



On Exhibition

PUBLIC NOTIFICATION

Draft Lake Wyangan Flood Study

At the Ordinary Meeting of Council held 24 March 2026, it was resolved that the draft Lake Wyangan Flood Study be placed on public exhibition for 42 days. Council is required to notify the public and provide the opportunity for submissions regarding this document.

The draft Lake Wyangan Flood Study may be viewed at the Council Chambers, 1 Benerembah Street Griffith, the Griffith City Library and on Council's website at connect.griffith.nsw.gov.au.

Anyone wishing to make comment on the draft Lake Wyangan Flood Study can do so in writing addressed to the General Manager, Griffith City Council, PO Box 485, GRIFFITH NSW 2680 or visit [Connect Griffith](https://connect.griffith.nsw.gov.au) to provide an online submission.

Submissions received will be included in a report to be presented to an Ordinary Meeting of Council. As such, copies of all submissions (including the writer's name and address) will form part of Council's Business Paper and be available to the public. Should you wish to have your contact details withheld it is recommended that you request this in your submission.

Comments or submissions will be received up to **4.00 pm, 8 May 2026**.

CLAUSE **CL04**

TITLE **Review of Lake Wyangan Flood Study**

FROM **Graham Gordon, Director Utilities**

TRIM REF **26/28331**

SUMMARY

Council adopted the Lake Wyangan Flood Study in 2012 and the Lake Wyangan Floodplain Risk Management Study and Plan in 2013, which require periodic review under the NSW Floodplain Development Manual (2023), particularly following significant flood events or changes in land use. Following substantial land use changes and, recent flood events, Council secured NSW Government funding in December 2023 and engaged Torrent Consulting Pty Ltd to undertake a review, which the Flood Study has now been completed and is presented for endorsement to proceed to public exhibition.

RECOMMENDATION

- (a) Council endorse the Lake Wyangan Flood Study to go on public exhibition for a period of 42 days.**
- (b) Should no submissions be received, the Lake Wyangan Flood Study be considered adopted as at the completion of the exhibition period.**
- (c) If submissions are received, a further report is to be provided to Council.**

REPORT

Council adopted the Lake Wyangan Flood Study in 2012 and the Lake Wyangan Floodplain Risk Management Study and Plan in 2013. In accordance with the NSW Floodplain Development Manual (2023), floodplain management plans should be periodically reviewed, particularly following significant flood events or changes in land use.

Over the past decade, land use within the Lake Wyangan catchment has changed significantly and the October 2022 flood event highlighted the need to reassess existing flood management measures. Council also approved the Lake Wyangan Pipeline Project which was not considered in the 2013 plan. A review was therefore required to incorporate these changes and consider additional flood mitigation and planning options.

In December 2023, Council received funding under the NSW State Floodplain Management Program, administered by the Department of Climate Change, Energy, the Environment and Water (DCCEEW), to undertake a review of the Lake Wyangan Flood Study and Floodplain Risk Management Study and Plan. In addition to this, Council resolved to contribute 1/3 of the funding from the Floodplain and Drainage Mitigation Reserves (Ordinary Meeting of Council – 12 December 2023: CCMM01 Review Of Lake Wyangan Flood Study And Floodplain Risk Management Plan).

Following a Request for Quotation (RFQ) process, Torrent Consulting Pty Ltd was commissioned in May 2024 to undertake the Review of Lake Wyangan Flood Study and Floodplain Risk Management Plan.

The Review of the Lake Wyangan Flood Study is now complete and is attached for endorsement to be placed on public exhibition.

OPTIONS

It is recommended that the Lake Wyangan Flood Study be placed on public exhibition to allow the community to provide feedback.

POLICY IMPLICATIONS

Griffith Flood Liable Lands Policy (CS-CP-403)

FINANCIAL IMPLICATIONS AND RISK

The Review was two thirds funded by the Department of Climate Change, Energy, the Environment and Water (DCCEE) and Council's Floodplain and Drainage Mitigation Reserve.

Moderate Low Risk: Minor financial loss > \$10,000 to \$1 million.

COMPLIANCE / LEGAL / STATUTORY IMPLICATIONS AND RISK

The Floodplain Risk Management Plan should be reviewed as per NSW Floodplain Management Manual guidelines.

Moderate Low Risk: Minor policy or regulatory breach resolved through amended practices.

ENVIRONMENTAL IMPLICATIONS AND RISK

Flood mitigation measures that can provide flood immunity to the community and also enhance the environment of the lake will be investigated in this review.

Minor Low Risk: Minimal environmental impact handled internally.

REPUTATION / COMMUNITY IMPLICATIONS AND RISK

Flood mitigation measures that can provide the 1% AEP flood immunity to the community will be investigated in this review.

Minor Low Risk: Limited adverse public/staff reaction and/or negative publicity.

SERVICE DELIVERY IMPLICATIONS AND RISK

Minor Low Risk: Nil impact to service delivery.

WHS / HR IMPLICATIONS AND RISK

Minor Low Risk: No injuries/Nil impact to service delivery.

LINK TO STRATEGIC PLAN

This item links to Council's Strategic Plan item 7.4 Reduce the risk and impacts of natural disasters on our community.

CONSULTATION

Senior Management Team

Floodplain Management Committee

ATTACHMENTS

- (a) Review of the Lake Wyangan Flood Study and FRMS&P Update (under separate cover)



Review of the Lake Wyangan Flood Study and FRMS&P Update

R.T2566.001.04



March 2026

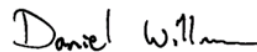
Flood Study - Draft for Public Exhibition

Torrent Consulting Pty Ltd
PO Box 57
Wallsend NSW 2287

ABN 11 636 418 089

www.torrentconsulting.com.au

Document: R.T2566.001.04.docx
Title: Review of the Lake Wyangan Flood Study and FRMS&P Update – Draft for Public Exhibition
Project Manager: Daniel Williams
Author: Daniel Suvaal
Client: Griffith City Council
Client Contact: Durgananda Chaudhary
Prepared: Verified:



Synopsis

This report documents the Flood Study stage of the Review of the Lake Wyangan Flood Study and Floodplain Risk Management Study and Plan Update.

Revision History

Revision	Description	Date
01	Progress Report	28/02/2025
02	Progress Report	12/06/2025
03	Progress Report	16/10/2025
04	Draft for Public Exhibition	17/03/2026

Disclaimer

This report has been prepared on behalf of and for the exclusive use of Griffith City Council and is subject to and issued in accordance with the agreement between Griffith City Council and Torrent Consulting Pty Ltd. Torrent Consulting Pty Ltd accepts no liability or responsibility whatsoever for it in respect of any use of or reliance upon this report by and third party

Z:\Projects\T2566_Lake_Wyangan_FRMS\Docs\R.T2566.001.04.docx



COPYRIGHT NOTICE



This document, 'Review of the Lake Wyangan Flood Study and FRMS&P Update' (2025), is licensed under the [Creative Commons Attribution 4.0 Licence](#), unless otherwise indicated.

Please give attribution to: © Griffith City Council (2025)

We also request that you observe and retain any notices that may accompany this material as part of the attribution.

Notice Identifying Other Material and/or Rights in this Publication:

The author of this document has taken steps to both identify third-party material and secure permission for its reproduction and reuse. However, please note that where these third-party materials are not licensed under a Creative Commons licence, or similar terms of use, you should obtain permission from the rights holder to reuse their material beyond the ways you are permitted to use them under the [Copyright Act 1968](#). Please see the Table of References at the rear of this document for a list identifying other material and/or rights in this document.

Further Information

For further information about the copyright in this document, please contact:

Griffith City Council
1 Benerambah Street
Griffith NSW 2680
admin@griffith.nsw.gov.au
1300 176 077

DISCLAIMER

The Creative Commons Attribution 4.0 Licence contains a Disclaimer of Warranties and Limitation of Liability. In addition: **This document (and its associated data or other collateral materials, if any, collectively referred to herein as the 'document') were produced by Torrent Consulting for Griffith City Council only. The views expressed in the document are those of the author(s) alone, and do not necessarily represent the views of the Griffith City Council. Reuse of this study or its associated data by anyone for any other purpose could result in error and/or loss. You should obtain professional advice before making decisions based upon the contents of this document.**

Review of the Lake Wyangan Flood Study and FRMS&P Update - Draft for Public Exhibition
Glossary and Abbreviations

Glossary and Abbreviations

This list of commonly used floodplain risk management terms and associated abbreviations has been taken (and undergone some minor alterations) from the NSW Government Flood Risk Management Manual (2023). This has then been expanded to include additional technical terms used in hydrological assessment and flood modelling.

Term	Abbr.	Definition	Context / Additional Information
Annual exceedance probability	AEP	The chance of a flood of a given or larger size occurring in any one year, usually expressed as a percentage	AEP is generally the preferred terminology. ARI is the historical way of describing a flood event, for example, a 1% AEP flood has a 1% or 1 in 100 chance of being reached or exceeded in any given year
Annual maxima series	AMS	A format of data representing the maximum recorded value each year within a dataset, typically used for flow records input to a flood frequency analysis	
Areal reduction factor	ARF	An adjustment that is made to probabilistic point rainfall estimations to represent an appropriate catchment average rainfall condition	The design rainfall estimates represent a single point location within the catchment, which is appropriate for very small catchment areas (< 1 km ²). For larger catchments, the average rainfall intensity
Australian height datum	AHD	A common national surface level datum often used as a referenced level for ground, flood and flood levels	0.0 m AHD corresponds approximately to mean sea level
Australian water outlook	AWO	An interactive website that provides Australia-wide information on key landscape water balance components including soil moisture, runoff, evapotranspiration and precipitation	The systems use a range of climate inputs, cutting-edge climate post-processing and downscaling techniques and assimilation of near real-time satellite soil moisture states (for forecasts) as inputs to the Australian Water Resource Assessment model, which provides a consistent set of hydrological outputs at a ~ 5km grid across Australia
Australian rainfall and runoff	ARR	a national guideline document, data and software suite that can be used for the estimation of design flood characteristics in Australia	First published in 1958, with a major revision culminating in ARR 2019, which is now referenced as ARR version 4.0. ARRR 4.2 is the current revision, including updated guidance on the application of future climate change impacts
Average recurrence interval	ARI	The long-term average number of years between the occurrence of a flood equal to or larger in size than the selected event	ARI is the historical way of describing a flood event. AEP is generally the preferred terminology, for example, a 100-year ARI flood that has 1 in 100 chance of being reached or exceeded in any given year. It is equivalent to a 1% AEP flood
Backwater		A non-convective section of watercourse, where the water level is a function of the downstream conditions rather than being produced by a flow (discharge)	

Review of the Lake Wyangan Flood Study and FRMS&P Update - Draft for Public Exhibition
Glossary and Abbreviations

Term	Abbr.	Definition	Context / Additional Information
Catchment		The area of land draining to a specific location	It includes the catchment of the primary waterway as well as any tributary streams and flowpaths
Chance		Flooding due to prolonged or intense rainfall (e.g. severe thunderstorms, monsoonal rains in the tropics, tropical cyclones)	Types of catchment flooding include riverine, local overland and groundwater flooding
Coastal inundation		Inundation due to tidal or storm-driven coastal events, including storm surges in lower coastal waterways. This can be exacerbated by wind-wave generation from storm events	In FRM this generally relates to the adverse consequences of floods with chance being related to AEP, for example, 1% chance or 1 in 100 chance per year is equivalent to 1% AEP
Consent authority		The authority or agency with the legislative power to determine the outcome of development and building applications	This may be the relevant local council or Minister
Consequence		The outcomes of an event or situation affecting objectives, expressed qualitatively or quantitatively	Consequences can be adverse (e.g. death or injury to people, damage to property and disruption of the community) or beneficial
Continuing flood risk		Risk to existing and future development that may be reduced by EM measures	Flood risk to the existing development and future development may be reduced by EM measures depending on flood constraints, however, these measures cannot remove all risk and a residual risk will remain
Critical duration		The duration of intense rainstorm that produces the greatest peak runoff conditions at a specific location in a catchment for a given probability	
Cunnane plotting position		A formula that estimates the non-exceedance probability for ordered data, often used in hydrology. It provides a nearly unbiased quantile estimate for common hydrological probability distributions	
Defined flood event	DFE	The flood event selected as a general standard for the management of flooding to development	Aims to reduce the frequency of flooding but does not remove all flood risk, for example, in selecting a 1% AEP flood as a DFE you are accepting that there is a 1 in 100 chance that a larger event will occur in any year. This risk is being built into the decision
Department of Climate Change, Energy, the Environment and Water	DCCEEW	The section of NSW government that works to protect the state's environment and heritage	

Review of the Lake Wyangan Flood Study and FRMS&P Update - Draft for Public Exhibition
Glossary and Abbreviations

Term	Abbr.	Definition	Context / Additional Information
Design flood		The flood selected as part of the FRM process that forms the basis for physical works to modify the impacts of flooding	The design flood may be considered the flood mitigation standard, for example, a levee may be designed to exclude a 2% AEP flood, which means that floods rarer than this may breach the structure and impact upon the protected area. In this case, the 2% AEP flood would not equate to the crest level of the levee, because this generally has a freeboard allowance, but it may be the level of the spillway to allow for controlled levee overtopping
Development		<p>May be treated differently depending on the following categorisation:</p> <ul style="list-style-type: none"> • infill development: the development of vacant blocks of land that are generally surrounded by developed properties and is permissible under current land zoning • new development: development of a completely different nature to that associated with the former land-use (e.g. the urban subdivision of a previously rural area) • redevelopment: rebuilding in an area (e.g. as urban areas age, it may become necessary to demolish and reconstruct buildings on a relatively large scale) 	<p>New developments involve rezoning and typically require major extensions of existing urban services, such as roads, water supply, sewerage and electric power</p> <p>Redevelopment generally does not require either rezoning or major extensions to urban services</p>
Development control plan	DCP	See <i>Environmental Planning and Assessment Act 1979</i>	
Digital elevation model	DEM	A 3D digital representation of terrain, containing elevation as a grid of height values	This can be defined more specifically as a digital surface model (DSM) or digital terrain model (DTM), with the former including bridges and trees and the latter being a bare earth representation
Ecologically sustainable development	ESD	As outlined in the Local Government Act 1993	Principles of ESD are outlined in the <i>Local Government Act 1993</i>
Emergency management	EM	A comprehensive approach to dealing with risks to the community arising from hazards. It is a systematic method for identifying, analysing, evaluating and managing these risks	May include measures to reduce flood frequency or consequences through prevention and mitigation measures, and preparation, as well as response and recovery should a flood occur (see PPRR)

Review of the Lake Wyangan Flood Study and FRMS&P Update - Draft for Public Exhibition
Glossary and Abbreviations

Term	Abbr.	Definition	Context / Additional Information
Existing flood risk		The risk an existing community is exposed to as a result of its location on the floodplain	Existing flood risk may be reduced by existing or proposed FRM measures leaving a residual flood risk to the existing community. Residual flood risk may be further reduced by addressing continuing risk
Extreme flood		a severe inundation that far surpasses typical flood levels, causing significant damage and disruption, often exceeding established safety thresholds and posing serious threats to life and property, such as a probable maximum flood	See also probable maximum flood
Flood		A natural phenomenon that occurs when water covers land that is normally dry. It may result from coastal inundation (excluding tsunamis) or catchment flooding, or a combination of both	Flooding results from 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 flowpaths associated with major drainage, and/or oceanic inundation resulting from super-elevated ocean levels
Flood (hydrologic and hydraulic) modelling		Hydrologic and hydraulic computer models to simulate catchment processes of rainfall, run-off, stream flow and distribution of flows across the floodplain or similar	They typically involve consideration of the local flood history, available collected data, and the development of models that are calibrated and validated, where possible, against historic flood events and extended to determine the full range of flood behaviour
Flood affected land		Equivalent to flood prone land	See the definition of flood prone land
Flood awareness		An appreciation of the likely effects of flooding, and a knowledge of the relevant flood warning, response and evacuation procedures facilitating prompt and effective community response to a flood threat	In communities with a low degree of flood awareness, flood warnings may be ignored or misunderstood, and residents confused about what they should do, when to evacuate, what to take with them and where to go
Flood constraints		Key constraints that flooding place on land	These include flood function, flood hazard, flood range, and flood emergency response classification. These can be used to inform FRM including consideration of options such as mitigation works, EM and land-use planning
Flood damage		The tangible (direct and indirect) and intangible costs (financial, opportunity costs, clean-up) of flooding	Tangible costs are quantified in monetary terms (e.g. damage to goods) Intangible damages are difficult to quantify in monetary terms and include the increased levels of physical, emotional and psychological health problems suffered by flood affected people that are attributed to a flood

Review of the Lake Wyangan Flood Study and FRMS&P Update - Draft for Public Exhibition
Glossary and Abbreviations

Term	Abbr.	Definition	Context / Additional Information
Flood education		Seeks to provide information to raise community awareness of flooding so as to enable individuals to understand how to manage themselves and their property in response to flood warnings	
Flood evacuation		The movement of people from a place of danger to a place of relative safety, and their eventual return	People are usually evacuated to areas outside of flood prone land with access to adequate community support Livestock may be relocated to areas outside of the influence of flooding
Flood frequency analysis	FFA	Flood frequency analysis refers to procedures that use recorded and related flood data to identify underlying probability model of flood peaks, at a particular location in the catchment, which can then be used to perform risk-based design and flood risk assessment, while providing input to regional flood estimation methods.	In flood frequency analysis flood peaks are considered to be random variables. A probabilistic model is then fit to the recorded dataset to provide estimates of design peak flood flows
Flood fringe areas		That part of the flood extents for the event remaining after the flood function areas of floodway and flood storage areas have been defined	
Flood function		The flood related functions of floodways, flood storage and flood fringe within the floodplain	Flood function is equivalent to hydraulic categorisation
Flood hazard		A flood that has the potential to cause harm or conditions with the potential to result in loss of life, injury and economic loss	The degree of hazard varies with the severity of flooding and is affected by flood behaviour (extent, depth, velocity, isolation, etc.)
Flood impact and risk assessment	FIRA	A study to assess flood behaviour, constraints and risk, understand offsite flood impacts on property and the community resulting from the development, and flood risk to the development and its users	These studies are generally undertaken for development and are to be prepared by a suitably qualified engineer experienced in hydrological and hydraulic analysis for FRM
Flood liable land		Equivalent to flood prone land	See the definition of flood prone land
Flood plan (local or state)	Local (LFP)	A sub-plan of an EM plan that deals specifically with flooding; they can exist at state, zone and local levels	The NSW Government develops flood plans as a legislative responsibility to determine how best to respond to floods. These community-based plans describe the risk to the community, outline agency roles and responsibilities, the agreed community emergency response strategy and how floods will be managed

Review of the Lake Wyangan Flood Study and FRMS&P Update - Draft for Public Exhibition
Glossary and Abbreviations

Term	Abbr.	Definition	Context / Additional Information
Flood planning area	FPA	The area of land below the FPL	The FPA is generally developed based on the FPL for typical residential development. Different types of development may have different FPLs applied within the FPA. In addition development controls will vary across the FPA due to varying flood constraints
Flood planning level	FPL	The combination of the flood level from the DFE and freeboard selected for FRM purposes	Different FPLs may apply to different types of development Determining the FPL for typical residential development should generally start with a DFE of the 1% AEP flood plus an appropriate freeboard (typically 0.5 m). This assists in determining the FPA
Flood prone land		Land susceptible to flooding by the PMF event	Flood prone land is also known as the floodplain, flood liable land and flood affected land
Flood risk		Risk is based on the consideration of the consequences of the full range of flood behaviour on communities and their social settings, and the natural and built environment	See also risk. The degree of risk varies with circumstances across the full range of floods. It is affected by factors including flood behaviour and hazard, topography and EM difficulties
Flood risk management	FRM	The management of flood risk to communities	
<i>Flood risk management manual: the policy and manual for the management of flood liable land</i>	the manual		The policy as outlined in this document sets the direction for FRM in New South Wales. The manual and its toolkit support the implementation of the policy through the combined efforts of all levels of government. This provides councils, statutory authorities, and state agencies and their staff, with indemnity for decisions they make and information they provide in accordance with the manual.
Flood storage areas		Areas of the floodplain that are outside floodways which generally provide for temporary storage of floodwaters during the passage of a flood and where flood behaviour is sensitive to changes that impact on temporary storage of water during a flood	See also flood function, floodways and flood fringe areas
Flood study		A comprehensive technical investigation of flood behaviour undertaken in accordance with the principles in this manual and consistent with associated guidelines A flood study defines the nature of flood behaviour and hazard across the floodplain by providing information on the extent, level and velocity of floodwaters,	Flood study

Review of the Lake Wyangan Flood Study and FRMS&P Update - Draft for Public Exhibition
Glossary and Abbreviations

Term	Abbr.	Definition	Context / Additional Information
		and on the distribution of flood flows considering the full range of flood events up to and including extreme events, such as the PMF	
Flood warnings		Warnings issued when there is more certainty that flooding is expected, are more targeted and are issued for specific catchments	Flood warnings include more specific predictions of the severity of expected flooding and may give quantitative figures such as expected river water heights at gauge stations
Floodplain		An area of low-lying ground adjacent to a watercourse, formed mainly of alluvial deposition and subject to periodic flooding.	In the manual, the term 'floodplain' is used as being equivalent to that of 'flood prone land'.
Floodways		Areas of the floodplain which generally convey a significant discharge of water during floods and are sensitive to changes that impact flow conveyance. They often align with naturally defined channels or form elsewhere in the floodplain	Floodways are sometimes known as flow conveyance areas
Flow		The rate of flow of water measured in volume per unit time, for example, cubic metres per second (m ³ /s)	Flow is different from the speed or velocity of flow, which is a measure of how fast the water is moving
Freeboard		A factor of safety typically used in relation to the setting of minimum floor levels or levee crest levels	Freeboard aims to provide reasonable certainty that the risk exposure selected in deciding on a specific event for development controls or mitigation works is achieved. Freeboards for development controls and mitigation works will differ. In addition freeboards for development control may vary with the type of flooding and with the type of development
Frequency		The measure of likelihood expressed as the number of occurrences of a specified event in a given time	For example, the frequency of occurrence of a 20% AEP or 5-year ARI flood is once every 5 years on average
FRM measures		Measures that can reduce flood risk	FRM measures may include FRM, flood mitigation, EM and land-use planning measures
FRM options		The FRM measures that might be feasible for the management of a particular area of the floodplain	Preparation of an FRM plan requires a detailed evaluation of FRM options
FRM plan		A management plan developed in accordance with the principles in this manual and its supporting guidelines	Previously known as a floodplain risk management plan or floodplain management plan. It may describe how particular areas of flood prone land are to be used and managed to achieve defined objectives
FRM study		A management study developed in accordance with the principles in this manual and its supporting guidelines	Previously known as a floodplain risk management study or floodplain management study

Review of the Lake Wyangan Flood Study and FRMS&P Update - Draft for Public Exhibition
Glossary and Abbreviations

Term	Abbr.	Definition	Context / Additional Information
Future flood risk		The risk future development and its users are exposed to as a result of its location on the floodplain	Future flood risk may be reduced by existing or proposed FRM measures and land-use planning controls that consider the flood constraints on the land. This leaves a residual flood risk to the new development and its users. This residual flood risk may be further reduced by addressing continuing flood risk
Gauge height		The height of a flood level at a particular water level gauge site related to a specified datum	The datum may or may not be the AHD
Generalised extreme value	GEV	A probability distribution that is a single, flexible model in statistics combining three types of extreme value distributions (Gumbel, Fréchet, Weibull) to describe the behaviour of maximum (or minimum) values from a large set of random data	
Generalised short duration method	GSDM	A hydrological method for the estimation of extreme rainfall in Australia, appropriate for storm durations up to six hours	See also generalised south-east Australia method, generalised tropical storm method and probable maximum precipitation
Generalised south-east Australia method	GSAM	A hydrological method for the estimation of extreme rainfall in (southern) Australia, appropriate for storm durations of 12 hours	See also generalised short duration method, generalised tropical storm method and probable maximum precipitation
Generalised tropical storm method	GSAM	A hydrological method for the estimation of extreme rainfall in (northern) Australia, appropriate for storm durations of 12 hours	See also generalised short duration method, generalised south-east Australia method and probable maximum precipitation
Green-Ampt	GA	A model that represents water infiltration into a homogenous soil with a uniform initial water content	
Hazard		A source of potential harm or conditions that may result in loss of life, injury and economic loss due to flooding	
Hydraulic roughness		Measures the resistance water encounters flowing over a surface, influenced by friction and obstructions like bedforms (dunes, ripples) in channels or vegetation on land	Governs water velocity and water levels and is crucial for predicting flood levels. See also Manning's 'n'
Hydraulics		The study of water flow in waterways and flowpaths; in particular, the evaluation of flow parameters such as water level and velocity	
Hydrograph		A graph showing flow (discharge) in a watercourse over time, with key components including the baseflow, fast-rising rising limb (runoff), peak discharge, and slower falling limb (groundwater return)	

Review of the Lake Wyangan Flood Study and FRMS&P Update - Draft for Public Exhibition
Glossary and Abbreviations

