Final Report

Wimmera Wetland Hydrology Investigation

Wimmera Catchment Management Authority

09 October 2019

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STUDY SUMMARY

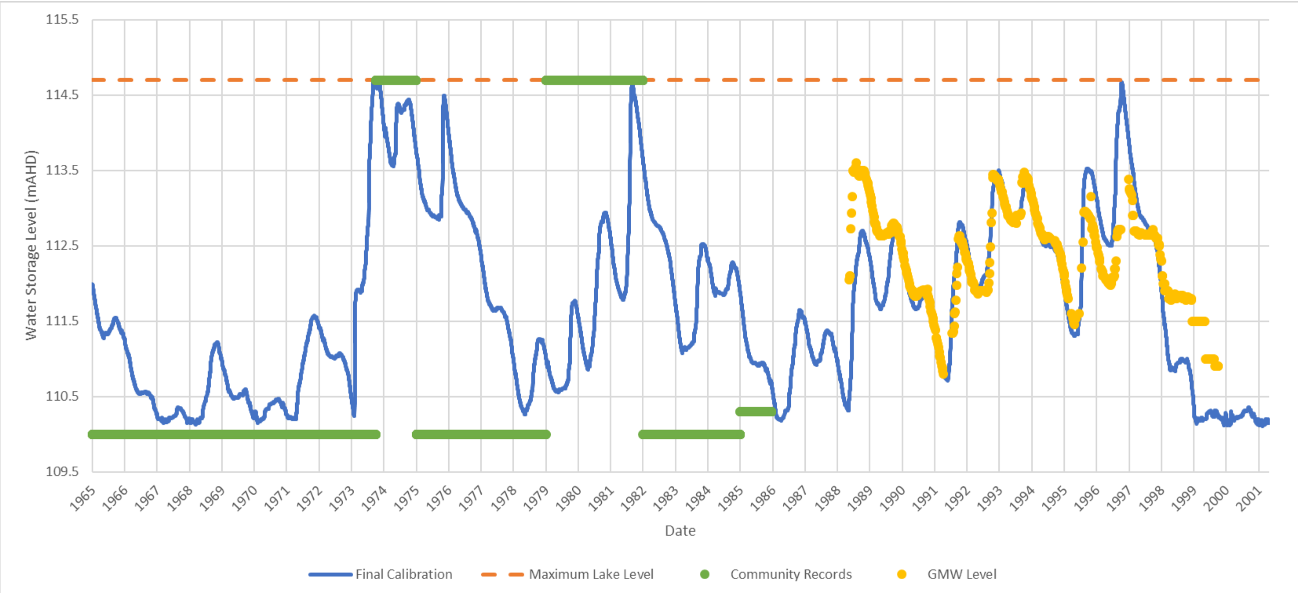
Background

The Wimmera Catchment Management Authority (Wimmera CMA) region includes numerous ephemeral waterways which drain to inland lakes and wetlands during wet conditions.

This study was completed in 2019 to look at the changes to the filling/drying regimes that three large wetlands in the west Wimmera (Natimuk Lake, St Mary's Lake and Lake Wallace) have experienced over the last couple of decades. The lakes are all high value, iconic wetlands and have experienced a reduction of flows entering the lakes over the years. Wimmera CMA commissioned Water Technology to complete the project.

Process

Water Technology undertook site inspections and reviewed previous technical reports on these lakes (e.g. salinity and groundwater investigations). A community meeting was also held in Natimuk, at which community members shared information on catchment issues for the three lakes. Lots of valuable historical information was obtained from the Natimuk Lake Foreshore Committee, Friends of Lake Wallace and others on water levels in the lakes over the years. The collated information enabled Water Technology to develop models which replicated historical lake levels as a basis for testing various catchment and climate scenarios to assess the potential impact on lake water levels. An example of the modelled and observed water levels within Lake Natimuk is shown below.



Observed and calibrated modelled water levels in Lake Natimuk levels between 1965 and 2001

Climate and Land Use Change

Reducing annual rainfall over recent decades has been the key factor in the reduction in flows and extended dry periods within the lakes. This is forecasted to continue under predicted climate change scenarios. However, there is a large degree of uncertainty in the predictions due to the reliance and unpredictability of changes to carbon emissions, future mitigation options and new scientific knowledge. Lake Natimuk is expected to be more severely affected by climate change than Lake Wallace and St Mary's Lake given its catchment size, catchment characteristics, the significant runoff required for it to fill and high evaporation rates.

Land use change over the recent decades has also reduced inflows in the lake, with changing agricultural practices meaning more rainfall is retained on farmland rather than running off into creeks and wetlands. To highlight the impact of land use change, catchment conditions within the model were changed to reflect continuously grazed land rather than the current conditions where agricultural land use is a mix of grazing and cropping. Modelled water levels in both the current and changed catchment conditions scenarios were then compared. In a continually grazed catchment, Lake Natimuk would overflow more than twice as often as it did historically, illustrating the substantial impact that land use practices have on runoff into waterways. It could be argued that this logic could also to both Lake Wallace and St Mary's Lake depending on the proportion of cropping and grazing land in their respective catchments.

Pre-European Conditions

Modelling was also used to predict the lake inflows that would have occurred if each lake catchment was the same as 200 years ago – covered with native vegetation. Native vegetation cover led to reduced inflows as it generally produces less runoff than agricultural land. The results from this scenario were used to illustrate that the wetlands were likely to have had lower average inflows 200 years ago than today, but would have still maintained valuable wetland habitat, supporting abundant and diverse native plant and animal populations. This demonstrates that even in the face of climate and land use change impacts, these lakes are still vitally important wetlands for flora and fauna.

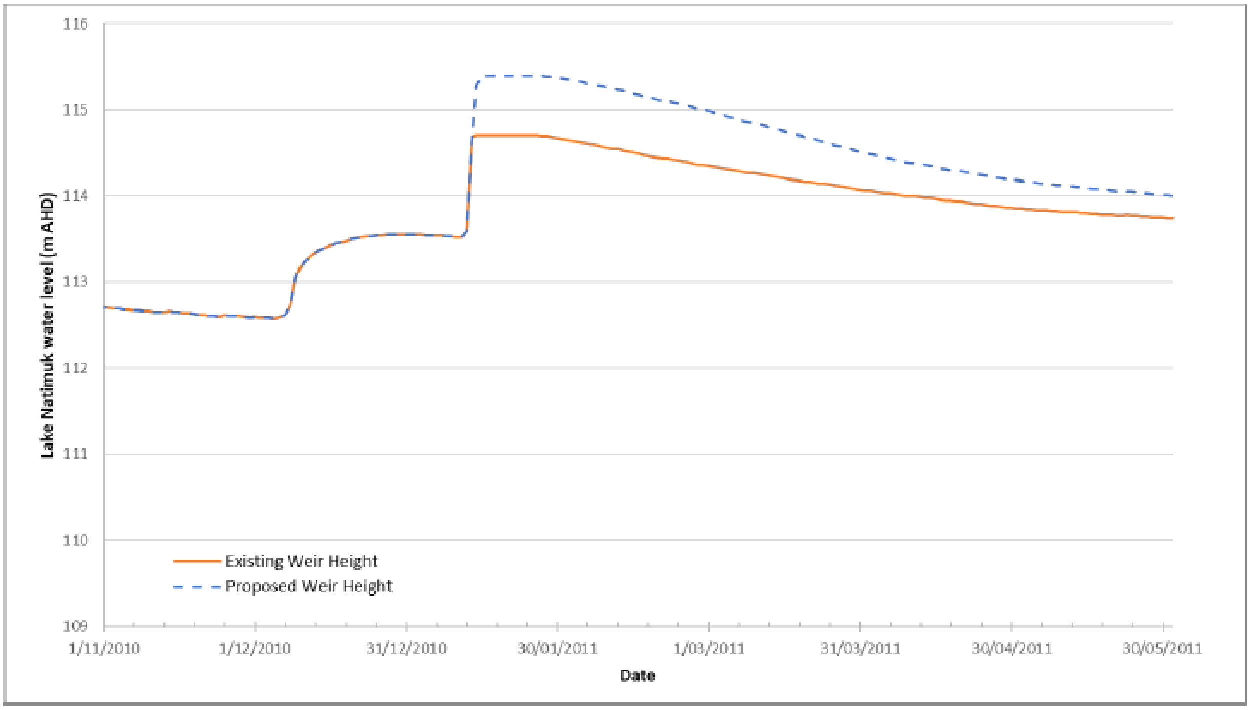
Changing the maximum water height in Lake Natimuk

Modelling was used to test the impact of raising the maximum operating level of Lake Natimuk by 0.7 m. Modelling has shown when the lake fills in this scenario, water levels are maintained above the current maximum water level for 3-4 months after isolated lake filling events. Beyond this time period, water levels are slightly higher than was shown for the current arrangement for anywhere between 3 months and four years, see the following example graph of late 2010 and early 2011. The increased weir height causes no water level impact post inflows earlier in 2010 when the current weir height was not reached, while in early 2011 both the existing and proposed weir heights are exceeded in their respective scenarios. The maximum water level difference is 0.7 m (the difference between the weir heights), this is maintained for around two weeks, after which point the lake water levels begin to decrease and the scenarios begin to converge. It takes about 3 months for the lake level to return to 114.7 m AHD (the current weir height) in the proposed weir height scenario. At this point the water level difference between the two scenarios is 0.5m. After 6 months the difference between the scenarios is around 0.25 m, 9 months it's 0.15m and 12 months it's 0.05m. Raising the outlet of Lake Natimuk would also slightly reduce the frequency of flows spilling downstream to Lake Wyn Wyn (from 8 to 6 times around every 100 years). However, it will not reduce the duration of time Lake Natimuk is dry.

Modelling also showed increasing the Lake Natimuk outlet height will cause some risk to local road infrastructure and vegetation. Risks were not extreme risks and will be manageable with the ability to be adjust the weir height. This modelling and preliminary assessment of risks was completed as a standalone report that is provided in Appendix B of this report.

Key message

This project has provided information to understand the drivers behind the reduction in inflows into lakes in the West Wimmera. Whilst it appears that climate and land use change will have serious impacts on the lakes' water regime and the social and economic values they provide, they will still be able to support a wide range of environmental values through their wet and dry phases.



Modelled water levels in Lake Natimuk with the existing and proposed increased outlet height from Nov 2010 to May 2011 post large inflows in 2010 and 2011.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

1.1 Project Background

Anecdotal evidence suggests the hydrological regime of wetlands and rivers in the Wimmera has altered, with inflows in recent years being comparatively infrequent and of limited volume. This has resulted in many terminal lakes and wetlands receiving limited inflows and experiencing lengthy dry periods.

Climate change and drought are noted as the key drivers for the limited inflows; however, changes to local drainage, land use, farm dams and modifications to terminal lakes such as the construction of weirs and spillways in some cases have also played a part in the change in hydrological regime.

This project assessed the potential for climate and land use change to affect the hydrological regime for Lake Natimuk, Lake Wallace and St Mary's Lake. The information generated and analysis undertaken through this project will inform the local community as well as enable Wimmera CMA to assess future planning and management options.

Photos of Lake Natimuk, Lake Wallace and St Mary's Lake are shown in Figure 1-1, Figure 1-2 and Figure 1-3 respectively, with details of the maximum volume, maximum depth and full supply area shown in Table 1-1.

FIGURE 1-1 LAKE NATIMUK (CREDIT: DAVID FLETCHER)

FIGURE 1-2 LAKE WALLACE

FIGURE 1-3 ST MARY'S LAKE

TABLE 1-1 PHYSICAL CHARACTERISTICS OF EACH LAKE

Lake	Max. volume (ML)	Max. Depth (m)	Max. storage area (Ha)
Lake Wallace	9,300	5.2	210
St Mary's Lake	3,900	4.8	91
Lake Natimuk	12,600	4.7	307

1.2 Study Area

The study area covers the individual catchments and water bodies of Lake Natimuk, Lake Wallace and St Mary's Lake. Each catchment has an individual complex system of constructed channels and natural drainage lines.

1.3 Reporting Purpose

This report is the final major deliverable completed as part of the *Wimmera Wetland Hydrology Investigation*. The report details the data collating process, how each of the three hydrologic models was constructed and calibrated to the available data, and the impact climate and land use change has had/will have on water levels in the lakes.

The key components of this report include:

- Data collation.
- Rainfall and streamflow analysis.
- Hydrologic model construction process, inputs and outputs.
- Detailed calibration of the Lake Natimuk model.
- Validation of the Lake Wallace and St Mary's Lake models.
- Climate and catchment change modelling.

1.4 Modelling Overview

The calibration and climate and catchment change methodology are described in four main components:

- A description of the hydrologic model and its inputs
- Each model's calibration and verification
- Climate change inputs and results
- Land use change inputs and results

This project used the eWater Source modelling package. Source is flexible, adaptive and integrated water management software that is designed to simulate all aspects of water resource systems. Source uses a graphical interface to develop a conceptual view of catchments in a node-link style modelling system for generating, transporting and transforming water and constituents within the major channels in a catchment.

Source was adopted for this project because of its flexibility. Building a Source model is relatively straightforward but requires an iterative calibration process. The flow chart shown in Figure 1-4 outlines the process of model calibration and climate change modelling. The data collation and analysis documented in this report was aimed at meeting the Source model requirements.

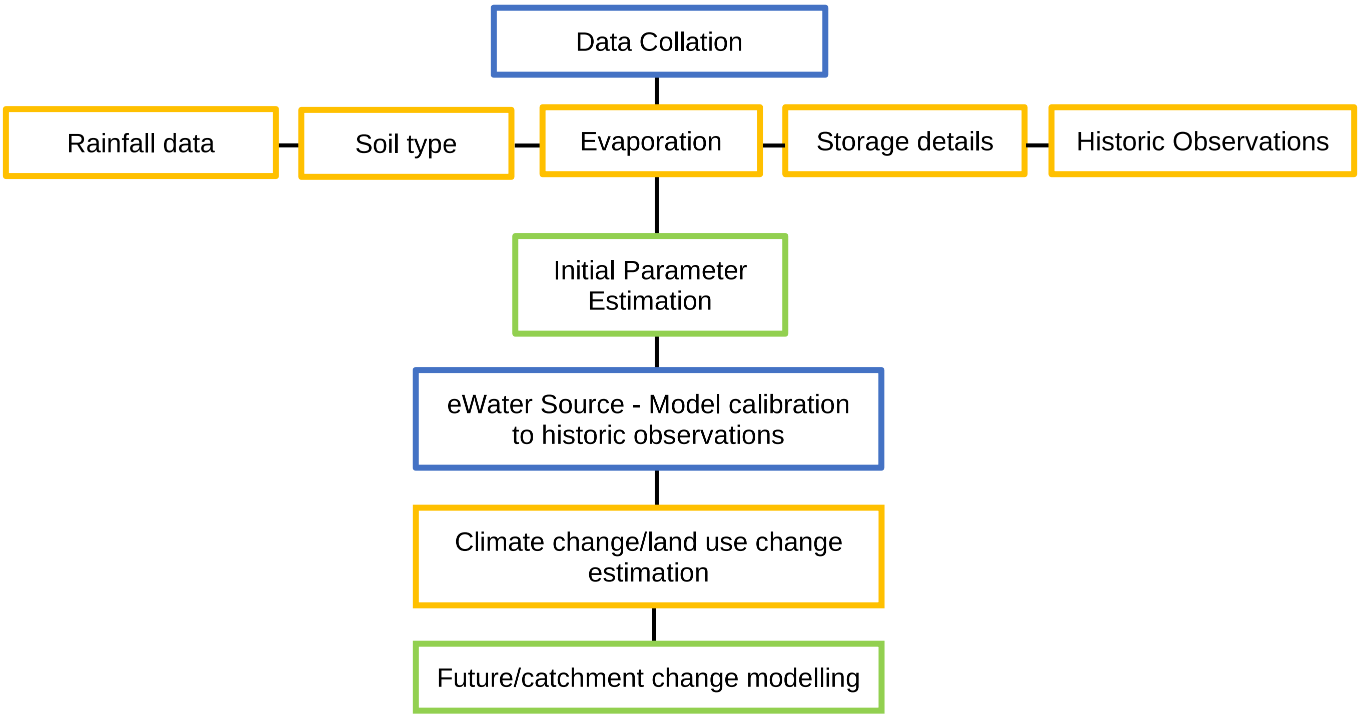


FIGURE 1-4 EWATER SOURCE MODELLING OVERVIEW

2 DATA COLLATION

2.1 Previous Studies

The following list outlines the previous studies undertaken in the region, which were collated as part of this data collation report. The key previous studies are highlighted in Bold and will be referenced throughout:

- **Natimuk Flood Investigation Study Report *(Water Technology, 2013)***
- **Wetland Extent and Drainage Line Mapping Project *(SKM, 2006)***
- **Land Use and Surface Water in the Lake Wallace and Mosquito Creek Catchments – South West Wimmera *(Hocking, 2007)***
- Additional Hydrological Investigations for the Diversion of Flow from the Lower to the Upper South East: Potential Impact of Forestry and Climate Change on Water Resource Availability *(Heneker, 2006)*
- Landuse Scenario Modelling of the Victorian Millicent Coast (West Wimmera) – South-West Region *(Hocking et al. & Phil Dyson and Associates, 2004)*
- **Western Wimmera Wetland Classification – Groundwater-Surface Water Interaction *(SKM, 2006)***
- Morambro Creek and Nyroca Channel PWCs and Morambro Creek PSWA 2015 *(DEWNR, 2016)*
- Determination of Sustainable Diversion Limits for Additional Wimmera Catchments *(SKM, 2008)*
- Natimuk Lake Sub-Catchment Salinity Control Project *(DPI, 2004)*
- **Hydrogeological Appraisal of the Natimuk Catchment *(DNRE, 2003)***
- Management Plan for the Natimuk-Douglas Saline Wetland System *(Birds Australia, 2002)*
- **Lake Wallace Catchment Management Plan *(West Wimmera Shire, 2002)***
- Nutrients, palaeolimnology and cyanobacterial blooms in Lake Wallace, Western Victoria *(G. Vinall, PhD Thesis, 2000)*
- **Preliminary assessment of water balance model for Lake Wallace, Edenhope *(Fawcett and Huggins DPI, Jan 2005)***
- The Wimmera Southern Mallee Socio-Economic Value of Recreational and Environmental Water *(Street Ryan, 2017)*
- Wimmera Land Resource Assessment *(Robinson et al., 2005)*
- **Documentation around the Lake Natimuk Weir Height, sourced by Wimmera Mallee Water and provided by the Lake Natimuk Foreshore Committee**

Details around the planning overlays and zones covering each wetland catchment are detailed in Appendix C.

2.2 Hydrology and Hydrogeology

2.2.1 Generalised climate data

Areas west of Horsham are classified as Cfb climate under the Koppen-Geiger climate mapping, with warm summers and cold winters, as shown in Figure 2-1. The mean annual rainfall of the region ranges from 300 mm to 600 mm, as shown in Figure 2-2. For example, the typical rainfall distribution across the year for the Natimuk (079036) gauge shown in Figure 2-3. Note the relatively consistent spread across the year, with higher totals in the winter-spring months. The higher disparity between mean and median rainfall in the spring and summer months also indicates a higher likelihood of large rainfall events during this time.

The average daily maximum temperatures range from 18 to 24 Degrees Celsius which contribute to pan evaporation rates of between 1400 – 1800 millimetres annually, as shown in Figure 2-4. Pan evaporation distinguishes the rate of evaporation combining the effects of temperature, humidity, rainfall, drought dispersion, solar radiation, and wind.

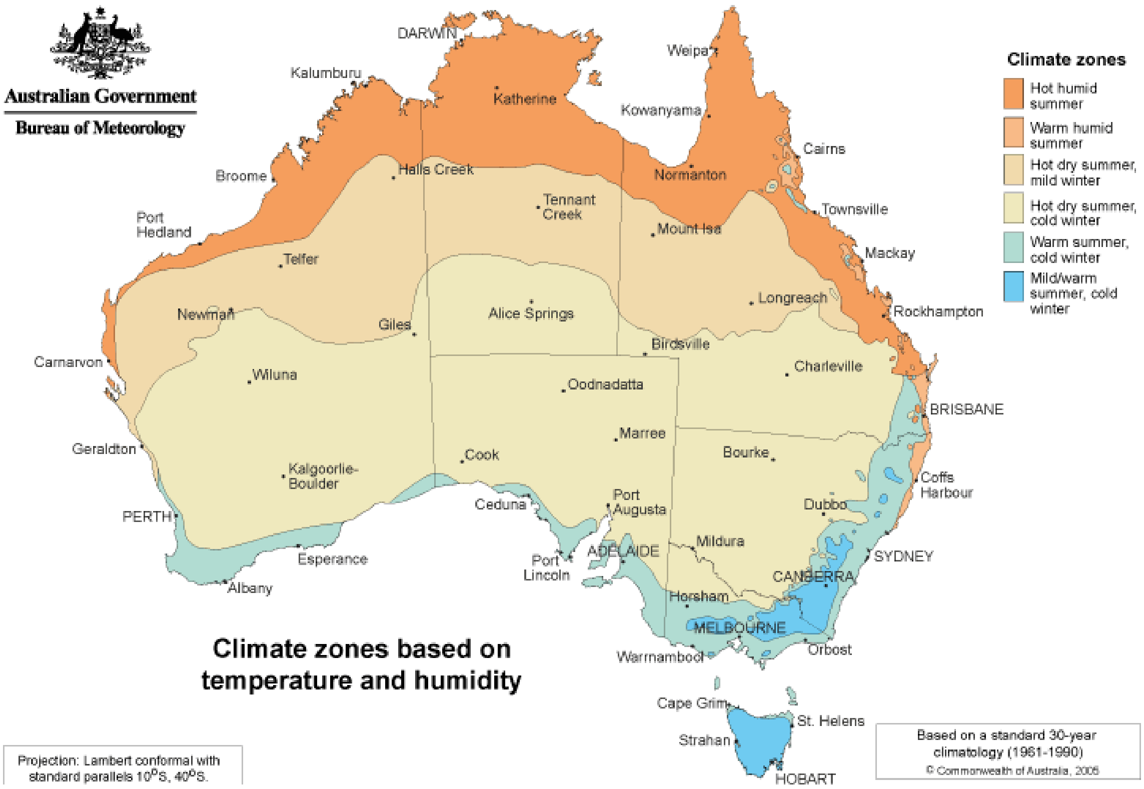


FIGURE 2-1 CLIMATIC ZONES AUSTRALIA (BOM)

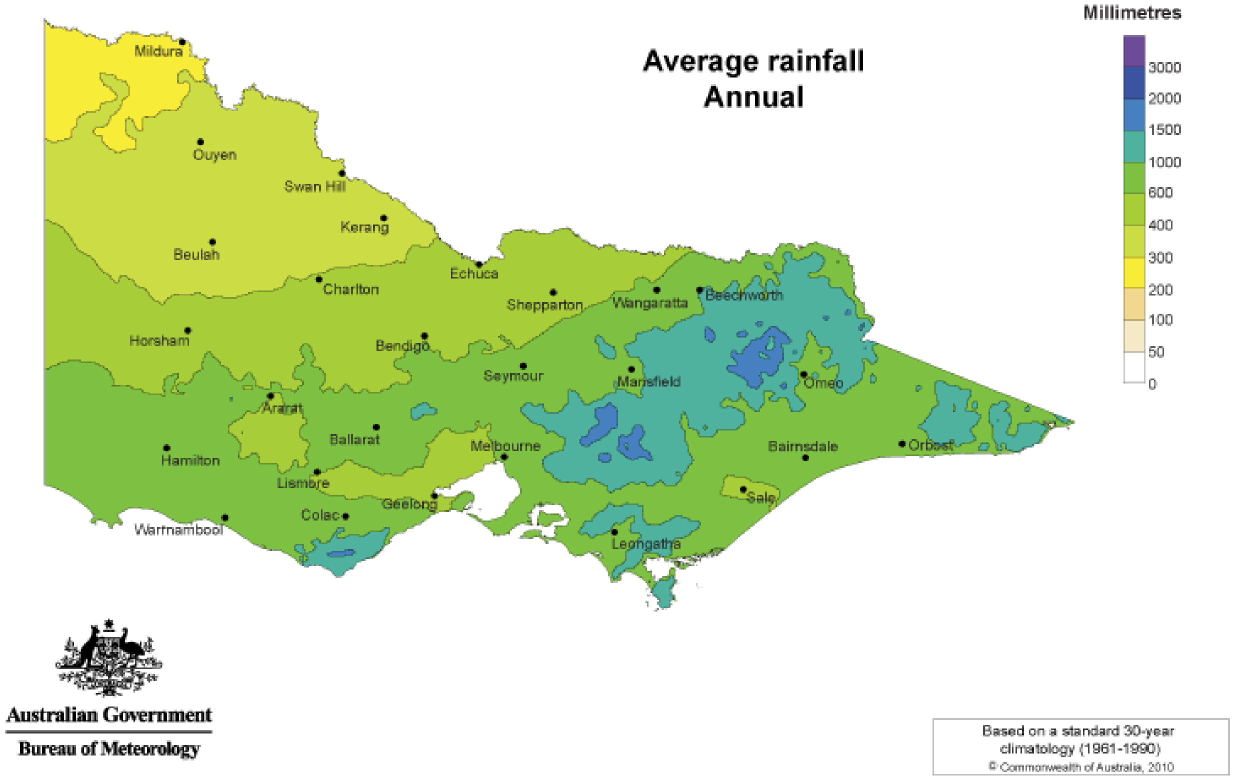


FIGURE 2-2 AVERAGE VICTORIAN ANNUAL RAINFALLS (BOM)

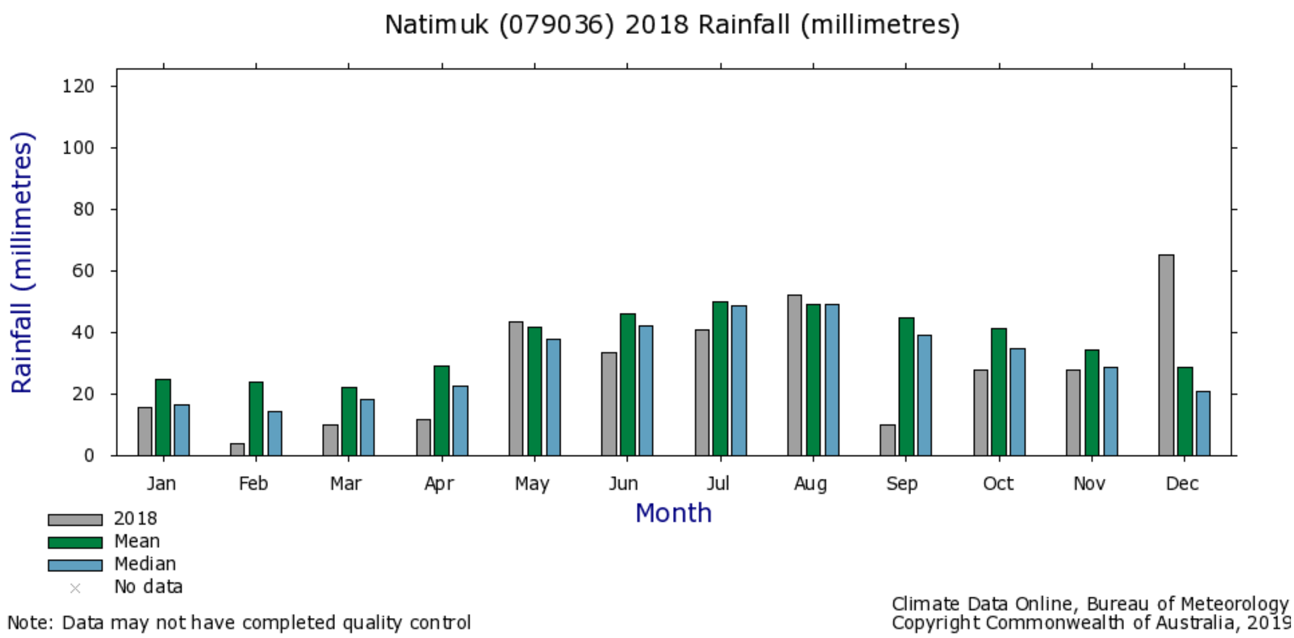


FIGURE 2-3 NATIMUK MEAN AND MEDIAN RAINFALL OVER A RECORDED PERIOD 1889 – 2018 (BOM)

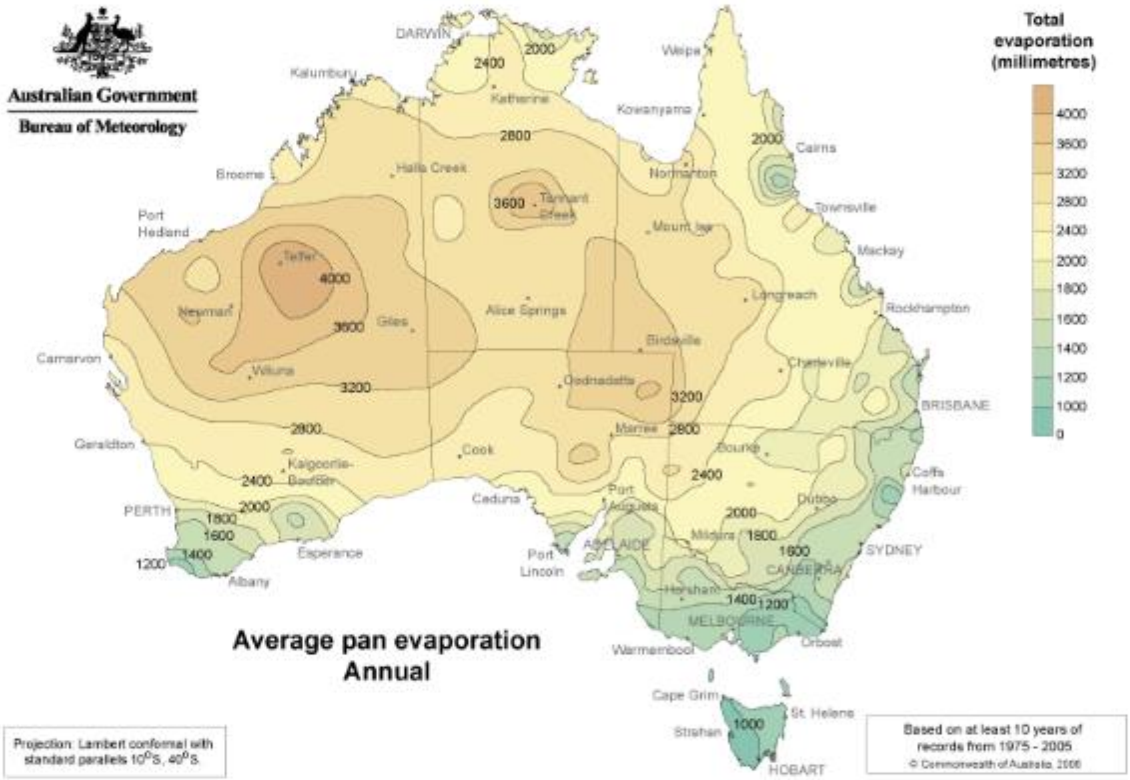


FIGURE 2-4 AVERAGE ANNUAL AUSTRALIAN EVAPORATION RATES (BOM)

2.2.2 Streamflow and Drainage

One active water surface level gauge exists within the study area, Natimuk Creek at McNeils Bridge (1579026). The gauge is located midway in the Lake Natimuk catchment, as shown in Figure 2-5. The McNeils Bridge gauge was commissioned in October 2016, so the gauge missed the late 2010 and early 2011 floods but recorded the December 2016 event. The data recorded by the gauge is shown in Figure 2-6.

Inflows to Lake Wallace were documented in late 1996 and early 1997 *(Fawcett and Huggins DPI, Jan 2005)* which were used to correlate surface water and groundwater interface specific to the Lake Wallace catchment.

No inflow data was available for St Mary's Lake

It is understood that all waterways across the site are ephemeral and only flow after significant rains. The Wimmera region catchments are typically sandy, with the lower floodplains, waterways, and waterbodies having heavier clays. As such, the sandy catchment tends to allow a significant amount of infiltration into the soil profile, requiring heavy rains to generate enough surface runoff to concentrate in the waterways. This characteristic is evident when visiting the catchment areas.

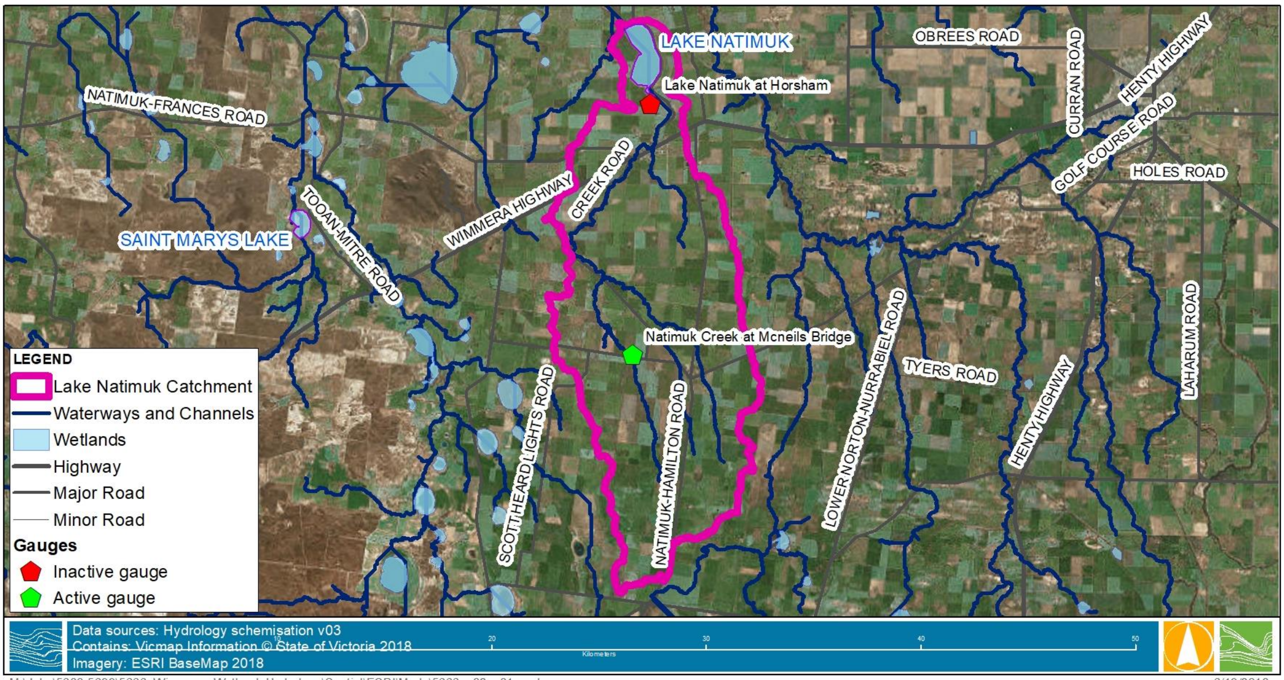


FIGURE 2-5 SURFACE WATER AND WATER LEVEL GAUGING LOCATIONS

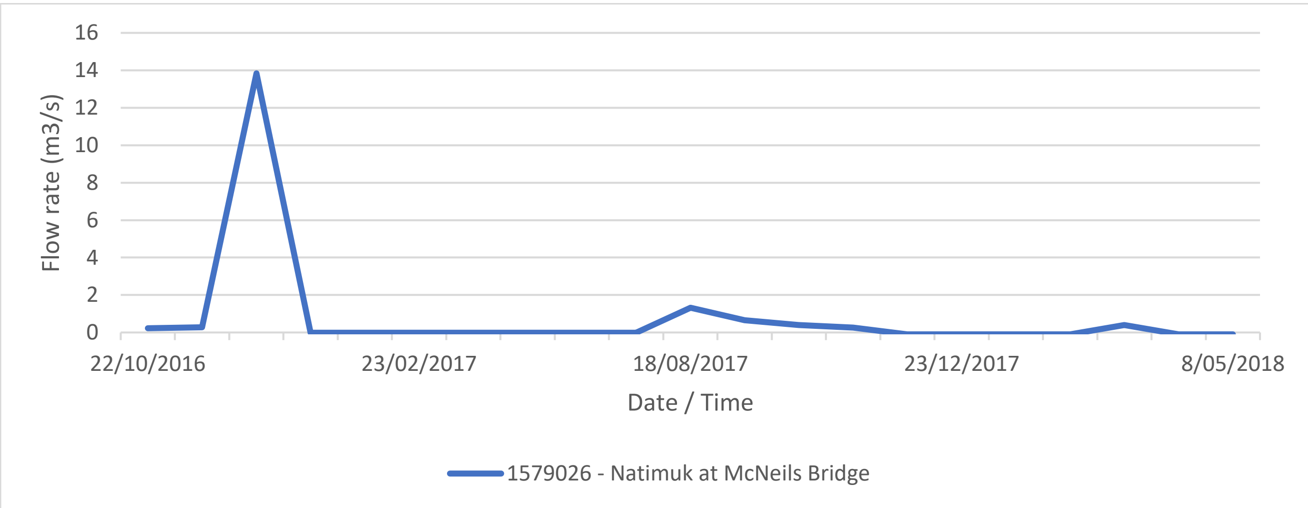


FIGURE 2-6 FLOW DATA CALCULATED FROM FOR THE NATIMUK CREEK AT MCNEILS BRIDGE GAUGE

2.2.3 Wetland water levels

There is limited recorded water level information available across the three lakes with only one formal gauge, Lake Natimuk at Horsham (415602). The gauge operated from 8th July 2009 through to 2014 recording a peak level in 2011. There are large gaps in the recorded data. The location of the gauge is shown in Figure 2-6, with the data recorded shown in Figure 2-7. Additional water level data collected by Wimmera Mallee Water was also sourced showing instantaneous (weekly) water level recordings through the late 1980s and 1990s.

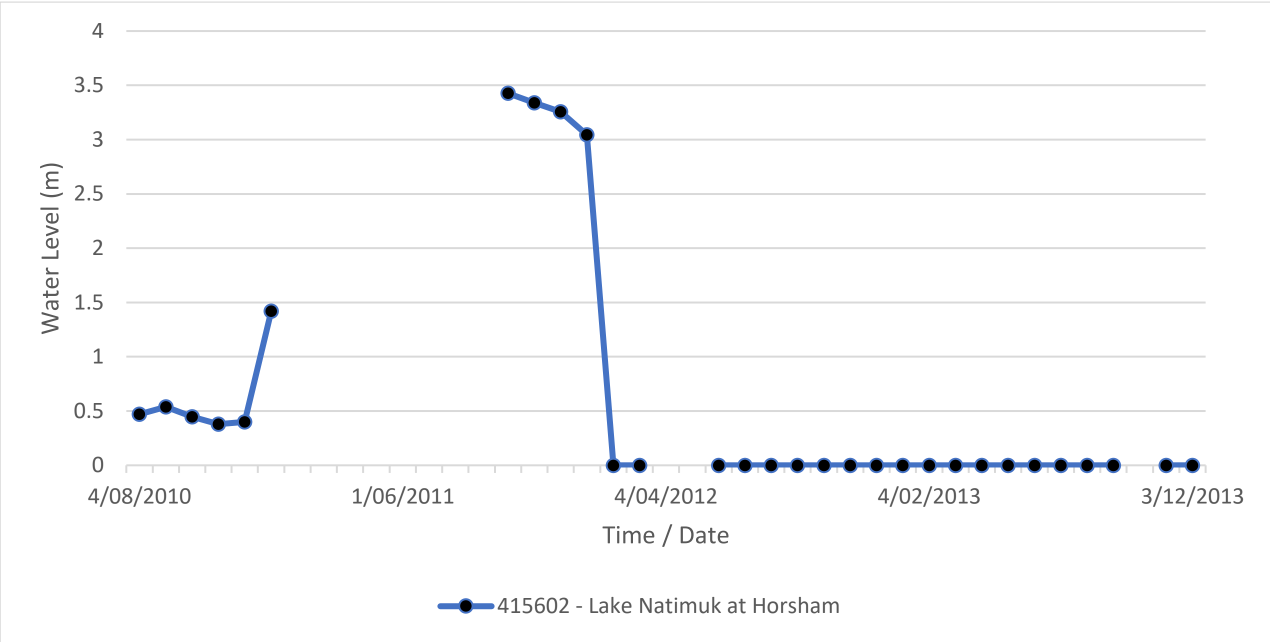


FIGURE 2-7 LAKE NATIMUK AT HORSHAM GAUGE RECORD

Along with the recorded wetland levels there are several opportunistic water level records or observed dates when the lakes were either empty, full or overflowing, particularly from newspaper articles/photos. Examples of this for Lake Wallace are shown in Figure 2-8 and Figure 2-9. The Lake Natimuk Foreshore Committee was also able to provide a host of additional information.

