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Lake Wyangan Flood Study

Final Report

R.N2038.001.03

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Lake Wyangan
Flood Study
Final Report

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Title :	Lake Wyangan Flood Study – Final Report
Author :	Daniel Williams
Synopsis :	Report for the Lake Wyangan Flood Study covering the development and calibration of computer models, establishment of design flood behaviour and flood mapping.

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EXECUTIVE SUMMARY

Introduction

The Lake Wyangan Flood Study has been prepared for Griffith City Council (Council) to define the existing flood behaviour in the Lake Wyangan catchment and establish the basis for subsequent floodplain risk management activities.

The primary objective of the Flood Study is to define the flood behaviour within Lake Wyangan through the establishment of appropriate numerical models. The study has produced information on flood flows, velocities, levels and extents for a range of flood event magnitudes under existing catchment and floodplain conditions. Specifically, the study incorporates:

- Compilation and review of existing information pertinent to the study and acquisition of additional data including survey as required;
- Undertaking a community consultation and participation program to identify local flooding concerns, collect information on historical flood behaviour and engage the community in the on-going floodplain risk management process;
- Development and calibration of appropriate hydrologic and hydraulic models;
- Determination of design flood conditions for a range of design event including the 20% AEP, 10% AEP, 2% AEP, 1% AEP, 0.5% AEP and extreme flood event;
- Presentation of study methodology, results and findings in a comprehensive report incorporating appropriate flood mapping; and
- Identification of key locations for consideration during the floodplain risk management process.

Catchment Description

The study catchment totals an area of around 825km^2 and incorporates the townships of Lake Wyangan and Nericon and numerous agricultural properties. The catchment is a closed system that drains to a number of storages, including Lake Wyangan, Tharbogang Swamp, Nericon Swamp and Campbells Swamp.

Substantial irrigation supply and drainage infrastructure has modified the natural drainage of the catchment. Historically, the majority of the catchment would have drained to Tharbogang Swamp, whereas now under typical low flow conditions it will drain to Lake Wyangan. In particular, the Lake View Drain and its associated agricultural drainage divert water from the Tharbogang Swamp catchment into Lake Wyangan.

The catchment has been largely cleared for farming purposes (80%, of which around 10% is irrigated agriculture). The other dominant land use is remnant vegetation at around 20%. Approximately 5km^2 of the catchment is open water or swamp and around 3km^2 is used for residential and rural residential purposes (both of which constitute <1% of the total catchment area).

Historical Flooding

There is little documented history of flooding in the catchment, as it is sparsely populated and has a low annual average rainfall of <400mm. Flood photographs provided by Council are only available for events in 1985 and 1989.

The March 1985 event is the largest recorded within the catchment, with a daily rainfall total of 150mm recorded at Griffith Airport. The duration of the event is unknown, given no available continuous rainfall record, but it is likely shorter than 12 hours, representing an event well in excess of a 1%AEP, when considered in relation to the standard intensity-frequency-duration (IFD) relationships for the study area.

The most significant event since lake level records began in 1986 is the March 1989 event. It totalled around 100mm of rainfall at Griffith Airport and caused flooding to farming properties around Lake Wyangan.

Community Consultation

The consultation has aimed to inform the community about the development of the flood study and its likely outcome as a precursor to subsequent floodplain risk management activities. It has provided an opportunity to collect information on their flood experience, in particular historical flood data related to catchment flooding.

Council mailed out a questionnaire to all residents and businesses located within the study area. Council received back 39 responses, of which 18 had comments relating to flooding. The focus of the questionnaire was to gather relevant flood information from the community, including photographs, observed flood depths and descriptions of flood behaviour within the catchment. Three responses included photographs showing flooding and drainage problems and another provided video footage.

Model Development

Development of hydrologic and hydraulic models has been undertaken to simulate flood conditions in the catchment. Hydrologic and hydraulic modelling has been undertaken using the TUFLOW two-dimensional (2D) software developed by BMT WBM and utilising a direct rainfall approach to model the catchment hydrology. The model simulates runoff routing, hydrological response, flood depths, extents and velocities. The 2D modelling approach is suited to model the complex interaction between channels and floodplains and converging and diverging of overland flow paths typical of the study catchment.

The floodplain topography is defined using a high resolution digital elevation model (DEM) derived from LiDAR survey for greater accuracy in predicting flows and water levels and the interaction of in-channel and floodplain areas. The study also included the modelling of the Lake View Branch Canal, Lake View Drain and associated cross-drainage structures, as they have a significant impact on flood propagation in the catchment.

Model Calibration and Validation

The selection of suitable historical events for calibration of computer models is largely dependent on available historical flood information.

The March 1989 event is the only significant flood event for which lake level and continuous rainfall records are available. Accordingly, the calibration process is focussed primarily on this event. The December 2007 event is also considered as it is the only other recent catchment event for which some evidence of catchment flooding is available. The March 1985 event is used for model verification purposes as it is the largest event known to have occurred in the catchment. The model calibration therefore is based on the limited historical data available for the three events.

A reasonable model calibration has been achieved given the available data for the catchment. The developed model is considered to provide a sound representation of the flooding behaviour of the catchment, as demonstrated through comparison of recorded peak water levels and known inundation areas for the historical events simulated.

Design Event Modelling and Output

The developed model has been applied to derive design flood conditions within the study catchment. Design rainfall depth is based on the generation of intensity-frequency-duration (IFD) design rainfall curves utilising the procedures outlined in AR&R (2001). The 18-hour storm duration was adopted for determining the critical conditions for the catchment and a 2-hour storm duration was also modelled to provide a critical condition for the local sub-catchments. Initial rainfall losses of 15mm, 35mm and 60mm were considered and the results for each value are compared.

The design events considered in this study include the 20% AEP (approx. 5-year ARI), 10% AEP (10-year ARI), 5% AEP (20-year ARI), 2% AEP (50-year ARI), 1% AEP (100-year ARI), 0.5% AEP (200-year ARI) and PMF events. The model results for the design events considered have been presented in a detailed flood mapping series for the study area. The flood data presented includes design flood inundation, peak flood depths and peak flood velocities.

Provisional flood hazard categorisation in accordance with Figure L2 of the NSW Floodplain Development Manual (2005) has been mapped for the 1% AEP event, in addition to the hydraulic categories (floodway, flood fringe and flood storage) for flood affected areas.

Model Uncertainties and Limitations

The model results are highly sensitive to the adopted rainfall loss conditions. Other sensitivity tests typically undertaken in flood studies, such as changing the adopted roughness parameters, would have minimal impact on the modelled flood levels in Lake Wyangan and Tharbogang Swamp, given it is a volume controlled system.

In addition to the uncertainty surrounding the initial loss parameter, there are a number of other model uncertainties or limitations which are discussed, including the representation of the Lake View Branch Canal, Lake View Drain and additional local drainage infrastructure. Some of the uncertainties and limitations of the modelling have been considered when recommending the design flood levels to be adopted for Lake Wyangan.

Conclusions

The objective of the study was to undertake a detailed flood study of the Lake Wyangan catchment and establish models as necessary for design flood level prediction.

Through the undertaking of the flood study it has been found that during flood events the majority of the catchment runoff flows to Tharbogang Swamp rather than Lake Wyangan, as had previously been assumed. Historically there has been little response of Lake Wyangan water levels to rainfall events within the catchment, with only the March 1989 event producing a significant response. The limited response in Lake Wyangan is due to a number of factors:

- It has a relatively small catchment area of around 100km^2, including diverted catchment runoff through the Lake View Drain (Lake Wyangan's natural catchment is around 75km^2);
- The calibration process found the catchment to indicate a high initial rainfall loss for the events considered. A large amount of rainfall (>60mm) is required before any catchment runoff is generated and a response in the lake can be observed; and
- A proportion of the catchment runoff volume is retained in temporary flood storages in the catchment, rather than further contributing to the flood storage in the lake.

Being a volume-driven closed-catchment system with no natural outlet, flood levels in Lake Wyangan and Tharbogang Swamp are directly related to the catchment runoff volume generated by any given flood event. The high rainfall losses generate relatively small effective rainfall depths and the flood levels are therefore highly sensitive to changes in the adopted initial loss value. The calibration process found an initial loss value of around 60mm to be appropriate for the events considered. However, due to the characteristics of the available design rainfall temporal pattern, this loss value was reduced for design purposes.

Tharbogang Swamp has a much larger catchment area than Lake Wyangan and therefore shows a much greater flood response. Unfortunately there has been no history of flood level recording in Tharbogang Swamp to compare to the modelled flood response.

The study also identified a number of local overland flow paths which impact of the planned development areas of Council's Growth Strategy 2030. It is important that these flow paths are taken into consideration during the stages of development planning.

The flood study will form the basis for the subsequent floodplain risk management activities, being the next stage of the floodplain risk management process. The key locations to consider during this process have been identified as:

- Locations where there is potential for cross-catchment flow transfer from the Tharbogang Swamp catchment into Lake Wyangan (potential changes to the existing flow distribution may result from future on-ground works in these localities) ; and
- Locations where the floodways occur within the proposed development areas of the Giffith Growth Strategy 2030.

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GLOSSARY

annual exceedance probability (AEP)	AEP (measured as a percentage) is a term used to describe flood size. It is a means of describing how likely a flood is to occur in a given year. For example, a 1% AEP flood is a flood that has a 1% chance of occurring, or being exceeded, in any one year. It is also referred to as the '100 year ARI flood' or '1 in 100 year flood'. The term 100 year ARI flood has been used in this study. See also average recurrence interval (ARI).
Australian Height Datum (AHD)	National survey datum corresponding approximately to mean sea level.
attenuation	Weakening in force or intensity
average recurrence interval (ARI)	ARI (measured in years) is a term used to describe flood size. It is the long-term average number of years between floods of a certain magnitude. For example, a 100 year ARI flood is a flood that occurs or is exceeded on average once every 100 years. The term 100 year ARI flood has been used in this study. See also annual exceedance probability (AEP).
catchment	The catchment at a particular point is the area of land that drains to that point.
design flood	A hypothetical flood representing a specific likelihood of occurrence (for example the 100yr ARI or 1% AEP flood).
development	Existing or proposed works that may or may not impact upon flooding. Typical works are filling of land, and the construction of roads, floodways and buildings.
discharge	The rate of flow of water measured in terms of volume per unit time, for example, cubic metres per second (m^3/s). Discharge is different from the speed or velocity of flow, which is a measure of how fast the water is moving for example, metres per second (m/s).
flood	A relatively high stream flow that overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or local overland flooding associated with major drainage before entering a watercourse, and/or coastal inundation resulting from super-elevated sea levels and/or waves overtopping coastline defences excluding tsunami.
flood behaviour	The pattern / characteristics / nature of a flood.
flood fringe	Land that may be affected by flooding but is not designated as floodway or flood storage.
flood hazard	The potential for damage to property or risk to persons during a flood. Flood hazard is a key tool used to determine flood severity and is used for assessing the suitability of future types of land use.The degree of flood hazard varies with circumstances across the full range of floods.

flood level	The height of the flood described either as a depth of water above a particular location (eg. 1m above a floor, yard or road) or as a depth of water related to a standard level such as Australian Height Datum (eg the flood level was 7.8 mAHD). Terms also used include flood stage and water level.
flood liable land	see flood prone land
floodplain	Land susceptible to flooding up to the probable maximum flood (PMF). Also called flood prone land. Note that the term flood liable land now covers the whole of the floodplain, not just that part below the flood planning level.
floodplain risk management study	Studies carried out in accordance with the Floodplain Development Manual (NSW Government, 2005) that assesses options for minimising the danger to life and property during floods. These measures, referred to as 'floodplain risk management measures / options', aim to achieve an equitable balance between environmental, social, economic, financial and engineering considerations. The outcome of a Floodplain Risk Management Study is a Floodplain Risk Management Plan.
floodplain risk management plan	The outcome of a Floodplain Risk Management Study.
flood planning levels (FPL)	The combination of flood levels and freeboards selected for planning purposes, as determined in Floodplain Risk Management Studies and incorporated in Floodplain Risk Management Plans. The concept of flood planning levels supersedes the designated flood or the flood standard used in earlier studies..
flood prone land	Land susceptible to inundation by the probable maximum flood (PMF) event. Under the merit policy, the flood prone definition should not be seen as necessarily precluding development. Floodplain Risk Management Plans should encompass all flood prone land (i.e. the entire floodplain).
flood stage	See flood level.
flood storage	Floodplain area that is important for the temporary storage of floodwaters during a flood.
flood study	A study that investigates flood behaviour, including identification of flood extents, flood levels and flood velocities for a range of flood sizes.
floodway	Those areas of the floodplain where a significant discharge of water occurs during floods. Floodways are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flow, or a significant increase in flood levels.
freeboard	A factor of safety usually expressed as a height above the adopted flood level thus determing the flood planning level. Freeboard tends to compensate for factors such as wave action, localised hydraulic effects and uncertainties in the design flood levels.

high flood hazard	For a particular size flood, there would be a possible danger to personal safety, able-bodied adults would have difficulty wading to safety, evacuation by trucks would be difficult and there would be a potential for significant structural damage to buildings.
hydraulics	The term given to the study of water flow in rivers, estuaries and coastal systems.
hydrology	The term given to the study of the rainfall-runoff process in catchments.
low flood hazard	For a particular size flood, able-bodied adults would generally have little difficulty wading and trucks could be used to evacuate people and their possessions should it be necessary.
m AHD	metres Australian Height Datum (AHD).
m/s	metres per second. Unit used to describe the velocity of floodwaters.
m^3/s	Cubic metres per second or 'cumecs'. A unit of measurement for creek or river flows or discharges. It is the rate of flow of water measured in terms of volume per unit time.
overland flow path	The path that floodwaters can follow if they leave the confines of the main flow channel. Overland flow paths can occur through private property or along roads. Floodwaters travelling along overland flow paths, often referred to as 'overland flows', may or may not re-enter the main channel from which they left; they may be diverted to another water course.
peak flood level, flow or velocity	The maximum flood level, flow or velocity that occurs during a flood event.
probable maximum flood (PMF)	The largest flood likely to ever occur. The PMF defines the extent of flood prone land or flood liable land, that is, the floodplain. The extent, nature and potential consequences of flooding associated with the PMF event are addressed in the current study.
probability	A statistical measure of the likely frequency or occurrence of flooding.
risk	Chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. In the context of this study, it is the likelihood of consequences arising from the interaction of floods, communities and the environment.
runoff	The amount of rainfall from a catchment that actually ends up as flowing water in the river or creek.
stage	See flood level.
topography	The shape of the surface features of land
velocity	The term used to describe the speed of floodwaters, usually in m/s.
water level	See flood level.

ACKNOWLEDGEMENTS

We would like to acknowledge the stakeholders and community members who have provided valuable input to the Lake Wyangan Flood Study, without their local knowledge and expertise the Study would not have been as comprehensive. This is particularly the case for the model calibration, where community input provided a substantial contribution. The key contributors to the Study include, but are not limited to, the following:

- Griffith City Council;
- NSW Office of Environment and Heritage;
- NSW Department of Lands;
- Floodplain Management Committee;
- Murrumbidgee Irrigation;
- Community members that responded to the questionnaire, particularly Mr. Vito Mancini, Mr. John Dickson and Mr. John Gardiner.

1 INTRODUCTION

The Lake Wyangan Flood Study has been prepared for Griffith City Council (Council) to define the existing flood behaviour in the Lake Wyangan catchment and establish the basis for subsequent floodplain risk management activities.

This project has been conducted under the Natural Disaster Resilience Grants Scheme and received State and Commonwealth financial support.

1.1 Study Location

The Lake Wyangan / Tharbogang Swamp catchment is around 825km^2 in size and is a closed system with no natural drainage outlet. The detailed investigation area forms the lower part of the catchment, bounded by the Lake View Branch Canal, and is located a few kilometres to the north of Griffith, as shown in Figure 1-1. Within the detailed investigation area, the future growth areas in Council's Growth Strategy 2030 (shown in Figure 1-1) are a particular focus.

The north and south lakes of Lake Wyangan are a prominent feature, being permanent water bodies. There are also a number of ephemeral wetlands, including Tharbogang Swamp, Nericon Swamp and Campbells Swamp. The Lake View Branch Canal supplies irrigation water to the local agriculture and is a major feature of the catchment as it intersects the majority of catchment runoff.

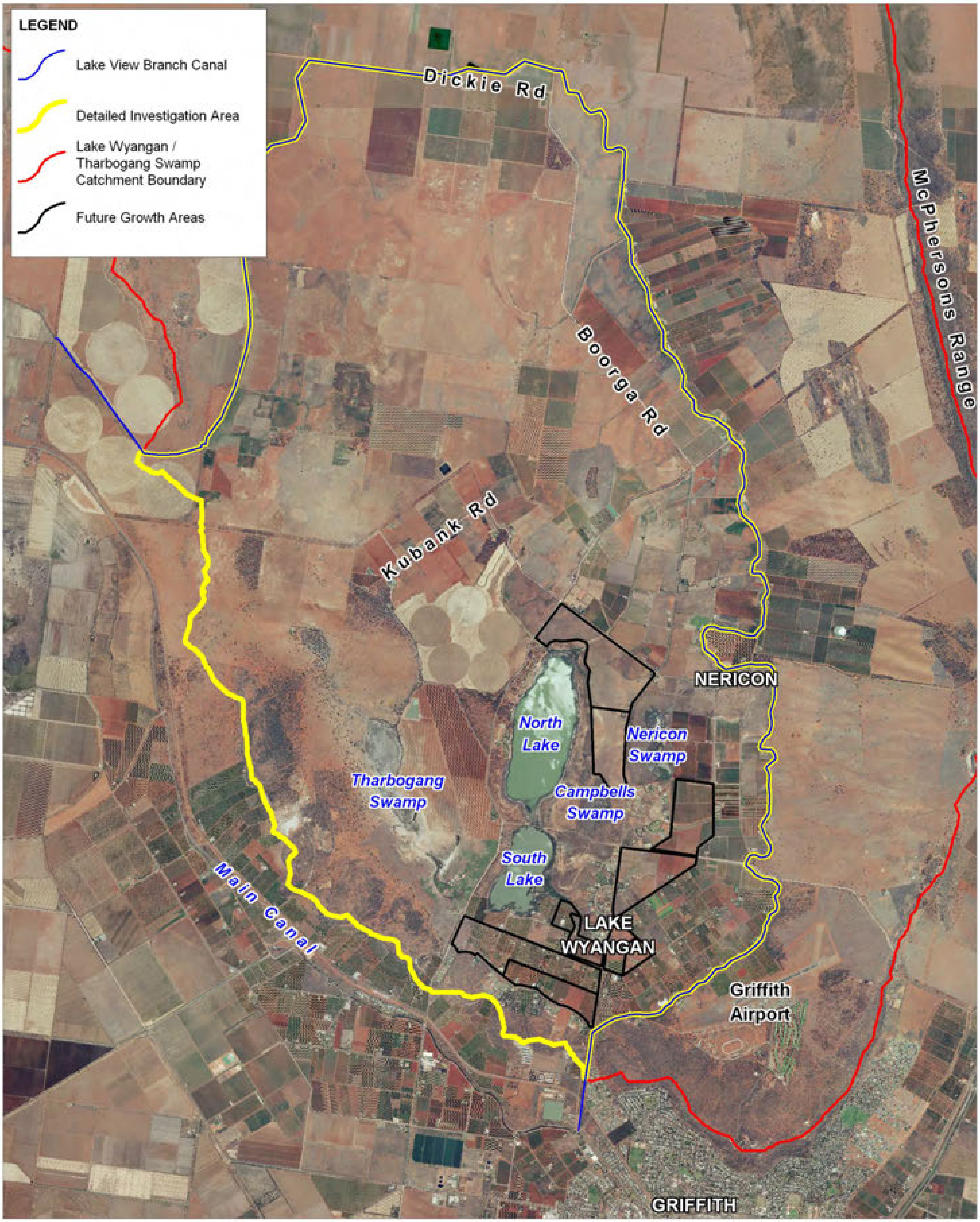
1.2 Study Background

A number of previous desktop studies have been undertaken to determine the 1% AEP flood level in Lake Wyangan, largely as supporting studies to development applications. These studies have produced significantly different estimates of the flood level, which creates uncertainty for Council when adopting flood planning levels for development within the study area. Hydrological models have been used to assess flooding in Lake Wyangan, but a detailed hydraulic modelling investigation of the entire study area had not been carried out prior to the undertaking of the current study.

There are two main mechanisms governing flood behaviour in the study area. Flood levels within the storages at the bottom of the catchment are driven by total runoff volumes from the Lake Wyangan / Tharbogang Swamp catchment. Longer duration catchment-wide events will provide the critical conditions for flood levels in Lake Wyangan and the surrounding properties. Local catchment runoff from shorter duration, higher intensity events will provide for the critical conditions on some of the flood flow paths, particularly in the east of the study area.

1.3 The Need for Floodplain Risk Management at Lake Wyangan

As evidenced in the 1985 and 1989 flood events, there are a number of properties within the Lake Wyangan Township and adjacent to the lakes that are at risk of flooding from both local overland flow paths and elevated lake levels. The wet weather of recent years has also highlighted problems with local drainage capacity.



Title:
Study Locality

Figure: 1-1

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Approx. Scale

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www.bmtwbm.com.au

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Within Council's Growth Strategy 2030 there is planned future development in areas surrounding Lake Wyangan, which includes land release for some 800 residential and rural residential lots over the next 20 years. An understanding of the flood behaviour and associated risks is required to effectively plan and manage this future development.

Floodplain risk management considers the consequences of flooding on the community and aims to develop appropriate floodplain risk management measures to minimise and mitigate the impact of flooding. This incorporates the existing flood risk associated with current development, and future flood risk associated with future development and changes in land use.

Accordingly, Council desires to approach local floodplain risk management in a considered and systematic manner. This study comprises the initial stages of that systematic approach, as outlined in the Floodplain Development Manual (NSW Government, 2005). The approach will allow for more informed planning decisions within Lake Wyangan.

1.4 The Floodplain Risk Management Process

The State Government's Flood Prone Land Policy is directed towards providing solutions to existing flooding problems in developed areas and ensuring that new development is compatible with the flood hazard and does not create additional flooding problems in other areas. Policy and practice are defined in the Government's Floodplain Development Manual (2005).

Under the Policy the management of flood liable land remains the responsibility of Local Government. The State Government subsidises flood mitigation works to alleviate existing problems and provides specialist technical advice to assist Councils in the discharge of their floodplain risk management responsibilities.

The Policy provides for technical and financial support by the State Government through the following four sequential stages:

Stages of Floodplain Risk Management

	Stage	Description
1	Flood Study	Determines the nature and extent of the flood problem.
2	Floodplain Risk Management Study	Evaluates management options for the floodplain in respect of both existing and proposed developments.
3	Floodplain Risk Management Plan	Involves formal adoption by Council of a plan of risk management for the floodplain.
4	Implementation of the Floodplain Risk Management Plan	Construction of flood mitigation works to protect existing development. Use of environmental plans to ensure new development is compatible with the flood hazard.

This study represents Stage 1 of the above process and aims to provide an understanding of local catchment flood behaviour within Lake Wyangan.

1.5 Study Objectives

The primary objective of the Flood Study is to define the flood behaviour within Lake Wyangan through the establishment of appropriate numerical models. The study has produced information on flood flows, velocities, levels and extents for a range of flood event magnitudes under existing catchment and floodplain conditions. Specifically, the study incorporates:

- Compilation and review of existing information pertinent to the study and acquisition of additional data including survey as required;
- Undertaking a community consultation and participation program to identify local flooding concerns, collect information on historical flood behaviour and engage the community in the on-going floodplain risk management process;
- Development and calibration of appropriate hydrologic and hydraulic models;
- Determination of design flood conditions for a range of design event including the 20% AEP, 10% AEP, 2% AEP, 1% AEP, 0.5% AEP and extreme flood event;
- Presentation of study methodology, results and findings in a comprehensive report incorporating appropriate flood mapping; and
- Identification of key locations for consideration during the floodplain risk management process.

The principal outcome of the flood study is the understanding of flood behaviour in the catchments and in particular design flood information that will underpin subsequent floodplain risk management activities.

1.6 About This Report

This report documents the Study’s objectives, results and recommendations.

Section 1 introduces the study.

Section 2 provides an overview of the approach adopted to complete the study.

Section 3 outlines the community consultation program undertaken.

Section 4 provides information on the additional survey collected for this study.

Section 5 details the development of the computer model.

Section 6 details the model calibration and validation process.

Section 7 presents the design flood conditions and modelling uncertainties.

2 STUDY APPROACH

2.1 The Study Area

2.1.1 Catchment Description

The study catchment totals an area of around 825km^2 and incorporates the townships of Lake Wyangan and Nericon and numerous agricultural properties. The catchment is a closed system that drains to a number of storages, including Lake Wyangan, Tharbogang Swamp, Nericon Swamp and Campbells Swamp.

The topography of the catchment is shown in Figure 2-1. The upper catchment, which forms part of the Cocoparra Range, is steep and largely elevated above 200m AHD. The middle section of the catchment is a relatively flat expanse, which is bounded by the southern extension of Tabbita Ridge to the west and by the McPhersons Range to the east. Elevations are typically between 120m AHD to 150m AHD. The study area forms the lower section of the catchment, where elevations are below 120m AHD. The deeper storage areas of Lake Wyangan and Tharbogang Swamp are evident in the topography shown on Figure 2-1.

The natural swamps in the bottom of the catchment include Lake Wyangan, Tharbogang Swamp, Nericon Swamp and Campbells Swamp. South Lake Wyangan was dammed to provide a more permanent water source, whilst North Lake Wyangan was previously mined for Gypsum and subsequently flooded to provide water for irrigation. Typical bed levels of Tharbogang Swamp and South Lake Wyangan are around 103m AHD, with North Lake Wyangan being a little deeper at around 101m AHD. Campbells Swamp and Nericon Swamp are located at higher levels of around 108m AHD and 113m AHD respectively.

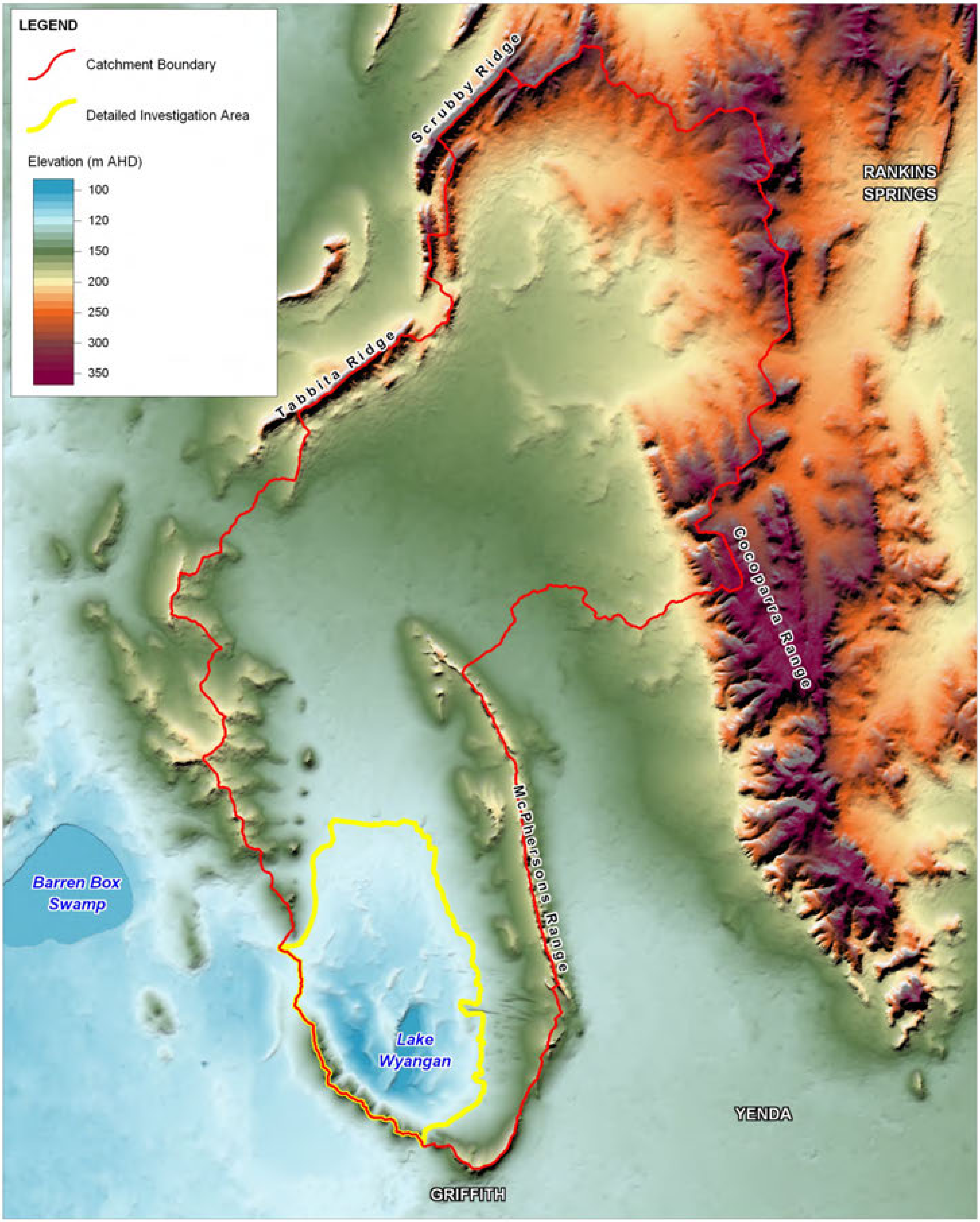
Substantial irrigation supply and drainage infrastructure has modified the natural drainage of the catchment. Historically, the majority of the catchment would have drained to Tharbogang Swamp, whereas now under typical low flow conditions it will drain to Lake Wyangan. In particular, the Lake View Drain and its associated agricultural drainage divert water from the Tharbogang Swamp catchment into Lake Wyangan.

The catchment has been largely cleared for farming purposes (80%, of which around 10% is irrigated agriculture). The other dominant land use is remnant vegetation at around 20%. Approximately 5km^2 of the catchment is open water or swamp and around 3km^2 is used for residential and rural residential purposes (both of which constitute <1% of the total catchment area).

The most significant transport route is Boorga Road, which connects the settlements of Lake Wyangan and Nericon to the City of Griffith.

2.1.2 History of Flooding

There is little documented history of flooding in the catchment, as it is sparsely populated and has a low annual average rainfall of <400mm. Flood photographs provided by Council are only available for events in 1985 and 1989.



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Topography of the Lake Wyangan / Tharbogang Swamp Catchment

Figure: 2-1

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Approx. Scale

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The March 1985 event is the largest recorded within the catchment, with a daily rainfall total of 150mm recorded at Griffith Airport. The duration of the event is unknown, given no available continuous rainfall record, but it is likely shorter than 12 hours, representing an event well in excess of a 1%AEP, when considered in relation to the standard intensity-frequency-duration (IFD) relationships for the study area. Photographs show substantial flooding to the Boorga Road – Smeeth Road intersection for this event and are presented in Section 6.5.6.

The most significant event since lake level records began in 1986 is the March 1989 event. It totalled around 100mm of rainfall at Griffith Airport and caused flooding to farming properties around Lake Wyangan.

In recent years, with increased rainfall following the extended drought period, a number of drainage issues have been highlighted. However, these represent specific local inadequacies in drainage capacities, rather than a broader flooding problem.

2.1.3 Previous Investigations

A number of investigations of the flooding characteristics of the study area have been undertaken over the last decade. These studies focused on assessing design flood levels in Lake Wyangan and in particular the 1 in 100 year (1% AEP) level. The studies include:

- Pelican Shores Peri-Urban Development – Lake Wyangan Flood Level Assessment (Hughes Trueman, 2000);
- Pelican Shores Peri-Urban Development – Lake Wyangan Flood Level Assessment (Hughes Trueman, 2001);
- Report on Lakes Road Western Annex – Flood Planning Levels (GHD, 2008);
- Lake Wyangan Investigation – Preliminary 100-Year Flood Level (GHD, 2008); and
- Sunset Waters, Boorga Road, Lake Wyangan, Griffith (Hughes Trueman, 2008).

The studies produced a wide range of flood level estimates, largely as a result of the variation in adopted parameters for the hydrological calculations, including uncertainty as to the catchment size. Further details of these previous investigations and their relevance in the context of the current flood study are presented in Section 2.2.1.

2.2 Compilation and Review of Available Data

2.2.1 Previous Studies

2.2.1.1 Pelican Shores Peri-Urban Development – Lake Wyangan Flood Level Assessment (Hughes Trueman, 2000)

The June 2000 Flood Level Assessment undertaken for the Pelican Shores development provided Lake Wyangan flood level estimates for the 5-year, 10-year, 20-year, 50-year and 100-year ARI design events. These flood levels were calculated using the Probabilistic Rational Method outlined in AR&R. A catchment area of around 740km^2 was adopted and a stage-storage relationship for Lake Wyangan was estimated from topographic maps. A runoff volume of 8,400 ML was derived for the 100-year ARI 24-hour duration event, which represents approximately 10% of the total catchment rainfall volume for the event. When adopting an initial lake level of 106.5m AHD, this provided a 100-year ARI flood level of 108.6m AHD.

2.2.1.2 *Pelican Shores Peri-Urban Development – Lake Wyangan Flood Level Assessment (Hughes Trueman, 2001)*

Following the original Pelican Shores Flood Level Assessment of June 2000, Council had requested a more detailed assessment to verify the estimated 100-year ARI flood level. The March 2001 Flood Level Assessment provided a revised flood level estimate, using an XP-RAFTS hydrological model. The catchment and storage characteristics were maintained from the previous study. An initial and continuing loss approach was adopted with parameters of 57mm and 2.5mm/h respectively. In addition to the rainfall losses a further 15% of loss by volume was applied to account for catchment storages, such as the Lake View Branch Canal. This was achieved by increasing the initial loss to 60mm. Modelling for a range of design storm durations found the 18-hour storm to be critical in terms of catchment runoff volume and resulting lake level. When adopting an initial lake level of 106.5m AHD, this provided a 100-year ARI flood level of 109.2m AHD.

2.2.1.3 *Report on Lakes Road Western Annex – Flood Planning Levels (GHD, 2008)*

The May 2008 Flood Level Assessment undertaken for the Lakes Road Western Annex development provided a 100-year ARI flood level estimate for Tharbogang Swamp, to be adopted as a flood planning level. It also included an estimate of the 100-year ARI flood level for Lake Wyangan. These flood levels were calculated using the Probabilistic Rational Method outlined in AR&R. Stage-storage relationships for Tharbogang Swamp and Lake Wyangan were derived from LiDAR elevation contours.

A catchment area of 500km^2 was adopted for Lake Wyangan, yielding a runoff volume of 12,500 ML for the 100-year ARI 8-hour duration event. This represents approximately 30% of the total catchment rainfall volume for this event. When adopting an initial lake level of 107.5m AHD, this provided a 100-year ARI flood level of 111.8m AHD. It was acknowledged that this was a conservative estimate as no account was taken of the additional swamp storages in the catchment.

For Tharbogang Swamp, uncertainty surrounding the contributing catchment area resulted in three scenarios being adopted for the estimation of the 100-year ARI flood level. These included a 13km^2 catchment area estimate by Umwelt in 2002, a 56km^2 estimate by GHD and the total adopted Lake Wyangan catchment of 500km^2. The contributing volumes to Tharbogang Swamp for each scenario were 240 ML, 1,200 ML and 12,500 ML respectively. When adopting an initial swamp level of 103m AHD (effectively dry), this provided 100-year ARI flood level estimates of 104m AHD, 105.1m AHD and 110.1m AHD for the three scenarios. The level of 105.1m AHD was recommended as being the most appropriate.

2.2.1.4 *Lake Wyangan Investigation – Preliminary 100-Year Flood Level (GHD, 2008)*

The July 2008 Lake Wyangan Investigation provided 100-year ARI flood level estimates for Lake Wyangan and Tharbogang Swamp, using an XP-RAFTS hydrological model. The stage-storage relationships for Lake Wyangan and Tharbogang Swamp were derived from LiDAR elevation contours. The contributing catchment areas for the two storages were determined from both the LiDAR contours and the topographic maps. The catchment areas for Lake Wyangan and Tharbogang Swamp were estimated to be around 500km^2 and 50km^2 respectively. An initial and continuing loss approach was adopted with parameters of 15mm and 2.5mm/h respectively, based on recommendations in AR&R. Modelling for a range of design storm durations found the 18-hour storm to be critical in terms of catchment runoff volume and corresponding lake level. When adopting an initial level of 106.0m AHD, this provided a 100-year ARI flood level of 112.1m AHD for Lake Wyangan. For Tharbognag Swamp, adopting an initial level of 103.0m AHD (effectively dry) provided a 100-year ARI flood level of 106.7m AHD.

2.2.1.5 Sunset Waters, Boorga Road, Lake Wyangan, Griffith (Hughes Trueman, 2008)

The July 2008 report for the Sunset Waters development compares the results from the two existing XP-RAFTS models, developed by Hughes Trueman in 2001 and GHD in 2008. It discusses differences between the adopted parameters in each model and argues that the Hughes Trueman model is more appropriate. A recommendation is made that the 109.2m AHD 100-year ARI flood level for Lake Wyangan be adopted, as determined by the 2001 Hughes Trueman report for the Pelican Shores development. Of interest is the reference made to an additional report prepared by Hughes Trueman in July 2008. This report adopted a total catchment area of 350km^2 and also included consideration of a catchment area of 160km^2 for downstream of the Lake View Branch Canal only. The 100-year ARI flood levels from this report were found to be 107.9m AHD and 106.9m AHD for the larger and smaller catchment sizes respectively. Both estimates adopted an initial lake level of 105.9m AHD.

2.2.2 Historical Flood Levels

Available flood level records in the catchment are limited. Water levels have been recorded in Lake Wyangan by Murrumbidgee Irrigation since 1986, typically at a weekly interval. The highest recorded water level in Lake Wyangan is around 106.8m AHD. This represents the flooding that resulted from the March 1989 storm event. However, the gauge was unreadable for three weeks following the event and so the peak flood level would have been higher than this. The highest recorded water levels aside from this event are around 106.5m AHD and relate to irrigation practices, rather than rainfall events.

In previous studies a peak flood level for Lake Wyangan of 107.5m AHD had been referenced and related to the March 1989 event. However, subsequent communications with Murrumbidgee Irrigation have found this level to have been incorrectly reported due to a datum mix-up. The gauge datum is known to be around 104.5m AHD, such that the highest gauge reading of 2.3m for the March 1989 event provides for a peak flood level estimate at 106.8m AHD.

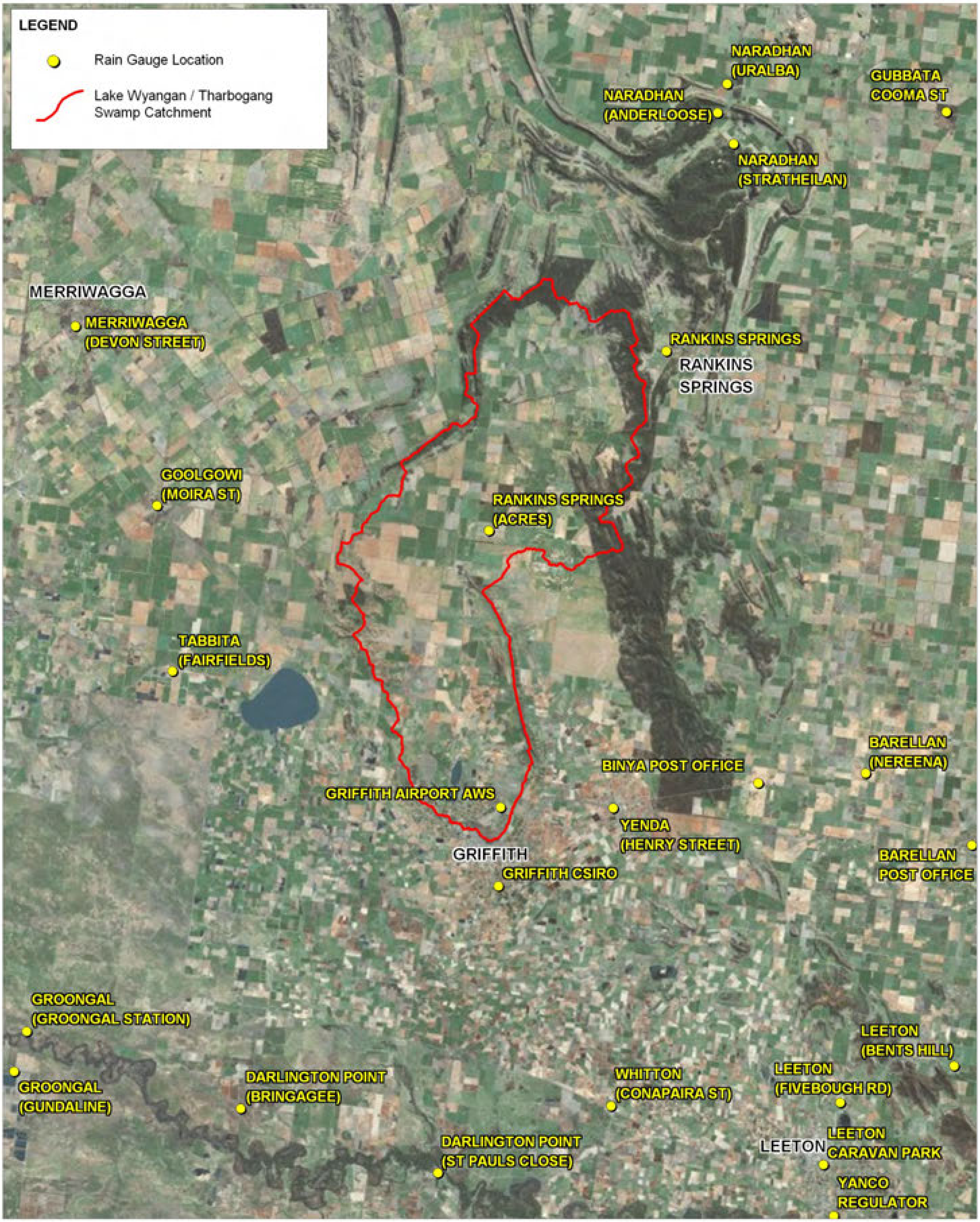
The available records were supplemented by some anecdotal evidence and photographs obtained through the community consultation process, as discussed in Section 3.2. Data obtained from historic records and the community consultation process is presented in Section 6, for the purposes of model calibration.

2.2.3 Rainfall Data

There is a network of rainfall gauges across the region, which are operated by the Bureau of Meteorology (BoM). There are two gauges located within the catchment and another 3km away at Rankins Springs that provide a reasonable coverage. The Griffith Airport site has daily records available from 1958, Rankins Springs (Acres) from 1968 and Rankins Springs from 1887. There are a further 21 rainfall gauges located within around 50km of the catchment that were operational until at least the 1980s, the majority of which are daily read gauges. A further 40 gauges that have ceased operation were located in the area, most of which were closed by the 1950s. The Griffith Airport site has been recording continuous rainfall data since 2000. The only other continuous rainfall data available is from the Griffith CSIRO site, which operated from 1989 to 2003. A list of the currently operational and recently closed rainfall stations is shown in Table 2-1, with their respective period of record. The location of the gauges is shown in Figure 2-2.

Table 2-1 Summary of Rainfall Gauges in the Lake Wyangan Locality

Station No.	Name	Operator	Type	Start Year	End Year
75174	Griffith CSIRO	CSIRO	Pluvio	1989	2003
75041	Griffith Airport AWS	BoM	Pluvio	1960	current
74005	Barellan Post Office	BoM	Daily	1878	current
74007	Leeton (Bents Hill)	BoM	Daily	1941	current
74062	Leeton Caravan Park	BoM	Daily	1913	2006
74094	Barellan (Nereena)	BoM	Daily	1901	current
74118	Whitton (Conapaira St)	BoM	Daily	1886	current
74123	Yanco Regulator	BoM	Daily	1915	1992
74254	Leeton (Fivebough Rd)	BoM	Daily	1992	current
75006	Binya Post Office	BoM	Daily	1876	current
75010	Darlington Point (Bringagee)	BoM	Daily	1894	current
75025	Goolgowi (Moira St)	BoM	Daily	1930	current
75026	Groongal (Groongal Station)	BoM	Daily	1878	current
75027	Gubbata Cooma St	BoM	Daily	1937	current
75044	Merriwagga (Devon Street)	BoM	Daily	1930	current
75050	Naradhan (Uralba)	BoM	Daily	1880	current
75057	Rankins Springs	BoM	Daily	1880	current
75064	Groongal (Gundaline)	BoM	Daily	1880	current
75079	Yenda (Henry Street)	BoM	Daily	1925	current
75143	Tabbita (Fairfields)	BoM	Daily	1969	1993
75146	Rankins Springs (Acres)	BoM	Daily	1968	current
75161	Naradhan (Anderloose)	BoM	Daily	1970	2003
75162	Naradhan (Stratheilan)	BoM	Daily	1970	1999
75166	Darlington Point (St Pauls Close)	BoM	Daily	1909	current



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Rainfall Gauges in the Vicinity of Lake Wyangan

Figure: 2-2

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A detailed discussion of the rainfall data available for the selected calibration events is discussed in Section 6.

2.2.4 Council Data

Digitally available information such as aerial photography, cadastral boundaries, topography, watercourses, drainage networks, land zoning, etc. were provided by Council in the form of GIS datasets.

LiDAR land survey data covering the entire study area was acquired in February 2004. Flood behaviour is inherently dependent on the ground topography and for this study an accurate representation of key catchment storages is essential. The LiDAR data enables a good representation of the stage-storage relationships, which have been extracted for presentation in Figure 2-3. Advanced GIS analysis also allows the LiDAR imagery to be assessed in concert with spatial 2-D flood model data, facilitating mapping, categorisation, and overall flood management. Existing flood information including flood photographs were also made available.

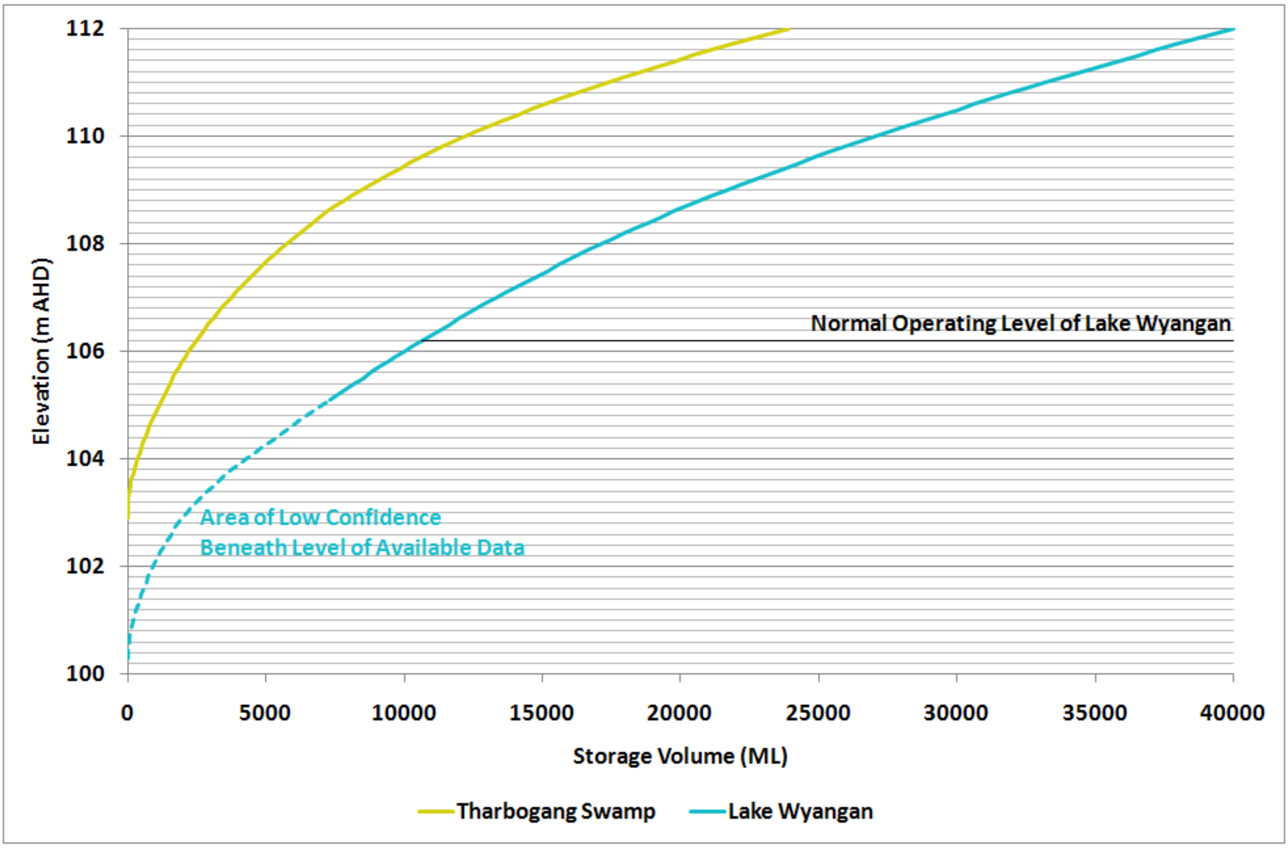


Figure 2-3 Stage Storage Curves for Lake Wyangan and Tharbogang Swamp

2.2.5 SRTM Data

The SRTM DEM-S, which is a 30m resolution Digital Elevation Model (DEM) derived from the Shuttle Radar Topographic Mission (SRTM), was provided through the State Government Office of Environment and Heritage under license for this study. It has been cleaned, filtered for vegetation and smoothed by CSIRO as part of the One-second DEM for Australia project. This dataset was used to provide topographic information for the broader catchment area, where LiDAR data was not available.

2.2.6 Murrumbidgee Irrigation Data

A number of datasets were provided by Murrumbidgee Irrigation, through Council. These included the spatial locations and structural details of the supply canals and drainage networks, which are a prominent feature of the study catchment.

2.3 Site Inspections

A number of site inspections were undertaken during the course of the study to gain an appreciation of local features influencing flooding behaviour. Some of the key observations to be accounted for during the site inspections included:

- Confirmation of catchment boundaries derived from analysis of available topographic data;
- Presence of local structural hydraulic controls such as levees and embankments that may have an impact on flooding behaviour;
- Confirmation of the location and configuration of the irrigation supply and drainage network, including associated cross-drainage structures;
- Location of existing development and infrastructure on the floodplain.

This visual assessment was useful for defining hydraulic properties within the hydraulic model and ground-truthing of topographic features identified from the available data.

2.4 Additional Survey

For catchment boundary confirmation a topographic survey was conducted by Council in the Boorga locality. A thorough investigation of the catchment delineation was presented in a report to Council in April 2011 and is included as Appendix B.

2.5 Community Consultation

The success of a floodplain risk management plan hinges on its acceptance by the community, residents within the study area, and other stake-holders. This can be achieved by involving the local community at all stages of the decision-making process. This includes the collection of their ideas and knowledge on flood behaviour in the study area, together with discussing the issues and outcomes of the study with them.

