2 bores in 2007
Curlwaa	5 in total (all currently operating)	1 bore in 1973 3 bores in 1975 1 bore in 1985
Mallee Cliffs	7 in total (all currently operating)	All bores in 2000-2001
Rufus River	4 wellpoint lines (each connected to about 40 wellpoints)	Commissioned in 1983

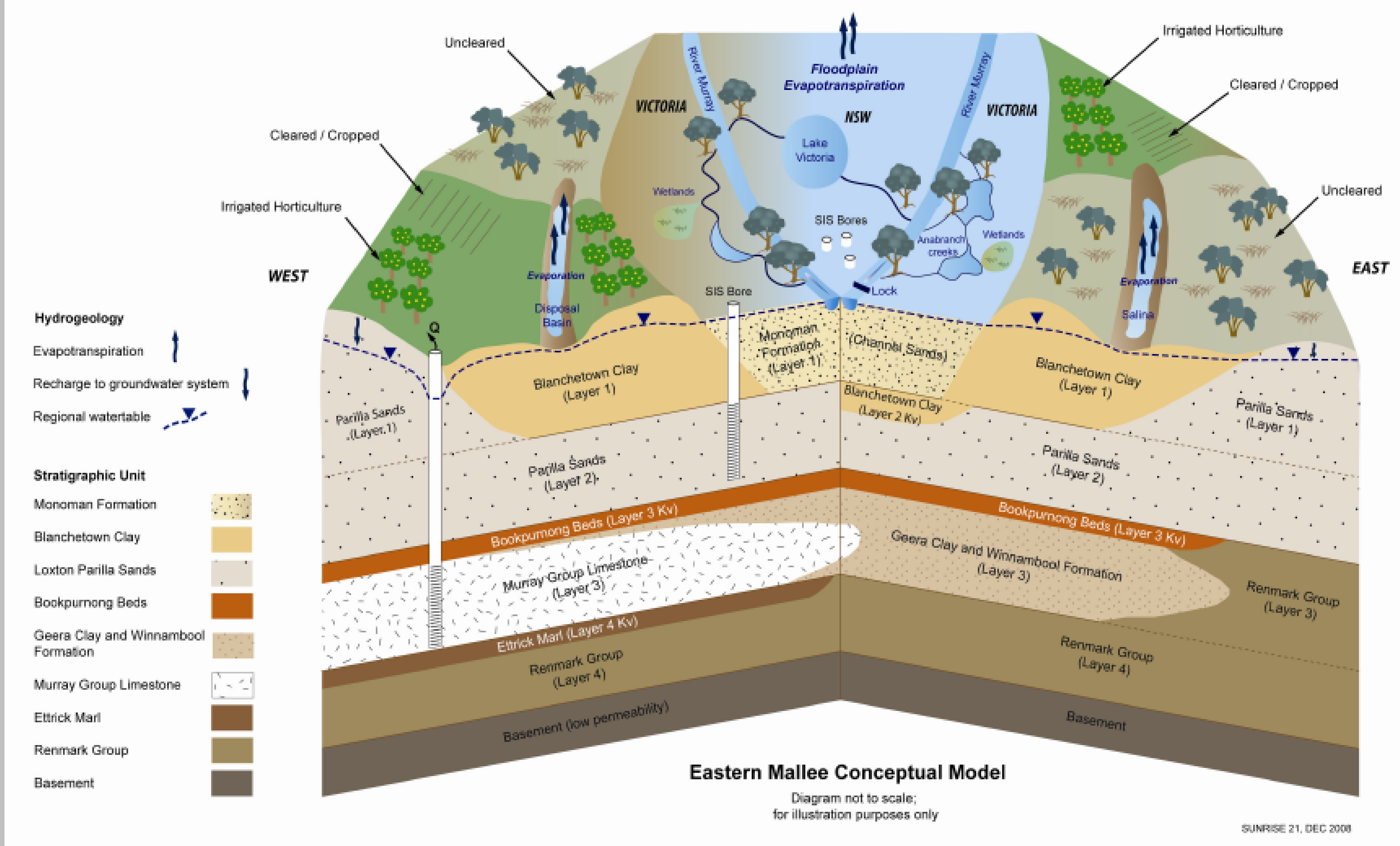
2.8.5 INTERACTION WITH LAKES

Lake Tyrrell is the largest of three salt lakes in the Tyrrell Basin with an area of 185km^2, located within the Mallee CMA. The two remaining salt lakes are Lake Wahpool and Lake Timboran. Direct rainfall in the winter months provides most of the surface water currently entering the lakes, with the lakes remaining water-covered for up to 3 months a year in the winter and early spring. The lakebeds are underlain by Parilla Sands, with the Parilla aquifer system contributing most of the salt load in the lake. "As upwelling regional groundwater reaches the Lake Tyrrell depression, it evaporates and concentrates and so becomes denser". It then sinks to mix with the regional groundwater crossflow atop the Geera Clay aquiclude" (Warren, 2006).

2.9 CONCEPTUAL MODEL

A conceptual block diagram summarising the conceptual model for the Mallee CMA is presented in Figure 2.3. The key features represented by the conceptual diagram are:

- The low permeability Bookpurnong Beds (not modelled as a specific layer) underlie the Parilla Sands, and effectively constrain any upwards vertical groundwater flow into the model domain;
- The Parilla Sands is the major regional aquifer; it can be unconfined and semi-confined, and it can be either in contact with the Monoman Formation or separated from it by the Blanchetown Clay;
- Overlying the Parilla Sands, the very low permeability Blanchetown Clay acts as a semi-confining unit, and can have saturated thicknesses of up to 50 metres; in some areas it is absent, either due to erosion processes (within the Murray trench) or due to non-deposition;
- Recharge occurs via rainfall, irrigation, leakage from surface water features, and river flow infiltration;
- Dryland recharge is complicated by the history of land clearing, the depth to the water table and the clay content of the unsaturated zone, which may introduce time lags into time- and space-variable recharge rates, especially where there is a thick and clay-rich unsaturated zone; however, there is data to indicate that time lags may not be significant in some areas, especially under irrigation areas (this is being further investigated);
- Groundwater discharge to the River Murray and/or floodplain is governed by the complex relationship between the groundwater head in the Parilla Sands and the Monoman Formation aquifers, evapotranspiration on the floodplain, and the dynamic river stage elevation;
- Discharge occurs through evapotranspiration in low-lying areas such as dryland salinas or the floodplain environment, with complex salt storage and release processes operating on the floodplain. Discharge also occurs within the Parilla Sands aquifer through the western boundary of the study area;
- There is no substantial groundwater pumping except that associated with salt interception schemes.



Uncleared
Cleared / Cropped
Irrigated Horticulture
WEST
EAST
VICTORIA
NSW
VICTORIA
River Murray
River Murray
Floodplain Evapotranspiration
Lake Victoria
Wetlands
SIS Bores
Anabranch creeks
Wetlands
Lock
SIS Bore
Evaporation
Disposal Basin
Evaporation
Salina
Q
Irrigated Horticulture
Cleared / Cropped
Uncleared
Hydrogeology
Evapotranspiration
Recharge to groundwater system
Regional watertable
Stratigraphic Unit
Monoman Formation
Blanchetown Clay
Loxton Parilla Sands
Bookpurnong Beds
Geera Clay and Winnambool Formation
Murray Group Limestone
Ettrick Marl
Renmark Group
Basement
Parilla Sands (Layer 1)
Blanchetown Clay (Layer 1)
Monoman Formation (Layer 1)
(Channel Sands)
Blanchetown Clay (Layer 2 Kv)
Blanchetown Clay (Layer 1)
Parilla Sands (Layer 1)
Parilla Sands (Layer 2)
Parilla Sands (Layer 2)
Bookpurnong Beds (Layer 3 Kv)
Bookpurnong Beds (Layer 3 Kv)
Murray Group Limestone (Layer 3)
Geera Clay and Winnambool Formation (Layer 3)
Renmark Group (Layer 3)
Ettrick Marl (Layer 4 Kv)
Renmark Group (Layer 4)
Renmark Group (Layer 4)
Basement (low permeability)
Basement
Eastern Mallee Conceptual Model
Diagram not to scale; for illustration purposes only
SUNRISE 21, DEC 2008

3 NUMERICAL MODEL DESIGN

3.1 GROUNDWATER MODELLING SOFTWARE

The MODFLOW modelling platform is used for this work, operating under the Groundwater Vistas Graphical User Interface (ESI Ltd, 2005). MODFLOW has industry-leading modules for simulating surface water and groundwater interaction. There have also been recent advances in the development of other modules (e.g. Banta, 2000; Harbaugh *et al.*, 2000), and likely further development in the future, which are expected to provide major benefit when applied to this project to simulate hydrological stresses and floodplain processes.

There continues to be major new developments in practical modelling approaches (rather than research-oriented approaches) based mainly on research outside Australia, but also on some within these shores. This is resulting in a range of integrated surface water and groundwater modelling packages becoming available, and it is expected that comprehensive and fully integrated surface water and groundwater models will be in standard use within five years, rather than the groundwater-focused or surface water-focused “integrated” models in current usage.

Notable Modflow and non-Modflow based platforms are:

- MODFLOW-based packages include ModHMS, an integrated catchment model, and MODFLOW-Surfact which includes more rigorous treatment of rewetting issues and unsaturated flow (a known shortcoming of the classical MODFLOW design);
- Mike-SHE is an integrated modelling package that is not based on MODFLOW and is known for its early reputation as having onerous data/budget/resourcing requirements and being suitable only for highly complex systems. Mike-SHE has been recently upgraded, and is receiving some of the most intensive code development worldwide. While Mike-SHE is not based on MODFLOW, it now provides an interface to it, and it also provides a comprehensive set of integrated surface and/or groundwater modules that range from very simple to highly complex, including unsaturated flow, such that it can model the entire hydrological cycle in a catchment;
- FeFlow (DHI Wasy) is a finite element modelling platform that provides advantages to modelling surface water-groundwater interactions in that the location and shape of water bodies can be more accurately modelled. However, this advantage is often outweighed by the difficulties in generating accurate water fluxes from the FeFlow software, which is a key model data output requirement for calculating salt loads;
- An object-oriented ZOOMQ3D is under development by the British Geological Survey and may provide future options for detailed regional scale and local scale modelling within the one package;
- A linkage between the surface water model IQQM and MODFLOW is an example of a development within Australia, designed to interactively model both surface and groundwater resources. The Integrated Quantity Quality Model (IQQM) is one of the adopted standard surface water management model for the Murray Darling Basin. However, only initial trials have been completed of the IQQM-MODFLOW link, and further development and testing is needed before the tool can be generally applied. This is being recommended to the MDBC on other projects.

In summary, while there is ongoing development of groundwater and integrated modelling codes, many of these developments involve MODFLOW or provide a transfer capability. Thus, it is virtually assured that further development of a MODFLOW-based model for any project will provide ongoing future utility.

3.2 MODEL EXTENT, GRIDDING AND BOUNDARY CONDITIONS

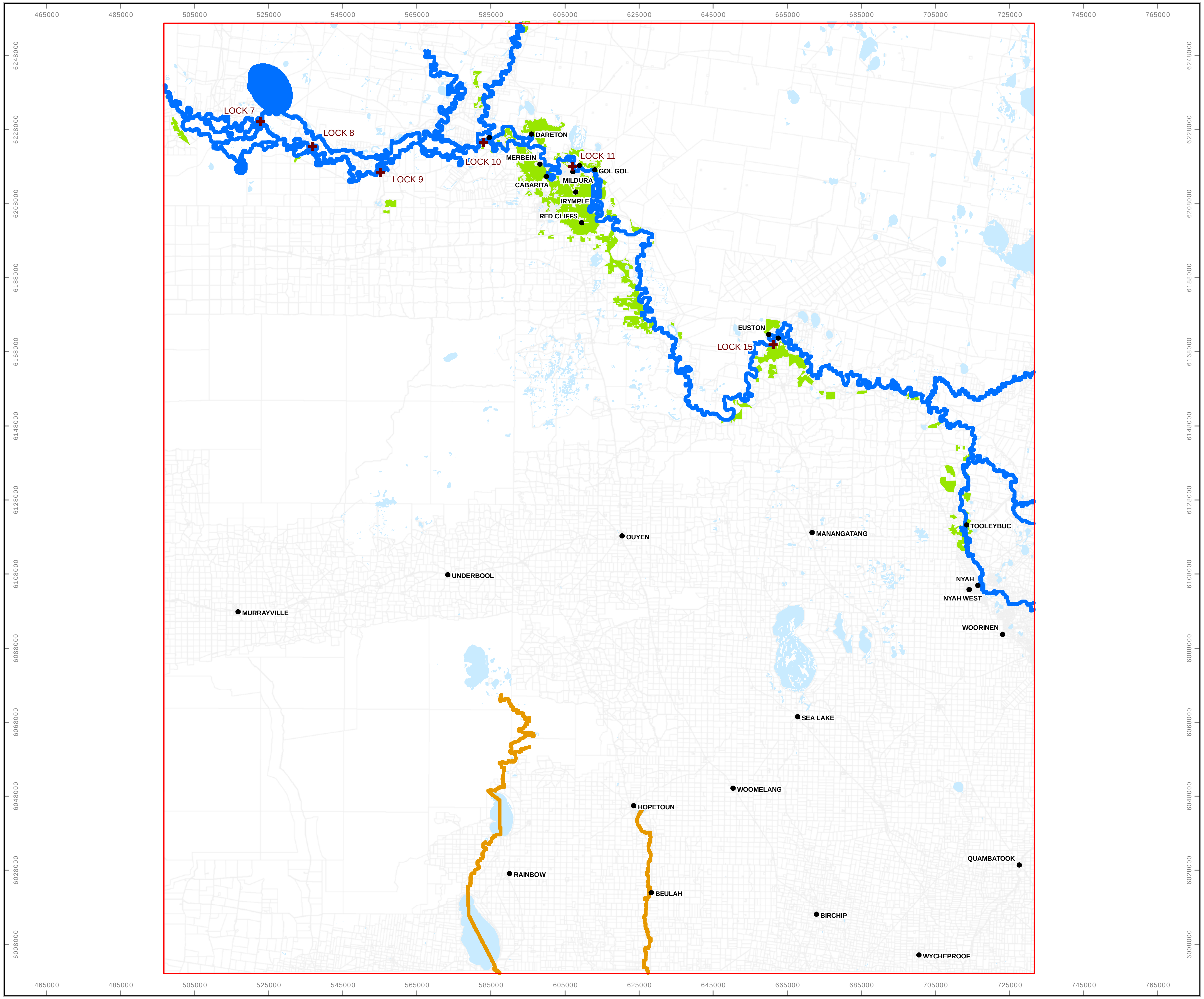
The previous EM1 model and its extensions, EM2 and EM4 were developed assuming that the principal aquifer unit was the Parilla Sands aquifer which is generally separated from the deeper units by the Bookpurnong Beds and Geera Clay. Since there was a need to represent the deeper

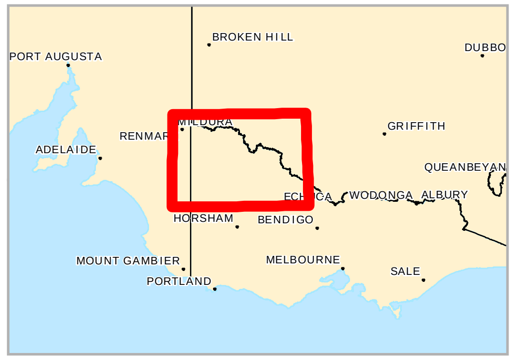
units to meet the secondary model purpose, the EM3 model includes aquifer and aquitard units extending to the Basement.

The extent of the model domain, along with the boundary conditions, is summarised as follows:

- Model domain covers the entire Mallee CMA area (plus small extensions into NSW, and also south into the Wimmera CMA area). The EM3 model area extends to the SA border from immediately west of Swan Hill, and from south of Lake Hindmarsh to north of Lake Victoria in NSW;
- The model has 1,283 rows and 1,175 columns, thus making 1,507,525 cells per layer, and 6,030,100 cells total (a very large Modflow model by any standard);
- The northern boundary, most of the western boundary and a mid-section of the eastern boundary, is specified as no-flow based on the regional water table contours being aligned orthogonal to the boundary. All the model boundaries in layer 1 are specified as no-flow;
- The southern boundary is a specified head boundary (consistent with the neighbouring Wimmera CMA model), with spatially variable head levels specified (ranging from 70 m AHD in the west to 110 m AHD in the east in layers 2 and 3; and ranging from 70 m AHD in the west to 90 m AHD in the east in layer 4;), consistent with the water levels provided on the hydrogeological map sheets;
- The southern part of the eastern boundary is a specified head boundary (consistent with the neighbouring North Central CMA model), with spatially variable head levels specified (ranging from 70 m AHD in the north to 90 m AHD in the south in layers 2 and 3, and ranging from 78 m AHD in the north to 90 m AHD in the south in layer 4), consistent with the water levels provided on the hydrogeological map sheets;
- The northern part of the eastern boundary is a specified head boundary, with spatially variable head levels specified (ranging from 53 m AHD in the north to 65 m AHD in the south in layer 2, and ranging from 53 m AHD in the north to 55 m AHD in the south in layers 3 and 4), consistent with the water levels provided on the hydrogeological map sheets;
- The northern part of the western boundary is a specified head boundary, with spatially variable head levels specified in layer 2 (ranging from 13 m AHD in the south to 18 m AHD in the north) and specified at a constant 24 and 30 m AHD in layers 3 and 4 respectively, consistent with the water levels provided on the hydrogeological map sheets.

Figures 3.1 – 3.4 presents the boundary condition arrangement, as well as the river and drain boundaries.





LEGEND

- Locks
- Localities
- Suface Water Bodies
- Irrigated Areas

MODEL FEATURES

- EM3 Model Boundary
- Rivers - DRN cells (Bed at 2m below Topography)
- Rivers - RIV Cells (Detailed BC data in Appendix)

N

0 15 30 45
Kilometres

SCALE 1:1,000,000 @ A3

GDA 1994 MGA Zone 54

DATA SOURCES

MCMA: Cultivated Areas
GA: Localities, Lakes, Locks
AQT: EM3 Model

Disclaimer: While all reasonable care has been taken to ensure the information contained on this map is up to date and accurate, no guarantee is given that the information portrayed is free from error or omission. Any relevance placed on such information shall be at the risk of the user. Please verify the accuracy of all information prior to use.

aquaterra

FIGURE 3.1

Modelled Boundary Conditions - Layer 1

AUTHOR	AL	REPORT NO	N/A
DRAWN	AL	REVISION	1
DATE	14/01/10	JOB NO.	A53B1 001

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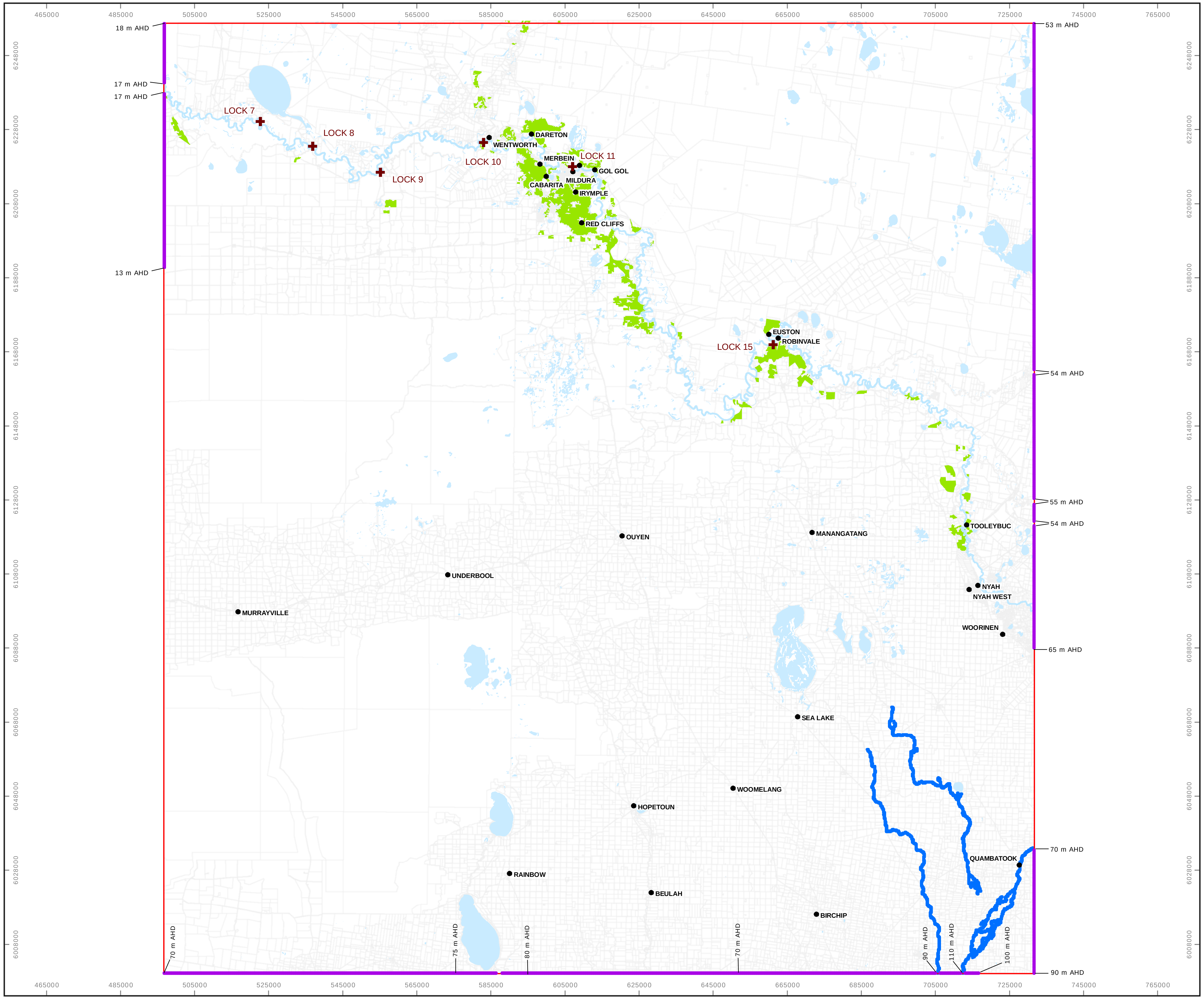

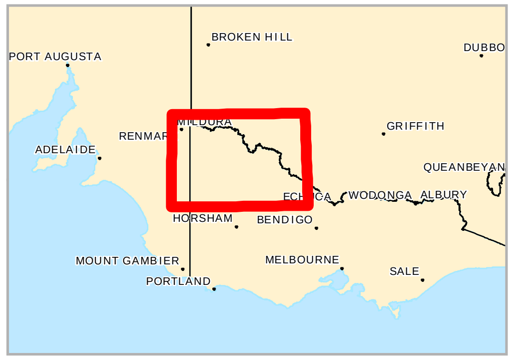

LEGEND

- Locks
- Localities
- Surface Water Bodies
- Irrigated Areas

MODEL FEATURES

- EM3 Model Boundary
- Inflow/Outflow - GHB cells (Specified head range)
- Rivers - RIV Cells (Detailed BC data in Appendix)

N

0 15 30 45
Kilometres

SCALE 1:1,000,000 @ A3

GDA 1994 MGA Zone 54

DATA SOURCES

MCMA: Cultivated Areas
GA: Localities, Lakes, Locks
AQT: EM3 Model

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FIGURE 3.2

Modelled Boundary Conditions - Layer 2

AUTHOR	AL	REPORT NO	N/A
DRAWN	AL	REVISION	1
DATE	14/01/10	JOB NO.	A53B1 002

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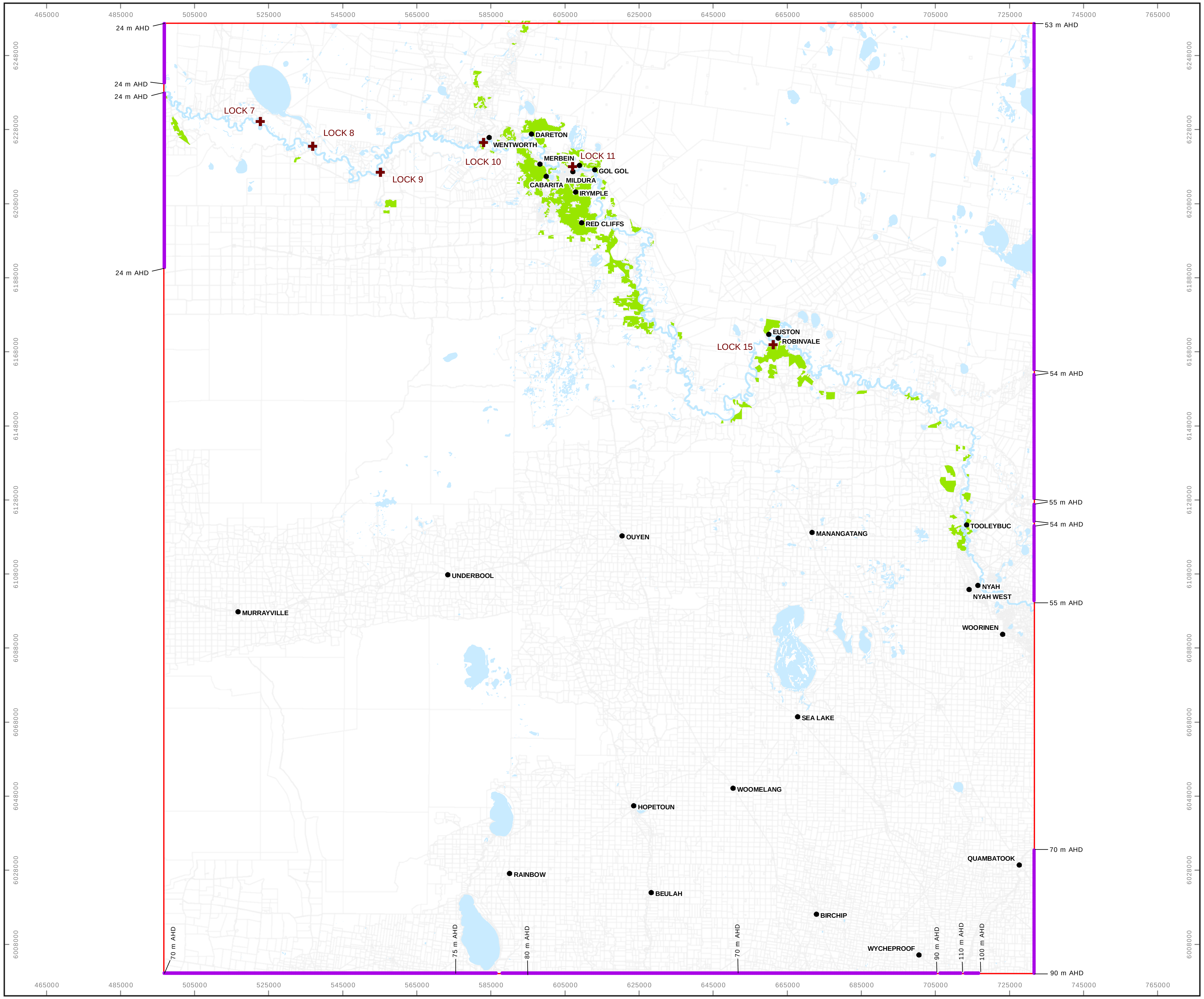

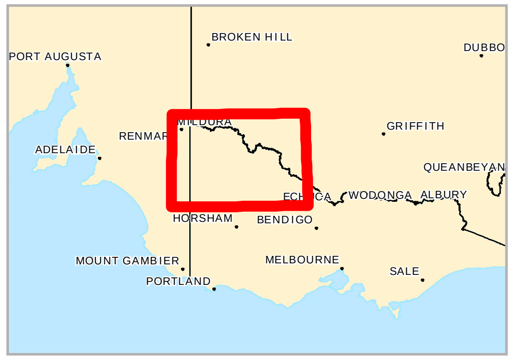

LEGEND

Locks

Localities

Surface Water Bodies

Irrigated Areas

MODEL FEATURES

EM3 Model Boundary

Inflow/Outflow - GHB cells (Specified head range)

Rivers - RIV Cells (Detailed BC data in Appendix)

N

0 15 30 45

Kilometres

SCALE 1:1,000,000 @ A3

GDA 1994 MGA Zone 54

DATA SOURCES

MCMA: Cultivated Areas
GA: Localities, Lakes, Locks
AQT: EM3 Model

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FIGURE 3.3

Modelled Boundary Conditions - Layer 3

AUTHOR	AL	REPORT NO	N/A
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DATE	14/01/10	JOB NO.	A53B1 003

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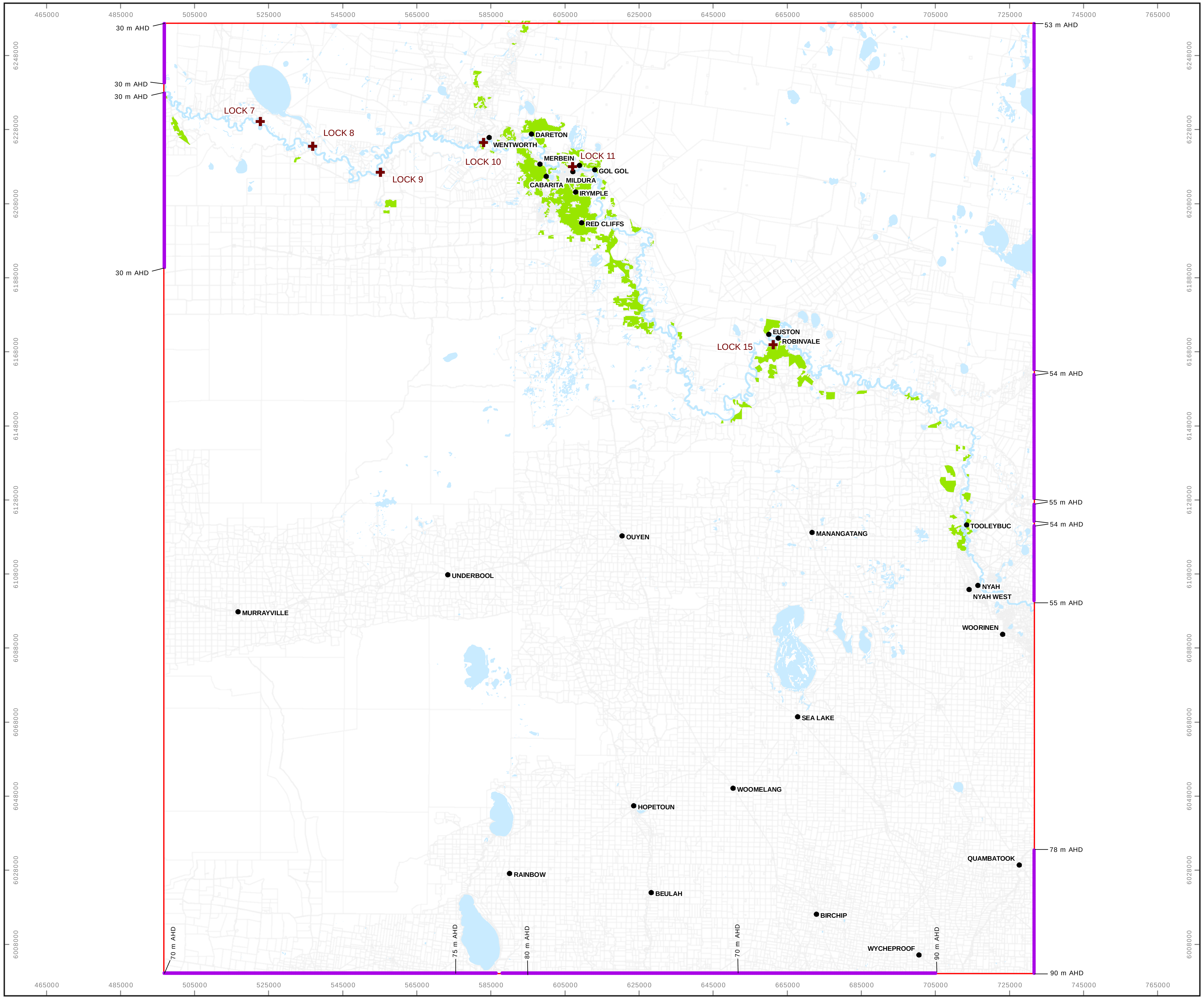

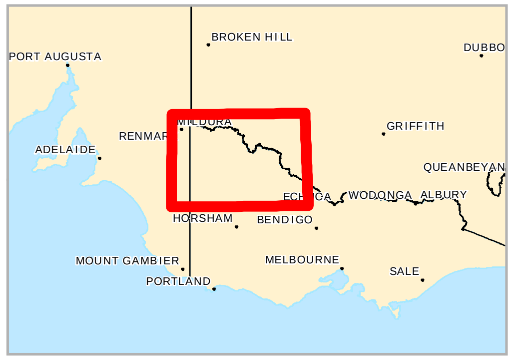

LEGEND

- Locks
- Localities
- Surface Water Bodies
- Irrigated Areas

MODEL FEATURES

- EM3 Model Boundary
- Inflow/Outflow - GHB cells (Specified head range)
- Rivers - RIV Cells (Detailed BC data in Appenidix)

N

0 15 30 45

Kilometres

SCALE 1:1,000,000 @ A3

GDA 1994 MGA Zone 54

DATA SOURCES

MCMA: Cultivated Areas
GA: Localities, Lakes, Locks
AQT: EM3 Model

Disclaimer: While all reasonable care has been taken to ensure the information contained on this map is up to date and accurate, no guarantee is given that the information portrayed is free from error or omission. Any relevance placed on such information shall be at the risk of the user. Please verify the accuracy of all information prior to use.

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FIGURE 3.4

Modelled Boundary Conditions - Layer 4

AUTHOR	AL	REPORT NO	N/A
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DATE	14/01/10	JOB NO.	A53B1 003

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3.3 MODEL LAYERS

3.3.1 SPATIAL EXTENT

The geology of the study area, and associated hydrogeological systems are described in detail in Sections 2.6 and 2.7. A summary of the aquifers/aquitards considered in the Mallee CMA is provided in the conceptual block diagram presented in Figure 2.1 as well as Table 3.1.

Table 3.1: Aquifers and Aquitards of Interest in the Study Area

Aquifer/ Aquitard Unit	Model Layer	Characteristics
Coonambidgal Formation	(not represented in EM3)	Low permeability unit overlying Monoman formation, producing short term semi-confined conditions.
Woorinen Formation	(not represented in EM3)	Low permeability unit overlying Blanchetown Clay, and mostly unsaturated across the study area.
Monoman Formation (Channel Sands)	Layer 1 within floodplain	High permeability unit within Murray Trench only, hydraulically connected to river channels.
Blanchetown Clay	Layer 1 outside floodplain, and Layer 2 (Kv) in areas where Monoman Formation overlies Blanchetown Clay within floodplain	Low permeability unit. Generally present outside the Murray Trench, and absent under the Murray Trench.
Parilla Sands	Layer 2, and Layer 1 in areas where Blanchetown Clay absent outside floodplain	Relatively high permeability unit present across entire Study Area, underlying the Channel Sands and Blanchetown Clay where present.
Bookpurnong Beds	Layer 3 (Kv)	Thin low permeability unit overlying the Murray Group Limestone, Geera Clay and Winnambool Formation.
Murray Group Limestone	Layer 3 (western part)	High permeability unit located in the western area of the Mallee CMA.
Geera Clay	Layer 3 (central part)	Low permeability unit. Predominantly overlies Renmark Group.
Winnambool Formation	Layer 3 (central part)	Low permeability unit. Predominantly overlies Murray Group Limestone.
Ettrick Marl	Layer 4 (Kv)	Relatively thin low permeability unit underlying the Murray Group Limestone. Separates the Renmark Group aquifer system from the Murray Group aquifer system.
Renmark Group	Layer 4, and Layer 3 where Parilla Sands directly overlies Renmark Group in east	High permeability unit present across majority of the study area.
Basement	Layer 4	Low permeability unit outcropping into the Renmark Group.

3.3.2 LAYER ELEVATIONS

At the time of EM1 model development, the most accurate digital elevation model (DEM) available for the topographical surface was the NASA SRTM DEM. For this project, a LIDAR topographical surface for the floodplain and a 20m grid spacing DEM for Victoria (Vicmap DEM) are available. The LIDAR surface is limited to the Murray floodplain, and was inserted into the Vicmap DEM (study area in Victoria) and the regional SRTM DEM (study area in NSW). The composite DEM was used as the upper reference surface for the EM3 model layer structure.

The use of the LIDAR DEM on the floodplain addresses a potential model limitation in regard to modelling shallow flow processes on the floodplain, as evapotranspiration from shallow water tables and stream-aquifer interaction processes are very dependent on accurate topographical information.

The current model development included a geological structure analysis of available bore logs from the EM1 model area, as well as the Victorian GMS, GEDIS and DPI databases accessed on 18 November 2008. The initial data, provided as "depth to" in metres, was converted to metres AHD based on the composite DEM. The converted bore log data was then extrapolated and smoothed to produce top and bottom elevation surfaces and isopach thicknesses for the Monoman Formation, Blanchetown Clay, Parilla Sand, Murray Group Limestone, Geera Clay, Winnambool Formation and Renmark Group units. Plots of layer elevations are presented in Appendix A.

The base of layer 1 is defined by assuming a minimum thickness of three metres for this layer generally. Where Monoman Formation and Blanchetown Clay are present, the bottom elevations for these units were applied to the base of layer 1 (while maintaining a minimum thickness of three metres).

The base of layer 2 is defined by the Parilla Sand base elevations, or the base of the equivalent Pliocene sand unit locally.

The base of layer 3 is defined by the Renmark Group top elevations. Ettrick Marl lies above the Renmark Group, however due to the thinness of the unit and the limited bore log data available, its thickness is assumed to be incorporated into layer 4. Renmark Group extends up into Layer 3 in areas to the east. Renmark Group top elevations are still applicable in these areas to represent base of layer 3 as the extrapolated layer surface grid provides a reasonable isopach thickness for layer 3 in these areas.

The base of layer 4 is defined by the top of basement elevations.

3.3.3 HYDROGEOLOGICAL PARAMETERISATION

Aquifer property values applied to the model layers have been constrained to physically realistic values, consistent with the range of values for parameters obtained from lithological and pumping test analysis undertaken on these units across the region and from a range of values used in EM series of models (values summarised in Table 2.1).

The values have been distributed spatially to the hydrogeological units. The horizontal and vertical hydraulic conductivity aquifer parameter distribution for each model layer is presented in plots in Appendix C and summarised in Table 3.2. The aquifer storage parameters (confined and unconfined) are not specified in the model since they are not required for steady state modelling.

Table 3.2: EM3 Hydrogeological Parameterisation

Layer(s)	Formation(s)	Horizontal Hydraulic Conductivity (Kh; m/d)	Vertical Hydraulic Conductivity (Kv; m/d)
1	Monoman Formation	15	1.5
1	Blanchetown Clay	0.0027	0.00027
1 and 2	Parilla Sands	20 (north) 50 (south)	5
2	Parilla Sands (with Blanchetown Clay influencing vertical leakage)	0.75	0.05
3	Murray Group Limestone (with Bookpurnong Beds influencing vertical leakage)	5 (north) 20 (south)	0.5 (north) 1 (south)
3	Murray Group Limestone (with Geera Clay/ Winnambool Formation and/or Bookpurnong Beds influencing vertical leakage)	0.1 (north) 5 (south)	0.001 (north) 0.01 (south
3	Geera Clay/ Winnambool Formation and Bookpurnong Beds	0.1 (north) 0.5 (south)	0.01
3 and 4	Renmark Group	25	0.5
4	Renmark Group (with Ettrick Marl influencing vertical leakage)	25	0.001
4	Basement	0.1	0.01

3.4 MODEL FEATURES FOR SURFACE WATER BODIES

3.4.1 RIVER MURRAY AND ASSOCIATED FEATURES

The numerical model uses MODFLOW River (RIV module) cells to represent the River Murray as well as major anabranch rivers, creeks and associated major lakes (notably Lake Victoria) downstream of Lock 10/Wentworth (refer Figures 3.1). The MODFLOW RIV package requires data on stage elevation, stream bed elevation and bed conductance.

The following assumptions have been applied to represent the River Murray:

- For each reach in the model, the bed level and the specified stage level are uniform (but the levels vary between reaches).
- Stage elevation data was collated from the EM1, EM2 and EM4 models. Where the EM3 model domain lay outside these models, to the far east and far north, the stage elevation of the connecting reach was extrapolated uniformly. It should be noted that the key data requirement is the River stage level, as it is this relationship between the stage level and the modelled groundwater level that governs the hydraulic loss/gain character of these major surface water bodies.
- Stream bed elevation data was based on river bathymetry which has been approximated from the water depth given by the NanoTEM survey (Telfer *et al.* 2006) reduced from the long term average pool level (stage elevation).
- Water depths indicate that the river is likely to be connected to the Monoman Formation. As the Monoman Formation is implemented in Layer 1, it is also appropriate for the river and associated features to be located in this layer.
- River bed conductance has been set to 150 m^2/day based on previous modelling work by Aquaterra (2009) in the region. There is scope to apply spatial distribution, e.g. to reduce this value for the floodplain anabranch creeks.

River reach details, including reach locality, stage and bed levels, are provided in Appendix D.

3.4.2 FLOODPLAIN WETLANDS

The representation of other significant surface bodies throughout the study area is summarised in Table 3.3.

Surface water bodies that have water level monitoring data and display a relatively low variation in water level (nominally selected as a standard deviation of 0.3 m or less) are assigned average water levels as a MODFLOW River feature. There are many of these basins, including the major ones of Lake Hawthorn, Lake Ranfurly, Basin 12/Psyche Bend Lagoon, Lambert's Swamp and Kings Billabong. The River Package allows for leakage to or from the water table, depending on the relative groundwater level.

There is no readily available water level data for Cardross Lakes and Mallee Cliffs Basin, however there is water balance data (SKM and AWE, 2003). These water bodies are represented in the model as recharge features using the MODFLOW Well Package, as per EM1 (Aquaterra, 2007).

Table 3.3: Floodplain Wetland Features in EM3 Model (Excluding Lindsay-Wallpolla)

Surface Water Body	Representation in Model	Recorded Values	Source of Data	Adopted Head or Rate
Mourquong Basin	Evaporative feature	--	SKM and AWE (2003)	Model to determine value (evaporation from shallow water table)
Lake Hawthorn	River package	34.4 to 35.8 m AHD (July 1988-May 2006) Average: 35.0 m AHD	Provided by Mallee CMA	35.0 m AHD
Lake Ranfurly	River package	33.6 to 34.4 m AHD (2004-06) Average: 34.0 m AHD (for Ranfurly East and West combined)	Provided by Mallee CMA	34.0 m AHD
Basin 12 and Psyche Bend	River package	--	Ecological Associates (2007)	36.0 m AHD
Fletcher's Lake	Evaporative feature	No data available	No data available	Model to determine value (evaporation from shallow water table)
Koorlong Basins	Nil	No data available	No data available	No data available, but located on the landward side of irrigation mound thus exclusion is unlikely to affect predictions
Wargan Basins	Nil	--	SKM and AWE (2003)	No groundwater interaction
Cardross Lakes	Recharge feature using Well package	--	SKM and AWE (2003)	164 ML/year recharge
Lamberts Swamp	River package	32.2 to 33.0 m AHD (July 1983-Dec 2004) Average: 32.5 m AHD	DSE (2007)	32.5 m AHD
Mallee Cliffs Basin	Recharge feature using Well package	--	SKM and AWE (2003)	822 ML/year recharge

Surface Water Body	Representation in Model	Recorded Values	Source of Data	Adopted Head or Rate
Rifle Butts Swamp	Nil	No data available	No data available	Relatively minor feature, exclusion is unlikely to affect predictions
Apex Park Lagoon	River package	Approx. 36 m AHD	Provided by G-MW	36.0 m AHD
Kings Billabong	River package	Maintained at 37 m AHD	SKM (2002)	37.0 m AHD
Gol Gol lake and swamp	Evaporative feature	--	Aquaterra (2007a)	Model to determine value (evaporation from shallow water table)
Bullock Swamp/Lake Iraak	Evaporative feature	--	Mallee CMA (2000)	Model to determine value (evaporation from shallow water table)
Karadoc Swamp	Evaporative feature	--	SKM (2002a)	Model to determine value (evaporation from shallow water table)
Rifle Butts Swamp	Nil	No data available	No data available	Relatively minor feature, exclusion is unlikely to affect predictions
Lake Tyrrell	Evaporative feature	TBC		Model to determine value (evaporation from shallow water table)
Lakes Wahpool and Timboram	Evaporative feature	TBC		Model to determine value (evaporation from shallow water table)
Lakes Albacutya and Hindmarsh	Evaporative feature	TBC		Model to determine value (evaporation from shallow water table)

All surface water features represented using the River package have an assumed bed conductance of 150 m^2/day.

All low-lying areas (with the exception of the river itself) are subject to evapotranspiration (ET) in the model. Thus all natural depressions, whether or not they are on the floodplain, and whether or not they receive small quantities of drainage water and/or floodwaters from the River, are represented in the model as potential evaporative (discharge) features, using the MODFLOW ET package. This provides the opportunity, where warranted, to apply site-specific parameters to the ET package to represent detailed water balance processes for any specific landscape feature. If there is data available on recharge to the water table from these features, then that can also be incorporated into the model.

No data is available for Fletcher's Lake and Koorlong Basins, and as they are on the landward side of irrigation mounds, and as groundwater levels are shallow at these locations (natural depressions), the MODFLOW ET package should ensure that these locations act as evaporative (discharge) features with little influence on fluxes to the River. This is also the situation for Mourquong Basin and Wargan Basins, which have previously been shown to have minimal interaction with groundwater in terms of leakage (SKM and AWE, 2003) and no specific representation in the model is implemented other than as an evaporative feature, which allows for quantification of discharge volumes.

While there is no data for Rifle Butt Swamp, given the small size of this water body, it is unlikely to have an appreciable influence on fluxes to the River, and is not specifically included in the model.

Recharge to the irrigated treelots and pastures of the Apex Park wastewater treatment facility (north-west of Mildura), and the lagoon is treated as a River feature.

3.4.3 STREAMS AND LAKES IN THE SOUTHERN PART OF THE MALLEE CMA

The numerical model uses MODFLOW DRAIN cells to represent the following major surface bodies that are located mostly within the southern part of the Study Area (refer Figure 3.2):

- Wimmera River;
- Outlet Creek;
- Yarriambiack Creek.

The MODFLOW Drain package works in a similar way to the River package, although it only allows for groundwater inflow to the drain (not leakage from the drain to the aquifer). The Drain package requires data on the drain bed level and bed conductance. The following assumptions were applied to represent the aforementioned major surface bodies:

- Drain bed is taken as two metres below surface elevation, determined from the composite DEM;
- Drain bed conductance has been set to 150 m^2/day.

The numerical model uses MODFLOW RIVER cells to represent the following major surface bodies that are located mostly within the south-eastern part of the Study Area (refer Figure 3.1), and are considered to be potential sources of leakage to the aquifer:

- Tyrrell Creek;
- Lalbert Creek;
- Avoca River;
- Mosquito Creek.

The following assumptions have been applied to represent these major surface bodies in the River package:

- River stage elevation is taken as 1.5 metres below surface elevation, determined from the composite DEM;
- River bed elevation is taken as two metres below surface elevation, determined from the composite DEM;
- River bed conductance has been set to 150 m^2/day.

3.5 EVAPOTRANSPIRATION

Evapotranspiration (ET) is applied using the MODFLOW Evapotranspiration package which requires data on the topography, the maximum ET rate, and the extinction depth (where ET reduces to zero).

