CORANGAMITE CMA
HEALTHY CATCHMENTS - HEALTHY WATERWAYS

Australian Government

Western District Lakes Hydrological Baseline
Final Report

Report No. J1291/R02

February 2010

Quality System
Quality Endorsed Company
ISO 9001:2000 QEC22878

WATER TECHNOLOGY
WATER, COASTAL & ENVIRONMENTAL CONSULTANTS

CORANGAMITE CMA
HEALTHY CATCHMENTS - HEALTHY WATERWAYS

Australian Government

Western District Lakes Hydrological Baseline
Final Report

Report No. J1291/R02
February 2010

WATER TECHNOLOGY
WATER, COASTAL & ENVIRONMENTAL CONSULTANTS

15 Business Park Drive
Notting Hill VIC 3168

Telephone **(03) 9558 9366**
Fax **(03) 9558 9365**

ACN No. **093 377 283**
ABN No. **60 093 377 283**

DOCUMENT STATUS

Issue	Revision	Date	Issued To	Prepared By	Reviewed By	Approved By
1	0	16/10/09	Corangamite Catchment Management Authority	SEL / BT	BT	BT
2	0	16/12/09	Corangamite Catchment Management Authority	SEL / BT	BT	BT
2	1	12/2/10	Corangamite Catchment Management Authority	SEL / BT	BT	BT

QFORM-AD-18 REV 5

It is the responsibility of the reader to verify the currency of revision of this report.

s:\j1200-1299\j1291-01_western_districts_lakes\docs\report\j1291r02_finaldraft3.doc

EXECUTIVE SUMMARY

The Western District Lakes (WDL) Ramsar site is situated within the Victorian Volcanic Plains bioregion, and is an important birdlife breeding ground for migrating shorebirds. The Corangamite Catchment Management Authority (CCMA) commissioned Water Technology to undertake a hydrological baseline investigation to improve the knowledge base of the Ramsar listed sites and develop a hydrological water balance of the lakes. The impact of climate change on the water balance and the resilience of the lakes to withstand the impact of climate change were then assessed. The project was segmented into a number of components including a data review, definition of the catchment and lake properties, water balance modelling and hydrologic analysis. Each component is described below.

Data Review & Gap Analysis

Data was collected from a number of sources to provide background information for the study and inputs required for modelling of the lake systems. The literature review revealed three of the nine RAMSAR listed lakes (Corangamite, Gnarpurt and Murdeduke) with sufficient data to provide a calibrated hydrologic model. Due to the significant amount of work already undertaken on lakes Corangamite and Gnarpurt it was the preference of the Corangamite CMA to focus on less studied lakes. Hydrologic models for two of the lakes, Lake Murdeduke and Lake Colongulac, were developed as part of this study.

Recently available LiDAR data has meant that the lakes and their associated catchments were able to be more accurately defined. As part of this study the LiDAR information was used to provide stage-storage-area for each of the nine lakes and delineate their surface water catchments. This data will help to not only provide the basis for further hydrological modelling of the other lakes, but also provide valuable information on the less studied lakes.

Stage-Storage-Area

The stage-storage-area relationships for each of the nine lakes were defined based on the 1m resolution LiDAR data. For a majority of the smaller lakes the LiDAR data set covered the entire lake, and therefore an accurate representation of the stage-storage-area relationships was formed. This fills an important knowledge gap in the understanding of many of the lakes, which have not previously had this relationship defined. Some of the larger lakes contained water at the time of the LiDAR survey and hence either additional data sources or interpolation across the base of the lakes was required. All assumptions are included in Section 4.2 of the report.

Outputs for this section include a stage-storage-area table; stage vs. storage and stage vs. area graphs; in addition to a map of the lake terrain showing the assumed extent of the lake.

Catchment Delineation

For each of the nine lakes the catchment boundaries were refined to reflect the improved resolution data sets. Where significant landscape features were present, such as lunettes, the previous catchment delineations provided similar results to the current study. The greatest variations were found where the terrain was relatively flat and only minute differences in elevation separate catchments between the lakes.

Outputs for this section include a table of lake area, catchment area and lake to catchment ratios; comparison to prior studies table; and catchment maps showing the delineation and the terrain data in which it was based.

Catchment Model Development

A WaterCAST catchment model was developed for both Lakes Murdeduke and Colongulac to simulate the current hydrologic behaviour of the lakes and then to assess the impacts of climate change. In addition to climate change scenarios the models are also able to simulate the effects of various management actions. They have also been set up to enable the inclusion of further data such as water quality parameters. In order to develop these models the following information was required:

- Sub-catchment delineations generated in the previous section
- Rivers and Creek flow paths to the lakes
- Any hydrologic processes such as time lags between the rainfall and modelled runoff
- Landuse (for future water quality modelling)
- Long Term rainfall data series
- Long Term Evaporation data series
- Hydrologic parameters for rainfall-runoff modelling
- Stage-storage-elevation data for the lakes
- Any extractions or point source inflows (such as the Camperdown Sewage Treatment Plant discharge into Lake Colongulac)

The SIMHYD hydrologic model was chosen to represent the rainfall runoff process. Parameters were calibrated to match the limited observed runoff and lake level data.

Model Calibration

Limited calibration data existed for Lake Murdeduke and Colongulac. Only lake levels for each of the lakes and runoff from one of the major tributaries into Lake Murdeduke (Mia Mia Creek) were available. The SIMHYD parameters were calibrated to the flows observed at the Mia Mia Creek gauge and then applied to the remainder of the catchment, assuming the hydrologic response is the same. A combination of the surface flows and baseflows were then calibrated to match observed water levels within the lakes.

These calibrated models provide important information regarding the relative inflows and outflows to the lake, and the influences on lake levels. Once the model had been calibrated to current conditions the model could then be used to assess the impacts of climate change on the lakes.

Hydrologic Analysis

A statistical analysis was undertaken on the output from the modelling with a time-series and relative influences of inflows, outflows, volumes and lake water levels presented.

The River Analysis Package (RAP) was also utilised to provide hydrologic analyses such as a low spells analysis to determine dry outs for the lakes, stage duration curves and volume duration curves. These analyses revealed both seasonal and longer term trends for the lakes. The responses from Lake Colongulac and Lake Murdeduke to the seasonal factors were similar, but over the long term they varied. Due to its size Lake Colongulac is much more susceptible to drying out.

Once a baseline condition had been established, the impacts of climate change were assessed by varying the input rainfall and evaporation. The simulation was rerun and compared to the base case to determine the differences in the water balance. For both lakes the impact of reduced rainfall and increased evaporation was a significant increase in dry outs for the lakes, particularly the smaller lakes. In the simulations Lake Murdeduke dried completely, which could have important impacts on the ecology of the larger lakes in the region.

Conclusions

The water balance models developed as part of this study have provided valuable information regarding the hydrologic influences on the lakes, and susceptibility of the region to climate change. The knowledge base for each of the nine lakes has also been improved by defining the lake stage-area-volume characteristics and refining the catchment delineations based on the highest resolution data available. Together this information provides a snapshot of the regional hydrologic behaviour, the relationships between the catchments and the lakes, as well as the differences that exist for each of the RAMSAR lakes. It is recommended that similar studies be conducted across all remaining lakes of the Western District Lakes Ramsar site.

Training

Once the modelling of Lake Colongulac and Lake Murdeduke was complete, training was provided to the CCMA staff to enable the CMA to undertake the modelling of the remaining lakes in-house. This was an important component of the project as it provided capacity building opportunities for the CMA and meant that the staff were well versed in the capabilities of the model.

TABLE OF CONTENTS

1 Introduction 1
- 1.1 Background 1

2 Data Review and Gap Analysis 2
- 2.1 Available Data 3
  - 2.1.1 Collated Data 3
  - 2.1.2 Reports 4
  - 2.1.3 Input Data 8
    - 2.1.3.1 Topography 8
    - 2.1.3.2 Lakes 10
    - 2.1.3.3 Rivers & Creeks 10
    - 2.1.3.4 Groundwater 10
    - 2.1.3.5 Significant River Diversions 10
    - 2.1.3.6 Land use 12
    - 2.1.3.7 Rainfall 13
      - 2.1.3.7.1 BOM 13
      - 2.1.3.7.2 SILO 14
    - 2.1.3.8 Evaporation 15
  - 2.1.4 Calibration Data 17
    - 2.1.4.1 Stream flow data 19
    - 2.1.4.2 Station Level data 20
    - 2.1.4.3 Lake Levels 21
    - 2.1.4.4 Irrigation Extractions 22
    - 2.1.4.5 Historical Sewerage Inflows 22
  - 2.1.5 Climate Change 22
  - 2.1.6 Data for Further Work 22
  - 2.1.7 Data Gaps 24
    - 2.1.7.1 Topography 24
    - 2.1.7.2 Flows / Levels 24
    - 2.1.7.3 Groundwater 25
    - 2.1.7.4 Sewerage Inflows 25
- 2.2 Data Review Summary 25
- 2.3 Proposed Project Methodology 25
  - 2.3.1 Modelling Approach 25

3 Site Investigation 27
- 3.1 Observations 27
  - 3.1.1 Beeac 28
  - 3.1.2 Bookar 29
  - 3.1.3 Colongulac 30
  - 3.1.4 Corangamite 31
  - 3.1.5 Cundare 32
  - 3.1.6 Gnarpurt 33
  - 3.1.7 Milangil 34
  - 3.1.8 Murdeduke 35

3.1.9 Terangpom 36

4 Stage-Storage-Area Calculations 37

4.1 Methodology 37
4.2 Data Limitations 37
4.3 Results 37
4.3.1 Beeac 38
4.3.2 Bookar 39
4.3.3 Colongulac 41
4.3.4 Corangamite 42
4.3.5 Cundare 45
4.3.6 Gnarpurt 46
4.3.7 Milangil 48
4.3.8 Murdeduke 50
4.3.9 Terangpom 52

5 Catchment Deliniation 54

5.1 Methodology 54
5.2 Data Limitations 54
5.3 Results 54
5.4 Comparison to Other Studies 55

6 Watercast Model Development 57

6.1 Catchments 58
6.2 Network 59
6.3 Functional Units 61
6.4 Rainfall-Runoff 63
6.5 Nodes 65
6.6 Links 66
6.7 Storages 66

7 Model Calibration 67

7.1 Available Data 67
7.2 Calibration Methodology 68
7.2.1 RRL Input Data 69
7.2.2 Mia Mia Gauge 70
7.3 Calibration Limitations 73
7.4 Calibration Results 73
7.4.1 SIMHYD Parameters 73
7.4.2 Comparison to Flow Gauge 74
7.4.3 Groundwater 76
7.4.4 Comparison to Lake Murdeduke Levels 76
7.4.5 Comparison to Lake Colongulac Levels 78

8 Hydrologic Analysis 79

8.1 Lake Murdeduke 79
8.1.1 Relative Hydrologic Influences 79
8.1.2 Mean water level on seasonal basis 80
8.1.3 Dry spells 81

8.1.4 Stage duration curve 81
8.1.5 Volume duration curve........ 81
8.2 Lake Colongulac........ 82
8.2.1 Relative Hydrologic Influences........ 82
8.2.2 Mean water level on seasonal basis 83
8.2.3 Dry spells 84
8.2.4 Stage duration curve 84
8.2.5 Volume duration curve........ 84
8.3 Climate Change 85
8.3.1 Lake Murdeduke........ 85
8.3.1.1 Relative Hydrologic Influences........ 86
8.3.1.2 Mean water level on seasonal basis 86
8.3.1.3 Dry Spells 87
8.3.1.4 Stage duration curve 87
8.3.1.5 Volume duration curve........ 88
8.3.2 Lake Colongulac........ 89
8.3.2.1 Relative Hydrologic Influences........ 89
8.3.2.2 Mean water level on seasonal basis 89
8.3.2.3 Dry spells 90
8.3.2.4 Stage duration curve 90
8.3.2.5 Volume duration curve........ 91
8.3.3 Overall Impact of Climate Change........ 92

9 Conclusion........ 92

10 Training 92

11 References........ 93

LIST OF FIGURES

Figure 1-1 Western District Lakes

Figure 2-1 LiDAR data at 1m (left) and 5m (right) resolution

Figure 2-2 2008 LiDAR extent

Figure 2-3 Lake Diversions & major catchments

Figure 2-4 Landuse Map

Figure 2-5 Landuse within Catchment

Figure 2-6 Average Annual Rainfall

Figure 2-7 SILO Rainfall

Figure 2-8 SILO Evaporation

Figure 2-9 SILO vs BOM Evaporation

Figure 2-10 Flow / Station Level Gauges

Figure 2-11 Water Levels within Lake Corangamite vs Cundare Pool 1960-2006

Figure 2-12 Water Quality Data

Figure 3-1 Google Earth Image of Lake Beeac

Figure 3-2 Photographs of Lake Beeac from Beeac township looking south and north

Figure 3-3 Google Earth Image of Lake Bookar

Figure 3-4 Photograph of Lake Bookar looking from the east

Figure 3-5 Google Earth Image of Lake Colongulac

Figure 3-6 Photograph of Lake Colongulac looking from the north-east

Figure 3-7 Google Earth Image of Lake Corangamite

Figure 3-8 Photographs of Lake Corangamite looking from (a) Red Rocks and (b) Northern bank

Figure 3-9 Google Earth Image of Lake Cundare

Figure 3-10 Photographs of Lake Cundare looking from the north-east

Figure 3-11 Google Earth Image of Lake Gnarpurt

Figure 3-12 Photographs of Lake Cundare looking from the south-east (Foxhow Rd)

Figure 3-13 Google Earth Image of Lake Milangil

Figure 3-14 Photographs of Lake Milangil looking from the east (Camperdown Rd)

Figure 3-15 Google Earth Image of Lake Murdeduke

Figure 3-16 Photographs of Lake Murdeduke looking from the east

Figure 3-17 Google Earth Image of Lake Terangpom

Figure 3-18 Photographs of Lake Terangpom looking from the north-west

Figure 4-1 Lake Beeac Stage-Area Plot

Figure 4-2 Lake Beeac Stage-Storage Plot

Figure 4-3 Lake Bookar Stage-Area Plot

Figure 4-4 Lake Bookar Stage-Storage Plot

Figure 4-5 Lake Colongulac Stage-Area Plot

Figure 4-6 Lake Colongulac Stage-Storage Plot

Figure 4-7 Lake Corangamite Stage-Area Plot

Figure 4-8 Lake Corangamite Stage-Storage Plot

Figure 4-9 Lake Cundare Stage-Area Plot

Figure 4-10 Lake Cundare Stage-Storage Plot

Figure 4-11 Lake Gnarpurt Stage-Area Plot

Figure 4-12 Lake Gnarpurt Stage-Storage Plot

Figure 4-13 Lake Milangil Stage-Area Plot

Figure 4-14 Lake Milangil Stage-Storage Plot

Figure 4-15 Lake Murdeduke Stage-Area Plot

Figure 4-16 Lake Murdeduke Stage-Storage Plot

Figure 4-17 Lake Terangpom Stage-Area Plot

Figure 4-18 Lake Terangpom Stage-Storage Plot

Figure 5-1 Differences in Catchment Delineation

Figure 6-1 WaterCAST Sub-Catchment Delineation – Lake Murdeduke

Figure 6-2 WaterCAST Sub-Catchment Delineation – Lake Colongulac

Figure 6-3 WaterCAST Network Delineation – Lake Murdeduke

Figure 6-4 WaterCAST Network Delineation – Lake Colongulac

Figure 6-5 Piggery on banks of Lake Murdeduke

Figure 6-6 SIMHYD Model Structure

Figure 6-7 Camperdown Treatment Plant Generated Outflows

Figure 7-1 Lake Murdeduke Gauge Height

Figure 7-2 Lake Colongulac Gauge Height

Figure 7-3 Mia Mia Creek Stage Height

Figure 7-4 Mia Mia Creek Flow

Figure 7-5 RRL Input Data – Rainfall, Evaporation, Observed Runoff

Figure 7-6 Average Daily Flow at Mia Mia Gauge

Figure 7-7 Monthly Rainfall vs Runoff for Mia Mia Gauge

Figure 7-8 Quality of Daily Flow Data at Mia Mia Gauge

Figure 7-9 Stage Discharge Curve for Mia Mia Gauge

Figure 7-10 Various flows based on Stage-Discharge Curves

Figure 7-11 Calibrated Runoff vs. Observed for Mia Mia Gauge

Figure 7-12 Monthly Log Scatter Plot of Calibrated Runoff vs. Observed

Figure 7-13 Flow Duration Curve (log) Calibrated Runoff vs. Observed

Figure 7-14 Calculated vs. Observed water levels in Lake Murdeduke

Figure 7-15 Calculated vs. Observed water levels in Lake Colongulac

Figure 7-16 Lake Colongulac Water Levels shown in Dekker & Williams, 1988

Figure 8-1 Lake Murdeduke Annual Water Balance

Figure 8-2 Lake Murdeduke Mean Seasonal Water Level

Figure 8-3 Lake Murdeduke Seasonal Stage Duration Curves

Figure 8-4 Lake Murdeduke Seasonal Volume Duration Curves

Figure 8-5 Lake Colongulac Yearly Water Balance

Figure 8-6 Lake Colongulac Mean Seasonal Water Level

Figure 8-7 Lake Colongulac Seasonal Stage Duration Curves

Figure 8-8 Lake Colongulac Seasonal Volume Duration Curves

Figure 8-9 Climate Change Analysis for Lake Murdeduke

Figure 8-10 Lake Murdeduke Mean Seasonal Water Level – Climate Change Scenario

Figure 8-11 Lake Murdeduke Seasonal Stage Duration Curves – Climate Change Scenario

Figure 8-12 Lake Murdeduke Seasonal Volume Duration Curves – Climate Change Scenario

Figure 8-13 Climate Change Analysis for Lake Colongulac

Figure 8-14 Lake Colongulac Mean Seasonal Water Level

Figure 8-15 Lake Colongulac Seasonal Stage Duration Curves - Climate Change Scenario

Figure 8-16 Lake Colongulac Seasonal Volume Duration Curves - Climate Change Scenario

Figure 11-1 Lake Beeac Stage-Area-Volume

Figure 11-2 Lake Bookar Stage-Area-Volume

Figure 11-3 Lake Colongulac Stage-Area-Volume

Figure 11-4 Lake Corangamite Stage-Area-Volume

Figure 11-5 Lake Cundare Stage-Area-Volume

Figure 11-6 Lake Gnarpurt Stage-Area-Volume

Figure 11-7 Lake Milangil Stage-Area-Volume

Figure 11-8 Lake Murdeduke Stage-Area-Volume

Figure 11-9 Lake Terangpom Stage-Area-Volume

Figure 11-10 Catchment Delineations within Region

Figure 11-11 Lake Beeac Catchment Delineation

Figure 11-12 Lake Bookar Catchment Delineation

Figure 11-13 Lake Colongulac Catchment Delineation

Figure 11-14 Lake Corangamite Catchment Delineation

Figure 11-15 Lake Cundare Catchment Delineation

Figure 11-16 Lake Gnarpurt Catchment Delineation

Figure 11-17 Lake Milangil Catchment Delineation

Figure 11-18 Lake Murdeduke Catchment Delineation

Figure 11-19 Lake Terangpom Catchment Delineation

Figure 11-20 LiDAR Limitations – Lake Colongulac

Figure 11-21 LiDAR Limitations – Lake Murdeduke

LIST OF TABLES

Table 2-1 Summary of Collated Data

Table 2-2 Lake Inflows

Table 2-3 Data Warehouse Information

Table 2-4 Flow Gauges for each Lake

Table 2-5 Station Levels for each Lake

Table 2-6 Climate Change Predictions

Table 2-7 Water Quality Data for each Lake

Table 4-1 Lake Beeac Stage/Area/Storage Calculations

Table 4-2 Lake Bookar Stage/Area/Storage Calculations

Table 4-3 Lake Colongulac Stage/Area/Storage Calculations

Table 4-4 Lake Corangamite Stage/Area/Storage Calculations

Table 4-5 Lake Cundare Stage/Area/Volume Calculations

Table 4-6 Lake Gnarpurt Stage/Area/Storage Calculations

Table 4-7 Lake Milangil Stage/Area/Storage Calculations

Table 4-8 Lake Murdeduke Stage/Area/Storage Calculations

Table 4-9 Lake Terangpom Stage/Area/Storage Calculations

Table 5-1 Catchment Delineation Parameters

Table 5-2 Catchment Delineation Parameters - Comparison

Table 6-1 Functional Unit Areas

Table 7-1 Optimised SIMHYD Parameters

Table 8-1 Lake Murdeduke Average Annual Volumes

Table 8-2 Lake Colongulac Average Annual Volumes

Table 8-3 Spells Analysis of Lake Colongulac

Table 8-4 Lake Murdeduke Average Annual Volumes – Climate Change

Table 8-5 Spells Analysis of Lake Murdeduke – Climate Change Scenario

Table 8-6 Lake Colongulac Average Annual Volumes – Climate Change

Table 8-7 Spells Analysis of Lake Colongulac – Climate Change Scenario

1 INTRODUCTION

1.1 Background

The Western District Lakes (WDL) Ramsar site is situated within the Victorian Volcanic Plains bioregion, one of the fifteen recognised national Biodiversity Hotspots. The WDL Ramsar site is critical to the breeding success of the Brolga, an iconic symbol of the area. The WDL Ramsar site is also important for migrating shorebirds, and is home to numerous threatened flora and fauna species. The nine RAMSAR listed lakes that are the focus of the study are displayed in Figure 1-1.

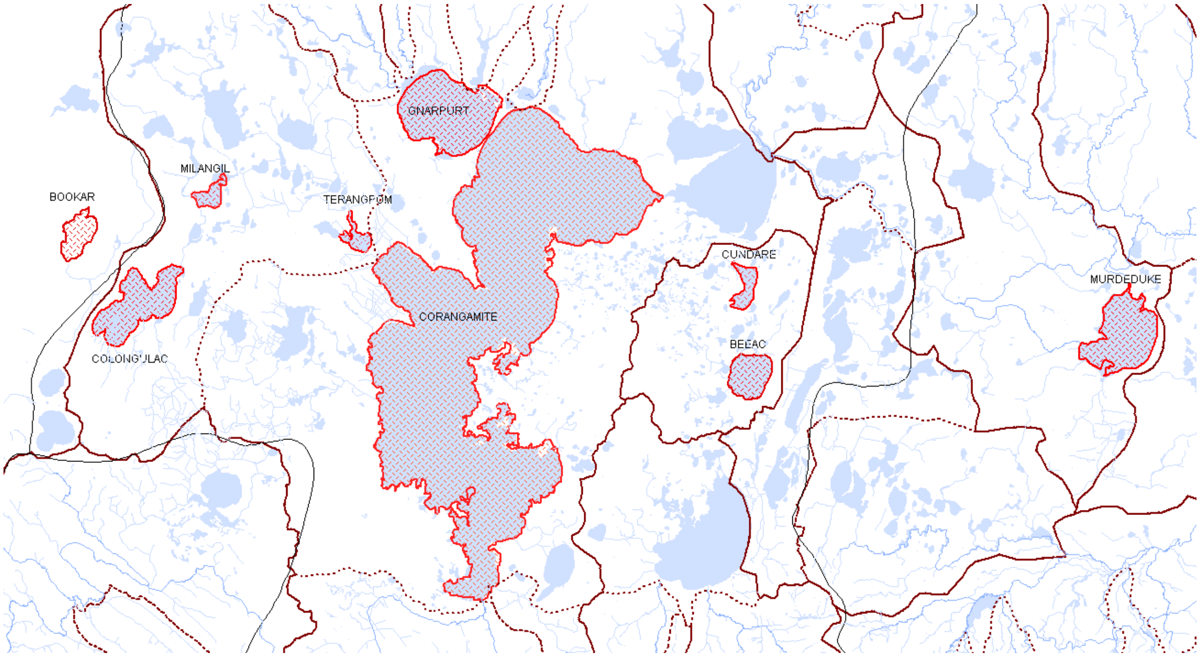


Figure 1-1 Western District Lakes

This project aims to develop baseline data regarding the hydrological water balance of the lakes, the impact of climate change on the water balance and the resilience of the lakes to withstand the impact of climate change.

2 DATA REVIEW AND GAP ANALYSIS

A review of all available data was conducted at the start of the project to gain a thorough understanding of the project prior to modelling and ensure all processes are accounted for. The following list summarises the data collected from various sources including Corangamite CMA, BOM and the Victorian Data Warehouse:

- GIS Data
    - Land use
    - Lidar
    - Aerial photography
    - Creek Centrelines & Lake outlines
    - Catchment Delineation
    - Structure Locations – groundwater bores
- Hydrology data
    - Rainfall
    - Evaporation
    - River flow and gauge heights
    - River Diversions
- Water Quality
    - DSE Data Warehouse gauges
- Background Reports
    - Strategic Management Plans of Lakes
    - Ecological Characteristics reports
    - Hydrologic reports
    - Regional Drainage Schemes
- Existing Models
    - Water Balance Model from GHD study

A gap analysis of the available data was undertaken, considering the spatial and temporal coverage of the data together with its quality and relevance to the project. The available data has then been compared with the model requirements to identify significant unknowns and data gaps that could prohibit the preparation of an effective water balance.

Most information deficiencies were able to be alleviated through appropriate data collection, numerical or physical modelling. However, there were also a range of variables that were unknown, requiring estimation based on reasonable assumptions and current accepted thinking and best practise.

2.1 Available Data

2.1.1 Collated Data

Table 2-1 Summary of Collated Data

Data Type	Source
GIS Data	
Land use	BRS – download from website
Topography	Lidar from CCMA
Aerial Photography	CCMA
Hydrology Data	
Rainfall	SILO & Bureau of Meteorology (BOM)
Evaporation	SILO
River Flow	Victorian Data Warehouse & Thiess
Gauge Heights	Victorian Data Warehouse & Thiess
Water Quality Data	
Water Quality Monitoring Data	Victorian Data Warehouse
Background Reports	
Lakes Strategic Management Plan	DNRE
Corangamite Wetland Inventory	CCMA
Ecological characteristics	Deakin University
Hydrological and geochemical processes controlling salinity	CSIRO
Physio-chemical limnology of eleven, mostly saline permanent lakes in Western Victoria, Australia	De Dekker & Williams report from CCMA
Groundwater-surface water interactions around some shallow lakes of the Corangamite Salinity Region – a summary report with management recommendations	Coram report from CCMA
A study of nutrients in Lake Murdeduke in Western Victoria and implications for environmental management	Segovia report for Melbourne Uni from CCMA
The Biological Status of Lake Corangamite and other lakes in Western Victoria	Williams report from CCMA
A condition analysis of the Western District Lakes in South-western Victoria	Muston report for Deakin Uni from CCMA
Review of Regional Drainage Schemes – Model Calibration Report	GHD report from CCMA
Existing Models	
Water Balance	GHD modelling from CCMA

2.1.2 Reports

A number of background reports were sourced to provide context to the overall project. Key information derived from each report is listed below:

Western District Lakes Ramsar Site – Strategic Management Plan, DNRE, 2002.

- Agencies responsible for various types of data – NRE for domestic stock licencing, EPA for licenced discharges, South West Water for Camperdown treatment plant, Southern Rural Water for diversions and extractions
- Background information for the site – types of wetlands, values, risks, management strategies
- Information on altered water regimes within the region –
    - Woady Yaloak Diversion Scheme – impacts on water level (-2m since 1980) and salinity levels
    - Artifically lowered outlets at Lake Gnarpurt and Lake Tengapom
    - Obstruction of the southern inflow to Lake Bookar from a constructed farm dam
    - Impeding the outflow of Lake Milangil by raising the adjacent roadway
    - Clearing of land in the Lake Beeac catchment has increased surface water runoff
- Possible scenario suggestion to increase the level of Lake Corangamite from 114 m AHD to 116 m AHD to restore biological health.
- Agriculture accounts for 80% of the basin's landuse including dairying, stock grazing, broad acre cropping and row cropping. Urban development is essentially limited to four major towns – Colac, Camperdown, Lismore and Linton.
- Water quality within the lakes is generally good and meets SEPP and ANZECC guidelines for dissolved oxygen, pH and heavy metals. Nutrients (Total Nitrogen and Total Phosphorus) and Chlorophyll-a are generally poor. Significant algal blooms occur in Lakes Milangil, Murdeduke, Colongulac, Coranagmite and Gnarpurt.
- The Camperdown sewage treatment plant has previously held an EPA licence to discharge into Lake Colongulac, however as of October 2001 this has been discharged to land.
- Lake Corangamite was considered at higher priority risk from altered water regimes with a potentially significant loss of environmental values and ecological character. Lakes Beeac, Bookar, Gnarpurt, Milangil and Teranpom received a medium risk category.

Corangamite Wetland Inventory, CCMA, 2005, report prepared by Centre for Environmental Management, University of Ballarat.

- General background information on ecological character of the lakes however sites chosen within the report do not correspond to the current study

Investigation and reporting of past and present ecological characteristics of seven saline lakes in the Corangamite Catchment Management Area, 2008, Kellie Hose, Bradley Mitchell & Janet Gwyther, Deakin University.

- Appendix 1 provided an easy reference guide to compare the lakes on parameters such as hydrology, tributaries, area, mean depth, maximum depth and catchment area.
- Details of various water quality parameters were provided
- The effects of climate change were considered in this study. Assumptions included reduced winter rainfall, reduced runoff, reduced stream flows, increased variability of stream flows, increased severe summer storms and increased evaporation. Effects included the probable reduction in lake area and lake depth and increased salinity. Lake Corangamite had the potential to completely dry out depending on the modification to the Woady Yaloak diversion. The shallower lakes such as Cundare and Beeac were expected to dry frequently.
- Dominant landuses within the catchments were defined as follows:
    - Corangamite – South-East: dairy cattle, row crops; North: broad acre crops, sheep
    - Gnarpurt – Sheep, beef cattle
    - Cundare – Sheep
    - Beeac – Sheep
- Freshwater springs discharge into Lake Corangamite, particularly along the south-western shore.
- Lake Gnarpurt has been connected to Lake Corangamite, which has artificially lowered the outlet and reduced water levels.

Hydrological and Geochemical processes controlling salinity of the groundwater dependent ecosystems in Corangamite CMA, CSIRO, 2007, Project No WLE/42-009.

- The significance of salinity within the lakes is detailed within this report. Allowing the WaterCAST model to be able to predict salinity concentrations will be useful for further studies.
- The major processes dominating the water inflows and outflows for each lake were identified as:

- Dominated by groundwater inflows and outflows – Corangamite, Martin, Cundare, Connewarre
- Dominated by groundwater inflows and evaporation as major outflow – Lake Murdeduke
- Dominated by surface inflows and groundwater outflows – Lake Terangapom

- Some parameters relevant to a water balance have been defined within this report. The following were assumed:
    - Infiltration = monthly rainfall – (evaporation loss * evaporation loss rate) where the evaporation loss rate takes into account the difference between actual and potential evaporation
    - Groundwater flow = hydraulic conductivity * (groundwater store level – lake level) / distance
    - Hydraulic conductivity = 102.952 m/month
    - Evaporation loss rate = 0.1457mm/month
    - Maximum evaporation = -82.6811 mm / month
    - Maximum infiltration = 37.6549 mm / month
- Historic lake levels for Colac and Corangamite have been displayed. Data for Corangamite is sourced back to 1959 and shows a downward trend in levels over time as a result of the diversion.

Physio-chemical limnology of eleven, mostly saline permanent lakes in Western Victoria, Australia. De Deckker & Williams, 1990.

- Figure showing water level simulation of Lake Colongulac from 1898 – 1978, including observed summer water levels post 1920. This information is important for the lake model calibration.

Groundwater-surface water interactions around some shallow lakes of the Corangamite Salinity Region – a summary report with management recommendations. Coram, 1996.

- Regional groundwater flow patterns, particularly around lake Murdeduke
- Lake water budget constructed for Lake Murdeduke
- Percentage inflows from groundwater and surface water for Lake Murdeduke and Lake Colongulac

A study of nutrients in Lake Murdeduke in Western Victoria and implications for environmental management. Segovia, 2001.

- Water balance for Lake Murdeduke was used as a comparison point for this study
    - Catchment definition
    - Surface inflows from major creeks defined
    - Rough groundwater inflows calculated
    - Water balance included some water quality components

The Biological Status of Lake Corangamite and other lakes in Western Victoria. Williams, 1992.

- Background information on each of the lakes including a photograph, general description of form and depths.

A condition analysis of the Western District Lakes in Southwestern Victoria. Muston, 2001.

- Physical parameters of most lakes within the region including volume, mean depth, maximum depth, secchi depth, lake area, catchment area, lake to catchment ratio, lake score. This information is used to compare values calculated in this study.
- Average water quality concentrations for most lakes are presented.

Review of Regional Drainage Schemes – Model Calibration Report. GHD, 2003.

- GHD has developed a water balance model for Lake Corangamite and Lake Colac, investigating the Lough Calvert and Woady Yaloak diversion schemes. The following data is relevant for our study:
    - Modelling results may be able to be incorporated into the WaterCAST models for Lakes Corangamite, Murdeduke, Garpurt and Cundare to reduce the data requirements
    - Limited records exist for the flows between the Cundare Pool and Lake Corangamite
    - Different climatic conditions were observed in the region prior to 1950
    - Historical Corangamite level probabilities pre and post the Woady Yaloak Scheme
    - No simple relationship could be made between lake levels in Corangamite and rainfall due to the complex nature of the Woady Yaloak diversion
    - Storage capacity, outlet and spillway elevations were provided for Lakes Corangamite, Gnarpurt, Cundare, Martin and Murdeduke
    - A constant groundwater loss of 2 ML/d was assumed for the Cundare Pool. Corangamite groundwater inflows can be calculated using the provided values

  - Operating instructions for the Woady Yalloak scheme are provided in a report by the Rural Water Commission, 1987. Releases are able to occur year round.
  - Between November 1997 and December 2002 it's likely that the Woady Yaloak diversion scheme was not in operation to enable the Cundare Pool levels to be increased for environmental purposes
  - Stage/Volume/Area calcs, outlet details and spillway details were availiable for Lake Corangamite, Cundare Pool, Lake Murdeduke and Lake Gnarpurt

2.1.3 Input Data

In order to develop the catchment and receiving models, a series of input data is required. In a broad sense these may be categorised into two sections:

- Topographic and stream data to define model structure (i.e. delineate catchments);
- Hydrologic data (rainfall, evaporation) to run the model.

Catchment delineation requires a series of inputs, most notably the location of major streams, and the topography to ascertain the watershed for each stream. This information was used to define the major catchment boundaries, which then were further delineated to model the hydrological response of the catchment. The major input layers had the following characteristics:

2.1.3.1 Topography

A terrain model of the region was derived from 1m LiDAR data in the vicinity of the lakes and 5m LiDAR data for the greater catchments. This highly detailed data enables the catchment boundaries to be accurately defined and provides more detailed data at the lake edges. The data is broken down into separate tiles what have been combined as part of this project. An example of the detail provided in each tile is shown in Figure 2-1.

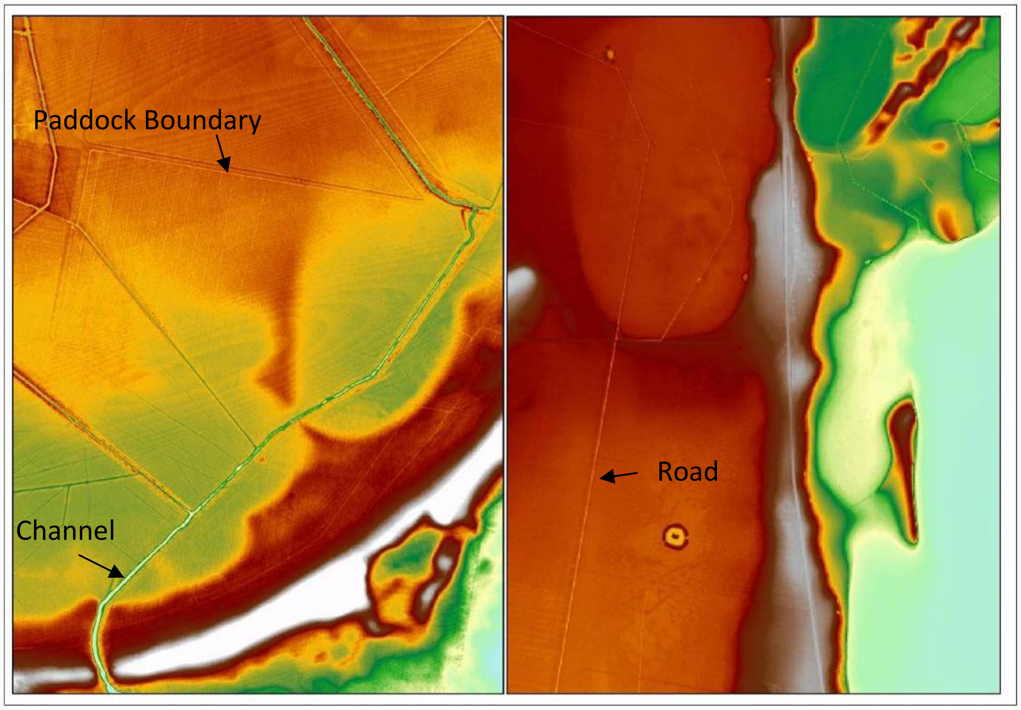


Figure 2-1 LiDAR data at 1m (left) and 5m (right) resolution

The extents of the 2008 LiDAR data are shown in Figure 2-2, where the black tiles represent the 1m data and the red the 5m resolution. In regions where the 2008 LiDAR data is missing, the 2003 LiDAR information was relied upon to define the catchment extents for each lake. The modelling of Lake Murdeduke was reliant on the 2003 data. Unfortunately some of the larger lakes could not be fully mapped due to the inability of LiDAR imaging to penetrate through water. These regions were supplemented with contour data.

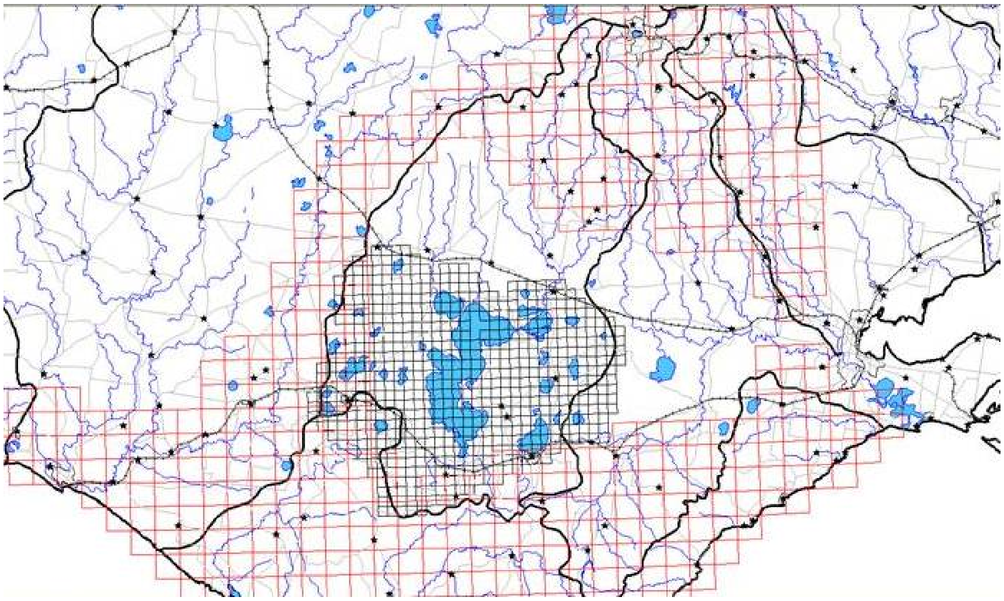


Figure 2-2 2008 LiDAR extent

2.1.3.2 Lakes

The Western District Lakes region consists of a number of major lakes, nine of which have been RAMSAR listed. Multiple studies have been conducted on Lake Corangamite, and to a lesser extent on Lake Gnarpurt, in relation to the lakes hydrology, ecological character and salinity sources. In contrast many of the other smaller lakes have had limited information and studies.

2.1.3.3 Rivers & Creeks

The Woady Yaloak River is the basin's major watercourse. Other major creeks include the Mia Mia Creek, Mack Creek, Pirron Yallock Creek, Spring Gully and Salt Creek. Numerous other minor unnamed creeks also contribute to the lakes. A list of the major overland inflows is shown in Table 2-2.

Table 2-2 Lake Inflows

Lake	River Inflows
Beeac	minor unnamed creeks (mostly groundwater inflow)
Bookar	minor unnamed creeks (mostly groundwater inflow)
Colongulac	minor unnamed creeks (mostly groundwater inflow)
Corangamite	Gnarkeet Chain of Ponds, Mack Creek, Pirron Yallock Creek, Tirrengowa Drain, Spring Gully, Lake Martin overflow (Woady Yaloak River), Lake Gnarpurt
Cundare	minor unnamed creeks (mostly groundwater inflow)
Gnarpurt	Salt Creek, Haunted Gully, Browns Waterholes, Mundy Gulley Creek, Lake Struan
Milangil	minor unnamed creeks (mostly groundwater inflow)
Murdeduke	Mia Mia Creek, Sandy Creek, Tunnel Drain
Terangpom	minor unnamed creeks

2.1.3.4 Groundwater

Significant hydrological interactions take place in the region as many of the lakes are groundwater fed. The WaterCAST model is able to represent these inflows / outflows as a net gain or loss to the model, however the interaction with the water table cannot be represented. For this reason it is suggested that lakes with a greater proportion of flow from the surface be investigated as part of this study.

2.1.3.5 Significant River Diversions

Two major river diversions occur within the catchment, the Woady Yaloak Diversion and Lough Calvert Drainage Scheme. The Woady Yaloak Diversion Scheme channels water from the Cundare Pool to the Barwon River via Warrambine Creek, effectively acting as a net loss to the lakes system. The Lough Calvert Drainage Scheme does not affect the RAMSAR lakes considered within this study. These two diversion schemes are shown in Figure 2-3.

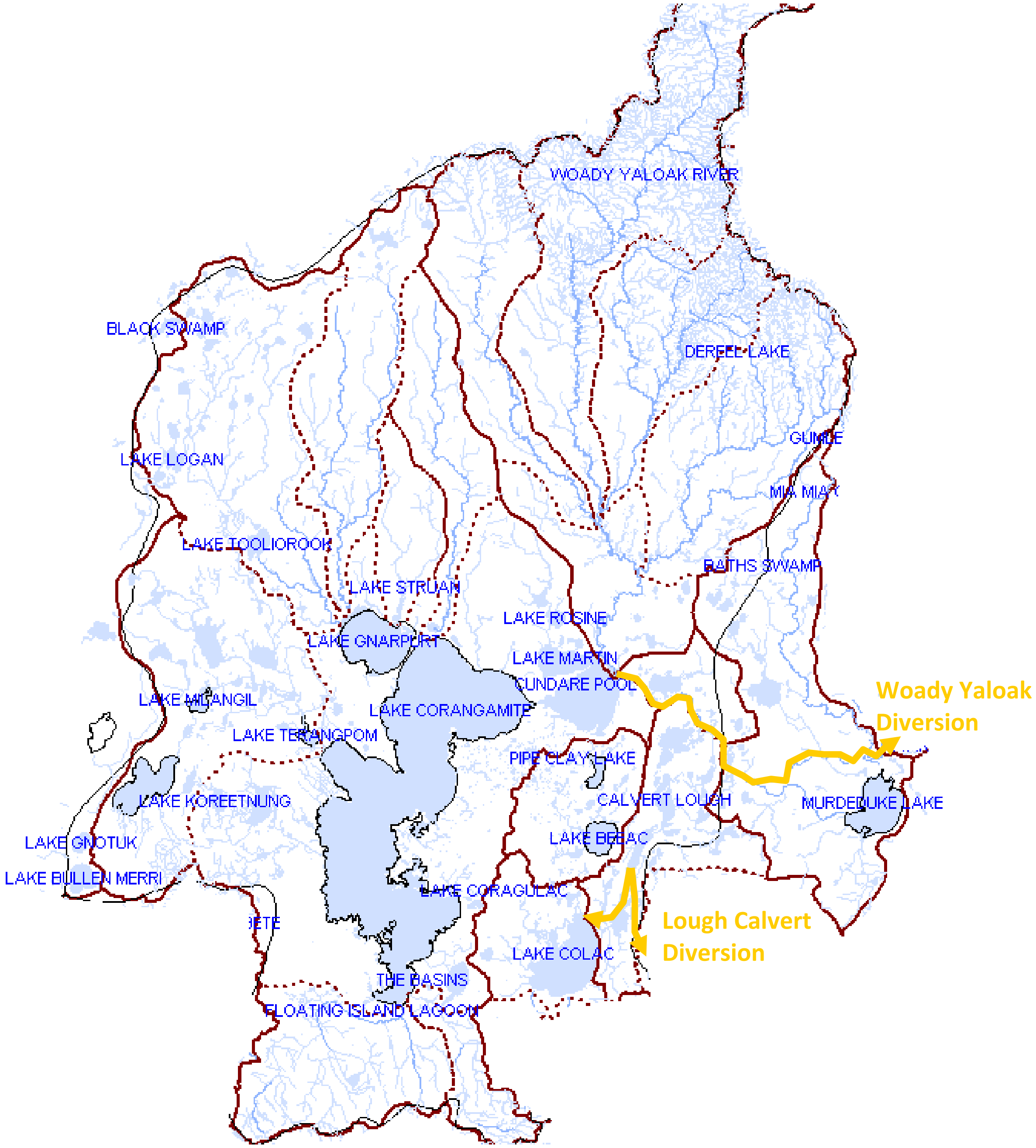


Figure 2-3 Lake Diversions & major catchments

2.1.3.6 *Land use*

Disaggregation of the catchment occurs by both watersheds and by major land use types. The land use data used in this study was sourced from the Bureau of Rural Sciences. Mapping relies on data from 2002 and it is assumed that no significant changes in land use have occurred since this time. As shown in Figure 2-4 the two principal land uses for the catchment are grazing and cropping, with minor softwood plantation and urban areas.