The key elements of the consultation process in undertaking the flood study have included:

- Issue of a questionnaire to obtain historical flood data and community perspective on flooding issues;
- Feedback through the Floodplain Management Committee meetings; and
- Public exhibition of Draft Report.

These elements are discussed in further detail in Section 3.

2.6 Development of Computer Models

2.6.1 Hydrological Model

Traditionally, for the purpose of the Flood Study, a hydrologic model is developed to simulate the rate of rainfall runoff from the catchment. The output from the hydrologic model is a series of flow hydrographs at selected locations such as at the upper limits of the modelled watercourses, which form the inflow boundaries to the hydraulic model.

In recent years the advancement in computer technology has enabled the use of the direct rainfall approach as a viable alternative. With the direct rainfall method the design rainfall is applied directly to the individual cells of the 2D hydraulic model. This is particularly useful for catchments where the sub-catchment boundaries are difficult to define or significant cross-catchment flows occur. This study has adopted the direct rainfall approach for modelling hydrology, details of which are discussed in Section 5.1.

Limitations of the direct rainfall modelling approach include the potential over-estimation of rainfall loss parameters, through the double accounting of the surface storage component. This forms part of the initial loss parameter in traditional hydrological modelling, but can also be accounted for by the topographic representation within the hydraulic model. The speed of flow routing through the catchment in the direct rainfall approach can also differ substantially from a traditional hydrological model. These potential limitations have been addressed through the model calibration process, whereby appropriate initial loss parameters for the catchment have been determined based on observed catchment response (volumetric runoff). Being a volume driven system, the response to catchment flow routing is not significant when determining peak flood levels.

2.6.2 Hydraulic Model

The TUFLOW hydraulic model (discussed in Section 5.2) developed for this study includes:

- two-dimensional (2D) representation of the Lake Wyangan / Tharbogang Swamp catchment covering an area of approximately 825 km^2 (complete coverage of the total catchment area); and
- one-dimensional (1D) representation of the Lake View Branch Canal and Lake View Drain.

The hydraulic model is applied to determine flood levels, velocities and depths across the study area for historical and design events.

2.7 Calibration and Sensitivity Testing of Models

The following criteria are generally used to determine the suitability of historical events to use for calibration or validation:

- The availability, completeness and quality of rainfall and flood level event data;
- The amount of reliable data collected during the historical flood information survey; and
- The variability of events – preferably events would cover a range of flood sizes.

The hydraulic model was primarily calibrated to the March 1989 flood event to establish the values of key model parameters and confirm that the models were capable of adequately simulating real flood events. Flood information relating to the March 1985 and December 2007 events has also been used to aid the model calibration and validation process.

The calibration and validation of the model is presented in Section 6. The flood levels in Lake Wyangan and Tharbogang Swamp were found to be highly sensitive to the adopted rainfall loss conditions, as discussed in Section 6.6. The testing of model sensitivity to the initial loss parameter was carried through to the design flood estimation, the results of which are presented in Section 7.2.1.

2.8 Establishing Design Flood Conditions

Design floods are statistical-based events which have a particular probability of occurrence. For example, the 1% Annual Exceedance Probability (AEP) event, which is sometimes referred to as the 1 in 100 year Average Recurrence Interval (ARI) flood, is the best estimate of a flood with a peak discharge that has a 1% (i.e. 1 in 100) chance of occurring in any one year. For the Lake Wyangan / Tharbogang Swamp catchment, design floods were based on design rainfall estimates according to Australian Rainfall and Runoff (IEAust, 2001).

The design flood conditions form the basis for floodplain risk management in the catchment and in particular design planning levels for future development controls. The predicted design flood conditions are presented in Section 7.2.

2.9 Mapping of Flood Behaviour

Design flood mapping is undertaken using output from the hydrodynamic model. Maps are produced showing water depth and velocity for each of the design events. The maps present the peak value of each parameter. Provisional flood hazard categories and hydraulic categories derived from the hydrodynamic model results are also mapped. Some mapping outputs are presented Section 7.2, with the full flood mapping series presented in Appendix A.

3 COMMUNITY CONSULTATION

3.1 The Community Consultation Process

The consultation has aimed to inform the community about the development of the flood study and its likely outcome as a precursor to subsequent floodplain risk management activities. It has provided an opportunity to collect information on their flood experience, in particular historical flood data related to catchment flooding.

The key elements of the consultation process have been as follows:

- Distribution of a questionnaire to all landowners, residents and businesses within the study area;
- Feedback through the Floodplain Management Committee meetings; and
- Public exhibition of the draft Flood Study.

These elements are discussed in detail below.

3.2 Community Questionnaire

A questionnaire was distributed to residents within the study area to collect information on their previous flood experience and flooding issues. The focus of the questionnaire was historical flooding information that may be useful for correlating with predicted flooding behaviour from the modelling.

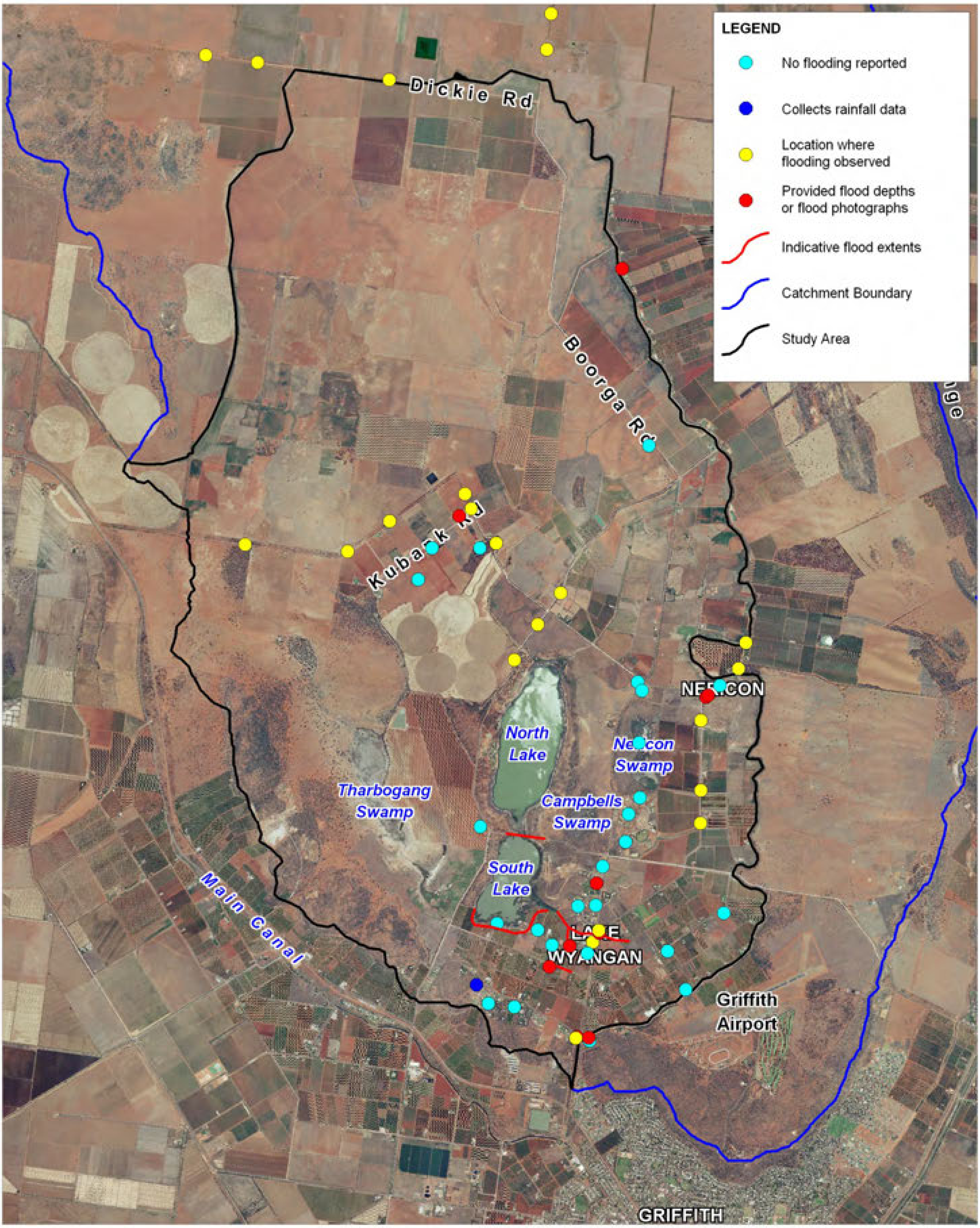
Council mailed out the questionnaire to all residents and businesses located within the study area. Council received back 39 responses, of which 18 had comments relating to flooding. The responses were compiled into a GIS layer. A copy of the questionnaire and some of the information received is included in Appendix C.

The focus of the questionnaire was to gather relevant flood information from the community, including photographs, observed flood depths and descriptions of flood behaviour within the catchment. Three responses included photographs showing flooding and drainage problems and another provided video footage. The responses also identified an additional location within the study area at which rainfall depths have been recorded since 2007.

The distribution of questionnaire responses is presented in Figure 3-1, in which the locations of responses with comments relating to flooding have been highlighted. Flooding issues were identified at the Boorga Road – Smeeth Road intersection and along Todd Road, Druitt Road, West Road and Dickie Road.

The comments relating to flooding that were received from the community were an important part of the calibration process, which is discussed in Section 6.

Many comments were received concerning local drainage problems. Whilst not a focus of the Flood Study, these issues are of concern to the Lake Wyangan community.



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Distribution of Responses to the Questionnaire

Figure: 3-1

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3.3 Floodplain Management Committee

Throughout the course of the study a number of Floodplain Management Committee meetings were held. The progress of the study was presented to the committee, who were able to provide valuable feedback on some of the information that was being presented. This included local knowledge of the catchment and historic flood events, which enabled findings of the study to be verified where possible. A community information session was also held to allow feedback from the wider community.

3.4 Public Exhibition

The Draft Report was approved by Council on 13th December 2011 and was placed on public exhibition until 2nd March 2012. No comments were received from the community following the exhibition of the report.

4 ADDITIONAL SURVEY

For catchment boundary confirmation a topographic survey was conducted by Council in the Boorga locality. The survey covered an area of around 30km^2, capturing elevations on a 200m spaced grid and along topographic features of particular importance. This survey information was not required for the Flood Study model development, but was used to confirm the topography of the SRTM DEM-S (discussed in Section 5.2.2) during the catchment delineation process. A thorough investigation of the catchment delineation was presented in a report to Council in April 2011 and includes a presentation of the survey information. This report included as Appendix B.

5 MODEL DEVELOPMENT

Computer models are the most accurate, cost-effective and efficient tools to assess a catchment's flood behaviour. Traditionally, for the purpose of the Flood Study, a hydrologic model and a hydraulic model are developed.

The **hydrologic model** simulates the catchment rainfall-runoff processes, producing the stormwater flows which are used in the hydraulic model.

The **hydraulic model** simulates the flow behaviour of the drainage network and overland flow paths, producing flood levels, flow discharges and flow velocities.

In recent years the advancement in computer technology has enabled the use of the direct rainfall approach as a viable alternative. With the direct rainfall method the design rainfall is applied directly to the individual cells of the 2D hydraulic model. This is particularly useful for catchments where the sub-catchment boundaries are difficult to define or significant cross-catchment flows occur. This study has adopted the direct rainfall approach for modelling hydrology and therefore only a single TUFLOW model has been developed.

Information on the topography and characteristics of the catchments, watercourses and floodplains are built into the model. Recorded historical flood data, including rainfall and flood levels, are used to simulate and validate (calibrate and verify) the model. The model produces as output, flood levels, flows (discharges) and flow velocities.

Development of a hydraulic model follows a relatively standard procedure:

1. Discretisation of the catchment, watercourses, floodplain, etc.
2. Incorporation of physical characteristics (channel details, floodplain levels, structures etc).
3. Establishment of hydrographic databases (rainfall, flood flows, flood levels) for historic events.
4. Calibration to one or more historic floods (calibration is the adjustment of parameters within acceptable limits to reach agreement between modelled and measured values).
5. Verification to one or more other historic floods (verification is a check on the model's performance without further adjustment of parameters).
6. Sensitivity analysis of parameters to measure dependence of the results upon model assumptions.

Once model development is complete it may then be used for:

- establishing design flood conditions;
- determining flood extents, levels and hydraulic categories for planning control; and
- modelling development or management options to assess the hydraulic impacts.

5.1 Hydrological Model

The hydrologic model simulates the rate at which rainfall runs off the catchment. The amount of rainfall runoff from the catchment is dependant on:

- the catchment slope, area, vegetation and other characteristics;
- variations in the distribution, intensity and amount of rainfall; and
- the antecedent conditions (dryness/wetness) of the catchment.

Hydrological modelling is undertaken to establish inflow boundaries to the TUFLOW hydraulic model (flow hydrographs from external catchments and local rainfall directly on to the flood-prone area). A direct rainfall approach has been adopted for the study using the TUFLOW software. The runoff routing and hydrological response of the catchment within the model is driven by the surface type and underlying topography. Where appropriate, runoff is diverted into 1D channels of the 2D/1D model. The general modelling approach and adopted parameters is discussed in the following sections.

5.1.1 Flow Path Mapping and Catchment Delineation

The Lake Wyangan / Tharbogang Swamp catchment drains an area of approximately 825km^2 to the permanent and ephemeral storages in the bottom of the catchment. The extent of the study hydrologic catchment is shown in Figure 5-1.

Flow path mapping and catchment delineation has been undertaken using the CatchmentSIM software. The generated DEM was imported into the software and following hydrologic conditioning, flow paths and catchment boundaries were generated.

The delineation of the hydrologic catchment boundary was important for defining the limits of the hydraulic model extent and the associated direct rainfall input. It can be seen from Figure 5-1 that the natural catchment of Lake Wyangan is only around 75km^2 in size, whilst the majority of the catchment (some 750km^2) naturally drains to Tharbogang Swamp. This was a significant discovery in understanding the nature of the catchment flooding. The irrigation infrastructure of Lake View Branch Canal and Lake View Drain diverts some of the catchment runoff from the Tharbogang Swamp catchment into Lake Wyangan. However, under flood conditions, when the capacity of the drains is exceeded, excess flood waters will predominantly drain to Tharbogang Swamp.

The delineation of the upper catchment extent is subject to some degree of uncertainty, as was evidenced by the wide range of adopted catchment areas for the previous studies. It had been unclear as to whether the well-defined upper catchment area of the Cocoparra Range drained to the west of the McPhersons Range and into Lake Wyangan / Tharbogang Swamp, or to the east of the Range into the Main Drain J catchment. The available topographic data suggested that it most likely drained to Lake Wyangan / Tharbogang Swamp. This was confirmed through site inspections and survey data collected by Council. A thorough investigation of the catchment delineation was presented in a report to Council in April 2011 and is included as Appendix B.

5.1.2 Rainfall Data

Rainfall information is the primary input and driver of the hydrological model, which simulates the catchments response in generating surface run-off. Rainfall characteristics for both historical and design events are described by:

- Rainfall depth – the depth of rainfall occurring across a catchment surface over a defined period (e.g. 270mm in 36hours or average intensity 7.5mm/hr); and

- Temporal pattern – describes the distribution of rainfall depth at a certain time interval over the duration of the rainfall event.

Both of these properties may vary spatially across the catchment.

The procedure for defining these properties is different for historical and design events. For historical events, the recorded hyetographs at continuous rainfall gauges provide the observed rainfall depth and temporal pattern. Where only daily read gauges are available within a catchment, assumptions regarding the temporal pattern may need to be made.

For design events, rainfall depths are most commonly determined by the estimation of intensity-frequency-duration (IFD) design rainfall curves for the catchment. Standard procedures for derivation of these curves are defined in AR&R (2001). Similarly AR&R (2001) defines standard temporal patterns for use in design flood estimation.

The rainfall inputs for the historical calibration/validation events are discussed in further detail in Section 6 and design events discussed in Section 7.

5.1.3 Surface Type Hydrologic Properties

The response of the catchment to the input rainfall data is dependant on the spatial distribution and hydrologic properties of the land use surface types. The properties assigned to each surface type (or material) within TUFLOW that influence the hydrologic response of the model are:

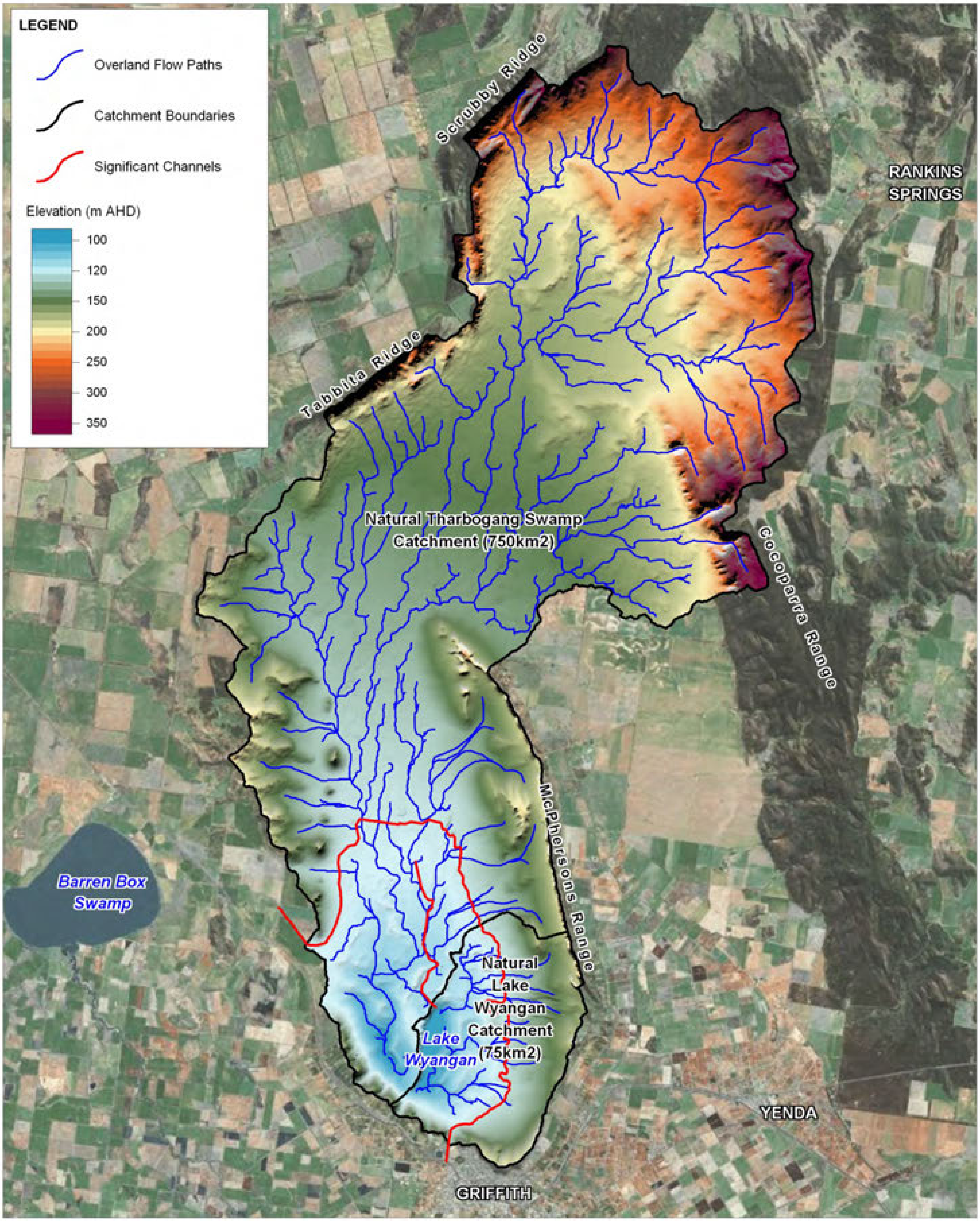
- Initial and continuing losses determine how much rainfall is lost to surface and soil storage etc. and therefore the effective rainfall contributing to surface runoff;
- Roughness parameters for sheet flow govern the speed with which the runoff will travel, influencing the hydrologic response of the model.

The material layers input to the model define these properties for each land use surface type within the catchment. Each material has an initial loss, continuing loss and roughness parameter assigned to it. Along with the model topography, it is these parameters which determine the runoff routing and hydrological response of the model.

5.2 Hydraulic Model

The overland flow regime in the study catchment is characterised by many wide, shallow interconnecting and varying flow paths. The catchment boundary is not well-defined in places and there is potential for cross-catchment flows to occur. In addition, there are a number of significant hydraulic controls that influence the routing and progression of flood flows through the catchment. Given this complex flooding environment, a 2D modelling approach is warranted for the overland flooding areas.

BMT WBM has applied the fully 2D software modelling package TUFLOW. TUFLOW was developed in-house at BMT WBM and has been used extensively for over fifteen years on a commercial basis by BMT WBM. TUFLOW has the capability to simulate the dynamic interaction of in-bank flows in open channels and overland flows through complex overland flow paths using a linked 2D / 1D flood modelling approach.



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Lake Wyangan / Tharbogang Swamp Catchment Boundary and Overland Flow Paths

Figure: 5-1

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5.2.1 Extents and Layout

Consideration needs to be given to the following elements in constructing the model:

- topographical data coverage and resolution;
- location of recorded data (eg. levels/flows for calibration);
- location of controlling features (eg. dams, levees, bridges);
- desired accuracy to meet the study's objectives;
- computational limitations.

With consideration to the available survey information and local topographical and hydraulic controls, a linked 1D/2D model was developed extending from the catchment depression storages at the downstream limit, to the head of the catchment. The significant elements of the irrigation network have been modelled as 1D branches embedded within the 2D (floodplain) domain. This approach enables the hydraulic capacity of the Lake View Branch Canal and Lake View Drain to be accurately defined by true channel dimensions, whilst enabling the overland flow to be represented in 2D. The model layout is presented in Figure 5-2.

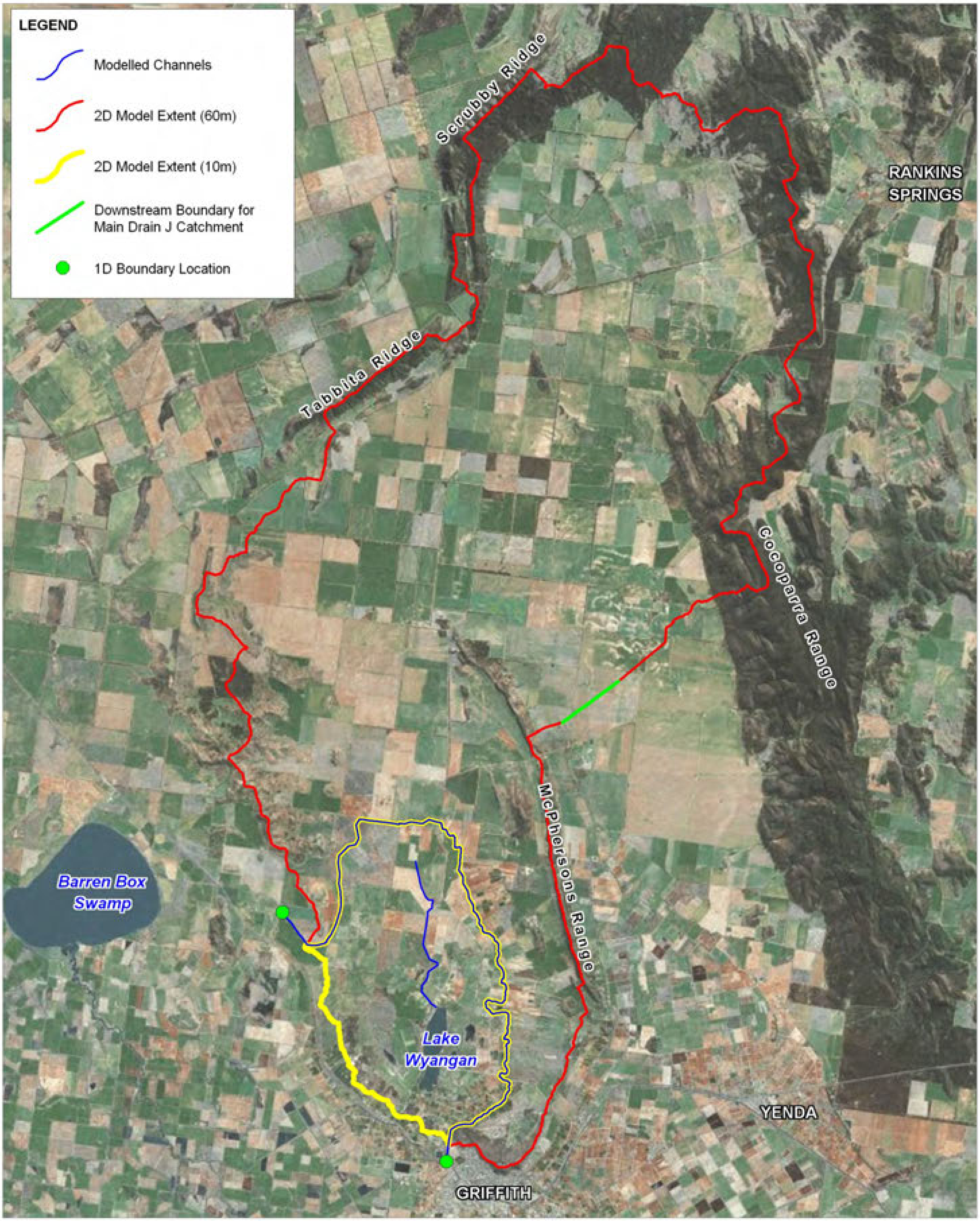
The floodplain area modelled within the 2D domain comprises a total area of some 860km^2 (up to approximately 350m AHD) which includes the entire of the Lake Wyangan / Tharbogang Swamp catchment. It also includes a small portion of the upper Main Drain J catchment, in order to determine the correct proportion of cross-catchment flows at the catchment boundary.

A TUFLOW 2D domain model resolution of 10m was adopted for the study area, with a resolution of 60m adopted for the broader catchment. It should be noted that TUFLOW samples elevation points at the cell centres, mid-sides and corners, so a 10m cell size results in DEM elevations being sampled every 5m. This resolution was selected to give necessary detail required for accurate representation of floodplain topography and its influence on overland flows. Elevation samplings at a 30m interval for the broader catchment utilise the maximum level of detail obtainable from the SRTM DEM-S data.

5.2.2 Topography

A high resolution DEM was derived for the study area from the LiDAR data provided by Council. It is a representation of the ground surface and does not include features such as buildings or vegetation. Beyond the study area, the base elevation data source is the SRTM DEM-S, which is a 30m resolution Digital Elevation Model (DEM) derived from the Shuttle Radar Topographic Mission (SRTM). It has been cleaned, filtered for vegetation and smoothed by CSIRO as part of the One-second DEM for Australia project. The ground surface elevation for the TUFLOW model grid points are sampled directly from the DEM.

The ability of the model to provide an accurate representation of the overland flow distribution on the floodplain ultimately depends upon the quality of the underlying topographic model. For the study area, a high resolution DEM (2m grid) was derived from LiDAR survey provided by Council. The model grid samples elevations from this DEM and so a high resolution was used to maximise the quality of information available during the sampling process.



Title:
Linked 1D/2D Model Layout

Figure:
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5.2.3 Hydraulic Roughness

The development of the TUFLOW model requires the assignment of different hydraulic roughness zones. These zones are delineated from aerial photography and cadastral data identifying different land-uses (eg. cleared land, scrub, roads, urban areas, etc) for modelling the variation in flow resistance.

The adopted hydraulic roughness (Manning's 'n') applied in the model according to land use type (material) is shown in Table 5-1. A roughness map for the catchment is shown in Figure 5-3, illustrating the subdivision of the model area by land use type.

Table 5-1 Adopted Hydraulic Roughness Coefficients Based on Land Use

Material	'n' Value
Urban Areas	0.05
Grassland / Agriculture	0.06
Woodland	0.12

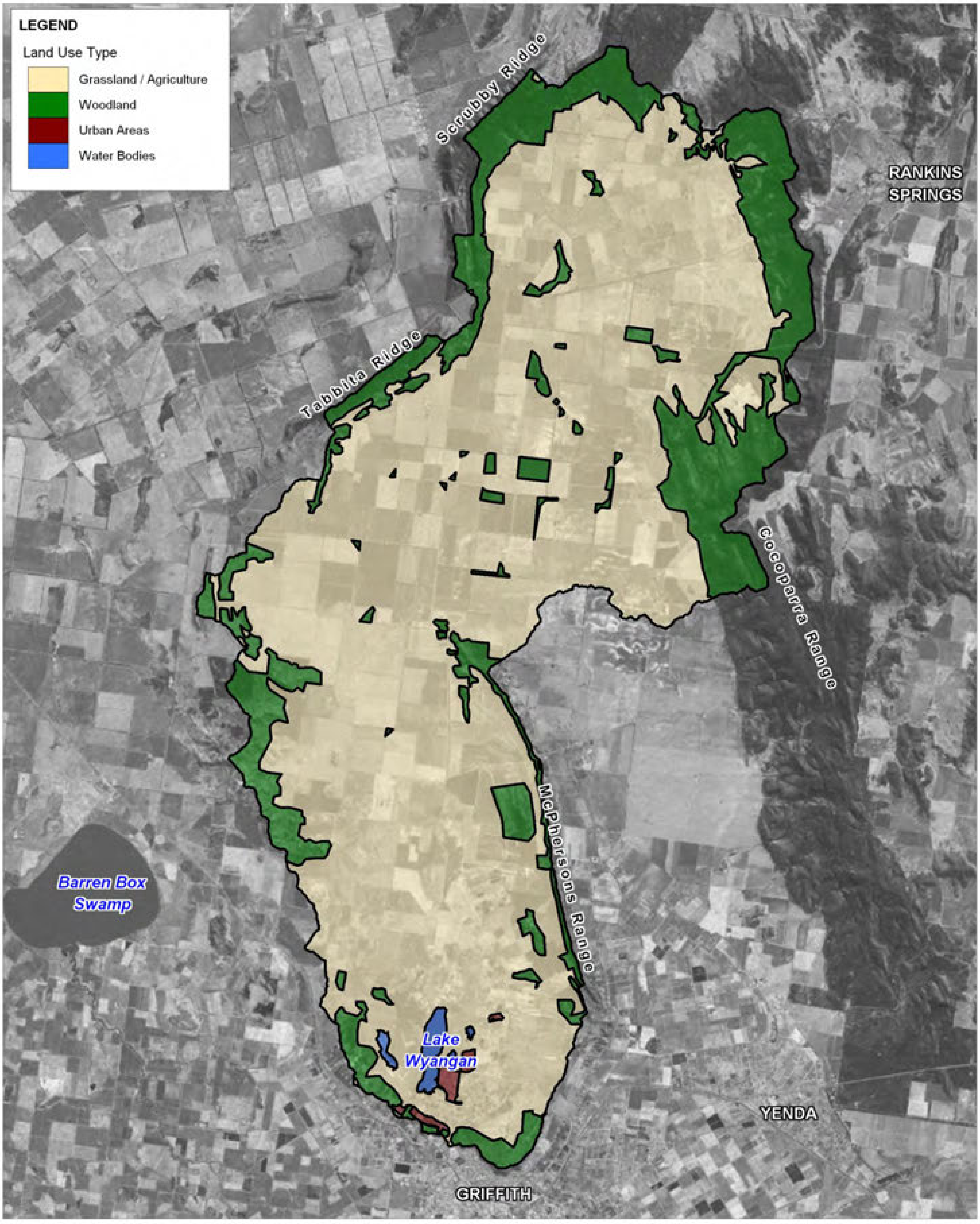
The available data is not sufficient to allow calibration of the model roughness values. The model parameters that were adopted are standard values that are appropriate to the land use types within the catchment. However, this does not have any significant implications for the modelled flood levels within Lake Wyangan and Tharbogang Swamp. Being a closed-catchment volume-driven system, the flood levels in the storages are a function of the effective rainfall and associated catchment runoff volume.

5.2.4 Channel Network

The study requires the modelling of the Lake View Branch Canal, Lake View Drain and associated cross-drainage structures, as they have a significant impact on flood propagation in the catchment. Council provided information from Murrumbidgee Irrigation (MI) as to the properties of the channel network. This data comprised a GIS layer of supply and drainage channel locations, together with details on dimensions and channel lining. Continuous channel bank and water level information was derived from the high resolution LiDAR DEM. These two data sources were used in conjunction with one another to derive representative cross-sections and levee profiles.

A sample long-section of the Lake View Branch Canal details extracted from the LiDAR is shown in Figure 5-4. The figure shows the elevations of the left and right bank levee crests and the approximate water surface profile. It can be seen that there is typically around a 0.5m freeboard between the operating water level in the canal and the levee crest. A sample cross-section derived from the MI channel dimensions and LiDAR derived water surface profile is presented in Figure 5-5.

The channel network, represented as a 1D layer in the model, is dynamically linked to the 2D domains along the levees. Catchment runoff will back up behind the Branch Canal right bank levee until the water level exceeds that of the levee crest. The storage capacity within the channel will then be filled before the water spills over the left bank levee and progresses downstream into the study area. The Lake View Drain provides cross-catchment flow transfer from the Tharbogang Swamp catchment to Lake Wyangan and is modelled similarly to the Branch Canal. The modelled channel network, which consists of a length of approximately 46km, is shown in Figure 5-2.



Title:

Modelled Land Use Map

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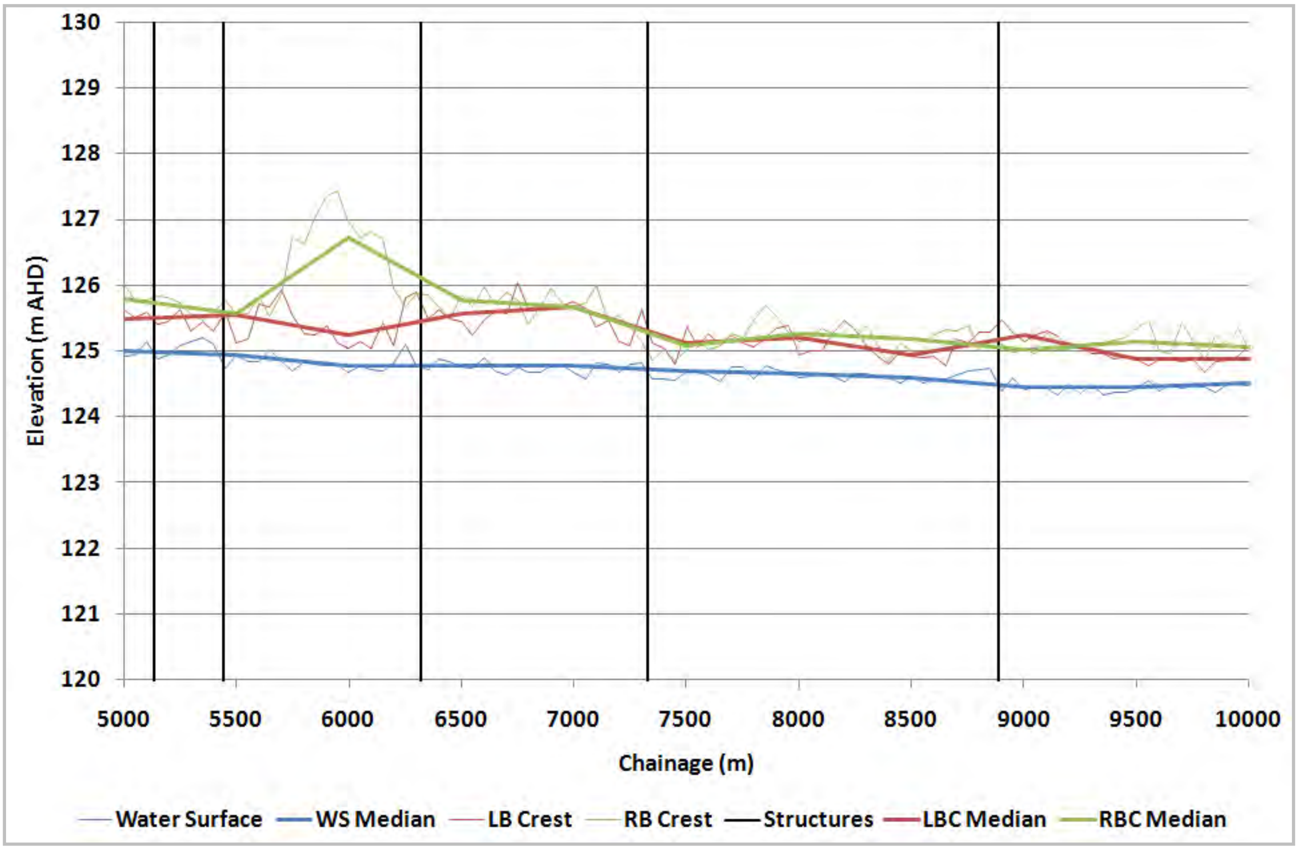


Figure 5-4 Sample Channel Long-Section

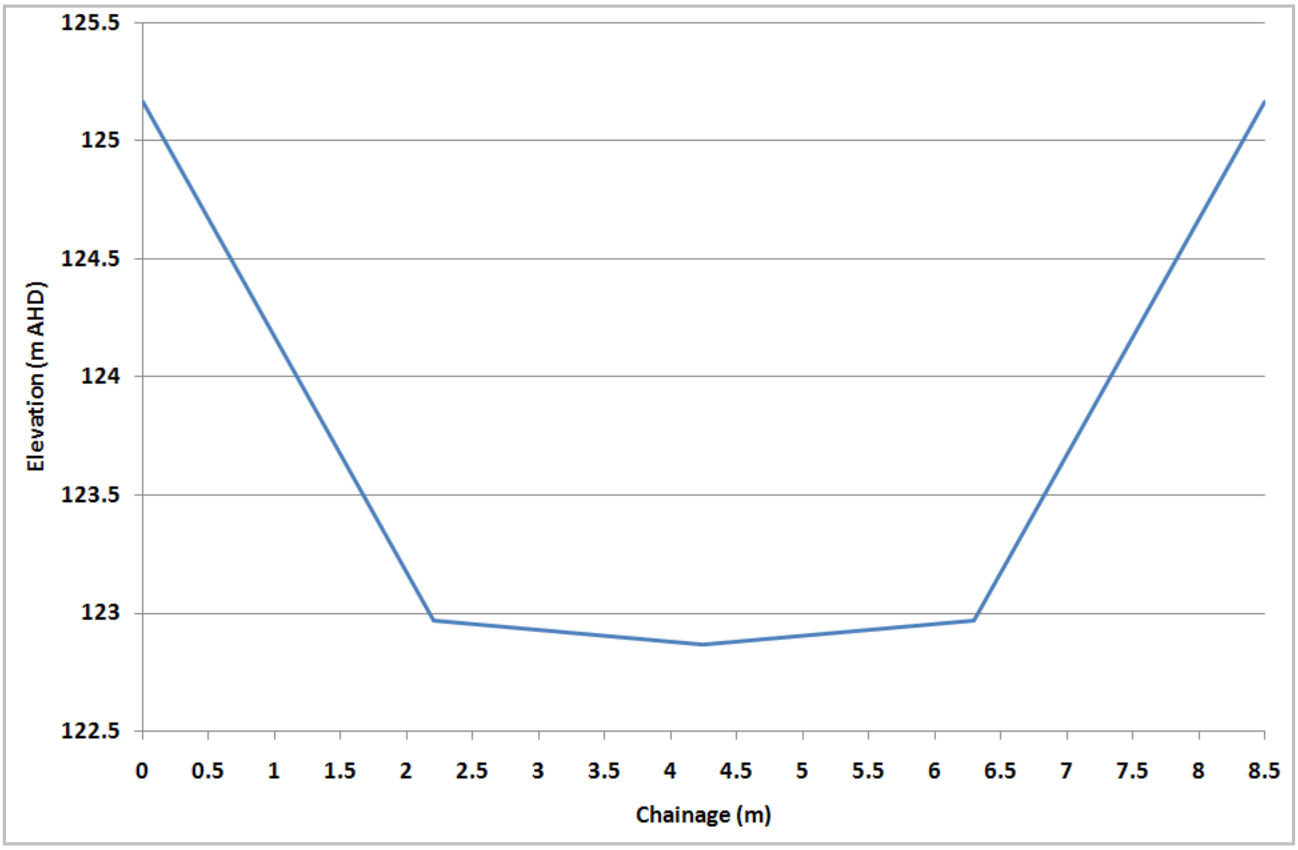


Figure 5-5 Sample Channel Cross-Section

There are a number of water level control structures located along the Lake View Branch Canal, at a typical interval of 1.5km. These have been modelled as weir structures, with levels set at the required elevation to maintain the appropriate water level in the channel. There are 16 such structures included within the modelled channel network.

For the magnitude of events under consideration in the study, the storage capacity within the Lake View Branch Canal is expected to be well exceeded, with the major proportion of flow spilling over the levee and progressing downstream into the study area. Therefore any limitations in the available data or model representation of the drainage system may not have a significant effect on calculated flood levels for the major flood events considered.

There are a large number of local rural drainage channels which have not been explicitly modelled. However, embankments related to these channels will be captured to some extent by the model elevations. These channels are primarily for local agricultural supply and drainage of irrigation water and do not have a significant impact on the catchment flood behaviour. The extent of Murrumbidgee Irrigation supply and drain canal infrastructure is presented in Figure 5-6.

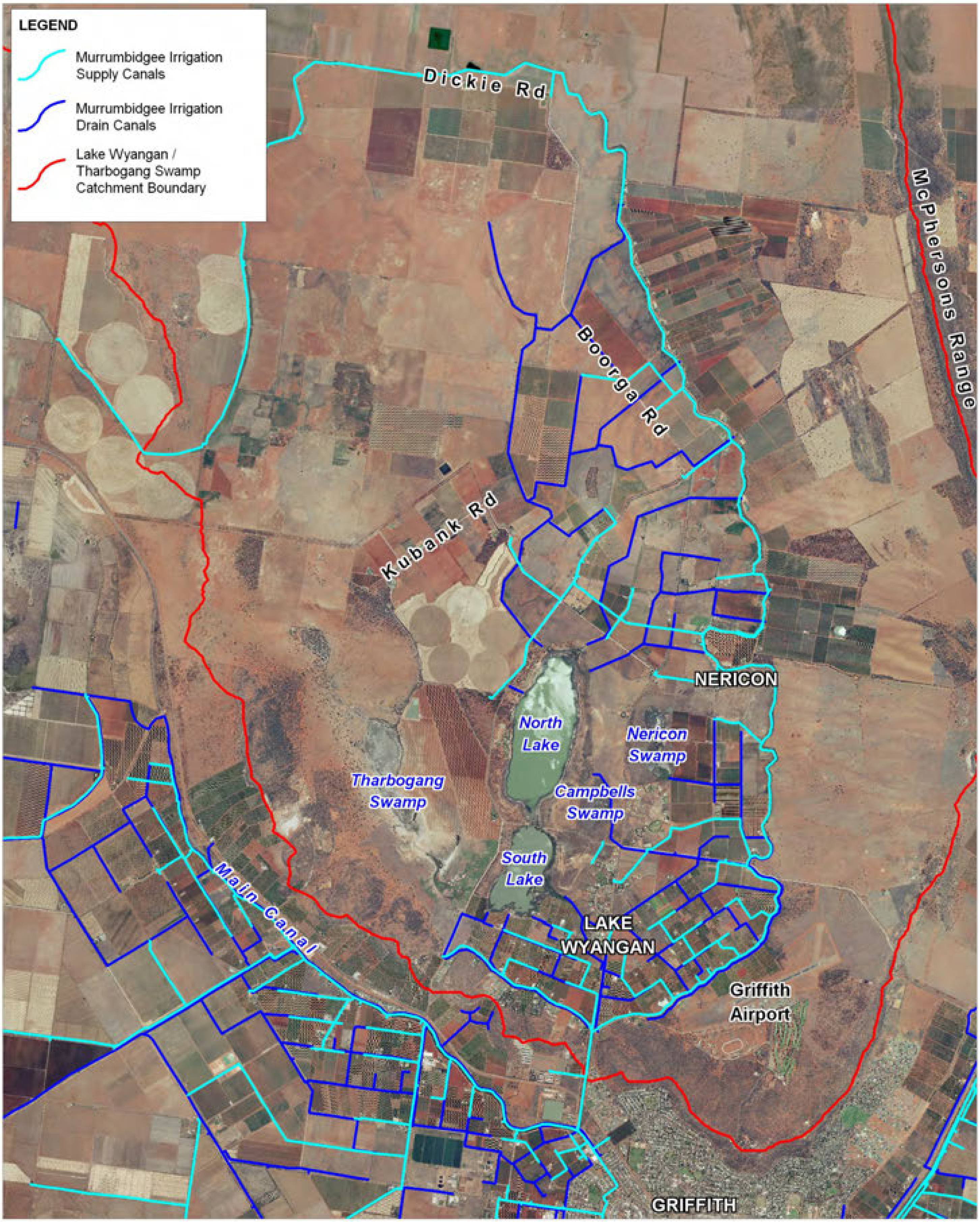
5.2.5 Cross-Drainage Structures

The Lake View Branch Canal presents a significant barrier to the progression of catchment runoff and cross-drainage infrastructure exists to convey catchment runoff under the canal. Through the site inspections the configuration of these cross-drainage structures has been found to typically comprise a single siphon of around 600mm diameter. There are 16 such cross-drainage structures which have been included in the hydraulic model, the locations of which are indicated on Figure 5-7. It can be seen that the cross-drainage locations generally correspond to the presence of incoming overland flow paths.

5.2.6 Boundary Conditions

The catchment runoff is determined through the hydrological component of the model and is applied directly to the TUFLOW model 2D domain, where it is routed as sheet flow until the runoff contribution is substantial enough to generate an overland flow path. Flow is transferred to the 1D domain where the levee crest of the channels is exceeded. Spilling of the channels occurs from the 1D to the 2D domain once the available storage capacity becomes exceeded. The 1D/2D linked model representation of the Lake View Branch Canal provides the boundary between the 60m resolution 2D domain of the broader catchment with the 10m resolution 2D domain of the study area.

A constant flow rate of $1m^3/s$ has been input to the upstream end of the Lake View Branch Canal and is extracted from the downstream end of the canal. This is representative of typical irrigation supply rates as documented in the Lake Wyangan Case Study (Umwelt, 2004). This representation ensures that excess flood flow inputs to the channel will spill over the left bank levee and into the study area, rather than being lost from the catchment via the downstream end of the Branch Canal. The irrigation supply off-takes from the Branch Canal have not been explicitly modelled, but in reality would likely convey flood flows from the canal downstream to the Lake Wyangan and Tharbogang Swamp storages. Whilst assuming no flow is lost from the catchment via the Branch Canal is a conservative approach, it is considered appropriate to compensate for the unaccounted conveyance of flood flows through the supply off-takes.



Title:

Murrumbidgee Irrigation Supply and Drain Canal Infrastructure

Figure: 5-6

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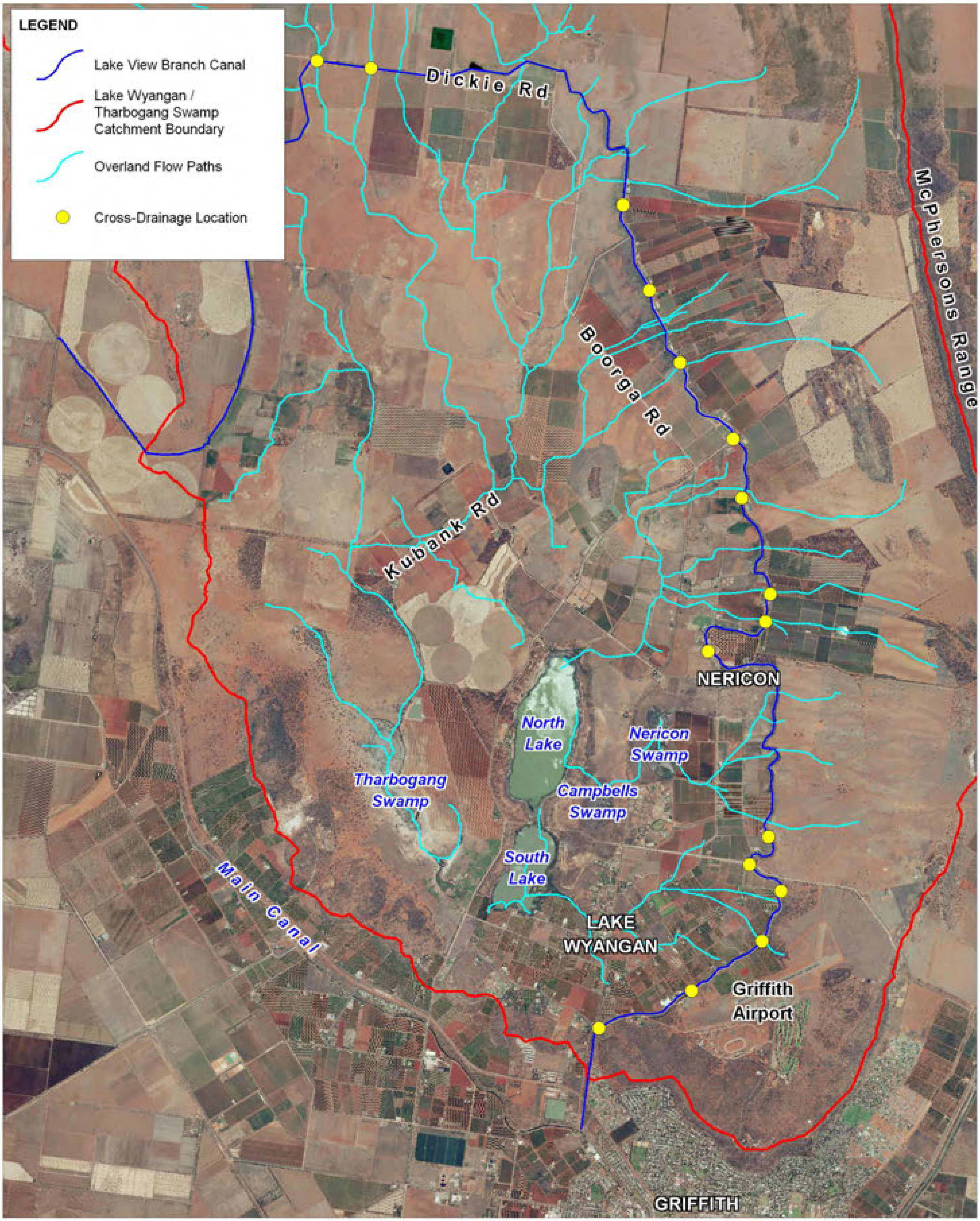

Title:
Cross-Drainage Structure Locations

Figure: 5-7

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Most of the modelled area drains to the Lake Wyangan or Tharbogang Swamp and the initial water levels adopted in these storages form the downstream boundary conditions for the model. For model calibration the initial water levels preceding the events have been adopted where known. For design purposes initial water levels are similar to the prevailing conditions. There is a maximum potential pumping extraction from Lake Wyangan of around 60ML/day, as discussed in Section 6.3.1. Pumped extraction of water from Lake Wyangan following a flood event could help to reduce the peak flood level. However, given the available pump capacity and the stage-storage relationship of the Lake, the potential reduction in levels would be no more than 0.1m. Therefore, the operation of pumps during flood events is not significant and has been omitted from this study.