Across the majority of the model a maximum ET rate of 900 mm/year has been applied at the surface of the model diminishing to zero at the extinction depth of 2 m, consistent with the EM2 and EM4 models as outlined below.

For the current assumption of an extinction depth of 2 metres, ET is active in the EM3 model only in those areas where the water table is quite close to the surface (e.g. Lake Tyrell and parts of the floodplain). In these areas, there is effectively an unlimited supply of water available for evapo(transpi)ration. In which case, ET discharge from the water table in the model is appropriate, whether or not ET from the unsaturated zone has already been calculated as part of the ENSYM model recharge estimation procedure. Further refinement of the ET rates and/or extinction depths will likely be required for the transient model, but for the purposes of the steady state calibration, an initially simple approach has been adopted.

3.5.1 EVAPOTRANSPIRATION ADOPTED FROM THE EM2 MODEL

Evapotranspiration in the area covered by the EM2 model domain has been split into two zones, the highland and the floodplain. Surface elevation on the floodplain is based on the relatively new digital elevation model (LIDAR), which greatly improves the simulation of ET in the floodplain, where ET is most active. The less accurate SRTM data outside the floodplain is less critical to the broad scale highland ET function, as ET is only active in the few low-lying areas.

In the highland regions (i.e. everywhere outside the floodplain), evaporation occurs only in areas of shallow water tables, which is mainly in low-lying areas, such as highly saline environments close to salinas and boinkas, where there is negligible use direct from the water table by transpiring plants. Uniformly across the highland areas, a maximum ET rate of 900 mm/year has been applied at the surface of the model. The maximum rate decreases linearly with depth to zero at the specified extinction depth of 2 m.

Within the floodplain, initial versions of the EM2 model adopted a blanket approach to ET, as described above (consistent with some models of the Murray-Darling Basin). However, Aquaterra previously identified that this methodology may be too simplistic in that it assumes transpiring plants use water from the capillary fringe of shallow water tables across the floodplain (i.e. regardless of salinity or vegetation type). Work by CSIRO suggests that plant water use from the capillary fringe is largely governed by salinity and vegetation type (pers. comm. Ian Overton and Tanya Doody, CSIRO, March 2009), i.e. high evaporation would be limited to areas of healthy red gum forest and relatively fresh groundwater near the main streams, whereas low evaporation would apply to area of Black Box and other vegetation on the floodplain terraces.

To address this issue in the current version of the EM2 model, ET on the floodplain was zoned according the vegetation type and salinity, and the learnings from this work have been applied to this EM3 model, as described below. Vegetation type has been classified into five broad classes based on the NSW vegetation surveys and Victorian Ecological Vegetation Class surveys:

- Red gum community;
- Black box community;
- Belah rosewood community;
- Chenopod shrubland;
- Lignum shrubland.

At locations where there are red gum communities and fresher groundwater (i.e. close to the rivers and creeks on the floodplain, which are also usually the areas where the water table is also shallowest), the maximum ET rate was set at 600 or 300 mm/year, dependent on the groundwater salinity. Elsewhere on the floodplain, in the four remaining vegetation communities listed above, the maximum ET rate was kept constant at 900 mm/year applied at the surface of the model. Extinction depth in both cases was set to 2 m in EM3 (whereas in the EM2 model, there was spatial variation in extinction depth). While this may seem counter-intuitive (ie. lower maximum ET rates in areas where ET should be higher), it should be noted that the areas of non-red gum vegetation correspond with higher salinity, and they also tend to be in the higher relief areas of floodplain terraces with a greater depth to water table. Thus the specification of a higher maximum rate with a 2m extinction depth has the effect of reducing the effective ET rate in the model in those vegetated but non-red gum and higher relief areas, but allowing for high evaporation (ie. little to no transpiration) in low-lying areas on the floodplain where the water table is close to the surface (eg. Mourquong).

3.5.2 EVAPOTRANSPIRATION IN THE LINDSAY-WALLPOLLA (EM4) AREA

Where the floodplain of the study area is located within the EM4 model domain (downstream of Lock 10/Wentworth in the Lindsay-Wallpolla area), more refined ET zones from the EM4 model were used. In these areas, a spatially variable maximum ET rate is specified, based on groundwater salinity, vegetation type and health data, ranging up to about 700 mm/year in small areas (and 1800 mm/year in areas of open water). A uniform ET extinction depth of two metres below surface elevation has again been specified in the model, but there is scope for refinement of this parameter during transient calibration.

Estimates of the maximum ET rate on the Lindsay-Wallpolla floodplain (EM4 model area) were provided to Aquaterra for the EM4 project by REM-SKM (2009), using the following methodology. Estimates of ET rates were based on vegetation type generally, and detailed riparian vegetation water balance studies in some areas, but only basic sap-flow measurements in other areas, according to REM-SKM. The ranges assigned to each species in the study area were varied depending on the groundwater salinity in the Channel Sands aquifer (i.e. low ET for

high salinity zones) and the vegetation health classification (lowest ET for stressed vegetation). An ET rate of 5 mm/d (1800 mm/yr) was assigned to surface water features.

For the purpose of this exercise, it is assumed that where the density of Red Gum or Black Box is thin (i.e. transpiration is relatively low), evaporative losses from the ground surface or other vegetation species make up the balance of the ET rate assigned to each zone (ie. ET rates were applied regardless of vegetation density). Where vegetation types other than Red Gum and Black Box predominated, ET of 0.65 mm/d (237 mm/yr) was applied as a background rate, consistent with previous EM regional groundwater model calibrations, and reflecting an actual ET rate (ie. limited by water available) rather than a potential ET (ie. not limited by water availability).

In the Red Gum and Black Box areas, ET zones were generated by intersecting the EVC spatial vegetation class coverages with the groundwater salinity contours in the Channel Sands aquifer. Where available, field vegetation health/stress data from Red Gum and Black Box field surveys in NSW and Bookpurnong was also considered. ET rates ranged from 0.9 to 1.9 mm/day (328 to 693 mm/yr) for Red Gum and 0.58 to 0.85 mm/d (182 to 310 mm/yr) for Black Box, and the groundwater salinity and/or the vegetation stress assessments available for certain areas were provided by T. Doody (CSIRO, pers. comm., 2008, cited in SKM, 2009).

Floodplain vegetation uses water from both the unsaturated soil profile and groundwater sources to satisfy its ET demand. REM-SKM indicated that the available data does not allow differentiation or partitioning between the sources of water accessed by the floodplain vegetation in the study area. As these rates were applied to the model as a maximum annual average ET rate (ie. for the condition of the modelled water table being at the topographic surface), with an extinction depth of 2 metres, the effective (depth-dependent) ET rate in the model is lower.

Appendix E presents the spatial distribution of evapotranspiration rates across the model. There is scope for further refinement of ET features (e.g. during transient calibration) in terms of maximum rates and extinction depths.

3.6 DSE SUPPLIED RECHARGE

Dryland rainfall and irrigation recharge is applied to the model using the MODFLOW Recharge Package. This package applies recharge directly to the top of the water table and thus represents deep drainage past the root zone of plants. DSE provided the recharge data sets (incorporating irrigation recharge). Zero time lag has been assumed as a simple assumption at this stage of model development.

Appendix F presents the spatial distribution of recharge rates across the model.

3.7 IRRIGATION AND SALT INTERCEPTION PUMPING

3.7.1 IRRIGATION PUMPING

Abstraction data was provided for the Grampians Wimmera Mallee Water regions, in the form of annual average metered abstraction volumes taken over five years (historical time period not specified) for irrigation, urban and intensive bores.

A total of 57 irrigation bores were incorporated into the EM3 model using the MODFLOW Well Package. They are situated in the Murray Group Limestone aquifer (layer 3 of the model), mostly in the south-west corner. Steady state abstraction rates vary from 5 to 4685 m^3/day, however it may be necessary to refine these rates as they are based on averaged volumes over an unknown period of time (rather than metered values).

3.7.2 SALT INTERCEPTION SCHEMES

Four of the five Salt Interception Schemes (SIS) operating in the study area have been incorporated into the EM3 model using the MODFLOW Wells Package. Historical pumping by the Rufus River SIS (in NSW) has not been incorporated into the model as limited data was available (from 2004 to 2008), and the data that was available was regarded as unreliable.

Average annual pumping rates, based on the period January 1997 to January 2003, for the remaining four SIS were incorporated into the model. The average annual pumping rates for the individual bores within the schemes are summarised in Table 3.4.

Table 3.4: EM3 SIS Average Annual Pumping Rates

Salt interception scheme	Bore number	Average annual pumping rate (m^3/day)
Mildura Merbein	MMIS-1	350.9
Mildura Merbein	MMIS-2	310.9
Mildura Merbein	MMIS-3	492.8
Mildura Merbein	MMIS-4a	673.9
Mildura Merbein	MMIS-5	423.8
Mildura Merbein	MMIS-6a	686.4
Mildura Merbein	MMIS-7	425.9
Mildura Merbein	MMIS-8	165.6
Mildura Merbein	MMIS-9	131.6
Mildura Merbein	MMIS-10	0.1
Mildura Merbein	MMIS-11	235.3
Mildura Merbein	MMIS-12	437.4
Mildura Merbein	MMIS-13	773.9
Mildura Merbein	MMIS-14	0.0
Mildura Merbein	MMIS-15	330.8
Mildura Merbein	MMIS-16	153.8
Mildura Merbein	MMIS-17	0.0
Buronga	GW039483	1,075.3
Buronga	GW040895	0.0
Buronga	GW087304	1,004.9
Buronga	GW087305	1,058.0
Buronga	GW087314	1,938.8
Buronga	GW087317	653.5
Buronga	GW088469	0.0
Buronga	GW088470	785.7
Curlwaa	Curlwaa 1	252.8
Curlwaa	Curlwaa 2	191.5
Curlwaa	Curlwaa 3	198.6
Curlwaa	Curlwaa 4	177.6
Mallee Cliffs	GW036622	274.9
Mallee Cliffs	GW036861	570.2
Mallee Cliffs	GW036864	323.4
Mallee Cliffs	GW036923	540.4
Mallee Cliffs	GW036924	7.6
Mallee Cliffs	GW036936	113.9

Salt interception scheme	Bore number	Average annual pumping rate (m^3/day)
Mallee Cliffs	GW036980	381.6

3.8 STEADY STATE WATER LEVELS

A steady-state model run is used to approximate long term average conditions. During the past decade the hydrological conditions are thought to reflect drier than long-term average conditions, therefore it is more appropriate to consider a quasi steady state representing the last few decades, and also the period for which a transient calibration would be conducted.

Taking these considerations into account, January 2000 was selected as a benchmark for the steady state calibration, consistent with the Baseline Date for MDBA salinity assessments.

4 STEADY STATE MODEL CALIBRATION

4.1 CALIBRATION APPROACH

The steady state calibration process was undertaken in compliance with the MDBC Groundwater Flow Modelling Guideline (2001). In identifying the period to represent the steady state conditions, the following was taken into account:

- Changing climatic conditions (ie. influence of droughts);
- Availability and quality of monitoring data;
- Experience with other modelling projects in the region.

The approach to calibration was to vary aquifer parameters and boundary conditions to achieve a match to measured data. Model calibration is demonstrated in quantitative (head value matches) and qualitative (pattern-matching) terms, by:

- Scatter plots of modelled versus measured head, and the associated statistical measure of the scaled root mean square (SRMS) value;
- Contour plans of modelled head, with posted spot heights of measured heads; and
- Modelled water balance components, and comparison with measured/estimated values

Calibration was somewhat constrained by the prescribed recharge dataset which was supplied by the DSE. Recharge values in this dataset differ from the results in some areas obtained with other models. The following strategy was applied to deal with this apparent discrepancy:

- Hydraulic conductivity values (both horizontal and vertical) were varied to achieve matches to observed water level measurements in areas not covered by previous modelling work;
- The head assignment in GHB boundary conditions was subject to some uncertainty due to outdated data or poor data cover and in some cases a trial and error technique was applied to setting boundary head values for individual layers;
- Only limited calibration work was attempted for areas such as Sunraysia where we believe the DSE recharge values set for irrigated areas are not consistent with (i.e. much lower than) widely adopted/accepted irrigation figures;
- As there were limits to what could be achieved by varying hydraulic parameters other than recharge within reasonable range of values, the residuals between modelled and observed values in some areas were provisionally accepted, although these could be improved with changes to the recharge dataset.

In addition to the above calibration targets we used our experience with well calibrated models (such as EM2 developed for Sunraysia and EM4 for the NW part of the model domain), where parameter values are constrained by previously computed and calibrated salt fluxes to the River Murray (Aquaterra, 2009b, 2008).

The main quantitative model performance indicator is the scaled RMS value (the RMS error term divided by the range of heads across the catchment. A 5% scaled RMS value for aquifer water levels was set in the project specifications as an appropriate upper range target. This approach is consistent with the Australian best practice groundwater modelling guidelines (MDBC, 2001).

4.2 STEADY STATE CALIBRATION RESULTS

Steady state calibration represents long term average groundwater conditions that do not include or account for any change in aquifer storage (i.e. no long term trend in piezometric levels).

During the calibration process a number of different parameters were adjusted in an effort to provide an adequate calibration performance. Horizontal and vertical hydraulic conductivity, recharge and general head boundaries (GHB) were all investigated and the sensitivities of these

elements to the model's performance is provided. Appendix G presents a selection of the model runs undertaken; the adjustment made for each run as well as an outline of some basic model performance statistics.

4.2.1 HYDRAULIC CONDUCTIVITY

The initial model runs showed general mounding of water levels in the south (i.e. modelled water levels were higher than observed) and flattening in the riverine and specifically irrigated areas (modelled water levels were lower than observed nearer to the river). Because lower modelled levels in irrigated areas can be explained by relatively low assigned recharge, more calibration effort was given to try to replicate the observed mounding effects.

To deal with mounding over the course of the calibration process, horizontal hydraulic conductivity in layers 2 and 3, predominantly in the aquifer units in those layers, was progressively increased. The runs in which horizontal hydraulic conductivity were adjusted indicate that this parameter does have a significant impact on lowering the SRMS, and significantly changes the modelled heads. However the final adopted parameter values are at the upper limit of reasonable values, e.g. the southern section of Parilla Sand aquifer is currently assigned 50 m/d and even at this value the water levels may be deemed to high. However, any further hydraulic conductivity increases to assist in the refinement of the model would likely be considered unrealistic for this hydrogeological system.

It is possible that local zones or lineaments of highly transmissive zones may be present within the modelled domain but there is little hydrogeological evidence or data available to formalise this in a workable approach. Rather than attributing localised high residuals to unproven high conductivity zones we followed the principle of parsimony and preferred the more regional/global changes to parameter values for individual lithologies that are conceptualised as broadly uniform and spatially extensive hydraulic conductivity zones.

Whilst altering horizontal hydraulic conductivity appears to have a marked affect on the model results, adjustment of the vertical hydraulic conductivity has comparatively little impact. The vertical hydraulic conductivity in layers 3 and 4 was successively increased over a number of model runs, with very little change in SRMS values and difference in changes to modelled heads. This would suggest that the model is not particularly sensitive to high values of the vertical hydraulic conductivity parameter in the steady state model, but may become more important in the transient modelling stage. The model performance was adversely affected when specifying lower values for vertical hydraulic conductivity.

4.2.2 HEAD-DEPENDENT FLOW BOUNDARIES

Hydraulic conductivity adjustment was in some cases not sufficient to account for differences between modelled and observed water levels, particularly in the southern and western sections of the model domain. As an additional measure we refined the Head-Dependent Flow boundaries (using the Modflow GHB package) in these areas, in particular the southern boundary. Modification of the GHBs generally did have a significant effect on model performance.

However, whilst overall there appears to be an improvement in model performance and this is certainly the case for water levels nearby the boundaries, there is a diminishing effect further away from the boundaries. As expected the water levels in the central region of the model do not appear to be sensitive to changes in boundary conditions.

The work on calibration with boundary conditions also suggests the presence of varying groundwater pressures with depth in individual lithological or aquifer units. This led to specification of non-uniform head levels in individual layers along some stretches of the boundaries, e.g. in the northern section of the western boundary as indicated in Section 2.2.1.

4.2.3 RECHARGE

The recharge values prescribed per model cell have been developed independently by DSE and were not subject to calibration (other than sensitivity testing in some cases). Our experience with calibration of this model and other modelling work carried in areas covered by the model domain indicates that the prescribed recharge implemented in the model may be too high for some parts of this catchment, particularly in the south. Large sections of the model domain in the south have prescribed values in excess of 5 mm/yr or even 15 mm/yr which is thought to

be unrealistic, and is not consistent with the significant body of research in this area (eg. Cook *et al.* 2004).

The notable exception is the Sunraysia irrigation region near the River Murray, where the prescribed recharge is considered insufficient when compared against the detailed EM2 recharge dataset which is based on measurements (and some estimates) of river diversion volumes, diversion losses, irrigation areas, water use efficiencies and drainage rates (Aquaterra, 2009b).

The degree to which recharge may be responsible for the mounding effects in the south was explored with several exploratory runs in which recharge was adjusted to lower values (ie, reductions down to 3 to 10 mm/yr). Considering the degree to which the rates were decreased, there was only a small variation in the SRMS and changes in modelled water levels, which suggests that recharge in those runs was not a particularly sensitive parameter. It is however possible that even those values were too high and therefore the resulting changes in the water level configuration were inadequate.

4.2.4 RIVER AND GHB CONDUCTANCE

Murray River bed conductance was adopted at 150 m^2/day. Spatial variation in river bed conductance was not considered at this stage.

GHB conductance was varied during the calibration process, increasing from 500 m/day to 10,000 m/day.

4.3 STEADY STATE CALIBRATION RESULTS

4.3.1 CALIBRATION STATISTICS

The steady state calibration statistics are summarised in Table 4.1 and the scatter plot of measured versus modelled head is shown in Figure 3.1. A scaled RMS value of 3.95% which is well within the 5% target, and a coefficient of determination of 1.04 (the target value is 1.00) is achieved, both consistent with the Groundwater Flow Modelling Guidelines (MDBC, 2001). However, calibration performance indicators in Appendix H and the scatter plot show some significant differences between modelled and measured levels in certain areas, indicating potential uncertainty in predictive model results.

Appendix H presents details on the calibration performance, including the bore coordinates, model layer assignment for the screened interval, observed head and modelled head. The completion aquifer for each bore has been based on data provided by the Victorian DSE Groundwater Management System (GMS) database, as well as lithological elevation data.

Table 4.1: Calibration Performance Indicators of Mallee CMA Steady State Model

Calibration Parameters		Value
Root Mean Square	RMS	3.45 m
Scaled RMS	SRMS	3.95 %
Coefficient of Determination	CD	1.04

The scatter plot in Figure 4.1 indicates that the majority of the modelled heads are close to the measured heads, with approximately half the modelled heads systematically lower, with differences ranging up to 8.83 m (average 2.18 m). Modelled heads observed to be higher than the measured heads had a greater difference range, from 0.01 to 14.75 m (average 2.73 m). 58 bores were excluded as outliers, all from Layer 1, as they were located in shallow or perched water tables (eg. in the Woorinen Formation) and therefore not explicitly represented by this model.

4.3.2 WATER LEVEL CONTOUR PLOTS

Figures 4.2 to 4.5 present the modelled water level contours incorporating residual plots. The grey shaded area within the model domain represents the dry cells, which can be observed to occur in layers 1 and 2. The general groundwater flow pattern for all four layers is from the

south-east to the north-west, which is in agreement with the known/mapped groundwater flow pattern.

It can be seen that the dry cell pattern dominates in layer 1 and the residuals around Lake Tyrell are not too high.

Water level contour plots for layer 2 (Figure 3.3) show an area of dry cells along the southern half of the western boundary indicating that measured and modelled water levels both lie close to the layer 2 interface. The residuals indicate that the irrigation areas in the Sunraysia region along the River Murray generally exhibit modelled water levels that are lower than the measured spot values, whilst those areas in the Parilla across the remainder of the model predominantly indicate modelled water levels higher than measured values. This suggests that the irrigation area recharge rates are too low, and perhaps the dryland area recharge rates may be too high.

Residuals in layer 3 and 4 both indicate that modelled water levels in the north are lower than measured spot values, whilst the opposite is observed in the south (aside from where southern drain and river features that are influencing the flow in layer 3, as well as layer 2). Layer 3 also shows some large discrepancies between the modelled and measured water levels around the Murrayville WSPA area to the west, indicating that there may be an issue with the level of accuracy in terms of the pumping data implemented.

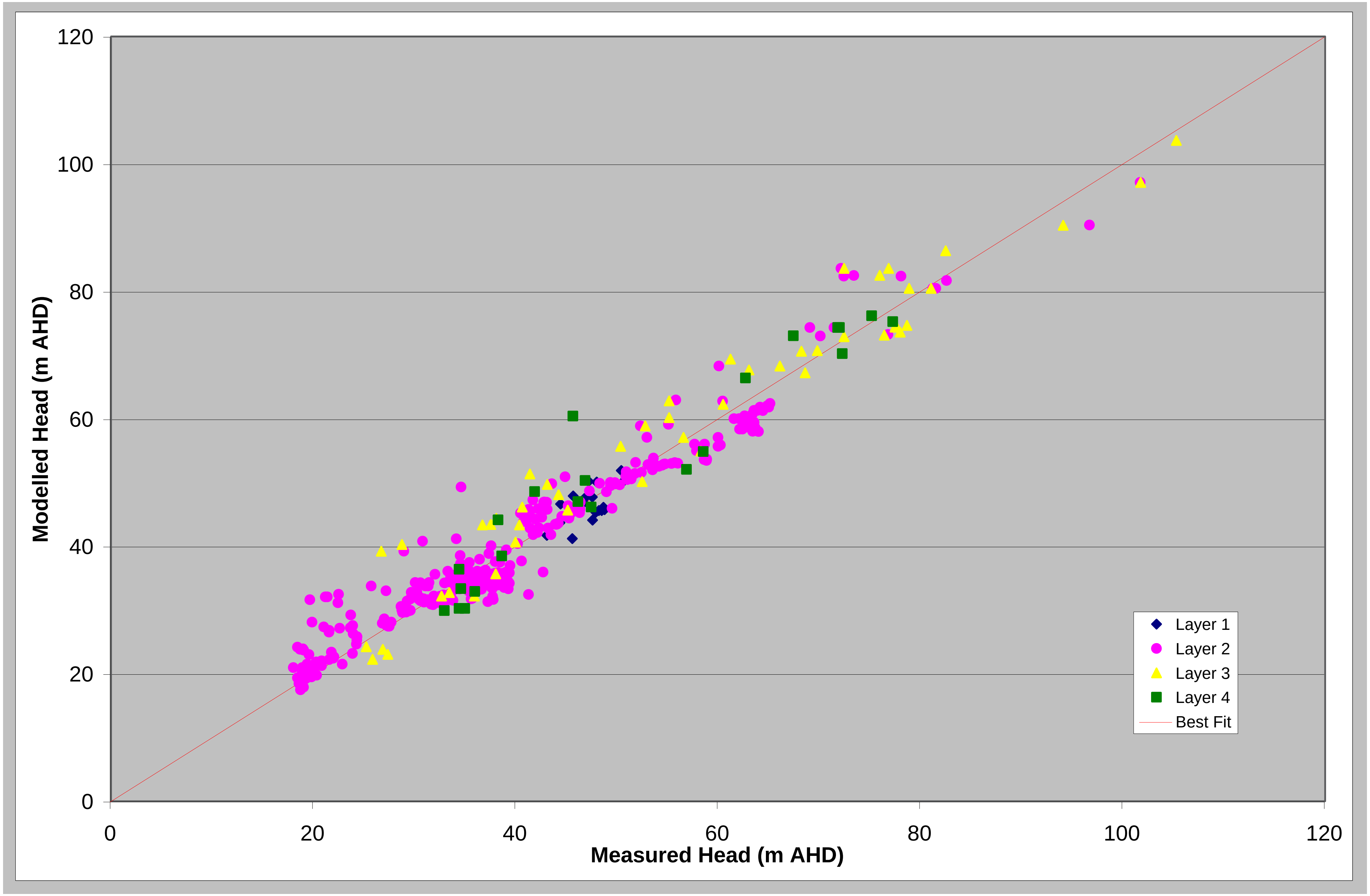
4.3.3 MODELLED WATER BALANCE

Table 4.2 shows the steady-state modelled water balance for the entire catchment. The largest component of flow into the catchment is from the head dependent boundaries; similarly they also make up the major catchment outflows.

The modelled water balance indicates that the rivers are generally a losing system at the catchment scale; however the numerical model indicates that there are some reaches along the Murray River that are gaining as shown in Figure 4.6. This is broadly consistent with the results of recent AEM and nanoTEM surveys that identify losing and gaining reaches or river (Telfer *et al.* 2006). It can also be seen that evapotranspiration is a more dominating process when compared to recharge in terms of the volumes of flow. This is consistent with the Mallee providing large groundwater discharge outlets such as saline lakes.

Table 4.2: EM3 Mallee Model Steady State Water Balance

Component	Inflow (m^3/day)	Outflow (m^3/day)
Wells	1,240	48,130
Drains	0	1,660
Recharge	440,130	0.0
Evapotranspiration	0	703,000
River Leakage	446,010	305,040
Head Dependent Boundaries	1,731,320	1,560,940
Total	2,618,700	2,618,770
Discrepancy (%)	0	



aquaterra

Steady state scatter plot of measured vs modelled heads FIGURE 4.1

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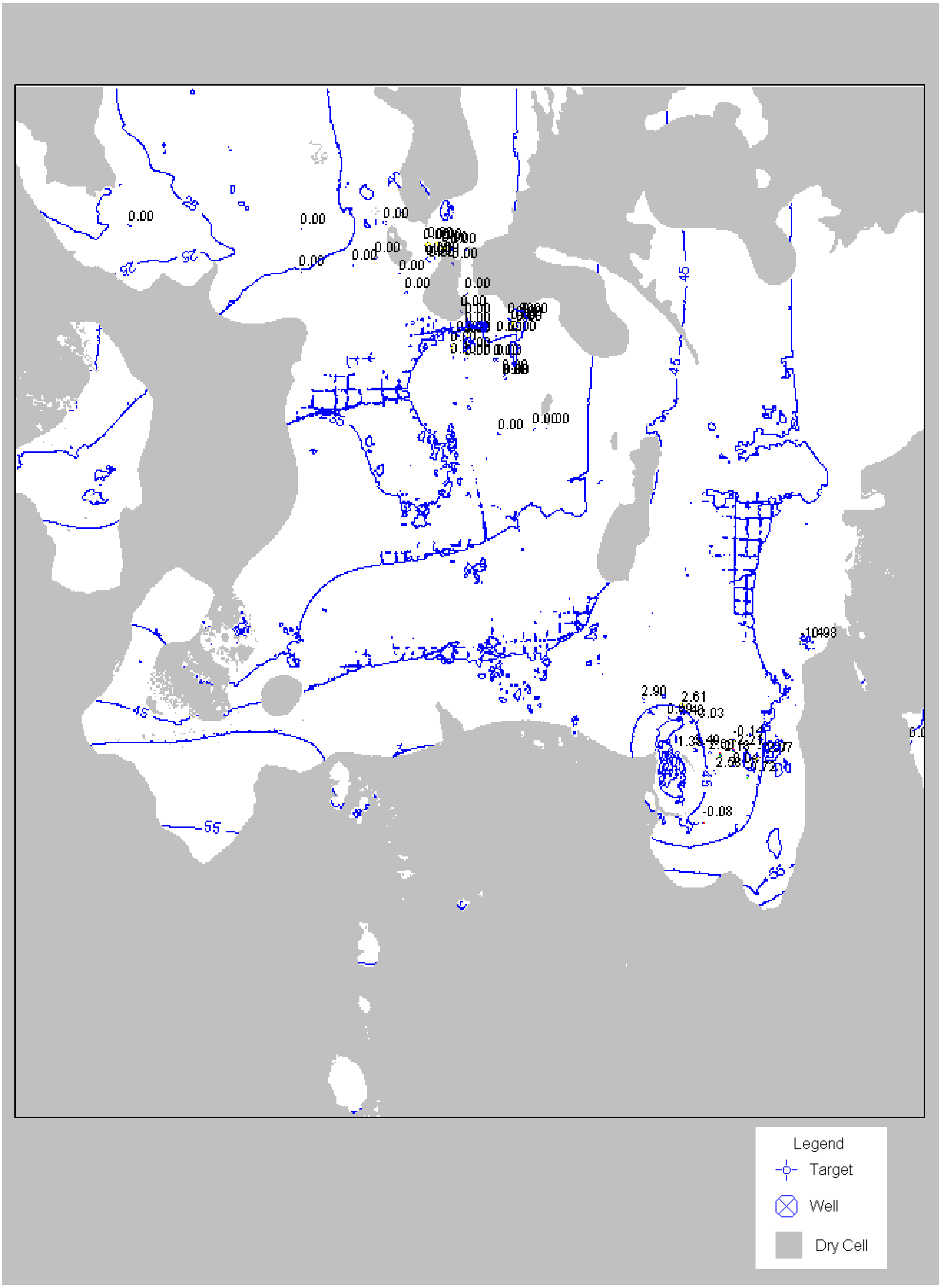

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LAYER 1 WATERLEVEL CONTOURS (m AHD) WITH RESIDUALS FIGURE 4.2

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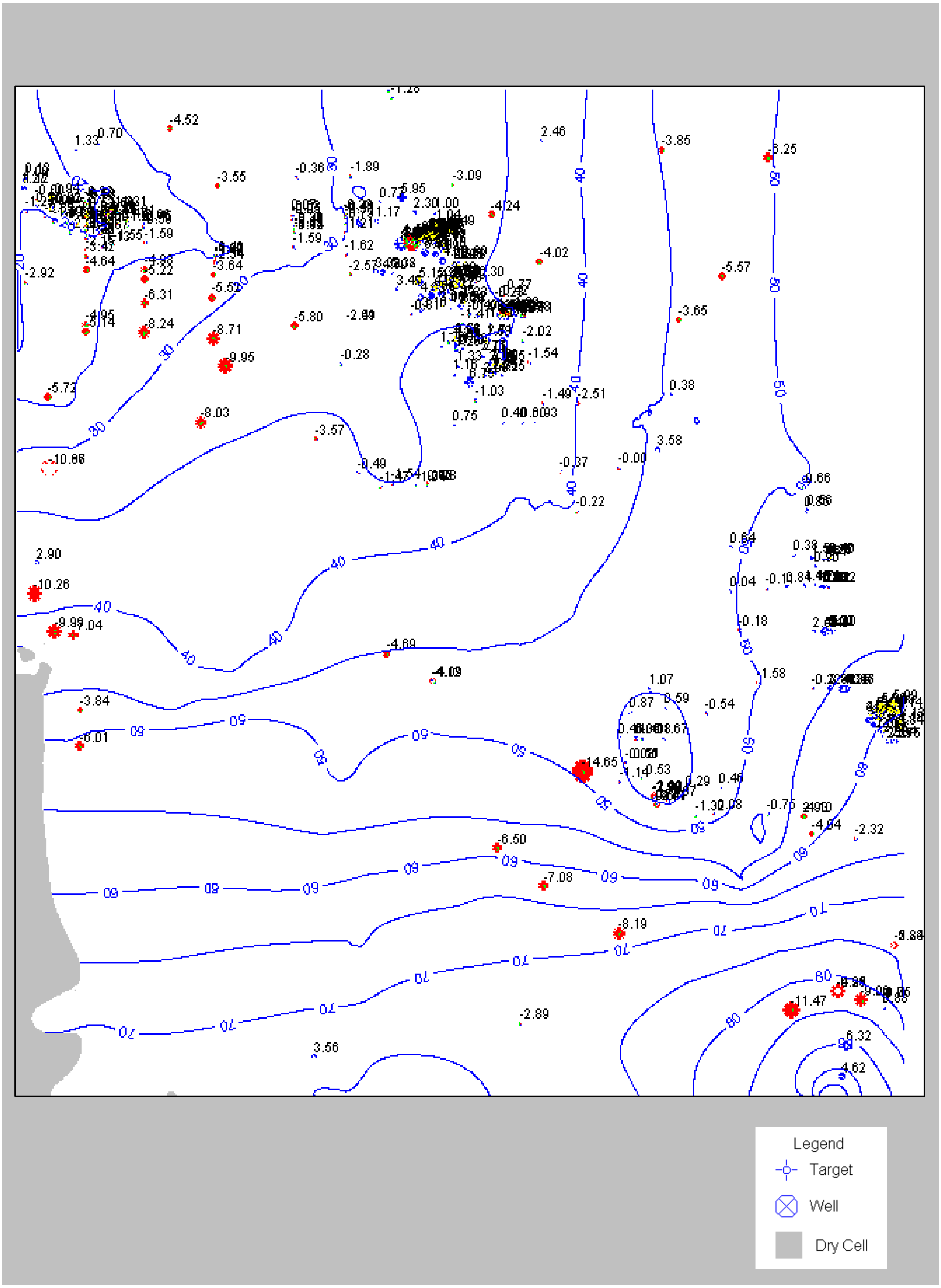
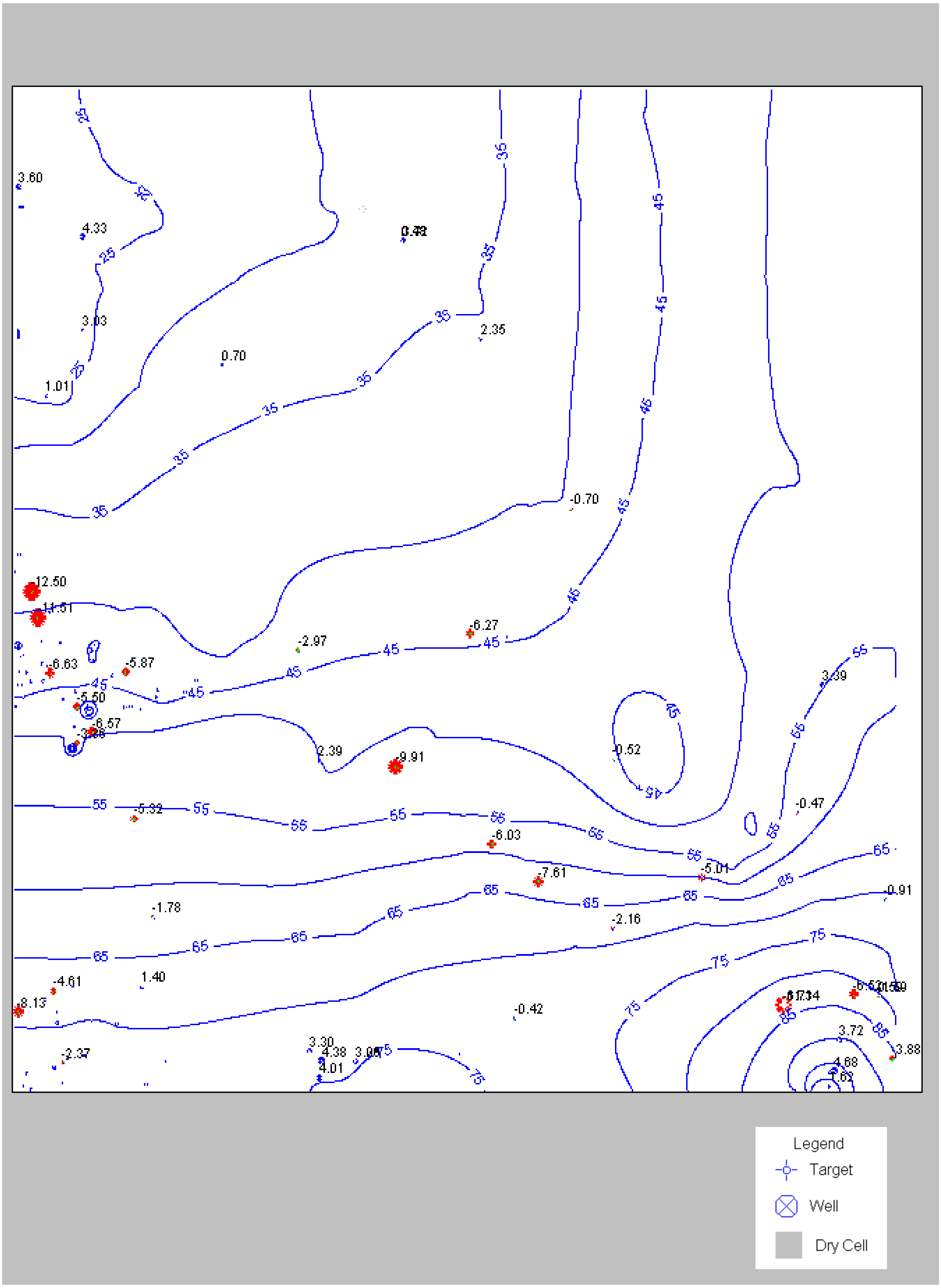


LAYER 2 WATERLEVEL CONTOURS (m AHD) WITH RESIDUALS FIGURE 4.3



LAYER 3 WATERLEVEL CONTOURS (m AHD) WITH RESIDUALS FIGURE 4.4

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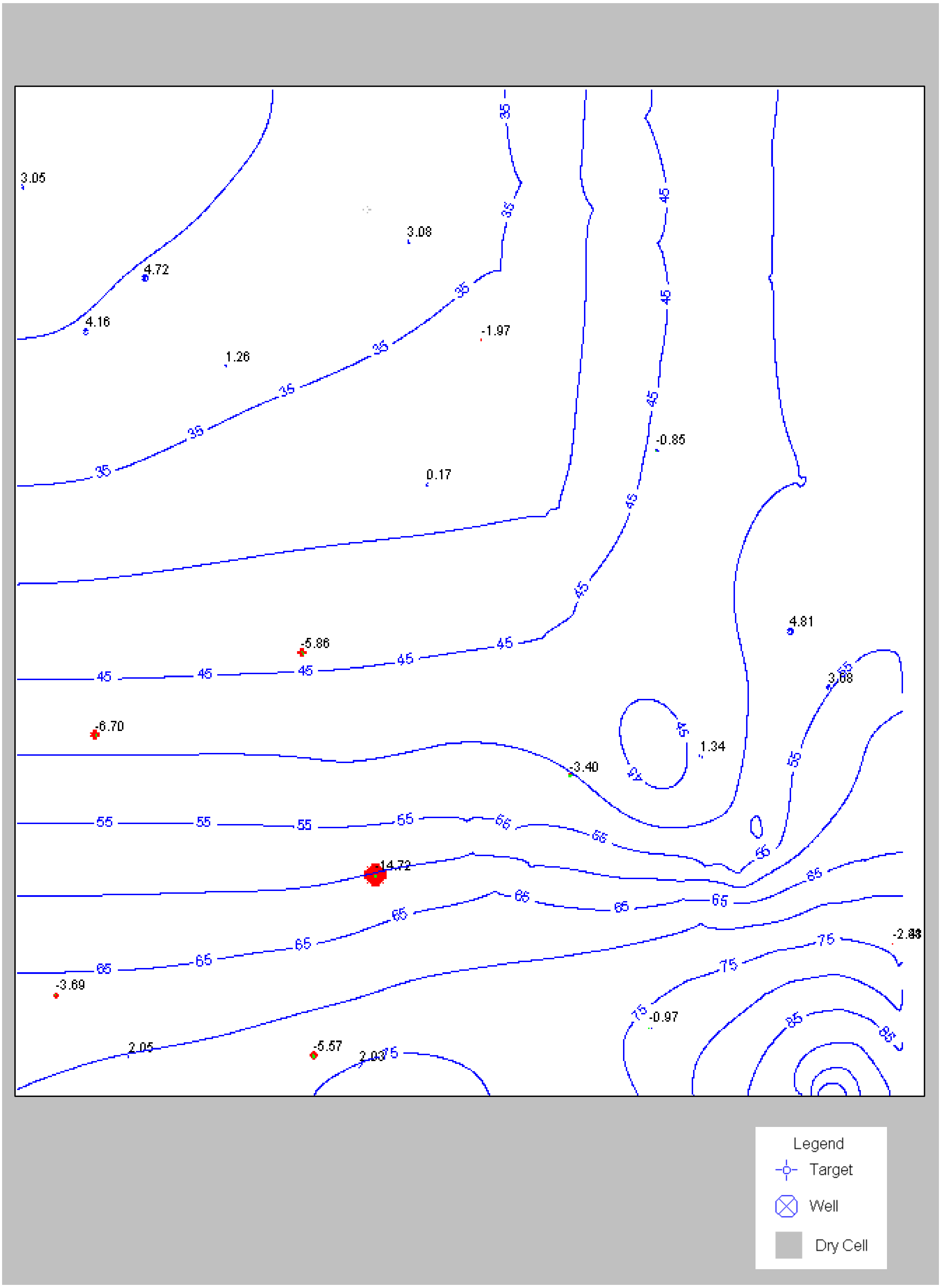

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LAYER 4 WATERLEVEL CONTOURS (m AHD) WITH RESIDUALS FIGURE 4.5

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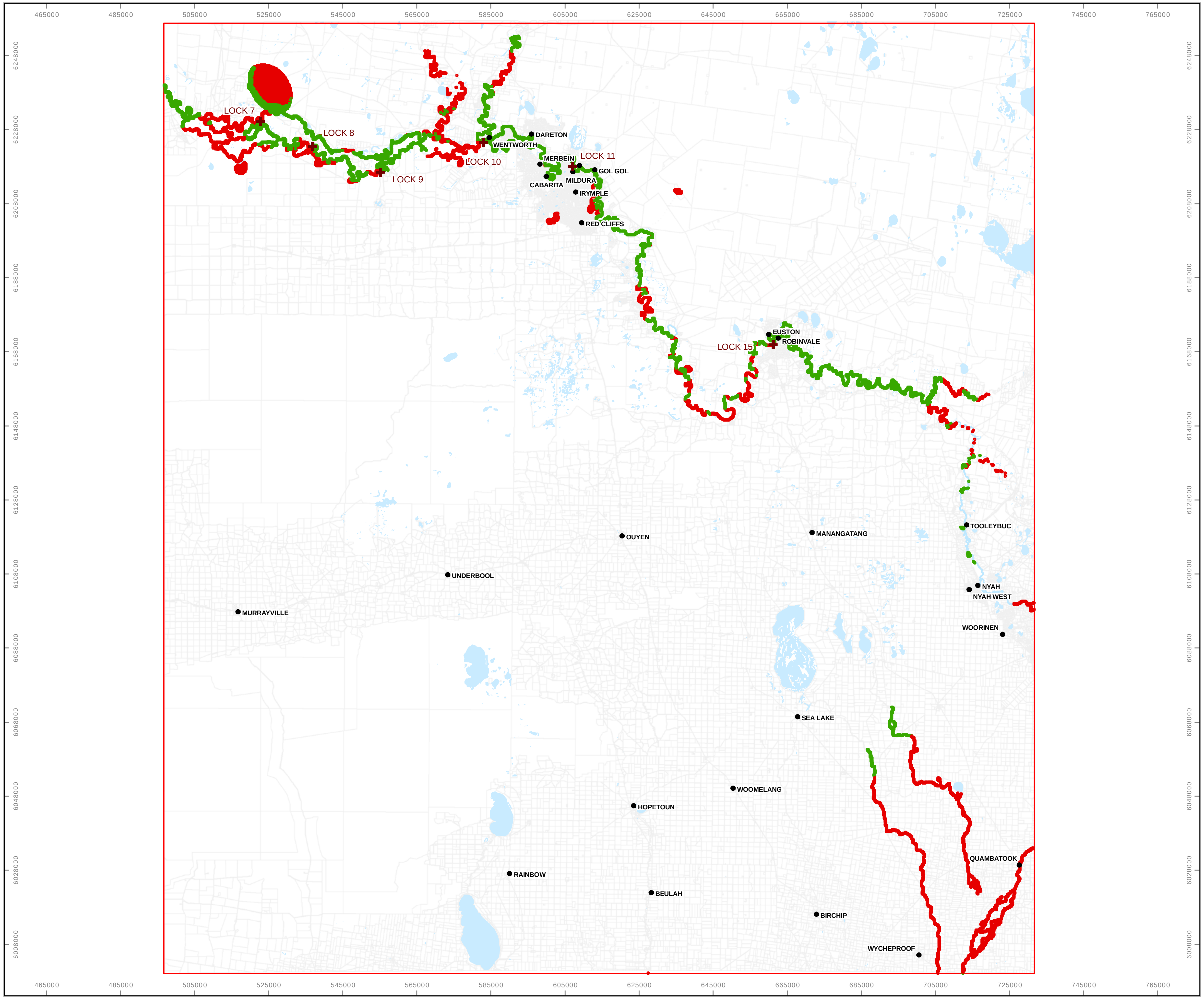

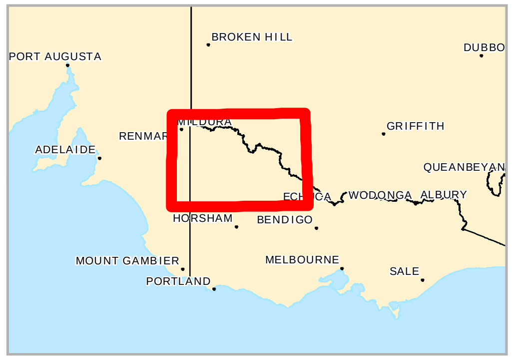

LEGEND

- Locks
- Localities
- Surface Water Bodies

MODEL FEATURES

- EM3 Model Boundary

Steady State Output

- Gaining
- Losing

N

0 15 30 45
Kilometres

SCALE 1:1,000,000 @ A3

GDA 1994 MGA Zone 54

DATA SOURCES

MCMA: Cultivated Areas
GA: Localities, Lakes, Locks
AQT: EM3 Model

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FIGURE 4.6

Modelled river gaining and losing reaches

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5 STEADY STATE MODEL SENSITIVITY

Sensitivity analysis in the modelling context is an evaluation of the effect that variations in input parameters have on the model output, to examine which parameters are likely to influence the accuracy of the model if their input values are inaccurate.

Key results of the sensitivity analysis are summarised in Table 5.1:

Table 5.1: Key Sensitivity Analysis Results

Parameter	Calibrated value (base case)	Perturbation	SRMS (%)
Calibrated model			3.95
Kh: Parilla Sands (north)	20 m/d	40 m/d	3.84
Kh: Parilla Sands (south)	50 m/d	25 m/d	4.01
Kh: MGL & Bookpurnong Beds (south)	20 m/d	10 m/d	3.89
Kh: Renmark Group	25 m/d	12.5 m/d	4.00
Kv: Geera Clay/Winnambool Formation & Bookpurnong Beds	0.01 m/d	0.1 m/d	3.93
Kv: Renmark Group and Ettrick Marl	0.001 m/d	0.01 m/d	3.97
Recharge: Maximum recharge 3 mm/yr	variable	max 3 mm/yr	3.73

The effects of parameter perturbations on the base case shown in examples (Table 5.1) suggest that the horizontal hydraulic conductivity has a significant effect on the calibration performance of the steady state model. There is a scope for better SRMS results, if, for example, hydraulic conductivity of the Parilla Sand aquifer in the north is doubled to 40 m/d. Such increases would have to be backed up by field evidence (eg. pumping tests), as the accepted range of physically realistic values does not extend this high. Note that in the southern part of the model the hydraulic conductivity of the Parilla Sand aquifer (base case) is 50 m/d, a value is regarded as very much at the upper limit of the realistic range.

Sensitivity analysis also suggests some scope for improvement by raising hydraulic conductivity in the two deeper aquifers, the Renmark Group and Murray Group Limestone.

The effects of the vertical hydraulic conductivity are relatively small, despite the order of magnitude perturbations examined. It is concluded that higher values of vertical hydraulic conductivity has lesser impacts on the calibration performance of the steady state model, but it may become more significant during the future transient calibration to test lower values of Kv.