Key dates, data available and data source for each of the three wetlands are shown in Table 2-1 with a graphical representation of the available Lake Natimuk and Lake Wallace data shown in Figure 2-10 and Figure 2-11 respectively. Data extracted and collated from the *West Wimmera Advocate*[1] is summarised in Table 2-1.

[1] A special thanks to Toni Domaschenz (*West Wimmera Advocate*) for providing the information and Greg Fletcher (WCMA) for summarising.

FIGURE 2-8 EDENHOPE – LAKE WALLACE FLOOD RECORD

FIGURE 2-9 EDENHOPE – LAKE WALLACE OVERFLOW RECORED

TABLE 2-1 COLLATED LAKE HYDROLOGY DATA

Lakes Hydrology		
Lake Natimuk		
Date	**Data Type**	**Source**
1890 – 2018	Rainfall	BoM
2010 – 2013	Water Level	DELWP
2016 – 2018	Water Level Natimuk Creek	FloodZoom
2018	Lake Dry	Site Visit
1996-1997	Lake Full	Foreshore Committee
1988-1999	Water level	Wimmera Mallee Water records
1985	Knee deep	Foreshore Committee clipping
1981	Lake Full	Foreshore Committee clipping
1979	Lake Full	Foreshore Committee clipping
1977-1978	Lake Dry	Foreshore Committee
1974	Lake Full	Foreshore Committee clipping
October 1973	Lake Filled	Foreshore Committee clipping
1967-1973	Lake Dry	Foreshore Committee
1944	Lake Dry	Foreshore Committee
1936	Lake Full	Foreshore Committee
1930	Lake Dry	Foreshore Committee
1910	Lake Full	Foreshore Committee
1894-1897	Lake Dry	Foreshore Committee

Lakes Hydrology		
1870	Lake spilled	Foreshore Committee clipping
St Marys Lake		
Date	**Data type**	**Source**
1890 – 2018	Rainfall	BoM
2018	Lake Dry	Site Visit
Lake Wallace		
Date	**Data type**	**Source**
1890 – 2018	Rainfall	BoM
1996 – 1997	Streamflow	Fawcett and Huggins
Drought (00 – 10)	Lake Dried	Lake Signage
2 Oct 1992	Overflow Flood	Lake Signage
19 Sept 1991	Overflow Flood	Lake Signage
27 June 1988	Overflow Flood	Lake Signage
7 Aug 1987	Overflow Flood	Lake Signage
20 Sept 1984	Overflow Flood	Lake Signage
19 Aug 1981	Overflow Flood	Lake Signage
4 Aug 1974	Overflow Flood	Lake Signage
27 Oct 1970	Overflow Flood	Lake Signage
7 Sept 1965	Overflow Flood	Lake Signage
27 Aug 1955	Overflow Flood	Lake Signage
11 Aug 1953	Overflow Flood	Lake Signage

Lakes Hydrology		
10 Jul 1950	Overflow Flood	Lake Signage
23 Jul 1946	Overflow Flood	Lake Signage
17 Aug 1923	Overflow Flood	Lake Signage

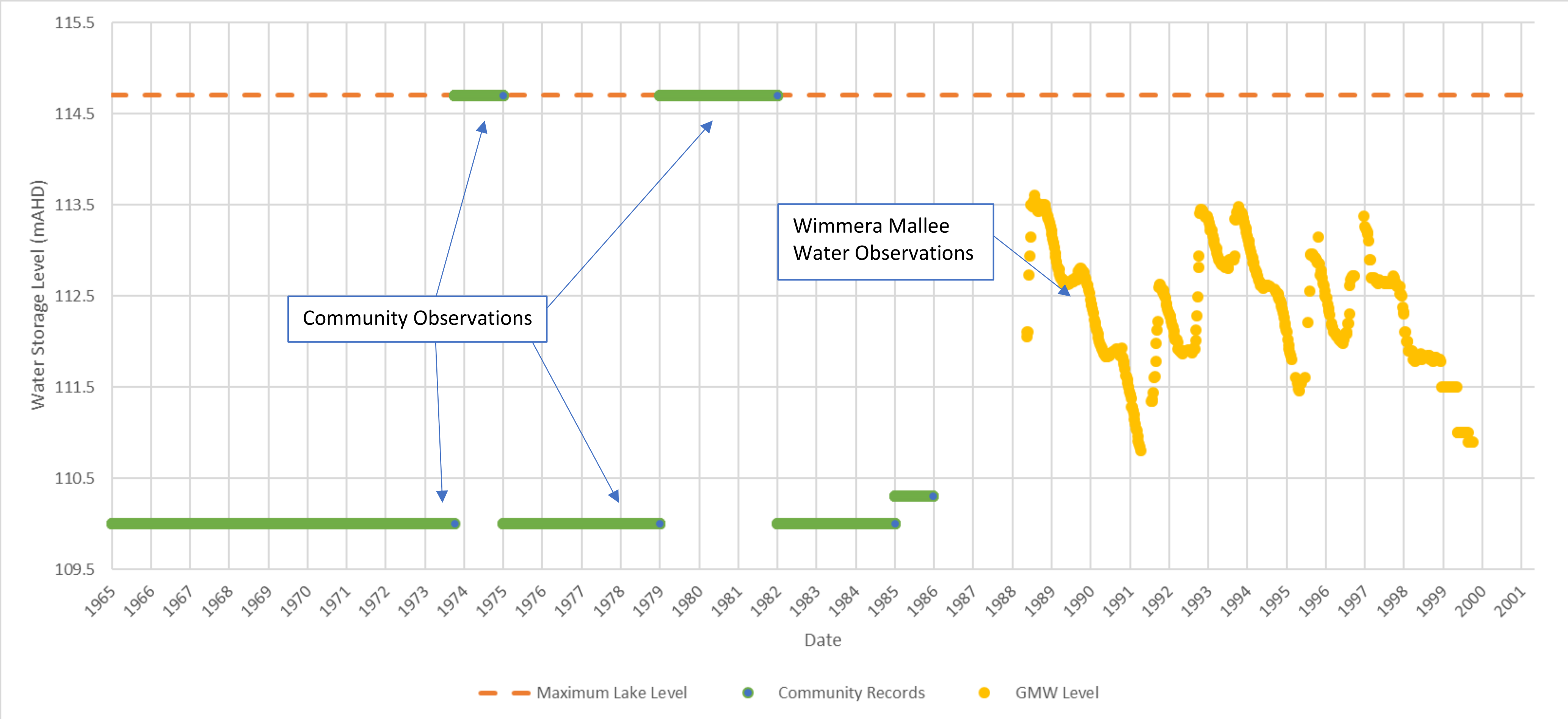


FIGURE 2-10 WATER LEVEL RECORDS FOR LAKE NATIMUK

TABLE 2-2 SUMMARISED LAKE WALLACE LAKE LEVEL INFORMATION

Date	Level
1923-1946	Lake did not overflow
Sept 1984	'lake almost full to overflowing', good inflows
Oct 1984	Lake overflows
April 1987	Lake looks full
July 1987	Head of the Lake Regatta
Nov 1987	Lake full for sailing
? 1996	Lake almost full
Jan 2003	Shallow water in the middle, 'expected to go dry in a week'. 'Lowest in living memory'
Feb 2003	Dry for Henley on Lake Wallace
Feb 2003	Went dry on 7 Feb
March 2003	Dry, event on dry lake bed
Oct 2003	No water visible in photo of southern part of lake
Sept 2004	Shallow water in lake, drain flowing well into lake
Jan 2005	Photo of shallow water in the lake
Jan 2007	Lake burnt for fairy grass
June 2007	No water visible in photo of southern part of lake
Sept 2007	Small area of shallow water with swans building nests
Dec 2007	Dry Lake sprayed for fairy grass
Sept 2008	Back Swamp full but not much in Lake Wallace
March 2009	Aerial photo shows lake is dry
Oct 2009	No water visible in photo of northern part of lake
Nov 2009	No water visible in photo of southern part of lake
May 2010	Small concrete barrier built in virtually dry drain into lake to retain water in drain
Sept 2010	'About 4 foot deep'
Oct 2010	Shallow water visible in photo
Dec 2010	Shallow water visible in photo
Feb 2011	'About 1/3 full'
March 2011	'About 6 feet of water'
Jan 2014	Photo of shallow water in the lake
April 2014	Photo of shallow water in the lake
Oct 2014	Water in the lake near the bottom of the pier, 'about half full'
Feb 2015	Water in the lake about 30 m from the bottom of the pier

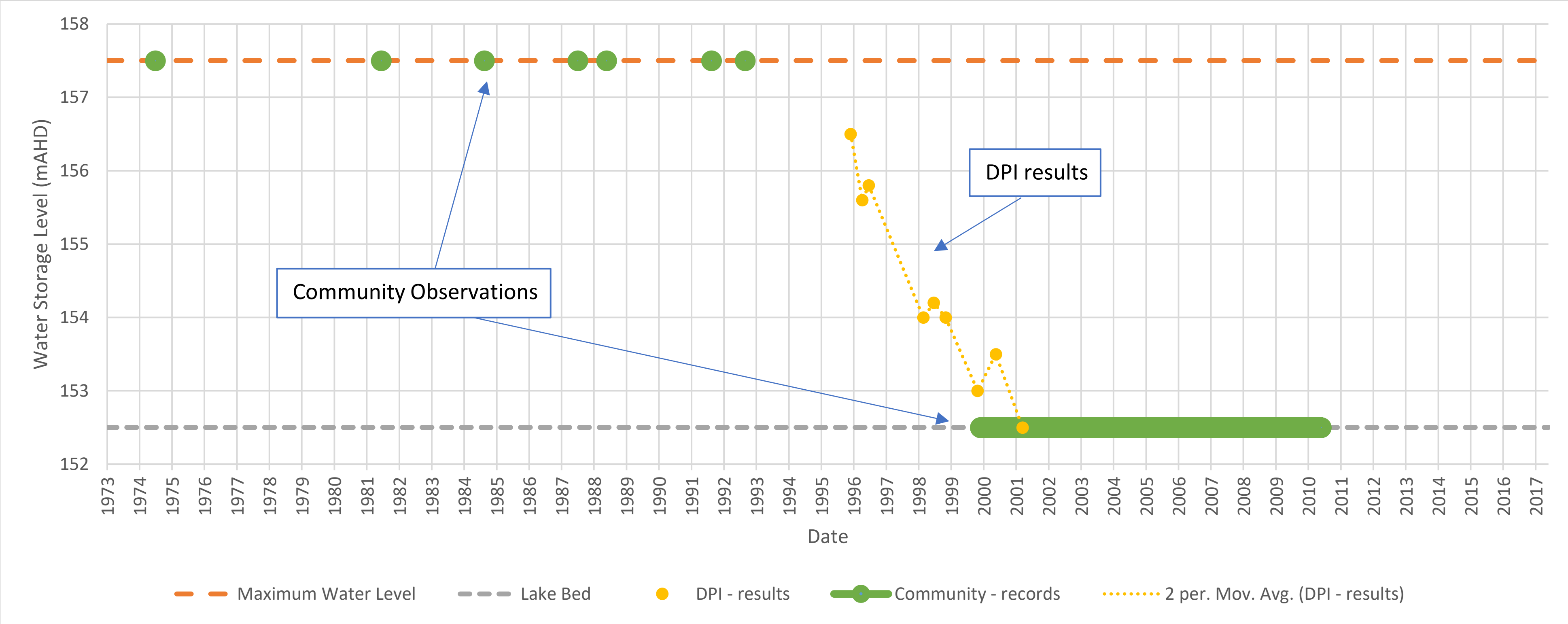


FIGURE 2-11 WATER LEVEL RECORDS FOR LAKE WALLACE

2.2.4 Rainfall data

Several Bureau of Meteorology (BoM) rainfall gauges and DELWP rainfall gauges were available at locations throughout the wetland catchment areas. This instantaneous data extends as far back as the 1990s, with daily rainfall data available from as far back as the 1880s. The gauges available included:

- 079036 Natimuk
- 079023 Horsham Polkemmet Rd
- 079100 Horsham Aerodrome
- 079008 Clear Lake
- 079082 Horsham
- 079025 Karnak (Rosedale)
- 079017 Goroke (Post Office)
- 079011 Edenhope (Post Office)
- 079099 Edenhope Airport
- 1079099 AWS Edenhope Airport
- 415256 Wimmera River @ U/S Dimboola

The location of the gauges with respect to the Lake Natimuk, St Marys Lake and Lake Wallace catchment areas, are shown in Figure 2-12, Figure 2-13 and Figure 2-14 respectively. These gauges were found through the DELWP portal FloodZoom and verified in DELWP data and Bureau of Meteorology data.

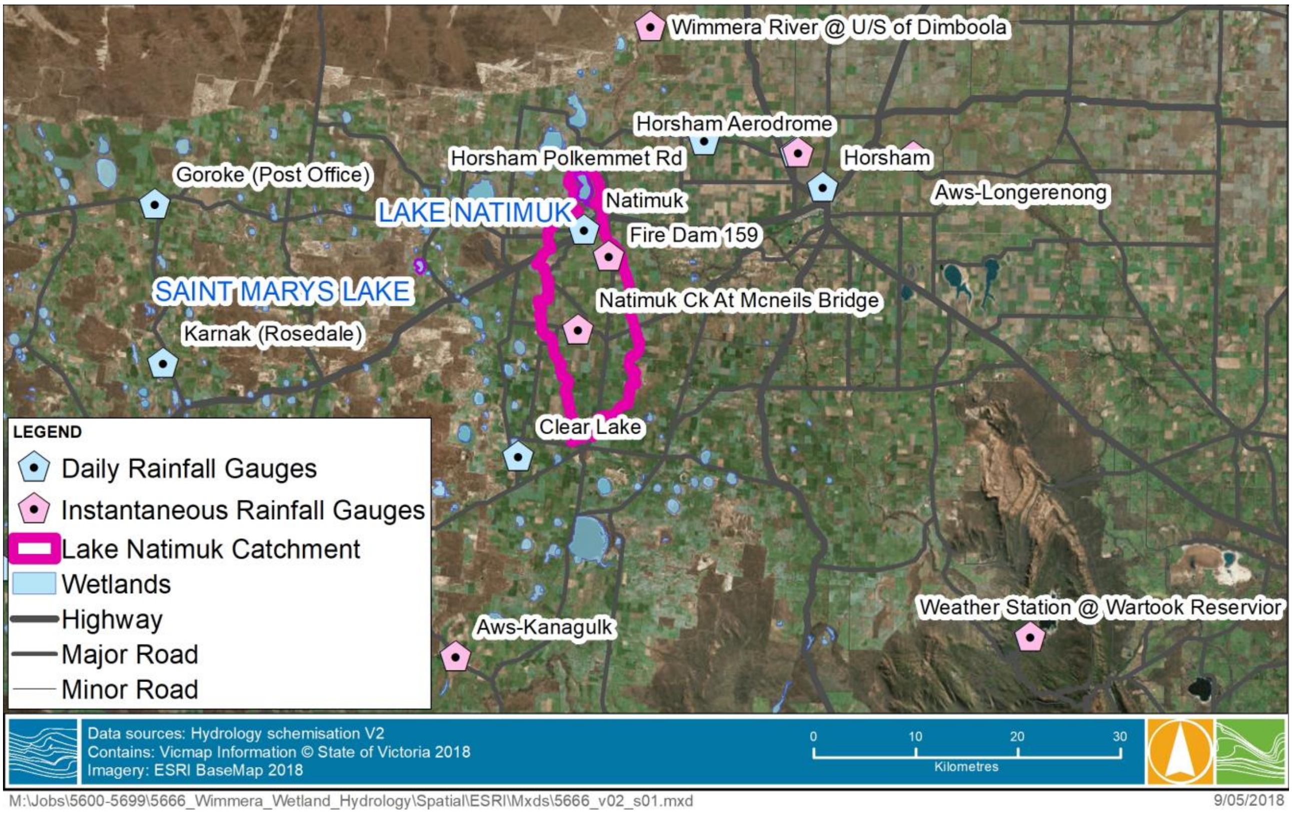


FIGURE 2-12 DAILY AND INSTANTANEOUS RAINFALL GAUGES – LAKE NATIMUK CATCHMENT

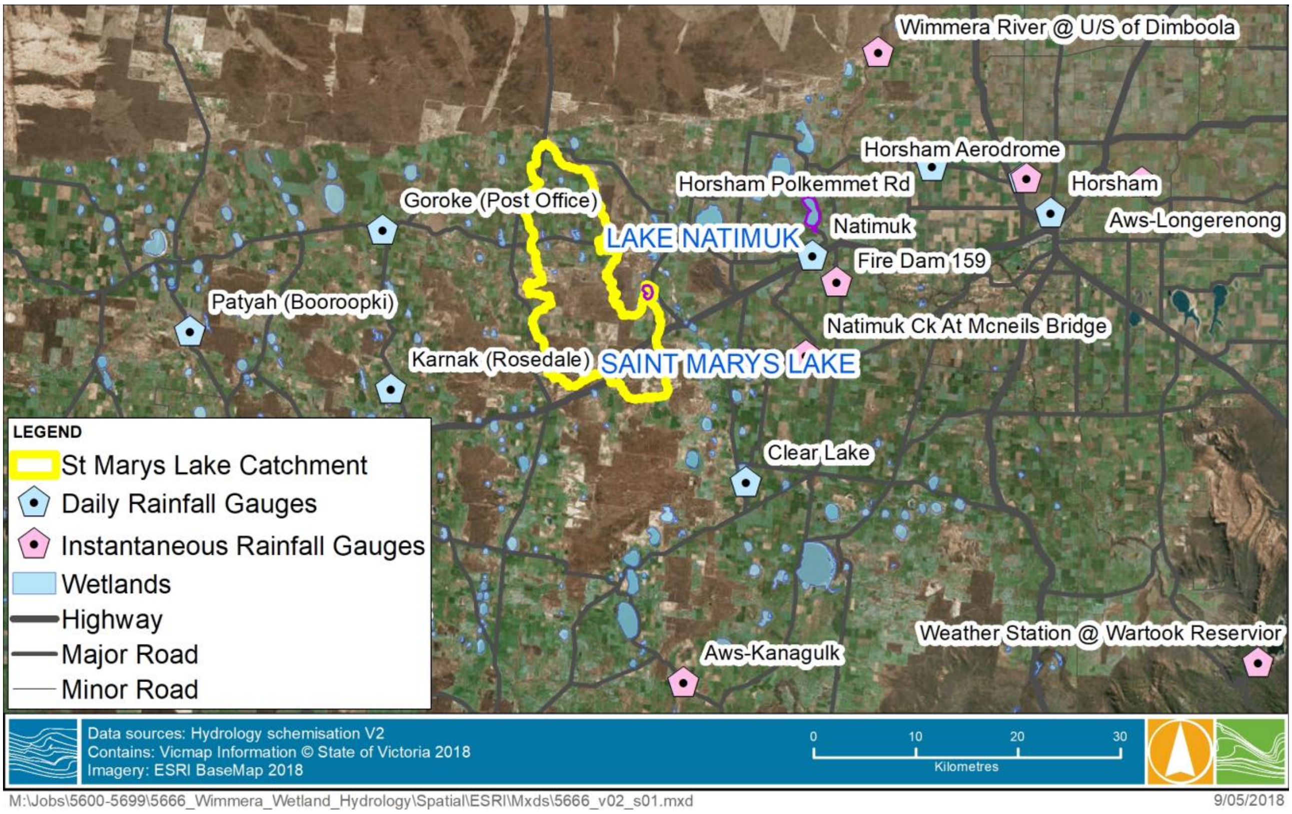


FIGURE 2-13 DAILY AND INSTANTANEOUS RAINFALL GAUGES – ST MARY'S LAKE CATCHMENT

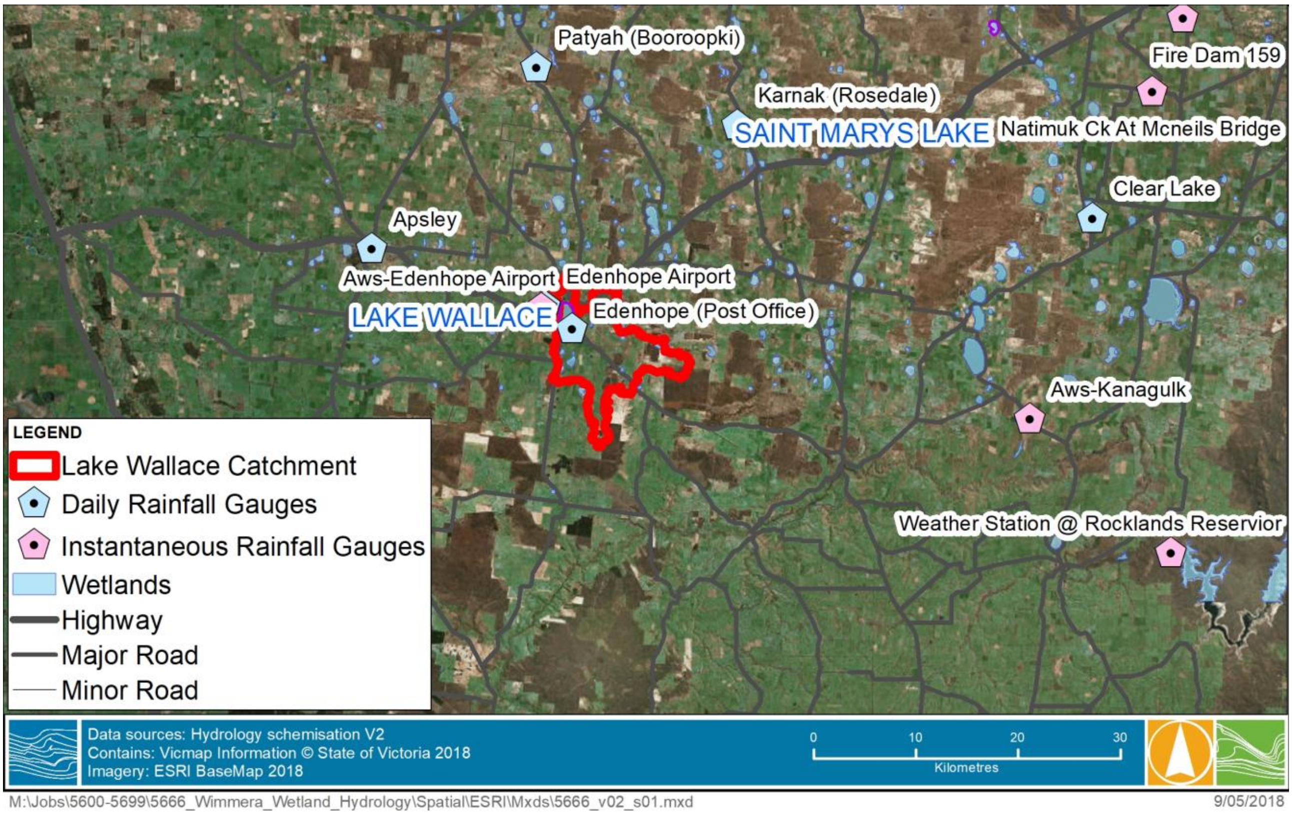


FIGURE 2-14 DAILY AND INSTANTANEOUS RAINFALL GAUGES – LAKE WALLACE CATCHMENT

2.2.5 Recent Flood Records

2.2.5.1 Overview

Anecdotal evidence and monitoring data have highlighted major past flood events included August 1981, December 2010, January 2011 and September 2016. No data was available for the August 1981 event; however, planning records and anecdotal evidence suggests the largest flood in living memory has been January 2011. This flood did not cover all three lake catchments and was predominately concentrated around Lake Natimuk as shown in Figure 2-16.

2.2.5.2 December 2010

2.2.5.2.1 RAINFALL

The December 2010 event was relatively isolated throughout the system. The rainfall occurred over a 3-day period up to 9 am on the 8th December 2010. Between 74.2 – 117.4 mm fell over the rainfall gauges outlined in Section 3.6. A distribution map over the 3-day period is shown in Figure 2-15. The maximum daily rainfall observed was 117.4 mm at the Dundas River @ Cavendish gauging station.

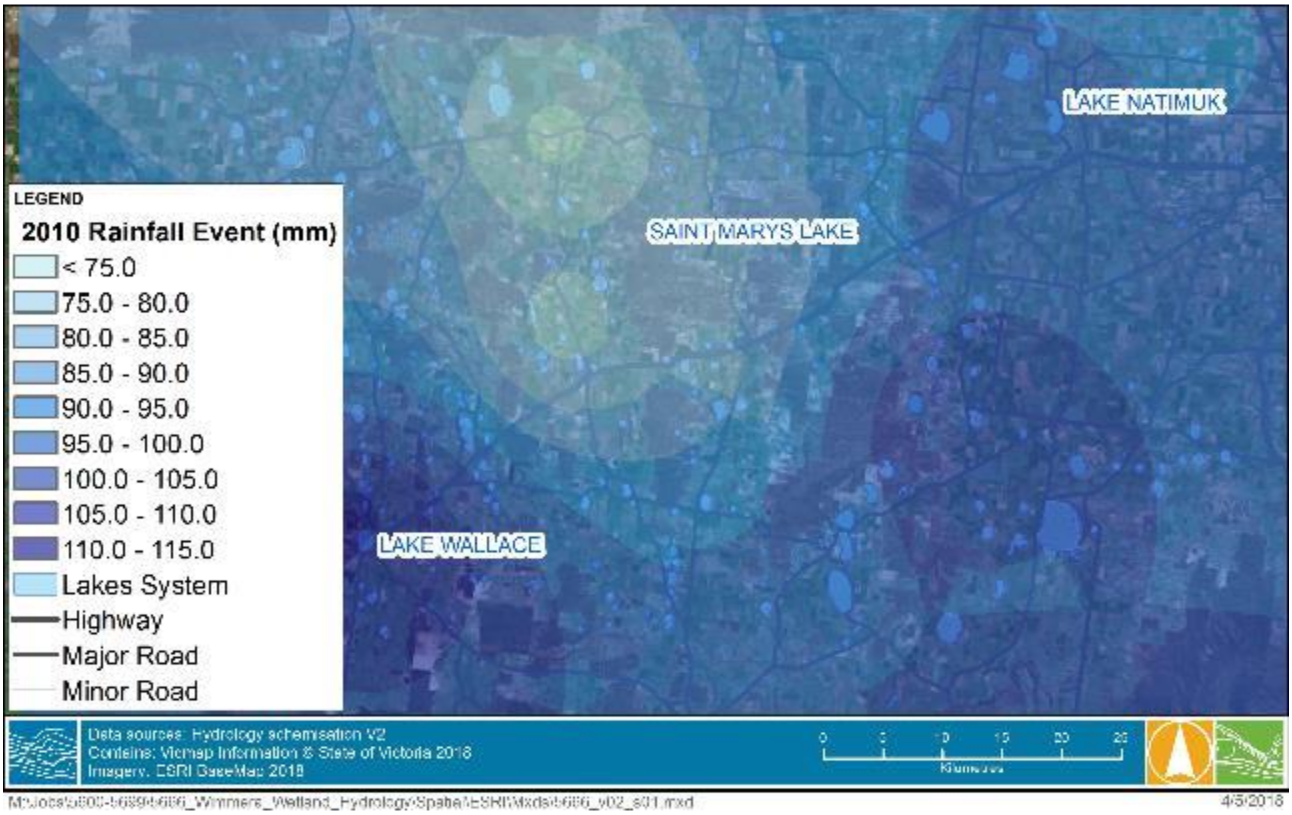


FIGURE 2-15 DECEMBER 2010 RAINFALL EVENT DISTRIBUTION

2.2.5.2.2 FLOODING

Natimuk Creek began flooding almost immediately after the rainfall event with little warning. No houses were recorded to have been inundated around Natimuk township. There were no surveyed heights for the December flood event; however anecdotal evidence was collated from the community around Natimuk through the Natimuk Flood Investigation *(Water Technology, 2012)*. In the township, responses confirmed the December 2010 event was 20 – 60 cm lower than the January 2011 event.

2.2.5.3 January 2011

2.2.5.3.1 RAINFALL

The January 2011 event, the largest in living memory was widespread across all of Victoria's catchments. Rainfall occurred over the 12th to the 14th of January. The largest total daily rainfalls were recorded in Clear Lake with 150.4 mm over that period. A rainfall distribution map for the event is shown in Figure 2-16.

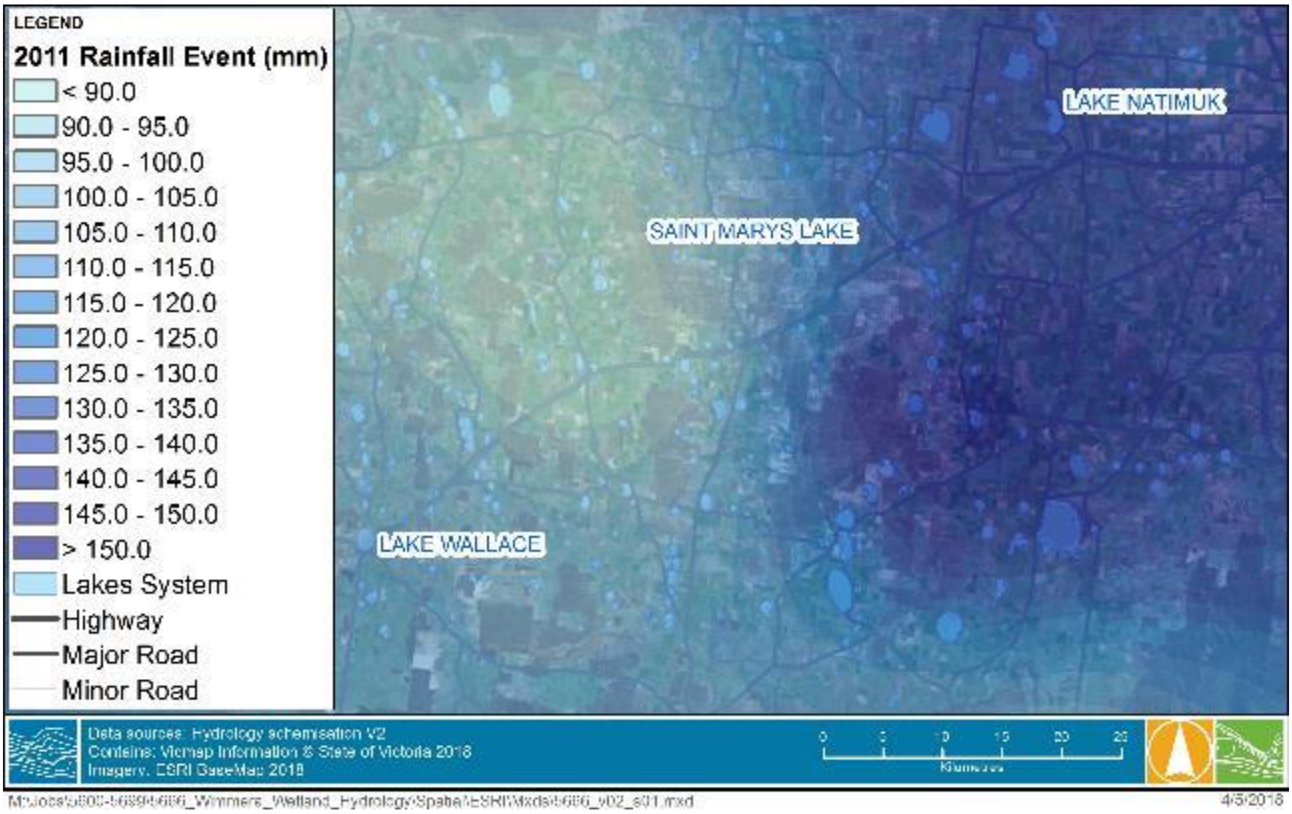


FIGURE 2-16 JANUARY 2011 RAINFALL EVENT DISTRIBUTION

2.2.5.3.2 FLOODING

A large number of houses and properties were inundated during the January 2011 event state-wide. The township of Natimuk experienced severe flooding with road closures over much of the Wimmera catchment area. The Lake Wallace and St Marys Lake catchments did not experience the same level of flooding and rainfall in January 2011, as shown in Figure 2-16. As the catchments were wet at the time, it can be assumed the lakes had significant inflow throughout this period.

2.2.6 Groundwater

There are several groundwater observation bores in the region. The groundwater monitoring "State Observation Bore Network" has provided several relevant bores with records back to 1971. The available bores include:

- Bore no.97886 (Lake Natimuk)
- Bore no.46147 (Lake Natimuk)
- Bore no.8004259 (St Marys Lake)

- Bore no.8003892 (Lake Wallace)
- Bore no.8003893 (Lake Wallace)
- Bore no.62210 (Lake Wallace)
- Bore no.62209 (Lake Wallace)

Anecdotally and through previous investigations *(Fawcett and Huggins DPI, Jan 2005)*, Lake Wallace is the only lake of the three which has a very strong link to groundwater levels. Lake Wyn Wyn, which Lake Natimuk overflows into also has a strong connection to groundwater. Lake Wallace water levels are influenced by both surface water and groundwater and as groundwater levels increase and decrease, Lake Wallace's water levels are also influenced. It is understood water in Lake Wallace generally replenishes groundwater reserves, as such it is classified as a "losing" component to the system. This is evident by the comparison between groundwater and Lake Wallace water levels, with the lake being consistently higher. The observation bores in proximity to Lake Wallace area shown in Figure 2-17.

FIGURE 2-17 GROUNDWATER GAUING STATIONS

2.3 Topography, geology and soil

There were two primary topographic data sources across the three wetlands, these include:

- DELWP VicMap Digital Terrain Model (DTM) with 10 metre resolution
- Wimmera CMA 2 metre resolution LiDAR data set

The Wimmera CMA LiDAR provided more accurate data and was used to determine the topography of the wetlands and their catchments.

The Lake Natimuk, St Mary's Lake and Lake Wallace catchment areas are shown in Figure 2-18, Figure 2-19 and Figure 2-20.

Lake Natimuk and St Mary's Lake are within the Murray Darling Basin and the Wimmera Drainage Division, Lake Wallace is within the Millicent Coast Drainage Division. The geological timeframe for development of the catchments is between the Late Proterozoic to Recent epochs. The area ranges between 120 to 150 meters AHD (Australian Height Datum) with nearby Mount Arapiles-Tooan a prominent outcropping of the Grampians group.

The region is defined as Drung alluvial plains and are characterised by backplains with flats, slopes and stream channels *(Robinson et al., 2005)*. The Douglas Depression extends around the subject area, an inlier of the Grampians sandstone complex in the area.

The region has a great diversity of soils which reflect the parentage with many of these being sodic in composition. There are four main Soil Categories in the Wimmera Region:

- Texture Contrast;
- Soils Lacking Strong Texture Contrast;
- Cracking Clay; and
- Sandy

These soils contribute to the evapotranspiration experienced in the region and the water holding capacity. Modelling reflects rainfall losses of these soil types and land-uses in the region.

Lake Natimuk has been noted as having gilgai soils which can form crabholes/gilgais, small wetland areas which retain surface water in wet times.

It should also be noted that during community consultation several members of the community raised that the decommissioning of stock and domestic channels since 2010 has caused a change to the catchment area contributing to Little Natimuk Creek and consequently Natimuk Lake. This was also raised during the Natimuk Flood Investigation community meetings. The consequence of these impacts was partially investigated through an expansion to the Lake Natimuk catchment area, this is discussed in Section 4.5.