In addition to the initial water levels of the storages, a downstream boundary has been applied to the modelled portion of the upper Main Drain J catchment. This additional catchment area was modelled in order to determine the correct proportion of cross-catchment flows at the catchment boundary. The modelled boundary condition is a stage-discharge relationship based on the model topography and an appropriate slope value derived from the DEM. The boundary is situated far enough from the catchment divide whereby it will not influence the flow split between the Lake Wyangan / Tharbogang Swamp and Main Drain J catchments.

6 MODEL CALIBRATION

6.1 Selection of Calibration Events

The selection of suitable historical events for calibration of computer models is largely dependent on available historical flood information. Ideally the calibration and validation process should cover a range of flood magnitudes to demonstrate the suitability of a model for the range of design event magnitudes to be considered.

An analysis of water level changes recorded in Lake Wyangan was undertaken using the gauge readings provided by Murrumbidgee Irrigation. Water levels in the North and South Lakes have been recorded approximately once a week since June 1986. Water levels in Lake Wyangan typically increase or decrease by up to 0.1m per week, depending upon total inputs and outputs to the Lake system. The largest increase in lake level occurred in March 1989, following a significant rainfall event in the catchment on the 14th.

Only on another 12 occasions within the 25 year period of record has a level increase of greater than 0.2m been recorded between gauge readings. On these occasions there is no clear relationship to the recorded rainfall between gauge readings and so it is likely that these instances are attributed to something other than rainfall events. All of the 12 lake rises greater than 0.2m occur between the months of June and December, with over half of them being from August to October. Seasonal irrigation practice are likely to be responsible for these larger lake level rises.

The only other significant flood event identified through the community consultation process was the March 1985 event, which relates to the highest daily rainfall total in the catchment of 150mm (recorded at Griffith Airport). However, this event predates the available lake level and continuous rainfall records. There is little calibration data available for this event, but some photos and anecdotal evidence have been provided by members of the community.

January 1984 saw three significant (>5-year ARI) catchment rainfall events within a month and would likely have resulted in some flooding. However, these also predate the period of lake level and continuous rainfall records and no additional information is available from other sources, and accordingly are not useable for calibration purposes.

Video footage and additional anecdotal evidence was received for a December 2007 event. This event appears to be relatively localised, with no significant flooding across the broader Lake Wyangan catchment.

The March 1989 event is the only significant flood event for which lake level and continuous rainfall records are available. Accordingly, the calibration process is focussed primarily on this event. The December 2007 event is also considered as it is the only other recent catchment event for which some evidence of catchment flooding is available. The March 1985 event is used for model verification purposes as it is the largest event known to have occurred in the catchment. The model calibration therefore is based on the limited historical data available for the three events. The available data, modelling approach and model results for each of these events are discussed in further detail in the following sections.

6.2 Antecedent Conditions

The adopted antecedent catchment conditions are particularly important for model calibration as they can have a significant impact on the effective rainfall and associated catchment runoff volume. The period of March to April 1989 gives a good indication as to the response of the catchment to preceding periods of rainfall. A significant rainfall event occurred on 14th and 15th March 1989, totalling some 103mm at Griffith, which provided a flood response within Lake Wyangan. In the two weeks following this event there were a further two rainfall events, which produced a combined total of over 120mm rainfall depth. This additional rainfall did not produce a significant water level increase in Lake Wyangan. This suggests that despite the substantial wetting of the catchment following the 14th March event, the subsequent rainfall events produced no catchment runoff. The catchment soils appear to be well draining and quickly able to recover following periods of heavy rainfall. Based on this evidence, no adjustments were made to the initial loss parameter for any calibration event due to the preceding rainfall conditions.

6.3 March 1989 Model Calibration

6.3.1 Lake Level Records

Unfortunately, the peak water level during the lake's response to the 14th March 1989 event was not captured, as access to the level gauges was not possible. The first gauge reading following the event was taken on 7th April, once the water levels had dropped sufficiently to enable access to the gauge location. The gauge reading on 7th April corresponds to a lake level of around 106.7m AHD. As the water level is above that of Jones Road (at around 106.5m AHD) it can be assumed that the water levels in the north and south lakes were similar.

It is reasonable to assume the lake level to have been higher immediately following the event than three weeks later when the gauge reading was taken on 7th April. In this three week period, water levels may have been dropped in Lake Wyangan due to potential losses from the lake through evaporation and pumping operations.

Evaporation rates at Lake Wyangan vary from around 15mm/day in summer to 0mm/day in winter (Umwelt, 2004) and would be in the order of 5-10mm/day during March. Adopting a 10mm/day evaporation rate over 23 days provides a 230mm evaporation loss. Inspection of the daily rainfall data for Griffith Airport indicates that an additional 120mm of rain fell in that same 23 day period. Assuming that the lake level rose by around 120mm through direct rainfall with no additional rise from catchment runoff would yield around a 0.1m potential lake level decrease due to net evaporation loss.

Pumped extraction from Lake Wyangan can include the following three sources:

- Jones Road pumps at a 33ML/day capacity;
- DC'U' pumps at a 21ML/day capacity; and
- Various extraction licenses at a combined 6ML/day capacity.

The total volume that can potentially be pumped out of the lake in 23 days is therefore around 1,300ML. For water levels around 107m AHD the combined surface area of the north and south lakes is around 3.5km^2. This would allow for a maximum drawdown of lake levels by pumped extraction of around 0.4m over the 23 day period. Taking the combined potential lake losses from net evaporation and pumped extraction, the maximum possible peak water level following the March 1989 flood event is around 107.2m AHD.

The actual lake losses through pumped extraction are likely to be less than 0.4m as this is dependant on the maximum pump capacity being utilised for the full 23 day period. Also, the Jones Road pumps discharge into the LVBC, from which some of this water will be recycled back into the lake through the irrigation drains. Given further evidence of flooding at the south of Lake Wyangan (detailed further in Section 6.3.6), a target Lake Wyangan calibration level of 106.8m AHD has been adopted for the March 1989 event. This constitutes a volumetric increase of around 2,000ML from the catchment runoff.

6.3.2 Peak Swamp Storage Levels

In addition to the north and south lakes there are a number of significant swamp storages located within the catchment for which no water level records are available. These include:

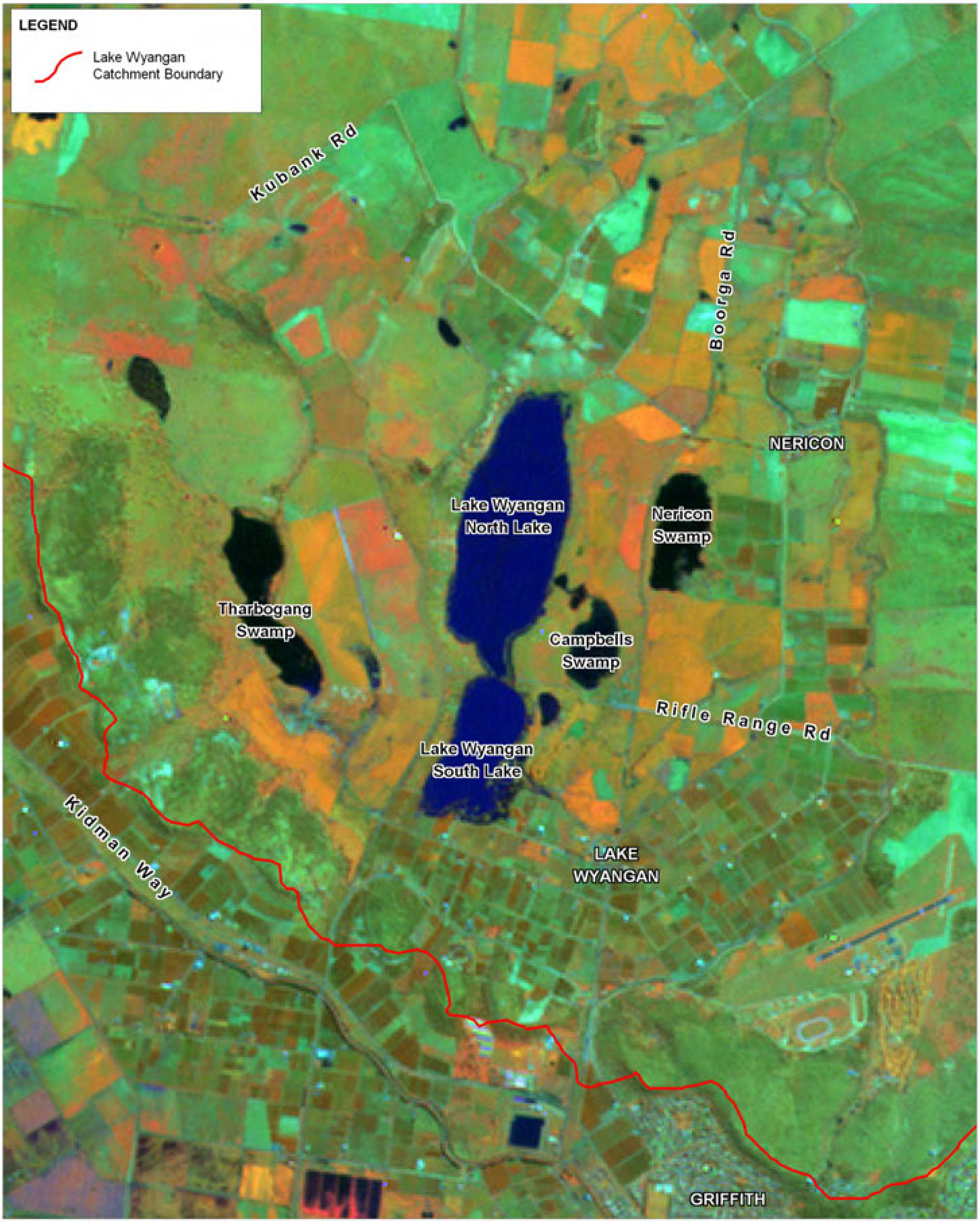
- Tharbogang Swamp;
- Nericon Swamp; and
- Campbells Swamp.

The location of these swamps is shown in Figure 6-1. The background mapping is a Landsat 5 image captured on 15th April 1989. It is a false colour composite image using bands 4, 5 and 3 (Near-infrared, Mid-infrared and Red). This combination of bands is useful for identifying water bodies and water content of soils etc. Open water bodies are clearly defined as blue or black areas. The elevated water levels of Lake Wyangan are notable in the image, including the flooding over Jones Road between the north and south lakes. A gauge reading in the north lake was taken the day before on 14th April and indicates a water level of around 106.7m AHD. Inspection of the satellite image against elevation contours from the LiDAR DEM around the southern shore of Lake Wyangan show the lake extent to fall between the 106.5m and 107.0m contours (consistent with the MI water level record). The satellite imagery therefore seems to be a reliable source for estimating water levels within the various swamp storages of the catchment.

The extent of open water in the swamps has been compared to the LiDAR DEM contours to assess the approximate water levels on 15th April. The net evaporation over the 30 day period between the calibration event and the satellite image has been estimated at around 0.1m. Taking this into account the following peak water levels have been derived for the swamp storages:

- 104.5m AHD in Tharbogang Swamp;
- 113.7m AHD in Nericon Swamp; and
- 109.0m AHD in Campbells swamp.

The natural catchment of Tharbogang swamp is around 750km^2 in size – some 90% of the total Lake Wyangan study area catchment. The water volume within Tharbogang swamp is an indicator of the runoff volume generated from the upper and middle Lake Wyangan study area catchment. A water level of 104.5m AHD is equivalent to around 700ML storage volume.



Title:

Swamp Storages in the Lake Wyangan Catchment Following the March 1989 Event

Figure: 6-1

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The combined Nericon Swamp and Campbells Swamp catchments total around $15km^2$, which is significant compared to the remaining catchment of $100km^2$ which contributes to the north and south lakes. Campbells and Nericon Swamps must have their available storage capacity exceeded before runoff from their catchments contributes to the north lake. This is far more likely to occur for Campbells Swamp than it is for Nericon.

6.3.3 Rainfall Data

The distribution of rainfall gauge locations in the vicinity of the Lake Wyangan catchment was shown in Figure 2-2 with their respective periods of record shown in Table 2-1. The gauges that best represent rainfall within the catchment are Griffith Airport, Rankins Springs (Acres) and Rankins Springs. These stations have recorded rainfall depth totals of 103mm, 71mm and 63mm respectively for the two day period 14^{th} – 15^{th} March 1989.

The hourly rainfall record for the March 1989 event recorded at the CSIRO Hanwood gauge is provided in Table 6-1. The record shows that the storm lasted around 15 hours, during which time around 103mm rainfall depth was recorded. It started in the early hours of 14^{th} March, lasting until late afternoon on 15^{th}. This record has been adopted as the temporal pattern for the catchment rainfall used in the model calibration process.

Table 6-1 Hourly Rainfall Record for the March 1989 Event

Time	Rainfall (mm)	
14/03/1989 01:00	0.0	14^{th} March Daily Rainfall
14/03/1989 02:00	0.0	
14/03/1989 03:00	3.0	
14/03/1989 04:00	6.1	
14/03/1989 05:00	5.3	
14/03/1989 06:00	6.9	
14/03/1989 07:00	8.4	
14/03/1989 08:00	5.1	
14/03/1989 09:00	8.1	
14/03/1989 10:00	12.9	15^{th} March Daily Rainfall
14/03/1989 11:00	11.7	
14/03/1989 12:00	9.1	
14/03/1989 13:00	5.6	
14/03/1989 14:00	8.4	
14/03/1989 15:00	5.8	
14/03/1989 16:00	5.1	
14/03/1989 17:00	1.0	
14/03/1989 18:00	0.0	
14/03/1989 19:00	0.3	
14/03/1989 20:00	0.3	
14/03/1989 21:00	0.0	
14/03/1989 22:00	0.0	
14/03/1989 23:00	0.0	
15/03/1989 00:00	0.3	

The spatial variation of rainfall depth for the March 1989 event has been analysed using the recorded daily rainfall totals at rainfall gauges in the vicinity of the Lake Wyangan catchment. The locations of the rain gauges together with their recorded rainfall depths for the March 1989 event are presented in Figure 6-2. The event rainfall depths were obtained from BoM and are a summation of the recorded rainfall depths for 14th and 15th March. A continuous surface of rainfall depths was interpolated from the point recordings. Rainfall depth contours extracted from this interpolation at 5mm intervals are included on Figure 6-2 to show the spatial variation of total rainfall depths for the March 1989 event across the Lake Wyangan catchment and the wider region.

It can be seen from Figure 6-2 that the band of heaviest rainfall is aligned approximately east to west and is situated over the southern end of the catchment. Rainfall depths decrease gradually to the south and more markedly to the north. A rainfall depth of 71mm was recorded at the Rankins Springs (Acres) gauge in the middle of the catchment. The rainfall depth reduced further still in the upper catchment, with a total of 63mm recorded at the Rankins Springs gauge. There is a consistent pattern in the recorded rainfall depths and this provides for a good interpolation.

To gain an appreciation of the relative intensity of the March 1989 event, the derived rainfall depths for various storm durations at three rain gauge locations is compared with the design IFD data for Lake Wyangan as shown in Figure 6-3.

The derived depth vs. duration profile for the March 1989 event from the adopted temporal pattern shows a storm containing no prominent intense rainfall burst. It shows a fairly consistent rainfall intensity, with the event steadily increasing in magnitude until a duration of around 13 hours, which is close to the total duration of the event. As a 13-hour duration storm the March 1989 event is equivalent to the design 1% AEP (100-year ARI) rainfall at Griffith Airport. Further up the catchment at the other two rain gauges the magnitude of 13-hour duration rainfall total is closer to a design 10% AEP (10-year ARI) event.

6.3.4 Initial Storage Conditions

The adopted initial water level conditions are particularly important for model calibration in the Lake Wyangan catchment as the water levels in the various storages at the onset of an event will have a significant impact on the peak flood levels. The runoff volume reaching the lake and swamp storages raises the water levels according to the stage-storage relationship above the initial water levels. For the north and south lakes gauged water levels are available from four days before the event on 10th March. These levels can readily be adopted as the initial lake levels for the model.

For the estimation of initial water levels in the remaining storages a similar approach was adopted to that described in Section 6.3.2, utilising available satellite imagery. A Landsat 5 image captured on 24th January 1989 was used to determine approximate water levels in the various swamp storages at the onset of the event. There is a period of 50 days between the available satellite image and the storm event, during which time only 37mm of rainfall was recorded at Griffith Airport. Evaporation rates are likely to have been in the order of 500mm for that period, assuming an average rate of 10mm/day. Therefore, water levels have been estimated from the 24th January satellite image using the LiDAR DEM and have been adjusted by -0.5m to determine the initial water level estimates.

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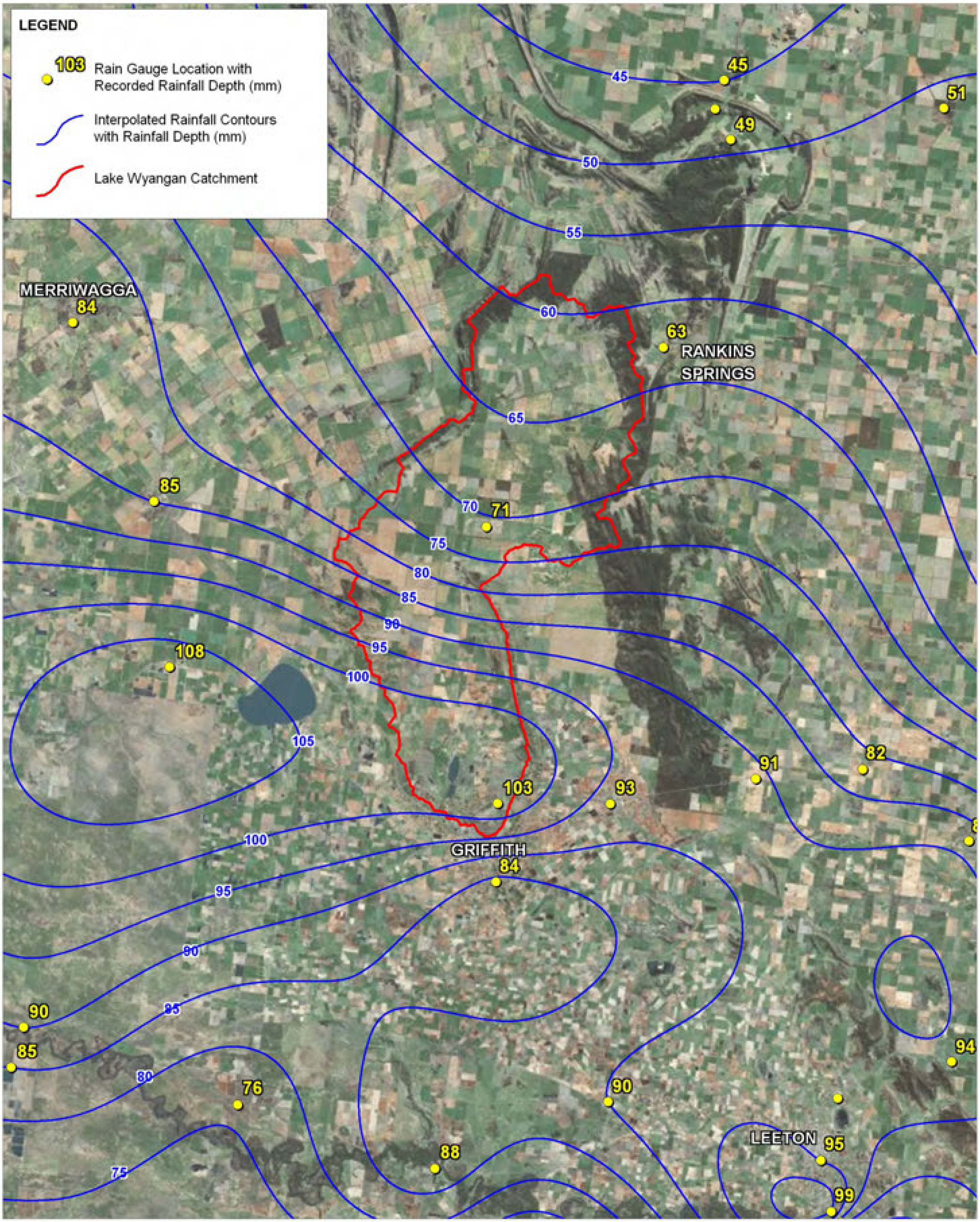

Title:
Spatial Variation of Rainfall Depths for the March 1989 Event

Figure: 6-2

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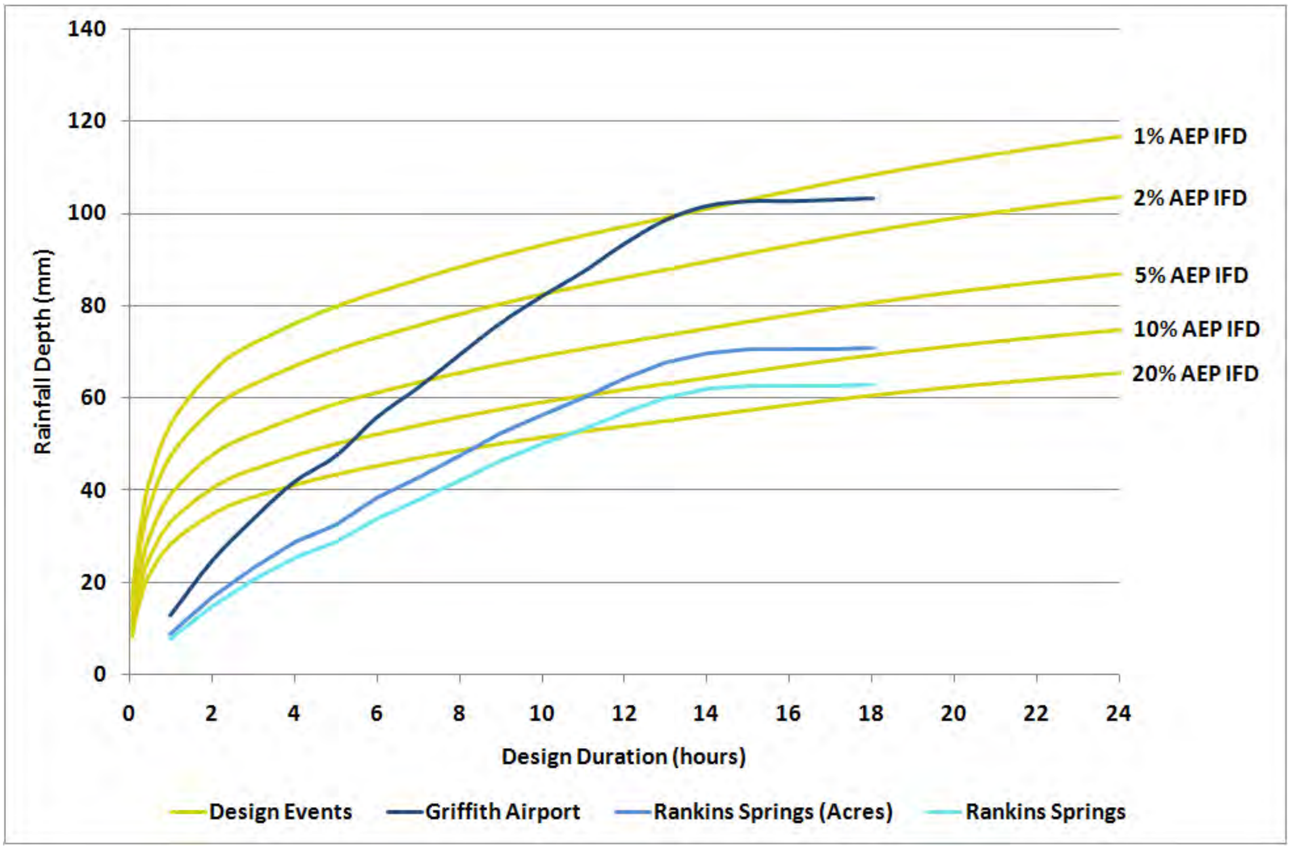


Figure 6-3 Comparison of Derived March 1989 Rainfall with IFD Relationships

The initial water level conditions adopted for each of the significant catchment storages are summarised below:

- 106.2m AHD in Lake Wyangan North Lake;
- 106.2m AHD in Lake Wyangan South Lake;
- 103m AHD in Tharbogang Swamp;
- 112.5m AHD in Nericon Swamp; and
- 108.5m AHD in Campbells Swamp.

The water levels in Lake Wyangan are typical of average lake conditions during non-drought conditions. The levels in Tharbogang and Nericon Swamps represent an effectively empty condition in each and Campbells Swamp has a reasonable depth of water.

6.3.5 Rainfall Losses

The initial loss-continuing loss model has been adopted in the TUFLOW model developed for the Lake Wyangan catchment. The initial loss component represents a depth of rainfall effectively lost from the system and not contributing to runoff and simulates the wetting up of the catchment to a saturated condition. The continuing loss represents the rainfall lost through soil infiltration once the catchment is saturated and is applied as a constant rate (mm/hr) for the duration of the runoff event.

As the Lake Wyangan catchment is a closed system the peak flood levels are driven by the runoff volume from any given event. The amount of rainfall lost through infiltration and surface storage therefore has a significant impact on the water levels attained in Lake Wyangan and the other swamp storages. The runoff total runoff volume and associated peak storage levels are therefore highly sensitive to changes in adopted rainfall losses. As such, the focus of the calibration process was to determine appropriate initial and continuing loss parameters for the catchment to best represent total volumetric runoff. Other factors such as flow routing through the catchment, roughness parameters and local hydraulic controls are much less influential and there is insufficient data available to calibrate these.

A number of calibration permutations were undertaken, utilising various combinations of initial and continuing loss values. The most appropriate rainfall loss conditions for generating the required volume of catchment runoff reaching Lake Wyangan and Tharbogang Swamp were found to be an initial loss of 60mm and a continuing loss of 4mm/h. Losses for urban areas of the catchment were set to 35mm and 1.5mm/h. The adopted rainfall losses are discussed in more detail in Section 6.6.

These relatively high loss values result in little effective rainfall to generate catchment runoff. The total and effective rainfall hyetographs for Griffith Airport and Rankins Springs (Acres) gauge locations are presented in Figure 6-4 and Figure 6-5 respectively for the March 1989 event. At Griffith Airport, where the most intensive rainfall in the catchment was located, the generation of effective rainfall does not initiate until halfway through the event. Only around 19mm of effective rainfall occurs before the rainfall intensity falls beneath the continuing loss of 4mm/h. At Rankins Springs (Acres), which is around halfway up the catchment, the total rainfall depth reduced to 71mm. This substantially reduces the effective rainfall generated from this area of the catchment. Less than 1mm of effective rainfall occurs towards the end of the event, once the initial loss is exceeded. The rainfall intensity then falls beneath 4mm/h and no further effective rainfall is generated.

Figure 6-6 shows the modelled rainfall distribution across the catchment, which divided the catchment into ten bands of varying rainfall depth. The total and effective rainfall depths for each band are shown on the figure and demonstrate the relatively small effective rainfall depths across the catchment. The upper catchment area generates virtually no effective rainfall or corresponding runoff. The lower half of the catchment only averages around 15mm effective rainfall. These relatively small amounts of effective rainfall make the catchment and model highly sensitive to event rainfall depths and temporal patterns. The modelled effective rainfall represents around 4,300ML of catchment runoff volume.

6.3.6 Observed and Simulated Flood Behaviour

The two key calibration points for the March 1989 event are the peak water levels for Lake Wyangan and Tharbogang Swamp, which are the locations to which the majority of the catchment runoff drains. The flood levels in these two storages have been estimated as 106.8m AHD and 104.5m AHD respectively, as discussed in Section 6.3.1 and Section 6.3.2. Figure 6-7 shows a flood photograph taken on a farm property at the south-west corner of Lake Wyangan. An assessment of flood extents shown in this and a number of other supporting photos against the topography of the LiDAR data has determined a best estimate of the water level to be around 106.8m AHD.

Figure 6-8 shows the modelled flood extents for the March 1989 event. The approximate location of the photograph presented in Figure 6-7 is indicated by the arrow. The red line is the 107m AHD elevation contour, extracted from the LiDAR DEM. Additional anecdotal evidence suggests that the March 1989 flood waters extended to but not beyond Todd Road. It can be seen from Figure 6-8 that

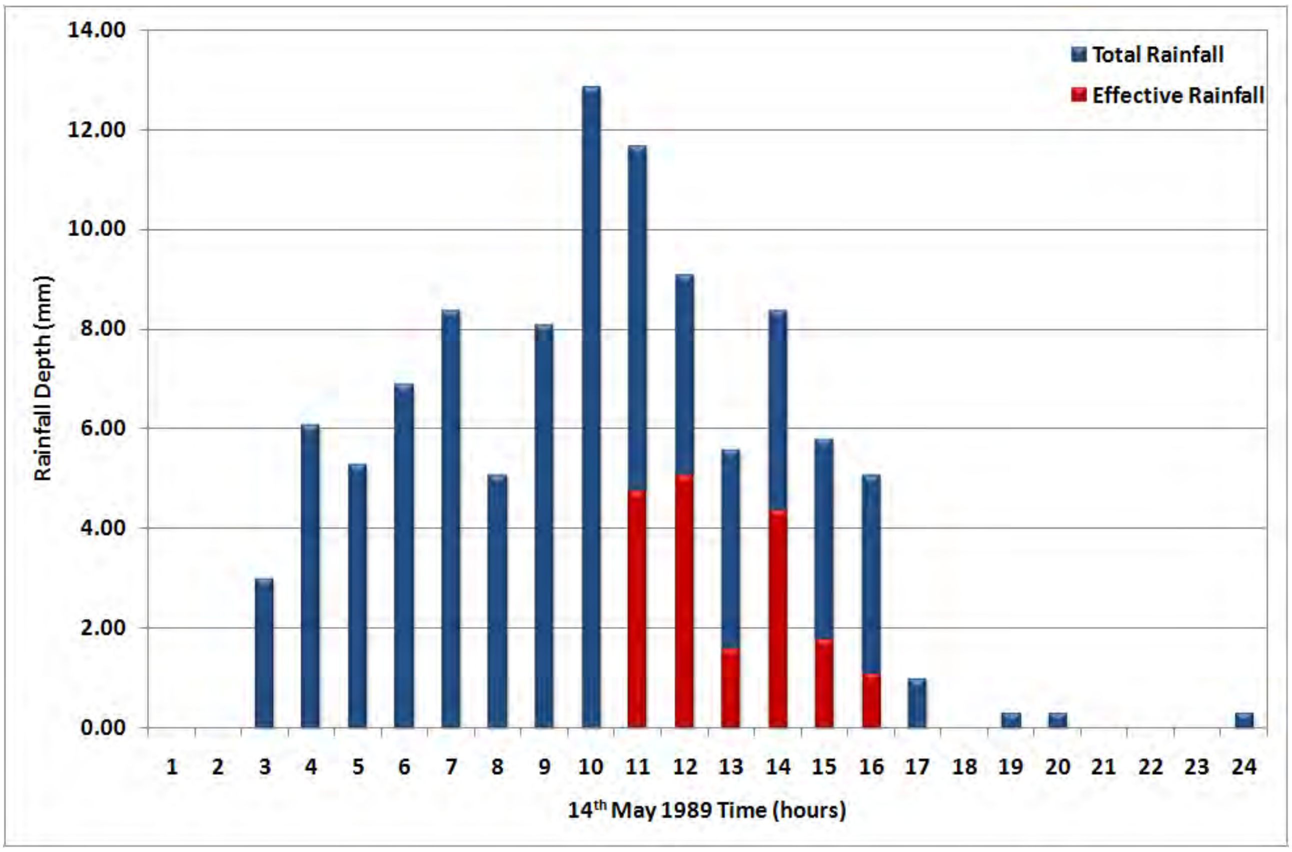


Figure 6-4 Effective Rainfall for the March 1989 Event at Griffith Airport

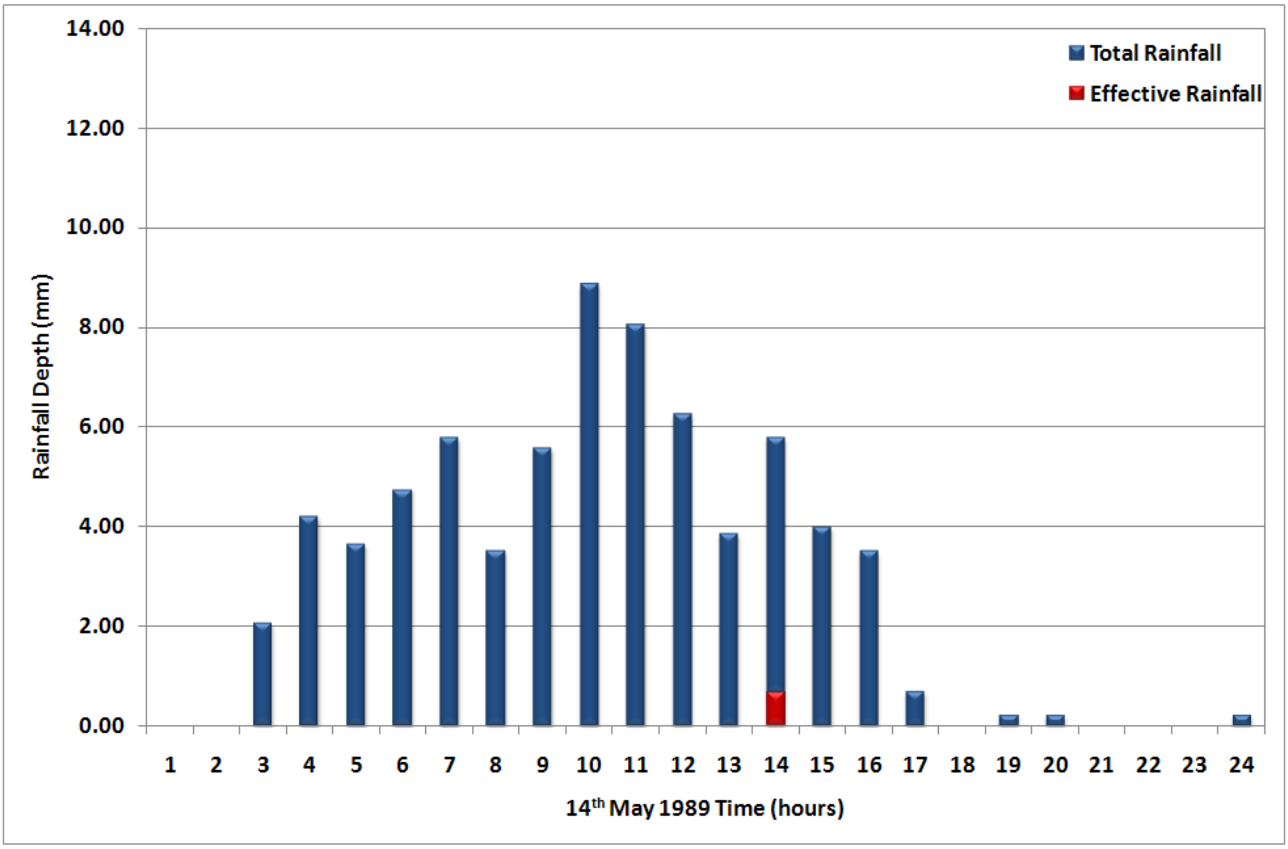
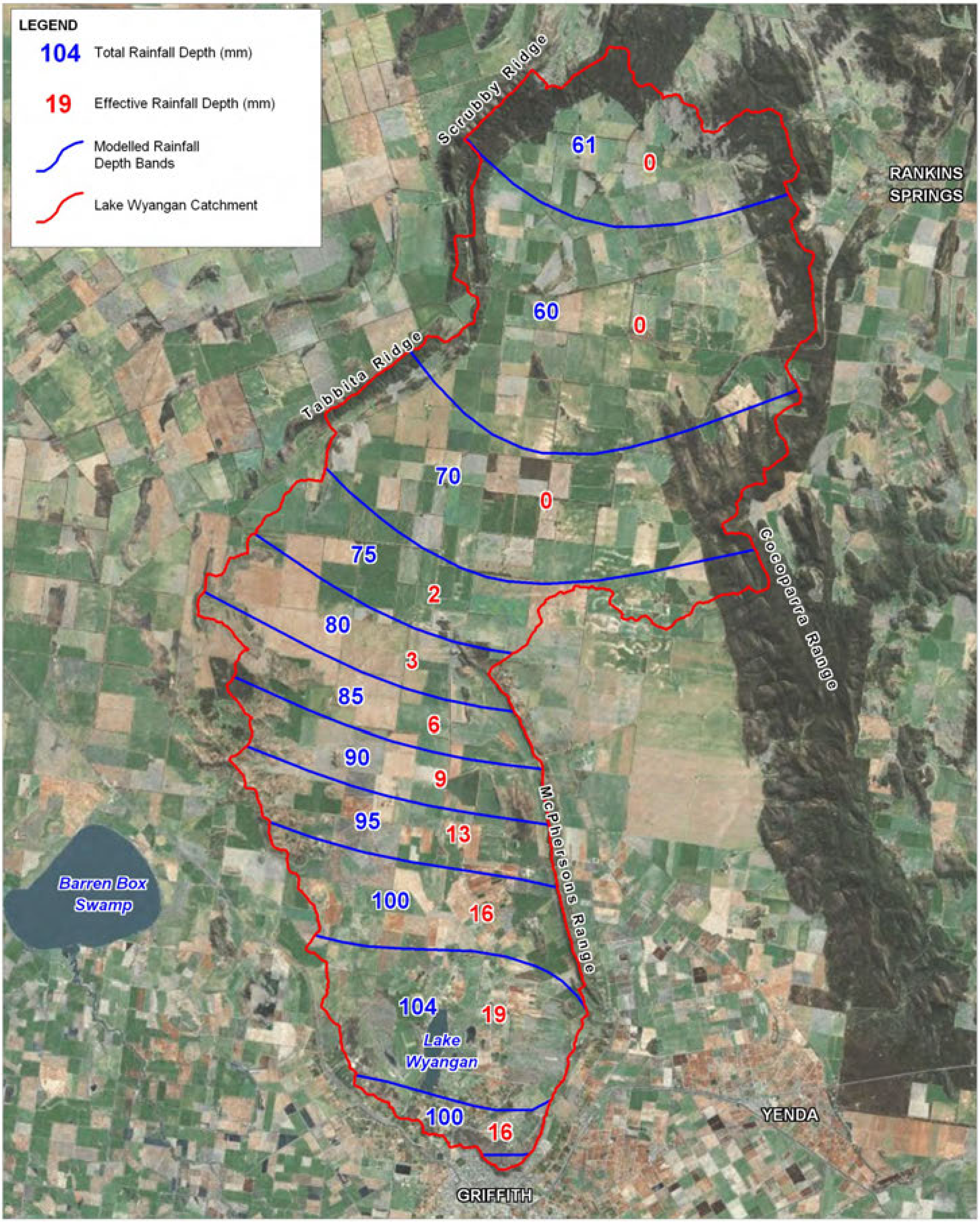


Figure 6-5 Effective Rainfall for the March 1989 Event at Rankins Springs Acres



Title:
Modelled Effective Rainfall for the March 1989 Event

Figure: 6-6

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Approx. Scale

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Filepath : K:\N2038_Lake_Wyangan_Flood_Study\MapInfo\Workspaces\DRG_014_110718_Mar89_Effective_Rainfall.WOR

Figure 6-7 Flood Photograph of Lake Wyangan for the March 1989 Event

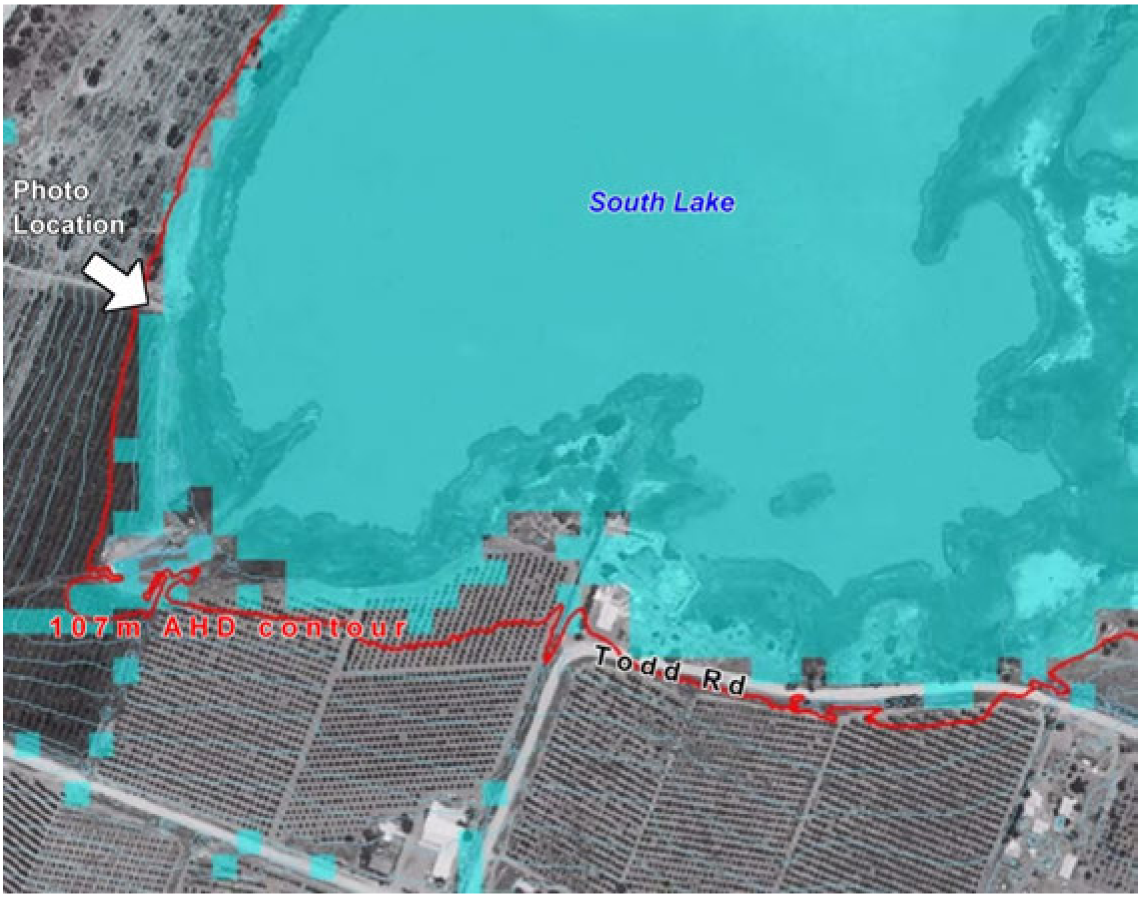


Figure 6-8 Modelled Lake Wyangan Flood Extents for the March 1989 Event

Todd Road sits between the modelled flood extent and the 107m contour. This supports the adopted peak flood level of 106.8m AHD for the March 1989 event over that of 107.5m AHD, as discussed in Section 6.3.1.

In addition to these locations, the peak water levels for Nericon Swamp and Campbells Swamp are also useful for assessing the calibration of model runoff volumes, but are not as significant as the two key storages. The best estimate of flood levels for Nericon and Campbells Swamps are 113.7m AHD and 109m AHD respectively, as discussed in Section 6.3.2. The modelled flood levels in these storages were as follows:

- 106.7m AHD in Lake Wyangan;
- 105.2m AHD in Tharbogang Swamp;
- 113.5m AHD in Nericon Swamp; and
- 108.7m AHD in Campbells Swamp.

The model results compare reasonably with the estimated peak flood levels, being within 0.3m at most calibration points. The model is tending to under-predict the flood levels in most of the storages, but within acceptable bounds given the inherent uncertainty of the available rainfall data and sensitivity of the catchment to small changes in effective rainfall. As mentioned in Section 6.3.1, there was an additional 120mm of rainfall in the south of the catchment within the three weeks following the March 1989 event. It has been assumed that this rainfall, which largely fell in two separate events, resulted in no additional catchment runoff. However, the storage levels may have been supplemented to some extent by this additional rainfall (and potentially also by baseflow from the 14th March event). If this was the case then the target calibration levels for the March 1989 event would have been slightly lower. It is therefore preferable for the model to under-predict than over-predict flood levels in Lake Wyangan for this event, considering the conditions over the weeks between the event and the available calibration data.

The target runoff volume contributing to the storage in Lake Wyangan and Tharbogang Swamp was around 2,700ML. The modelled effective rainfall generated around 4,300ML of runoff volume, of which around 2,900ML contributed to the peak storage levels in Lake Wyangan and Tharbogang Swamp. The remaining runoff volume is attributed to numerous local catchment storages and losses to the LVBC. The model is highly sensitive to the rainfall loss parameters and the impacts of this sensitivity are discussed in Section 6.6.

6.4 December 2007 Model Validation

The December 2007 event was used to validate model parameters adopted through the calibration of the March 1989 event. The event was known to be a short, intense burst of rainfall on the evening of 21st December, which resulted in little response in Lake Wyangan but did result in some local flooding further up the catchment.

6.4.1 Lake Level Records

The lake levels were recorded on the day of the event and ten days later on 31st December. They show only a 0.15m level increase in the north lake and a 0.04m increase in the south lake. These are similar to the usual weekly variations experienced in the lake and so it is difficult to derive appropriate target calibration levels. However, the records do suggest that a small amount of catchment runoff may have entered Lake Wyangan.

6.4.2 Peak Swamp Storage Levels

Landsat 7 images are available before and after the event on 20th December and 5th January. The images show no real discernable differences to the storages of Nericon and Campbells Swamps, both of which are in a fairly dry condition. Tharbogang Swamp shows the storage level following the event to be between 103.5m and 104m AHD. Given the substantial evaporation that is likely to have occurred over the two weeks following the event (in which time there was no additional rainfall), a target level of 104m AHD is deemed appropriate.

6.4.3 Rainfall Data

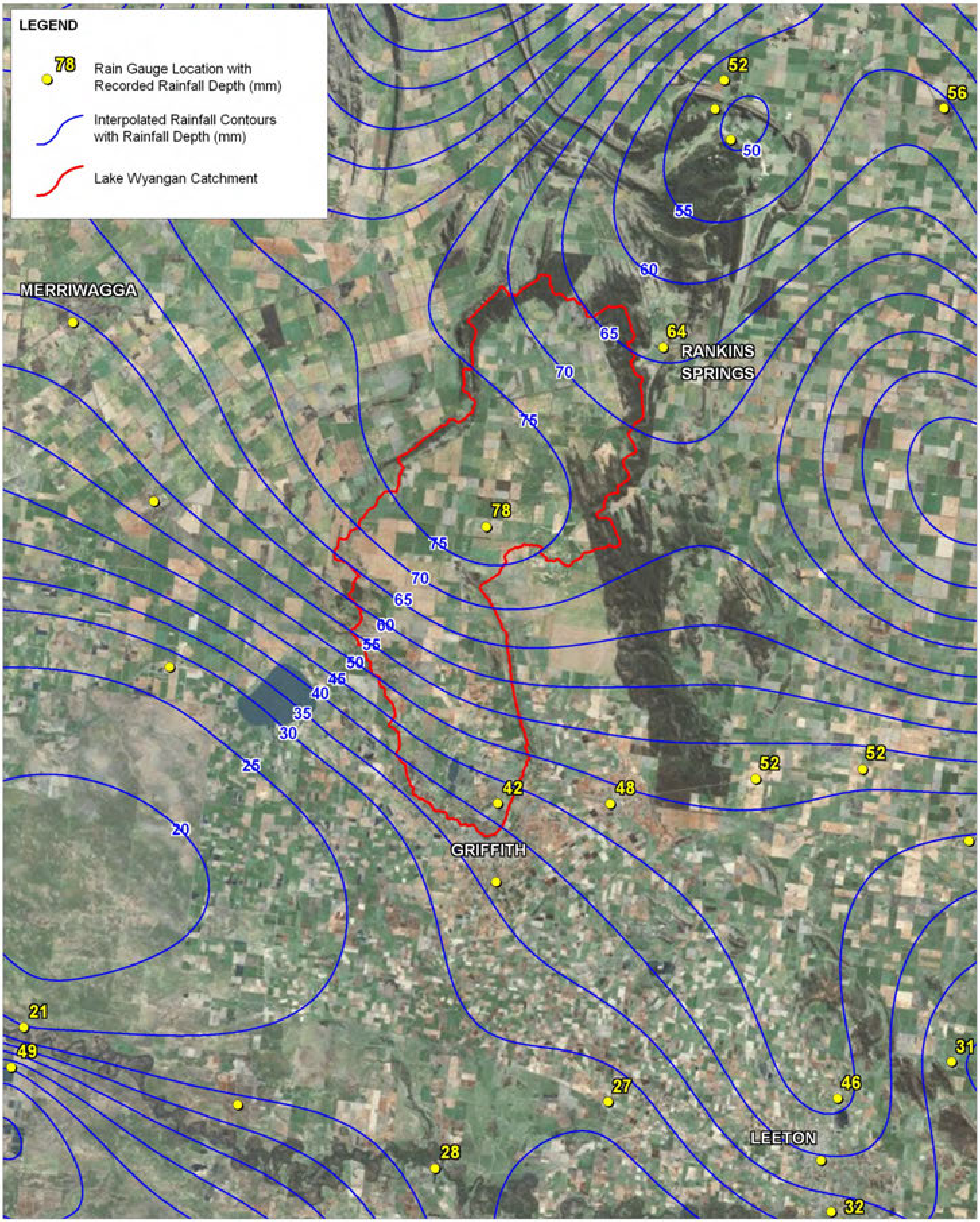
The distribution of rainfall gauge locations in the vicinity of the Lake Wyangan catchment was shown in Figure 2-2 with their respective periods of record shown in Table 2-1. The gauges that best represent rainfall within the catchment are Griffith Airport, Rankins Springs (Acres) and Rankins Springs. These stations have recorded rainfall depth totals of 42mm, 78mm and 64mm respectively for 22nd December 2007.

The continuous rainfall record for the December 2007 event recorded at the Griffith Airport AWS gauge is provided in Table 6-2. The record shows that the storm lasted around five hours, during which time around 41mm rainfall depth was recorded. It occurred on the evening of 21st December, which is part of the 22nd December daily rainfall record This record has been adopted as the temporal pattern for the catchment rainfall used in the model verification process.