Recharge perturbation had quite a significant impact – as would be expected. In the case shown in Table 5.1 all recharge values in the DSE dataset above 3 mm/yr was constrained to not exceed 3 mm/yr. This had the effects of removing recharge values that were up to one or two orders of magnitude higher. This resulted in the most significant reduction of the SRMS statistic and demonstrates the high sensitivity to recharge of the steady state model.

The sensitivity analysis identified several key parameters that are critical for improved model performance:

- Irrigation recharge – this was not changed during this study but it is known from work on other projects such as EM2 that it has a great impact on the accuracy of matching the water table mounding effects, and subsequent river/aquifer interaction and hydrological balances. It is suggested that the steady state model results and sensitivity assessment demonstrates that the irrigation area recharge values provided by DSE are too low and not realistic, and an alternative recharge dataset should be developed and applied as the basis for an alternative model calibration;

- Hydraulic conductivity of the Parilla Sands aquifer - this is the most important aquifer in this region and is most prone to any impacts resulting from landuse changes, so accurate calibration in this unit is important for model capability;
- Hydraulic conductivity of the Murray Group Limestone and Renmark Group - both represent deeper units of the aquifer system and have the potential to be commercially utilised for water supply and irrigation.

6 MODEL CAPABILITY

6.1 MODEL CAPABILITY

The aim of this project is to develop catchment models that will be used to assess the impacts of land use change on groundwater regime and stream-aquifer interaction as part of the DSE ‘ecoMarkets’ initiative. The Mallee CMA Region Groundwater Flow Phase 1 model (EM3) is a steady state model which was developed and calibrated as part of this project.

Work is in progress to refine and expand the Phase 1 model of this project, building upon the conceptualisation and data sets developed and collated to enable the construction and calibration of a transient model (Phase 2 model).

A key purpose of this work is to demonstrate that the model can be developed further, with readily available data, and to use the model results to help identify where data deficiencies critically constrain the use of the model as a management tool.

This report documents that a sound steady state model platform has been established for the Mallee catchment which is fit for the purpose of assessment of groundwater regime changes due to broad land use impacts, as well as the potential use by other stakeholders such as water utilities to assist with groundwater resource management.

The continued transient modelling, which will be undertaken in the next phase of the project, will provide a further demonstration of the model capability.

6.2 ISSUES LOG

There are several knowledge/data gaps that can influence the confidence in the results produced by the model and should be addressed ideally before or during the transient calibration phase.

The sensitivity analysis and trial and error calibration process showed that key parameters that influence model outcomes are recharge and hydraulic conductivity, but also parameters that are associated with evapotranspiration and possibly floodplain processes.

The main knowledge/data gaps and/or uncertainties within the study area that affect the conceptual model are summarised in Table 6.1:

Table 6.1: Key Model Issues

Feature	Limitation	Measure required
Groundwater levels in Parilla Sands	The model generally over predicts groundwater levels in the Parilla Sand aquifer	Consider refinement of recharge model, and/or interaction between recharge, hydraulic conductivity and boundary conditions
Groundwater levels in irrigation areas in northern Mallee near River Murray	The model generally under predicts water level in the irrigated areas	Refine irrigation recharge model
Floodplain processes	There is scope for refinement of the ET feature, and there will likely be a need to incorporate floodplain inundation recharge features to areas of wide floodplain (eg Lindsay-Walpolla). It is questionable whether the DSE recharge model can provide this level of detail.	Keep these issues under review during the transient calibration process.

Feature	Limitation	Measure required
ET processes, topo accuracy	The DEM is accurate on the floodplain (Lidar), but not outside the floodplain (approximately +/- 10 metres). This is probably only a significant issue in close proximity to low-lying areas with shallow water tables such as around Lake Tyrell, and saline evaporative features in the study area (eg. Hattah, Noora, near Underbool).	Implement more accurate topo information in areas of regional groundwater discharge
ET processes	Evapotranspiration is currently set up with uniform parameters across the majority of the model (excluding ET rate in EM2 and EM4 model regions), although there is the option to incorporate site-specific data where warranted, especially on the floodplain.	Apply a really distributed model of the ET rates
Groundwater levels in irrigation areas in western Mallee in the MGL aquifer	The model generally over predicts groundwater levels in the irrigated areas	Investigate obtaining more accurate pumping data from Grampian Wimmera Mallee Water

6.3 RECOMMENDATIONS

While the overall calibration statistic is favourable and well within the required limit there are areas where additional improvement could be achieved to better represent the regional groundwater system of the Mallee CMA. Further work is recommended in the following areas:

- Reconsider recharge model especially in irrigated areas, but also in dryland areas.
- Incorporate updated pumping rate information for the borefields on the western boundary
- Update the long-term pumping rate estimates from Grampian Wimmera Mallee Water (request lodged)
- Refine surface elevations at regional discharge points (Eg. Lake Tyrrell)
- Refine the ET parameterisation where warranted
- Refine the recharge model by incorporating floodplain processes which would become even more relevant during the transient phase model development and calibration.

7 REFERENCES

Aquaterra (2009a) Mallee CMA Region Groundwater Flow Model (EM3) – Design. Prepared for the Department of Sustainability and Environment (Vic). Dated 11 March 2009.

Aquaterra (2009b) Sunraysia Sub-Regional Groundwater Flow Model (EM2.3) Final Report. Prepared for Goulburn-Murray Water and Murray Darling Basin Authority. Dated 16 October 2009.

Aquaterra (2009c) Lake Gol Gol Hydrogeological Investigations. Report prepared for Lower Murray Darling CMA, August 2009.

Aquaterra (2008). Lock 10 to SA Border Groundwater model (EM4). Prepared for SKM. Dated 8 December 2008.

Aquaterra (2007). Mallee Zone 5-year Rolling Salinity Review – Hydrogeological Modelling for Victoria and NSW, B-Register 'Legacy of History' Assessments, Eastern Mallee Model version 1 (EM1). Prepared for the Murray-Darling Basin Commission.

AWE (2007). Sunraysia Salt Interception Hydrogeology and Engineering Design Inputs. Australian Water Environments report 45682i.

AWE (2009). Sunraysia Salt Interception Red Cliffs Aquifer Test. Prepared for Goulburn Murray Water, September 2009.

Banta ER (2000). MODFLOW-2000, the U.S. Geological Survey modular ground-water model - Documentation of packages for simulating evapotranspiration with a segmented function (ETS1) and drains with return flow (DRT1). U.S. Geological Survey Open-File Report 00-466, 127 pp.

Barnett SR, Osei-bonsu K (2006). Mallee PWA – Murrayville WSPA Groundwater Model. South Australia Department of Water, Land and Biodiversity Conservation. DWLBC Report 2006/27

Brodie, R. (AGSO) (1992). Anabranch Hydrogeological Map (1:250,000 scale). Australian Geological Survey Organisation, Canberra, Australia.

Brown CM, Stephenson AE (1991). Bulletin 235 Geology of the Murray Basin South Eastern Australia. Bureau of Mineral Resources, Geology & Geophysics. Department of Primary Industries & Energy. Commonwealth of Australia.

Bureau of Meteorology (2001). Climatic Atlas of Australia – Evapotranspiration.

Cook PG, Leaney FW, Miles M (2004). Groundwater Recharge in the Northeast Mallee Region, South Australia. CSIRO Land and Water Technical Report 24/05.

Dudding, M. *et al.* Rural Water Corporation, Victoria (1993). St Arnaud Hydrogeological Map (1:250,000 scale). Australian Geological Survey Organisation, Canberra, Australia.

Environmental Simulations International (ESI) Limited (2005). URL for Groundwater Vistas: http://www.groundwatermodels.com/Software.php

Ghassemi F, Jakeman AJ, Thomas GA (1987) Groundwater modelling and simulation of salinity management options in the Sunraysia region of Victoria. Report to the River Murray Commission. Centre for Resource and Environmental Studies, Australian National University Canberra.

Harbaugh AW, Banta ER, Hill MC, McDonald MG (2000). MODFLOW-2000, the U.S. Geological Survey modular ground-water model - User guide to modularization concepts and the Ground-Water Flow Process. U.S. Geological Survey Open-File Report 00-92, 121 pp.

Hocking , M. and Dyson, P. (2006) Mallee water balance – the role of evaporation on salinity area in the Victorian Mallee dryland. *Proceedings of the Royal Society of Victoria* 118(2): 211-227. ISSN 0035-9211.

Jolly ID (1996). The effects of river management on the hydrogeology and hydroecology of arid and semi-arid floodplains. Floodplain Processes. Anderson MG, Walling DE, Bates PD (eds). pp.577-609.

Kellet, J.R. (AGSO) (1994). Balranald Hydrogeological Map (1:250,000 scale). Australian Geological Survey Organisation, Canberra, Australia.

McAuley, C. *et al.* Rural Water Corporation, Victoria (1992). Horsham Hydrogeological Map (1:250,000 scale). Australian Geological Survey Organisation, Canberra, Australia.

Merrick NP and Middlemis H. (1988) Buronga salt Interception Scheme; Optimisation of Groundwater Pumping. NSW Department of Water Resources Technical Services Report No. TS88.003, Sydney.

Merrick NP, Middlemis H, Rozlapa K, Williams RM (1999) Buronga Salt Interception Scheme Review. Department of Land & Water Conservation. Centre for Natural Resources. CNR99.034

Middlemis (1990) Buronga salt interception scheme numerical model. M. Eng. Sc. Project Report. University of New South Wales, School of Civil Engineering.

Mildura Rural City Council (2001). Sunraysia Drainage Strategy 2000 Stage 1. Final Report. April 2001.

Murray-Darling Basin Commission (2001). Groundwater Flow Modelling Guideline. Prepared for the Murray-Darling Basin Commission by Aquaterra. Dated 16 January 2001.

O'Rorke, M.E. *et al.* Victorian Rural Water Commission (1992). Swan Hill Hydrogeological Map (1:250,000 scale). Bureau of Mineral Resources, Geology and Geophysics, Canberra, Australia.

REM-SKM. 2009. River Murray Floodplain Salinity .Assessment. Report to Lower Murray-Darling CMA. 17 March 2009.

Robinson, M. *et al.* Victorian Rural Water Commission (1992). Ouyen Hydrogeological Map (1:250,000 scale). Bureau of Mineral Resources, Geology and Geophysics, Canberra, Australia.

Rural Water Commission (1991). Mildura Hydrogeological Map (1:250,000 scale). Bureau of Mineral Resources, Geology and Geophysics, Canberra, Australia.

SKM and AWE (2003). Integration and Optimisation of Salt Interception in the Sunraysia region. Final Report to Department of Land and Water Conservation.

SKM (2005a) *Mallee CMA Numerical Water Trade Models – Hydrogeological Conceptualisation (Draft B).* Prepared for the Mallee CMA. Dated 3 February 2005.

SKM (2005b) *Mallee CMA Numerical Water Trade Models – Model Calibration Report (Draft).* Prepared for the Mallee CMA. Dated 4 February 2005.

SKM (2008a) *Mallee Drilling Program – Volume 2: Vertical Leakage Estimates*. Prepared for the Mallee CMA. Dated 1 April 2008.

SKM (2008b) *Mallee Drilling Program – Volume 1: Hydrogeological and Geophysical Factual Report*. Prepared for the Mallee CMA. Dated 19 February 2008.

Telfer AL, Hatch MA, and PA Shintodewi (2006). Atlas of Instream NanoTEM 2006. Australian Water Environments report 45755bb.

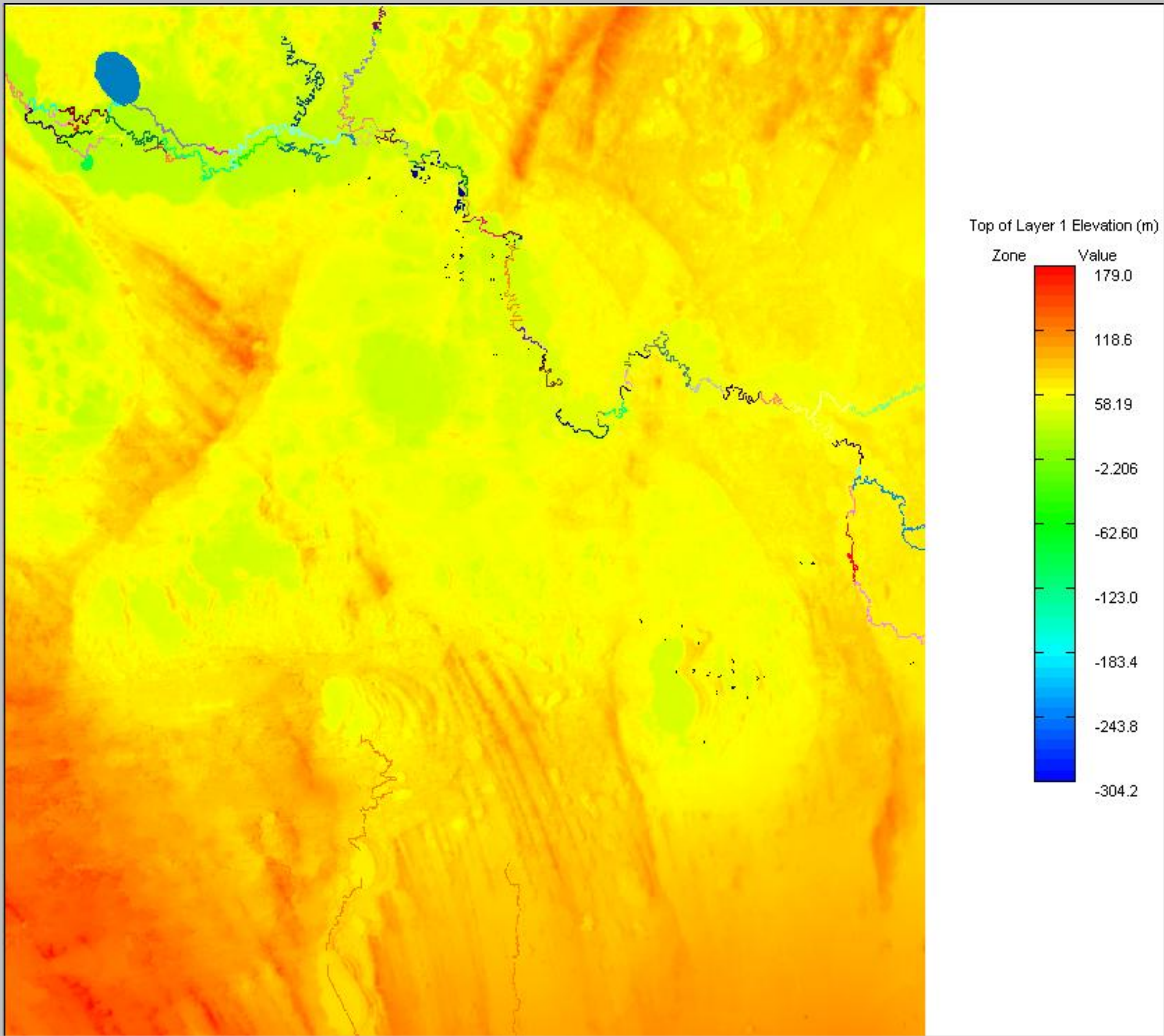
Thorburn PJ, Hatton TJ, Walker GR (1993). Combining measurements of transpiration and stable isotopes of water to determine groundwater discharge from forests. Journal of Hydrology, 150: 563-587.

Thorne R, Hoxley G, Chaplin H (1989). Draft Nyah to the South Australian Border Hydrogeological Study Volume 1 Report. Investigations Branch Report 1988/5, Investigations Branch, Rural Water Commission of Victoria.

Warren, J.K (2006). Evaporites: Sediments, Resources and Hydrocarbons. Birkhäuser Publishing Ltd, 1035 pp.

Williams RM, Erny M (2001) Buronga Salt Interception Scheme Redesign Implications of Pumping Tests. CNR2001.035.

APPENDIX A EM3 MODEL LAYER STRUCTURE



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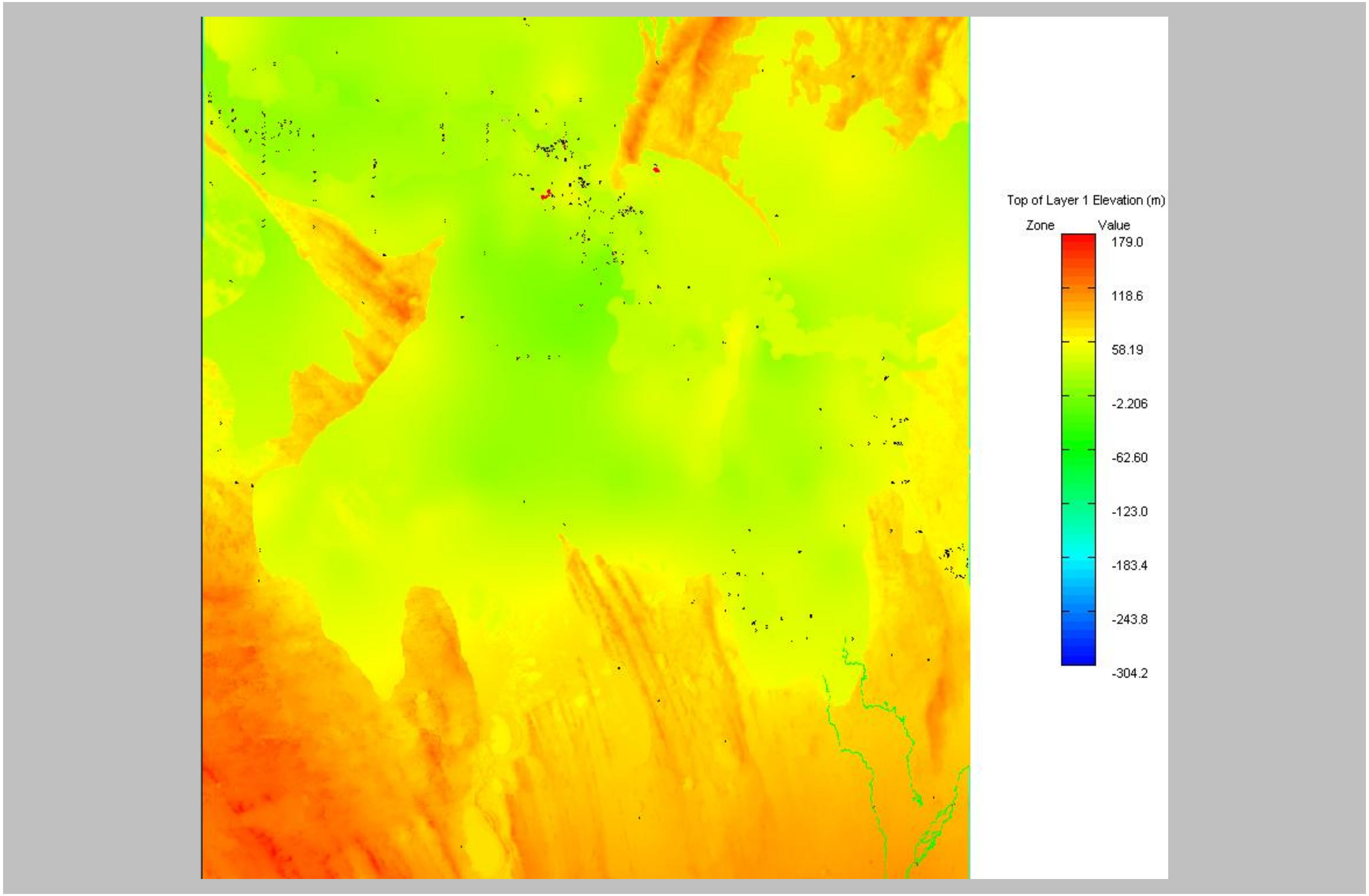
Modelled elevation of top of layer 1 FIGURE A1



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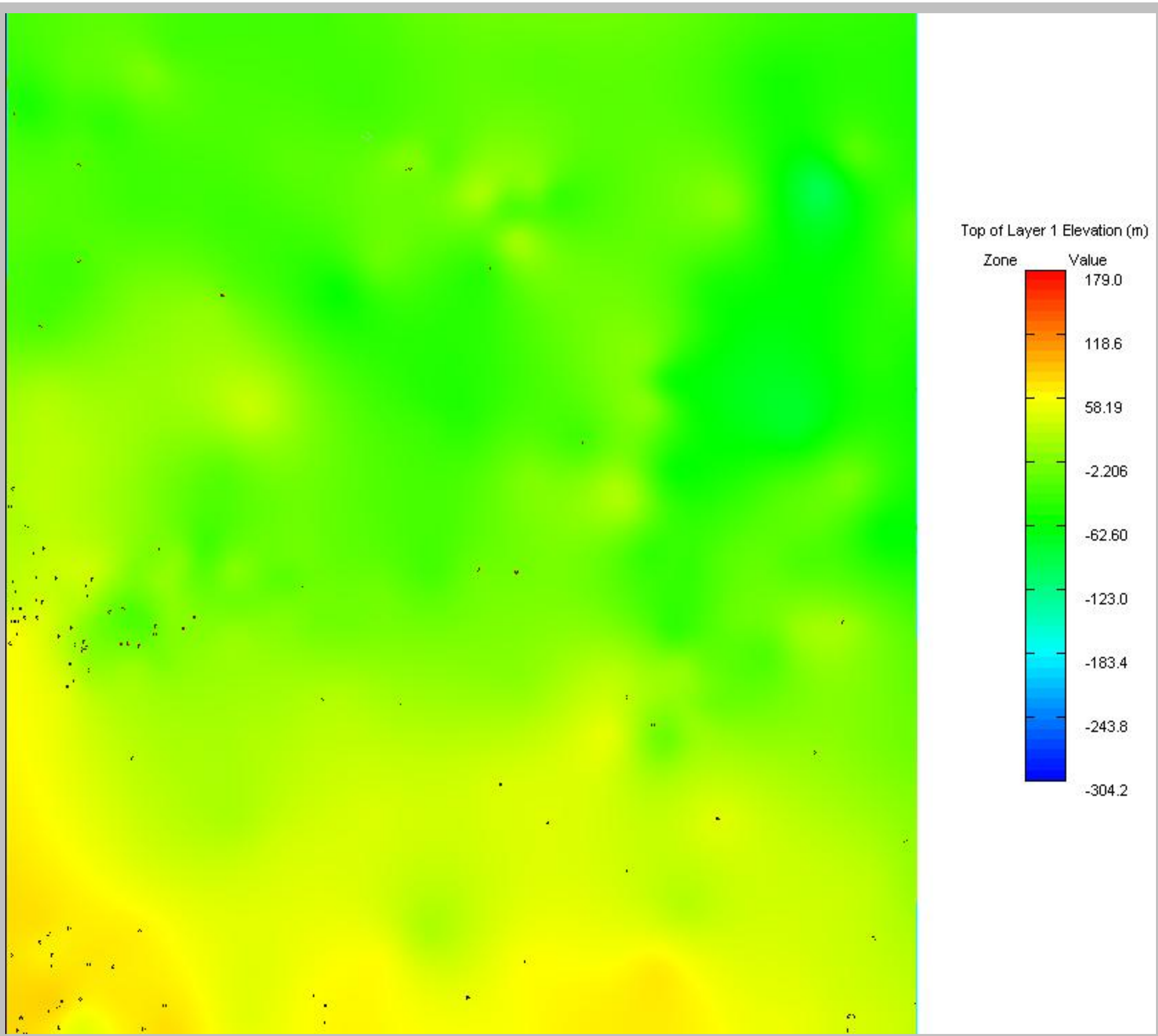
Modelled elevation of top of layer 2 FIGURE A2



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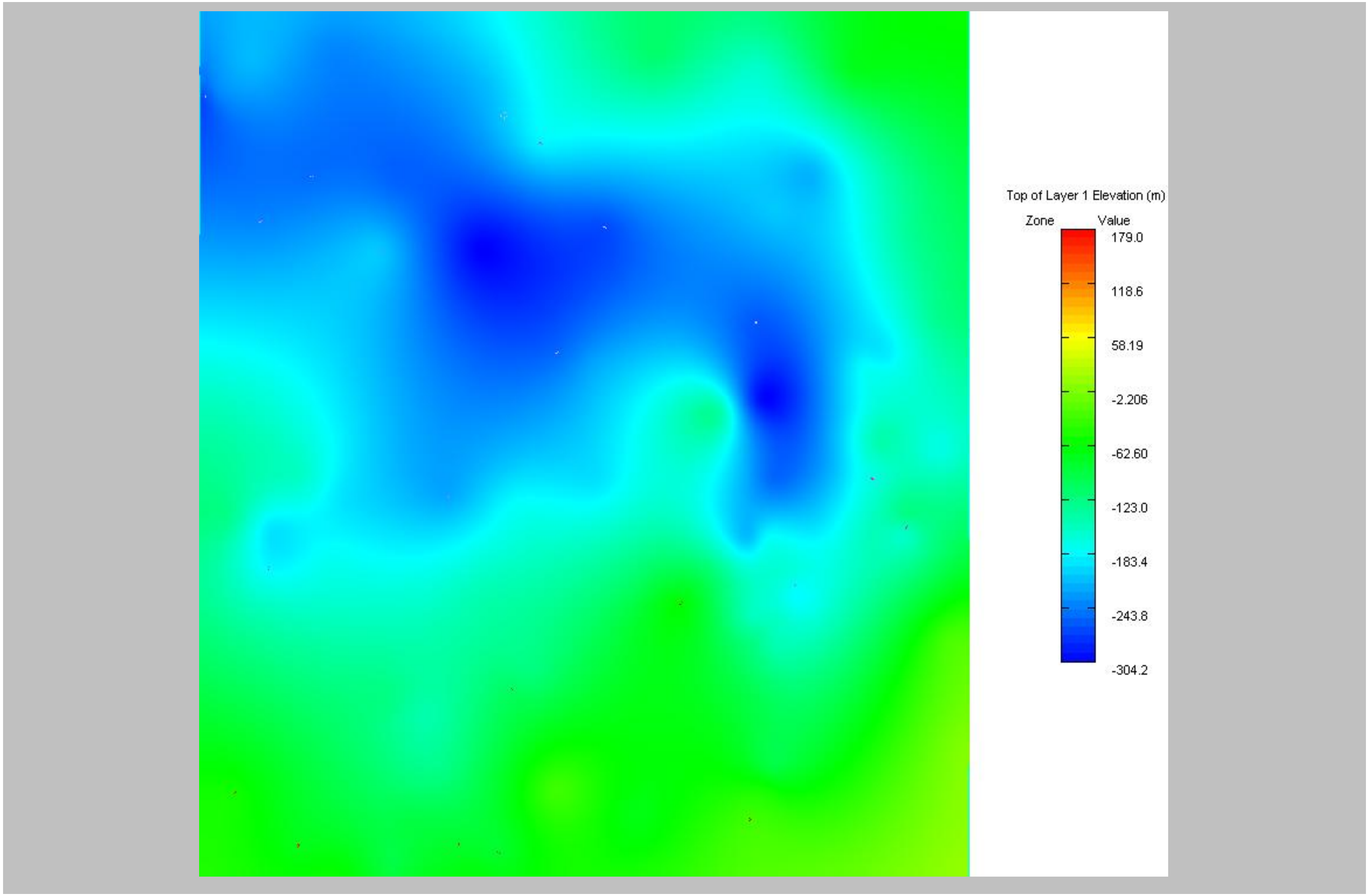
Modelled elevation of top of layer 3 FIGURE A3



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Modelled elevation of top of layer 4 FIGURE A4

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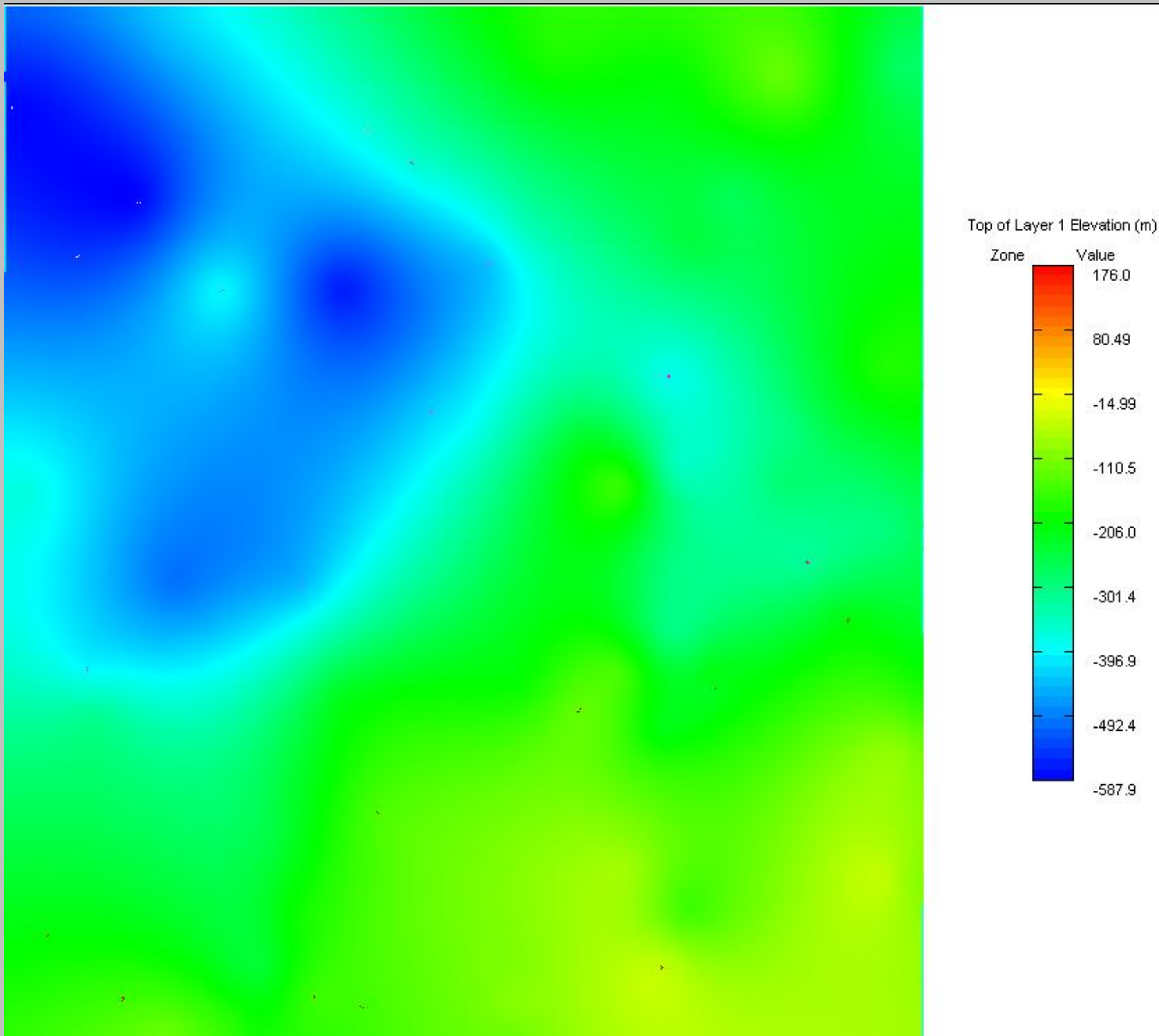

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Modelled elevation of base of layer 4 FIGURE A5

APPENDIX B PREVIOUS RECHARGE MODELLING IN EASTERN MALLEE

Uncleared Dryland

In areas that retain native vegetation, conventional wisdom assumes that the rainfall recharge rate is estimated to be a constant 0.1 mm/yr (Aquaterra, 2007).

Cleared Dryland Recharge and Time Lags

The basic conceptual model of dryland recharge is that rainfall percolating through the unsaturated zone is either intercepted/transpired by vegetation or evaporates from the soil, or it continues to percolate through the root zone to enter the water table as groundwater recharge. It is generally accepted that recharge within areas that have been cleared is typically greater than areas of native vegetation due to the reduction in evapotranspiration as a result of replacing deep-rooted vegetation with shallower rooted species. It is also generally accepted that there is a time lag between increased root zone drainage due to clearance and when the wetted front enters the water table as recharge.

In cleared areas, EM1 used dryland recharge rates and time lags which were estimated using the SIMRAT model by URS et al. (2005), which was based in part on Cook et al. (2004). This approach requires an annual rainfall, a soil texture (to 2 m depth) and cleared agriculture land use coverage as input. The SIMRAT model estimates that the recharge rate increases with time from the uncleared dryland rate to a maximum rate of around 10 mm/yr for the majority of areas, but reaches up to 30 mm/yr in areas of higher rainfall combined with sandy soils.

Time lags for the wetted front from vegetation clearance recharge to reach the water table were estimated by the SIMRAT model at between 10 and 250 years. Analysis of hydrograph data by Aquaterra for this study suggests that the initial time lags have passed in areas where there are no bores showing increasing head over the recent monitoring period, suggesting initial time lags are less than 70 years (i.e. the time between clearance around 1900 and the beginning of broad scale groundwater monitoring around the mid 1970s). The alternative suggestion is that no recharge has occurred and hence the effect is yet to be observed, and this is likely to be a variable effect across the study area. In addition, it is noted that SIMRAT assumes that the Blanchetown Clay is “heavy clay” based on investigations in the Riverland region of SA and unsaturated flow parameters have been assigned accordingly. Observations in the field indicate that the Blanchetown Clay can vary from a sandy silt to a high plasticity clay. Time lags are sensitive to these unsaturated flow parameters and SIMRAT may therefore be over estimating time lags.

Once the initial time lag has occurred and the wetted front has passed, the time lag between any changes to the surface application of rainfall due to changes to climatic conditions (such as drought) and the response in the water table is significantly reduced. This reduction occurs because the post-wetted-front soil profile has a higher moisture content and hence vertical unsaturated flow is much more rapid (as hydraulic conductivity is related to moisture content in an unsaturated flow context). The time lags estimated by SIMRAT are based on the initial wetting front propagation and therefore, are not necessarily applicable once the wetted front has passed. Analysis by Aquaterra suggests that time lags may in fact be much less than the time lags from the wetted front propagation predicted by SIMRAT.

In some areas, water levels have responded almost immediately to changes in the climatic trend, particularly during the transition from a wetter period to a drier period around the mid 1990s in the cleared and uncleared areas. This suggests that cleared dryland recharge time lags are less than one year in some areas, and, for the purposes of this study, can be assumed to be zero in terms of years for those areas. That is not to say that the cleared dryland time lags are, in fact, zero, as the analysis indicates that time lags are of the order of months (but not multiple years). In simple terms, it is not possible to achieve a calibration to monitoring bore hydrographs that show a response to the last 10 years of drought if a time lag of more than 10 years is believed to apply (i.e. as suggested by SIMRAT).

It is possible that some of the cleared dryland monitoring bores are close enough to the irrigation areas (where it is generally accepted that time lags are effectively zero in terms of years) that they are showing a response to decays in the water table mounds under irrigation areas. However, there are some bores in cleared dryland areas that are remote from irrigation areas that also show a decreasing water table during the recent drought period.

In other areas, where is no response to the recent drought evident in the monitoring records, scenario and/or sensitivity modelling will be undertaken to determine the most appropriate time lag to apply to recharge to achieve a match to monitoring bore levels.

As was found for the time lag phenomena, the water level change due to changes in climatic conditions is generally somewhat similar for both cleared and uncleared areas, apart from some specific location close to Lake Tyrrell, where observed levels show a continuing rising trend.

A greater water level variation, however, is observed for the area in proximity to Neckarboo Ridge, suggesting a greater amount of recharge, possibly due to the absence or thinning of Blanchetown Clays at this location.

Irrigated Areas

Recharge rates in irrigated areas are generally higher than the post-clearing dryland recharge rates, due to deep drainage from excess irrigation water. The recharge to the water table is termed "root zone drainage" (RZD), and it depends mainly on the application volume, irrigation efficiency, soil type and whether drainage schemes are present.

At present, there is considerable scientific debate about irrigation efficiencies and RZD, mainly because there is little specific information that can be used to be definitive about irrigation efficiency changes with time. For the purposes of this project, rather than engage in that debate about irrigation efficiency, the irrigation recharge assumptions described below are discussed in terms of effective recharge to the water table.

The SIMRAT model (URS et al, 2005) assumes 85% water use efficiency based on the amount of water applied and the quantity taken up by plants. Of the remaining 15%, approximately 5% is allowed for losses such as surface runoff, evaporation and removal via subsurface drains, leaving 10% to be recharged to the water table as RZD (URS *et al*, 2005). Analysis of drainage monitoring data by Aquaterra during development of EM1 (Aquaterra, 2007) indicates that the volume removed by drainage in the irrigated areas of the Eastern Mallee is approximately 7.5% of the water applied, greater than that assumed by SIMRAT (5% minus surface runoff and evaporation losses). For EM1, 7.5% was applied as the basic (RZD) recharge rate to the water table, assuming surface runoff and evaporation losses to be minimal, which resulted in recharge to the aquifer of between 51 and 144 mm/year, across the irrigation regions in 2000. This basic rate was further refined during model calibration, as discussed in Sections 3 and 4, and there is scope to further refine assumptions around the RZD rate for periods prior to 1988.

Based on measurements made during 2002/2003, water use efficiency at Red Cliffs, FMIT, Buronga and Coomealla irrigation districts was estimated to be between 88% and 90% (Sunrise 21, 2006), whereas the estimate for Red Cliffs during 1996/1997 was 72% (SunRISE 21, 2006). This suggests that there is some variation in the water use efficiency with time (generally towards more efficient use), which is a refinement that was not implemented to the previous EM1 model, and has been used to guide assumptions about reductions with time in irrigation recharge rates for the EM2 model (Aquaterra, 2008).

Time lags that represent the delay between the initial surface application of irrigation and when the increased recharge due to irrigation propagates to the water table were estimated for EM1 (Aquaterra, 2007) based on the SIMRAT model vertical flux algorithm. Estimates of time lags under irrigation areas were between 10 and 40 years (as provided by DEH from the SIMRAT model, assuming 120 mm/year RZD; Aquaterra, 2007; and URS *et al.*, 2005). However, the EM1 model assumed that the time lags also applied once the wetted front has been received at the water table and produced rising water level trends within the Mildura/Merbein/Redcliffs irrigated areas which are not reflected in the bore hydrographs (e.g. bore 7840, Aquaterra, 2007). In fact, these hydrographs generally show a slight downward trend in measured levels since the mid 1980s (SKM and AWE, 2003), which can be attributed to one or a combination of factors such as improved irrigation practice, local variations in rainfall recharge, and reduced annual average river levels (ie. the drought).

Based on review by Aquaterra of data from the one available nested bore in the Mildura/Redcliffs/Merbein irrigations districts, it is noted that whilst a declining trend is apparent, the head difference above and below the Blanchetown Clay aquitard is relatively constant over the period of review (mid 1980s to 2002), which indicates that vertical flow through the aquitard (i.e. recharge to Parilla Sands) is also relatively constant over the period.

Constant recharge suggests that the aquifers are in equilibrium and that time lag do not influence the irrigation recharge process on a semi-regional scale.

As discussed above, SIMRAT predicts time lags for the wetted front from increased recharge due to irrigation commencing (or vegetation clearance) and the response in the water table. This time lag is not applicable once the wetted front has passed. Once passed, the time lag between changes to irrigation practices and responses in the water table are significantly reduced as the moisture content of the soil is higher and hence vertical unsaturated flow is much more rapid (as hydraulic conductivity is related to moisture content in an unsaturated flow context). In addition, SIMRAT assumes zero initial saturation and a constant unsaturated thickness over time (i.e. it is based on algorithms that were initially derived for dryland areas). Further, application of these lag times to EM1 produced a delayed response to recharge that is not consistent with monitoring bore levels and trends. The timing of irrigation inputs to the EM2 model have been reviewed to provide a reasonable representation of the spatial and temporal trends in recharge, notably including observed drops in measured water levels during the current drought, which would not be possible to achieve with time lags of more than 10 years.

APPENDIX C MODELLED HYDRAULIC CONDUCTIVITY DISTRIBUTION

Zone	Geological Unit(s)	Kh (m/day)	Kv (m/day)
1	Parilla Sands	20	5
2	Blanchetown Clay	0.0027	0.00027
3	Monoman Formation	15	1.5
4	Parilla Sands Blanchetown Clay	0.72	0.05
5	Murray Group Limestone Bookpurnong Beds	5	0.5
6	Geera Clay Winnambool Formation Bookpurnong Beds	0.1	0.01
7	Murray Group Limestone Bookpurnong Beds Geera Clay Winnambool Formation	0.1	0.001
8	Renmark Group	25	0.5
9	Renmark Group Ettrick Marl	25	0.001
10	Basement	0.1	0.01
11	Murray Group Limestone Bookpurnong Beds	20	1
12	Murray Group Limestone Bookpurnong Beds Geera Clay Winnambool Formation	5	0.01
13	Geera Clay Winnambool Formation Bookpurnong Beds	0.5	0.01
14	Renmark Group	25	0.5
15	Parilla Sands	50	5

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Horizontal and vertical hydraulic conductivity zonation FIGURE C1

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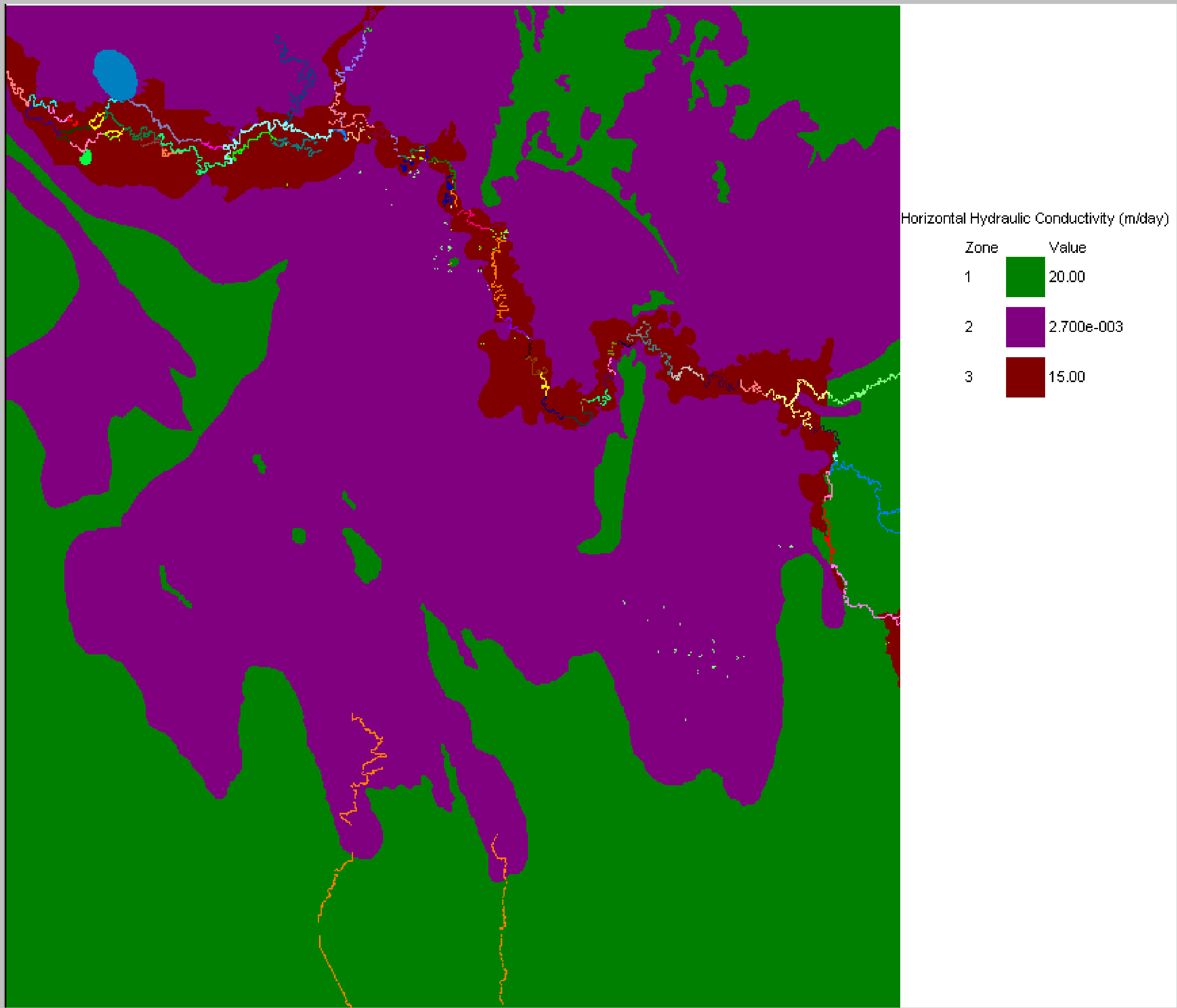

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Modelled horizontal hydraulic conductivity distribution for layer 1 FIGURE C2

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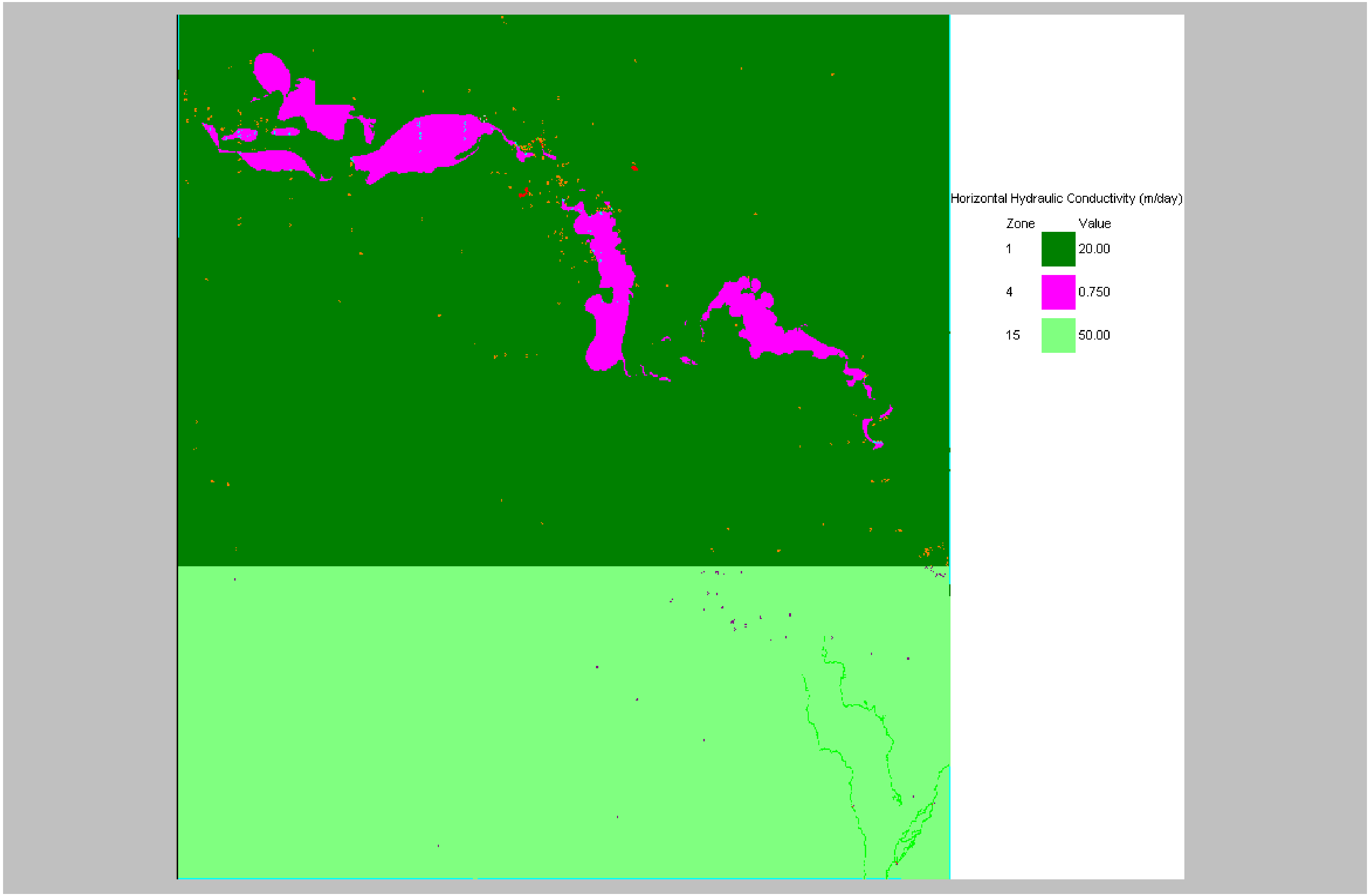