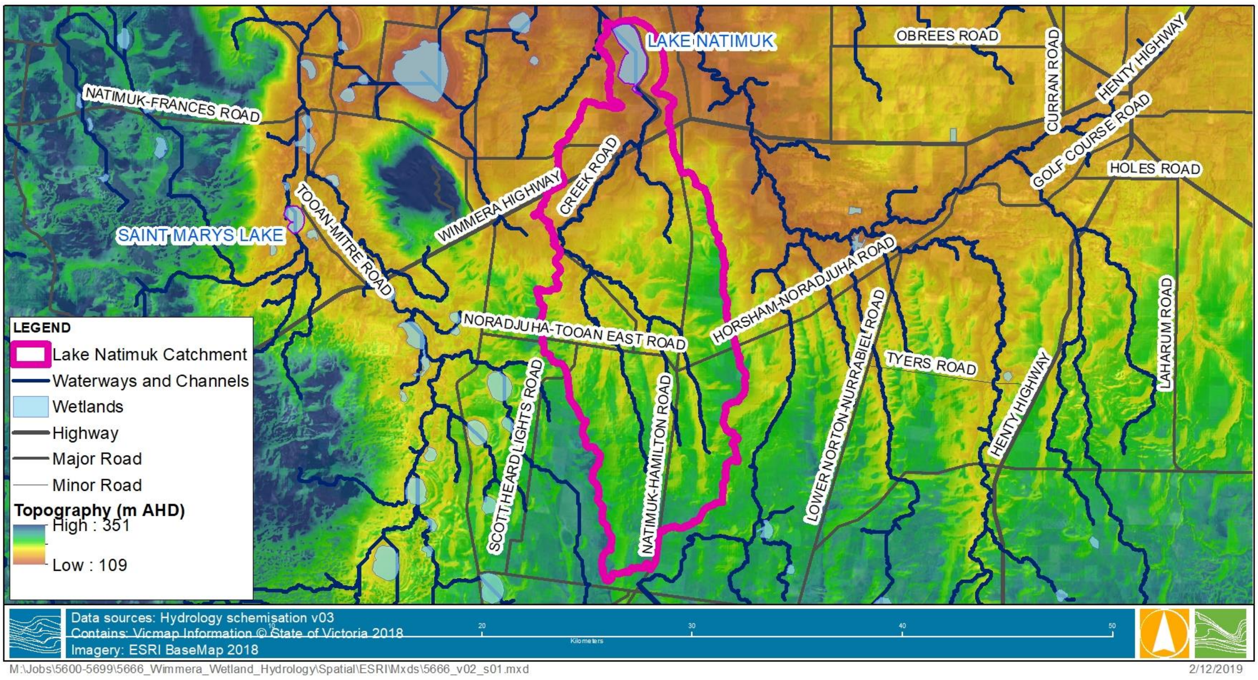


FIGURE 2-18 LAKE NATIMUK - TOPOGRAPHY AND CATCHMENT AREA

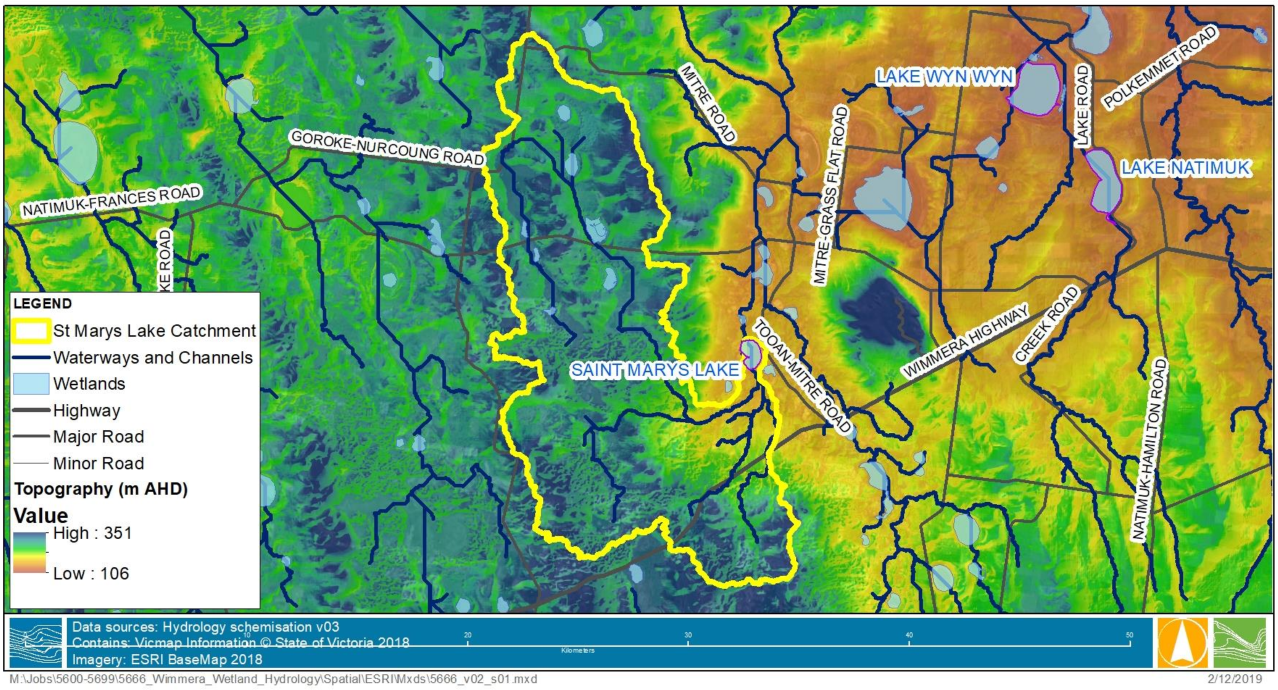


FIGURE 2-19 ST MARYS LAKE - TOPOGRAPHY AND CATCHMENT AREA

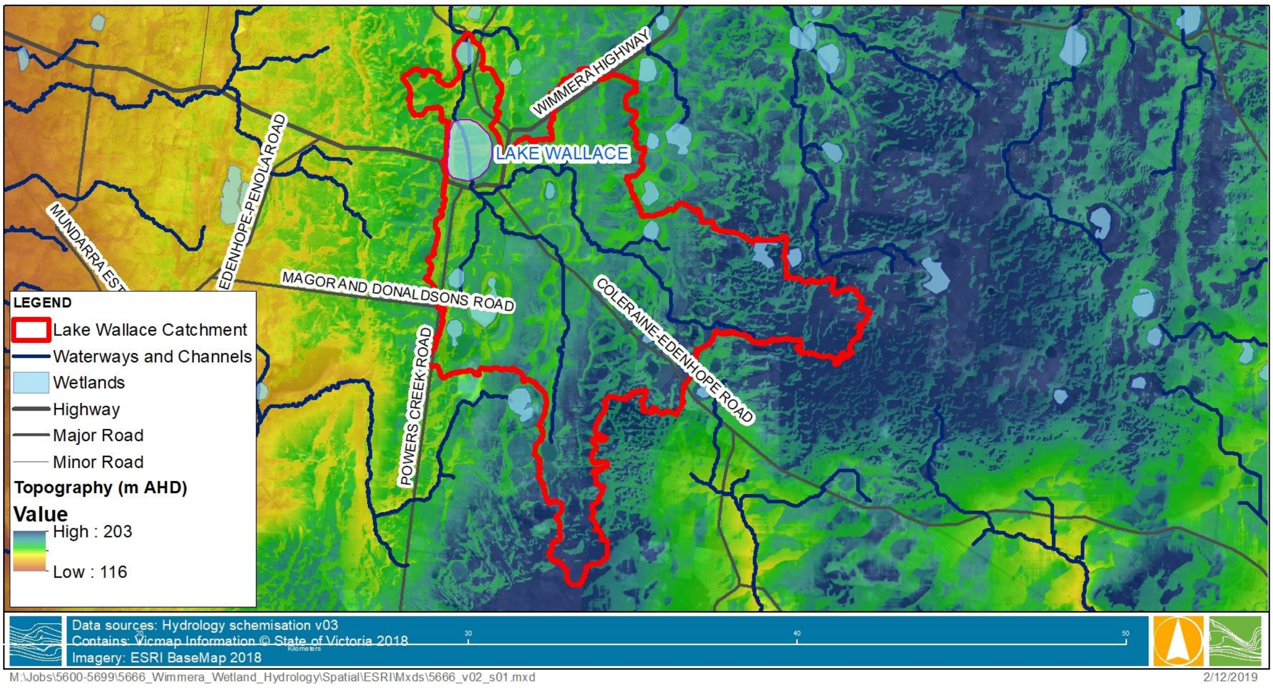


FIGURE 2-20 LAKE WALLACE - TOPOGRAPHY AND CATCHMENT AREA

2.4 Biodiversity

The subject catchments are listed as within the Wimmera bioregion which is typified by flat and gently undulating plains. It is the largest of the state's bioregions that are characterised by plains woodlands: Plains Woodland, Plains Grassy Woodland, Plains Grassland, Red Gum Wetland and Grassy Woodland. The western portion, where the subject sites are located, is typified by ancient stranded ridges and interspersed with clay plains. There are a mixture of swamps, lakes, lagoons and lunettes.

A large amount of the native vegetation has been cleared to allow agricultural use of the land. The largest remnants remain along roadside reserves, surrounding the lakes themselves and in some state parks. The bioregion has many surface water bodies as the clay soils and climatic conditions allow for surface water accumulation.

The Victorian Government's online toolbox, "NatureKit", provides a visual representation of the current environmental attributes associated with the area, as shown in Appendix D. The mapping outlines the key EVC number, name, group and sub-group including the geographical nature of the subject lakes and associated catchments as shown in Table 2-3. This data provides a characterisation of the natural environment and is important in developing a thorough understanding of the local environments, habitats, flora and fauna native to the region. Lake Wallace and Lake Natimuk have a bio-conservation status "D" which is "Depleted". This means that greater than 30% to 50% of the area's pre-European extent remains intact due to various actions such as historic land-clearing. Unfortunately, limited information was available for St Mary's Lake.

The EVC names, groups and subgroups allow for understanding of the species likely to inhabit the area and allow for greater protection pending any development occurring.

TABLE 2-3 BIOREGIONS WITH KEY STATUS COMPONENTS

Lake	EVC Number	Bio-conservation Status	Geographic Occurrence	EVC Name	EVC Group and Subgroup Name
Lake Wallace	636	D	Rare	Brackish Lake Aggregate	Salt-tolerant / succulent shrubland
St Marys Lake	983	N/A	N/A	N/A	N/A
Lake Natimuk	939	D	Rare	Lake Bed Herbland / Red Gum Swamp Mosaic	Wetlands / Freshwater

A site visit was undertaken for all three lakes, assessing their ecological attributes. A more comprehensive assessment was undertaken for Lake Natimuk which was the focus of the *Lake Natimuk Weir Modification, Ecological Impact Report*. The details of this are outlined in Appendix B, while assessment of Lake Wallace and St Marys Lake was more opportunistic. Given the nature of the assessments is was unlikely to provide a true indication of the species richness.

Conditions at Lake Wallace were very windy with considerable chop and wave generation at the time of inspection. A moderate number of aquatic birds were in more sheltered areas of the lake fringes, often where aquatic flora such as Water Ribbons were present. Habitat within the lake and its supply drainage lines are suitable for the Growling Grass Frog (*Litoria ranifornmis*). The presence of an open water body, deep water and aquatic flora provides this species with adequate habitat for reproduction. Water Ribbons (*Triglochin procera*) and inundated grasses provide suitable habitat for basking frogs with occasional Tall Spike-rush (*Eleocharis sphacelate*). Though not observed at the time of assessment it is likely that the aquatic vegetation provides suitable platforms for nesting aquatic birds. At the time of inspection, there were many ducks (mainly Teals and Pacific Black Duck), Swamphens, Herons and Eurasian Coots utilising the lake due to the presence of permanent water.

St Marys Lake was dry at the time of inspection so very little information can be determined on the potential fauna species which may utilise the lake; however, the species present at Lake Wallace are likely to be similar expected to be similar to those at Lake Wallace in wet times with some differences due to the varying inundation characteristics.

Across both Lake Wallace and St Marys Lake the outer fringing vegetation mainly consists of River Red Gums overstorey, providing suitable habitat for various bird species including honeyeaters, rosellas and wattlebirds. Lake Wallace had a more consistent and intact woodlands surrounding it with significant revegetation on the eastern side. The presence of hollows in large trees surrounding the lakes provide nesting opportunities for arboreal mammals and hollow nesting bird species such as galahs and some waterbirds. Brush-tailed possum scats were observed beneath large trees. Bats (specifically microbats) are likely to utilise many of the hollows and feed on insects attracted by the lake’s water and aquatic habitat.

2.5 Cultural Heritage

Jardwadjali and Wergaia indigenous people are the traditional custodians of the land, with the Jardwadjali predominately occupying the Wimmera Plains, the location of the subject sites. Indigenous culture is evident by the large number relics throughout the region, as such, the region holds immense cultural significance for the local indigenous community. A review of the cultural heritage information associated with these wetlands was not part of the scope of this project however given information available about wetlands elsewhere in the region, it would be expected that they would contain a wealth of culturally significant sites.

2.6 Key Land Uses

European history of the Wimmera began with squatters arriving to establish sheep grazing runs. This is when exotic pest and weed species such as rabbits and wild oats were introduced, degrading the native environment in the region. As settlement continued in the region, many trees were felled to increase agricultural and pastoral practises in the region. Dryland cereal cropping was later established and continues to this day as the prominent production industry. There are several other production industries in the area including:

- Intensive animal production (pigs, ducks);
- Plantation forestry;
- Aquaculture (yabbies)
- Mineral exploration; and
- Apiculture

Due to the drier conditions prevailing in the region (as well as other drivers such as commodity prices) many farmers have increasingly transitioned from grazing to dryland cropping. There are still some reasonably sizeable sections of native vegetation in some parts of the study area.

3 RAINFALL AND STREAMFLOW TRENDS

3.1 Rainfall

The three gauges that best represent rainfalls due to their proximity and their long data record over the three subject catchment areas are Natimuk (Lake Natimuk), Goroke (Post Office) (St Marys Lake) and Edenhope (Post Office) (Lake Wallace). Figure 3-1, Figure 3-2, and Figure 3-3 show the daily rainfall data available at each gauge respectively.

The data record for each gauge was graphed to demonstrate potential trends in the data over time. Several years were excluded from the dataset due to incomplete annual totals. In each dataset there was the same trend pattern, the data recorded from the 1880s to late 1970s showed a relatively stable average (as shown in the Natimuk and Goroke gauges and rise in rainfall at the Edenhope gauge). The average rainfall in the 1970s and early 1980s was above the historic average but trended down from the mid-1970s with a steady decrease in rainfall average across all three gauges. There are outlying years including 1992, 2016 and 2010, all showing high annual totals.

The trend in average annual rainfall is also demonstrated by a rolling average at the Natimuk gauge, as shown in Figure 3-4. The highest average rainfall occurs in the mid-1960s at around 530 mm, this then declines through the 1970s to today, to around 430mm. The late 1940s and early 1950s was particularly wet with large annual totals. Today's average rainfall is not dissimilar to that recorded in the mid-1940s. This is a decline in average rainfall of around 100mm in 80 years. The gradient of the declining rainfall can be separated into two slopes, pre and post the mid-1990s. After around 1993 the decline in average rainfall accelerates, exacerbated by the Millennium Drought.

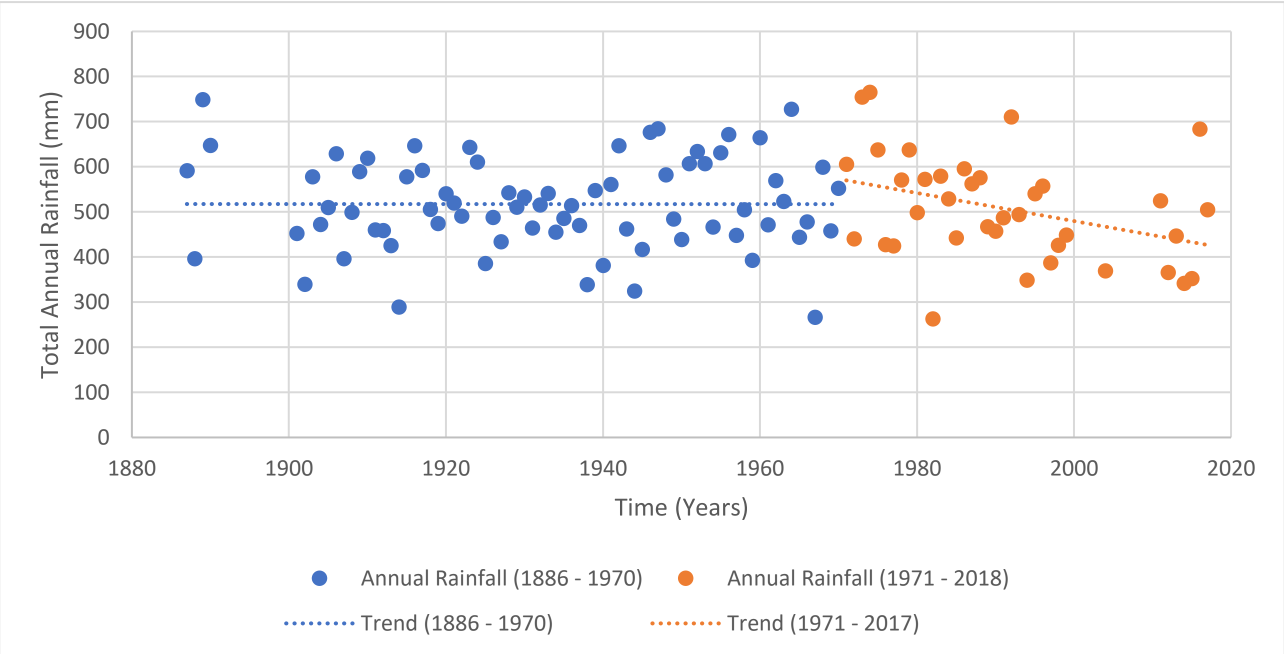


FIGURE 3-1 AVAILABLE ANNUAL RAINFALL DATA FOR THE NATIMUK (LAKE NATIMUK) GAUGE

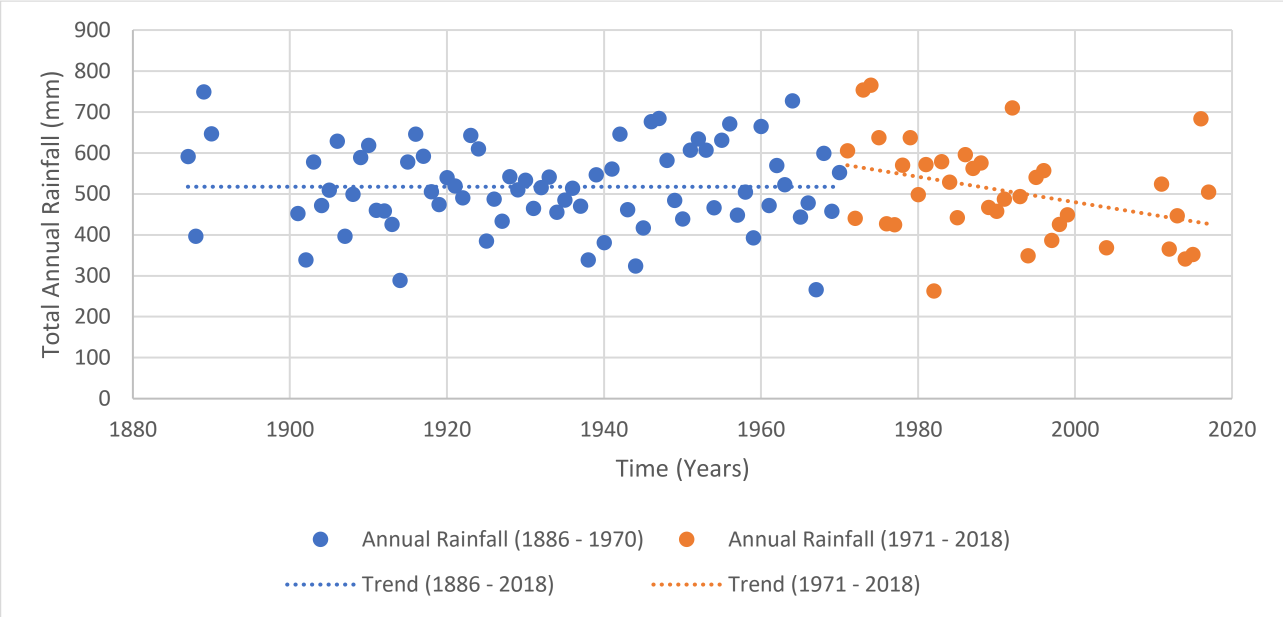


FIGURE 3-2 AVAILABLE ANNUAL RAINFALL DATA FOR THE GOROKE (POST OFFICE) GAUGE

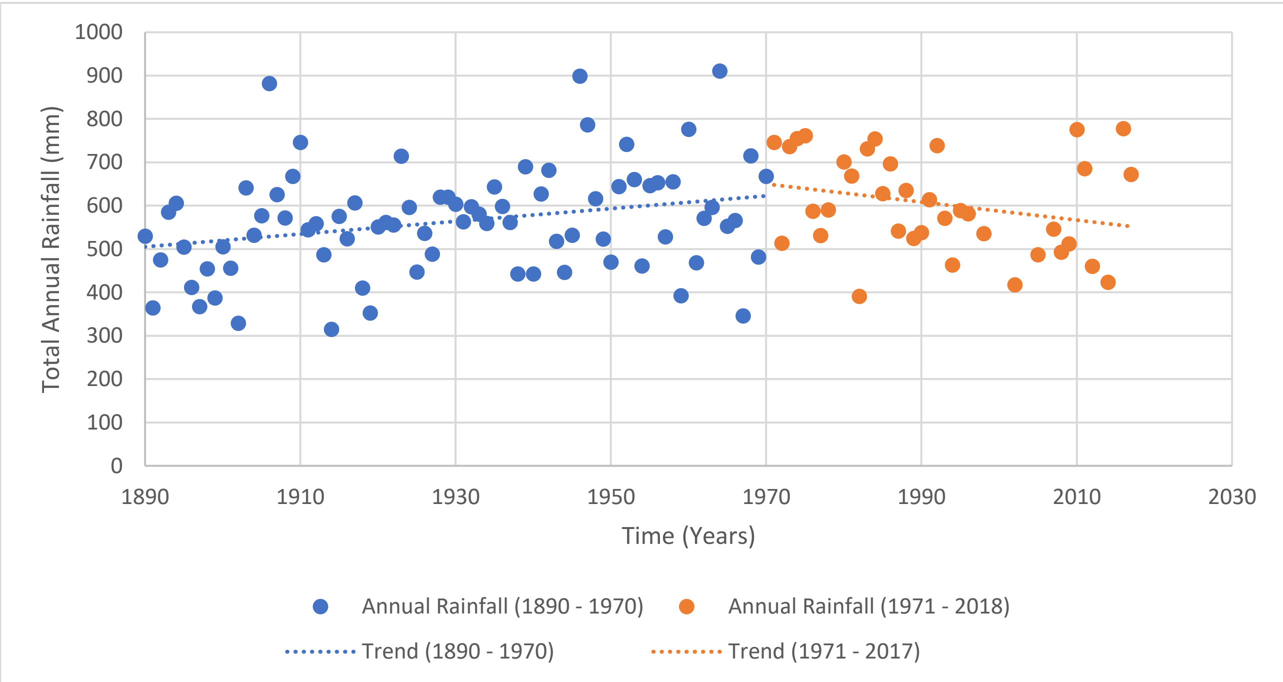


FIGURE 3-3 AVAILABLE ANNUAL RAINFALL DATA FOR THE EDENHOPE (POST OFFICE) GAUGE

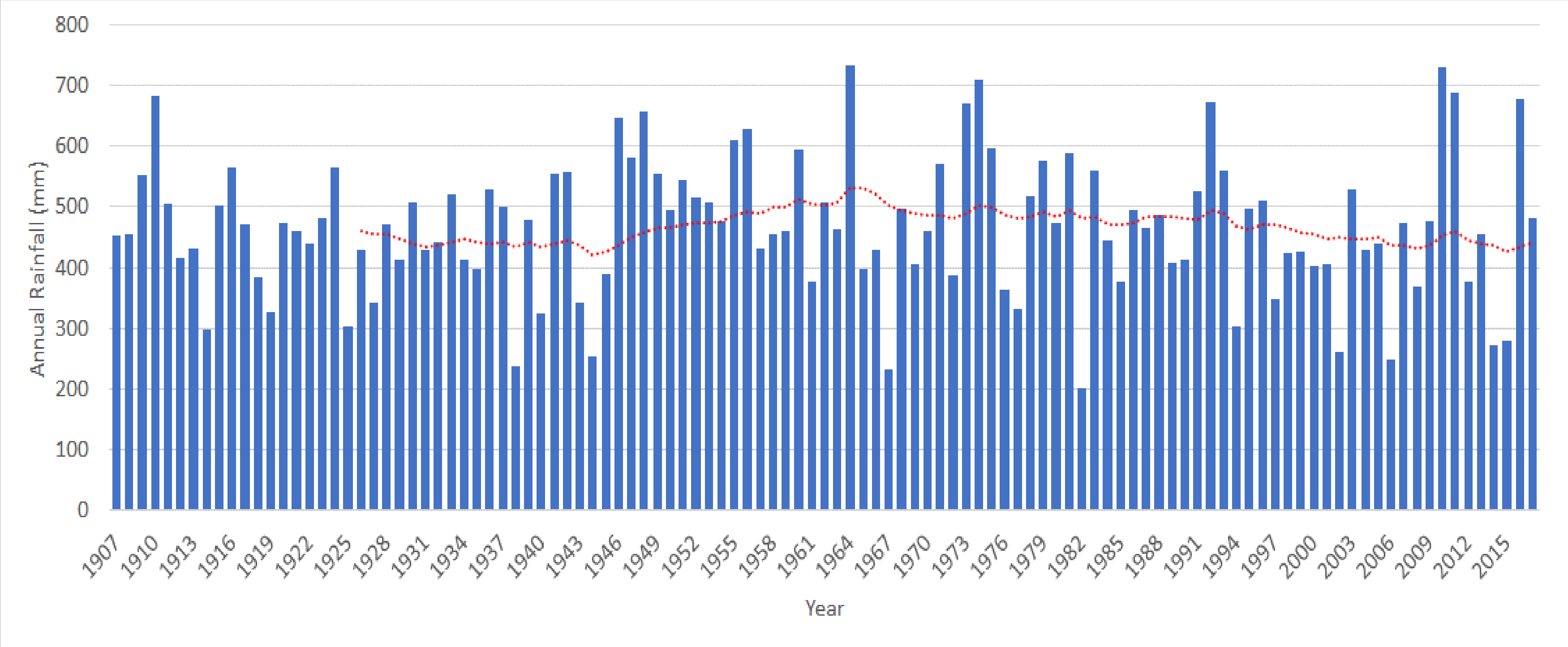


FIGURE 3-4 ANNUAL TOTALS AND A ROLLING AVERAGE FOR THE NATIMUK GAUGE

Figure 3-5 and Figure 3-6 show a similar trend over Australia. Data analysis from the BoM indicates the Wimmera Region average annual rainfall has reduced by 0 to 10 mm per decade over the available period of record, whilst the reduction in average annual rainfall from 1970 to 2017 is between 10 mm and 40 mm per decade. This is matched by the rainfall observations used in this project.

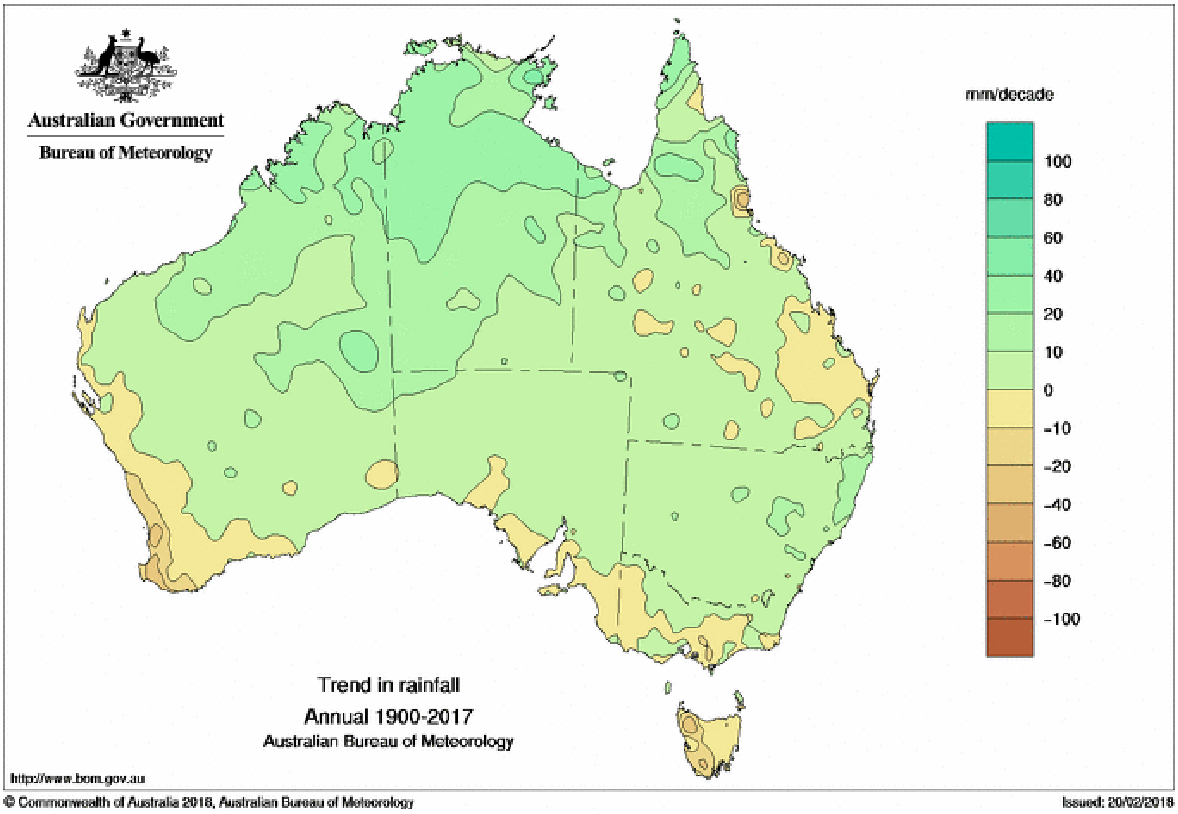


FIGURE 3-5 ANNUAL RAINFALL TREND DATA 1900-2017 (BOM)

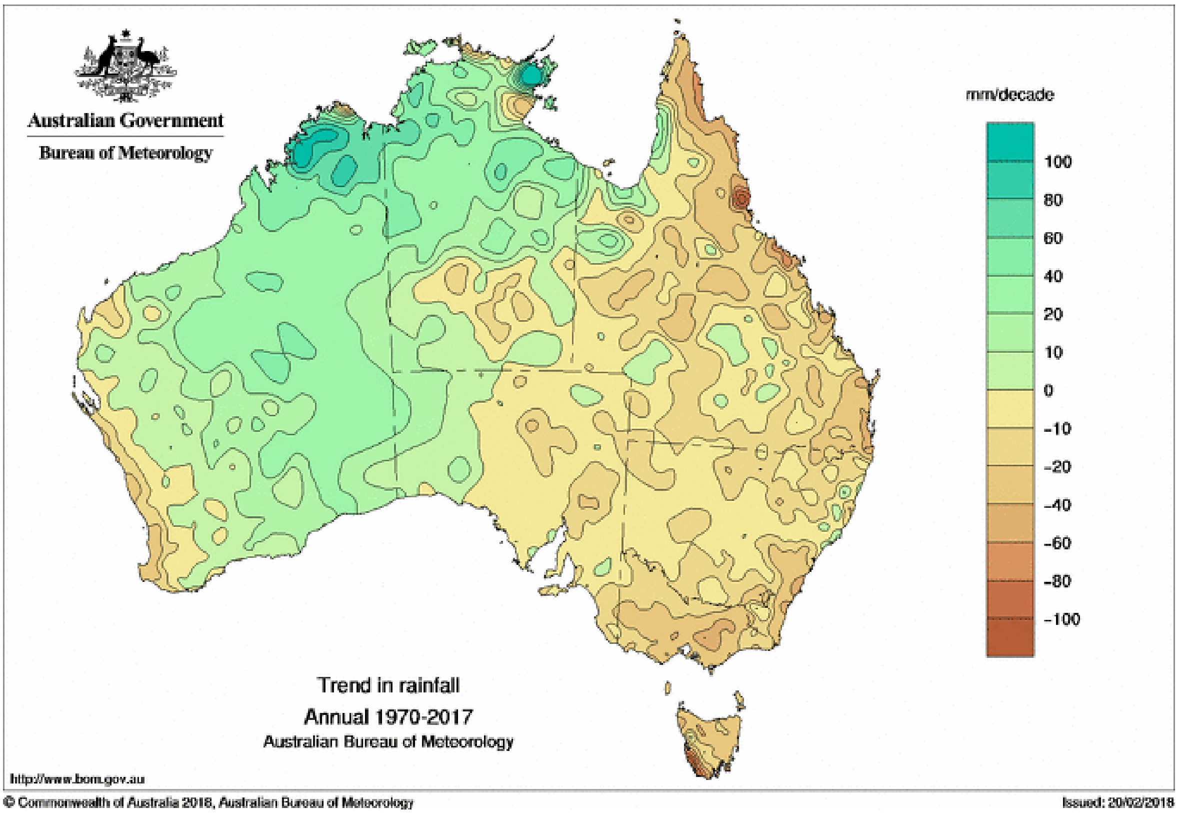


FIGURE 3-6 ANNUAL RAINFALL TREND DATA 1970-2017 (BOM)

3.2 Lake Level/Streamflow

Regular monitoring data (monthly/weekly readings) for Lake Natimuk and Natimuk Creek was not recorded over a long enough duration to determine trends, with large gaps in the recorded data.

Water levels of Lake Wallace and surrounding groundwater were recorded between 1996 and 2004 (DPI), as outlined in Figure 3-7. The data shows a strong correlation between rainfall, lake surface water levels and groundwater levels.

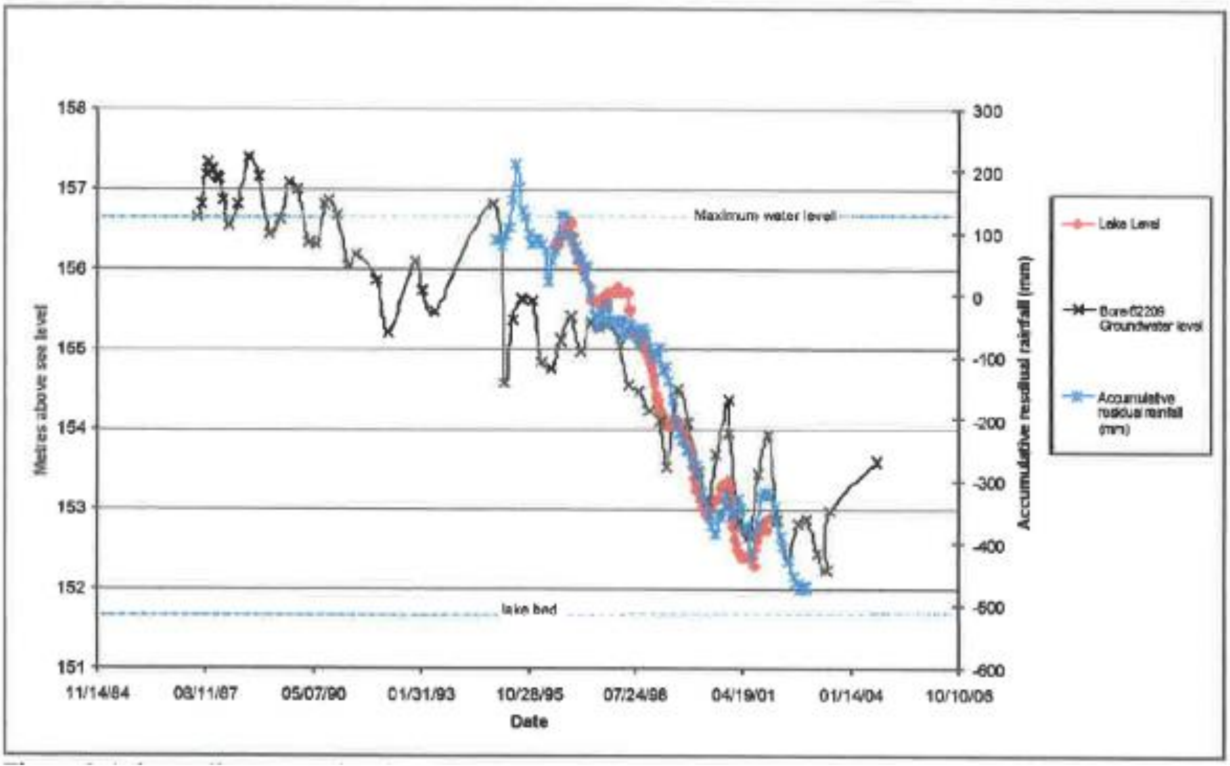


FIGURE 3-7 LAKE WALLACE WATER LEVELS, GROUNDWATER LEVELS AND ACCUMULATED RAINFALL (DPI)

4 MODELLING

4.1 Model Inputs

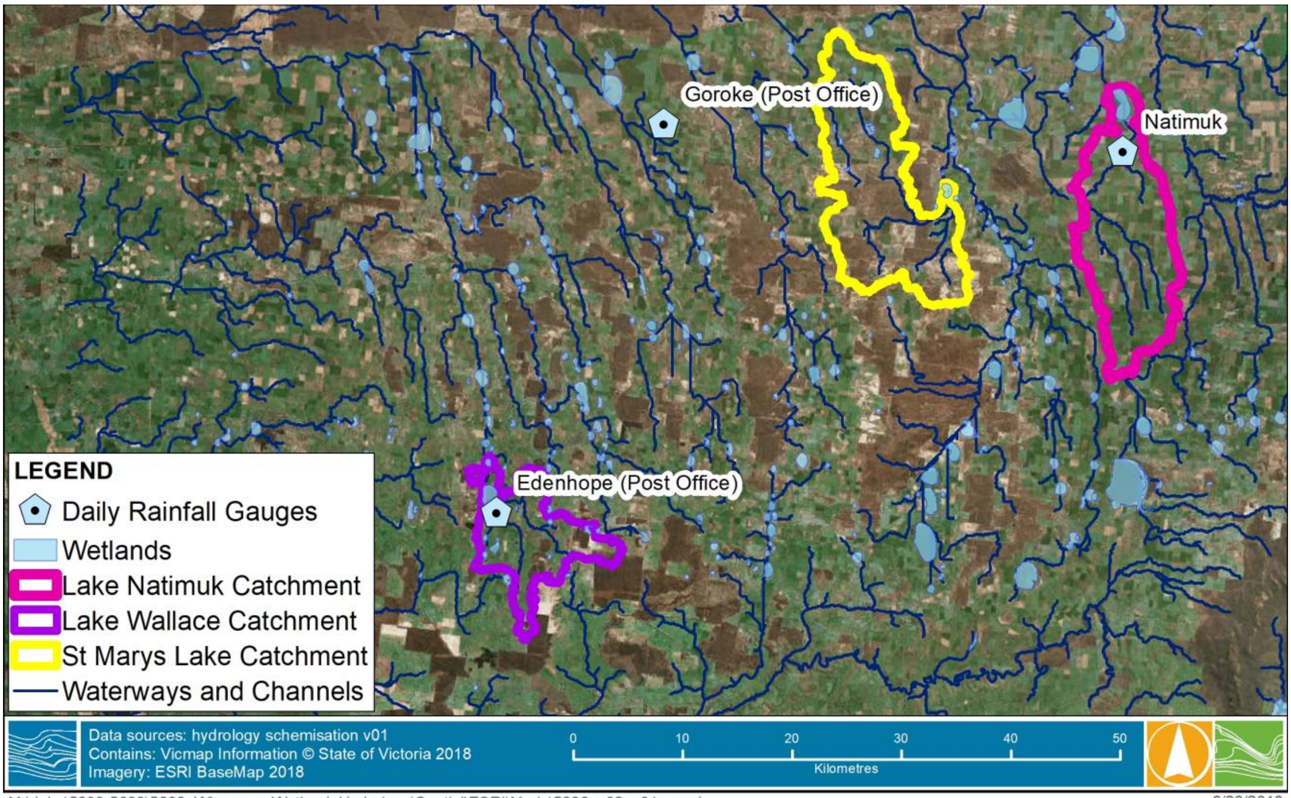
4.1.1 Catchment Delineation

Each lake catchment area was delineated based on the Wimmera CMA 2 m LiDAR (Light Detection and Ranging) data captured in 2005. The LiDAR data was processed in ESRI's terrain modelling software *ArcHydro,* delineating specific sub-catchments and associated drainage reaches. Each catchment was then inserted into separate Source models for Lake Natimuk, St Marys Lake and Lake Wallace.

4.1.2 Rainfall

Rainfall data was collected at three daily gauge locations, one within or near each lake catchment area; the Natimuk gauge (079036) was use for modelling of Natimuk Lake, the Goroke (Post Office) gauge (079017) for St Marys Lake and the Edenhope (Post Office) gauge (079011) for Lake Wallace, the location of these gauges is shown in Figure 4-1.

Each gauge record was reviewed to determine any data gaps but no major gaps were identified. The data was imported into each respective Source model.



M:\Jobs\5600-5699\5666_Wimmera_Wetland_Hydrology\Spatial\ESRI\Mxds\5666_v02_s01a.mxd 6/26/2018

FIGURE 4-1 SELECTED RAINFALL GAUGES PER SUB-CATCHMENT

4.1.3 Potential Evapotranspiration

Measured Potential Evapotranspiration (PET) was included in each Source model as part of the calibration and verification process. There are fewer gauges measuring PET than rainfall, with the closest two gauges were located at Longerenong (79028) and Kanagulk (79097). Figure 4-3 shows the location of the gauges. During model calibration Longerenong gauge data was used as an input to the Lake Natimuk and St Mary's Lake Source models while Kanagulk was used for Lake Wallace. Where no measured data was available, average monthly data was used.

A review of the PET data revealed the Longerenong gauge showed increased evaporation potential from 1996 to 2001, after which point data recording ceased. There are several potential explanations for such increases, for example the evaporation data may have been recorded differently from previous years. The available PET data for each gauge is shown in Figure 4-3. This data was only used in the model calibration not scenario modelling.