Term	Abbr.	Definition	Context / Additional Information
Hydrology		The study of the rainfall and run-off process; in particular, the evaluation of peak flows, flow volumes and the derivation of hydrographs for a range of floods	
Hyetograph		A bar graph showing rainfall intensity over specific time intervals, used in hydrology to understand storm patterns for flood prediction and drainage design	
Integrated planning and reporting framework	IP&R framework	The IP&R framework includes a suite of integrated plans that set out a vision and goals and strategic actions to achieve them. It involves a reporting structure to communicate progress to council and the community as well as a structured timeline for review to ensure the goals and actions are still relevant	Preparation of FRMS and plans and implementation and maintenance of works requires linkages to the IP&R framework
Intensity-frequency-duration	IFD	A probabilistic estimation of rainfall across a 3-dimensional matrix of rainfall depth, storm duration and probability	Design rainfall depth estimations at a single point increase with the duration of the rainstorm and also with a reducing probability
Light detection and ranging	LiDAR	A remote sensing method that uses pulsed laser light to measure distances and create detailed 3D maps or models of the Earth's surface, objects, and environments	It is often mounted on aircraft or drones and generates dense "point clouds" of data, offering high accuracy and penetration of vegetative foliage
Likelihood		A qualitative description of probability and frequency	See also frequency and probability
Likelihood of occurrence		The likelihood that a specified event will occur	With respect to flooding, see also AEP and ARI
Local environmental plan	LEP	See <i>Environmental Planning and Assessment Act 1979</i>	
Local government area	LGA		The area serviced by the local government council
Local overland flooding	LOF	Inundation by local run-off on its way to a waterway, rather than overbank flow from a waterway	
Local strategic planning statement	LSPS		Local strategic planning statements assist councils to implement the priorities set out in

Z:\Projects\T2566_Lake_Wyangan_FRMS\Docs\R.T2566.001.04.docx



Review of the Lake Wyangan Flood Study and FRMS&P Update - Draft for Public Exhibition
Glossary and Abbreviations

Term	Abbr.	Definition	Context / Additional Information
			their community strategic plan and actions in regional and district plans
Log Pearson III	(LP3)	A key statistical method in hydrology, used for flood frequency analysis to predict extreme events like floods by fitting skewed data, commonly found in river flows.	It transforms data into logarithms, calculating the mean, standard deviation, and skewness of these log-transformed values, then using a table to find a frequency factor (K) to estimate future flood magnitudes at given probabilities, and finally converting back to original units
Loss		Any negative consequence or adverse effect, financial or otherwise	
Manning's 'n'		A common roughness coefficient used in hydraulic engineering, representing a channel's resistance to water flow, with higher 'n' values indicating rougher surfaces (like natural streams with debris) and lower values indicating smoother surfaces (like concrete pipes)	A dimensionless factor used in Manning's Equation to calculate flow velocity and discharge in open channels, with typical values varying significantly, from around 0.01 for smooth surfaces to over 0.10 for very rough or vegetated areas. See also hydraulic roughness
Merit-based approach		Weights social, economic, ecological and cultural impacts of land-use options for different flood prone areas together with flood damage, hazard and behaviour implications, and environmental protection and wellbeing of the state's rivers and floodplains	<p>The merit approach operates at 2 levels.</p> <p>At the strategic level it allows for the consideration of social, economic, ecological, cultural and flooding issues to determine strategies for the management of future flood risk, which are formulated into council plans, policy and environmental planning instruments</p> <p>At a site-specific level, it involves consideration of the merits of a development consistent with council LEPs, DCPs and local FRM policies, and consistent with FRM plans</p>
Model for effluent disposal using land irrigation	MEDLI	A Windows-based computer model developed by the Queensland Government to simulate the long-term effects of irrigating land with treated effluent	It is used to design and assess wastewater reuse schemes for sewage treatment plants, abattoirs, and intensive rural industries, preventing soil degradation and groundwater contamination
NSW Floodplain Management Program	the program	The NSW Government's program of technical support and financial assistance to local councils to enable them to understand and manage their flood risk	The program, manual and FRM guides support the delivery of the policy through a partnership across governments
NSW Flood prone land policy	the policy	The <i>NSW Flood prone land policy</i> included in the manual	

Z:\Projects\T2566_Lake_Wyangan_FRMS\Docs\R.T2566.001.04.docx

Review of the Lake Wyangan Flood Study and FRMS&P Update - Draft for Public Exhibition
Glossary and Abbreviations

Term	Abbr.	Definition	Context / Additional Information
Peaks-over-threshold	POT	A technique in flood frequency analysis that models extreme river flows by analysing all events exceeding a set high flow rate (threshold)	
Pluviograph		An instrument that measures the amount of water that has fallen (i.e. a rain gauge), with a feature to register the data in real time, providing a detailed sub-daily dataset of the temporal pattern of recorded rainfall	
Prevention, preparedness, response and recovery	PPRR	<p>Involves:</p> <ul style="list-style-type: none"> • prevention: to eliminate or reduce the level of the risk or severity of emergencies • preparedness: enhances the capacity of agencies and communities to cope with the consequences of emergencies • response: to ensure the immediate consequences of emergencies to communities are minimised • recovery: measures that support individuals and communities affected by emergencies in the reconstruction of physical infrastructure and restoration of physical, emotional, environmental and economic wellbeing 	In the flood context prevention involves FRM (including flood mitigation), EM and land-use planning measures
Probability		A statistical measure of the expected chance of a flood	For example, AEP
Probable maximum flood	PMF	The largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation (PMP), and where applicable, snow melt, coupled with the worst flood-producing catchment conditions	<p>This is equivalent to the probable maximum precipitation flood in Australian Rainfall and Runoff (ARR)</p> <p>The PMF in ARR is used for estimating dam design floods</p>
Probable maximum precipitation	PMP	The greatest depth of precipitation for a given duration meteorologically possible over a given size storm area at a particular location at a particular time of the year, with no allowance made for long-term climatic trends (World Meteorological Organization 1986)	PMP is the primary input to PMF estimation
Rainfall intensity		The rate at which rain falls, typically measured in millimetres per hour (mm/h)	Rainfall intensity varies throughout a storm in accordance with the temporal pattern of the storm

Review of the Lake Wyangan Flood Study and FRMS&P Update - Draft for Public Exhibition
Glossary and Abbreviations

Term	Abbr.	Definition	Context / Additional Information
Rating curve		A hydrological graph showing the relationship between a watercourse's water level (stage) and its flow (discharge), typically employed at gauging station locations	A gauging station typically measures the water level within a watercourse, with estimates of flow being derived from the adopted rating curve. See also spot gaugings
Real-time kinetic	RTK	A high-precision satellite positioning technology that uses a fixed base station to send correction data to a mobile receiver, achieving centimetre-level accuracy for GNSS by correcting atmospheric and satellite errors	GNSS (Global Navigation Satellite System) is the umbrella term for satellite constellations like GPS (US), GLONASS (Russia), Galileo (EU), and BeiDou (China) that provide positioning, navigation, and timing (PNT) data globally via satellite signals, allowing receivers to calculate locations on Earth, land, sea, and air
Residual flood risk		The risk to the existing and future community that remains with FRM, EM and land-use planning measures in place to address flood risk	FRM measures cannot remove all flood risk, but rather they reduce residual flood risk
Risk		'The effect of uncertainty on objectives' (ISO 2018)	See also flood risk. Note 4 of the definition in ISO31000:2018 also states that 'risk is usually expressed in terms of risk sources, potential events, their consequences and their likelihood'
Risk analysis		The systematic use of available information to determine how often specified (flood) events occur and the magnitude of their likely consequences	
Run-off		The amount of rainfall that ends up as streamflow, also known as rainfall excess	
State environmental planning policy	SEPP	See <i>Environmental Planning and Assessment Act 1979</i>	
Scenario		A scenario may relate to current, historical or assumed future floodplain, catchment and climate conditions	Flood behaviour varies over time with changes in key catchment and floodplain (such as the scale of development) and climatic conditions (including climate change), and due to the implementation of FRM measures. A range of scenarios are generally needed to understand and assess flood behaviour
Shared socioeconomic pathways	SSPs	Scenarios used in climate modelling that describe plausible future global developments in society, economy, and technology (like population, growth, education, energy use) to explore different levels of greenhouse gas emissions and climate change impacts	
Spot gaugings		Specific, manual measurements of water flow (discharge) at predetermined points in a watercourse, often done periodically to	See also rating curve

Review of the Lake Wyangan Flood Study and FRMS&P Update - Draft for Public Exhibition
Glossary and Abbreviations

Term	Abbr.	Definition	Context / Additional Information
		calibrate rating curves at water level recording gauging stations	
Stage		Equivalent to water level; measured with reference to a specified datum	Measurement may relate to AHD, a local datum or a local water level gauge
Storm surge		The increases in coastal water levels above predicted astronomical tide level (i.e. tidal anomaly) resulting from a range of location-dependent factors	These factors may include the inverted barometer effect, wind and wave setup and astronomical tidal waves, together with any other factors that increase tidal water level
Tailwater		Waters located immediately downstream from a hydraulic structure, such as a dam, spillway, bridge or culvert	In the context of hydraulic modelling this term is also used when referencing the water level conditions at the downstream limit (boundary) of the model
Technical working group	TWG	A term typically associated with the people responsible for the ongoing review and project decision making process during the undertaking of a flood study	The TWG typically comprises staff from the consultancy responsible for delivery of the flood study, together with relevant local and state government staff
Two-dimensional unsteady flow	TUFLOW	A suite of advanced 1D/2D/3D computer simulation software for flooding, urban drainage, coastal hydraulics, sediment transport, particle tracking and water quality	With over 35 years of continuous development, TUFLOW is internationally recognised as the industry leader for hydraulic modelling accuracy, speed and workflow efficiency
Velocity		The speed of floodwaters, measured in metres per second (m/s)	
Vulnerability		The degree of susceptibility and resilience of a community, its social setting, and the built environment to flooding	Vulnerability is assessed in terms of ability of the community and environment to anticipate, cope and recover from flood events

Executive Summary

Introduction

The Review of the Lake Wyangan Flood Study and Floodplain Risk Management Study and Plan Update is being prepared for Griffith City Council (Council) to improve the understanding of flood behaviour and impacts and better inform management of flood risk in the study area with consideration of the available information, and relevant standards and guidelines.

The study comprises an overland flow flood investigation of Lake Wyangan township and the surrounding rural environs to determine the suitability and feasibility of land uses consistent with supporting local growth and development.

The outcomes of this flood study will enable the understanding of flood-related issues across the study area and provide Council with a basis to prioritise floodplain risk management activities. The improved definition of flood behaviour will also aid in Council's management of flood risk and be used in conjunction with land use planning and development controls and flood emergency management and response.

Study Background

The study considers rainfall-runoff from the entire catchment of Lake Wyangan. However, the focus of the study is within the southern part of the catchment, where most of the existing and future urban development is located. The main study area can be described as the area bounded by the Lake View Branch Canal to the north and east and the catchment divide to the south and west.

The Lake Wyangan catchment is an endorheic basin, having no natural drainage outlet. It includes the terminal lake and wetland storage areas of Lake Wyangan, Tharbogang Swamp, Nericon Swamp and Campbell's Swamp.

For this study, a TUFLOW model was developed for the simulation of catchment flood hydrology using the direct rainfall method to represent the rainfall-runoff process. The hydrological model incorporates the approach developed by Torrent Consulting's research, as presented at the Hydrology and Water Resources Symposium 2023, which uses the full functionality of the TUFLOW soil infiltration routines to address the shortcomings of other simplified rainfall loss methods. The design flood hydrology is simulated in accordance with the ARR 2019 guidelines, which is an updated approach from that used in the previous studies.

A key limitation in model calibration and design flood estimation identified in the previous studies was the very small amount of effective rainfall, i.e. that which is converted to observed catchment runoff following infiltration losses. This made the modelled catchment runoff highly sensitive to the adopted initial and continuing loss parameters. This current study sought to reduce this uncertainty using a more sophisticated infiltration loss model and the additional calibration data available. However, the uncertainty associated with the limited available rainfall records and highly complex catchment hydrology has prevented a meaningful calibration of model parameters to match the observed catchment runoff conditions.

Since the completion of the existing studies there have been two significant flood events in Sep-Oct 2016 and Oct-Nov 2022. Both events experienced prolonged periods of high monthly rainfall totals, which is different to the other recent major flood event of March 2012, which was a single intense rainstorm. Catchment runoff and localised flooding was also experienced in January 2022.

The impacts of flooding within the catchment can be broadly classified into three categories:

- Short duration intense rainfall within the local catchment area draining to Lake Wyangan from the hillslopes to the east, creating overland flood flow paths within the Lake Wyangan suburban area, such as occurred in March 1985.
- Intense rainfall of a longer duration resulting in catchment runoff from the broader catchment draining to Tharbogang Swamp and the Lake View Drain, which becomes more likely during periods of prolonged wet weather. This causes overland flood flow inundation through properties located between Dickie Road and the Kubank Estate, which may last for an extended period of days, such as occurred in March 2012 and January 2022.
- When the above mechanism extends for a period of weeks then a significant volume of water is discharged to the terminal lake systems within the catchment, resulting in flooding of areas surrounding Lake Wyangan and Tharbogang Swamp, such as occurred in Oct-Nov 2022. Being a terminal system, output from the lakes is limited to evaporation losses plus any pumped extraction. The elevated water level in Lake Wyangan persisted well into 2023 following the Oct-Nov 2022 flood event.

Flood behaviour was predicted for a range of design floods based on detailed TUFLOW hydrological and hydraulic modelling developed for the study catchments. Modelling of the local catchment and lake storage flood conditions was validated using flood information for historical events, where available.

Community Consultation

A consultation plan to engage with the community at various stages throughout the project duration is an important component of the study. The key elements of the community consultation plan include:

- Meeting with local landholders that were impacted during the 2016 and 2022 flood events.
- Liaison with landholders from the upper catchment area to obtain additional rainfall records
- Community Information session at the public exhibition phase to inform of study progress and findings.
- Formal Public Exhibition of the Draft Flood Study document and request for feedback.

In addition to the broader community engagement, study progress at regular intervals is reported to the technical working group, including representatives from Griffith City Council and NSW DCCEEW.

Model Development

Three TUFLOW models were developed to simulate flood behaviour within the study catchment:

- A hydrological model to simulate rainfall-runoff contributing to flooding in the terminal storages of Lake Wyangan and Tharbogang Swamp. This includes the main overland flow path within the catchment, which impacts the Kubank Estate. The details for key hydraulic controls were also represented in the model, as they impact the flood hydrology.
- A hydrological model to simulate rainfall-runoff of the local catchment areas in the south-eastern area of the catchment, which have a much shorter critical duration than the broader catchment.
- A detailed hydraulic model to simulate the main overland flood flow paths within the south-eastern area of the catchment, where most of the existing and future urban development is located. Details of local drainage channels and hydraulic structures were represented, with inflows being sourced from the local catchment hydrological model.

The Lake Wyangan / Tharbogang Swamp TUFLOW model is principally a hydrological model, developed to simulate the rainfall-runoff process of the study catchment. However, it also includes details of some key hydraulic controls that impact the flood hydrology, such as Lake View Drain and cross-drainage structures under the Lake View Branch Canal. The model is also suitable for the mapping of the main catchment flood flow path, which impacts the Kubank Estate and flows into Tharbogang Swamp. The model is also used for

the derivation of design flood levels in Lake Wyangan and Tharbogang Swamp that result from a single event-driven flood response.

The key inputs that inform the hydrological modelling process are:

- Topographic data – from the 2016 photogrammetric survey and 2021 LiDAR survey
- Hydraulic roughness – derived from aerial imagery of land surface coverage, used to represent the hydrological response (runoff routing) of the catchment to rainfall, including a higher roughness appropriate for shallow sheet flow conditions.
- Rainfall losses – derived from the Green-Ampt infiltration method, informed by soil texture, soil depth and soil moisture data. Irrigated agriculture areas were given higher initial soil moisture conditions, with areas of almond farming also given a degree of imperious surface coverage.
- Drainage infrastructure – key drainage channels and structures were included within the model to ensure that catchment runoff is directed to the applicable receiving terminal lake storage. Lake View Drain is particularly important in this regard, as it crosses the natural catchment divide between Lake Wyangan and Tharbogang Swamp.

The local catchment TUFLOW hydrological model covers an area of around 70 km² and includes the North and South Lake Wyangan catchments, and the Nericon Swamp and Campbell's Swamp catchments. The local catchment hydrological model extends from the ridgeline of the McPherson Range to the south and east, and to the natural divide of the Lake Wyangan and Tharbogang Swamp catchments to the north and west. The modelling methodology is largely consistent with that of the broader catchment model. Results from the local catchment model were extracted and input as flow hydrographs to the local catchment hydraulic model.

The TUFLOW hydraulic model covers an area of some 28 km², including the residential and semi-rural localities bordered by Lake Wyangan, Lake View Branch Canal, and Mallinsons Road. The model was constructed using a 4 m horizontal grid cell resolution, with the sub-grid sampling (SGS) routine in TUFLOW implemented to utilise the full detail of the underlying DEM data within the model grid cell geometry. Again, key drainage channels and structures were incorporated within the model and debris blockage assumptions were also applied.

Model Calibration and Validation

The original Lake Wyangan Flood Study considered the March 1985, March 1989 and December 2007 events for model calibration. The March 2012 event occurred shortly after completion of the study and so it was investigated as part of the Lake Wyangan Floodplain Risk Management Study. Since the previous studies there have been additional events in Sep-Oct 2016 and Oct-Nov 2022, the latter of which produced the highest recorded flood level in Lake Wyangan. These events have all been considered in the context of this current study update.

The model calibration process for the original Lake Wyangan Flood Study found modelling the catchment flood hydrology to be extremely challenging, for reasons including:

- A general paucity of data including both rainfall and water level records
- The substantial apparent soil losses exhibited by previous flood events
- The sensitivity of modelled runoff volume to small changes in effective rainfall
- Cross-catchment flow transfer via the Lake View Drain.

The March 2012 event is the largest to impact the broader region in recent recorded history. The half-hourly rainfall record from Griffith Airport indicates a 24-hour duration event, which began on the morning of 3 March

and during which 143 mm was recorded. This exceeds a 1-in-200 AEP event when compared to the BOM IFD data.

Modelling of the March 2012 event was highly sensitive to small change in rainfall applied to the model and the antecedent soil moisture conditions. The degree of uncertainty associated with these datasets exceeds that of the model parameters. The model calibration process identified that combinations ranging between a 110 mm to 120 mm rainfall depth and initial soil moisture conditions ranging between 40% to 50% will produce simulated results that are comparable to the observed event conditions.

A mass balance assessment was undertaken for the Oct-Nov 2022 flood event, as the multi-storm composition of the event is too complex for hydrological simulation. However, the mass balance assessment enables some meaningful observations to be made:

- It is likely that most of the water entering Lake Wyangan and Tharbogang Swamp came from local catchment sources rather than the central and upper catchment areas.
- The 24 October rainfall event triggered the inflow of central and upper catchment runoff into the lower catchment area.
- Almost all the central and upper catchment inputs entered Lake Wyangan via Lake View Drain, with there being limited potential for significant contributions to Tharbogang Swamp given the recorded water levels in that waterbody.
- There is an additional loss of around 85 ML/d from Lake Wyangan between 24 November and 9 December, which closely matches the corresponding volumetric increase in the Tharbogang Swamp storage. This is a function of the emergency pump transfer that was undertaken from Lake Wyangan to Tharbogang Swamp.
- The gradients of volumetric loss associated with evaporation match the observed data at the end of the event, once the rainfall and pumping have ceased.
- There is estimated 4500 ML of runoff volume from the local catchments reporting to Lake Wyangan, which equates to an effective rainfall depth of 31 mm. From the approximately 315 mm of rainfall recorded during the period, this represents a runoff coefficient of around 10%.
- The estimated 3400 ML of additional runoff volume from the central and upper catchment areas equates to an effective rainfall depth of only 5 mm and a runoff coefficient of only 1.5%.

The March 1985 event is truly exceptional. A daily rainfall total of 150 mm was recorded at Griffith Airport, with only 45 mm recorded at Hanwood and 29 mm at Yenda. To the north and west, all rainfall gauges recorded zero for the day. It would be easy to dismiss this record as an error were it not for the photographic evidence (as presented within the original Lake Wyangan Flood Study), which shows a 200 m wide overland flood flow path from Smeeth Road flowing over Boorga Road at the intersection. A model validation process demonstrates reasonable consistency between the modelled and observed flood behaviour from local catchment runoff during very intense rainfall such as occurred during this historical flood event.

A detailed review of available satellite imagery was undertaken for the historical flood events and provides some insight into the catchment response to a range of rainfall conditions.

Design Flood Hydrology

Design flood hydrology was simulated using the TUFLOW models in accordance with the ARR 4.2 guidelines. The adopted design rainfall conditions considered the following key parameters:

- The spatial variability of rainfall across the catchment
- The application of an areal reduction factor

- A critical duration assessment
- Application of appropriate climate change impacts to design rainfall intensity.

The 24-hour storm duration was found to be the critical condition for the broader catchment flooding, with local catchment flooding typically exhibiting a 45-minute to 9-hour critical duration.

As per the updated ARR 4.2 climate change guidance, an adjustment was made to the adopted design rainfall to account for potential increases in rainfall intensity. The rainfall adjustment is determined through a combination of an expected increase in global mean temperature and an associated percentage increase in design rainfall intensity per degree of warming.

For this assessment the Shared Socioeconomic Pathway SSP2 was adopted for the near-term flood planning horizon, which represents a continuation of historic global attitudes towards climate policy, i.e. a neutral rather than optimistic or pessimistic outlook. The SSP3 climate change scenario was adopted for the long-term flood planning horizon, which assumes future challenges to climate change adaption and mitigation. The SSP2-4.5 climate scenario has a best-estimate warming of around 1.2°C for the near-term (2021-2040) horizon, while SSP3-7.0 estimates around 3.3°C of warming for the long-term (2081-2100) horizon.

For the broader catchment model a total increase in design rainfall intensity of 9.7% was derived for the near-term horizon and 28.9% for the long-term horizon. For the local catchment flood mechanism, a total increase in design rainfall intensity ranging between 10.2% and 18.3% was derived for the near-term horizon and between 30.5% and 58.6% for the long-term horizon.

Design Flood Results

The modelled peak flow and peak flood level conditions are tabulated at key locations across the study area within this report document. The full suite of design flood mapping outputs is provided in the accompanying appendices. Flood mapping outputs are provided for the near-term (2040) planning horizon, with additional outputs that are integral to future flood planning decisions also provided for the long-term (2100) planning horizon.

Flood hazard classification mapping was undertaken in accordance with Guideline 7-3 of the Australian Disaster Resilience Handbook 7 Managing the Floodplain: A Guide to Best Practice in Flood Risk Management in Australia (AIDR, 2017). Flood function mapping was produced using the following criteria:

- Floodway is defined as areas where the peak value of velocity multiplied by depth ($V \cdot D$) $> 0.2 \text{ m}^2/\text{s}$, with all drainage channels also being considered as floodway
- Flood Storage comprises areas outside the Floodway where peak depth $> 0.5 \text{ m}$, with all wetland areas also being considered as flood storage; and
- Flood Fringe comprises areas outside the Floodway where peak depth is less than the thresholds for Flood Storage.