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Modelled horizontal hydraulic conductivity distribution for layer 2 FIGURE C3

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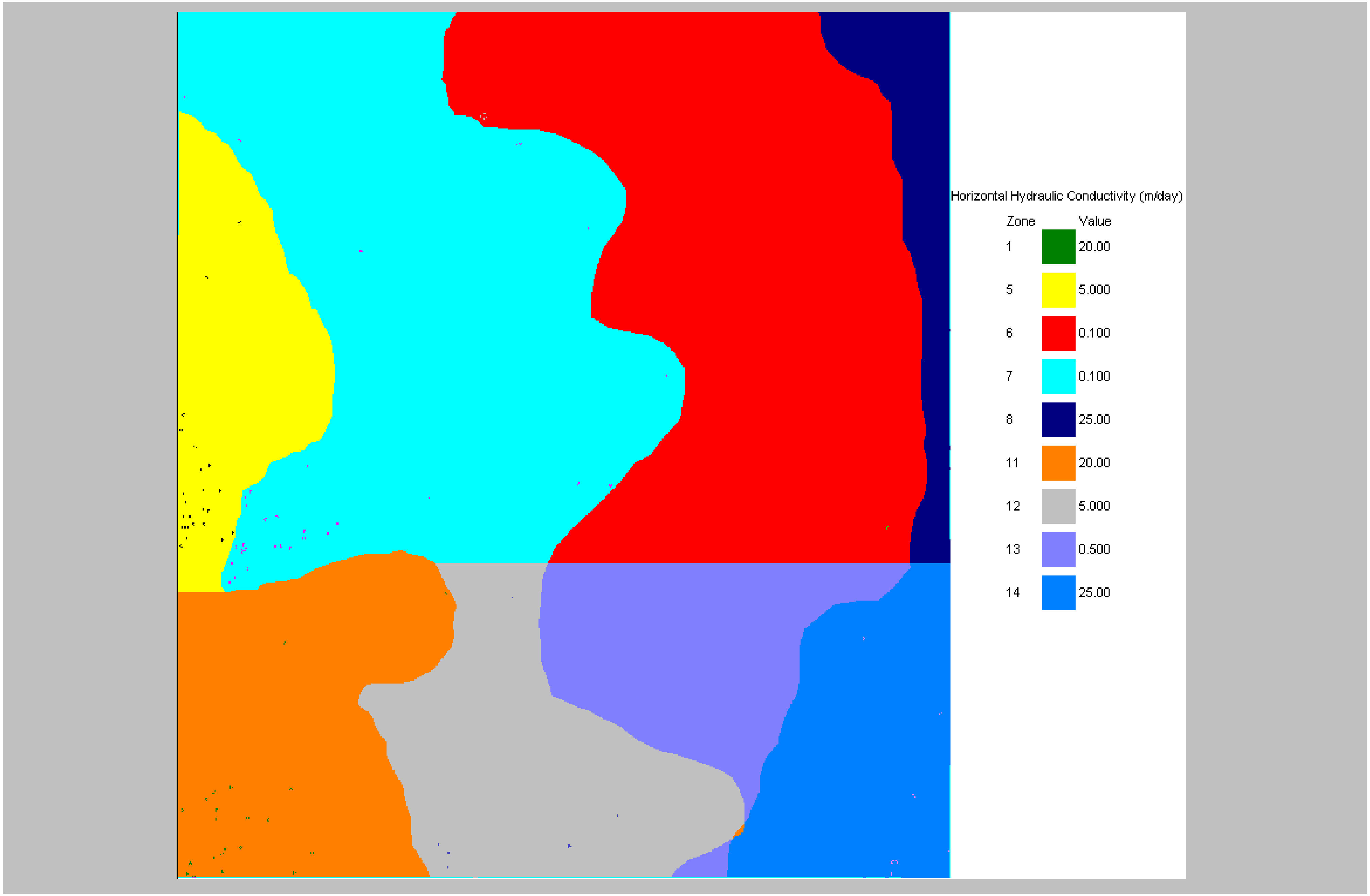

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Modelled horizontal hydraulic conductivity distribution for layer 3 FIGURE C4

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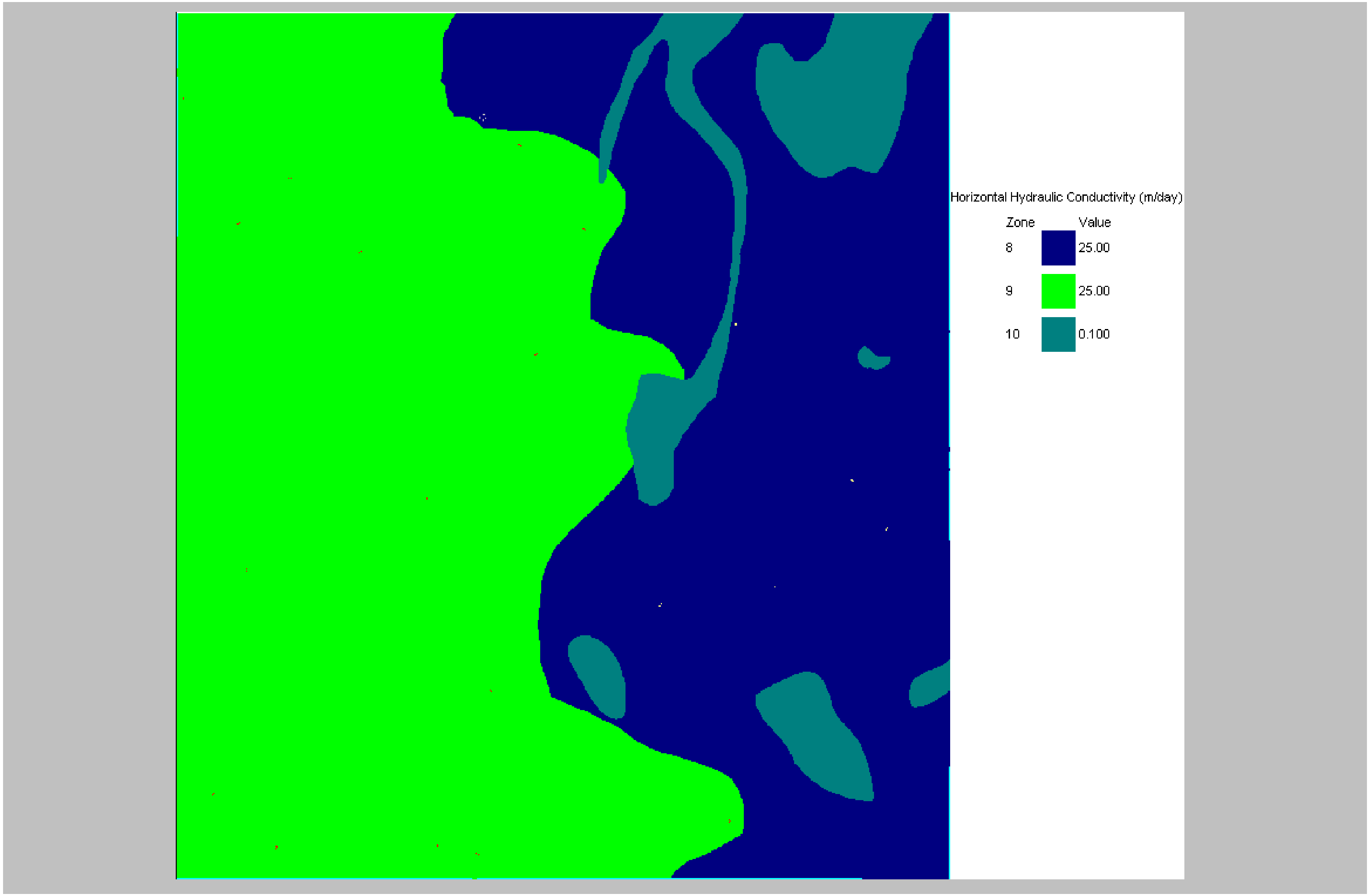

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Modelled horizontal hydraulic conductivity distribution for layer 4 FIGURE C5

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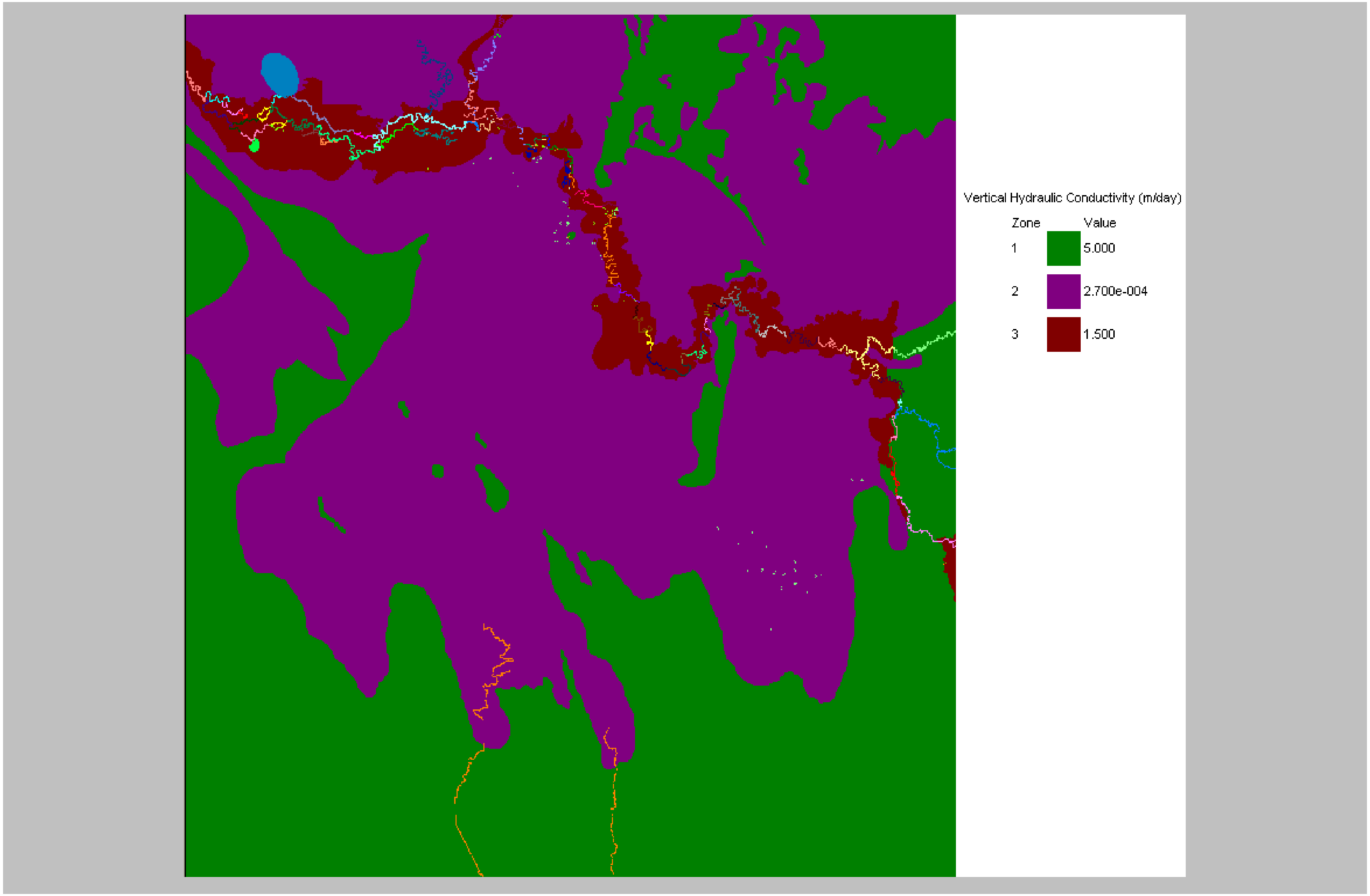

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Modelled vertical hydraulic conductivity distribution for layer 1 FIGURE C6

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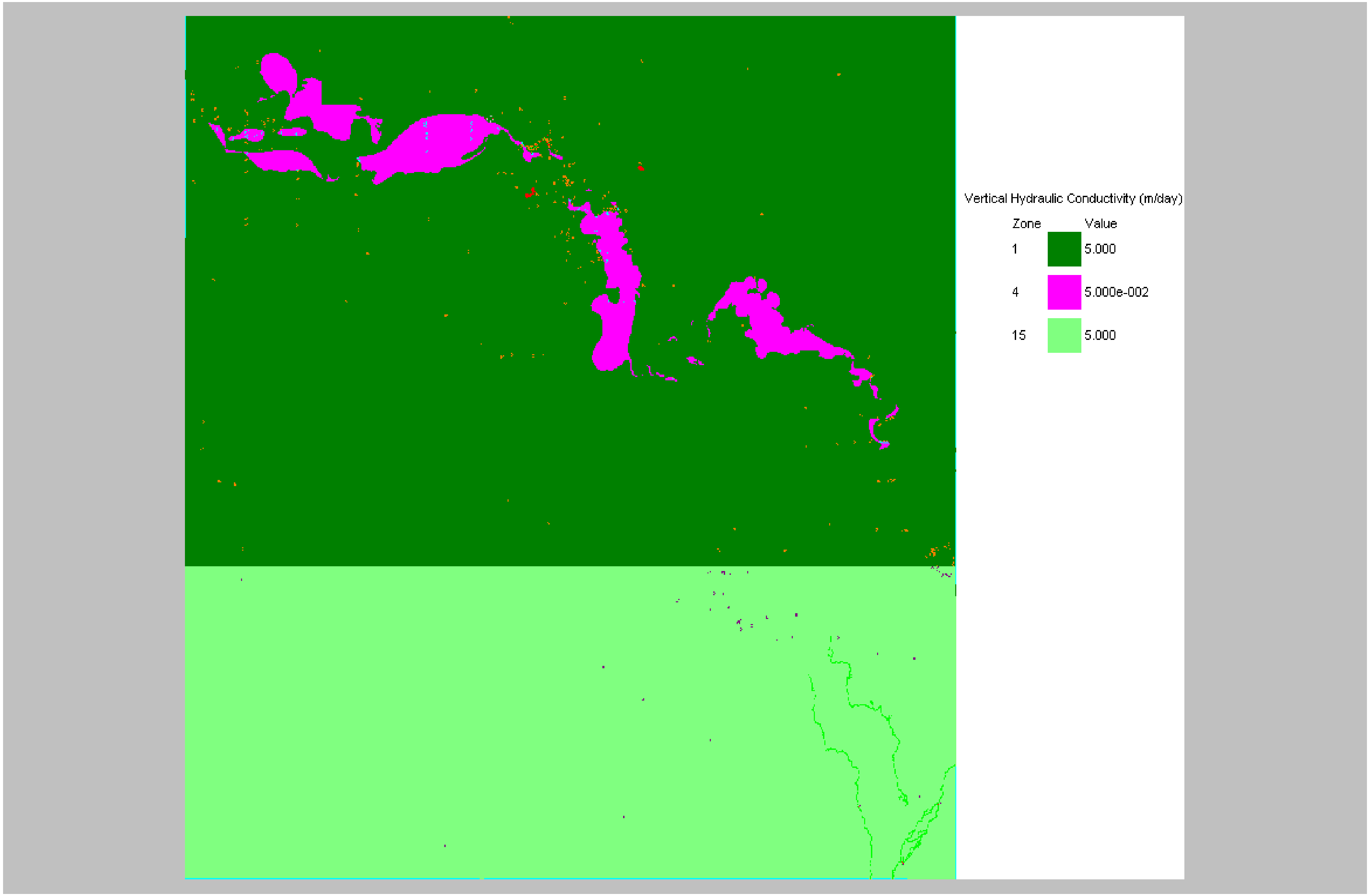

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Modelled vertical hydraulic conductivity distribution for layer 2 FIGURE C7

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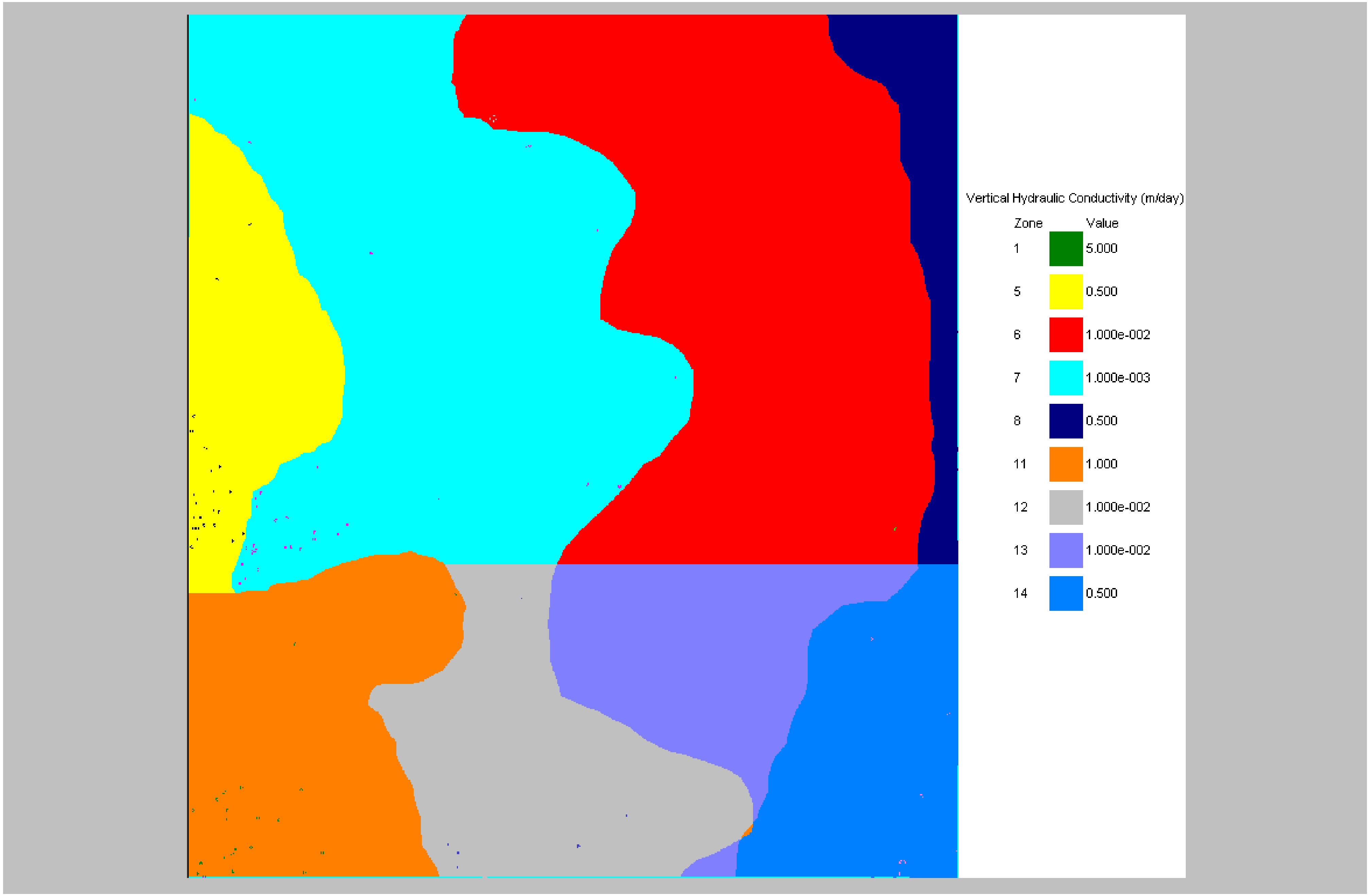

Modelled vertical hydraulic conductivity distribution for layer 3 FIGURE C8

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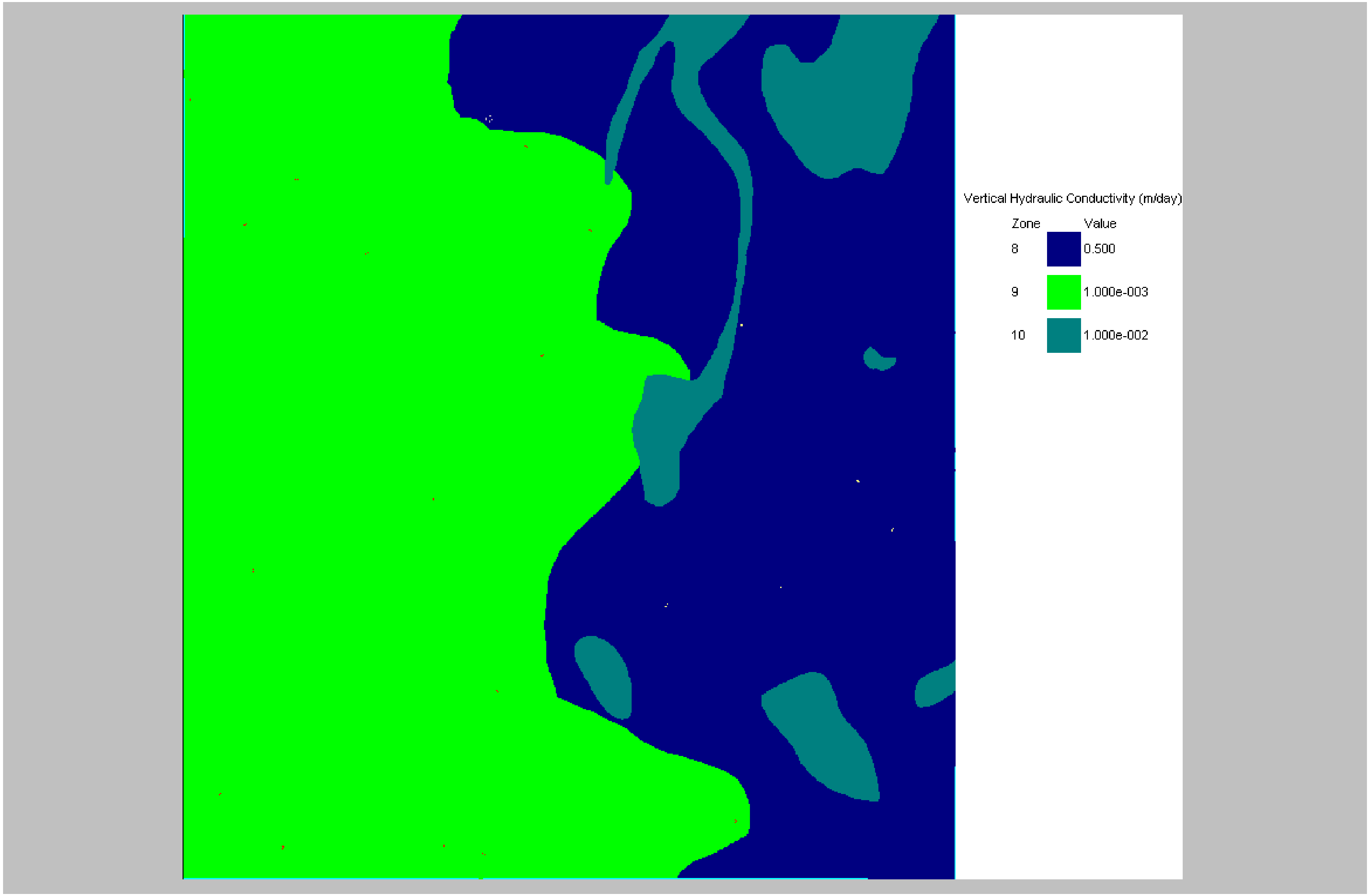

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Modelled vertical hydraulic conductivity distribution for layer 4 FIGURE C9

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APPENDIX D RIVER MURRAY AND ASSOCIATED FEATURES – RIVER REACH DETAILS

Reach	Long term average Stage (mAHD)	Assumed Depth of Bed below stage (m)	Bed Level (mAHD)	Reach	Long term average Stage (mAHD)	Assumed Depth of Bed below stage (m)	Bed Level (mAHD)
0	30.92	3.42	27.50	105	39.00	2.00	37.00
1	35.00	1.00	34.00	106	39.50	1.50	38.00
2	22.10	4.00	18.10	107	40.00	1.50	38.50
3	24.75	4.00	20.75	108	40.50	2.00	38.50
4	27.39	4.00	23.39	109	41.00	2.00	39.00
5	30.79	4.00	26.79	110	41.50	2.00	39.50
6	19.26	2.00	17.26	111	42.00	2.00	40.00
7	19.26	0.50	18.76	112	42.50	2.00	40.50
8	19.26	0.50	18.76	113	43.50	2.00	41.50
9	22.10	1.00	21.10	114	47.50	5.00	42.50
10	21.00	0.00	21.00	115	48.00	4.00	44.00
11	20.30	0.00	20.30	116	48.50	4.00	44.50
12	19.26	0.50	18.76	117	49.00	3.00	46.00
13	23.96	4.00	19.96	118	49.50	2.00	47.50
14	23.96	2.00	21.96	119	50.00	3.00	47.00
15	27.39	2.00	25.39	120	52.00	2.00	50.00
16	22.10	0.50	21.60	121	51.00	3.00	48.00
17	23.50	0.00	23.50	122	52.00	3.50	48.50
18	27.39	0.50	26.89	123	53.00	3.50	49.50
19	27.50	0.00	27.50	124	53.50	3.00	50.50
20	27.39	2.00	25.39	125	55.00	2.00	53.00
21	30.79	2.00	28.79	126	55.50	2.00	53.50
30	34.45	6.90	27.55	201	19.26	4.00	15.26
40	34.45	4.13	30.32	202	19.26	3.00	16.26
50	34.45	4.68	29.77	203	19.26	2.00	17.26
59	34.45	4.12	30.33	204	19.26	4.00	15.26
69	34.45	5.88	28.57	205	19.26	3.00	16.26
80	31.67	4.15	27.52	206	34.45	4.63	29.82
90	31.67	4.33	27.34	300	35.20	2.57	32.63
100	34.00	1.00	33.00	301	34.61	4.93	29.68
101	32.00	2.00	30.00	302	31.45	5.07	26.38
102	37.50	1.50	36.00	303	31.33	4.88	26.45
103	38.00	1.50	36.50	304	31.14	6.36	24.78
104	38.50	1.50	37.00	305	32.00	2.00	30.00

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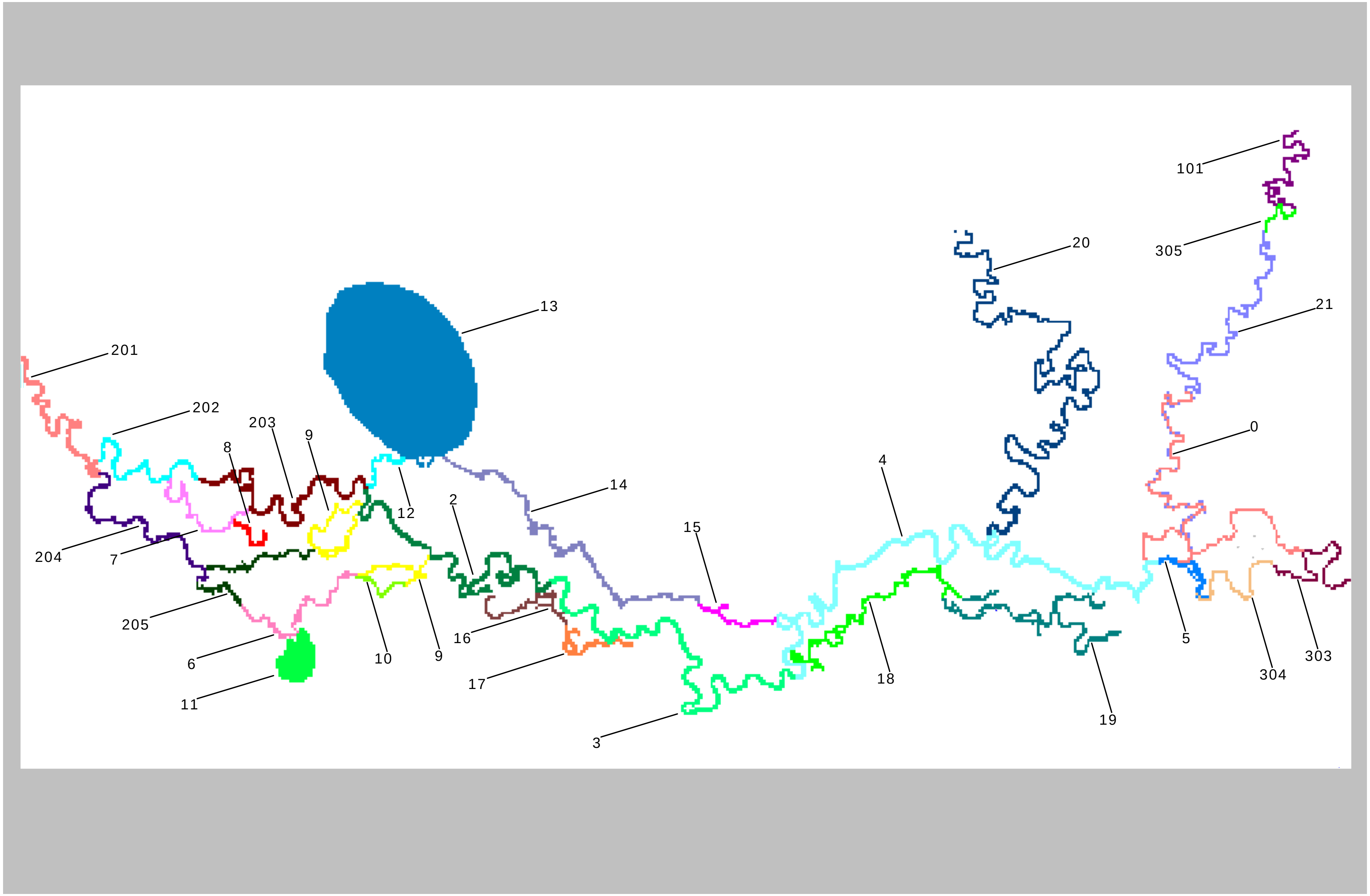
River Murray and associated features - river reach details

FIGURE D1

F:\Jobs\A53\B1_Mallee\600\602_Calib\Appendices\[Appendix_D.xls]FigD1



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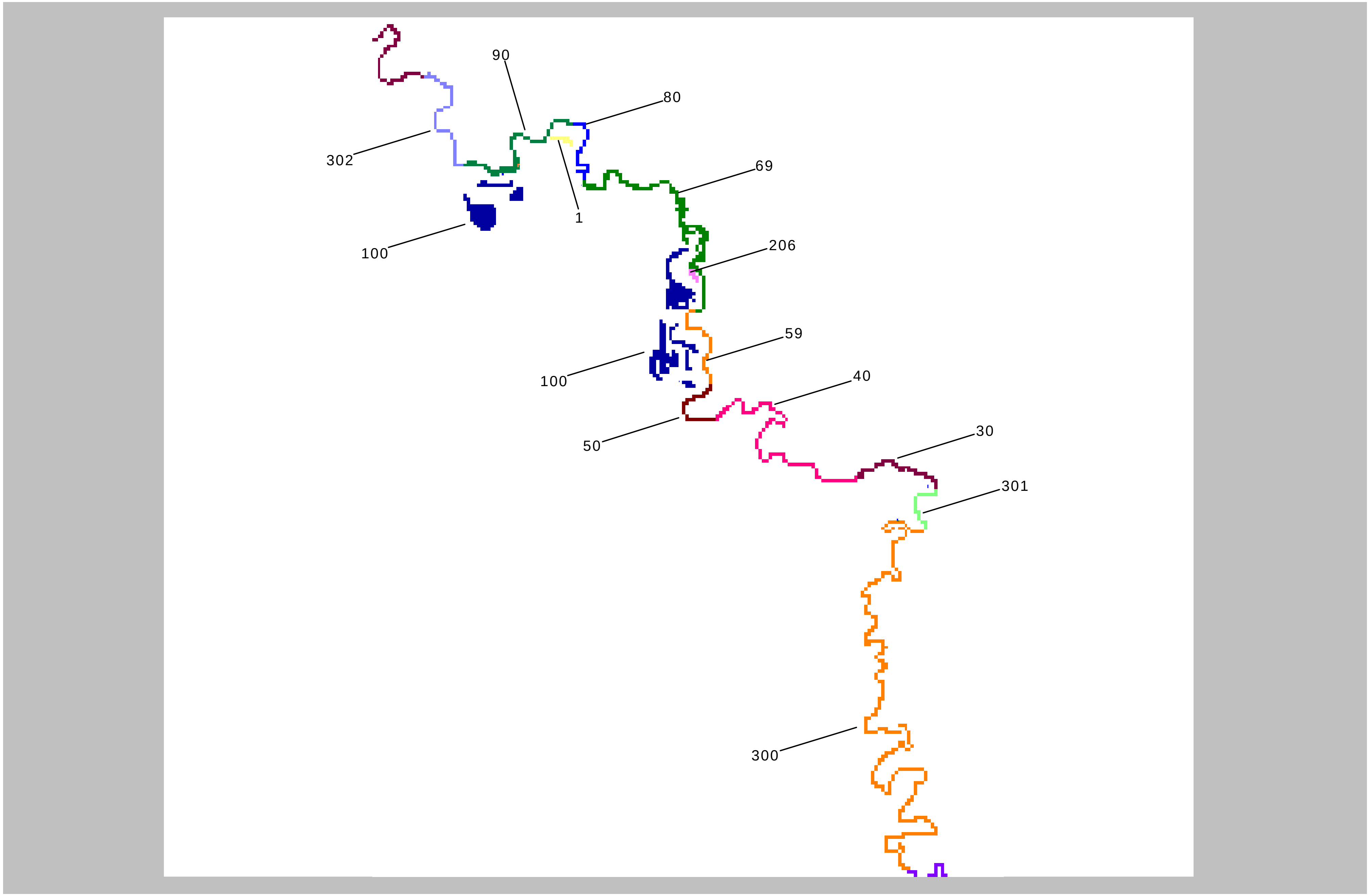
MODELLED RIVER REACHES FIGURE D2

F:\Jobs\A53\B1_Mallee\600\602_Calib\Appendices\[Appendix_D.xls]FigD2



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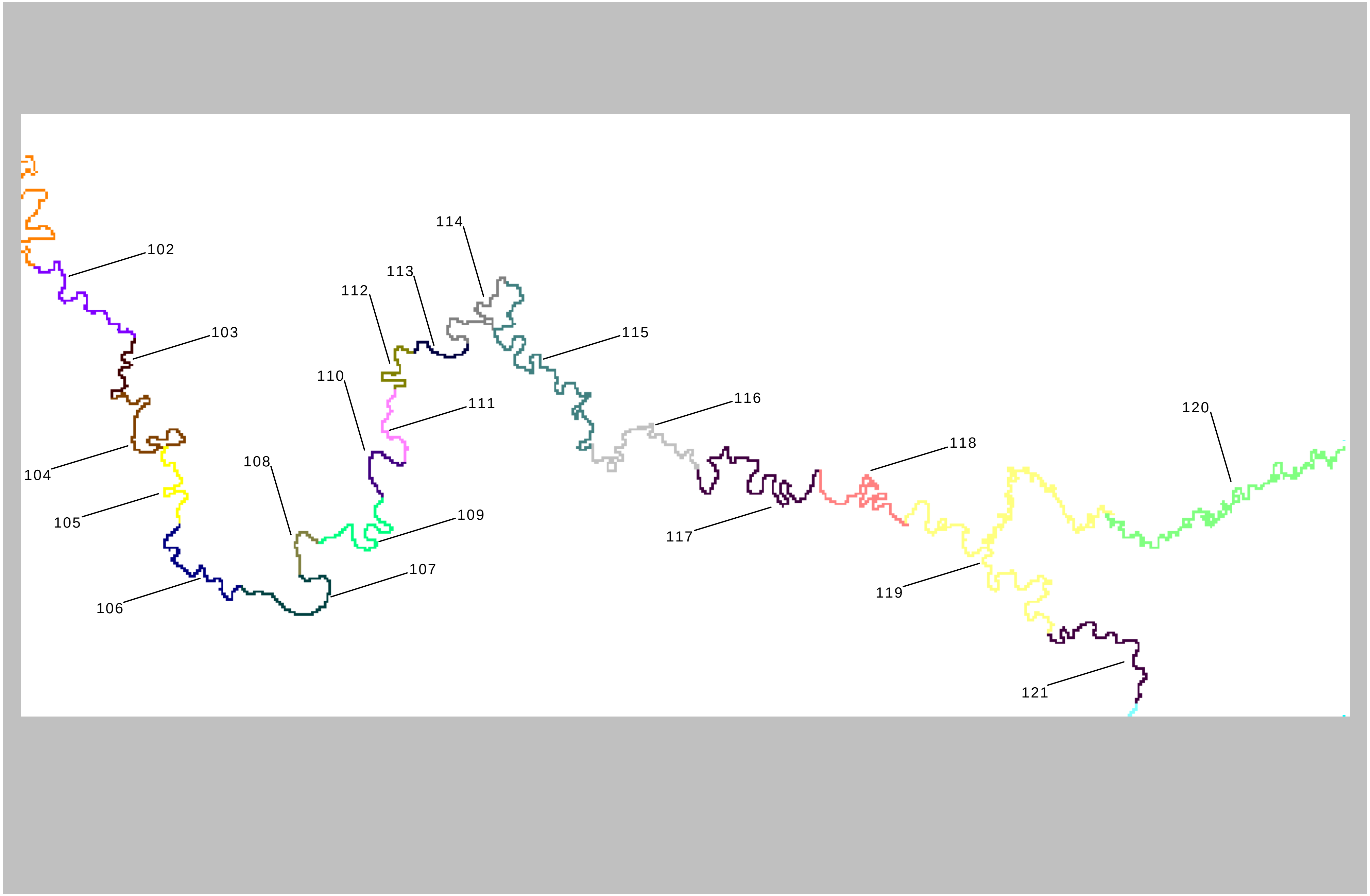
MODELLED RIVER REACHES FIGURE D3

F:\Jobs\A53\B1_Mallee\600\602_Calib\Appendices\[Appendix_D.xls]FigD3



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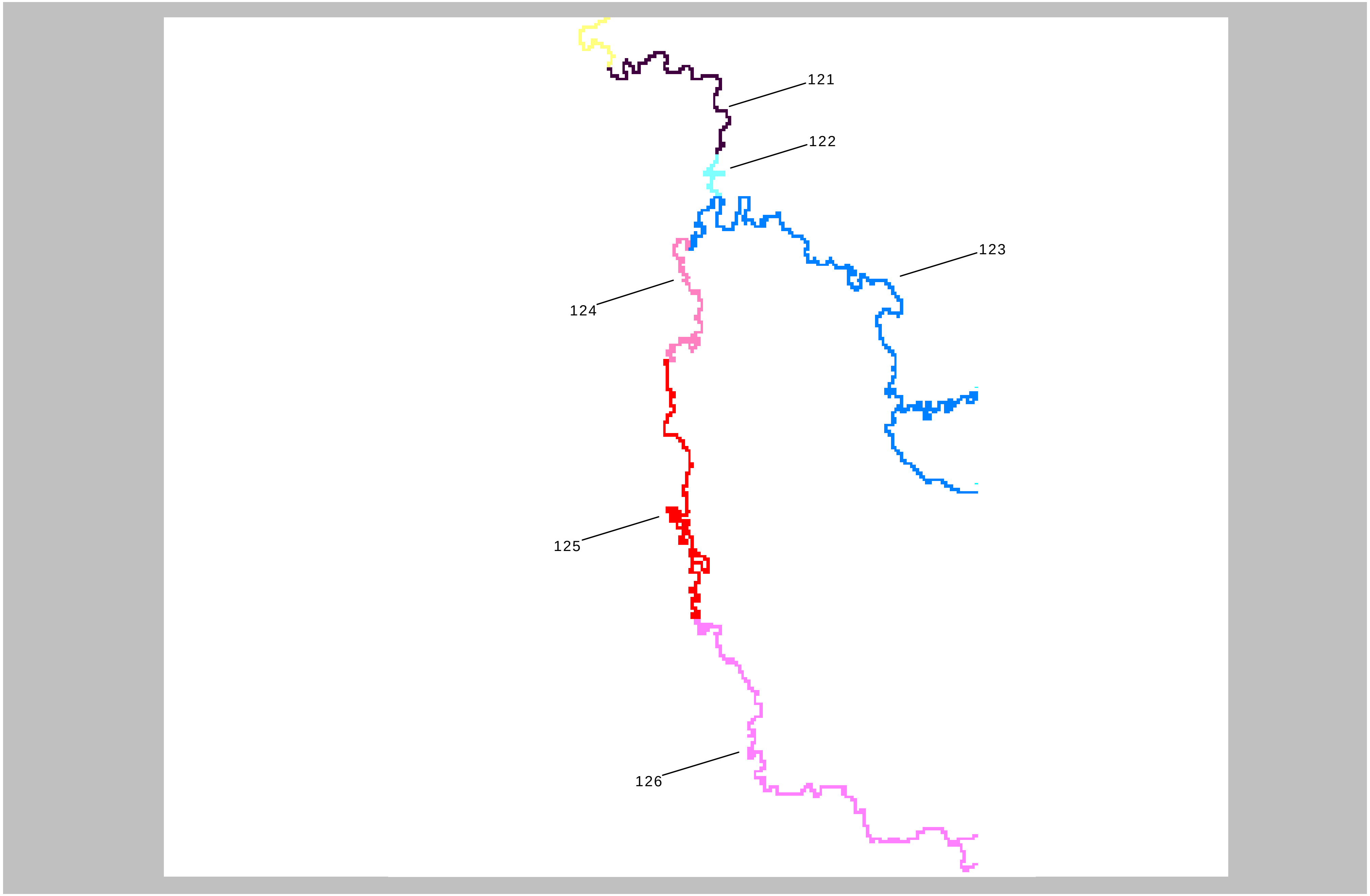
MODELLED RIVER REACHES FIGURE D4

F:\Jobs\A53\B1_Mallee\600\602_Calib\Appendices\[Appendix_D.xls]FigD4



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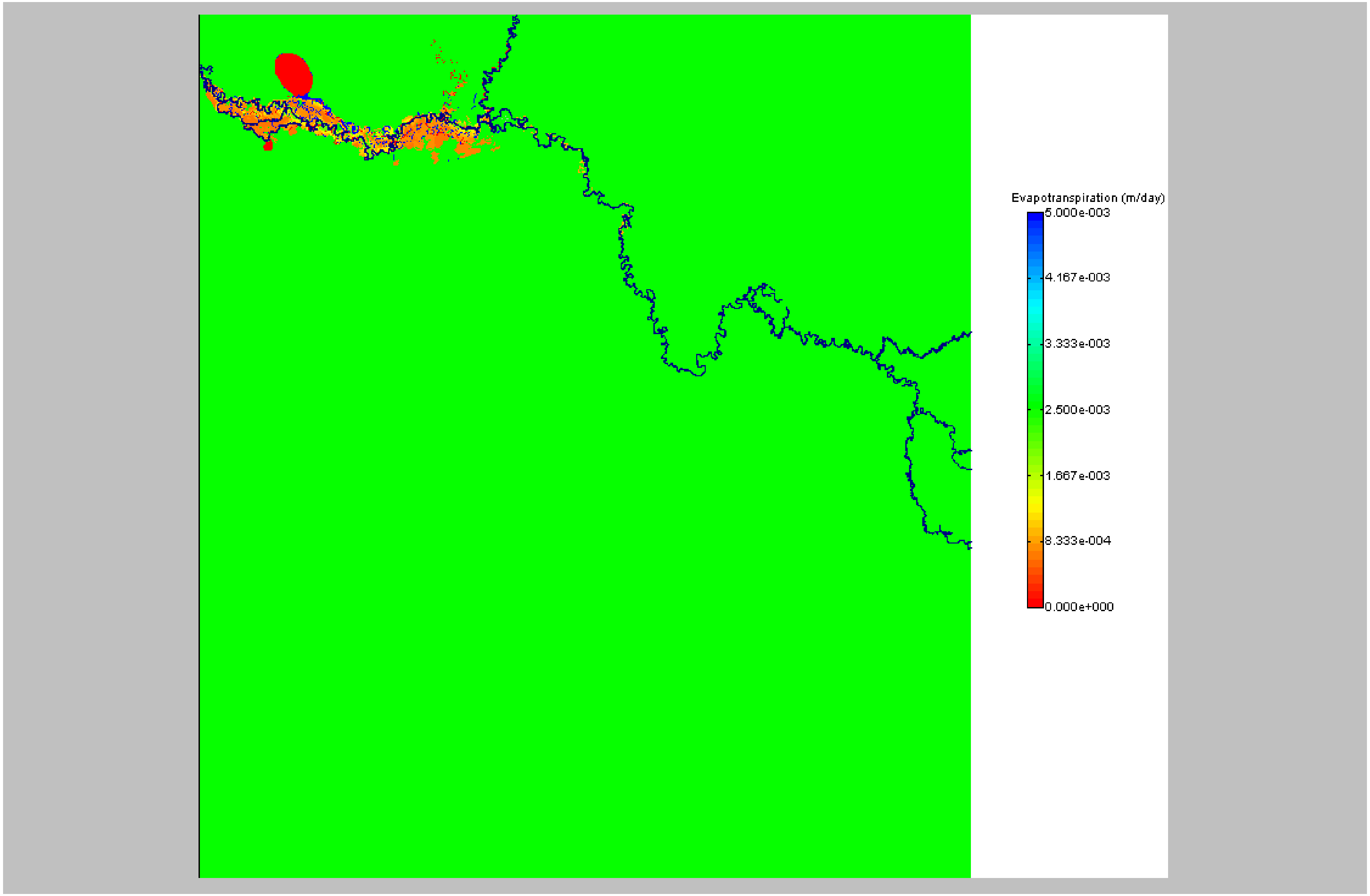
MODELLED RIVER REACHES FIGURE D5