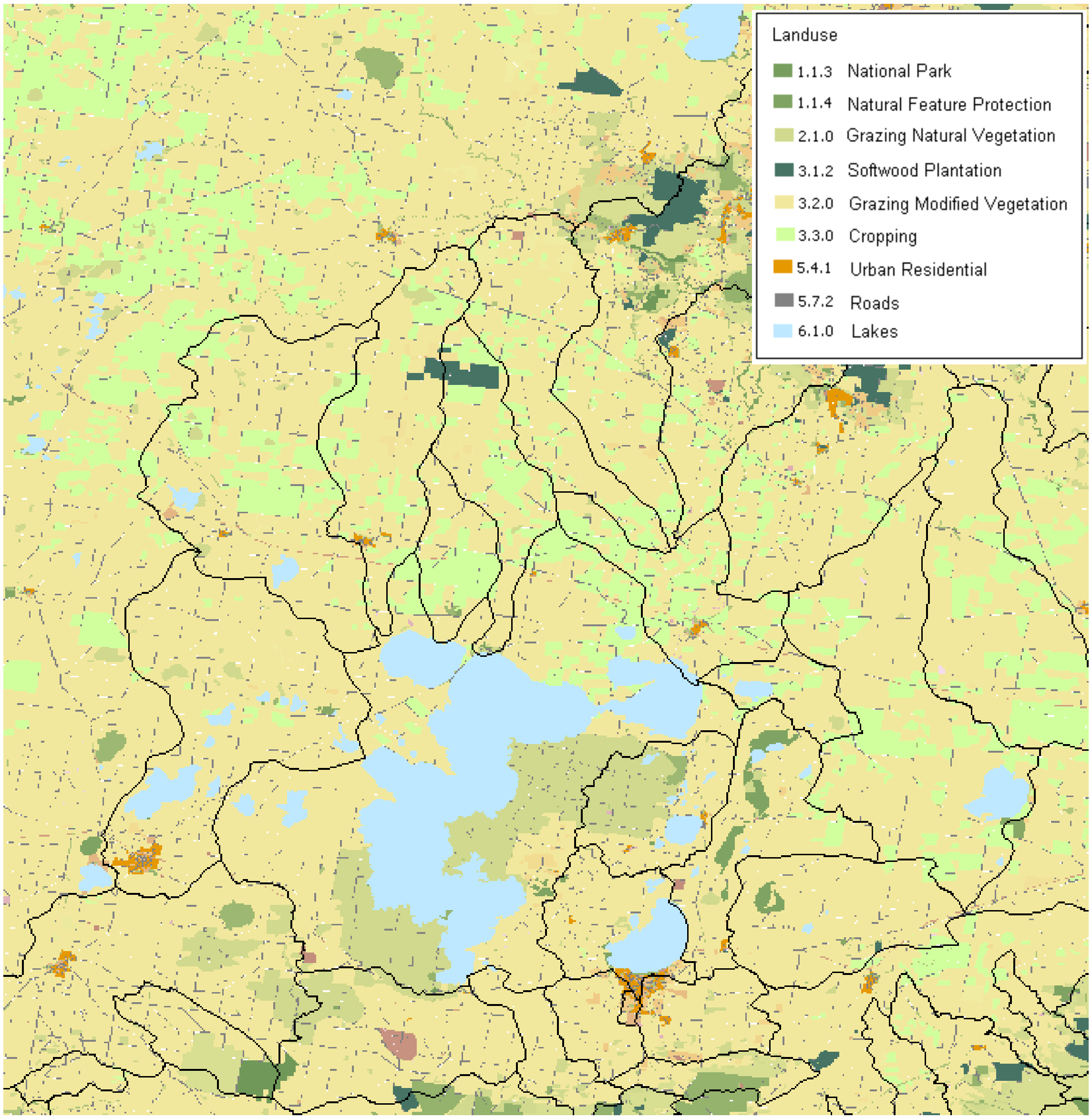


Figure 2-4 Landuse Map

Figure 2-5 displays the landuse within the Corangamite catchment as a percentage of the total area. Notable landuses are grazing modified pastures (65%), Cropping (13%), Grazing natural vegetation (9%), Production Forestry (3%) and Residential (3%). It is suggested that these 5 landuse categories be selected as functional units for the study.

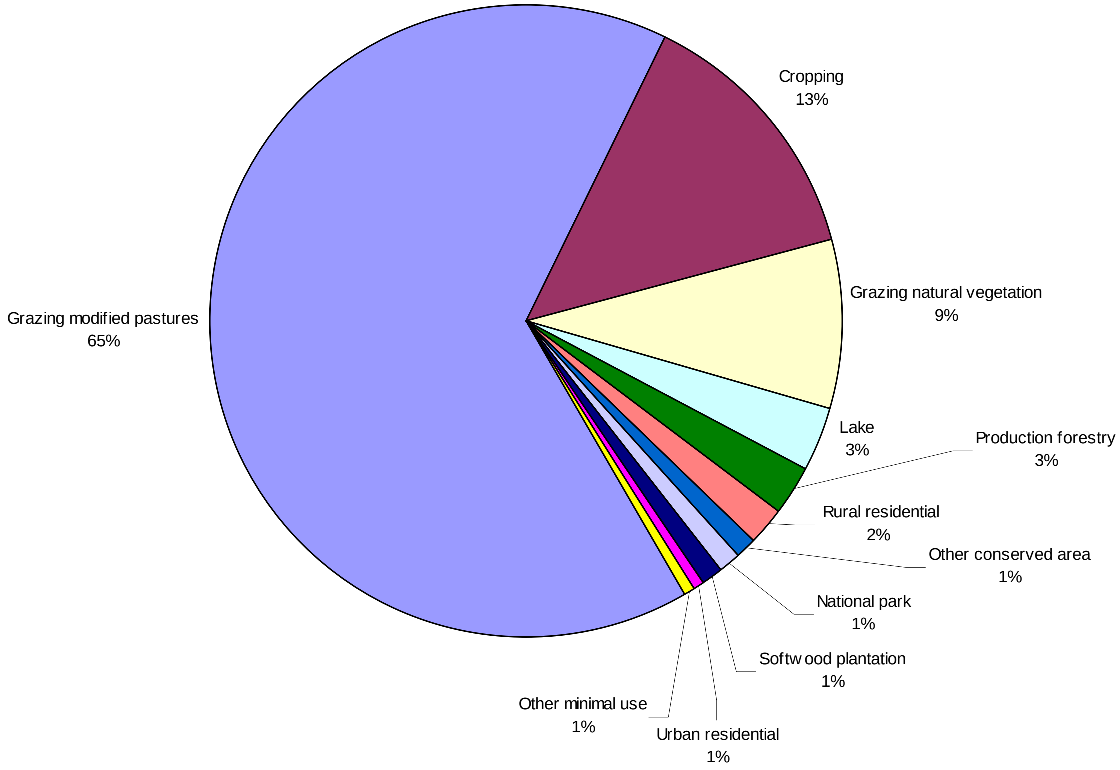


Figure 2-5 Landuse within Catchment

In addition to the catchment delineation, the following meteorological data represents the important driving variables to the models:

2.1.3.7 Rainfall

2.1.3.7.1 <u>BOM</u>

The Bureau of Meteorology (BOM) has a series of rainfall stations within the Western District Lakes catchment. Data from all stations that had a significant rainfall record was collected and collated. The spatial distribution of stations is shown in Figure 2-6. In the vicinity of the lakes the average annual rainfall varies, however values generally range between 550mm and 600mm. Some of this variation can be attributed to the period of gauging at each site, with some sites very close together showing significant differences in average annual rainfall. No obvious rainfall gradients were present within the catchment.

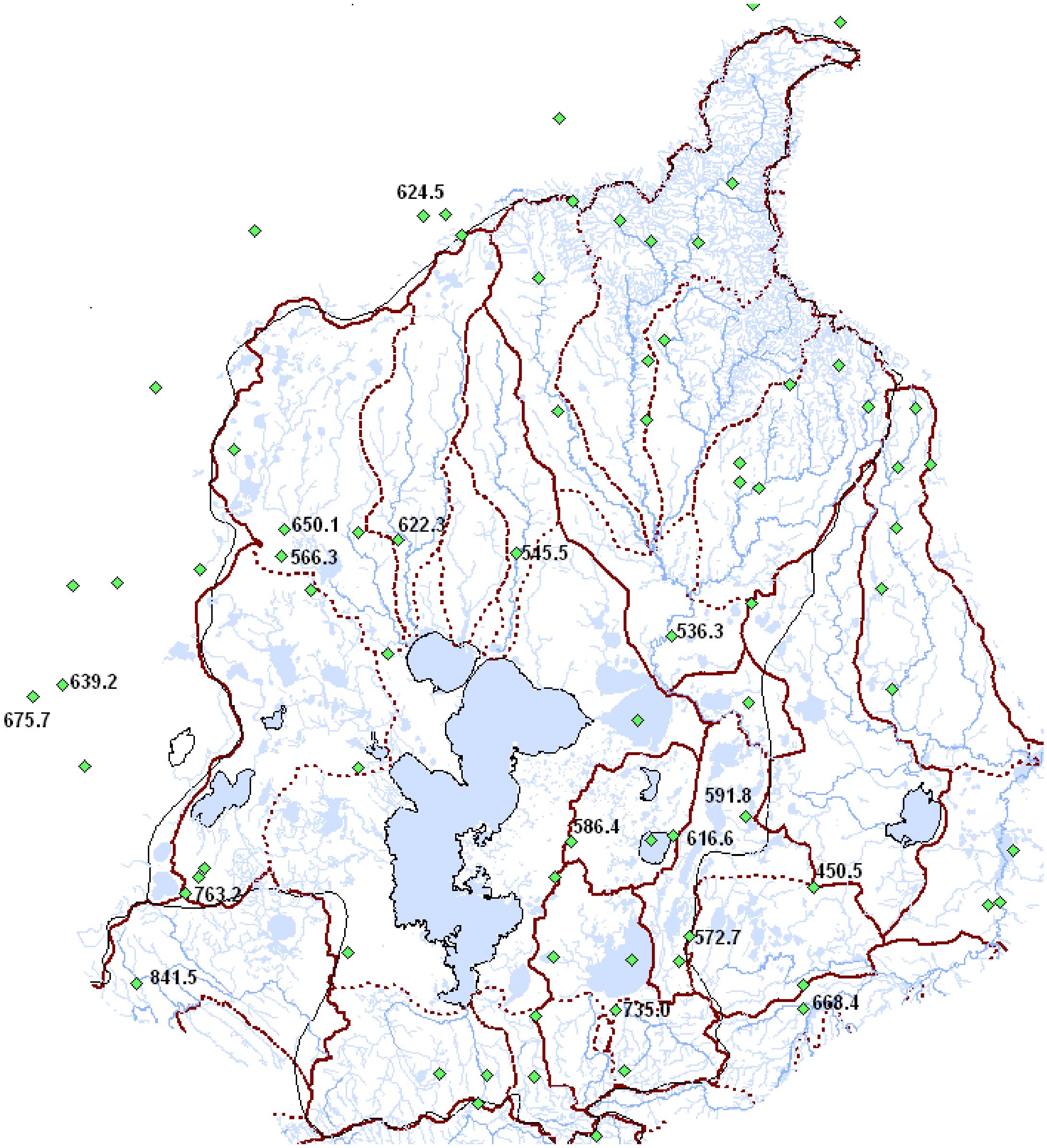


Figure 2-6 Average Annual Rainfall

2.1.3.7.2 SILO

SILO holds gridded rainfall and evaporation data based on an interpolation of the rainfall records from nearby stations. The SILO data was extracted at a central point (Lat / Long -38.20, 143.50) to represent the rainfall and evaporation for the catchment. This location was chosen as a central point between Lake Corangamite and Lake Murdeduke, and should be suitable for the localised catchments of the smaller lakes. The infilled time series ranges from 1/1/1989 – 5/10/2009. This was considered the most appropriate rainfall to use for the project as the values have been interpolated from all nearby stations and the series is continuous.

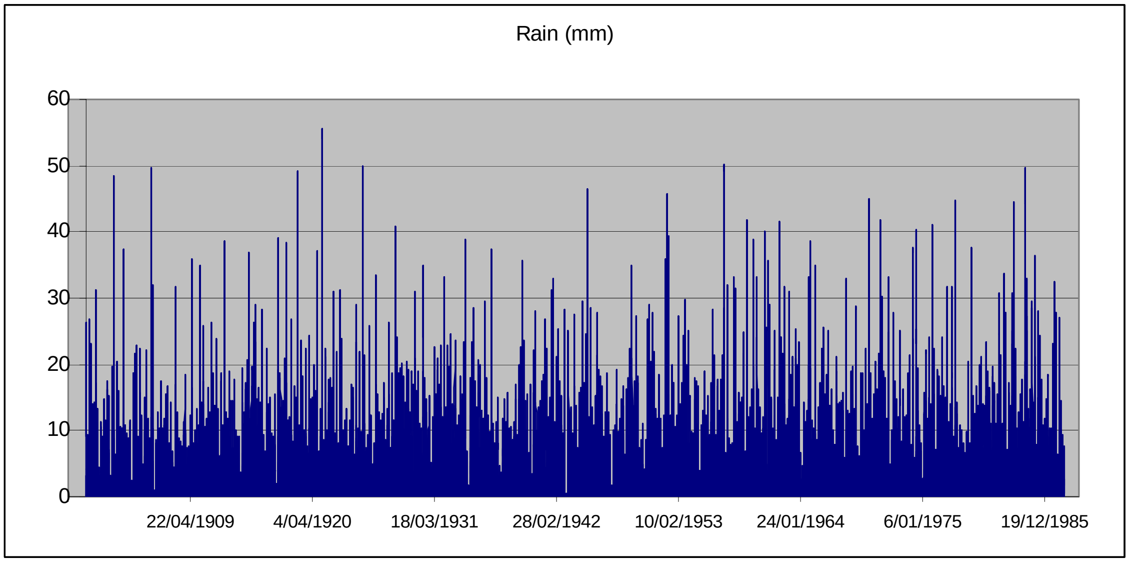


Figure 2-7 SILO Rainfall

The following statistics relate to the SILO data:

Mean Annual Rainfall	591 mm
Mean Daily Rainfall	1.619 mm
Median Daily Rainfall	0.1 mm
Maximum Daily Rainfall	90.5 mm
Minimum Daily Rainfall	0 mm

The mean annual rainfall of 591mm is consistent with the BOM values shown in Figure 2-6.

2.1.3.8 Evaporation

Two forms of evaporation data are provided by SILO, measured pan evaporation (Evap) and calculated potential evapotranspiration (FAO56) using the Penmann-Monteith equation. For this study the FAO56 was used to represent both evaporation off the catchment and the lakes. The two data sets are shown in Figure 2-8.

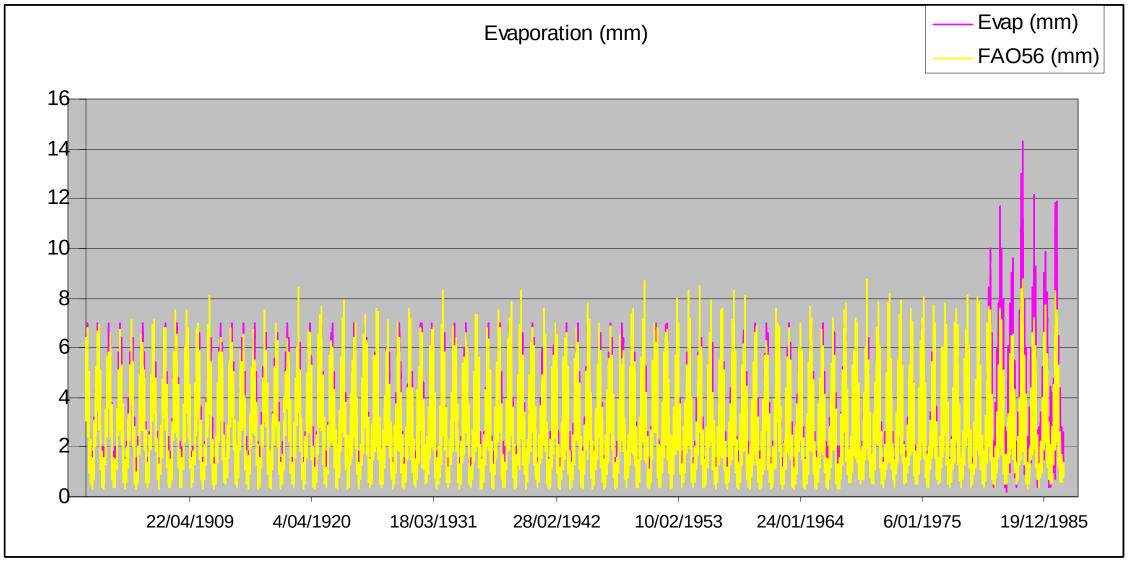


Figure 2-8 SILO Evaporation

When compared to the measured evaporation at the nearest BOM station (Wurdee Boluc) the Penman-Monteith evaporation has a similar average evaporation rate (Figure 2-9). The Wurdee Boluc station shows a greater range in values than the SILO Penman-Monteith evaporation estimates. This is primarily due to the fact that the observed values have not yet had a pan evaporation factor applied, which will reduce the observed evaporation. Considering the limited differences in values it is considered appropriate to use the Penman-Monteith values to represent the evaporation within the catchments and lakes. This also means that it is unnecessary to apply any pan coefficients, which vary seasonally, and may require adjustment over time with changes to the site (e.g. tree growth), or changes to equipment (e.g. installation of bird guards on evaporation pans).

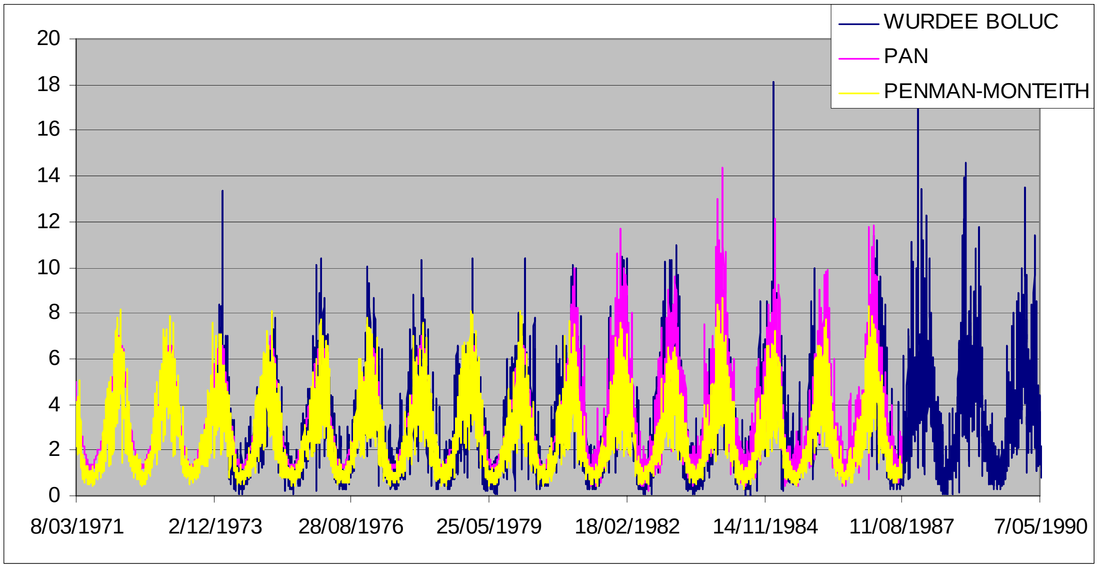


Figure 2-9 SILO vs. BOM Evaporation

2.1.4 Calibration Data

Data is required to calibrate the rainfall-runoff modelling. The key data that exists to assist in this process are:

- Streamflow
- Station Levels
- Lake Levels

This data was sourced from the Victorian Data Warehouse, Thiess and CCMA. Table 2-3 displays the Victorian Data Warehouse gauges located within the catchments and the data available.

For the current study the critical calibration information is the daily flow rate for stream inflows and water levels within the lakes.

Table 2-3 Data Warehouse Information

						Water Quality Data						
Site No.	Site Name	Daily Flow	Discharge	Station Levels	Rainfall	Dissolved Oxyg	Water Condition	Salinity	PH	Suspended Solids	Nitrogen	Phosphorus
233210	LEIGH RIVER @ GRENVILLE											
233211	BIRREGURRA CREEK @ RICKETTS MARSH	■	■	■		■	■	■	■	■	■	■
233212	BARWON RIVER @ BIRREGURRA											
233220	WARRAMBINE CREEK @ WINGEEL	■		■								
233223	WARRAMBINE CREEK @ WARRAMBINE	■	■	■	■	■		■	■	■	■	■
233227	LAWALUK CREEK @ GUMLEY	■		■								
233228	BOUNDARY CREEK @ YEODENE	■	■	■		■	■	■	■	■	■	■
233247	BARWON RIVER @ KILDEAN LANE	■	■	■		■	■	■	■	■	■	■
233248	LEIGH RIVER @ SHELFORD (GOLF HILL)	■		■	■			■				
233251	MIA MIA CREEK U/S LAKE MURDEDUKE	■		■	■			■				
233252	SANDY CREEK U/S LAKE MURDEDUKE											
233702	LOUGH CALVERT OUTFALL CHANNEL @ D/S WARRAWIE REGULATOR	■		■				■				
233901	GROUNDWATER OBERSERV. BORE @ WARRAMBINE CK BASIN BORE 1			■								
234200	WOADY YALOAK RIVER @ PITFIELD	■	■	■		■	■	■	■	■	■	■
234201	WOADY YALOAK RIVER @ CRESSY (YARIMA)	■	■	■	■	■	■	■	■	■	■	■
234202	PIRRON YALLOCK CREEK @ SWAN MARSH											
234203	PIRRON YALLOCK CREEK @ PIRRON YALLOCK (ABOVE HWY BR)	■	■	■		■	■	■	■	■	■	■
234204	HAUNTED GULLY @ U/S LAKE GNARPURT		■				■	■	■			
234205	NO. 1 WATERWAY @ LAKE TERANGPOM		■			■	■	■	■			
234207	BROWNS WATERHOLES @ LAKE GNARPURT											
234212	BROWNS WATERHOLES @ D/S LISMORE (URARA)	■		■	■			■				
234213	GNARKEET CHAIN OF PONDS @ HAMILTON HWY (BERRYBANK)		■	■		■	■	■	■			
234600	LAKE MURDEDUKE			■		■	■	■	■	■	■	■
234602	LAKE CORANGAMITE @ LESLIE MANOR							■	■	■	■	■
234603	LAKE CORANGAMITE @ WOOL WOOL			■		■	■	■	■			
234605	LAKE GNARPURT @ GNARPURT					■	■	■	■	■	■	■
234606	LAKE COLONGULAC @ CAMPERDOWN					■	■	■	■		■	■
234607	LAKE GNOTUK @ CAMPERDOWN					■	■	■	■	■	■	■
234608	LAKE BULLEN MERRI @ CAMPERDOWN					■	■	■	■	■	■	■
234610	LAKE BOOKAR @ CAMPERDOWN		■			■	■	■	■			
234611	LAKE KARIAH @ CAMPERDOWN					■	■	■	■			
234612	LAKE COLAC @ COLAC							■	■	■	■	■
234615	LAKE CUNDARE @ SOUTH SHORE					■	■	■	■	■	■	■
234616	LAKE COLAC (H.G.) @ MEREDITH PARK	■		■	■			■				
234700	WOADY YALOAK CHANNEL @ 7 MILE 37 CHAIN MEASURING WEIR	■		■				■				
234702	PITTONG TILE DRAIN @ PITTONG			■								
235253	COBDEN CREEK @ COBDEN SEWERAGE TREATMENT PLANT											
235602	LAKE ELINGAMITE @ COBDEN					■	■	■	■			

2.1.4.1 Stream flow data

The Victorian Data Warehouse has stream flow data at a number of locations (refer to Figure 2-10 and Table 2-3). As flow gauging is a critical calibration component, this will place limitations on the number of lakes that can be accurately calibrated. Ungauged catchments can still be modelled, however the results will be less accurate than those of gauged catchments. Extensive data sets are only available for some of the inflows to Lakes Corangamite, Gnarpurt and Murdeduke. Other sites contain only limited data sets with occasional flow records rather than continuous monitoring.

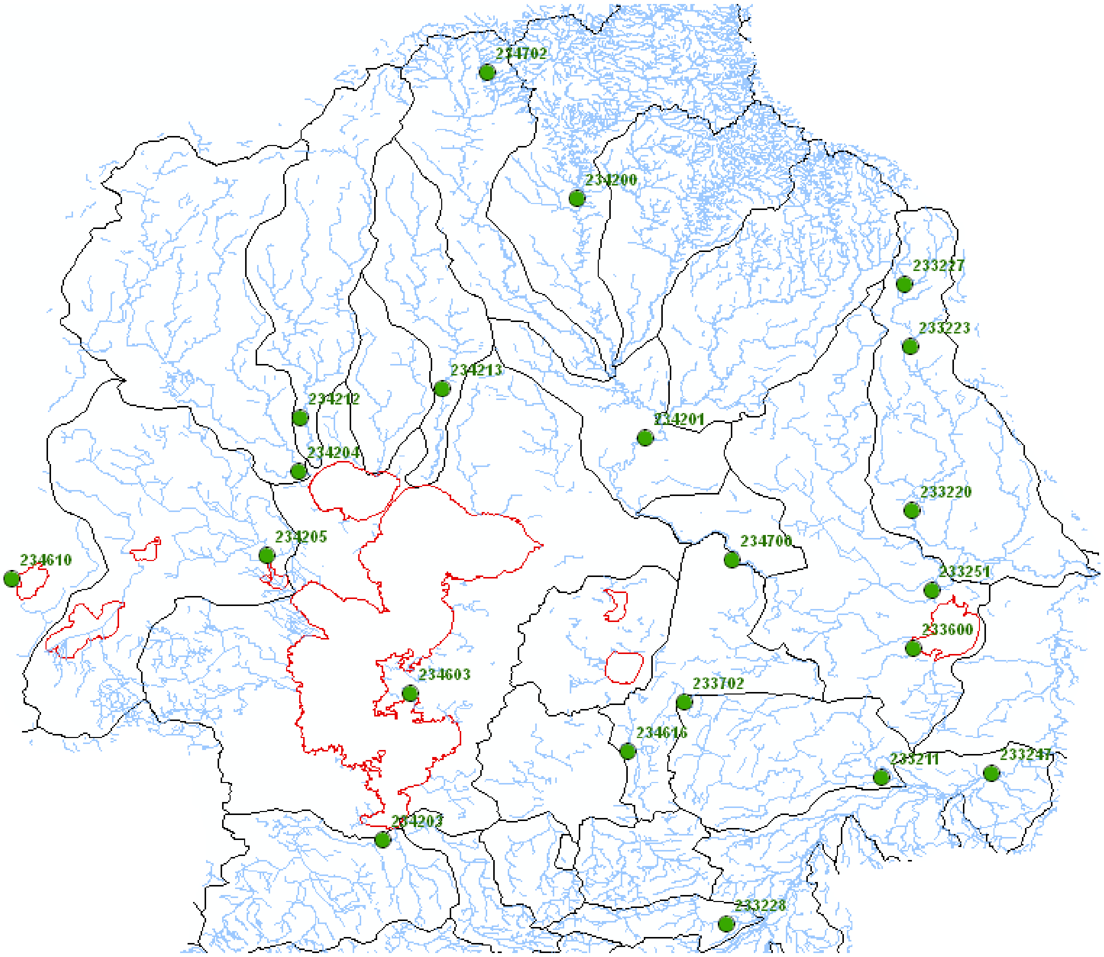


Figure 2-10 Flow / Station Level Gauges

Table 2-4 Flow Gauges for each Lake

Lake	Flow Gauges
Beeac	None
Bookar	234610 (limited records)
Colongulac	None
Corangamite	234201 (1963 – 2008) 234203 (1973 – 2009) 234213 (limited records) 234700 (1984 – 2008)
Cundare	None
Gnarpurt	234204 (limited records) 234212 (1993 – 2009)
Milangil	None
Murdeduke	233251 (1997 – 2009)
Terangpom	234205 (limited records)

2.1.4.2 Station Level data

Station Level data will assist in the calibration of lake levels. The data was sourced from the Victorian Data Warehouse. Extensive records are held for the inflows to Lakes Corangamite, Gnarpurt and Murdeduke. As these sites also have flow data a stage-discharge relationship can be formed.

Table 2-5 Station Levels for each Lake

Lake	Station Levels
Beeac	intermittent data
Bookar	None
Colongulac	None
Corangamite	234603 (limited records) 234203 (1973 – 2009) 234213 (limited records) 234700 (1984 – 2008)
Cundare	None
Gnarpurt	234212 (1993 – 2009)
Milangil	None
Murdeduke	233600 (limited records) 233251 (1997 – 2009)
Terangpom	None

2.1.4.3 Lake Levels

Monthly lake level data of Lake Corangamite and Cundare Pool was provided by CCMA from 1960 – 2006. Over this period the levels within Lake Corangamite have progressively dropped while the Cundare Pool fluctuates around a more consistent level (Figure 2-11). This lake level data provides useful calibration data for the hydrological models.

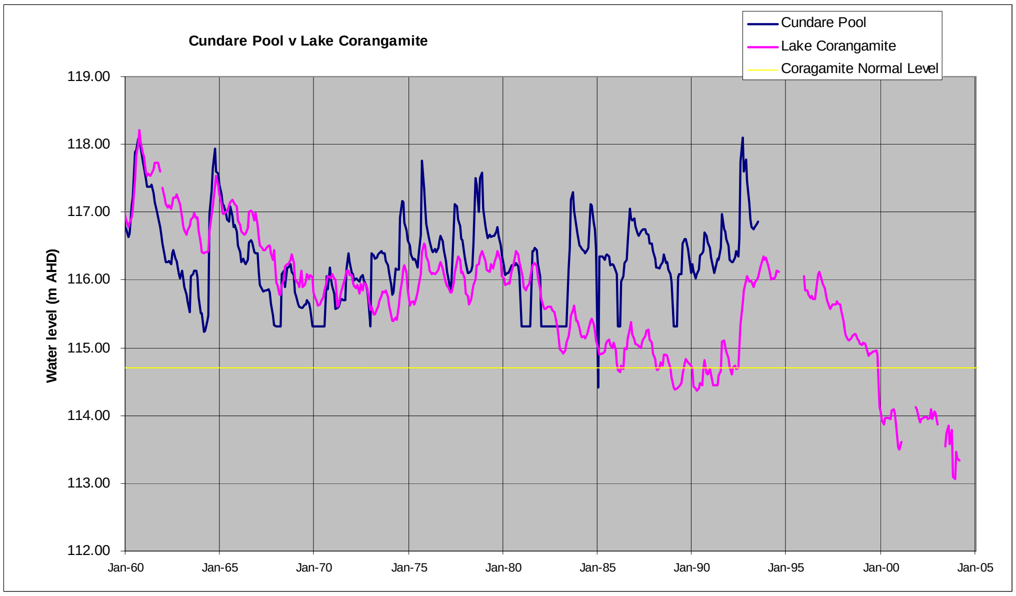


Figure 2-11 Water Levels within Lake Corangamite vs. Cundare Pool 1960-2006

Lake levels have also been provided by Thiess for lakes Colongulac and Murdeduke.

2.1.4.4 Irrigation Extractions

Irrigation from surface water provides a water loss within their respective subcatchments, and hence are an important consideration when calibrating these subcatchments. Southern Rural Water was contacted regarding any irrigation extractions from surface waters. A representative indicated that they were unaware of any extractions in the Western Lakes district.

2.1.4.5 Historical Sewerage Inflows

Lake Colongulac has historically received an inflow from the Camperdown Sewerage Treatment Plant. This was a critical inflow to the lake as it is non-rainfall dependent. Wannon Water was able to provide some details regarding the plant which have been detailed in further sections.

2.1.5 Climate Change

To assess the impact of climate change on the lakes the latest Department of Sustainability report for Corangamite was sourced. This report specifies that Lake Corangamite is expected to decrease by 5 – 40%. Parameters that will impact the model in a 2030 climate scenario are shown in Table 2-6.

Table 2-6 Climate Change Predictions

	Average Rainfall (%)	Potential Evaporation (%)	Rainfall Intensity (%)	Number of Rainy Days (%)
Annual	-4% (-8% to 0)	2% (1 to 5%)	1.3% (-10.3 to 15.6%)	-5% (-15 to -2%)
Spring	-7% (-15 to -1%)	2% (-1 to 5%)	0.8% (-16.8 to 17.7%)	-8% (-24 to -2%)
Summer	-3% (-10 to 5%)	2% (0 to 4%)	-0.2% (-21.2 to 18.6%)	-6% (-23 to 0%)
Autumn	-2% (-8 to 5%)	4% (2 to 6%)	2.0% (-3.8 to 19.1%)	-3% (-18 to 3%)
Winter	-4% (-11 to 1%)	6% (-2 to 18%)	1.7% (-8.3 to 19.3%)	-4% (-11 to 1%)

Source: Climate Change in the Corangamite Region. DSE, 2008.

The input rainfall and evaporation files were modified to represent the impact of climate change on the lakes. The seasonal changes to the average rainfall and potential evaporation were represented as a change in magnitude to the SILO data used in the base case. No adjustment to the rainfall was made for rainfall intensity or number of rainy days.

2.1.6 Data for Further Work

The hydrological models were designed to allow for further data to be incorporated at a later stage, particularly the inclusion of water quality data where available. The Victorian Water Quality Monitoring Network already holds records for stations within the catchments. Key parameters, including measures of salinity, nitrogen, phosphorus and suspended solids are available at some sites. The spatial distribution of sites is shown in Figure 2-12.

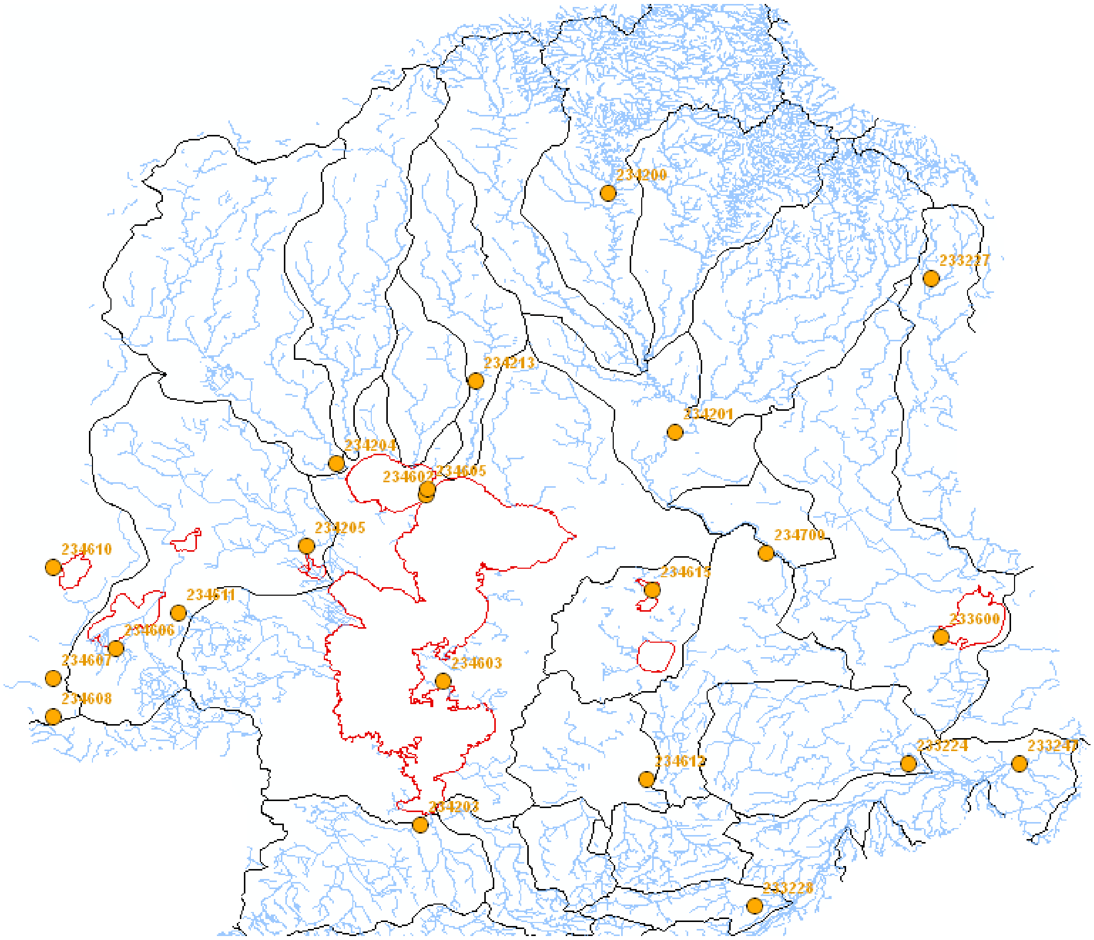


Figure 2-12 Water Quality Data

Table 2-7 Water Quality Data for each Lake

Lake	Water Quality Data
Beeac	None
Bookar	234610 (limited records)
Colongulac	234606 (1984 – 2009)
Corangamite	234603 (limited records) 234203 (1973 – 2009) 234213 (limited records)
Cundare	234615 (2005 – 2009)
Gnarpurt	234204 (limited records) 234212 (continuous EC 1993 – 2009) 234602 (limited records) 234605 (limited records)
Milangil	None
Murdeduke	233600 (1993 - 2009) 233251 (continuous EC 1997 – 2009)
Terangpom	234205 (limited records)

Continuous salinity levels are available for Lakes Gnarpurt and Murdeduke. Other sites have more inconsistent data records (taken as a grab sample) that are not correlated to any flows. Parameters measured vary between sites.

2.1.7 Data Gaps

2.1.7.1 Topography

Previous catchments and lake volumes have been defined using contour data. With the availability of detailed LiDAR data it was decided that it would be useful to update the catchment delineation and stage-storage-area relationships for each lake. A limitation to this LiDAR data was that in the centre of the larger lakes where water was pooled, the LiDAR is unable to penetrate the water and cannot provide survey of the bed of the lake. The LiDAR survey was infilled with contour data where required.

2.1.7.2 Flows / Levels

In order to obtain a higher degree of confidence in modelling results, an increase in the flow and lake level gauging within the catchment is required. Lake Corangamite holds the greatest amount of data for calibration, whereas many other lakes have little to no information.

Continuous recording stations provide the most useful data for hydrological analysis as they show the responses of the lake to rainfall and other inflows.

Without this observed data modelling can still be undertaken but will have lesser accuracy as the model estimates cannot be validated.

2.1.7.3 Groundwater

Groundwater inflows and outflows to the lakes can have a critical impact on the lake levels and susceptibility to climate change. Research and monitoring of the groundwater flow will allow a better definition of the lake water balance. This is particularly important for the lakes that are predominantly groundwater sourced.

Groundwater flow into the lakes was estimated based on available groundwater and lake levels and hydraulic conductivity. The available literature provided enough information to make these simplistic estimates.

2.1.7.4 Sewerage Inflows

Only basic data was able to be sourced from Wannon Water, with no flow or water quality gauging information available.

2.2 Data Review Summary

A data collection and review was undertaken for the Western District Lakes Hydrological Baseline project. Both input and calibration data were analysed to determine the availability and quality of the data. Required inputs to the model include data in the fields of GIS and Hydrology.

Some considerable knowledge gaps were defined as part of the analysis, which will require further investigation in future studies. A significant benefit of the proposed model, however, is the ability to update components when further data becomes available. It is anticipated that additional data, such as groundwater flows, water quality and lake level data will potentially become available in the future.

2.3 Proposed Project Methodology

The following methodology was developed based on the outcomes of the Data Review and Gap Analysis and in consultation with Corangamite CMA.

2.3.1 Modelling Approach

The literature review revealed three lakes (Corangamite, Gnarpurt and Murdeduke) with sufficient data to provide a calibrated hydrologic model. Due to the significant amount of work already undertaken on lakes Corangamite and Gnarpurt it was the preference of the Corangamite CMA to focus on less studied lakes. As such lakes Murdeduke and Colongulac were chosen as indicative lakes for the region, with sufficient data at Lake Murdeduke to undertake a suitable model calibration.

Recently available LiDAR data has enabled the lakes and their associated catchments to be more accurately defined. As part of this study the LiDAR information was used to provide stage-storage-area for each of the nine lakes and delineate their surface water catchments. This data will help to not only provide the basis for further hydrological modelling of the other lakes, but also provide valuable information on the less studied lakes.

The revised study methodology seeks to improve the knowledge gaps for the region while providing an indication on the current hydrology and impacts of climate change on two of the lakes. At the completion of this study the CMA will have gained further information about all of the lakes, and will have the basis to undertake a hydrological analysis of all lakes in the future. The hydrological analysis of Lakes Murdeduke and Colongulac will provide information on the relationship between the catchment and the lakes, but also have the flexibility to investigate the impacts of management actions on the lake levels. Further to this the models were set up to enable additional flow and water quality data to be added when available, providing a model that can evolve with new information.

3 SITE INVESTIGATION

Subsequent to submitting the data review and proposed method report, a site investigation was undertaken by the study team and CCMA on 23rd October 2009. This opportunity to visit the site provided invaluable information about the catchment dynamics and the lake formations.

3.1 Observations

The following section details the observations made during the site visit and provides a brief background to each of the nine RAMSAR lakes.

3.1.1 Beeac

Lake Beeac is an extremely shallow waterbody with a well defined bank around the edge of the lake. The township of Beeac was in close proximity to the lake's edge providing easy vehicular access. At the time of the site visit the lake level was relatively low. The proximity of the township, and its associated runoff, could be an important water quality consideration for future modelling. Dairying was the dominant land use to the north of the lake.

Figure 3-1 Google Earth Image of Lake Beeac

Figure 3-2 Photographs of Lake Beeac from Beeac township looking south and north

3.1.2 Bookar

Lake Bookar is the western most lake in the district. During the site visit a very low water level was observed. The catchment was limited and well defined, with inflows dominated by groundwater. The lake was surrounded by dairying.

Figure 3-3 Google Earth Image of Lake Bookar

Figure 3-4 Photograph of Lake Bookar looking from the east

3.1.3 Colongulac

Lake Colongulac is surrounded by grazing with the township of Camperdown in close proximity to the south. Camperdown Sewerage treatment plant is located on the southern shore of the lake. Lunettes form the eastern and western banks of the lake.

Figure 3-5 Google Earth Image of Lake Colongulac

Figure 3-6 Photograph of Lake Colongulac looking from the north-east

3.1.4 Corangamite

Lake Corangamite is the largest of the lakes in the district. During the site investigation we visited the northern bank and a viewpoint from Red Rocks (east of the lake). The northern portion of the lake was much shallower, with significant areas of exposed lake bed. Corangamite is a terminal lake with inflows from both groundwater and surface water.