Contents**Contents**

1	Introduction.....	1
1.1	Background	1
1.2	Study Location	1
1.3	The Floodplain Risk Management Process	1
1.4	Study Objectives.....	3
1.5	Report Outline	4
2	Study Background.....	5
2.1	Study Area	5
2.1.1	Catchment Description.....	5
2.2	Data Collection and Review.....	7
2.2.1	Review of Previous Studies	7
2.2.2	Historical Flood Events.....	7
2.2.3	Rainfall and Water Level Records	12
2.2.4	Soil Type and Moisture Data.....	13
2.2.5	Topographic and Land Use Data	15
2.2.6	Satellite Imagery.....	18
2.2.7	Data Gaps and Recommendations	18
3	Community Consultation	22
3.1	Consultation Plan.....	22
3.2	Community Consultation	22
3.3	Site Inspection	22
3.4	Public Exhibition.....	23
4	Model Development	24
4.1	Modelling Approach	24
4.2	Lake Wyangan / Tharbogang Swamp Catchment Model	25
4.2.1	Model Extent and Topography	25
4.2.2	Drainage Infrastructure	28
4.2.3	Hydraulic Roughness.....	28
4.2.4	Rainfall Losses.....	30

Contents

4.3	Local Catchment Hydrological Model.....	30
4.3.1	Model Extent and Topography	30
4.3.2	Drainage Infrastructure	32
4.3.3	Hydraulic Roughness.....	32
4.3.4	Rainfall Losses.....	32
4.3.5	Hydrograph Extraction	32
4.4	Local Catchment Hydraulic Model	32
4.4.1	Model Extent and Topography	32
4.4.2	Drainage Infrastructure	34
4.4.3	Hydraulic Roughness.....	35
5	Model Calibration and Validation	36
5.1	Selection of Calibration and Validation Events	36
5.2	March 2012 Event.....	37
5.3	October-November 2022 Event	41
5.4	March 1985 Event.....	44
5.5	Satellite Imagery Observations	46
6	Design Flood Hydrology.....	51
6.1	Lake Wyangan / Tharbogang Swamp Catchment	51
6.1.1	Design Rainfall Spatial Variability	51
6.1.2	Aerial Reduction Factor	51
6.1.3	Critical Duration Assessment	53
6.1.4	Climate Change	53
6.2	Local Catchment.....	53
6.2.1	Aerial Reduction Factor	53
6.2.2	Critical Duration Assessment	53
6.2.3	Climate Change	54
6.3	Extreme Flood Event.....	54
7	Design Flood Results	55
7.1	Lake Wyangan / Tharbogang Swamp Catchment Model	55
7.2	Local Catchment Model.....	57
7.2.1	Design Flood Conditions.....	57

7.2.2	Flood Hazard	57
7.2.3	Flood Function	61
8	Conclusions	63
9	References	64
Appendix A	Lake Wyangan / Tharbogang Swamp Design Flood Mapping	65
Appendix B	Local Catchment Flood Mapping	93

List of Figures

Figure 1-1	Lake Wyangan Catchment Drainage	2
Figure 1-2	Flood risk management process (NSW Flood Risk Management Manual).....	3
Figure 2-1	Lake Wyangan Catchment Topography	6
Figure 2-2	Catchment Rainfall and Soil Conditions for 2012	9
Figure 2-3	Catchment Rainfall and Soil Conditions for 2016	9
Figure 2-4	Catchment Rainfall and Soil Conditions for 2022	10
Figure 2-5	Surface Water Flooding near Lee Lane in October 2016	10
Figure 2-6	Flooding Along Lake View Drain in October 2022	11
Figure 2-7	Flooding Along Zanotto Road in October 2022	12
Figure 2-8	Cumulative Rainfall and Storage Volume Increase for Oct-Nov 2022 Flood Event .	13
Figure 2-9	Rainfall Gauge Locations	14
Figure 2-10	Catchment Soil Texture	16
Figure 2-11	Digital Elevation Model Data	17
Figure 2-12	Sentinel 2 Imagery on 23 September 2016	19
Figure 2-13	Sentinel 2 Imagery on 18 November 2022.....	20
Figure 4-1	Lake Wyangan / Tharbogang Swamp Catchment Model Schematic	26
Figure 4-2	LiDAR Survey Data Extents	27
Figure 4-3	Modelled Cross-drainage Structure Locations	29
Figure 4-4	Local Catchment Hydrological Model Schematic.....	31
Figure 4-5	Local Catchment Hydraulic Model Schematic	33
Figure 5-1	Griffith Airport Rainfall Hyetograph for March 2012 Event.....	37

Figure 5-2	March 2012 Event Spatial Rainfall Distribution.....	38
Figure 5-3	March 2012 Event Rainfall and Initial Soil Moisture Sensitivity Testing.....	40
Figure 5-4	Mass Balance Calculations for Lake Wyangan 2022 Event	42
Figure 5-5	Mass Balance Calculations for Tharbogang Swamp 2022 Event	43
Figure 5-6	March 1985 Flood Event at Smeeth Road	45
Figure 5-7	Flow Path Modelling in Central Catchment Area.....	47
Figure 5-8	Flow Path Modelling in Lower Catchment Area	49
Figure 5-9	Change in Flood Flow Paths in the 2022 Floods	50
Figure 6-1	Modelled Design Rainfall Zones.....	52
Figure 7-1	Relationship Between Modelled Event Rainfall and Total Runoff Volume.....	56
Figure 7-2	Local Catchment Design Flood Extents 2040 Flood Planning Horizon	60
Figure 7-3	General Flood Hazard Vulnerability Curves (AIDR, 2017)	62

List of Tables

Table 4-1	Modelled Hydraulic Structure Blockage	34
Table 5-1	Default Saturated Hydraulic Conductivity Values for Green-Ampt in TUFLOW.....	40
Table 6-1	Modelled Spatial Variability of Design Rainfall.....	51
Table 6-2	Adopted Critical Design Storm Events	54
Table 7-1	Near-Term Design Flood Levels Lake Wyangan and Tharbogang Swamp	55
Table 7-2	Long-Term Design Flood Levels Lake Wyangan and Tharbogang Swamp	55
Table 7-3	Modelled Design Flows (m^3/s)	58
Table 7-4	Modelled Design Flood Levels (m^3/s)	59
Table 7-5	Combined hazard curves - vulnerability thresholds (AIDR, 2017)	61

1 Introduction

1.1 Background

The Review of the Lake Wyangan Flood Study and Floodplain Risk Management Study and Plan Update is being prepared for Griffith City Council (Council) to improve the understanding of flood behaviour and impacts and better inform management of flood risk in the study area with consideration of the available information, and relevant standards and guidelines.

The existing studies completed by BMT WBM are now over a decade old and at that time there was limited catchment flood information available. However, subsequent flood events in Sep-Oct 2016 and Oct-Nov 2022 have provided a more comprehensive calibration dataset. The 2022 flood event is of particular importance, given that it exceeded the 0.5% AEP design flood level estimate in Lake Wyangan, resulting in the inundation of two residential properties, the causeway and other infrastructure surrounding the lake. The 2016 and 2022 events were the result of prolonged catchment rainfall and wet antecedent conditions rather than intense isolated rainstorms.

In addition to the recent flooding in the catchment, there has been significant agricultural development that will impact the volume of runoff being drained to Lake Wyangan. Accordingly, Council seeks to undertake a detailed review and update of the existing Flood Study and Floodplain Risk Management Study and Plan (FRMSP) to better understand the current flood risk and options for the long-term floodplain risk management. Since the undertaking of the existing studies there has been substantial agricultural development that has expanded the irrigated area in the vicinity of Dickie Road.

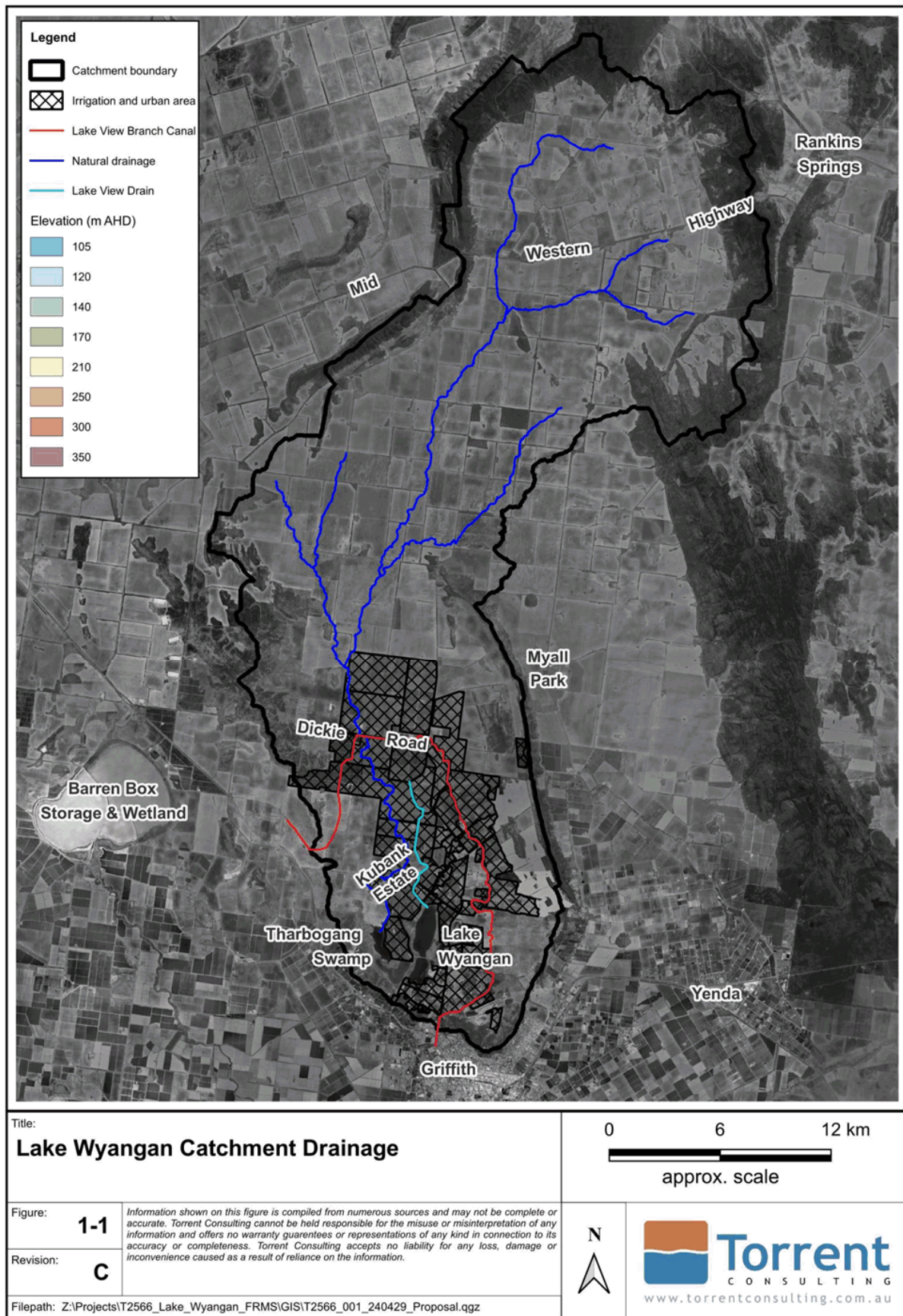
1.2 Study Location

Lake Wyangan is in the northern Riverina region of New South Wales, approximately 5 km north of Griffith. The Lake Wyangan / Tharbogang Swamp catchment covers an area of approximately 760 km² and incorporates the smaller catchments draining to Campbell's Swamp and Nericon Swamp, as shown in Figure 1-1.

Residential areas are located to the east and south of Lake Wyangan, with regional access available via Boorga Road north toward Rankins Springs or south toward Griffith. Irrigated agriculture covers a large portion of the southern part of the catchment, in proximity to the Lake View Branch Canal. The extent of irrigation has increased significantly in the Dickie Road area within the last 15 years.

1.3 The Floodplain Risk Management Process

The NSW Government has worked in partnership with Councils to understand and manage flood risk to communities across New South Wales under the NSW Flood prone land policy (the policy) since 1984. The primary objective of the policy is to reduce the impacts of flooding and flood liability on communities and individual owners and occupiers of flood prone property, and to reduce private and public losses resulting from floods, utilising ecologically positive methods wherever possible. The *Flood risk management manual: the policy and manual for the management of flood liable land* (NSW Dept. Planning & Environment, 2023) and its toolkit support the implementation of the policy.



Under the policy, the management of flood liable land remains the responsibility of Councils, with the State Government providing specialist technical advice to assist Councils in the discharge of their floodplain management responsibilities and may subsidise flood mitigation works to alleviate existing problems. Councils are encouraged to develop and implement Floodplain Risk Management (FRM) plans through the FRM process outlined in Figure 1-2.

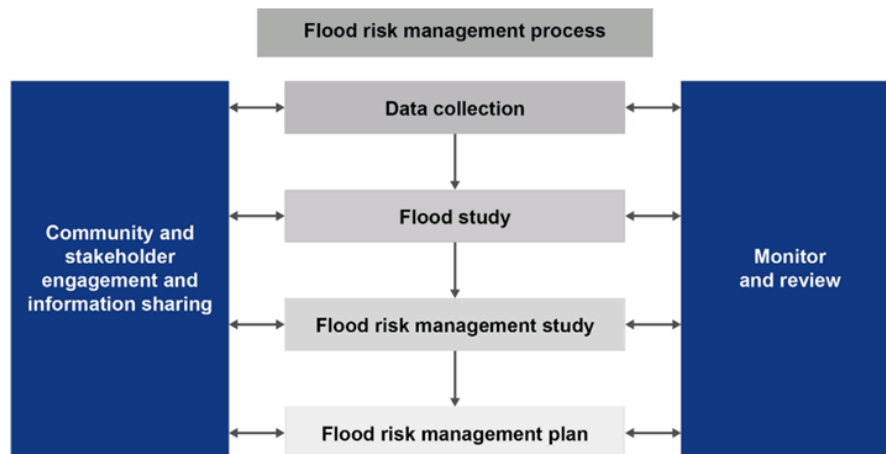


Figure 1-2 Flood management process (NSW Flood Risk Management Manual)

This study represents the "Flood Study" stage of the above process and aims to provide an understanding of flood behaviour within the study area.

1.4 Study Objectives

The primary objective of the Flood Study is to define the flood behaviour within the study area through the establishment of appropriate numerical models. The developed models simulate expected flood behaviour within the local catchments, Lake Wyangan and Tharbogang Swamp storages, providing 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, as required.
- Development of appropriate hydrological and hydraulic models and model calibration to observed historical event data, where available.
- Determination of design flood conditions for a range of design magnitude events up to the Probable Maximum Flood (PMF) event, also considering future flooding conditions incorporating potential climate change influence.
- Presentation of the study methodology, results and findings in a comprehensive report incorporating appropriate flood mapping.

The principal outcome of the flood study is the understanding of flood behaviour in the study area and in particular design flood level information to assist in future flood planning and assessment of flood risk management options.

1.5 Report Outline

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

Section 1 introduces the study.

Section 2 details the study area and provides information on the data collected for this study.

Section 3 outlines the community consultation program undertaken.

Section 4 provides an overview of the approach adopted to complete the study and details the development of the computer models.

Section 5 details the model calibration and validation process.

Section 6 details the development of the design flood hydrology.

Section 7 presents the design flood simulation results and associated flood mapping.

2 Study Background

2.1 Study Area

The study considers rainfall-runoff from the entire catchment of Lake Wyangan, which is shown on Figure 1-1. However, the focus of the study is within the southern part of the catchment, where most of the existing and future urban development is located. The main study area can be described as the area bounded by the Lake View Branch Canal to the north and east and the catchment divide to the south and west.

2.1.1 Catchment Description

The Lake Wyangan catchment is an endorheic basin, having no natural drainage outlet. It includes the terminal lake and wetland storage areas of Lake Wyangan, Tharbogang Swamp, Nericon Swamp and Campbell's Swamp.

There are two main flood mechanisms that impact the study area. Local catchment runoff activates overland flood flow paths within the south-eastern portion of the catchment, within which most of the existing and future urban development is located. Short duration, high intensity rainfall is the critical driver for flooding experienced in this area, as occurred in March 1985.

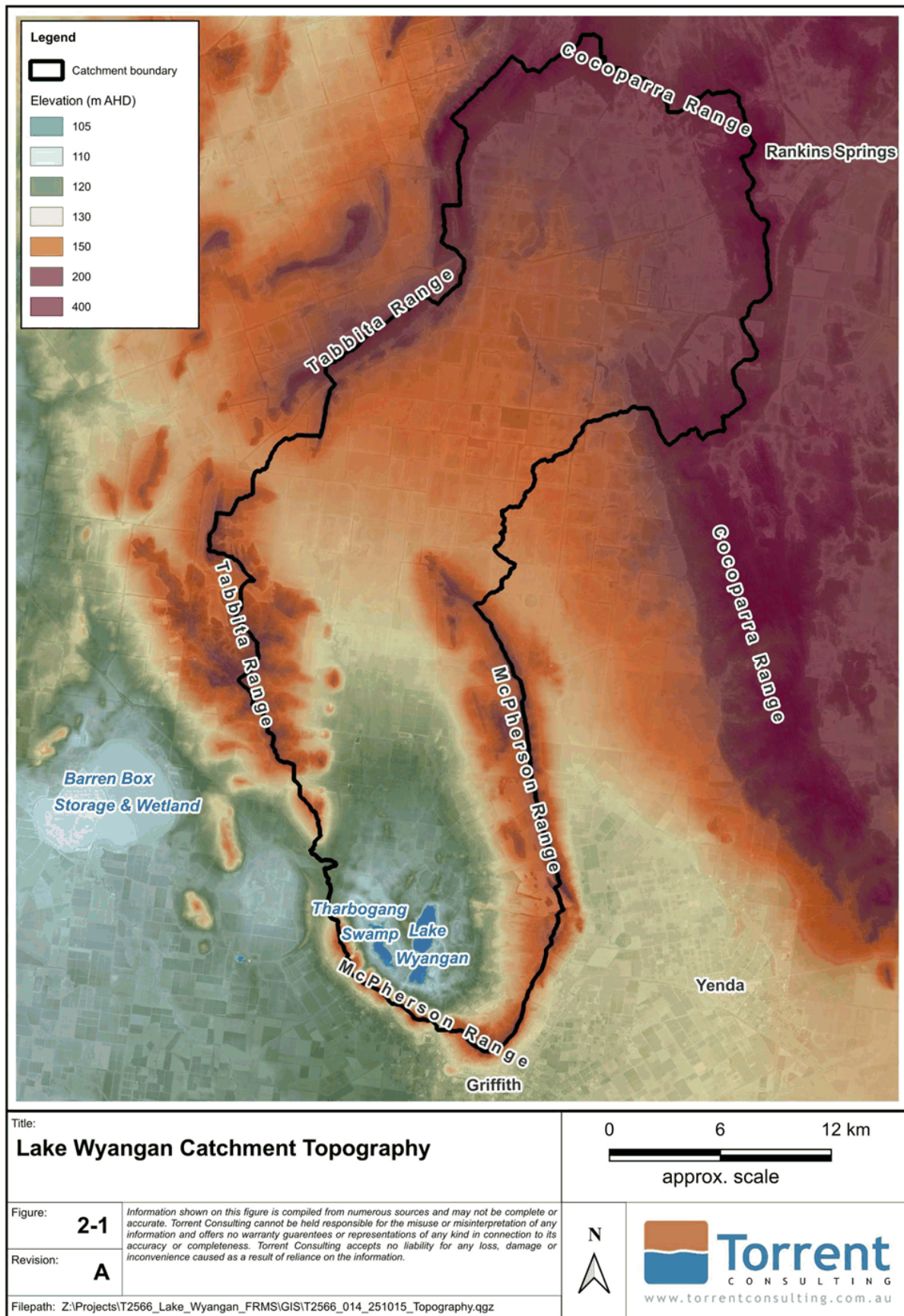
Elevated flood levels within the lake and wetland storages are more likely to occur in response to longer duration rainstorms, with heavy rainfall over a day or more, as occurred in March 2012. However, prolonged periods of wet weather with several smaller rainstorms can also combine to generate significant runoff volumes, as occurred in Sep-Oct 2016 and Oct-Nov 2022.

The catchment is mostly flat, with typical surface gradients of around 0.2%. However, the catchment boundary is often clearly defined by an elevated ridge of rock hills. The upper catchment area is fringed by high country that forms the northern limit of the Cocoparra Range, with the lower catchment being bound by the McPherson Range to the south and east and Tabbita Range to the west, as shown in Figure 2-1.

The catchment boundary between the northern end of the McPherson Range and the Cocoparra Range to the east is poorly defined, with potential for cross-catchment drainage. This area contains a few small terminal wetland catchments, located on the saddle between the Lake Wyangan catchment and the Myall Park catchment, which drains south towards Yenda. The Myall Park catchment is also a natural terminal system, but irrigation infrastructure now connects it to Main Drain J.

The catchment has been largely cleared of native vegetation, with remnants principally occurring along the ranges that form the catchment divide. However, there are some remnants on the valley floor, such as Pulletop Nature Reserve.

The catchment soils are naturally sandy, with a large capacity for rainfall and runoff infiltration. The local flood behaviour is therefore sensitive to changes in land use that increase the runoff potential.



2.2 Data Collection and Review

Upon commissioning, all relevant data and information for the catchment was obtained through Council and other relevant organisations (e.g. DCCEEW, Murrumbidgee Irrigation (MI), Bureau of Meteorology (BOM), etc.). The relevant data includes:

- LiDAR and photogrammetric survey datasets downloaded via the ELVIS Foundation Spatial Data Portal
- Weekly water level records for Lake Wyangan from December 2017 to September 2025
- Rainfall records from the BOM and Wunderground sites
- GIS information including cadastral boundaries, topography, watercourses, aerial photography, drainage networks, land zoning, vegetation communities, soil landscapes, etc.
- Relevant previous studies and planning documents, including the Lake Wyangan Flood Study (BMT 2012) and Lake Wyangan FRMSP (BMT 2013).

2.2.1 Review of Previous Studies

Despite there being an existing TUFLOW model developed for the previous studies undertaken by BMT, it is much more efficient to develop a new model from scratch for this review. The existing model required a 1D representation of the Lake View Branch Canal to separate and transition modelled runoff from a coarse upper catchment resolution (60 m) to a finer (10 m) resolution within the detailed study area. Subsequent developments in TUFLOW capabilities now enable multiple 2D model domains to seamlessly transition into one another (Quadtree functionality) and to capture detail beyond the resolution of the 2D model grid cell (sub-grid sampling). However, there are individual model layers that were transferred across to the new model for efficiency of model development.

For this study, a TUFLOW model was developed for the simulation of catchment flood hydrology using the direct rainfall method to represent the rainfall-runoff process. The hydrological model incorporates the approach developed by Torrent Consulting's research, as presented at the Hydrology and Water Resources Symposium 2023, which uses the full functionality of the TUFLOW soil infiltration routines to address the shortcomings of other simplified rainfall loss methods. The design flood hydrology is simulated in accordance with the ARR 2019 guidelines, which is an updated approach from that used in the previous studies.

A key limitation in model calibration and design flood estimation identified in the previous studies was the very small amount of effective rainfall, i.e. that which is converted to observed catchment runoff following infiltration losses. This made the modelled catchment runoff highly sensitive to the adopted initial and continuing loss parameters. This current study sought to reduce this uncertainty using a more sophisticated infiltration loss model and the additional calibration data available. However, the uncertainty associated with the limited available rainfall records and highly complex catchment hydrology has prevented a meaningful calibration of model parameters to match the observed catchment runoff conditions.

2.2.2 Historical Flood Events

Since the completion of the existing studies there have been two significant flood events in Sep-Oct 2016 and Oct-Nov 2022. Both events experienced prolonged periods of high monthly rainfall totals,

which is different to the other recent major flood event of March 2012, which was a single intense rainstorm. Catchment runoff and localised flooding was also experienced in January 2022.

The impacts of flooding within the catchment can be broadly classified into three categories:

- Short duration intense rainfall within the local catchment area draining to Lake Wyangan from the hillslopes to the east, creating overland flood flow paths within the Lake Wyangan suburban area, such as occurred in March 1985.
- Intense rainfall of a longer duration resulting in catchment runoff from the broader catchment draining to Tharbogang Swamp and the Lake View Drain, which becomes more likely during periods of prolonged wet weather. This causes overland flood flow inundation through properties located between Dickie Road and the Kubank Estate, which may last for an extended period of days, such as occurred in March 2012 and January 2022.
- When the above mechanism extends for a period of weeks then a significant volume of water is discharged to the terminal lake systems within the catchment, resulting in flooding of areas surrounding Lake Wyangan and Tharbogang Swamp, such as occurred in Oct-Nov 2022. Being a terminal system, output from the lakes is limited to evaporation losses plus any pumped extraction. The elevated water level in Lake Wyangan persisted well into 2023 following the Oct-Nov 2022 flood event.

To provide context to the relative catchment conditions experienced during the flood events, the BOM Australian Water Outlook (AWO) soil moisture data and daily rainfall records have been reviewed and are summarised in Figure 2-2, Figure 2-3 and Figure 2-4 for the years 2012, 2016 and 2022, respectively. The rainfall data represents an average of the two BOM daily rainfall gauges located within the catchment.

From comparison of Figure 2-3 and Figure 2-4 the November 2022 flood event does not appear as large as the September 2016 event. However, the November 2022 event resulted in the highest flood level on record in Lake Wyangan. This is likely a function of higher intensity of rainstorm that was experienced in 2022 than 2016, with the combination of wet antecedent catchment conditions and intense rainfall being required to initiate significant surface water runoff.

Satellite imagery indicates that some surface water flooding was generated sometime between mid-June and mid-July 2016, most likely associated with the ~50 mm rainstorm recorded in the 20 June daily rainfall record. However, the main flood event occurred prior to late-September, most likely associated with the ~45 mm rainstorm recorded in the 10 September daily rainfall record. Frequent but less intense rainstorms then occurred throughout the next 3-4 weeks, prolonging the flood event into early-to-mid October. The flooding principally impacted land holders between Dickie Road and Tharbogang Swamp, with the total volume of runoff being insufficient to result in adverse flooding in Lake Wyangan.

Figure 2-5 shows a still image from drone footage taken on 4 October 2016. It is from a location between Kubank Road and Lee Lane, looking north-west across fields newly prepared for future almond farming.