F:\Jobs\A53\B1_Mallee\600\602_Calib\Appendices\[Appendix_D.xls]FigD5

APPENDIX E MODELLED STEADY STATE EVAPOTRANSPIRATION DISTRIBUTION



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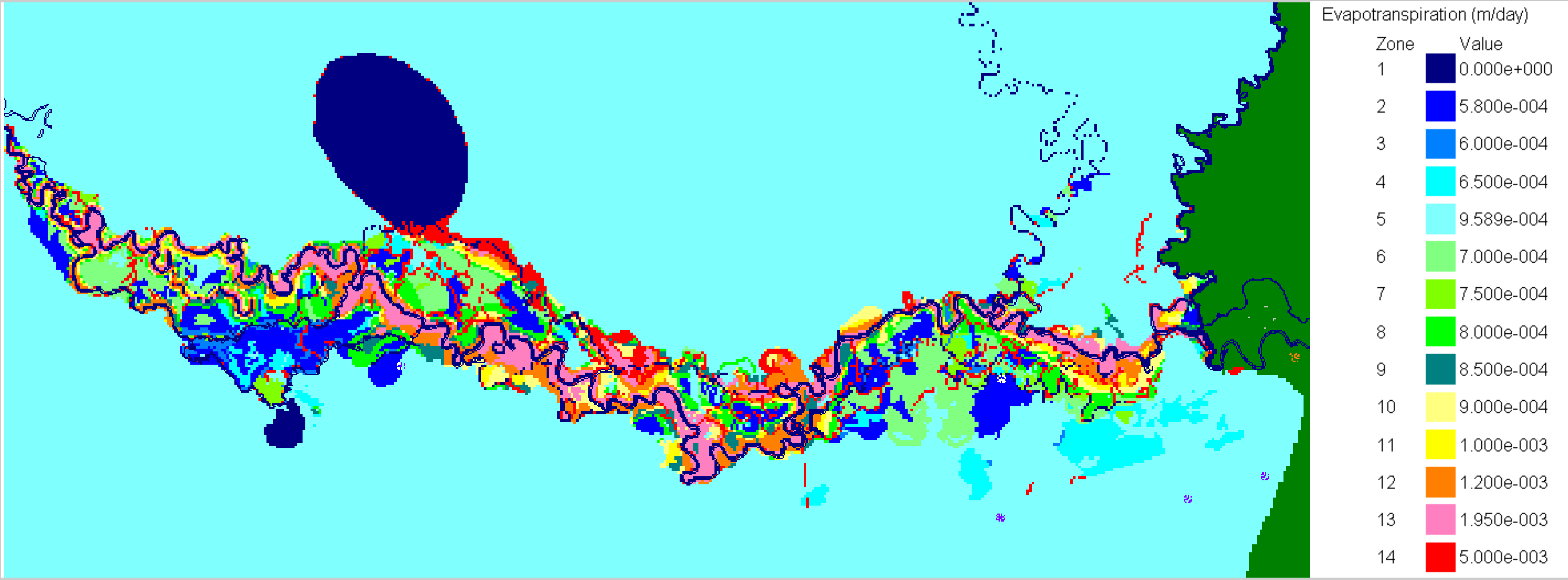
Modelled Steady State Evapotranspiration Distribution FIGURE E1

F:\Jobs\A53\B1_Mallee\600\602_Calib\Appendices\[Appendix_E1.xls]L1_ET



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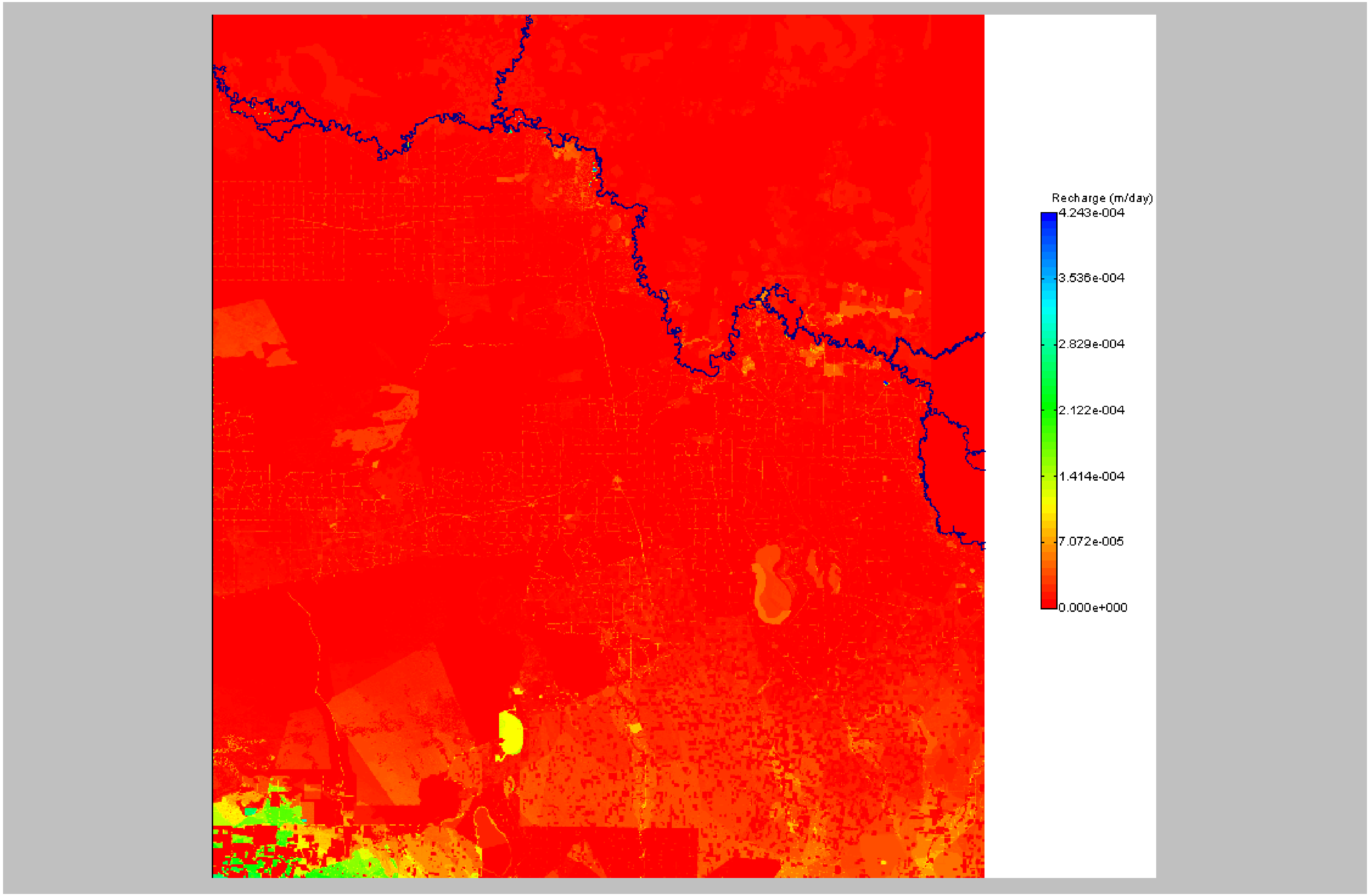
EM4.2 EVAPOTRANSPIRATION PARAMETERS FIGURE E2

f:\jobs\a53\b1_mallee\600\602_calib\appendices\figc2.doc

APPENDIX F MODELLED STEADY STATE RECHARGE DISTRIBUTION



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Modelled Steady State Recharge Distribution FIGURE F1

F:\Jobs\A53\B1_Mallee\600\602_Calib\Appendices\[Appendix_F.xls]L1_Rch

APPENDIX G STEADY STATE MODEL CALIBRATION RUN LOG

Model	Model Adjustment	Model Outcomes
1	? Initial model run	? SRMS = 5.71% ? Water balance discrepancy = -0.01% ? Difference range for modelled heads lower than measured heads = 0.01 – 16.91 m (average 2.92 m) ? Difference range for modelled heads higher than the measured heads = 0.01 – 52.56 m (average 3.46 m)
2	? MGL and Bookpurnong Beds Kh ? MGL and Bookpurnong Beds Kv increased from 0.1 to 0.5 m/day	? SRMS = 5.14% ? Water balance discrepancy = -0.01% ? Difference range for modelled heads lower than measured heads = 0.00 – 16.91 m (average 2.78 m) ? Difference range for modelled heads higher than the measured heads = 0.01 – 27.17 m (average 3.00 m)
3	? Southern GHB removed in far-east corner ? GHB along southern model boundary extends from 70m AHD (west) to 95m AHD (east) ? Western GHB in the north corner extends from 17 m AHD (south) to 18 m AHD (north)	? SRMS = 5.30% ? Water balance discrepancy = -0.01% ? Difference range for modelled heads lower than measured heads = 0.00 – 14.99 m (average 2.69 m) ? Difference range for modelled heads higher than the measured heads = 0.01 – 27.80 m (average 3.25 m)
4	? Avoca River in south-east corner converted from drain to river feature ? MGL and Bookpurnong Beds Kh increased from 5 to 7 m/day in the south	? SRMS = 5.16% ? Water balance discrepancy = -0.01% ? Difference range for modelled heads lower than measured heads = 0.00 – 14.99 m (average 2.70 m) ? Difference range for modelled heads higher than the measured heads = 0.01 – 23.15 m (average 3.19 m)
5	? Parilla Sands Kh increased from 7.5 to 10 m/day ? MGL & Bookpurnong Beds & Geera Clay/Winnambool Formation Kh increased from 0.1 to 1 m/day in the south ? Bookpurnong Beds & Geera Clay/Winnambool Formation Kh increased from 0.1 to 0.5 m/day in the south	? SRMS = 5.12% ? Water balance discrepancy = -0.01% ? Difference range for modelled heads lower than measured heads = 0.00 – 14.98 m (average 2.60 m) ? Difference range for modelled heads higher than the measured heads = 0.01 – 22.37 m (average 3.31 m)
6	? Renmark Group Kv increased from 0.01 to 0.5 m/day	? SRMS = 5.11% ? Water balance discrepancy = 0.00% ? Difference range for modelled heads lower than measured heads = 0.00 – 14.99 m (average 2.63 m) ? Difference range for modelled heads higher than the measured heads = 0.01 – 22.38 m (average 3.28 m)
7	? MGL & Bookpurnong Beds & Geera Clay/Winnambool Formation Kv increased from 0.001 to 0.01 m/day in the south	? SRMS = 5.11% ? Water balance discrepancy = 0.00% ? Difference range for modelled heads lower than measured heads = 0.00 – 14.99 m (average 2.64 m) ? Difference range for modelled heads higher than the measured heads = 0.01 – 22.35 m (average 3.27 m)
8	? Renmark Group and Ettrick Marl Kv increased from $1x10^{-7}$ to $1x10^{-5}$ m/day	? SRMS = 5.06% ? Water balance discrepancy = -0.02% ? Difference range for modelled heads lower than measured heads = 0.00 – 14.98 m (average 2.63 m) ? Difference range for modelled heads higher than the measured heads = 0.01 – 21.25 m (average 3.24 m)
9	? MGL & Bookpurnong Beds Kh increased from 7 to 20 m/day in the south ? MGL & Bookpurnong Beds & Geera Clay/Winnambool Formation Kh increased from 1 to 5 m/day in the south ? Parilla Sands Kh increased from 10 to 50 m/day in the south ? MGL & Bookpurnong Beds Kv increased from 0.5 to 1 m/day in the south ? Renmark Group and Ettrick Marl Kv increased from $1x10^{-5}$ to 0.001 m/day	? SRMS = 4.78% ? Water balance discrepancy = -0.01% ? Difference range for modelled heads lower than measured heads = 0.01 – 15.05 m (average 2.58 m) ? Difference range for modelled heads higher than the measured heads = 0.07 – 15.92 m (average 3.18 m)

Model	Model Adjustment	Model Outcomes
10	? Run 8 parameters ? Southern GHB modified to more greatly reflect Basin in the Box water level contours	? SRMS = 5.08% ? Water balance discrepancy = -0.02% ? Difference range for modelled heads lower than measured heads = 0.00 – 14.99 m (average 2.74 ? Difference range for modelled heads higher than the measured heads = 0.01 – 20.37 m (average 3.10 m)
11	? Run 9 parameters ? Southern GHB modified to more greatly reflect Basin in the Box water level contours	? SRMS = 4.75% ? Water balance discrepancy = 0.00% ? Difference range for modelled heads lower than measured heads = 0.01 – 15.05 m (average 2.79 ? Difference range for modelled heads higher than the measured heads = 0.04 – 15.50 m (average 2.93 m)
12	? Conductance for all GHBs increased from 500 to 1000 m/day ? Western GHB in the north corner increased to 24 and 30 m AHD in Layers 3 and 4 respectively	? SRMS = 4.77% ? Water balance discrepancy = 0.01% ? Difference range for modelled heads lower than measured heads = 0.00 – 11.93 m (average 2.69 ? Difference range for modelled heads higher than the measured heads = 0.01 – 15.53 m (average 3.11 m)
13	? MGL & Bookpurnong Beds Kv increased from 0.5 to 1 m/day in the north ? MGL & Bookpurnong Beds & Geera Clay/Winnambool Formation Kv increased from 0.001 to 0.02 m/day in the north	? SRMS = 4.78% ? Water balance discrepancy = -0.01% ? Difference range for modelled heads lower than measured heads = 0.01 – 11.93 m (average 2.78 ? Difference range for modelled heads higher than the measured heads = 0.01 – 15.51 m (average 3.07 m)
14	? Run 12 parameters ? Maximum recharge of 10 mm/yr across the model	? SRMS = 4.72% ? Water balance discrepancy = 0.00% ? Difference range for modelled heads lower than measured heads = 0.00 – 12.32 m (average 2.71 ? Difference range for modelled heads higher than the measured heads = 0.03 – 15.57 m (average 3.03 m)
15	? Maximum recharge of 3 mm/yr across the model	? SRMS = 4.59% ? Water balance discrepancy = 0.00% ? Difference range for modelled heads lower than measured heads = 0.00 – 12.88 m (average 2.81 m) ? Difference range for modelled heads higher than the measured heads = 0.02 – 14.78 m (average 2.83 m)
16	? Run 12 parameters (including original recharge) ? Conductance for all GHBs increased from 1000 to 10,000 ? Southern GHB extended further in the east with higher end point (105 m AHD)	? SRMS = 4.77% ? Water balance discrepancy = -0.02% ? Difference range for modelled heads lower than measured heads = 0.00 – 8.85 m (average 2.61 m) ? Difference range for modelled heads higher than the measured heads = 0.04 – 15.88 m (average 3.18 m)
17	? Modified GHB head levels based on Hydrogeological map sheets	? SRMS = 4.72% ? Water balance discrepancy = -0.01% ? Difference range for modelled heads lower than measured heads = 0.00 – 9.45 m (average 2.75 ? Difference range for modelled heads higher than the measured heads = 0.04 – 14.86 m (average 3.01 m)
18	? Further refinement of GHB head levels (particularly along the southern and south-east boundaries)	? SRMS = 4.07% ? Water balance discrepancy = 0.00% ? Difference range for modelled heads lower than measured heads = 0.00 - 8.86 m (average 2.21m) ? Difference range for modelled heads higher than the measured heads = 0.02 - 14.99 m (average 2.78m)
19	? Parilla Sands Kh increased from 10 to 20 in the north	? SRMS = 3.95% ? Water balance discrepancy = 0.00% ? Difference range for modelled heads lower than measured heads = 0.00 - 8.83 m (average 2.18 m) ? Difference range for modelled heads higher than the measured heads = 0.01 – 14.75 m (average 2.73 m)

APPENDIX H MODELLED STEADY STATE VS MEASURED CALIBRATION BORE DETAILS AND PERFORMANCE

Bore	Easting	Northing	Layer	Measured	Computed	Weight	Residual
40599	665521.3	6099577.3	1	44.36	43.68	1	0.68
40603	685921.4	6084977.3	1	46.78	47.50	1	-0.72
40620	669021.3	6102577.3	1	47.92	45.32	1	2.60
40621	672471.3	6091527.3	1	47.60	44.12	1	3.48
40622	676221.3	6090727.3	1	48.21	45.62	1	2.59
40623	677921.4	6086177.3	1	48.67	46.12	1	2.55
40625	682321.4	6094077.3	1	47.57	47.71	1	-0.14
40626	679021.3	6090377.3	1	44.43	46.62	1	-2.19
40627	682371.4	6091577.3	1	45.68	47.89	1	-2.21
40628	688821.4	6089777.3	1	47.20	50.17	1	-2.97
40629	690121.4	6089677.3	1	48.00	50.08	1	-2.08
40630	673471.3	6098427.3	1	48.78	45.76	1	3.02
40632	674721.4	6073727.2	1	46.71	46.82	1	-0.11
40634	682521.4	6087377.3	1	46.01	45.97	1	0.04
40643	668421.3	6099177.3	1	45.59	41.19	1	4.40
40644	667921.3	6091177.3	1	43.07	41.70	1	1.37
40649	658821.3	6104027.3	1	48.50	45.62	1	2.88
128042	699838.4	6118337.3	1	50.42	51.90	1	-1.48
128045	702845.4	6118471.3	1	50.75	50.37	1	0.38
7300	606952.2	6218959.4	2	31.92	31.59	1	0.33
7301	606922.2	6219161.4	2	32.33	31.57	1	0.76
7303	607129.2	6219402.4	2	31.11	31.48	1	-0.37
7304	606825.2	6219584.4	2	31.44	31.52	1	-0.08
7306	606436.2	6219945.4	2	31.66	31.48	1	0.18
7308	606815.2	6220175.4	2	30.99	31.38	1	-0.39
7310	607361.2	6219981.4	2	31.22	31.37	1	-0.15
7321	599557.2	6218033.4	2	35.60	31.77	1	3.83
7340	600841.2	6217903.4	2	30.92	31.25	1	-0.33
7355	603350.2	6217975.4	2	31.33	31.58	1	-0.25
7357	603509.2	6218026.4	2	31.96	31.55	1	0.41
7361	603377.2	6218368.4	2	30.88	31.46	1	-0.58
7363	603533.2	6218605.4	2	30.61	31.46	1	-0.85
7367	603442.2	6217744.4	2	31.78	31.74	1	0.04
7376	606857.2	6218765.4	2	31.74	31.64	1	0.10
7379	606041.2	6218871.4	2	33.30	31.71	1	1.59
7460	607161.2	6217855.4	2	32.84	31.79	1	1.05
7463	610637.2	6207820.4	2	37.69	34.16	1	3.53
7474	606909.2	6218747.4	2	31.62	31.63	1	-0.01
7475	605101.2	6219624.4	2	32.45	31.41	1	1.04
7476	605123.2	6219611.4	2	33.12	31.41	1	1.71
7491	613041.2	6192274.4	2	36.56	35.16	1	1.40
7516	613112.2	6193442.4	2	35.63	35.12	1	0.51
7517	613112.2	6193441.4	2	36.80	35.12	1	1.68
7536	613069.2	6190544.4	2	35.15	35.25	1	-0.10
7591	626044.2	6199326.4	2	30.59	34.27	1	-3.68
7593	626837.2	6199197.4	2	31.45	34.31	1	-2.86
7609	624154.2	6199383.4	2	34.85	34.19	1	0.66
7613	624107.2	6199131.4	2	34.64	34.22	1	0.42
7614	624037.2	6198953.4	2	35.07	34.24	1	0.83
7618	624923.2	6198701.4	2	35.02	34.29	1	0.73
7620	624793.2	6198629.4	2	35.13	34.30	1	0.83
7622	625278.2	6197906.4	2	34.90	34.53	1	0.37
7625	625145.2	6197927.4	2	34.84	34.51	1	0.33
7632	613067.2	6190131.4	2	36.52	35.29	1	1.23

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Modelled steady state vs modelled calibration bore details and performance FIGURE H1

Bore	Easting	Northing	Layer	Measured	Computed	Weight	Residual
7651	621621.2	6192829.4	2	37.95	35.24	1	2.71
7662	614655.2	6197111.4	2	33.57	34.98	1	-1.41
7664	613066.2	6191450.4	2	36.83	35.18	1	1.65
7666	611115.2	6192284.4	2	33.93	35.17	1	-1.24
7671	624844.2	6199440.4	2	31.38	34.23	1	-2.85
7673	614760.2	6190754.4	2	37.05	35.29	1	1.76
7678	604027.2	6200126.4	2	37.81	34.72	1	3.09
7684	613015.2	6207687.4	2	35.70	34.00	1	1.70
7686	613623.2	6206342.4	2	35.86	34.03	1	1.83
7688	613007.2	6206587.4	2	36.50	34.03	1	2.47
7690	612616.2	6207345.4	2	36.45	34.02	1	2.43
7694	611037.2	6205036.4	2	37.04	34.32	1	2.72
7695	609207.2	6204446.4	2	38.66	34.48	1	4.18
7696	609066.2	6206981.4	2	39.14	34.29	1	4.85
7697	609131.2	6201457.4	2	37.76	34.70	1	3.06
7698	612016.2	6200980.4	2	36.51	34.67	1	1.84
7700	613784.2	6201715.4	2	36.22	34.38	1	1.84
7701	600566.2	6217870.4	2	30.95	31.23	1	-0.28
7702	601683.2	6217613.4	2	30.76	31.58	1	-0.82
7703	602070.2	6217606.4	2	30.93	31.58	1	-0.65
7704	602120.2	6217486.4	2	37.79	31.65	1	6.14
7706	603343.2	6217899.4	2	31.29	31.63	1	-0.34
7707	603914.2	6218075.4	2	32.88	31.71	1	1.17
7708	604161.2	6219183.4	2	31.97	31.47	1	0.50
7709	604229.2	6219254.4	2	31.79	31.47	1	0.32
7710	604301.2	6219324.4	2	31.58	31.46	1	0.12
7711	605900.2	6220030.4	2	32.37	31.22	1	1.15
7712	607226.2	6219544.4	2	31.18	31.46	1	-0.28
7726	626467.2	6198539.4	2	34.53	34.36	1	0.17
7727	622069.2	6197293.4	2	35.62	34.40	1	1.22
7732	606816.2	6218998.4	2	32.14	31.61	1	0.53
7734	612729.2	6207565.4	2	36.05	34.01	1	2.04
7740	611477.2	6202929.4	2	36.74	34.50	1	2.24
7743	603736.2	6203707.4	2	38.89	34.54	1	4.35
7744	606489.2	6203944.4	2	39.21	34.55	1	4.66
7745	603343.2	6207462.4	2	39.37	34.22	1	5.15
7747	607472.2	6205748.4	2	39.27	34.42	1	4.85
7788	601594.2	6217721.4	2	30.53	31.54	1	-1.01
7831	530721.1	6202077.4	2	21.04	27.35	1	-6.31
7832	548921.1	6193077.4	2	22.43	31.15	1	-8.72
7833	570221.1	6219777.4	2	26.82	27.94	1	-1.12
7837	530721.1	6210677.4	2	21.54	26.52	1	-4.98
7839	570321.1	6196277.4	2	27.19	33.00	1	-5.81
7840	609621.2	6212877.4	2	38.18	33.89	1	4.29
7842	593821.2	6209877.4	2	37.69	33.40	1	4.29
7843	584121.1	6196877.4	2	31.08	33.78	1	-2.70
7844	584121.1	6196877.4	2	31.36	33.78	1	-2.42
7850	612321.2	6171027.4	2	37.00	36.25	1	0.75
7852	625421.2	6171877.4	2	37.98	37.58	1	0.40
7863	618821.2	6198877.4	2	36.52	34.55	1	1.97
7865	633621.2	6171777.4	2	38.42	37.49	1	0.93
7866	630621.2	6171877.4	2	38.43	37.83	1	0.60
7867	624971.2	6186427.4	2	37.59	35.24	1	2.35
7870	623021.2	6186677.4	2	38.15	35.65	1	2.50

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Modelled steady state vs modelled calibration bore details and performance FIGURE H2

Bore	Easting	Northing	Layer	Measured	Computed	Weight	Residual
7875	613521.2	6186377.4	2	36.90	35.57	1	1.33
7879	616421.2	6199377.4	2	34.12	34.52	1	-0.40
7880	601021.2	6199477.4	2	33.82	34.64	1	-0.82
7883	583521.1	6224777.4	2	29.60	29.93	1	-0.33
7886	583621.1	6224477.4	2	29.46	29.86	1	-0.40
7888	583621.1	6223977.4	2	29.17	29.68	1	-0.51
7890	583621.1	6222577.4	2	28.82	29.61	1	-0.79
7892	583721.1	6220077.4	2	28.76	29.97	1	-1.21
7894	583921.1	6214677.4	2	28.96	30.58	1	-1.62
7896	569721.1	6224977.4	2	27.50	27.43	1	0.07
7898	569621.1	6224577.4	2	27.41	27.44	1	-0.03
7900	569621.1	6223777.4	2	27.39	27.44	1	-0.05
7902	570221.1	6221577.4	2	27.28	27.54	1	-0.26
7906	570221.1	6221077.4	2	27.18	27.64	1	-0.46
7908	570221.1	6220477.4	2	27.16	27.77	1	-0.61
7909	570221.1	6219777.4	2	27.10	27.94	1	-0.84
7910	570121.1	6216477.4	2	27.02	28.61	1	-1.59
7914	549148.1	6214214.4	2	24.25	24.67	1	-0.42
7915	530221.1	6221877.4	2	21.96	22.41	1	-0.45
7917	530121.1	6222277.4	2	21.58	22.24	1	-0.66
7920	530221.1	6221377.4	2	22.05	22.63	1	-0.58
7924	530821.1	6217477.4	2	21.78	23.37	1	-1.59
7926	515221.0	6220577.4	2	19.10	19.56	1	-0.46
7927	515221.0	6220177.4	2	19.47	19.95	1	-0.48
7928	515121.0	6224277.4	2	18.92	19.54	1	-0.62
7929	515221.0	6219677.4	2	19.18	20.30	1	-1.12
7930	515221.0	6218777.4	2	19.13	20.53	1	-1.40
7931	515221.0	6218777.4	2	19.21	20.53	1	-1.32
7932	515221.0	6215777.4	2	19.37	21.52	1	-2.15
7934	515121.0	6213977.4	2	19.58	23.00	1	-3.42
7935	515071.0	6196577.4	2	18.96	23.91	1	-4.95
7936	498621.0	6233577.4	2	18.98	17.98	1	1.00
7938	515121.0	6210477.4	2	19.06	23.70	1	-4.64
7940	499121.0	6234177.4	2	18.59	18.46	1	0.13
7941	498921.0	6231677.4	2	19.03	17.91	1	1.12
7942	499321.0	6225477.4	2	18.91	20.16	1	-1.25
7943	499121.0	6207377.4	2	18.03	20.95	1	-2.92
7944	530621.1	6194577.4	2	19.87	28.11	1	-8.24
7945	549399.1	6213795.4	2	24.30	25.30	1	-1.00
7948	514881.0	6228407.4	2	19.14	19.37	1	-0.23
7949	515061.0	6228037.4	2	18.90	19.40	1	-0.50
7950	515321.0	6227477.4	2	18.86	19.44	1	-0.58
7951	549345.1	6213308.4	2	24.33	25.80	1	-1.47
7952	549238.1	6212332.4	2	23.93	26.28	1	-2.35
7953	548919.1	6209377.4	2	23.90	27.54	1	-3.64
7954	548521.1	6203577.4	2	23.69	29.21	1	-5.52
7955	613661.2	6212317.4	2	34.15	34.07	1	0.08
7956	613261.2	6212247.4	2	33.97	34.05	1	-0.08
7957	612701.2	6212327.4	2	34.28	34.03	1	0.25
7961	611821.2	6212177.4	2	35.30	34.01	1	1.29
7962	609477.2	6217198.4	2	33.89	33.22	1	0.67
7964	609533.2	6216782.4	2	34.03	33.26	1	0.77
7966	609481.2	6216272.4	2	34.46	33.30	1	1.16
7967	609370.2	6215332.4	2	35.51	33.41	1	2.10

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Modelled steady state vs modelled calibration bore details and performance FIGURE H3

Bore	Easting	Northing	Layer	Measured	Computed	Weight	Residual
7968	625586.2	6199107.4	2	34.44	34.28	1	0.16
7969	628021.2	6199313.4	2	33.56	34.34	1	-0.78
7972	599293.2	6218320.4	2	35.70	31.82	1	3.88
7973	599037.2	6217919.4	2	37.72	32.11	1	5.61
7974	598529.2	6217128.4	2	41.26	32.43	1	8.83
7976	611971.2	6207927.4	2	36.75	34.05	1	2.70
7978	611921.2	6208877.4	2	36.68	34.05	1	2.63
7980	612571.2	6208377.4	2	36.02	34.02	1	2.00
7982	613571.2	6207327.4	2	35.49	33.97	1	1.52
7984	614421.2	6207077.4	2	34.68	33.95	1	0.73
7986	612821.2	6208377.4	2	35.50	33.99	1	1.51
7990	613221.2	6208077.4	2	35.10	33.97	1	1.13
7992	614321.2	6200777.4	2	36.48	34.32	1	2.16
7994	614571.2	6201427.4	2	36.13	34.21	1	1.92
7996	614971.2	6202627.4	2	35.24	34.01	1	1.23
26105	730421.4	6093677.3	2	64.87	62.03	1	2.84
26106	730471.4	6094227.3	2	65.02	61.84	1	3.18
26107	730521.4	6095577.3	2	64.42	61.29	1	3.13
26110	725771.4	6098327.3	2	63.59	58.43	1	5.16
26116	725771.4	6099177.3	2	63.41	58.05	1	5.36
26117	725771.4	6099177.3	2	63.95	58.05	1	5.90
26118	728221.4	6098677.3	2	63.67	58.59	1	5.08
26119	730021.4	6098077.3	2	63.58	59.43	1	4.15
26120	728921.4	6099677.3	2	64.01	58.02	1	5.99
26125	727221.4	6090377.3	2	63.54	61.31	1	2.23
26126	727221.4	6090377.3	2	63.90	61.31	1	2.59
26127	727221.4	6090377.3	2	63.66	61.31	1	2.35
26128	721671.4	6096977.3	2	62.13	58.39	1	3.74
26129	721671.4	6096977.3	2	62.40	58.39	1	4.01
26130	725071.4	6095577.3	2	62.92	59.39	1	3.53
26131	725071.4	6095577.3	2	63.15	59.39	1	3.76
26132	724221.4	6092877.3	2	61.56	60.01	1	1.55
26133	724221.4	6092877.3	2	62.33	60.01	1	2.32
26134	724221.4	6092877.3	2	62.06	60.01	1	2.05
26135	725871.4	6092877.3	2	62.63	60.47	1	2.16
26136	726071.4	6091627.3	2	63.40	60.75	1	2.65
26138	724921.4	6097577.3	2	63.44	58.63	1	4.81
26139	724221.4	6098077.3	2	63.51	58.36	1	5.15
26140	724221.4	6097377.3	2	63.40	58.61	1	4.79
26142	722321.4	6095877.3	2	62.50	58.79	1	3.71
26144	724921.4	6096527.3	2	63.34	59.02	1	4.32
26146	723321.4	6096677.3	2	62.87	58.71	1	4.16
26147	723721.4	6094727.3	2	62.76	59.38	1	3.38
26151	729671.4	6090377.3	2	65.15	62.40	1	2.75
26152	728521.4	6090527.3	2	64.16	61.82	1	2.34
26155	717269.4	6103947.3	2	58.66	56.01	1	2.65
26157	716371.4	6103833.3	2	60.23	55.88	1	4.35
26158	715331.4	6103857.3	2	60.01	55.68	1	4.33
26159	712234.4	6103910.3	2	57.88	54.99	1	2.89
26160	707334.4	6104005.3	2	53.61	53.83	1	-0.22
26161	692857.4	6105427.3	2	48.31	49.89	1	-1.58
26162	712462.4	6118664.4	2	58.81	53.71	1	5.10
26163	712055.4	6118710.4	2	58.88	53.67	1	5.21
26164	711590.4	6118642.4	2	58.63	53.61	1	5.02

Bore	Easting	Northing	Layer	Measured	Computed	Weight	Residual
26165	710528.4	6118474.4	2	58.85	53.45	1	5.40
26166	707791.4	6118444.4	2	55.39	52.99	1	2.40
26168	688013.3	6118818.3	2	49.81	49.99	1	-0.18
26169	711521.4	6129777.4	2	51.84	53.16	1	-1.32
26170	711121.4	6129777.4	2	55.72	53.10	1	2.62
26171	710621.4	6129777.4	2	56.03	53.01	1	3.02
26172	710421.4	6129877.4	2	53.65	52.97	1	0.68
26173	710021.4	6129977.4	2	54.75	52.92	1	1.83
26174	709521.4	6130027.4	2	54.64	52.87	1	1.77
26175	708521.4	6130177.4	2	54.48	52.72	1	1.76
26176	705421.4	6130277.4	2	53.53	52.10	1	1.43
26177	700621.4	6130077.4	2	52.44	51.60	1	0.84
26178	695221.3	6129377.4	2	50.89	51.00	1	-0.11
26179	685621.3	6128777.4	2	49.82	49.79	1	0.03
26182	717270.4	6103946.3	2	57.68	56.01	1	1.67
26186	656121.3	6160177.4	2	42.15	42.15	1	0.00
26188	712121.4	6137277.4	2	53.43	53.03	1	0.40
26189	711921.4	6137277.4	2	53.41	52.99	1	0.42
26190	711221.4	6136877.4	2	53.07	52.82	1	0.25
26191	710221.4	6136777.4	2	54.15	52.54	1	1.61
26192	707321.4	6137277.4	2	53.52	51.99	1	1.53
26193	702521.4	6137977.4	2	51.78	51.40	1	0.38
26195	685821.3	6140077.4	2	50.29	49.65	1	0.64
26196	708221.4	6135227.4	2	53.42	52.52	1	0.90
26198	706021.3	6149677.4	2	51.00	50.44	1	0.56
26199	705621.3	6149277.4	2	51.43	50.57	1	0.86
26942	715121.5	6004977.1	2	101.73	97.11	1	4.62
26948	726421.5	6022577.2	2	82.58	81.70	1	0.88
27001	599480.2	6218638.4	2	32.99	31.41	1	1.58
27023	609021.2	6191077.4	2	36.46	35.20	1	1.26
27031	603221.2	6217097.4	2	33.58	32.28	1	1.30
27032	602421.2	6217077.4	2	32.51	32.17	1	0.34
27033	601721.2	6217077.4	2	31.91	32.20	1	-0.29
27034	602621.2	6217327.4	2	32.18	31.89	1	0.29
27035	602721.2	6217577.4	2	31.83	31.49	1	0.34
27051	606182.2	6220060.4	2	31.52	31.41	1	0.11
27054	602908.2	6217622.4	2	30.69	31.52	1	-0.83
27057	602517.2	6217698.4	2	30.81	31.54	1	-0.73
27058	602116.2	6217403.4	2	30.78	31.70	1	-0.92
27061	602211.2	6217386.4	2	29.56	31.73	1	-2.17
27065	601776.2	6217333.4	2	30.44	31.68	1	-1.24
27067	601742.2	6217234.4	2	30.50	31.92	1	-1.42
27069	601798.2	6217419.4	2	30.92	31.50	1	-0.58
27073	601358.2	6217546.4	2	30.70	31.73	1	-1.03
27074	601476.2	6217515.4	2	30.88	31.74	1	-0.86
27075	601503.2	6217647.4	2	19.66	31.61	1	-11.95
27077	601613.2	6217413.4	2	30.90	31.75	1	-0.85
27079	602790.2	6217636.4	2	29.26	31.40	1	-2.14
27102	591821.1	6210077.4	2	36.63	33.25	1	3.38
27108	505721.0	6225977.4	2	19.66	19.66	1	0.00
27109	506221.0	6226577.4	2	19.47	19.49	1	-0.02
27110	509721.0	6222777.4	2	19.02	19.82	1	-0.80
27111	510021.0	6223077.4	2	18.99	19.63	1	-0.64
27112	515121.0	6221077.4	2	19.10	19.49	1	-0.39

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Modelled steady state vs modelled calibration bore details and performance FIGURE H5

F:\Jobs\A53\B1_Mallee\600\602_Calib\Appendices\[Appendix_H.xls]FigH5

Bore	Easting	Northing	Layer	Measured	Computed	Weight	Residual
27113	514971.0	6222177.4	2	18.99	19.61	1	-0.62
27114	515221.0	6225377.4	2	18.91	19.43	1	-0.52
27115	519321.1	6216677.4	2	19.68	20.82	1	-1.14
27117	518821.1	6219777.4	2	19.67	20.34	1	-0.67
27118	517921.1	6221077.4	2	19.81	19.48	1	0.33
27121	521021.1	6223477.4	2	19.80	20.35	1	-0.55
27122	520821.1	6223677.4	2	20.05	20.27	1	-0.22
27124	520621.1	6224697.4	2	19.70	20.89	1	-1.19
27125	520121.1	6225277.4	2	19.63	21.29	1	-1.66
27126	521221.1	6224177.4	2	19.73	20.46	1	-0.73
27127	526021.1	6221877.4	2	20.81	22.02	1	-1.21
27131	522621.1	6217277.4	2	20.28	21.83	1	-1.55
27132	519821.1	6221877.4	2	19.76	19.76	1	0.00
27134	512721.0	6222377.4	2	19.08	19.48	1	-0.40
27136	510921.0	6220077.4	2	18.91	20.97	1	-2.06
27138	509121.0	6225377.4	2	18.95	19.46	1	-0.51
27140	501821.0	6228677.4	2	19.26	19.26	1	0.00
27142	597421.2	6205777.4	2	37.47	34.07	1	3.40
27145	597321.2	6205777.4	2	37.47	34.06	1	3.41
27147	596121.2	6209977.4	2	38.85	33.54	1	5.31
27150	596121.2	6210077.4	2	38.90	33.52	1	5.38
27155	602221.2	6215827.4	2	35.37	32.93	1	2.44
27162	523471.1	6222577.4	2	20.81	21.28	1	-0.47
27164	521721.1	6225827.4	2	20.13	21.45	1	-1.32
27166	523471.1	6225527.4	2	20.30	21.61	1	-1.31
27167	525841.1	6223277.4	2	20.79	21.80	1	-1.01
27168	505761.0	6229097.4	2	18.42	19.36	1	-0.94
27170	515421.0	6222497.4	2	19.04	19.66	1	-0.62
27171	506421.0	6223077.4	2	19.21	20.40	1	-1.19
27172	506271.0	6226527.4	2	19.08	19.50	1	-0.42
27177	623102.2	6184160.4	2	38.19	35.84	1	2.35
27179	622571.2	6184497.4	2	39.38	35.84	1	3.54
27182	622841.2	6185097.4	2	38.28	35.80	1	2.48
27184	622131.2	6186477.4	2	37.91	35.76	1	2.15
27186	622261.2	6186717.4	2	38.69	35.75	1	2.94
27188	620321.2	6188947.4	2	37.63	35.63	1	2.00
27190	619921.2	6188927.4	2	38.38	35.62	1	2.76
40600	679271.3	6097727.3	2	46.38	46.93	1	-0.55
40609	660221.3	6084977.3	2	43.92	43.46	1	0.46
40610	660221.3	6084877.3	2	44.08	43.47	1	0.61
40614	666321.3	6074327.2	2	41.27	45.76	1	-4.49
40615	666021.3	6074327.2	2	46.36	45.82	1	0.54
40616	666321.3	6074327.2	2	43.11	45.76	1	-2.65
40617	669221.3	6075477.2	2	42.59	44.55	1	-1.96
40618	656321.3	6080277.2	2	45.18	46.37	1	-1.19
40619	656221.3	6091327.3	2	45.34	44.91	1	0.43
40624	673921.3	6077927.3	2	45.53	45.29	1	0.24
40631	682821.4	6078677.3	2	48.97	48.54	1	0.43
40633	676571.4	6071577.2	2	47.30	48.67	1	-1.37
40635	662321.3	6091177.3	2	41.71	41.81	1	-0.10
40637	662321.3	6081077.3	2	42.30	42.89	1	-0.59
40640	657821.3	6085177.3	2	44.56	44.68	1	-0.12
40641	668421.3	6099177.3	2	44.21	43.63	1	0.58
40646	667921.3	6091177.3	2	43.48	41.82	1	1.66

Bore	Easting	Northing	Layer	Measured	Computed	Weight	Residual
40647	665521.3	6076427.2	2	41.97	44.26	1	-2.29
40648	659121.3	6097977.3	2	45.27	44.42	1	0.85
40650	664121.3	6104077.3	2	46.33	45.27	1	1.06
40653	681321.4	6072077.2	2	49.38	49.49	1	-0.11
40658	695621.4	6071977.3	2	50.92	51.68	1	-0.76
40661	707321.4	6066877.3	2	55.10	59.14	1	-4.04
40663	718821.4	6065677.3	2	60.45	62.77	1	-2.32
49987	660281.3	6084884.3	2	44.00	43.43	1	0.57
49989	660521.3	6091227.3	2	41.42	42.86	1	-1.44
49990	660521.3	6091327.3	2	43.22	42.85	1	0.37
49991	660496.3	6091477.3	2	43.18	42.86	1	0.32
50073	602571.2	6155627.3	2	34.55	35.60	1	-1.05
50074	596171.2	6156077.3	2	33.58	35.13	1	-1.55
50075	593071.2	6155377.3	2	34.07	35.55	1	-1.48
51347	665471.3	6076627.2	2	41.07	44.09	1	-3.02
51348	665471.3	6076877.2	2	40.78	43.87	1	-3.09
51350	665021.3	6076327.2	2	41.41	44.49	1	-3.08
58765	624021.3	6063177.2	2	52.33	58.89	1	-6.56
63995	630021.3	6018577.1	2	70.10	73.00	1	-2.90
64361	505521.0	6159877.3	2	21.18	32.05	1	-10.87
64362	505521.0	6159877.3	2	21.37	32.05	1	-10.68
65736	587121.2	6159027.3	2	35.15	35.64	1	-0.49
65738	575971.1	6167577.4	2	32.02	35.60	1	-3.58
69464	621051.2	6192677.4	2	36.84	35.26	1	1.58
75796	644971.3	6149077.4	2	40.19	40.41	1	-0.22
77032	552071.1	6186117.4	2	22.50	32.46	1	-9.96
79619	545571.1	6171777.4	2	25.72	33.76	1	-8.04
81834	515121.0	6194777.4	2	18.68	23.82	1	-5.14
85568	505121.0	6178177.4	2	18.44	24.16	1	-5.72
85933	716521.5	6012977.2	2	96.71	90.39	1	6.32
86776	498171.0	6231677.4	2	18.74	17.47	1	1.27
95114	607121.2	6105777.3	2	42.82	46.94	1	-4.12
95116	606821.2	6105877.3	2	42.77	46.92	1	-4.15
95530	666421.3	6164677.4	2	49.53	45.95	1	3.58
97332	646621.3	6082877.2	2	34.61	49.30	1	-14.69
97603	705221.4	6071277.3	2	60.00	57.07	1	2.93
97605	705221.4	6071277.3	2	52.97	57.07	1	-4.10
98347	605621.2	6155927.3	2	37.04	36.08	1	0.96
98348	605621.2	6155927.3	2	33.30	36.08	1	-2.78
98349	605621.2	6155927.3	2	36.83	36.08	1	0.75
98351	605621.2	6155907.3	2	36.20	36.09	1	0.11
98363	594721.2	6112677.3	2	40.48	45.19	1	-4.71
103161	582461.1	6186667.4	2	34.04	34.33	1	-0.29
104801	530771.1	6208277.4	2	21.58	26.81	1	-5.23
104804	515121.0	6218777.4	2	19.34	20.57	1	-1.23
109463	636321.3	6053627.2	2	55.83	62.95	1	-7.12
110116	701931.4	6021917.2	2	72.15	83.62	1	-11.47
110128	656221.3	6041577.2	2	60.08	68.30	1	-8.22
110129	712234.4	6103910.3	2	58.36	54.99	1	3.37
110186	729131.5	6038527.2	2	69.07	74.31	1	-5.24
110871	714071.5	6026827.2	2	72.42	82.37	1	-9.95
110872	714071.5	6026827.2	2	78.09	82.37	1	-4.28
110873	720441.5	6024607.2	2	73.41	82.47	1	-9.06
110907	585051.1	6209437.4	2	30.23	32.80	1	-2.57

Bore	Easting	Northing	Layer	Measured	Computed	Weight	Residual
112459	575513.3	6010074.0	2	76.80	73.25	1	3.55
112523	726921.5	6024327.2	2	81.53	80.48	1	1.05
112524	726921.5	6024327.2	2	81.23	80.48	1	0.75
112525	729131.5	6038527.2	2	71.46	74.31	1	-2.85
115238	604521.2	6215477.4	2	36.27	33.11	1	3.16
115241	604921.2	6214977.4	2	39.26	33.32	1	5.94
119369	501941.0	6226727.4	2	20.33	19.78	1	0.55
121826	504171.0	6224327.4	2	19.45	20.28	1	-0.83
124769	607636.2	6214459.4	2	37.61	33.52	1	4.09
130553	591904.1	6223090.4	2	32.35	31.18	1	1.17
137190	506806.0	6118427.3	2	30.79	40.79	1	-10.00
137191	511811.0	6117487.3	2	34.13	41.18	1	-7.05
137196	501566.0	6128078.3	2	28.94	39.22	1	-10.28
137199	513655.1	6098281.2	2	43.06	46.91	1	-3.85
137201	513489.1	6089222.2	2	44.88	50.90	1	-6.02
137294	502131.0	6135977.3	2	40.58	37.70	1	2.88
141391	625064.2	6183838.4	2	36.70	35.45	1	1.25
141392	620543.2	6183527.4	2	39.02	35.93	1	3.09
141393	616641.2	6181867.4	2	42.70	35.95	1	6.75
141394	612488.2	6183994.4	2	36.82	35.67	1	1.15
141395	618094.2	6177423.4	2	35.31	36.35	1	-1.04
GW036646	683440.0	6209100.0	2	41.70	47.27	1	-5.57
GW036664	635620.0	6243392.0	2	39.44	36.99	1	2.45
GW036724	704810.0	6155230.0	2	49.35	50.01	1	-0.66
GW036740	672200.0	6197930.0	2	42.22	45.87	1	-3.65
GW036782	512270.0	6241400.0	2	22.85	21.52	1	1.33
GW036784	585145.0	6234440.0	2	28.67	30.57	1	-1.90
GW036790	695700.0	6239190.0	2	43.57	49.82	1	-6.25
GW036809	595150.0	6256310.0	2	30.36	31.85	1	-1.49
GW036851	537350.0	6246550.0	2	22.61	27.14	1	-4.53
GW036854	667750.0	6241050.0	2	41.37	45.22	1	-3.85
GW036858	635175.0	6212750.0	2	34.51	38.53	1	-4.02
GW036878	631075.0	6198700.0	2	34.53	37.24	1	-2.71
GW036910	598740.0	6229000.0	2	37.24	31.30	1	5.94
GW040351	596000.0	6254520.0	2	30.60	31.90	1	-1.30
GW087012	592892.0	6227823.0	2	31.65	30.89	1	0.76
GW087026	602096.0	6225347.0	2	33.81	31.52	1	2.29
GW087039	611510.0	6220739.0	2	32.86	32.38	1	0.48
GW087045	607830.0	6219810.0	2	31.23	31.39	1	-0.16
GW087054	607332.0	6225123.0	2	31.82	30.84	1	0.98
GW087103	669980.0	6179019.0	2	46.13	45.75	1	0.38
GW087122	614874.0	6212953.0	2	34.63	33.83	1	0.80
GW087128	618330.0	6207710.0	2	34.12	34.43	1	-0.31
GW087131	623527.0	6202506.0	2	34.56	34.79	1	-0.23
GW087132	624552.0	6203139.0	2	34.73	35.15	1	-0.42
GW087133	625796.0	6204370.0	2	34.94	35.72	1	-0.78
GW087134	628811.0	6198843.0	2	34.88	35.87	1	-0.99
GW087135	630417.0	6198918.0	2	35.16	36.94	1	-1.78
GW087140	630765.0	6192634.0	2	35.43	37.45	1	-2.02
GW087142	632375.0	6187056.0	2	36.43	37.97	1	-1.54
GW087146	645415.0	6176508.0	2	37.58	40.10	1	-2.52
GW087150	636168.0	6176589.0	2	37.36	38.85	1	-1.49
GW087170	640604.0	6159204.0	2	39.07	39.44	1	-0.37
GW087238	627600.0	6199875.0	2	32.96	34.25	1	-1.29