Table 6-2 Hourly Rainfall Record for the December 2007 Event

Time	Rainfall (mm)	
21/12/2007 15:30	0.0	22nd December Daily Rainfall
21/12/2007 16:00	0.4	
21/12/2007 16:28	10.6	
21/12/2007 16:55	2.0	
21/12/2007 17:24	0.8	
21/12/2007 17:34	3.6	
21/12/2007 18:00	6.4	
21/12/2007 18:24	0.2	
21/12/2007 19:00	9.6	
21/12/2007 19:30	4.6	
21/12/2007 20:00	2.0	
21/12/2007 20:30	0.8	
21/12/2007 21:00	0.0	

The spatial variation of rainfall depth for the December 2007 event has been analysed using the recorded daily rainfall totals at rainfall gauges in the vicinity of the Lake Wyangan catchment. The locations of the rain gauges together with their recorded rainfall depths for the December 2007 event are presented in Figure 6-9. The event rainfall depths were obtained from BoM and are the recorded rainfall depths for 22nd December. A continuous surface of rainfall depths was interpolated from the



Title:

Spatial Variation of Rainfall Depths for the December 2007 Event

Figure: 6-9

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Approx. Scale

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Filepath : K:\N2038_Lake_Wyangan_Flood_Study\MapInfo\Workspaces\DRG_016_110719_Dec07_Rainfall.WOR point recordings. Rainfall depth contours extracted from this interpolation at 5mm intervals are included on Figure 6-9 to show the spatial variation of total rainfall depths for the December 2007 event across the Lake Wyangan catchment and the wider region.

It can be seen from Figure 6-9 that the area of heaviest rainfall is situated over the middle of the catchment. Rainfall depths decrease gradually to the north-east and more markedly to the south-west. There is a sparser distribution of available recorded rainfall depths than for the March 1989 event, but still a reasonable interpolation is achieved.

To gain an appreciation of the relative intensity of the December 2007 event, the derived rainfall depths for various storm durations at three rain gauge locations is compared with the design IFD data for Lake Wyangan as shown in Figure 6-10.

The derived depth vs. duration profile for the December 2007 event from the adopted temporal pattern shows a storm with two prominent intense rainfall bursts. The magnitude of the event is greatest at a four hour duration. As a four hour duration storm the December 2007 event is approaching the design 1% AEP (100-year ARI) rainfall at Rankins Springs (Acres). It is around a design 5% AEP (20-year ARI) event magnitude at Rankins Springs and a 20% AEP (approx. 5-year ARI) event magnitude at Griffith Airport.

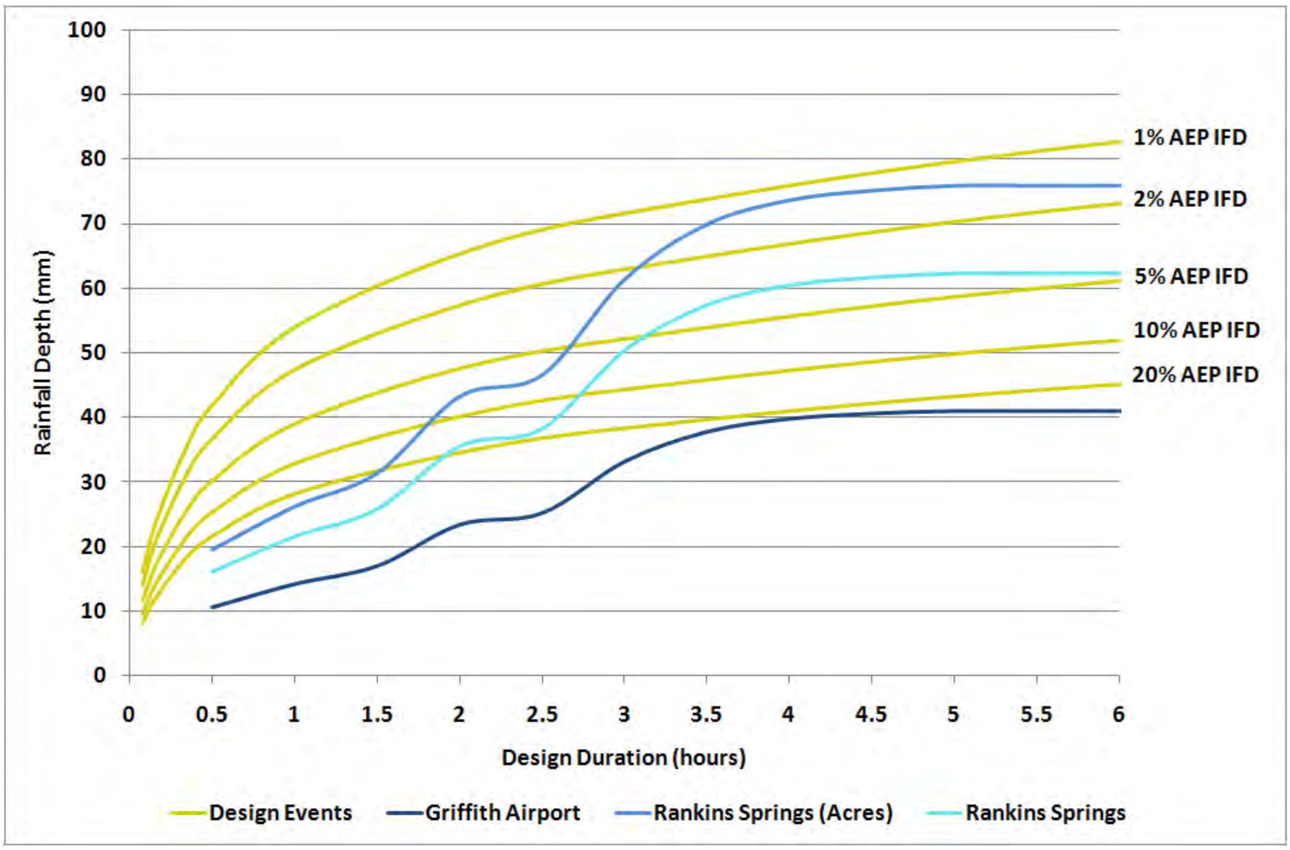


Figure 6-10 Comparison of Derived December 2007 Rainfall with IFD Relationships

6.4.4 Initial Storage Conditions

For the north and south lakes gauged water levels are available on the day of the event on 21st December. These levels can readily be adopted as the initial lake levels for the model.

For the estimation of initial water levels in the remaining storages a similar approach was adopted to that described in Section 6.3.2, utilising available satellite imagery. A Landsat 7 image captured on 20th December 2007 was used to determine approximate water levels in the various swamp storages at the onset of the event. As the image was captured the day before the event there is no need to correct the levels for rainfall and evaporation. Therefore, water levels have been estimated directly from the 20th December satellite image using the LiDAR DEM.

The initial water level conditions adopted for each of the significant catchment storages are summarised below:

- 104.5m AHD in Lake Wyangan North Lake;
- 105.3m AHD in Lake Wyangan South Lake;
- 103m AHD in Tharbogang Swamp;
- 112.5m AHD in Nericon Swamp; and
- 107.5m AHD in Campbells Swamp.

The water levels in Lake Wyangan South Lake are typical of average lake conditions during drought conditions, whereas the North Lake level is exceptionally low. The levels in Tharbogang, Nericon and Campbells Swamps represent an effectively empty condition in each.

6.4.5 Rainfall Losses

As discussed in Section 6.3.5 an initial loss of 60mm and a continuing loss of 4mm/h have been adopted.

These relatively high loss values result in little effective rainfall to generate catchment runoff. The total and effective rainfall hyetograph for the Rankins Springs Acres gauge location is presented in Figure 6-11. The first rainfall burst of the event totals around 44mm so at the onset of the second rainfall burst there is only 16mm of initial rainfall loss remaining. The second rainfall burst contains some 31mm of rain and generates around 10mm of effective rainfall. At the other gauge locations in the catchment virtually no effective rainfall is generated.

Figure 6-12 shows the modelled rainfall distribution across the catchment, which divided the catchment into ten bands of varying rainfall depth. The total and effective rainfall depths for each band are shown on the figure and demonstrate the small effective rainfall depths across the catchment. The lower catchment area generates virtually no effective rainfall or corresponding runoff. The middle and upper catchment only averages less than 10mm effective rainfall. These small amounts of effective rainfall make the catchment and model highly sensitive to event rainfall depths and temporal patterns. The modelled effective rainfall represents around 3,300ML of catchment runoff volume.

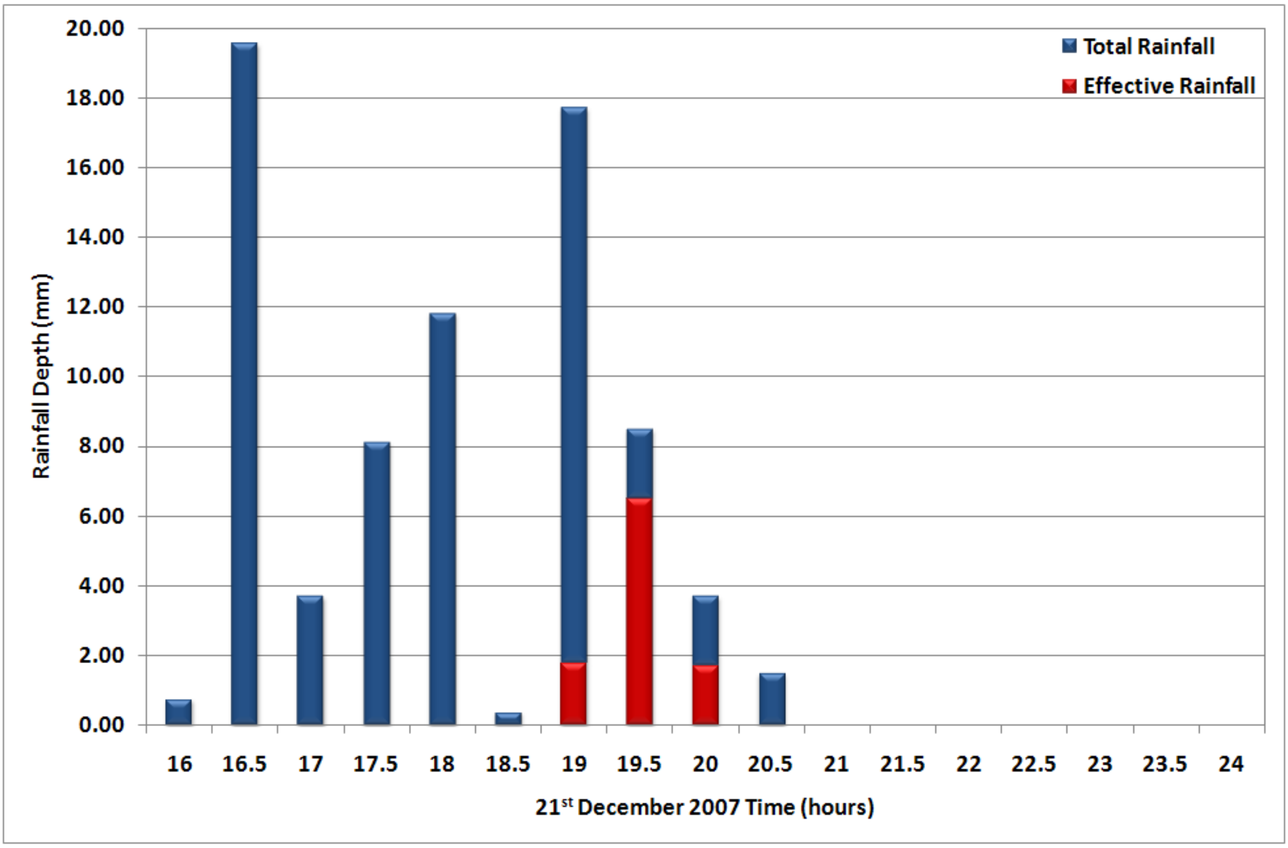
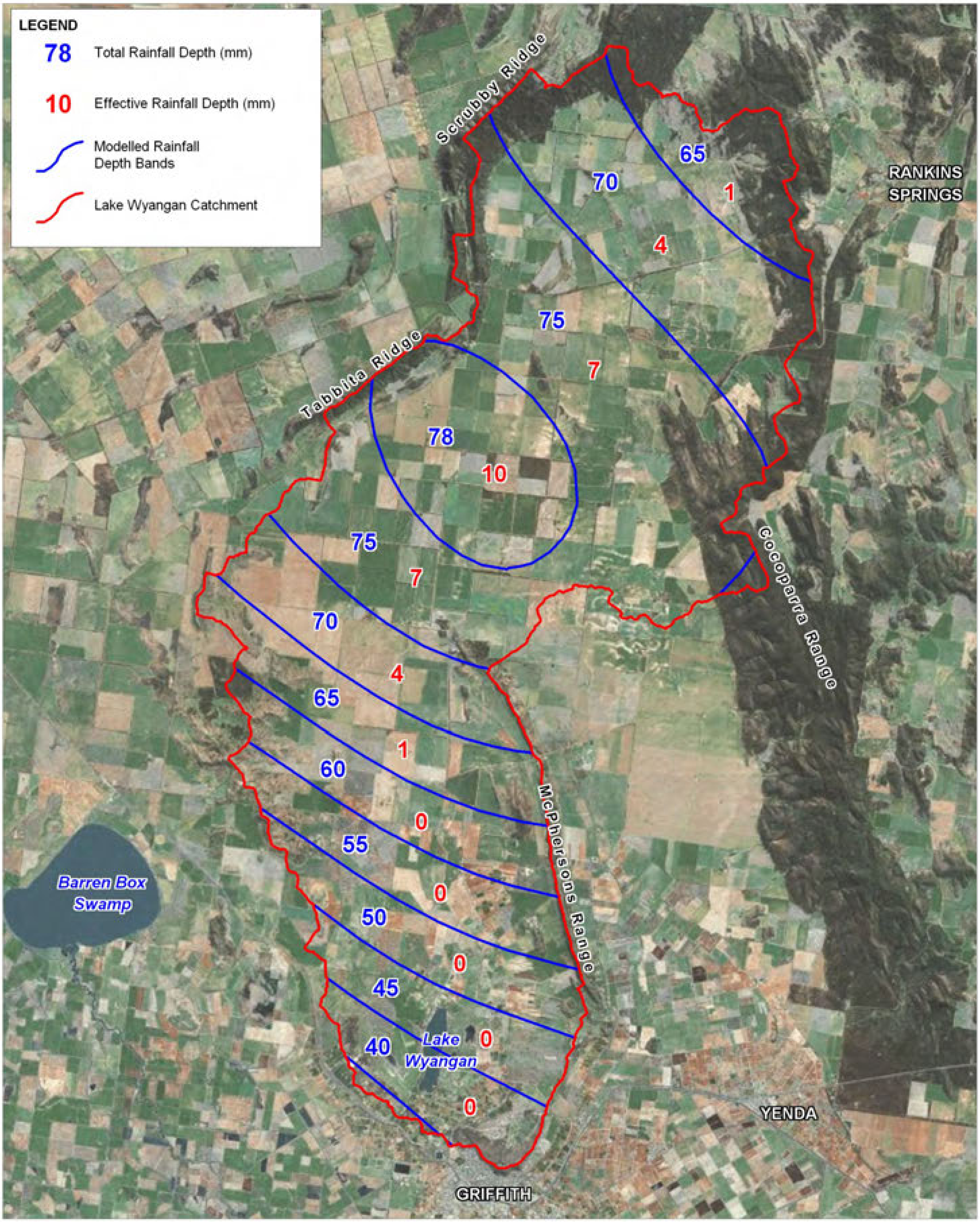


Figure 6-11 Effective Rainfall for the December 2007 Event at Rankins Springs Acres

6.4.6 Observed and Simulated Flood Behaviour

For the December 2007 event the water level in Lake Wyangan North Lake increased by around 0.2m and the level in Tharbogang Swamp increased by around 0.5m. In addition to this information, video footage of flooding was obtained from a property on West Road. This property is situated in the main flood flow path of the upper and middle Lake Wyangan catchment, which drains to Tharbogang Swamp. The property was known to have flood waters flowing through it for at least four hours and possibly as long as an entire day. A still image extracted from the video footage is presented in Figure 6-13.

As discussed in Section 6.4.5, the December 2007 did not produce much effective rainfall – all of which occurred in the upper and middle regions of the catchment. The generated catchment runoff will have progressed beyond the Lake View Branch Canal and flowed through the West Road property before ultimately contributing to the volumetric storage increase in Tharbogang Swamp. Adopting an initial loss of between 50mm and 60mm will generate enough effective rainfall to initiate this flood response in the model. Figure 6-14 shows the modelled flood behaviour at the West Road location, with the arrow indicating the approximate location of the image presented in Figure 6-13. The modelled flood extents and pattern of flood progression match well with the observable information in the flood video.



Title:

Modelled Effective Rainfall for the December 2007 Event

Figure: 6-12

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Approx. Scale

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Figure 6-13 Flood Photograph of West Road for the December 2007 Event

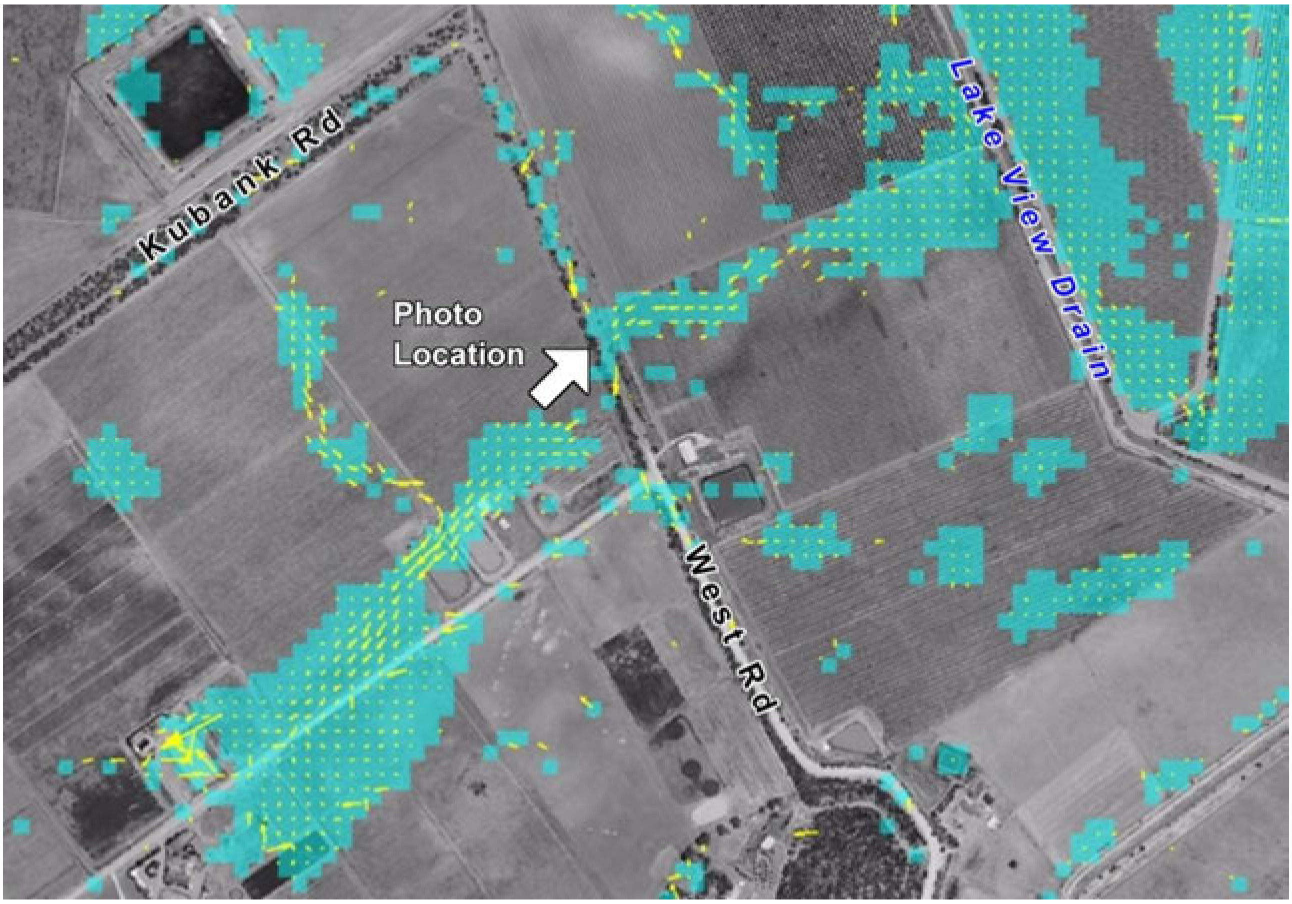


Figure 6-14 Modelled Flood Behaviour at West Road

6.5 March 1985 Model Validation

The March 1985 event was used to validate model parameters adopted through the calibration of the March 1989 event. The event represents the largest daily rainfall depth recorded within the study area, with around 150mm rainfall at Griffith Airport on 20th March. However, no rainfall was recorded in the catchment gauges. The event is known to have caused flooding at the Boorga Road – Smeeth Road intersection and a significant water level rise in Lake Wyangan.

6.5.1 Lake Level Records

The March 1985 event occurred before the official recording of lake levels and so limited data is available. An approximate extent of flooding around the south shore of Lake Wyangan was indicated on a response to the community questionnaire and this extent appears to correspond to a flood level of around 107.5m AHD. Figure 6-15 shows the Lake Wyangan flood extent for a level of 107.5m AHD against the approximate extent obtained through the community questionnaire, which shows a similar alignment.

Figure 6-15 Approximate Flood Extent for the March 1985 Event

6.5.2 Peak Swamp Storage Levels

There is no available satellite imagery close enough to the date of the flood event to be of any use in identifying storage levels within the swamps, so this information is unknown.

6.5.3 Rainfall Data

The distribution of rainfall gauge locations in the vicinity of the Lake Wyangan catchment was shown in Figure 2-2 with their respective periods of record shown in Table 2-1. The gauges that best represent rainfall within the catchment are Griffith Airport, Rankins Springs (Acres) and Rankins Springs. These stations have recorded rainfall depth totals of 150mm, 0mm and 0mm respectively for 20th March 1985.

No local continuous rainfall record exists for the March 1985 event, such that the event temporal pattern is unknown.

The spatial variation of rainfall depth for the March 1985 event has been analysed using the recorded daily rainfall totals at rainfall gauges in the vicinity of the Lake Wyangan catchment. The locations of the rain gauges together with their recorded rainfall depths for the March 1985 event are presented in Figure 6-16. The event rainfall depths were obtained from BoM and are the recorded rainfall depths for 20th March. A continuous surface of rainfall depths was interpolated from the point recordings. Rainfall depth contours extracted from this interpolation at 10mm intervals are included on Figure 6-16 to show the spatial variation of total rainfall depths for the March 1985 event across the Lake Wyangan catchment and the wider region.

It can be seen from Figure 6-16 that the storm event appears to have been an extremely intense localised cell, centred over the southern Lake Wyangan catchment. Rainfall depths decrease markedly in every direction, reducing to 0mm at around 30km distance. Due to high local variation of rainfall depths recorded at the gauges there is an inherent uncertainty with the spatial interpolation.

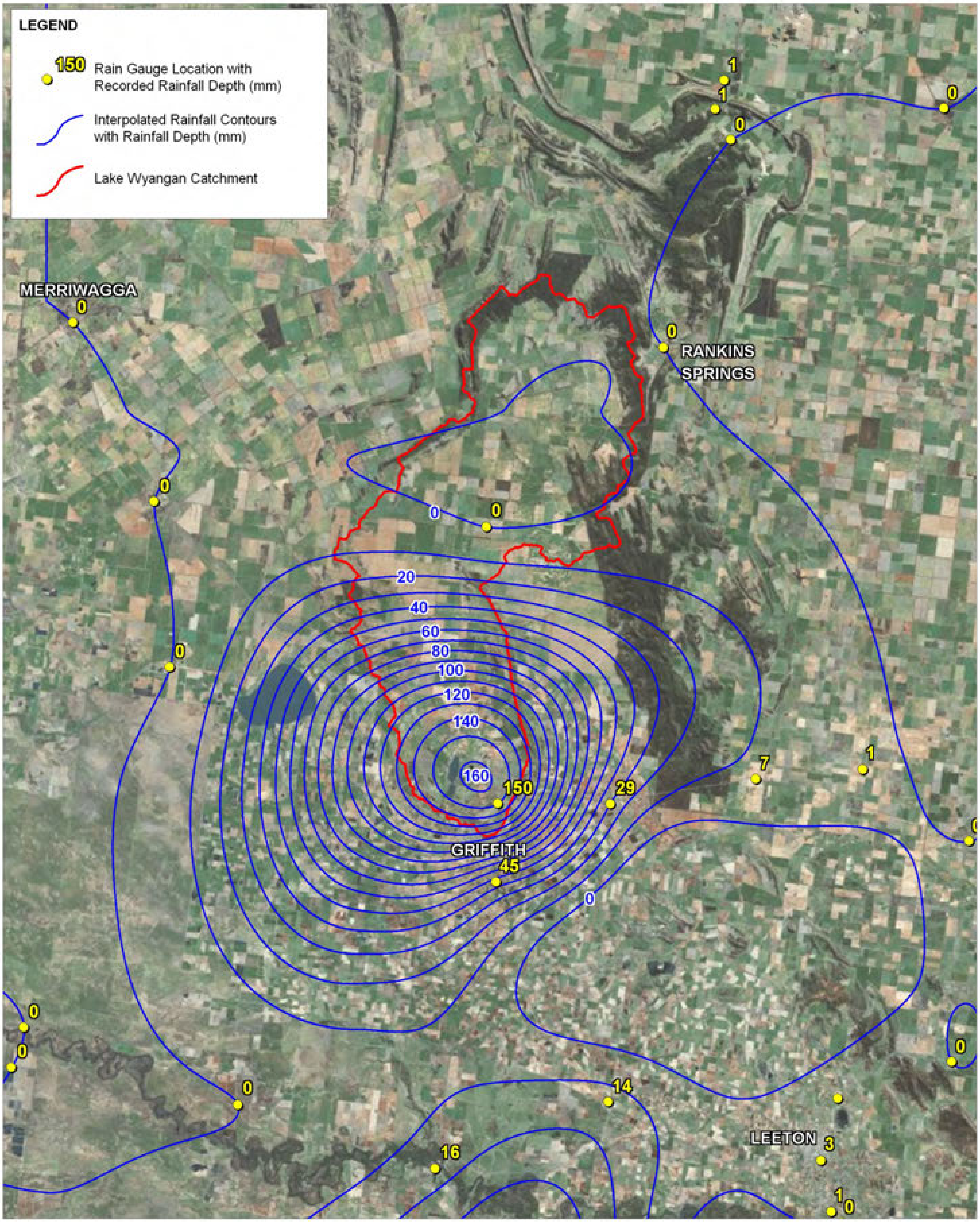
A rainfall depth of 150mm represents a significant event magnitude. For example, the 3-hour 1% AEP design event rainfall depth is 72mm and the 12-hour 1% AEP design event rainfall depth is 97mm. The recorded March 1985 event rainfall depth of 150mm represents an event 50-100% greater than the 1% AEP.

6.5.4 Initial Storage Conditions

There is no available water level record or satellite imagery data available to assess the antecedent conditions in the lake and swamp storages. Therefore, an average water level for the month of March during non-drought periods has been adopted in Lake Wyangan. This is a level of around 106.2m AHD in the North Lake and 105.9m AHD in the South Lake. For the swamps it has been assumed that the storages were empty at the onset of the event.

6.5.5 Rainfall Losses

As discussed in Section 6.3.5 an initial loss of 60mm and a continuing loss of 4mm/h have been adopted. Despite these high loss values, a significant effective rainfall is generated by the March 1985 event given the large total rainfall depth.



Title:
Spatial Variation of Rainfall Depths for the March 1985 Event

Figure: 6-16

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6.5.6 Observed and Simulated Flood Behaviour

Much of the flooding information received from the community related to the March 1985 event. People reported significant flooding to the Boorga Road – Smeeth Road intersection (see photograph in Figure 6-17, which has been taken looking north along Boorga Road) and the nearby drainage channels. Flooding was also reported to a property on Druitt Road (see photograph in Figure 6-18). An approximate flood extent was also indicated around the southern shore of Lake Wyangan on one of the questionnaire responses. Comparing this extent to the LiDAR DEM shows that the peak flood level in Lake Wyangan may have been around 107.5m AHD. This would constitute around a 5,000ML volumetric increase in lake storage.

The modelled volumetric increases in Lake Wyangan were around 6,000ML for the 3-hour duration event and over 3,000ML for the 12-hour event. These results suggest that the duration of the event was very short, in the order of 3 hours. This may be expected from such a localised and intense storm.

Figure 6-19 shows the modelled flood behaviour at the Boorga Road – Smeeth Road intersection, with the pink marker points representing the approximate locations of the corresponding markers presented in Figure 6-17. It can be seen that a significant flood flow path has been generated by the model. The flooding across Boorga Road is around 200m in width and is over 0.6m at the deepest location. This is consistent with the evidence presented in Figure 6-17, showing extensive flooding at this location. The truck is standing in water to a similar depth indicated by the modelling. Despite the limited data available, the model is providing results which are consistent with the observed flood behaviour during the event.

Figure 6-17 Flooding at the Boorga Road – Smeeth Road Intersection (March 1985)

Figure 6-18 Flooding at Druitt Road (March 1985)

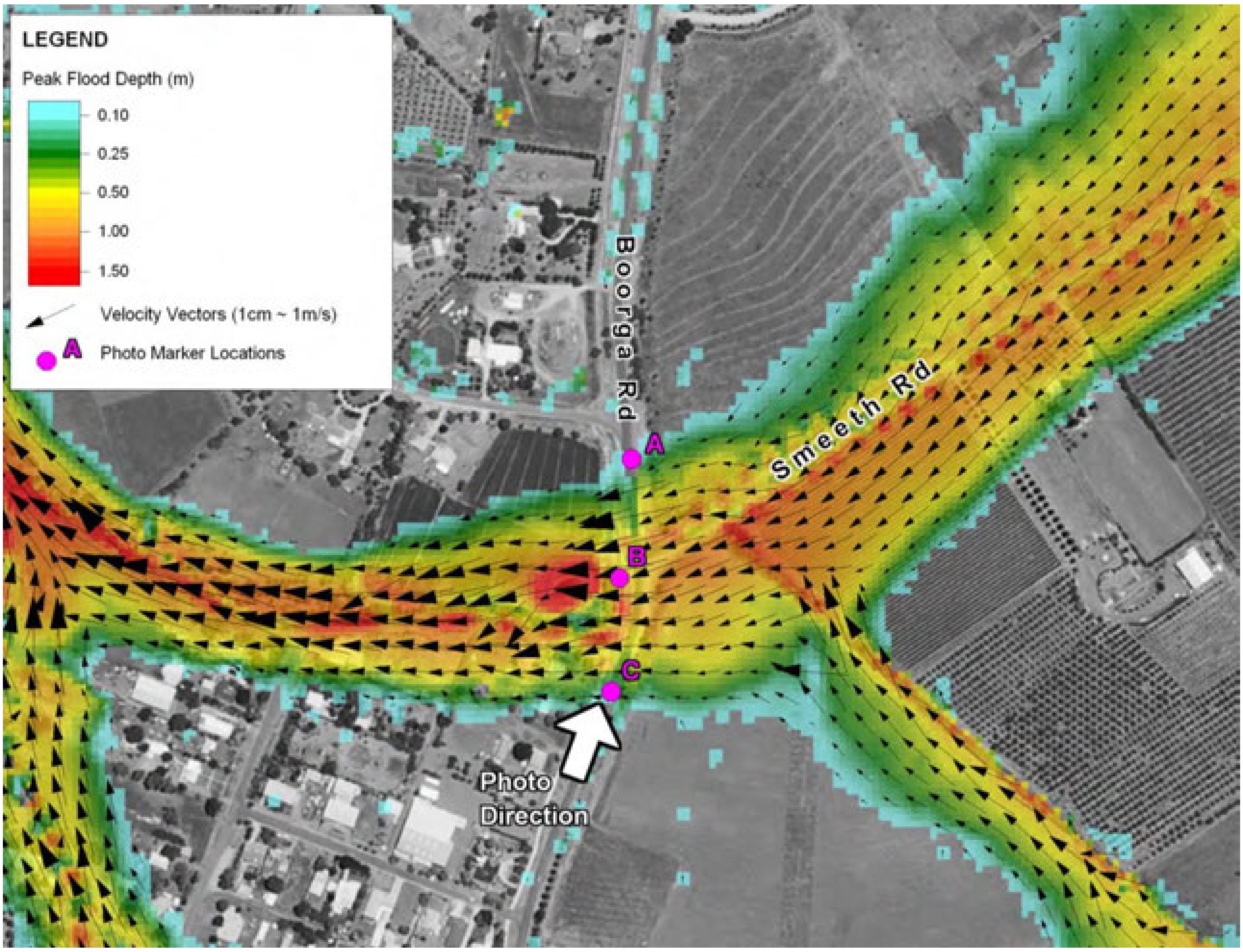

Figure 6-19 Modelled Flood Behaviour at Boorga Road – Smeeth Road

6.6 Discussion on Rainfall Loss Parameters

As discussed in the previous sections, flood levels in Lake Wyangan are highly sensitive to the adopted rainfall loss parameters. Typical design loss rates applicable for NSW catchments west of the Great Dividing Range are an initial loss of 15 mm and continuing loss of 4mm/hr (AR&R, 2001). However, from the observations of lake level response to rainfall events since 1985, the initial loss for the Lake Wyangan catchment for these events is significantly higher. Through the model calibration process, the losses required to provide the most appropriate volume of catchment runoff were a 60mm initial loss and 4mm/hr continuing loss. Only on 13 occasions within the 25 year period of lake level records has a level increase of greater than 0.2m been recorded between gauge readings. During this period there is no clear relationship to the recorded rainfall, except for the March 1989 event. There have been numerous instances of >40mm rainfall recorded at Griffith Airport (including five events >50mm) that have not provided a water level response in Lake Wyangan.

The March 1989 event, which totalled around 100mm rainfall depth, is the only event since lake levels were recorded that shows a significant contribution of catchment runoff to the lake storage volume. Events that totalled in the order of 60-70mm however, resulted in no apparent rise in lake storage levels. The October 2005 rainfall event is a good example for indicating that a high initial loss is appropriate. In the four hours between 21:00 on 20th and 01:00 on 21st a rainfall depth of 59mm was recorded at Griffith Airport AWS. Inspection of the lake level records for this event shows that they rose by only a few cm, which is probably attributed to the rain falling directly on to the lake.

The adopted continuing loss of 4mm/h for Lake Wyangan is consistent with the recommendations of AR&R.

The model is highly sensitive to the rainfall loss parameters, as the amount of effective rainfall for any given event will be relatively small in comparison to the total rainfall depth. For example, adjusting the rainfall losses for the March 1989 calibration model significantly increases the runoff volume and storage volume within Lake Wyangan and Tharbogang Swamp, as indicated by the results presented in Table 6-3. Reducing the continuing loss from 4mm/h to 2.5mm/h almost doubles the runoff volume contributing to the storages of Lake Wyangan and Tharbogang Swamp, significantly over-estimating the target calibration volume of 2,700ML. Reducing the initial loss from 60mm to 50mm has a similar magnitude of impact.

Table 6-3 Volumetric Sensitivity to Rainfall Loss Values (March 1989 Event)

Modelled Rainfall Losses	Total Catchment Runoff Volume (ML)	Change in Wyangan / Tharbogang Storage Volume (ML)
IL60mm CL4mm/h	4,300	2,900
IL60mm CL2.5mm/h	7,500	5,200
IL50mm CL2.5mm/h	11,900	7,400

Note: Target combined volumetric increase for Wyangan/Tharbogang is around 2,700ML

The sensitivity of the model to these parameters has significant implications for the design events.

6.7 Determination of Design Model Parameters

As has been discussed in this calibration process, an initial loss value of 60mm was found to be representative of the catchment hydrology. However, caution must be taken when carrying such as loss rate through to design, due to the limitations of the available design temporal rainfall patterns. Figure 6-20 shows the design catchment rainfall adopted for the 1% AEP 18-hour event. It can be seen that the main rainfall burst of the design temporal pattern is located at the onset of the rainfall event. The amount of effective rainfall will therefore be significantly reduced by a large initial loss value, as much of the remaining rainfall intensity is lower than the 4mm/h continuing loss rate. Adopting an initial loss of 60mm would result in no effective rainfall being generated until the 5th hour of the event. If the main rainfall burst were situated towards the middle or end of the design temporal pattern then the initial loss would be depleted by the lower intensity preceding rainfall and the main burst would generate a significant amount of effective rainfall.

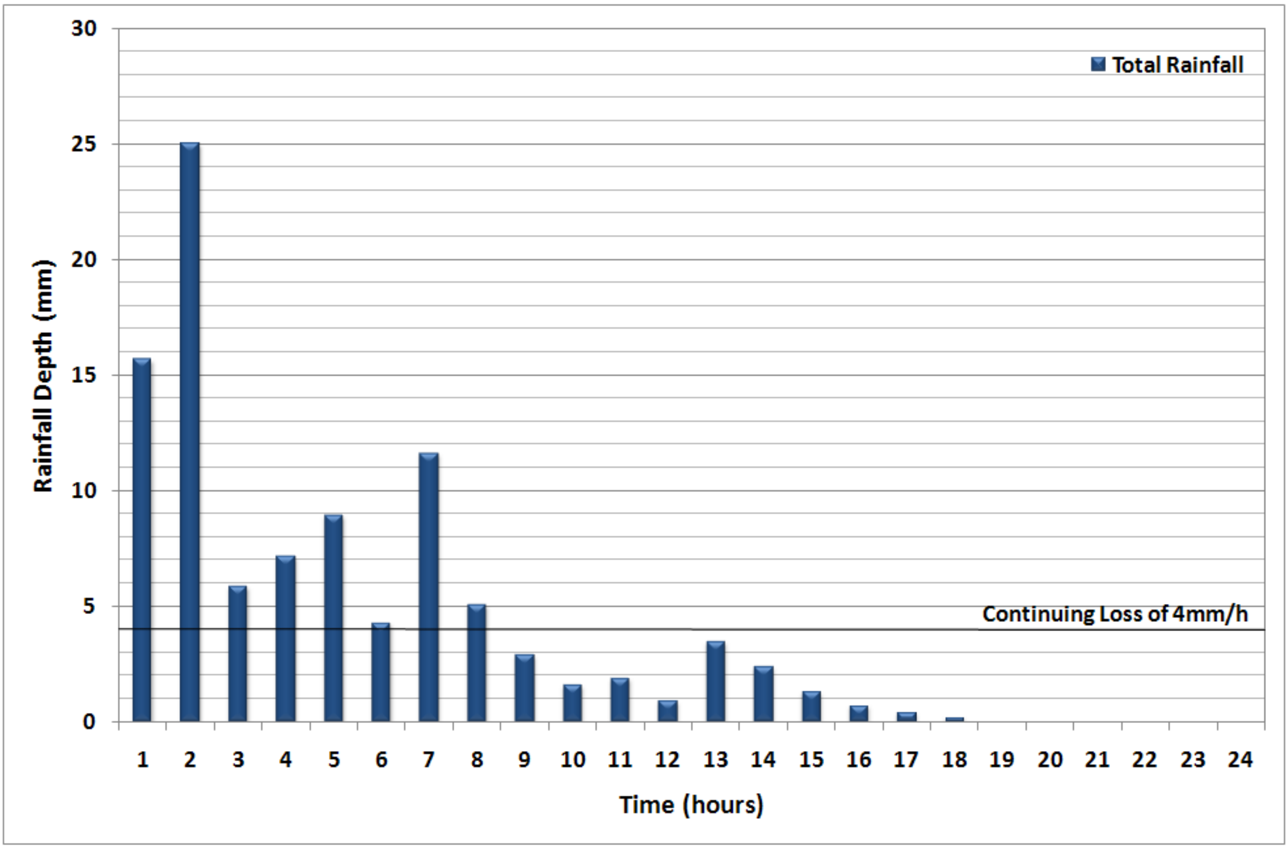

Figure 6-20 Design Rainfall for the 1% AEP 18-hour Event

This limitation of the available design temporal rainfall patterns means that the initial loss value determined through the calibration process should not be used for design purposes.

The design rainfall guidance in AR&R only divides NSW into two zones – one for the area east of the Great Dividing Range and one west of the Divide. The recommended loss parameters for these zones are as follows:

- 10-35mm initial loss and 2.5mm/h continuing loss for areas east of the Divide (Zone 1); and
- 15mm initial loss and 4mm/h continuing loss for areas west of the Divide (Zone 2).

The recommended loss parameters west of the Divide are based on the arid interior, but are applied east to the western slopes of the Divide. The study area is situated between the arid region and the Dividing Range and so does not have appropriate rainfall loss recommendations.

For the purposes of design event rainfall in this study, the continuing loss of 4mm/h for Zone 2 has been adopted, together with the 35mm initial loss from Zone 1. This combination of loss parameters was considered most appropriate, given the high losses indicated by the calibration process whilst compensating for the limitations of the available design rainfall temporal pattern. Given the sensitivity of the catchment flooding to the adopted initial loss parameter, design events were also modelled using an initial loss of 15mm (as recommended by AR&R for the arid regions of NSW) and 60mm (as determined by the calibration process). Modelling three initial loss conditions of 15mm, 35mm and 60mm will provide a best estimate and upper and lower bounds of design flood levels.

7 DESIGN FLOOD CONDITIONS

Design floods are hypothetical floods used for planning and floodplain risk management investigations. They are based on having a probability of occurrence specified either as:

- Annual Exceedance Probability (AEP) expressed as a percentage; or
- Average Recurrence Interval (ARI) expressed in years.

This report uses the AEP terminology. Refer to Table 7-1 for a definition of AEP and the ARI equivalent.

Table 7-1 Design Flood Terminology

ARI[1]	AEP[2]	Comments
0.5%	200 years	A hypothetical flood or combination of floods which represent the worst case scenario likely to occur on average once every 200 years.
1%	100 years	As for the 0.5% AEP flood but with a 1% probability or 100 year return period.
2%	50 years	As for the 0.5% AEP flood but with a 2% probability or 50 year return period.
5%	20 years	As for the 0.5% AEP flood but with a 5% probability or 20 year return period.
10%	10 years	As for the 0.5% AEP flood but with a 10% probability or 10 year return period.
20%	Approx. 5 years	As for the 0.5% AEP flood but with a 20% probability or 5 year return period.
Extreme Flood / PMF[3]		A hypothetical flood or combination of floods which represent an extreme scenario.

1 Average Recurrence Interval (years)
2 Annual Exceedance Probability (%)
3 A PMF (Probable Maximum Flood) is not necessarily the same as an Extreme Flood.

In determining the design floods it is necessary to take into account the critical storm duration of the catchment (small catchments are more prone to flooding during short duration storms while for large catchments longer durations will be more critical. In the case of a volume driven system such as Lake Wyangan, the critical duration is that which generates the greatest volume of catchment runoff.

7.1 Design Rainfall

Design rainfall parameters are derived from standard procedures defined in AR&R (2001) which are based on statistical analysis of recorded rainfall data across Australia. The derivation of location specific design rainfall parameters (e.g. rainfall depth and temporal pattern) for Lake Wyangan is presented below.

7.1.1 Rainfall Depths

Design rainfall depth is based on the generation of intensity-frequency-duration (IFD) design rainfall curves utilising the procedures outlined in AR&R (2001). These curves provide rainfall depths for various design magnitudes (up to the 1% AEP) and for durations from 5 minutes to 72 hours.

The Probable Maximum Precipitation (PMP) is used in deriving the Probable Maximum Flood (PMF) event. The theoretical definition of the PMP is "the greatest depth of precipitation for a given duration that is physically possible over a given storm area at a particular geographical location at a certain time of year" (AR&R, 2001). The ARI of a PMP/PMF event ranges between 10^4 and 10^7 years and is beyond the "credible limit of extrapolation". That is, it is not possible to use rainfall depths determined for the more frequent events (100 year ARI and less) to extrapolate the PMP. The PMP has been estimated by trebling the rainfall of the 1% AEP event.

Being a volume-driven closed-catchment system, the critical storm duration for determining peak flood levels in Lake Wyangan and Tharbogang Swamp is that which produces the greatest volume of catchment runoff. An analysis of design rainfall depths and temporal patterns was undertaken to calculate the effective rainfall depth for a range of storm durations. The 18-hour duration was found to provide the greatest depth of effective rainfall and therefore catchment runoff. This is consistent with the previous hydrological studies within the catchment.

A storm duration of 2-hours has also been modelled to provide peak flood conditions for the local catchments to the east of Lake Wyangan. Being relatively small in size they are potentially more prone to higher flooding from intense storms extending over a few hours. The 2-hour duration events for the local catchments have been modelled using a 15mm initial rainfall loss.

Table 7-2 shows the average design rainfall intensities based on AR&R adopted for the modelled events.

Table 7-2 Average Design Rainfall Intensities (mm/hr)

Duration (hours)	Design Event Frequency					
	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP
2	17.3	20.1	23.8	28.7	32.7	36.6
18	3.37	3.84	4.49	5.35	6.03	6.73

7.1.2 Areal Reduction Factor

The design rainfall intensities derived according to AR&R are applicable strictly to a point. For larger catchments, it is not realistic to assume that the same rainfall intensity can be maintained over the entire area and an areal reduction factor (ARF) is typically applied.

The study area is 825km^2 in size and for an 18-hour duration design event AR&R recommends an ARF of 0.91, i.e. 9% reduction. However, as part of the ongoing review of AR&R, ARFs were derived for Victoria by Siriwardena and Weinmann (1996) and, in an AR&R Review Forum held in November 2005 it was recommended that pending the derivation of ARFs for NSW the Victorian values be adopted for application in southern NSW. This recommendation was made on the basis that the initial findings from the ARFs being derived for NSW using the same approach provided similar results. The ARFs for Victoria are typically greater than those derived using the ARF curves in AR&R. For example, for a catchment area of 825km^2 and an 18-hour duration design event, the ARF is approximately 0.83, i.e. 17% reduction. It is understood that revised ARFs for NSW have yet to be finalised.

In light of Griffith being located on the north western fringe of “southern NSW”, the relative magnitude of rainfall losses for the catchment draining to Tharbogang Swamp / Lake Wyangan, and the sensitivity of lake/swamp levels to runoff volume, it was decided to adopt the more conservative ARFs for this larger catchment in this study. Further, for the shorter 2-hour duration local catchment events again a more conservative approach involving no ARF was applied to the design rainfalls, as the individual catchments being considered are no larger that around 15km^2.

7.1.3 Temporal Patterns

The IFD data presented in Table 7-2 provides for the average intensity that occurs over a given storm duration. Temporal patterns are required to define what percentage of the total rainfall depth occurs over a given time interval throughout the storm duration. The temporal patterns adopted in the current study are based on the standard patterns presented in AR&R (2001).

The same temporal pattern has been applied across the whole catchment. This assumes that the design rainfall occurs simultaneously across each of the modelled sub-catchments. The direction of a storm and relative timing of rainfall across the catchment may be determined for historical events if sufficient data exists, however, from a design perspective the same pattern across the catchment is generally adopted.

7.1.4 Rainfall Losses

The rainfall losses adopted for the design floods are different to those used for model calibration and verification, for reasons discussed in Section 6.7. Initial losses of 15mm, 35mm and 60mm have been adopted and the results of each are reported. A continuing loss of 4mm/h has been adopted for all design runs.

7.1.5 Initial Storage Conditions

For design purposes the normal operating levels within Lake Wyangan have been adopted as the initial water levels. The water level record from the gauge readings was used to derive average conditions for the North Lake and South Lake. Only the ‘non-drought’ period of 1986 to 2001 was to calculate the average water levels and the much lower levels recorded from 2002 onwards were excluded. This provided the following typical water levels:

- 106.2m AHD for the North Lake; and
- 105.8m AHD for the South Lake.

A dry initial condition was adopted for the remaining ephemeral wetlands in the catchment, with the storages assumed to be empty at the onset of the modelled events.

7.2 Design Flood Results

The design flood results are presented in a flood mapping series in Appendix A. For the key simulated design events including the 20% AEP (approx. 5-year ARI), 10% AEP (10-year ARI), 5%

AEP (20-year ARI), 2% AEP (50-year ARI), 1% AEP (100-year ARI), 0.5% AEP (200-year ARI) and PMF events, a map of peak flood depth, velocity and provisional hazard is presented covering the study area. The results presented in the flood maps have been derived from a combination of modelled design events, to reflect the recommendations of Section 7.2. The methodology for combining the flood model results can be summarised as follows:

- For the Lake Wyangan storages the results of the 18-hour duration events with a 15mm initial rainfall loss have been adopted;
- For the local catchments east of Lakes Road and the Lake View Drain, the results of the 2-hour duration events with a 15mm initial rainfall loss have been adopted; and
- For the main catchment flooding, including Tharbogang Swamp, the results of the 18-hour duration events with a 35mm initial rainfall loss have been adopted.

7.2.1 Peak Flood Levels and Volumes

The mapping series contained in Appendix A focus on the study area, which is similar to the extent of the 10m resolution modelled area. The flood extents for the 1% AEP design event for the entire Lake Wyangan / Tharbogang Swamp catchment have been presented in Figure 7-1. For all other mapping within the report, flood results have been trimmed to the study area.

It can be seen that the upper catchment is comprised of two main flow path alignments, which combine at the upper catchment outlet. The flow path alignments between this location and the Lake View Branch Canal are numerous and complex, with individual flow paths often splitting and re-joining in a braided pattern. The main flow path of the catchment then continues south of the Canal and into Tharbogang Swamp. A number of smaller local catchments flow westwards from the McPhersons Range and into Lake Wyangan.

Table 7-3 shows the modelled peak flood levels within the main storages of the study catchment, for each of the initial loss conditions. The results show that the flood levels in both Lake Wyangan and Tharbogang Swamp are highly sensitive to the adopted initial loss conditions. This is due to the large proportion of rainfall volume that is lost and results in a relatively small effective rainfall. The range of modelled flood levels for Tharbogang Swamp is much greater than that of Lake Wyangan. This is due to Tharbogang Swamp having a much larger catchment area than Lake Wyangan, being around seven times the size.

It is recommended that the design levels from the 15mm initial loss condition be adopted for Lake Wyangan and from the 35mm condition for Tharbogang Swamp. These values have been highlighted in bold text within Table 7-3. As discussed in Section 6.7, the 35mm initial loss was the preferred design flood condition for the catchment and represents the best estimate of design runoff volumes for the 18-hour duration events. However, due to the relatively small size of the catchment contributing to Lake Wyangan (<100km^2), flood levels within the Lake are more susceptible to localised higher intensity storms, as evidenced by the March 1985 event. The adopted catchment storm of 18-hour duration with an aerial reduction factor of 0.91 may not provide the critical flood condition for Lake Wyangan.