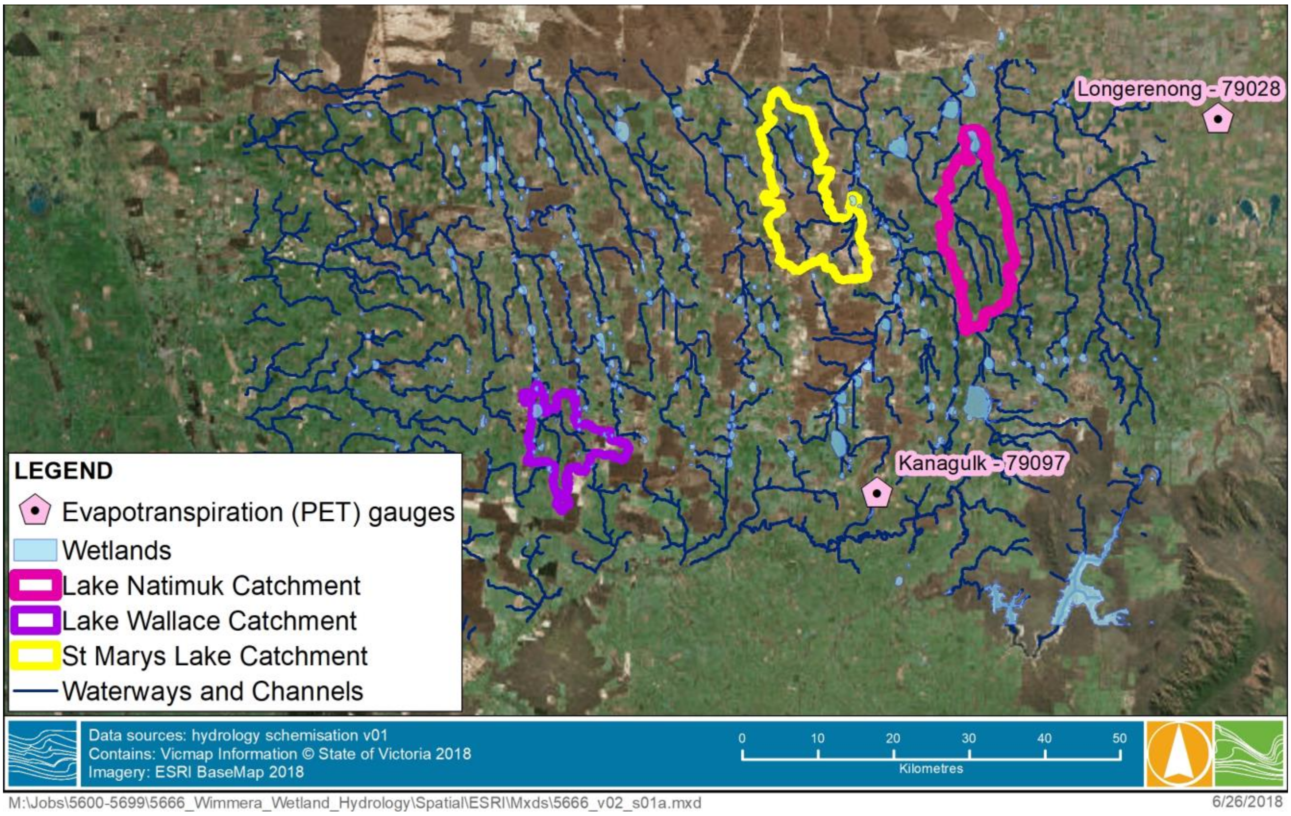


FIGURE 4-2 EVAPOTRANISPIRATION GAUGES FOR EACH SUB-CATCHMENT

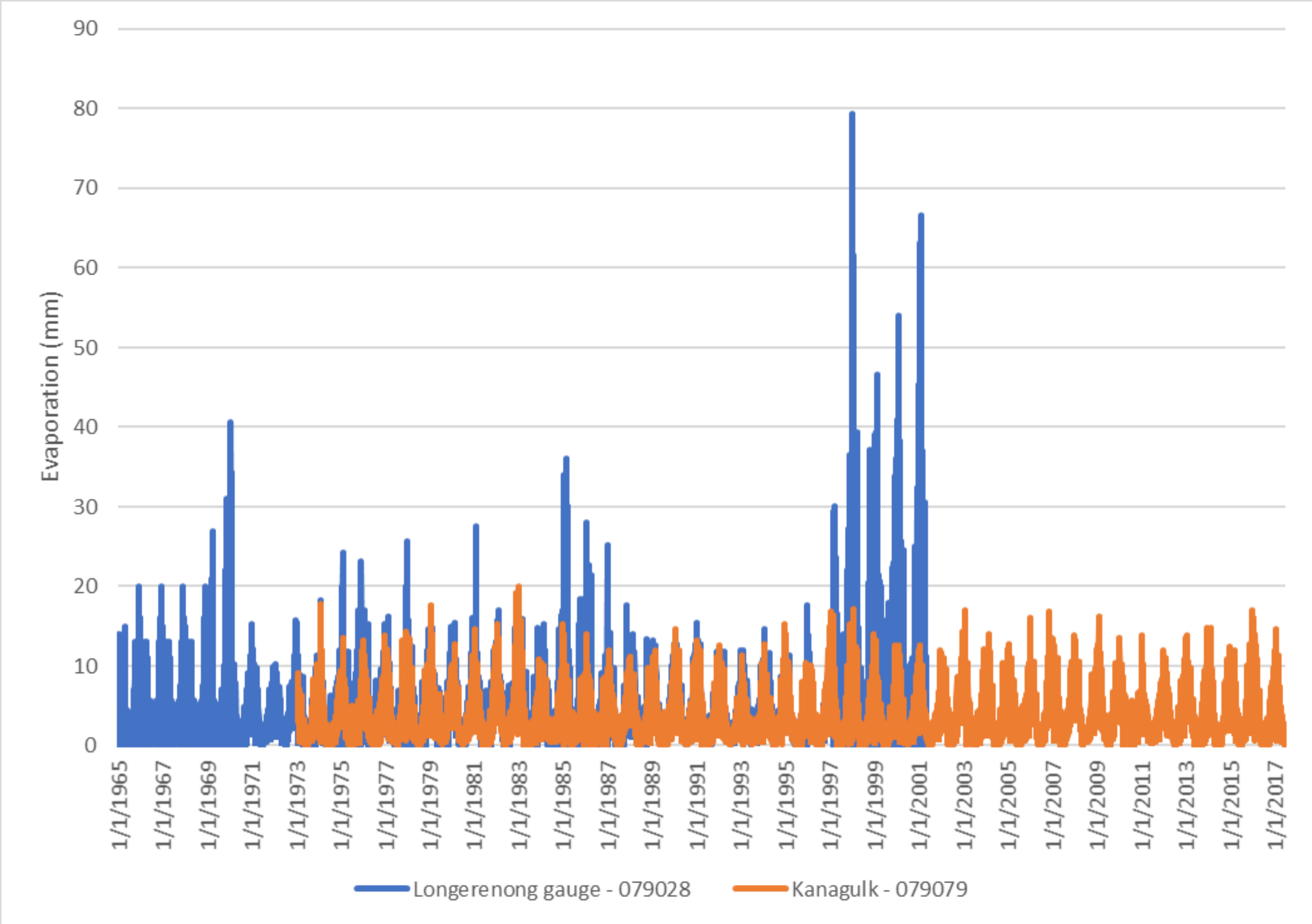


FIGURE 4-3 EVAPOTRANSPIRATION POTENTIAL (PET) OF THE NEARBY GAUGES

4.1.4 Land Use

Source modelling utilises functional units to group similar hydrologic responses to land use in each catchment. All three catchments were predominately agricultural with some water bodies and township areas. The functional units were therefore specified manually as “Agriculture”, “Surface Water” and “Township”, as shown in Table 4-1. Each functional unit present was directly related to the GR4J parameters, these are discussed further in Section 4.2.2. The functional units were separated into “Area” and “Area Ratios” which determined the area for which the parameters are applied.

The Victorian Planning Zones were used to define the functional groups. Townships and roadways zones were grouped in “Township”, environmental and recreational zones were grouped as “Environmental Significance” and agriculture and pastoral zones were grouped as “Agriculture”. Agriculture can be broadly separated into two groups; cereal cropping and grazing. During this project an analysis of each functional group and their impact on runoff volumes was undertaken. This is discussed further in Section 4.4.

TABLE 4-1 FUNCTIONAL UNIT ALLOCATIONS

Functional Unit	Area (km^2)	Area Ratio (%)
Lake Natimuk		
Agriculture	178.0	93.2%
Environmental Significance (Surface Water, Parks, etc)	9.0	4.7%
Township	3.9	2.1%
St Mary's Lake		
Agriculture	133.4	71.2%
Environmental Significance (Surface Water, Parks, etc)	55.1	28.8%
Lake Wallace		
Agriculture	73.7	84.81%
Environmental Significance (Surface Water, Parks, etc)	9.4	10.82%
Township	3.8	4.37%

4.1.5 Wetland Storage

For each of the three wetlands a relationship between water level, volume and surface area was determined using the Wimmera CMA LiDAR. The determined relationships for Lake Natimuk, St Mary's Lake and Lake Wallace are shown Figure 4-4, Figure 4-5 and Figure 4-6 respectively.

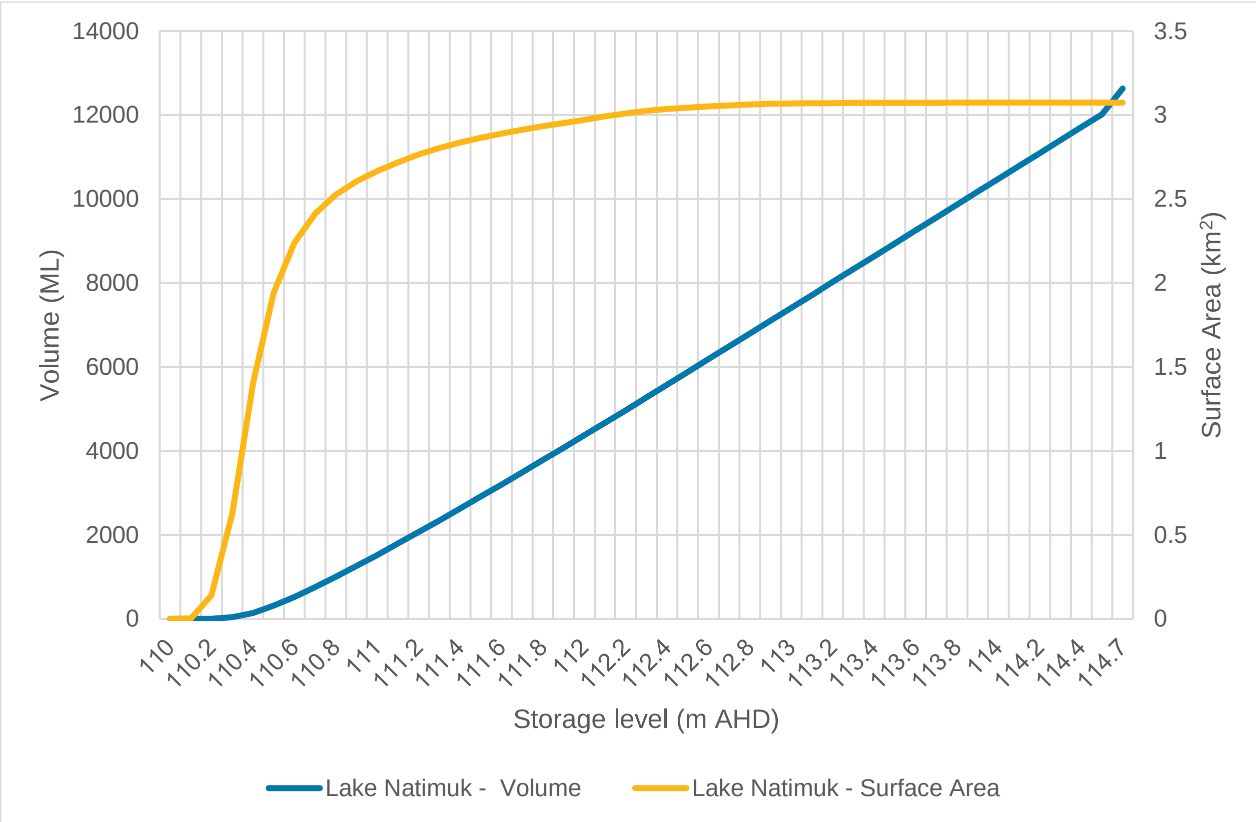


FIGURE 4-4 LAKE NATIMUK STORAGE DATA

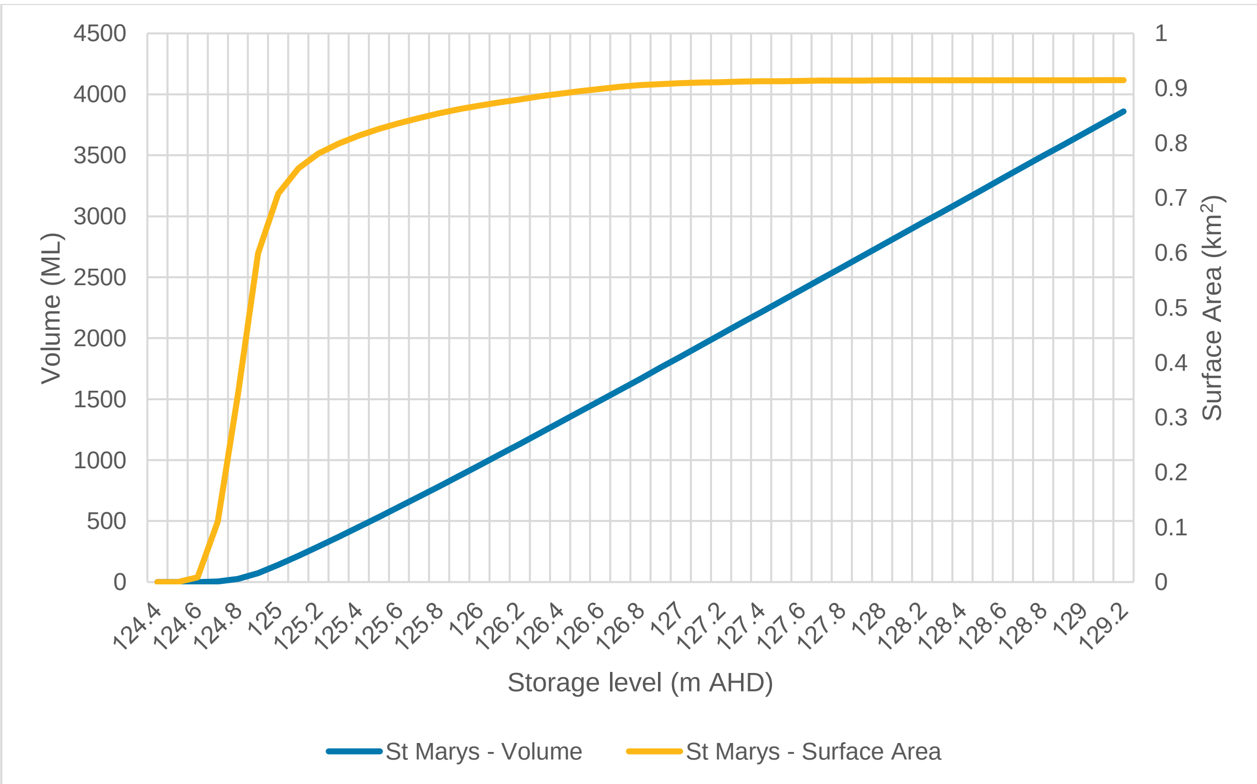


FIGURE 4-5 ST MARYS LAKE STORAGE DATA

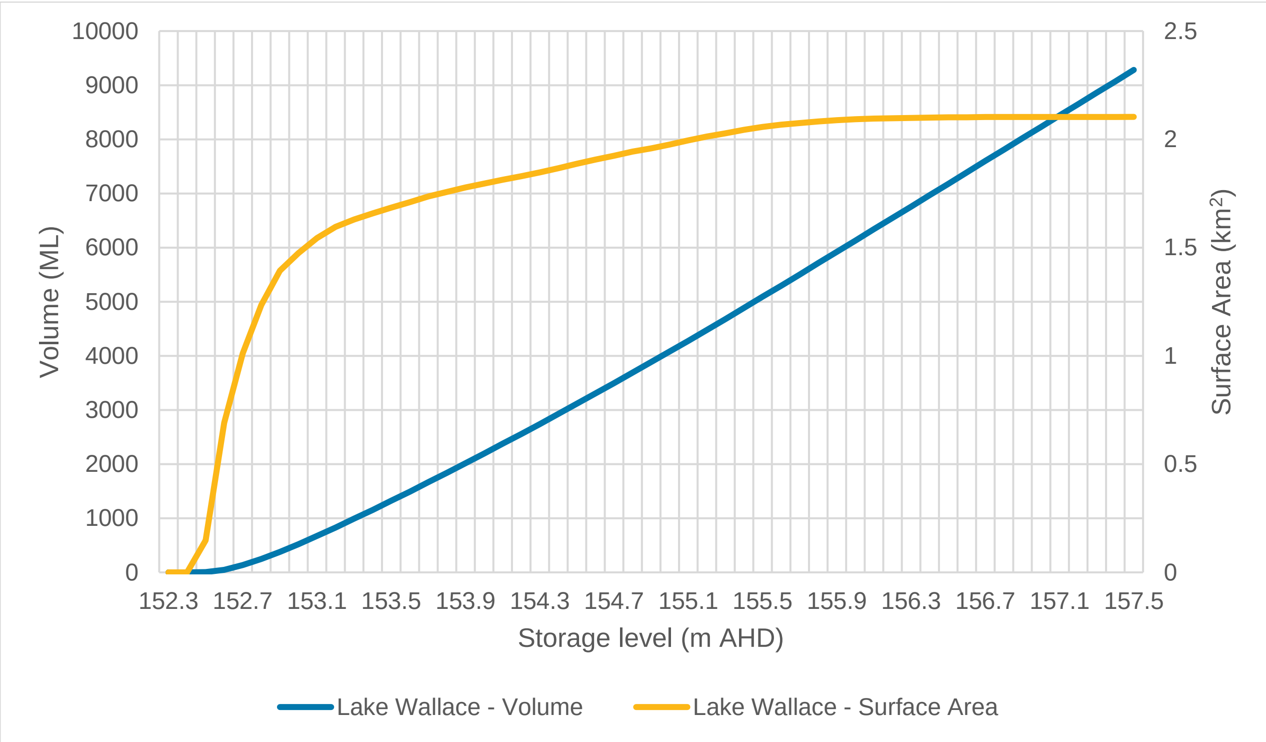


FIGURE 4-6 LAKE WALLACE STORAGE DATA

4.2 Calibration/Verification

4.2.1 Overview

The Source model calibration/verification was undertaken in three steps:

- The Lake Natimuk model was initially calibrated using the overlapping period of daily rainfall and PET data from 1965 – 2001. Lake Natimuk was used as the primary source for the calibration due to the amount of calibration data available, with several newspaper articles, signposts, and community recollections of water levels, times of overflow and times of dry.
- The calibration parameters determined were then adopted for the Lake Wallace model, which were modified slightly to match the observed data and represent the different catchment conditions.
- A combination of the Lake Wallace and Lake Natimuk calibration parameters were then adopted for St Marys Lake. Unfortunately, St Marys Lake didn't have any historic data that could be used in the calibration process.

The Source model calibration and verification was an intensive process of trial and error, refining the model parameters which influence the rate at which water enters or leaves each wetland.

4.2.3 Calibration Parameters

The Source calibration was completed using the GR4J model. GR4J requires four key parameters and two independent variables, these are as follows:

- Key Parameters
  - X1 - Capacity of the production soil (SMA) store
    - X1 represents the soils ability to retain rainfall as a depth in mm.
  - X2 - Water exchange coefficient
    - X2 represents how well water is transferred between runoff and subsurface water
  - X3 - Capacity of the routing store
    - X3 represents the water routed from X1 (capacity of the soil moisture store) in depth mm.
  - X4 - Time parameter for unit hydrographs
    - X4 is the timestep for routing calculations.
- Independent Variables
  - Rainfall and Potential Evapotranspiration (PET).

x1 and x3 are positive, x4 is greater than 0.5 and x2 can either be positive, zero or negative. The units, default value and potential parameter range is shown in Table 1.

TABLE 4-2 GR4J PARAMETERS AND THEIR DEFAULT VALUES (EWATER)

Parameter	Description	Units	Default	Range
x1	Capacity of the production soil (SMA) store	mm	350	1 – 1500
x2	Water exchange coefficient	none	0	-10.0 – 5.0
x3	Capacity of the routing store	mm	40	1 – 500
x4	Time parameter for unit hydrographs	days	0.5	0.5 – 4.0

4.2.4 Storage Nodes and Flow pathways

Each Source model comprised of a series of nodes and associated routing links (flow paths). Generally, nodes were the centroid of a catchment or storage. The Lake Natimuk required several nodes, in order to include Lake Wyn Wyn, downstream of Lake Natimuk.

Each storage used the Backwater Euler Method *(eWater SOURCE, 2018 – Source User Guide 4.5, https://wiki.ewater.org.au/)*,which allows for greater flexibility in the configuring of the storages. The primary benefit to this is applying operating constraints to the storages. Each storage used minimum and maximum operating constraints taken from the initial ground surface level of the wetlands to the maximum ground surface level to which the wetland would overflow, the details of each wetland's operating constraints is shown in Table 4-3.

TABLE 4-3 OPERATING CONSTRAINTS

Wetlands	Minimum Operating	Maximum Operating	Maximum Storage Level
Lake Natimuk	110.0 m AHD	114.7 m AHD	114.7 m AHD
St Mary's Lake	124.4 m AHD	129.2 m AHD	129.2 m AHD
Lake Wallace	152.3 m AHD	157.5 m AHD	157.5 m AHD

Each wetland was modelled as having an "Ungated Spillway" outlet which represents overflow into the following downstream wetland.

The final configuration was the "Seepage" associated with each of the storage nodes. This data is not easily accessible as the much of the previous data does not provide ample information to accurately assess these parameters. However, a report "Storage Seepage & Evaporation" from NCEA states average seepages of 10 – 40 mm/day (Cotton Catchment Communities, 2011). The maximum seepage rate of 15 mm/day was exponentially projected at 114.7 metres AHD.

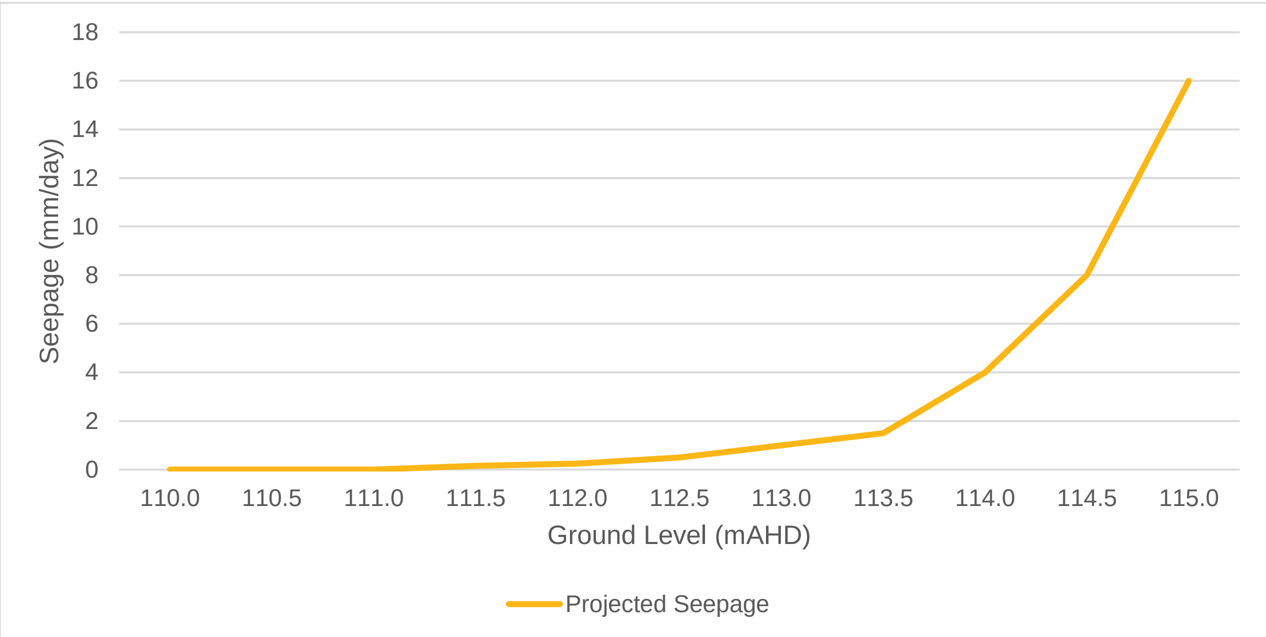


FIGURE 4-7 CHOSEN PROJECTED SEEPAGES FROM WIMMERA WETLANDS

4.2.5 Lake Natimuk

Calibration of the Source model parameters (X1, X2, X3 and X4) required an iterative process to best replicate the recorded data. Figure 4-8 shows the original and final calibrated results for the model with Table 4-4 highlighting the calibrated values.

The x1 parameter was initially lowered from the default 350 mm due to the expected lower soil capacity. x1 remained constant at 150 throughout modelling. The x2 parameter (water exchange coefficient) was set at zero for the townships, -2 for agricultural areas and -1 for wet areas. The final calibration parameter was x3 where the capacity of route storing was increased throughout the catchment.

TABLE 4-4 CALIBRATED RESULTS

Sub-areas	Functional Unit	X1 (1/1500 mm)	X2 (-10/5 mm)	X3 (1/500 mm)	X4 (0.5/4 d)
SC1	Agriculture	150	-2	50	0.5
	Township	150	0	50	0.5
	Water Surface	150	-1	50	0.5
SC2	Agriculture	150	-2	50	0.5
	Township	150	0	50	0.5
	Water Surface	150	-1	50	0.5
SC3	Agriculture	150	-2	50	0.5
	Township	150	0	50	0.5
	Water Surface	150	-1	50	0.5

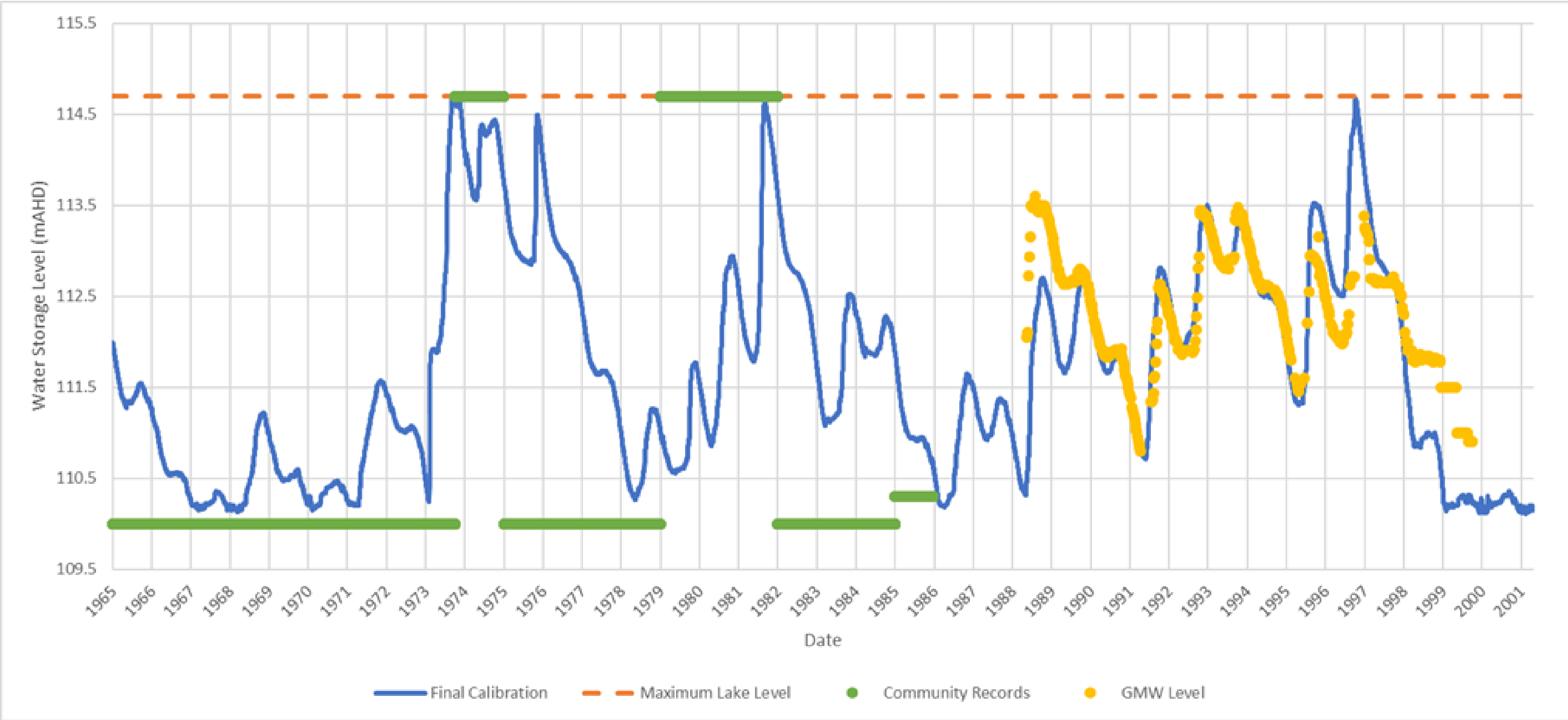


FIGURE 4-8 CALIBRATION RESULT DATA FOR LAKE NATIMUK

The model was shown matched community observations and Wimmera Mallee Water recording. The peaks of 1974 – 1975 show the impact of large rainfall totals and with Lake Natimuk exceeding capacity twice. The community observations generally only state Lake Natimuk is either full or dry; however, what constitutes as "full" or "dry" can relatively subjective with the lake having a high level potentially constituting "full" and almost empty "dry".

The Wimmera Mallee Water data provides a more continuous recording of lake level, however no AHD datum for the data exists. Without an AHD level the data can only be used to determine how well the model matches the rise and fall of the lake level. As shown in Figure 2-10, the model calibration matches the recorded lake level rise and fall very closely from around 1990 to 1996.

4.2.6 Lake Wallace

The model parameters adopted during the Lake Natimuk calibration were initially adopted for Lake Wallace with some necessary changes to represent the groundwater interaction within Lake Wallace and large number of existing wetlands upstream of the lake. Additional to anecdotal observations of overflow, Lake Wallace water levels were outlined in the "Preliminary assessment of water balance model for Lake Wallace, Edenhope" *(Fawcett and Huggins DPI, Jan 2005)*. The actual data from this analysis was not available in digital form but the graphical representation was used as a basis for comparison.

The previously recorded data collated *(Fawcett and Huggins DPI, Jan 2005)* is shown with a comparison of the modelled and observed water levels is shown in Figure 4-10.

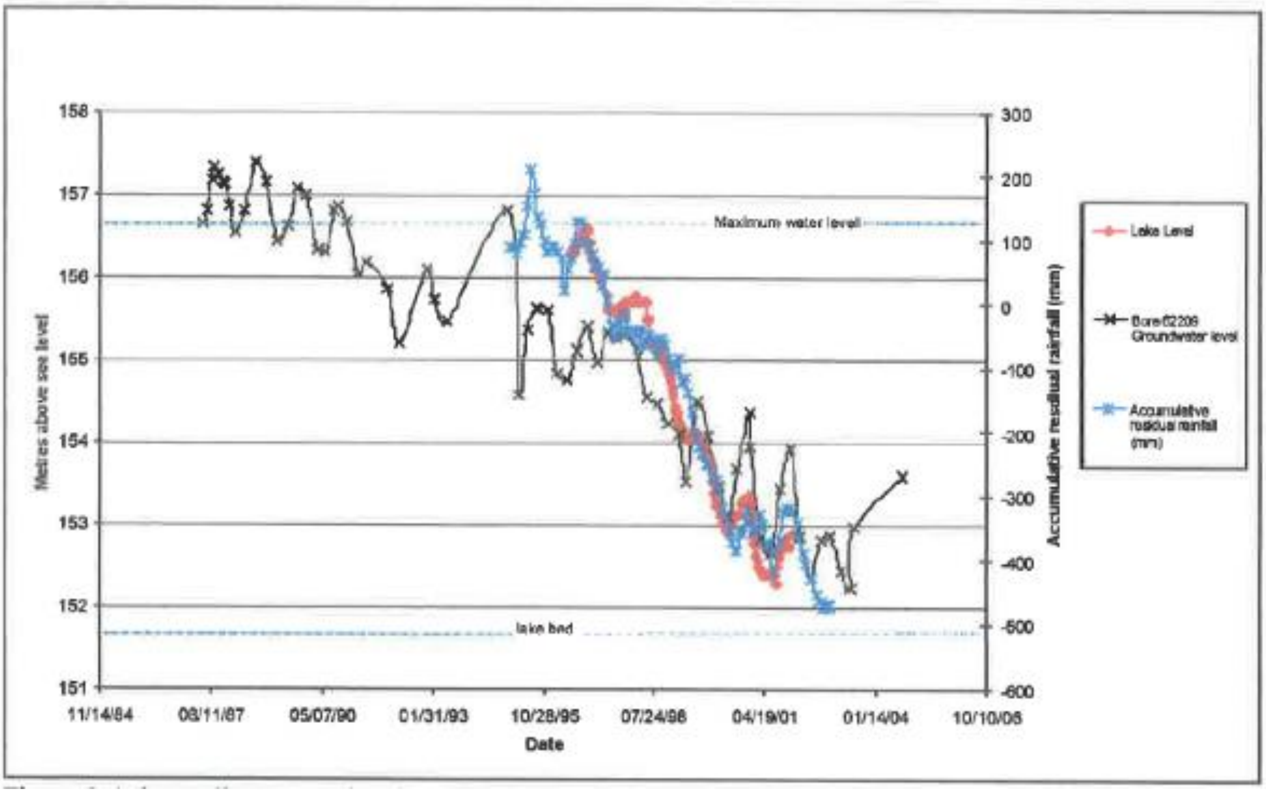


FIGURE 4-9 WETLAND STORAGE LEVEL AND GROUNDWATER LEVELS AT LAKE WALLACE (DPI)

A sign showing the months and years Lake Wallace exceeded capacity was used as the primary calibration data along with the data within the *Fawcett and Huggins* report. Also data was available from descriptions and photos in the *West Wimmera Advocate*. Lake Wallace exceeded capacity in 1995, 1981, 1988, 1991 and 1992, all of which were represented in the model. The lake also exceeded capacity in 1983 and 1988, the model showed increases in height but did not exceed spillway.

Fawcett and Huggins report showed a period of lake level decline from around 1995 to 2002, however the model does not show this decline in level until 1996, and it occurs much more slowly than the report suggests. The drying observed in the DPI results from 1996 to 2001 is mirrored later in the calibrated results from 2000 to 2003.

This may be due to several factors including increased infiltration to groundwater and extraction for Edenhope's water supply which is not currently represented in the model, this is estimated at about 160 ML/yr[2]. The lake bed level also varies from approximately 151.7 m AHD in 2005 and 152.3 m AHD in 2011, which is likely due to LiDAR picking up dense vegetation in the bottom of the lake, deposition of sediments and/or some water remaining in the bottom of the lake with the LiDAR was captured. The 2005 LiDAR was used to develop modelling of the lake.

[2] Pers. Com. GWMWater.

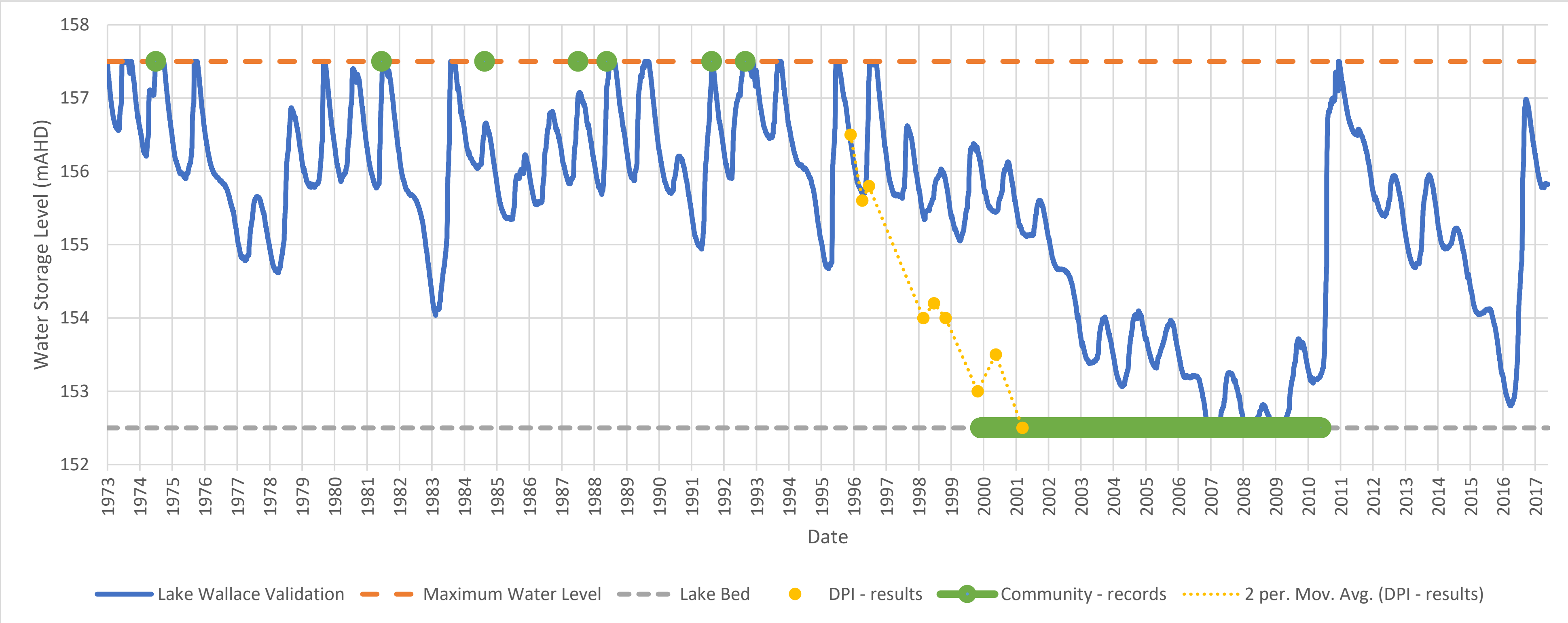


FIGURE 4-10 VALIDATION WETLAND STORAGE LEVEL AT LAKE WALLACE

4.2.7 St Mary's Lake

A combination of the Lake Natimuk and Lake Wallace calibration parameters were adopted for the St Mary's Lake catchment. There was no calibration data available to verify the water levels. The modelled water levels are shown in Figure 4-11. The major difference between the models of St Mary's Lake and Lake Wallace was the wetland seepage factor. Due to the location of the wetland within the Parilla Sands belt, the seepage factor was increased to represent the average seepage factors as outlined by the *Food and Agriculture Organisation of the United Nations* shown in Table 4-5 below. A seepage factor of 200 mm/day was chosen to represent a largely salty sandy wetland, there is uncertainty around the seepage rates but without calibration data the opportunity to confirm the adopted rates is limited.