Figure 3-7 Google Earth Image of Lake Corangamite

Figure 3-8 Photographs of Lake Corangamite looking from (a) Red Rocks and (b) Northern bank

3.1.5 Cundare

Lake Cundare has very similar morphology to Lake Beeac, with a very well defined steep bank and localised catchment. Inflows to the lake are dominated by groundwater rather than surface flows. The local catchment is dominated by grazing.

Figure 3-9 Google Earth Image of Lake Cundare

Figure 3-10 Photographs of Lake Cundare looking from the north-east

3.1.6 Gnarpurt

Lake Gnarpurt is a relatively shallow lake which has been essentially cut off from Lake Corangamite due to sediment build up between the lakes (forming a lunette). VicRoads invests a significant amount of time clearing sediment from the dry lake bed off Foxhow Road. The connection pipe had been silted over. A sand bar has also been formed on the south-eastern side of the lake. Lake Gnarpurt has a reasonable sized catchment as it has a number of surface water inflows.

Figure 3-11 Google Earth Image of Lake Gnarpurt

Figure 3-12 Photographs of Lake Cundare looking from the south-east (Foxhow Rd)

3.1.7 Milangil

Lake Milangil is a shallow lake located in the west of the catchment. A lunette has formed on the south-eastern edge of the lake providing an obstruction to catchment inflows. Nearby landuses include cropping to the west and grazing.

Figure 3-13 Google Earth Image of Lake Milangil

Figure 3-14 Photographs of Lake Milangil looking from the east (Camperdown Rd)

3.1.8 Murdeduke

Lake Murdeduke was relatively contained on the eastern bank, with a greater catchment area to the west and north. Dominant landuses in the catchment are cattle grazing and cropping. The eastern bank was covered by an extensive piggery.

The water level was relatively high compared to previous years however evidence of higher historic levels was evident (boat ramp, tyres along higher banks). During the site investigation the water colour of the lake was bright orange, the likely source of which is the release of copper fixing bacteria.

Figure 3-15 Google Earth Image of Lake Murdeduke

Figure 3-16 Photographs of Lake Murdeduke looking from the east

3.1.9 Terangpom

As Lake Terangpom is the only fresh / mildly brackish lake in the system it had an observably different flora and extensive birdlife. A steep bank was observed on the south-eastern side of the lake from a lunette but otherwise the topography was relatively flat. The local catchment is dominated by grazing.

Figure 3-17 Google Earth Image of Lake Terangpom

Figure 3-18 Photographs of Lake Terangpom looking from the north-west

4 STAGE-STORAGE-AREA CALCULATIONS

4.1 Methodology

In order to fill the knowledge gap for these lakes an initial step is to define the elevation-storage-area characteristics for each of the lakes using the provided 1m LiDAR data. This information can then be used to define each lake in future studies.

The LiDAR data was converted into a surface terrain within the GIS package ArcGIS. The volume and surface area was then calculated using a processor in ArcGIS for various elevations within the lakes. A shapefile defining the edge of the lake was provided by CCMA which was used as the extent of the analysis. The maximum depth of the lake is calculated from the base of the wetland to this extent.

4.2 Data Limitations

LiDAR is unable to penetrate water, so in areas where the lakes were inundated at the time of LiDAR survey, large gaps in the data required infilling. LiDAR data is unavailable in the centre of the larger lakes, either lower resolution data such as contours or interpolation methods were employed to determine the lake volumes and areas.

Lake Murdeduke was not captured within the 1m LiDAR data set and hence the lake interpolation was based on the older 5m resolution LiDAR set. A substantial portion of the lake was missing due to the lake being partially full and hence a supplementary source of information was required. A 1m contour of the lake bathymetry was presented in Segovia (2001) and due to the lack of any other data sources this was used when LiDAR information was not available. Figure 11-21 depicts the base data and interpolated terrain.

4.3 Results

The higher resolution datasets have enabled a more accurate description of the lake's stage/area/storage relationships. The following section provides the details of these relationships with a visual representation of the lake shown in Appendix A including gaps in the LiDAR. Note that these gaps have been infilled to calculate the stage/area/storage relationships.

4.3.1 Beeac

Lake Beeac is bounded by a lunette on its eastern side and has a maximum depth of 1.6m. The stage/area/storage calculations (as shown in Table 4-1, Figure 4-1 and Figure 4-2) show a very steep bank, where the increase in area is relatively small compared to the increase in stage. This was observed during the site visit to the lakes. Lake Beeac has a maximum volume of 19478 ML.

Table 4-1 Lake Beeac Stage/Area/Storage Calculations

Stage (mAHD)	Area (ha)	Storage (ML)
114.5	169	66
114.75	649	1477
115	650	3100
115.25	651	4727
115.5	652	6356
115.75	653	7988
116	654	9622
117.5	658	19478

The Lake Beeac Catchment Management Plan (SKM, 1997) produced a Storage/Depth/Area relationship for Lake Beeac. The current analysis extends further up the bank than the SKM study, and shows a higher storage volume.

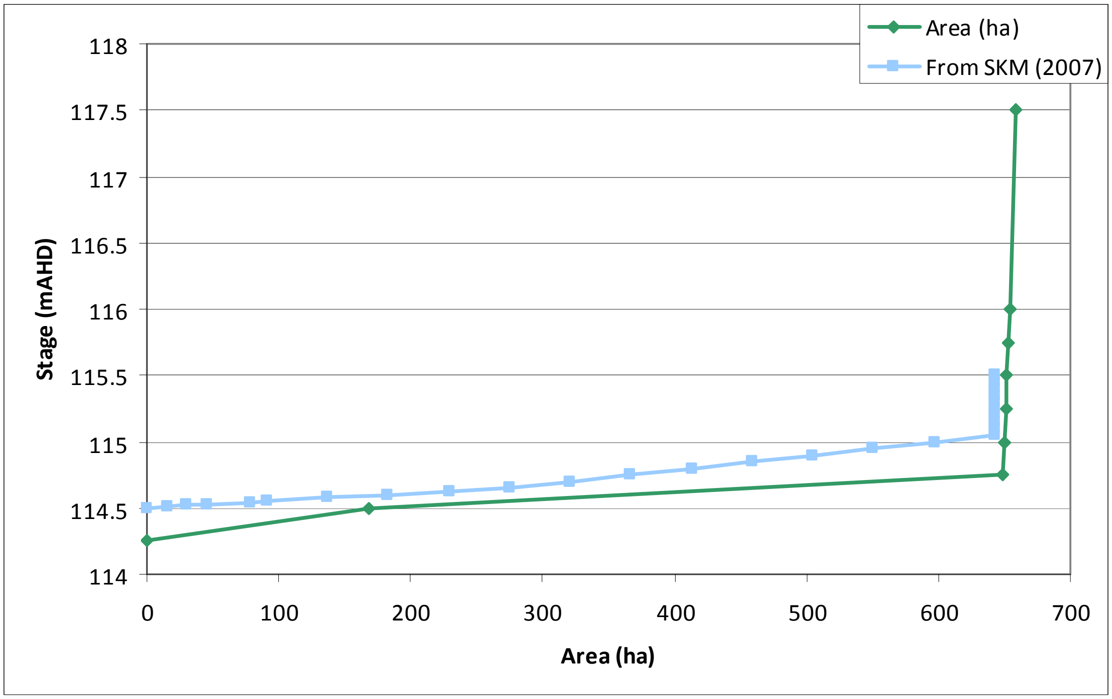


Figure 4-1 Lake Beeac Stage-Area Plot

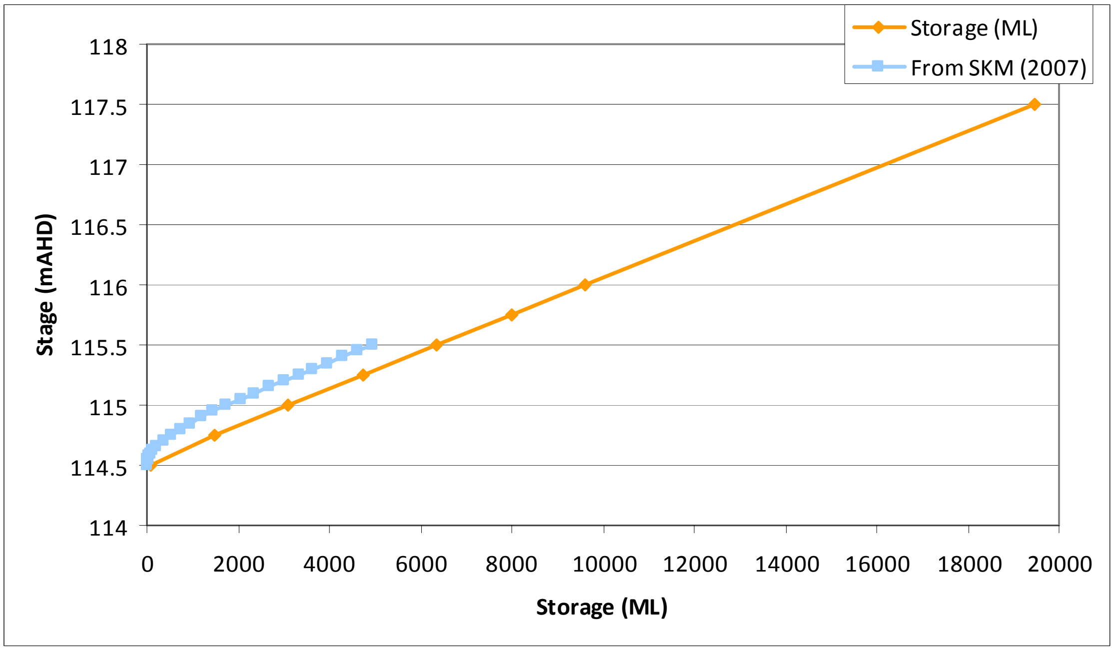


Figure 4-2 Lake Beeac Stage-Storage Plot

4.3.2 Bookar

The LiDAR data set captured all of Lake Bookar and hence the Stage/Area/Storage calculations have a high degree of accuracy. Elevations within the lake range from 133.3 m AHD to 136 m AHD, with a maximum depth of 2.7m (Table 4-2). The maximum storage is 10,150 ML, with a relatively linear stage-volume curve. Refer to Figure 4-3 and Figure 4-4 for the Stage-Area and Stage-Storage plots.

Table 4-2 Lake Bookar Stage/Area/Storage Calculations

Stage (mAHD)	Area (ha)	Storage (ML)
133.5	111	83
133.75	294	638
134	333	1428
134.25	367	2306
134.5	404	3266
134.75	439	4321
135	458	5446
135.25	465	6600
135.5	472	7772
135.75	476	8957
136	478	10150

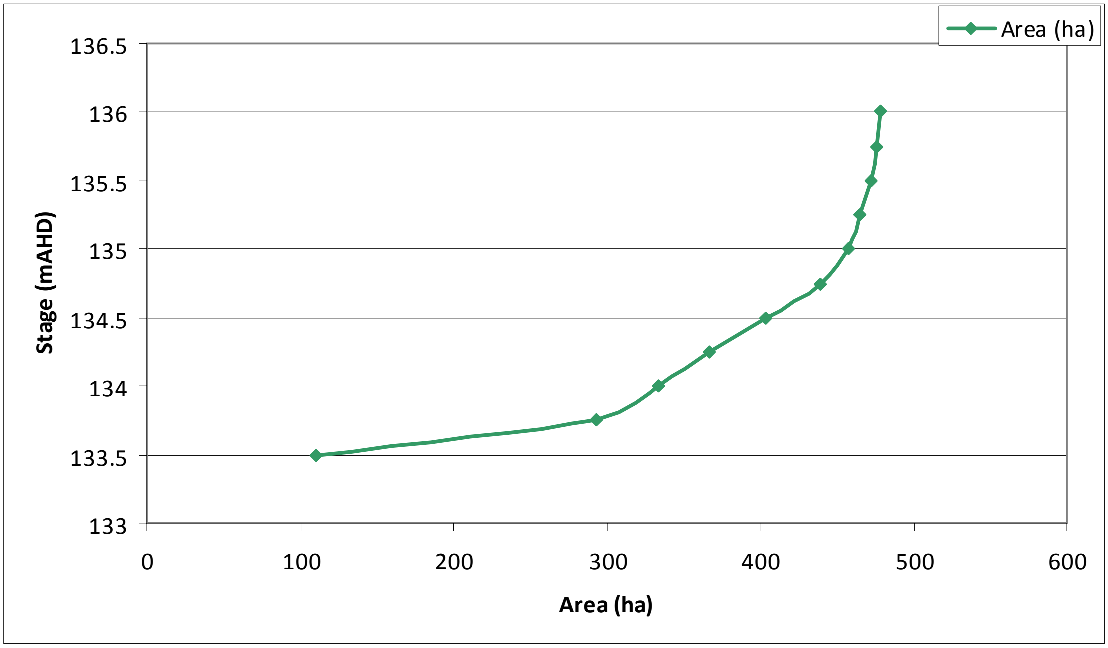


Figure 4-3 Lake Bookar Stage-Area Plot

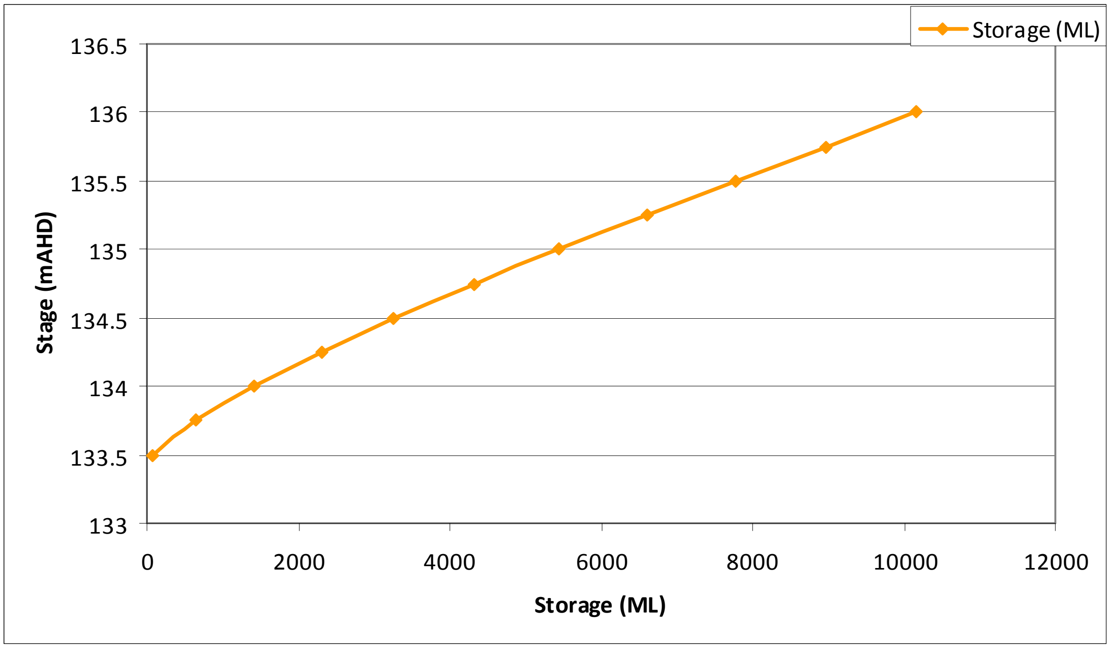


Figure 4-4 Lake Bookar Stage-Storage Plot

4.3.3 Colongulac

The eastern and western banks of Lake Colongulac are fairly well constrained by lunettes, and a low lying area connecting lake Colongulac to Lake Kariah to the north. Lake Colongulac has a maximum depth of 2.9m, with a maximum storage of 31,518 ML. Stage-Area and Stage-Volume curves are shown in Figure 4-5 and Figure 4-6 respectively, with values in Table 4-3.

Table 4-3 Lake Colongulac Stage/Area/Storage Calculations

Stage (mAHD)	Area (ha)	Storage (ML)
134.5	1	0
134.75	900	1048
135	1087	3547
135.25	1235	6467
135.5	1309	9648
135.75	1372	13004
136	1433	16509
136.25	1481	20155
136.5	1509	23894
136.75	1525	27688
137	1540	31518

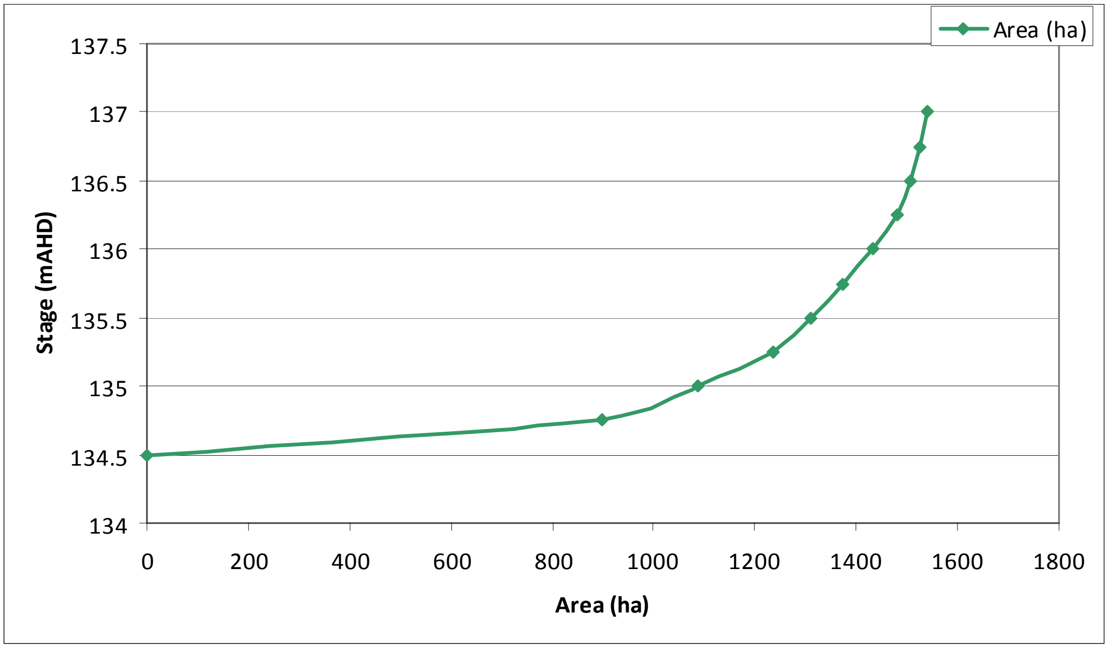


Figure 4-5 Lake Colongulac Stage-Area Plot

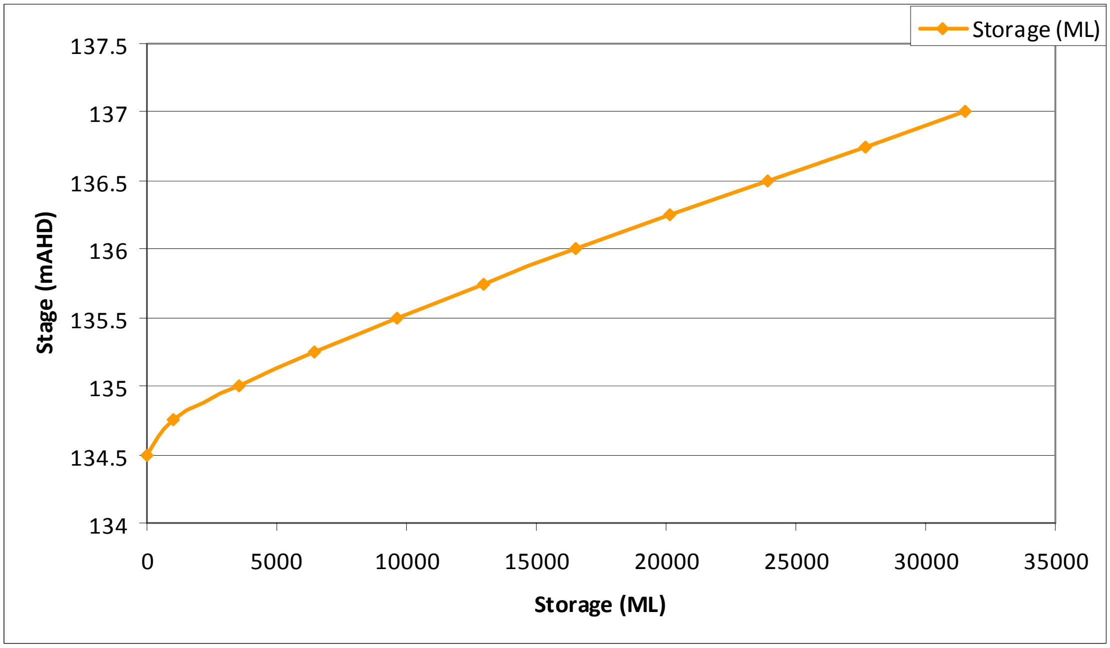


Figure 4-6 Lake Colongulac Stage-Storage Plot

4.3.4 Corangamite

Lake Corangamite is the largest of the Western District Lakes. The lake has a maximum depth of 5.7m and can hold up to 1,150,000 ML. The volume and area calculations are similar to those shown in SKM (1997), however the volumes at each stage are slightly lower in the current study.

Table 4-4 Lake Corangamite Stage/Area/Storage Calculations

Stage (mAHD)	Area (ha)	Storage (ML)
112.5	512	126
112.75	8484	10162
113	11305	35412
113.25	13095	65955
113.5	16492	102214
113.75	19470	147946
114	20789	198507
114.25	21478	251424
114.5	21963	305743
114.75	22397	361206
115	22810	417723
115.25	23164	475206
115.5	23488	533520
115.75	23800	592630
116	24040	652456
116.25	24245	712812
116.5	24458	773689
116.75	24661	835093
117	24821	896963
117.25	24914	959141
117.5	24976	1021508
117.75	25024	1084009
118	25066	1146624

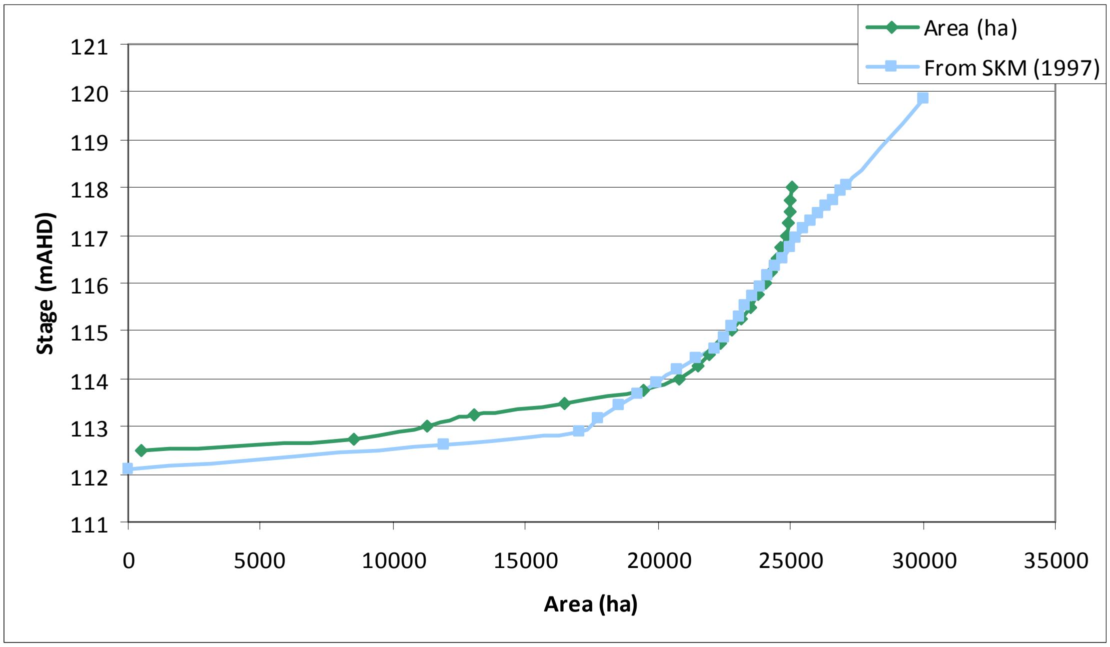


Figure 4-7 Lake Corangamite Stage-Area Plot

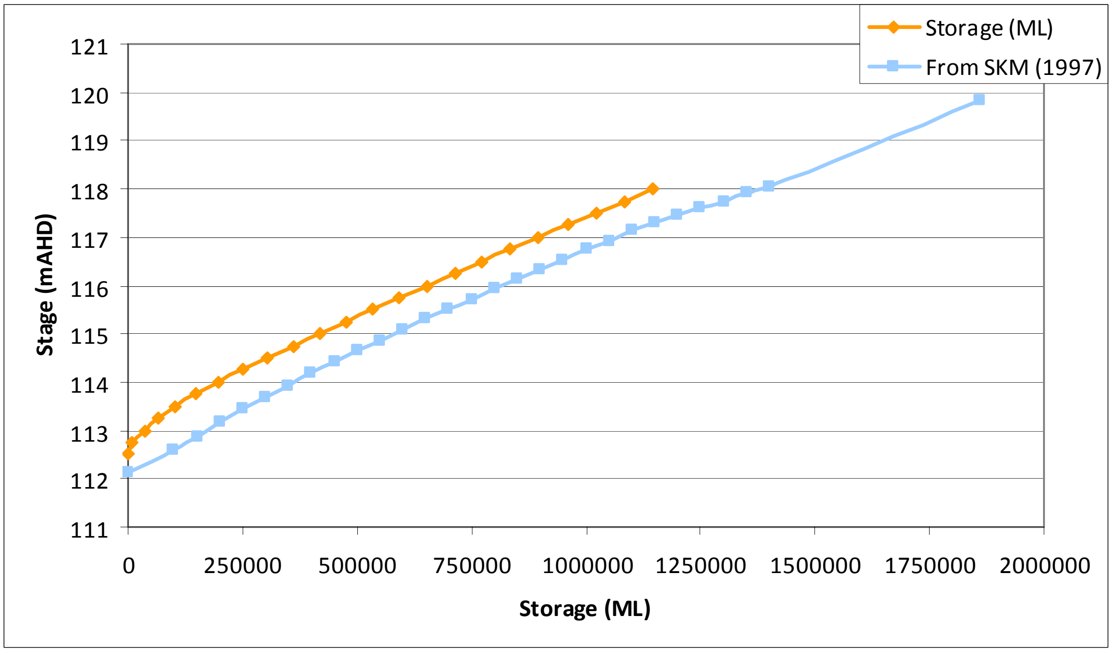


Figure 4-8 Lake Corangamite Stage-Storage Plot

4.3.5 Cundare

Lake Cundare ranged in elevation from 114.08 m AHD to 117 m AHD, with a maximum depth of 2.92 m. As shown in Figure 11-5, the lake's edge is constrained on the eastern side by a substantial lunette. The extent of the lake on the western edge was assumed to be extent of the defined RAMSAR site (shown by the black extent in Figure 11-5). The Stage-Area-Volume calculations for Lake Cundare are presented in Table 4-5 and graphically displayed in Figure 4-9 and Figure 4-10. The steep banks of Lake Cundare, observed during the site visit, are displayed in the stage-area plot.

Table 4-5 Lake Cundare Stage/Area/Volume Calculations

Stage (mAHD)	Area (ha)	Storage (ML)
114.25	33	6
114.5	285	501
114.75	299	1238
115	300	1987
115.25	302	2739
115.5	304	3497
115.75	306	4259
116	307	5025
116.25	308	5793
116.5	309	6564
116.75	309	7337
117	310	8110

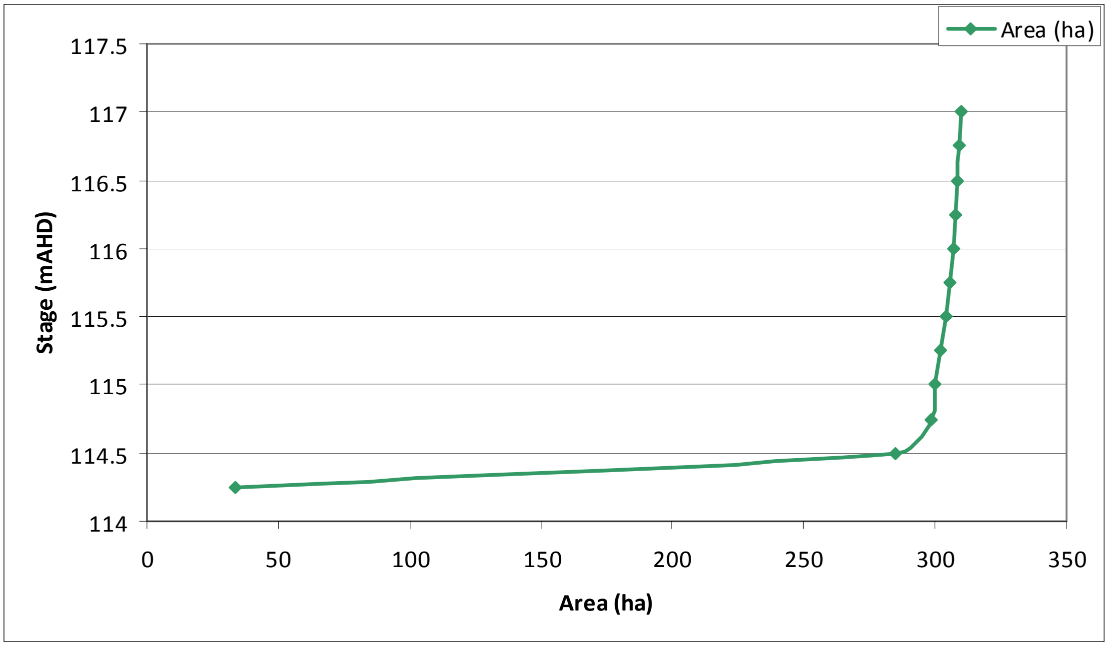


Figure 4-9 Lake Cundare Stage-Area Plot

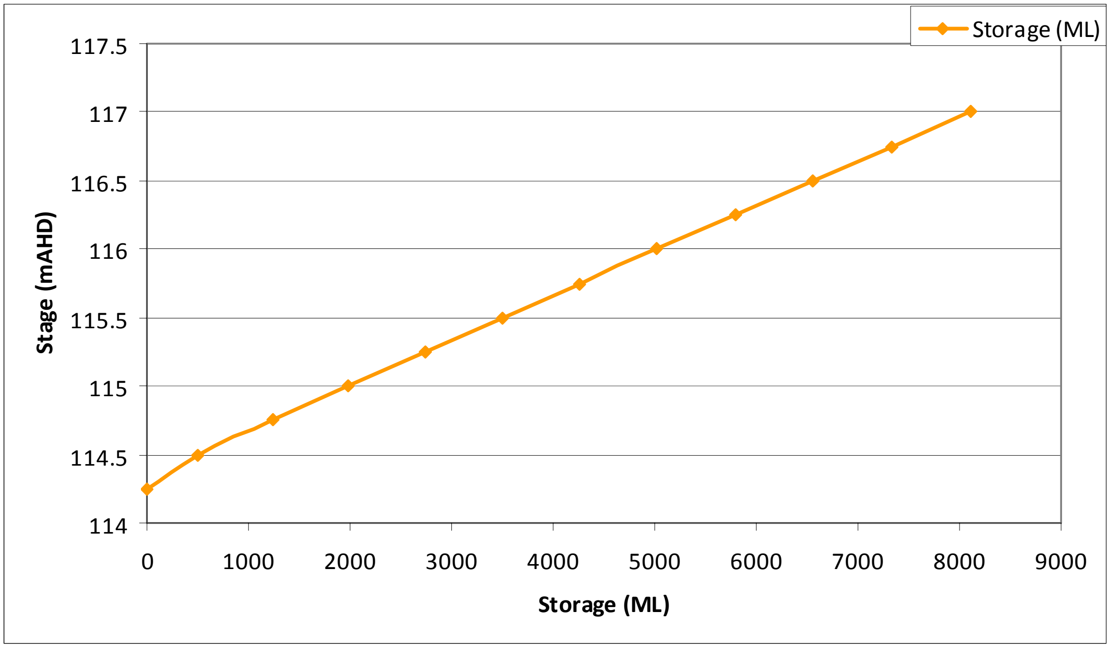


Figure 4-10 Lake Cundare Stage-Storage Plot

4.3.6 Gnarpurt

Lake Gnarpurt ranges from 113.27 m AHD to 116.75 m AHD, with a maximum volume of 76,500 ML. The areas are relatively similar to the SKM (1997) report, however there are differences at the banks of the lake. The storage-volume graphs show similar results (Figure 4-12)

Table 4-6 Lake Gnarpurt Stage/Area/Storage Calculations

Stage (mAHD)	Area (ha)	Storage (ML)
113.27	0	0
113.5	1656	1864
113.75	2123	6696
114	2201	12121
114.25	2241	17677
114.5	2269	23314
114.75	2294	29019
115	2315	34783
115.25	2335	40595
115.5	2359	46463
115.75	2380	52388
116	2398	58361
116.25	2411	64372
116.5	2423	70414
116.75	2438	76490
117	2454	82604
117.25	2468	88757
117.5	2478	94941

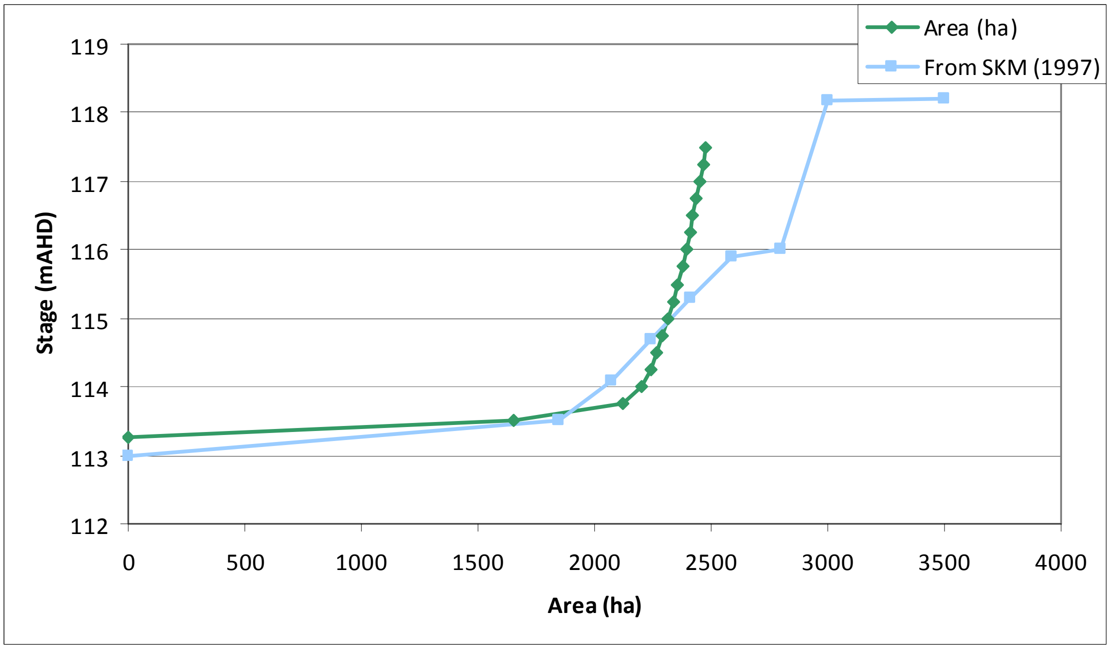


Figure 4-11 Lake Gnarpurt Stage-Area Plot

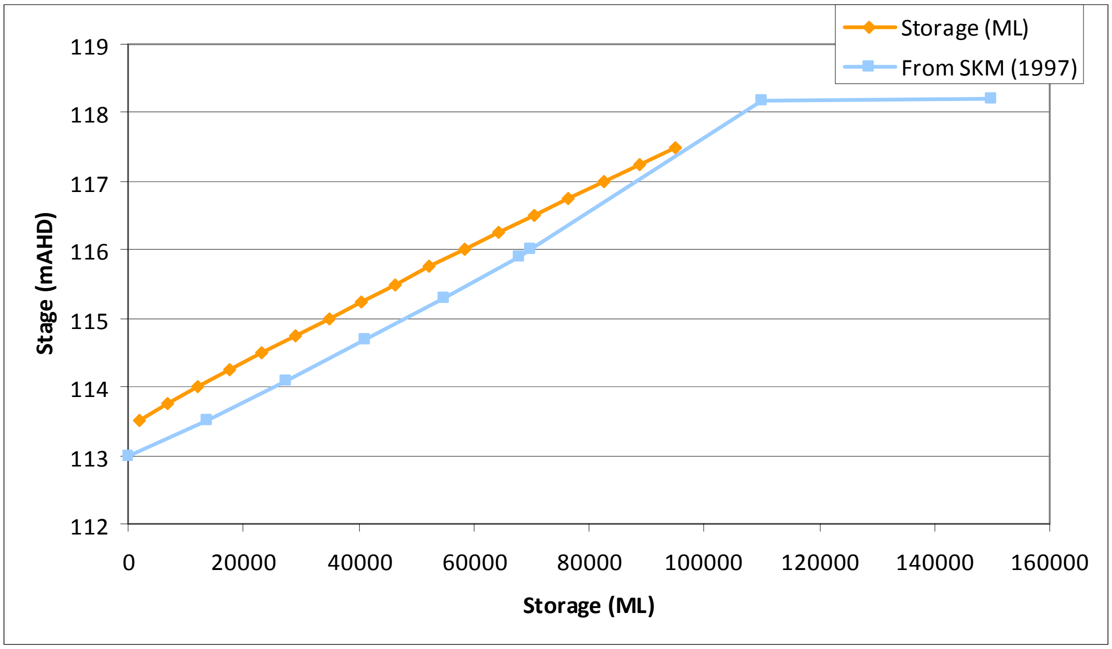


Figure 4-12 Lake Gnarpurt Stage-Storage Plot

4.3.7 Milangil

Lake Milangil has an elevation range from 131.3 m AHD to 134 m AHD with a maximum depth of 2.7m. The lake's south-east edge is a significant lunette, with a number of sandy bars located within the lake as a result. Stage/Storage/Area graphs and table are shown in Table 4-7, Figure 4-13 and Figure 4-14

Table 4-7 Lake Milangil Stage/Area/Storage Calculations

Stage (mAHD)	Area (ha)	Storage (ML)
131.5	107	66
131.75	159	414
132	182	839
132.25	206	1324
132.5	220	1858
132.75	225	2415
133	227	2981
133.25	228	3550
133.5	228	4120
133.75	229	4691
134	229	5263

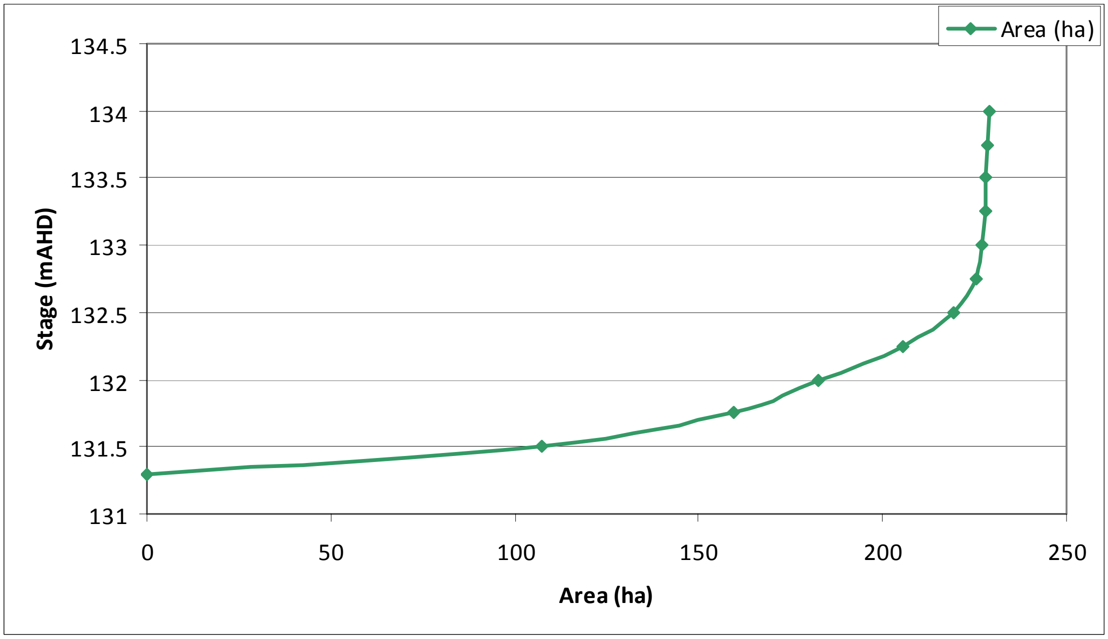


Figure 4-13 Lake Milangil Stage-Area Plot

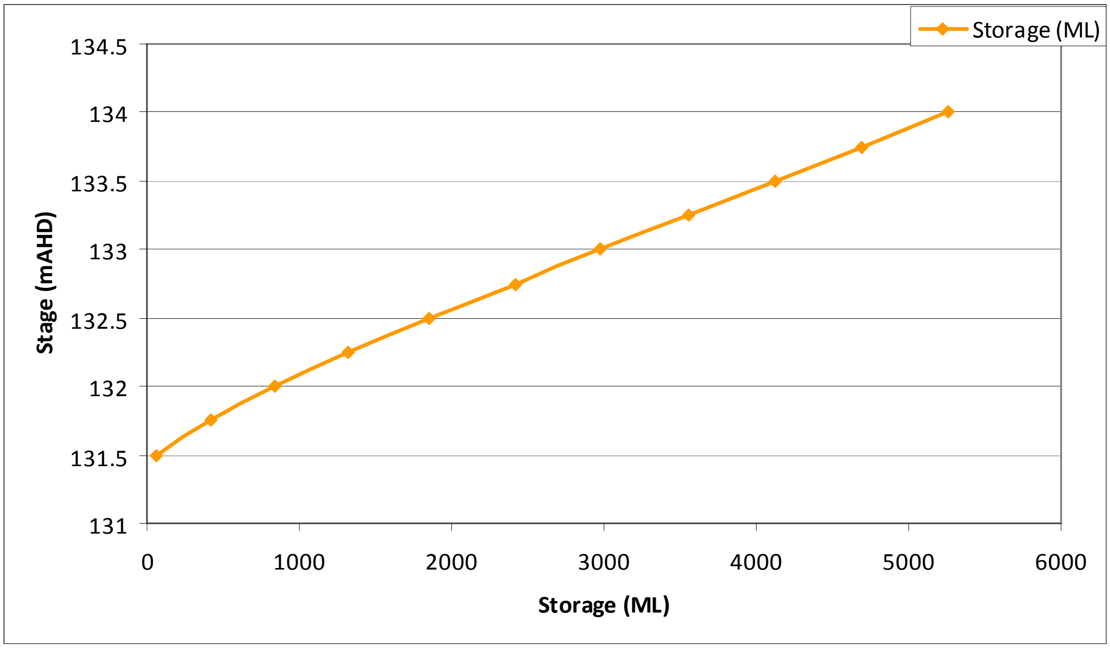


Figure 4-14 Lake Milangil Stage-Storage Plot

4.3.8 Murdeduke

Lake Murdeduke has a maximum area of 1660 ha and a maximum volume of 68003 ML. The elevations range from 80.3 m AHD to 85.5 m AHD (maximum depth 5.2m), with a relatively flat base. Details are provided in Table 4-8, Figure 4-15 and Figure 4-16.