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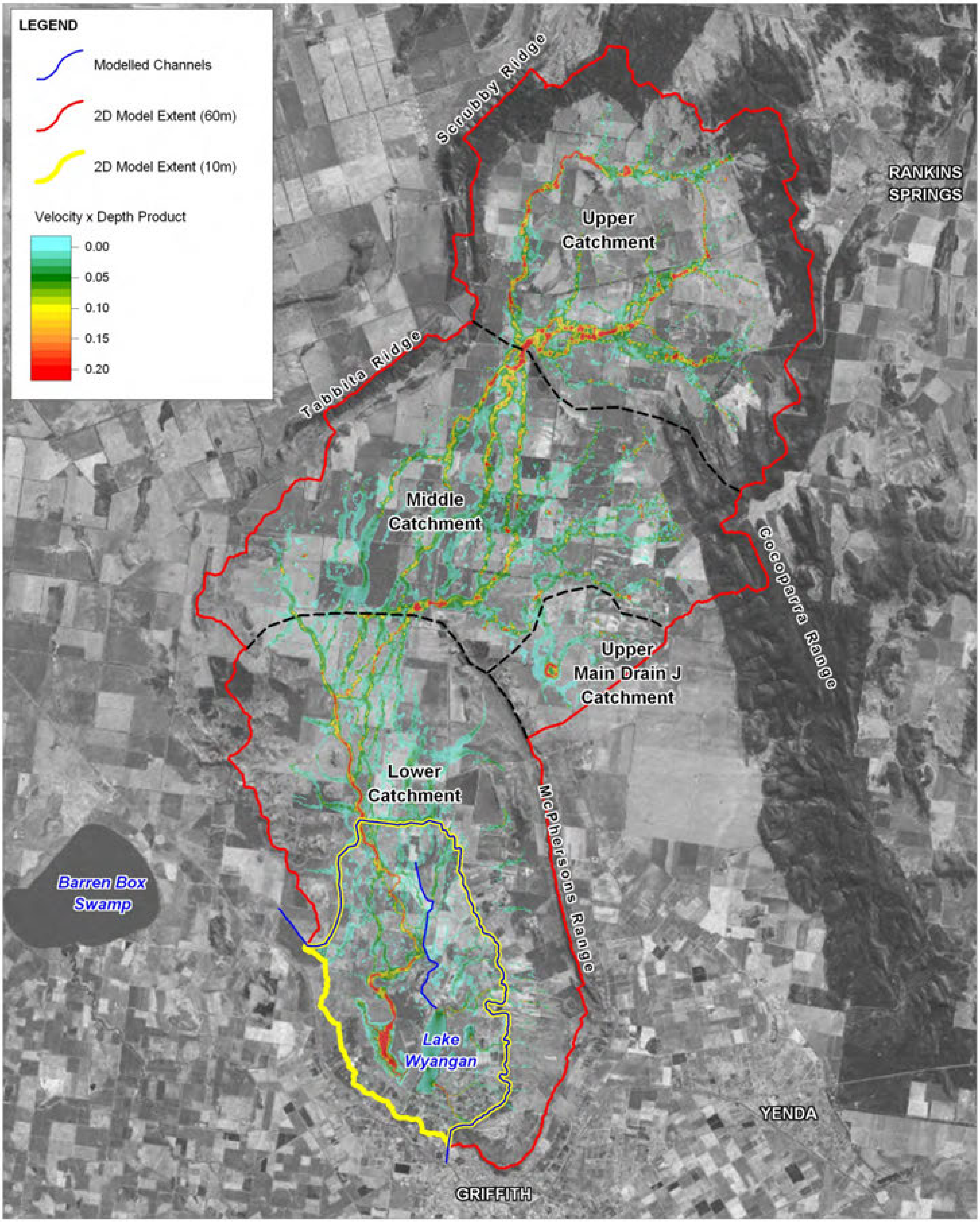

Title:

Catchment Flood Extents for the 1% AEP Design Event

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Table 7-3 Summary of Design Flood Levels

	Design Event	Peak Flood Level (m AHD)		
		North Lake	South Lake	Tharbogang Swamp
15mm IL	20% AEP 18h	**106.5**	**106.0**	106.6
	10% AEP 18h	**106.5**	**106.5**	108.1
	5% AEP 18h	**106.8**	**106.8**	109.6
	2% AEP 18h	**107.2**	**107.2**	110.7
	1% AEP 18h	**107.6**	**107.6**	111.6
	0.5% AEP 18h	**108.1**	**108.1**	112.2
35mm IL	20% AEP 18h	106.4	105.9	**103.5**
	10% AEP 18h	106.5	105.9	**104.2**
	5% AEP 18h	106.5	106.0	**105.8**
	2% AEP 18h	106.5	106.5	**108.0**
	1% AEP 18h	106.9	106.9	**109.8**
	0.5% AEP 18h	107.2	107.2	**110.8**
60mm IL	20% AEP 18h	106.3	105.9	103.4
	10% AEP 18h	106.3	105.9	103.4
	5% AEP 18h	106.3	105.9	103.5
	2% AEP 18h	106.5	106.0	104.6
	1% AEP 18h	106.5	106.2	106.6
	0.5% AEP 18h	106.6	106.6	108.5

As mentioned in Section 2.1.1 the Lake View Drain provides cross-catchment flow transfer from the Tharbogang Swamp catchment into Lake Wyangan. However, the elevated banks of the Drain prevent flood flow from the main Tharbogang Swamp flow path entering the Drain. The Lake View Drain has spare capacity to transfer a greater volume of water to Lake Wyangan should local conditions enable the flood flows to enter the Drain. The uncertainty of this cross-catchment flow transfer is discussed further in Section 7.3.2. Therefore, adopting a 15mm initial loss condition for Lake Wyangan design flood levels is not overly conservative as it accounts for potential higher flood levels due to intense localised storms and a potentially greater flow transfer from the Tharbogang Swamp catchment.

Adopting the recommended design flood levels for Lake Wyangan would place the March 1989 event somewhere between the 5% AEP and 2% AEP events. This is consistent with the rainfall event magnitudes that were presented in Figure 6-3.

Being a closed-catchment system, the peak flood levels in Lake Wyangan and Tharbogang Swamp are directly related to the amount of effective rainfall. The effective rainfall is a function of both the magnitude of rainfall event and the adopted rainfall loss conditions. Figure 7-2 shows the effective rainfall generated by the combinations of modelled flood events and initial loss conditions.

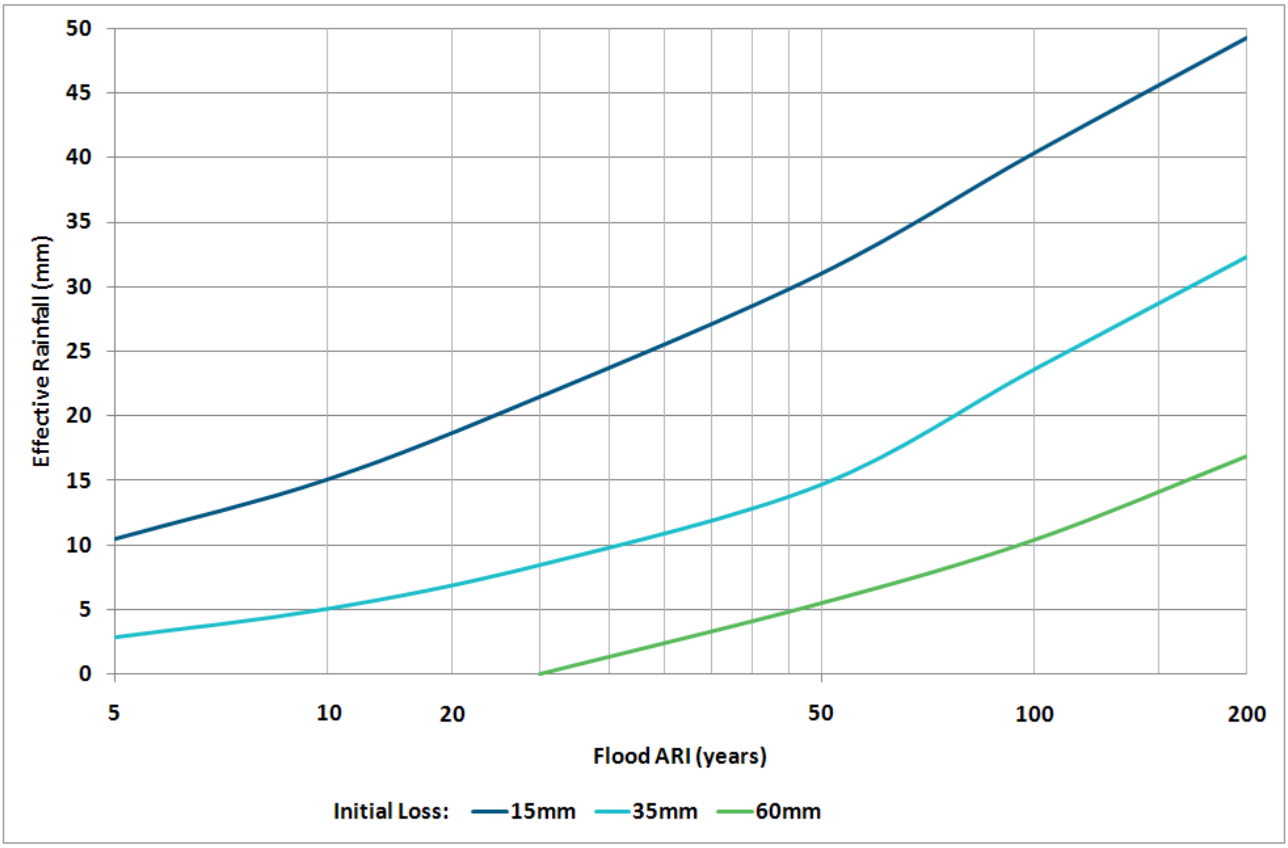


Figure 7-2 Relationship between Flood ARI, Initial Loss and Effective Rainfall

The flood model results show a strong relationship between effective rainfall and the resultant flood levels in Lake Wyangan and Tharbogang Swamp. This relationship is presented in Figure 7-3 and shows the modelled effective rainfall and flood level combinations, together with curves that best model this relationship. These curves enable the peak water levels in Lake Wyangan and Tharbogang Swamp to be estimated given an effective rainfall total for the catchment.

As shown in Table 7-3, the flood levels in Lake Wyangan and Tharbogang Swamp are highly sensitive to the adopted initial loss conditions. This is due to the significant impact on the amount of effective rainfall and the generated catchment runoff volumes. Figure 7-4 provides an analysis of rainfall volume distributions for the 1% AEP event under the various initial loss conditions. This includes:

- Rainfall volume lost to the soil through infiltration and micro-scale surface storage;
- Runoff volume held in temporary flood storages or lost through cross-catchment flows;
- Flood storage contribution to Lake Wyangan; and
- Flood storage contribution to Tharbogang Swamp.

For this event a total of almost 80GL of rainfall falls on the catchment. The majority of this volume is lost to the soil through infiltration and is represented by the hydrological rainfall losses. This will also include some losses to vegetation interception and micro-scale surface storage. This loss constitutes around 60% of the total rainfall for the 15mm initial loss and almost 90% for the 60mm initial loss.

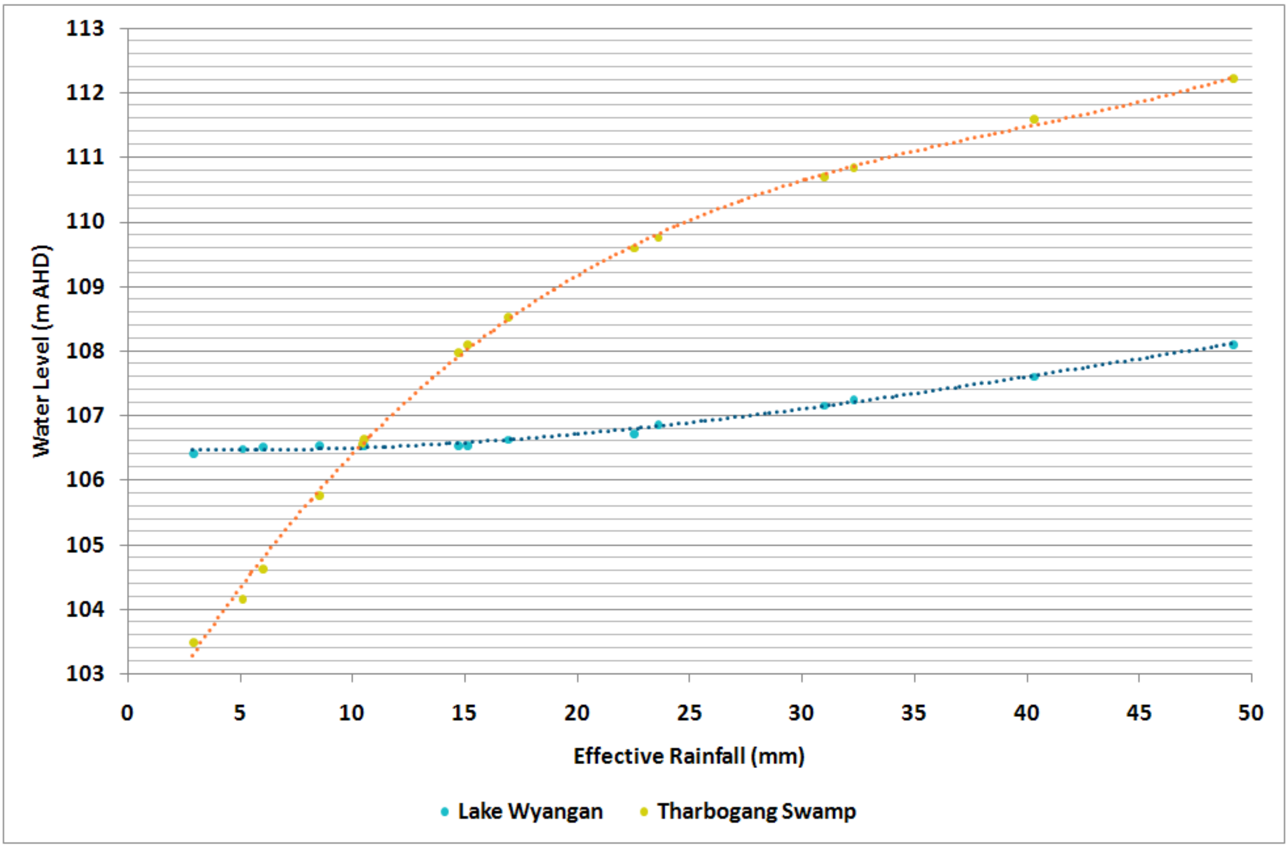


Figure 7-3 Relationship between Effective Rainfall and Peak Storage Levels

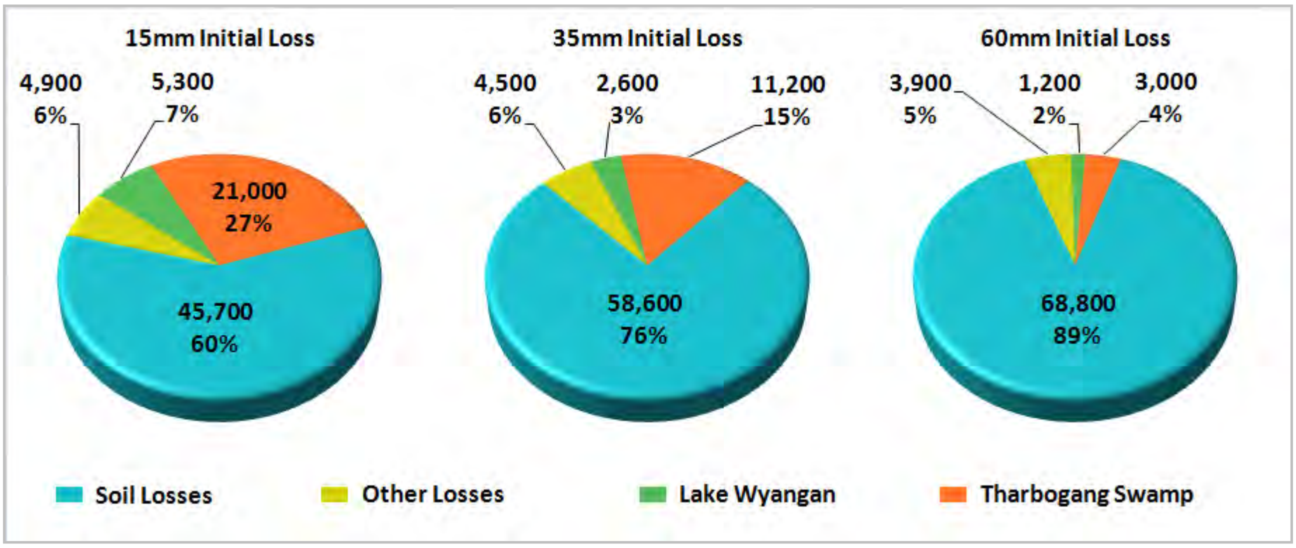


Figure 7-4 Distribution of Catchment Rainfall Volumes (ML)

A fairly consistent 5-6% of the rainfall volume is also lost within the system and does not contribute to an increase in storage volume within Lake Wyangan or Tharbogang Swamp. The majority of these other losses are to temporary flood storages in the catchment, including the smaller ephemeral wetlands, storage within and behind the Lake View Branch Canal, dam storages and flood waters trapped behind embankments or in local topographic depressions. A small amount of volume is also lost as cross-catchment flow to the Main Drain J catchment.

The rainfall volume that contributes to Lake Wyangan and Tharbogang Swamp is a relatively small proportion of the total catchment rainfall – being around 34% for the 15mm initial loss condition and only 6% for the 60mm initial loss. The volume contributing to Tharbogang Swamp is much greater than that of Lake Wyangan, as is to be expected given the larger catchment area. The volume contributing to Tharbogang Swamp is almost three times that of Lake Wyangan for the 60mm initial loss condition, almost four times for the 15mm initial loss and five times for the 35mm initial loss.

For the PMF event, flood waters exceed the storage capacity of Tharbogang Swamp, spill over Lakes Road and into Lake Wyangan. This spill occurs across the low section of Lakes Road, situated near the south-west corner of Lake Wyangan. The flood storage levels within Tharbogang Swamp and Lake Wyangan then equalise, giving a peak flood level of 116.1m AHD.

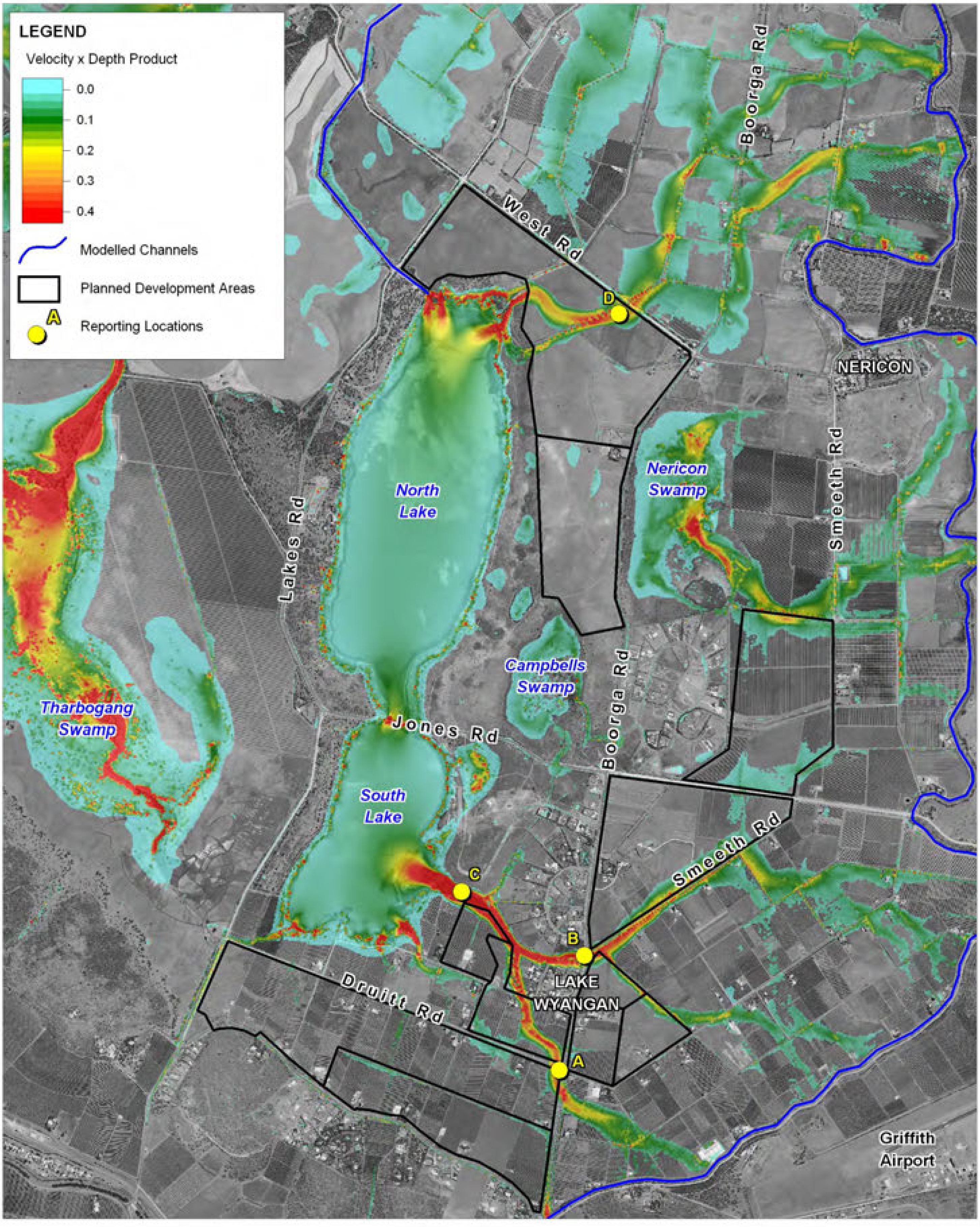
7.2.2 Flood Depths, Flows and Velocities

For the local catchments to the east of Lake Wyangan 2-hour duration events were modelled with a 15mm initial loss. Results from the 1% AEP event are presented in Figure 7-5 and show the velocity x depth product, which highlights the major flow paths. The planned development areas from Council's Growth Strategy 2030 are included to provide their spatial context in relation to the flood flow paths. It can be seen that flooding is absent from most of the development areas, but there are a few flood flow paths that would require consideration during the stages of development planning.

There are two main flow paths which contribute to Lake Wyangan – one to the North Lake (reporting location D) and another to the South Lake (reporting location C). A third flow path contributes to Nericon Swamp. The northern flow path crosses West Road at reporting location D. The southern flow path is formed from two main tributaries, which cross Boorga Road at reporting locations A and B. The flow hydrographs at these reporting locations are presented in Figure 7-6. The inflows to the North Lake and South Lake are comparable in volume, with both elevated flow periods lasting around eight hours. The peak inflow to the North Lake is around $30m^3/s$ and that to the South Lake is over $45m^3/s$. The two flow paths contributing to the South Lake inflow are also comparable and have elevated flow conditions for around five hours. The peak flow at location A is over $20m^3/s$ and at location B it is over $30m^3/s$. These two locations were flagged by the community questionnaire as having experienced flooding problems, as was a location west along Druitt Road from location A, where a smaller flow path can be observed in Figure 7-5.

Other than the main catchment inflow from the north, there are no additional significant local catchment flow paths that contribute to Tharbogang Swamp.

The peak flood depths at all reporting locations are in the order of 0.6m. The peak velocities at location A and location B are around 1.5m/s and 1.0m/s respectively, whereas at both location C and location D the peak velocities are around 0.8m/s.



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Local Catchment Results for the 1% AEP Event

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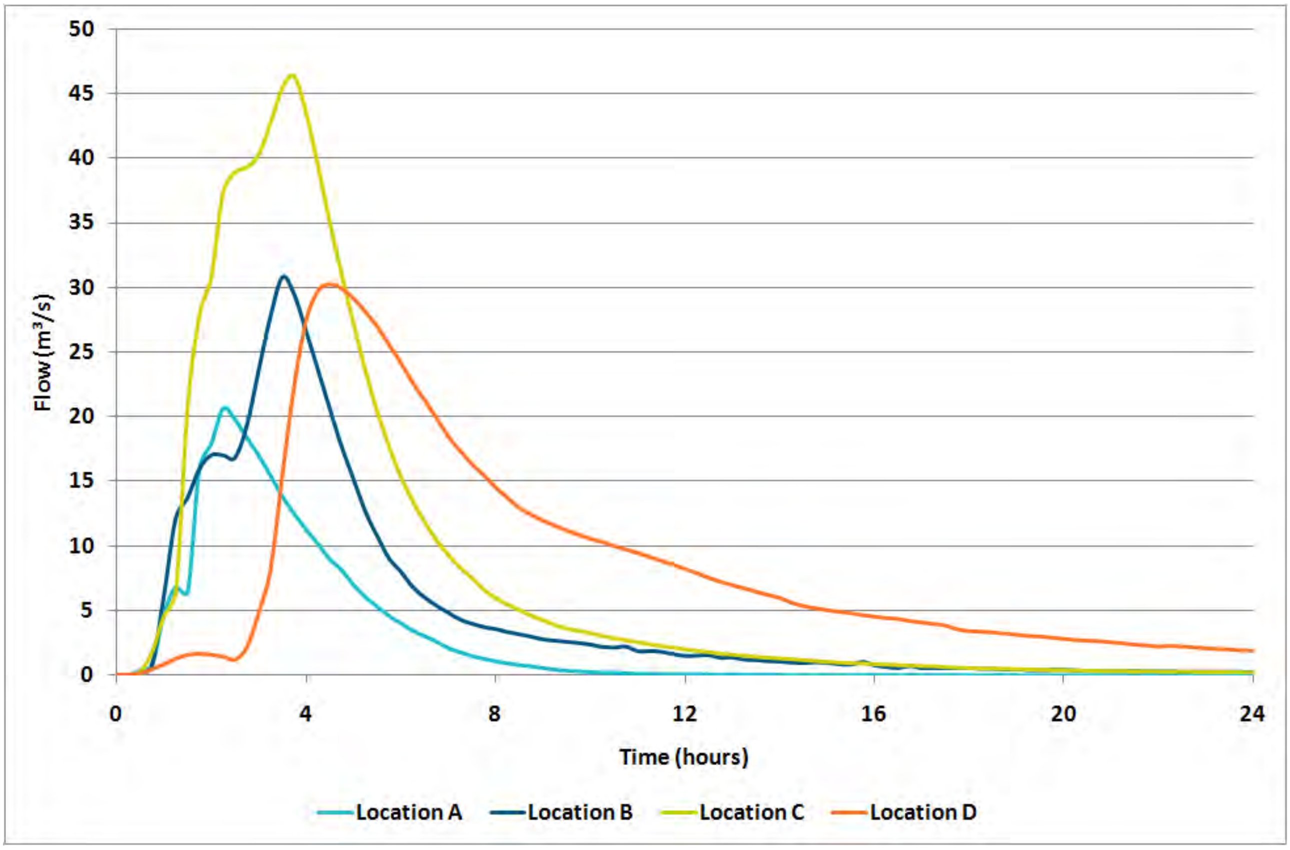


Figure 7-6 1% AEP Flow Hydrographs at Selected Locations

7.2.3 Hydraulic Categorisation

There are no prescriptive methods for determining what parts of the floodplain constitute floodways, flood storages and flood fringes. Descriptions of these terms within the Floodplain Development Manual (NSW Government, 2005) are essentially qualitative in nature. Of particular difficulty is the fact that a definition of flood behaviour and associated impacts is likely to vary from one floodplain to another depending on the circumstances and nature of flooding within the catchment.

The hydraulic categories as defined in the Floodplain Development Manual are:

- **Floodway -** Areas that convey a significant portion of the flow. These are areas that, even if partially blocked, would cause a significant increase in flood levels or a significant redistribution of flood flows, which may adversely affect other areas.
- **Flood Storage -** Areas that are important in the temporary storage of the floodwater during the passage of the flood. If the area is substantially removed by levees or fill it will result in elevated water levels and/or elevated discharges. Flood Storage areas, if completely blocked would cause peak flood levels to increase by 0.1m and/or would cause the peak discharge to increase by more than 10%.
- **Flood Fringe -** Remaining area of flood prone land, after Floodway and Flood Storage areas have been defined. Blockage or filling of this area will not have any significant affect on the flood pattern or flood levels.

A number of approaches were considered when attempting to define flood impact categories for the study area. Approaches to define hydraulic categories that were considered for this assessment included partitioning the floodplain based on:

- Peak flood velocity;
- Peak flood depth;
- Peak velocity * depth (sometimes referred to as unit discharge);
- Cumulative volume conveyed during the flood event; and
- Combinations of the above.

The definition of flood impact categories that was considered to best fit the application within the study area was based on a combination of velocity*depth and depth parameters. The adopted hydraulic categorisation is defined in Table 7-4.

Hydraulic category mapping is included in Appendix A and has been determined using the 1% AEP event. It is also noted that mapping associated with the flood hydraulic categories may be amended in the future, at a local or property scale, subject to appropriate analysis that demonstrates no additional impacts (e.g. if it is to change from floodway to flood storage).

Table 7-4 Hydraulic categories

Floodway	Velocity * Depth > 0.1	Areas and flow paths where a significant proportion of floodwaters are conveyed (including all bank-to-bank creek sections).
Flood Storage	Velocity * Depth < 0.1 and Depth > 0.5 metres	Areas where floodwaters accumulate before being conveyed downstream. These areas are important for detention and attenuation of flood peaks.
Flood Fringe	Velocity * Depth < 0.1 and Depth < 0.5 metres	Areas that are low-velocity backwaters within the floodplain. Filling of these areas generally has little consequence to overall flood behaviour.

7.2.4 Provisional Hazard

The NSW Government's Floodplain Development Manual (2005) defines flood hazard categories as follows:

- **High hazard** – possible danger to personal safety; evacuation by trucks is difficult; able-bodied adults would have difficulty in wading to safety; potential for significant structural damage to buildings; and
- **Low hazard** – should it be necessary, trucks could evacuate people and their possessions; able-bodied adults would have little difficulty in wading to safety.

The key factors influencing flood hazard or risk are:

- Size of the Flood
- Rate of Rise - Effective Warning Time

- Community Awareness
- Flood Depth and Velocity
- Duration of Inundation
- Obstructions to Flow
- Access and Evacuation

The provisional flood hazard level is often determined on the basis of the predicted flood depth and velocity. This is conveniently done through the analysis of flood model results. A high flood depth will cause a hazardous situation while a low depth may only cause an inconvenience. High flood velocities are dangerous and may cause structural damage while low velocities have no major threat.

Figures L1 and L2 in the Floodplain Development Manual (NSW Government, 2005) are used to determine provisional hazard categorisations within flood liable land. These figures are reproduced in Figure 7-7.

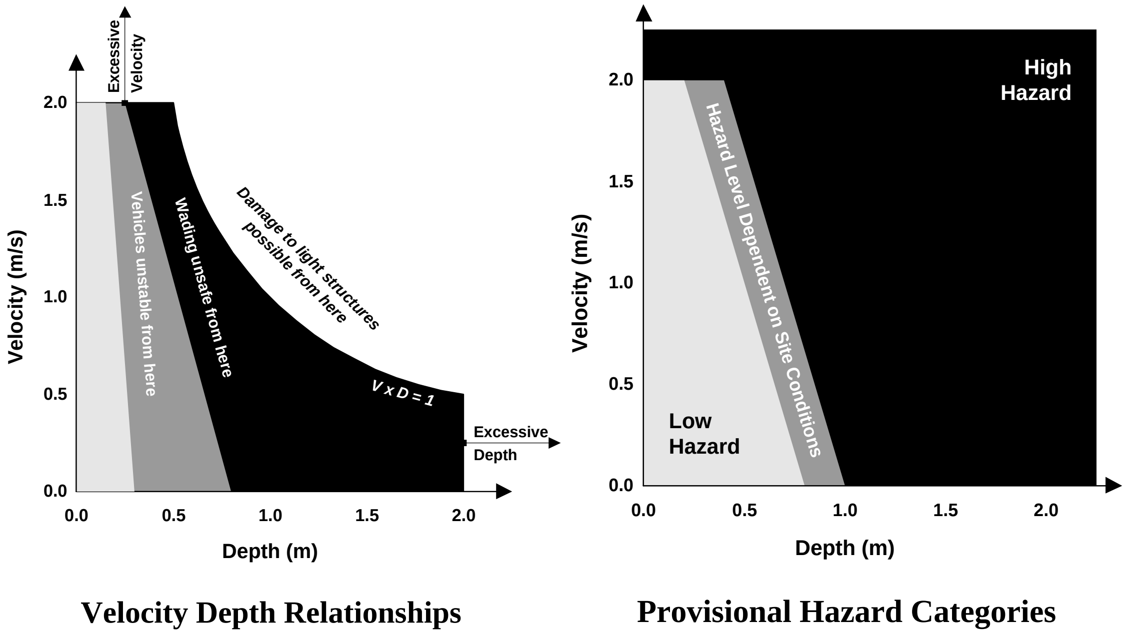


Figure 7-7 Provisional Flood Hazard Categorisation

The provisional hydraulic hazard is included in the mapping series for each simulated design event provided in Appendix A.

7.3 Model Uncertainties and Limitations

As discussed in Section 7.2.1, the model results are highly sensitive to the adopted rainfall loss conditions. Other sensitivity tests typically undertaken in flood studies, such as changing the adopted roughness parameters, would have minimal impact on the modelled flood levels in Lake Wyangan and Tharbogang Swamp, given it is a volume controlled system.

In addition to the uncertainty surrounding the initial loss parameter, there are a number of other model uncertainties or limitations which merit discussion and these are detailed in this section.

7.3.1 Lake View Branch Canal

The supply canal network associated with the Lake View Branch Canal is a complex system with numerous control structures and off-takes. With regards to flooding, the operating details of this network are likely to be insignificant. The most important consideration is to the available flood storage within the Canal, which must be filled before spilling to the study area occurs. The storage conditions within the Canal have been approximated by running a constant $1m^3/s$ operating flow through the canal and inserting simple weir structures at the known control locations in order to achieve water levels similar to reality – typically a level around 0.5m below the bank crest. This representation will provide a reasonable estimate of actual available flood storage within the Canal.

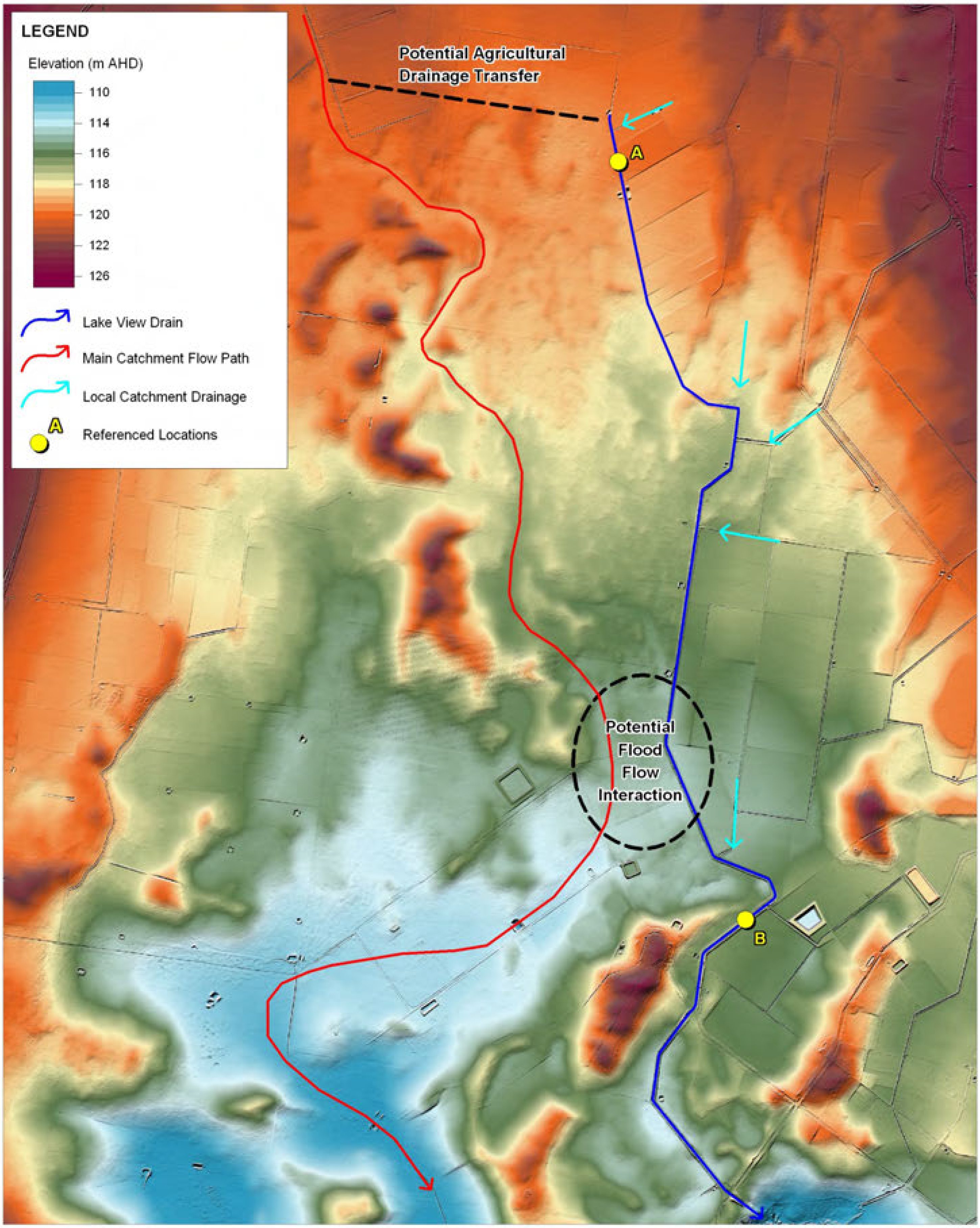
The constant flow condition being fed into the top and extracted from the end of the Lake View Branch Canal, forces all additional flow entering the Canal to fill the available storage and then spill into the study area. With these conditions, no flow is lost from the system through the end of the canal, which is a slightly conservative approach. If the Canal was allowed to freely discharge from the study area then around $4m^3/s$ would be flowing out of the model, at the capacity of the channel. This would constitute a volumetric loss in the order of 1000-2000ML, or around 10% of the total volume contributing to Lake Wyangan and Tharbogang Swamp. However, this represents the largest possible loss conditions, with the flow through the end of the Canal likely to be much smaller (although probably greater than $1m^3/s$) as most of the flow will be pushed through the off-takes or spill over the Canal bank.

The Lake View Branch Canal banks have been modelled using the best estimate of crest elevations obtainable from the LiDAR data. These elevations will have a significant impact on the location and quantity of water spilling out of the Canal and into the study area. In some areas this will be sensitive to small changes in bank elevations. Although the broad distribution of flows spilling from the Canal is likely to provide a good representation, small variations may be expected dependant on localised bank crest conditions.

7.3.2 Lake View Drain

The Lake View Drain provides irrigation drainage for agriculture located to the north and north-east of Lake Wyangan. The Drain discharges to the north-west corner of the North Lake. The Drain cuts through the ridge that separates the natural catchments of Lake Wyangan and Tharbogang Swamp and as such provides for potential cross-catchment flow transfers.

Figure 7-8 shows the location of the Lake View Drain with the natural topography of the Lake Wyangan and Tharbogang Swamp catchments. Local catchment drainage from the east of the Drain, which would naturally drain to Tharbogang Swamp, is intercepted by the Drain and transferred to Lake Wyangan. The right bank crest elevation of the Drain is much higher than that of the left bank, which prevents the water from filling the drain and spilling back into the Tharbogang Swamp catchment. This elevated right bank also prevents flood waters of the main catchment flow path from entering the Drain, in the area of potential flood flow interaction. However, localised bank conditions not captured within the model, or a breach of the bank during a flood event, could allow for a greater interaction with the main catchment flow path and would result in a greater volume of water being transferred cross-catchment through the Drain.



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Interaction of Lake Wyangan and Tharbogang Swamp Catchments

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The only other location with potential of flow transfer from the Tharbogang Swamp catchment to the Lake View Drain is at the northern end of the Drain, where there is some agricultural drainage infrastructure. However, from the available LiDAR data and aerial images, there does not appear to be a continuous drainage connection. Differences between the drainage alignment in the LiDAR data (February 2004) and the aerial imagery (November 2008) suggest recent modifications to the drainage have been made in this area and may still be ongoing. It is noted that this would have the potential to impact on flood flow transfers between the Tharbogang Swamp and Lake Wyangan catchments.

Some small allowance for flow transfer via the agricultural drainage has been incorporated into the model. This provides a flow rate of around $3m^3/s$ within the Lake View Drain at location A for the 1% AEP design event. However, the Drain has a capacity of around 10m3/s at this location and so higher flows within the Drain are possible if there is sufficient potential for water to enter the Drain at the northern end. For the 1% AEP design event a peak flow rate of around $10m^3/s$ is being transferred from the Tharbogang Swamp catchment to the Lake Wyangan catchment through location B, with a total volumetric transfer of around 1200ML. If the Drain were running full at the upstream end then this would result in around a $17m^3/s$ peak flow transfer and a much greater volumetric transfer. An increased flow transfer of this magnitude would result in an additional 1000-2000ML being transferred from the Tharbogang Swamp catchment to Lake Wyangan – effectively increasing the total volumetric contribution to Lake Wyangan by 50%.

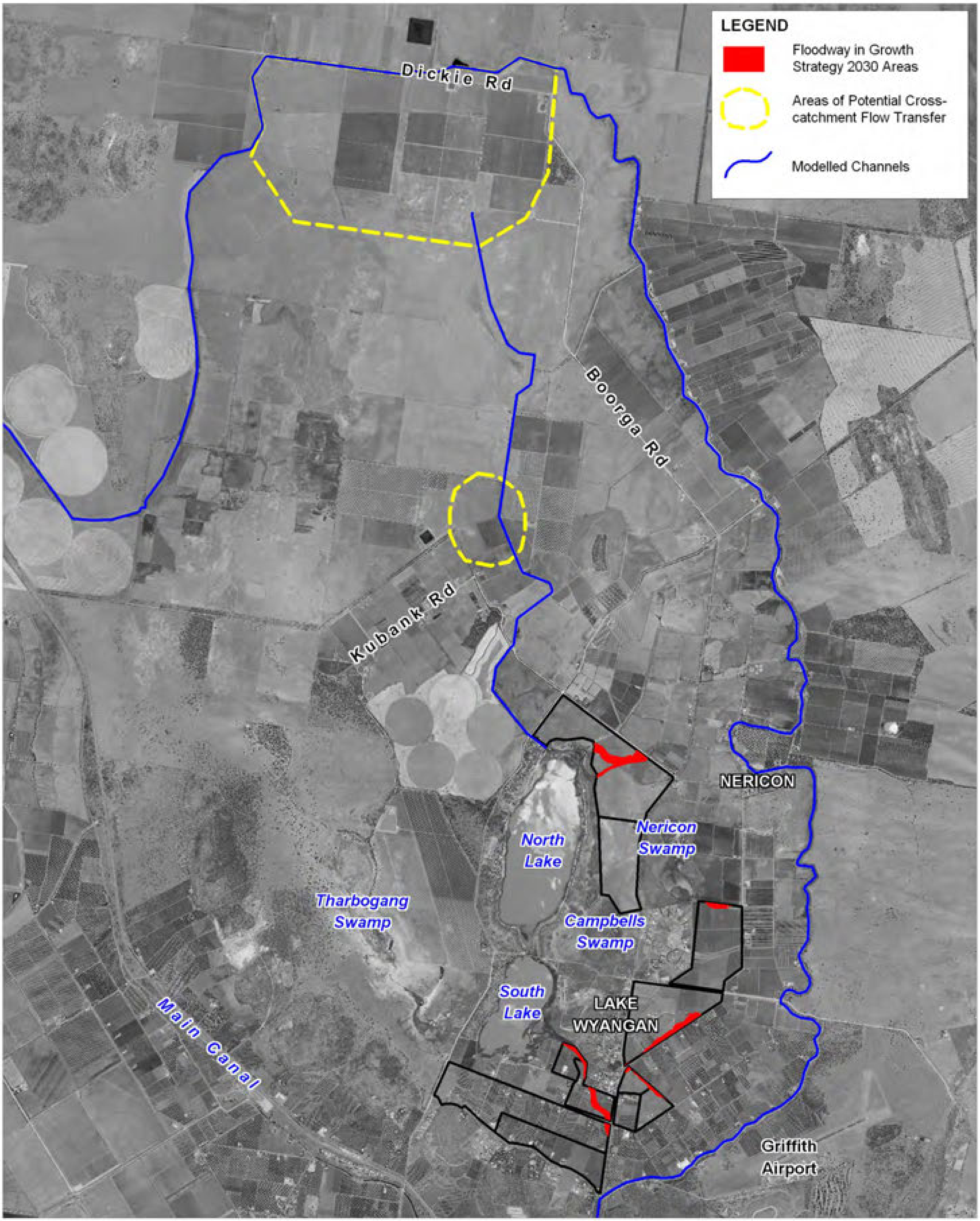
Given the potential for additional flow transfer through the Lake View Drain, either through the agricultural drainage at the northern end or in the area of potential flood flow interaction with the main catchment flow path, it was recommended to adopt the 15mm initial loss flood levels for Lake Wyangan. This conservatism accounts for the uncertainty of cross-catchment flow transfer from Tharbogang Swamp to Lake Wyangan and also the likelihood of localised high intensity storms, as discussed in Section 7.2.1.

7.3.3 Local Drainage Infrastructure

In addition to the Lake View Branch Canal and Lake View Drain, there is an extensive network of irrigation supply and drainage infrastructure located within the study area. The hydraulics of these less significant channels has not been explicitly modelled. However, the bank elevations will be captured to some extent by the model elevations from the LiDAR data. The complexity of modelling such a network, incorporating channel hydraulics, bank crest elevations and hydraulic control structures is beyond the scope of this study and is unlikely to have a significant impact on catchment flood results. However, localised differences in modelled flood results and the actual flood behaviour may occur as a result of this limitation.

7.4 Key Locations for Future Consideration

Through the catchment modelling process undertaken for this study, three locations have been identified that should be considered from a future floodplain risk management perspective. These include the two locations identified on Figure 7-8 where there is potential for cross-catchment flow transfer from the Tharbogang Swamp catchment to Lake Wyangan. Future ground works undertaken in these areas may have the potential to change the existing flow distribution. The other key consideration is the locations where floodways occur within the proposed future development areas of the Growth Strategy 2030. These key locations are identified on Figure 7-9.



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Key Locations for Future Consideration

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8 CONCLUSIONS

The objective of the study was to undertake a detailed flood study of the Lake Wyangan catchment and establish models as necessary for design flood level prediction.

In completing the flood study, the following activities were undertaken:

- Collation of historical flood information for the study area;
- Consultation with the community to acquire additional historical flood information;
- Development of a 2D/1D hydrodynamic model (using TUFLOW software) to simulate hydrology and flood behaviour in the catchment;
- Calibration of the developed model using the available flood data, primarily relating to the March 1989 event;
- Prediction of design flood conditions in the catchment and production of design flood mapping series.

Through the undertaking of the flood study it has been found that during flood events the majority of the catchment runoff flows to Tharbogang Swamp rather than Lake Wyangan, as had previously been assumed. Historically there has been little response of Lake Wyangan water levels to rainfall events within the catchment, with only the March 1989 event producing a significant response. The limited response in Lake Wyangan is due to a number of factors:

- It has a relatively small catchment area of around 100km^2, including diverted catchment runoff through the Lake View Drain (Lake Wyangan's natural catchment is around 75km^2);
- The calibration process found the catchment to indicate a high initial rainfall loss for the events considered. A large amount of rainfall (>60mm) is required before any catchment runoff is generated and a response in the lake can be observed; and
- A proportion of the catchment runoff volume is retained in temporary flood storages in the catchment, rather than further contributing to the flood storage in the lake.

Being a volume-driven closed-catchment system with no natural outlet, flood levels in Lake Wyangan and Tharbogang Swamp are directly related to the catchment runoff volume generated by any given flood event. The high rainfall losses generate relatively small effective rainfall depths and the flood levels are therefore highly sensitive to changes in the adopted initial loss value. The calibration process found an initial loss value of around 60mm to be appropriate for the events considered. However, due to the characteristics of the available design rainfall temporal pattern, this loss value was reduced for design purposes.

Tharbogang Swamp has a much larger catchment area than Lake Wyangan and therefore shows a much greater flood response. Unfortunately there has been no history of flood level recording in Tharbogang Swamp to compare to the modelled flood response. The recommended design flood levels for Lake Wyangan and Tharbogang Swamp are presented in Table 8-1.

Table 8-1 Recommended Design Flood Levels

Design Event	Peak Flood Level (m AHD)	
	Lake Wyangan	Tharbogang Swamp
20% AEP 18h	106.5	103.5
10% AEP 18h	106.5	104.2
5% AEP 18h	106.8	105.8
2% AEP 18h	107.2	108.0
1% AEP 18h	107.6	109.8
0.5% AEP 18h	108.1	110.8
PMF (3x1%AEP 18h)	116.1	116.1

There remains an inherent amount of uncertainty in the design flood levels given the sensitivity of the two storages to changes in the modelled initial rainfall loss. In addition, cross-catchment flow transfer from the Tharbogang Swamp catchment to Lake Wyangan is provided via the Lake View Drain. The magnitude of this transfer during a significant flood event is uncertain and would impact on the resultant flood levels in Lake Wyangan and Tharbogang Swamp.

The study also identified a number of local overland flow paths which impact of the planned development areas of Council's Growth Strategy 2030. It is important that these flow paths are taken into consideration during the stages of development planning.

The flood study will form the basis for the subsequent floodplain risk management activities, being the next stage of the floodplain risk management process. The key locations to consider during this process have been identified as:

- Locations where there is potential for cross-catchment flow transfer from the Tharbogang Swamp catchment into Lake Wyangan (potential changes to the existing flow distribution may result from future on-ground works in these localities) ; and
- Locations where the floodways occur within the proposed development areas of the Giffith Growth Strategy 2030.