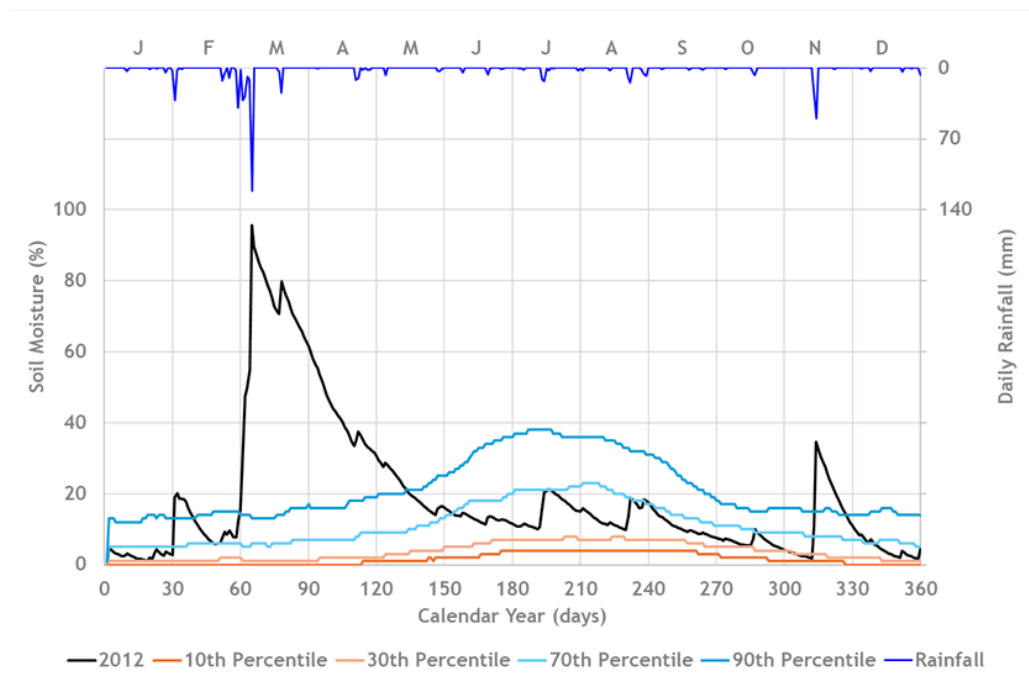


Figure 2-2 Catchment Rainfall and Soil Conditions for 2012

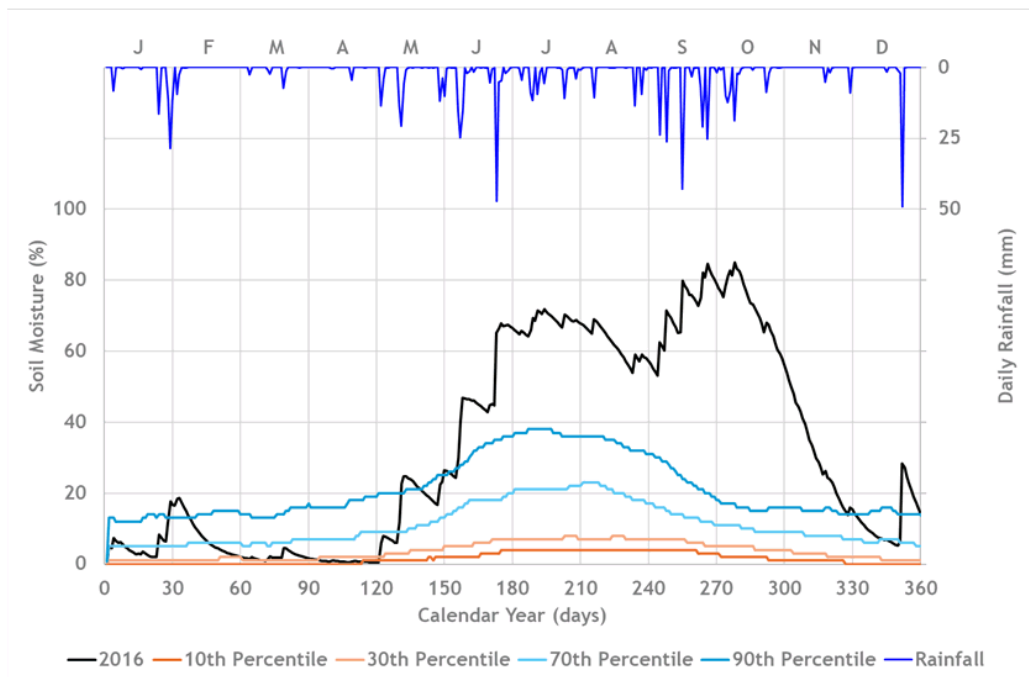


Figure 2-3 Catchment Rainfall and Soil Conditions for 2016

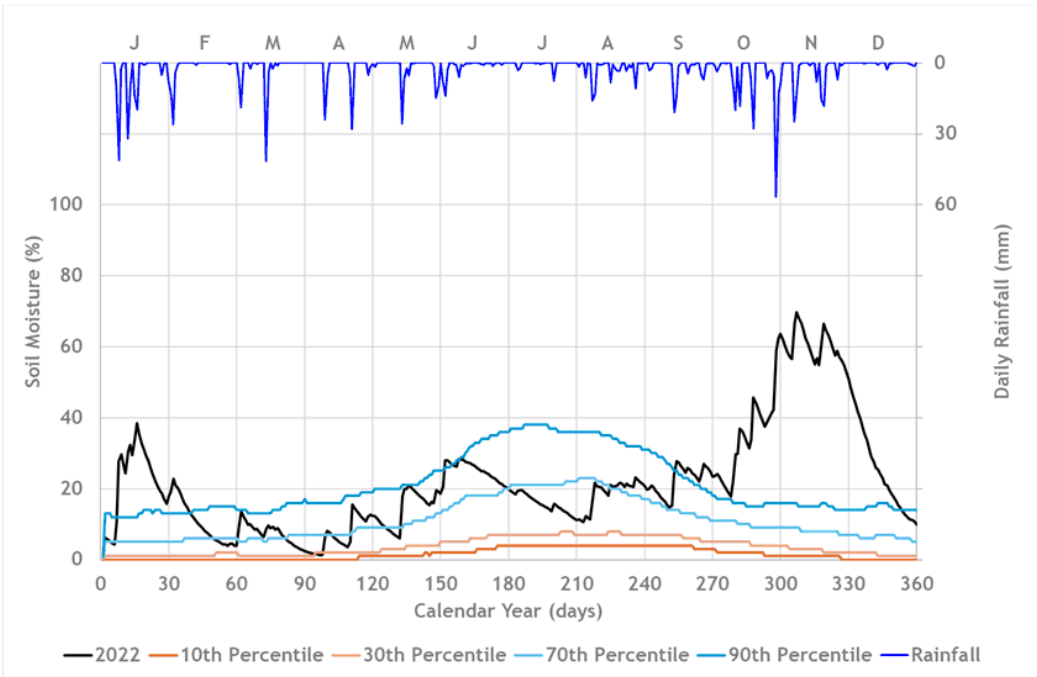


Figure 2-4 Catchment Rainfall and Soil Conditions for 2022



Figure 2-5 Surface Water Flooding near Lee Lane in October 2016

In 2022, satellite imagery shows some minor surface water flooding on 10 January, which further progresses on 12 January and 15 January but has receded by 4 February. Surface water runoff was likely initiated during the rainstorm associated with the ~50 mm recorded in the 6-7 January daily record. This was followed by a further two rainstorms of ~40 mm within the next week that will have further contributed to the flooding that was experienced. Again, the flooding principally impacted land holders between Dickie Road and Tharbogang Swamp, with the total volume of runoff being insufficient to result in adverse flooding in Lake Wyangan.

The main flood event in 2022 (and the largest recorded within Lake Wyangan) occurred during the spring. Satellite imagery shows that minor surface water flooding first occurred sometime between 4 September and 14 September, most likely associated with the ~35 mm rainstorm recorded in the 9-10 September daily record.

Further surface water flooding is evident in satellite imagery on 9 October and 17 October, with ~50 mm rainfall recorded 5-8 October, followed by ~35 mm rainfall 13-14 October. The main flood event occurred in late October, with over 100 mm rainfall recorded in a week, including a ~90 mm rainstorm 24-25 October. This late October rainfall initiated a response in Lake Wyangan, with the water level rising by around 1.6 m in the southern lake during November. The flooding was further contributed to by ~90 mm additional rainfall throughout November. The lake levels eventually returned to normal operating water levels around 12 months after the November 2022 flood event.

Figure 2-6 and Figure 2-7 show still images from drone footage taken on 25 October 2022. The former is looking north along Lake View Drain, from the point nearest to the intersection of West Road and Kubank Road. The latter is looking north-east along Zanotto Road in the Kubank Estate.



Figure 2-6 Flooding Along Lake View Drain in October 2022



Figure 2-7 Flooding Along Zanotto Road in October 2022

2.2.3 Rainfall and Water Level Records

During the undertaking of the existing studies the availability of water level records for Lake Wyangan was very limited. Since the completion of the existing studies, weekly level readings have been recorded for the north and south lakes of Lake Wyangan, beginning December 2017. Therefore, this data is only useful for the analysis and model calibration for the November 2022 flood event. During that event additional level readings were occasionally taken for Lake Wyangan and in Tharbogang Swamp. In conjunction with a stage-storage relationship for the lakes, this enables the volume of water entering the terminal waterbodies to be determined.

Figure 2-8 shows the recorded storage level data for Lake Wyangan and Tharbogang Swamp converted to a total volumetric increase in storage volume across the period of the November 2022 flood event. An indicative cumulative rainfall total is also shown for reference, derived from the two BOM daily rainfall gauges located within the catchment.

There is a scarcity of BOM rain gauge data available for the study area. This is demonstrated in Figure 2-9, which shows the spatial location of currently active BOM daily rainfall gauges. Pluviograph data is available for the Griffith Airport gauge. The only other BOM gauge within the catchment is located at "Acres" on Pulletop Road, Boorga, about mid-way up the catchment.

The Wunderground website has data available from a range of privately operated weather stations. There are four gauges on Wunderground that were operational in 2022 that provide potentially useful

additional data for the analysis and model calibration of the November 2022 flood event. The location of these gauges is also shown in Figure 2-9.

The coverage of rainfall gauge data for the November 2022 flood event is reasonable for the lower quarter of the catchment but there is only a single daily gauge representing the upper three quarters of the catchment. This creates a substantial level of uncertainty for model calibration to such a degree that no meaningful conclusions can be drawn from the model results as to their accuracy at representing the rainfall-runoff process for the catchment.

To address this shortcoming in data availability, an effort was made to source additional rainfall records from a network of 12 landholders across the upper catchment area. However, only a single dataset was obtained, which is near the BOM gauge, as shown in Figure 2-9.

Temporal rainfall (pluviograph) data is available from the BOM Griffith Airport gauge and the network of Wunderground gauges.

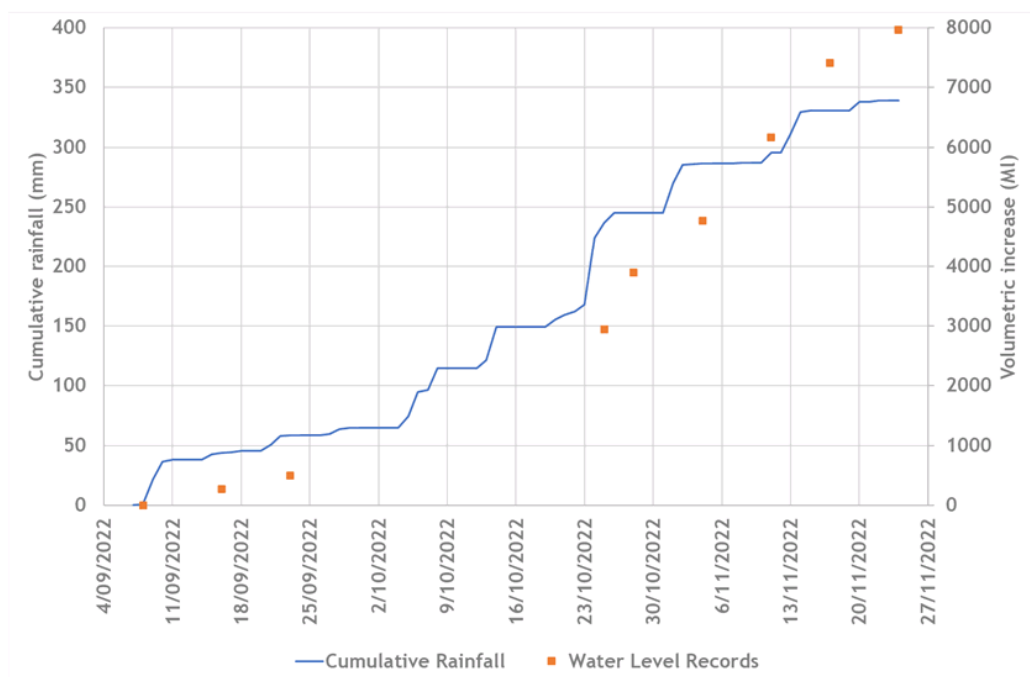
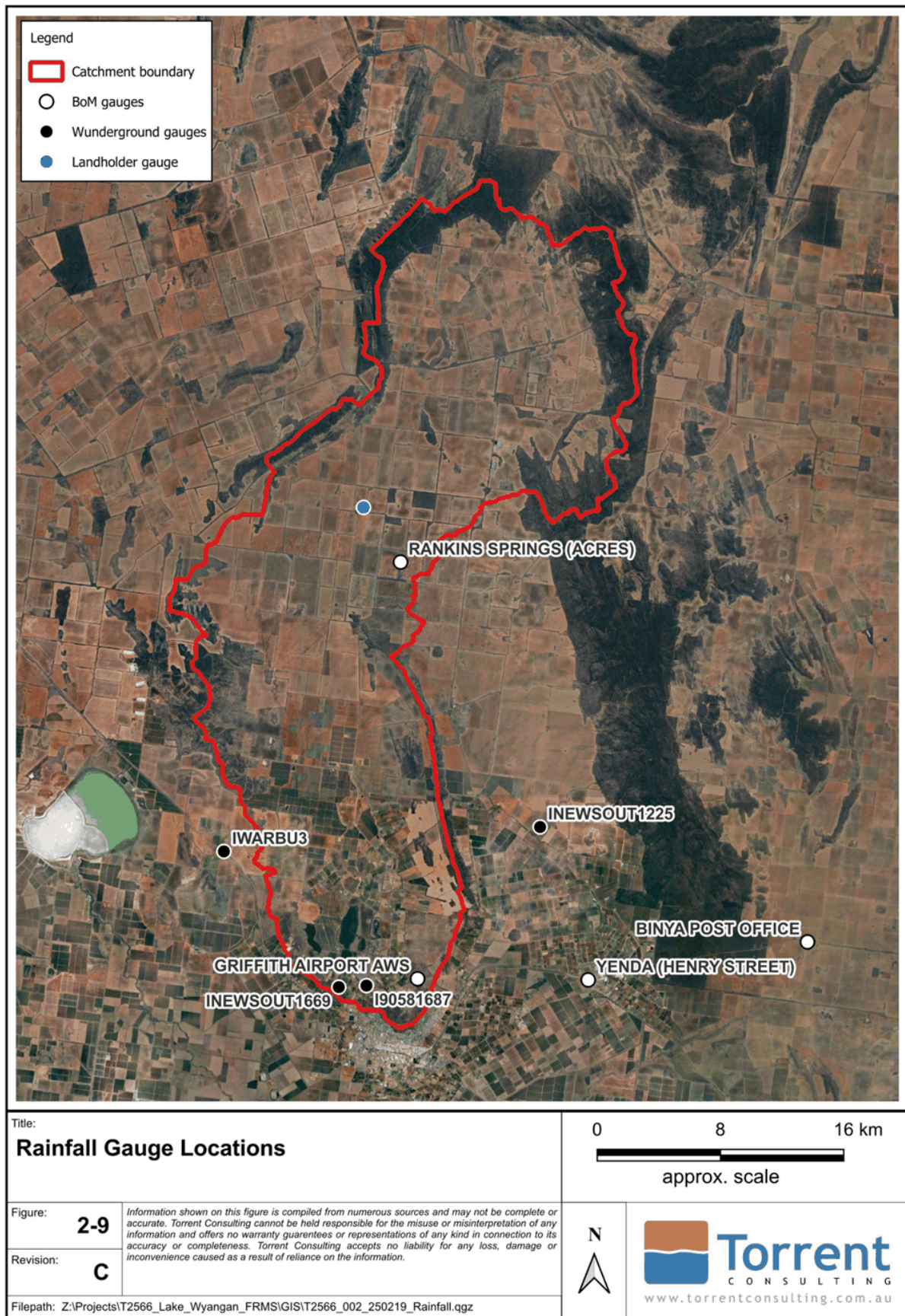


Figure 2-8 Cumulative Rainfall and Storage Volume Increase for Oct-Nov 2022 Flood Event

2.2.4 Soil Type and Moisture Data

At the time the modelling for the existing studies was undertaken, the whole-of-catchment direct rainfall simulation that was adopted was cutting-edge for such a large catchment. The method is necessary to represent the catchment hydrology given the dominance of runoff routing, transitional losses and complex flow paths.



There have been significant improvements in the capability of TUFLOW to represent catchment hydrological processes since the existing studies were completed. This includes the ability to better represent the physical soil characteristics of the catchment to derive infiltration losses and runoff volumes. Torrent Consulting has undertaken a research project developing a rainfall-runoff modelling method using this capability, which was presented in a technical paper at the Hydrology and Water Resources Symposium 2023.

The hydrological model structure also enables the impact of agricultural irrigation development to be readily assessed, through appropriate changes to local soil moisture conditions, which can even be varied seasonally, if required. This ability is not readily translatable to a lumped hydrological sub-catchment model or an initial and continuing loss model.

As well as the soil moisture data from the BOM AWO service discussed in Section 2.2.2, the TUFLOW hydrological simulation requires data indicating soil texture and depth across the catchment. An estimation of the soil texture can be derived from a NSW Government gridded dataset for the sand, silt and clay content at varying depths through the soil profile. A representative soil texture map for the catchment at soil depths of 0.1-0.3 m is shown in Figure 2-10.

A CSIRO gridded dataset is available estimating the spatial distribution of total soil (solum) depth. This indicates typical solum depths of 0.3-0.5 m throughout the range country of the upper catchment, around a 1.0 m solum depth through the mid-catchment area, and 1.8 m throughout much of the lower catchment.

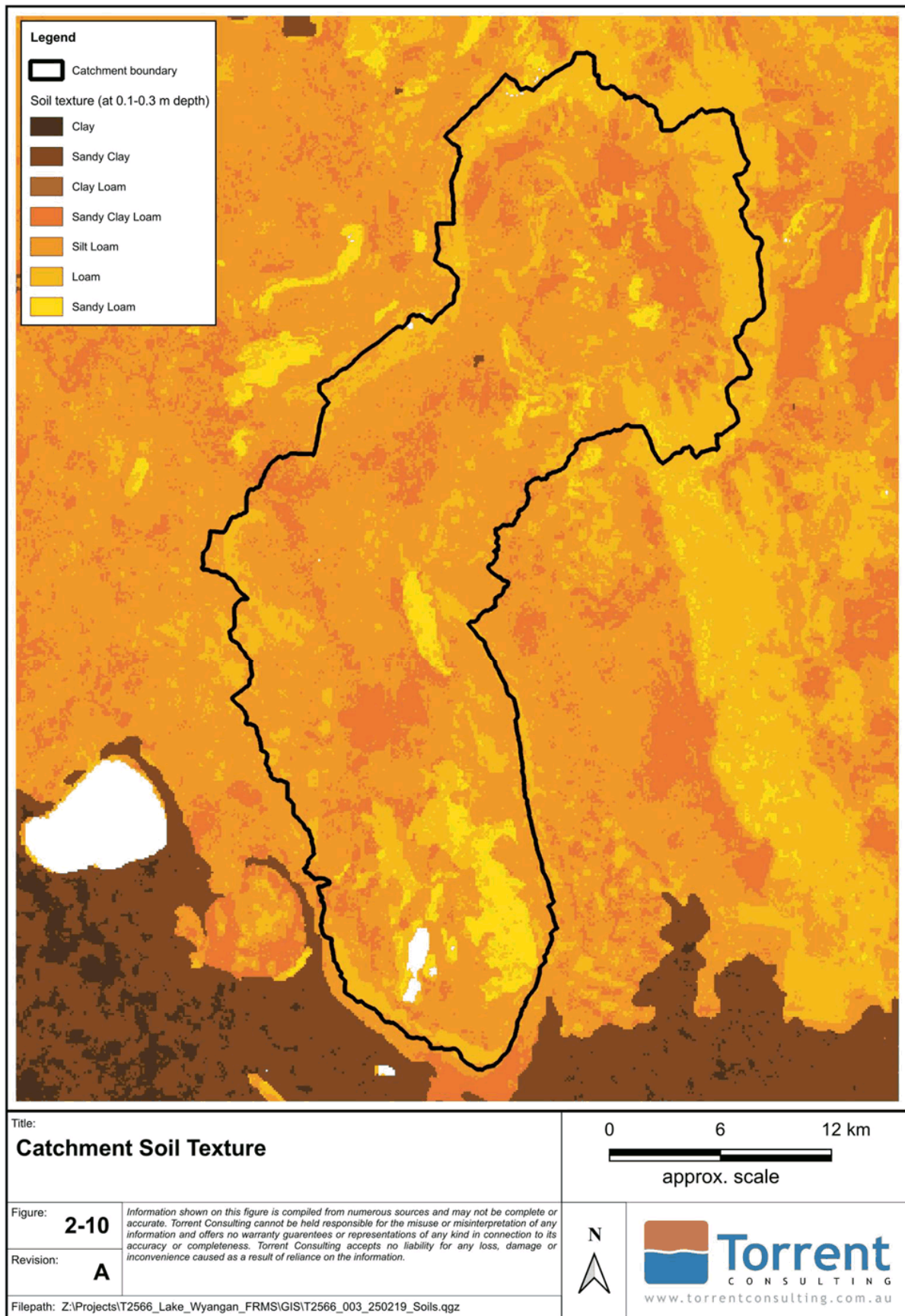
2.2.5 Topographic and Land Use Data

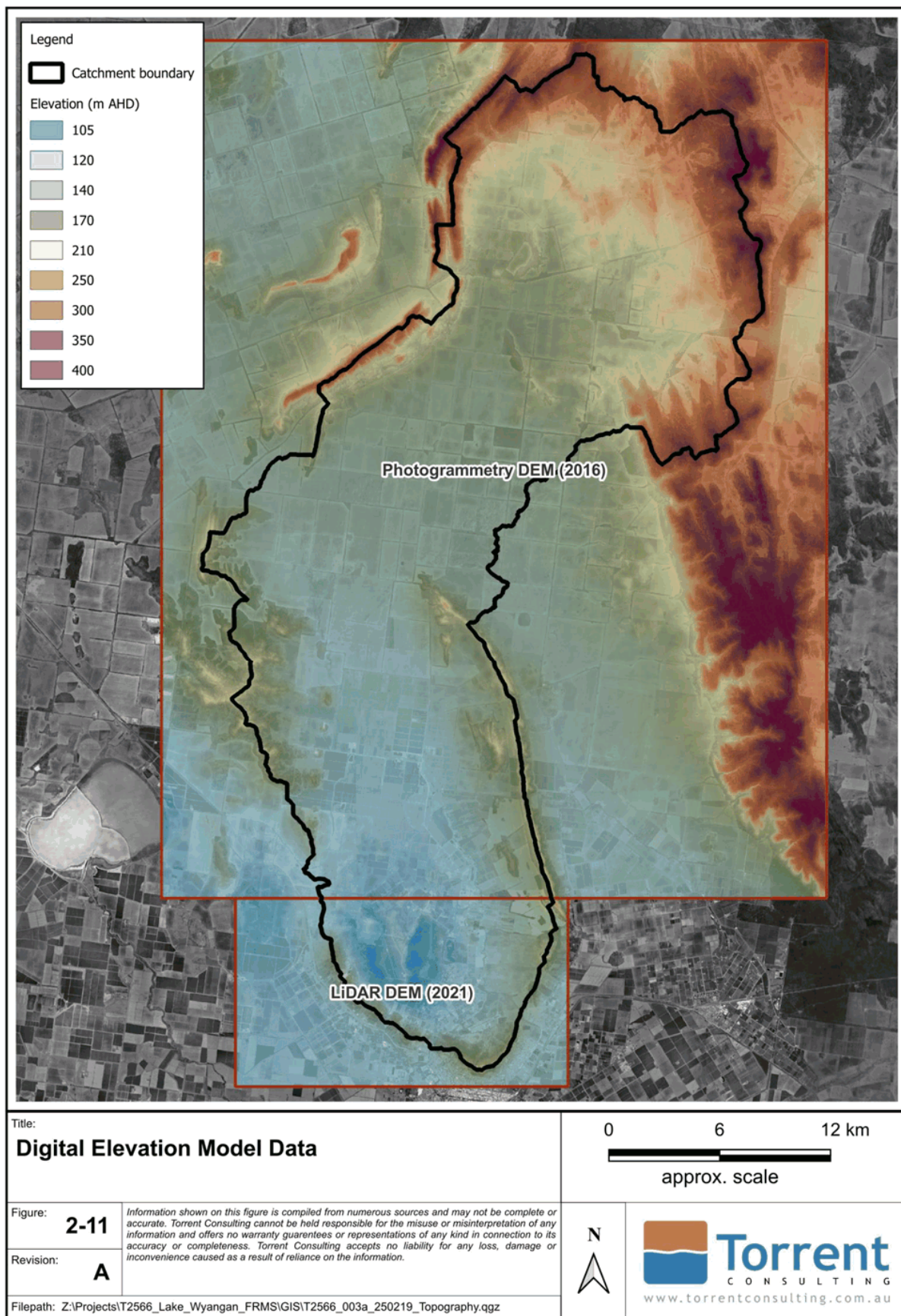
There are two key topographic survey datasets integral to the TUFLOW model development. The highest quality dataset providing full coverage of the catchment is the statewide 5 m grid resolution photogrammetric Digital Elevation Model (DEM), which is dated 2016 and was captured as part of the ADS40 aerial imagery survey. The southern 11% of the catchment area (south from approximately Nericon) is covered by a higher quality LiDAR DEM. It is dated 2021 and is available at a 1 m grid resolution. The DEM topography is presented in Figure 2-11, along with the extent of the corresponding source DEM.