Bore	Easting	Northing	Layer	Measured	Computed	Weight	Residual
GW087331	607691.0	6222292.0	2	32.53	31.50	1	1.03
GW087335	607799.0	6217979.0	2	32.36	31.60	1	0.76
GW087530	622519.0	6224658.0	2	30.07	34.32	1	-4.25
GW087533	612235.0	6232273.0	2	29.68	32.78	1	-3.10
GW087550	570841.0	6234267.0	2	27.70	28.10	1	-0.40
GW087580	518518.0	6242940.0	2	23.88	23.18	1	0.70
GW087622	550010.0	6232016.0	2	23.66	27.22	1	-3.56
6520	656221.3	6085077.3	3	45.13	45.69	1	-0.56
27002	599952.2	6217852.4	3	32.66	32.18	1	0.48
36210	715121.5	6004977.1	3	101.76	97.08	1	4.68
49950	528721.1	6069677.2	3	50.36	55.70	1	-5.34
49951	533721.1	6044677.1	3	60.49	62.28	1	-1.79
50349	680021.4	6054677.2	3	55.17	60.20	1	-5.03
56413	577921.2	6084477.2	3	52.50	50.15	1	2.35
58764	624021.3	6063177.2	3	52.79	58.88	1	-6.09
61573	526521.1	6107227.2	3	37.53	43.41	1	-5.88
63994	630021.3	6018577.1	3	72.46	72.90	1	-0.44
65270	713821.5	6001277.1	3	105.30	103.68	1	1.62
66477	517531.1	6091867.2	3	43.12	49.70	1	-6.58
69463	621051.2	6192677.4	3	38.02	35.68	1	2.34
75795	644971.3	6149077.4	3	39.97	40.67	1	-0.70
77031	552071.1	6186117.4	3	33.44	32.75	1	0.69
77110	572521.2	6112877.3	3	40.36	43.34	1	-2.98
77304	730721.5	6008127.2	3	82.50	86.38	1	-3.88
79279	600571.2	6217727.4	3	35.92	32.21	1	3.71
81833	515121.0	6194777.4	3	26.86	23.83	1	3.03
82220	506271.0	6106937.2	3	36.70	43.34	1	-6.64
85570	505121.0	6178177.4	3	25.23	24.22	1	1.01
85932	716521.5	6012977.2	3	94.10	90.38	1	3.72
86775	498171.0	6231677.4	3	25.85	22.25	1	3.60
86885	618221.2	6117077.3	3	38.09	44.38	1	-6.29
92807	728571.5	6048977.2	3	69.80	70.71	1	-0.91
96445	720411.5	6024577.2	3	75.98	82.50	1	-6.52
97604	705221.4	6071277.3	3	56.59	57.07	1	-0.48
98254	507321.0	6025527.1	3	63.05	67.67	1	-4.62
98297	497821.0	6020177.1	3	61.22	69.35	1	-8.13
103354	530721.1	6026577.1	3	68.60	67.21	1	1.39
104803	515121.0	6218777.4	3	27.36	23.03	1	4.33
108158	509721.0	6007277.1	3	68.24	70.61	1	-2.37
109464	636321.3	6053627.2	3	55.16	62.81	1	-7.65
110130	712234.4	6103909.3	3	58.31	54.93	1	3.38
110163	656221.3	6041577.2	3	66.10	68.28	1	-2.18
110164	598521.2	6083077.2	3	41.40	51.36	1	-9.96
110179	701931.4	6021917.2	3	72.46	83.60	1	-11.14
110180	701931.4	6021917.2	3	76.87	83.60	1	-6.73
112180	578764.3	6007568.0	3	77.99	73.61	1	4.38
112181	587765.3	6007565.0	3	77.48	74.40	1	3.08
112182	587766.3	6007561.0	3	77.65	74.41	1	3.24
112183	578311.2	6003265.0	3	78.67	74.66	1	4.01
112186	575514.3	6010070.0	3	76.44	73.14	1	3.30
112521	726921.5	6024327.2	3	78.88	80.47	1	-1.59
112522	726921.5	6024327.2	3	81.06	80.47	1	0.59
137194	503141.0	6121291.3	3	28.75	40.28	1	-11.53
137195	501566.0	6127982.3	3	26.72	39.24	1	-12.52

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Modelled steady state vs modelled calibration bore details and performance FIGURE H9

Bore	Easting	Northing	Layer	Measured	Computed	Weight	Residual
137198	513658.1	6098283.2	3	40.64	46.15	1	-5.51
137200	513493.1	6089222.2	3	44.23	48.11	1	-3.88
52367	729141.5	6038477.2	4	71.83	74.32	1	-2.49
52368	729146.5	6038477.2	4	72.00	74.32	1	-2.32
58111	526721.1	6009577.1	4	72.28	70.24	1	2.04
66476	517531.1	6091867.2	4	41.88	48.59	1	-6.71
69462	620221.2	6192777.4	4	34.40	36.38	1	-1.98
77030	552121.1	6186127.4	4	34.59	33.34	1	1.25
77102	572421.2	6112927.3	4	38.25	44.13	1	-5.88
79278	600621.2	6217727.4	4	35.96	32.89	1	3.07
81832	515121.0	6194777.4	4	34.41	30.26	1	4.15
86774	498171.0	6231677.4	4	32.94	29.89	1	3.05
88000	701821.4	6118327.3	4	56.88	52.07	1	4.81
95513	666421.3	6164677.4	4	46.15	47.00	1	-0.85
98290	507371.0	6025477.1	4	62.70	66.40	1	-3.70
98350	605621.2	6155927.3	4	38.63	38.47	1	0.16
103893	664621.4	6017427.1	4	75.18	76.16	1	-0.98
104800	530721.1	6208277.4	4	34.96	30.25	1	4.71
105664	591821.2	6055977.2	4	45.66	60.41	1	-14.75
110161	643421.3	6081477.2	4	46.86	50.31	1	-3.45
110162	678021.4	6086477.3	4	47.47	46.15	1	1.32
112179	587763.3	6007570.0	4	77.27	75.24	1	2.03
112185	575514.3	6010066.0	4	67.44	73.02	1	-5.58
112492	712233.4	6103910.3	4	58.53	54.86	1	3.67

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Modelled steady state vs modelled calibration bore details and performance FIGURE H10

F:\Jobs\A53\B1_Mallee\600\602_Calib\Appendices\[Appendix_H.xls]FigH10

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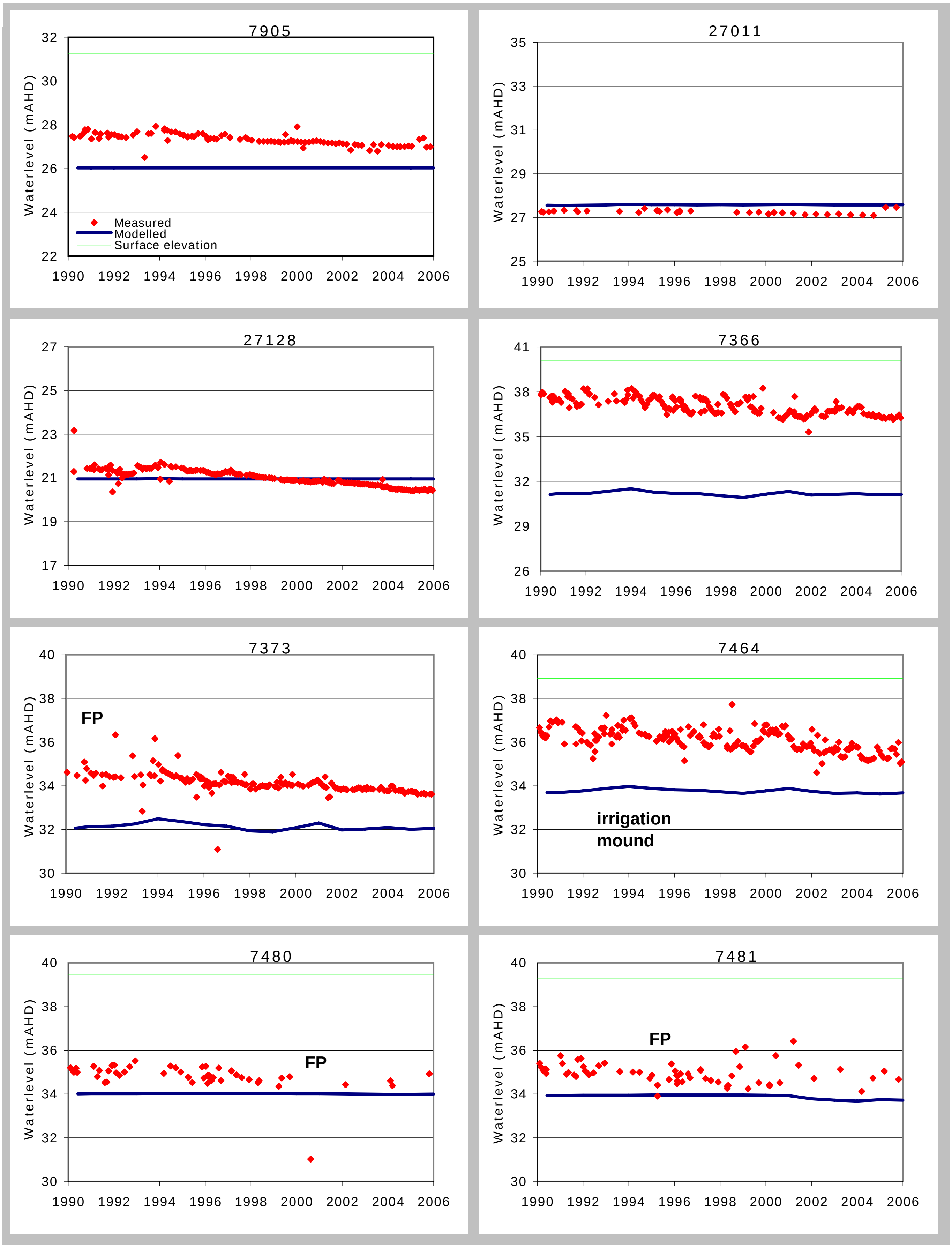
Water and Environment

APPENDIX J TRANSIENT HYDROGRAPHS – REFER TO CD

TRANSIENT HYDROGRAPHS – BASE CASE CALIBRATION
(FIGURES J1 – J19)



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HYDROGRAPHS, LAYER 1 FIGURE J1

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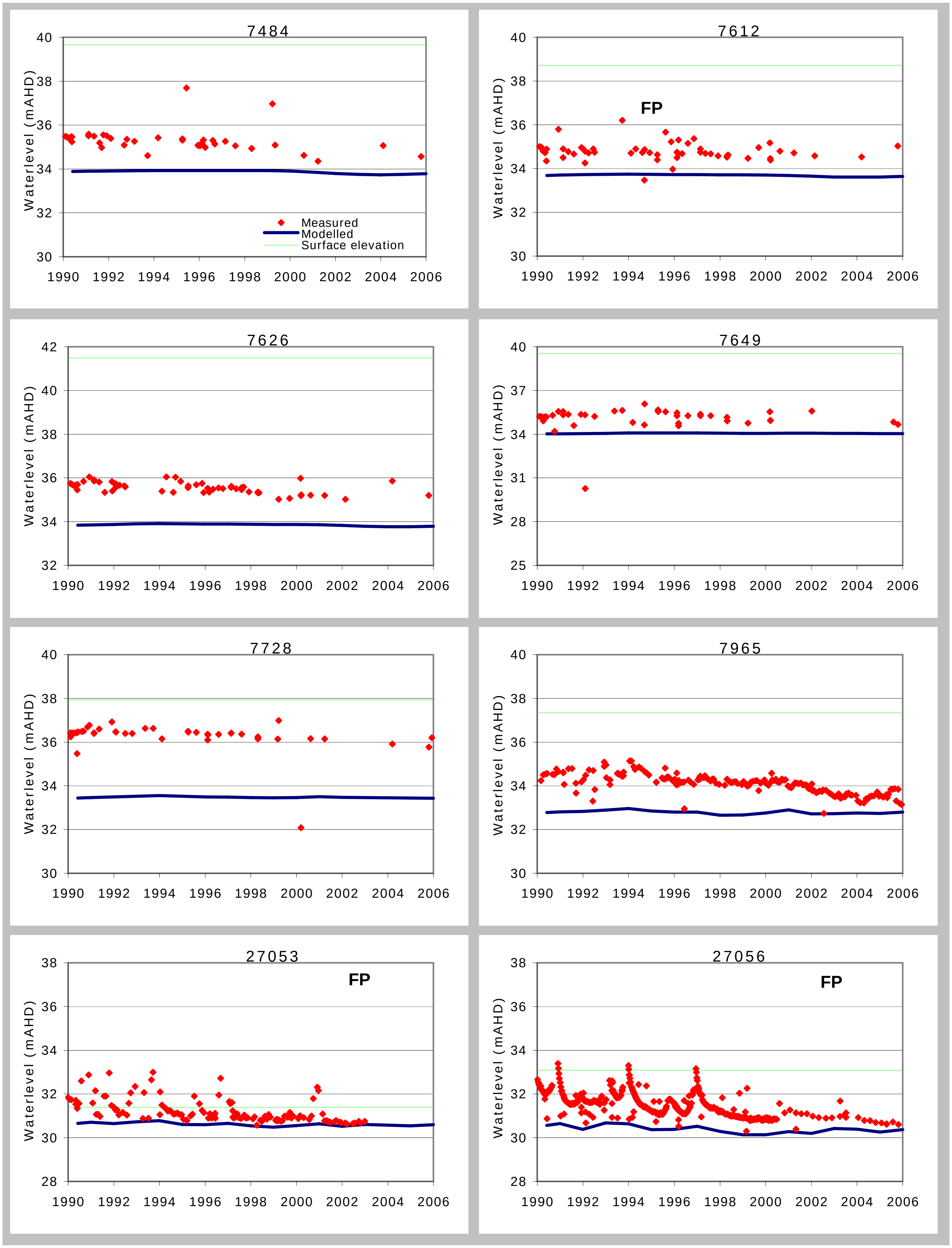

HYDROGRAPHS, LAYER 1 FIGURE J2

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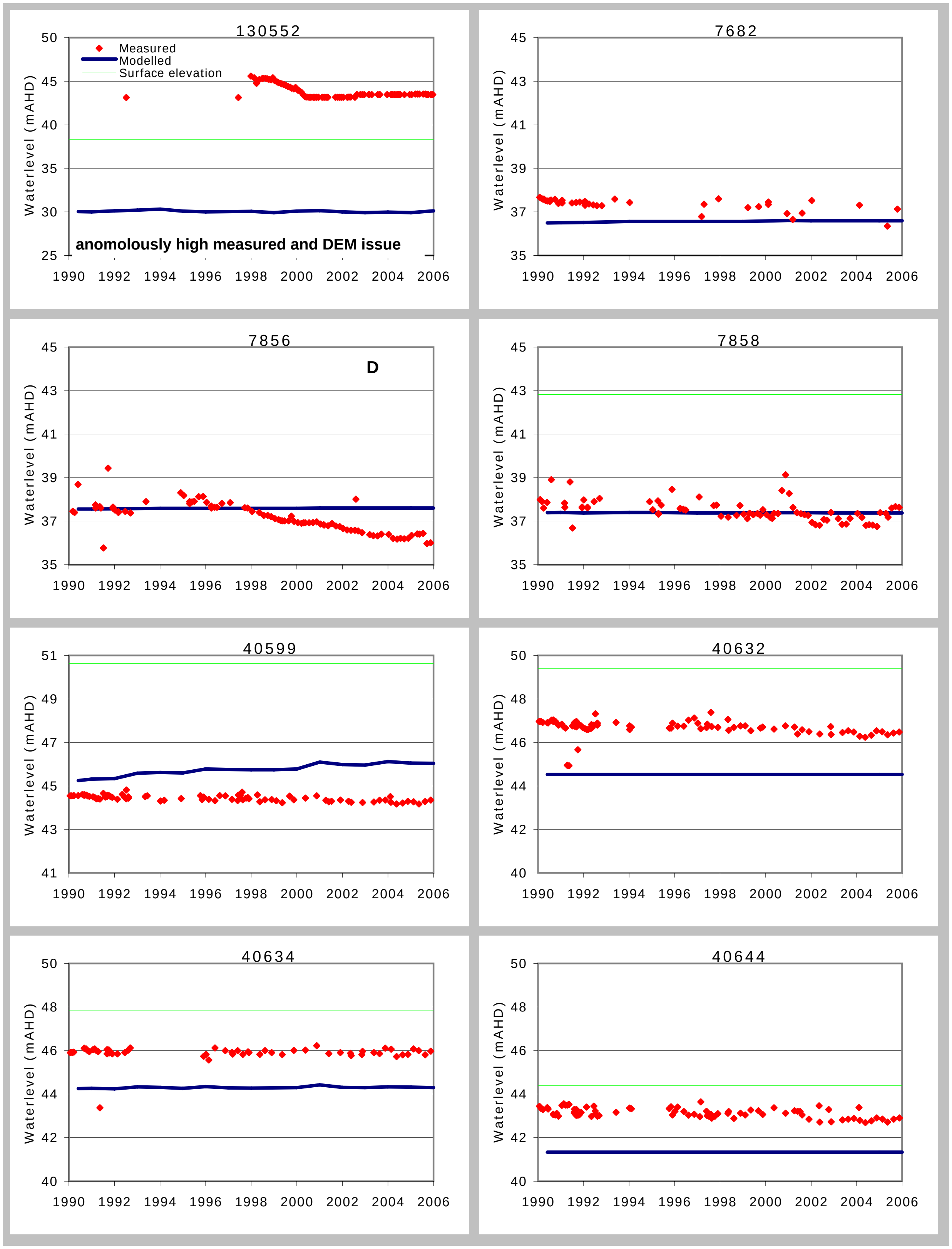

HYDROGRAPHS, LAYER 1 FIGURE J3

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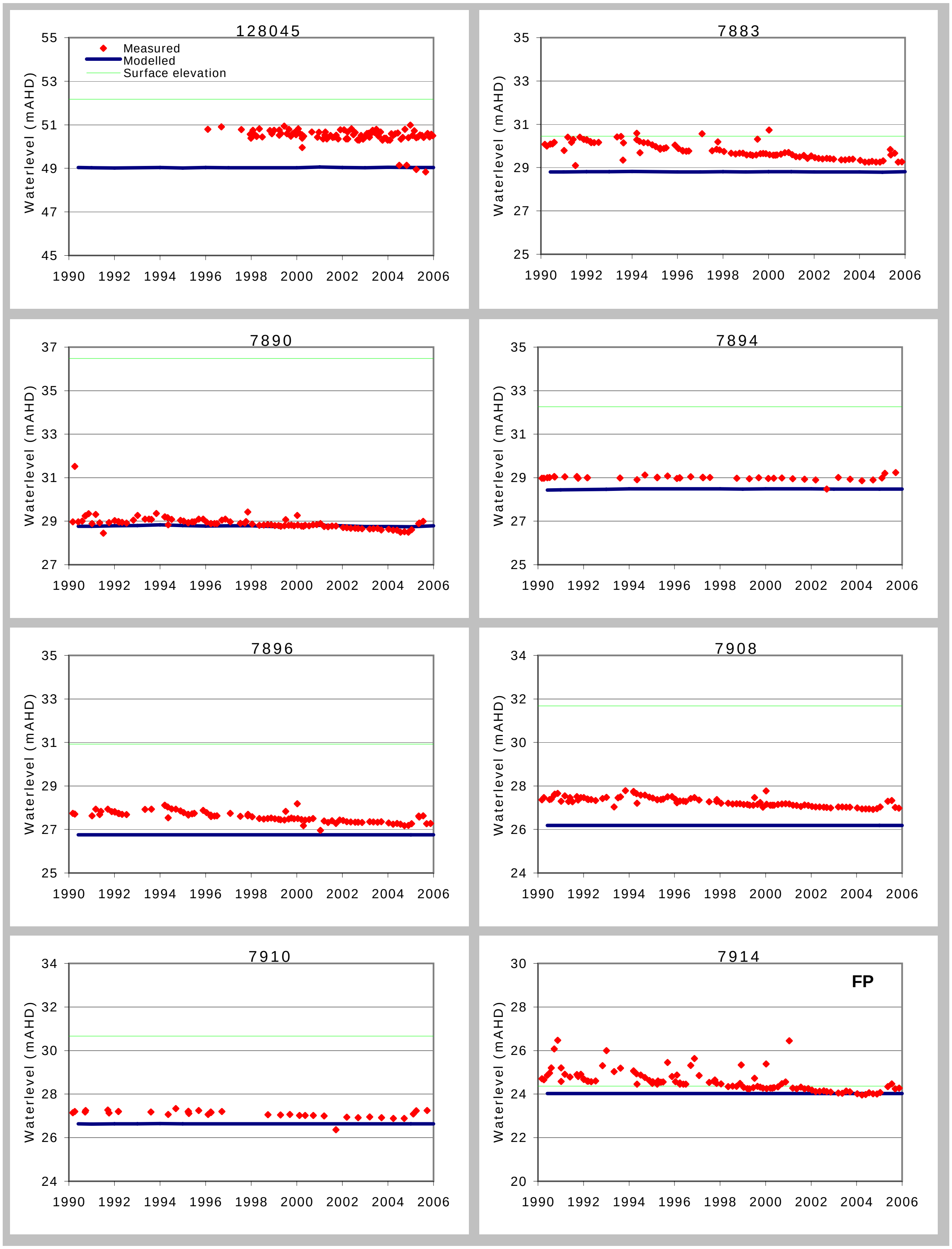
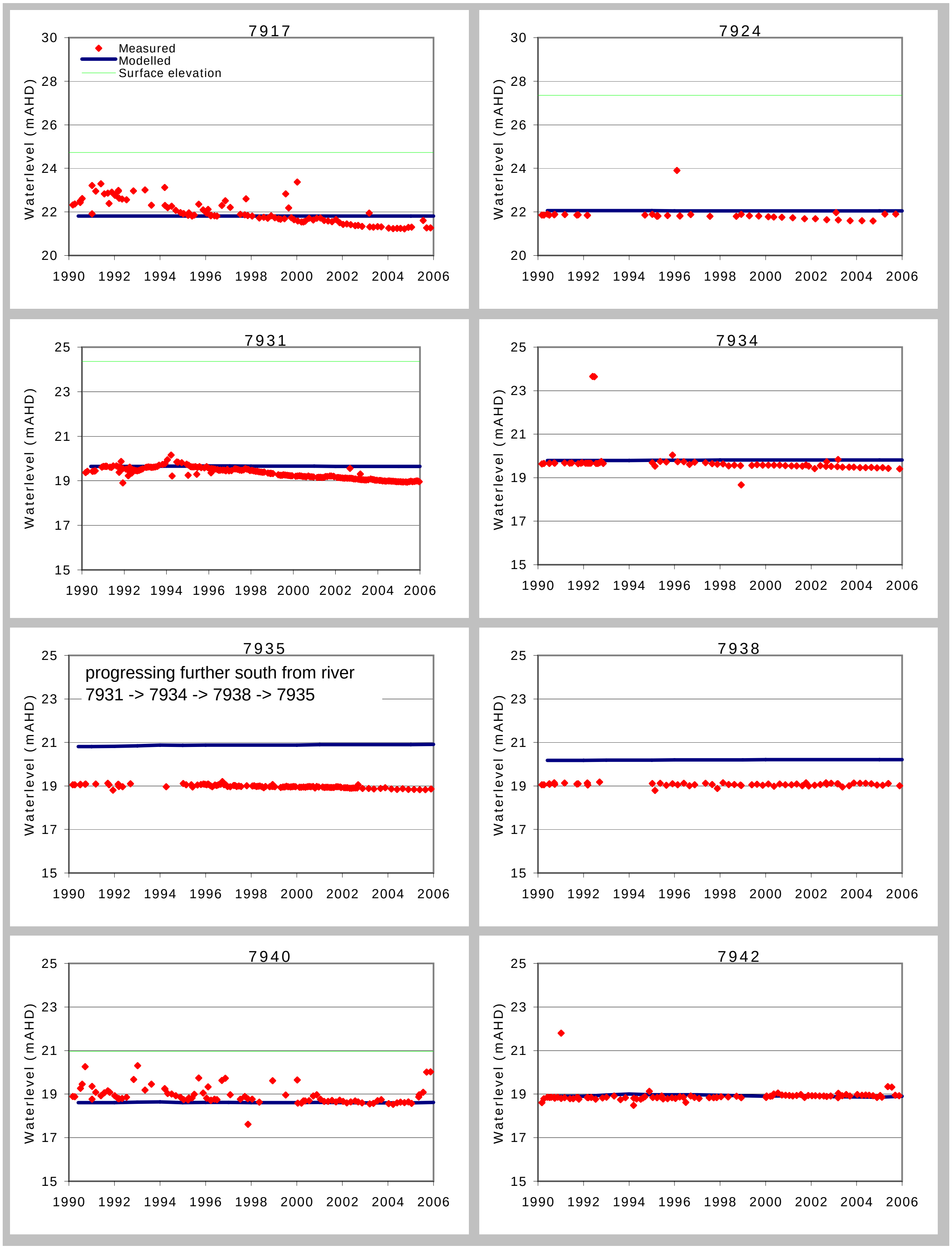

128045
7883
7890
7894
7896
7908
7910
7914
FP
Measured
Modelled
Surface elevation
Waterlevel (mAHD)
1990 1992 1994 1996 1998 2000 2002 2004 2006



HYDROGRAPHS, LAYER 2 FIGURE J5

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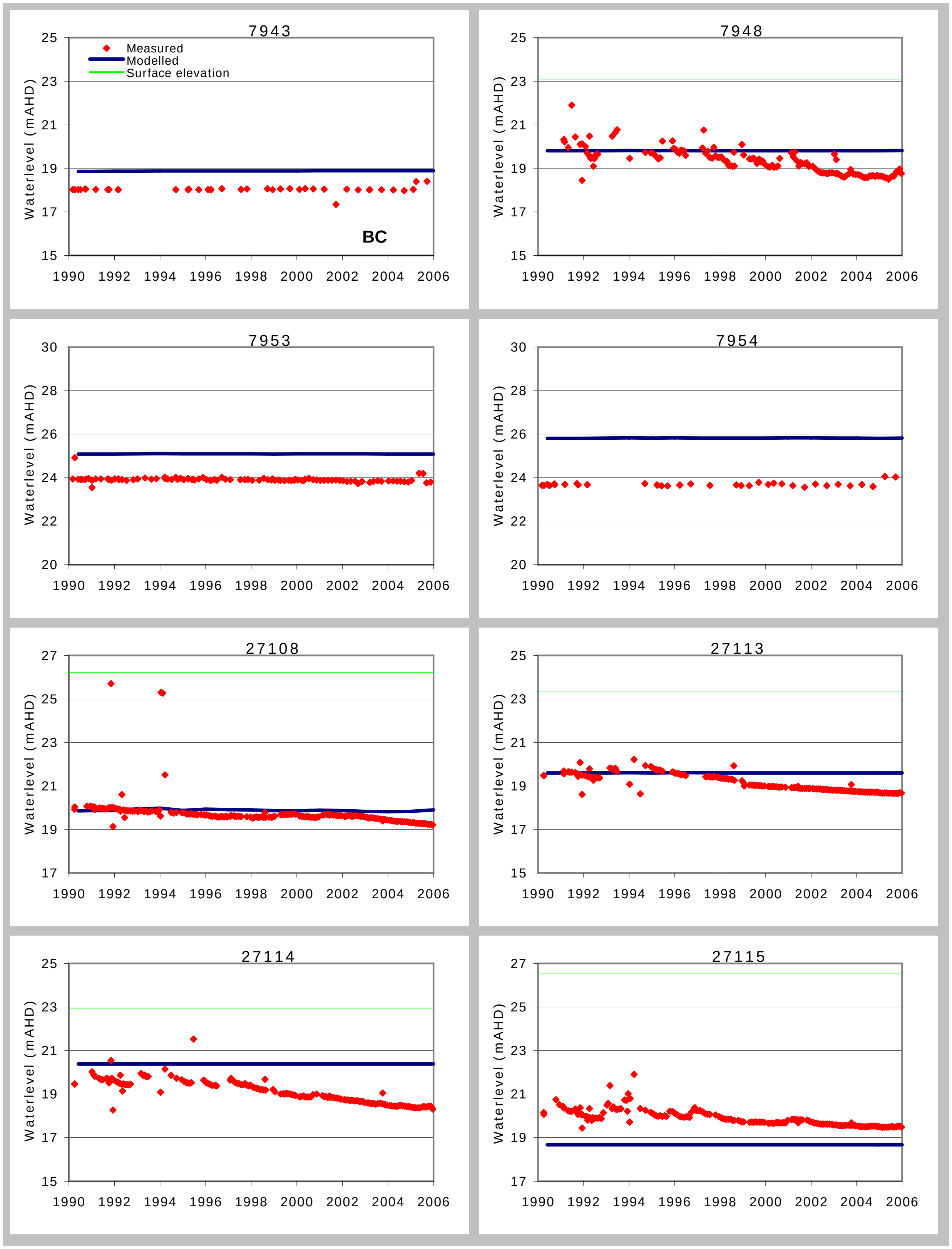
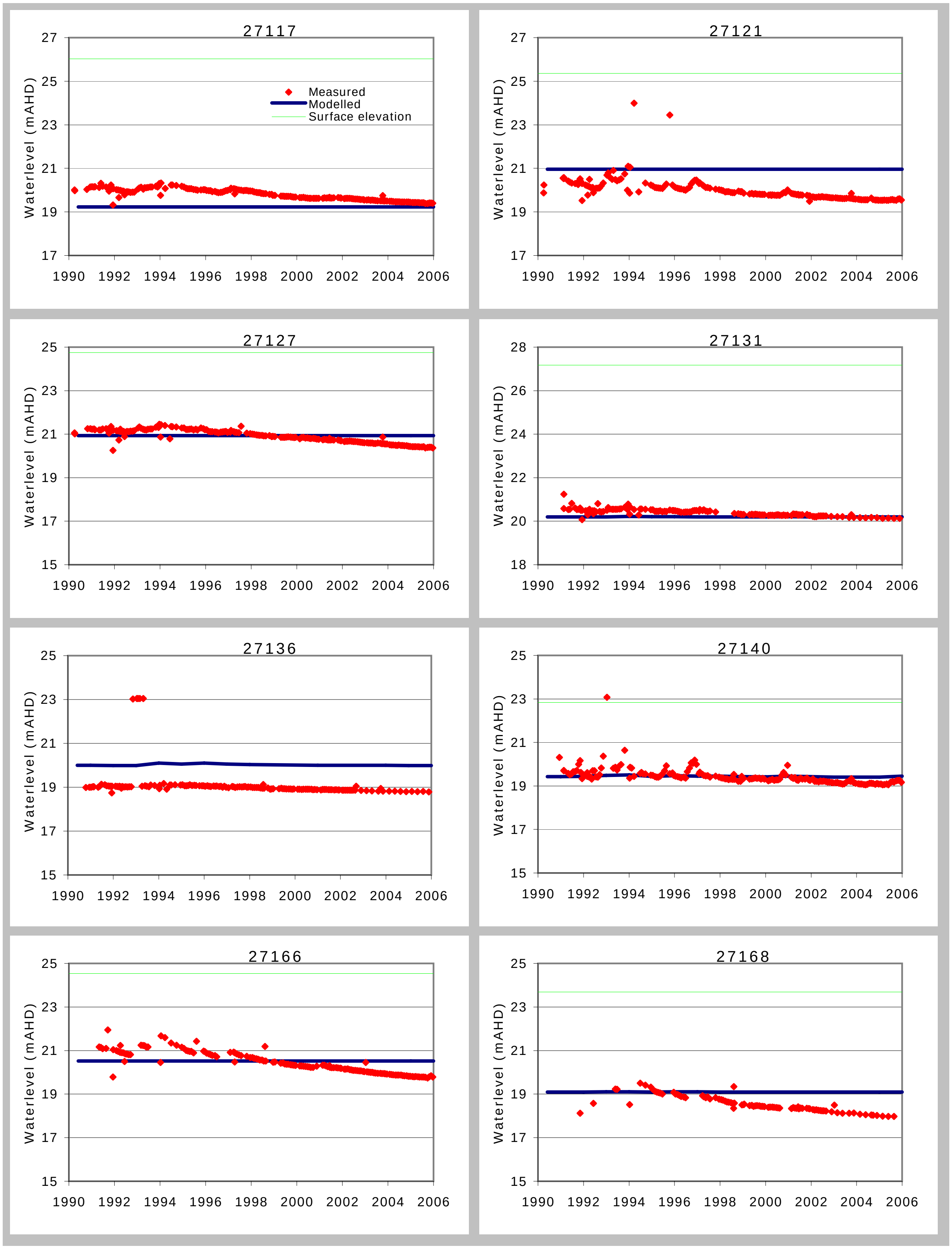


HYDROGRAPHS, LAYER 2 FIGURE J6



HYDROGRAPHS, LAYER 2 FIGURE J7

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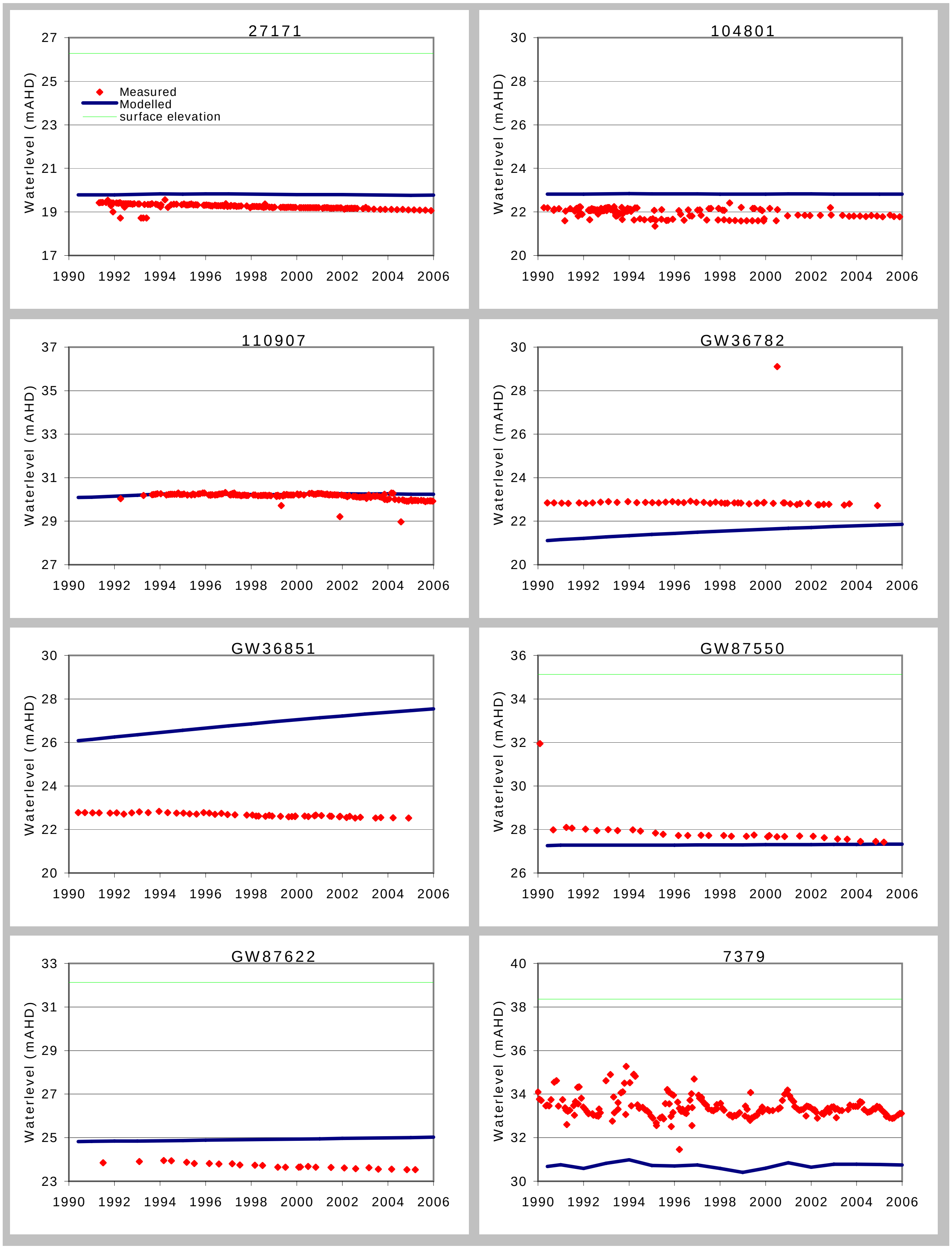

HYDROGRAPHS, LAYER 2 FIGURE J8

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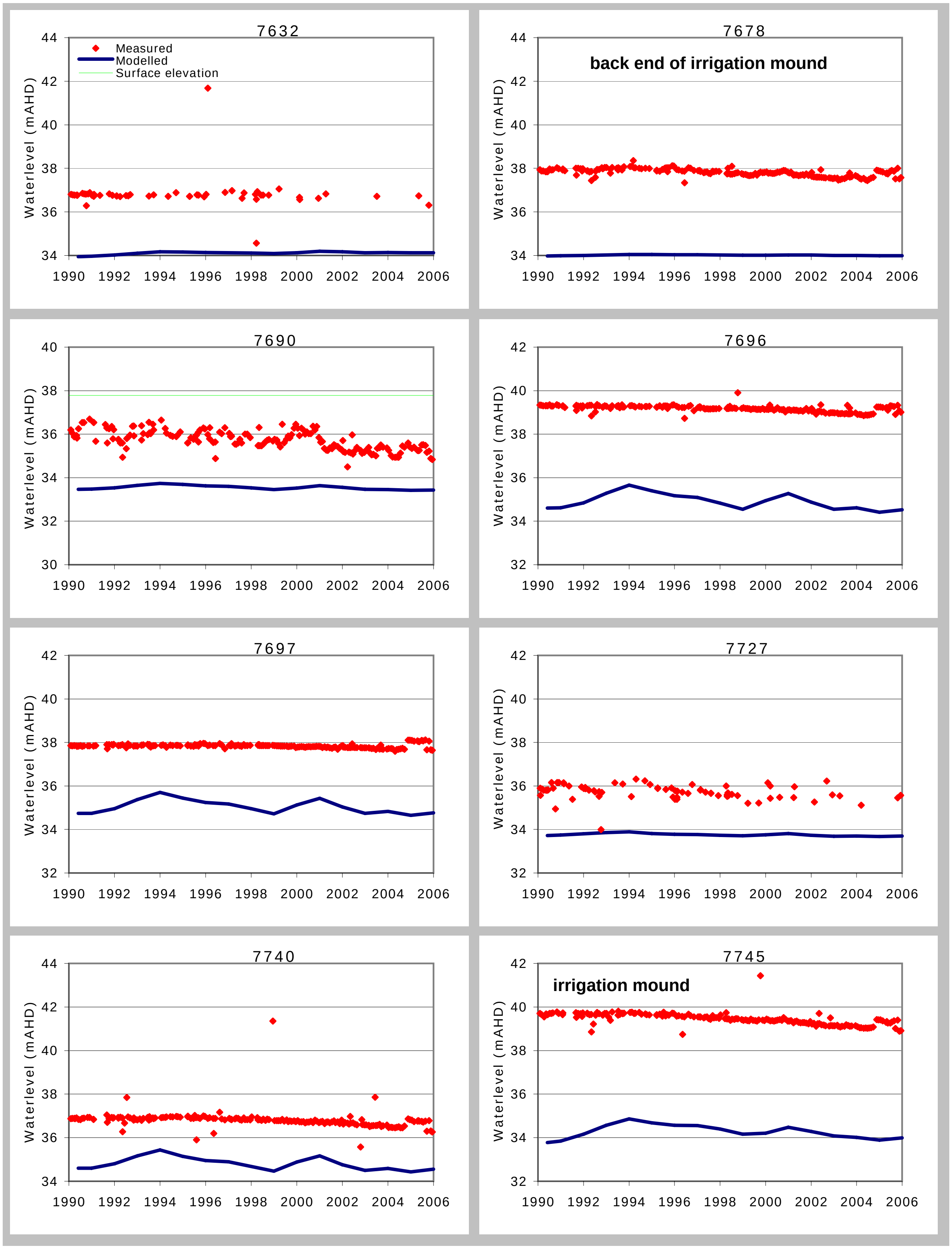
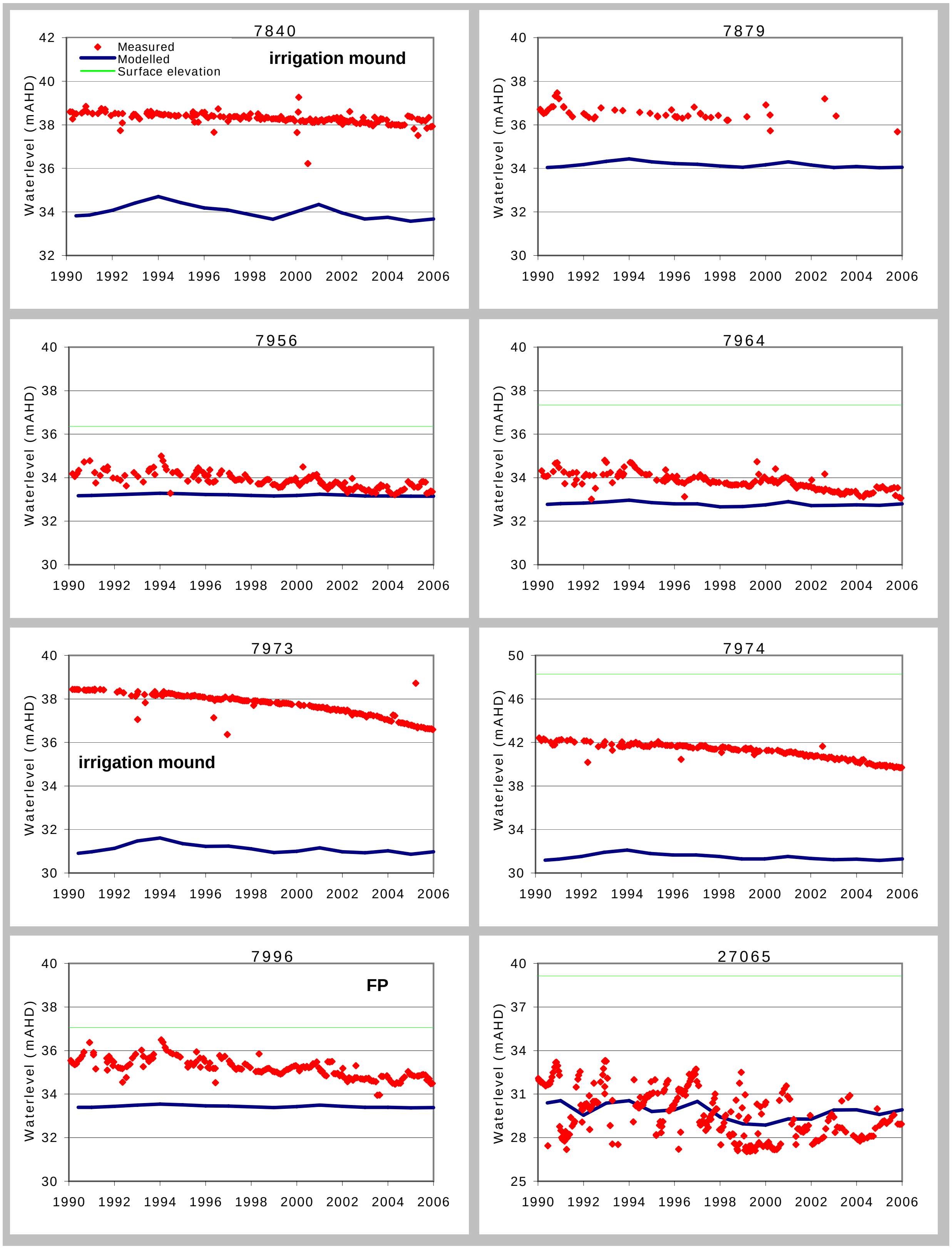


HYDROGRAPHS, LAYER 2 FIGURE J9



HYDROGRAPHS, LAYER 2 FIGURE J10

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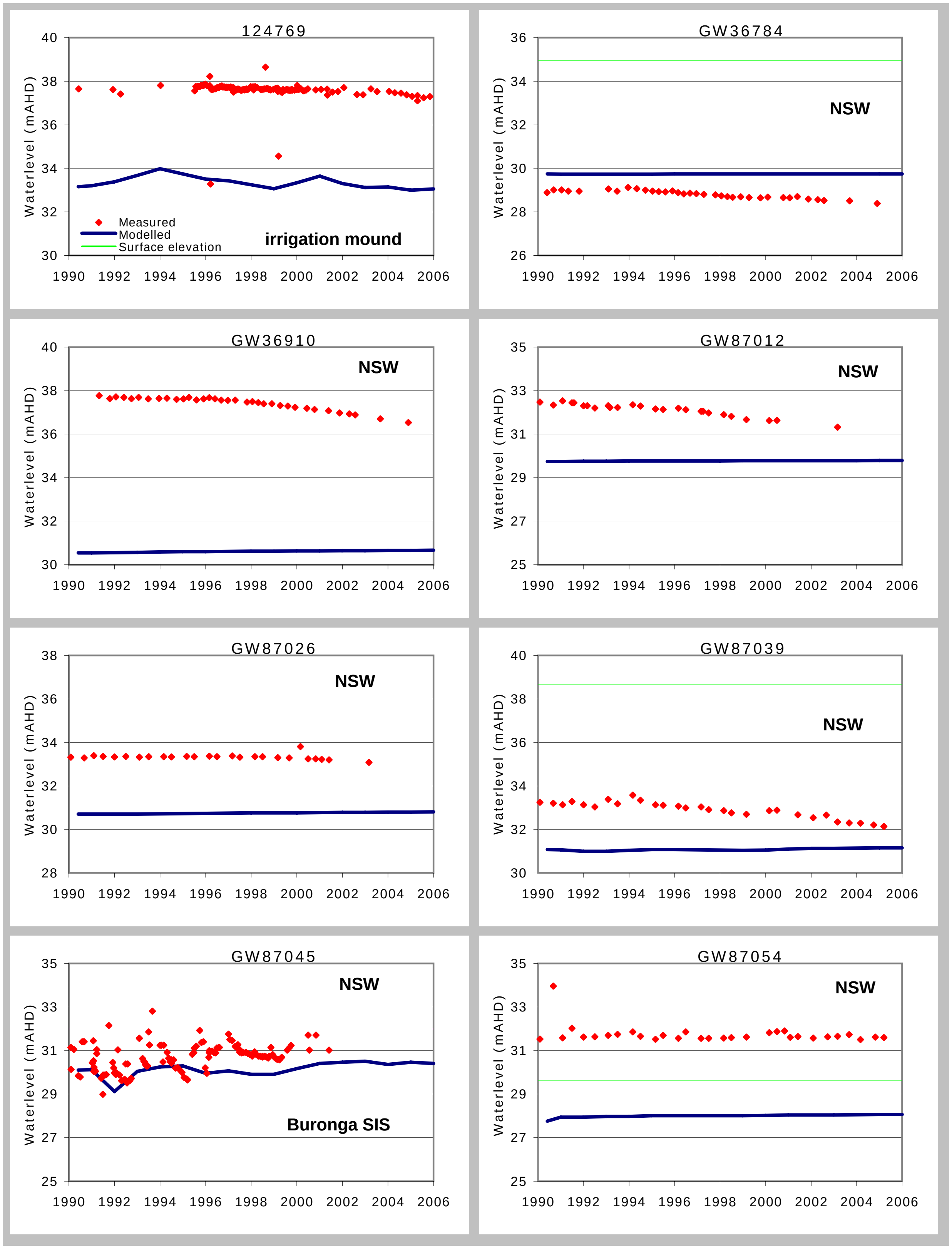