Table 4-8 Lake Murdeduke Stage/Area/Storage Calculations

Stage (mAHD)	Area (ha)	Storage (ML)
80.5	795	1525
80.75	886	3624
81	988	5963
81.25	1100	8571
81.5	1161	11416
81.75	1202	14369
82	1244	17428
82.25	1287	20592
82.5	1318	23852
82.75	1347	27184
83	1376	30587
83.25	1405	34062
83.5	1423	37600
83.75	1439	41178
84	1454	44794
84.25	1470	48450
84.5	1503	52161
84.75	1542	55967
85	1583	59872
85.25	1619	63877
85.5	1660	68003

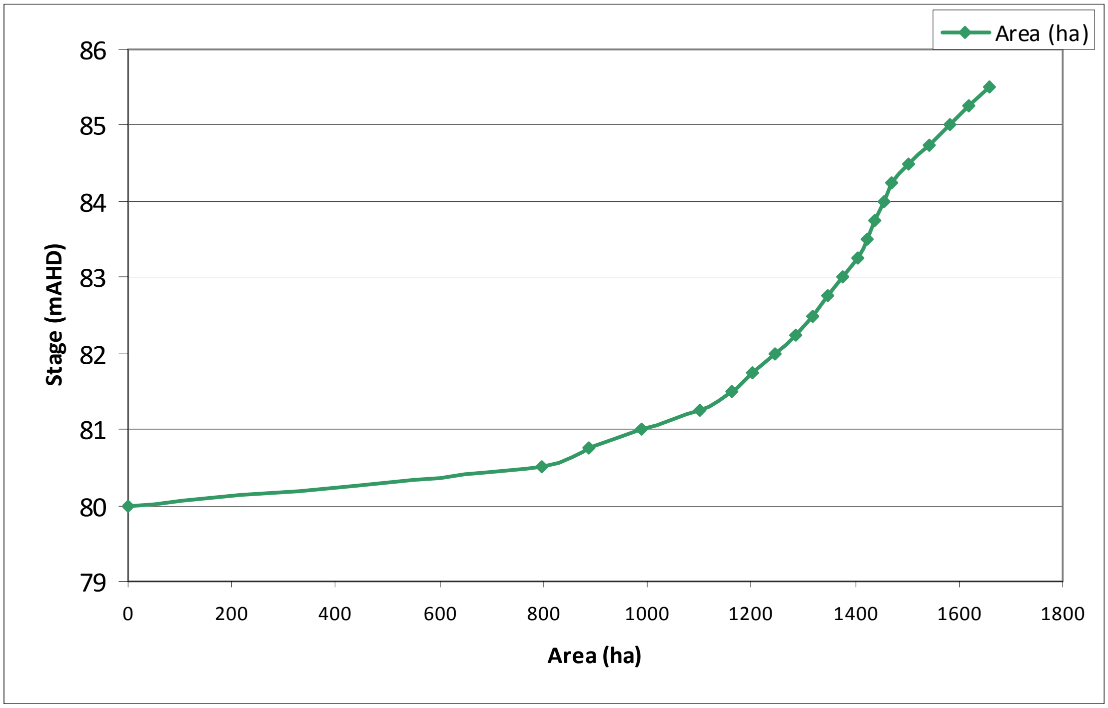


Figure 4-15 Lake Murdeduke Stage-Area Plot

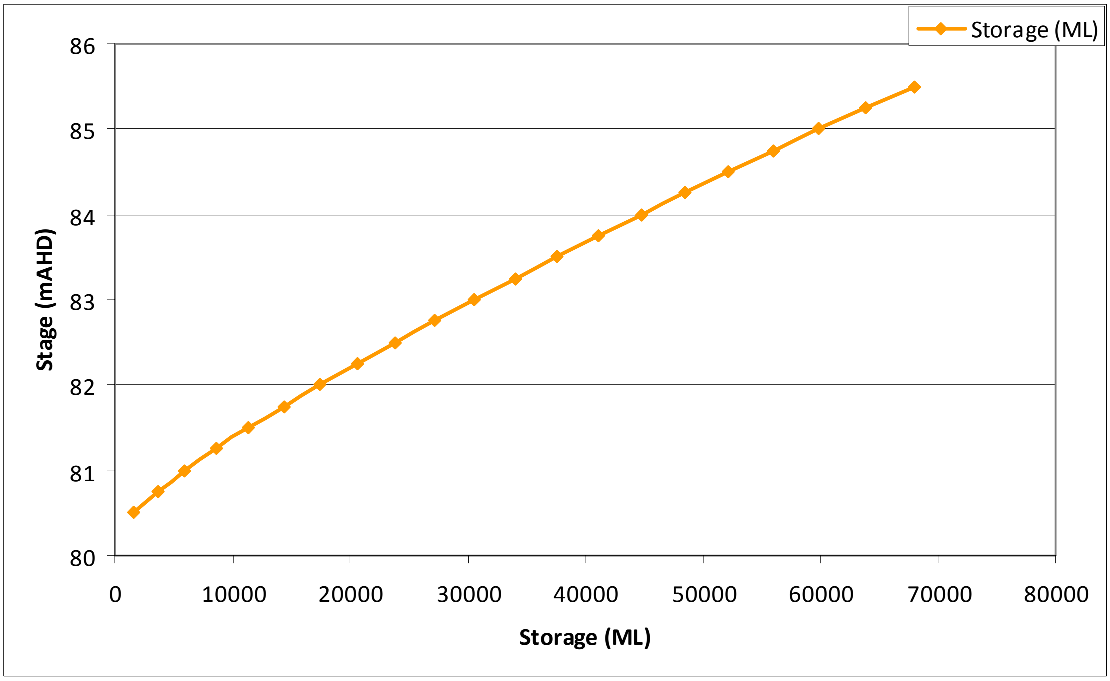


Figure 4-16 Lake Murdeduke Stage-Storage Plot

4.3.9 Terangpom

Lake Terangpom is the smallest of the RAMSAR lakes, with an area of 216 ha and a maximum volume of 4568 ML. As per a number of the other lakes a lunette has formed on the south-western edge of the lake, providing a steep bank on that side. The lake has a maximum depth of 2.8m. Refer to Figure 4-17, Figure 4-18 and Table 4-9 for details.

Table 4-9 Lake Terangpom Stage/Area/Storage Calculations

Stage (mAHD)	Area (ha)	Storage (ML)
119.75	0	0
120	54	29
120.25	118	262
120.5	145	592
120.75	184	1012
121	192	1484
121.25	195	1969
121.5	198	2461
121.75	207	2966
122	213	3492
122.25	215	4028
122.5	217	4568

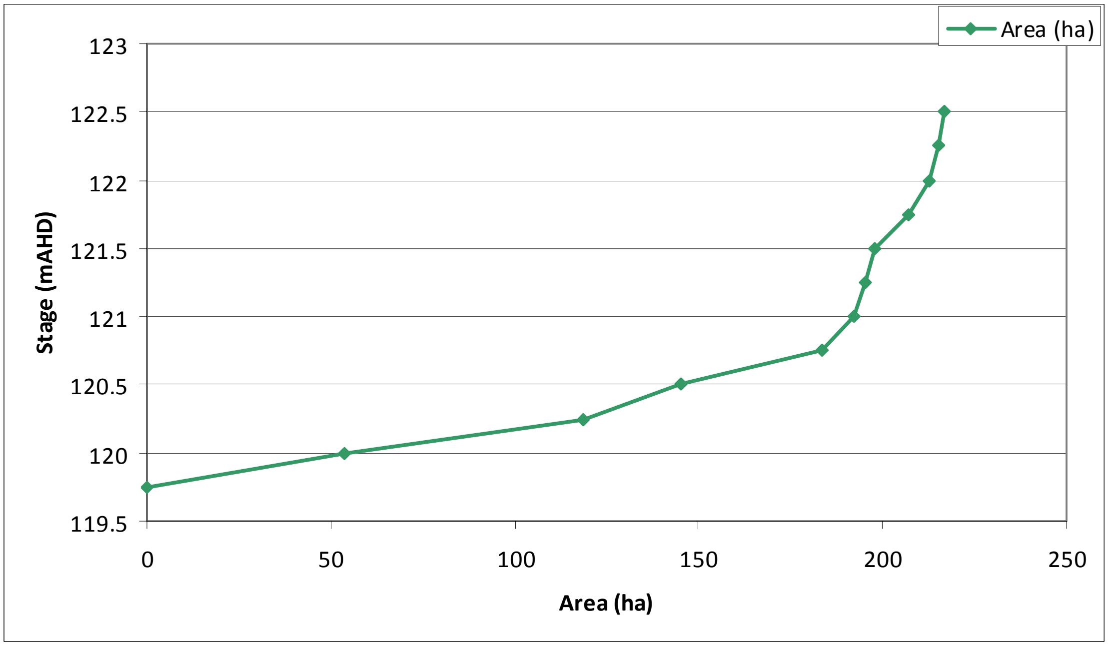


Figure 4-17 Lake Terangpom Stage-Area Plot

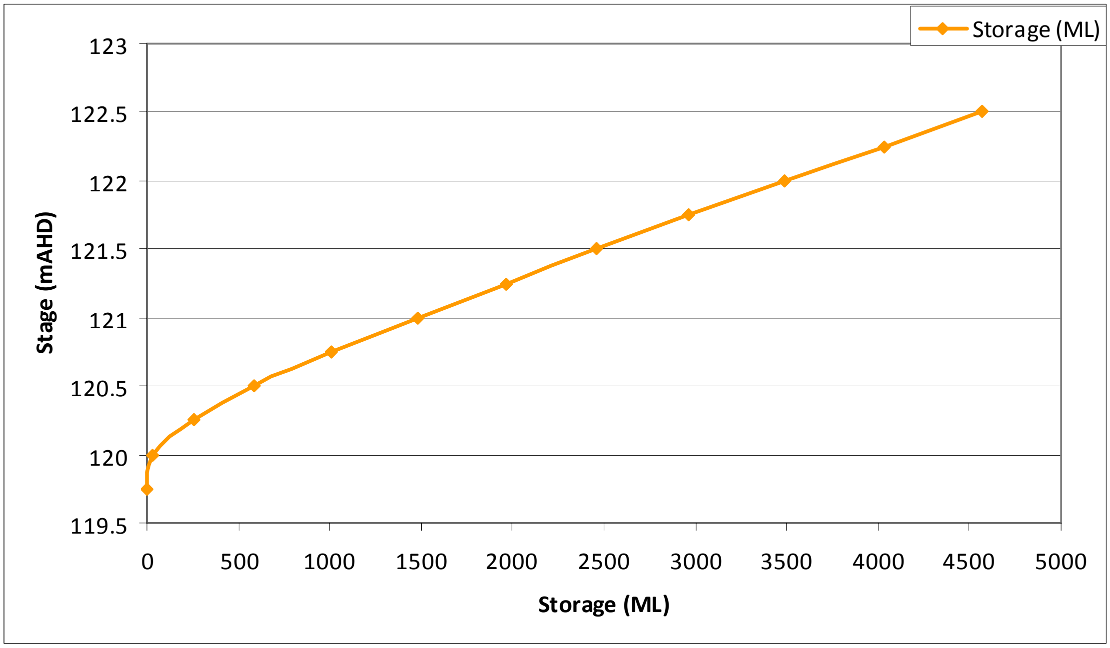


Figure 4-18 Lake Terangpom Stage-Storage Plot

5 CATCHMENT DELINIATION

5.1 Methodology

Sub catchment delineation was undertaken for each of the nine lakes based on overland watersheds. Although all of this data will not be used for further hydrological analysis for many of the lakes, it does provide critical information for the CMA on the lesser studied lakes. This information is intended to inform future condition assessments and provide recommendations for future management actions within the lakes' catchment.

The delineation was based on the most recent 1 m resolution LiDAR data. This more accurate information will enable the study team to determine the watershed areas in this relatively flat region. The catchment delineation was provided in both digital and printed map form.

Lake areas were based on the RAMSAR wetlands boundary as provided by CCMA. Boundaries were checked against the LiDAR data to ensure consistency.

5.2 Data Limitations

The physical form of the Western District Lakes has been determined by the regional volcanic history and subsequent geomorphic processes, providing a series of complex landforms in the vicinity of the lakes. Judgement is required to determine the catchment boundary around the complex minor craters, as small flows may be stored locally with larger flows spilling through the minor craters and into the major lakes.

5.3 Results

The most recent LiDAR information provided the highest resolution data to complete the catchment delineations. The ability to see the smaller scale variations in height has led to some refinement of the catchment outlines compared to the data provided by Corangamite CMA and prior studies.

Appendix B displays the catchment delineations. Table 5-1 provides details on the lake and catchment areas.

Table 5-1 Catchment Delineation Parameters

	Lake Area (ha)	Catchment Area (ha)	Lake: Catchment Ratio
Beeac	658	3502	0.19
Bookar	478	6379	0.07
Colongulac	1540	9304	0.17
Corangamite	25066	125320	0.20
Cundare	310	1073	0.29
Gnarpurt	2478	68300	0.04
Milangil	229	4307	0.05
Murdeduke	1660	34990	0.05
Terangpom	217	19180	0.01

Lake Corangamite is significantly larger than the other lakes in the region (by at least a factor of 10) as it is a terminal lake for the system. Its catchment area is also relatively large due to the numerous surface water inflows. Lake Cundare has a similar lake to catchment ratio despite the fact it is one of the smallest lakes. The lakes range from 1 – 27% of the total catchment areas.

5.4 Comparison to Other Studies

Catchment delineations have been defined for the lakes in various other studies, and compiled in the Muston (2001) and Williams (1992) reports. A comparison between these two data sets has revealed some inconsistencies between the results based on the data sources used (as shown in

Table 5-2).

Table 5-2 Catchment Delineation Parameters - Comparison

	Other Studies Lake Area (ha)	% Difference in Lake Area	Other Studies Catchment Area (ha)	% Difference in Catchment Area
Beeac	608	8%	3778.7	- 8%
Bookar	485	-1%	5370	16 %
Colongulac	1460	5%	8340	10 %
Corangamite	2516	*90%*	128500	- 3%
Cundare	300	- 3%	963.6	10 %
Gnarpurt	2732	- 10%	41500	*39 %*
Milangil	240	- 5%	4915.2	- 14 %
Murdeduke	1500	10%	17451.5	*50%*
Terangpom	250	- 15%	2631.8	*86 %*

A 50% difference was observed between the recent catchment area definition of Lake Murdeduke and the results displayed in Muston (2001). The CCMA catchment boundary based on contour information yielded an area of 37,600 hectares, much more similar to the area defined in this study. The Muston (2001) values also underestimated the area of Lake Corangamite by a factor of ten.

For Lake Bookar the catchment areas varied by 16% from previous studies, however Williams (1992) derived the same lake to catchment ratio and lake size. Williams (1992) also derived a catchment area for Lake Gnarpurt of 67,000 hectares which is more in line with the current study values compared to the much lower value in Muston (2001) of 41,500 hectares.

An 86% difference in catchment size was observed between prior studies and the current study for Lake Terangpom. The significant difference is due to the assumption that all minor lakes upstream of Lake Terangpom will drain to this location before eventually entering Lake Corangamite.

In addition to the published catchment areas the CCMA also held a polygon layer of the catchments which was based on the 5m resolution LiDAR data. These catchments have been updated using the 1m resolution LiDAR. As shown by Figure 5-1 the catchment delineations are improved by the higher resolution data as crests can be more accurately defined.

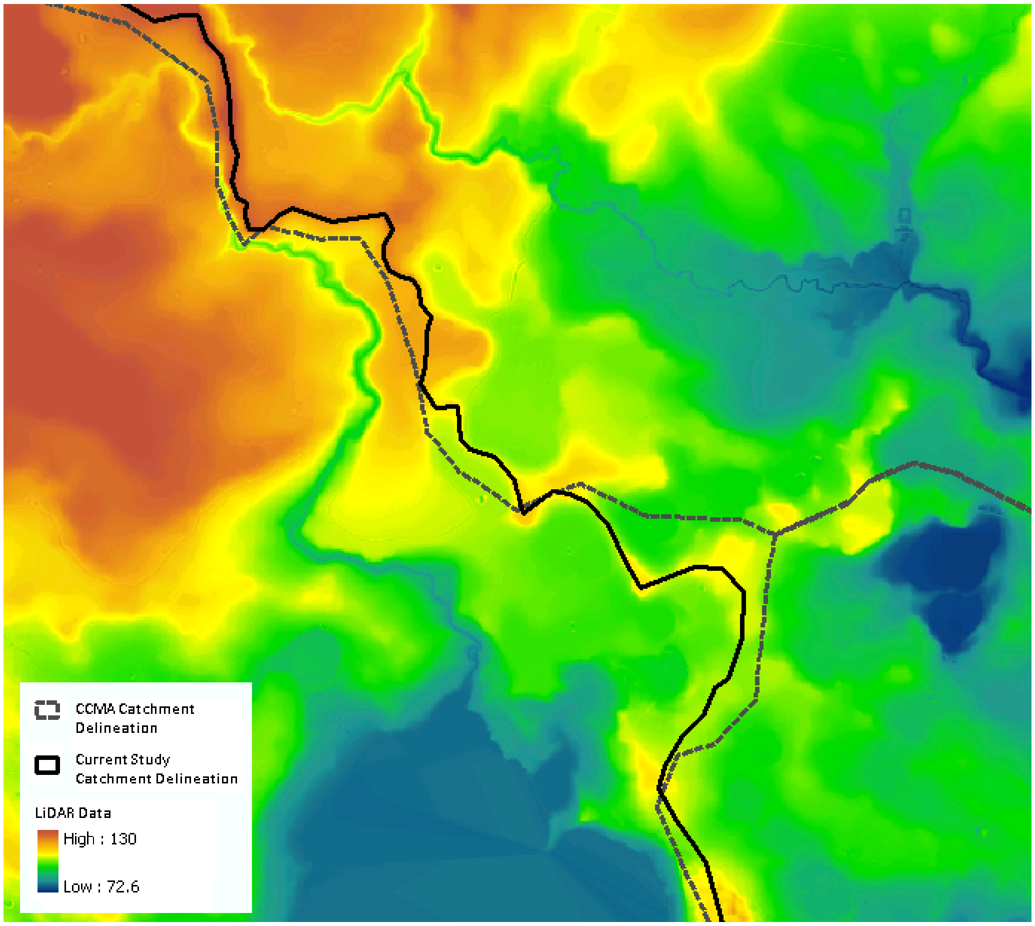


Figure 5-1 Differences in Catchment Delineation

6 WATERCAST MODEL DEVELOPMENT

WaterCAST is a modelling software application created specifically for spatio-temporal catchment modelling. The basic platform provides essential basic operations, such as flow and water quality modelling and scenario comparison, while the plug-in capability allows addition of custom-built models for specific requirements.

The model construction falls into eight broad categories:

1. Sub-catchment delineation
2. Network definition
3. Functional Unit definition
4. Hydrology
5. Water Quality constituents
6. Pollutant Generation
7. Node & Link models
8. Filtering

Data inputs, assumptions and results are presented in the following sections.

6.1 Catchments

Catchment delineation requires a series of inputs, most notably the location of major streams, and the topography to ascertain the watershed for each river. This information is used to define the major catchment boundaries, which then may be further delineated based on other information. Using the catchment delineation from Section 5.3 and further definition of subcatchments based on topography, major inflow points and location of gauging stations the subcatchment delineations shown in Figure 6-1 and Figure 6-2 were produced.

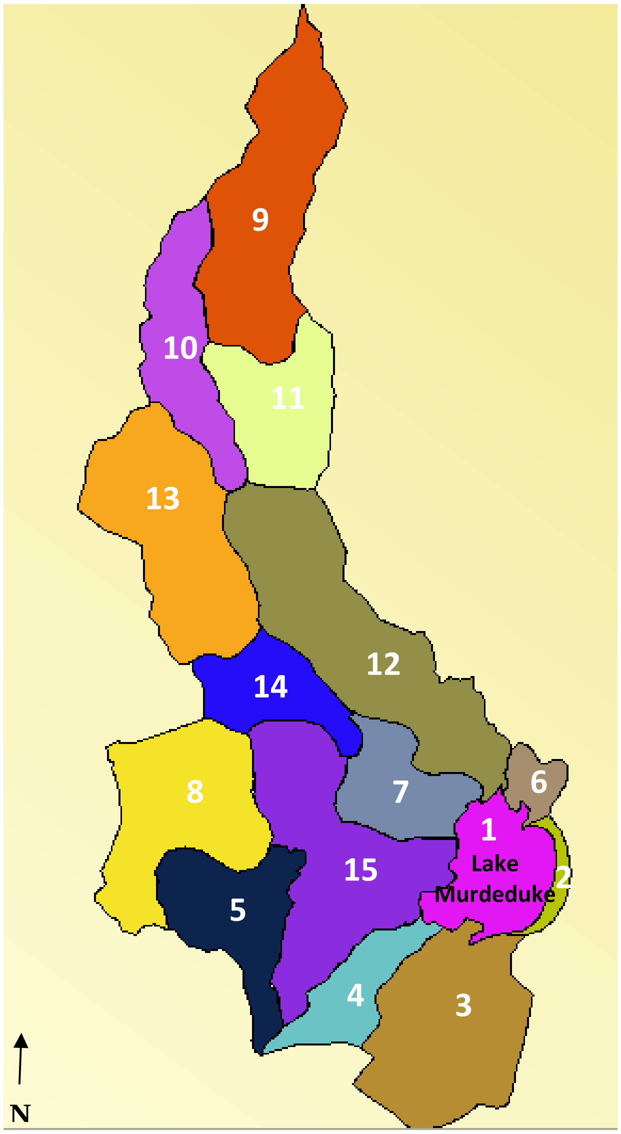


Figure 6-1 WaterCAST Sub-Catchment Delineation – Lake Murdeduke

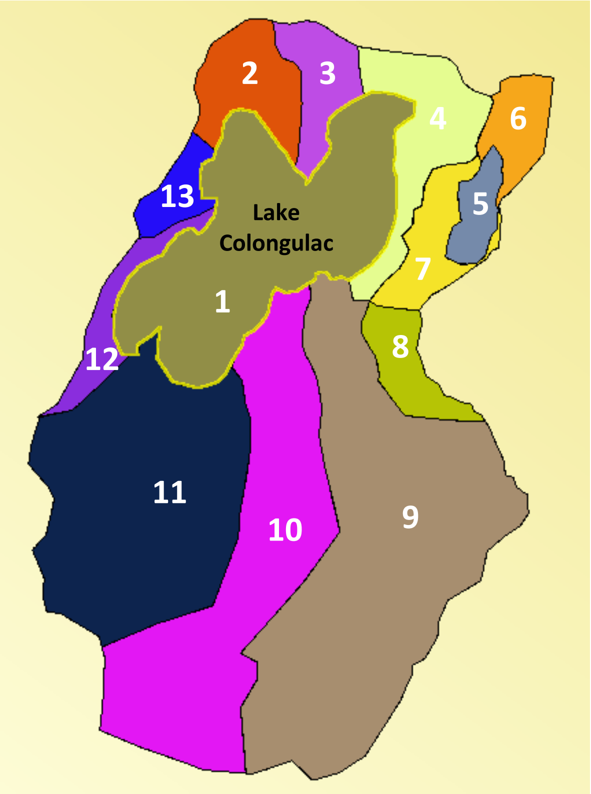


Figure 6-2 WaterCAST Sub-Catchment Delineation – Lake Colongulac

6.2 Network

Following the sub-catchment delineation, the stream/drainage network was defined. The stream/drainage network routes the flow between sub-catchments to the catchment outlet, rather than the actual flow paths. The lakes are closed systems, and are hence the receiving waterbodies for the catchment. An outlet node must be defined outside of the model, however, no outflow will occur from the lakes. Refer to Figure 6-3 and Figure 6-4.

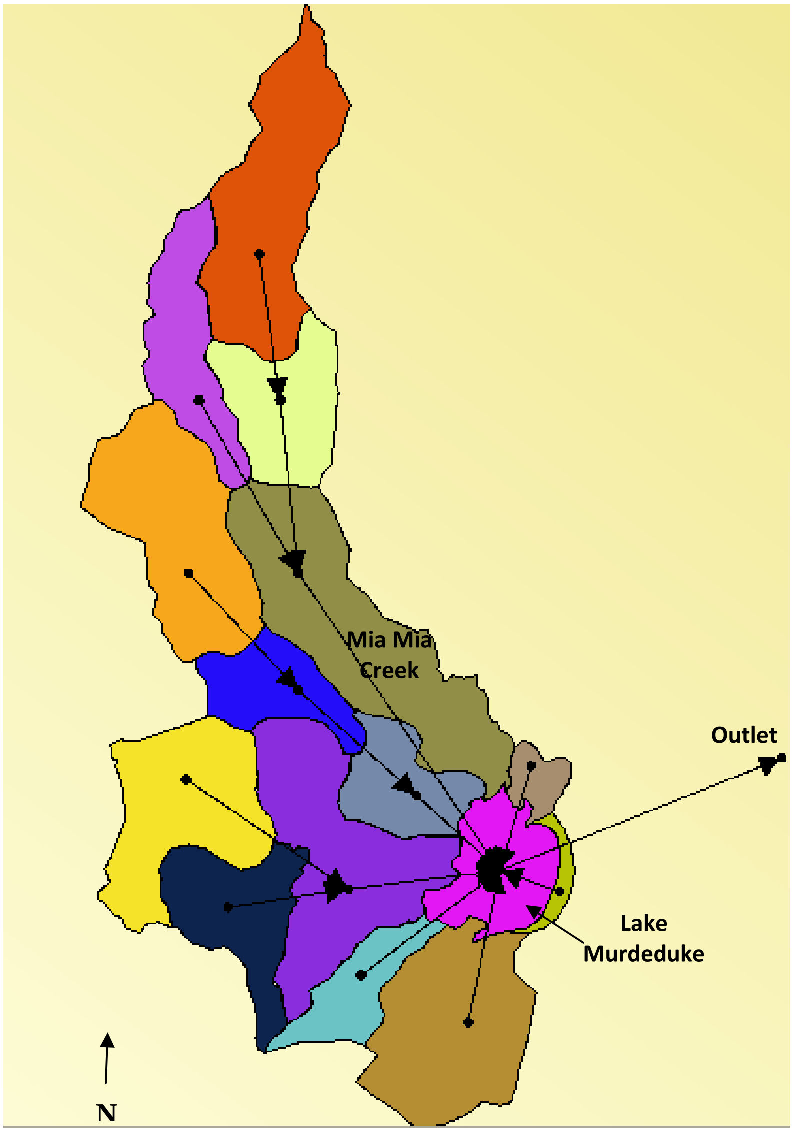


Figure 6-3 WaterCAST Network Delineation – Lake Murdeduke

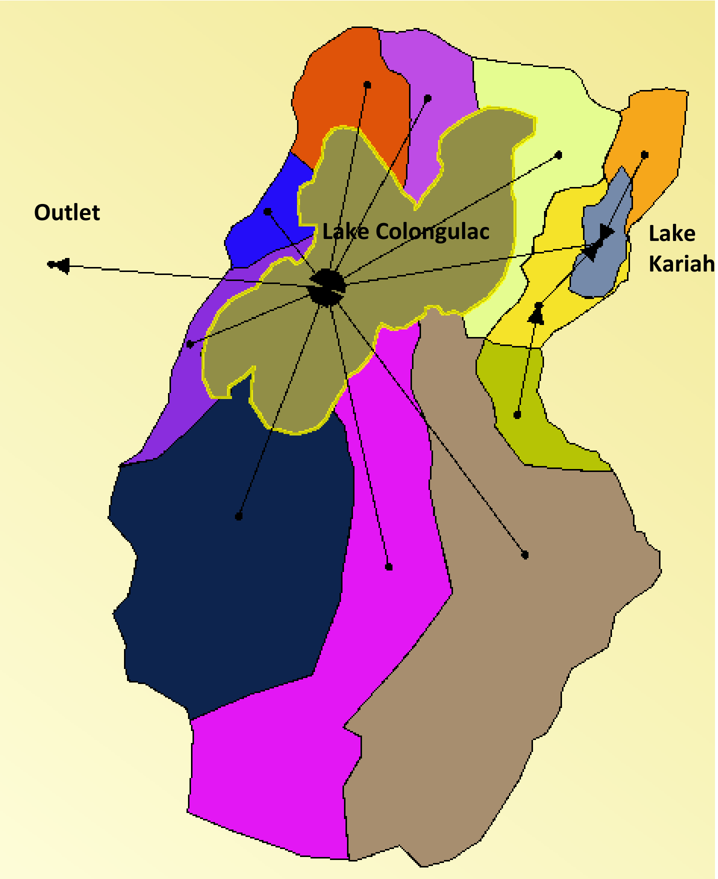


Figure 6-4 WaterCAST Network Delineation – Lake Colongulac

6.3 Functional Units

Functional units describe areas with common hydrological behaviours. For this model, the land use groups were employed as an indicator of the flows and nutrients generated within the catchment. Five land uses groups were chosen based on the prevalence within the catchment, and ability to model all significant processes. Based on the literature review, the dominant landuses were as follows:

- Grazing modified pastures (65%)
- Cropping (13%)
- Grazing natural vegetation (9%)
- Production Forestry (3%)
- Residential (3%)

The proportional area of each of these landuse categories was completed for the lakes catchments. As the sub-catchments have been delineated based on watersheds, there are multiple land uses (functional units) in each sub-catchment. The remaining area was lumped into a hydrologically similar functional unit called "other". Table 6-1 displays the relative areas of each functional unit. Note sub-catchment numberings correlate to the numbers displayed in Figure 6-1 and Figure 6-2.

Table 6-1 Functional Unit Areas

Subcatchment	Cropping	Grazing	Lake	Other	Production Forestry	Residential
Lake Murdeduke						
1	0 %	9 %	100 %	0 %	0 %	0 %
2	36 %	41 %	0 %	22 %	0 %	1 %
3	36 %	59 %	0 %	3 %	0 %	2 %
4	22 %	77 %	0 %	0 %	0 %	2 %
5	4 %	95 %	0 %	0 %	0 %	1 %
6	53 %	46 %	0 %	0 %	0 %	1 %
7	13 %	86 %	0 %	0 %	0 %	1 %
8	38 %	60 %	0 %	0 %	0 %	2 %
9	4 %	95 %	0 %	0 %	0 %	2 %
10	15 %	84 %	0 %	0 %	0 %	2 %
11	0 %	98 %	0 %	0 %	0 %	2 %
12	27 %	71 %	0 %	0 %	0 %	2 %
13	17 %	80 %	0 %	0 %	0 %	3 %
14	47 %	52 %	0 %	0 %	0 %	1 %
15	20 %	78 %	0 %	0 %	0 %	2 %
Lake Colongulac						
1	0 %	0 %	100 %	0 %	0 %	0 %
2	0 %	99 %	0 %	0 %	0 %	1 %
3	0 %	99 %	0 %	0 %	0 %	1 %
4	0 %	99 %	0 %	0 %	0 %	1 %
5	0 %	0 %	100 %	0 %	0 %	0 %
6	0 %	99 %	0 %	0 %	0 %	1 %
7	0 %	99 %	0 %	0 %	0 %	1 %
8	0 %	99 %	0 %	0 %	0 %	1 %
9	0 %	98.3 %	0 %	0.7 %	0 %	1 %
10	0 %	72.9 %	0 %	0 %	0 %	27.1 %
11	0 %	64.7 %	0 %	0.6 %	0 %	34.7 %
12	0 %	99 %	0 %	0 %	0 %	1 %
13	0 %	99 %	0 %	0 %	0 %	1 %

In the Lake Murdeduke catchment the ‘other’ landuse is a significant portion of sub catchment 2 (west of lake). This refers to the piggery on the eastern banks of Lake Murdeduke (refer to Figure 6-5).

Figure 6-5 Piggery on banks of Lake Murdeduke

The Lake Colongulac catchment contained a quarry (Subcatchment #9) and the Camperdown Treatment Facility (Subcatchment #11) which were treated as the functional unit ‘other’.

6.4 Rainfall-Runoff

SIMHYD is a daily conceptual rainfall-runoff model that estimates daily stream flow from daily rainfall and areal potential evapotranspiration data. It fits into the spatially distributed framework provided by WaterCAST (via spatially varying rainfall, runoff properties assigned by land-use or other attributes) and can provide reliable predictions of streamflow. SIMHYD was chosen as the most appropriate rainfall-runoff model for the region due to its simplicity and the smaller parameter inter-dependency. SIMHYD also increases the likelihood of transferring optimised model parameters from one catchment to other catchments with similar characteristics.

The model contains three storages for interception loss, soil moisture and groundwater. The model has seven parameters as follows:

- Baseflow Coefficient
- Impervious Threshold
- Infiltration Coefficient
- Infiltration Shape
- Interflow Coefficient
- Pervious Fraction
- Rainfall Interception Store Capacity
- Recharge Coefficient
- Soil Moisture Store Capacity

The structure of the SIMHYD model is shown in Figure 6-6.

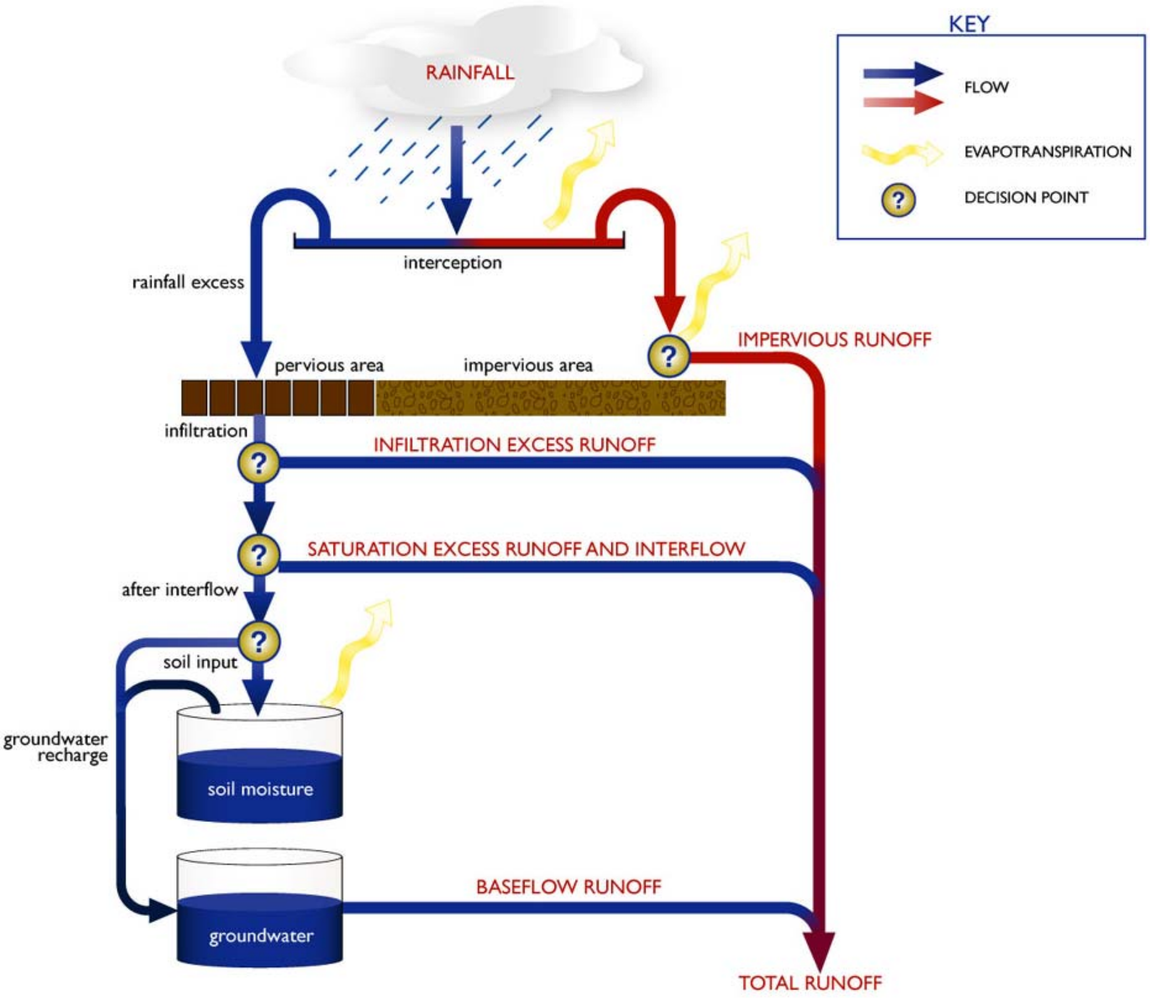


Figure 6-6 SIMHYD Model Structure

(Source: WaterCAST Component Models Manual, 2008)

The rainfall data was sourced for the region using the SILO data drill information. The infilled time series ranges from 1/1/1989 – 5/10/2009 producing a 20 year simulation time. Details are provided in Section 2.1.3.7. The BOM rainfall stations closest to Lake Colongulac showed a consistent 5% increase in the rainfall depth compared to the SILO data. A constant 5% adjustment was therefore applied to the SILO data to match this observation.

The Mia Mia Creek flow gauge was used to calibrate the model and refine the regional soil parameters. These soil parameters were then applied to the ungauged sub-catchments. As only one gauge was available, it is not possible to generate different parameters for individual functional units as part of this study.

6.5 Nodes

Nodes have been placed at locations of any gauging stations located within the catchment (both flow and water quality). This enables extraction of data from this point and all future calibration of the model to these gauges. Nodes were also placed at any river intersections or places of hydrologic significance to allow extraction of data at this point.

The Camperdown Sewerage Treatment Facility was included as a point source of water (and in future could contain water quality parameters too). No gauging data was available and instead Wannon Water was able to provide some typical conditions for the plant, including:

- Flows from the plant are weather dependent
- Volume is generally 280 – 375 ML/year
- 10 – 15 ML/year have been used to irrigate a local golf course
- Post 1999 the outflows have not been discharged into the lake

Based on this information it was therefore considered most appropriate to generate an inflow relative to the rainfall series, but scaled to match the measured flows. The inflows to Lake Colongulac range from 1961 when the plant was commissioned to 1999.

Figure 6-7 displays the generated outflows from the Camperdown Treatment plant.

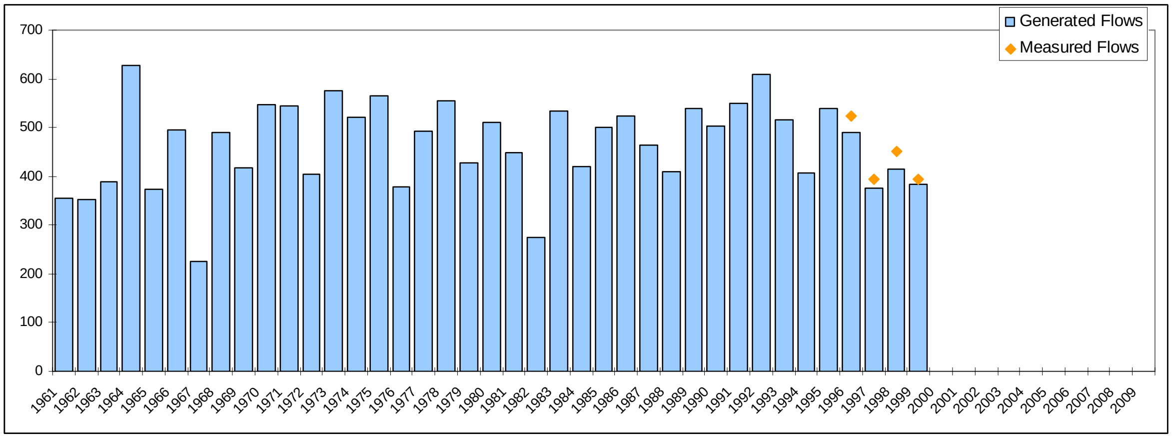


Figure 6-7 Camperdown Treatment Plant Generated Outflows

6.6 Links

The links within the model represent the surface water inflows to each of the lakes. Modification to the timing of any flows may be included as a flow lag within the model based on calibration to flow gauging. If no gauging station is available (which is the case for many of the smaller lakes) an assumed lag based on the stream reach length can be applied, however all gauging data matched with observed levels so lags were not required.

6.7 Storages

The lakes were included in the model as a wetland storage. This provides the modeller with the ability to adjust the lake management (controlled outflows, extractions) and view storage levels under various scenarios. The stage-area-volume calculations undertaken as part of the study was used to define the storages. SILO rainfall and evaporation were applied to each of the storages to replicate the direct processes on the lakes.

7 MODEL CALIBRATION

The hydrologic conditions within Lake Murdeduke and Colongulac were calibrated to all available hydrological data to achieve the best representation of the regional conditions. As the lakes chosen have less calibration data than Corangamite or Gnarpurt, the interpretation of the results will have to take into account the data limitations.

7.1 Available Data

The available calibration data includes:

- Gauge Height at Lake Murdeduke (Station 233600) on a monthly interval from 1980 – 2000, then 2005 – 2006.

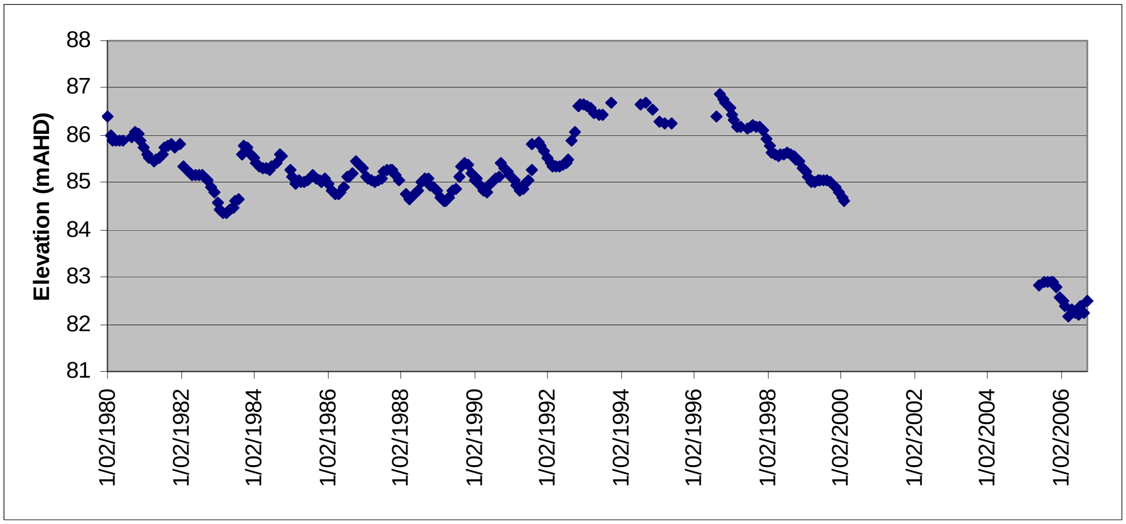


Figure 7-1 Lake Murdeduke Gauge Height

- Gauge Height at Lake Colongulac (Station 234606) on a monthly interval from 1965 – 1997, then 2005 – 2006.

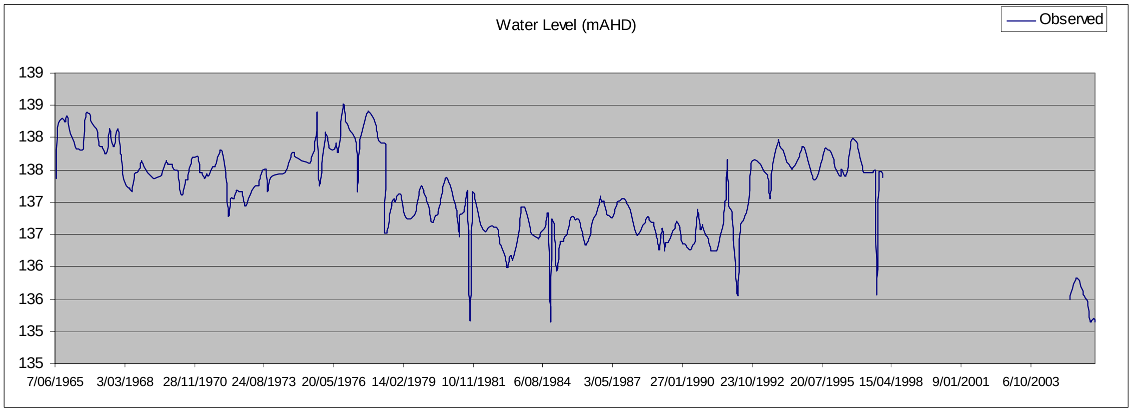


Figure 7-2 Lake Colongulac Gauge Height

- Station Level Data at Mia Mia Creek (upstream of Lake Murdeduke) (Station 233251) from 1997 - 2009

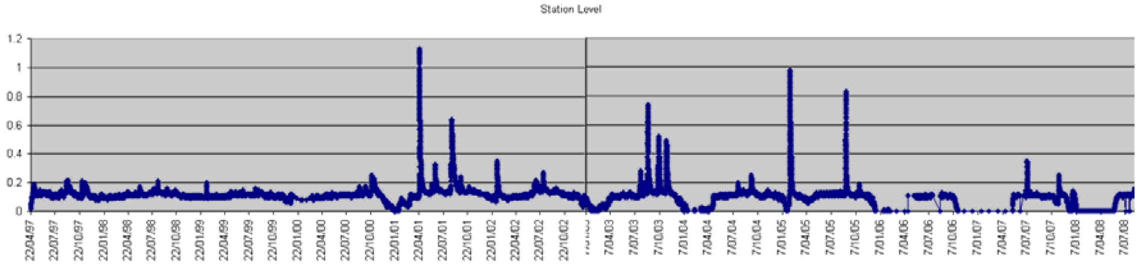


Figure 7-3 Mia Mia Creek Stage Height

- Flow Data at Mia Mia Creek (upstream of Lake Murdeduke) (Station 233251) from 1997 - 2009

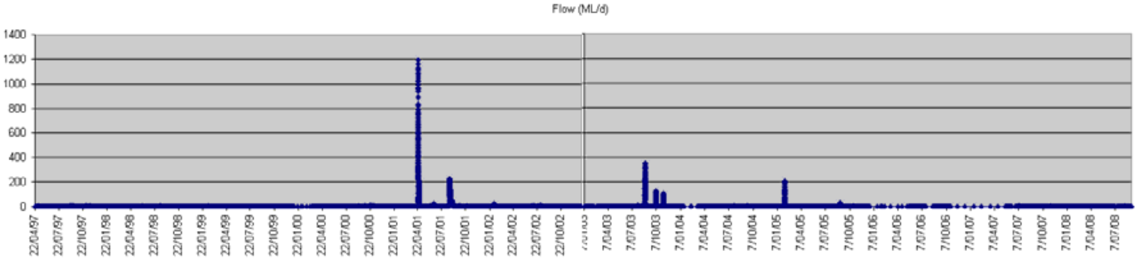


Figure 7-4 Mia Mia Creek Flow

7.2 Calibration Methodology

The calibration involved using the Rainfall Runoff Library (RRL) developed originally by the Cooperative Research Centre for Catchment Hydrology to calibrate SIMHYD parameters for the Mia Mia creek flow gauge. This approach has several strengths, namely:

(i) various automated optimization methods can be used to develop a parameter set;
(ii) calibration can use either daily or monthly observed stream flows.