TABLE 4-5 SEEPAGE LOSSES

Natural Soil Type	Seepage Losses (mm/day)
Sand	25.00 – 250.00
Sandy loam	13.00 – 76.00
Loam	8.00 – 20.00
Clayey loam	2.50 – 15.00
Loamy clay	0.25 – 5.00
Clay	1.25 – 10.00

The modelled results show a catchment that is dependent entirely on rainfall with large amounts of seepage into the geological Parilla Sand feature. Community consultation suggested large dry periods, which is replicated in the results as St Marys Lake has been drying from 2001. The water storage levels rise and fall relatively quickly which is due to its size and the other abovementioned influences.

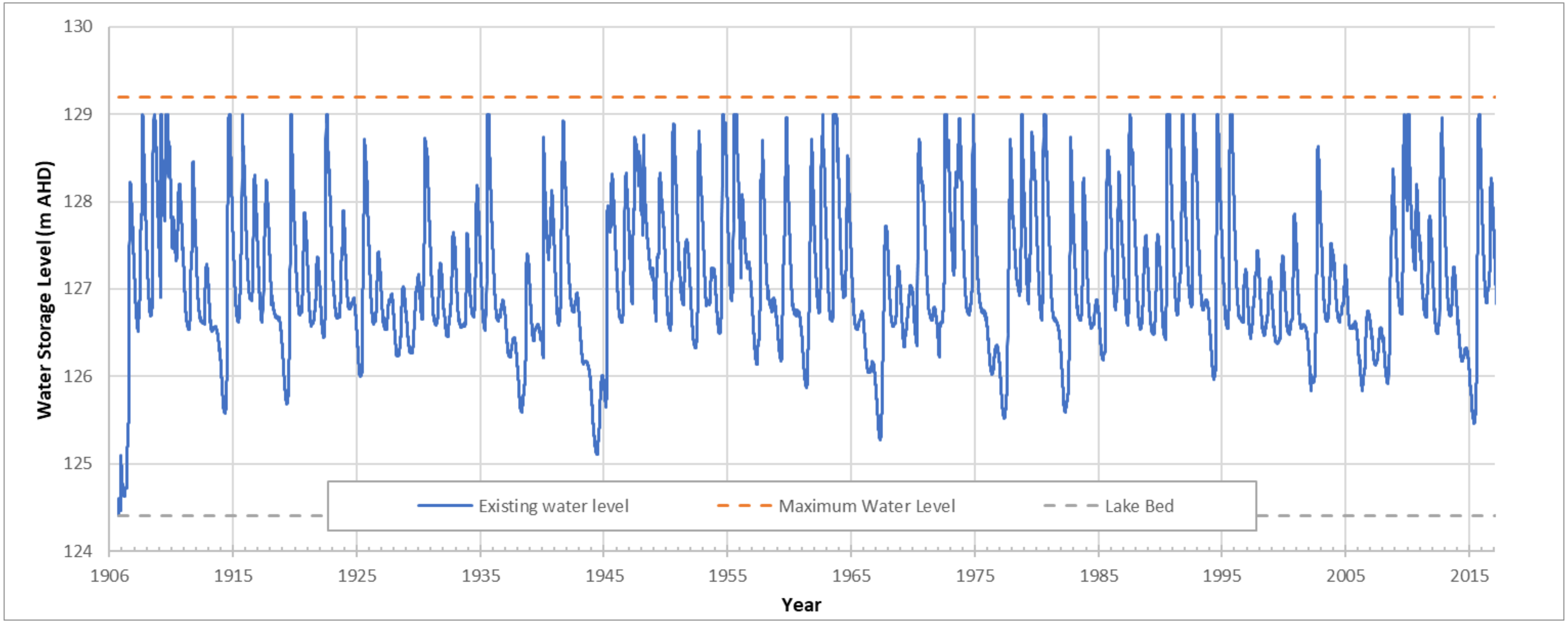


FIGURE 4-11 ST MARYS LAKE RESULTS

4.3 Climate Change Modelling

4.3.1 Methodology

Lake Natimuk, St Marys Lake and Lake Wallace are located in the “Murray Basin Climate Zone” according to the Bureau of Meteorology (BoM) and the Commonwealth Scientific and Industrial Research Organisation (CSIRO) classifications. There are a set of 40 global climate projection models used to assist in the analysis and representation of future temperature, evaporation, and rainfall. These models relate results to the Representative Concentration Pathway (RCP) projections and the specific locations throughout Australia. There are predictions for four RCPs, these are as follows:

- RCP8.5 - a future with little curbing of emissions, with a CO_2 concentration continuing to rapidly rise, reaching 940 ppm by 2100.
- RCP6.0 – lower emissions, achieved by application of some mitigation strategies and technologies. CO_2 concentration rising less rapidly (than RCP8.5), but still reaching 660 ppm by 2100 and total radiative forcing stabilising shortly after 2100.
- RCP4.5 - CO_2 concentrations are slightly above those of RCP6.0 until after mid-century, but emissions peak earlier (around 2040), and the CO_2 concentration reaches 540 ppm by 2100.
- RCP2.6 - the most ambitious mitigation scenario, with emissions peaking early in the century (around 2020), then rapidly declining. Such a pathway would require early participation from all emitters, including developing countries, as well as the application of technologies for actively removing carbon dioxide from the atmosphere. The CO_2 concentration reaches 440 ppm by 2040 then slowly declines to 420 ppm by 2100) *(Detlef P. van Vuuren et. al. (2011), The representative concentration pathways: An Overview)*.

The future impacts from anthropogenic greenhouse gas and aerosol emissions remains highly uncertain with many known and unknown influences and of the above scenarios none is considered more likely given the response to reducing greenhouse emissions is highly politicised completely unknown. A graphical comparison of the pathways is represented in Figure 4-12 below.

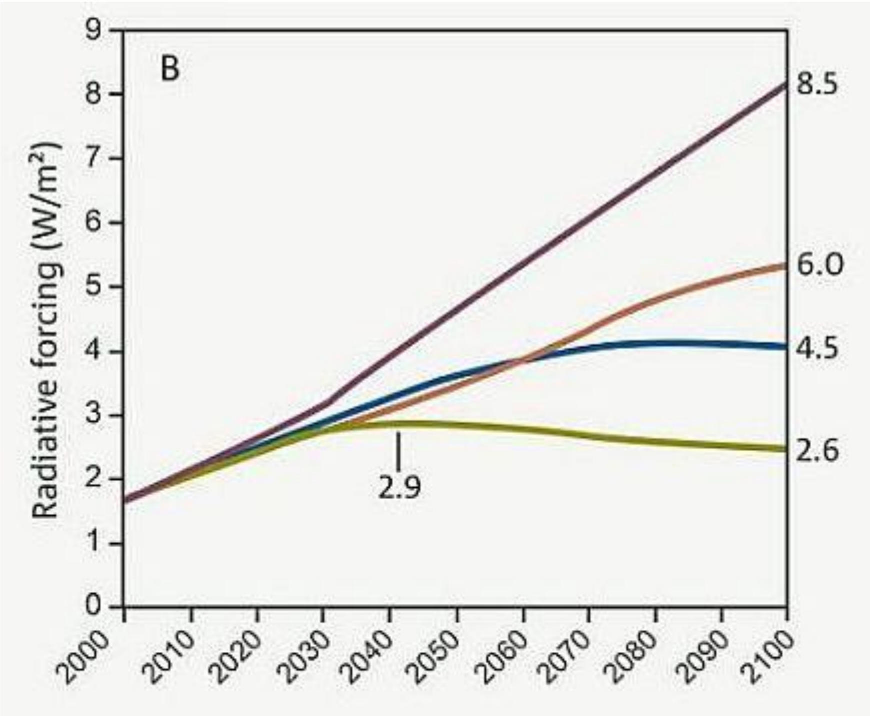


FIGURE 4-12 RADIATIVE FORCING FOR THE DIFFERENT RCPS. THE NUMBERS ON THE RIGHT SHOW THE FINAL RADIATIVE FORCING AT 2100 AND GIVE EACH SCENARIO ITS NAME (8.5, 6.0, 4.5, AND 2.6 W/M^2) (CLIMATE CHANGE IN AUSTRALIA TECHNICAL REPORT)

Given the uncertainty of which RCP scenario will be relevant in the future it was determined RCP 4.5 and 8.5 would be modelled in this project giving a lower and higher RCP scenario. Modelling all the available scenarios was not considered useful, just adding to the numerous uncertainties.

The impact of each RCP scenario was modelled by adjusting historic rainfall and evapotranspiration data for each lake as per the recommendations from Climate Change in Australia *(Climate Change in Australia provides projections for Australia's Natural Resource Management regions via https://www.climatechangeinaustralia.gov.au/en/.)* The website is maintained by the CSIRO. The climate change scenarios modelled were grouped by season, as outlined in the CSIRO projection software, with the maximum and minimum projected rainfall change for the RCP 4.5 and the RCP 8.5 as shown in Table 4-6. As well as the minimum and maximum predictions with each RCP, the mean was also modelled.

Evapotranspiration rates are predicted to increase by a maximum 4.59% for the RCP 4.5 and 8.5 outcomes.

The gauged rainfall data was manipulated per season, with a maximum decrease of -48% rainfall seen in RCP 8.5 over spring and a maximum increase of 27% also seen in RCP 8.5, over summer.

Modelling was completed modifying the available historic rainfall data and average evaporation data for each lake, then enabled a comparison between existing and climate change conditions.

TABLE 4-6 RAINFALL AND EVAPOTRANSPIRATION PROJECTED CHANGES

Seasons	RCP 4.5 (% change)		RCP 8.5 (% change)	
	Minimum	Maximum	Minimum	Maximum
Summer	-0.17	0.10	-0.13	0.27
Autumn	-0.23	0.18	-0.29	0.26
Winter	-0.21	0.07	-0.38	0.04
Spring	-0.28	0.05	-0.48	0.06
Evaporation	-0.0459			

4.3.2 Lake Natimuk

As expected, the mean (average between maximum and minimum predictions) 4.5 and 8.5 RCP model results showed lower general water levels from that observed in current conditions. Figure 4-13 and Figure 4-14 show the RCP 4.5 and RCP 8.5 water level results respectively, in the mean rainfall reduction scenario. The minimum and maximum scenarios are shown in Appendix A.

Modelling of historic data showed Lake Natimuk filled and spilled approximately 11 times within the 112 years of modelled results with an average depth of 1.93 m (112.06 metres AHD). This is compared to a mean depth of 1.22 m and 3 spills in 112 years of modelled results in the mean RCP 4.5 scenario and an average depth of 0.57m and 1 spill in 112 years of modelled results in the mean RCP 8.5 scenario. Average depth and number of spill predictions for each RCP are shown in Table 4-7.

TABLE 4-7 LAKE NATIMUK - HISTORIC AND CLIMATE CHANGE COMPARISON

Scenario		Average water depth (m)	No. of times spills within 112 years
Historic Data		1.93	11
RCP 4.5	Min.	0.45	-
	Mean	1.22	3
	Maximum	2.33	13
RCP 8.5	Min.	0.18	-
	Mean	0.57	1
	Maximum	2.45	14

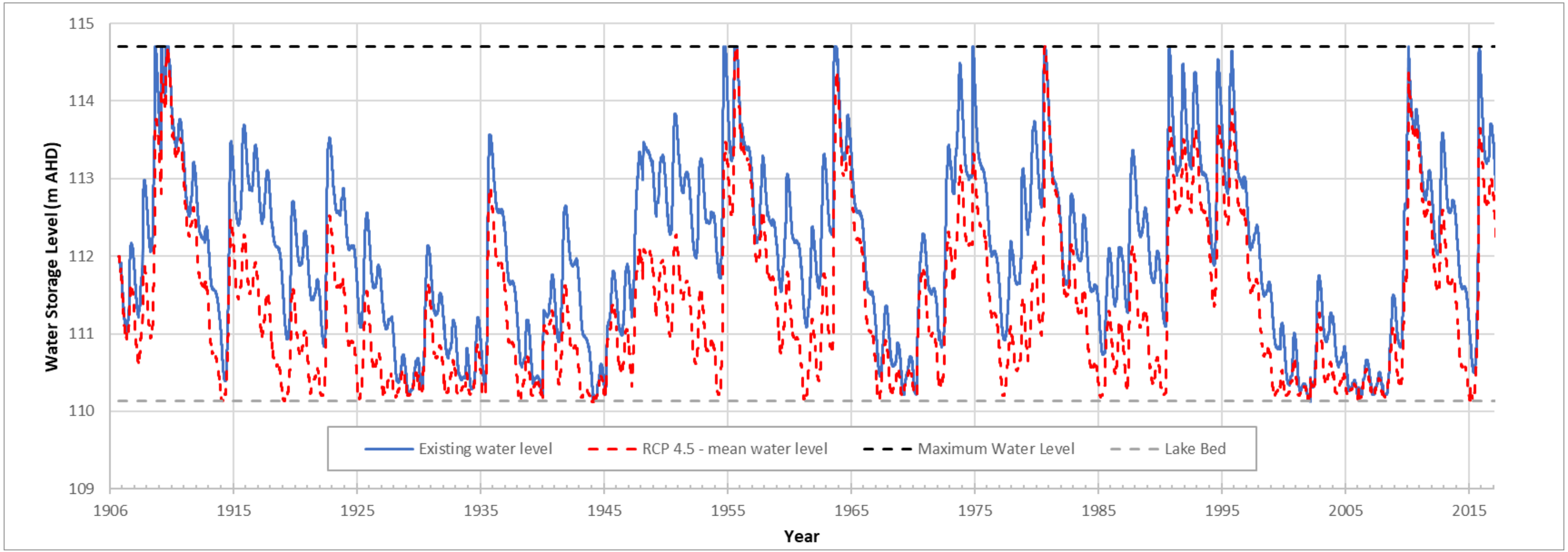


FIGURE 4-13 RCP 4.5 FOR LAKE NATIMUK

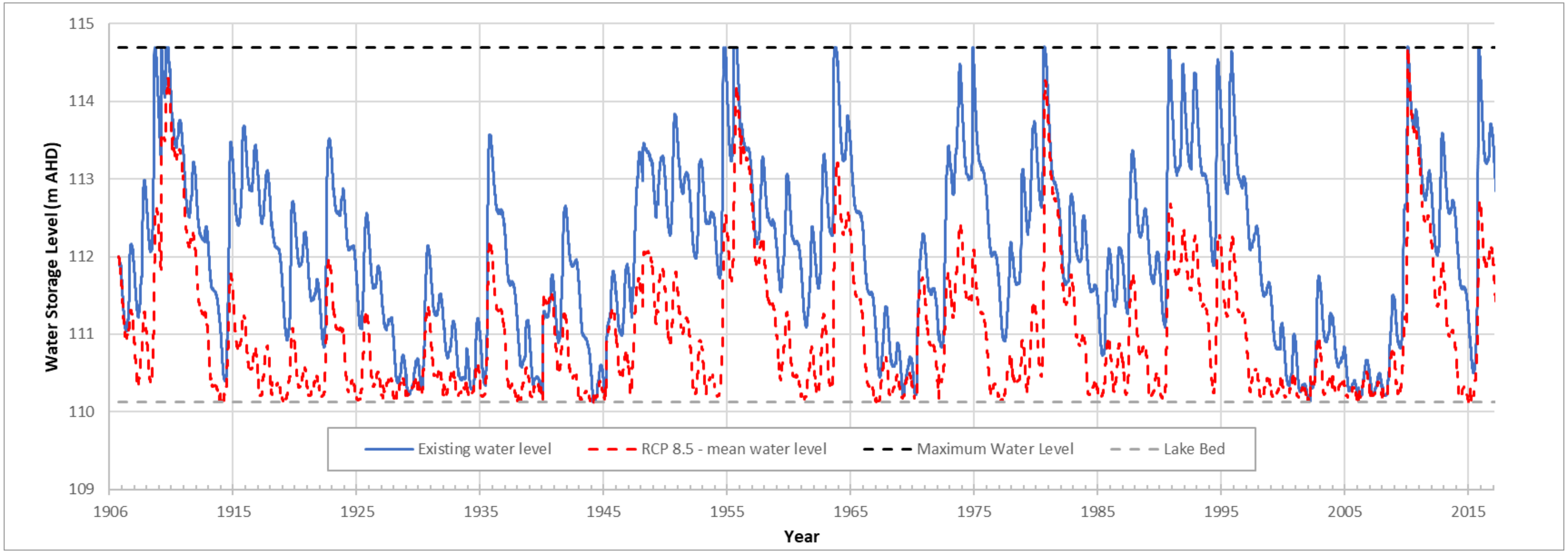


FIGURE 4-14 RCP 8.5 FOR LAKE NATIMUK

4.3.3 St Mary's Lake

The RCP 4.5 and 8.5 scenarios have a similar effect on St Mary's Lake with a reduction in depth across both mean rainfall prediction scenarios. The mean RCP 4.5 and 8.5 water level predictions are shown in Figure 4-15 and Figure 4-16. The minimum and maximum scenarios are shown in Appendix A.

Modelling of historic data showed St Mary's Lake doesn't spill, this is consistent with observations from the community. Within the 112 years of modelled results, the lake has an average depth of 2.68 m. This is compared to a mean depth of 2.36 m in the mean RCP 4.5 scenario and an average depth of 2.08m in the mean RCP 8.5 scenario. Average depth and number of spill predictions for each RCP are shown in Table 4-8.

The modelled average depths appear to be higher than would be expected, with water consistently in St Mary's Lake, when this is not believed to be the case. Unfortunately, there are no recorded levels within the lake to enable a more comprehensive calibration.

TABLE 4-8 ST MARYS LAKE - HISTORIC AND CLIMATE CHANGE COMPARISON

Scenario		Average water depth (m)
Historic Data		2.68
RCP 4.5	Min.	1.50
	Mean	2.36
	Maximum	2.83
RCP 8.5	Min.	0.78
	Mean	2.08
	Maximum	2.88

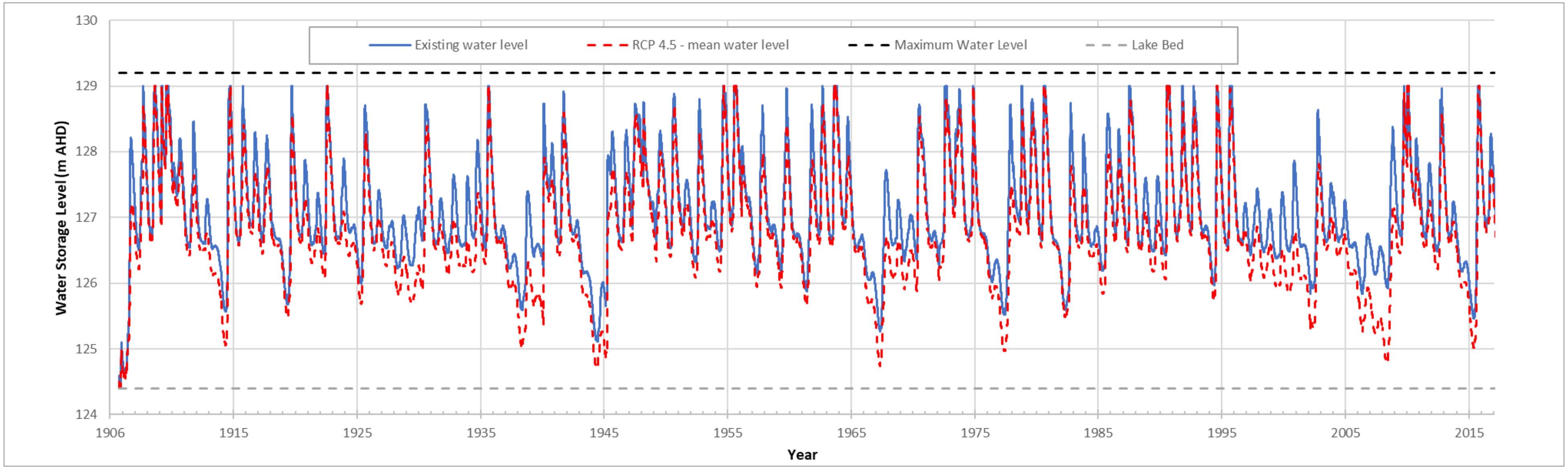


FIGURE 4-15 RCP 4.5 FOR ST MARYS LAKE

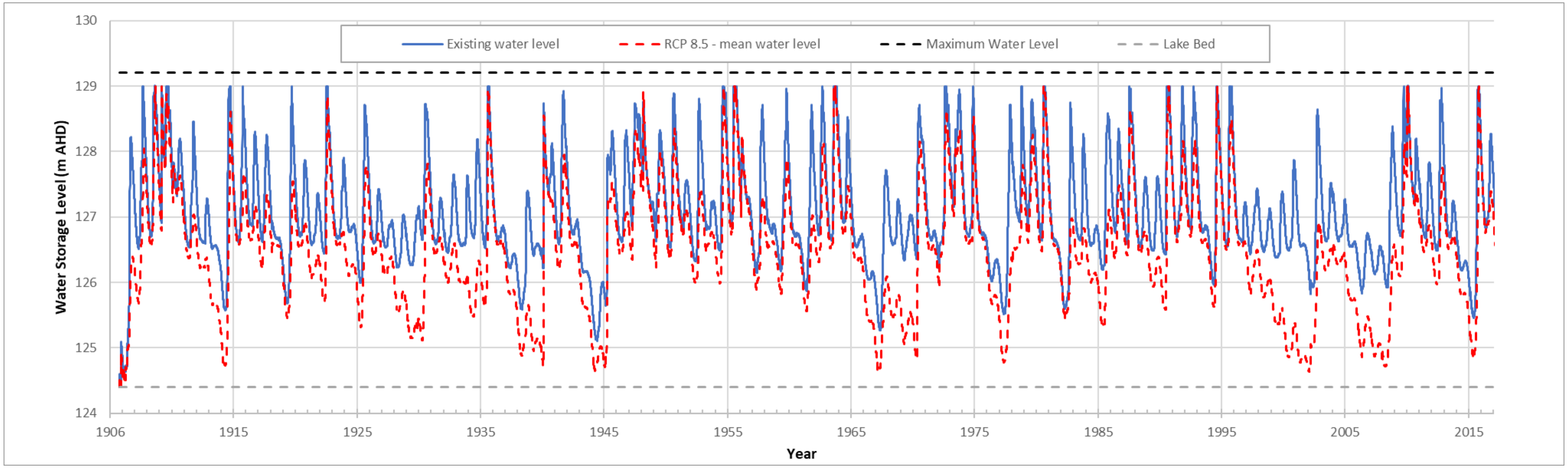


FIGURE 4-16 RCP 8.5 FOR ST MARYS LAKE

4.3.4 Lake Wallace

As shown for Lake Natimuk and St Mary's Lake, the mean (average between maximum and minimum predictions) 4.5 and 8.5 RCP model results show lower general water levels from that observed in current conditions. Figure 4-17 and Figure 4-18 show the RCP4.5 and RCP 8.5 water level results respectively, in the mean rainfall reduction scenario. The minimum and maximum scenarios are shown in Appendix A.

Modelling, based on historic data showed Lake Wallace filled and spilled approximately 32 times within the 112 years of modelled results with an average depth of 3.65 m (156.65 metres AHD). This is compared to a mean depth of 3.23 m and 24 spills in 112 years of modelled results in the mean RCP 4.5 scenario and an average depth of 2.73m and 9 spills in 112 years of modelled results in the mean RCP 8.5 scenario. Average depth and number of spill predictions for each RCP are shown in Table 4-9.

TABLE 4-9 LAKE WALLACE - HISTORIC AND CLIMATE CHANGE COMPARISON

Scenario		Average water depth (m)	No. of times spills within 112 years
Historic Data		3.65	32
RCP 4.5	Min.	1.95	3
	Mean	3.23	24
	Maximum	3.79	32
RCP 8.5	Min.	0.40	-
	Mean	2.73	9
	Maximum	3.83	36

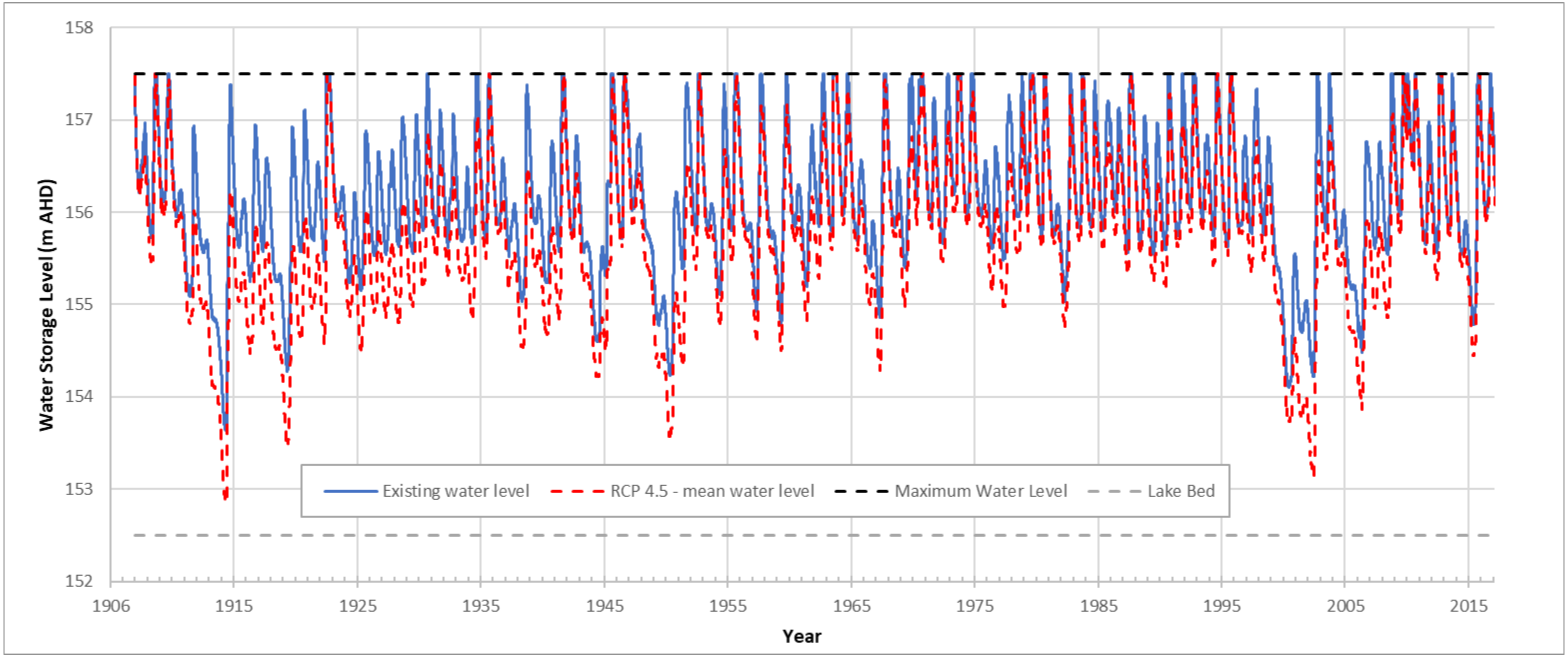


FIGURE 4-17 RCP 4.5 FOR LAKE WALLACE

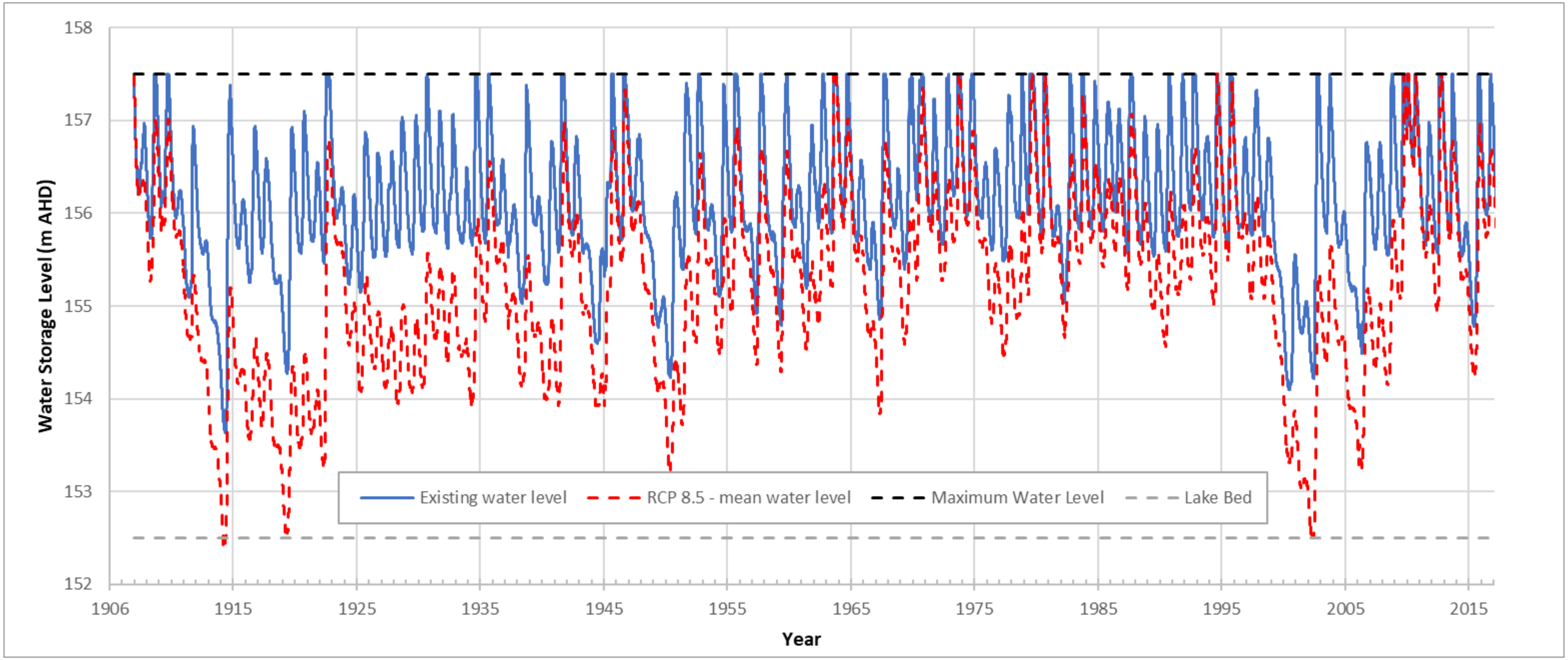


FIGURE 4-18 RCP 8.5 FOR LAKE WALLACE

4.3.5 Summary

Modelling the RCP 4.5 and 8.5 scenarios has shown the most likely consequence of climate change is decreased water levels in all three wetlands. It has also shown that Lake Natimuk and St Marys Lake are the most impacted, with Lake Wallace's groundwater interaction reducing the impact of reduced flows. Lake Natimuk is the most affected of the three wetlands. Lake Natimuk's catchment is the most developed with the largest proportion of agricultural land and has the largest surface area and therefore greatest increase to evaporation. Given the broad range of climate change predictions, no definitive statement can be made about decreases to depths in the wetlands.

4.4 Land Use Change

4.4.1 Overview

The current land use surrounding the Wimmera wetlands is characterised predominately by cereal and legume agriculture with some native vegetation (particularly in the St Mary's Lake catchment). These current conditions have been used as the basis for the calibrated models and identify key wet (flood) and dry (drought) periods from data accumulated by the local community and government organisations, as outlined in Section 2.3. The calibration parameters representing the current agricultural practices were modified to represent modified land use in two scenarios:

- Set stock grazing across the catchments; and
- Pre-European catchment conditions

To model the change in land use, the calibrated potential infiltration and runoff were modified. These processes are represented in the *eWater* SOURCE modelling software by the X1 and X2 parameters in the GR4J model, as outlined in Section 2.3.2.

The scenarios were modelled with the observed rainfall, evaporation and seepage data within each model. The large potential range in applicable parameters (as discussed in Table 4-2) made it difficult to justify potential changes, to better understand how sensitive water levels were to the X1 and X2 parameters a sensitivity analysis was conducted.

Three sensitivity runs were modelled, with the adopted parameters and results as follows:

- Sensitivity Test 01 - X1=350 X2=0 (default parameters)
  - Resulted in lower storage water levels at 111.49 metres AHD and fewer spillages, reflecting a catchment area with reduced runoff and delayed peaks that do not mirror recorded data.
- Sensitivity Test 02 - X1=350 X2= -2 (calibrated value - chosen to observe the impact of the X1 parameter).
  - Resulted in the lowest water storage level average of 110.83 metres AHD, barely higher than the invert of Lake Natimuk. The peaks are delayed significantly from the associated rainfall as runoff is limited in the area.
- Sensitivity Test 03 - X1= 150 (calibrated value), X2=0.
  - Resulted in regular spills over the previous 100 years with the highest average water storage level at 112.93 metres AHD. This is due to a catchment that receives large amounts of runoff not limited by the other waterways and natural or anthropogenic water storages. The water storage level is impacted by the interaction with the groundwater rather than limited runoff.

A graphical comparison of the sensitivity analysis is shown in Figure 4-19. The modelling demonstrated as X1 is increased, runoff is lowered. The water storage level lowers drastically resulting in little water volumes over the previous 100 years, which as calibrated prior is not an accurate representation. As the X2 parameter increases a higher interaction with groundwater has a significant influence on Lake Natimuk.

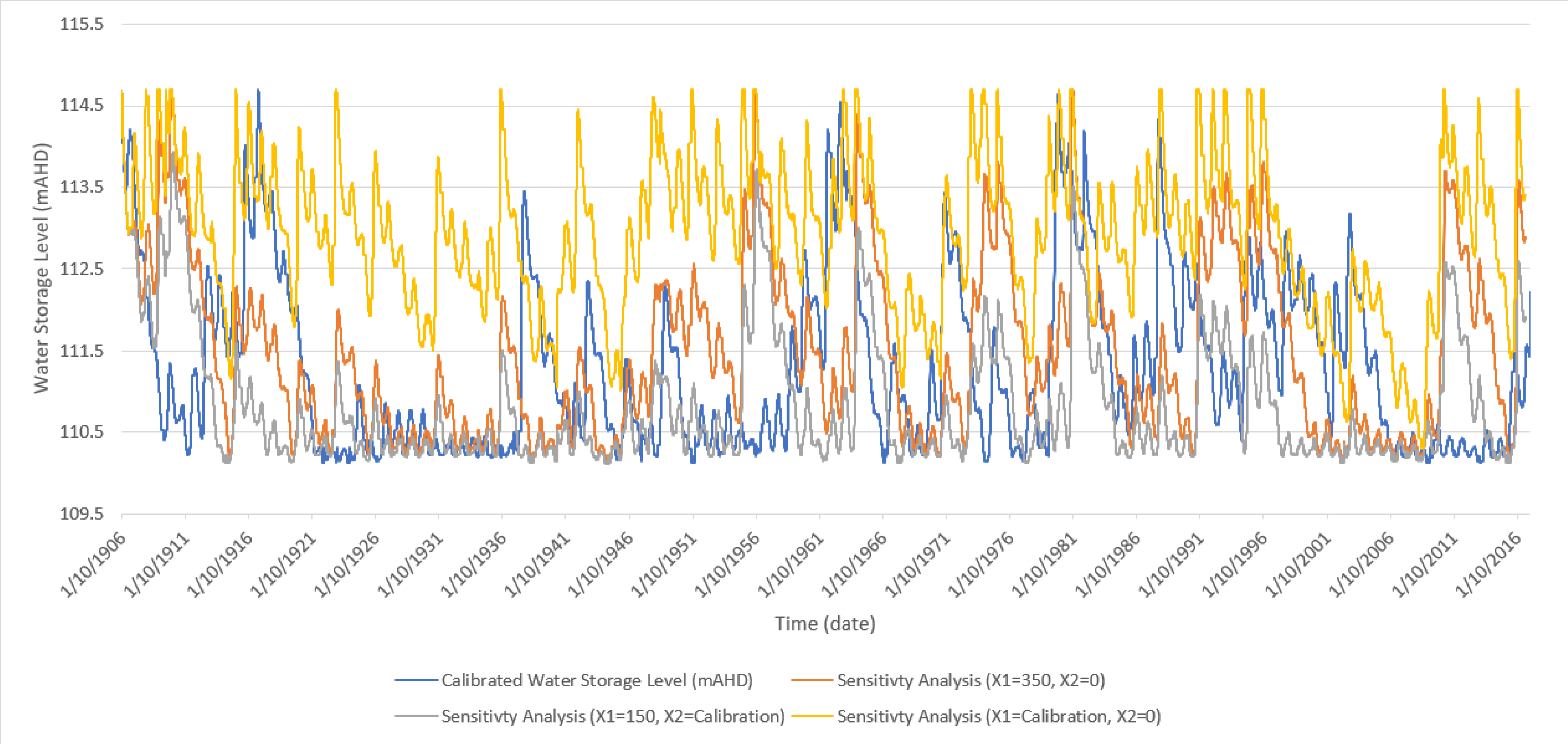


FIGURE 4-19 LAKE NATIMUK SENSITIVITY ANALYSIS

4.4.2 Set Stock Grazing Conditions

4.4.2.1 Methodology

The conventional 'continuous grazing' or 'set stocking' (stock remaining in a single paddock for long periods) land use changes the response of infiltration and runoff conditions throughout the grazed area. Compaction of the soil from these practices lowers soil moisture retention and infiltration characteristics, therefore increasing runoff within paddocks. The comparison with the cereal and legume cultivation (current conditions) is a higher infiltration and soil moisture retention with low runoff.

The Department of Agriculture and Water Resources completed by the Australian research division, Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) recently completed the Australian Agricultural Census collating data from the 2015/2016 financial year. The census data separates the wetlands subject to this report across the Horsham and West Wimmera Regions. The data collected indicated the split between grazed and cropped agricultural land was around 50:50. This is considered to have shifted from land use more dominated by grazing. ABARES data indicates around a 10% increase in cropping agriculture between 1993 and 2006, this trend is likely to have continued from 2006 to the 2015/16 census date, indicating cropping was likely to have occupied less than 40% of the agricultural land use, with greater than 60% grazing.

To represent these differences X1 – *capacity of the production soil (SMA) store* and X2 – *Water exchange coefficient* were altered to better represent the alternate land use. Table 4-10 provides the altered parameters with the *'Agriculture'* functional unit now representing grazing land use.

TABLE 4-10 SET STOCK GRAZING CONDITIONS PARAMETER COMPARISON

Parameter		Set Stock Grazing	Calibrated (Lake Natimuk)
X1	Agriculture	100	150
	Township	150	
	Water Surface	150	
X2	Agriculture	-1	-2
	Township	0	
	Water Surface	-1	
X3		50	
X4		0.5	

4.4.2.2 Results

4.4.2.2.1 LAKE NATIMUK

Alternation of the Source model to represent a change in land use to 'set stocking' has caused increases to runoff and Lake Natimuk water levels and overflow frequency. The lake spills more regularly from 11 to 27 times in 112 years period, more than doubling the modelled existing conditions. This is coupled by significantly reduced the dry periods, for example the mid-1930s and early 2000s where much larger inflows have increased the level of Lake Natimuk.

A comparison of the water level results is shown in Figure 2-17.

4.4.2.2.2 ST MARY'S LAKE

Modelling of St Mary's Lake and modification to the catchment to 'set stocking' agricultural use shows similar results to that of Lake Natimuk, with increased runoff and therefore water levels. The differences are particularly evident in periods of low water levels in existing conditions, from 1900-1920s and 1990s.

Each of the wetland catchments assessed has been impacted by the creation of farm dams and their inclusion is inherent in the model calibration. St Mays Lake has been particularly affected by the creation of a new large dams within its catchment which would have reduced flows reaching the lake. While no specific modelling has been undertaken to assess the impact of farm dams, it is clear the creation of additional dams or augmentation of current ones will further reduce inflows to systems which are already suffering from reductions to inflows and are expected to see further reductions due to climate and continued land use change. The creation of new dams, particularly large dams, should be considered carefully by agencies as they will further reduce inflows to already stressed wetlands.