9 REFERENCES

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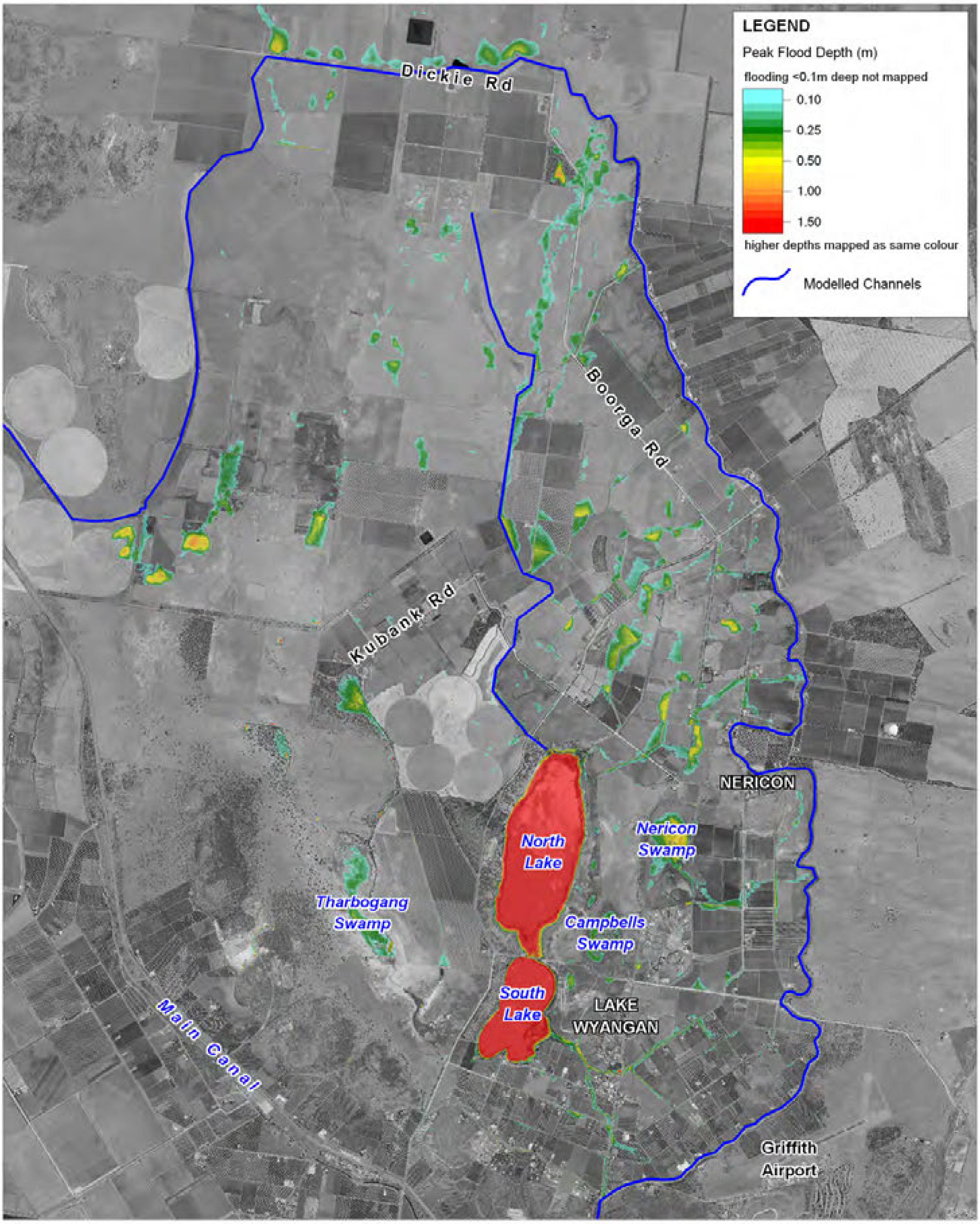
APPENDIX A: DESIGN FLOOD MAPPING



Title:

Lake Wyangan Flood Study
Peak Flood Depths: 20% AEP Event

Figure: **A-1**

Rev: **A**

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Approx. Scale

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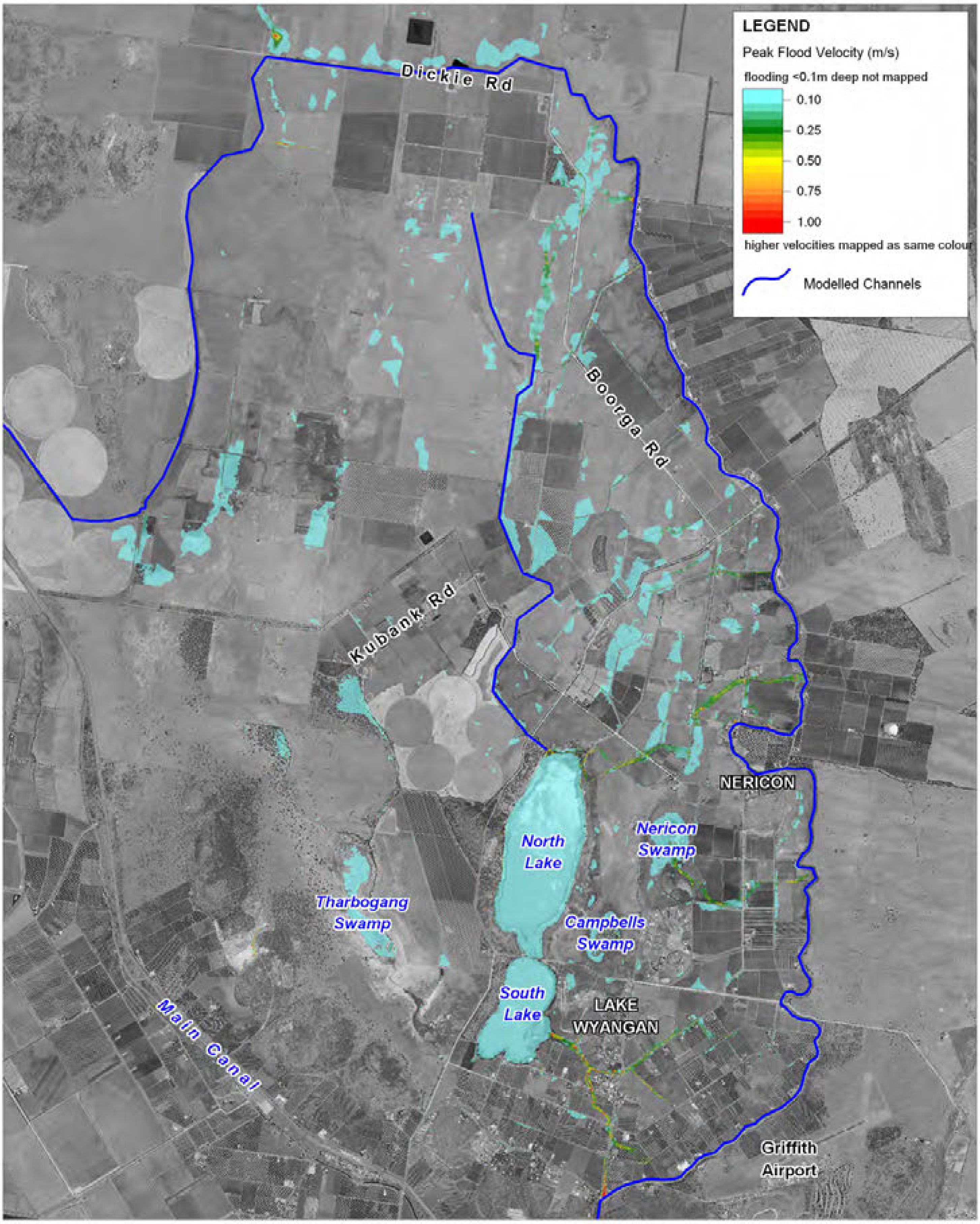

Title:

Lake Wyangan Flood Study
Peak Flood Velocities: 20% AEP Event

Figure: A-2

Rev: A

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Approx. Scale

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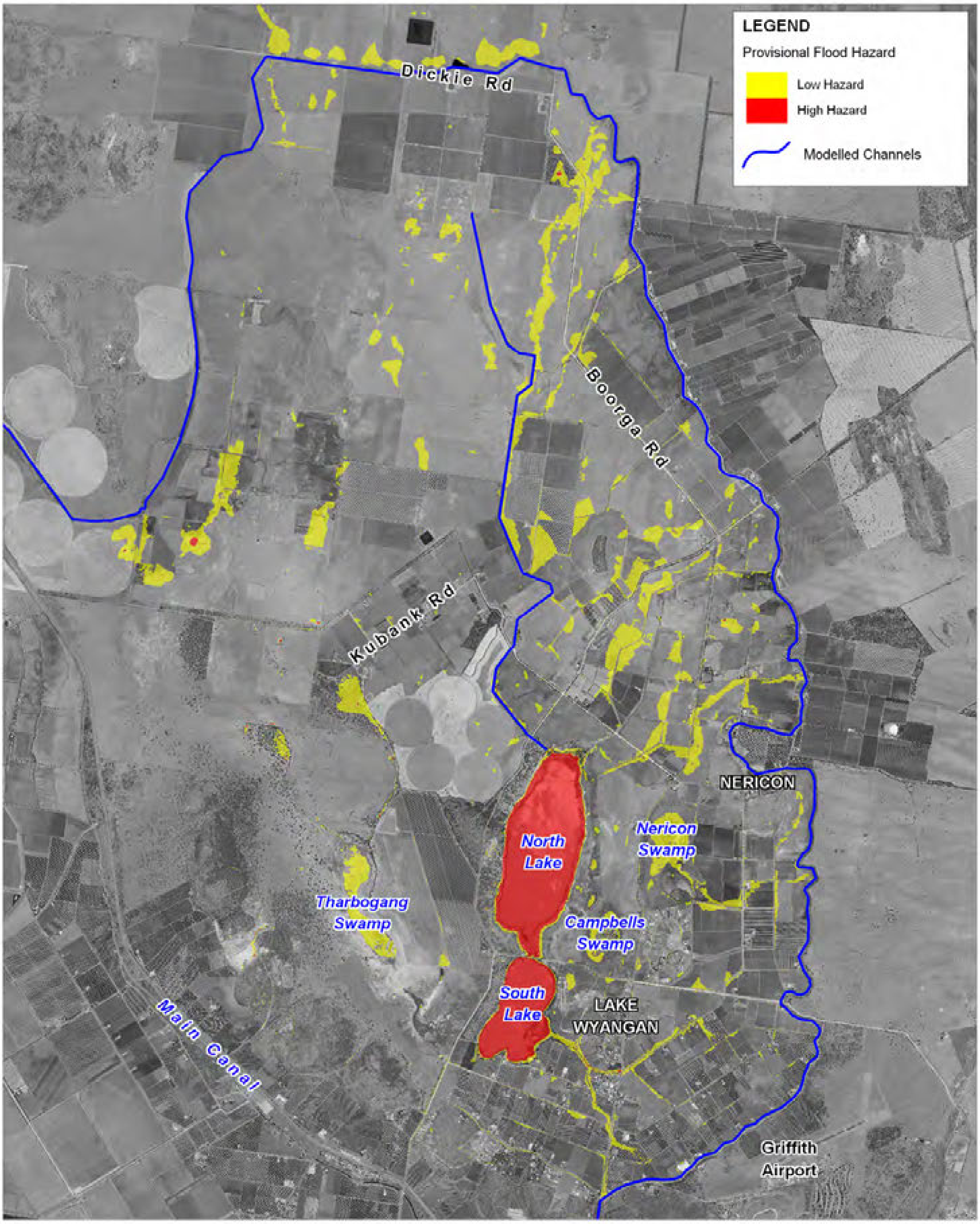

Title:

Lake Wyangan Flood Study
Provisional Flood Hazard: 20% AEP Event

Figure: **A-3**

Rev: **A**

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Approx. Scale

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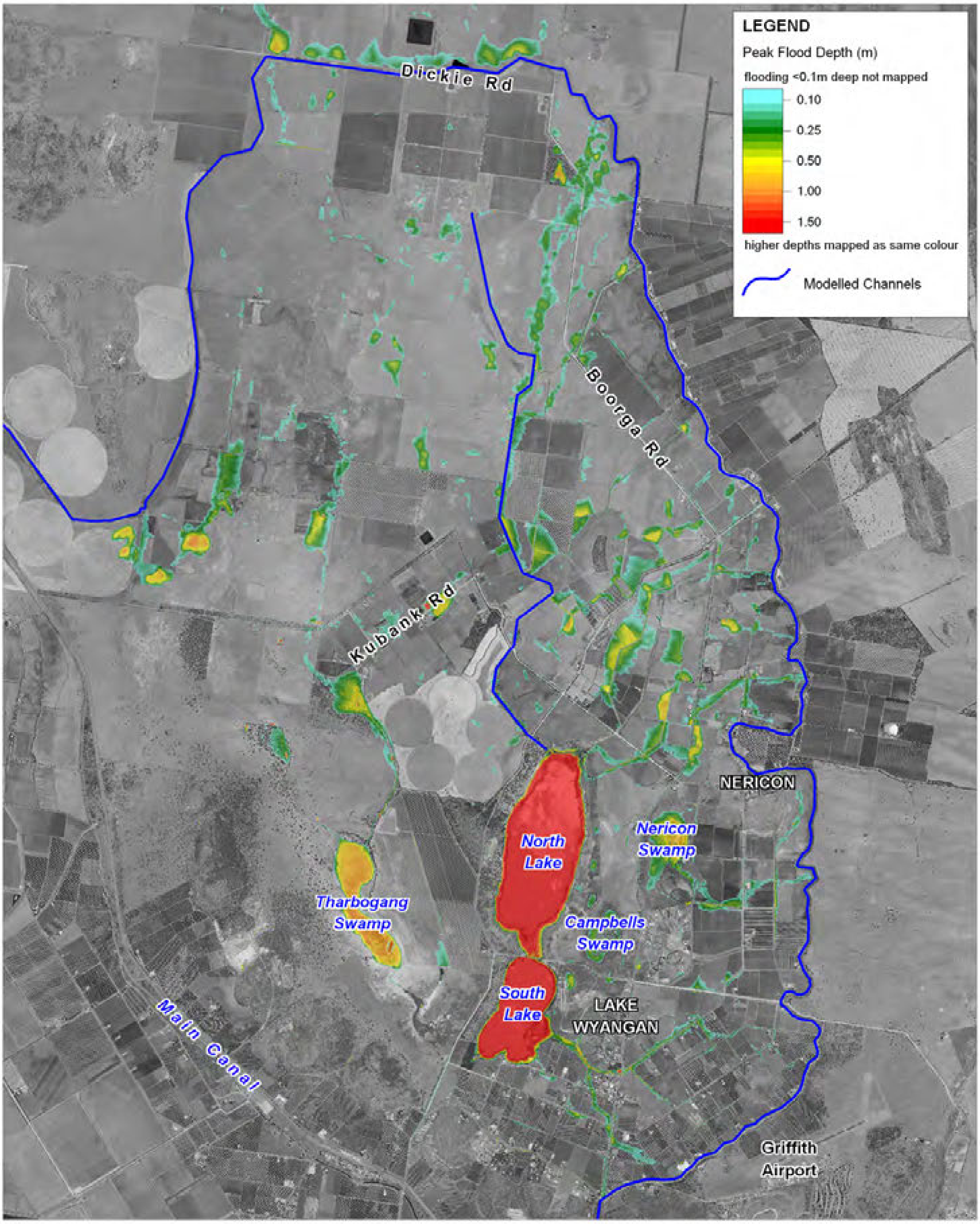

Title:

Lake Wyangan Flood Study
Peak Flood Depths: 10% AEP Event

Figure: A-4

Rev: A

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Approx. Scale

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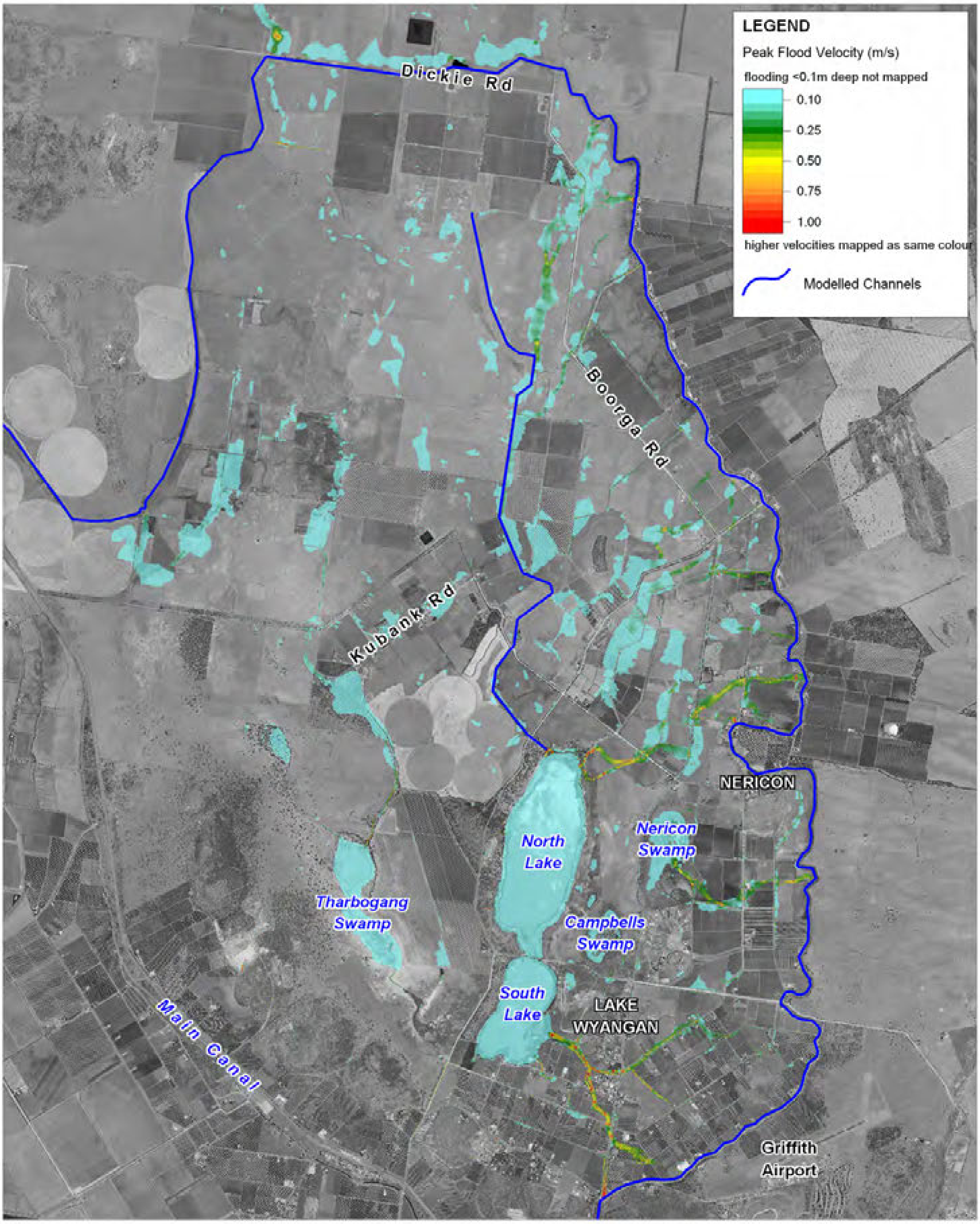

Title:
Lake Wyangan Flood Study
Peak Flood Velocities: 10% AEP Event

Figure: **A-5**

Rev: **A**

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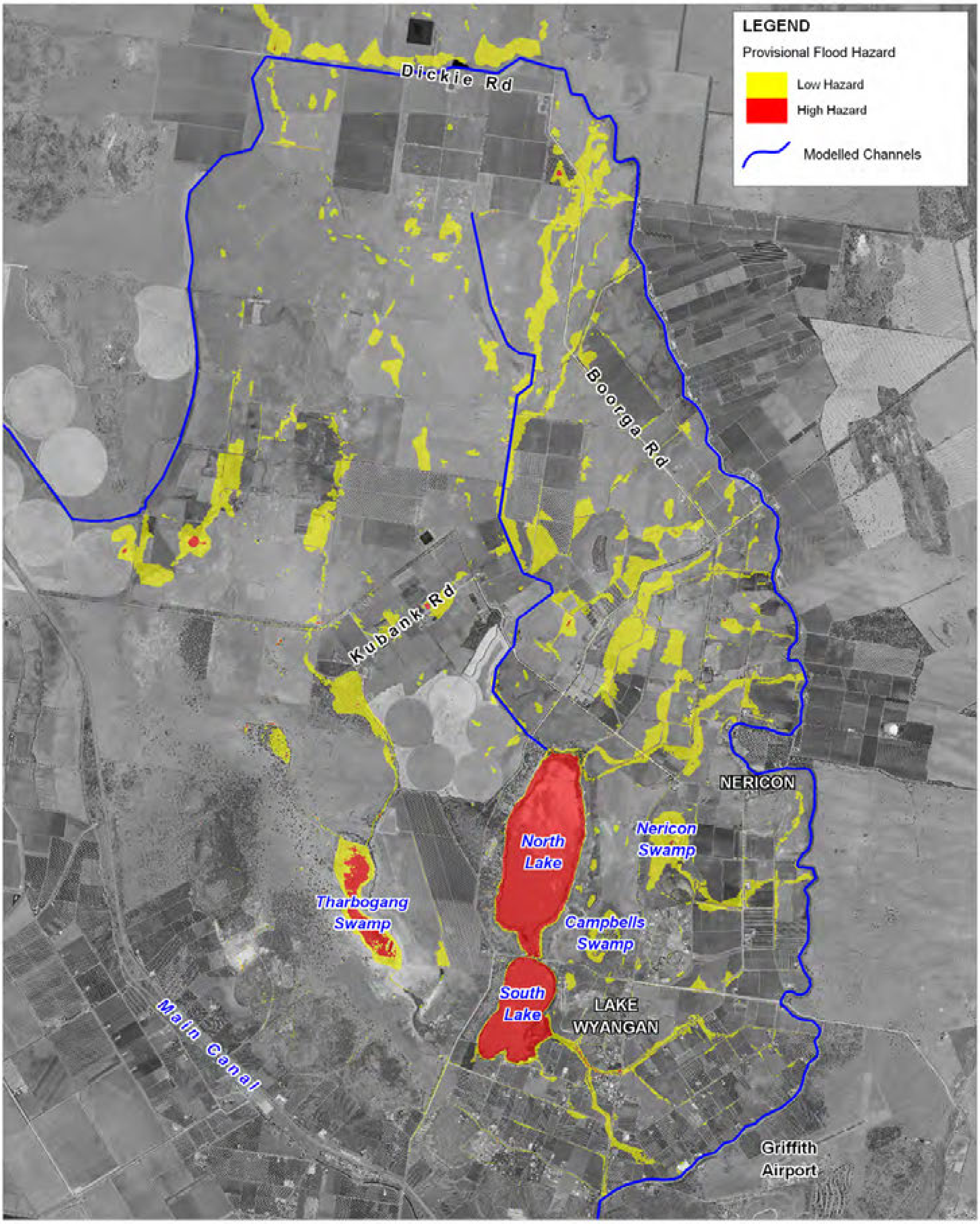

Title:

Lake Wyangan Flood Study
Provisional Flood Hazard: 10% AEP Event

Figure: **A-6**

Rev: **A**

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Approx. Scale

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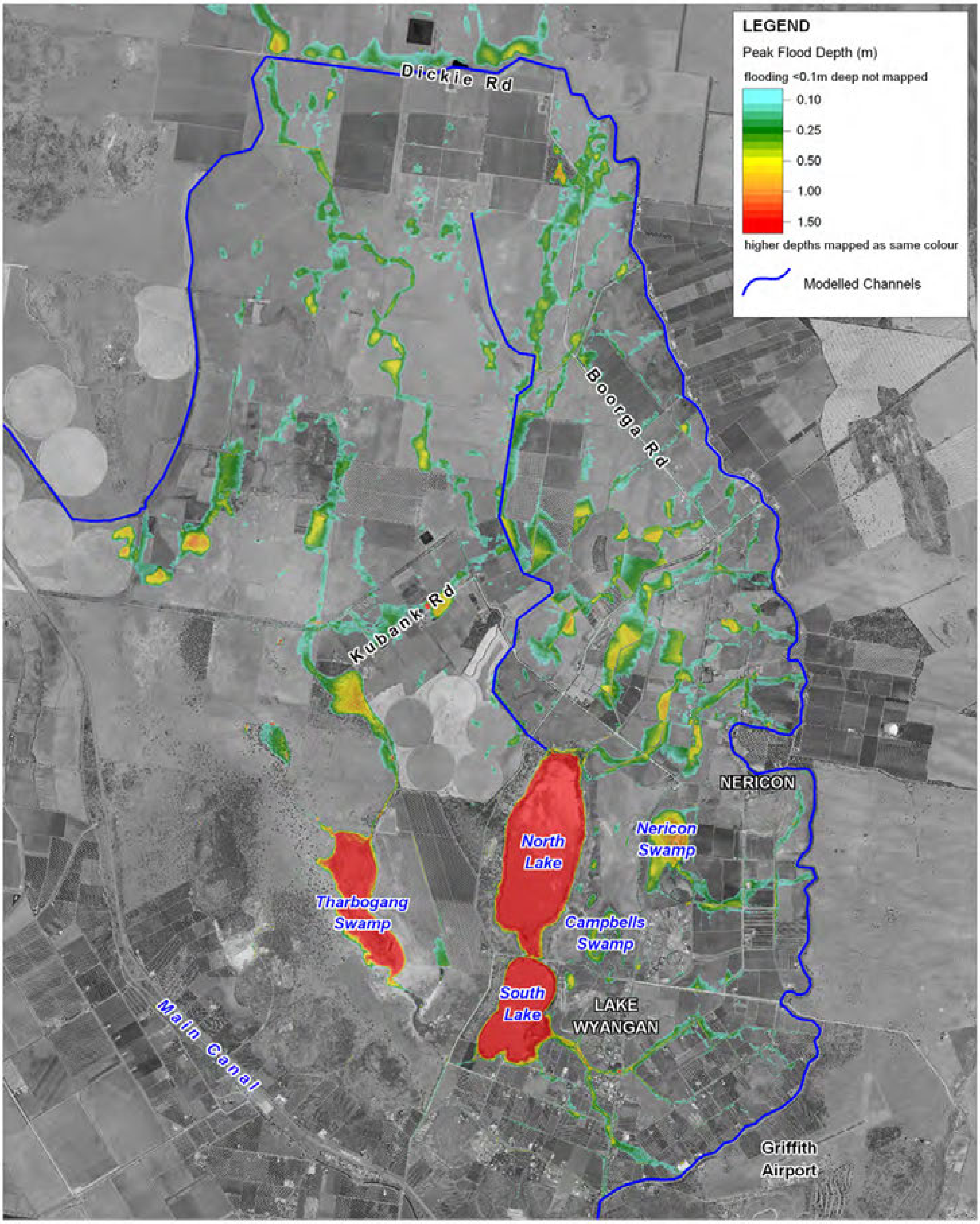

Title:

Lake Wyangan Flood Study
Peak Flood Depths: 5% AEP Event

Figure: A-7

Rev: A

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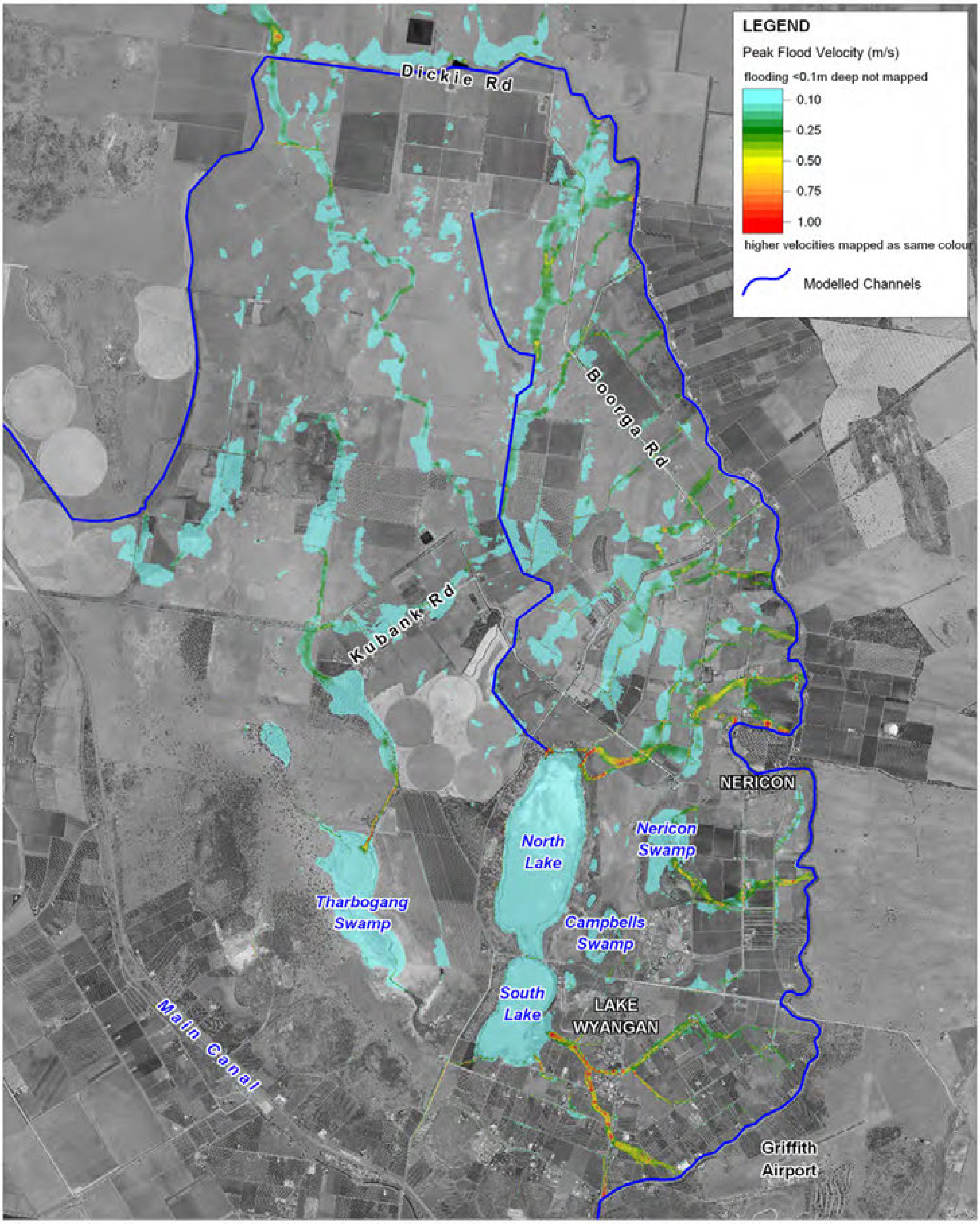

Title:

Lake Wyangan Flood Study
Peak Flood Velocities: 5% AEP Event

Figure: **A-8**

Rev: **A**

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Approx. Scale

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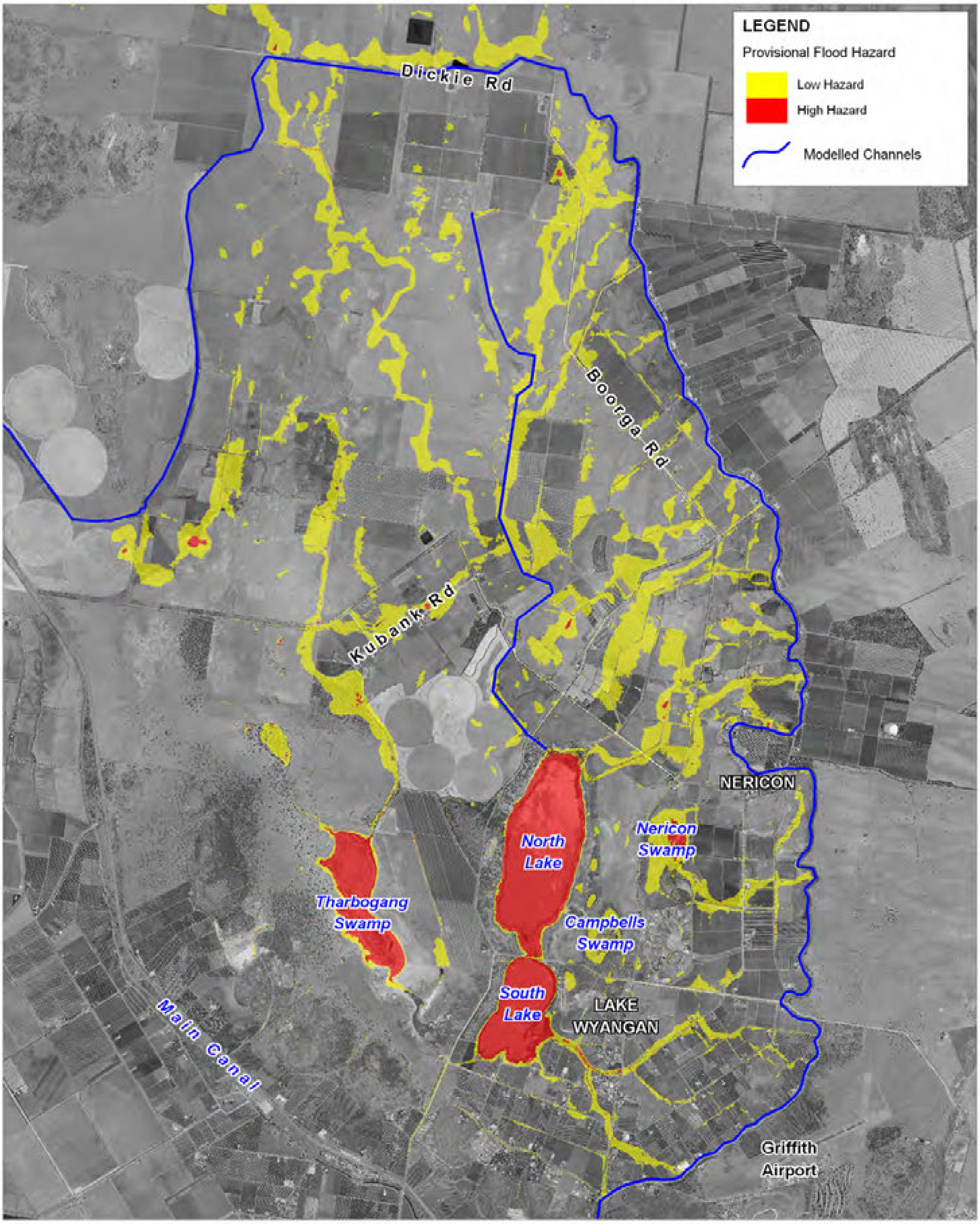

Title:

Lake Wyangan Flood Study
Provisional Flood Hazard: 5% AEP Event

Figure: **A-9**

Rev: **A**

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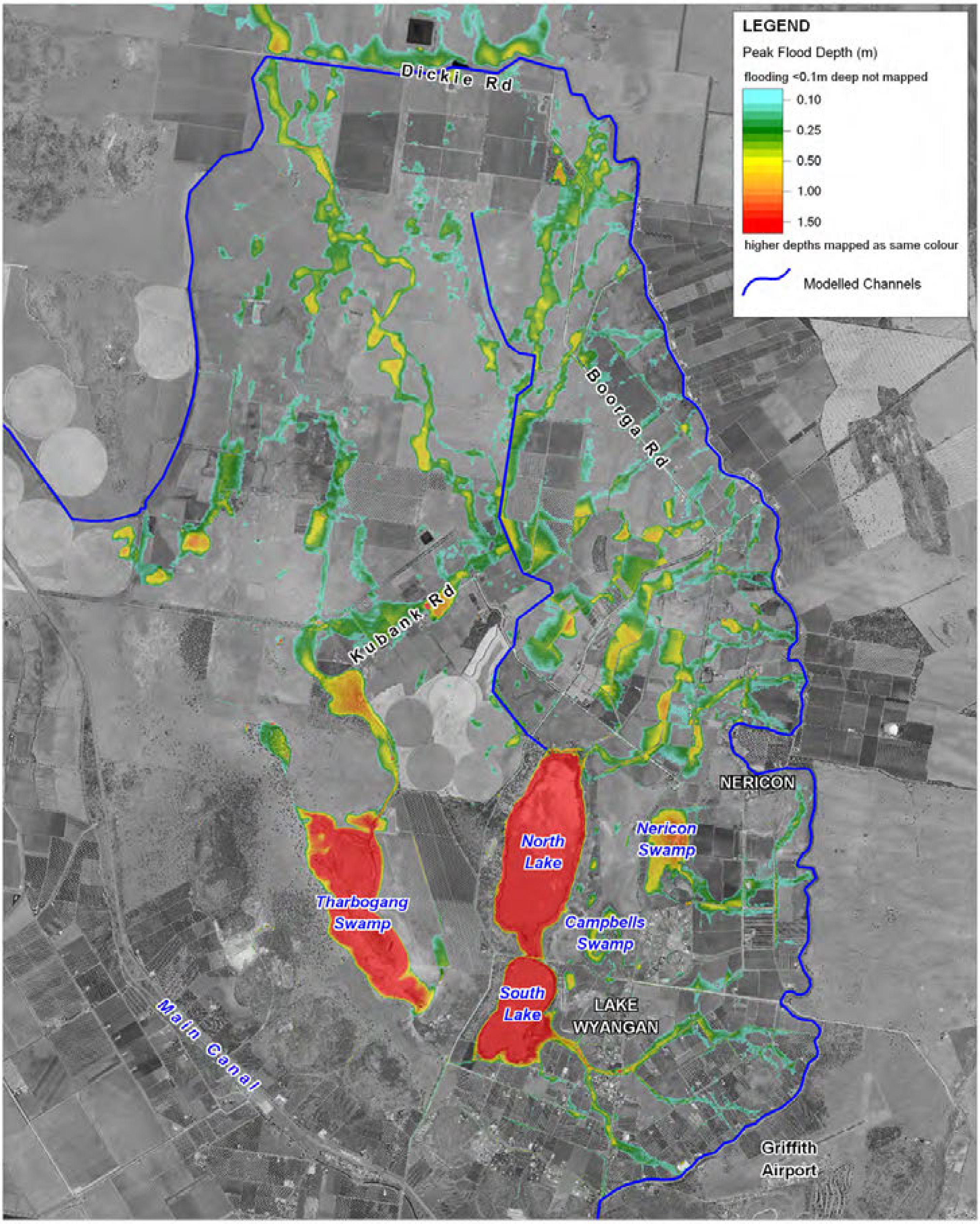

Title:

Lake Wyangan Flood Study
Peak Flood Depths: 2% AEP Event

Figure: A-10

Rev: A

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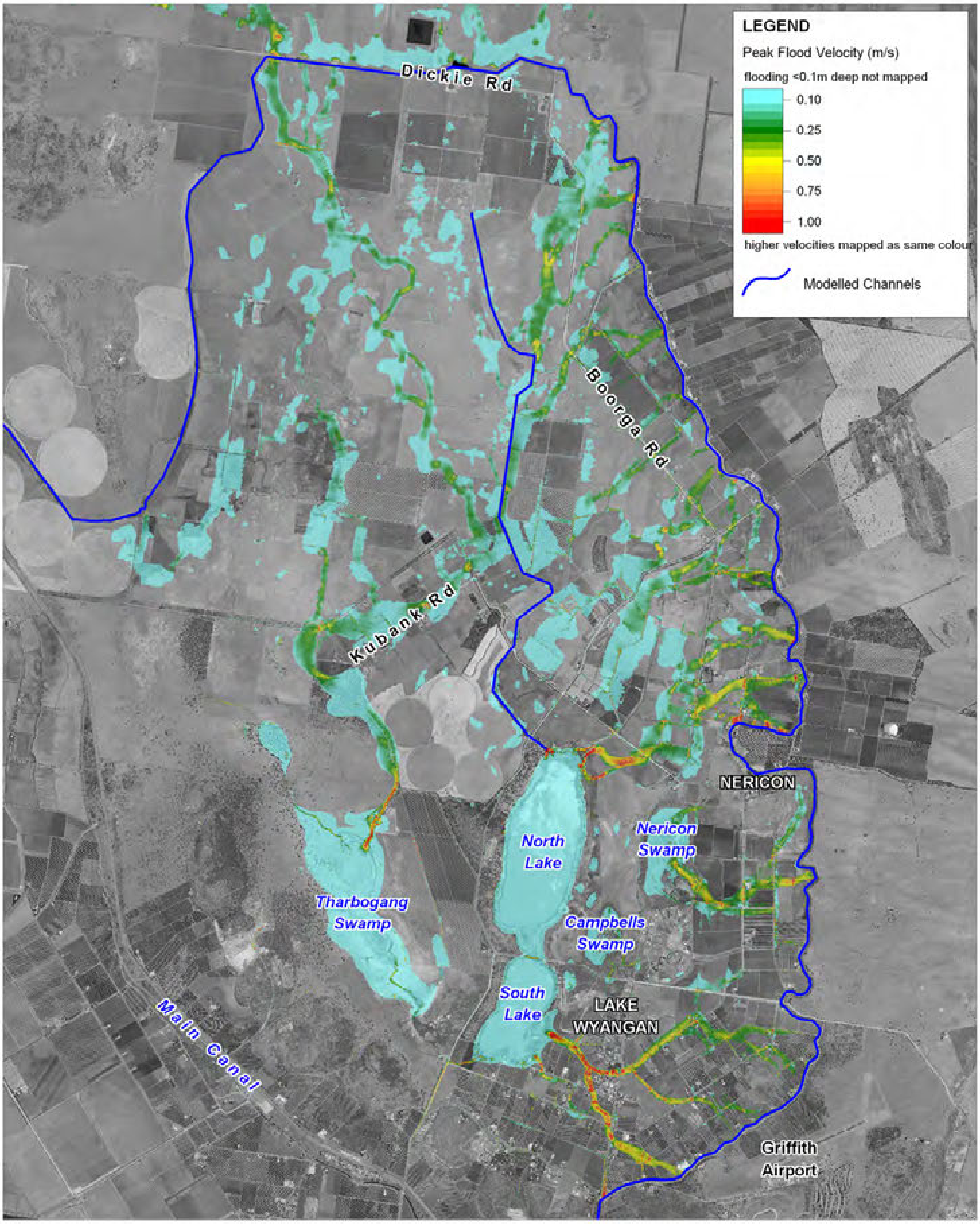

Title:
Lake Wyangan Flood Study
Peak Flood Velocities: 2% AEP Event

Figure: A-11

Rev: A

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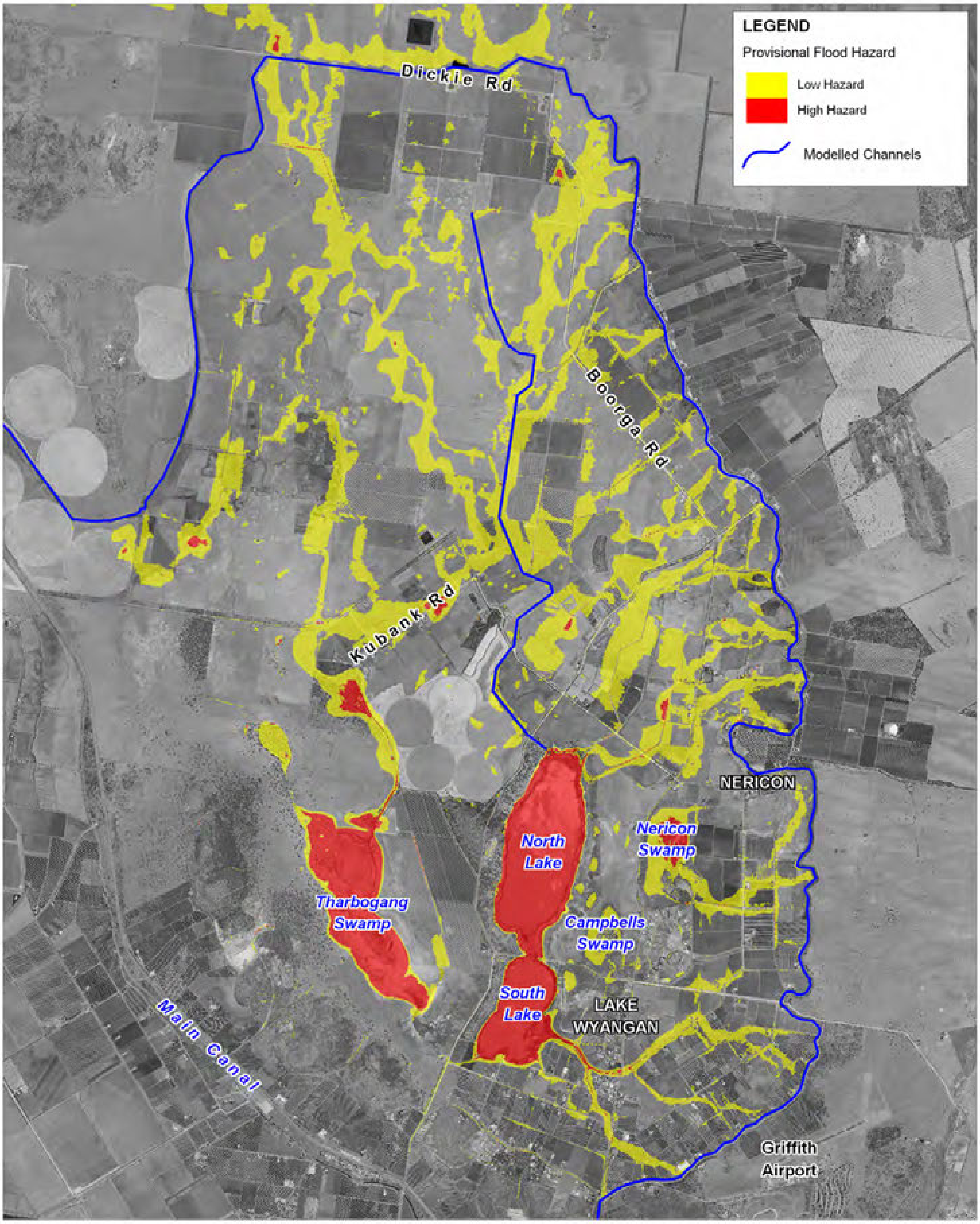

Title:

Lake Wyangan Flood Study
Provisional Flood Hazard: 2% AEP Event

Figure:	Rev:
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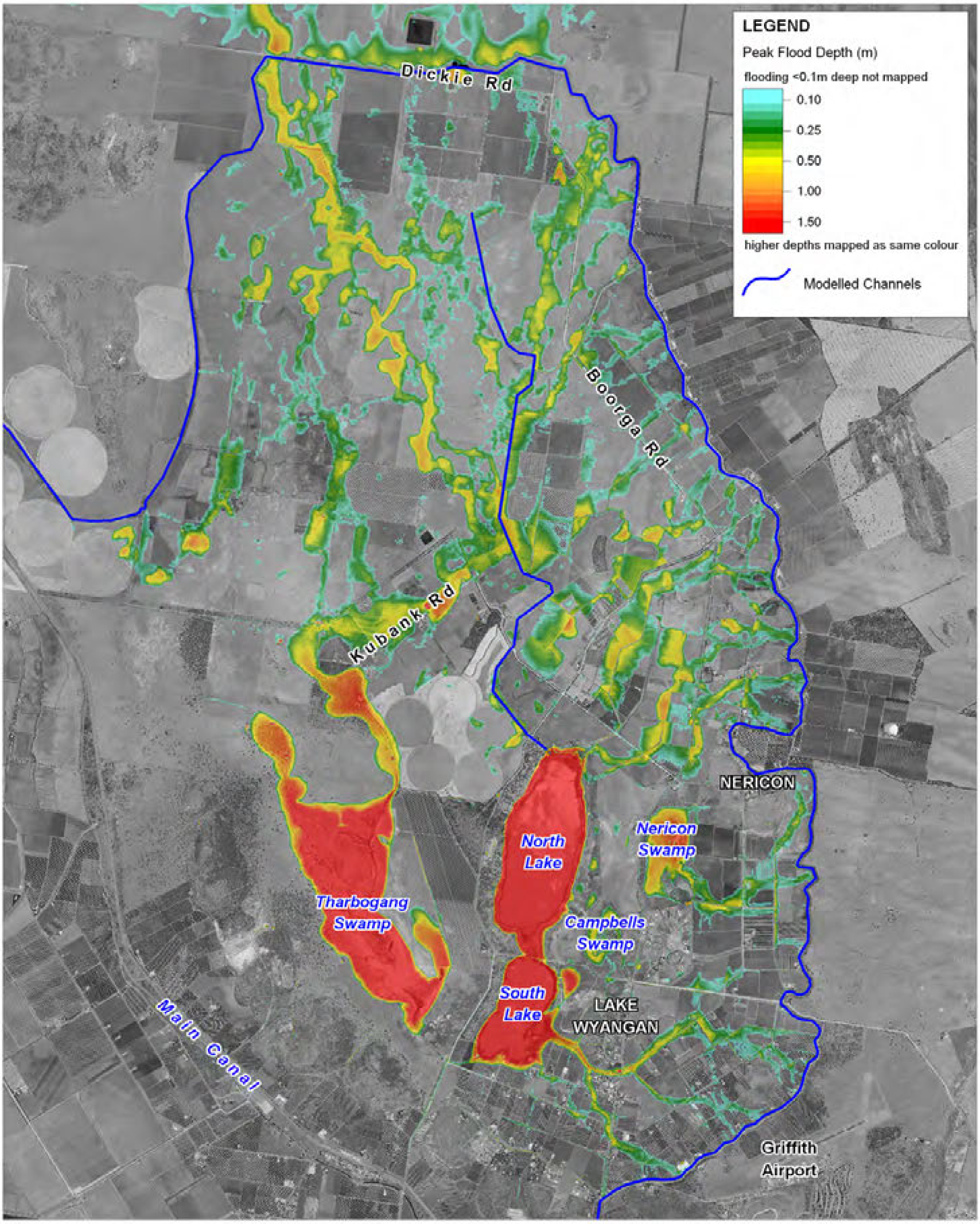

Title:

Lake Wyangan Flood Study
Peak Flood Depths: 1% AEP Event

Figure: A-13

Rev: A

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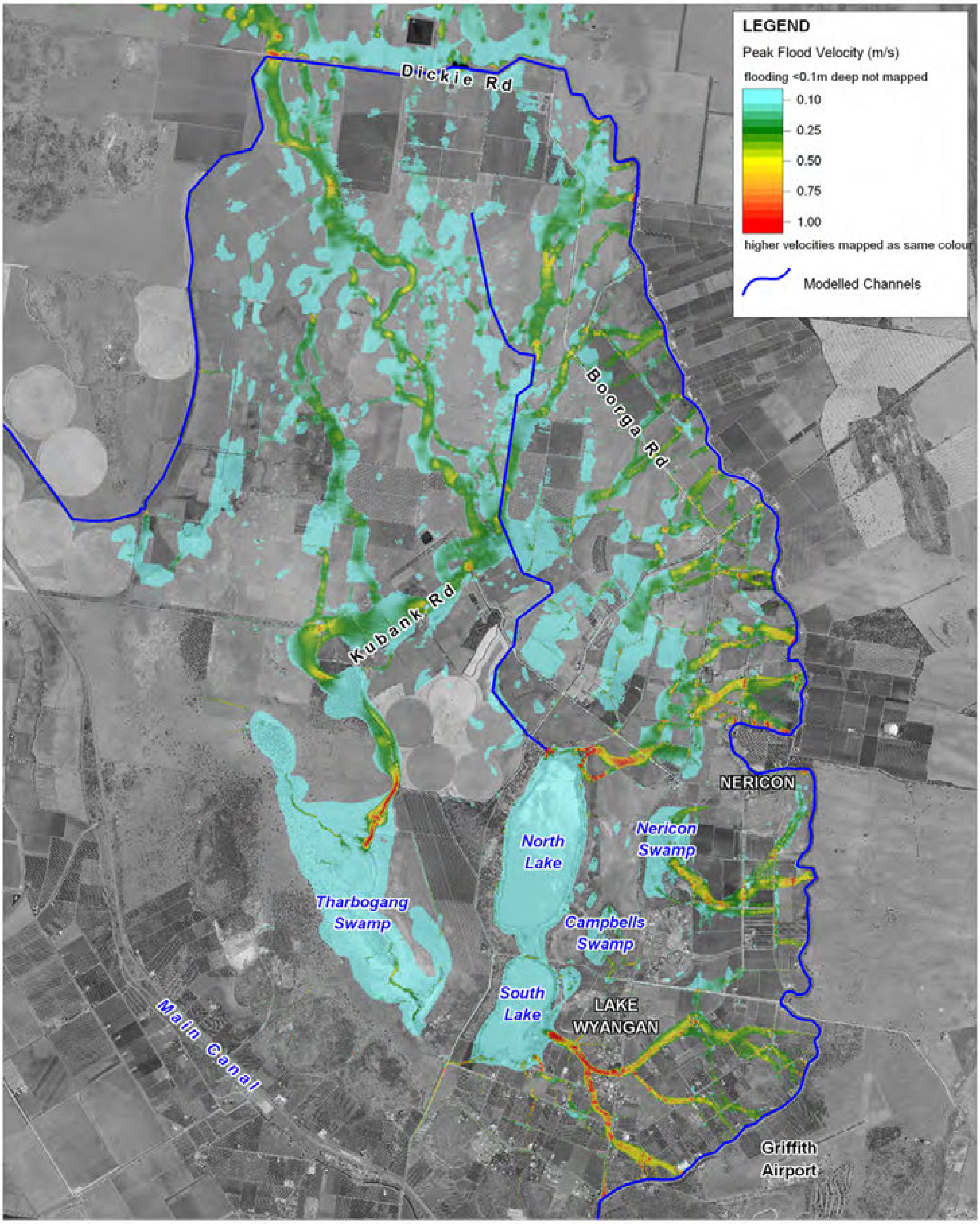