The weaknesses of this package are that:

(i) only individual sub catchments can be calibrated at any one time with a single set of parameters (meaning differences in land use or nested gauged catchments cannot be represented);
(ii) the individual gauged sub catchments were in some cases aggregations of several WaterCAST sub catchments with different functional units and in WaterCAST the reaches linking these can also have abstractions removed from the modelled streamflow but not in RRL; and

(iii) it was intended to parameterise the final WaterCAST SIMHYD model with different parameter sets for various functional units, this was also not readily achieved using the RRL and the lack of flow gauges. Instead all functional units are assumed to have the same hydrologic response until further data is available.

The infiltration coefficient and infiltration shape parameters were fixed based on outcomes from a study using SIMHYD in a large catchment in SE Queensland (Chiew et al, 2002 - referred to subsequently as the SEQ study). In the SEQ study, an Environmental Management Support System (EMSS) was developed which was the predecessor of E2 and WaterCAST. For the hydrological modelling, separate parameter sets were developed for forested, urban and non-forested land uses that were then applied to all sub catchments in the region. A FORTRAN program was developed (Chiew et al 2002) to optimise SIMHYD using the pattern-search optimization algorithm to generate regional parameter sets, by running simultaneous simulations of several gauged sub catchments with both land uses. This method used monthly observed flows from selected gauges for calibration.

The remaining model parameters were calibrated individually using the optimizer in RRL. The closest match to the data was achieved with a pattern search optimisation method. Within RRL two objective functions need to be defined to determine which hydrological processes are most important for the study. Matching flow values (using the sum of difference of logs as the primary objective function) and the flow duration curve (as the secondary objective function) was considered most important for this study.

7.2.1 RRL Input Data

RRL requires the input of a rainfall, evaporation and observed flow time series in order to generate a calculated runoff. The generated runoff is matched as closely as possible to the observed runoff by modifying the soil and store parameters. In order to generate the flow for a 100 Year time period the SILO rainfall and evaporation data was used. The Mia Mia flow gauge only extended from 1997 – 2009 but with a change in location on 26 September 2005. The period from 1997 – 2005 was chosen for the calibration period. Figure 7-5 displays the input data to the SIMHYD model (rainfall, evaporation and observed flow).

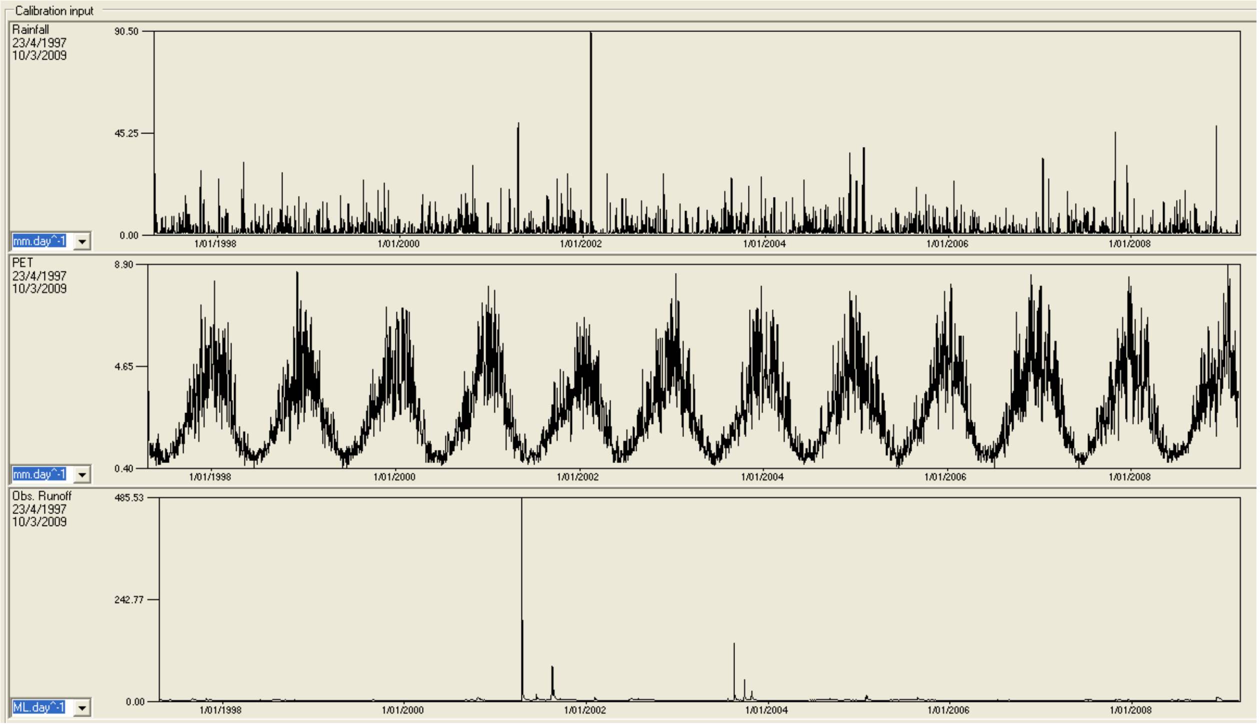


Figure 7-5 RRL Input Data – Rainfall, Evaporation, Observed Runoff

7.2.2 Mia Mia Gauge

The flow gauge at Mia Mia Creek runs from 1997 – 2009, in which time two significant events have been observed (refer Figure 7-6). Generally the gauge displays a limited response for the amount of rainfall on the catchment indicating the dominance of groundwater inflows.

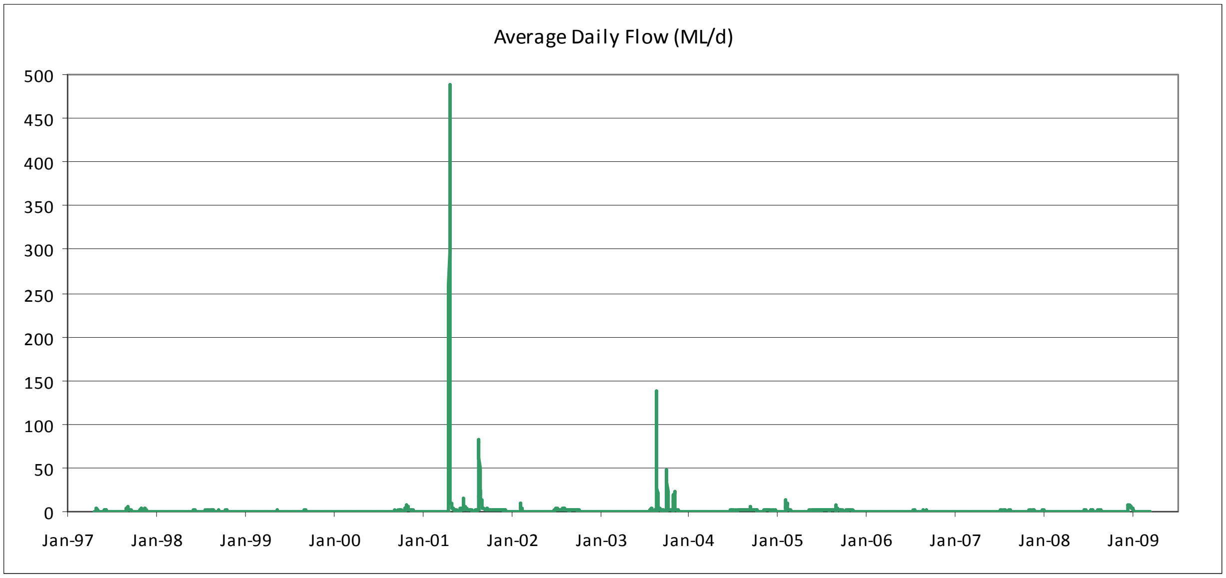


Figure 7-6 Average Daily Flow at Mia Mia Gauge

When plotting the rainfall versus runoff for the gauge on a monthly basis, the dominance toward the low flows for various rainfall events can be clearly seen (Figure 7-7).

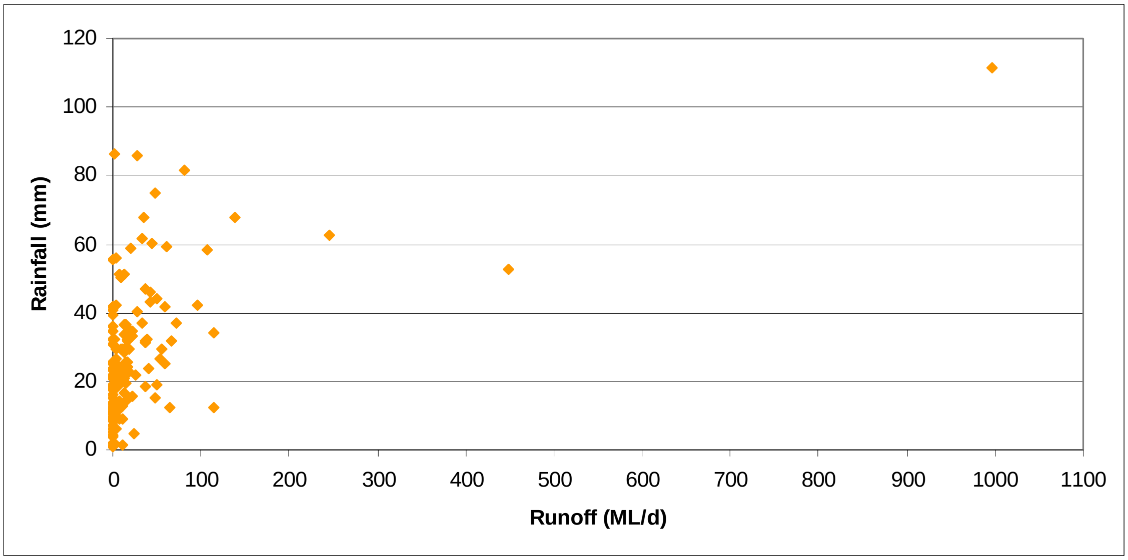


Figure 7-7 Monthly Rainfall vs. Runoff for Mia Mia Gauge

Quality codes for each of the flow readings were obtained from Thiess. The red markers in Figure 7-8 indicate the readings that have been interpolated from a stage-runoff curve rather than observed values. All high flow readings fall into this category.

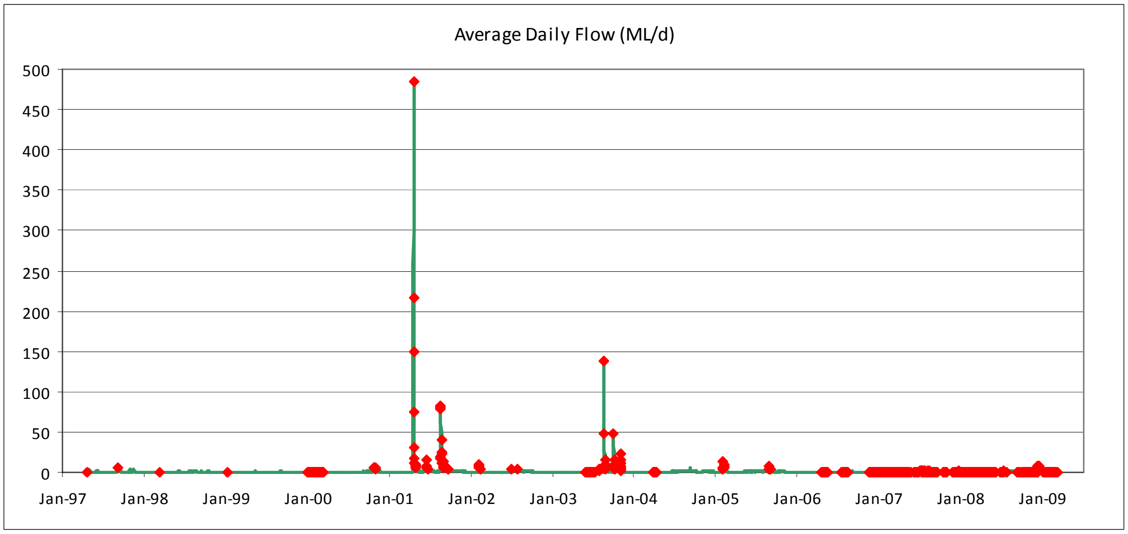


Figure 7-8 Quality of Daily Flow Data at Mia Mia Gauge

An examination of the stage flow rating curve was undertaken. The stage-discharge curve (as shown in Figure 7-9) displayed two distinct curves. These two curves have not been defined at two different periods of time, hence the choice of curve would significantly alter the generated flow at Mia Mia creek. Thiess has chosen values between these two curves to represent the flow for a given stage on the creek.

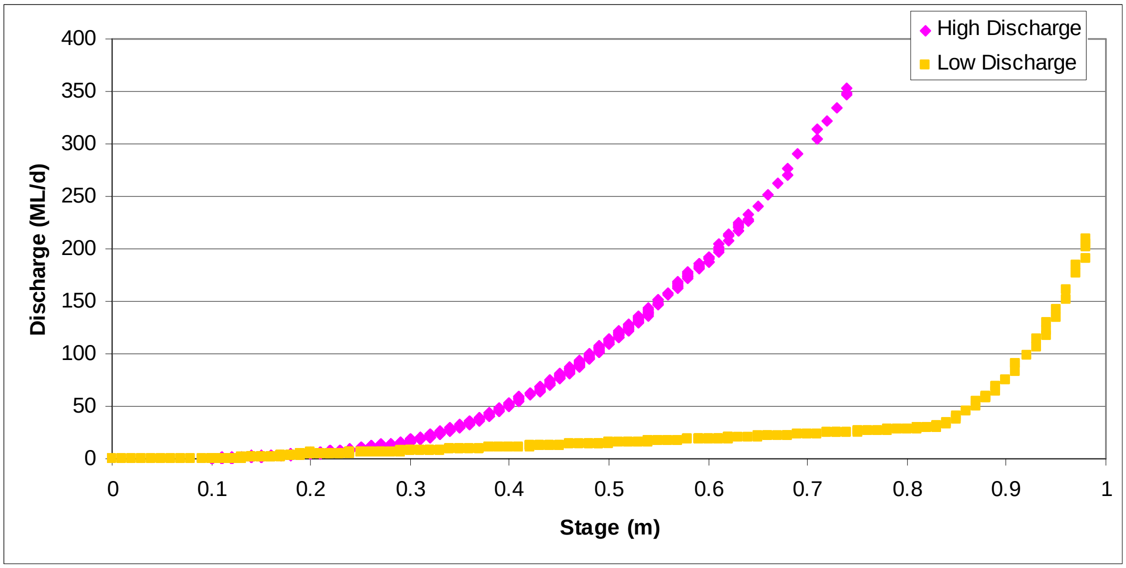


Figure 7-9 Stage Discharge Curve for Mia Mia Gauge

The calculated daily flow for each observed stage heights was calculated using the high and low stage-discharge curves. Where the discharge was known rather than interpolated from these curves the actual value was used. Significant differences were observed between the available flow data and the flows generated from the stage-discharge curves, (Figure 7-10). The lower curve was considered to be more representative of the conditions likely to be observed at the site, rather than the values provided by Thiess.

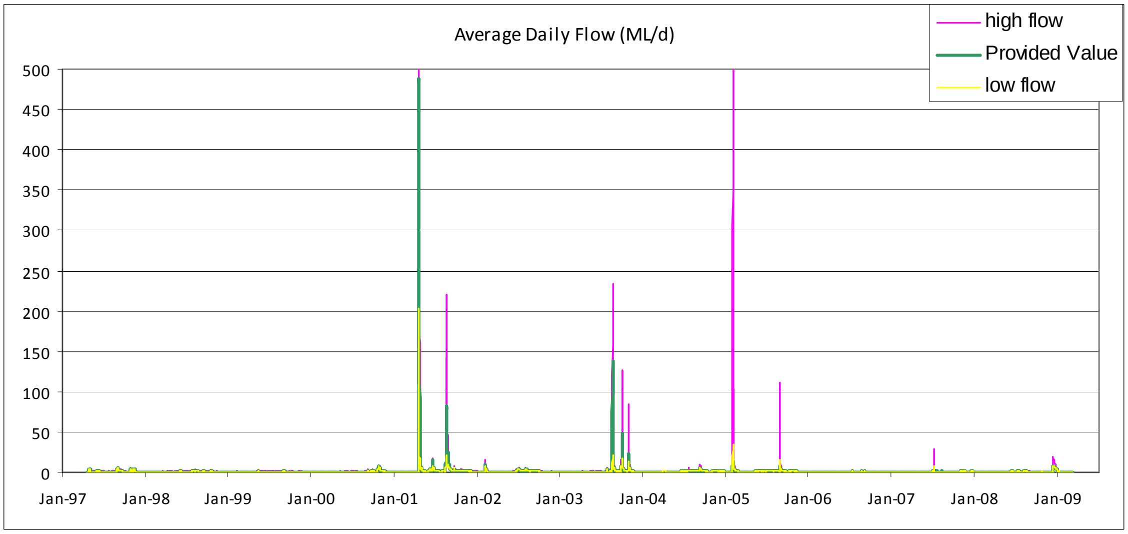


Figure 7-10 Various flows based on Stage-Discharge Curves

7.3 Calibration Limitations

The best fit between the modelled and observed flows was generated within SIMHYD. The fit was based on choice of the objective function and often a choice has to be made whether to match the high or low frequency events. As baseflow dominates the catchment, coupled with the uncertainty in the higher flows, it was considered more appropriate to match the low flows rather than replicate the infrequent high flows. A good calibration was achieved but in general the lowest flows were slightly overestimated and the median range flows slightly underestimated.

7.4 Calibration Results

7.4.1 SIMHYD Parameters

Using RRL the optimised SIMHYD parameters were defined. Table 7-1 displays the optimised values for the Mia Mia gauge. These values have then been assumed for the remaining catchment.

Table 7-1 Optimised SIMHYD Parameters

Parameter	Value	Chiew et al. (2005) optimised parameters
Baseflow Coefficient	0.10	0.12
Impervious Threshold	4.9 mm	
Infiltration Coefficient	350	200
Infiltration Shape	1.0	1.5
Interflow Coefficient	0.012	0.31
Pervious Fraction	0.996	
Recharge Interception Store Capacity	4.6 mm	3.2 mm
Recharge Coefficient	0.06	0.11
Soil Moisture Store Capacity	255 mm	195 mm

These SIMHYD values are indicating a high proportion of the flow entering baseflow rather than surface runoff. This is a factor of the relatively undeveloped catchment (high pervious fraction) and high infiltration parameters. When compared to Chiew et al (2005) study for ungauged catchments around Australia, there is a much smaller saturation excess runoff and interflow as a result of the reduced interflow coefficient. This is directing more water towards the groundwater rather than producing surface runoff. These results correlate with observations and commentary in the available literature for the Western District Lakes.

7.4.2 Comparison to Flow Gauge

Generally a reasonable match was achieved between the observed and calculated runoff (Figure 7-11). The higher baseflows and responses to rainfall have been simulated, with the only major variation being the significant flow event observed in April 2001.

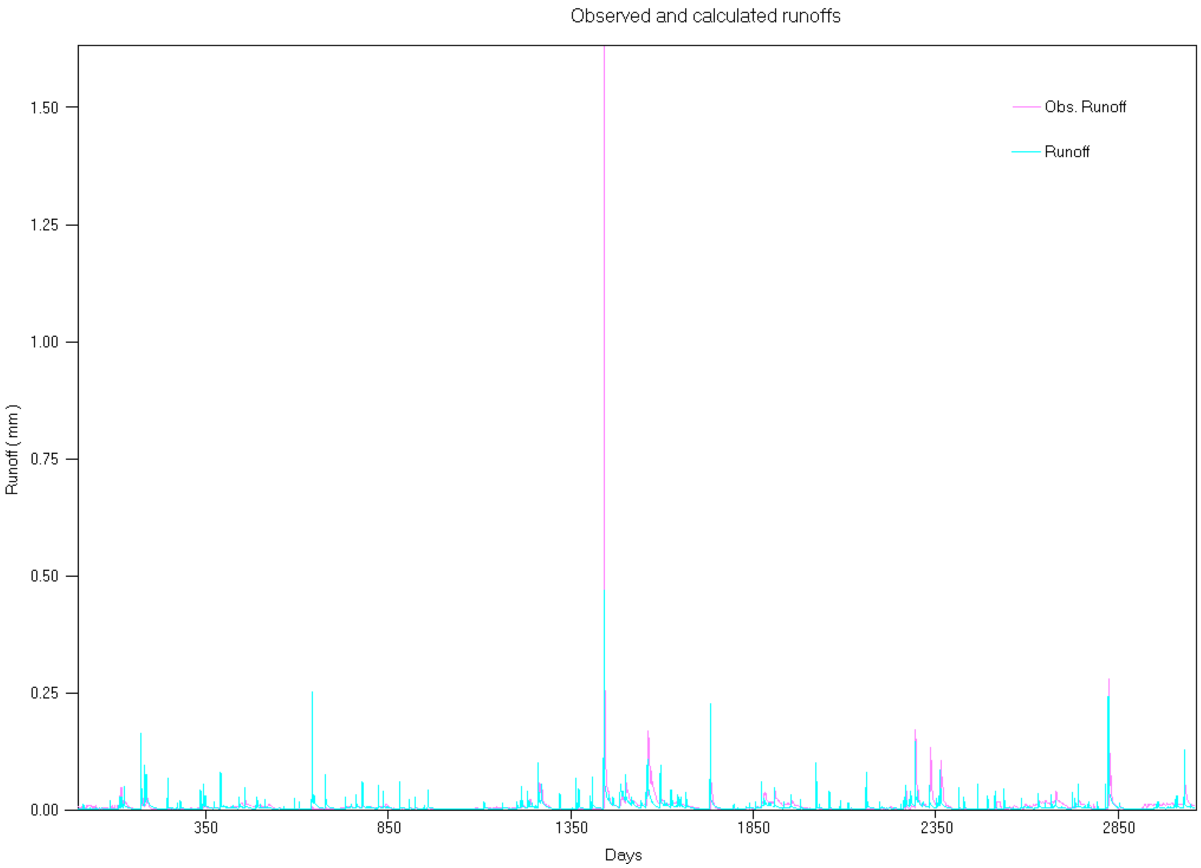


Figure 7-11 Calibrated Runoff vs. Observed for Mia Mia Gauge

A log scatter plot of the observed vs. calculated flows on a monthly basis was generated (Figure 7-12). A monthly timescale was used to place less weighting on individual events. This plot demonstrates that the high observed flows are represented quite well within the model, with some of the lowest flows being overestimated.

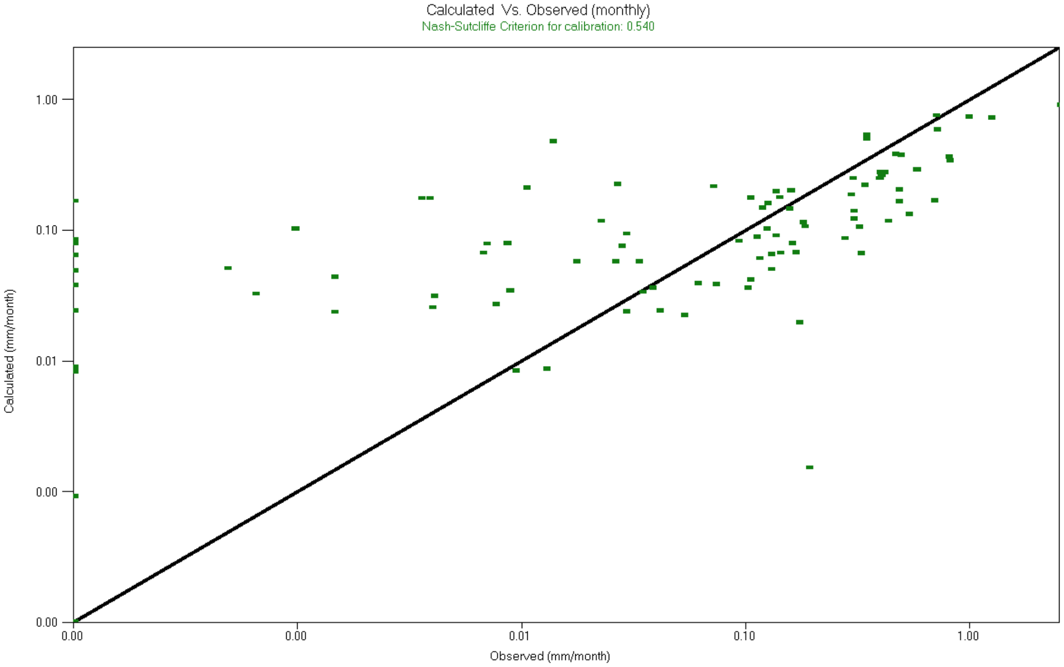


Figure 7-12 Monthly Log Scatter Plot of Calibrated Runoff vs. Observed

This trend is also represented in the flow duration curve where low baseflows are overestimated, median range flows are slightly underestimated and high flows are reasonably represented (Figure 7-13). Modification to the optimisation function enabled a closer match to the flow duration curve at various sections. However, this led to a significant over or under estimation of flows in the rest of the curve.

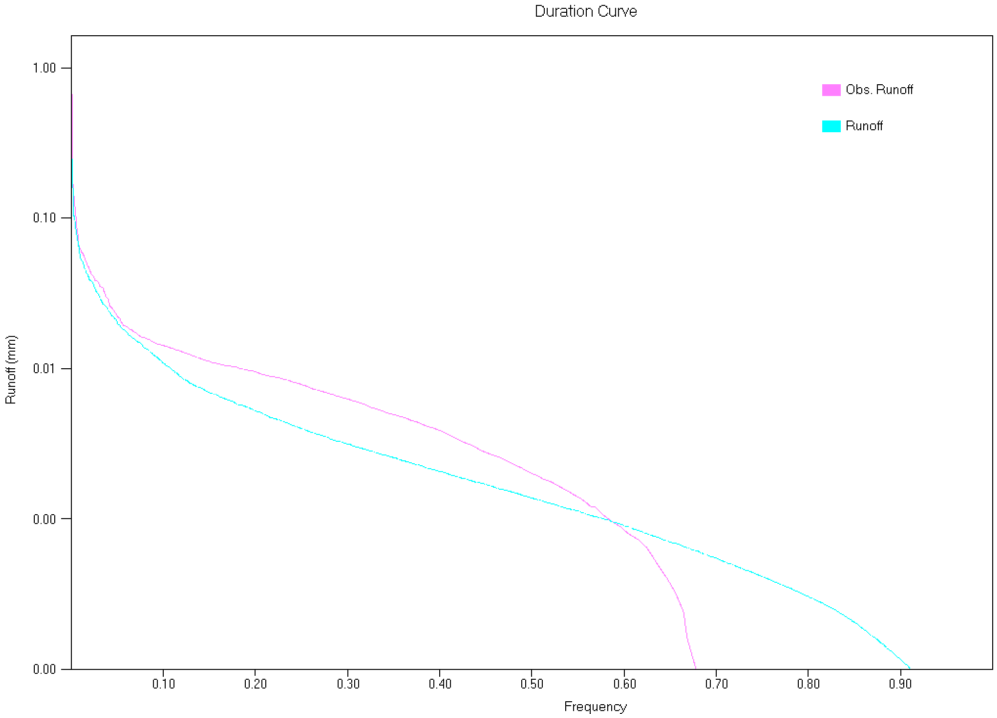


Figure 7-13 Flow Duration Curve (log) Calibrated Runoff vs. Observed

The above calibration plots demonstrate that the calibration is not perfect, and could potentially be improved with further work. However it was thought that given the large amount of uncertainty in the gauged flows (with the multiple rating curves etc), that further work was not warranted. This was also reviewed in light of the reasonable fit between the observed and modelled lake water levels. The ability of the model to reproduce the observed lake levels is really the ultimate test for the WaterCAST models.

7.4.3 Groundwater

Once the SIMHYD parameters were applied to the entire catchment the WaterCAST model was run. Outputs were then compared to Lake Murdeduke observed levels to determine if any additional catchment scale groundwater inflows were required.

A constant net outflow of 2.9 ML/day was required to match the general baseflow level within the lake. This was added manually to the model as this process is unable to be represented in WaterCAST.

In order to replicate the results at Lake Colongulac a net groundwater inflow of 4.15 ML/day was required.

These results are consistent with findings from Coram (1996) where a net groundwater inflow of 14% is observed at Lake Colongulac, and a net groundwater outflow of 2% observed for Lake Murdeduke.

7.4.4 Comparison to Lake Murdeduke Levels

Monthly water level data from 1980 – 2000, then 2005 – 2006 was available at Lake Murdeduke from Thiess. Supplementary data at a six hour timescale for 2008 – 2009 was provided by the University of Ballarat (Geology). The best fit for the observed data is shown in Figure 7-14.

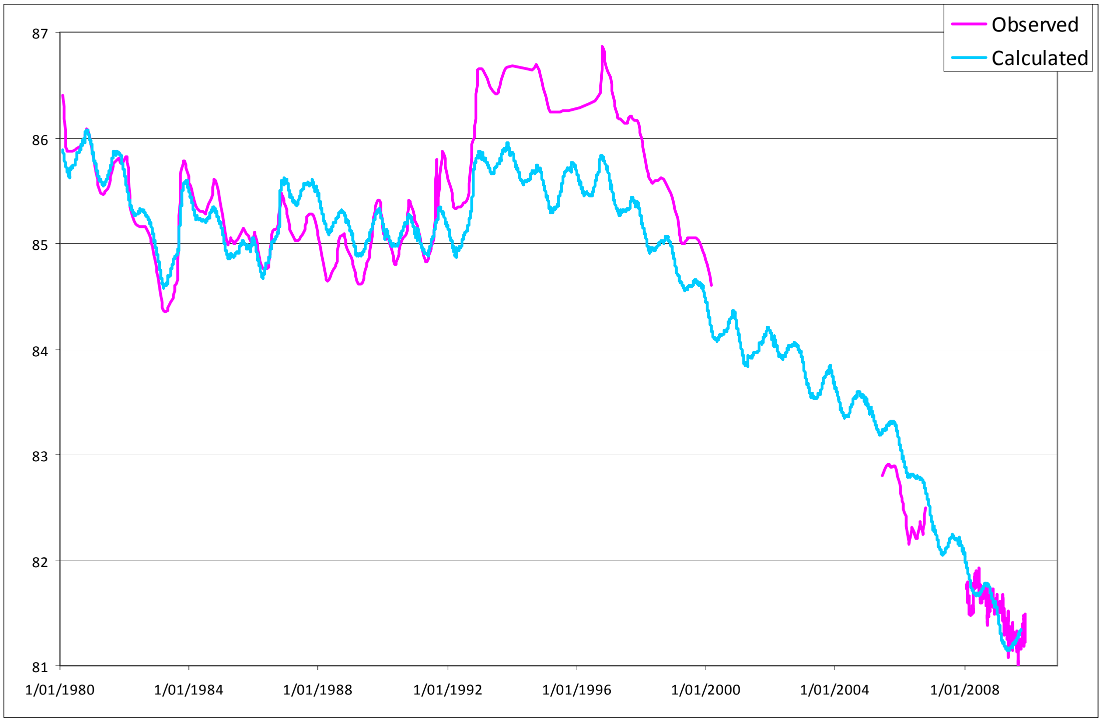


Figure 7-14 Calculated vs. Observed water levels in Lake Murdeduke

Water levels within the lake tend to fluctuate on a seasonal basis in the order of 0.25m. This seasonal fluctuation is then overlayed on longer term water level trends based on the rainfall in the catchment. Base flows are an important component to the water level within Lake Murdeduke, providing the long term responses to high and low rainfall periods. Steep increases in water levels are dominated by high rainfall events and significant surface water flow.

The WaterCAST simulation is run from 1889 to 2009. The model is therefore providing a good replication of the observed levels when it reaches the start of the gauging in 1980. From 1980 the model is providing a good representation of the general water level trends, baseflow levels and six monthly variations in levels. The long term downwards trend observed between 1996 and 2009 was well represented within the model.

The high flow event in 1992 was unable to be replicated accurately by the model, with a 0.9m difference in water levels. No significant rainfall events or consistent rainfall events were recorded prior to this spike in observed water levels, and therefore the rainfall-runoff model was unable to replicate these flows. The SIMHYD parameters provided a reasonable representation of the high flows at the Mia Mia gauge as shown by the flow duration curve, so it is unknown what has caused this discrepancy. It could potential be caused by incorrect flow gauging (gauges are often inaccurate at high flows), or perhaps a secondary flow path that is activated at high flows that is not included in the model.

7.4.5 Comparison to Lake Colongulac Levels

Once the Lake Murdeduke model was calibrated the SIMHYD parameters were then applied to the Lake Colongulac WaterCAST model. Preferably a new set of parameters would be derived for this lake based on local gauges, however with the lack of any calibration data the Murdeduke set was used.

The model was able to achieve a relatively close representation of the observed values from 1978 to 2006. However, the period from 1965 to 1978underestimates the lake water levels significantly. The modelled water level showed a close fit to the modelled water level from Dekker & Williams (1988) in the period from 1900 to 1965. The period post 1965 showed water levels slightly higher than that modelled by Dekker & Williams (1988). The modelled water levels compared to observed levels are shown in Figure 7-15, with modelling results from Dekker & Williams (1988) displayed in Figure 7-16.

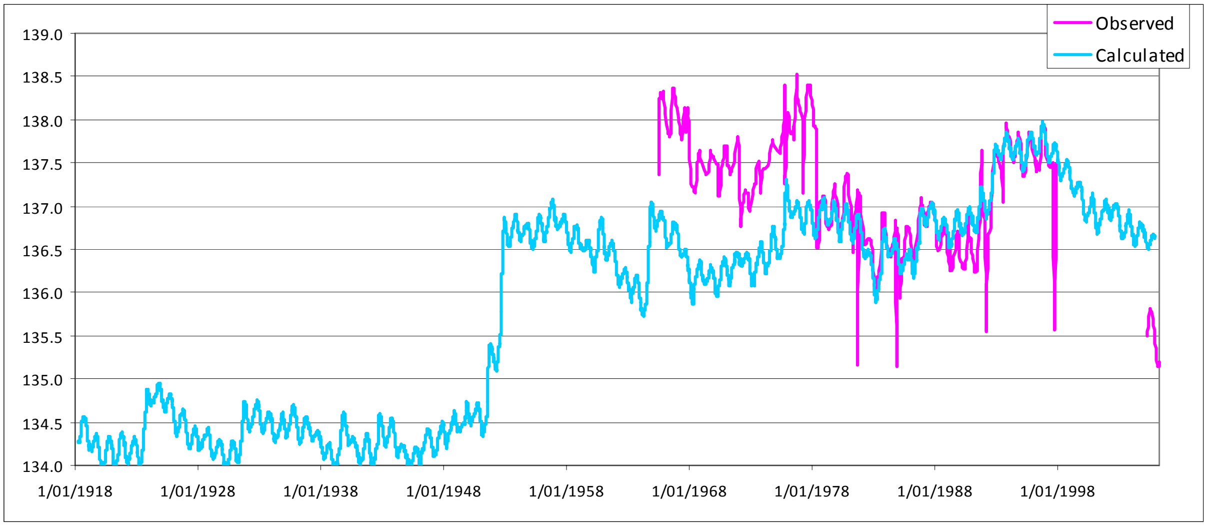


Figure 7-15 Calculated vs. Observed water levels in Lake Colongulac

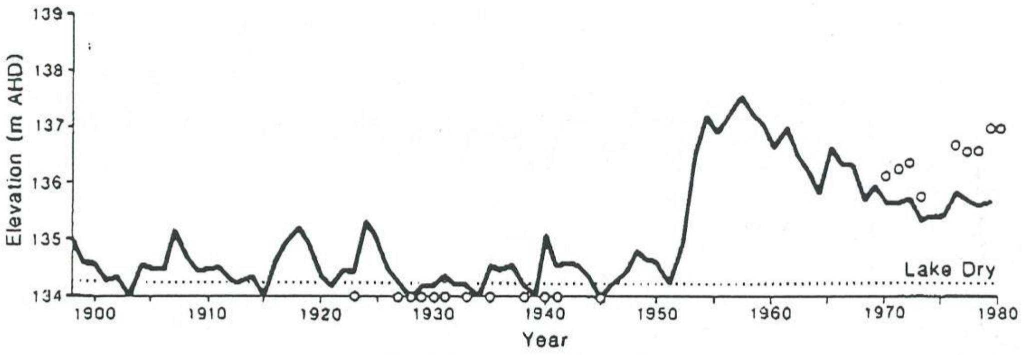


Fig. 3. Lake Colongulac water level simulation (1898 – 1978). The levels shown assume no waste inflow. Open circles indicate observed summer water levels (with waste inflow). Elevation (m AHD), water level above Australian Height Datum [sea-level]. After Gutteridge *et al.* (1980).

Figure 7-16 Lake Colongulac Water Levels shown in Dekker & Williams, 1988

As per the Murdeduke model the seasonal variation in water levels was reasonably well defined. In the period from 1965 – 1978 the model under predicts the water level by approximately 1m, however the seasonal variation is similar to the observed values. The period between 1978 and 1998 is replicated reasonably well. Sudden drops in water level throughout this period are likely to be due to instrument error as the water level rebounds (by up to 2m) within the next monthly reading.

8 HYDROLOGIC ANALYSIS

A statistical analysis was undertaken on the output from the modelling and included time-series of inflows, outflows, volumes and lake water levels. Duration curves and a dry spells analysis was also conducted using eWater's River Analysis Package (RAP).

Once a baseline condition had been established, the impacts of climate change were assessed by varying the input rainfall and evaporation. The simulation was then rerun and compared to the base case to determine the differences in the water balance.

8.1 Lake Murdeduke

The general hydrological pattern of Lake Murdeduke is very similar to many wetlands within the Western District Lakes region. The wetlands fill in high rainfall events both by surface water and groundwater flow. After the rainfall events the wetlands drain down to their natural level, and then slowly evaporate until another event fills them again. One of the problems in recent times is that the frequency, magnitude and duration of these larger rainfall events have been significantly reduced such that wetlands do not fill to the same degree and the extended period between events enhances the wetland drying phase, resulting in reduced levels and extents compared to long-term average conditions.

8.1.1 Relative Hydrologic Influences

Evaporation is the dominant outflow process for Lake Murdeduke, as this is the only outflow from the lake and hence the outflows are equal to the sum of inflows for the system. Direct rainfall on the lake accounts for approximately 64% of the total inflow, 30% for surface water inflow and 6% for groundwater inflows. The dominance of direct rainfall is due to the large lake surface and a significant proportion of rainfall that is stored in subsurface water stores throughout the catchment.

Table 8-1 Lake Murdeduke Average Annual Volumes

Surface Water Inflow	Rainfall	Groundwater	Evaporation
13 ML	27 ML	-3 ML	-42 ML

The annual change in storage varies significantly, from +130 ML to -33 ML depending on the relative inflows and outflows. Groundwater and evaporation are essentially constant, and hence the annual storage volume changes with the combined effects of surface water inflows and rainfall events (Figure 8-5).

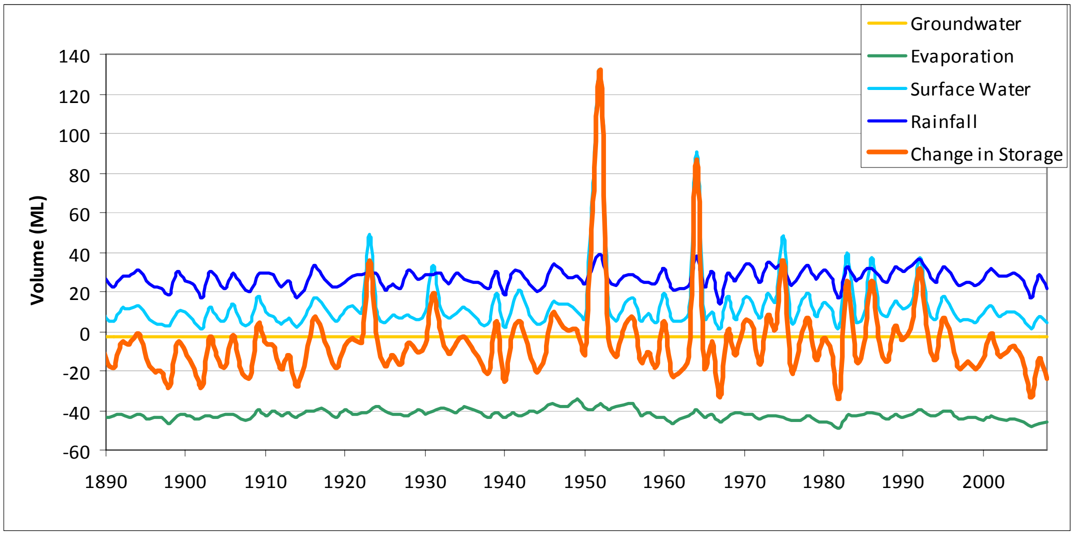


Figure 8-1 Lake Murdeduke Annual Water Balance

8.1.2 Mean water level on seasonal basis

The water level within Lake Murdeduke fluctuates both on a seasonal time scale and on a longer term regional climate time-scale. Generally on a seasonal basis the water level fluctuates by 0.2m, with roughly equal losses in Summer and Autumn compared to the gains in Winter and Spring. As the seasonal fluctuations are generally evened out throughout the year it is longer term regional climate trends that impact the most on the water level within the lake. Dramatic rainfall events and consecutive years with higher than average rainfall raise the water level of the lake to above average levels. Conversely long dry periods with lower than average rains drain the lake down over the decades.

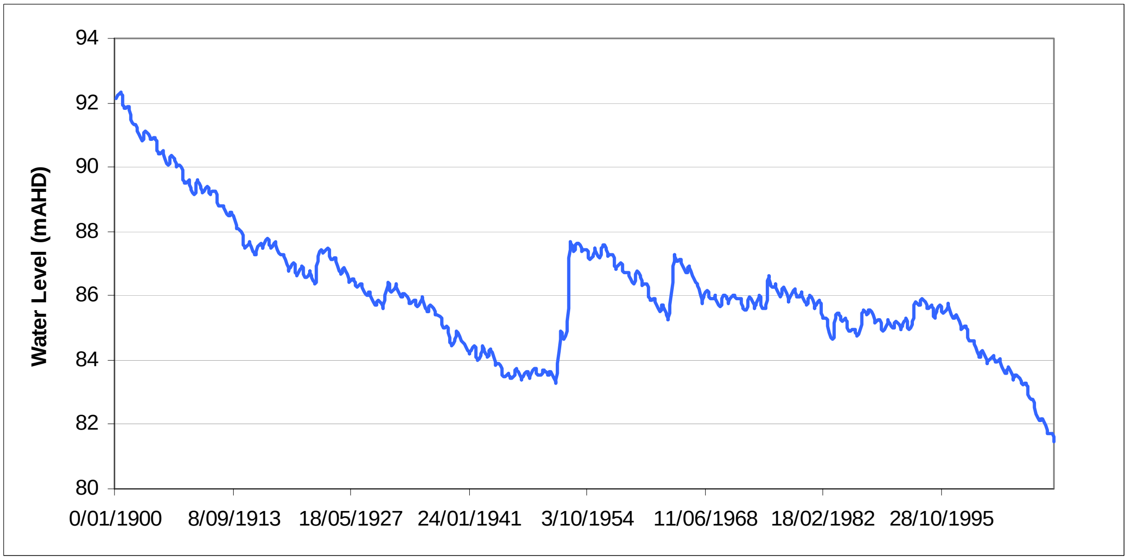


Figure 8-2 Lake Murdeduke Mean Seasonal Water Level

8.1.3 Dry spells

Assuming a minimum water level of 80.5 m AHD, the number of dry spell periods was calculated. There were no periods where the lake was dry between 1889 and 2009, with a minimum modelled level of 81.14 m AHD.