Both the LiDAR and photogrammetric survey data are suitable for hydrological and rural flood modelling applications. Whilst the specified vertical accuracy of LiDAR is ± 0.3 m and the photogrammetry is ± 0.9 m, the typical apparent accuracies when using these datasets and comparing them to ground-based survey data are much better – more in the order of ± 0.1 m and ± 0.3 m, respectively.

These two aerial survey DEMs were filtered using a multi-directional lee method, which removes speckled noise inherent in aerially acquired survey whilst retaining hard edges of linear features such as channels and embankments.

MI provided a very high-quality photogrammetry derived DEM for use in the Griffith Main Drain J and Mirrool Creek Flood Study and have been contacted to obtain any terrain datasets that they might have in their possession for use in this study. MI has indicated a willingness to provide any such data, and it is understood that available data has been compiled and is pending approval to be issued.





2.2.6 Satellite Imagery

The use of satellite imagery proved invaluable in both the undertaking of the existing Lake Wyangan studies and the Mirrool Creek studies. For the September 2016 and November 2022 flood events there is Sentinel 2 satellite imagery available. The imagery is a higher resolution than the Landsat data used for the previous studies, being of around a 10 m grid rather than 30 m grid. It also has a higher frequency of repeat visits to each location, being around five days, rather than the 16 days of Landsat. This provides a high-quality data source from which to assess the surface water runoff condition from the catchment and the TUFLOW model in reflecting the observed runoff.

Sample Sentinel 2 images from the September 2016 and November 2022 flood events are shown in Figure 2-12 and Figure 2-13, respectively. The figures show false colour composites, projecting the Sentinel 2 spectral bands 11 (short wave infra-red), 5 and 8A (upper and lower limits of the vegetation red edge range) as red, green and blue, respectively. Surface water shows up as a dark inky blue colour, with faded areas of this colour identifying land that has recently experienced surface water flows. In each case, the selected images represent the maximum extent of flooding that was identified in the available satellite imagery.

The satellite images provide an excellent snapshot of the hydrological conditions across the catchment at the times for which they are available. As well as being an important source for model calibration of surface water flow paths, they are also a good indicator for when significant rainfall has not generated catchment runoff. Limitations in the use of satellite imagery for model calibration purposes include the intermittent capture dates, which may not represent the peak flood conditions experienced. This is further impacted by cloud cover, which reduces the period at which suitable images are available.

2.2.7 Data Gaps and Recommendations

The principal data gap is the lack of available rainfall data. The model calibration events typically exhibit a pronounced variance in rainfall recorded between the eastern and western sides of the catchment, which is likely the influence of both the MacPherson and Cocoparra Ranges. These significant topographic features are aligned north-south, with an effectively infinite expanse of flat land to the west and undulating topography of the western slopes of the Great Dividing Range to the east.

The interpolation of gridded rainfall data from BOM only has the single gauge at Boorga to inform what is precipitating within the catchment. The sensitivity of catchment runoff to threshold levels of soil moisture means that the soil parameters are a key factor in the hydrological modelling being able to reliably represent the expected catchment response to rainstorm events. With the current substantial uncertainty regarding observed rainfall records across the catchment, it is not possible to inform the modelled soil parameters with any meaningful certainty.

An effort was made to obtain additional rainfall data from landholders across the upper catchment area, although minimal additional data was ultimately available. However, through undertaking the model calibration process, it is apparent that the generation of surface water runoff (in both the real world and the modelling) is a complex function of both antecedent soil moisture conditions and rainfall intensity. Intense rainfall can produce surface water runoff which may then infiltrate into the soil later within its transition through the catchment.





Wetter preceding soil moisture conditions and the occurrence of subsequent rainfall events following the initiation of runoff both increase the probability of overland flood flow paths being maintained and reaching the lower catchment areas.

This highly complex catchment hydrological modelling cannot be calibrated without both a rich temporal and spatial availability of rainfall and soil moisture data. Lake level records at a daily or sub-daily (rather than the current weekly) interval would also be beneficial if improved model input data become available. However, none of these datasets are expected to exist in the near-term future. Whilst the modelling of local flood flow paths can be undertaken with a reasonable degree of certainty using standard design flood simulation approaches, the assessment of design flood levels in Lake Wyangan (and Tharbogang Swamp) require a higher level, first principles analysis.

3 Community Consultation

3.1 Consultation Plan

A consultation plan to engage with the community at various stages throughout the project duration is an important component of the study. The key elements of the community consultation plan were meeting with landowners affected by recent flood events of 2016 and 2022 and the formal public exhibition of the Draft Flood Study, which provides opportunity for review and submissions.

In addition to the broader community engagement, study progress at regular intervals is reported to the technical working group, including representatives from Griffith City Council and NSW DCCEEW.

A summary of the consultation elements undertaken since the study inception is provided below.

3.2 Community Consultation

Community consultation was undertaken through a meeting with local landholders from the Kubank Estate area that were affected by the 2016 and 2022 flood events, held on site on 9 August 2024. They were able to provide detailed information regarding the movement and extent of flood waters in the area, together with photographs and video footage.

The key issue raised by the landholders was that they perceive the expansion of almond farming north of Kubank Estate to have had an impact on surface water runoff through their land. The almond farming practices include significant channel diversion works and increased surface water runoff.

Another issue highlighted was that the levee created by the deposition of the excavated channel material along the western bank of Lake View Drain prevents the main overland flood flow path arriving from the north from entering the drain. This pushes more water through Kubank Estate and into Tharbogang Swamp. The landholders would like to see this water allowed to flow more freely into Lake View Drain.

Potential mitigation measures were also suggested by the landholders, including augmenting an existing drainage alignment that crosses Kubank Road on the bend around 3.9 km east of the Kidman Way. The potential for cutting a drainage channel through the catchment divide and divert water to Barren Box Storage and Wetland was also mentioned.

Contact was also made with landholders located further up the catchment, between Dickie Road and Rankins Springs. This was principally to acquire additional rainfall records, as the coverage of official gauges across that area is limited to a single daily-read gauge at Boorga. Unfortunately, only one additional set of rainfall data was able to be acquired, and this was close to the existing BOM gauge.

3.3 Site Inspection

A site reconnaissance of the study area and local catchment was undertaken in association with the Project Inception meeting. Whilst the Torrent Consulting team are highly familiar with the catchment, the site inspection provided the opportunity for a contemporary view of the study area and an appreciation of recent catchment modification or other local features influencing flooding behaviour. This included the expanded irrigated agriculture areas (e.g. around Dickie Road) and residential development areas.

Some of the key observations accounted for during the site inspection included:

Z:\Projects\T2566_Lake_Wyangan_FRMS\Docs\R.T2566.001.04.docx



- Topographic features and hydraulic controls (e.g. current condition of embankments, hydraulic structures, culverts, bridges, drains, etc).
- Floodplain and waterway characteristics (vegetation growth and types, channel roughness, etc).
- Confirmation of structure locations, type and configuration.
- Extent of new development and changes to large scale farming practices.

3.4 Public Exhibition

To be completed following Public Exhibition

4 Model Development

4.1 Modelling Approach

The nature of catchment flood hydrology is better suited to the adoption of hydraulic simulation than traditional lumped catchment hydrological modelling, for reasons including:

- The lack of a natural watercourse within the catchment, with runoff conveyed in a series of braided overland flood flow paths
- The shallow catchment gradient and shallow depth of flood flow paths results in a significant attenuation of the flood wave propagation
- The sandy soils and long lag time for upper catchment runoff to reach the lower catchment result in transitional infiltration losses.

The advantages of using TUFLOW as a hydrological modelling tool were identified during the original Lake Wyangan Flood Study (BMT WBM, 2012) and this method has been retained for this current study update. There have been significant improvements in the capability of TUFLOW to represent catchment hydrological processes since the previous studies were completed. This includes the ability to better represent the physical soil characteristics of the catchment to derive infiltration losses and runoff volumes.

The adopted hydrological modelling uses a method developed by Torrent Consulting, which was presented in a technical paper at the Hydrology and Water Resources Symposium 2023. This represents the soil profile as three separate layers at depths of 0.0-0.1 m, 0.1-0.3 m and >0.3 m. The total soil depth is derived from a CSIRO gridded dataset and soil texture properties from a NSW Government gridded dataset.

The Green-Ampt infiltration routine is used in TUFLOW, with soil water holding capacity attributes taken from the MEDLI guidelines and soil moisture data for both event-specific (calibration) and long-term probabilistic (design) conditions from the BOM AWO. The hydrological model structure also enables the potential for the impact of agricultural irrigation development to be quantified, through appropriate changes to local soil moisture and runoff conditions.

Three TUFLOW models were developed to simulate flood behaviour within the study catchment:

- A hydrological model to simulate rainfall-runoff contributing to flooding in the terminal storages of Lake Wyangan and Tharbogang Swamp. This includes the main overland flow path within the catchment, which impacts the Kubank Estate. The details for key hydraulic controls were also represented in the model, as they impact the flood hydrology. The model development is discussed in further detail in Section 4.2.
- A hydrological model to simulate rainfall-runoff of the local catchment areas in the south-eastern area of the catchment, which have a much shorter critical duration than the broader catchment. The model development is discussed in further detail in Section 4.2.4.
- A detailed hydraulic model to simulate the main overland flood flow paths within the south-eastern area of the catchment, where most of the existing and future urban development is located. Details of local drainage channels and hydraulic structures were represented, with inflows being sourced from the local catchment hydrological model. The model development is discussed in further detail in Section 4.4.

4.2 Lake Wyangan / Tharbogang Swamp Catchment Model

The Lake Wyangan / Tharbogang Swamp TUFLOW model is principally a hydrological model, developed to simulate the rainfall-runoff process of the study catchment. However, it also includes details of some key hydraulic controls that impact the flood hydrology, such as Lake View Drain and cross-drainage structures under the Lake View Branch Canal. The model is also suitable for the mapping of the main catchment flood flow path, which impacts the Kubank Estate and flows into Tharbogang Swamp. The model is also used for the derivation of design flood levels in Lake Wyangan and Tharbogang Swamp that result from a single event-driven flood response.

4.2.1 Model Extent and Topography

The Lake Wyangan / Tharbogang Swamp TUFLOW model covers around 890 km² of potentially contributing catchment area. This includes some 120 km² of residual catchment area located between the Lake Wyangan / Tharbogang Swamp and Myall Park catchments, as shown in Figure 4-1. The residual catchment area is flat and drains to some small terminal ephemeral wetlands. It is included in the model to ensure that any potential cross-catchment flows are represented.

When discussing the flood hydrology, it is useful to refer to the sub-catchments identified in Figure 4-1. The North Lake Wyangan and South Lake Wyangan catchments drain to the respective halves of the Lake Wyangan waterbody. There are also two smaller terminal catchments located between these that drain to Nericon Swamp and Campbell's Swamp. The remainder (majority) of the catchment naturally drains to Tharbogang Swamp. However, part of the catchment is diverted through the Wyangan / Tharbogang catchment divide into North Lake Wyangan. The main overland flow path for runoff from the Upper and Central catchment areas is bisected by the Lake View Branch Canal, with siphon structures to facilitate cross-drainage.

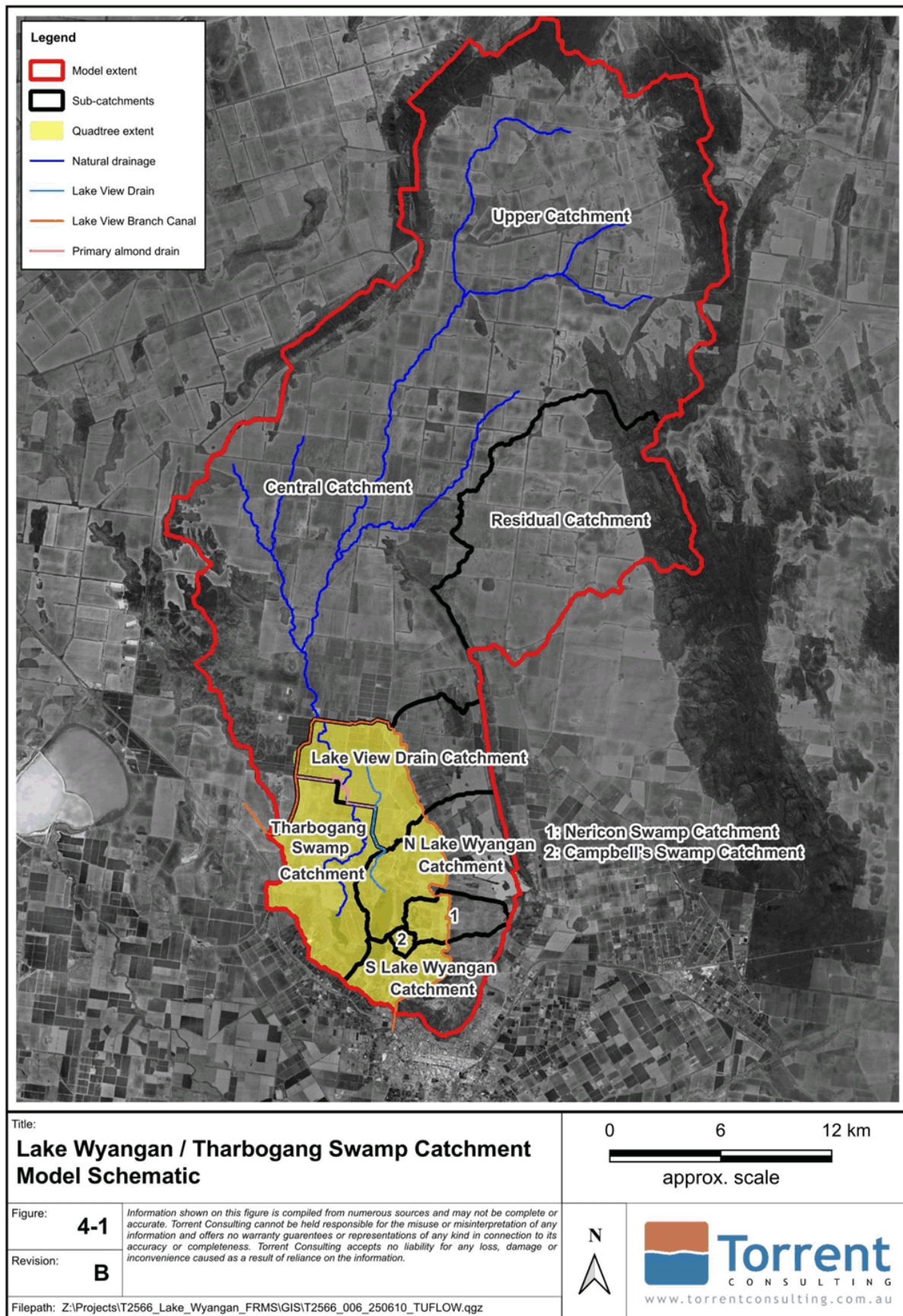
Once having crossed the Lake View Branch Canal, the main overland flow path then naturally drains to Tharbogang Swamp. However, the construction of Lake View Drain (for return flows associated with irrigation offtakes from the Lake View Branch Canal) can divert a portion of overland flow across the catchment divide and into Lake Wyangan. Further, the recent expansion in irrigation agriculture in the Dickie Road area has further modified the natural drainage and will now direct additional surface flows east to the Lake View Drain.

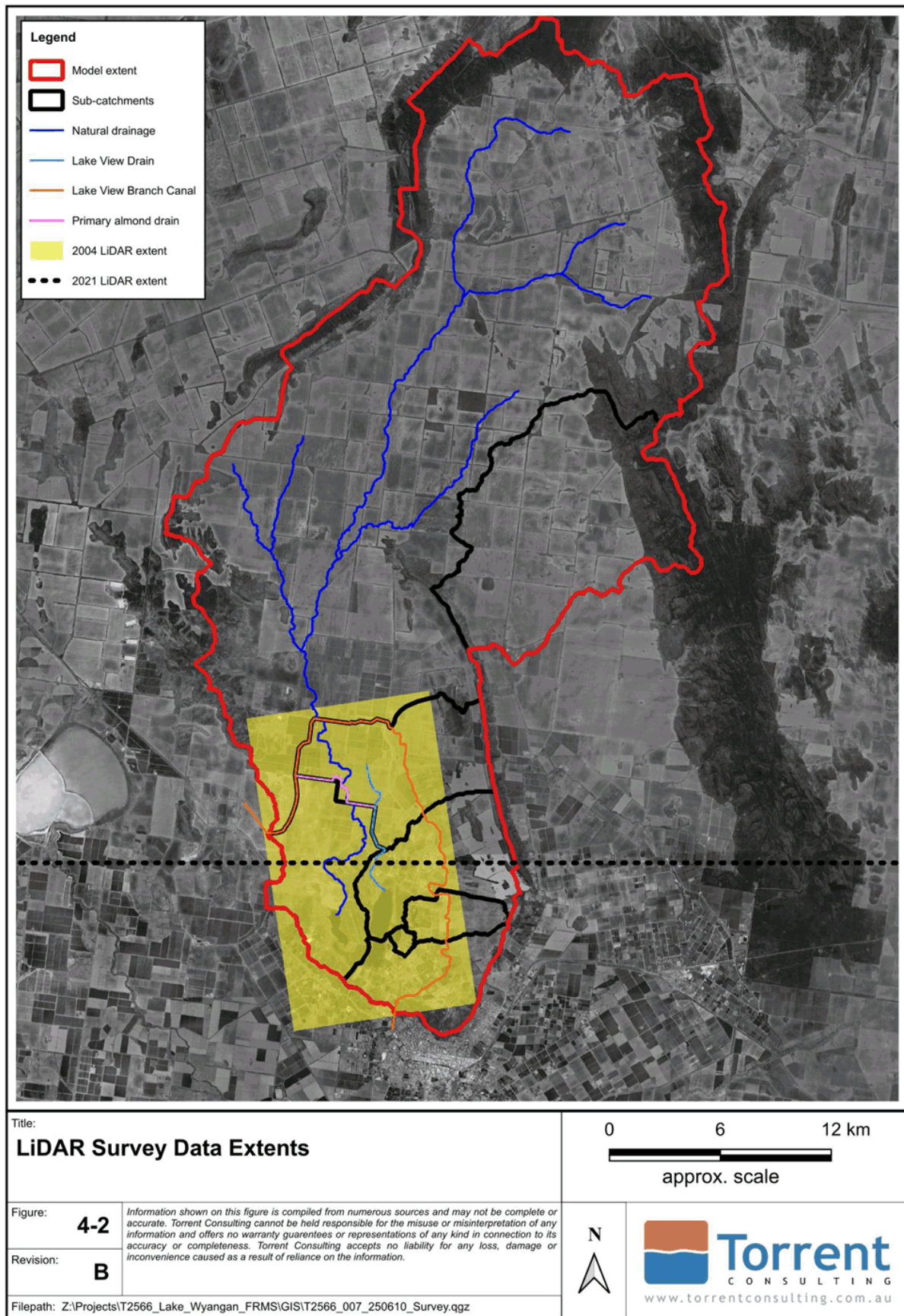
The model is constructed using a 200 m horizontal grid cell resolution, with the Quadtree functionality of TUFLOW employed to provide a finer resolution of 25 m within the area bounded by the Lake View Branch Canal, as shown in Figure 4-1.

The model utilises the statewide photogrammetric survey dataset, for which the coverage is largely dated 2016-17. The dataset is a gridded Digital Elevation Model (DEM) with a 5 m horizontal cell resolution. Whilst not as accurate as LiDAR survey, it provides a good quality dataset for hydrological purposes.

There is an NSW Spatial Services 2021 LiDAR survey dataset for Griffith accessible through the ELVIS Foundation Spatial Data portal. It is available as a 1 m horizontal resolution DEM and extends south from the 6216000 northing (GDA 2020 MGA Zone 55), as shown in Figure 4-2. Spatial layers from Figure 4-1 are retained in Figure 4-2 for context.

There is also a 2004 LiDAR survey dataset available as a 5 m horizontal resolution DEM from the TUFLOW model developed for the 2012 Lake Wyangan Flood Study. However, it is apparent that the quality of filtering is not comparable to the modern LiDAR datasets and so the photogrammetric





data is preferred. Nevertheless, it is useful in providing a representative ground surface prior to the extensive agricultural expansion in the Dickie Road area, which predates the photogrammetry.

The sub-grid sampling (SGS) routine in TUFLOW has been implemented to utilise the full detail of the underlying DEM data within the coarser model grid cell geometry.

Design and work as executed (WAE) survey drawings for recent (2021) surfacing works and upgrades to Boorga Road, Dickie Road and Jones Road were provided by Council, the details of which have been incorporated within the TUFLOW model, including crest levels, table drains, and cross-drainage.

4.2.2 Drainage Infrastructure

The principal drainage infrastructure asset in the Lake Wyangan / Tharbogang Swamp catchment is the Lake View Drain, the purpose of which is to take returned irrigation water from the Dickie Road area and drain it into North Lake Wyangan. Because of the functional importance of Lake View Drain to the catchment flood hydrology, it has been implemented as a 1D representation in the TUFLOW model, dynamically linked to the 2D domain. This ensures that any cross-catchment flow transfer is represented as accurately as possible. The primary drainage channel servicing the extensive almond growing area south of Dickie Road was also provided a 1D representation, as it diverts overland flows from the natural drainage alignment into Lake View Drain.

Details of cross-drainage structures were brought across from the TUFLOW model developed for the original Lake Wyangan Flood Study and were incorporated into the model developed for this study update. Most of these structures provide local catchment cross-drainage under the Lake View Branch Canal. Where possible, the details of these structures were verified through site inspection and additional structures were added, where required. The location of the modelled cross-drainage structures used in the Lake Wyangan / Tharbogang Swamp model is shown in Figure 4-3.

For the Lake Wyangan / Tharbogang Swamp model, minor cross-drainage structures and drainage channels throughout the area surrounding Lake Wyangan have not been incorporated as they are far too numerous, unnecessarily complicated and of little benefit to warrant a detailed representation. Sub-grid-sampling of the underlying 1 m LiDAR survey dataset provides a suitable representation for capturing the drainage alignments to ensure runoff is conveyed to the downstream storages.

4.2.3 Hydraulic Roughness

When simulating the catchment-wide rainfall-runoff process in TUFLOW as a hydrological model, the adopted hydraulic roughness values play a key role in accurately modelling the catchment response. One of the key outcomes of the research undertaken for the Hydrology and Water Resources Symposium paper was that the application of the Log Law depth varying bed resistance produced a much-improved calibration to observed data than standard fixed values. This method applies a very high roughness at shallow depths, which then reduces to standard roughness values once the depths are more representative of major flow paths rather than sheet flow.

The catchment was split into areas of cleared and forested land, with Manning's 'n' values of 0.06 and 0.12 adopted, respectively. Water bodies and urban areas were also identified, with 'n' values of 0.02 and 0.05 being adopted.



4.2.4 Rainfall Losses

Rainfall losses were modelled using the Green-Ampt infiltration method, with a three-layer soil model comprising a 0.1 m deep topsoil, 0.2 m transition zone and a variable depth subsoil layer. The depth of the subsoil layer was derived from the September 2019 CSIRO gridded soil depth mapping dataset.

Soil types for each layer were derived from the September 2022 NSW DPE gridded soil properties mapping dataset, with classification based on the clay, silt, and sand content. The available water holding capacity for each soil type was based on the MEDLI guidelines. Initial Soil Moisture (ISM) was calculated from data sourced from the Australian Water Outlook website published by BOM. The standard Green-Ampt parameters for suction and hydraulic conductivity were adopted.

Impervious areas were applied to the different land uses, with cleared/maintained and vegetated areas nominated at 100% pervious, water bodies at 100% impervious and urban areas at 40% impervious, with the Green-Ampt losses interpolated accordingly.

The Green-Ampt method effectively implements a continuous loss rate that diminishes as the soil begins to wet, approaching the specified saturated hydraulic conductivity. This better represents natural systems, with a loss decay curve rather than absolute values for initial and continuing loss rates. Whilst in heavy clay catchment the transition between the apparent initial and continuing loss can be reasonably approximated through the application of simple initial and continuing loss values, this transition occurs over a much longer period in sandy soils.

The BOM AWO data is representative of natural catchment systems, with drier conditions that persist across the irrigated agricultural and urban areas of the catchment. Therefore, initial soil moisture conditions were set to field capacity within these areas, to better represent the expected antecedent conditions.

Areas of irrigated agriculture used for almond farming were also assigned an impervious surface coverage of 60%. This is representative of the highly compacted surface between rows of trees, which is required for the efficient harvesting of almond crops. Urban areas were nominated at 40% impervious within the model, with the Green-Ampt losses reduced accordingly.