Title:

Lake Wyangan Flood Study
Peak Flood Velocities: 1% AEP Event

Figure: A-14

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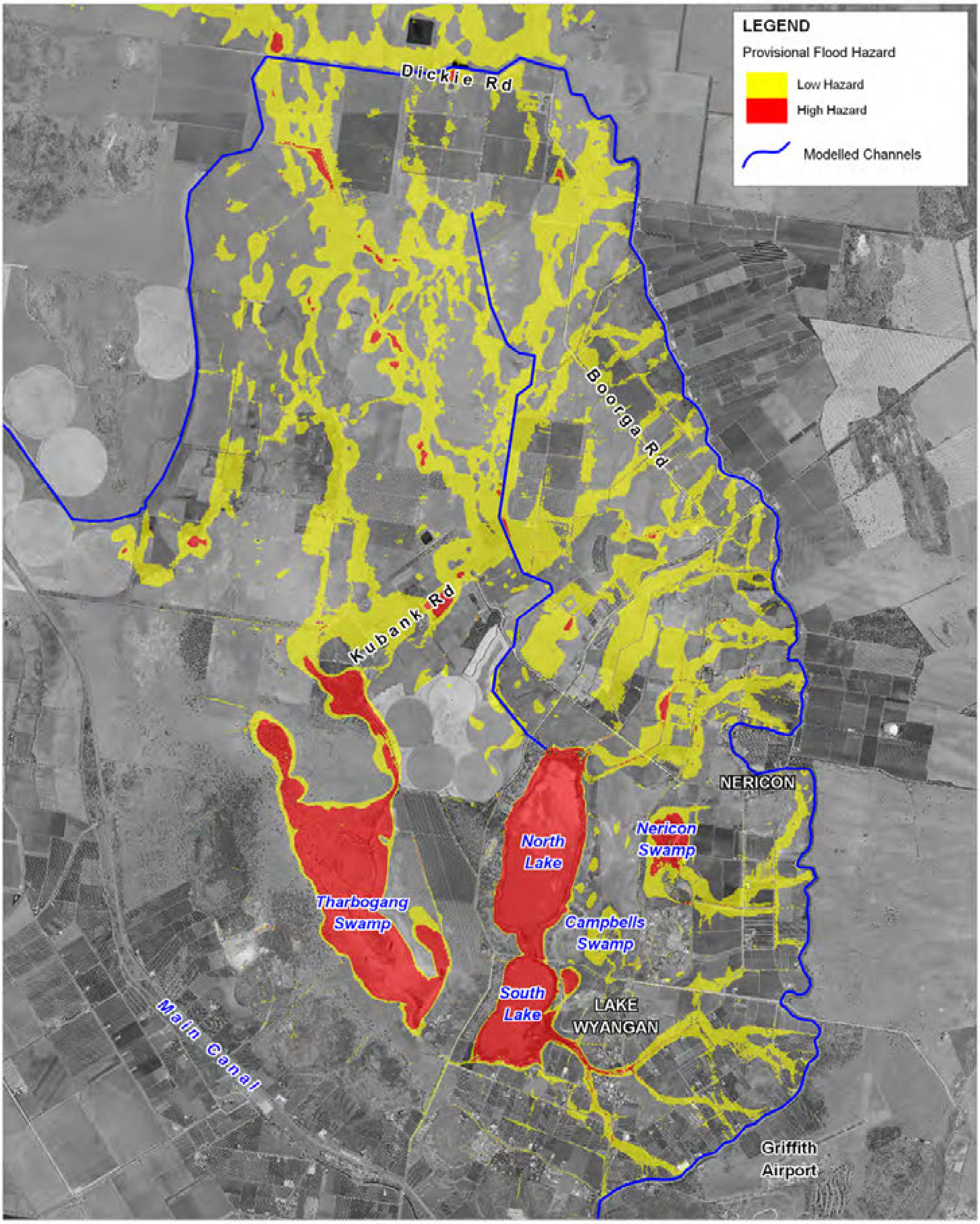

Title:

Lake Wyangan Flood Study
Provisional Flood Hazard: 1% AEP Event

Figure: A-15

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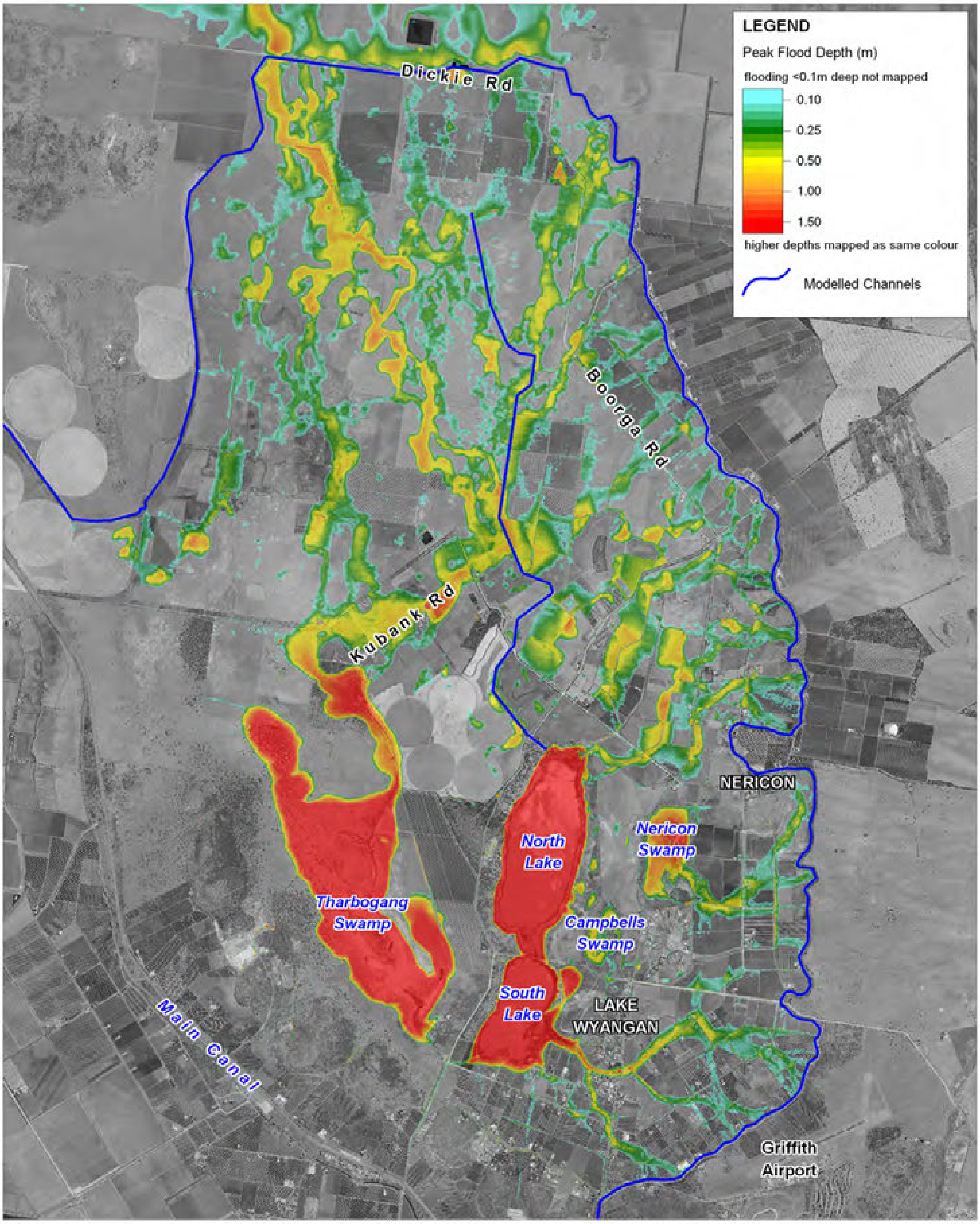

Title:

Lake Wyangan Flood Study
Peak Flood Depths: 0.5% AEP Event

Figure: A-16

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Approx. Scale

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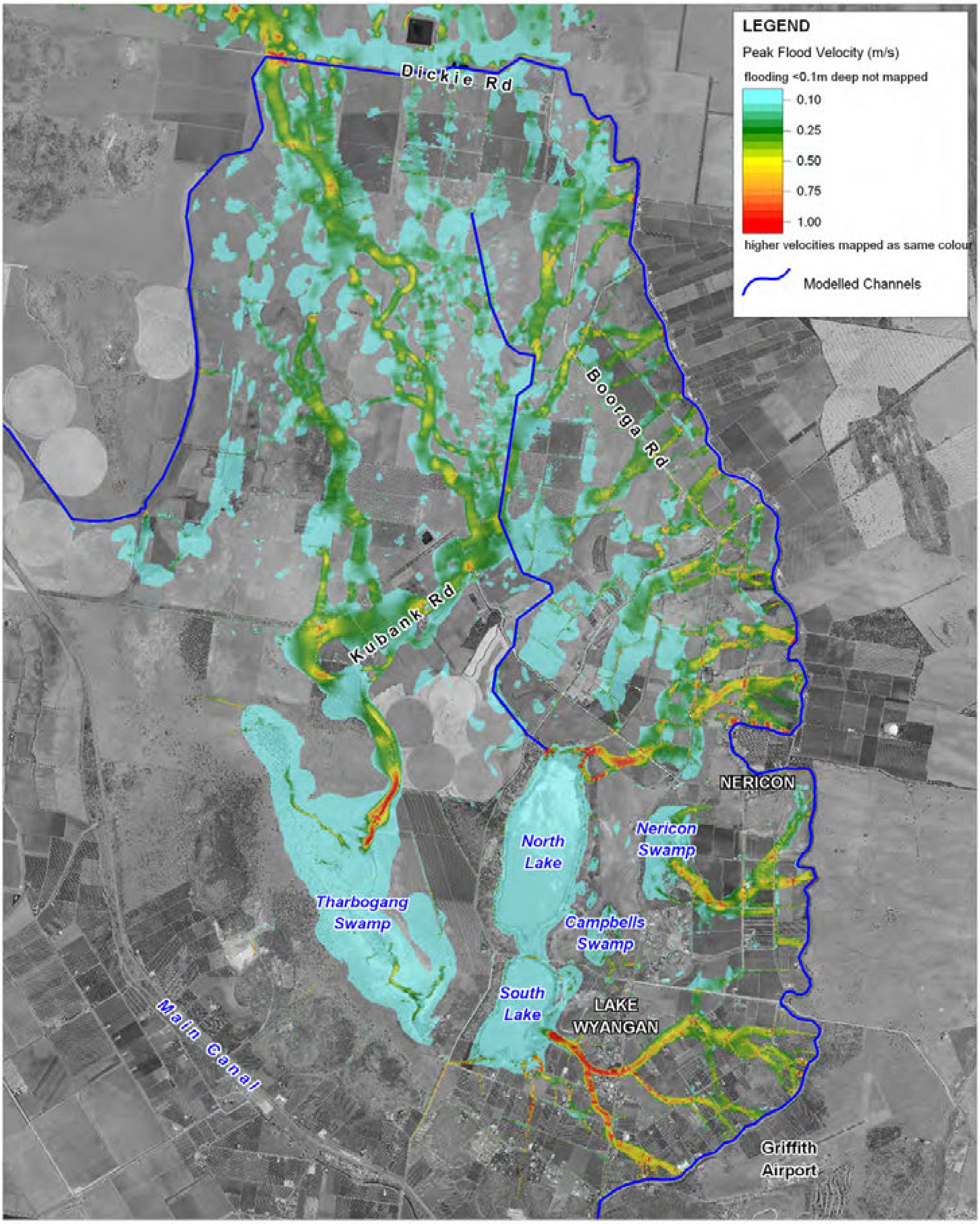

Title:

Lake Wyangan Flood Study
Peak Flood Velocities: 0.5% AEP Event

Figure: **A-17**

Rev: **A**

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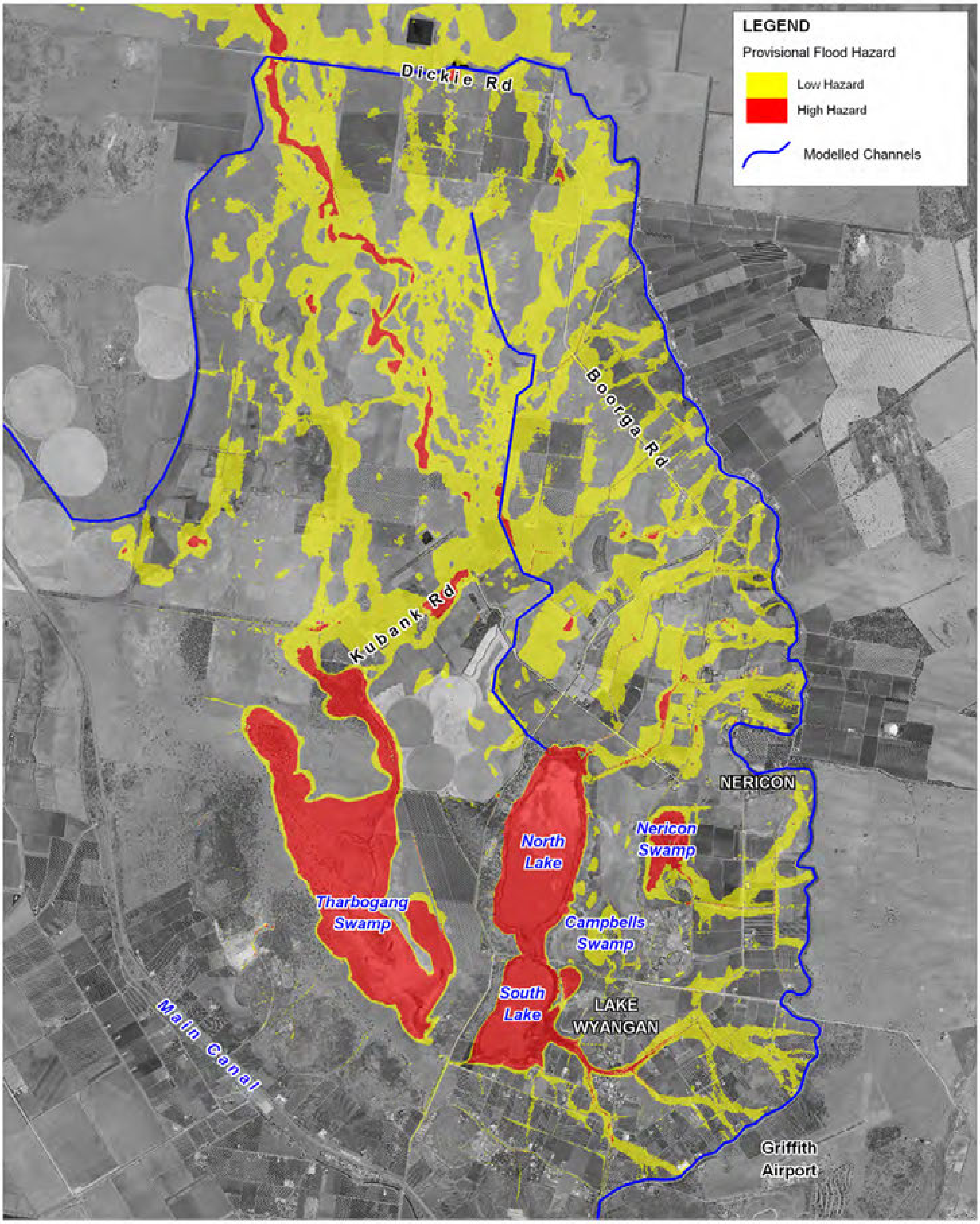

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Lake Wyangan Flood Study
Provisional Flood Hazard: 0.5% AEP Event

Figure: **A-18**

Rev: **A**

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Approx. Scale

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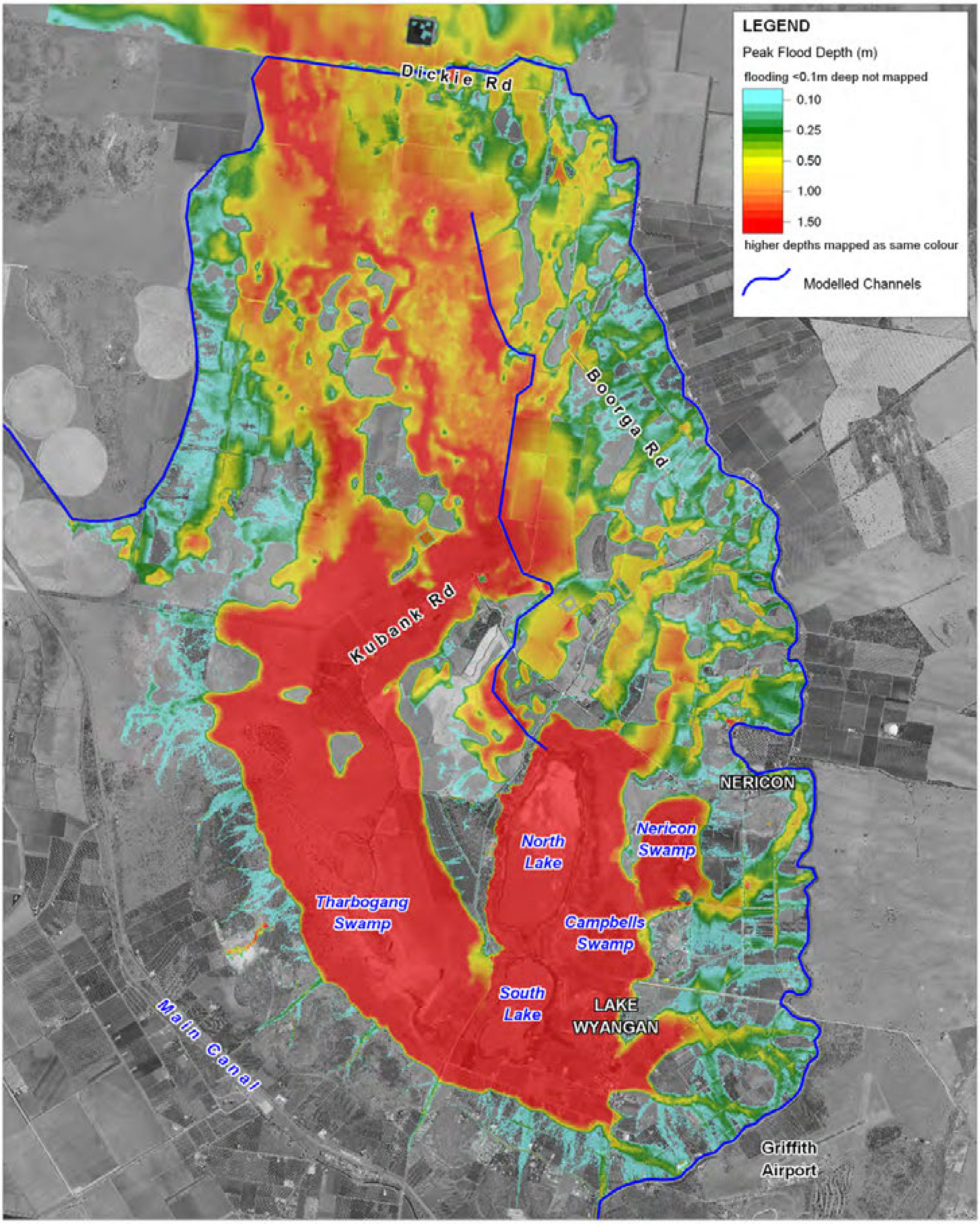

Title:

Lake Wyangan Flood Study
Peak Flood Depths: 3x1% AEP (PMF) Event

Figure: **A-19**

Rev: **A**

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Approx. Scale

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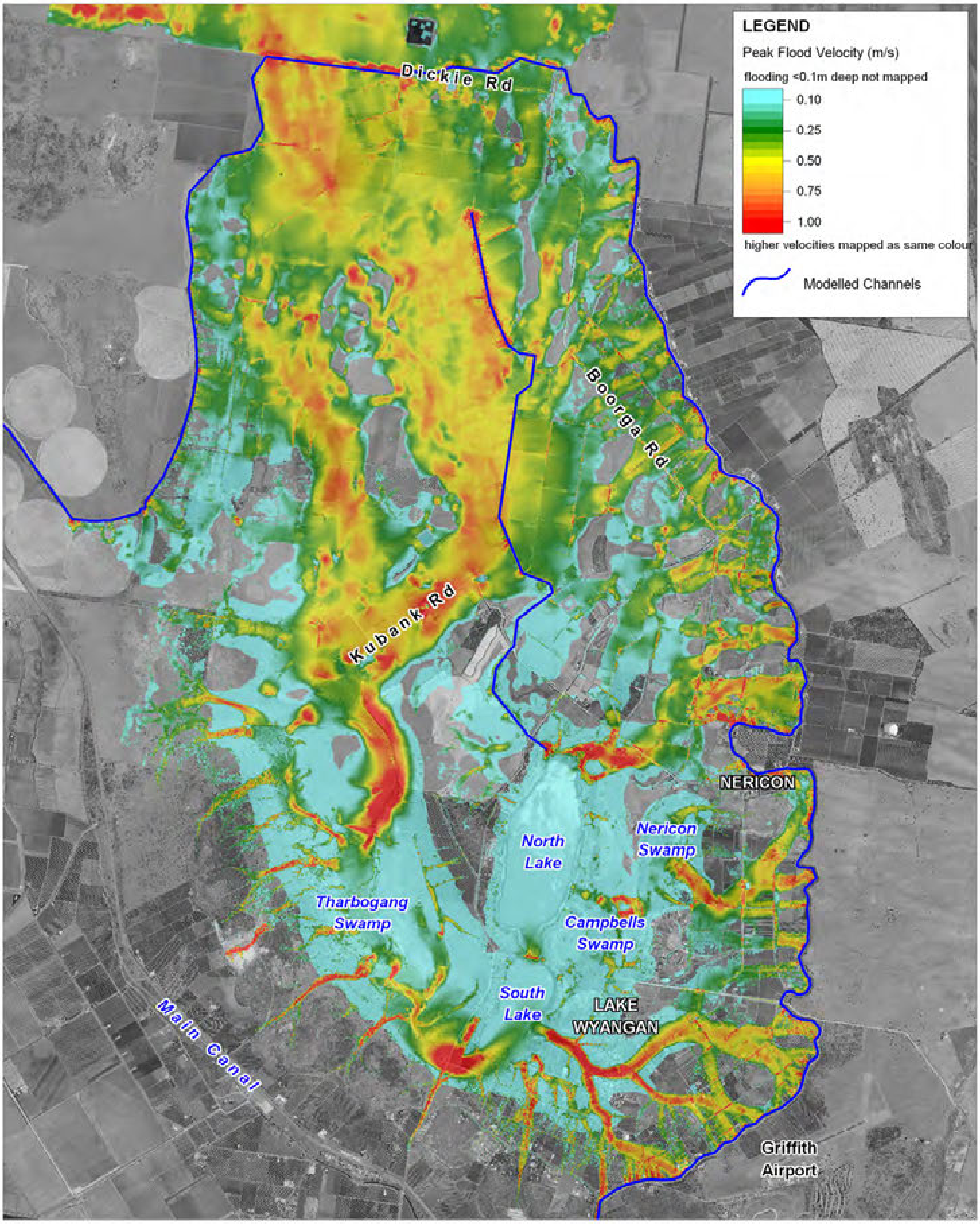

Title:

Lake Wyangan Flood Study
Peak Flood Velocities: 3x1% AEP (PMF) Event

Figure: A-20

Rev: A

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Approx. Scale

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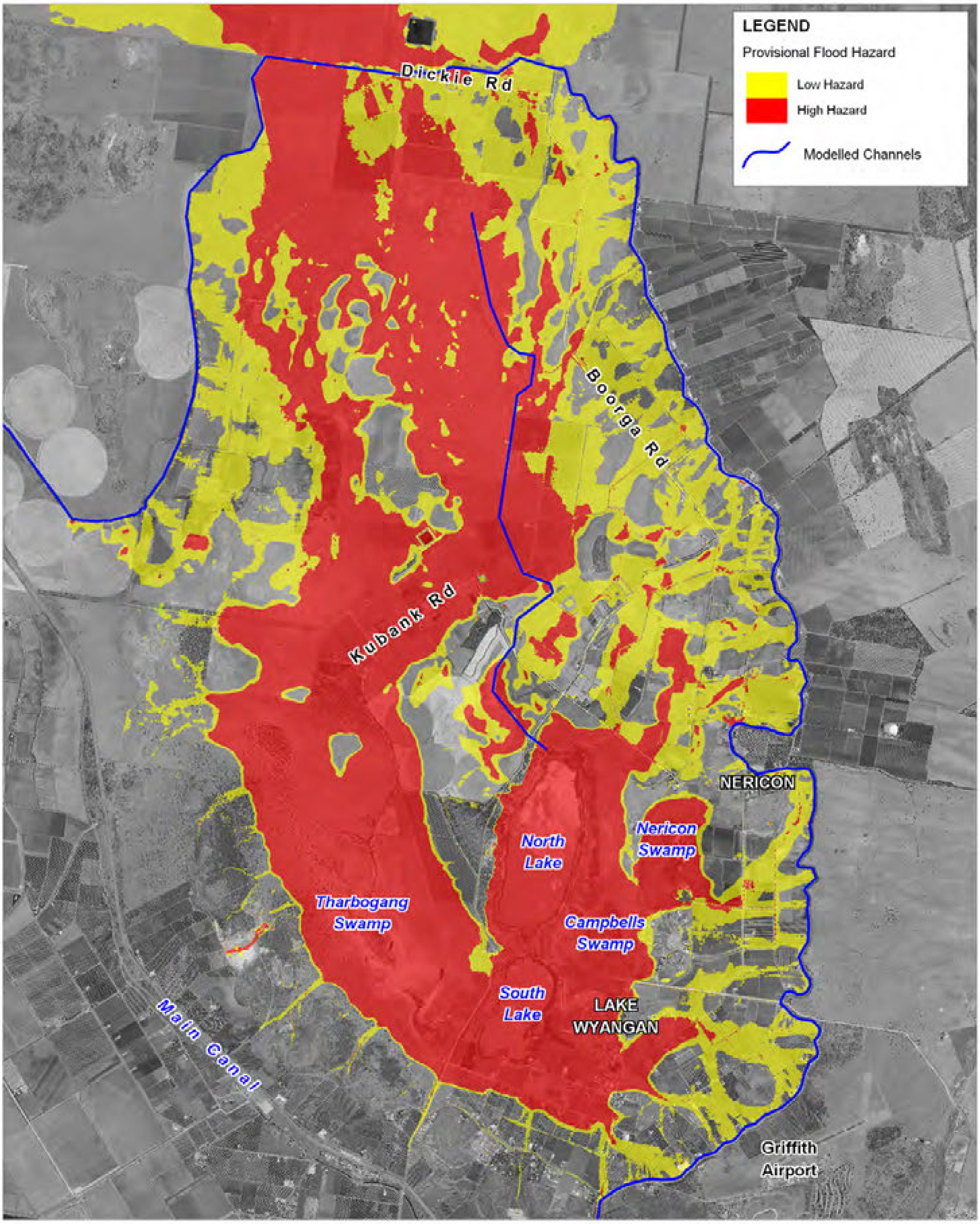

Title:

Lake Wyangan Flood Study
Provisional Flood Hazard: 3x1% AEP (PMF) Event

Figure: **A-21**

Rev: **A**

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Approx. Scale

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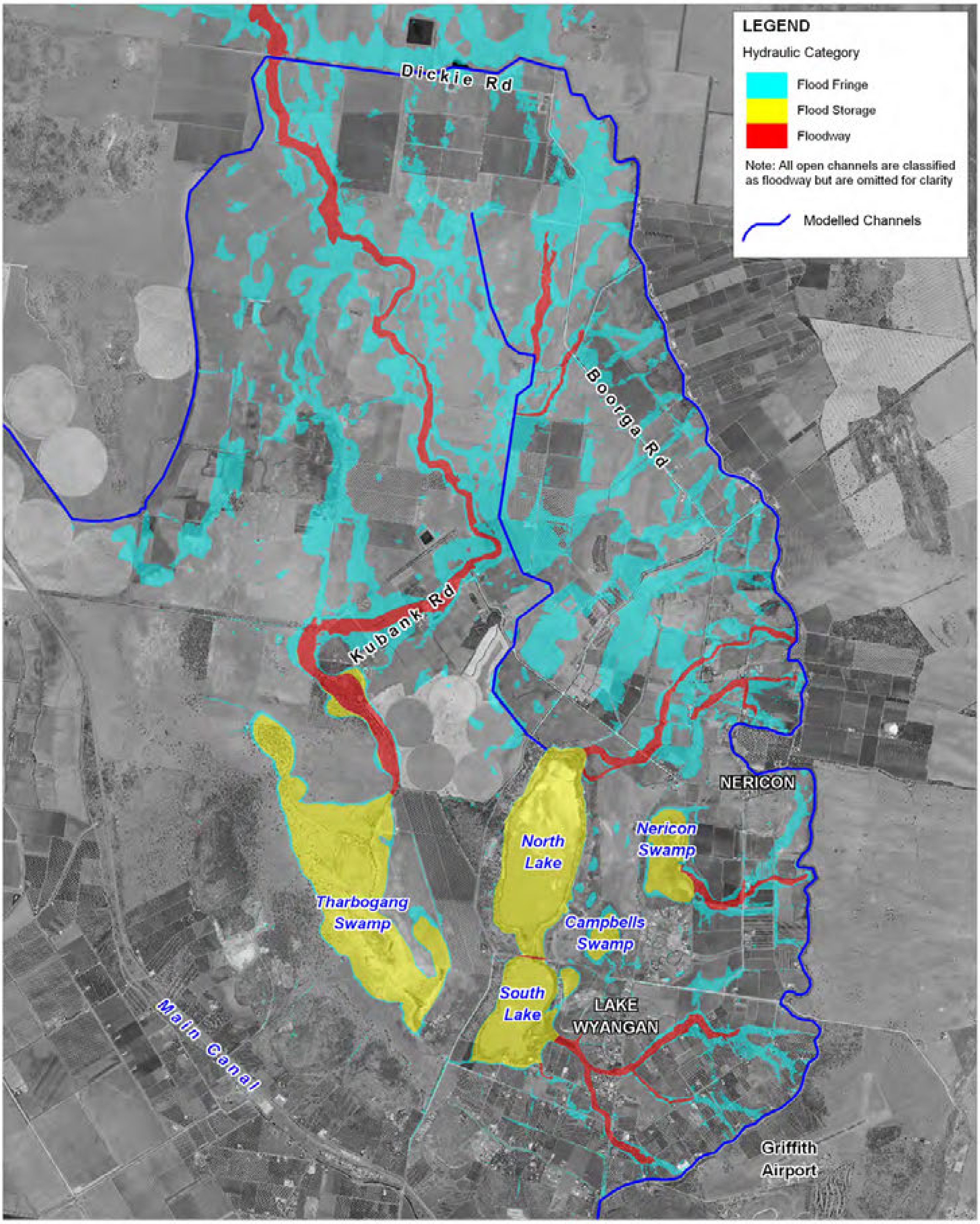

Title:

Lake Wyangan Flood Study
Hydraulic Categories Defined at the 1% AEP Event

Figure: A-22

Rev: A

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Approx. Scale

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APPENDIX B: CATCHMENT DELINEATION REPORT

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Tel: +61 2 4940 8882
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ABN 54 010 830 421 003

www.wbmpl.com.au

Our Ref: DJL: L.N2038.001.01.docx

19 April 2011

Griffith City Council
PO Box 485
Griffith, NSW 2680

Attention: Mr. Durgananda Chaudhary

Dear DN

RE: LAKE WYANGAN FLOOD STUDY – CATCHMENT DELINEATION

Through the initial phases of our data review and catchment model development, BMT WBM is able to present the following findings into the catchment delineation and broad scale catchment hydrology for the Lake Wyangan catchment.

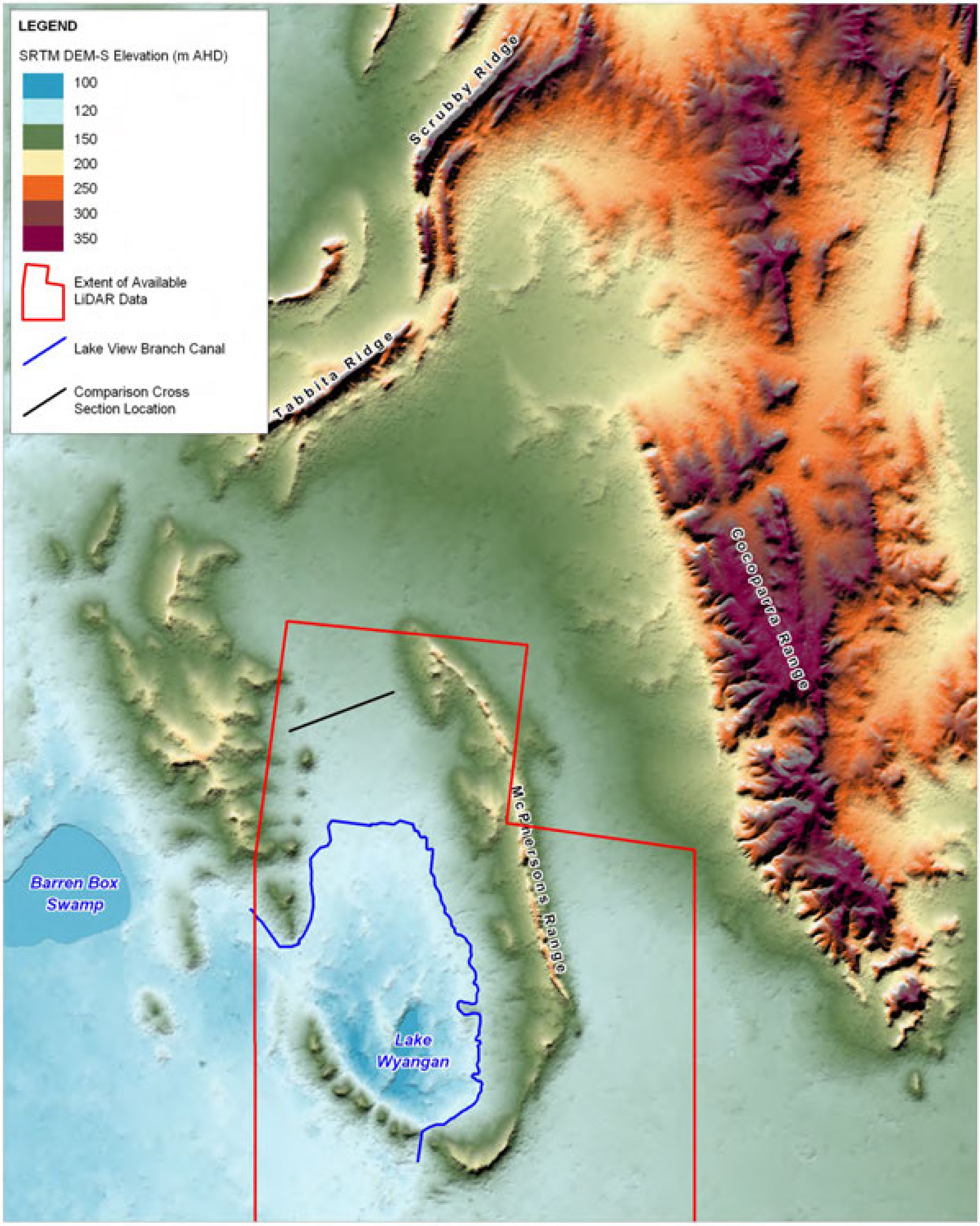
1. REVIEW OF DIGITAL ELEVATION DATA

Through Council, digital elevation data was acquired for the entire Lake Wyangan catchment and the surrounding region. The base elevation data source is the SRTM DEM-S, which is a 30m resolution Digital Elevation Model (DEM) derived from the Shuttle Radar Topographic Mission (SRTM). It has been cleaned, filtered for vegetation and smoothed by CSIRO as part of the One-second DEM for Australia project.

For the southern part of the catchment, much more detailed Light Detection and Ranging (LiDAR) survey elevation data was available. This data was captured and processed by AAM Hatch from a flight in February 2004. This ground point data was provided by Council in xyz text format, with distance between points at a typical spacing of 2m. The point data was used to create a gridded DEM of a similar 2m resolution. The topography of the SRTM DEM-S data and the extent of available LiDAR data is shown in Figure 1.

A composite DEM was constructed, combining both the LiDAR and SRTM datasets. It was important that when combined there should be no sudden discontinuity when transitioning from one dataset to the other, so the SRTM data was adjusted slightly to overcome this. A comparison of LiDAR and SRTM elevations showed that on average the SRTM elevations were around 0.5m lower than those of the LiDAR. Therefore, the SRTM dataset was initially raised by 0.5m and then a comparison was made at the interface with the LiDAR DEM. The difference in elevations along this interface was applied to the SRTM elevations, in order that they matched those of the LiDAR. The applied difference was gradually reduced across a transitional buffer zone, with elevations at or beyond 500m from the edge of the LiDAR DEM remaining unchanged (aside from the initial 0.5m raising). The composite DEM consists of the LiDAR data where available (resampled to a resolution of 30m) and the modified SRTM DEM-S data elsewhere.

Figure 2 shows a cross section (the location of which is shown in Figure 1) through the available DEM data. It can be seen that for wide flat areas of the catchment such as this, the SRTM DEM-S data matches reasonably well with that of the LiDAR DEM. The shape of the topography is well represented and the elevation differences of around 0.5m are small, considering the differences in accuracy of the two datasets. It is likely that the flat, open nature of the catchment, with little vegetation interference, has contributed to the consistency between the two datasets. It is considered that the 30m resolution composite DEM is likely to be of sufficient quality for modelling broad catchment hydrology and identifying flood flow paths. However, the detail of the 2m resolution LiDAR DEM is required to accurately model the effect of local hydraulic controls.



Title:
Extent of Available Elevation Data

Figure: 1

Rev: A

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Approx. Scale

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Filepath : K:\N2038_Lake_Wyangan_Flood_Study\MapInfo\Workspaces\DRG_001_110217_Elevation_Data.WOR

Figure 2 SRTM DEM-S and LiDAR DEM Comparison

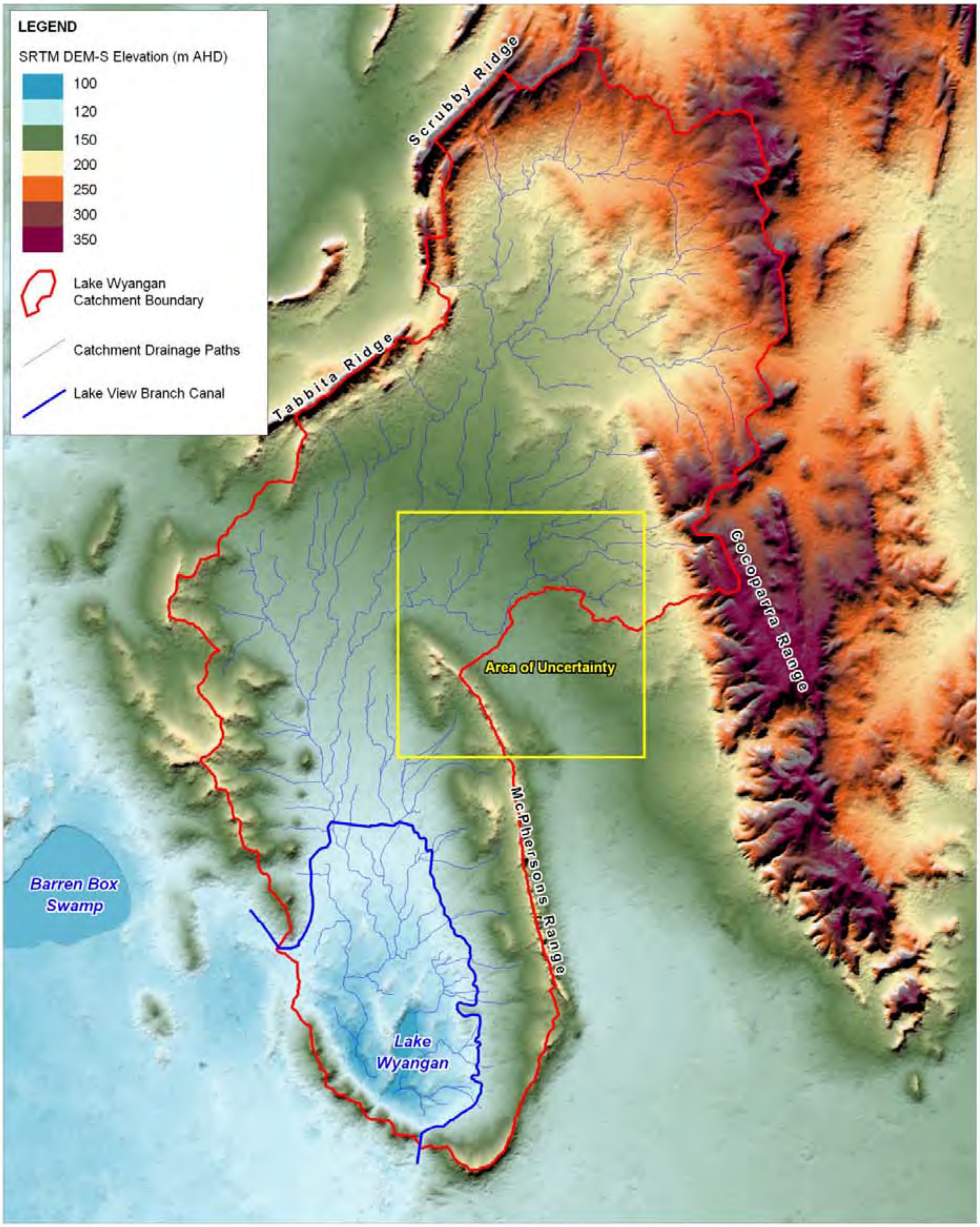
2. LAKE WYANGAN CATCHMENT DELINEATION

The CatchmentSIM modelling software was used to determine the catchment drainage paths and subsequent delineation of the hydrologic catchment boundary. The composite LiDAR-SRTM DEM was imported as the base topography and this was treated with the automated software routines to remove flat and sink cells. The resultant catchment is some 825km^2 in size as shown in Figure 3 along with major drainage paths as defined by the topography.

The catchment extent is generally well defined by topographic features such as the McPherson Range, Cocoparra Range, Tabbita Ridge and Scrubby Ridge. However, the flat nature of the floodplain area between the northern end of the McPherson Range and the Cocoparra Range to the east, makes exact delineation of the catchment boundary difficult. This area of uncertainty is highlighted on Figure 3. The elevations through this area range by little more than a couple of metres.

In order to address this uncertainty, a more detailed investigation was undertaken. A catchment model was constructed using the TUFLOW software. This hydrodynamic model has a model grid resolution of 60m, with elevation points at a 30m spacing. This fully utilises the available scale of elevation data – in this case the 30m resolution composite LiDAR-SRTM DEM. A large flood event was simulated, inputting design rainfall directly to the 2D model grid. This would provide for a more rigorous assessment of flood flow paths as it utilises hydraulic equations, rather than just slope and aspect derivatives of the DEM. The model boundary was extended around 10km to the south of the CatchmentSIM delineated boundary in the area of uncertainty between the McPherson Range and the Cocoparra Range.

Peak velocity and depth results were extracted from the TUFLOW model and were combined to produce a velocity x depth product and is presented in Figure 4. It can be seen that the flood flow paths derived using TUFLOW broadly correspond to the drainage paths delineated using CatchmentSIM. However, there is greater complexity within the TUFLOW results, with multiple splitting and merging of flood flow paths evident. The upper catchment is well defined by the Cocoparra Range, with around 250km^2 draining through an outlet to the east of Tabbita Ridge. The middle catchment then opens out into a wide, flat expanse, with a number of parallel and interacting flood flow paths. These then form one major flow path at the northen end of the McPherson Range, which then flows west and into the lower Lake Wyangan catchment. Here the flow paths split again, before forming a single main flood flow path at the western side of the floodplain. The majority of the water from the upper and middle catchment areas outlets to Tharbogang Swamp to the west of Lake Wyangan. However, the



Title:

Lake Wyangan Catchment Delineation

Figure: 3

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0 5 10km

Approx. Scale

BMT WBM

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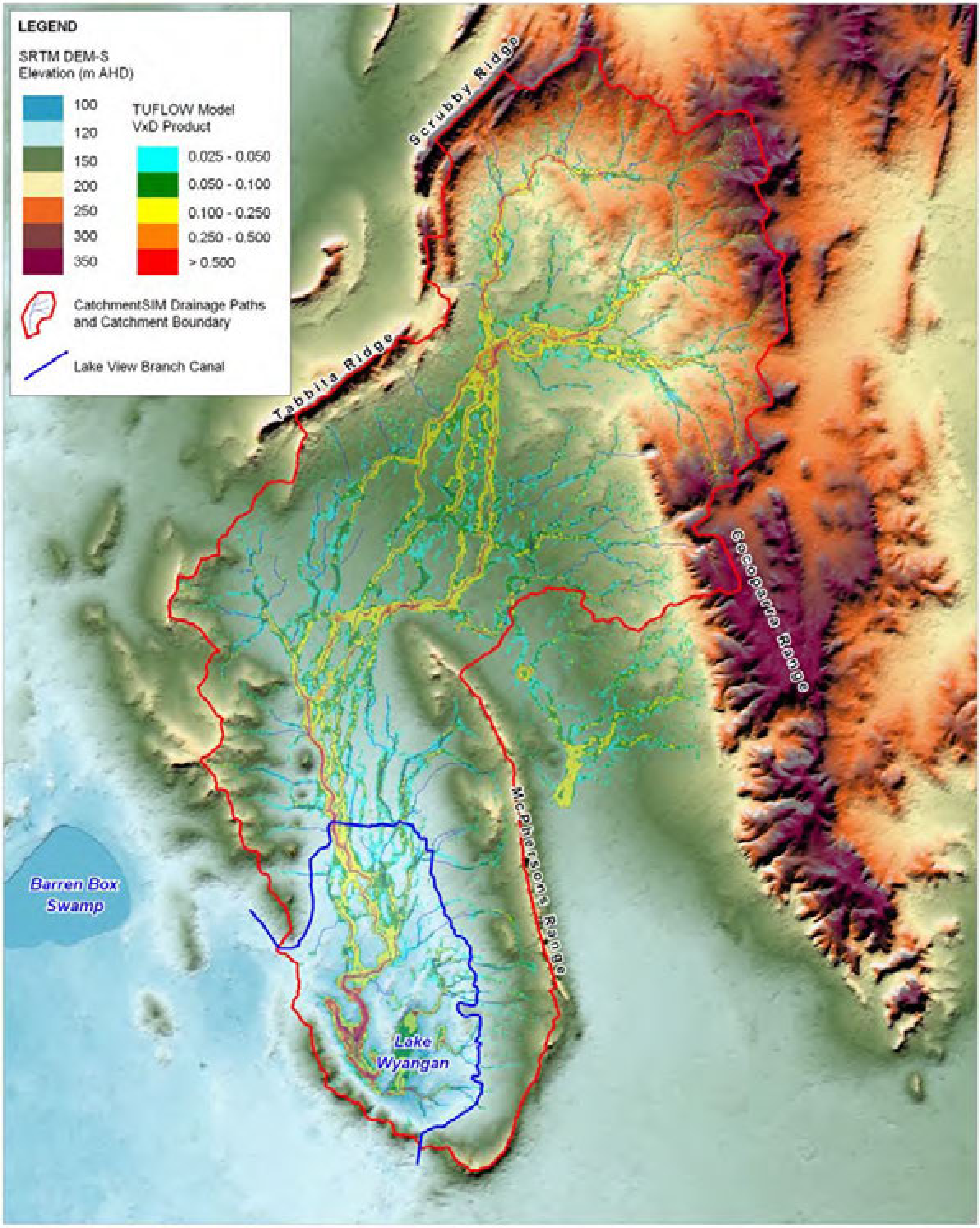

Title:

Broad Scale TUFLOW Catchment Model Results

Figure: 4

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Approx. Scale

BMT WBM

www.wbmpl.com.au

Filepath : K:\N2038_Lake_Wyangan_Flood_Study\MapInfo\Workspaces\DRG_003_110218_TUFLOW_Results.WOR model does not yet include the Lake View Branch Canal or Lake View Drain, both of which will alter the flood behaviour of the lower catchment, particularly the latter, which will transfer a significant amount of flow from the Tharbogang Swamp catchment into Lake Wyangan.

Figure 5 shows the TUFLOW results in more detail for the area of uncertainty. Google imagery is used as the background mapping. Using the available elevation data and TUFLOW model results some hydrologic catchment boundaries have been drawn on the figure for discussion purposes. It is difficult to see in the figure, but when observing the TUFLOW results with the aerial imagery in a GIS environment, there is a good correlation between the locations of the model derived flood flow paths and differences in colouration of the vegetation/ground surface in the imagery. The surface tends to appear darker along the alignment of the major drainage paths and paler in the drier, more elevated areas, such as the local ridge lines. This gives a certain level of confidence in the model results and DEM data used to derive them.

The main flow path of the middle Lake Wyangan catchment can be seen being diverted to the west by a dry ridge of land. This ridge has been observed on site and is at least two metres in height. It was originally thought that this ridge would likely form the catchment divide between the Lake Wyangan catchment and the Main Drain J catchment to the south. However, the model results suggest that this ridge forms the boundary between the Lake Wyangan catchment and a smaller local catchment of some 100km^2, marked on Figure 5 as “Local Catchment A”. The model results suggest that this local catchment drains west through a low point at “Location 1”, contributing to the greater Lake Wyangan catchment. There may also be additional cross-catchment outlets during higher flows at “Location 2” and “Location 3”, the former draining west to the Lake Wyangan catchment and the latter to another local catchment to the south – “Local Catchment B”.