8.1.4 Stage duration curve

A seasonal stage duration curve was generated within RAP, as shown in Figure 8-3. A consistent shape observed for each season, indicating a very little difference in levels between seasons. Spring had slightly higher water levels and Autumn had the lowest for each duration. For all seasons the stage duration curve is steep for the low frequency events, indicating a significant rise in water level (as a result of rare high flow events). Only 25% of the modelled water levels are above 87.4 m AHD and half the modelled levels are above 85.9 m AHD. The water level fell below 83.5 m AHD (water depth 3m) 7% of the time and below 82.5 m AHD (water depth 2m) 2% of the time.

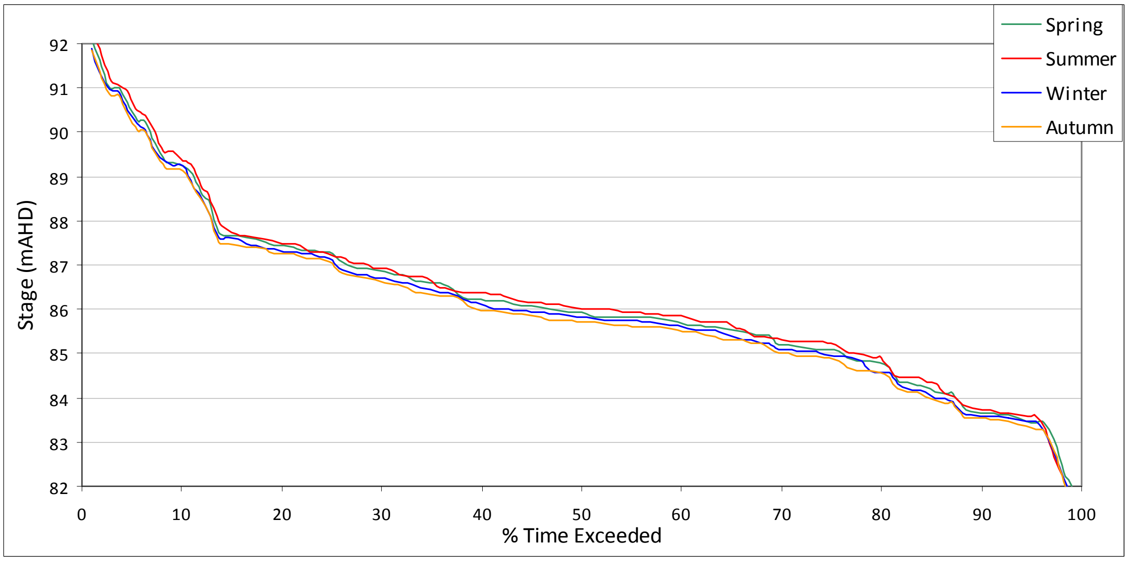


Figure 8-3 Lake Murdeduke Seasonal Stage Duration Curves

8.1.5 Volume duration curve

The seasonal volume duration curve for Lake Murdeduke is displayed in Figure 8-4. The volume of the lake exceeds 60,000 ML 70% of the time. The lowest modelled storage volume for Summer was much lower than the other seasons, 5,900 ML compared to 11,500 ML.

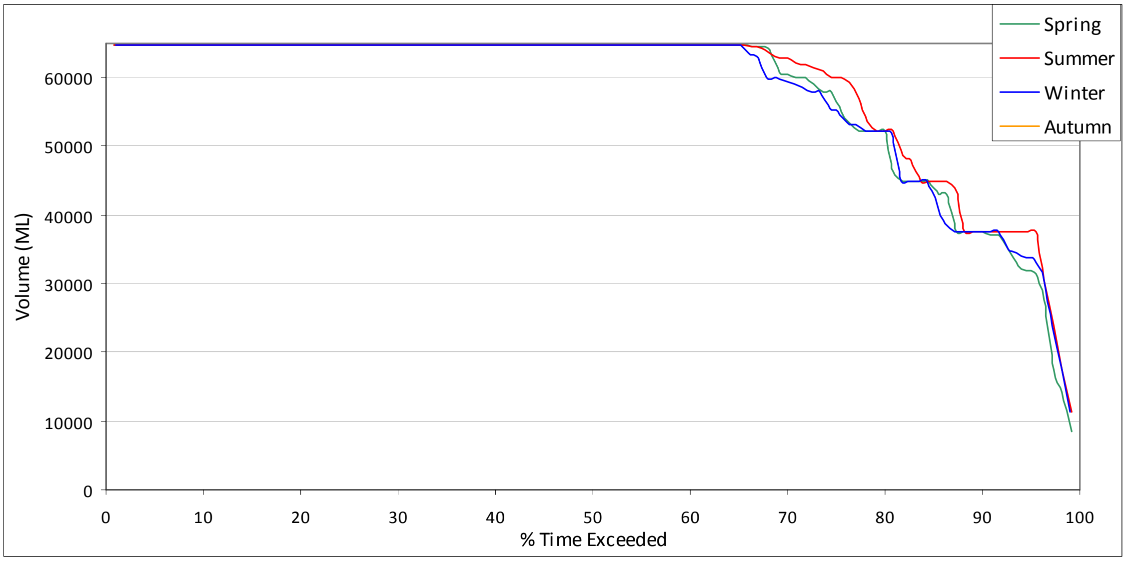


Figure 8-4 Lake Murdeduke Seasonal Volume Duration Curves

8.2 Lake Colongulac

Lake Colongulac has a much smaller catchment area than Lake Murdeduke and hence it responds to the local hydrology much quicker. This also makes the system much more responsive to the effects of climate change.

8.2.1 Relative Hydrologic Influences

Evaporation is the dominant outflow process for Lake Colongulac, as this is the only outflow from the lake and hence the outflows are equal to the sum of inflows for the system. Direct rainfall on the lake accounts for approximately 68% of the total inflow, 14% for surface water inflow, 16% for groundwater inflows and approximately 2% for the Camperdown Treatment Plant. The dominance of direct rainfall is due to a large lake surface and a significant proportion of rainfall that is stored in subsurface water stores throughout the catchment. The inflows from the Camperdown Treatment Plant are minute in comparison to other inflows.

Table 8-2 Lake Colongulac Average Annual Volumes

Surface Water Inflow	Rainfall	Groundwater	Evaporation
4 ML	18 ML	4 ML	-27 ML

The annual change in storage varies significantly, from +45 ML to -12 ML depending on the relative inflows and outflows. Groundwater and evaporation are essentially constant, and hence the annual storage volume changes with the combined effects of surface water inflows and rainfall events (Figure 8-5).

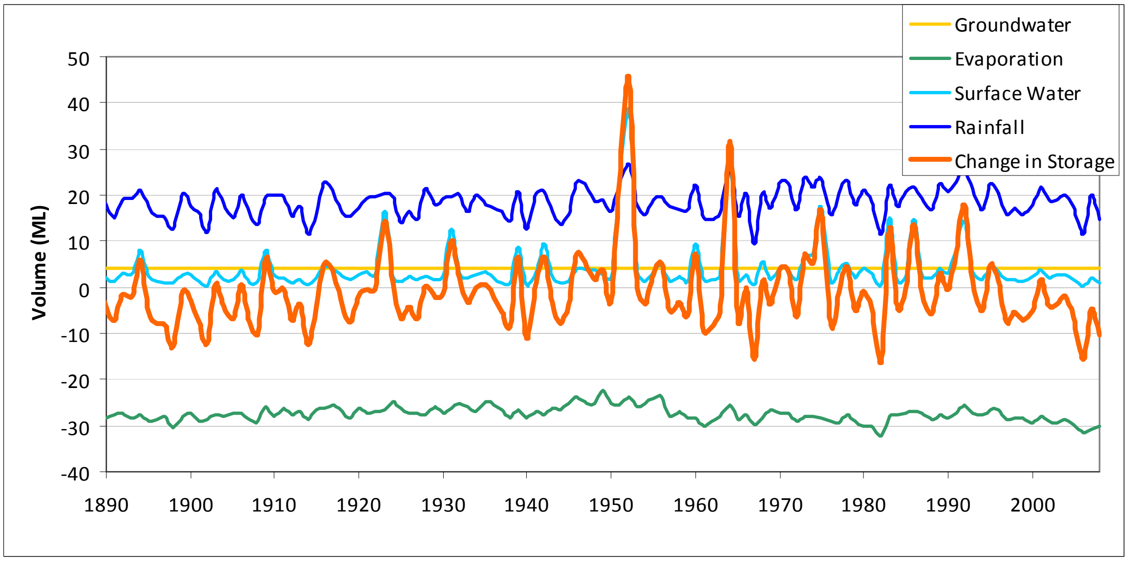


Figure 8-5 Lake Colongulac Yearly Water Balance

8.2.2 Mean water level on seasonal basis

Like Lake Murdeduke, the water level within Lake Colongulac fluctuates both on a seasonal time scale and on a longer term regional climate time scale. Generally on a seasonal basis the water level fluctuates by 0.2m, with roughly equal losses in Summer and Autumn compared to the gains in Winter and Spring (Figure 8-6). As the seasonal fluctuations are generally evened out throughout the year it is longer term regional climate trends that impact the most on the water level within the lake. Dramatic rainfall events and consecutive years with higher than average rainfall raise the water level of the lake to above average levels. Conversely long dry periods with lower than average rains drain the lake down over the decades.

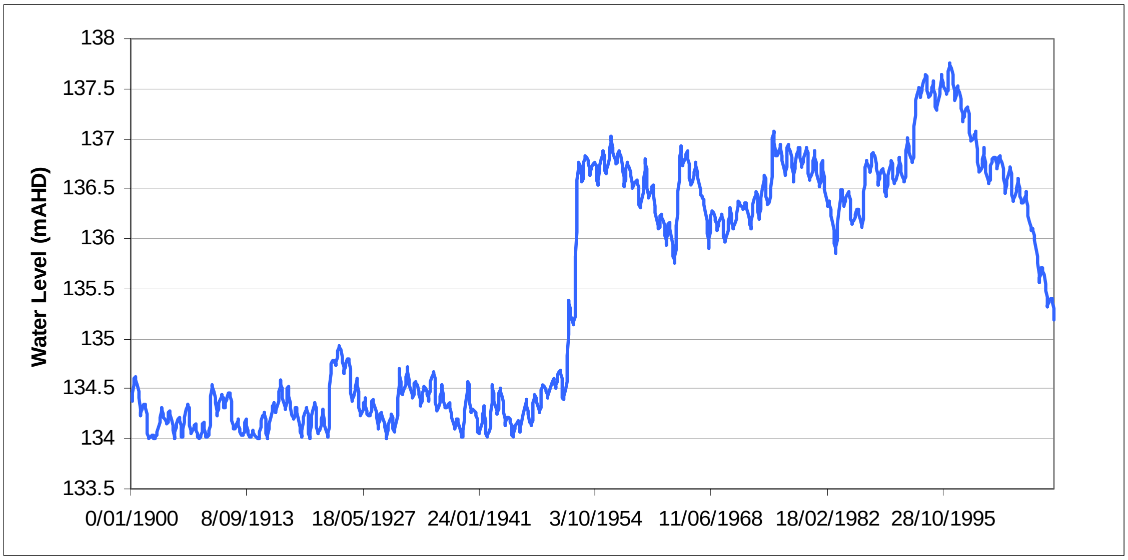


Figure 8-6 Lake Colongulac Mean Seasonal Water Level

8.2.3 Dry spells

Assuming a dry level of 134 m AHD, a Spells analysis of Lake Colongulac was undertaken (as shown in Table 8-3). 98 low spells were observed from 1889 to 2009, with a mean dry spell duration of 10 days. The longest dry spell duration was 46 days. Dry outs occurred 6.5% of the time.

Table 8-3 Spells Analysis of Lake Colongulac

Low Spell Threshold	134.0 m AHD
Number of Low Spell	98
Longest Low Spell	46 days
Mean Duration of Low Spell	10.7 days
Total Duration of Low Spell	1055 days
Total of periods Between Low Spells	15002 days
Mean period Between Low Spells	154.7 days
Longest period Between Low Spells	3153 days

8.2.4 Stage duration curve

The stage duration curve, as shown in Figure 8-7, indicates some differences in water level on a seasonal basis. Spring always has a higher water level than the other seasons, winter and summer are often similar, and autumn has the lowest level. 50% of the time the water level is approximately 135.6 m AHD and the water level only exceeds 137 m AHD 6% of the time. Dry outs occur 4% of the time for summer and autumn, 1% of the time for spring, and less than 0.5% for winter.

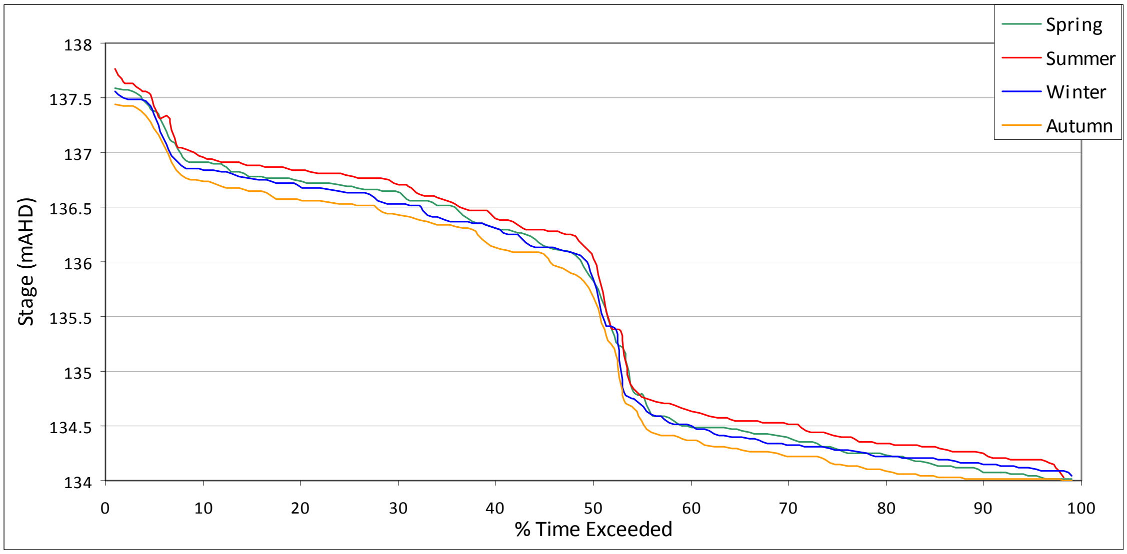


Figure 8-7 Lake Colongulac Seasonal Stage Duration Curves

8.2.5 Volume duration curve

50% of the time the volume of Lake Colongulac remains above 5,000 ML, as shown by the volume duration curve (Figure 8-8). The curve then shows a sharp decline in volume between the 53% and 58% exceedence, where for most seasons the volume of the lake is essentially zero 42% of the time. The lake is dry for Autumn 43% of the time, Winter and Summer 42% of the time, and Spring 39% of the time. The higher rainfalls in Spring enable the lake to withstand drying out better than the other months.

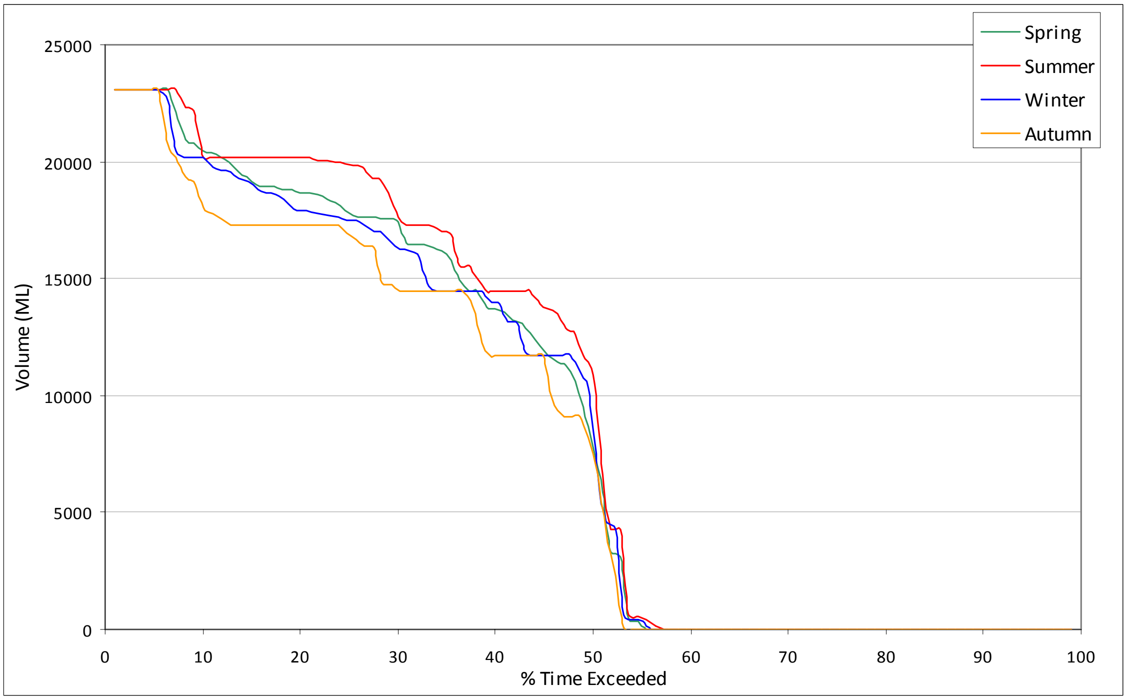


Figure 8-8 Lake Colongulac Seasonal Volume Duration Curves

8.3 Climate Change

A 2030 climate change scenario was modelled within WaterCAST to determine the impact of a reduced rainfall and higher evaporation on the lake levels. Details of the climate change parameters are shown in Section 2.1.5.

8.3.1 Lake Murdeduke

The climate change scenario was run over the same time period as the basecase to determine the differences in water levels. Figure 8-9 displays the water level under basecase and climate change scenarios assuming the water level was the same on 1/1/1930. At this point in time the water level within the lake is quite high compared to current levels.

The graph shows a much steeper decline in levels for the climate change scenario with a higher evaporation rate. During significant rainfall events the magnitude of water level increase has reduced (as a result of less rainfall). These factors have led to a drying out of the system on many occasions.

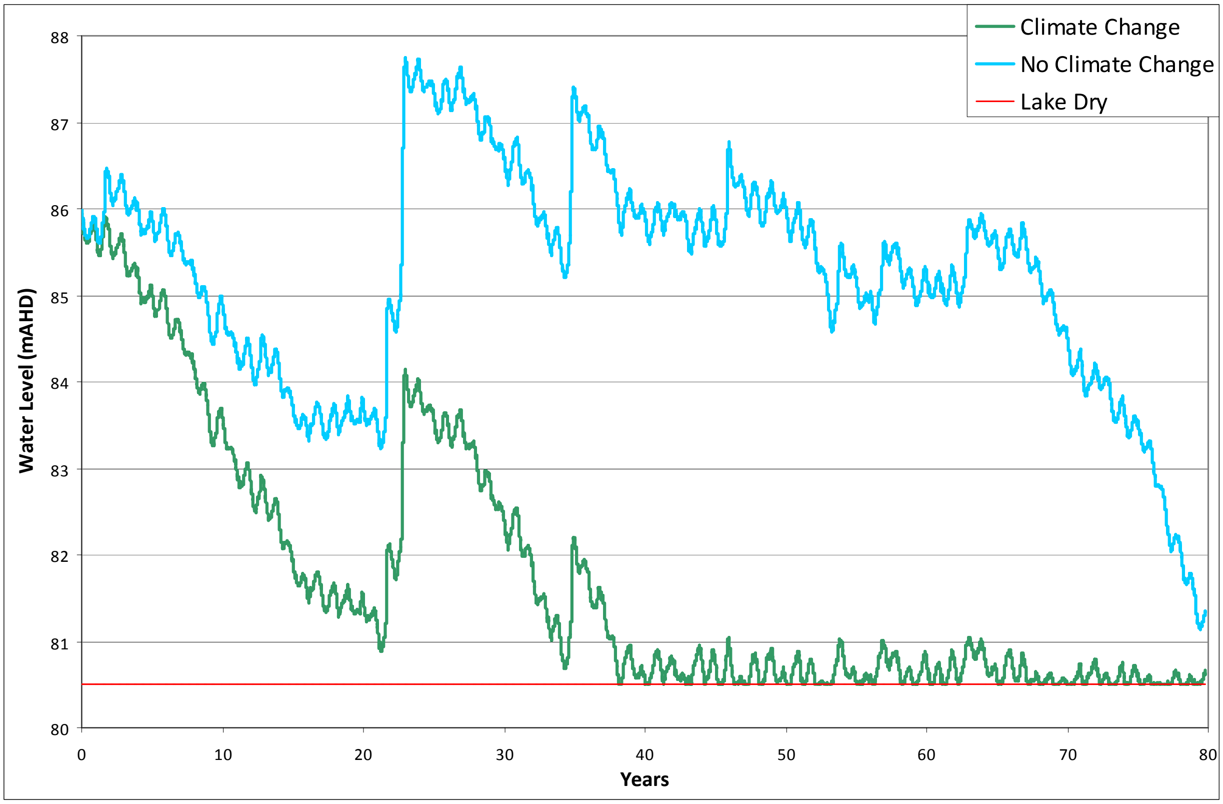


Figure 8-9 Climate Change Analysis for Lake Murdeduke

8.3.1.1 Relative Hydrologic Influences

Under climate change conditions the annual average volume of evaporation in the water balance has increased, leading to a net loss of water from the lake as the outflows exceed inflows over the simulation period. This is due to both increased evaporation and a decreased rainfall, leading to a reduced surface water inflow.

Table 8-4 Lake Murdeduke Average Annual Volumes – Climate Change

Surface Water Inflow	Rainfall	Groundwater	Evaporation
10 ML	26 ML	-3 ML	-43 ML

8.3.1.2 Mean water level on seasonal basis

As per the basecase the water level within Lake Murdeduke fluctuates both on a seasonal time scale and on a longer term regional climate time scale. Generally on a seasonal basis with no climate change conditions the water level fluctuates by 0.2m, but under climate change the Summer and Autumn losses are greater than the gains in Winter and Spring (0.25m lost and 0.15m gained). This has contributed to the gradual decline in water level throughout time, with a dramatic lowering of the lake water level over a long period of time (Figure 8-10).

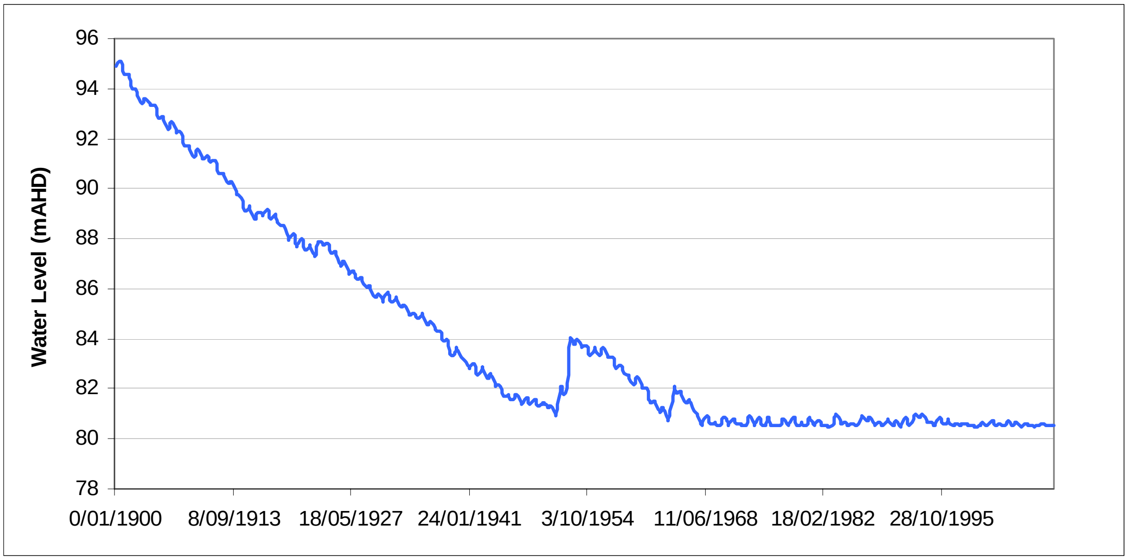


Figure 8-10 Lake Murdeduke Mean Seasonal Water Level – Climate Change Scenario

8.3.1.3 Dry Spells

For the basecase scenario there were no dry spells in the analysis. The impact of climate change is a significant increase in dry spells, where the lake is now dry on 3638 days (24% of the time). On average the dry spells last for a month, with the longest dry spell lasting 130 days (Table 8-5). This increase in dry spells has ecological implications for the larger lakes in the region. As well as increased dry spells the lake level is well below the base case lake level (around 5 m lower) for the majority of the simulation.

Table 8-5 Spells Analysis of Lake Murdeduke – Climate Change Scenario

Low Spell Threshold	80.5 m AHD
Number of Low Spell	115
Longest Low Spell	130 days
Mean Duration of Low Spell	31.6 days
Total Duration of Low Spell	3638 days
Total of periods Between Low Spells	11454 days
Mean period Between Low Spells	100.5 days
Longest period Between Low Spells	1000 days

8.3.1.4 Stage duration curve

The climate change stage duration curve is significantly different to the basecase, with an almost linear decline in water depth with percentage exceedence below 0.5. This characteristic was displayed in all seasons. 25% of the time the water level is lower than 80.6 m AHD. The lake is dry 10% of the time in Autumn and Summer, 2% of the time for Spring, and 1% for Winter (Figure 8-11).

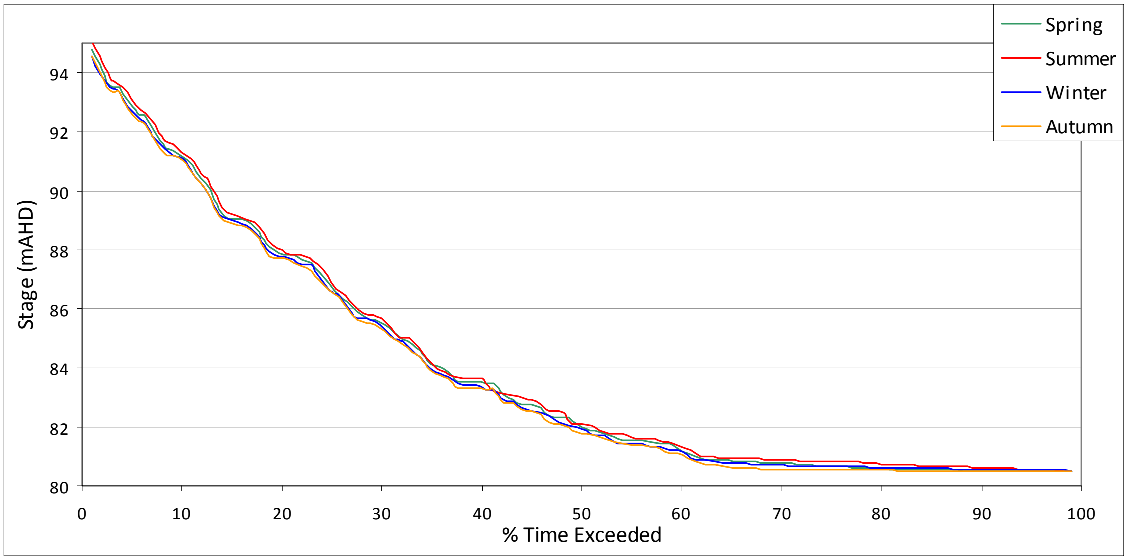


Figure 8-11 Lake Murdeduke Seasonal Stage Duration Curves – Climate Change Scenario

8.3.1.5 Volume duration curve

The lake volumes do not significantly change for the highest 35% of results, with a difference of only 4,000 ML. A significant decline in volume is then observed for the mid ranges of percentage exceedence values. Minimal volumes exist in the lake for 65% of the time in all seasons (Figure 8-12).

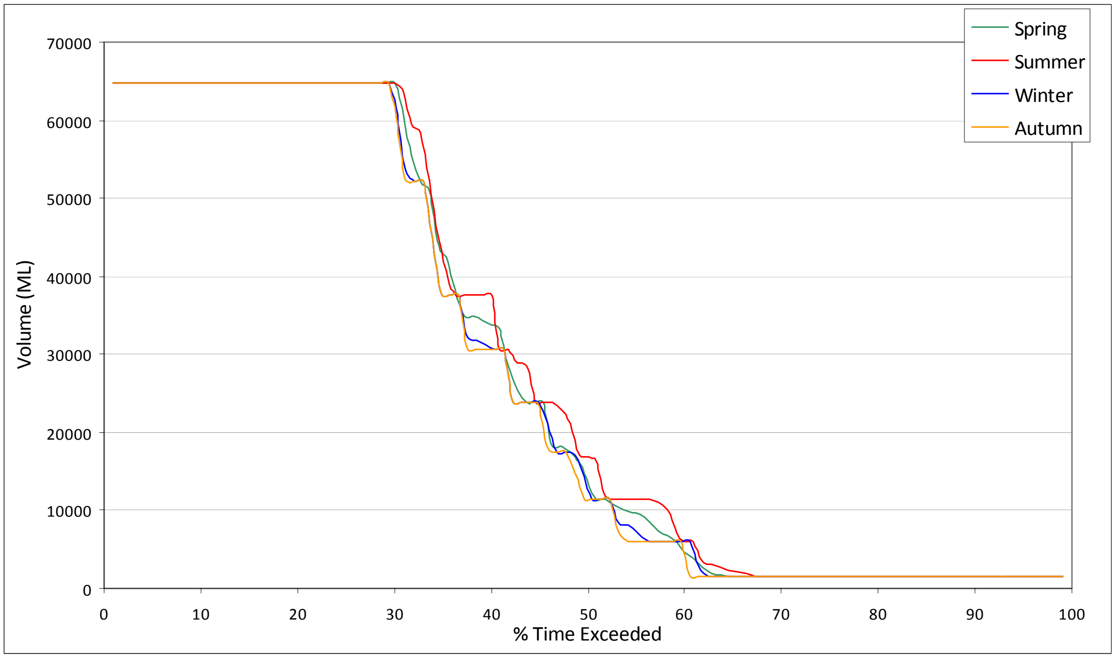


Figure 8-12 Lake Murdeduke Seasonal Volume Duration Curves – Climate Change Scenario

8.3.2 Lake Colongulac

The effect of climate change was also assessed on Lake Colongulac using the same procedure as for Lake Murdeduke. Similarly, the high evaporation and low rainfall have significantly increased the dry out rate of the lake (refer Figure 8-13), with the lake drying more frequently and for longer than under basecase conditions.

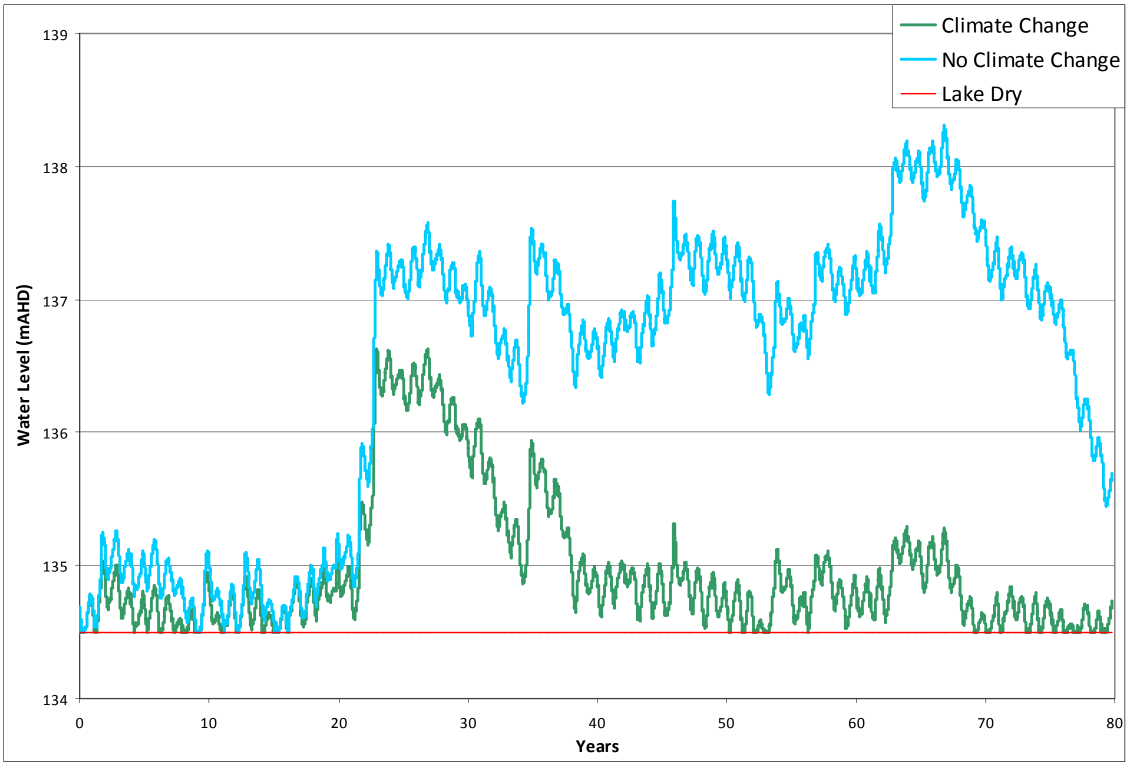


Figure 8-13 Climate Change Analysis for Lake Colongulac

8.3.2.1 Relative Hydrologic Influences

The increased evaporation and reduced rainfall has led to a net loss of water from the system, with outflows exceeding inflows to the lake. The proportion of each of the inflows has remained similar to the non-climate change scenario.

Table 8-6 Lake Colongulac Average Annual Volumes – Climate Change

Surface Water Inflow	Rainfall	Groundwater	Evaporation
3 ML	18 ML	4 ML	-27 ML

8.3.2.2 Mean water level on seasonal basis

Climate Change has led to a minor reduction in the winter/spring gains and an increase in the summer/autumn losses for the lake. This gradual overall loss of water exacerbates the long term trends of declining water level.

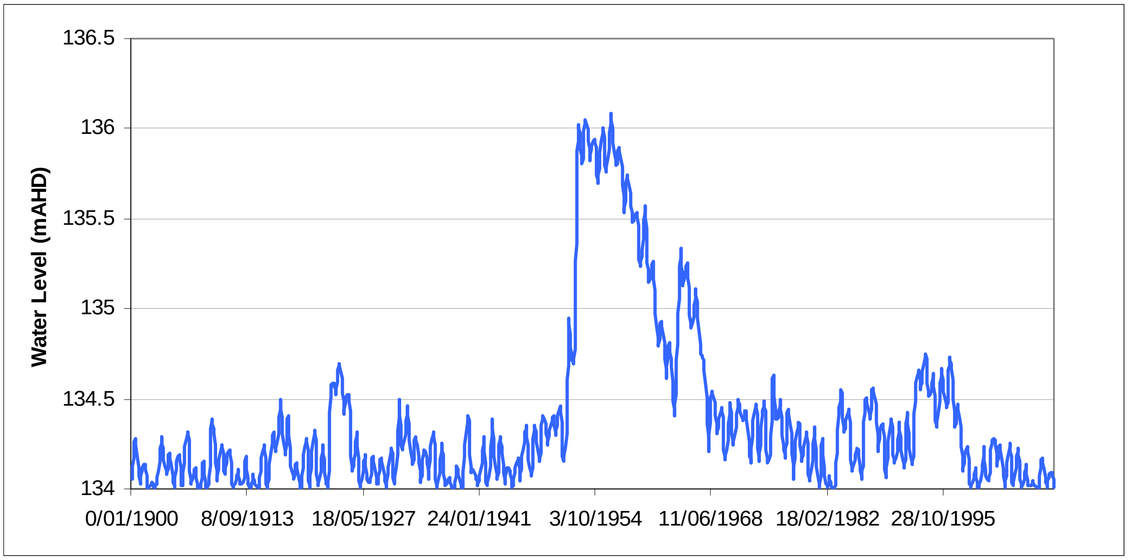


Figure 8-14 Lake Colongulac Mean Seasonal Water Level

8.3.2.3 Dry spells

For the basecase scenario there were 98 dry spells in the analysis compared to 134 for the climate change scenario. The length of the longest dry spell has also increased by 29%, however the mean duration is approximately the same. The results in Table 8-7 are showing more frequent dry spells rather than a significant increase in the spell length.

Table 8-7 Spells Analysis of Lake Colongulac – Climate Change Scenario

	Basecase	Climate Change	% Change
Low Spell Threshold	134.0 m AHD	134.0 m AHD	
Number of Low Spell	98	134	27%
Longest Low Spell	46 days	65 days	29%
Mean Duration of Low Spell	10 days	10 days	0%
Total Duration of Low Spell	1055 days	3099 days	66%
Total of periods Between Low Spells	15002 days	37177 days	60%
Mean period Between Low Spells	154.7 days	124.3 days	-25%
Longest period Between Low Spells	3153 days	12432 days	75%

8.3.2.4 Stage duration curve

The Lake Colongulac with climate change conditions stage duration curve is shown in Figure 8-15. The shape of the curve has changed from the basecase, where there is a much higher likelihood for low water levels. 75% of the time the water level is likely to be below134.5 m AHD. Dry outs occur 15% of the time in Autumn and Summer, 2% of the time for spring and less than 1% of the time for winter.

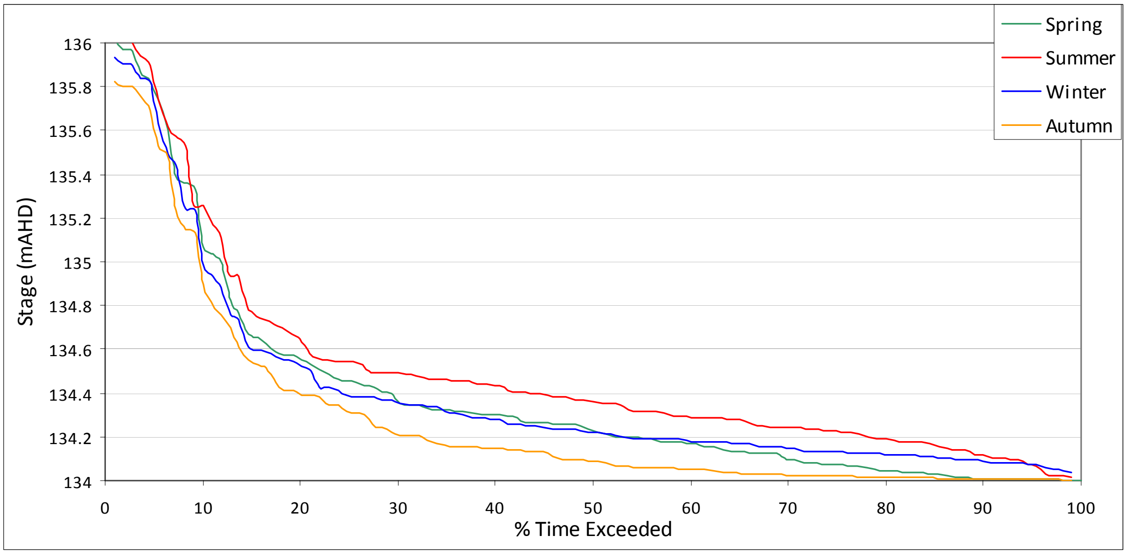


Figure 8-15 Lake Colongulac Seasonal Stage Duration Curves - Climate Change Scenario

8.3.2.5 Volume duration curve

15% of the time the volume of the lake is above 1,000 ML in the Climate Change scenario (refer Figure 8-16). The curve then sharply declines, where only 1 ML is within the lake 18% of the time. Dry out occurs approximately 80% of the time, where spring is able to withstand the dry out slightly better than the other seasons.

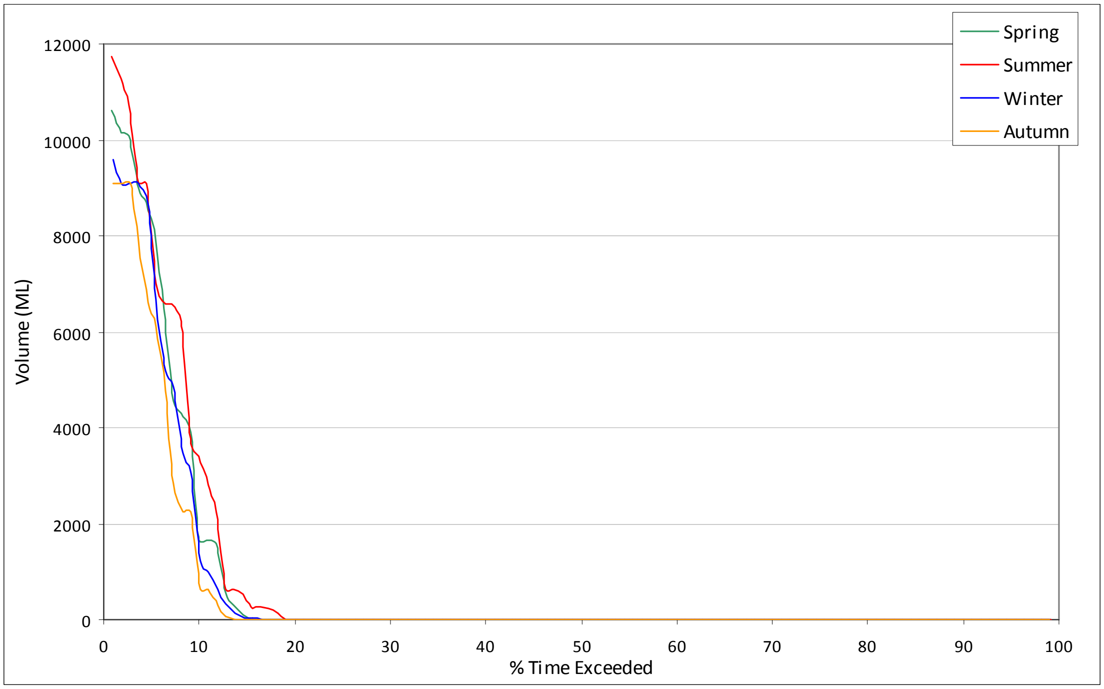


Figure 8-16 Lake Colongulac Seasonal Volume Duration Curves - Climate Change Scenario

8.3.3 Overall Impact of Climate Change

As demonstrated on Lake Murdeduke and Lake Colongulac, the Western District Lakes are very susceptible to dry out under current climate change predictions for the region. As many of the lakes are dominated by groundwater inflows and evaporation, the lake levels are responsive to the change in climate. This will lead to a greater number of periods where the smaller lakes dry out, and some of the larger lakes that were usually able to maintain at least some water within them will also dry out. This will in turn have an impact on the ecology within these systems.

9 CONCLUSION

The hydrology of the Western District Lakes region was investigated and explored within this project. As part of this process the available literature was collated and assessed to determine any knowledge gaps. Many of these gaps were based on the lack of knowledge for the smaller lakes compared to Lake Corangamite. With the latest high resolution data available, the definition of the lakes stage-storage- area and catchment delineations were able to be generated for all the RAMSAR lakes in the region. This provides invaluable data for further investigations.

It was decided to concentrate on two of the smaller lesser known lakes in the study area, Lake Murdeduke and Lake Colongulac, as there have been limited studies on these smaller lakes in the past. These sites had some (although limited) information in which to calibrate the hydrologic models. Baseline conditions were reasonably well replicated with calibrated models, providing confidence in the processes affecting the lake levels. These models were then able to be used to assess the impact of climate change on the lakes, determining the susceptibility to higher evaporation and lower rainfall.

There were many similarities in the hydrologic behaviour of lakes Colongulac and Murdeduke. However the differences became apparent when assessing dry spells for both lakes under the base case, and became further apparent under climate change conditions. Lake Murdeduke has a much larger catchment area and hence has the potential to generate larger surface water inflows, buffering it from drying out as often as Lake Colongulac.