A comparison of the water level results is shown in Figure 4-21.

4.4.2.2.3 LAKE WALLACE

Lake Wallace model results show water level differences similar to Lake Natimuk and St Marys Lake with a changed land use to 'set stocking', leading to increased water levels. However, Lake Wallace has a much higher interaction with groundwater, making the increased runoff results not as pronounced. A much larger portion of the catchment is also vegetated or existing wetlands, opposed to Lake Natimuk which is almost all agricultural.

A comparison of the water level results is shown in Figure 4-22, a closer perspective of the modelled time period is shown from the 1970's to 2017.

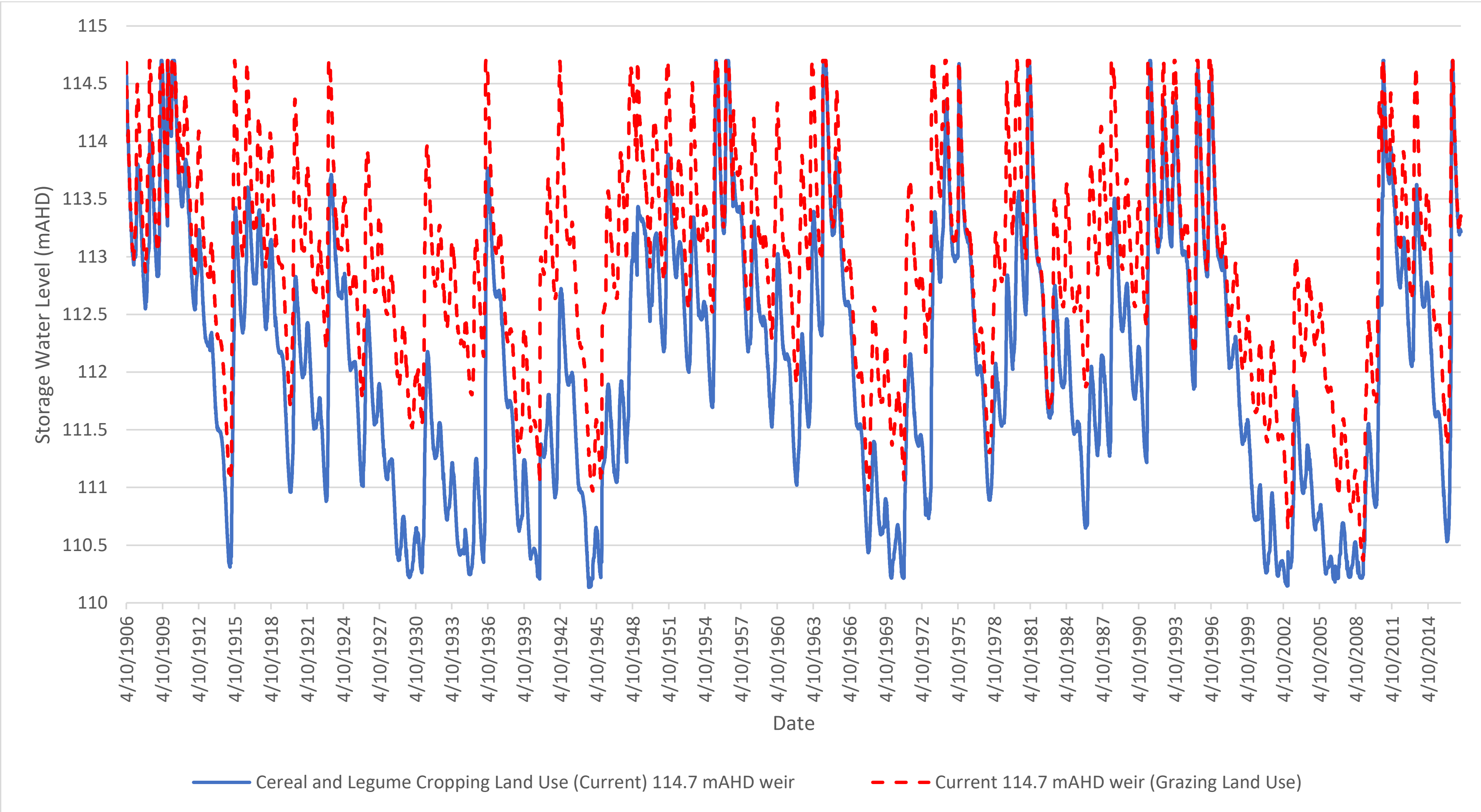


FIGURE 4-20 COMPARISON BETWEEN CEREAL & LEGUME CROPPING AND SET STOCK GRAZING LAND USE IN THE LAKE NATIMUK CATCHMENT

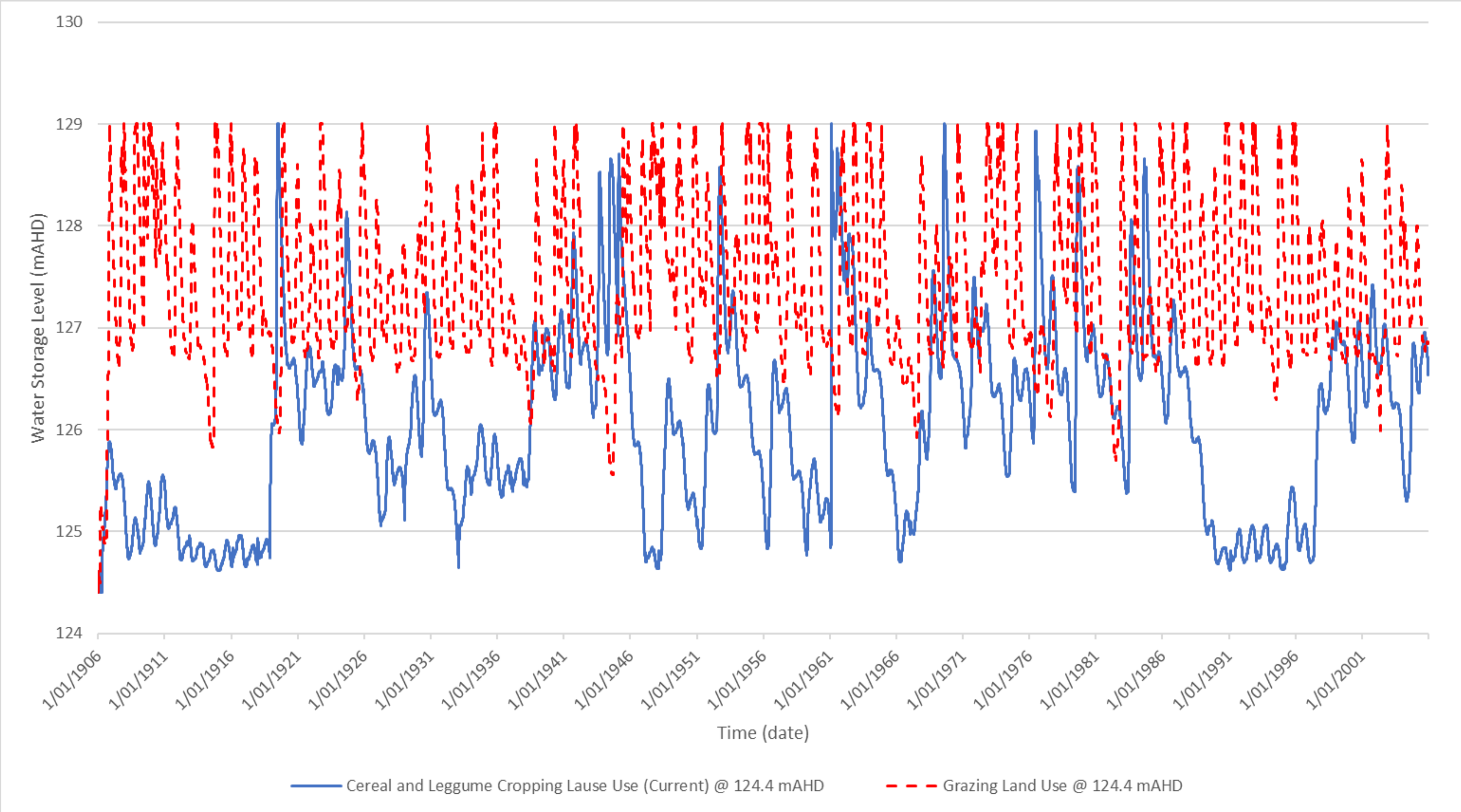


FIGURE 4-21 COMPARISON BETWEEN CEREAL & LEGUME CROPPING AND SET STOCK GRAZING LAND USE IN THE ST MARYS LAKE CATCHMENT

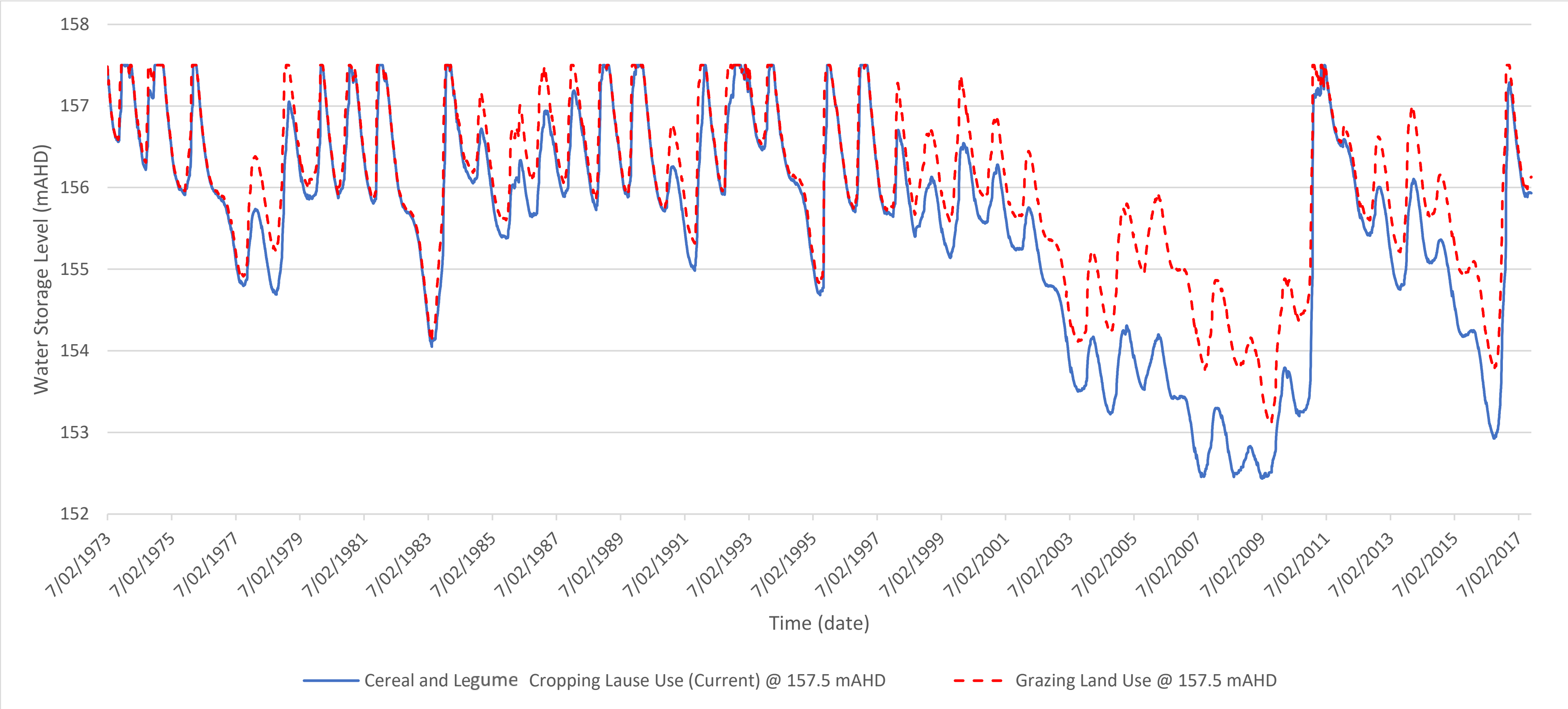


FIGURE 4-22 COMPARISON BETWEEN CEREAL & LEGUME CROPPING AND SET STOCK GRAZING LAND USE IN THE LAKE WALLACE CATCHMENT

4.4.3 Pre-European Catchment Conditions

4.4.3.1 Overview

European colonisation has led to extensive deforestation through increasing agricultural production. The pre-European catchment conditions are difficult to determine as catchment changes have been drastic in many areas. However, the remaining remnant forested woodlands and wetlands can provide a guide for the likely pre-European catchment conditions and be used to determine what that historic regime would have been to compare against current a climate change scenario modelling.

Similar to modelling variable agricultural land use, the X1 and X2 values of soil production store and water exchange were modified to represent pre-European conditions. The altered values are shown in Table 4-11 compared to those adopted during the model calibration. The X2 parameter was altered to represent a catchment that had a relatively consistent water exchange based upon the Lake Natimuk model *Water Surface* functional unit.

TABLE 4-11 PRE-EUROPEAN CONDITIONS PARAMETER COMPARISON

<table>
<tr><th colspan="2">Parameter</th><th>Pre EU</th><th>Calibrated (Lake Natimuk)</th></tr>
<tr><td rowspan="3">X1</td><td>Agriculture</td><td>250</td><td>150</td></tr>
<tr><td>Township</td><td>250</td><td>150</td></tr>
<tr><td>Water Surface</td><td colspan="2">150</td></tr>
<tr><td rowspan="3">X2</td><td>Agriculture</td><td>-1</td><td>-2</td></tr>
<tr><td>Township</td><td>-1</td><td>0</td></tr>
<tr><td>Water Surface</td><td colspan="2">-1</td></tr>
<tr><td colspan="2">X3</td><td>50</td><td></td></tr>
<tr><td colspan="2">X4</td><td colspan="2">0.5</td></tr>
</table>

4.4.3.2 Results

4.4.3.2.1 LAKE NATIMUK

Model results for Lake Natimuk show a reduction in peak levels throughout period of record and generally lower water levels. This is due to the greater exchange between rainfall and groundwater and a reduction in runoff. Greater coverage of deep-rooted vegetation, leaf litter etc. in the region would have likely decreased the amount of runoff from entering existing waterways regularly, allowing for localised pooling within the catchment.

A comparison of the water level results is shown in Figure 4-23.

4.4.3.2.2 ST MARY'S LAKE

Pre-European land use conditions has a similar impact on inflows and water levels at St Mary's Lake. The impact appears to be more pronounced on St Mary's Lake with a large reduction in water levels through the late 1920s and 1990s. Water levels only fluctuate to a minor degree through these periods.

A comparison of the water level results is shown in Figure 4-24.

4.4.3.2.3 LAKE WALLACE

Lake Wallace is impacted by a change in catchment conditions to pre-European land use in a similar fashion to Lake Natimuk and St Marys Lake, with lower inflows and therefore water levels. However, the difference is not as pronounced, similar to the changing agricultural practice modelling. This is likely to be due Lake Wallace's the interaction with groundwater which is not observed at Lake Natimuk or St Marys Lake.

A comparison of the water level results is shown in Figure 4-25.

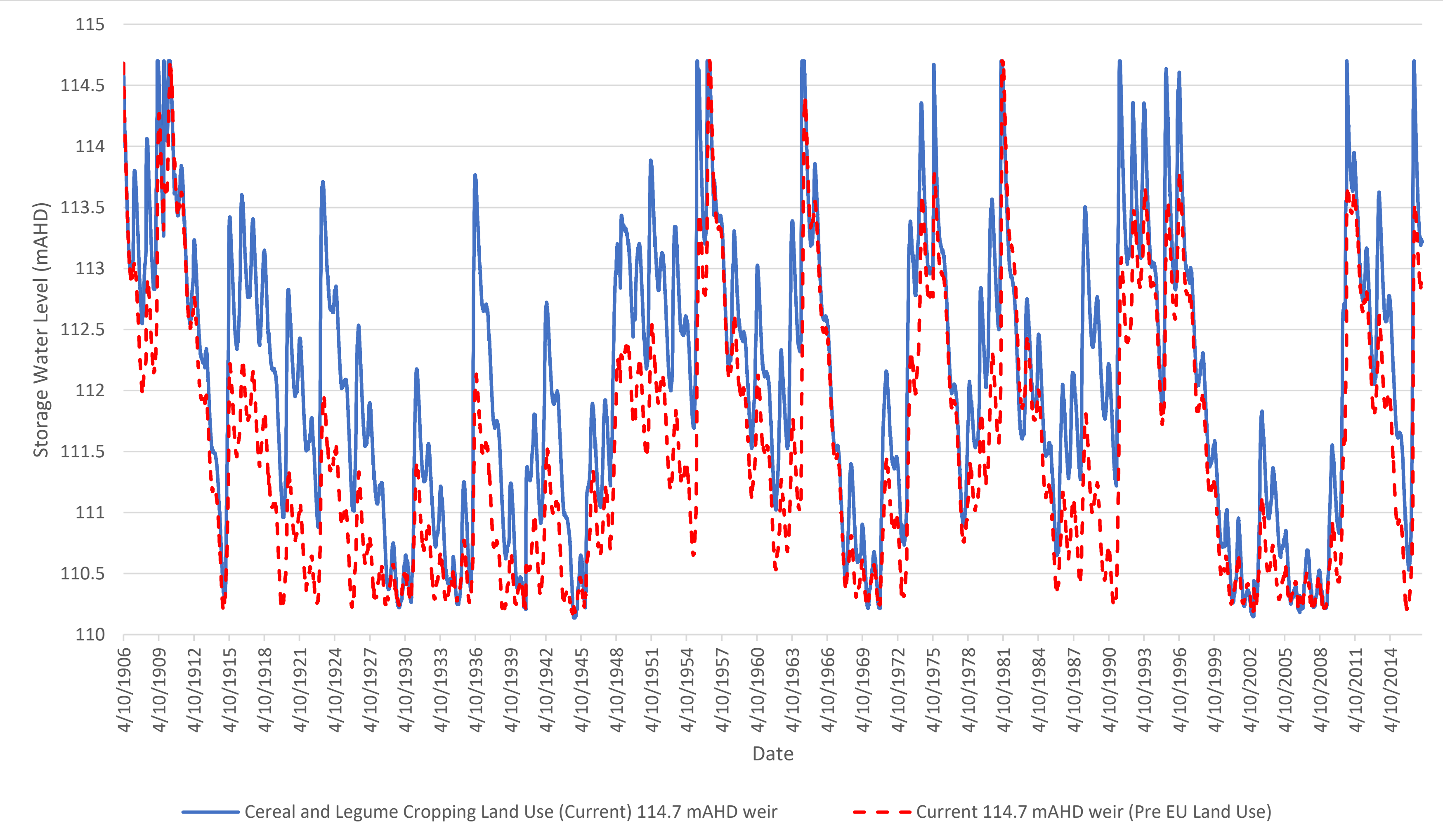


FIGURE 4-23 COMPARISON BETWEEN CURRENT (CEREAL & LEGUMES) AND PRE-EUROPEAN LAND USE IN LAKE NATIMUK CATCHMENT

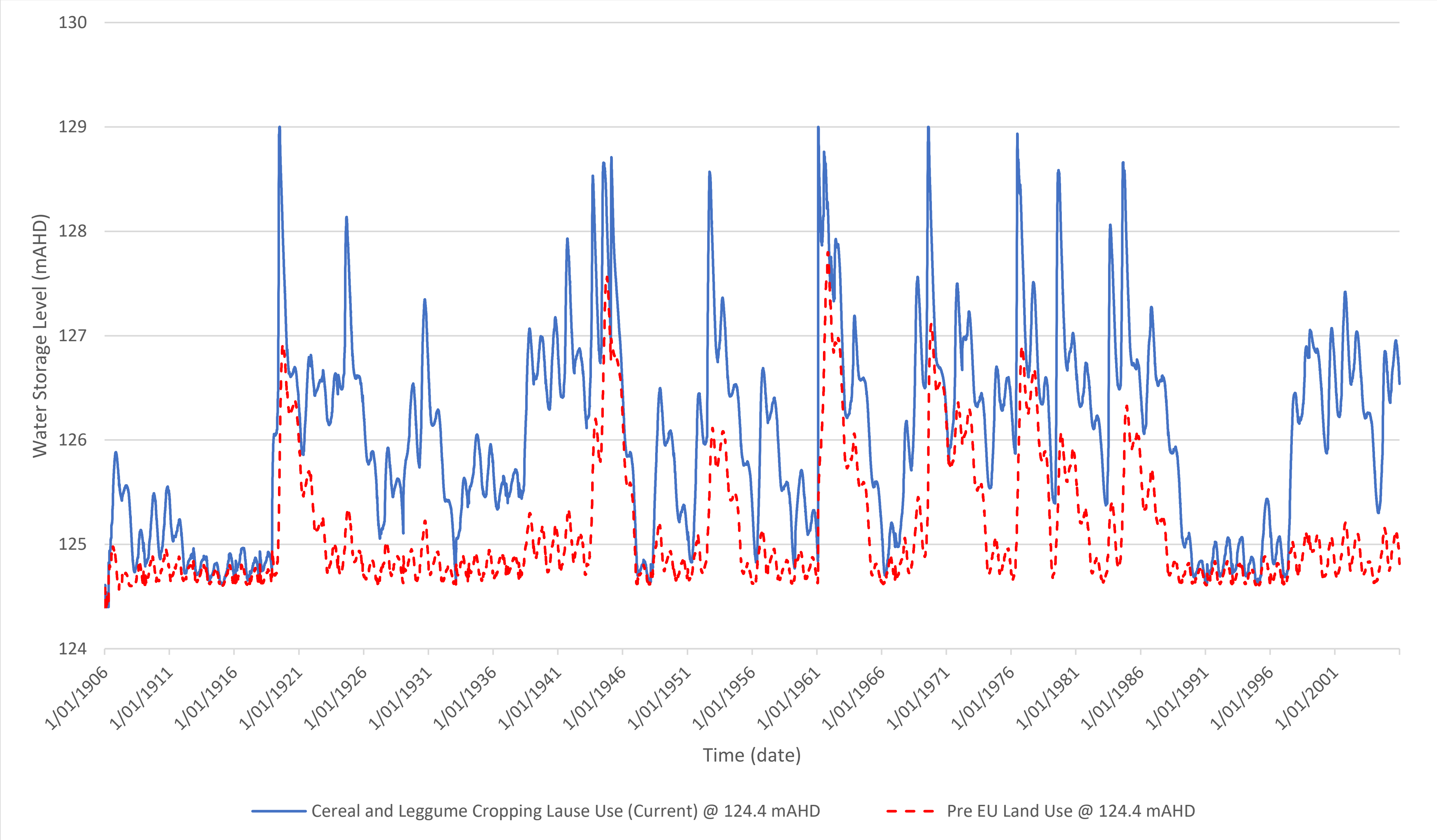


FIGURE 4-24 COMPARISON BETWEEN CURRENT (CEREAL & LEGUMES) AND PRE-EUROPEAN LAND USE IN ST MARYS LAKE CATCHMENT

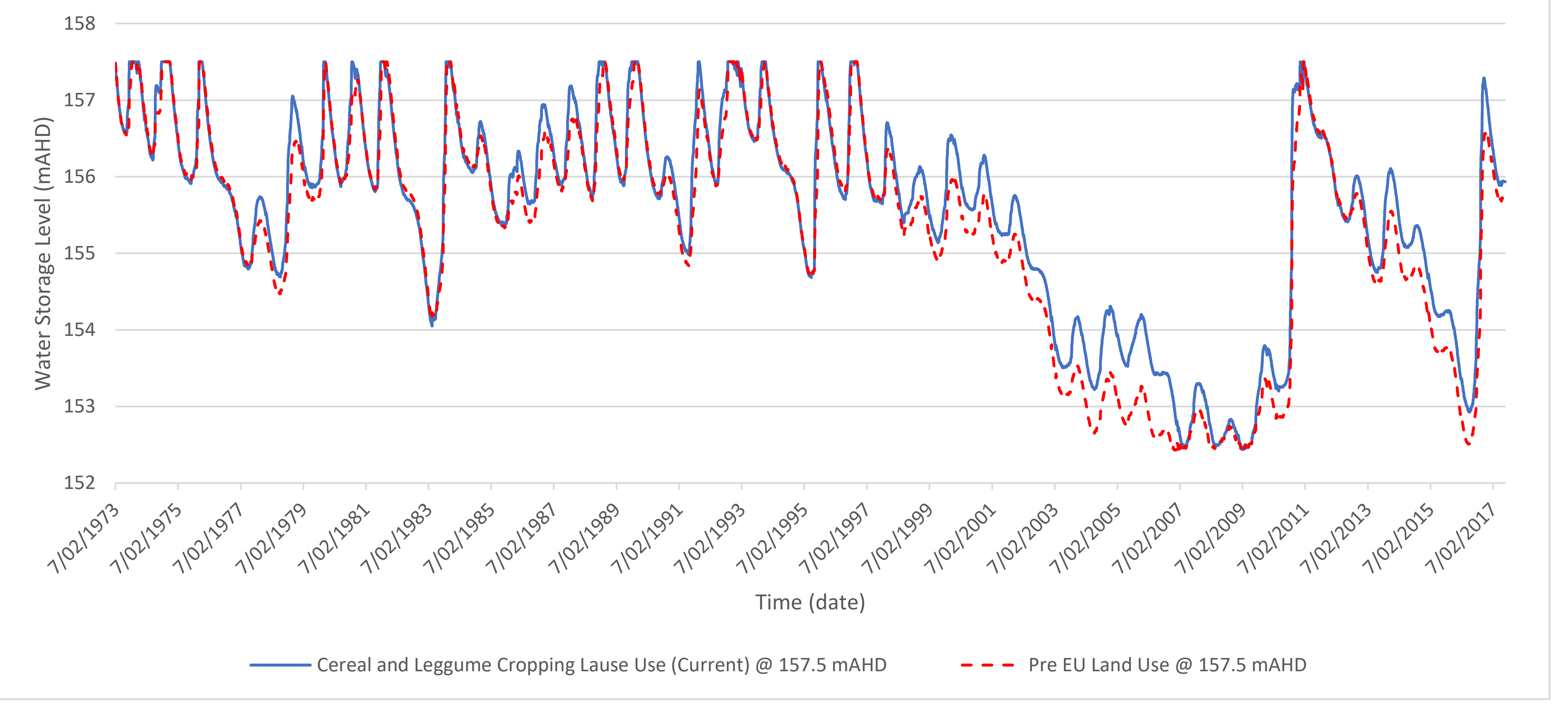


FIGURE 4-25 COMPARISON BETWEEN CURRENT (CEREAL & LEGUMES) AND PRE-EUROPEAN LAND USE IN LAKE WALLACE CATCHMENT

4.5 Lake Natimuk – Catchment area increases

4.5.1 Summary

During this project, members of the Natimuk community highlighted the potential to modify the catchment area contributing to Lake Natimuk through minor drainage changes. The fringes of the Lake Natimuk catchment are very flat with subtle changes to topography or infrastructure (roads/culverts) able to divert water into or out of Lake Natimuk's catchment, this could be caused by sedimentation in a drain or blockage of a culvert. This is especially apparent in the area surrounding Ryans Road and Cook's Lane/Quick Sinclair Russells Road. Changes were proposed in the three separate locations listed below, with corresponding figure references and estimated areas to increase catchment areas:

- Ryans Road, 16.4 km^2- Figure 4-26
- Cook's Lane/Quick Sinclair Russells Road, 6.8 km^2 - Figure 4-27
- Three Chain Road, 8.2 km^2 - Figure 4-28

The total maximum area of increase was determined as 25.4 km^2, it should be noted that this is a conservative assessment of the maximum potential area increase.

FIGURE 4-26 RYANS ROAD POTENTIAL CATCHMENT INCREASE

FIGURE 4-27 COOK'S LANE/QUICK SINCLAIR RUSSELLS ROAD POTENTIAL CATCHMENT INCREASE

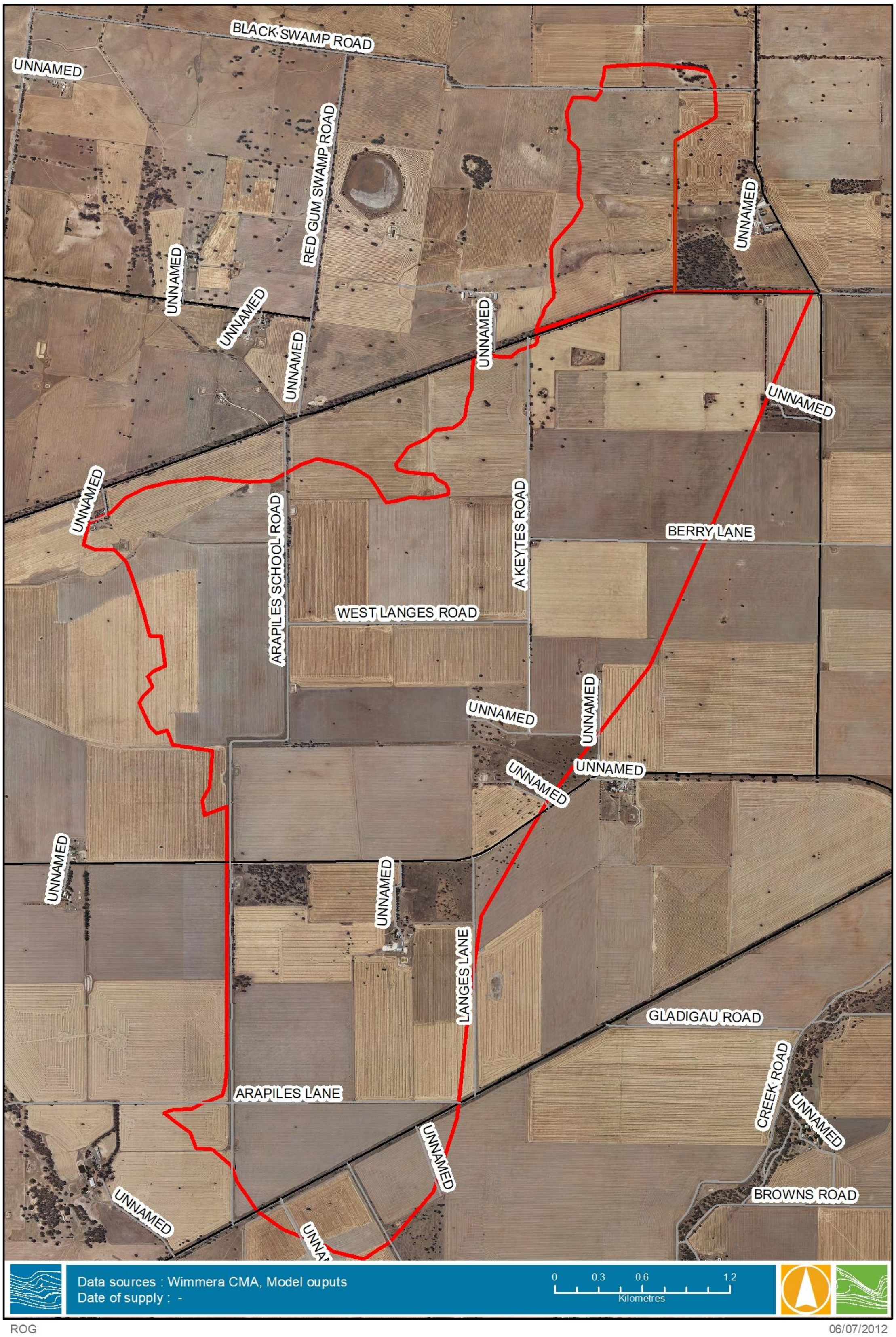


FIGURE 4-28 THREE CHAIN ROAD POTENTIAL CATCHMENT INCREASE

4.5.2 Modelling

Modelling was completed with all three potential area increases in one 'best case' scenario. A comparison between existing and extended catchment conditions was completed, a water level comparison is shown in Figure 4-29 with a closer perspective of the 2000-2017 period shown in

Figure 4-30. The model results show a general increase in water levels, most of this is at the peak level after each inflow event. On average, the depth in Lake Natimuk is increased by around 0.24 m. The impact on the number of days above various depth thresholds is shown in Table 4-12.

The percentage of time the lake is at a depth expected to be deep enough to allow recreational use has increased by around 9% (assuming around a maximum depth of 2m at its deepest point would meet this criteria, this is not reflective of any gauge heights on gauges surrounding the lake at a maximum depth of 3m).

TABLE 4-12 THE IMPACT OF AN EXTENDED CATCHMENT ON VARIOUS DEPTH THRESHOLDS

Depth threshold (m)	% of time above		
	Existing Conditions	**Extended catchment area**	**Change**
4	4%	5%	1%
3	19%	25%	6%
2	47%	56%	9%
1	76%	82%	7%

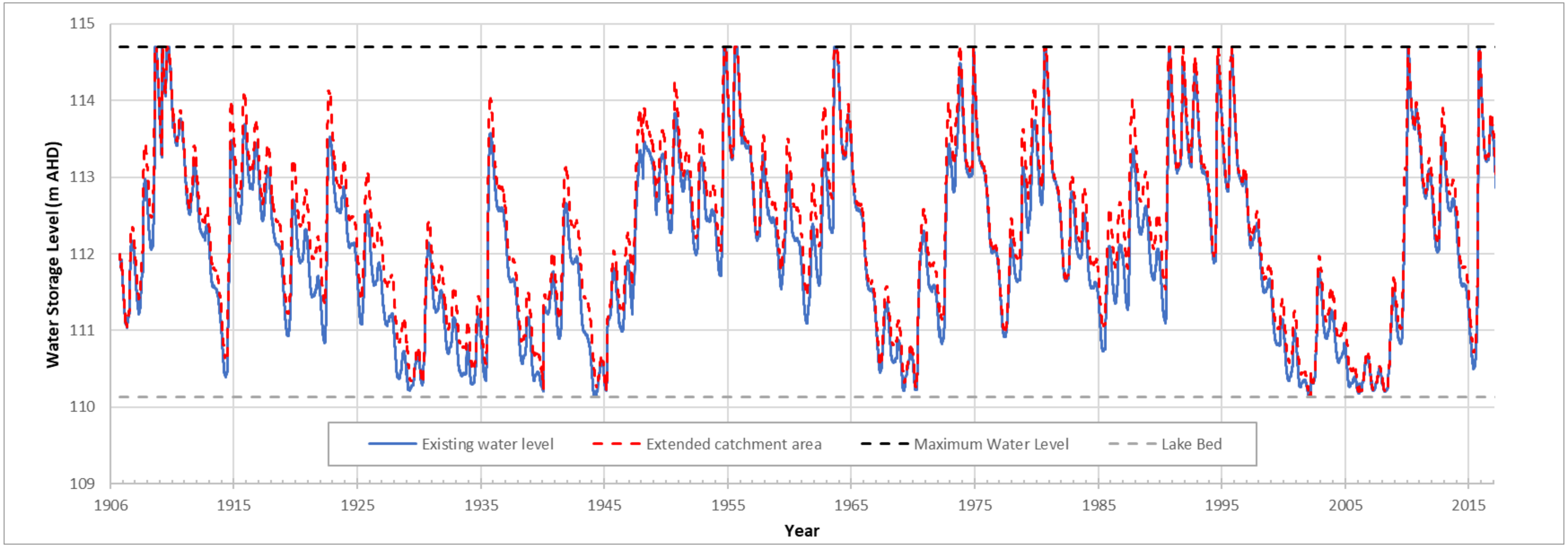


FIGURE 4-29 EXISTING AND EXTENDED CATCHMENT MODEL RESULTS

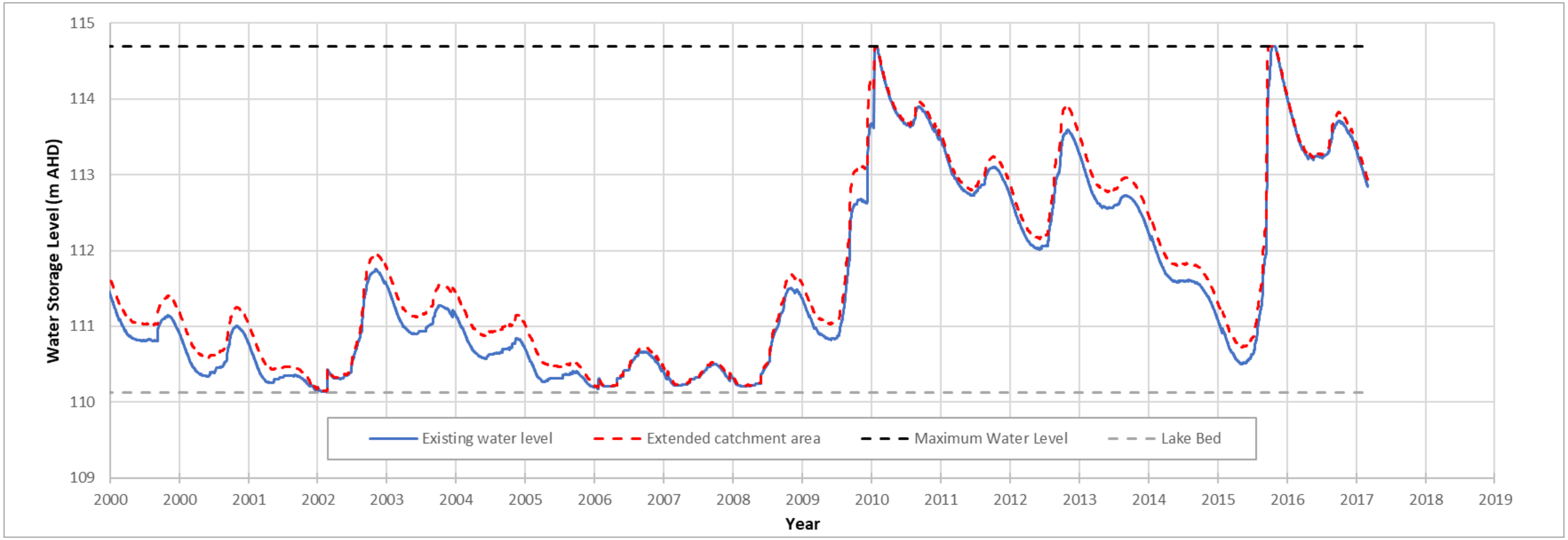


FIGURE 4-30 EXISTING AND EXTENDED CATCHMENT MODEL RESULTS – 2010-2017

5 DISCUSSION

The modelling completed in this project has demonstrated the potential impact of climate change on Lake Natimuk, St Mary's Lake and Lake Wallace. In general, decreased water levels are expected but the uncertainty around what the climate will be also leaves a large level of uncertainty in the impacts. This is particularly the case as high intensity rainfall events are set to increase while average rainfall totals are set to decrease. This may change the way the wetlands are most likely to receive water, moving from a scenario where they receive water during wet winter/springs to the main source of water coming from single high rainfall events.

The change from traditional 'set stocked' livestock management to more modern cereal and legume cropping has also decreased runoff and inflows to the wetlands. Continual improvements to soil moisture retention techniques will likely increase this impact.

Determining whether land use change or reduced rainfall totals is the main contributor to reduced levels in the wetlands is difficult due to the inherent link between them. As rainfall has reduced, agricultural practices have improved to retain soil moisture out of necessity, this is expected to continue.