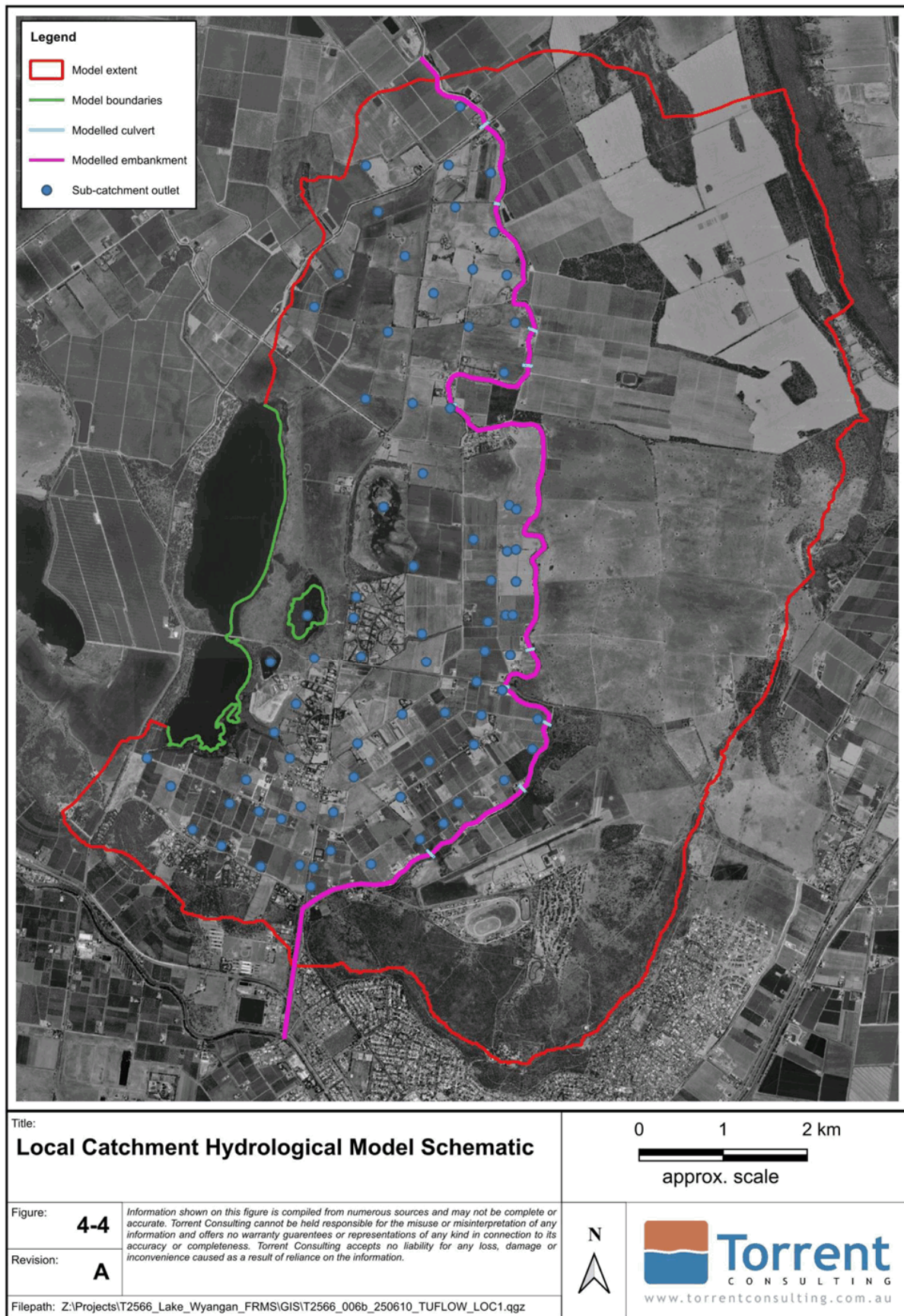
The soil infiltration occurs dynamically during the TUFLOW model simulation rather than directly to the input rainfall and therefore represents transitional losses.

4.3 Local Catchment Hydrological Model

4.3.1 Model Extent and Topography

The local catchment TUFLOW hydrological model covers an area of around 70 km² and includes the North and South Lake Wyangan catchments, and the Nericon Swamp and Campbell's Swamp catchments, as presented in Figure Figure 4-4. The local catchment hydrological model extends from the ridgeline of the McPherson Range to the south and east, and to the natural divide of the Lake Wyangan and Tharbogang Swamp catchments to the north and west.

The local model utilises the photogrammetric survey and the NSW Spatial Services 2021 LiDAR survey datasets used in the Lake Wyangan / Tharbogang Swamp model. The LiDAR data was pre-processed using GIS-based terrain analysis techniques to remove sinks within the grid and create a hydrologically corrected DEM. This prevents the initial loss of catchment rainfall to artificial storages.



This was not undertaken for the Lake Wyangan / Tharbogang Swamp model, as natural depressions are a key characteristic of the catchment flood hydrology.

The Lake View Branch Canal formation is a major hydraulic obstruction to runoff draining the hillslopes to the east of Lake Wyangan and Nericon. Therefore, the Lake View Branch Canal embankments were enforced, and cross-drainage structures were included in the local hydrological model. This also ensures that the sink removal treatment of the DEM does not result in an overestimation of the discharge across Lake View Branch Canal when extracting flows for input to the hydraulic model.

To the west of Lake View Branch Canal, a series of interconnected drainage channels convey floodwater through the residential and semi-rural areas, downstream to the terminal lake and wetland storages.

The model was constructed using a 10 m horizontal grid cell resolution, with the sub-grid sampling (SGS) routine in TUFLOW implemented to utilise the full detail of the underlying DEM data within the model grid cell geometry.

4.3.2 Drainage Infrastructure

As for the Lake Wyangan / Tharbogang Swamp model, cross drainage structures under the Lake View Branch Canal were represented within the hydrological model as 1D elements dynamically linked to the 2D domain, as shown in Figure 4-3 and Figure 4-4.

4.3.3 Hydraulic Roughness

The hydraulic roughness parameters adopted for the local catchment model are consistent with the Lake Wyangan / Tharbogang Swamp model, as described in Section 4.2.3.

4.3.4 Rainfall Losses

The soil infiltration and impervious surface coverages adopted for the local catchment model are consistent with the Lake Wyangan / Tharbogang Swamp model, as described in Section 4.2.4.

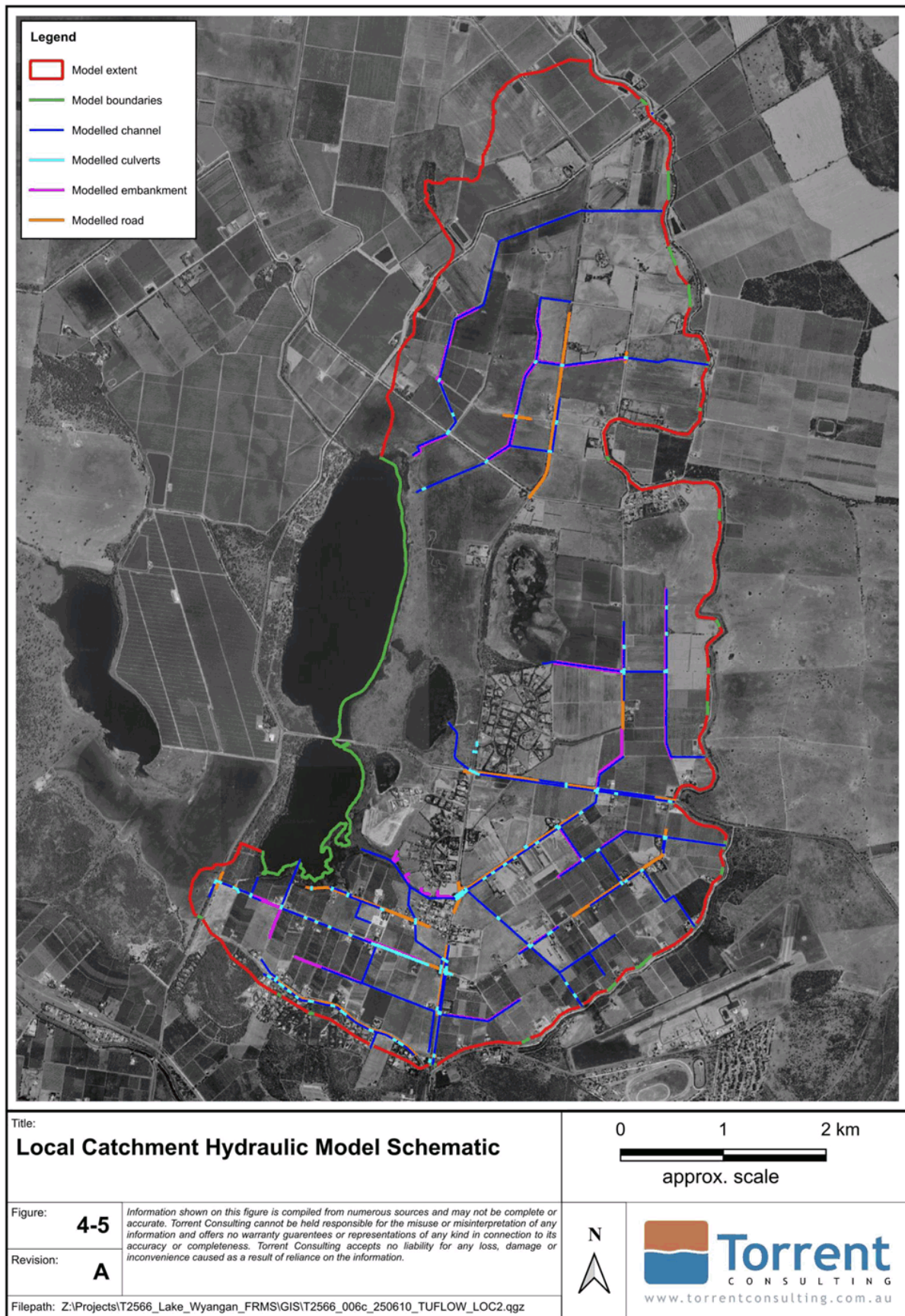
4.3.5 Hydrograph Extraction

The flows simulated by the rainfall-runoff process of the TUFLOW hydrological model were extracted at major drainage alignments downstream of Lake View Branch Canal and Mallinsons Road, with 57 sub-catchment locations identified for input to the hydraulic model, as shown in Figure 4-4. The hydrological model was configured to enable extraction of local sub-catchment flows independently of the combined total flows, as is typically undertaken in traditional lumped catchment hydrological models.

4.4 Local Catchment Hydraulic Model

4.4.1 Model Extent and Topography

The TUFLOW hydraulic model covers an area of some 28 km², including the residential and semi-rural localities bordered by Lake Wyangan, Lake View Branch Canal, and Mallinsons Road, as presented in Figure 4-5.



The model was constructed using a 4 m horizontal grid cell resolution, with the sub-grid sampling (SGS) routine in TUFLOW implemented to utilise the full detail of the underlying DEM data within the model grid cell geometry.

The local field drainage network was enforced using a Z Shape representation, providing flow continuity along the drain alignments. Road crests and other raised embankment features were also enforced using a similar methodology. The alignment of these drains and embankments is shown in Figure 4-5.

A drainage design has been developed by Griffith City Council to support the expected increase in catchment runoff associated with future residential subdivision within Lake Wyangan. The details of this drainage design for which works are imminently due to be undertaken were incorporated into the TUFLOW hydraulic model for the simulation of the design flood conditions. Additional drainage upgrade works to support future population growth are assessed in the FRMS.

4.4.2 Drainage Infrastructure

As discussed in Section 4.4.1, existing linear drainage channels and future upgrade works are represented in the 2D model domain, through modification of the model geometry. There are numerous cross-drainage structures located along the local drainage network, where the alignment crosses road corridors and driveway accesses, as shown in Figure 4-5. These were represented as 1D elements dynamically linked to the 2D domain. The limited data was used for these structures where available, however, the sizes of most were confirmed through site inspection and reasonable assumptions as to typical pipe sizes, with invert levels being estimated from the LiDAR data.

4.4.2.1 Structure Blockage

Australian Rainfall and Runoff Guidebook Version 4.2 (ARR) recommends applying blockage to hydraulic structures and outlines a methodology to determine inlet blockage factors through consideration of debris availability, debris mobility, debris transportability and waterway opening of the structure.

The ARR guideline provides an assessment procedure for estimation of the design blockage condition. The guideline considers the characteristics of the debris source area to assess the potential for debris blockage at the structure.

This process determined a low debris potential, with an L10 width of 1.5 m being adopted. The structure blockage percentage applied in the modelled blockage scenario, based on the width of clear structure openings, is shown in Table 4-1. These values were adopted for the simulation of design flood event conditions.

Table 4-1 Modelled Hydraulic Structure Blockage

Inlet Width	Adopted L ₁₀	Blockage
$W < L_{10}$	$W < 1.5 \text{ m}$	25%
$L_{10} < W < 3 * L_{10}$	$1.5 \text{ m} < W < 4.5 \text{ m}$	0%
$W > 3 * L_{10}$	$W > 4.5 \text{ m}$	0%

4.4.3 Hydraulic Roughness

In the TUFLOW hydraulic model, the hydraulic roughness was consistent with that adopted for the hydrological model, with an additional roughness value represented along the drainage channel network. A value of 0.035 was adopted, which is a typical value for engineered channels with no in-channel obstructions and minor vegetative growth.

5 Model Calibration and Validation

Model calibration is limited to the Lake Wyangan / Tharbogang Swamp catchment model, as there is insufficient data available for calibration of the local catchment models. However, there is some limited data to enable validation of the local catchment models for the March 1985 event.

5.1 Selection of Calibration and Validation Events

The original Lake Wyangan Flood Study considered the March 1985, March 1989 and December 2007 events for model calibration. The March 2012 event occurred shortly after completion of the study and so it was investigated as part of the Lake Wyangan Floodplain Risk Management Study. Since the previous studies there have been additional events in Sep-Oct 2016 and Oct-Nov 2022, the latter of which produced the highest recorded flood level in Lake Wyangan. These events have all been considered in the context of this current study update.

The model calibration process for the original Lake Wyangan Flood Study found modelling the catchment flood hydrology to be extremely challenging, for reasons including:

- A general paucity of data including both rainfall and water level records
- The substantial apparent soil losses exhibited by previous flood events
- The sensitivity of modelled runoff volume to small changes in effective rainfall
- Cross-catchment flow transfer via the Lake View Drain.

It was hoped that in undertaking this study update, advances in hydrological modelling capability and data for the recent record event in Oct-Nov 2022 would serve to enable an improvement in model calibration and reduce the associated uncertainty in simulating catchment runoff. Unfortunately, this was not possible, as the paucity of data and substantial uncertainty in the spatial and temporal distribution of rainfall is still insufficient to calibrate the complex hydrological processes. Nevertheless, the model calibration process does provide some insights into further understanding of this terminal lake system and the inherent uncertainties, which are discussed in this section.

The March 2012 flood is the largest single rainstorm event recorded in the region. It has been used to validate the hydrological modelling of the event-driven rainfall runoff process, as detailed in Section 5.2. The Oct-Nov 2022 event has the largest observed response in Lake Wyangan flood level and is also the only event for which accurate flood level records are available. Information regarding flood levels reached within the lake storages for events prior to this is limited to estimates from satellite imagery, where available.

As discussed in Section 2.2.2, the Oct-Nov 2022 event is a series of rainstorms that combine with wet antecedent soil moisture conditions to generate the observed runoff volume, although the principal initiation of flooding relates to a ~90 mm rainstorm on 24-25 October. Representation of this event is beyond the capabilities of rainfall-runoff model simulation and so quantitative investigation of the event is limited to a water balance analysis, as detailed in Section 5.3.

The March 1985 event is a highly localised and intense rainstorm over the south-east hillslopes draining to Lake Wyangan. It is useful for model validation of local catchment rainfall-runoff conditions, as detailed in Section 5.4.

Sentinel 2 satellite imagery from both the Sep-Oct 2016 and Oct-Nov 2022 events is also used for visual validation purposes for the modelled overland flow paths, as detailed in Section 5.5.

5.2 March 2012 Event

The March 2012 event is the largest to impact the broader region in recent recorded history. The half-hourly rainfall record from Griffith Airport indicates a 24-hour duration event, which began on the morning of 3 March and during which 143 mm was recorded, as shown in Figure 5-1. This exceeds a 1-in-200 AEP event when compared to the BOM IFD data.

The Griffith Airport record represents the only available temporal data, with other data being limited to daily read gauges. The combined daily records for 3 March and 4 March from BOM gauges provide a good estimate as to the variability in spatial rainfall for the event. One additional set of private rainfall records has also been sourced from the central catchment area, as shown in Figure 5-2.

The rainfall totals in Figure 5-2 are a few millimetres higher than the event total, as there is a small amount of rainfall recorded outside of the 24-hour period of the main storm event. The paucity of data from the broader Rankins Springs area is evident, with only a single gauge located at Naradhan (which has subsequently closed). There is uncertainty regarding the total rainfall depth over the upper catchment, but it is expected to be between around 110 mm to 120 mm. The central to lower catchment area likely received a total rainfall of between around 130 mm to 145 mm.

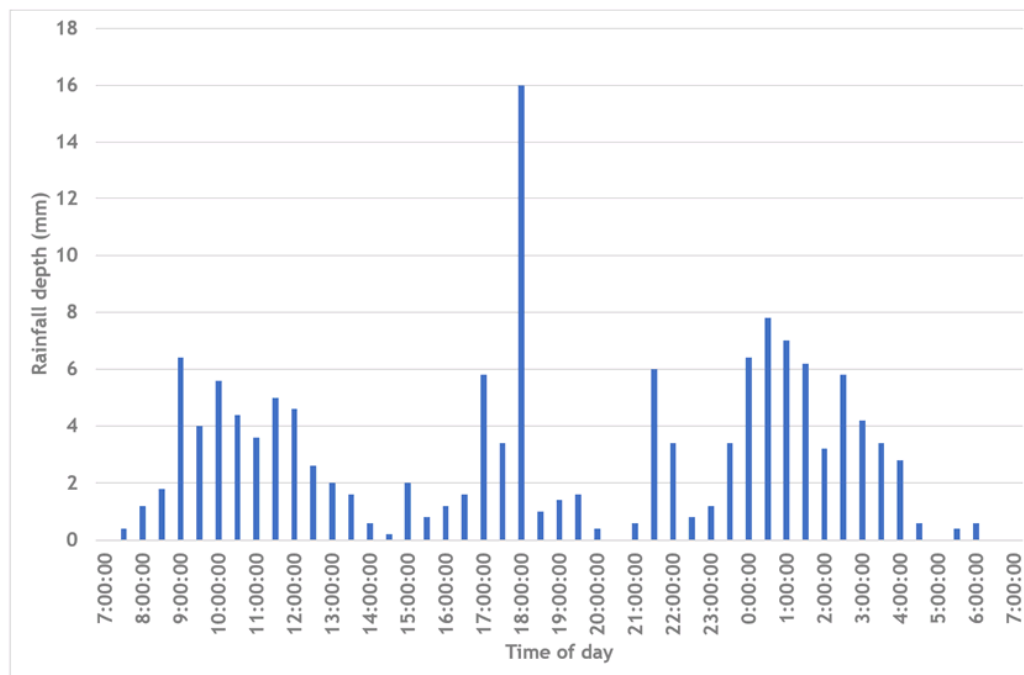
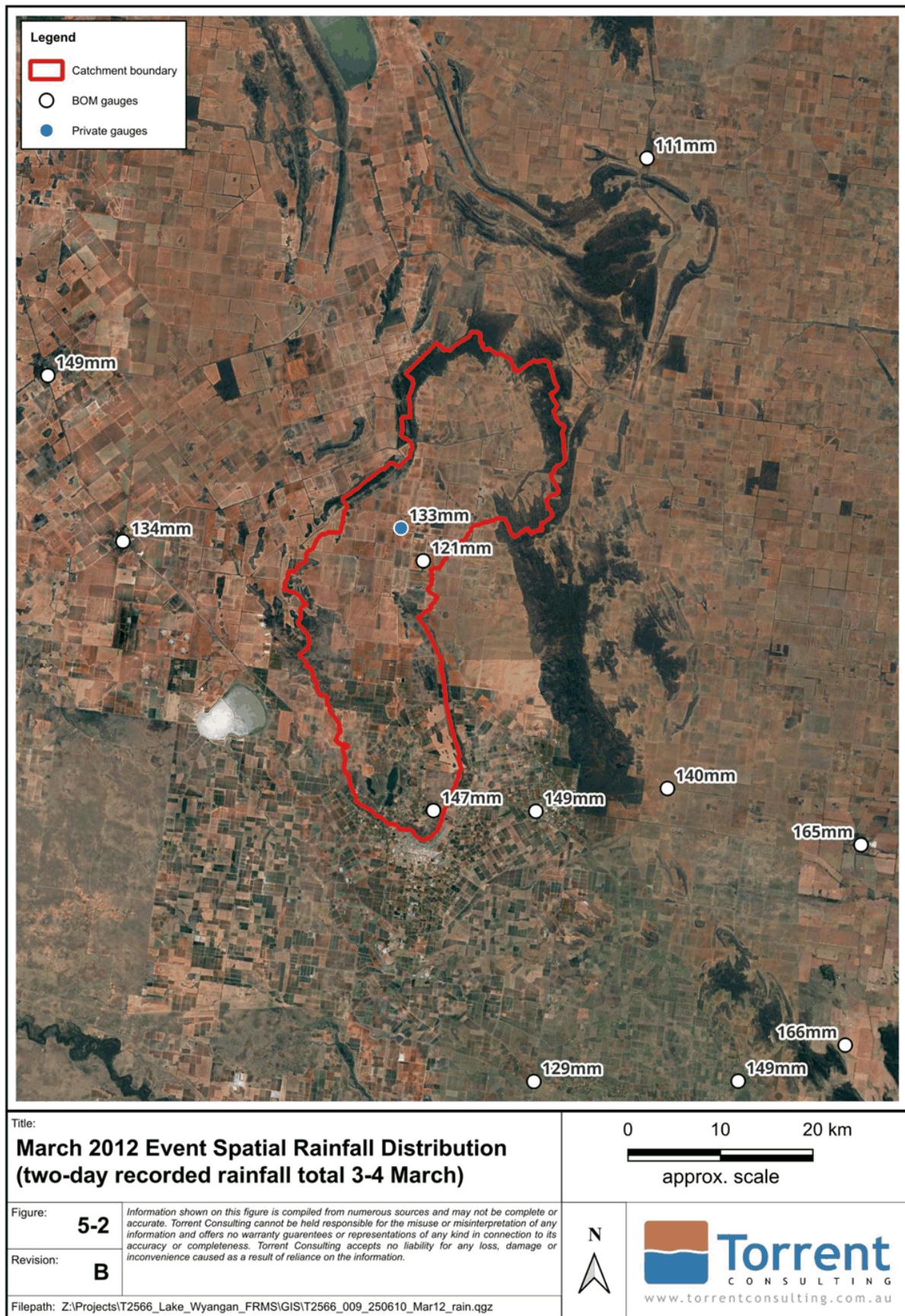


Figure 5-1 Griffith Airport Rainfall Hyetograph for March 2012 Event

Gridded soil moisture estimates from the AWRA-L model (accessible through the BOM AWO site) prior to the March 2012 event vary between 41% in the lower catchment up to 62 % in the upper catchment.



There is no lake level record available for the March 2012 event to accurately derive the observed catchment runoff volume. It also predates the detailed Sentinel 2 satellite imagery and so the resultant peak flood levels in the lake storages have been estimated using a Landsat 7 satellite image from 12 March 2012. The best estimate of peak flood levels is around 106.8 m AHD in Lake Wyangan and 105.6 m AHD in Tharbogang Swamp. To estimate the lake storage levels prior to the event, the Landsat 7 image from 25 February 2012 has been used. The best estimate of initial water levels is around 104.5 m AHD in north Lake Wyangan and 105.5 m AHD in south Lake Wyangan, with Tharbogang Swamp being effectively empty. This represents an estimated runoff volume of around 7900 ML reaching the combined terminal lake storages.

When using the TUFLOW model to simulate the best estimate of rainfall and initial soil moisture conditions across the catchment, the resultant volume of runoff reaching the combined terminal lake storages is around 14,000 ML, which is an overestimation of almost 80%

The potential reasons for the overestimation of observed catchment runoff volumes for the March 2012 event include:

- The inherent uncertainty in the spatial and temporal rainfall record in representing the true conditions that occurred across the catchment.
- The initial soil moisture values are also a product of modelling and are subject to their own associated uncertainties.
- The adopted soil loss model relies on spatial datasets that also have inherent uncertainty.
- The relationship between antecedent catchment conditions, effective rainfall (the depth of rainfall resulting in runoff) and runoff volume in the catchment is also complex and the hydrological model may be limited in its capability to accurately reproduce the natural catchment systems.
- The significant uncertainty in estimating initial and resultant water levels in each of the lake storages.
- Evaporative losses from the lake storages and overland flow paths are not represented in the modelling.

To assess the sensitivity of the TUFLOW hydrological model to the uncertainties in rainfall and soil conditions, a range of simulations was undertaken varying parameters for:

- The total catchment average rainfall depth during the event (adopting values of 100 mm, 120 mm and 140 mm)
- The initial soil moisture conditions (adopting values of 40%, 50% and 60%)
- The soil infiltration rates (adopting the default Green-Ampt values for saturated hydraulic conductivity (refer Table 5-1) and by raising and lowering these values by 33%)

The results of the model sensitivity testing are presented in Figure 5-3 for the combinations of modelled rainfall and initial soil moisture conditions. This identifies that combinations ranging between a 110 mm to 120 mm rainfall depth and initial soil moisture conditions ranging between 40% to 50% will produce simulated results that are comparable to the observed event conditions. This suggests that potentially the AWRA-L soil moisture estimation is too high, the catchment average rainfall was lower than is apparent from the few gauge records and/or the hydrological model tends to overestimate rainfall-runoff reaching the terminal lake storages.