In order to prioritise future assessments of the remaining lakes, perhaps the catchment area to lake area ratios could be used to assess the most at risk lakes, with lakes with the smallest catchment area most susceptible to drying out.

10 TRAINING

Upon completion of the modelling and reporting Corangamite CMA staff were given the opportunity to have a training session on WaterCAST. This involved a set of notes on the development of a WaterCAST model and included a day long interactive presentation on the development, calibration and interpretation of a WaterCAST model. One of the models developed in this study was used as the basis of the training presentation.

11 REFERENCES

Argent, R. M, Perraud, J-M, Podger, G.M, Murray, N (2008) WaterCAST Component Model Reference Manual, eWater CRC, Canberra.

BRS (2003) Land Use in South-West Victoria - Glenelg-Hopkins and Corangamite Region (Zone 54). http://adl.brs.gov.au/mapserv/landuse/ [Accessed 2/10/09]. Bureau Rural Sciences.

Chiew, F & Scanlon, P. (2002). Estimation of pollutant concentrations for EMSS: modelling of the south-east Queensland region. Cooperative Research Centre for Catchment Hydrology, 2002.

Chiew, F & Siriwardena, L. (2005). Estimation of SIMHYD Parameter Values for Application in Ungauged Catchments. MODSIM 2005 International Congress on Modelling and Simulation. Modelling and Simulation Society of Australia and New Zealand, December 2005.

Coram, J (1996). Groundwater-surface water interactions around some shallow lakes of the Corangamite Salinity Region – a summary report with management recommendations.

CSIRO (2007). Hydrological and Geochemical processes controlling salinity of the groundwater dependent ecosystems in Corangamite CMA. Project No WLE/42-009.

De Deckker, P & Williams,WD. (1990). Physio-chemical limnology of eleven, mostly saline permanent lakes in Western Victoria, Australia. Hydrobiologica 182 (3), 275 – 286.

DNRE (2002). Western District Lakes Ramsar Site – Strategic Management Plan.

DSE (2008) Climate Change in the Corangamite Region.
http://www.climatechange.vic.gov.au/CA256F310024B628/0/E4AD0F0650FDC4B6CA25747400132C54/$File/Corangamite_WEB.pdf [Accessed 6/10/09].

GHD (2003). Review of Regional Drainage Schemes – Model Calibration Report.

Hose, K, Mitchell, B & Gwyther, J (2008). Investigation and reporting of past and present ecological characteristics of seven saline lakes in the Corangamite Catchment Management Area. Deakin University.

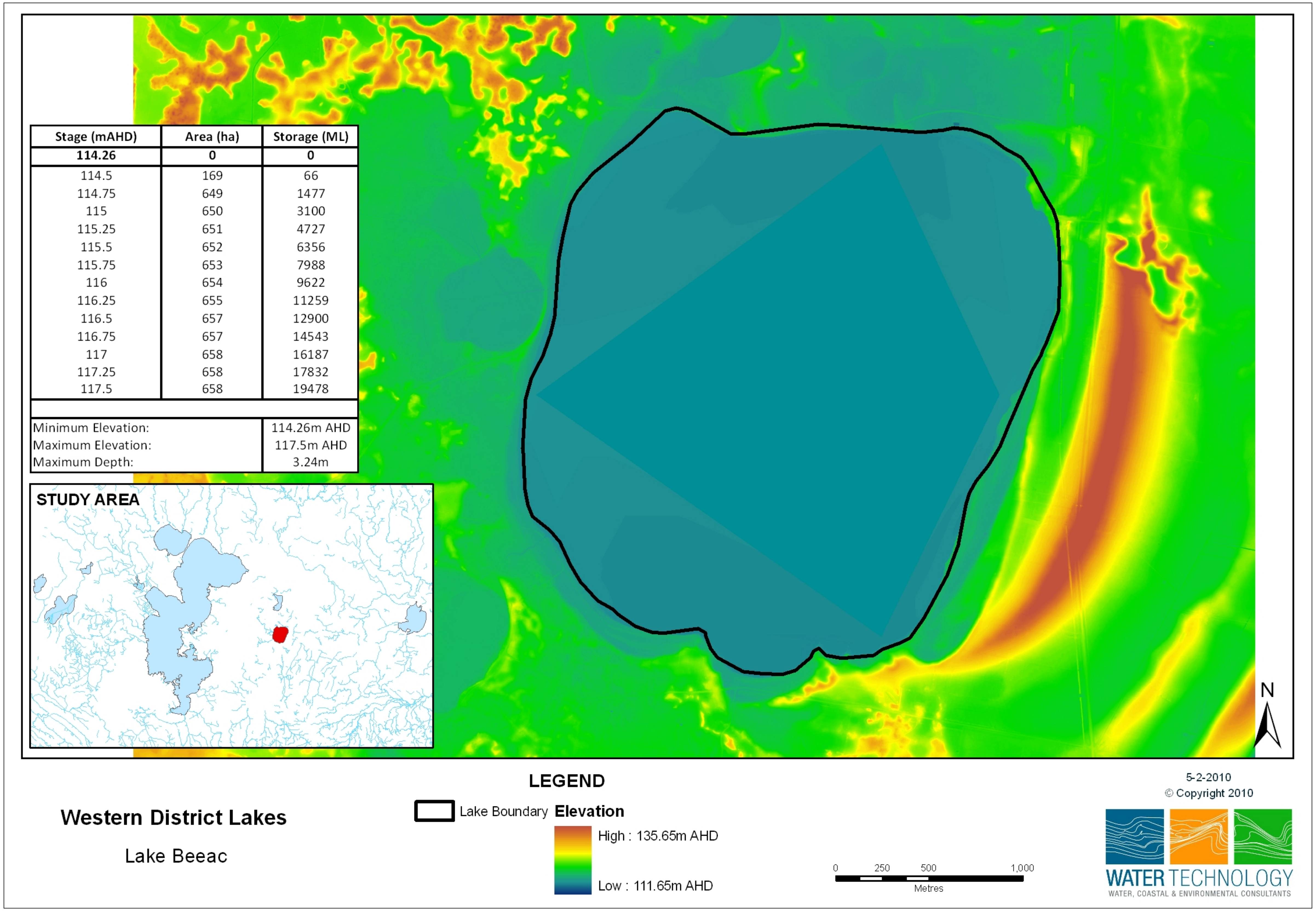
Muston, S (2001). A condition analysis of the Western District Lakes in South-western Victoria. School of Ecology and Environment, Deakin University. October 2001.

Segovia, I (2001). A study of nutrients in Lake Murdeduke in Western Victoria and implications for environmental management. MSc, Hydrogeology and Environmental Science, School of Earth Sciences, Melbourne University.

Williams, W.D. (1992). The biological status of Lake Corangamite and other lakes in Western Victoria. Department of Zoology, University of Adelaide. Report for the Department of Conservation and Environment, Colac. April 1992.

APPENDIX A

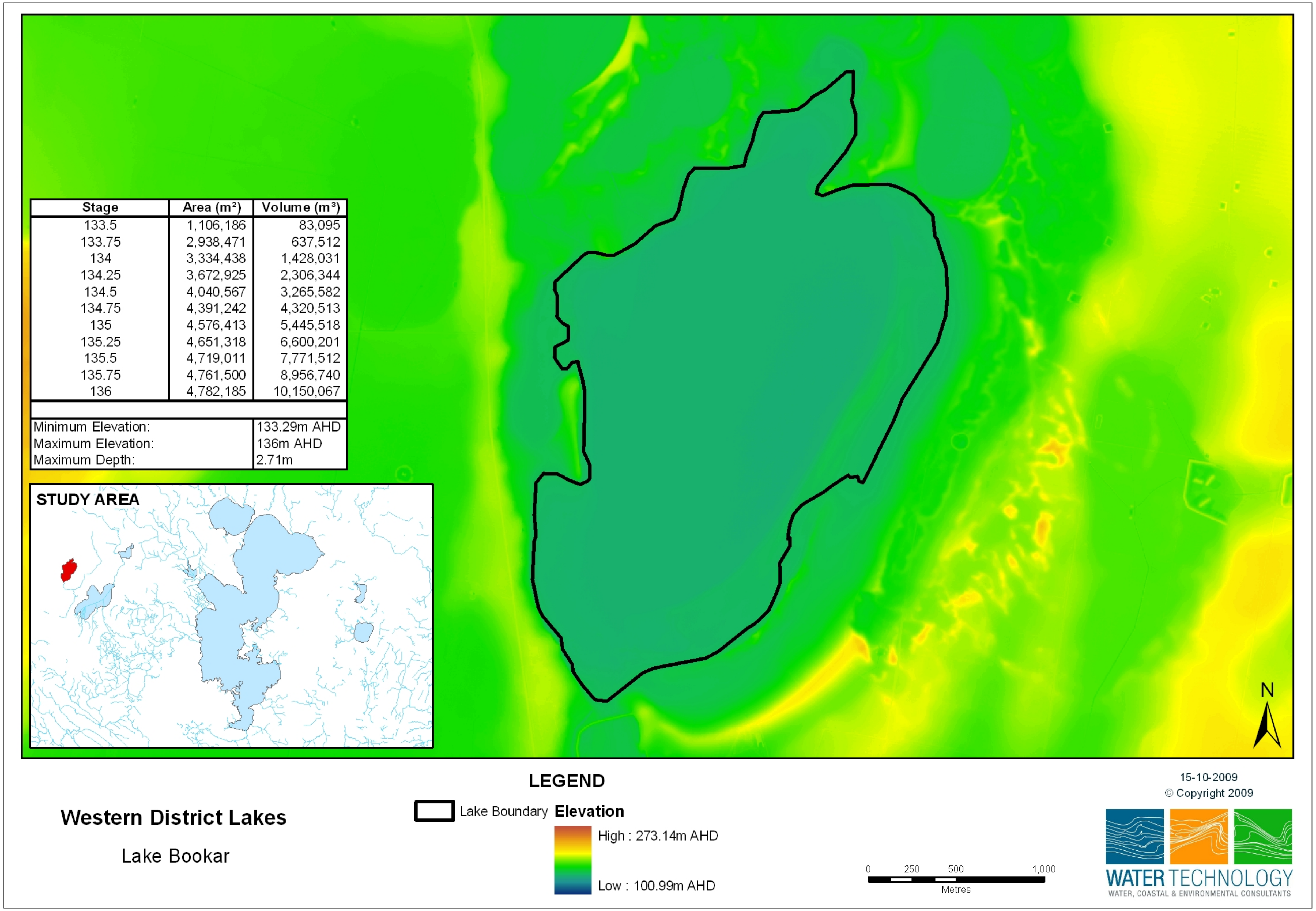
STAGE-STORAGE-AREA RELATIONSHIPS



Stage (mAHD)	Area (ha)	Storage (ML)
114.26	**0**	**0**
114.5	169	66
114.75	649	1477
115	650	3100
115.25	651	4727
115.5	652	6356
115.75	653	7988
116	654	9622
116.25	655	11259
116.5	657	12900
116.75	657	14543
117	658	16187
117.25	658	17832
117.5	658	19478

Minimum Elevation:	114.26m AHD
Maximum Elevation:	117.5m AHD
Maximum Depth:	3.24m

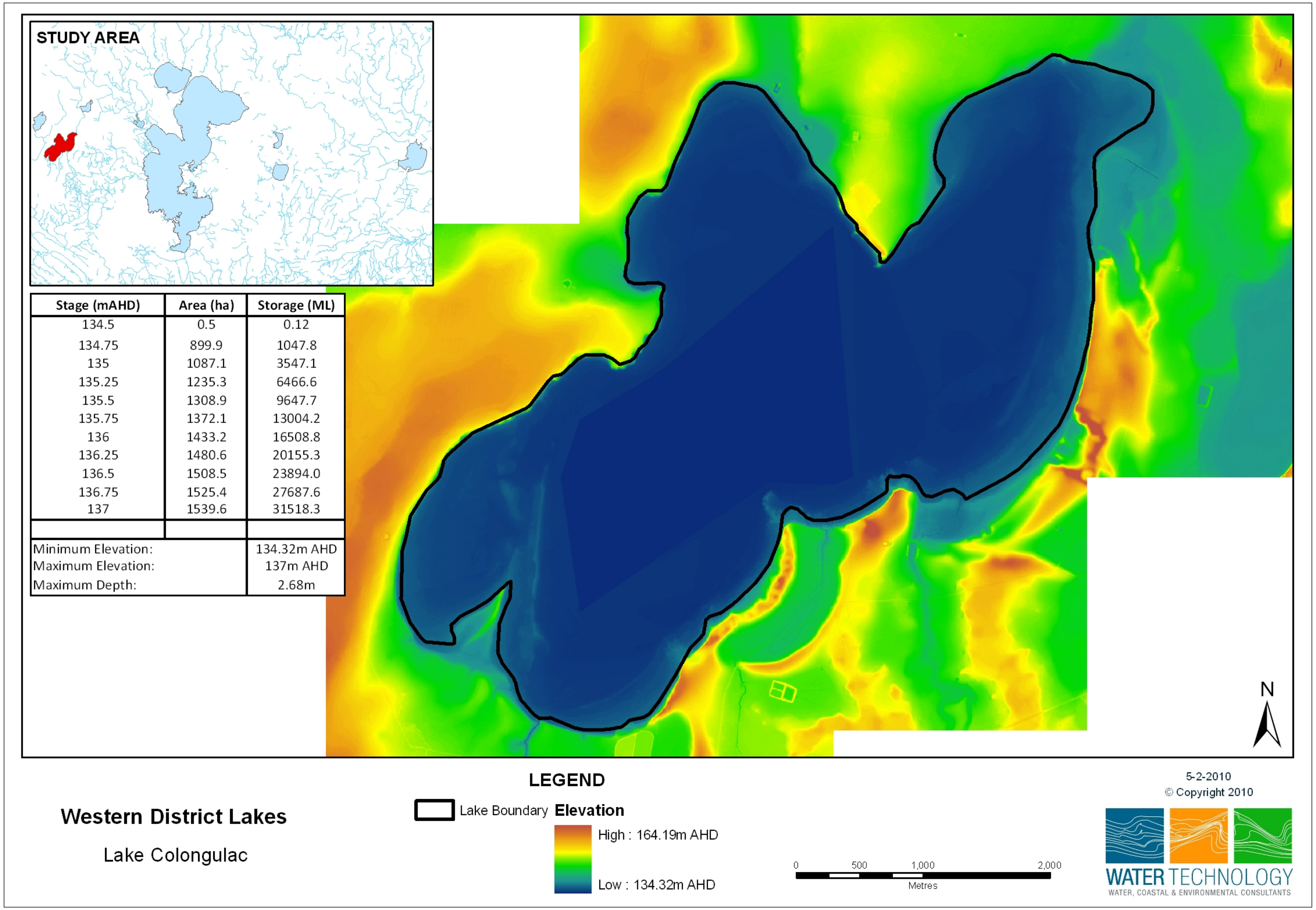
Figure 11-1 Lake Beeac Stage-Area-Volume



Stage	Area (m²)	Volume (m³)
133.5	1,106,186	83,095
133.75	2,938,471	637,512
134	3,334,438	1,428,031
134.25	3,672,925	2,306,344
134.5	4,040,567	3,265,582
134.75	4,391,242	4,320,513
135	4,576,413	5,445,518
135.25	4,651,318	6,600,201
135.5	4,719,011	7,771,512
135.75	4,761,500	8,956,740
136	4,782,185	10,150,067

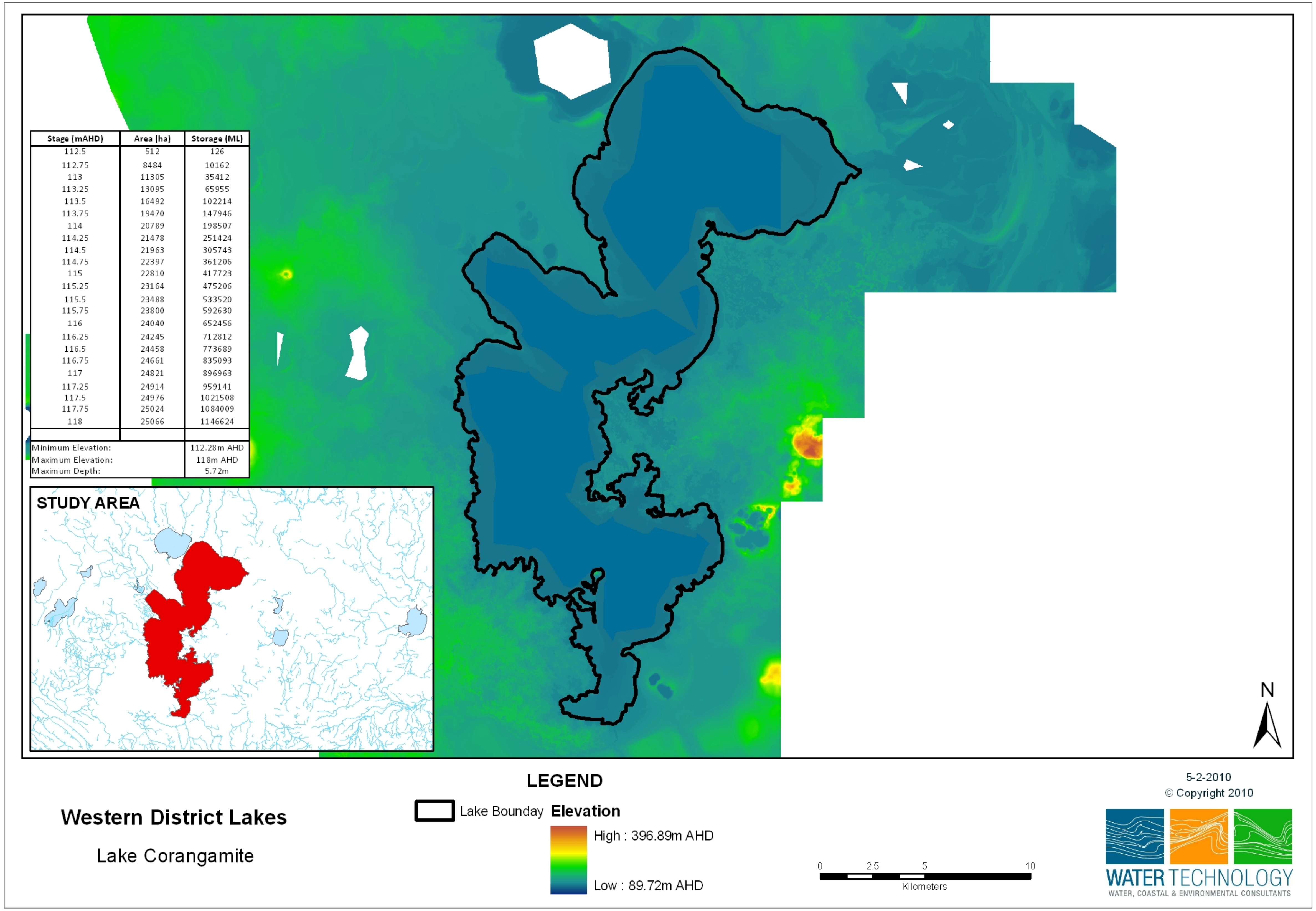
Minimum Elevation:	133.29m AHD
Maximum Elevation:	136m AHD
Maximum Depth:	2.71m

Figure 11-2 Lake Bookar Stage-Area-Volume



Stage (mAHD)	Area (ha)	Storage (ML)
134.5	0.5	0.12
134.75	899.9	1047.8
135	1087.1	3547.1
135.25	1235.3	6466.6
135.5	1308.9	9647.7
135.75	1372.1	13004.2
136	1433.2	16508.8
136.25	1480.6	20155.3
136.5	1508.5	23894.0
136.75	1525.4	27687.6
137	1539.6	31518.3
Minimum Elevation:		134.32m AHD
Maximum Elevation:		137m AHD
Maximum Depth:		2.68m

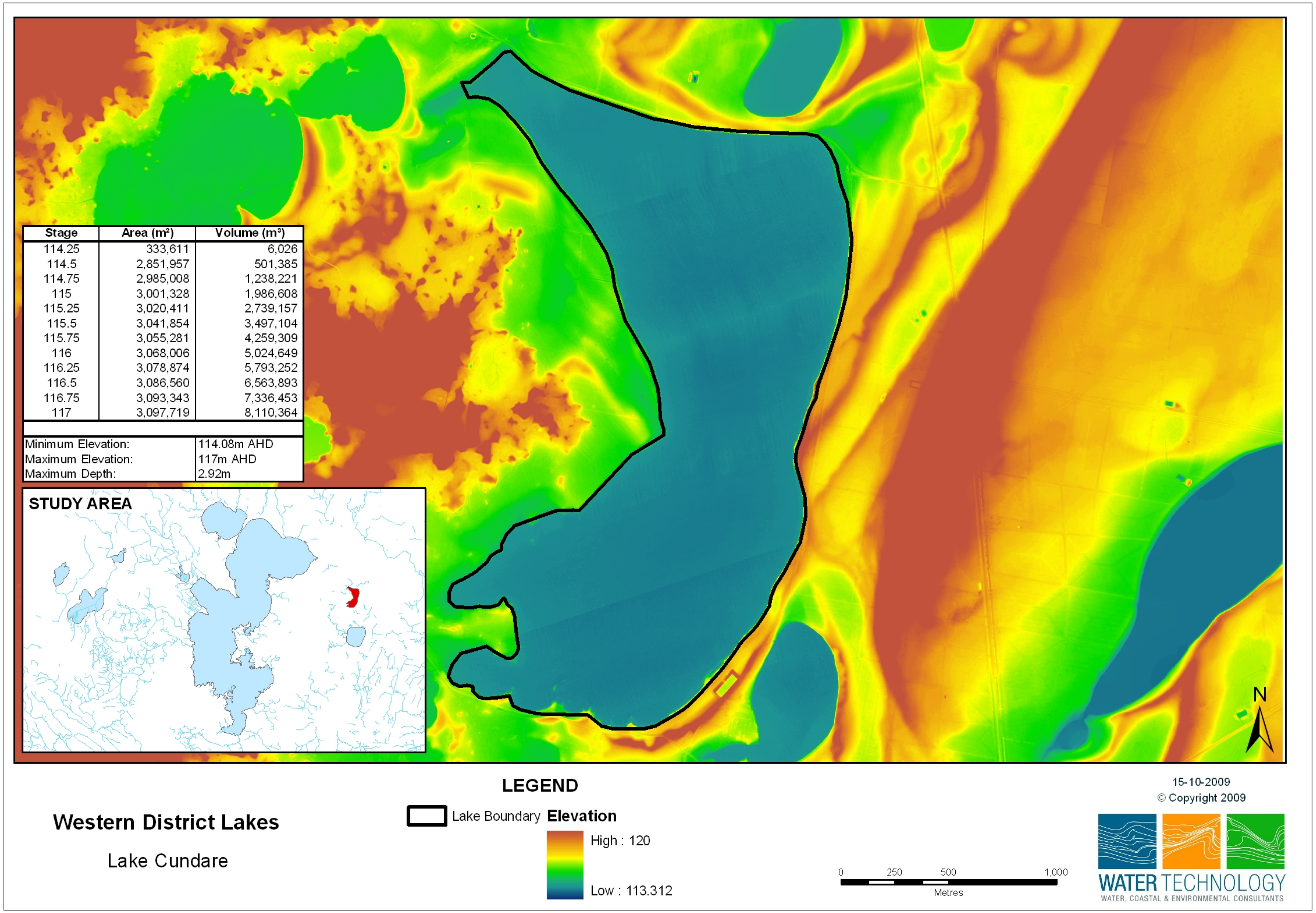
Figure 11-3 Lake Colongulac Stage-Area-Volume



Stage (mAHD)	Area (ha)	Storage (ML)
112.5	512	126
112.75	8484	10162
113	11305	35412
113.25	13095	65955
113.5	16492	102214
113.75	19470	147946
114	20789	198507
114.25	21478	251424
114.5	21963	305743
114.75	22397	361206
115	22810	417723
115.25	23164	475206
115.5	23488	533520
115.75	23800	592630
116	24040	652456
116.25	24245	712812
116.5	24458	773689
116.75	24661	835093
117	24821	896963
117.25	24914	959141
117.5	24976	1021508
117.75	25024	1084009
118	25066	1146624

Minimum Elevation: 112.28m AHD
Maximum Elevation: 118m AHD
Maximum Depth: 5.72m

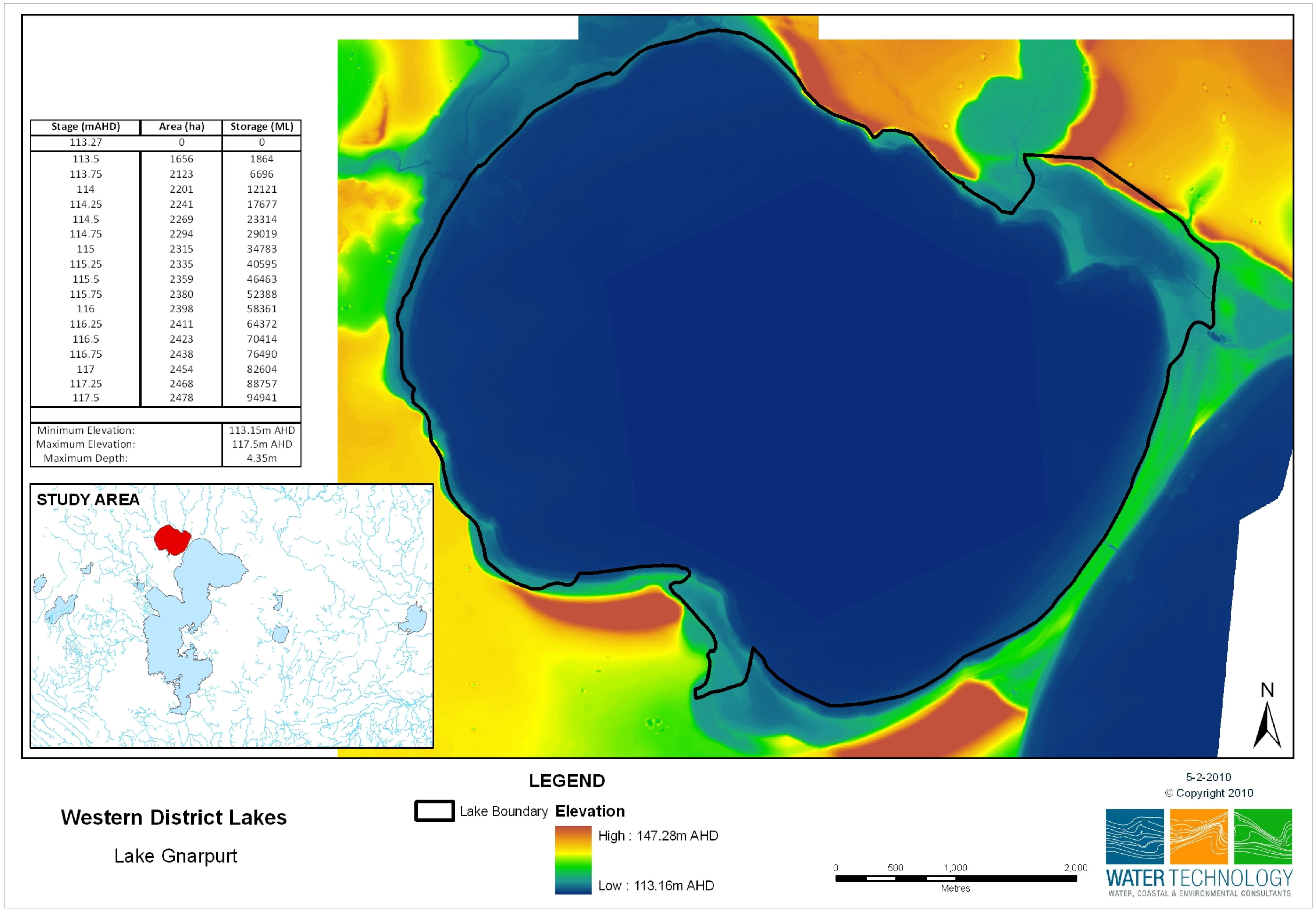
Figure 11-4 Lake Corangamite Stage-Area-Volume



Stage	Area (m^2)	Volume (m^3)
114.25	333,611	6,026
114.5	2,851,957	501,385
114.75	2,985,008	1,238,221
115	3,001,328	1,986,608
115.25	3,020,411	2,739,157
115.5	3,041,854	3,497,104
115.75	3,055,281	4,259,309
116	3,068,006	5,024,649
116.25	3,078,874	5,793,252
116.5	3,086,560	6,563,893
116.75	3,093,343	7,336,453
117	3,097,719	8,110,364

Minimum Elevation:	114.08m AHD
Maximum Elevation:	117m AHD
Maximum Depth:	2.92m

Figure 11-5 Lake Cundare Stage-Area-Volume



Stage (mAHD)	Area (ha)	Storage (ML)
113.27	0	0
113.5	1656	1864
113.75	2123	6696
114	2201	12121
114.25	2241	17677
114.5	2269	23314
114.75	2294	29019
115	2315	34783
115.25	2335	40595
115.5	2359	46463
115.75	2380	52388
116	2398	58361
116.25	2411	64372
116.5	2423	70414
116.75	2438	76490
117	2454	82604
117.25	2468	88757
117.5	2478	94941

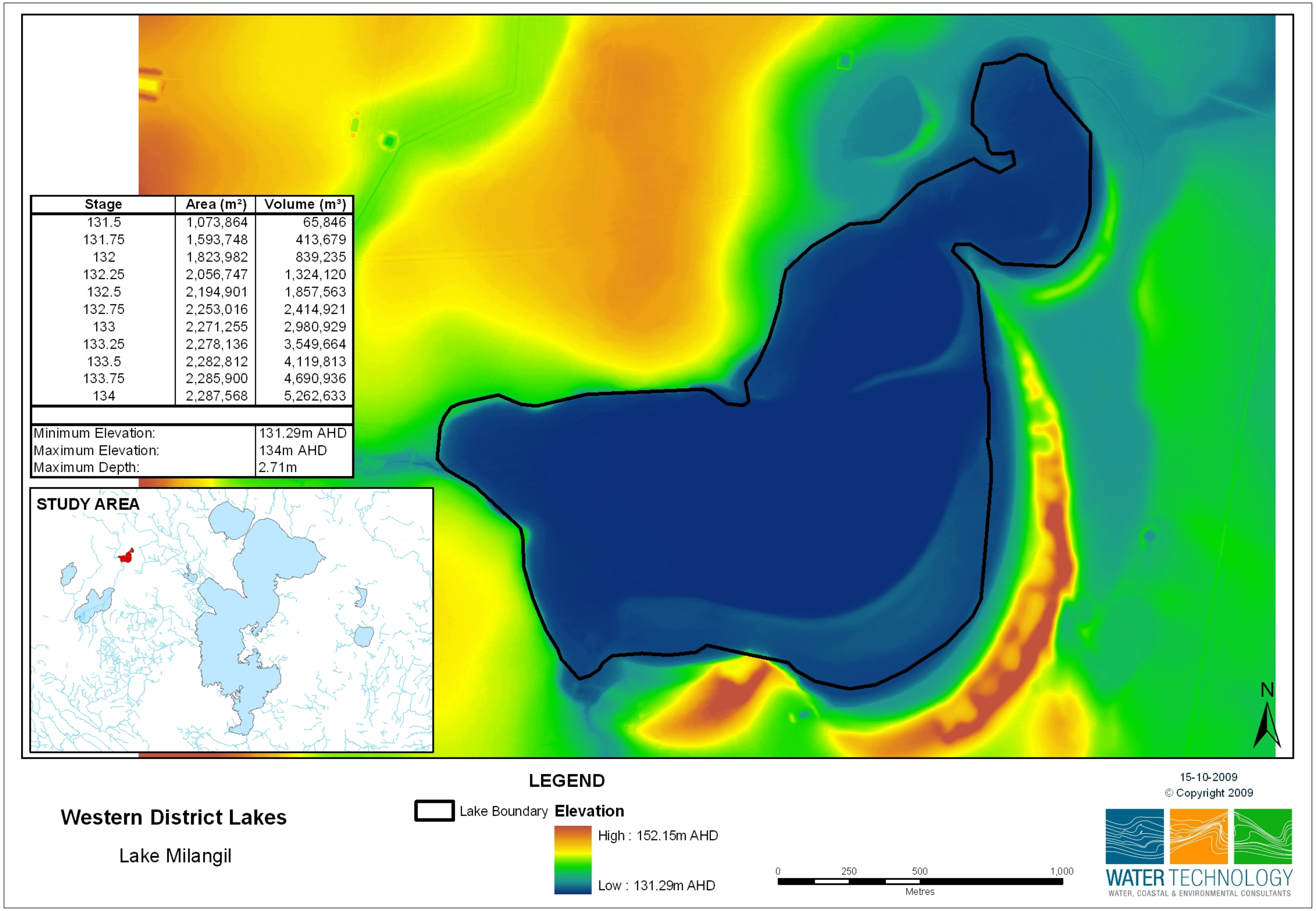
Minimum Elevation:	113.15m AHD
Maximum Elevation:	117.5m AHD
Maximum Depth:	4.35m

Western District Lakes

Lake Gnarpurt

5-2-2010

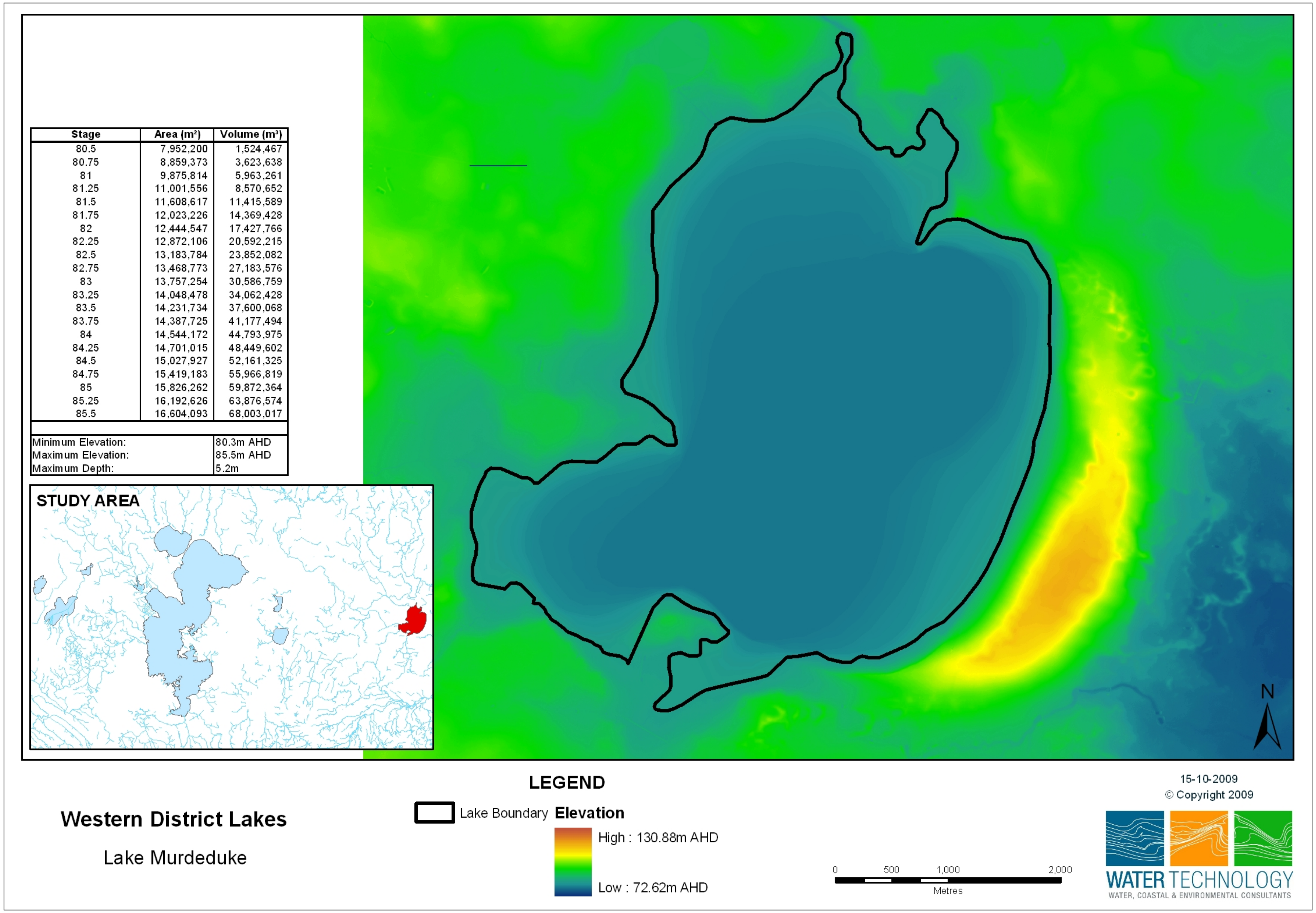
Figure 11-6 Lake Gnarpurt Stage-Area-Volume



Stage	Area (m²)	Volume (m³)
131.5	1,073,864	65,846
131.75	1,593,748	413,679
132	1,823,982	839,235
132.25	2,056,747	1,324,120
132.5	2,194,901	1,857,563
132.75	2,253,016	2,414,921
133	2,271,255	2,980,929
133.25	2,278,136	3,549,664
133.5	2,282,812	4,119,813
133.75	2,285,900	4,690,936
134	2,287,568	5,262,633

Minimum Elevation:	131.29m AHD
Maximum Elevation:	134m AHD
Maximum Depth:	2.71m

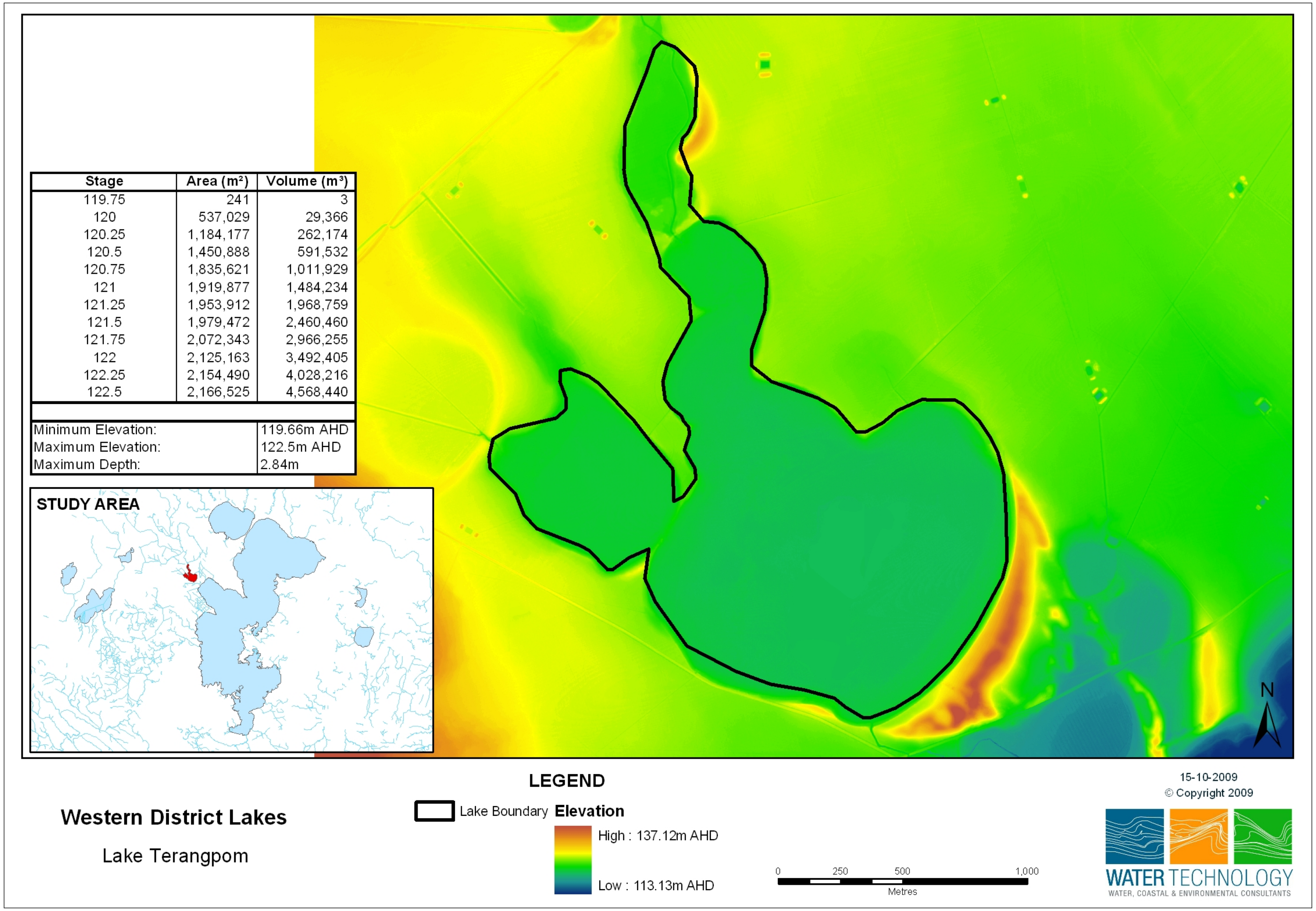
Figure 11-7 Lake Milangil Stage-Area-Volume



Stage	Area (m²)	Volume (m³)
80.5	7,952,200	1,524,467
80.75	8,859,373	3,623,638
81	9,875,814	5,963,261
81.25	11,001,556	8,570,652
81.5	11,608,617	11,415,589
81.75	12,023,226	14,369,428
82	12,444,547	17,427,766
82.25	12,872,106	20,592,215
82.5	13,183,784	23,852,082
82.75	13,468,773	27,183,576
83	13,757,254	30,586,759
83.25	14,048,478	34,062,428
83.5	14,231,734	37,600,068
83.75	14,387,725	41,177,494
84	14,544,172	44,793,975
84.25	14,701,015	48,449,602
84.5	15,027,927	52,161,325
84.75	15,419,183	55,966,819
85	15,826,262	59,872,364
85.25	16,192,626	63,876,574
85.5	16,604,093	68,003,017

Minimum Elevation:	80.3m AHD
Maximum Elevation:	85.5m AHD
Maximum Depth:	5.2m

Figure 11-8 Lake Murdeduke Stage-Area-Volume



Stage	Area (m²)	Volume (m³)
119.75	241	3
120	537,029	29,366
120.25	1,184,177	262,174
120.5	1,450,888	591,532
120.75	1,835,621	1,011,929
121	1,919,877	1,484,234
121.25	1,953,912	1,968,759
121.5	1,979,472	2,460,460
121.75	2,072,343	2,966,255
122	2,125,163	3,492,405
122.25	2,154,490	4,028,216
122.5	2,166,525	4,568,440

Minimum Elevation:	119.66m AHD
Maximum Elevation:	122.5m AHD
Maximum Depth:	2.84m