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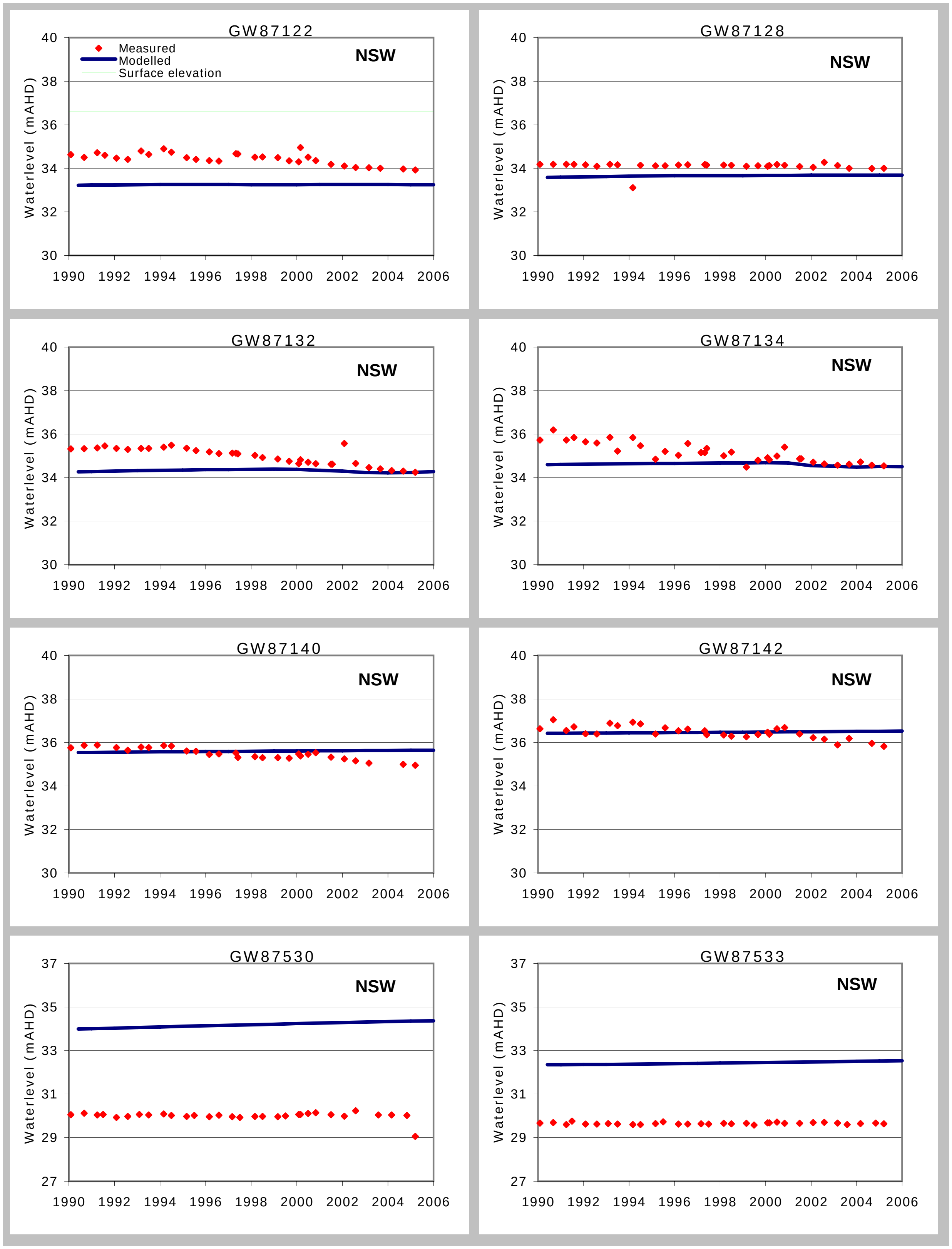
HYDROGRAPHS, LAYER 2 FIGURE J11



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HYDROGRAPHS, LAYER 2 FIGURE J12

F:\Jobs\A53\B1_Mallee\600\602_Calib\HIST\Appendices\Appendix_J\[HIST_Hydrographs_hms14.xls]FigJ12

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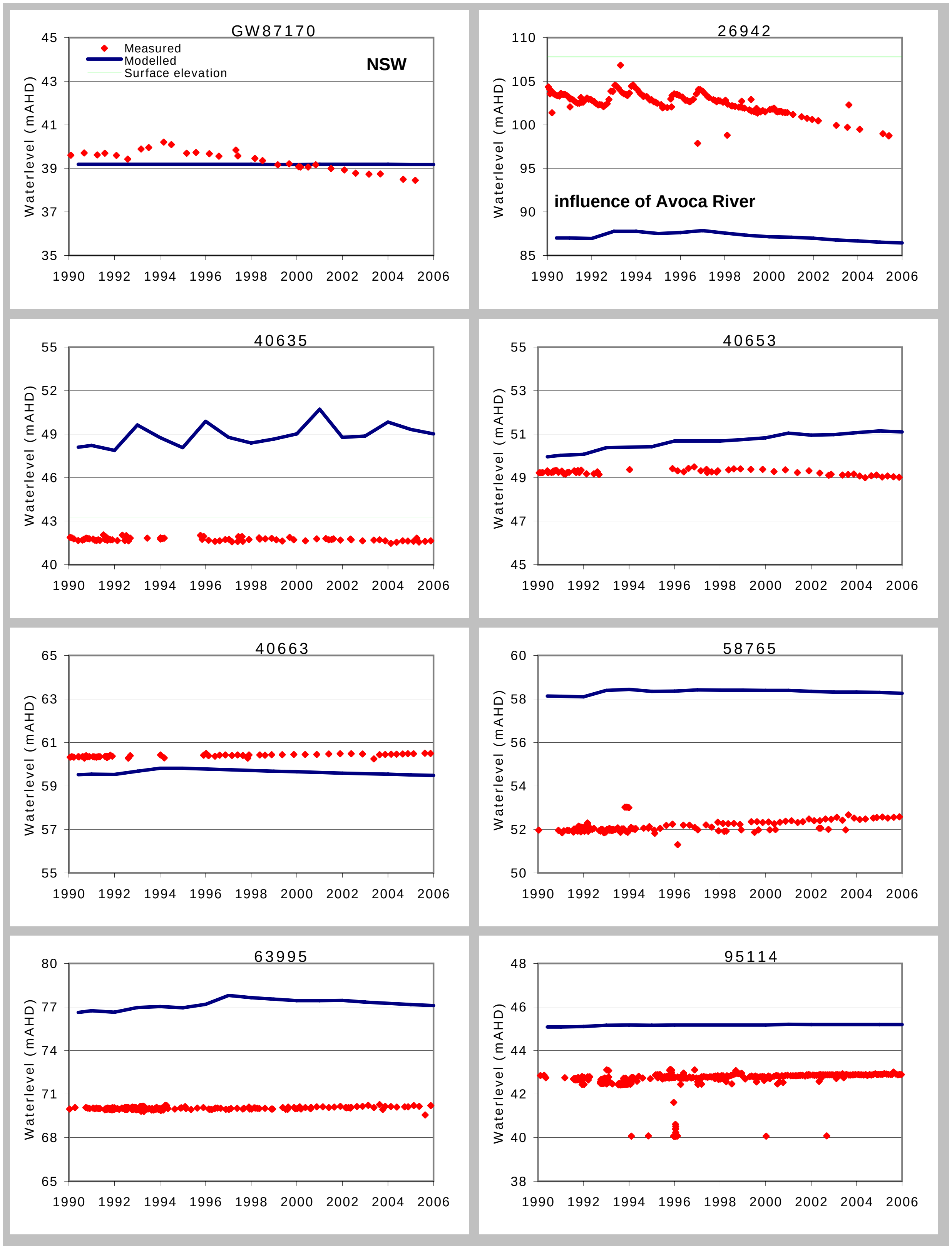
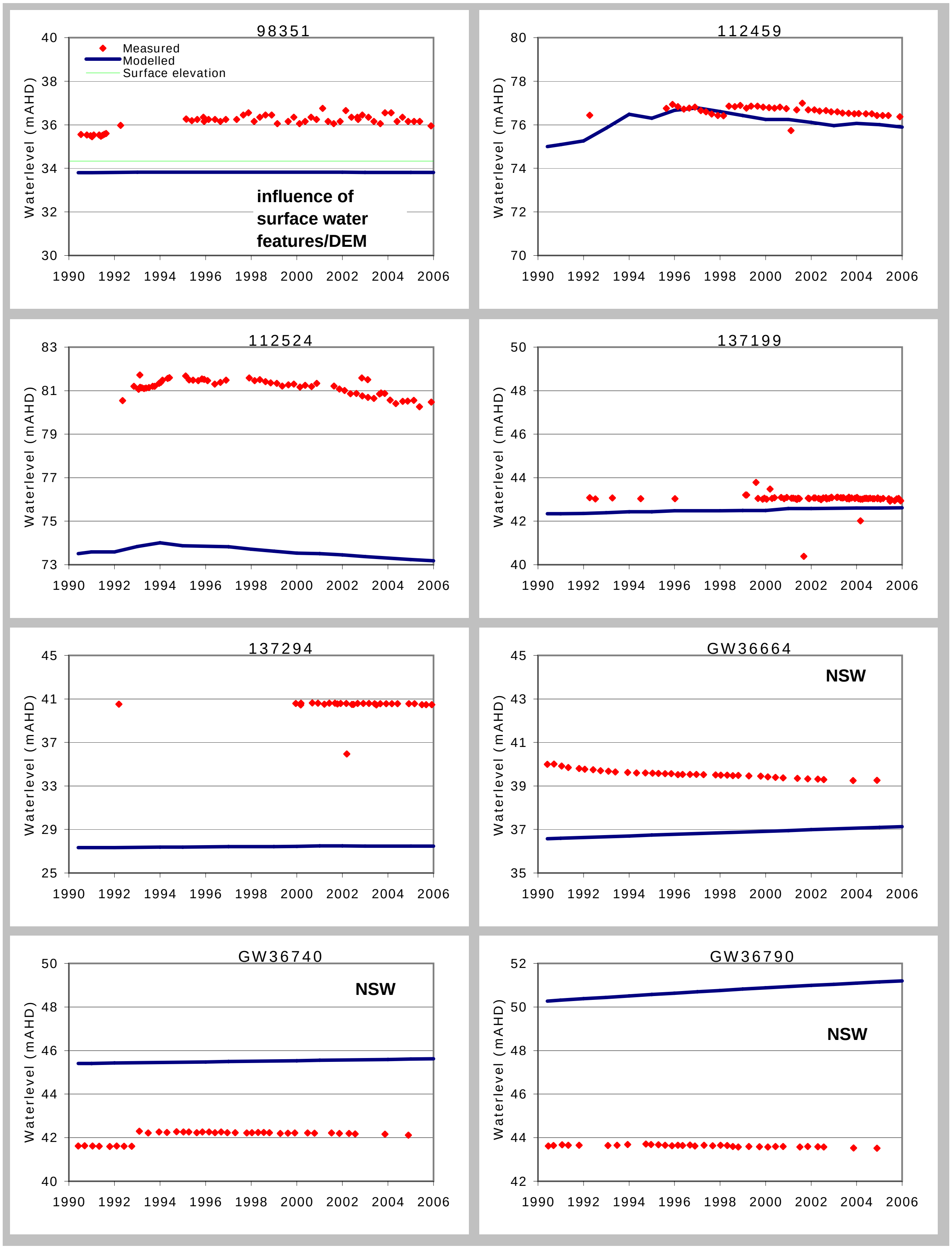
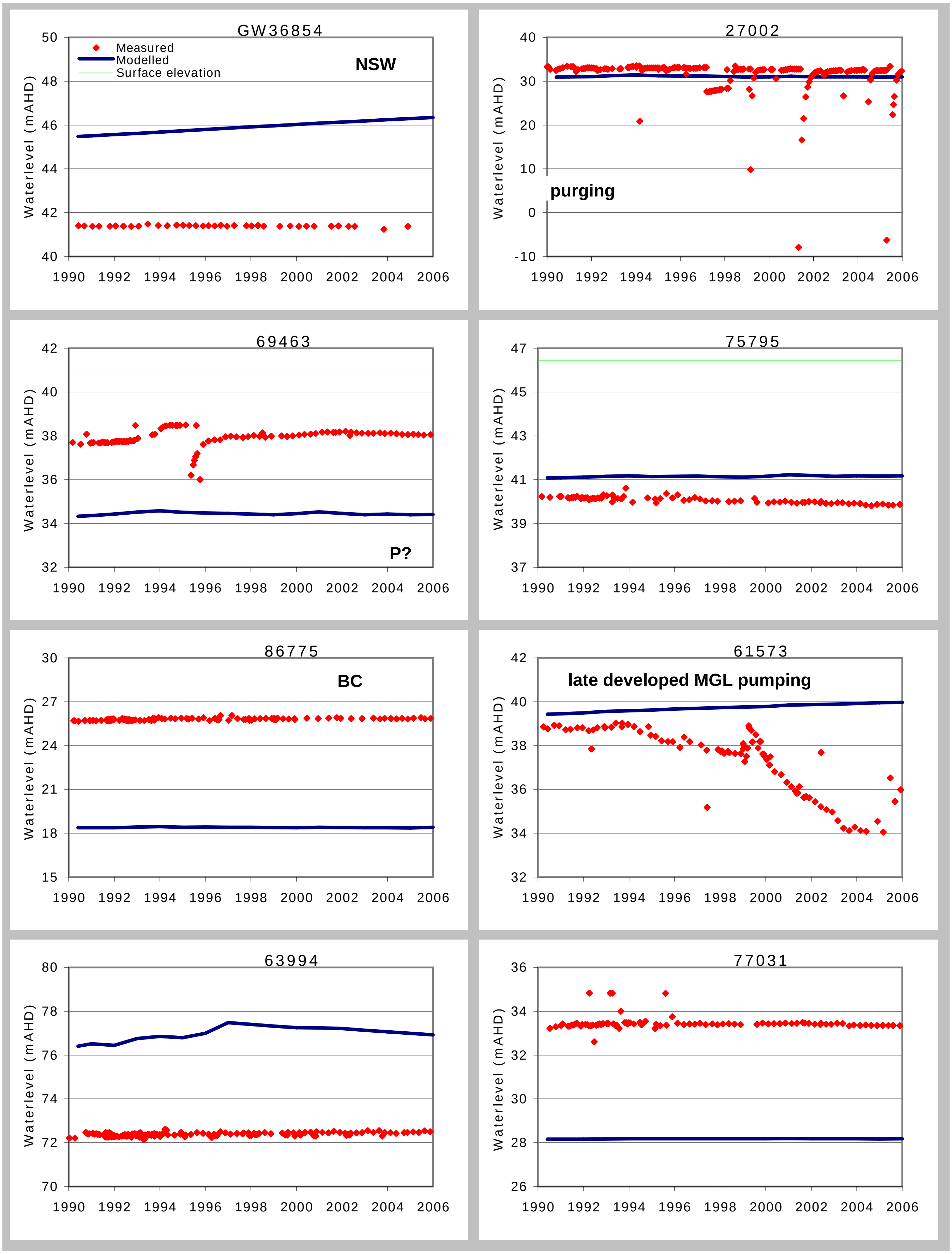
HYDROGRAPHS, LAYER 2 FIGURE J13



HYDROGRAPHS, LAYER 2 FIGURE J14



HYDROGRAPHS, LAYER 2 FIGURE J15



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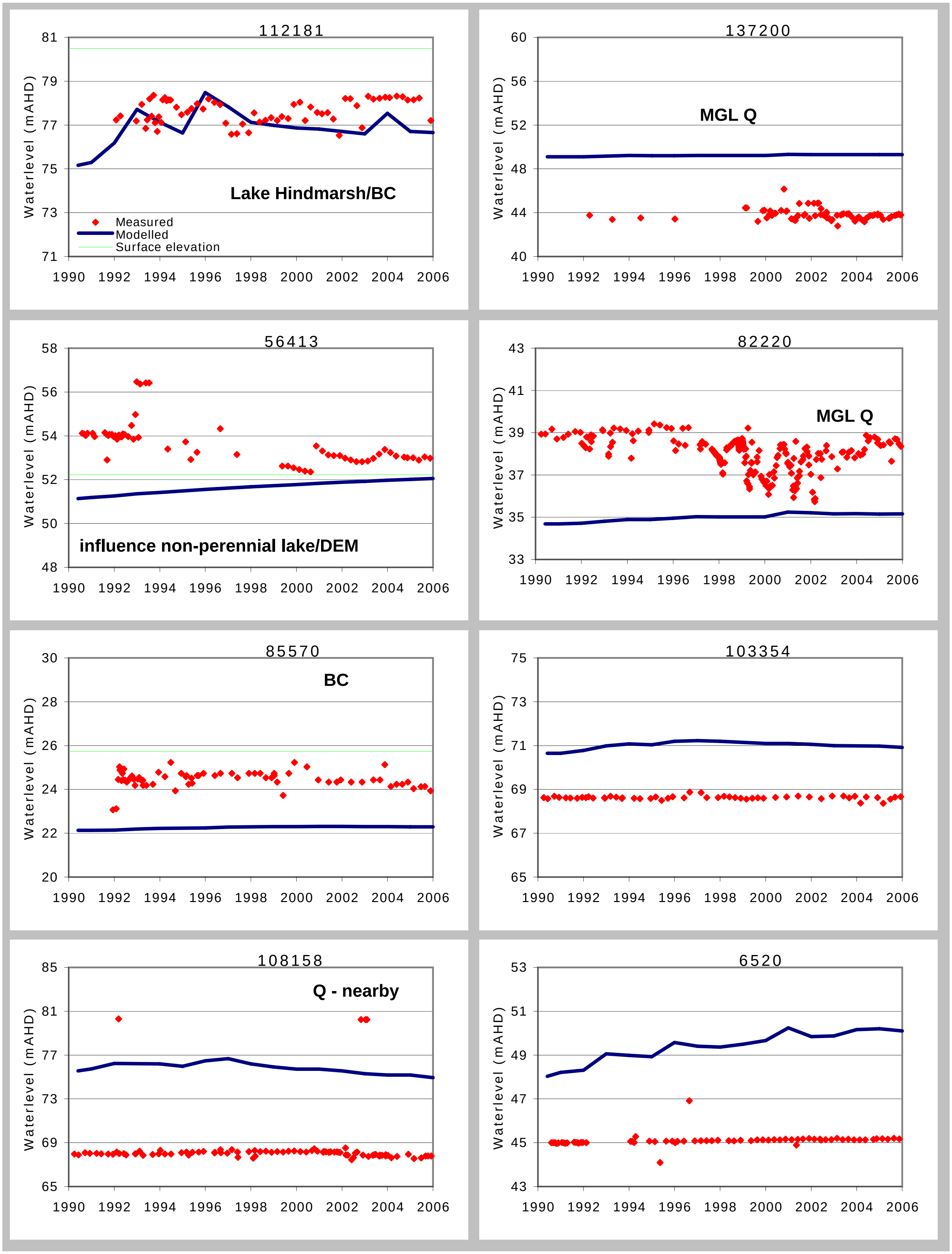
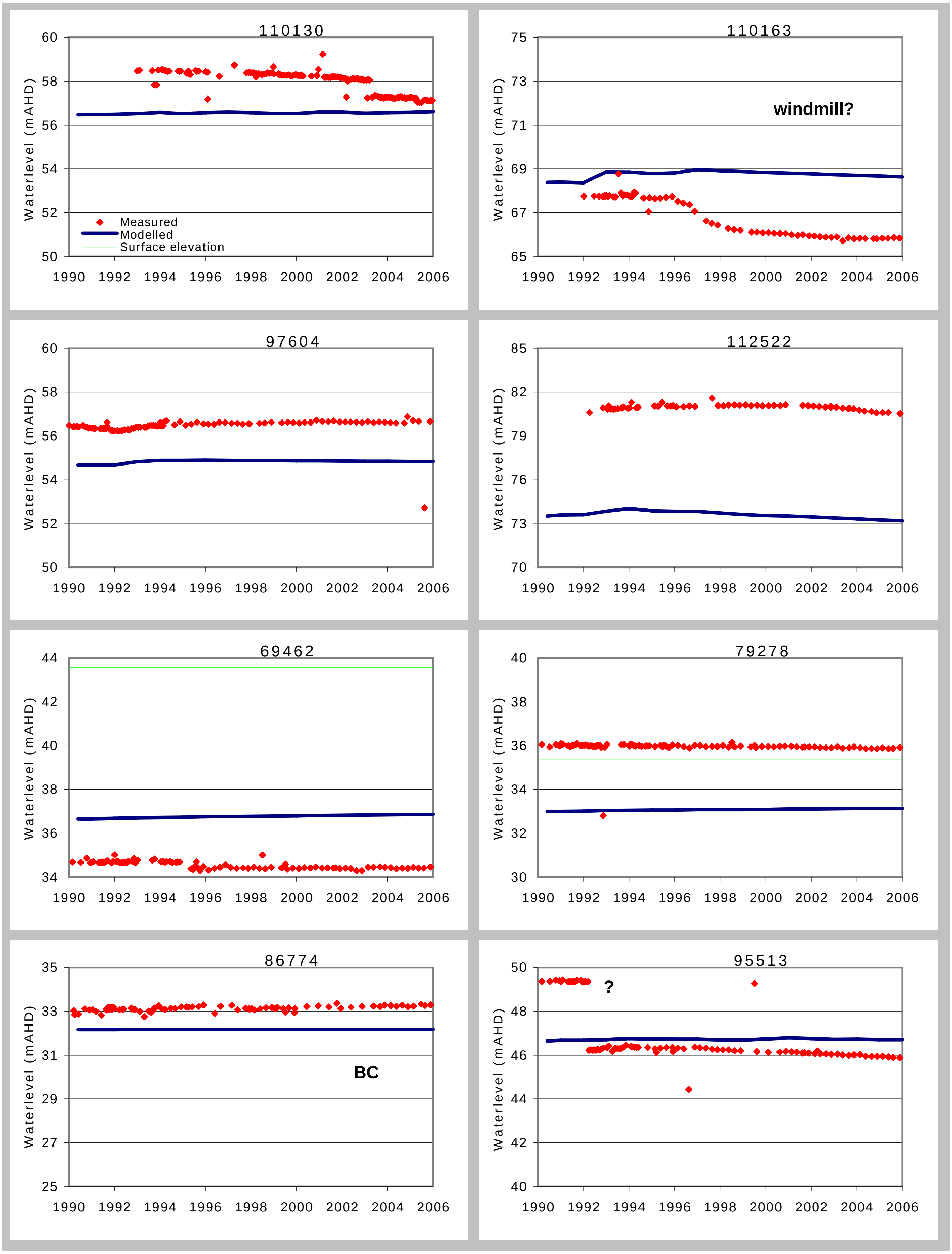
HYDROGRAPHS, LAYER 2&3 FIGURE J16



HYDROGRAPHS, LAYER 3 FIGURE J17



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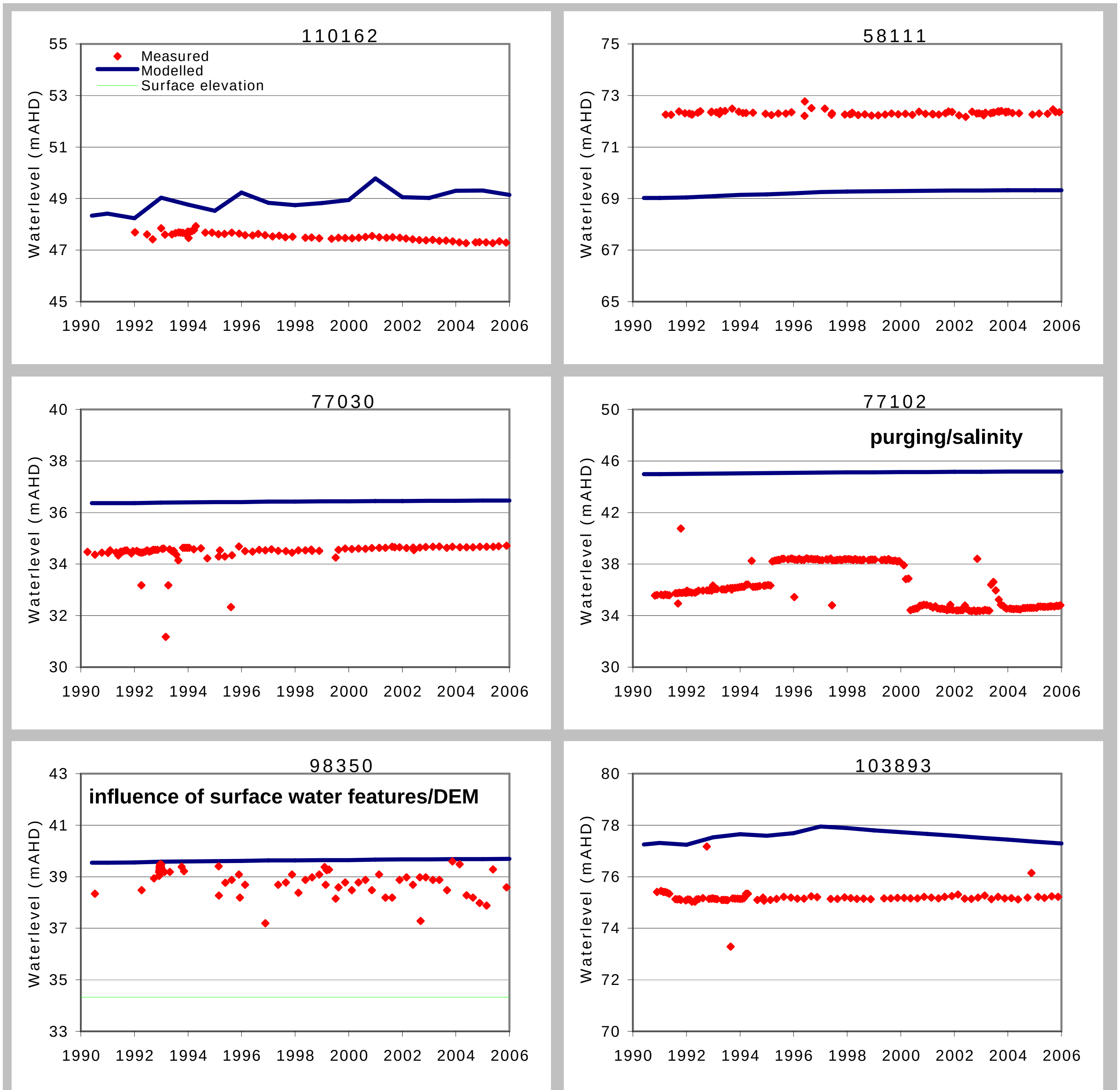
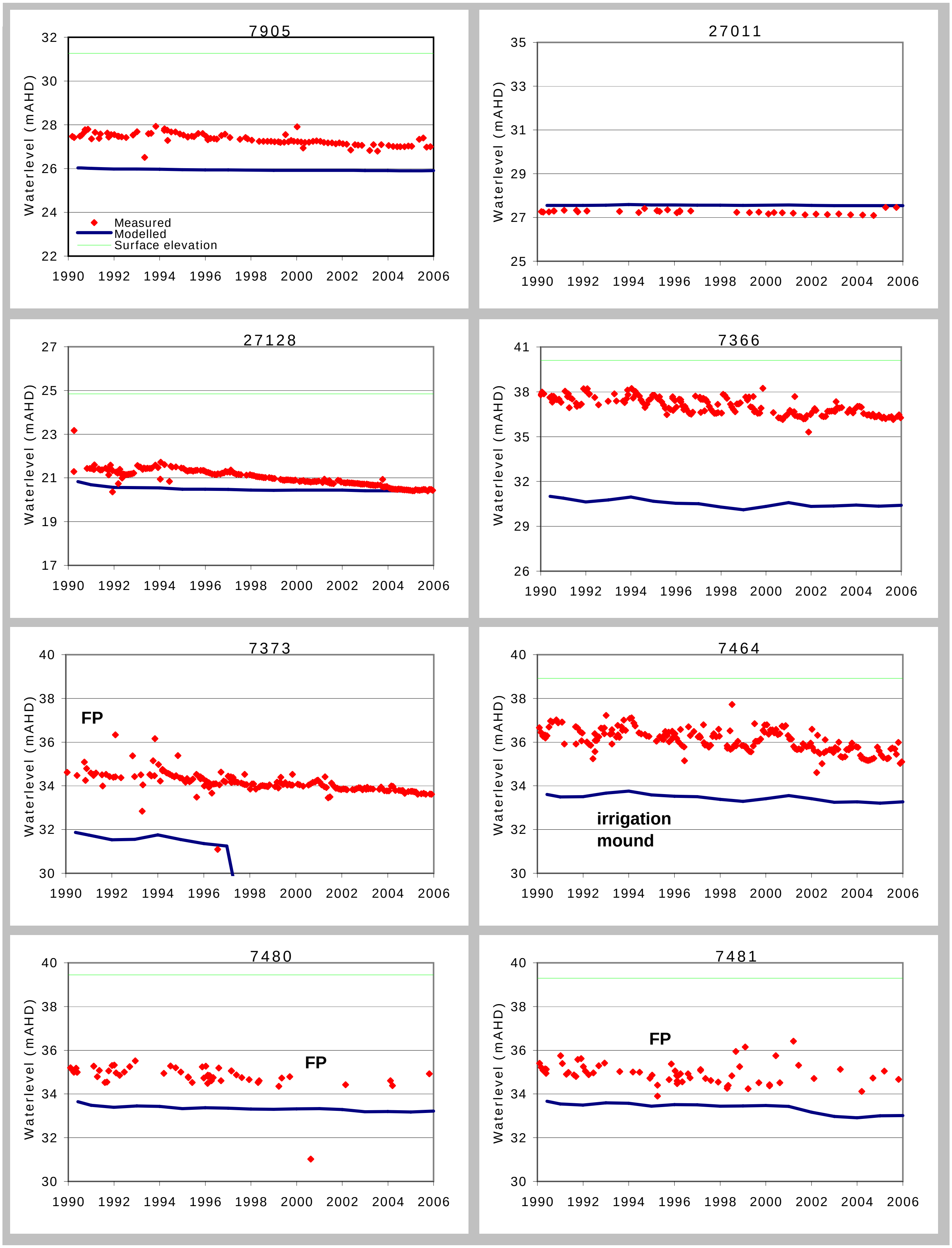
HYDROGRAPHS, LAYER 3&4 FIGURE J18



HYDROGRAPHS, LAYER 4 FIGURE J19

TRANSIENT HYDROGRAPHS – SENSITIVITY RUN WITH RIVER CONDUCTANCE SET TO 50 M^2/DAY AND TIME VARIED ET (FIGURES J20 – J38)



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HYDROGRAPHS, LAYER 1 FIGURE J20

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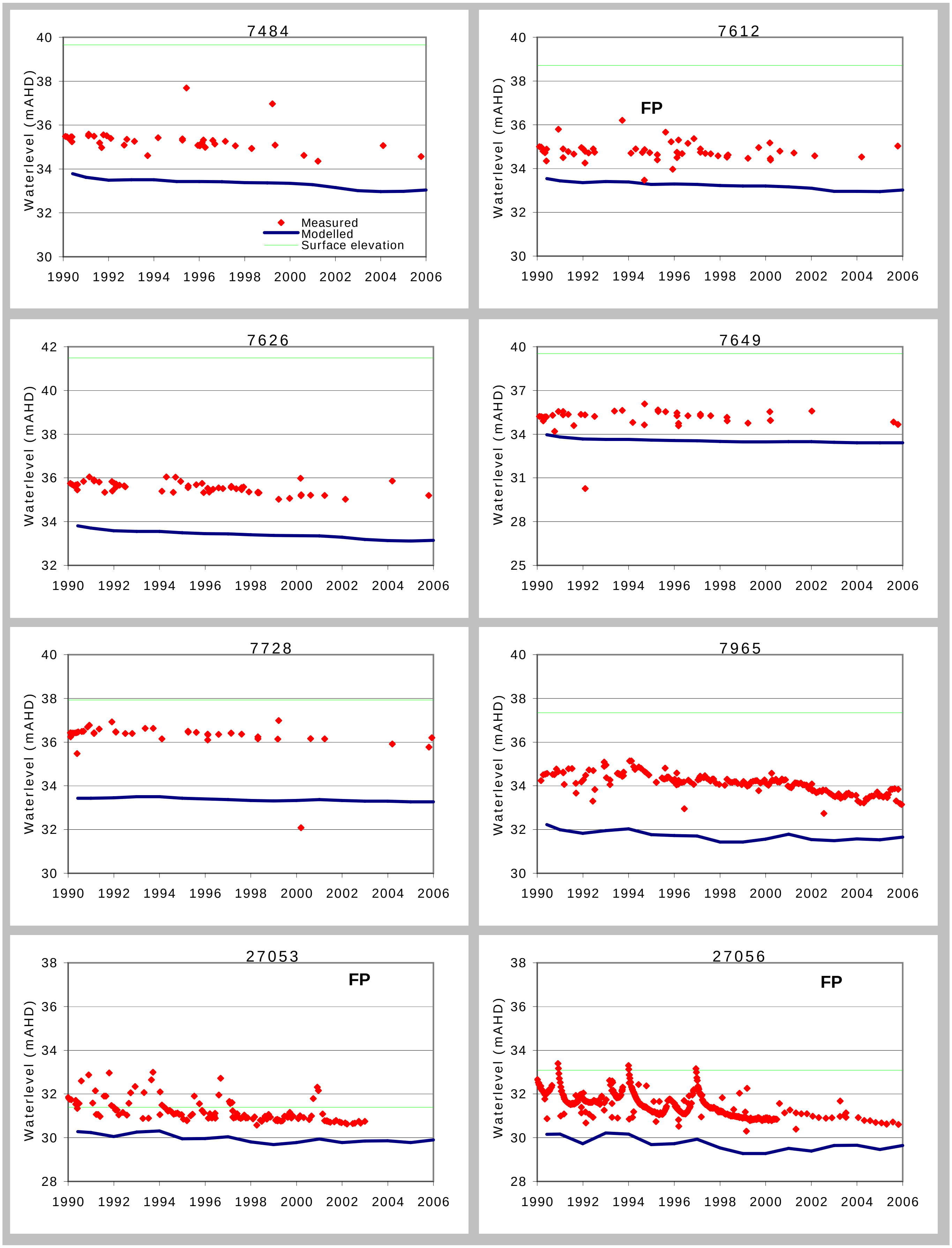
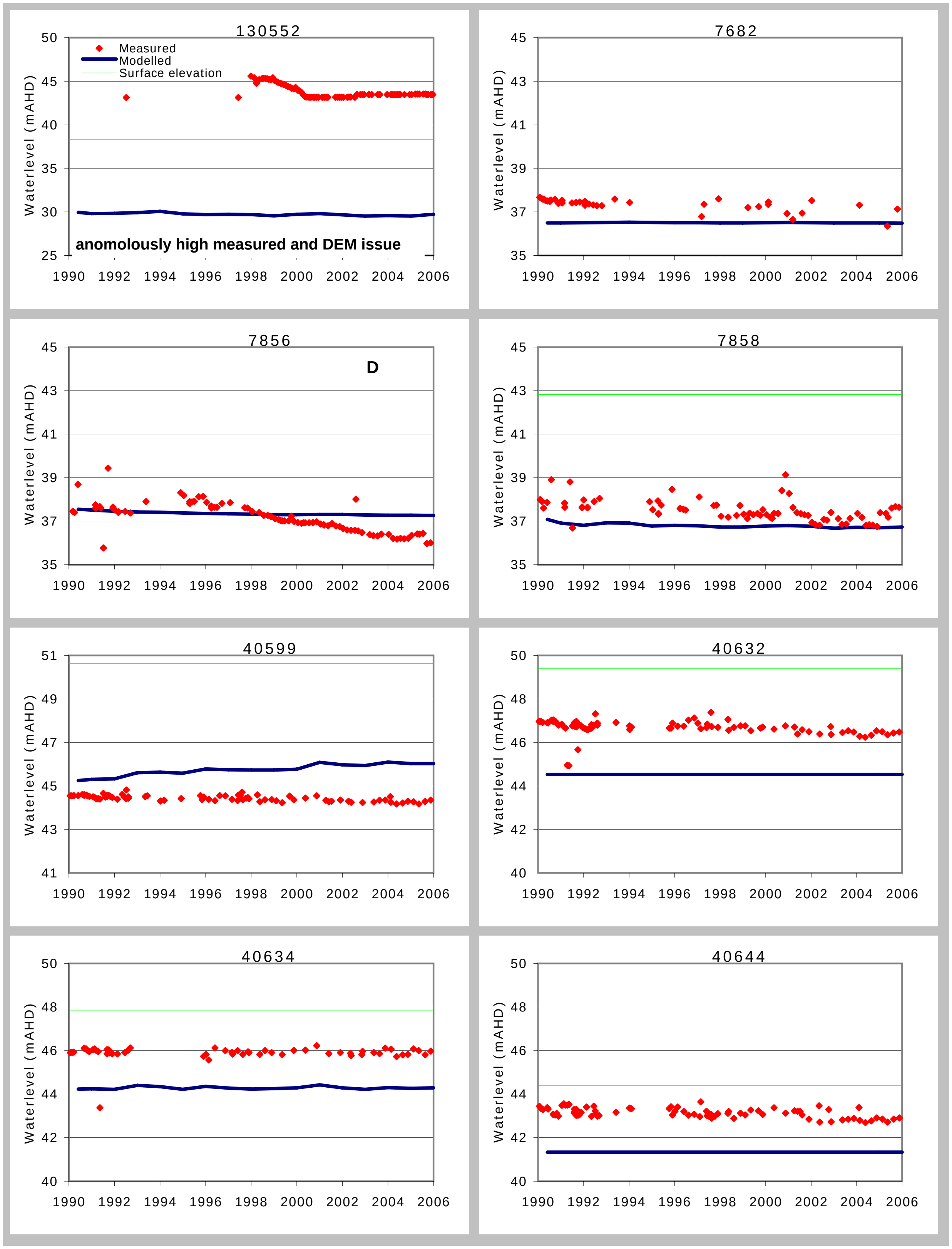
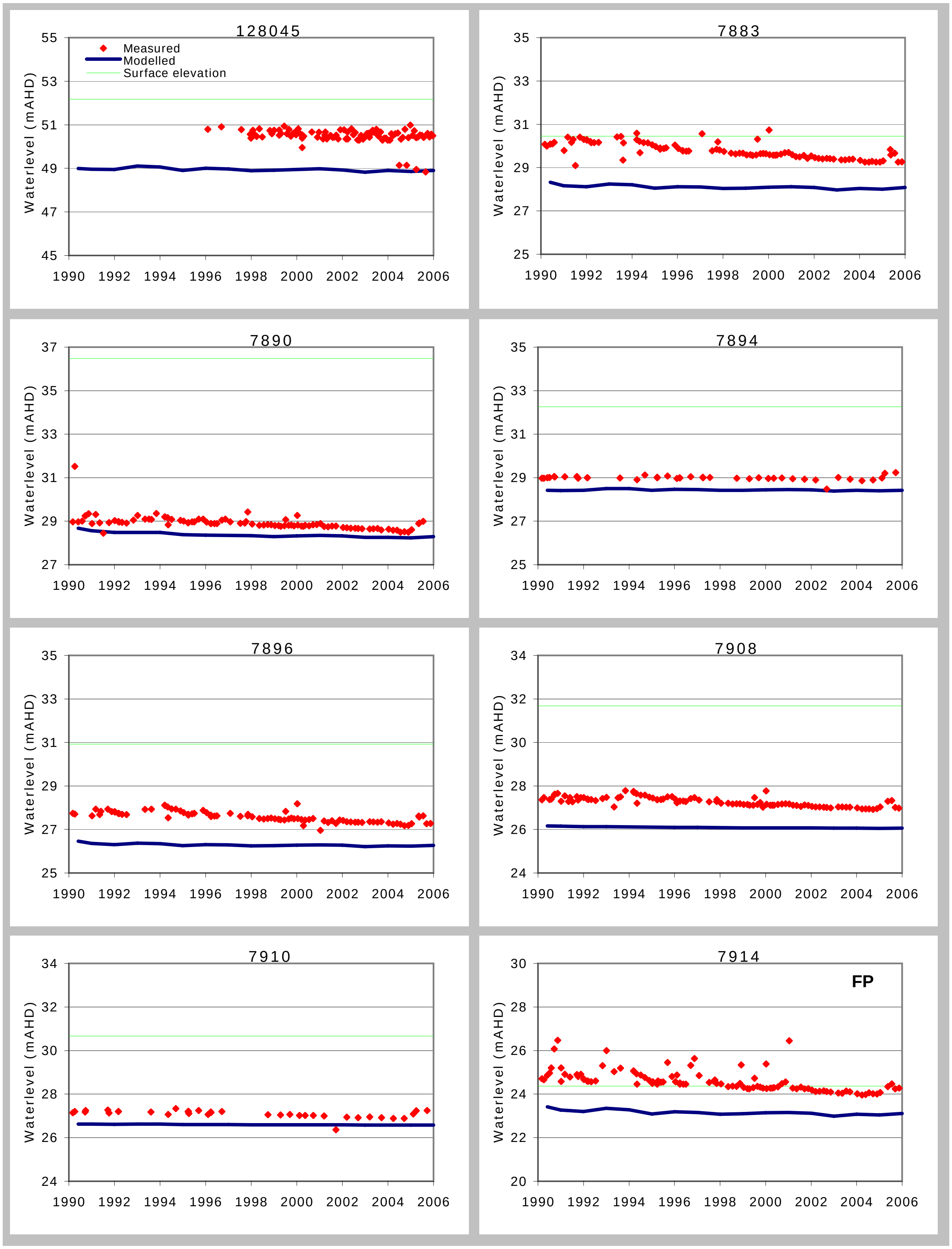


HYDROGRAPHS, LAYER 1 FIGURE J21

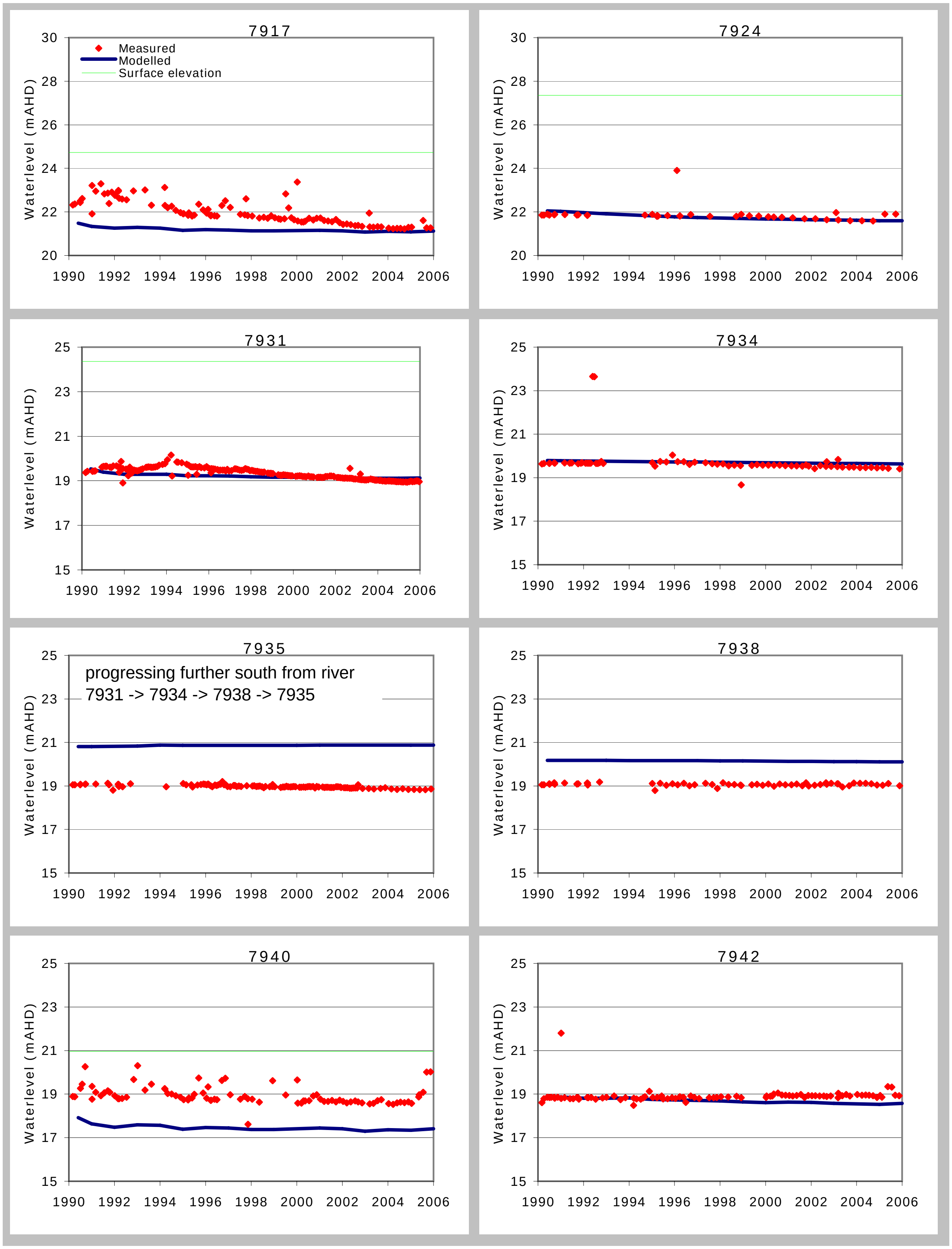


HYDROGRAPHS, LAYER 1 FIGURE J22

F:\Jobs\A53\B1_Mallee\600\602_Calib\HIST\Appendices\Appendix_J\[HIST_Hydrographs_hms14_riv50ET.xls]FigJ22



HYDROGRAPHS, LAYER 1&2 FIGURE J23



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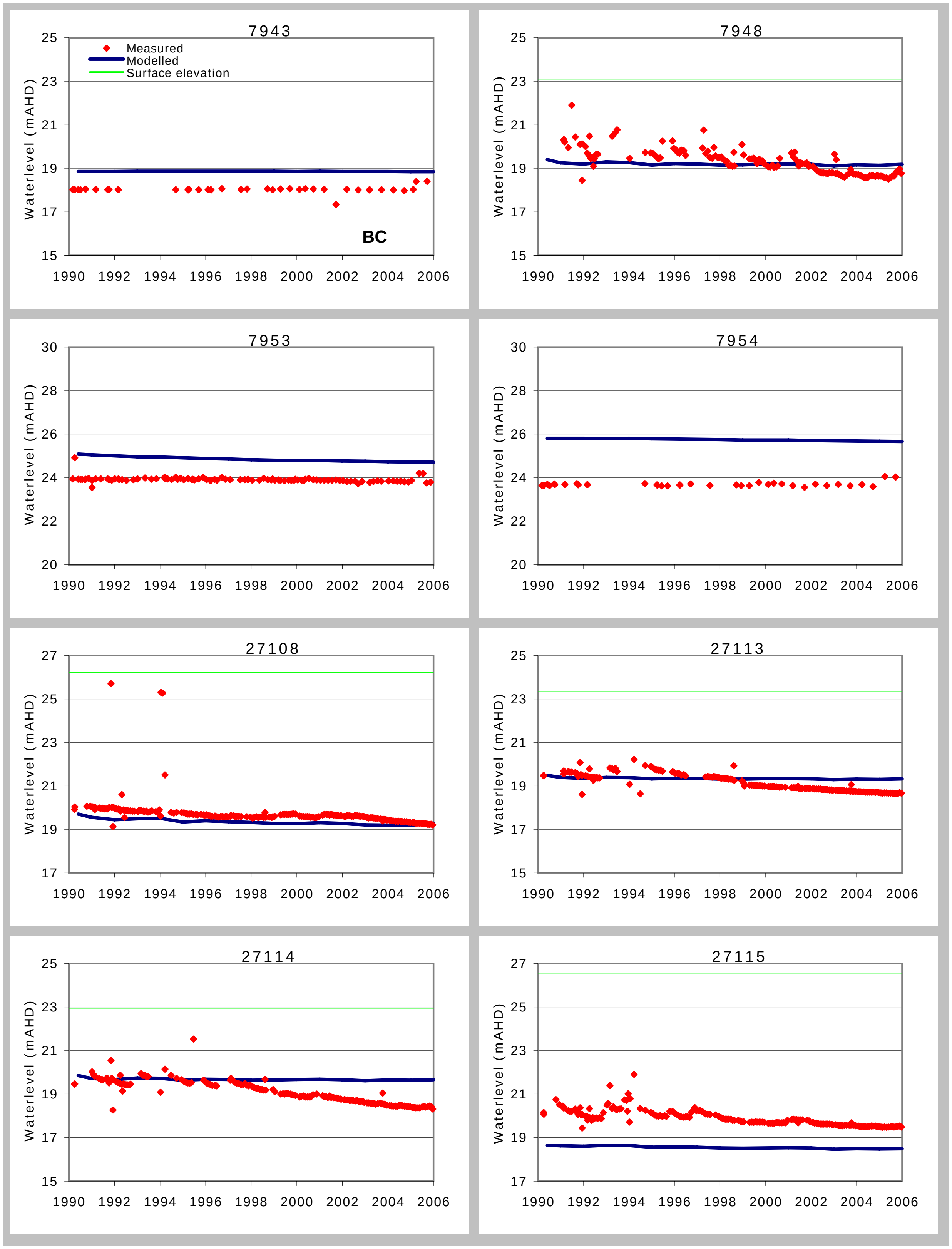
HYDROGRAPHS, LAYER 2 FIGURE J24