The model also exhibited a large sensitivity to the adopted soil infiltration rates, albeit to a slightly lesser degree than that exhibited by the range of rainfall and soil moisture parameters that were tested.

Table 5-1 Default Saturated Hydraulic Conductivity Values for Green-Ampt in TUFLOW

Soil Texture	Saturated Hydraulic Conductivity (K_{sat}) (mm/h)
Clay	0.3
Silty Clay	0.5
Sandy Clay	0.6
Clay Loam	1.0
Silty Clay Loam	1.0
Sandy Clay Loam	1.5
Silt Loam	3.4
Loam	7.6
Sandy Loam	10.9
Loamy Sand	29.9
Sand	117.8

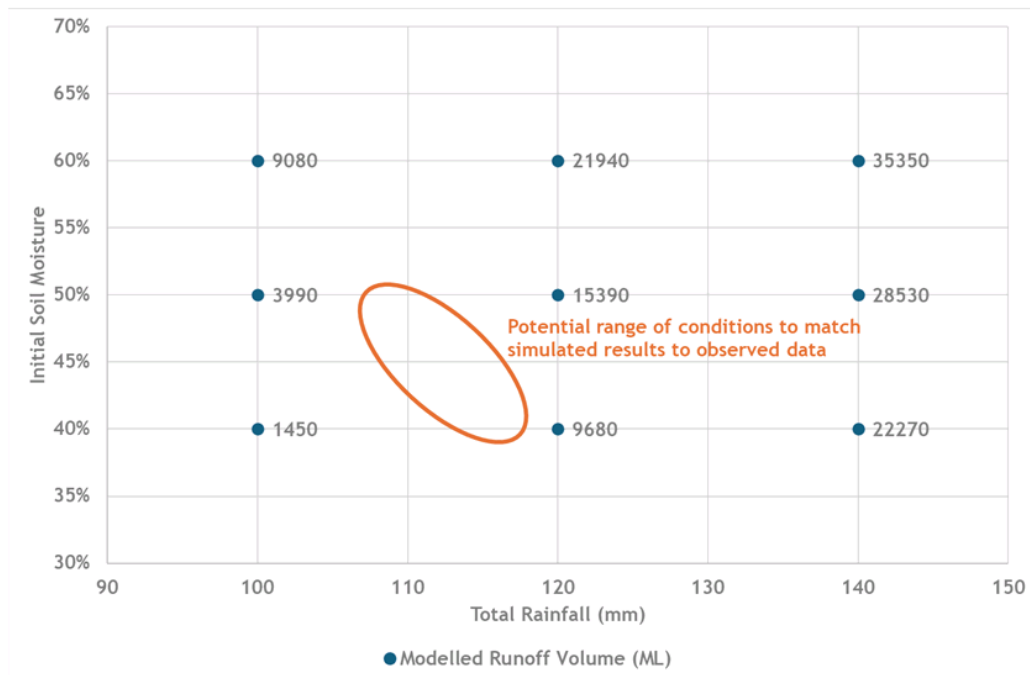


Figure 5-3 March 2012 Event Rainfall and Initial Soil Moisture Sensitivity Testing

5.3 October-November 2022 Event

As for the September-October 2016 event, the flood event of October-November 2022 was more so a function of a prolonged period of wet weather rather than being driven by a single intense storm event, such as occurred in March 1985 and March 2012. On initial review of the long-term rainfall and soil moisture data that was presented in Figure 2-3 and Figure 2-4, it would appear that the 2016 event is much more significant than 2022, with a much longer sustained period of wet catchment conditions. However, although local runoff and flood inundation was experienced in the 2016 event, there is no evidence of a significant volume of water entering Lake Wyangan or Tharbogang Swamp.

In reviewing the available rainfall data in more detail, there is a potential explanation for why the 2022 event produced a much greater volume of catchment runoff volume when compared to the 2016 event. Once the catchment soils are initially wetted in May 2016, almost 450 mm of rainfall is recorded in the catchment over a period of around five months from June through October. During this period there are ten rainstorms of around 20 mm or more, totalling some 325 mm. Most of these events are no larger than 30 mm, with only two exceeding 50 mm, and one more over 40 mm. The two largest events are the first in the period, when the soil moisture level has not reached its highest levels.

In the 2022 event the catchment soils are initially wetted in September, followed by a 6–7-week period during which around 270 mm rainfall is recorded in the catchment. During this period there are six rainstorms of around 20 mm or more, totalling some 235 mm. Whilst these totals are lower than the prolonged wet period in 2016, they occur over only a third of the timeframe, as such, the average weekly rainfall in the 2022 wet period is almost twice that of 2016, being around 42 mm compared to 22 mm.

Further to this, there is a single event around 24 October in which 90 mm is recorded at Griffith Airport in an 18-hour period, although closer to 50 mm is recorded within the central catchment area. The Griffith record represents around a 2% AEP when compared to the BOM IFD data. Only one week later another event exceeding 50 mm is recorded in the central catchment area, albeit closer to 30 mm at Griffith that time. Another lesser rainfall event then follows around two weeks later.

It is expected that the significant rainfall event of 24 October generated a large volume of catchment runoff that was then further supplemented by the following rain events over the next three weeks. Photographic and video evidence received from the community is dated 25 October 2022, which supports the 24 October being the most significant in terms of flood-producing rainfall. The recorded water level in Lake Wyangan begins to rise significantly following this date and continues to rise steadily for a further month, peaking at 108.4 m AHD on 24 November, prior to water being pumped out and transferred to Tharbogang Swamp.

Attempts were made to simulate the catchment rainfall-runoff response, but the uncertainties and sensitivities associated with simulation of the March 2012 event are increased by an order of magnitude for 2022, with it being a quasi-continuous simulation rather than a single event. The soil loss model is principally for event-based rather than long-term simulation and so the individual rainfall events during the 6-7-week period need to be modelled individually, with different initial soil moisture, initial lake levels and rainfall inputs for each successive event. The anticipated method was to simulate the few largest events and compare the results to the observed data. However, the simulations failed to generate the volume of runoff that was recorded without unreasonably increasing the rainfall and/or soil moisture inputs.

Ultimately, the process of simulating the 2022 flood event didn't provide any opportunity to calibrate soil loss parameters, which was the principal intelligence to be gained from the calibration exercise. Therefore, a simple water balance spreadsheet model was created to provide some insight into the catchment flood hydrology. Daily rainfall records were obtained for the two catchment BOM gauges and the four local Wunderground gauges shown in Figure 2-9, plus the private gauge shown in Figure 5-2. Daily modelled soil moisture conditions from AWRA-L were sourced for three point locations in the lower, central and upper catchment areas, plus open water evaporation for the lower catchment.

The balance of net rainfall and evaporation for the north Lake Wyangan, south Lake Wyangan and Tharbogang Swamp waterbodies was calculated using their approximate surface area, which doesn't vary much with depth. The local catchment area contributing to each waterbody was then used to calculate a volumetric runoff based on the recorded rainfall data. The soil moisture multiplied by a coefficient of runoff was used to calculate the volume of effective rainfall. For the upper catchment area, a lower limit of soil moisture content had to be set below which runoff does not contribute to the lakes, with the effective rainfall and contributing runoff volume being calculated using the difference between the soil moisture and the threshold value.

The runoff coefficients were calibrated to match the recorded levels in the waterbodies, which were converted to volumes using a stage-storage relationship. Figure 5-4 shows the results of the water balance assessment, plotting the total recorded storage volume within Lake Wyangan. The calculated volumetric inputs from local catchment sources are shown and were calibrated to match the initial lake level observations in September. The additional volumetric input required to match the observed peak was used to calibrate the input from the central and upper catchment areas. The results for Tharbogang Swamp are provided in Figure 5-5.

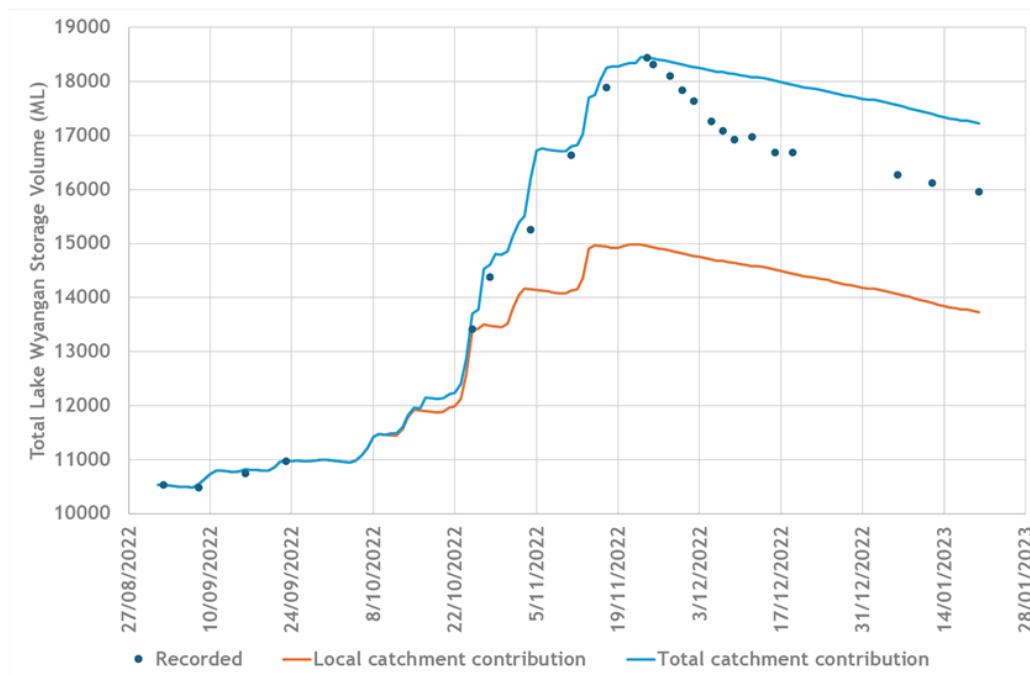


Figure 5-4 Mass Balance Calculations for Lake Wyangan 2022 Event

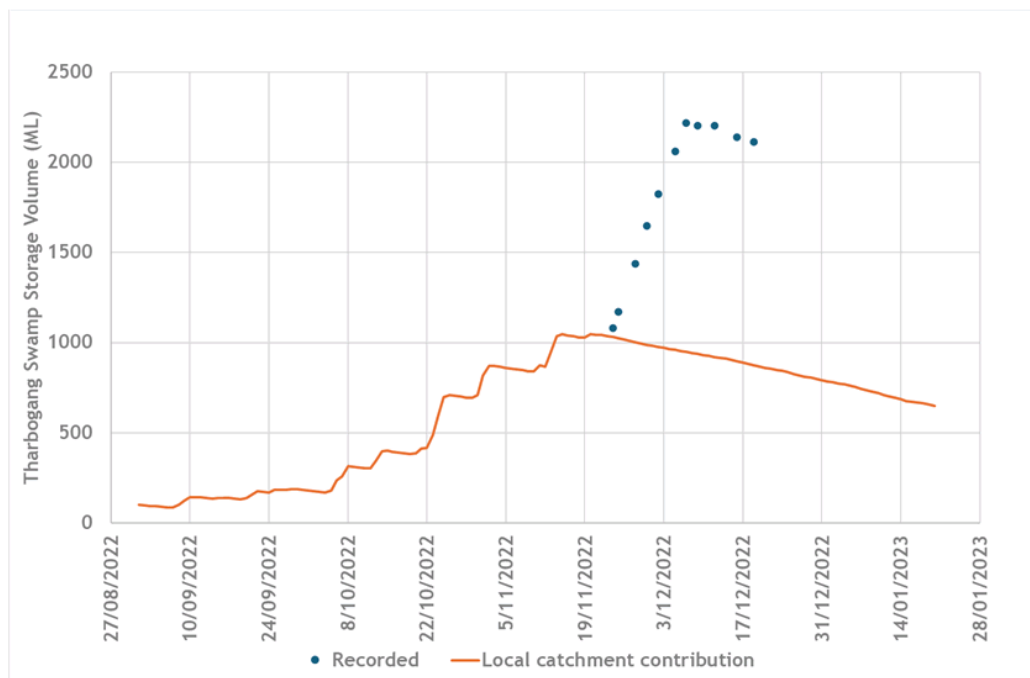


Figure 5-5 Mass Balance Calculations for Tharbogang Swamp 2022 Event

As for the TUFLOW hydrological modelling, there are inherent data uncertainties associated with the mass balance assessment and assumptions made as to contributing catchments and the conversion of rainfall to effective rainfall. However, it does enable some meaningful observations to be made:

- It is likely that most of the water entering Lake Wyangan and Tharbogang Swamp came from local catchment sources rather than the central and upper catchment areas.
- The 24 October rainfall event triggered the inflow of central and upper catchment runoff into the lower catchment area.
- Almost all the central and upper catchment inputs entered Lake Wyangan via Lake View Drain, with there being limited potential for significant contributions to Tharbogang Swamp given the recorded water levels in that waterbody.
- There is an additional loss of around 85 ML/d from Lake Wyangan between 24 November and 9 December, which closely matches the corresponding volumetric increase in the Tharbogang Swamp storage. This is a function of the emergency pump transfer that was undertaken from Lake Wyangan to Tharbogang Swamp.
- The gradients of volumetric loss associated with evaporation match the observed data at the end of the event, once the rainfall and pumping have ceased.
- There is estimated 4500 ML of runoff volume from the local catchments reporting to Lake Wyangan, which equates to an effective rainfall depth of 31 mm. From the approximately 315 mm of rainfall recorded during the period, this represents a runoff coefficient of around 10%.
- The estimated 3400 ML of additional runoff volume from the central and upper catchment areas equates to an effective rainfall depth of only 5 mm and a runoff coefficient of only 1.5%.

Whilst the central and upper catchment runoff contribution to Lake Wyangan has been calibrated to match the recorded peak level, the timing of the inputs is a direct result of the catchment rainfall (with an allowance for a few days lag time being made). However, the inflow is expected to have occurred at a much steadier rate, with catchment runoff ponding upstream of the Lake View Branch Canal at Dickie Road and the cross-drainage transfer being limited by the capacity of the siphon structures. The capacity of Lake View Drain itself will also have been a limiting factor, with photographic evidence (refer Figure 2-6) indicating that it was at full capacity on 25 October near Kubank Road. The assessment indicates that over a period of 30 days, an average of around 115 ML/d was transferred to Lake Wyangan through Lake View Drain. At its peak this flow transfer was in the order of 315 ML/d.

5.4 March 1985 Event

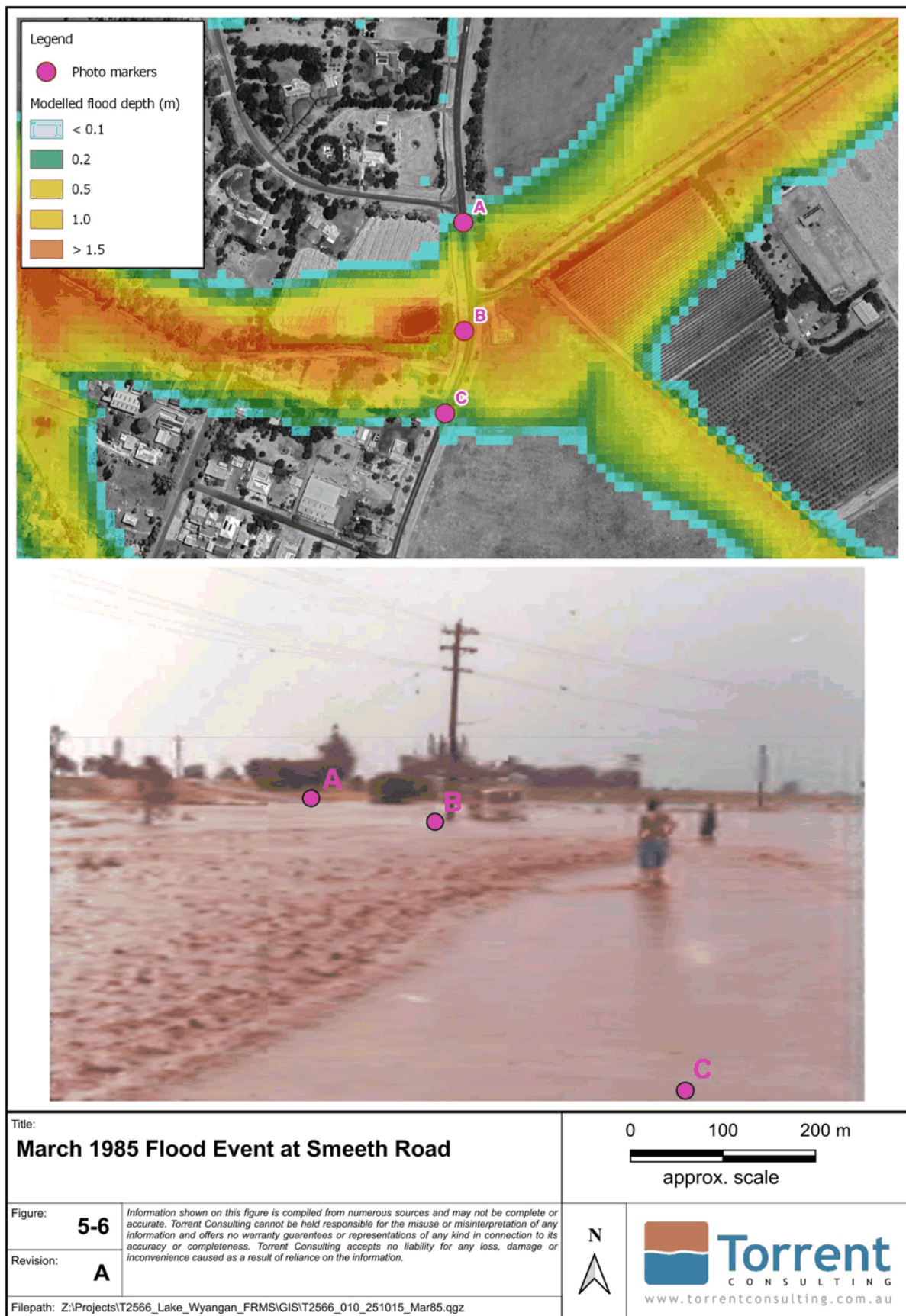
The March 1985 event is truly exceptional. A daily rainfall total of 150 mm was recorded at Griffith Airport, with only 45 mm recorded at Hanwood and 29 mm at Yenda. To the north and west, all rainfall gauges recorded zero for the day. It would be easy to dismiss this record as an error were it not for the photographic evidence (as presented within the original Lake Wyangan Flood Study), which shows a 200 m wide overland flood flow path from Smeeth Road flowing over Boorga Road at the intersection.

With no temporal rainfall record available, the original Flood Study modelled it occurring over a three-hour period and found the results to be consistent with the photographic record. This has been undertaken using the model developed for this current study review and again produced consistent results, despite using a different soil loss method, as shown in Figure 5-6. This is to be expected given the very high percentage of effective rainfall inevitably resulting from the rainfall intensity.

Given how locally concentrated the March 1985 rainstorm was, it is almost certain that it occurred over a much shorter duration than three hours, with a one-hour or two-hour duration seeming more likely. This is supported by anecdotal evidence published in editions of The Area News at the time. In the 20 March issue of the newspaper, the 45 mm record at Hanwood is noted as being between 11:00 and 14:00 on 19 March. There is also reference to the much greater depth recorded at the airport and that is mostly fell within an hour. The reference to the airport rainfall in the 21 March issue is that it fell in less than two hours.

The 1% AEP rainfall depths from the BOM IFD data are 48 mm, 60 mm and 67 mm for a one-hour, two-hour and three-hour duration, respectively. Extrapolating the IFD data (available up to the 1-in-2000 AEP) estimates the AEP of the recorded 150 mm depth at 1-in-1,000,000 for a 90-minute storm duration. The rainfall intensity local to the airport is therefore a real-world example of an Extreme Flood or Probable Maximum Flood (PMF) event.

When simulated over a shorter period than three hours, the modelled peak flood depths are greater than those shown in Figure 5-6. However, the photograph may not be representative of the peak condition reached during the event and it is also likely that less than 150 mm fell across some of the local catchment area draining to Smeeth Road. Nevertheless, the model validation process demonstrates reasonable consistency between the modelled and observed flood behaviour from local catchment runoff during very intense rainfall.



5.5 Satellite Imagery Observations

The remote-sensed imagery from the Landsat and Sentinel satellites represents the most comprehensive available model validation datasets, with only the lake level records for the Oct-Nov 2022 event and localised drone-captured images of flooding on 4 October 2016 and 25 October 2022 providing improved detail.

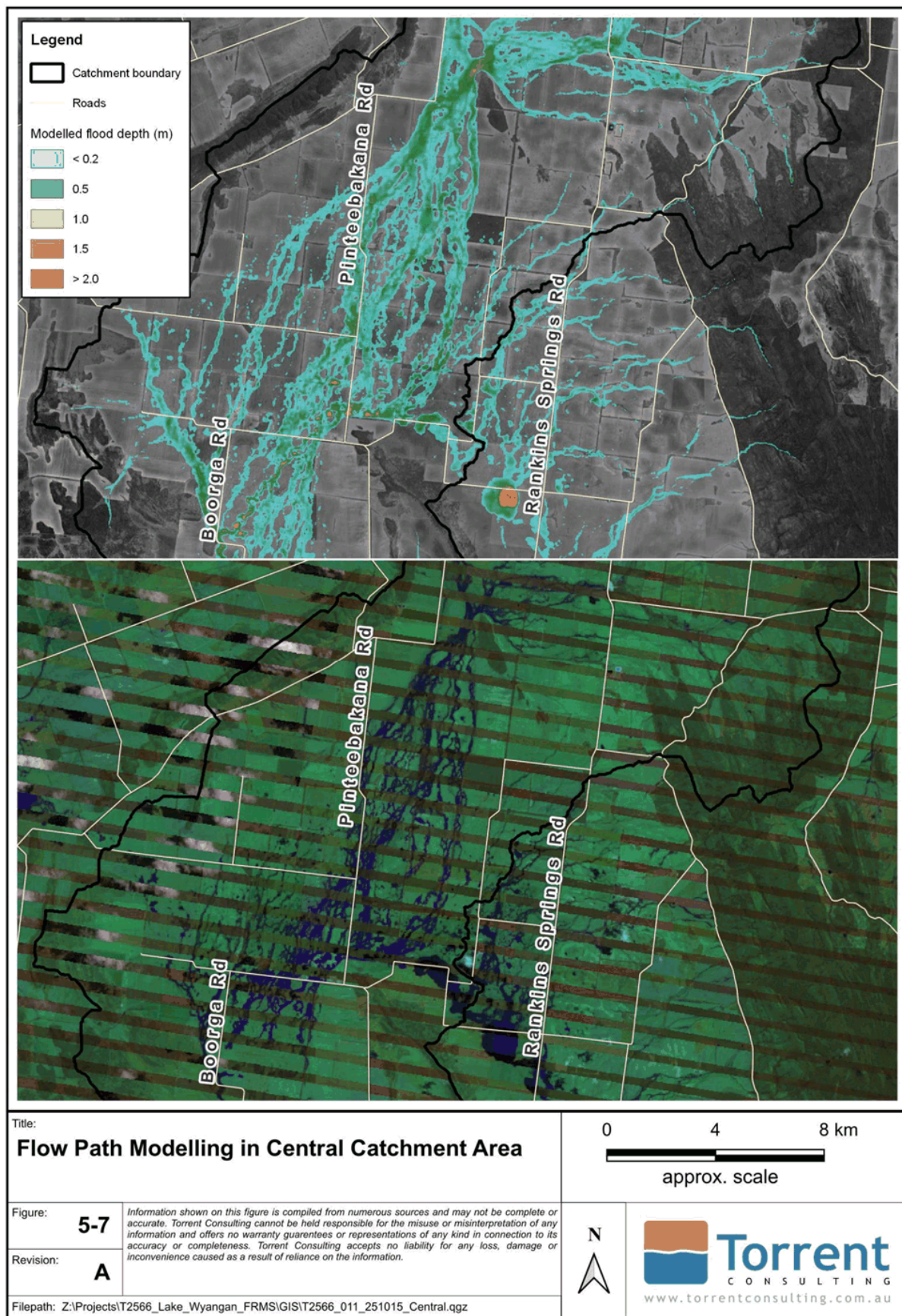
The high quality and temporal availability of the Sentinel 2 satellite imagery (as discussed in Section 2.2.6) provides additional insights into the observed catchment flood behaviour. Whilst these are beyond the scale of potential model calibration, they are useful in understanding any implications for the design flood scenarios, including further model development.

The Sentinel 2 imagery for the 2016 event shows no evidence of catchment runoff prior to 15 June, followed by a large response between then and 12 July, which will be a result of the 50 mm rain event around 20 June. The catchment then progressively dries until an even larger response between 21 August and 23 September, which will be a result of the 40 mm rain event around 10 September. The catchment then dries with no further runoff evident.