Figure 11-9 Lake Terangpom Stage-Area-Volume

APPENDIX B

CATCHMENT DELINIATION MAPS

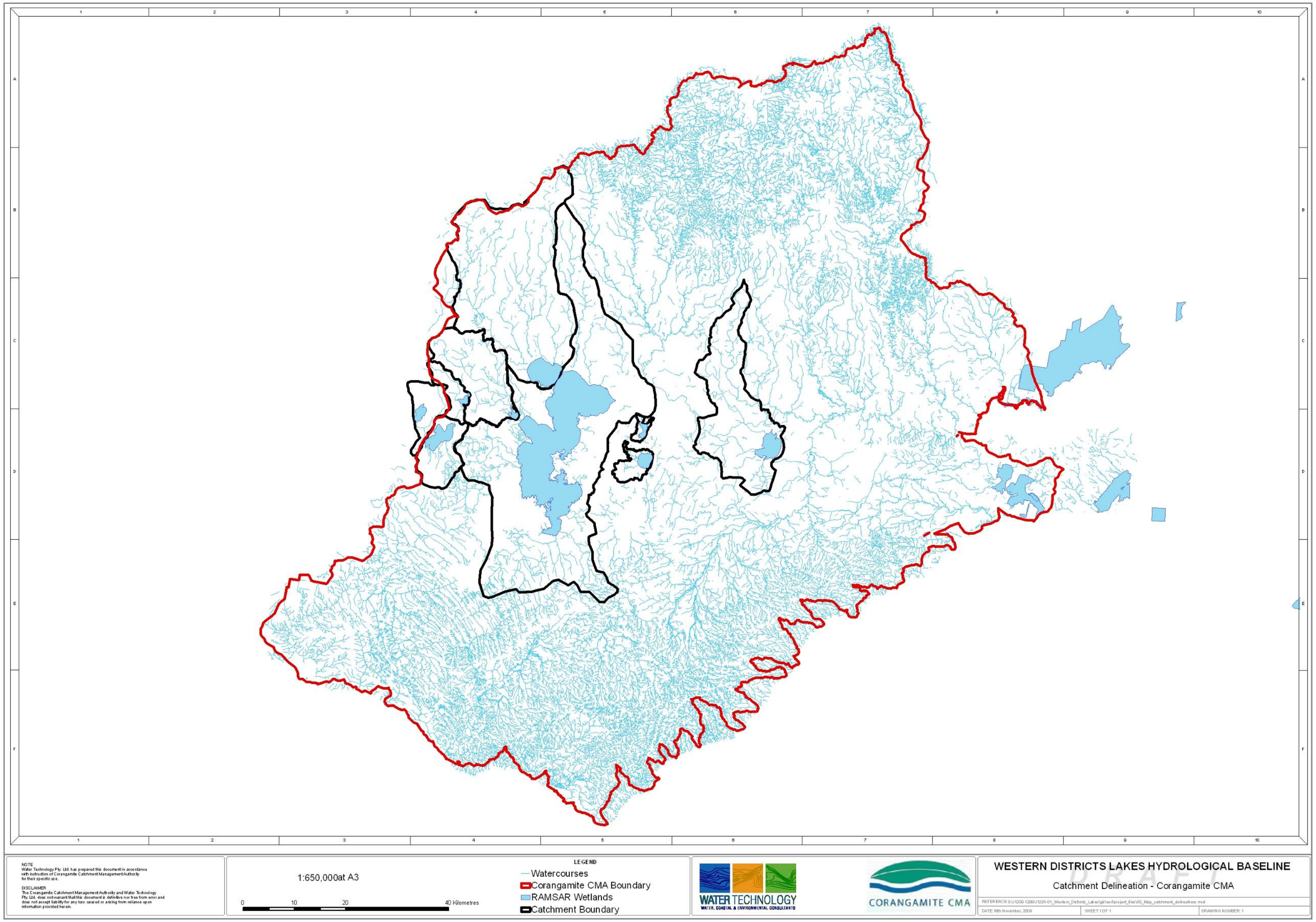


Figure 11-10 Catchment Delineations within Region

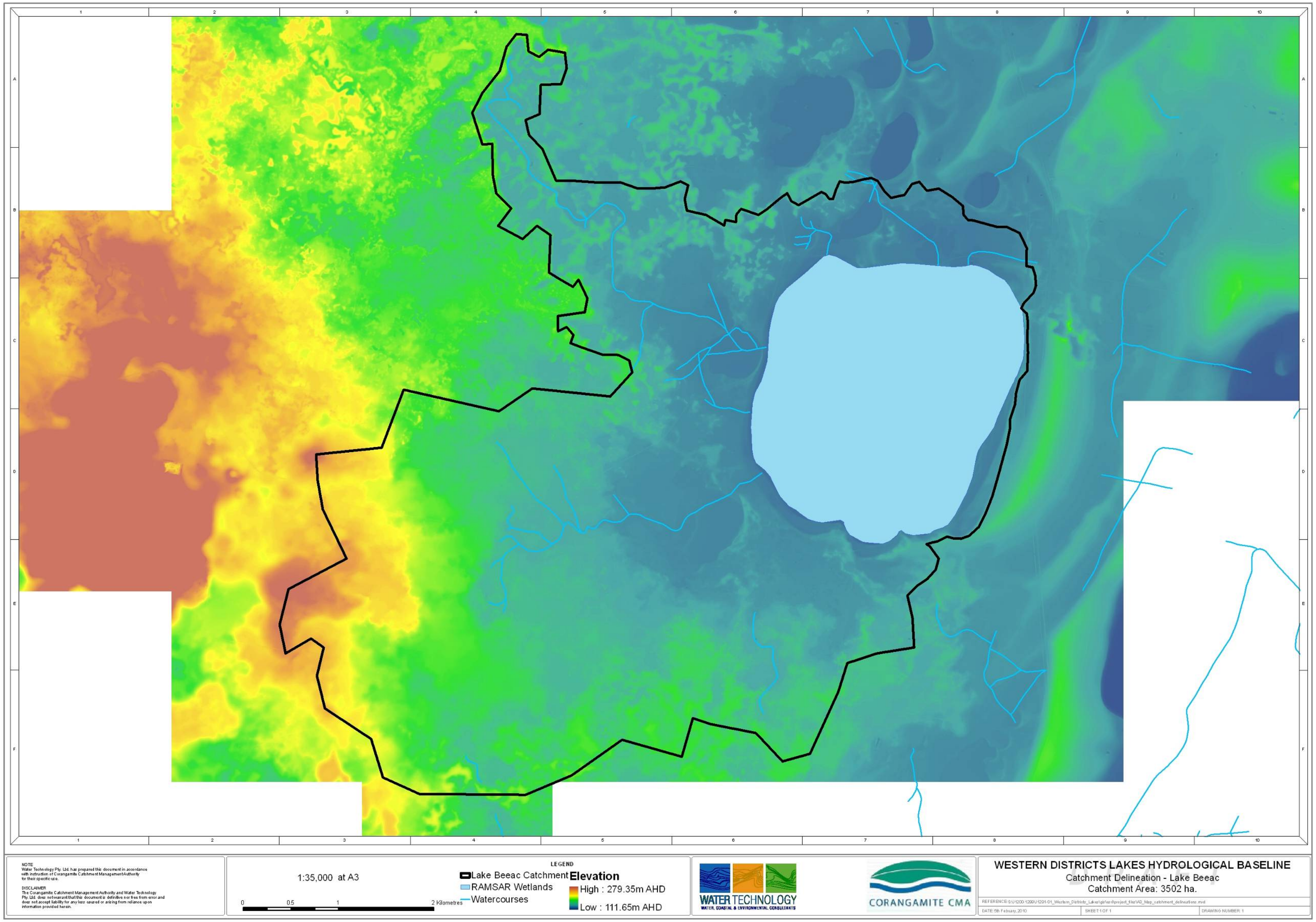


Figure 11-11 Lake Beeac Catchment Delineation

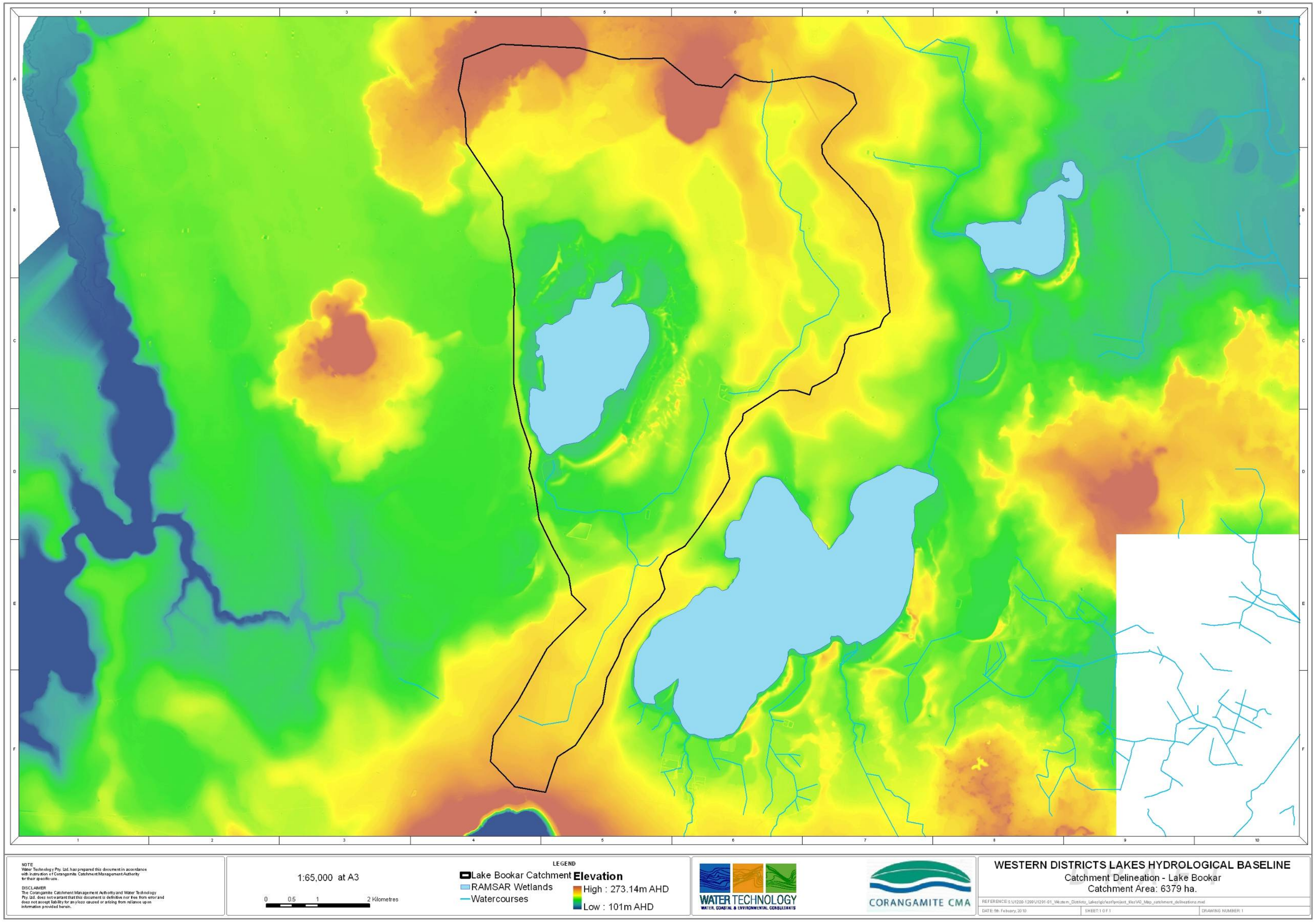


Figure 11-12 Lake Bookar Catchment Delineation

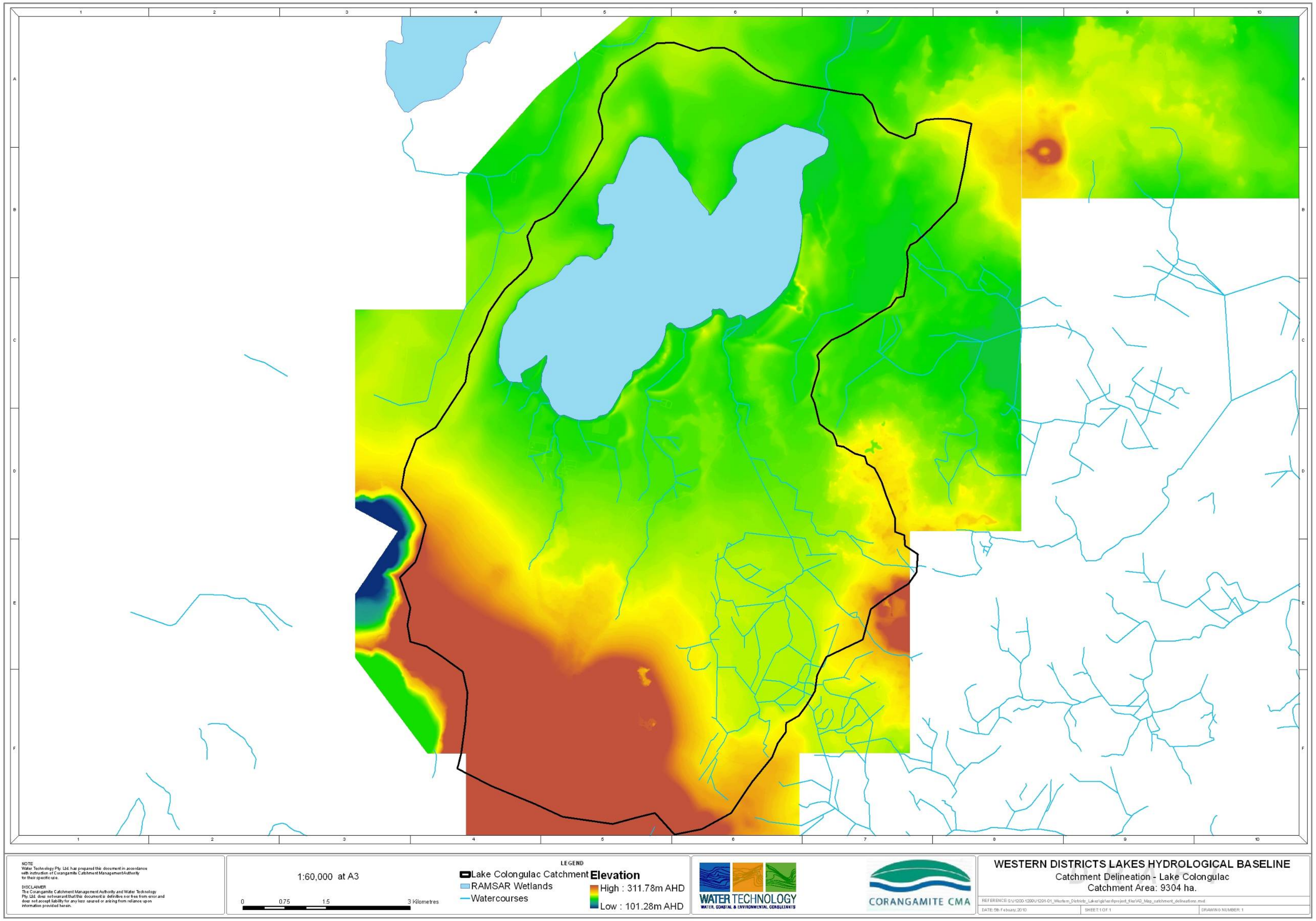


Figure 11-13 Lake Colongulac Catchment Delineation

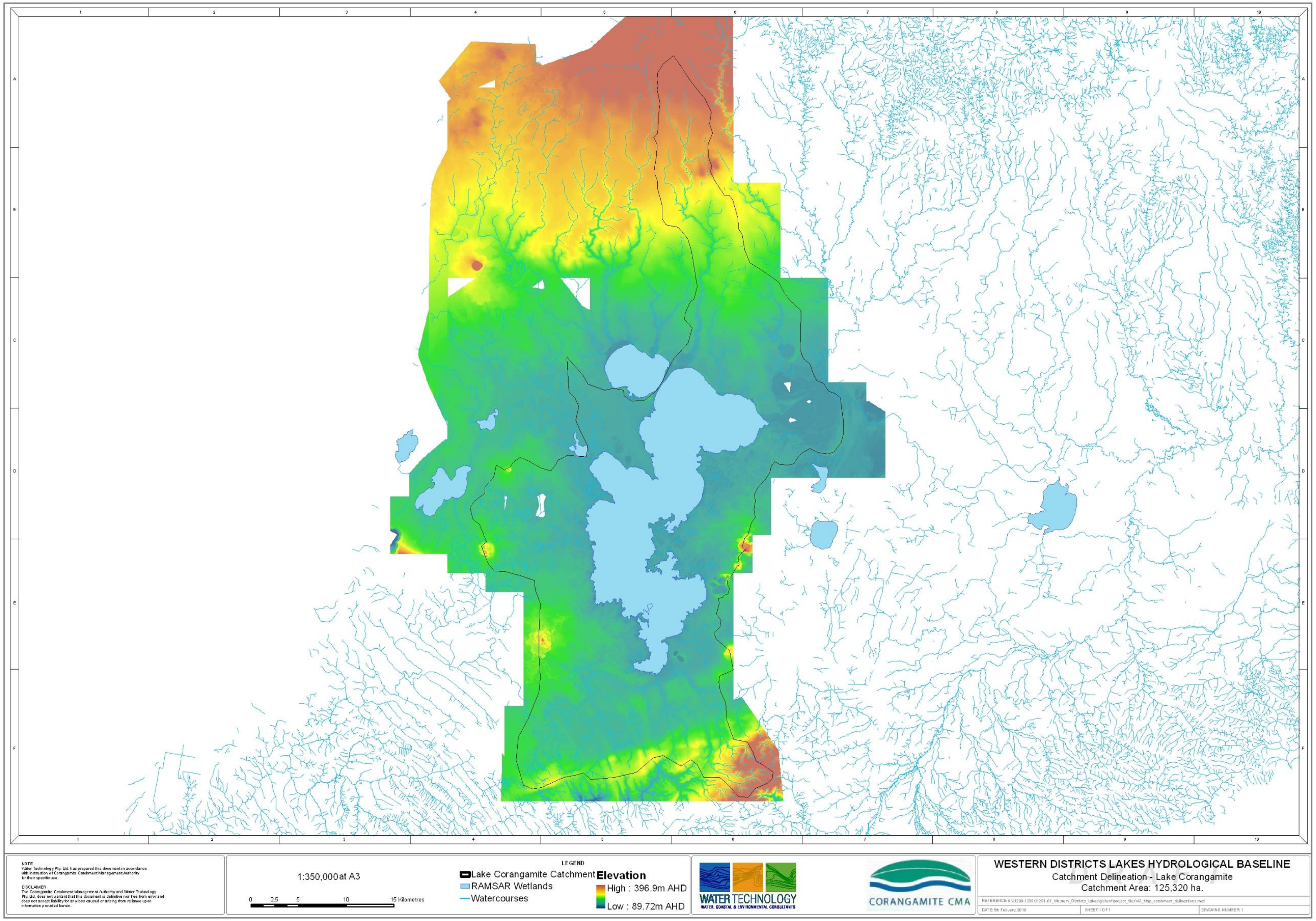


Figure 11-14 Lake Corangamite Catchment Delineation

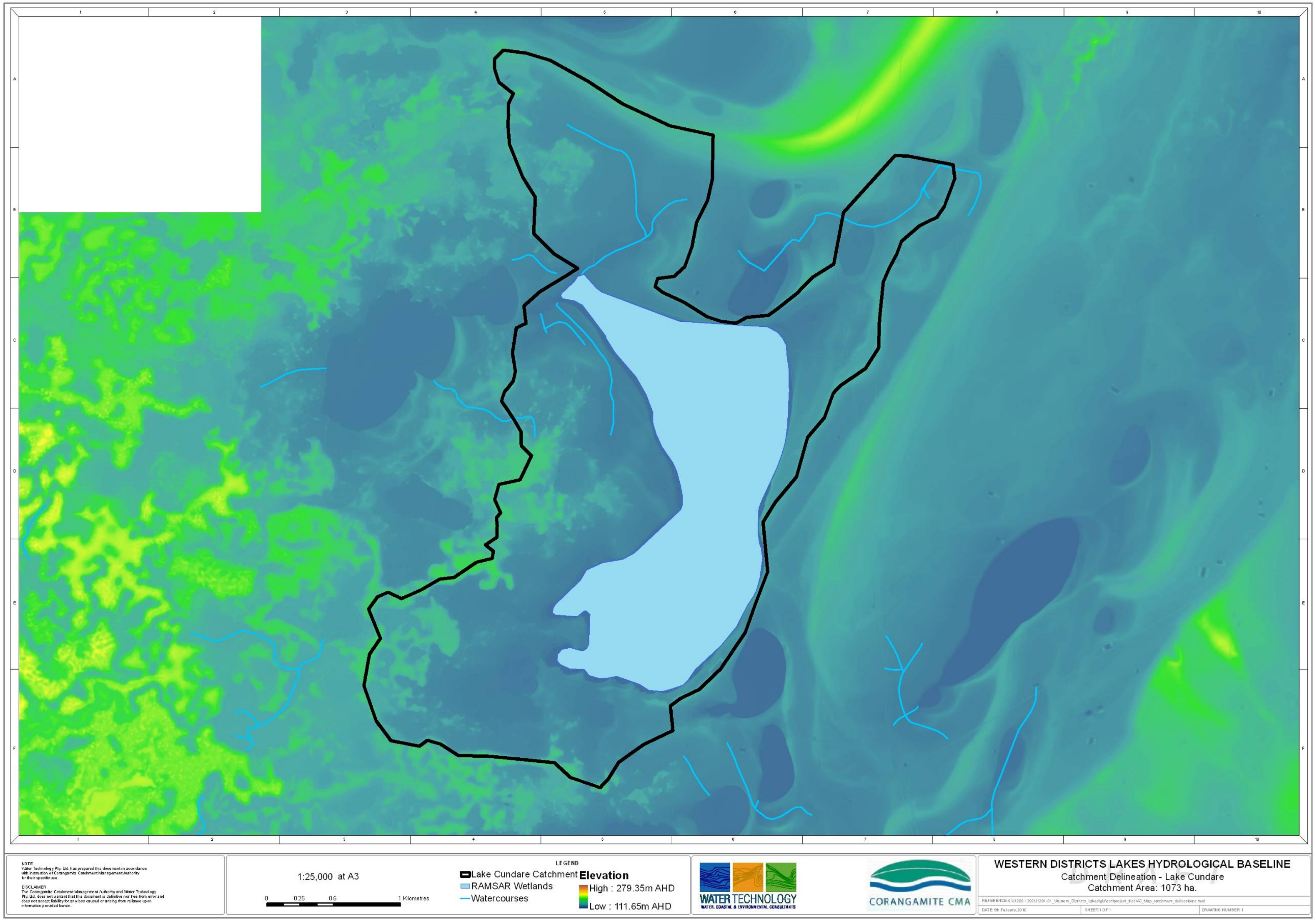


Figure 11-15 Lake Cundare Catchment Delineation

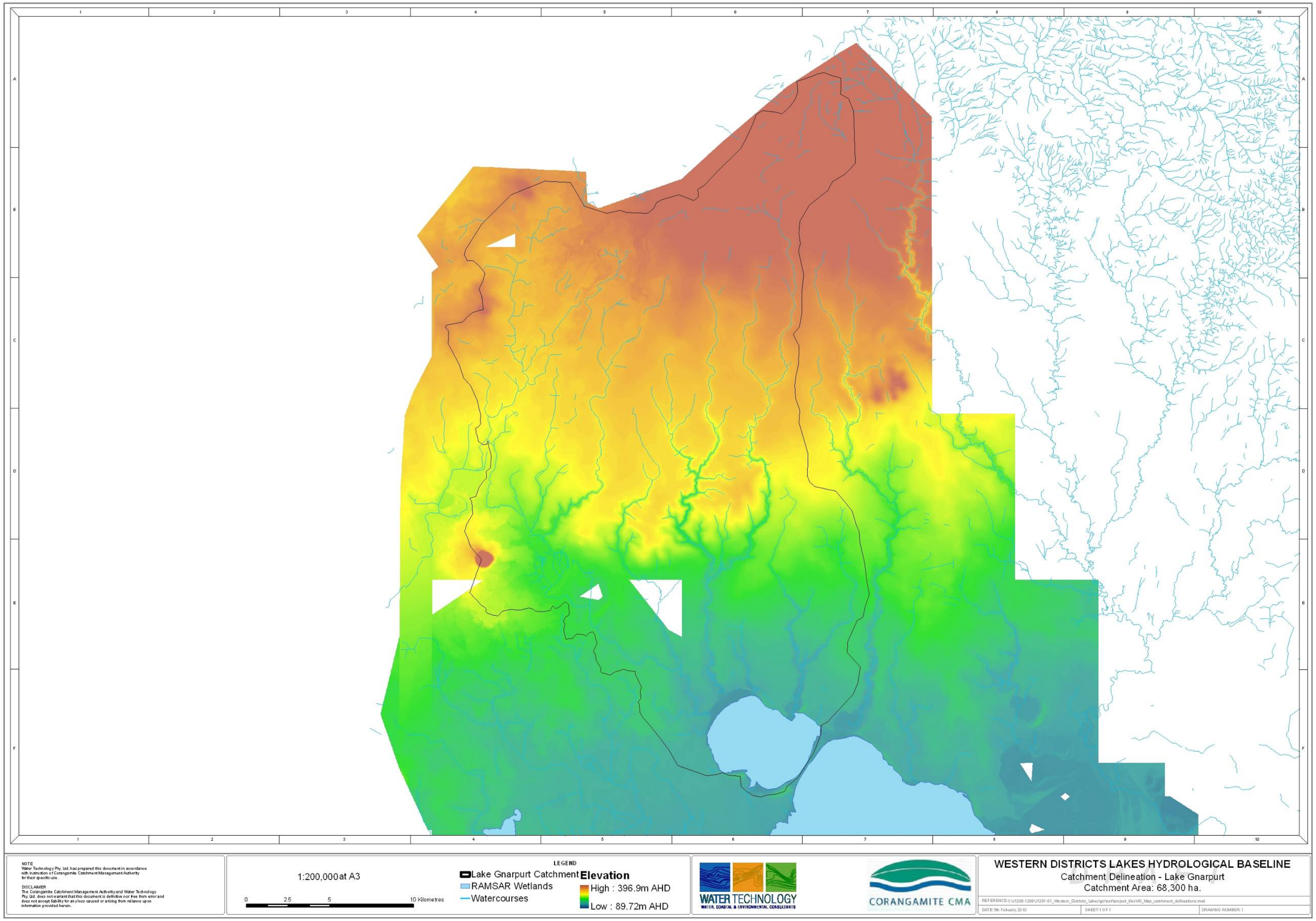


Figure 11-16 Lake Gnarpurt Catchment Delineation

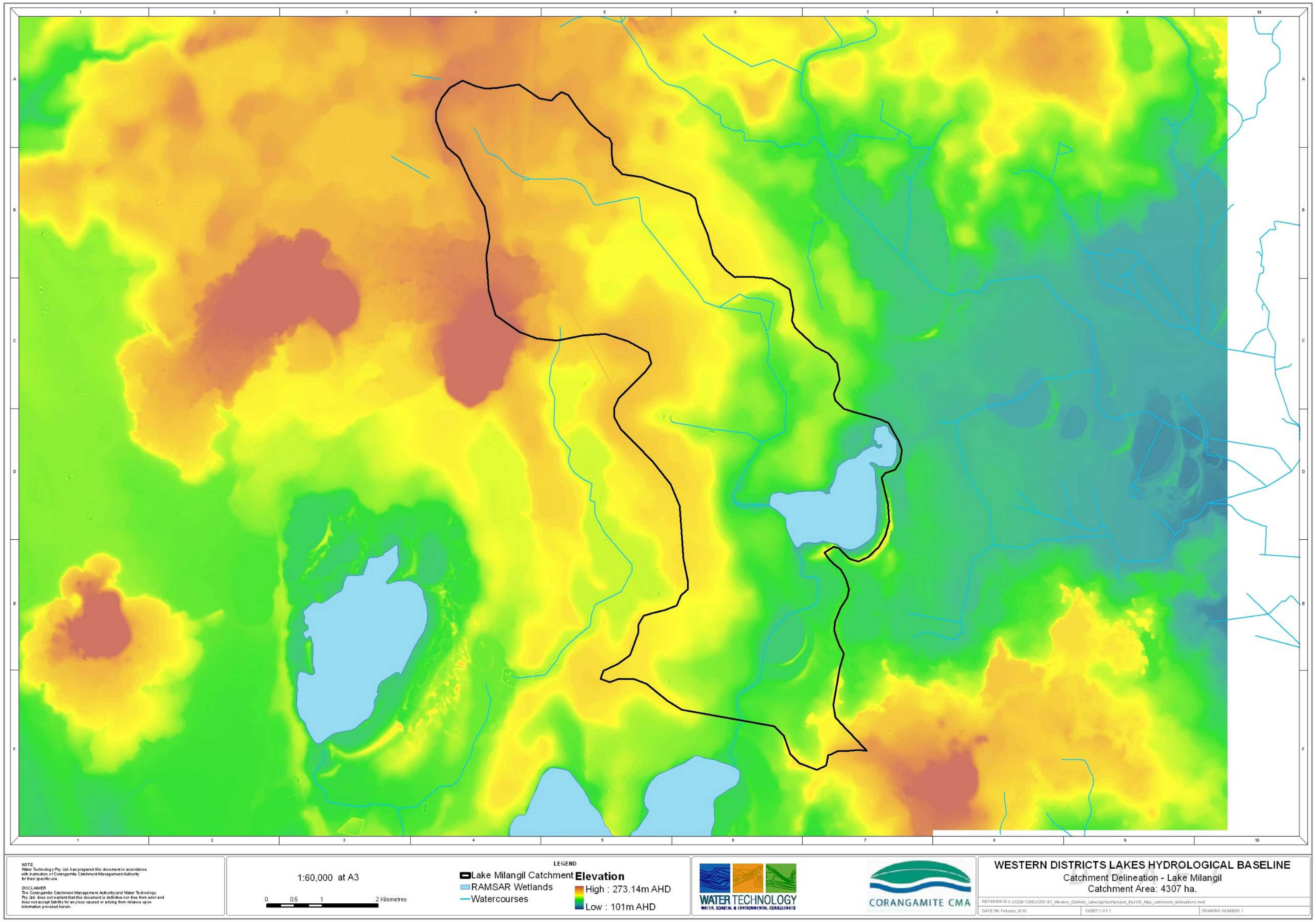


Figure 11-17 Lake Milangil Catchment Delineation

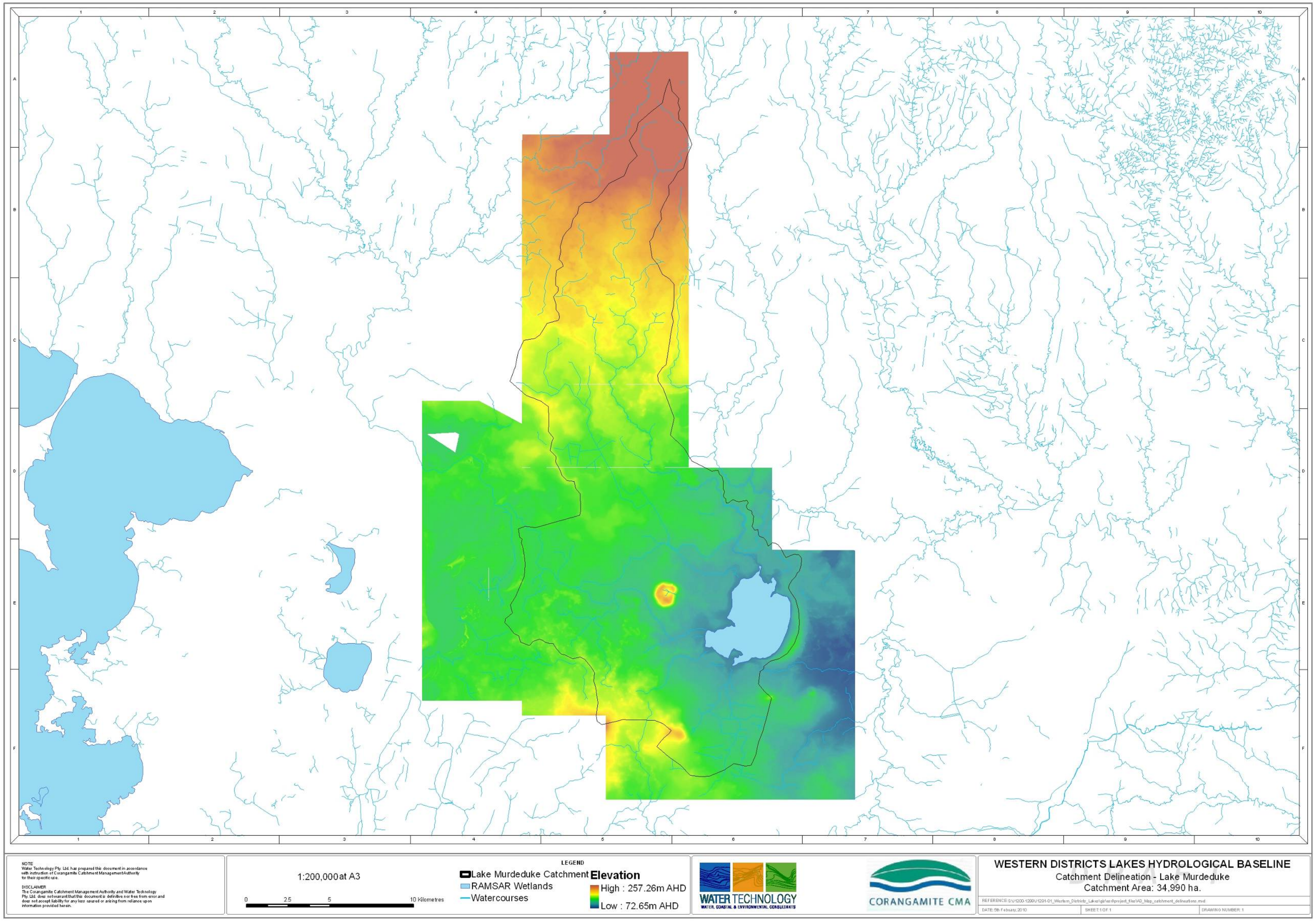
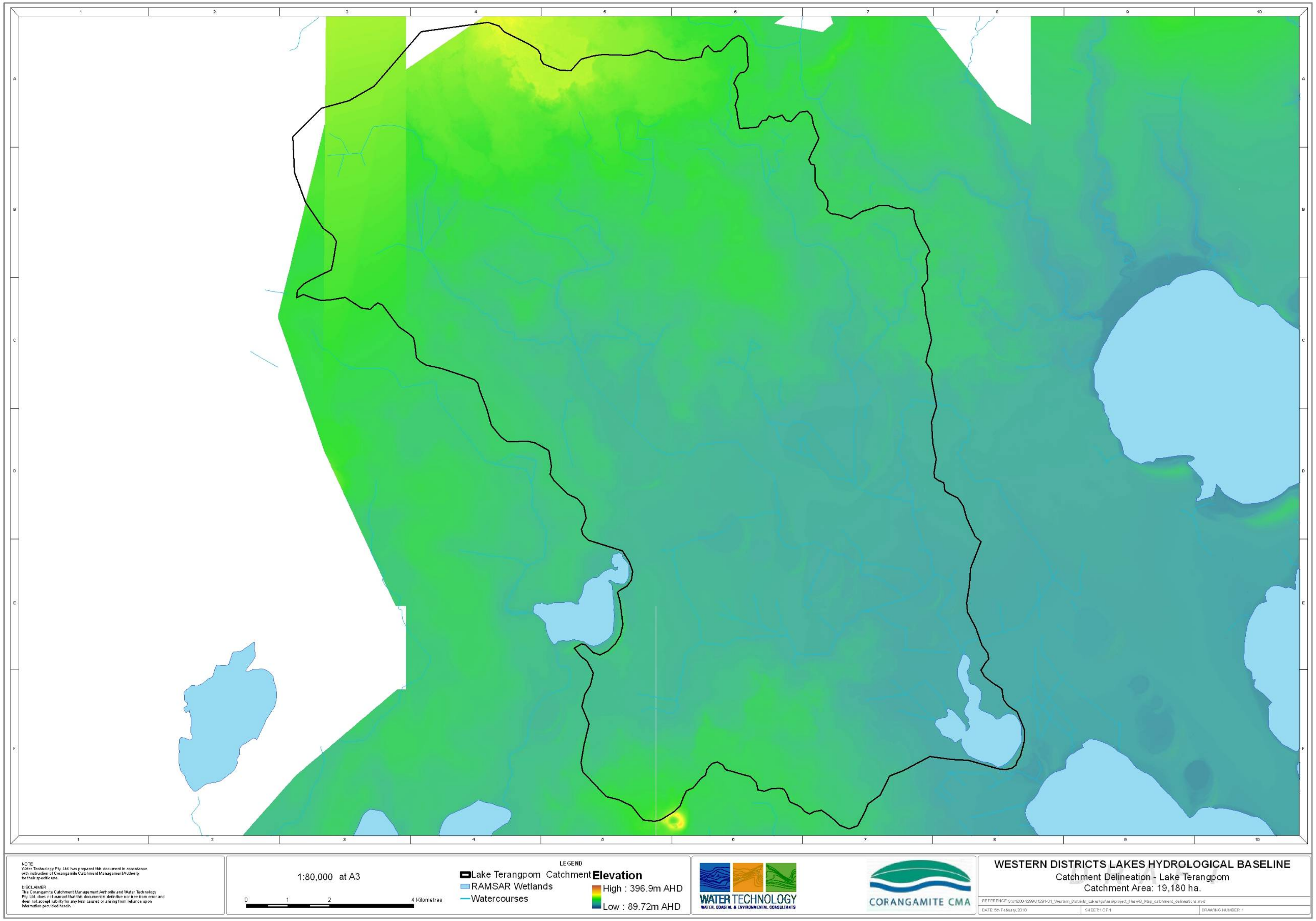


Figure 11-18 Lake Murdeduke Catchment Delineation



NOTE
Water Technology Pty. Ltd. has prepared this document in accordance with instruction of Corangamite Catchment Management Authority for their specific use.

DISCLAIMER
The Corangamite Catchment Management Authority and Water Technology Pty. Ltd. does not warrant that this document is definitive nor free from error and does not accept liability for any loss caused or arising from reliance upon information provided herein.

Figure 11-19 Lake Terangpom Catchment Delineation

APPENDIX C

LIDAR LIMITATIONS

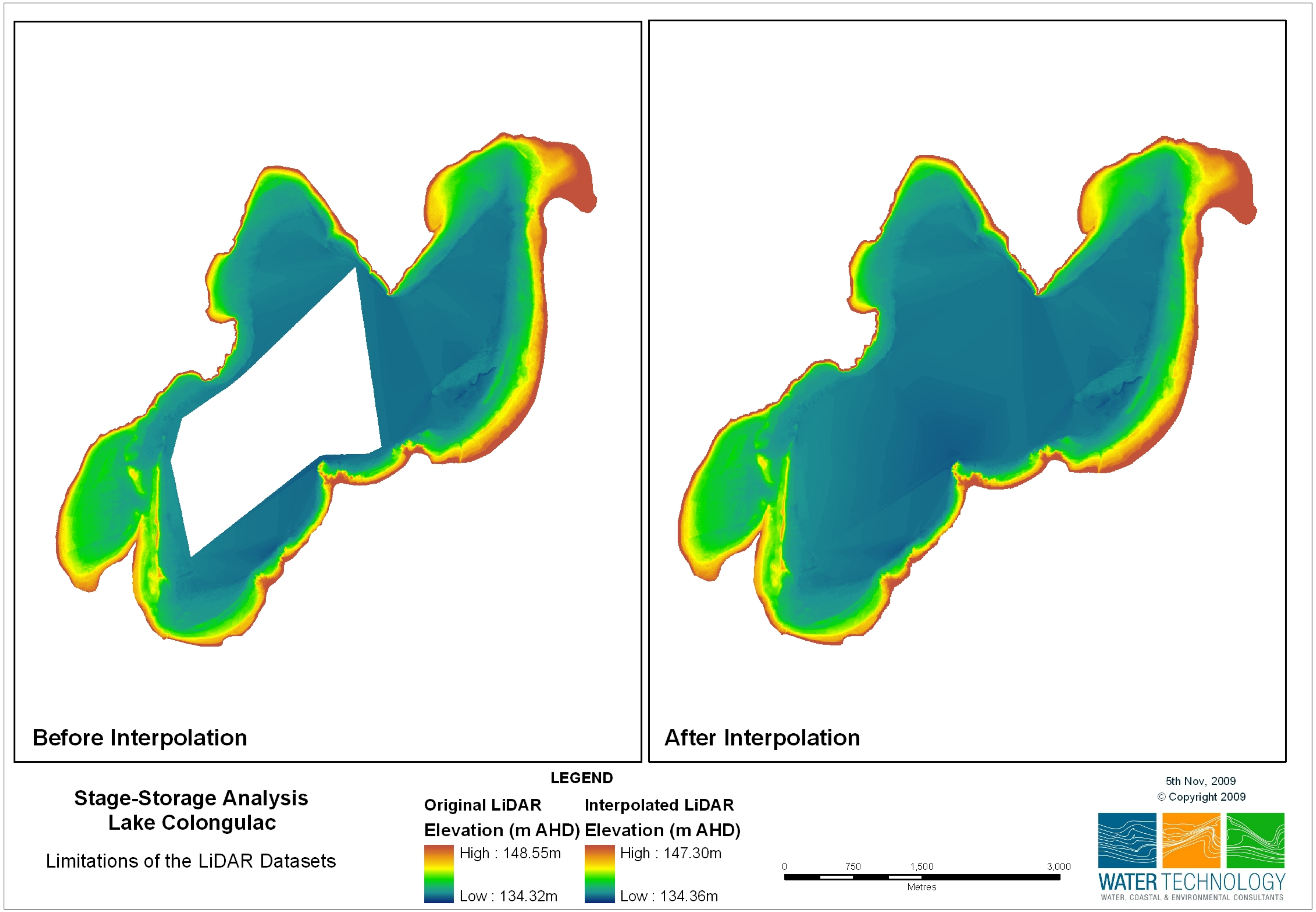


Figure 11-20 LiDAR Limitations – Lake Colongulac

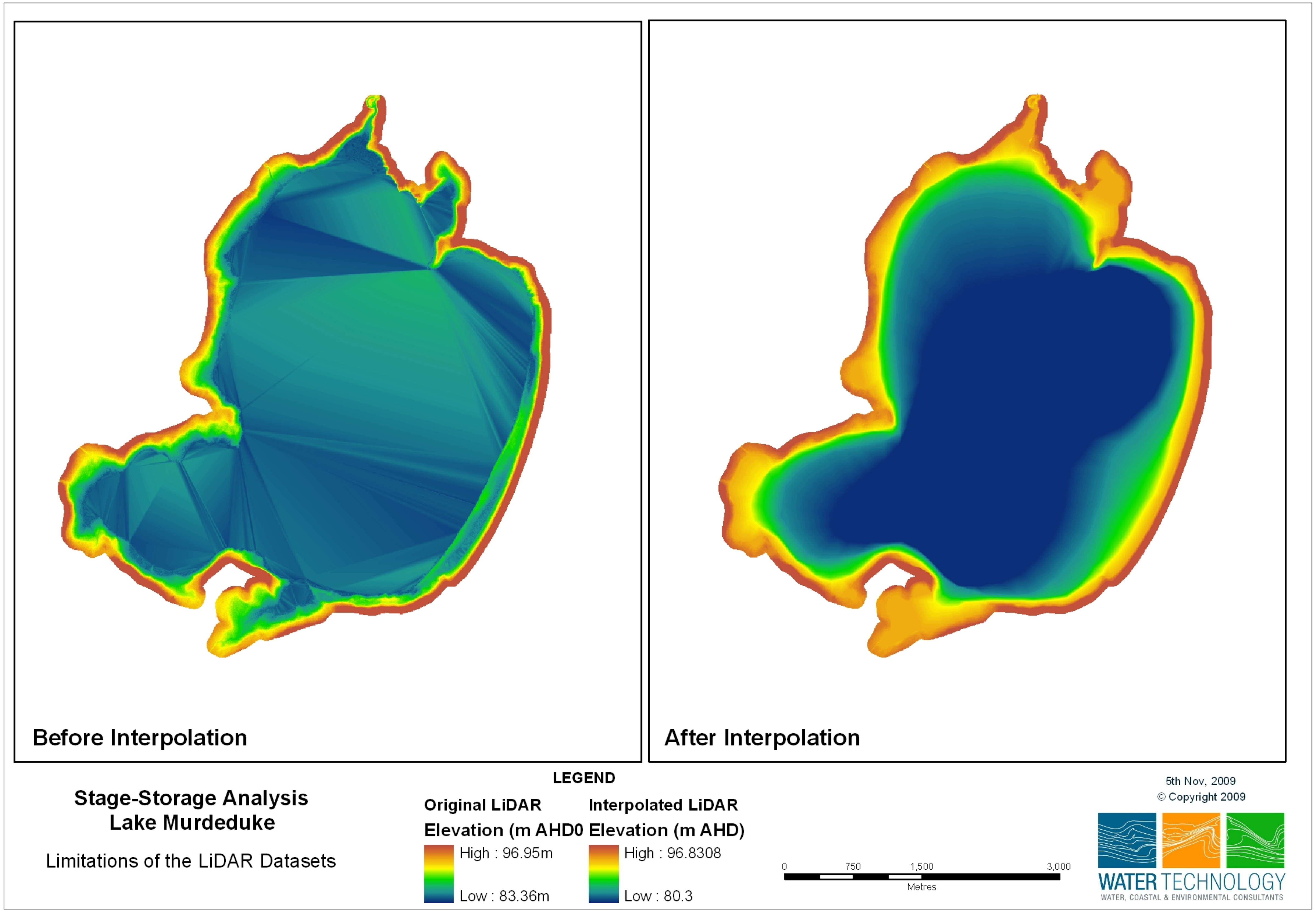


Figure 11-21 LiDAR Limitations – Lake Murdeduke