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HYDROGRAPHS, LAYER 2 FIGURE J25

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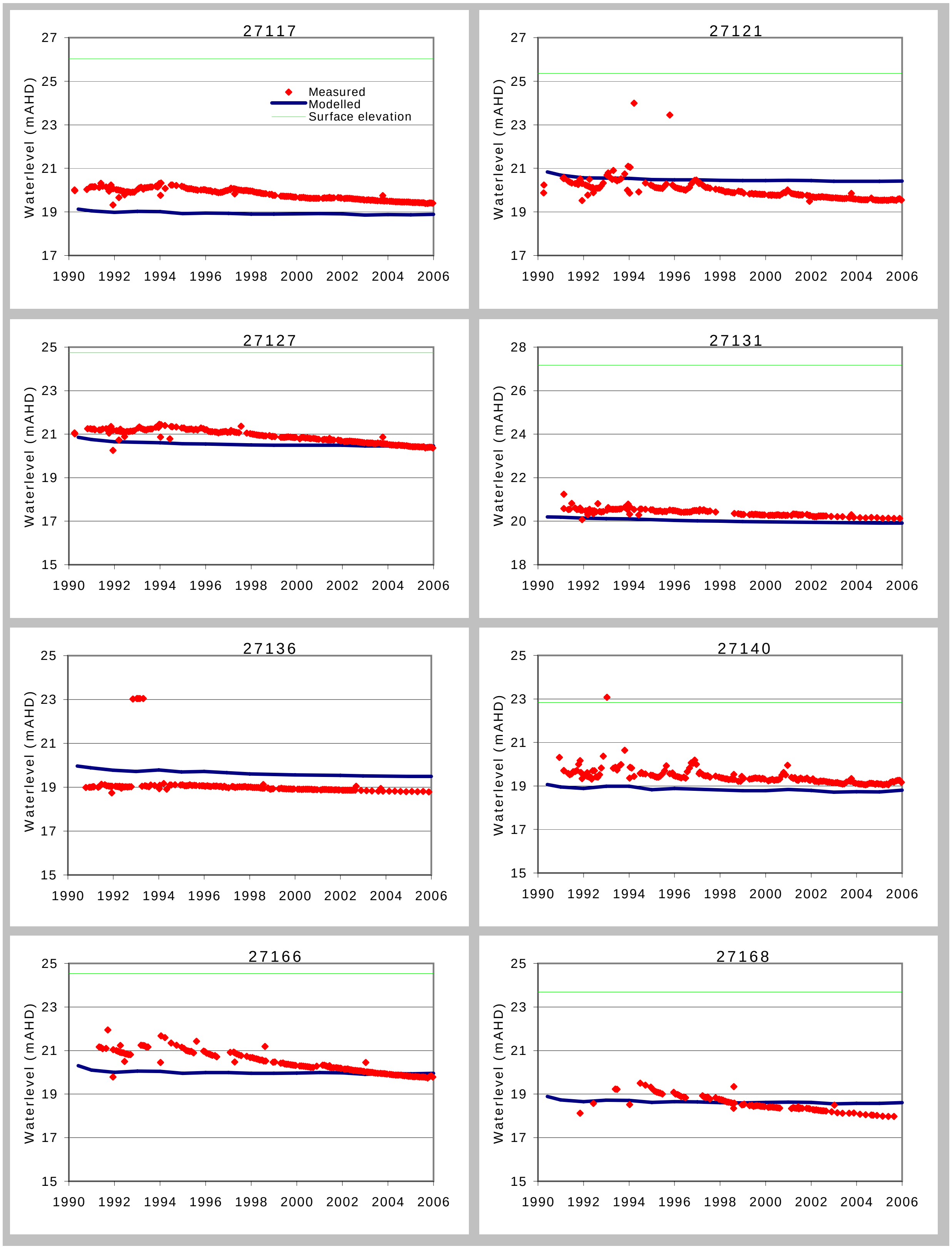

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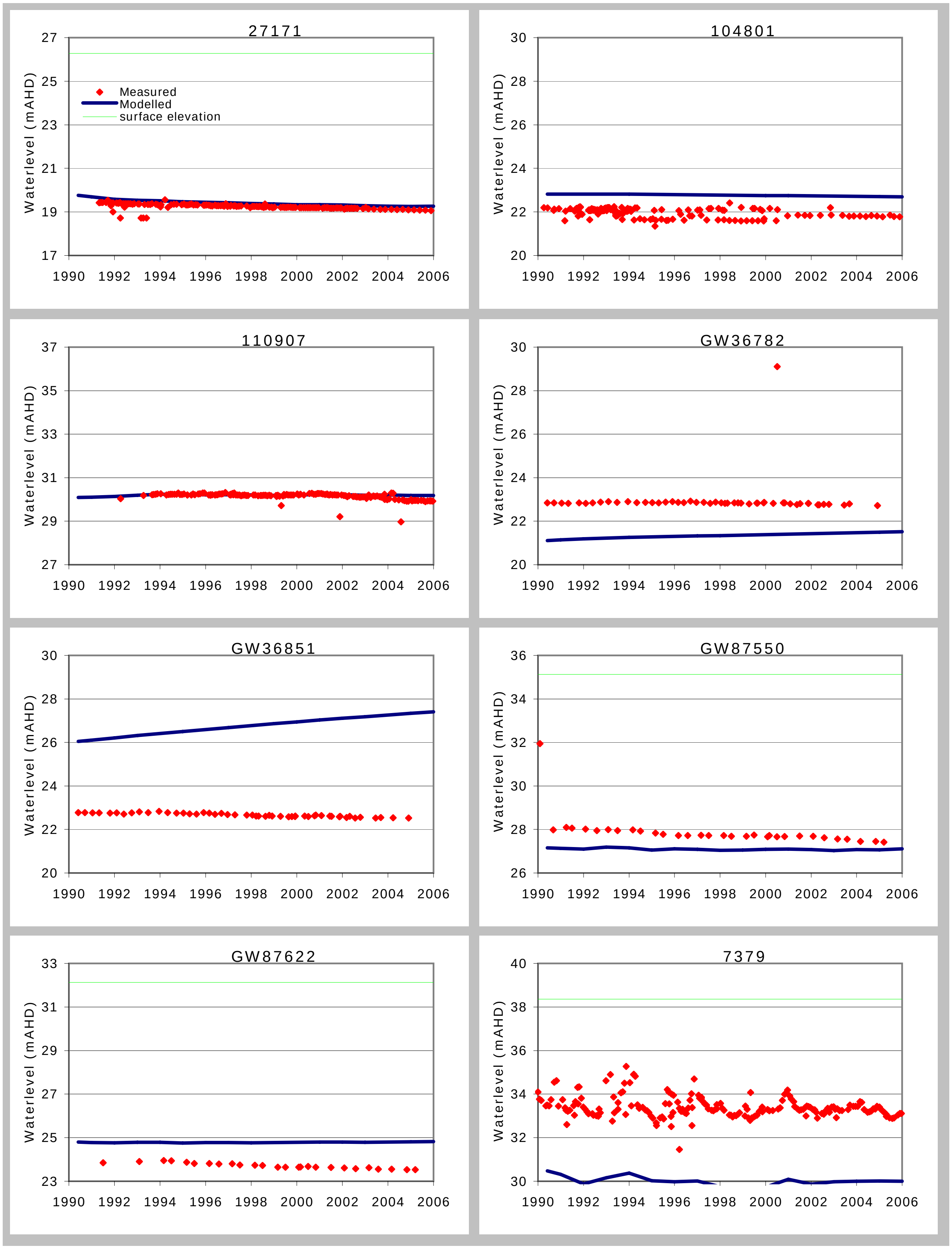
HYDROGRAPHS, LAYER 2 FIGURE J26



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HYDROGRAPHS, LAYER 2 FIGURE J27

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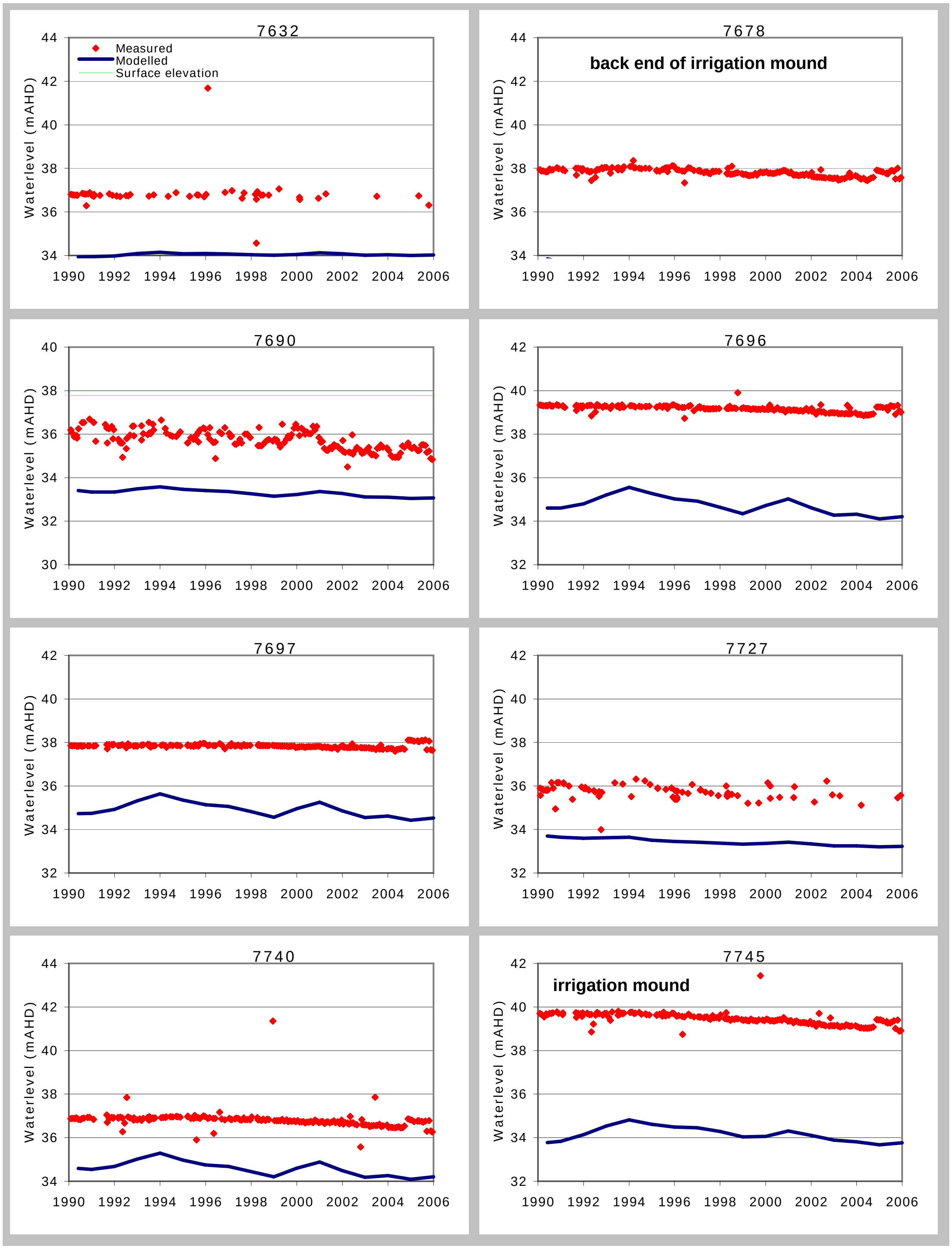

HYDROGRAPHS, LAYER 2 FIGURE J28

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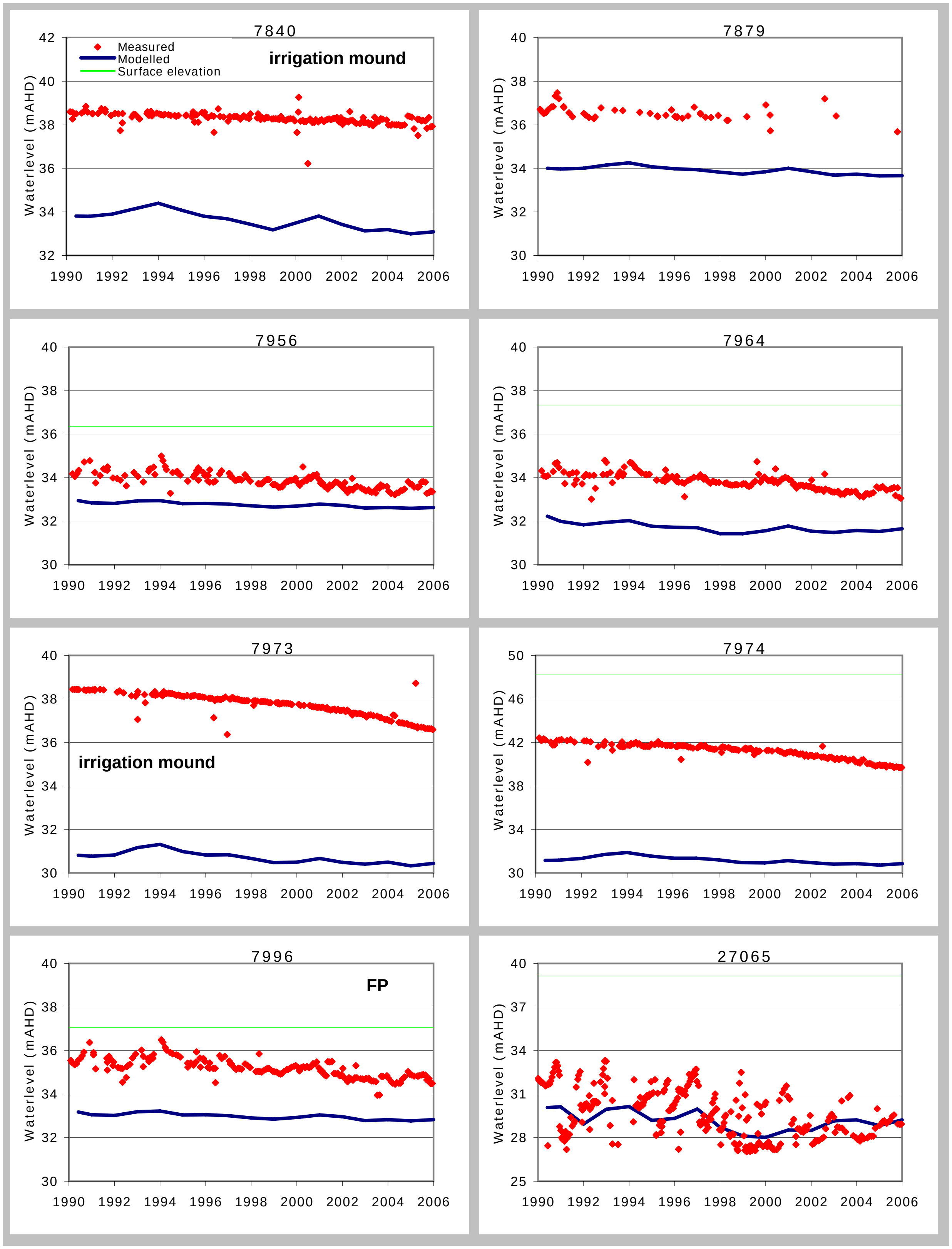

HYDROGRAPHS, LAYER 2 FIGURE J29

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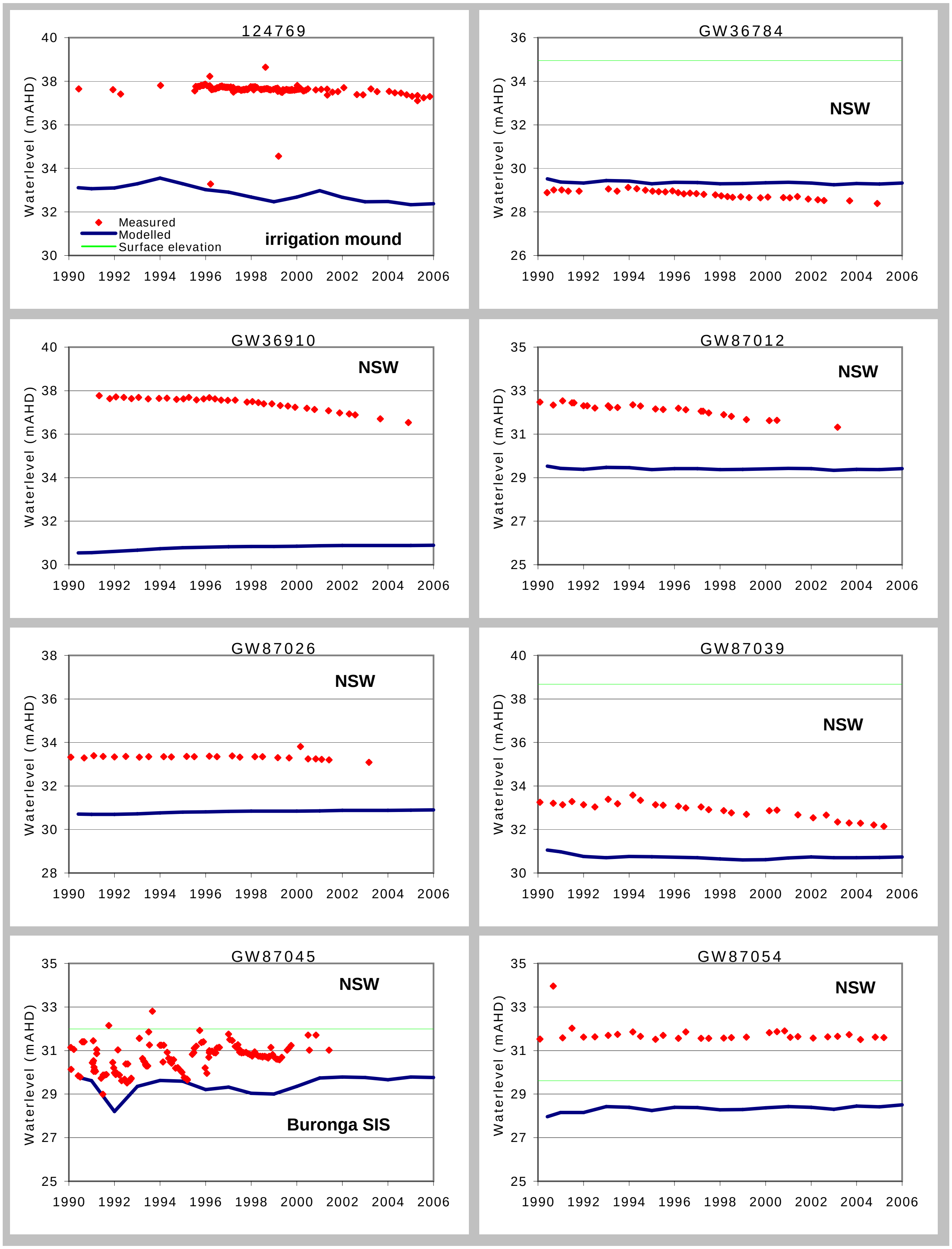
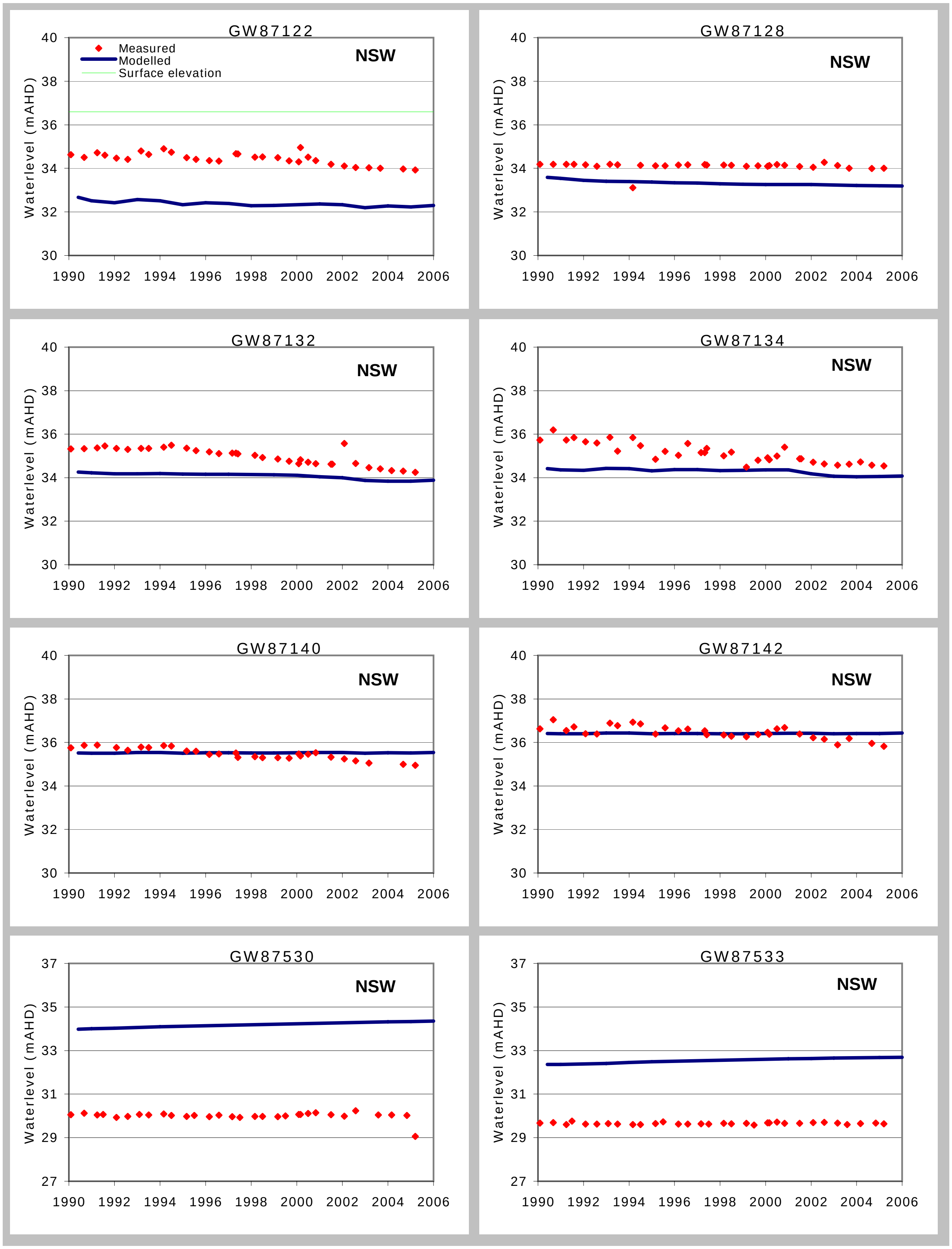

124769
Waterlevel (mAHD)
Measured
Modelled
Surface elevation
irrigation mound
GW36784
NSW
GW36910
NSW
GW87012
NSW
GW87026
NSW
GW87039
NSW
GW87045
NSW
Buronga SIS
GW87054
NSW


GW87122
NSW
Measured
Modelled
Surface elevation
Waterlevel (mAHD)
GW87128
GW87132
GW87134
GW87140
GW87142
GW87530
GW87533
1990 1992 1994 1996 1998 2000 2002 2004 2006

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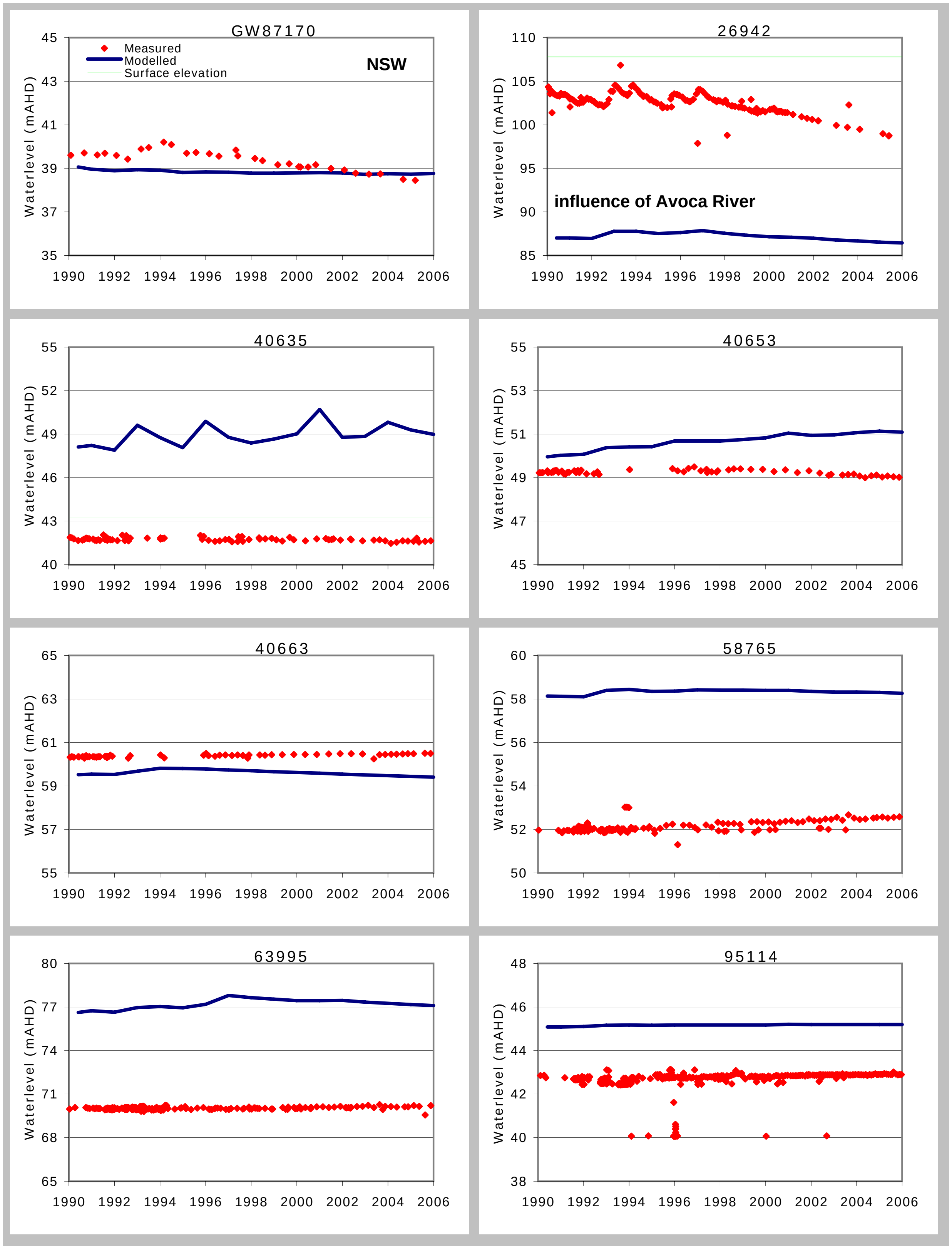
HYDROGRAPHS, LAYER 2 FIGURE J32

F:\Jobs\A53\B1_Mallee\600\602_Calib\HIST\Appendices\Appendix_J\[HIST_Hydrographs_hms14_riv50ET.xls]FigJ32



HYDROGRAPHS, LAYER 2 FIGURE J33

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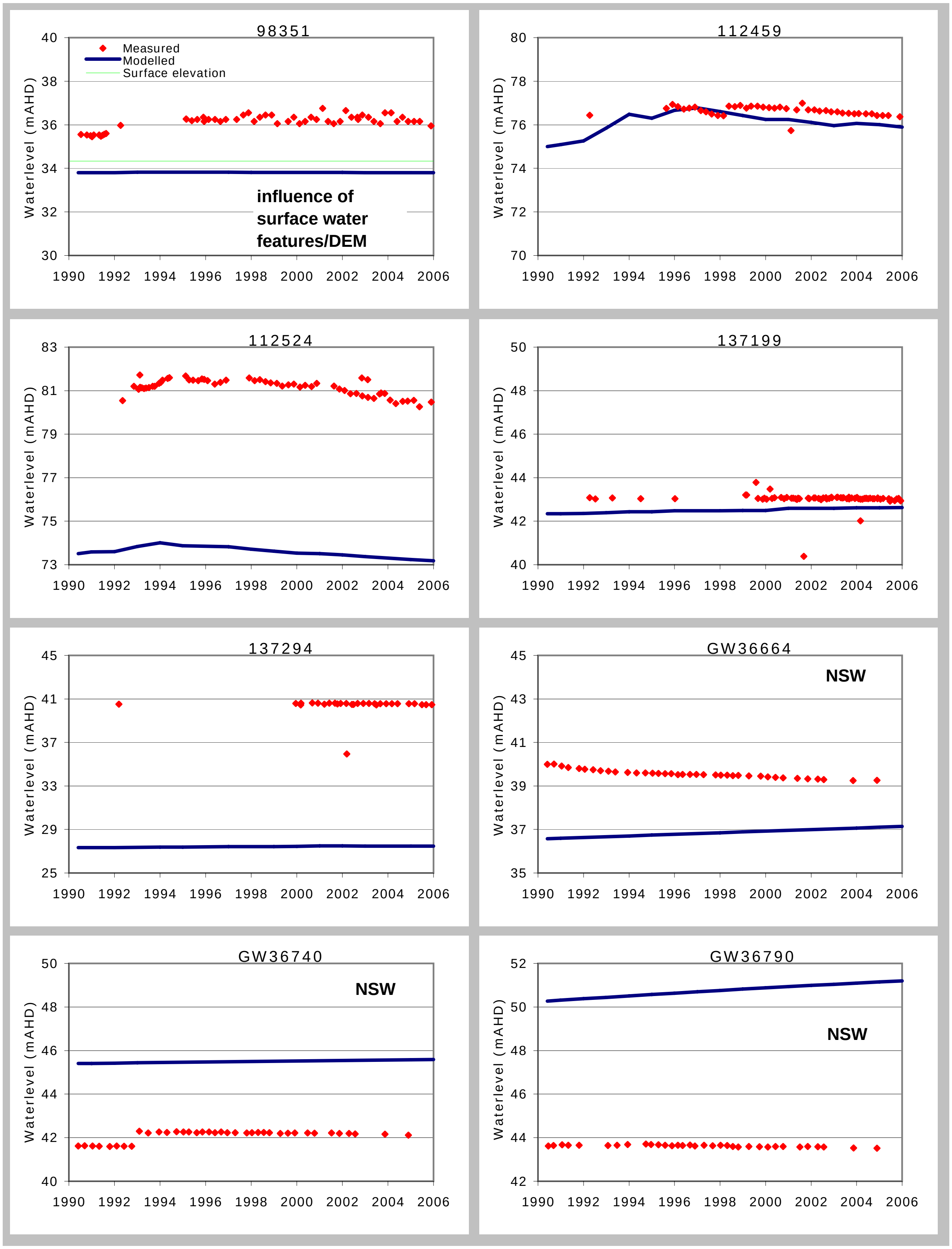

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HYDROGRAPHS, LAYER 2 FIGURE J34

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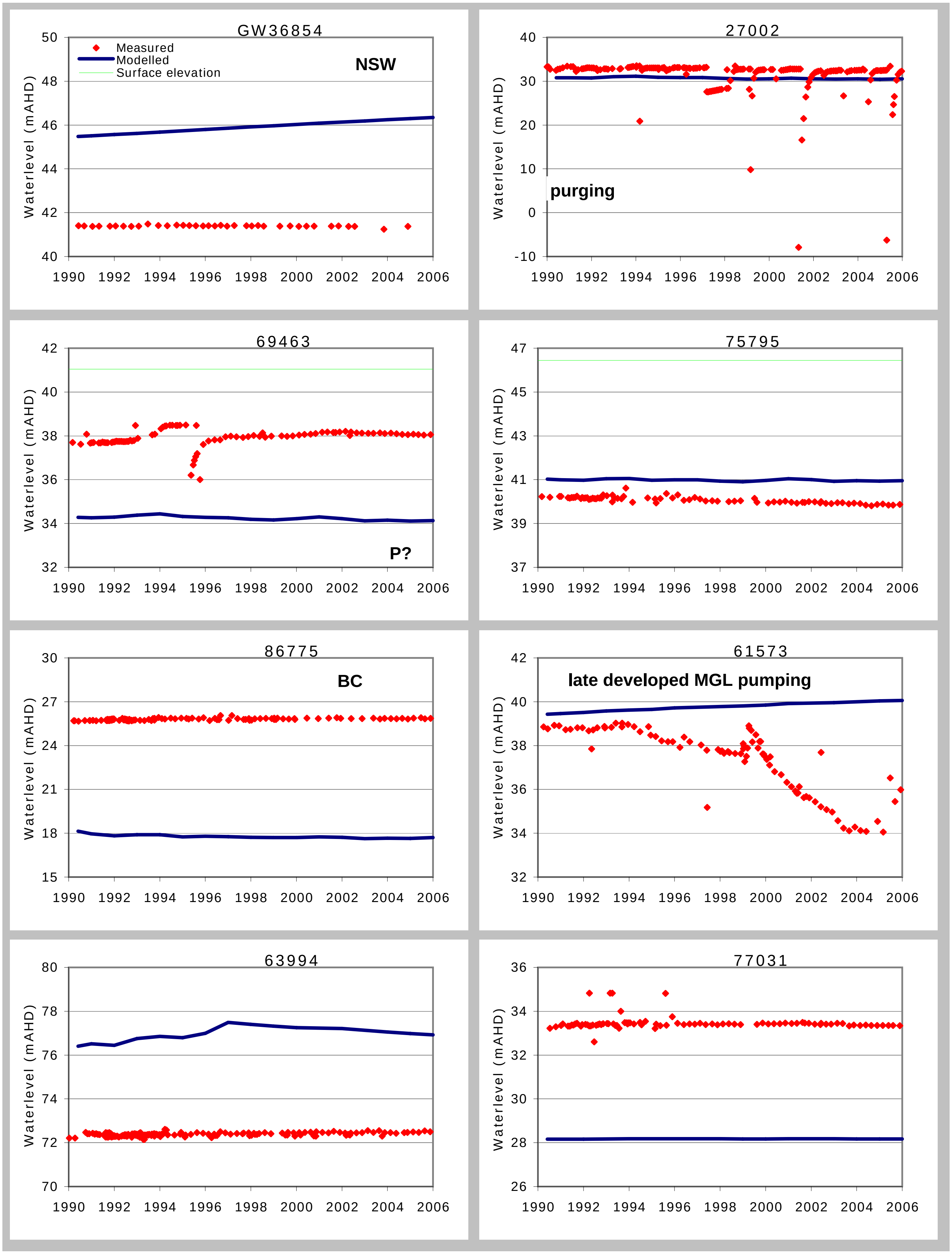

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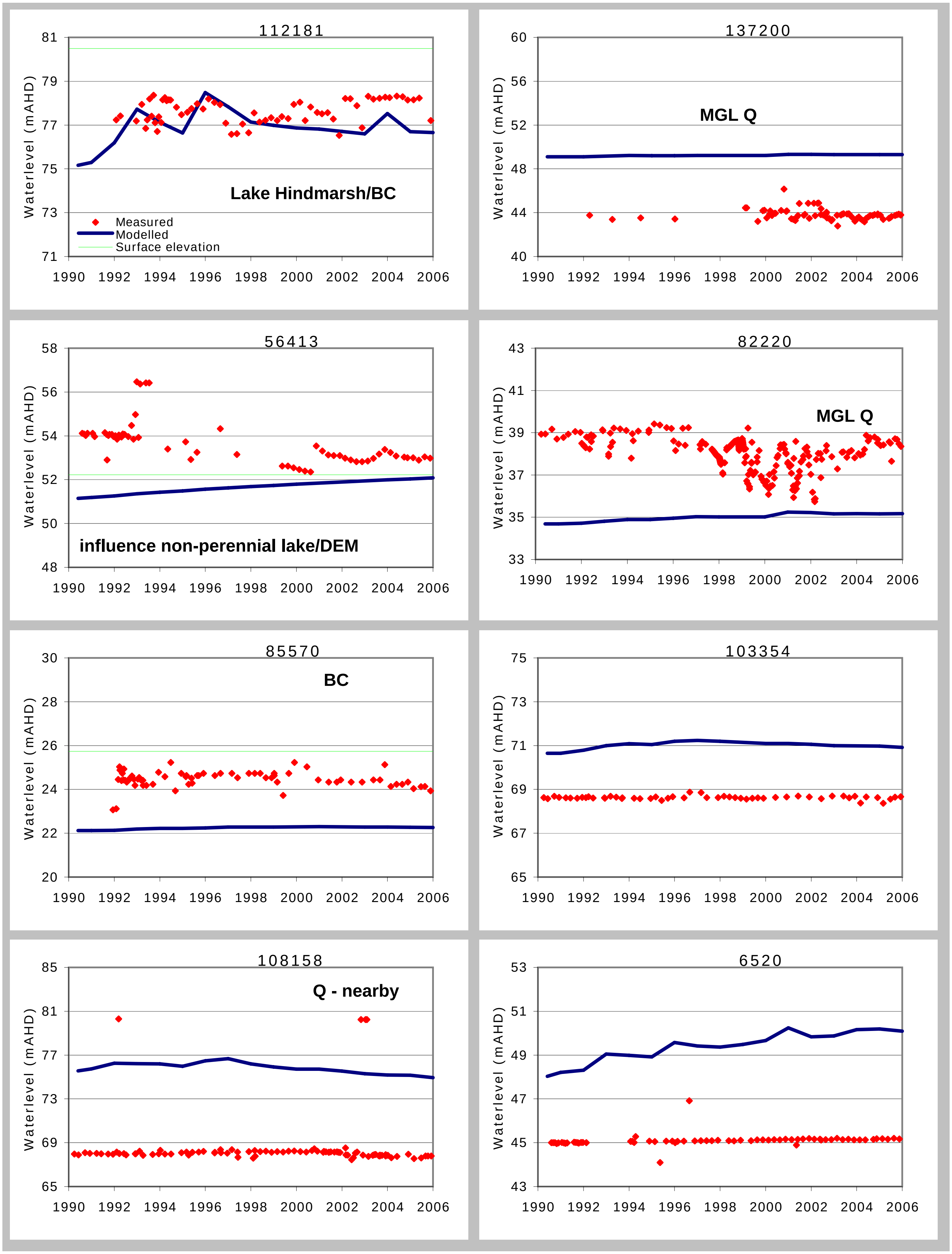
HYDROGRAPHS, LAYER 2&3 FIGURE J35



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HYDROGRAPHS, LAYER 3 FIGURE J36

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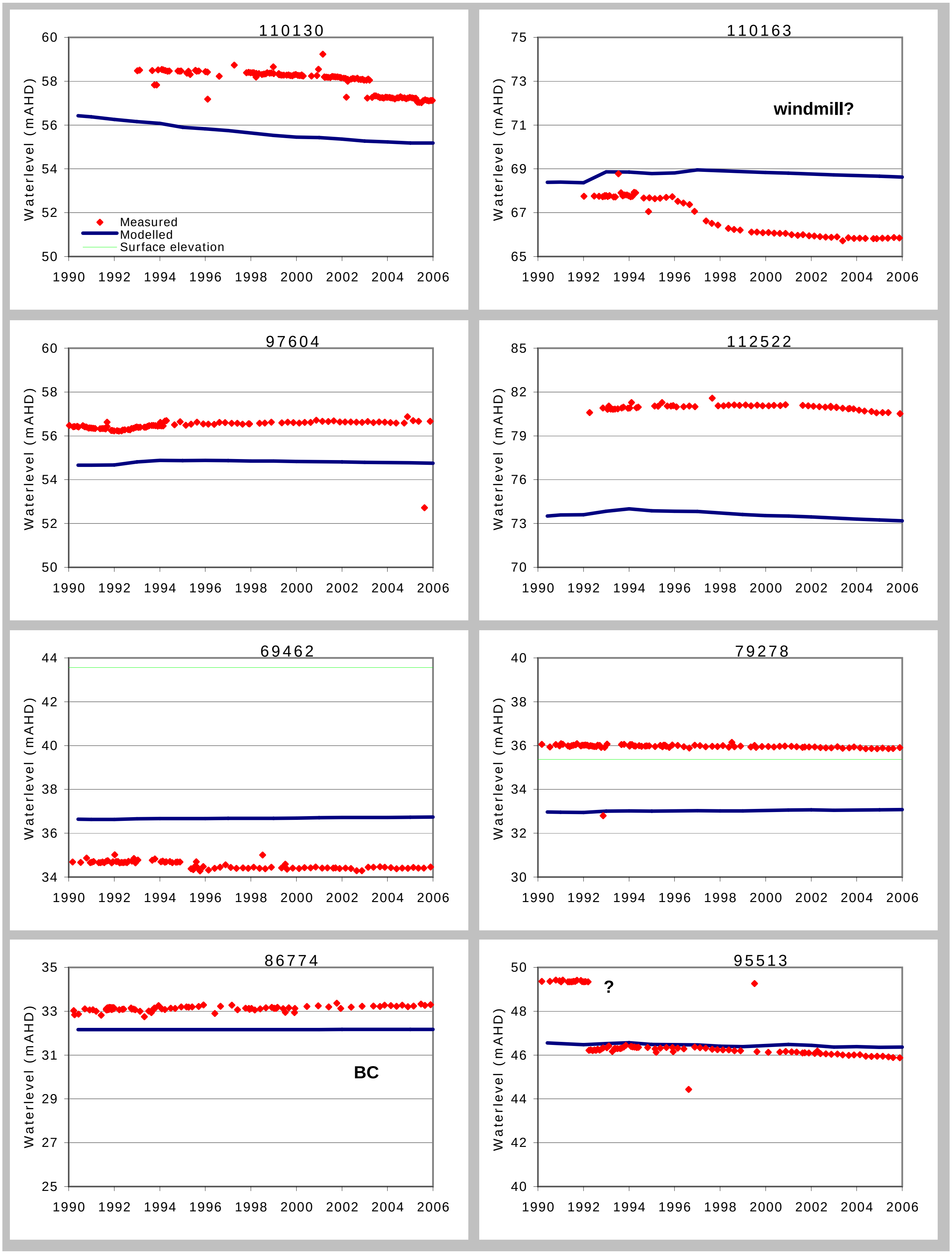

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HYDROGRAPHS, LAYER 3&4 FIGURE J37

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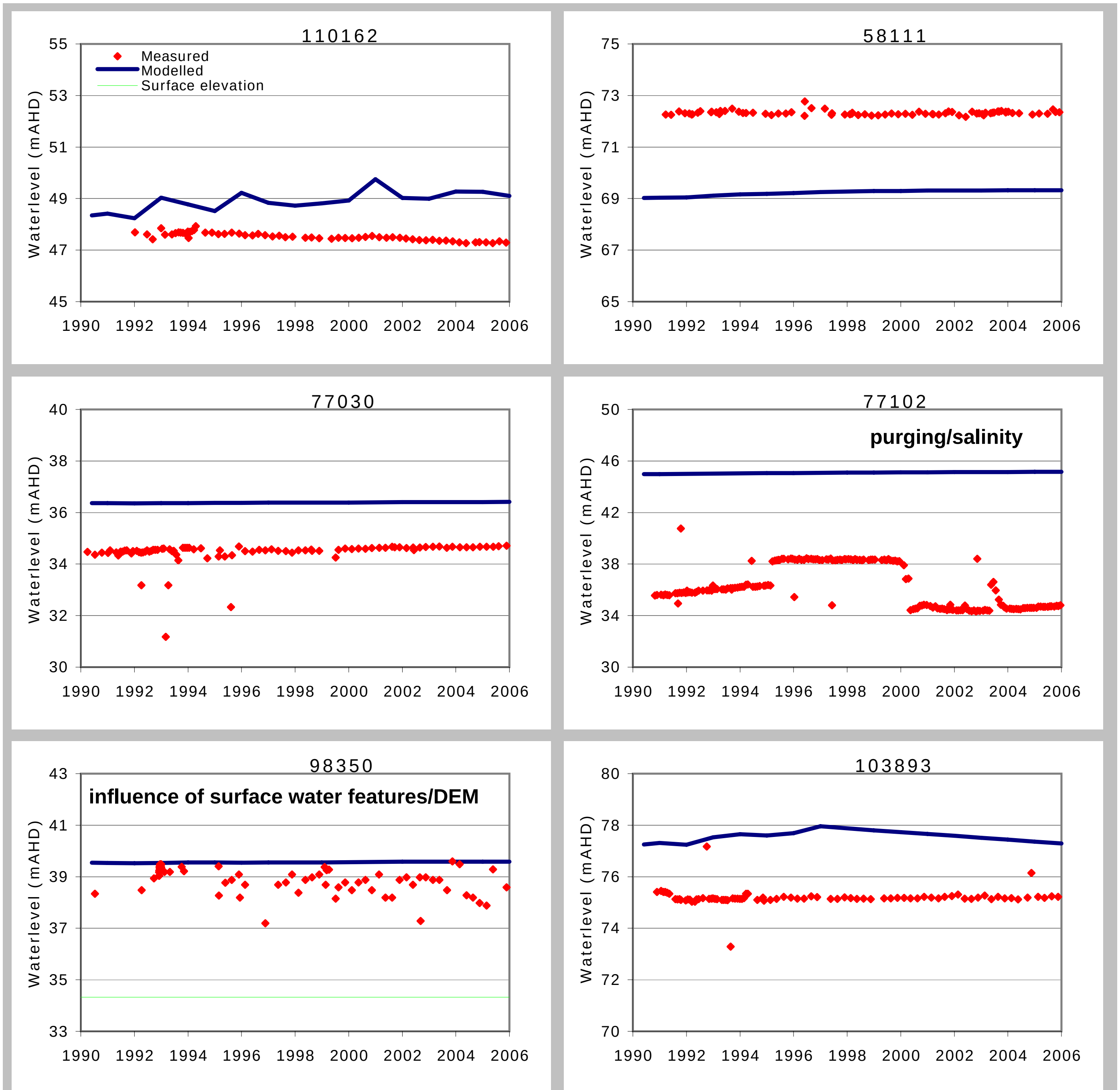

HYDROGRAPHS, LAYER 4 FIGURE J38

F:\Jobs\A53\B1_Mallee\600\602_Calib\HIST\Appendices\Appendix_J\[HIST_Hydrographs_hms14_riv50ET.xls]FigJ38

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