The continuing reduction in water levels and inflow frequency in Lake Natimuk, St Marys Lake and Lake Wallace has the potential to change their values, with a reduction in recreational use and tourism potential. This reduction is already being felt in Natimuk with reductions in tourists visiting Lake Natimuk. Modelling also showed that the wetlands will continue to periodically receive reasonable inflow volumes and hold modest water levels in the wetlands, but that on average the levels will be lower than in the past. Modelling of pre-European catchment conditions showed similar decreases to wetland inflows and water levels to that determined in the Mean RCP 4.5 climate change scenario. Although the impact of land use and climate change was not modelled in a single combined scenario, it is clear continued agricultural improvements to retain soil moisture and reductions in rainfall occurring concurrently will result in exacerbated impacts on wetland levels and should be investigated further in future assessment.

Despite lower inflows during pre-European times, the wetlands still functioned as valuable habitat for wetland/terrestrial flora and fauna. This indicates under the future reduced inflow scenario created by climate and land use change; the wetlands will remain as valuable habitat. The community and government agencies will need to adjust their expectations of inflows to each wetland and prepare their response to generally lower water levels. Options to increase inflows to the wetlands could be considered such as modifying catchment areas (as reviewed for Lake Natimuk in Section 4.5).

Of the three wetlands, Lake Natimuk is likely at most risk of changed hydrologic regime due to climate change and improved agricultural soil moisture retention techniques. This is due to the very high proportion of the catchment which is agricultural and the relatively high surface area of Lake Natimuk, making it more susceptible to increases in evaporation. The size of the impact at Lake Natimuk is followed by St Marys Lake and Lake Wallace. Lake Wallace has a degree of protection given its connection to groundwater. However, this assumes groundwater levels and interaction is unchanged across the modelled scenarios. The changing climate and land use are likely to impact groundwater supply; the extent of this impact is unknown.

6 RECOMMENDATIONS

Based on the modelling undertaken and results generated during this project, the following recommendations are made:

- Further communication with Perennial Pasture Systems and Victorian No-Till Farming Association be used to better understand the reduction in runoff caused by a shift from grazing to cereal cropping and improvements to cereal cropping. Field trials and the modelling undertaken during this project could help predict changes to wetland systems across the Wimmera CMA management region.
- Determine the potential economic gains that could be achieved by the maximum average potential increases to Lake Natimuk level and cost the proposed Lake Natimuk catchment increases in order to complete a cost benefit analysis to determine the financial viability of the proposed works.
- Make the general community aware that it is highly likely that the IPCC climate change predictions, continued land use change and their combination will cause a reduction in average water levels across all three lakes assessed in this investigation and in Wimmera wetlands in general. The extent of this impact is not certain but reduced wetland levels is the most likely scenario.
- If there is a strong community desire to offset the reductions in volumes entering Lake Natimuk and Lake Wallace then the potential for supplementary water delivery to Lake Natimuk and Lake Wallace be could be considered from appropriate entitlements. Consideration of the cost of delivery, economic, social and environmental benefits will be required.
- The creation of new dams or augmentation of current dams, particularly large dams, within wetland catchments should be considered carefully by agencies. The cumulative impact of dams will further reduce inflows to already stressed wetlands. Improved state policy around farm dam development is recommended to better manage the impact of dam creation on receiving waterways and downstream agricultural use.

APPENDIX A
CLIMATE CHANGE MIN AND MAX MODEL RESULTS

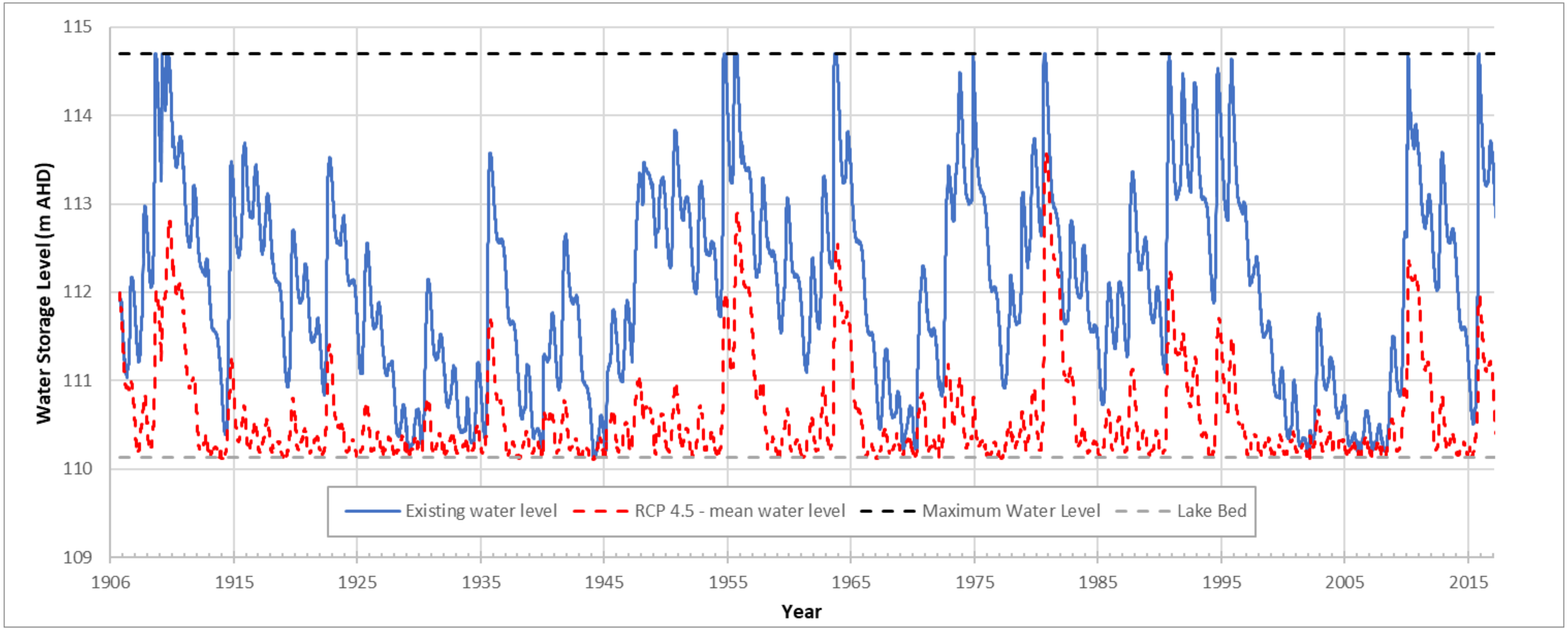


FIGURE 6-1 MIN RCP 4.5 FOR LAKE NATIMUK

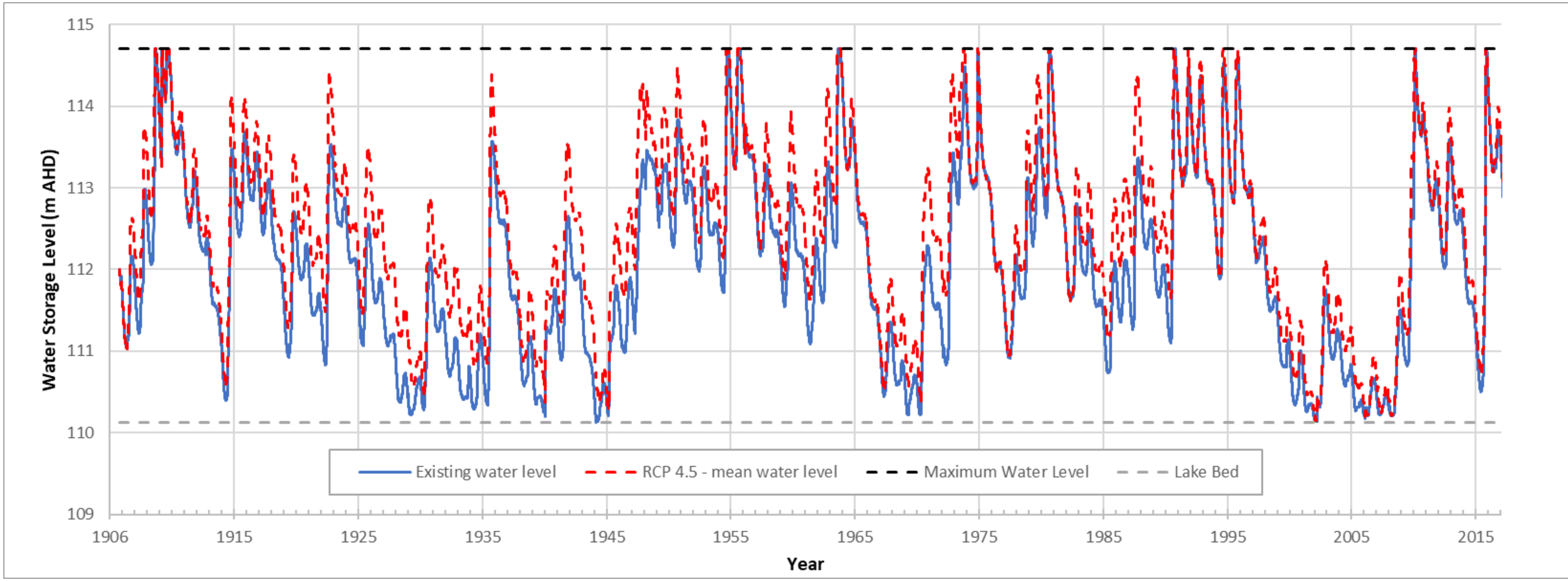


FIGURE 6-2 MAX RCP 4.5 FOR LAKE NATIMUK

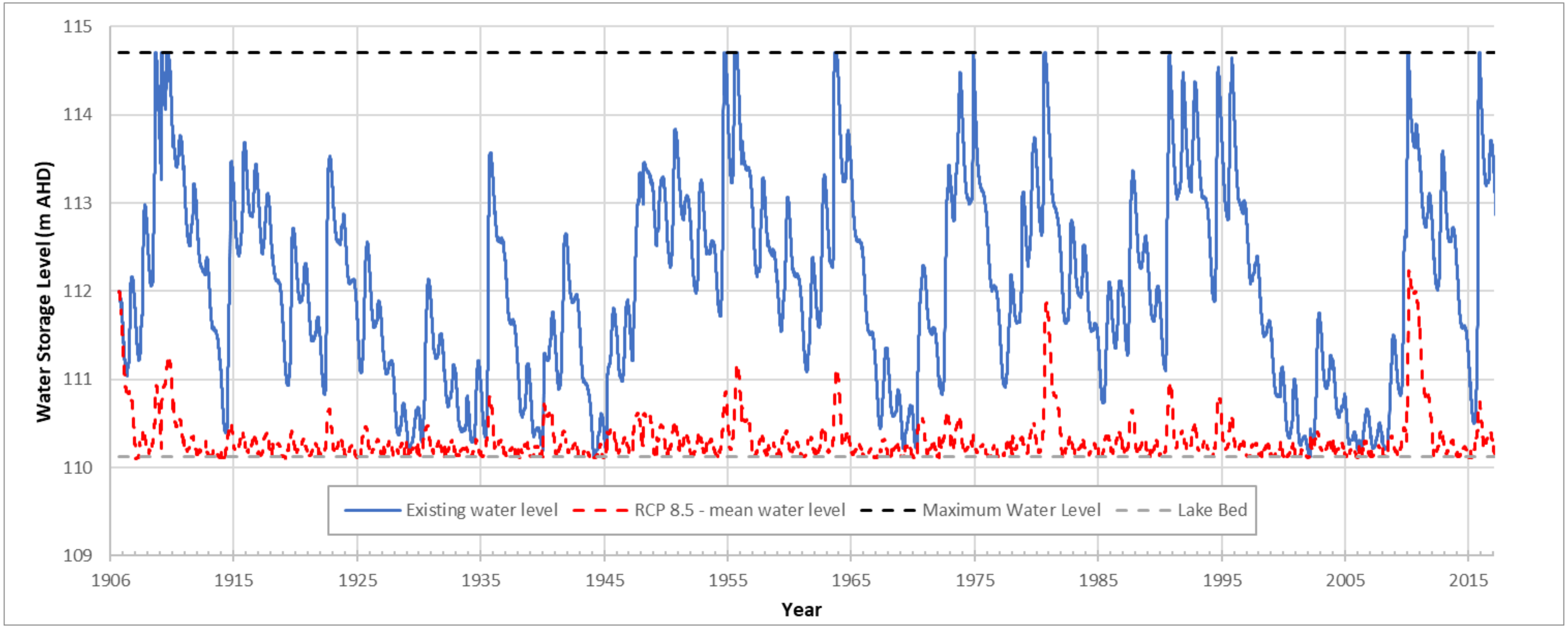


FIGURE 6-3 MIN RCP 8.5 FOR LAKE NATIMUK

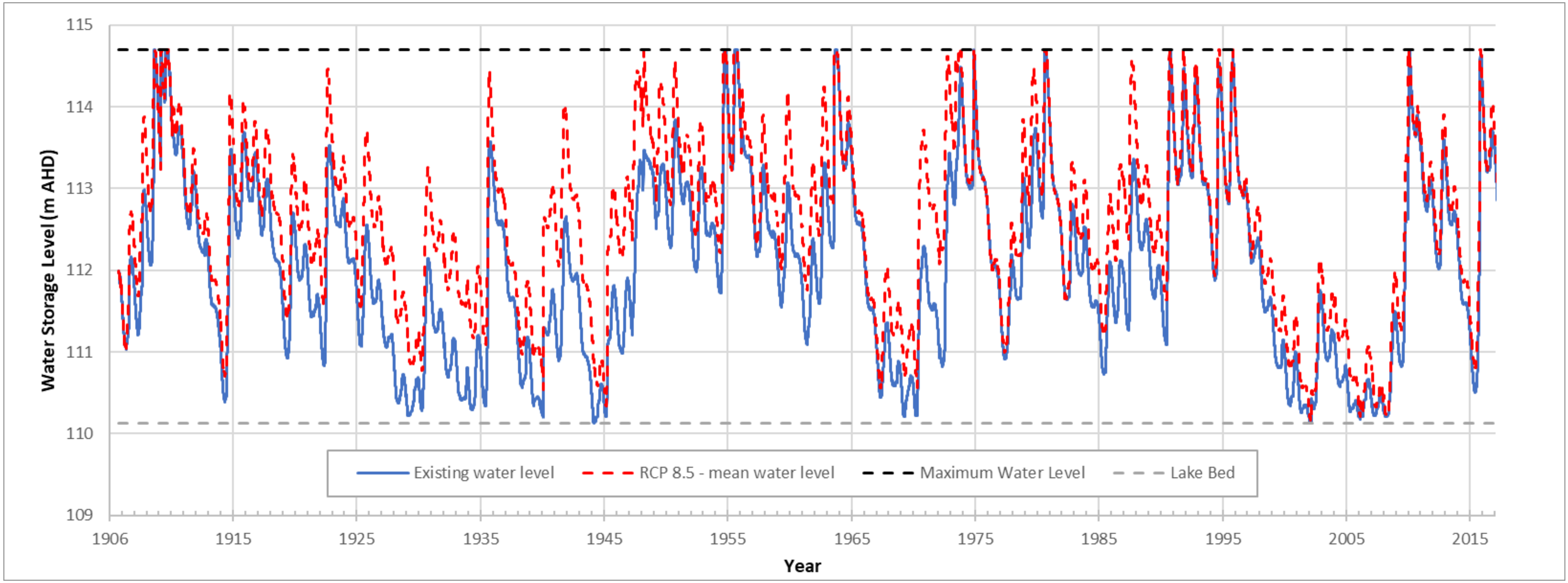


FIGURE 6-4 MAX RCP 8.5 FOR LAKE NATIMUK

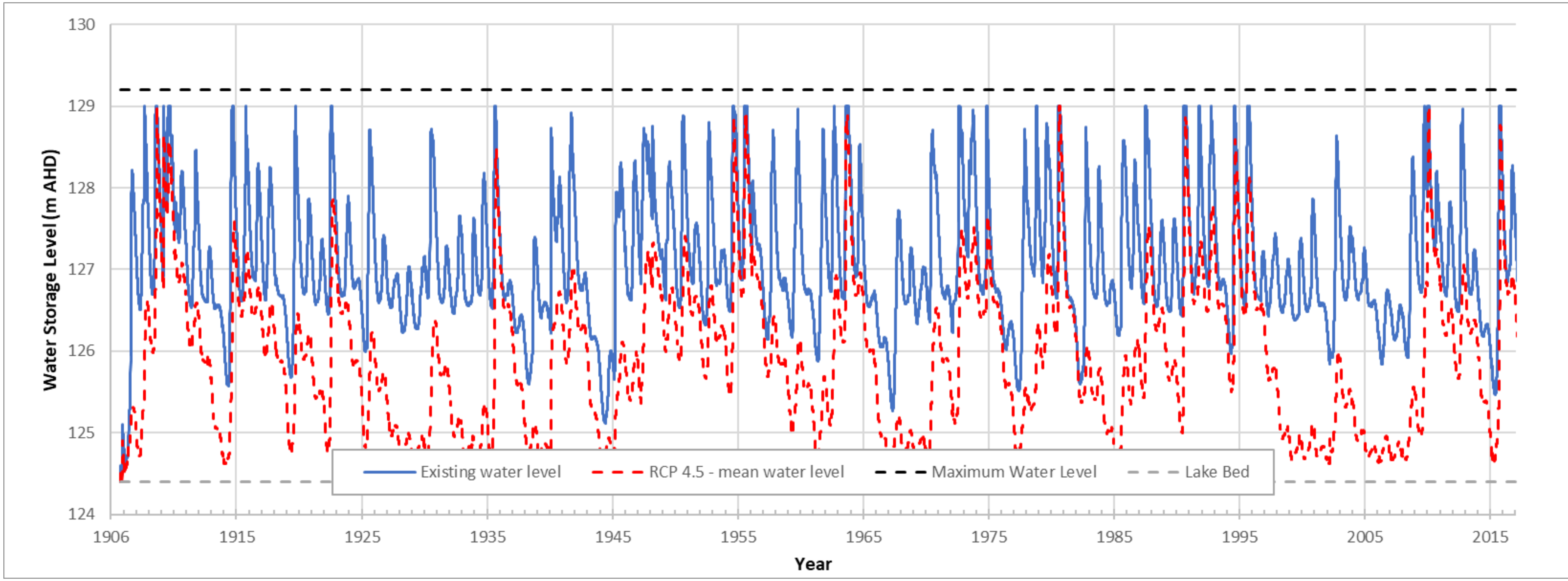


FIGURE 6-5 MIN RCP 4.5 FOR ST MARYS LAKE

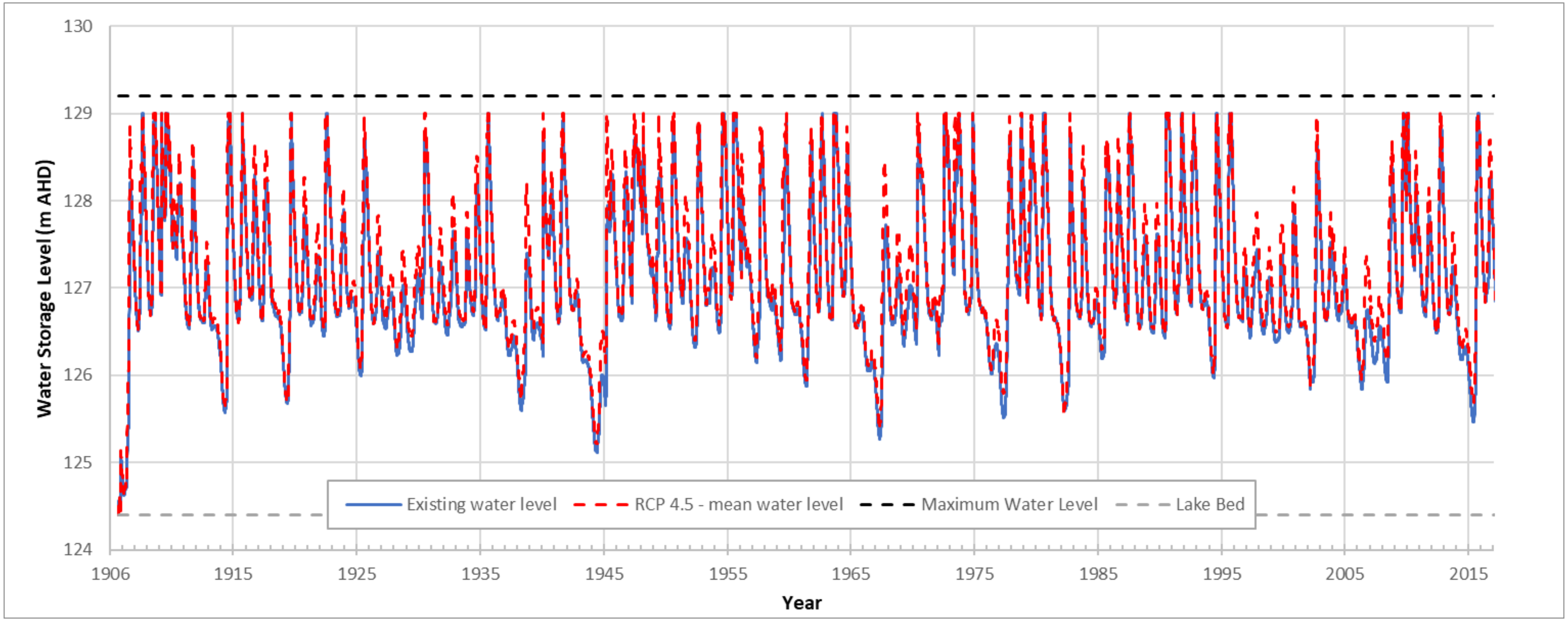


FIGURE 6-6 MAX RCP 4.5 FOR ST MARYS LAKE

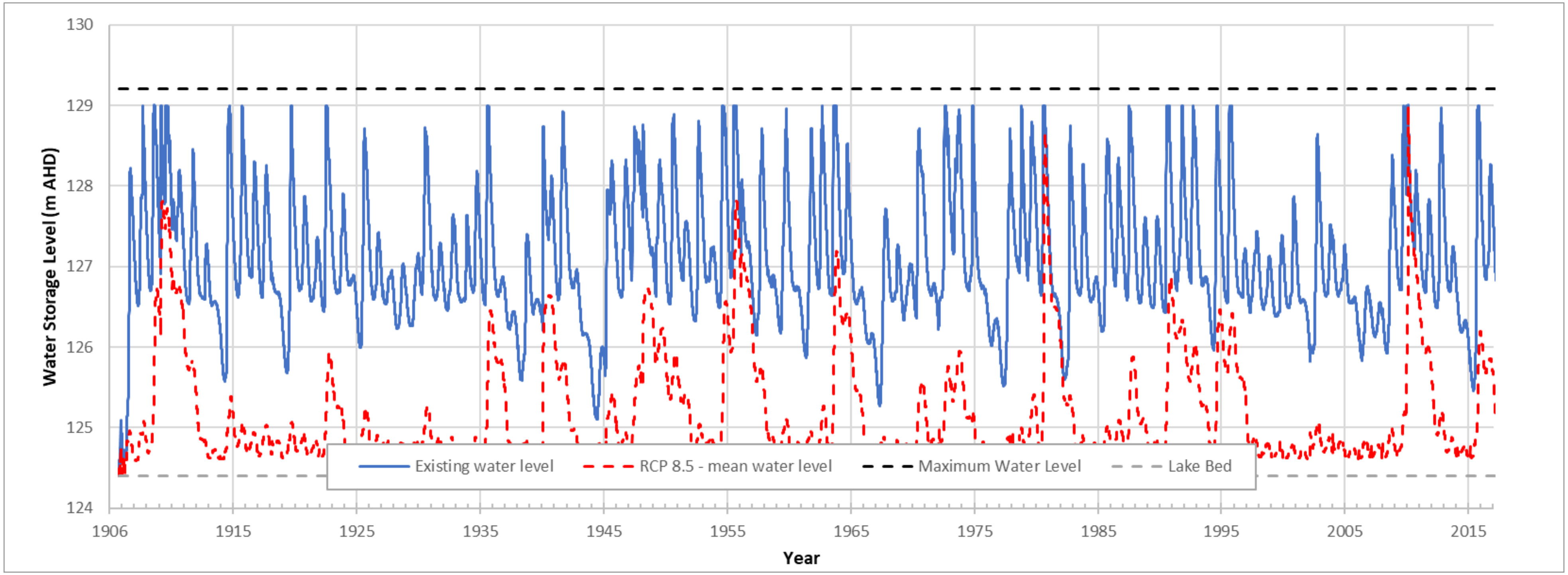


FIGURE 6-7 MIN RCP 8.5 FOR ST MARYS LAKE

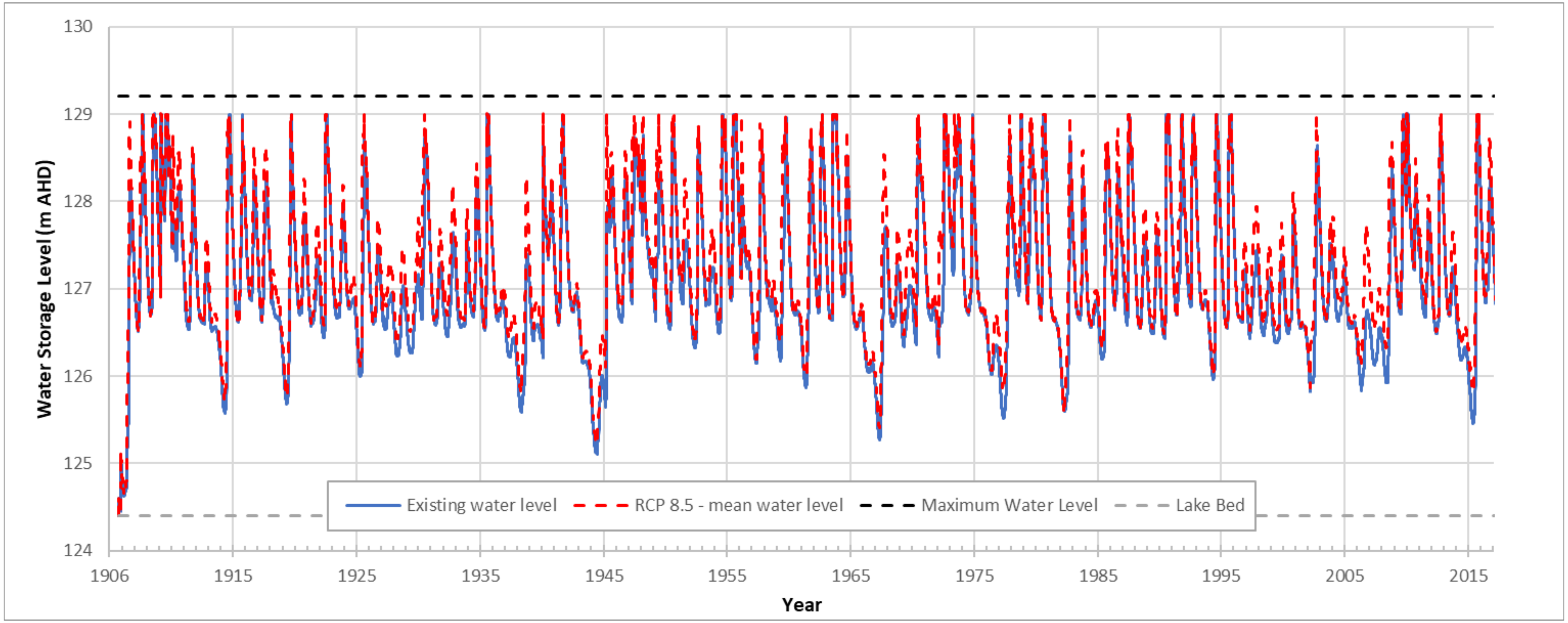


FIGURE 6-8 MAX RCP 8.5 FOR ST MARYS LAKE

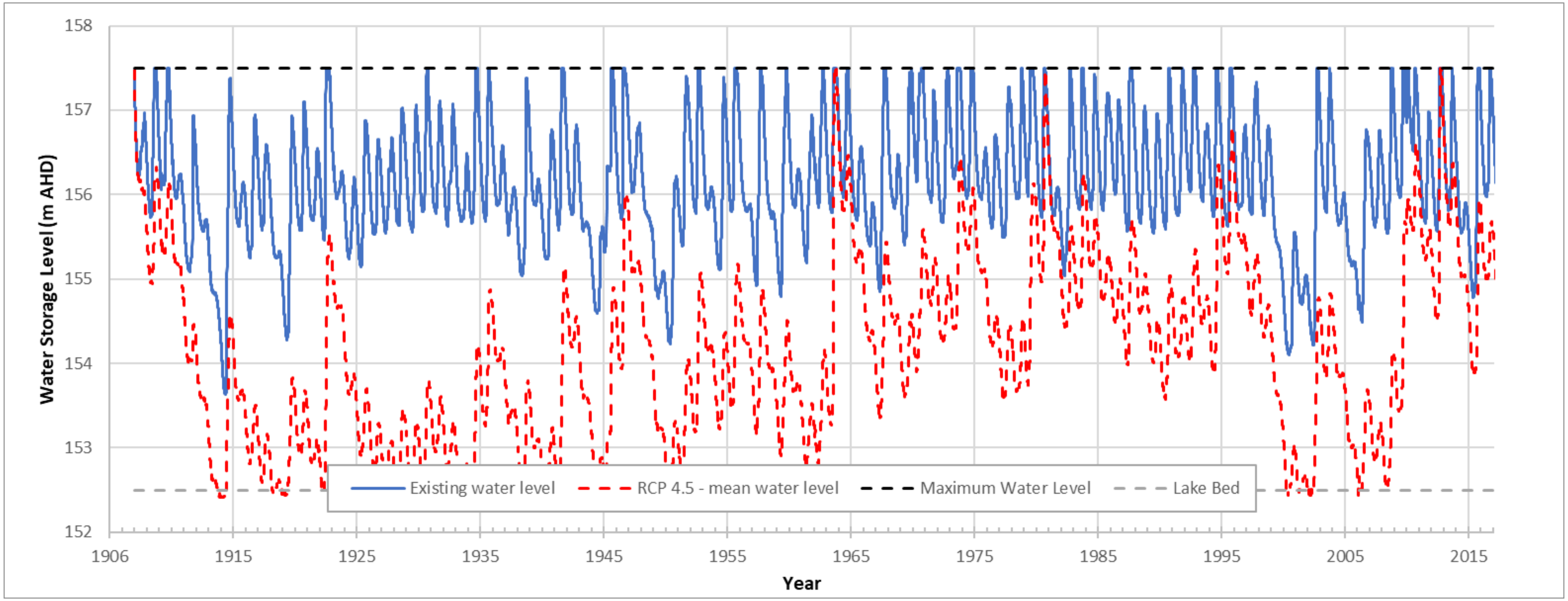


FIGURE 6-9 MIN RCP 4.5 FOR LAKE WALLACE

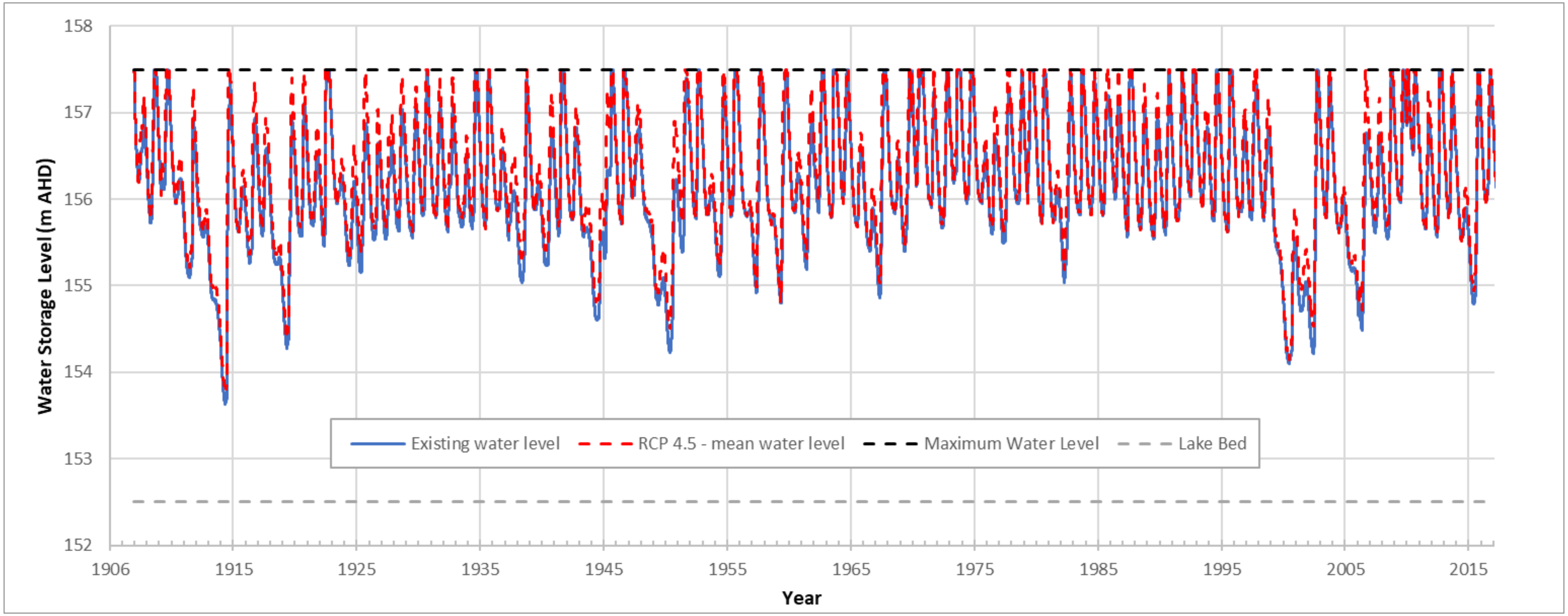


FIGURE 6-10 MAX RCP 4.5 FOR LAKE WALLACE

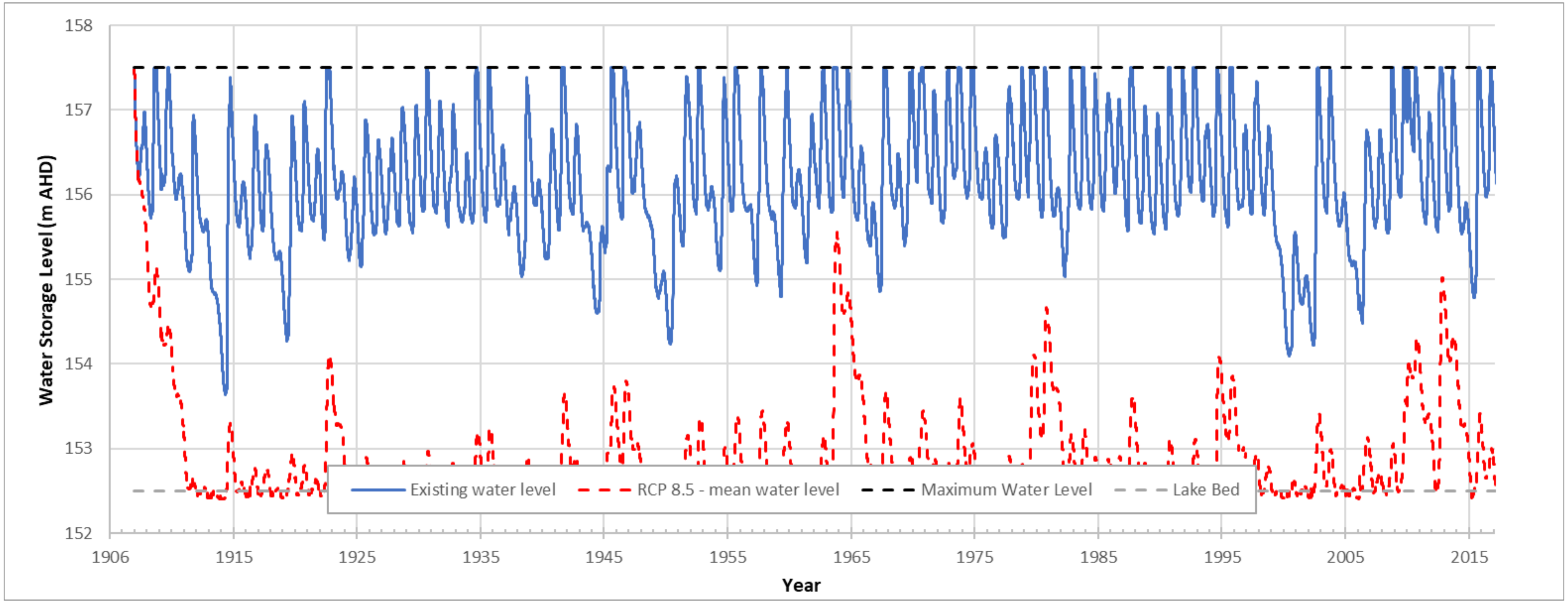


FIGURE 6-11 MIN RCP 8.5 FOR LAKE WALLACE

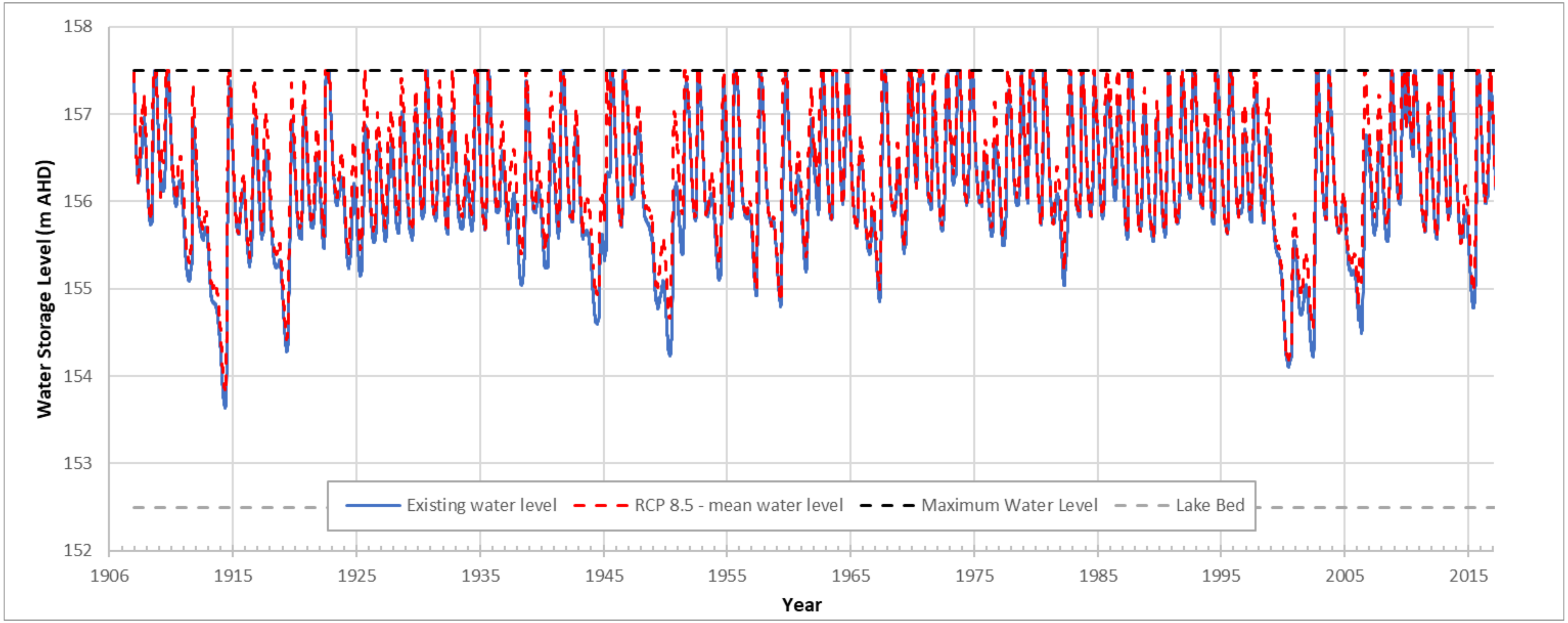


FIGURE 6-12 MAX RCP 8.5 FOR LAKE WALLACE

APPENDIX B LAKE NATIMUK WEIR MODIFICATION, ECOLOGICAL IMPACT REPORT

Provided as an attachment

APPENDIX C
CATCHMENT PLANNING OVERLAYS AND ZONES

Within each catchment there are several planning zones and overlays such as Public Conservation and Resource Zone (PCRZ), Farming Zone (FZ) and Environmental Significance Overlay – Schedule 2 (ESO2) relevant to both the Horsham Rural City Council and West Wimmera Shire Council Planning Schemes, and a Land Subject to Inundation Overlay (LSIO) particularly in the Horsham Rural City Council[3]. The overlays and zones are shown in Figure 6-13, Figure 6-14, Figure 6-15 and Figure 6-16, Figure 6-17 and Figure 6-18 respectively. Flood related overlays are associated with St Mary's Lake only Figure 2-3.