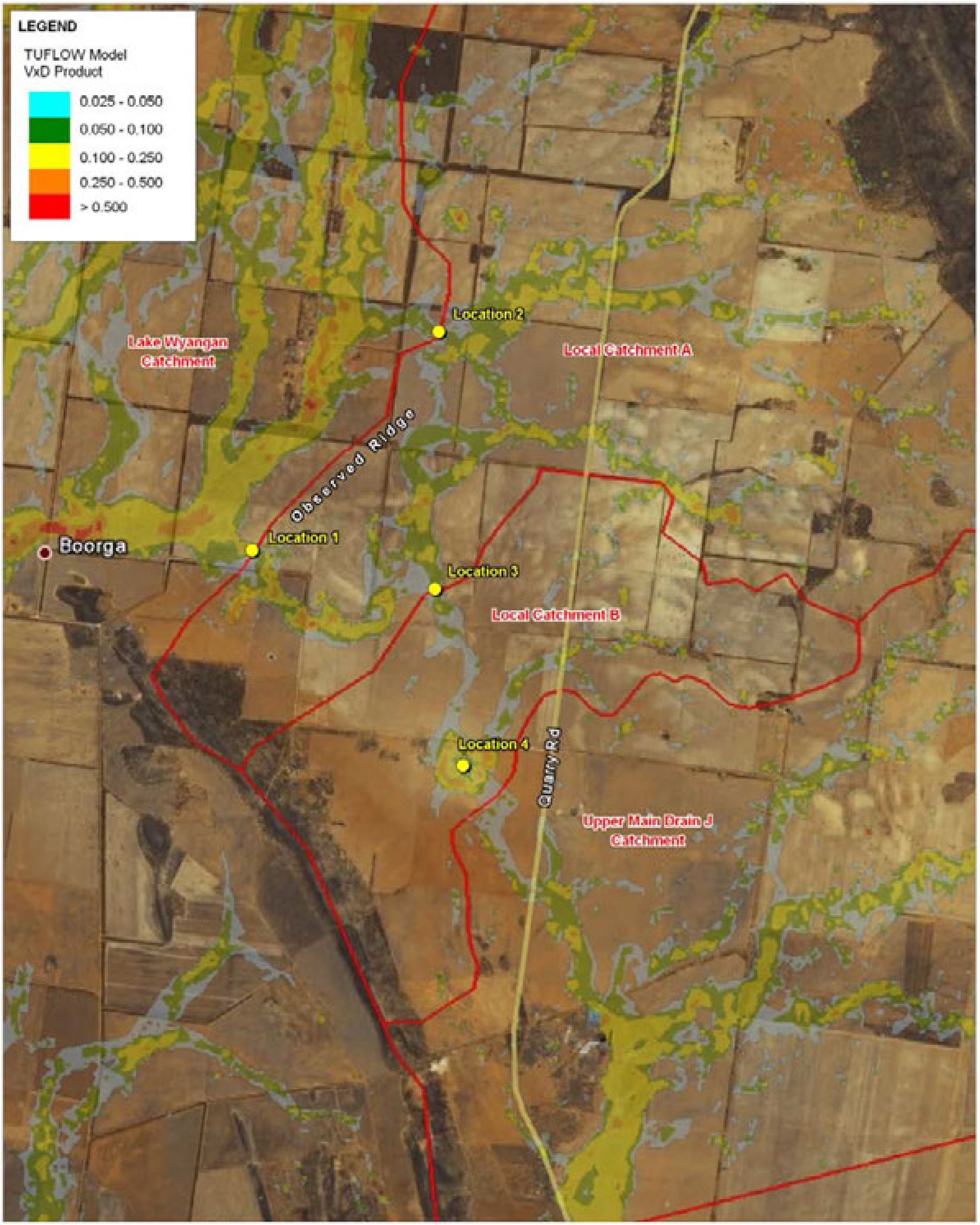
“Local Catchment B” is around 25km^2 in size and appears to drain to a local depression at “Location 4”. During high flow conditions, when the storage capacity of this depression is exceeded, the excess flow will outlet to the upper Main Drain J catchment to the south. The TUFLOW results suggest that the catchment divide between westward and southerly flow directions occurs along the catchment boundary between “Local Catchment A” and “Local Catchment B”. However, during high flows it is likely there will be some cross-catchment flow due to the flat nature of the topography. The greatest amount of uncertainty is associated with “Local Catchment A” as localised topographic features may influence the flood flow paths and the amount of flow contributing to the Lake Wyangan catchment and Main Drain J catchment.

3. SUPPORTING EVIDENCE FOR THE DELINEATED CATCHMENT EXTENT

Correct delineation of the Lake Wyangan catchment is critical to the success of the flood study. The catchment delineation is hugely significant as if in reality the well defined upper catchment area drains east of the McPherson Range (and thus contributes to the Main Drain J catchment) the estimated total catchment area could be out by almost 100% (825km^2 as opposed to around 420km^2). Given the uncertainty surrounding the delineation of the Lake Wyangan catchment and its significant influence on catchment hydrological modelling and subsequent calibration attempts, a broad assessment of catchment topography was made to support or otherwise the inclusion of the upper catchment area in the Lake Wyangan catchment.

A series of elevation sections were extracted from the composite LiDAR-SRTM DEM to better understand the nature of the topography in the floodplain areas to the east and west of the McPherson Range. The alignments along which these elevation sections were extracted are presented in Figure 6. Two long sections (A1 and A2) have been extracted along the bottom of the floodplain to the west (A1) and east (A2) of the McPherson Range. They originate from the location at which the main flood flow path from the upper catchment would deviate either to the east or the west of the McPherson Range. The long sections are presented together on Figure 7. It can be seen that the floodplain gradient along alignment A1 is reasonably constant, with elevations dropping by 16m over the 12km length. Along alignment A2 however, the topography undulates, but the gradient is essentially flat for the first 6km, after which there is a drop of 6m over the remaining 6km length. The topographic features delineating “Local Catchment A” and “Local Catchment B” from Figure 5 can be seen and these catchment extents have been marked accordingly on Figure 7. The steeper gradient of section A1 suggests that the upper catchment flood flows are much more likely to continue to the west of the McPherson Range (i.e. contributing to the Lake Wyangan catchment and not Main Drain J).

Two cross sections (B1 and B2) have been extracted through the floodplains to the west and the east of the McPherson Range respectively. They are both located approximately 5km along the alignment of the long sections and are both situated within the coverage of the LiDAR data, so should pick up any significant topographic features. The cross sections are presented together on Figure 8. It can be seen that the floodplain east of the McPherson Range (B2) is around 6m above that to the west of the range. The floodplain width indicated on section B2 is approximately 2km, whereas for section B1 it is at least as wide as the 3km shown.



Title:

TUFLOW Model Results in Area of Uncertainty

Figure: 5

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Approx. Scale

BMT WBM

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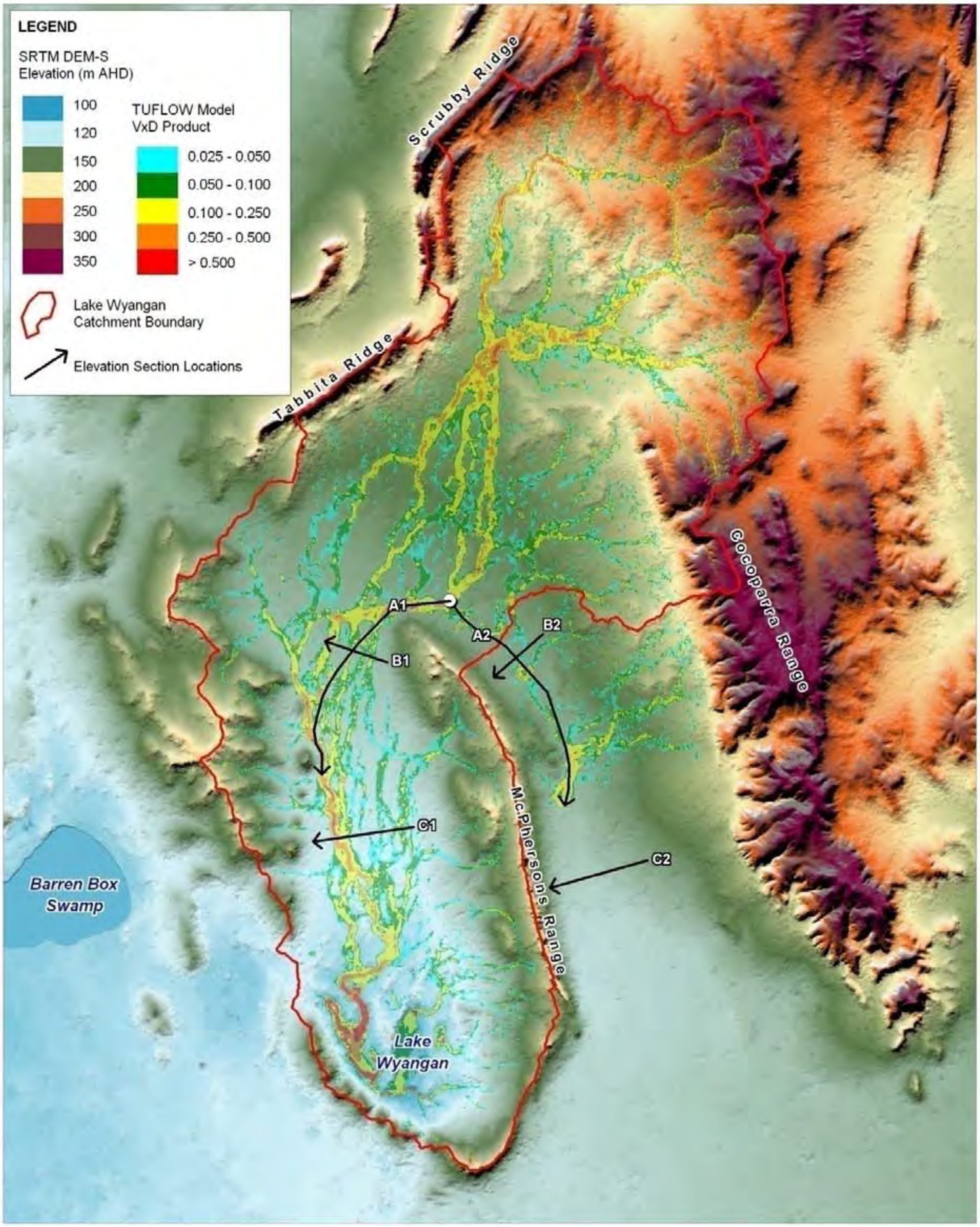

Title:

Location of Extracted Elevation Sections

Figure: 6

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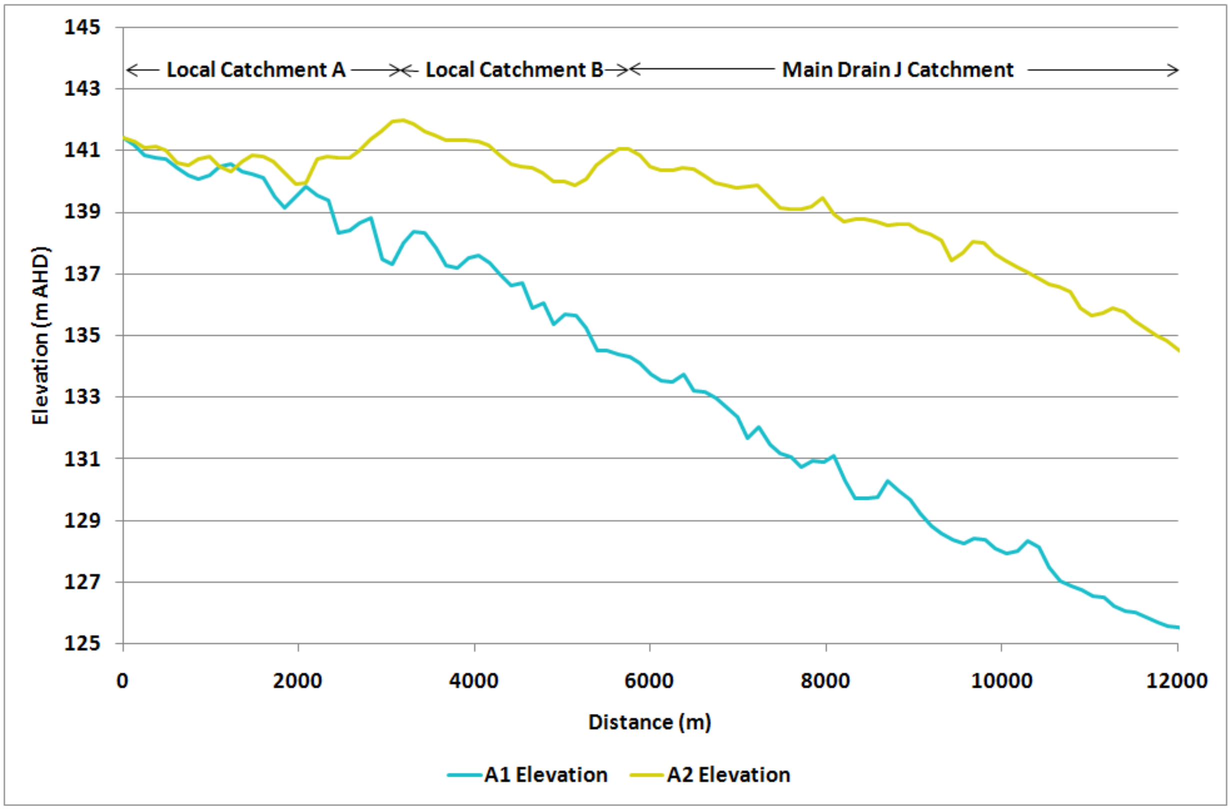


Figure 7 Elevation Sections A1 and A2

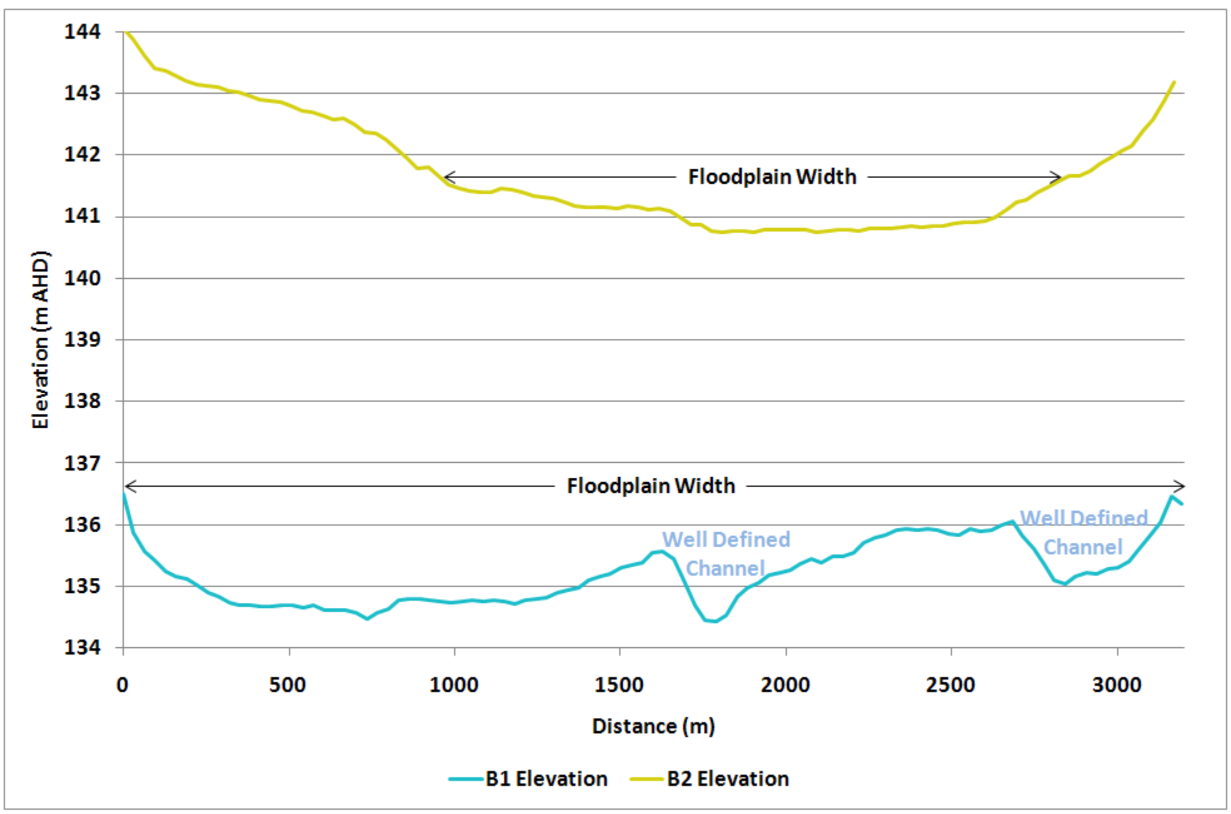


Figure 8 Elevation Sections B1 and B2

There are also two well defined channel features evident in the topography of section B1, which are each around 1m deep and 300m wide. There are no such features evident in section B2. The floodplain topography to the west of the McPherson Range is indicative of conveying significant flood flow paths, which over time have formed the channels now present. The topography to the east of the range is relatively flat and smooth in comparison, suggesting no significant flood flow paths are present.

An additional two cross sections (C1 and C2) have been extracted a further 10km or so along their respective floodplains. Again, they are both situated within the coverage of the LiDAR data, so should pick up any significant topographic features. The cross sections are presented together on Figure 9. It can be seen that the floodplain east of the McPherson Range (C2) is around 8m above that to the west of the range. The floodplain width indicated on section C2 is approximately 2km, whereas for section C1 it is at least as wide as the 5km shown. There are also two well defined channel features evident in the topography of section C1, which are each around 1m deep. One is around 500m in width and the other around 1km wide. There is the suggestion of a defined channel within section C2, but it is much less pronounced. It is probably around 500m wide, but only about 0.5m deep. The floodplain topography to the west of the McPherson Range is indicative of conveying significantly more flood flow than that to the east of the range. The relative topography of each floodplain seems reflective of the delineated contributing catchment at each location, which is around 480km^2 in the case of C1 and around 180km^2 for C2.

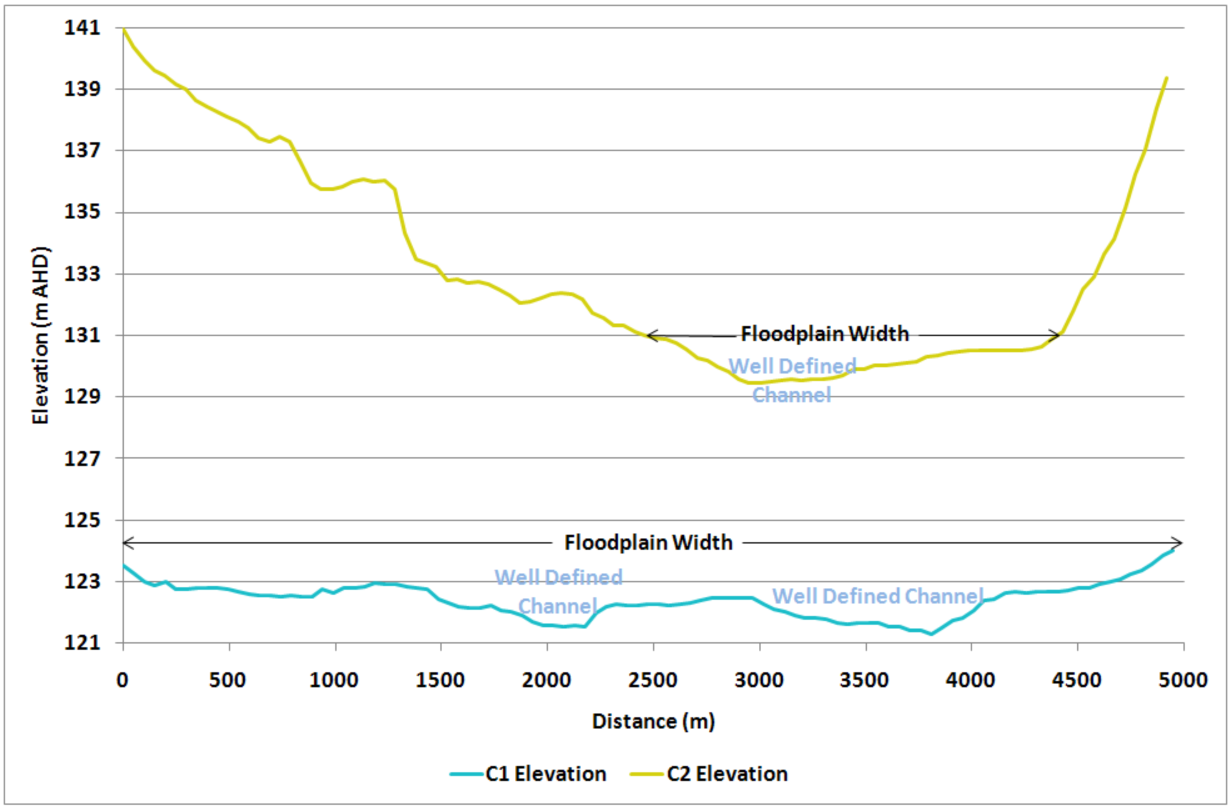
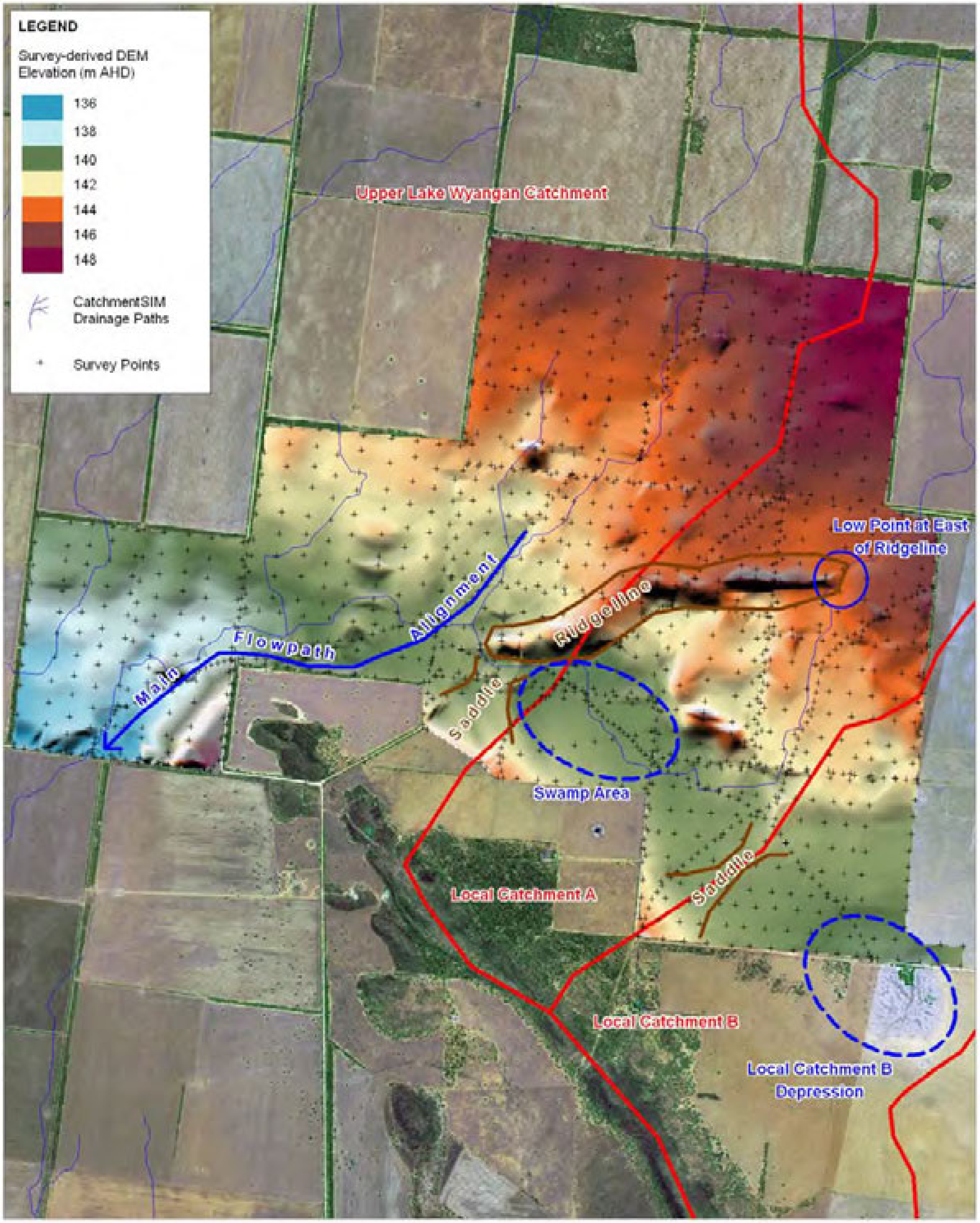


Figure 9 Elevation Sections C1 and C2

4. GROUND SURVEY

Following the initial investigations discussed above, Council undertook a local ground survey to improve the confidence in the topographic details implied by the SRTM data in the area of uncertainty. The data capture covered an area of some 30km^2 and included surveyed points on a 200m grid and points every 100m along the suspected 'ridge' and gully' alignments. The survey points were used to interpolate a DEM, which is presented in Figure 10. The general topography of the area captured by the survey points corresponds well to that of the SRTM DEM-S, although absolute elevations differ. It can be seen that the flowpath alignments derived from the SRTM data also fit well with the survey topography. The ridgeline feature present in the SRTM data and observed on site is clearly defined by the survey.



Title: **Topography Captured by Ground Survey**

Figure: 10

Rev: A

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In addition to the acquisition of topographic data, Council's surveyor liaised with local farmers, who's comments regarding flooding in the area are presented in Figure 11. The two "flow" arrows that point in a south-westerly direction correspond to the main flowpath alignment indicated on Figure 10. The indicated "flood area" would appear to refer to an expansive area of multiple flood flow paths to the north of the surveyed ridgeline, evident from the model results presented in Figure 5. The south-easterly orientated "flow" arrow indicates that some spilling of flood flow from the main alignment occurs over the saddle area at the southern end of the surveyed ridgeline. The spill water will then fill a local depression in the topography, located between the two surveyed saddle locations. This depression area corresponds to the "swamp area" indicated by the farmers. It is likely that additional flood water from "Local Catchment A" (from Figure 5) will also contribute to the filling of this depression, entering through the low point at the eastern end of the surveyed ridgeline. When the volume of flood water in this depressed area exceeds the available storage, spilling will occur back into the main flowpath alignment and/or to the south-east to fill the depression in "Local Catchment B".

In summary, the topographic information obtained from the survey and the comments from local farmers support the data that was previously available and the modelling that was based upon it. Although absolute elevations of the SRTM DEM-S may differ from those of the ground survey, the topographic forms that influence the movement of water within the catchment appear to be adequately represented. This provides increased confidence in using the SRTM data for the purposes of modelling catchment hydrology. However, the absolute elevations are not accurate enough to derive reliable flood levels from hydraulic modelling in this area. This is not of importance for the Lake Wyangan Flood Study, which only requires hydraulic modelling in areas where more accurate LiDAR data is available. The commentary from the local farmers supports both the details captured by the ground survey and the results of the preliminary catchment modelling.

There is still some uncertainty regarding local hydraulic controls, which influence the distribution of overland flow from "Local Catchment A". There are several locations at which overland flow from "Local Catchment A" may transfer to the Upper Lake Wyangan Catchment. More detailed survey of these localtions would be required to determine precisely the proportion of flow which enters the Upper Lake Wyangan Catchment and that which drains to "Local Catchment B" and possibly beyond to the Main Drain J Catchment. The current modelling suggests that most of the flow from "Local Catchment A" will drain to the Lake Wyangan Catchment.

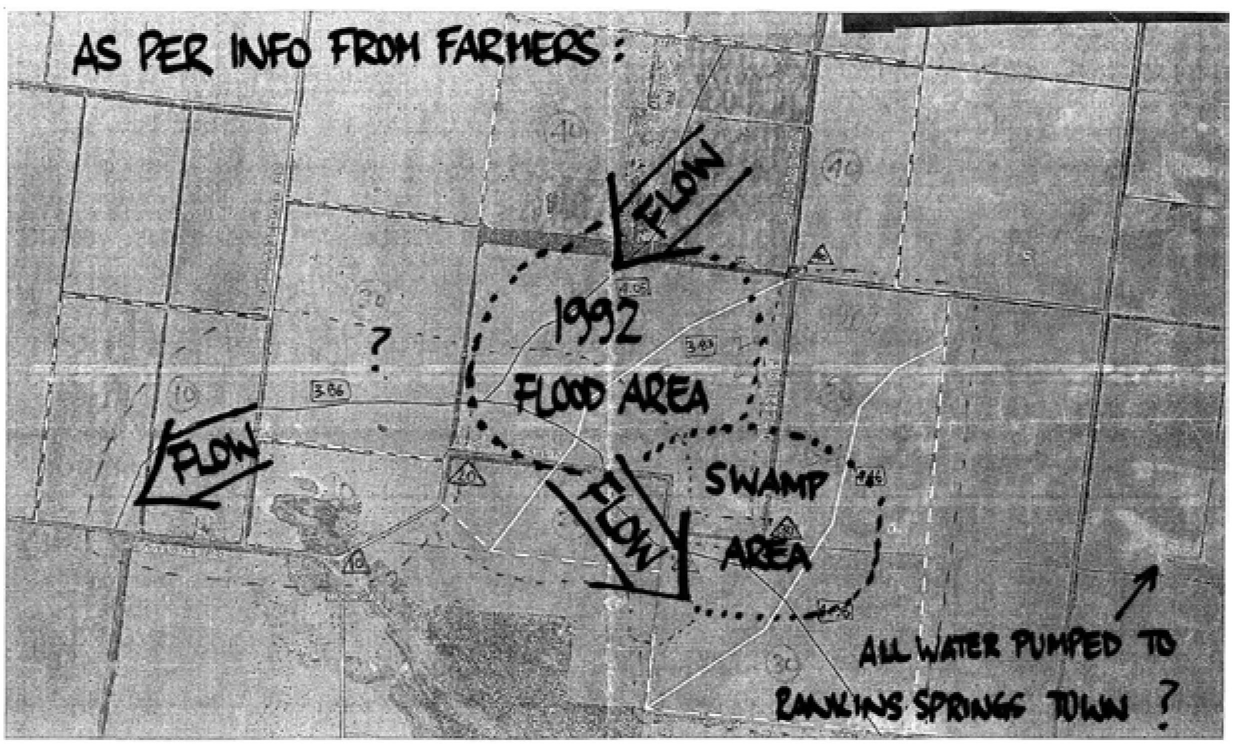

Figure 11 Flood Comments from Local Farmers

5. CONCLUSIONS

From the investigations discussed in this report it is likely that the initial catchment delineation of some 825km^2 undertaken using CatchmentSIM is correct. The elevation datasets of the SRTM DEM-S and the available LiDAR DEM correspond well in the flat floodplain areas. Through the construction of the composite LiDAR-

SRTM DEM a solid base on which to make catchment hydrological assessments is available. However, given the relatively flat topography at the northern end of the McPherson Range, the impact of local topographic features has the potential to significantly influence catchment hydrology. This includes the possibility that the upper catchment in the Cocoparra Range drains to the east of the McPherson Range and into the Main Drain J catchment. Topographic survey data and comments from local farmers acquired by Council have further increased confidence in the SRTM DEM and the resultant catchment modelling outputs. However, uncertainty still remains as to the precise flow split of “Local Catchment A”.

Additional high accuracy elevation data, such as ground survey or LiDAR, would be required to at several locations in order to be certain of the catchment flow contribution of “Local Catchment A” to the Lake Wyangan Catchment. However, the evidence presented in this report suggests that the likelihood of any significant flow contribution from the upper catchment draining to the east of the McPherson Range is small. The evidence for this includes:

- Drainage paths derived from the DEM through both CatchmentSIM and TUFLOW;
- Correspondence of the modelled flood flow path locations to differing colouration in the aerial imagery;
- Observation of a significant ridgeline during a site inspection of the area;
- Comparison of the characteristics of the relative floodplain topography to the east and west of the McPherson Range;
- Topographic ground survey to support features present in the SRTM data and observed on site; and
- Comments from local farmers regarding flood propagation in the area of uncertainty.

We trust that this report provides some insight into the delineation of the Lake Wyangan catchment and justifications for adoption of the approximate 825km^2 catchment area. Please give myself or Dan Williams a call on 02 4940 8882for further information or clarification regarding any aspect of this report.

Yours Faithfully
BMT WBM Pty Ltd

Darren Lyons
Associate
Newcastle Water & Environment Manager

APPENDIX C: COMMUNITY QUESTIONNAIRE

Lake Wyangan Flood Study
Questionnaire Feb 2011

Griffith City Council is undertaking a detailed flood study of the Lake Wyangan catchment to help identify flooding problem areas. We are seeking the community's help by collecting information on any flooding or drainage problems that you may have experienced in the past. Please take a minute or two to read through these questions and provide responses wherever you can. Please return this form to Griffith City Council by 31st March in the enclosed envelope (no stamp required).

Do you have any photographs or video of flooding that you are willing to share with Council?

☐ Yes ☐ No

Contact details:

Name:...

Address:..

....

Phone or email:...

....

Q1: Have you experienced flooding on your property? Please provide the date(s) if known.

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Q2: Are you able to indicate the depth that flood waters reached on your property or elsewhere such as roads?

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....

Q3: A map is provided on the back, please mark up your property or known flooding areas. Additional space is provided to add other comments.

Q4: Do you want to be kept informed of the study progress? (please tick)

☐ Yes ☐ No

Project Contacts

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Ph: 02 4940 8882
Darren.Lyons@bmtwbm.com.au

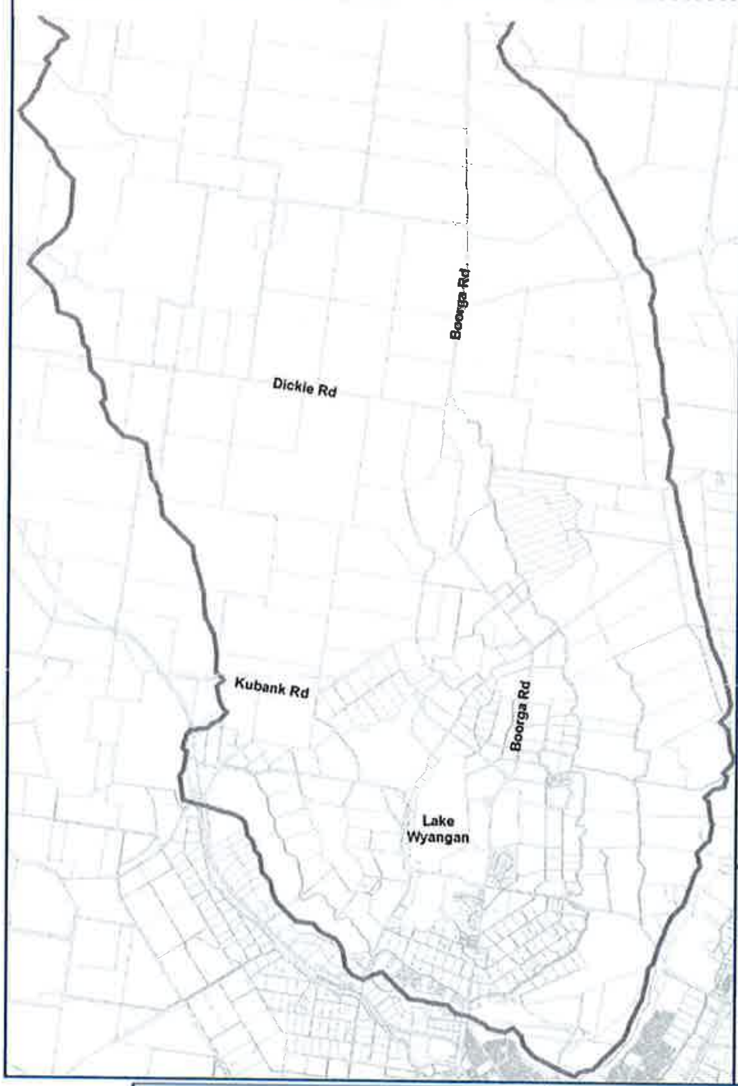
Durganananda Chaudhary (Griffith City Council)
Ph: 02 6969 4857
Durganananda.Chaudhary@griffith.nsw.gov.au

Mailing Address

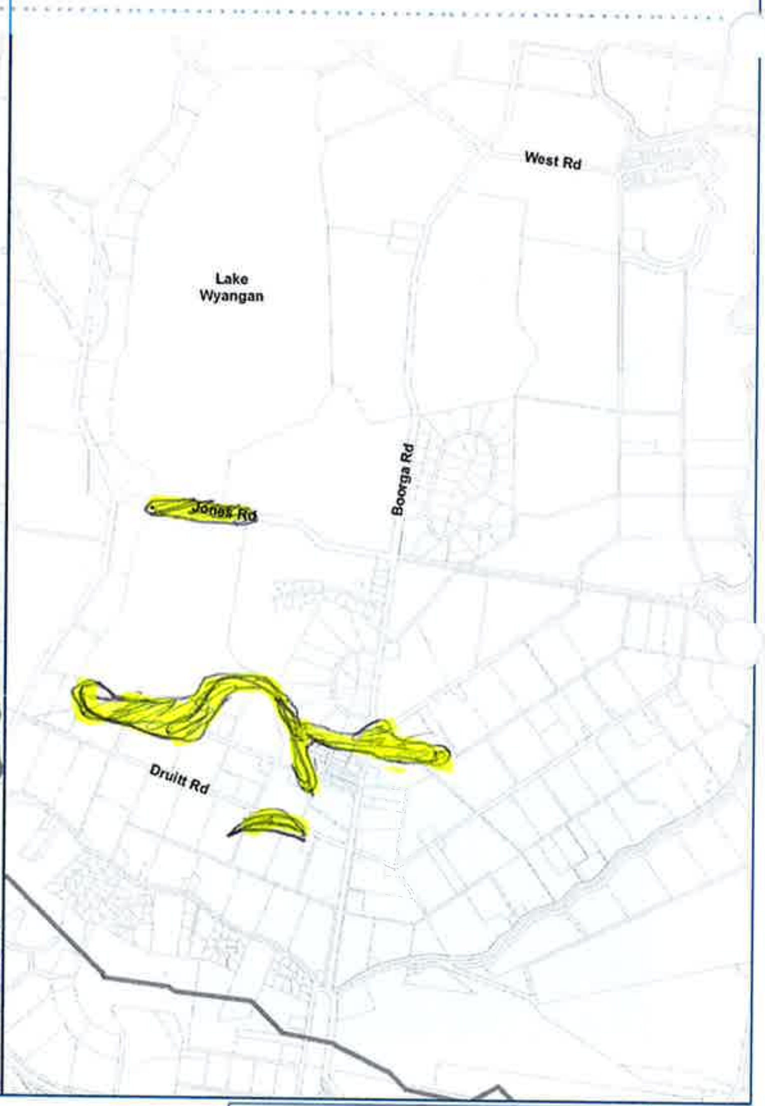
Please provide any additional comments or information that you think will help the study

Please provide any additional comments or information that you think will help the study

BAD FLOODING AT JUNCTION OF BOORA AND SMEETH ROADS MARCH 1985
HAVE PHOTOS, CAUSEWAY BETWEEN LAKES FLOODED, LOWER END OF
TODD ROAD, ALSO FARMS ON THE SOUTHERN END OF SMALL LAKE.



Please mark your property or other known flooding sites around Lake Wyangan



Please mark your property or other known flooding sites in the broader catchment

1985

DRUITT RD

(See the Map)

1985

BOORGA RD - SMEETH ~~DRUITT~~ RD JUNCTION

(See the map)

1985

BOORGA RD - SMEETH ~~DRUITT~~ RD JUNCTION

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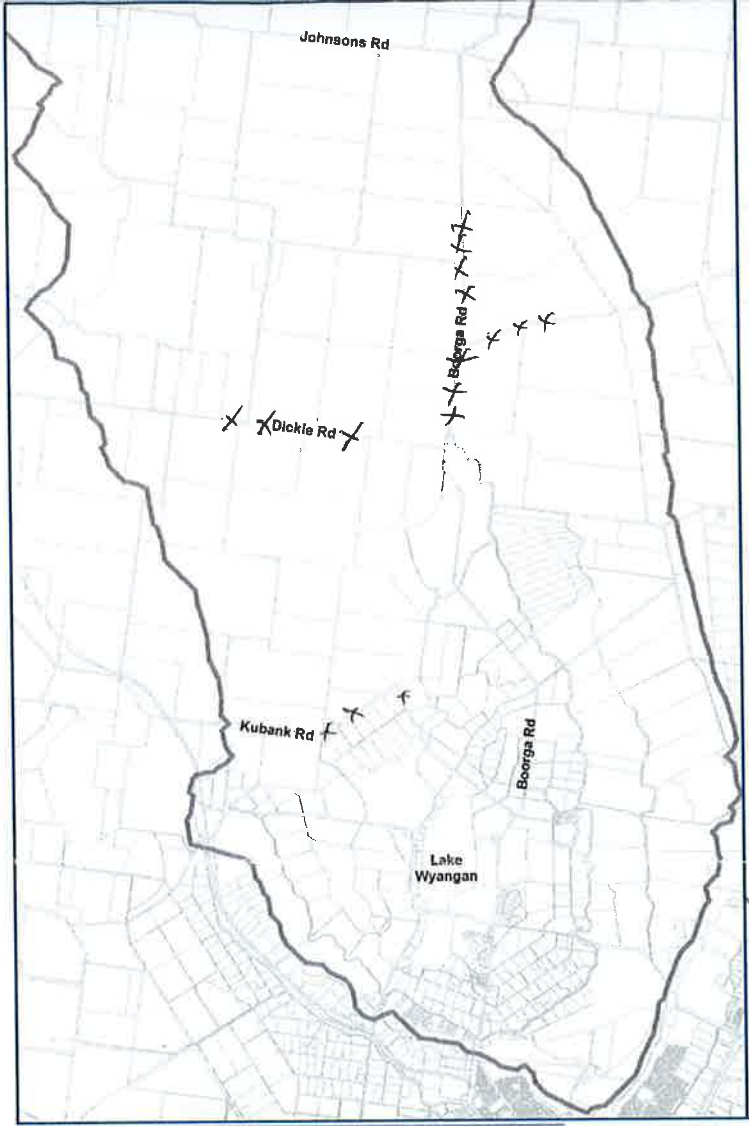
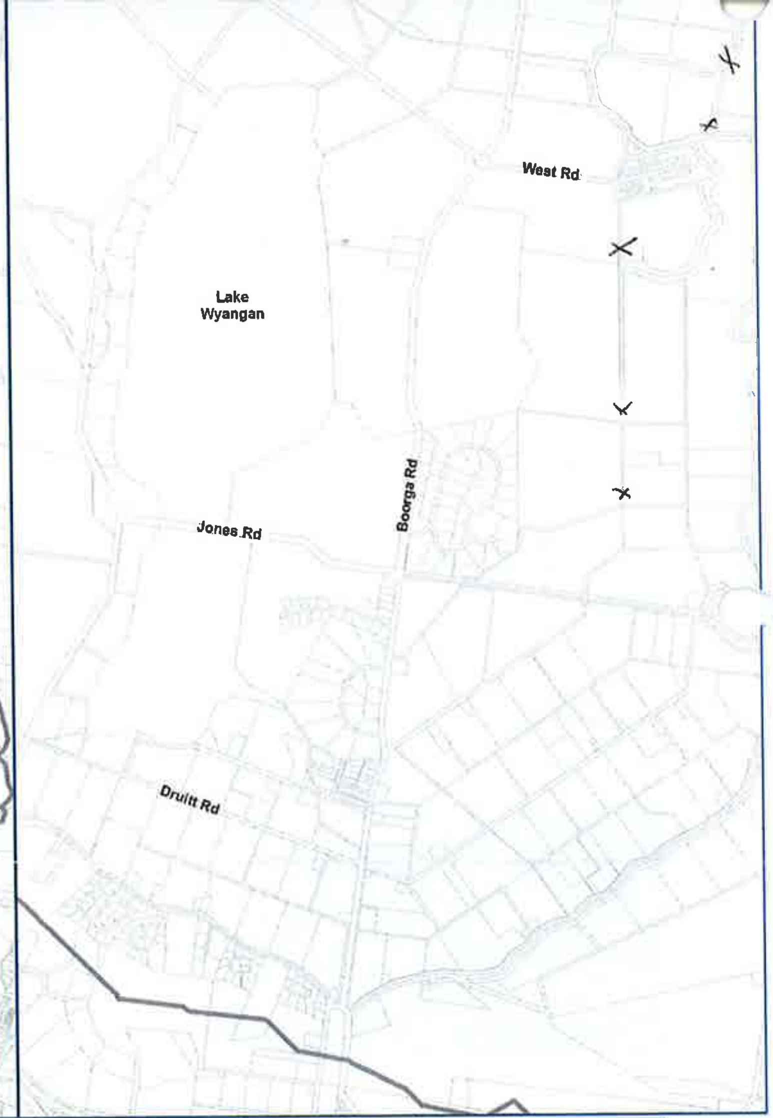
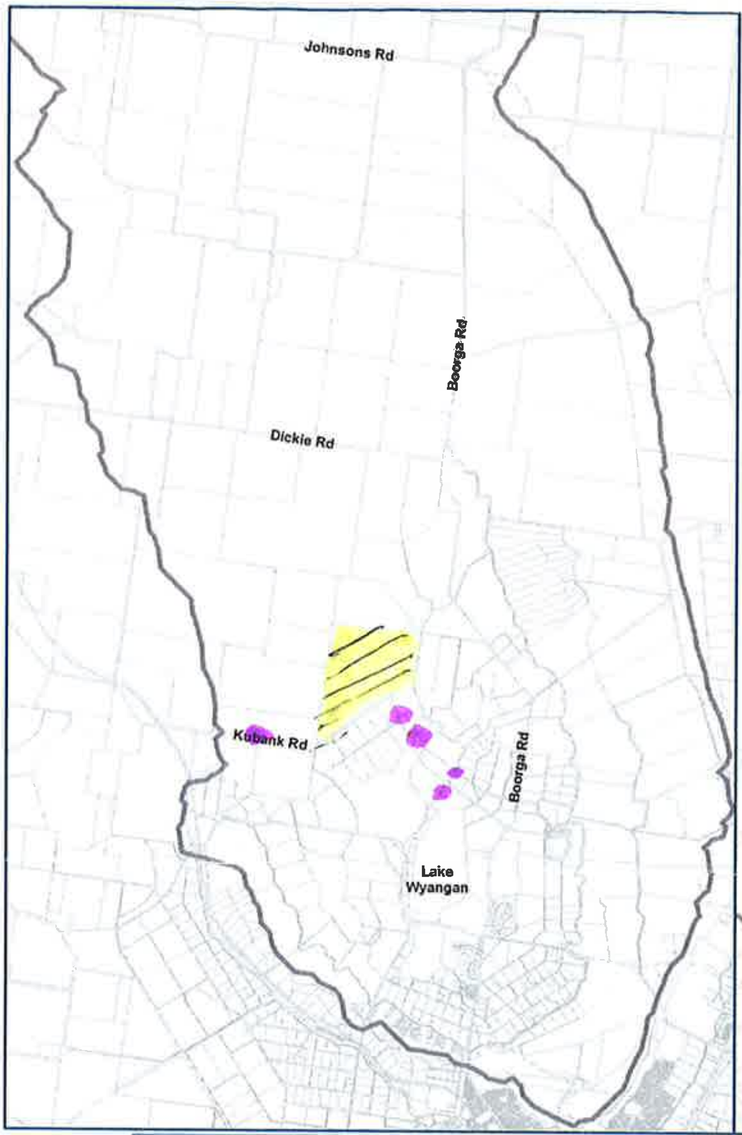
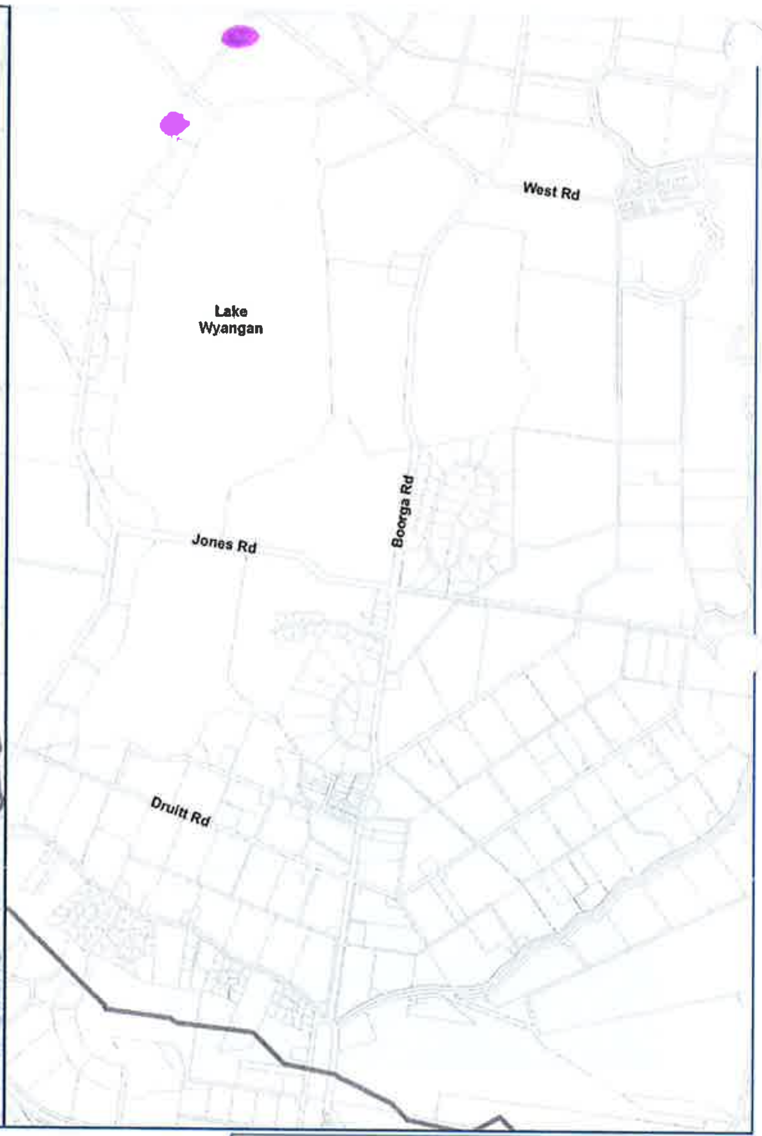


Please mark your property or other known flooding sites around Lake Wyangan



Please mark your property or other known flooding sites in the broader catchment





Please mark your property or other known flooding sites around Lake Wyangan

Please mark your property or other known flooding sites in the broader catchment

Property

ROAD FLOODING