The land tenure of each lake differs depending on the overall use of each system, all are located on Crown Land and therefore are under governmental control; however, Lake Wallace and its management is delegated to a committee from GWMWater, due to its previous role as a water supply storage. St Mary's Lake and Lake Natimuk are managed by Parks Victoria under the Crown Land Reserve Act.

The wetlands are in an area of undulating farmland. The area is scattered with patches of high environmental value, such as the wetlands subject to this investigation which also have high cultural significance. Edenhope and Natimuk also benefit from Lake Wallace and Lake Natimuk for the tourism they provide to the townships with both lakes having caravan parks located on their shores. The importance of the lakes to the towns was a very strong point raised by the community. In the *Wimmera Southern Mallee: Socio-Economic Value of Recreational and Environmental Water 2017* (Street Ryan, 2017) highlighted that $8.8 million dollars was contributed to the Wimmera Southern Mallee through recreational water use in the 2016-2017 financial year with Lake Wallace generating $840,000 in the 2017-2018 financial year.

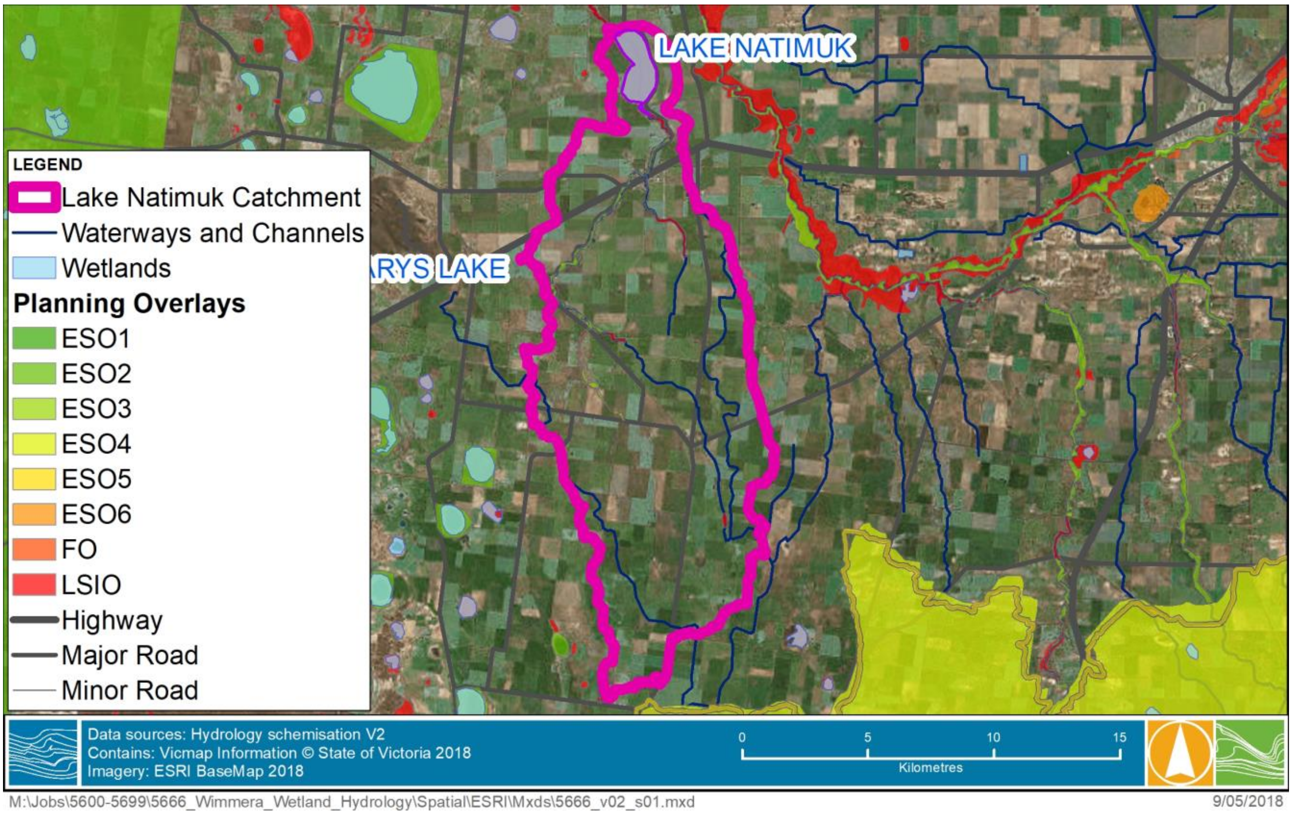


FIGURE 6-13 VICTORIAN PLANNING OVERLAYS FOR LAKE NATIMUK

5666-01_R03V06_Wimmera_Wetlands_Study_Report Final

[3] Victorian Planning Scheme Online

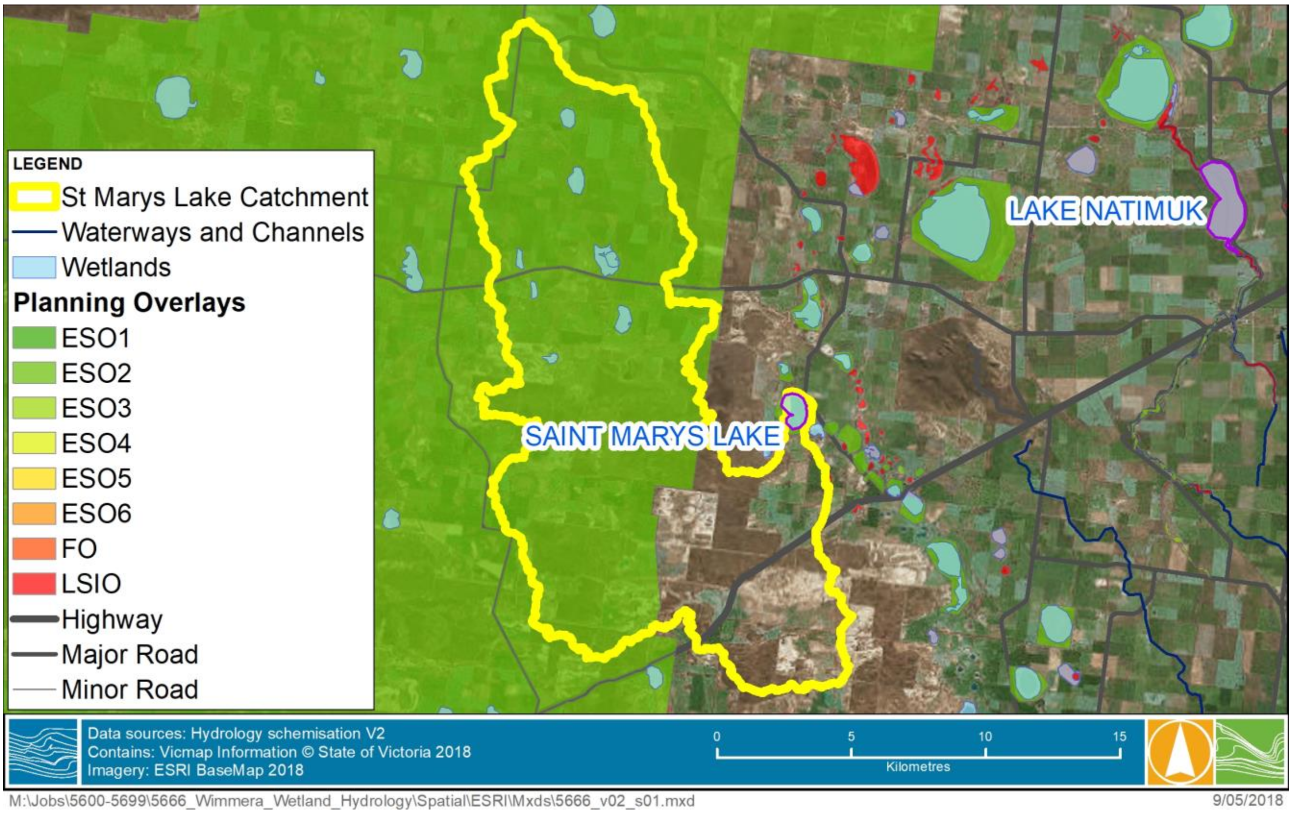


FIGURE 6-14 VICTORIAN PLANNING OVERLAYS FOR ST MARYS LAKE

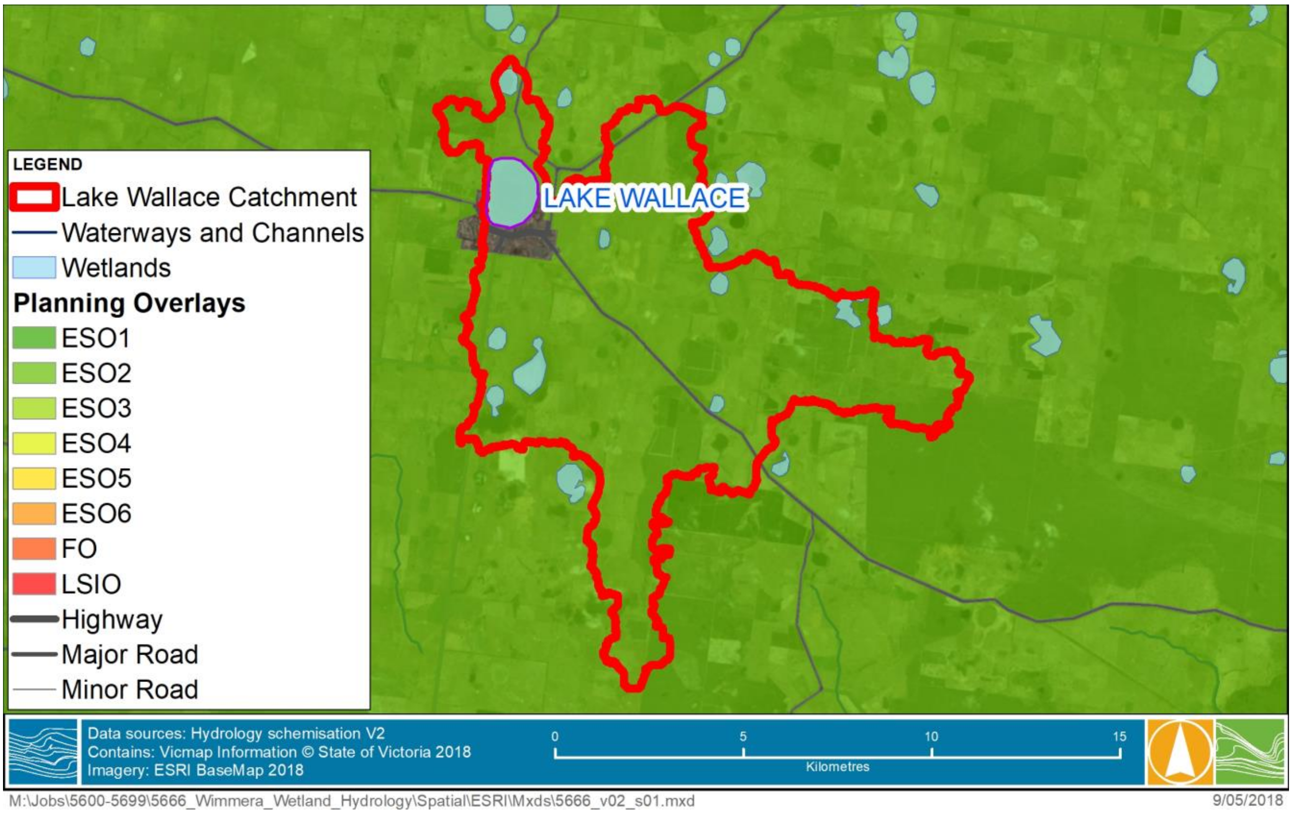


FIGURE 6-15 VICTORIAN PLANNING OVERLAYS FOR LAKE WALLACE

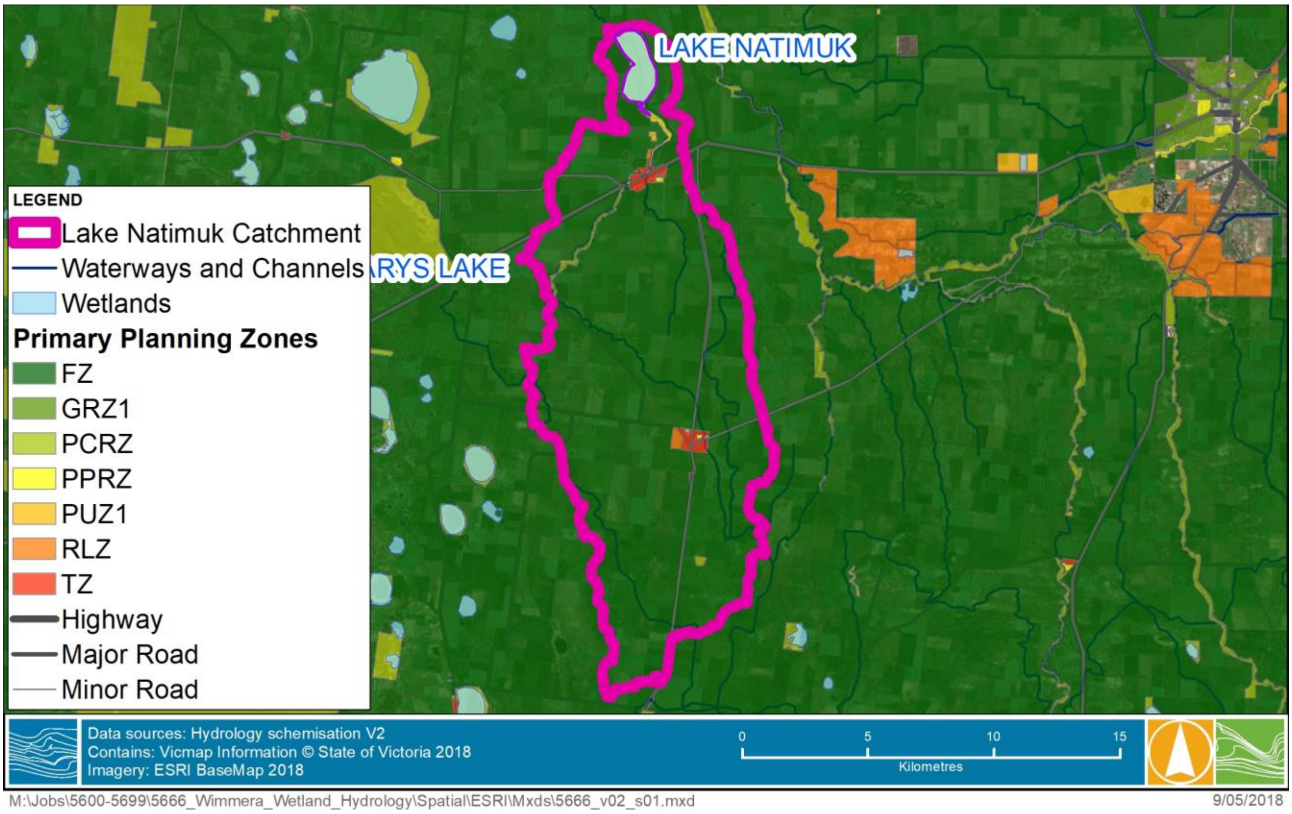


FIGURE 6-16 VICTORIAN PLANNING ZONES FOR LAKE NATIMUK

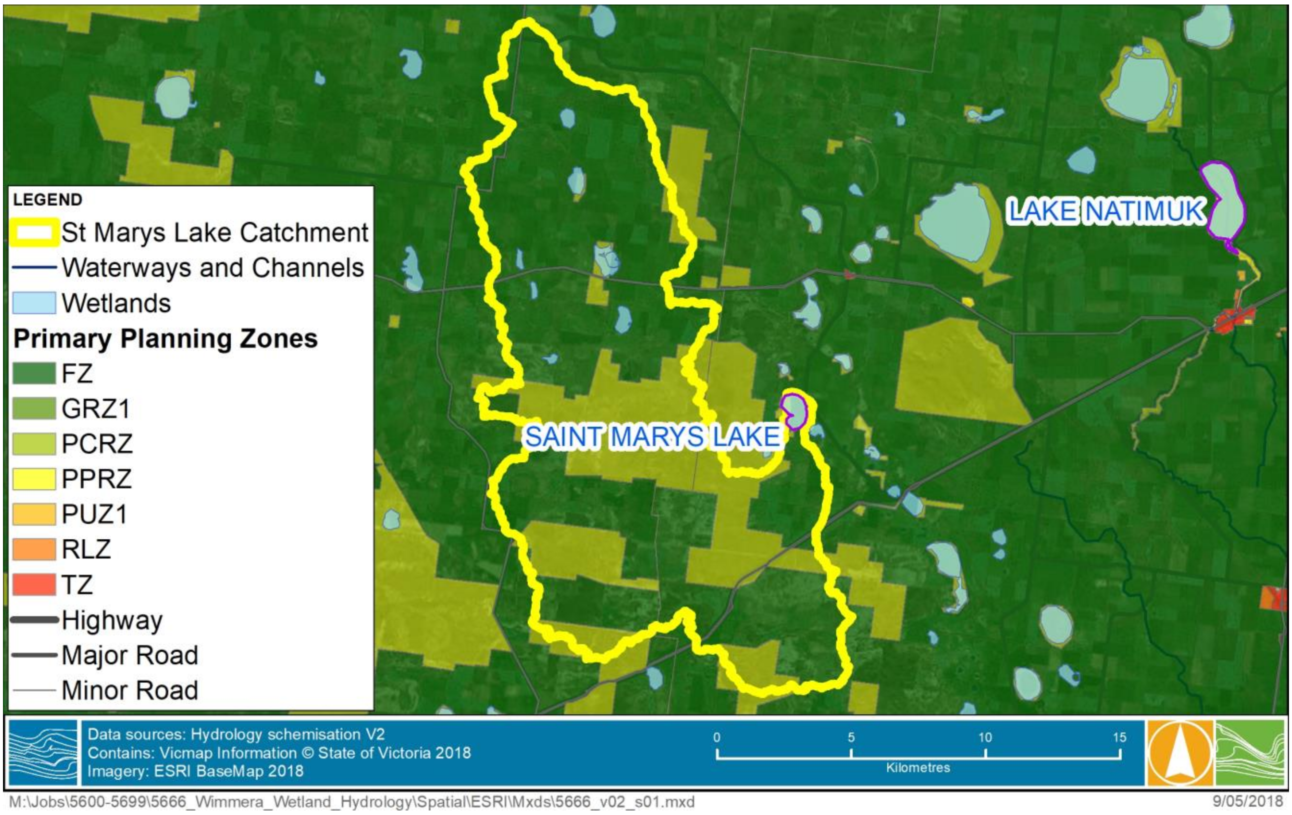


FIGURE 6-17 VICTORIAN PLANNING ZONES FOR ST MARYS LAKE

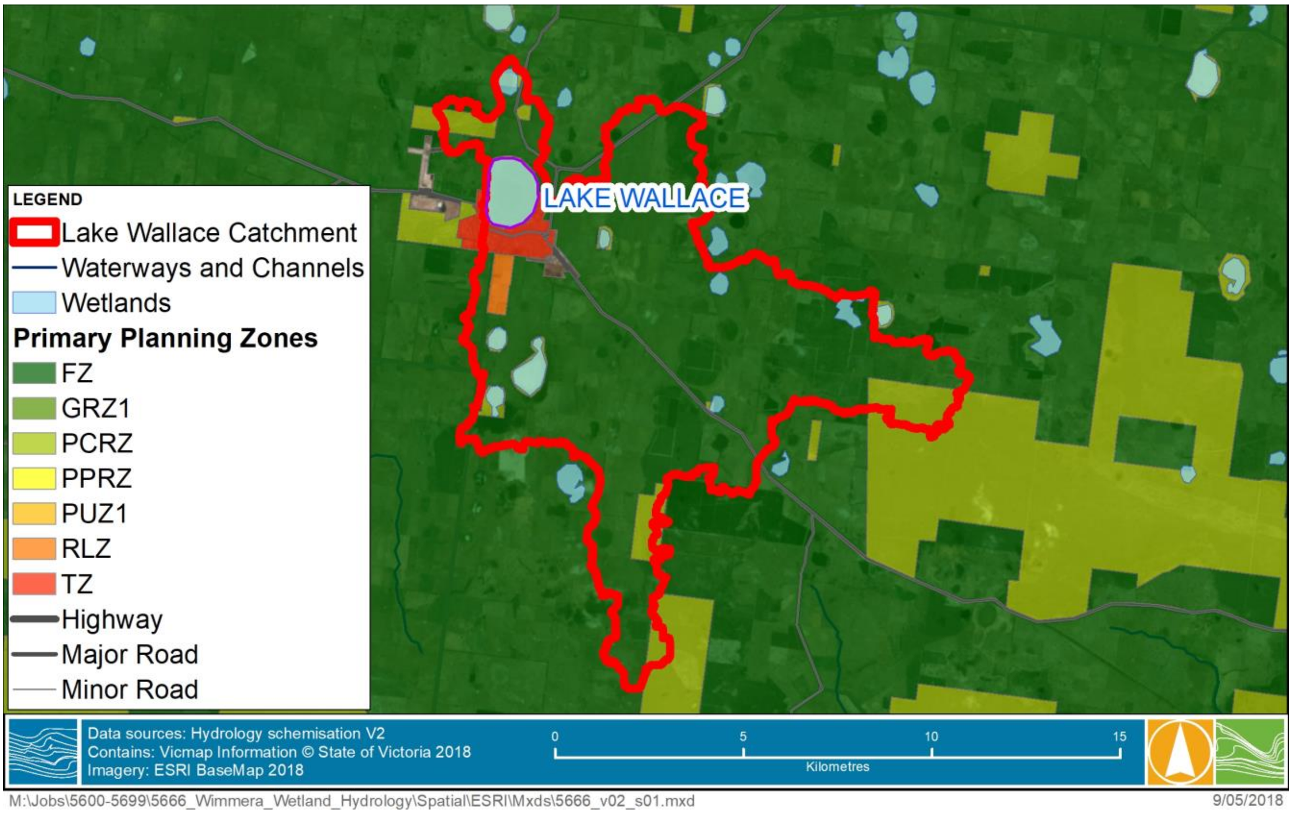


FIGURE 6-18 VICTORIAN PLANNING ZONES FOR LAKE WALLACE

APPENDIX D
CATCHMENT PLANNING OVERLAYS AND ZONES

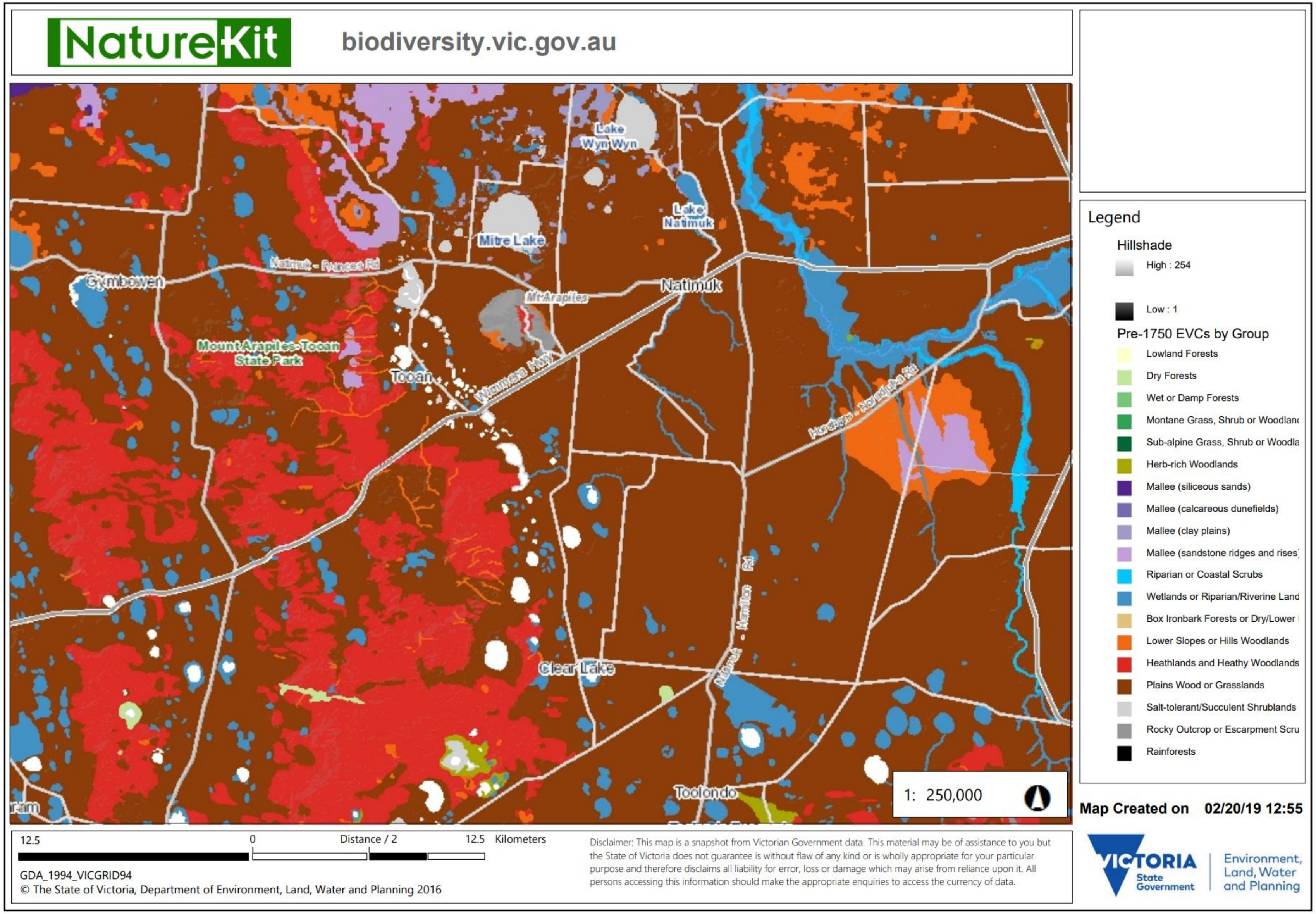


FIGURE 6-19 NATUREKIT SPECIFIC BIOREGIONS – ST MARYS LAKE AND LAKE NATIMUK

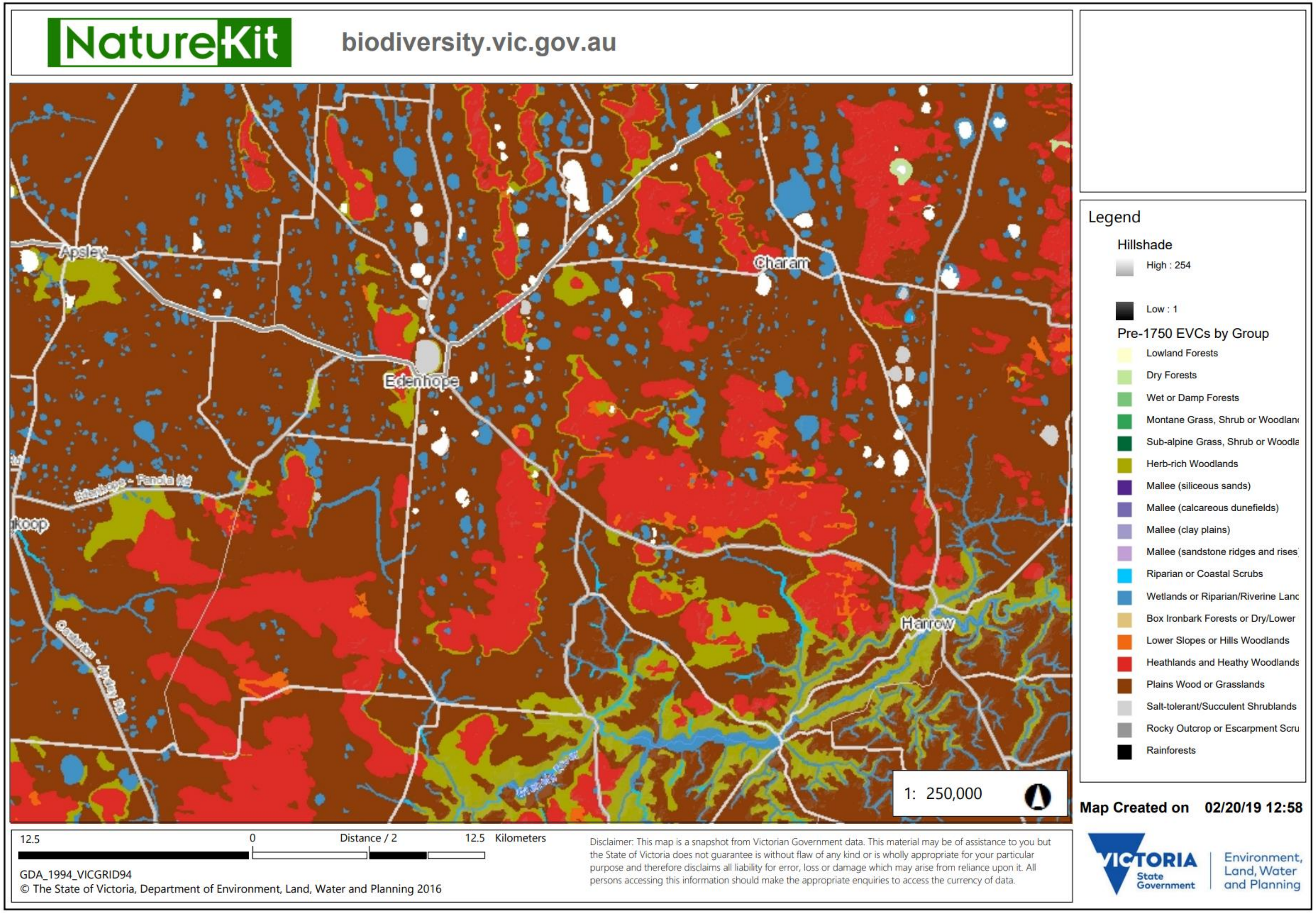


FIGURE 6-20 NATUREKIT SPECIFIC BIOREGIONS – LAKE WALLACE

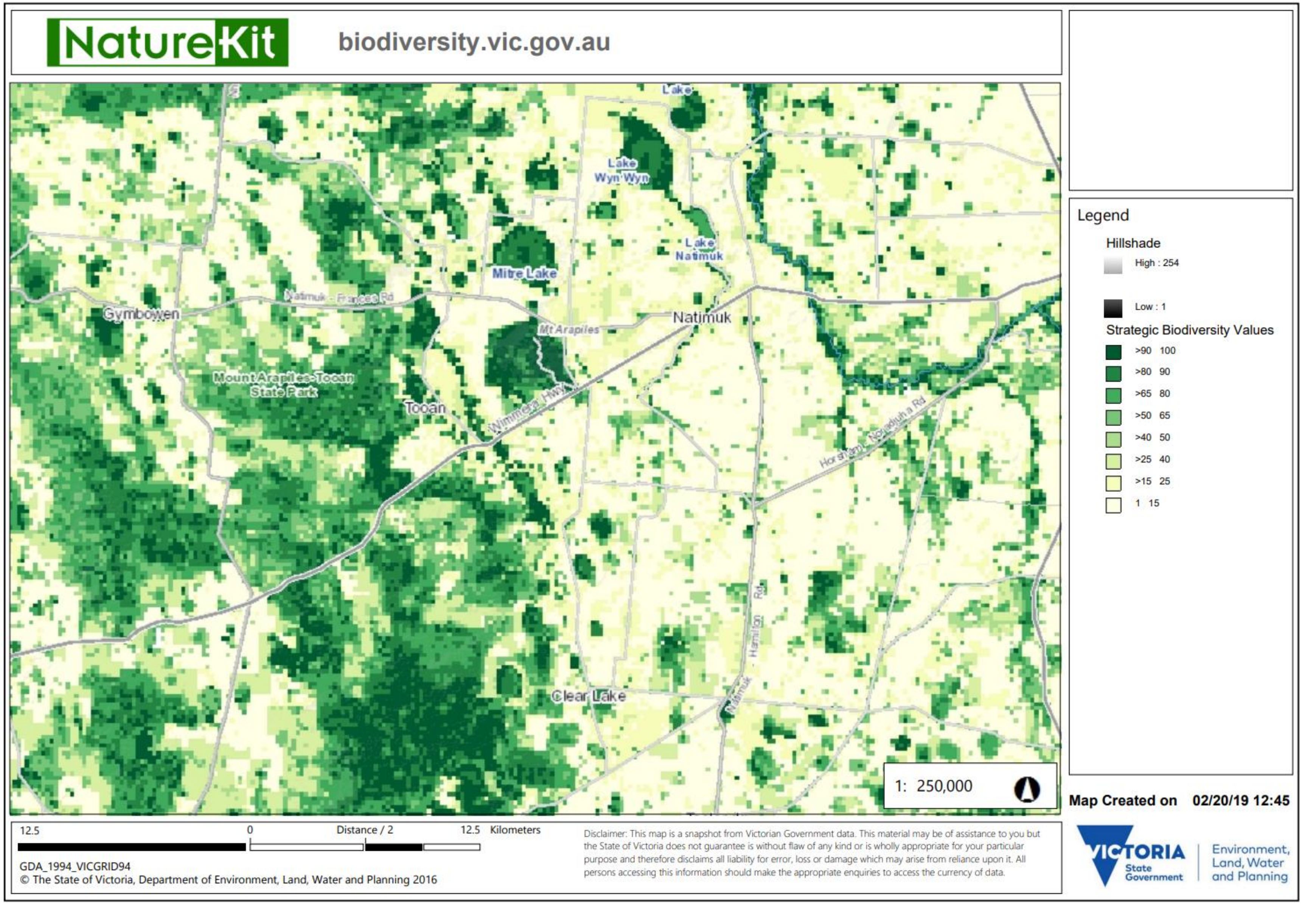


FIGURE 6-21 NATUREKIT ECOLOGICAL NICHE SITES – ST MARYS LAKE AND LAKE NATIMUK

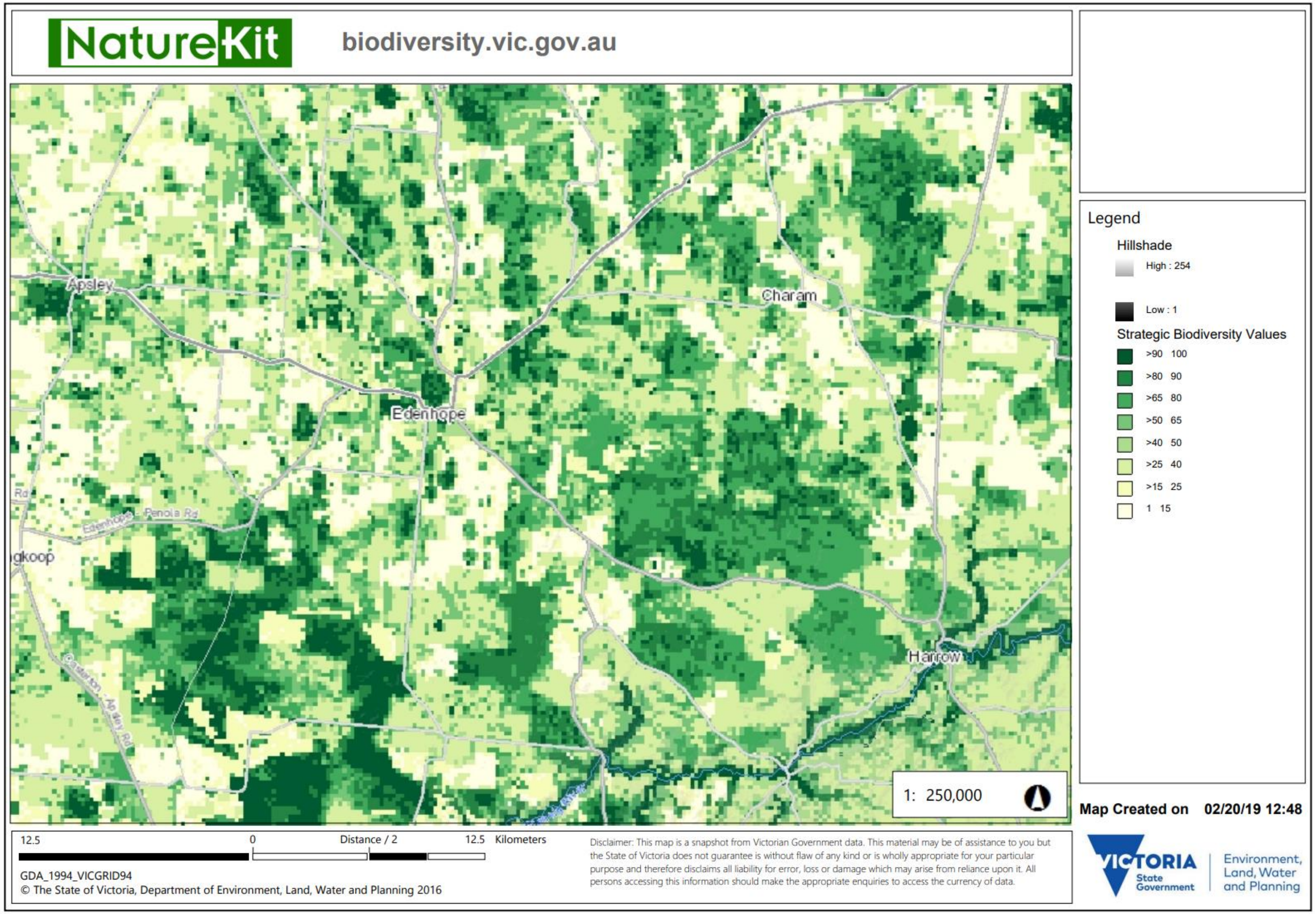


FIGURE 6-22 NATUREKIT ECOLOGICAL NICHE SITES – LAKE WALLACE

Melbourne

15 Business Park Drive
Notting Hill VIC 3168
Telephone (03) 8526 0800
Fax (03) 9558 9365

Brisbane

Level 3, 43 Peel Street
South Brisbane QLD 410:
Telephone (07) 3105 14ᴗᴗ
Fax (07) 3846 5144

Adelaide

1/198 Greenhill Road
Eastwood SA 5063
Telephone (08) 8378 8000
Fax (08) 8357 8988

Perth

Ground Floor
430 Roberts Road
Subiaco WA 6008
Telephone 0438 347 968

Geelong

PO Box 436
Geelong VIC 3220
Telephone 0458 015 664

Gippsland

154 Macleod Street
Bairnsdale VIC 3875
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First Floor, 40 Rowan Street
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