The Sentinel 2 imagery for 2022 shows that the catchment is dry at the turn of the year but with some localised runoff evident in an image from 10 January. There is increased runoff evident from 12 January and then even more so on 15 January. The rainfall record shows a series of events on 7, 11 and 14 January of around 40 mm to 60 mm each. There is also evidence of catchment runoff in early and mid-March, corresponding to a couple of rain events at those times but it is limited to the central catchment area.

The central catchment area dries following the March rainfall, although there is still evidence of scattered ponded water in depressions into July, with fresh runoff then evident in early to mid-September. The catchment then dries, before additional runoff can be observed in early to mid-October. There is a month-long gap in imagery that is substantially obscured by cloud cover between 17 October and 18 November, with the latter image showing a significant amount of additional runoff to the former, during which the primary and secondary rainstorms of the flood event have occurred. The catchment has largely dried by 6 December expect for scattered pockets of ponded water across the central catchment area.

From the multitude of imagery available, there are two locations within the catchment that exhibit more frequent occurrence of runoff than elsewhere. The first is in the central catchment area, in the proximity of Boorga – both to the east into the residual catchment area towards Myall Park and to the west on the main catchment flow path that heads south to Dickie Road. Figure 5-7 shows a composite satellite image of this area, using principally the Landsat 7 image from 4 March 2012, supplemented with the Sentinel 2 image from 18 November 2022. The former provides the greatest clarity and extent of flood flow paths in this area but has data gaps forming a striped image, associated with failure of one of the sensors following launch. The 2022 imagery is used to fill these gaps and provide a more complete picture of overland flood flow behaviour.



The green colouration within the satellite imagery shows cleared areas in light green and vegetated areas in darker green. There are some areas of red visible in the Sentinel 2 image that indicate a healthy crop coverage. Both images depict flood flow paths in inky blue, with brighter areas being wet at the time of image capture and duller areas being areas of shallower water or wet ground.

A modelled rainfall-runoff condition is provided in Figure 5-7 for visual comparison and shows a good degree of consistency between the modelled and observed patterns of overland flood flow paths and areas of ponded water.

A similar visual comparison confirming consistency between the modelled and observed patterns of overland flood flow paths is provided for the lower catchment area in Figure 5-8. Again, it utilises a composite satellite image combining Landsat 7 imagery from 4 March 2012 but in this instance supplemented with the Sentinel 2 image from 23 September 2016. The 2016 image has been used in preference to 2022 as it maintains consistency of flood flow paths with 2012. The extensive implementation of almond agriculture and realignment of the Lake View Branch Canal following the 2016 flood event has altered the extent of flooding, as evidenced in the 2022 Sentinel 2 imagery.

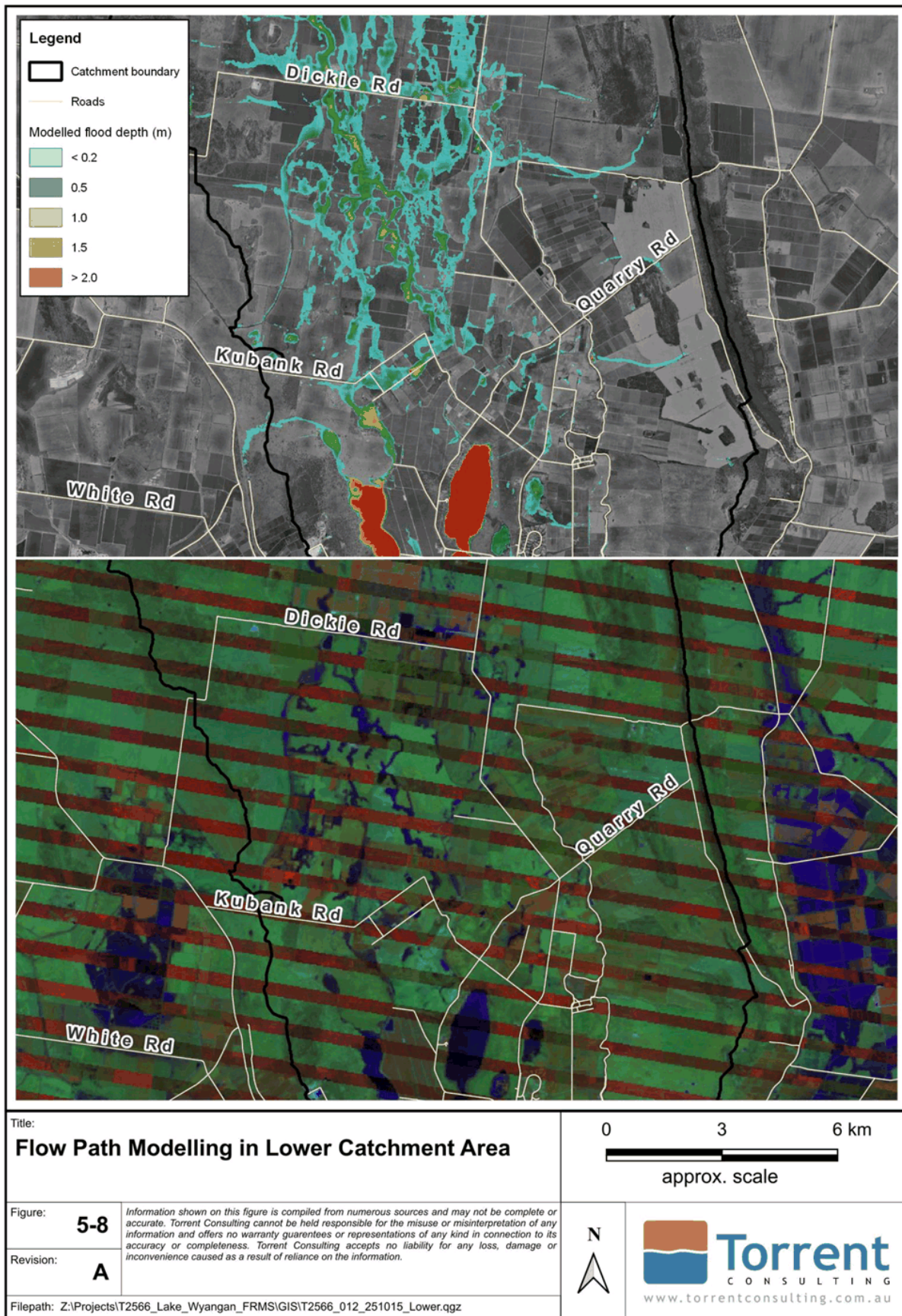
Figure 5-9 shows a comparison between the observed flood flow paths between Dickie Road and Kubank Road for the March 2012 and January 2022 events. A few changes in the flood extents captured by the satellite imagery can be observed between the two images, including:

- The realignment (straightening) of the Lake View Branch Canal on the western side of the floodplain locally alters the extent of ponded water behind the canal.
- There is a reduction in overland flow paths in the area immediately east of the Lake View Branch Canal and north of Kubank Road, as the drainage channel along the southern boundary of the almond farming has diverted the natural flow paths east to Lake View Drain. This diverts more flow through the Kubank Estate that would previously have drained to the west.
- The main flood flow path arriving at the Kubank Estate is now aligned slightly further to the east, which is again attributable to the drainage diversion along the southern boundary of the almond farming.

The above modifications to the overland flood flow progression between Dickie Road and Kubank Road are important to capture in the design modelling that is undertaken to support the assessment of potential floodplain risk management options in the update of the FRMS.

Satellite imagery has also been used to estimate the volume of runoff entering the terminal lakes for historic flood events in lieu of available water level records, which are limited to the 2022 event:

- March 1989 event: 3400 ML.
- March 2012 event: 7900 ML.
- Sep-Oct 2016 event: 3400 ML.





6 Design Flood Hydrology

6.1 Lake Wyangan / Tharbogang Swamp Catchment

6.1.1 Design Rainfall Spatial Variability

There is relatively little spatial variability of design rainfall within the BOM IFD data because of how flat the broader landscape is. However, there is a trend for increased rainfall in the upper catchment area associated with the increased elevation and topographic variability. Preliminary model simulations identified the 24-hour storm duration as being critical for catchment runoff volumes in the terminal lake systems. The BOM design rainfall IFDs were obtained for the lower catchment area for simulation in the local catchment model. These were then scaled to provide higher rainfall depths across the upper catchment, based on the spatial variability of the 1% AEP 24-hour duration rainfall.

The design rainfall inputs to the Lake Wyangan / Tharbogang Swamp model were varied spatially across the catchment using the five zones shown in Figure 6-1. The rainfall scaling applied to each zone is detailed in Table 6-1. The design rainfall across the northern end of the Cocoparra Range (Zone E, which forms the upper catchment divide) is around 14% higher than that within the lower catchment area (Zone A).

Table 6-1 Modelled Spatial Variability of Design Rainfall

Zone	IFD Scaling	ARF Adjustment	Composite Adjustment
A	1.000	1.040	1.040
B	1.025	1.010	1.035
C	1.055	0.991	1.046
D	1.095	0.986	1.080
E	1.140	0.970	1.106

6.1.2 Aerial Reduction Factor

The Aerial Reduction Factor (ARF) is applied to design point rainfall data to account for spatial variability of rainfall, with the peak design intensities unlikely to occur over larger catchment areas. The BOM design rainfall IFDs obtained for the Lake Wyangan / Tharbogang Swamp catchment model adopted an ARF based on the total catchment area of around 780 km². However, flooding in Lake Wyangan and Tharbogang Swamp is more likely to occur from rainfall within the lower catchment area, as the urban areas and irrigated agriculture generate a greater volume of runoff. The upper catchment area generates less frequent runoff, much of which is then infiltrated during transition of the flood wave, prior to reaching the Lake View Branch Canal and Dickie Road.

The ARF was therefore varied across the study catchment, consistent with the spatial zones used for design rainfall depth variability discussed in Section 6.1.1. The modelled rainfall was increased by 4% in Zone A, as shown in Table 6-1. This provides consistency with the adoption of an ARF applicable to the area of Zone A, which is around 160 km².



As the cumulative catchment area increases with each design rainfall zone, the ARF adjustment is calculated on an area weighting basis accordingly. This gives a net adjustment of 1.000 across all five zones. Values representing the composite adjustment (i.e. the product of the IFD scaling and ARF adjustment) to the design rainfall are also provided in Table 6-1. This indicates that the design rainfall IFDs obtained from the BOM are being increased by around 4% for most of the catchment and by around 9% across the upper catchment. Adjustments for climate change impacts are applied independently, as discussed in Section 6.1.4.

6.1.3 Critical Duration Assessment

The design point rainfall with the corresponding adjustments discussed in Section 6.1.1 and Section 6.1.2 was applied directly to the hydrological model to simulate the rainfall-runoff process, with ten temporal patterns modelled for each storm duration. Storm durations ranging from 12 hours to 72 hours were simulated, with the results being analysed in the terminal catchment storages to identify the critical duration for each design flood event probability. A representative temporal pattern was then selected for each, as being best representative of the mean condition of the temporal pattern suite for each of the events. The 24-hour duration was found to produce the critical flood response in Lake Wyangan and Tharbogang Swamp across the full range of events.

6.1.4 Climate Change

As per the updated ARR 4.2 climate change guidance, an adjustment was made to the adopted design rainfall to account for potential increases in rainfall intensity. The rainfall adjustment is determined through a combination of an expected increase in global mean temperature and an associated percentage increase in design rainfall intensity per degree of warming.

For this assessment the Shared Socioeconomic Pathway SSP2 was adopted for the near-term flood planning horizon, which represents a continuation of historic global attitudes towards climate policy, i.e. a neutral rather than optimistic or pessimistic outlook. The SSP3 climate change scenario was adopted for the long-term flood planning horizon, which assumes future challenges to climate change adaption and mitigation. The SSP2-4.5 climate scenario has a best-estimate warming of around 1.2°C for the near-term (2021-2040) horizon, while SSP3-7.0 estimates around 3.3°C of warming for the long-term (2081-2100) horizon.

Using Equation 1.6.1 of ARR 4.2, this gives a total increase in design rainfall intensity of 9.7% for the near-term horizon and 28.9% for the long-term horizon.

6.2 Local Catchment

6.2.1 Aerial Reduction Factor

For the local catchment model, adoption of the full model area to derive the ARF would likely underestimate rainfall depths for critical sub-catchment flows. Therefore, the ARF was derived from a typical contributing catchment size of around 5 km². The resultant ARF values were applied to the design rainfall depths for the local catchment model.

6.2.2 Critical Duration Assessment

The design point rainfall with corresponding ARF was applied directly to the hydrological model to simulate the rainfall-runoff process, with ten temporal patterns modelled for each storm duration.

Storm durations ranging from 10 minutes to 24 hours were simulated, with the model results analysed at 20 locations across the local catchment to identify the critical durations and temporal patterns that most consistently produced peak flow conditions.

Given the broad range of durations producing critical conditions across the catchment, four storm durations were selected for each design event probability that most comprehensively provide results that match or were otherwise as close as possible to the critical condition. The hydrological model results selected for simulation in the hydraulic model are shown in Table 6-2.

Table 6-2 Adopted Critical Design Storm Events

Design Probability	Critical Durations (mins)	Temporal Patterns
10% AEP	60, 270, 720 and 1080	4566, 4698, 4793 and 4830
5% AEP	60, 540, 720 and 1080	4566, 4761, 4790 and 4832
2% AEP	45, 180, 360 and 540	4550, 4649, 4720 and 4745
1% AEP	45, 180, 360 and 540	4550, 4649, 4720 and 4745
0.5% AEP	45, 120, 270 and 540	4550, 4615, 4684 and 4745
0.2% AEP	45, 120, 180 and 360	4550, 4613, 4651 and 4587

6.2.3 Climate Change

The procedures for the estimation of climate change impacts to flood hydrology in the ARR 4.2 guidance were adopted, consistent with that of the Lake Wyangan / Tharbogang Swamp catchment simulation discussed in Section 6.1.4.

Using Equation 1.6.1 of ARR 4.2, this gives a total increase in design rainfall intensity ranging between 10.2% and 18.3% for the near-term horizon and between 30.5% and 58.6% for the long-term horizon.

6.3 Extreme Flood Event

The PMF conditions were simulated for the full catchment and local catchment flood events. However, the results of the PMF event are excessive, particularly for the local catchment flood conditions. This is to be expected given the approximate 1-in-10,000,000 AEP of a local catchment PMF event. Therefore, an Extreme Flood Event condition has been simulated, which adopts three-times the rainfall of the 1% AEP event. This is consistent with the previous Lake Wyangan Flood Study and is expected to be closer to a 1-in-10,000 AEP condition than a 1-in-10,000,000 AEP.

7 Design Flood Results

7.1 Lake Wyangan / Tharbogang Swamp Catchment Model

The modelled peak flood levels reached within the storages of Lake Wyangan and Tharbogang Swamp were extracted from the catchment model results across the full range of simulated design events. The results of the near-term (2040) climate change scenario are shown in Table 7-1. The total catchment runoff volume contributing to the combined peak flood conditions in Lake Wyangan and Tharbogang Swamp is also provided for context. The results for the long-term (2100) climate change scenario are shown in Table 7-2.

Table 7-1 Near-Term Design Flood Levels Lake Wyangan and Tharbogang Swamp

Design Probability	Lake Wyangan (m AHD)	Tharbogang Swamp (m AHD)	Total Runoff Volume (ML)
10% AEP	106.35	104.2	1000
5% AEP	106.5	104.25	1600
2% AEP	106.7	104.5	2400
1% AEP	107.1	104.9	4200
0.5% AEP	107.9	106.1	8600
0.2% AEP	108.6	108.8	17 100
Extreme	117.0	117.0	170 000
PMF*	120.2	120.2	340 000

Table 7-2 Long-Term Design Flood Levels Lake Wyangan and Tharbogang Swamp

Design Probability	Lake Wyangan (m AHD)	Tharbogang Swamp (m AHD)	Total Runoff Volume (ML)
10% AEP	106.5	104.25	1600
5% AEP	106.7	104.5	2400
2% AEP	107.3	105.25	5200
1% AEP	108.2	107.05	11 300
0.5% AEP	108.7	109.2	18 900
0.2% AEP	109.15	110.75	27 800
Extreme	118.1	118.1	220 000
PMF*	120.2	120.2	340 000

The runoff volume at the PMF event increases with the storm duration and by the 36-hour duration generates a sufficient volume of runoff to fill the entire depression storage of the endorheic basin. At a level of around 120 m AHD, water will spill from the catchment through the lowest point of the western divide and into the Barren Box Storage and Wetland via Warburn. The PMF level has therefore been capped at 120.2 m AHD, as flood levels greater than this cannot be reached.

The modelled runoff volume reaching the terminal lake storages of Lake Wyangan and Tharbogang Swamp is limited for 24-hour rainfall depths of less than 110 mm but then increases significantly once this threshold is exceeded. This is because the sandy catchment soils have a high infiltration to absorb most rainfall events. However, once a degree of saturation is reached, then the effective rainfall increases rapidly with additional event rainfall. Figure 7-1 shows the relationship between the modelled 24-hour rainfall depths and the total catchment runoff volume reaching the terminal lake storages.

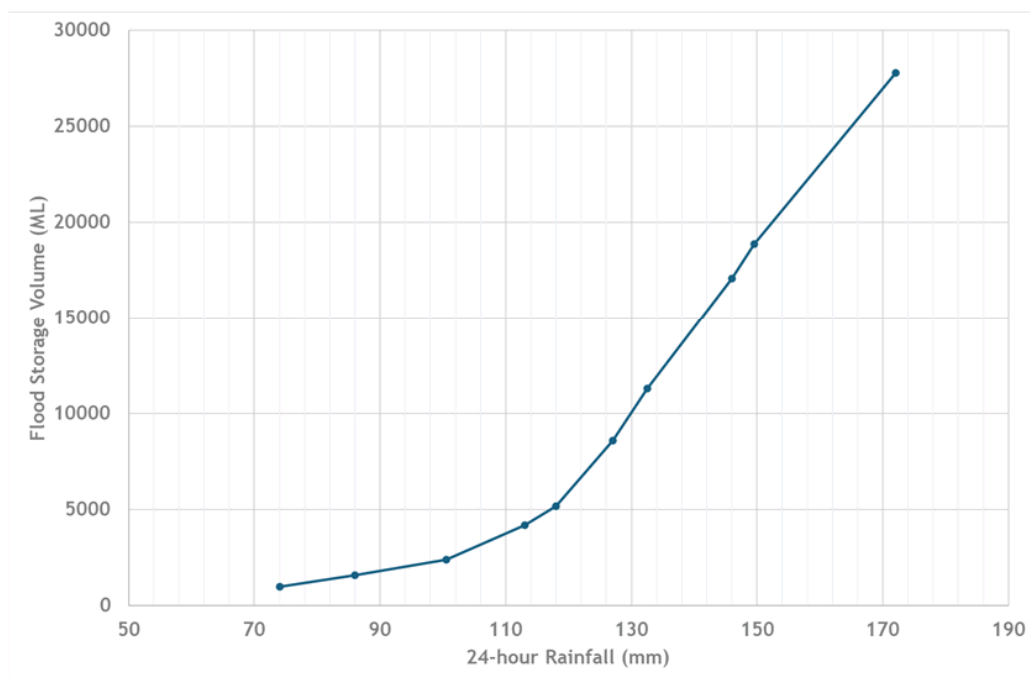


Figure 7-1 Relationship Between Modelled Event Rainfall and Total Runoff Volume

Because of the sensitivity of the modelled peak flood levels in Lake Wyangan to relatively small changes in rainfall depth for the rare to very rare flood event range, careful consideration needs to be given to the adoption of an appropriate Flood Planning Level (FPL). This will be assessed in detail within the subsequent Floodplain Risk Management Study, including sensitivity analyses and residual risk analysis.

For context, the estimated runoff volume entering the terminal lake storages is around 8000-8500 ML for both the March 2012 and Oct-Nov 2022 flood events. That is in the order of a 0.5% (1-in-200) AEP under the near-term (2040) climate change scenario and between a 2% (1-in-50) and 1% (1-in-100) AEP under the long-term (2100) climate change scenario. The difference in flood level within Lake Wyangan experienced during those two historic events is principally a function of the

antecedent conditions. The storage level in Lake Wyangan was very low prior to the March 2012 event but was above normal operating level prior to the Oct-Nov 2022 event. The extensive increase in almond farming in the Dickie Road area will also have directed a greater proportion of catchment runoff into Lake Wyangan rather than Tharbogang Swamp during the more recent of the two events.

Flood mapping outputs of peak flood depth, flood hazard and flood function associated with Lake Wyangan / Tharbogang catchment flood events is provided in Appendix A. A flood depth cutoff limit of 50 mm has been applied to limit the mapped flood extents in areas of very shallow inundation.

7.2 Local Catchment Model

The flow hydrographs extracted from the TUFLOW hydrological model were applied to the hydraulic model to establish the design flood conditions within the local catchment. Figure 7-2 shows the modelled flood extents for the 5% AEP, 1% AEP, and Extreme Flood events for the near-term (2040) planning horizon, with the reporting locations corresponding to the locations presented in Table 7-3 and

Table 7-4.

7.2.1 Design Flood Conditions

Design flood flows for local catchment flooding are presented in Table 7-3 for the full range of design flood events. Modelled flood levels for these locations are presented in

Table 7-4. Locations have been principally selected to indicate conditions at road drainage crossings, with additional locations selected along major drainage paths.

The flood extent mapping presented in Figure 7-2 shows that local catchment runoff is generally contained within the local drainage network at the 5% AEP event, with some shallow overland flow paths activated due to spilling from the channels. At the 1% AEP event, these breakout flows are occurring across a wider area, with broad depressions beginning to fill with floodwater. The Extreme Event flooding is much more extensive across the local catchment, with most of the modelled area subject to inundation, creating several islands of high ground.

Except for at the Extreme Flood event, hazardous flood conditions are principally confined to the local drainage channel network. Urban areas of the catchment remain flood free up to the 0.2% AEP, however, some residential dwellings on rural properties are impacted by flooding.

The full suite of design flood mapping outputs for local catchment flood events is provided in Appendix B. Flood mapping outputs are provided for the near-term (2040) planning horizon, with additional outputs that are integral to future flood planning decisions also provided for the long-term (2100) planning horizon. A flood depth cutoff limit of 50 mm has been applied to limit the mapped flood extents in areas of very shallow inundation.

7.2.2 Flood Hazard

The flood hazards have been determined in accordance with Guideline 7-3 of the Australian Disaster Resilience Handbook 7 Managing the Floodplain: A Guide to Best Practice in Flood Risk Management in Australia (AIDR, 2017). This produces a six-tier hazard classification, based on modelled flood depths, velocities, and velocity-depth product. The hazard classes relate directly to the potential risk posed to people, vehicles, and buildings, as presented in Figure 7-3.

Table 7-3 Modelled Design Flows (m³/s)

Site	Location	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP	Extrm.
1	Int. West and Zillotto Road	0.1	0.3	0.9	1.1	2.3	8.4	1120.4
2	West Road	0.5	1.2	2.0	2.5	5.1	16.2	N/A
3	Boorga Road	0.0	0.2	0.6	1.1	3.1	9.7	52.0
4	Boorga Road	0.1	0.3	1.2	2.4	3.8	7.6	982.1
5	Int. Masonwells and Boorga Roa	0.0	0.0	0.0	0.1	1.6	3.4	N/A
6	Boorga Road	0.1	0.5	1.6	5.1	14.2	25.5	543.1
7	Jones Road	0.7	1.5	2.8	3.9	5.2	6.9	84.2
8	Int. Mancini Dr and Boorga Rd	0.7	1.3	2.1	2.8	3.5	4.6	38.5
9	Smeeth Road	0.7	1.4	2.5	5.3	8.4	15.5	N/A
10	Smeeth Road	0.1	0.2	0.4	0.5	0.6	0.9	N/A
11	Int. Smeeth and Boorga Road	2.1	4.7	9.7	18.3	32.0	53.3	1323.6
12	Smeeth Road	0.0	0.0	0.0	0.0	0.0	2.7	1071.3
13	Jones Road	1.5	3.3	6.5	14.4	24.0	38.9	228.6
14	McCarthy Road	0.6	1.4	3.5	5.7	9.8	15.4	336.8
15	McCarthy Road	0.0	0.0	2.5	4.2	5.8	7.9	93.9
16	McCarthy Road	0.1	0.3	2.5	8.1	14.9	24.1	740.3
17	Todd Road	1.5	2.3	5.1	8.0	11.5	16.6	247.8
18	Boorga Road	1.2	1.8	4.2	7.2	10.3	15.0	340.7
19	Todd Road	0.2	0.4	0.9	1.2	1.5	3.1	239.8
20	Druitt Road	0.2	0.3	1.5	3.2	4.4	7.5	12.0
21	Drain	0.0	0.0	1.0	2.5	4.1	8.2	140.8
22	Drain	0.2	0.3	1.3	2.4	4.2	6.6	73.6
23	Druitt Road	0.4	0.7	1.2	1.7	2.3	4.5	79.8
24	Int. Lakes and Druitt Road	0.2	0.6	1.3	2.6	4.5	8.1	148.2

Table 7-4 Modelled Design Flood Levels (m³/s)

Site	Location	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP	Extrm.
1	Int. West and Zillotto Road	115.0	115.1	115.1	115.2	115.2	115.4	116.2
2	West Road	114.2	114.4	114.7	114.9	115.1	115.3	116.6
3	Boorga Road	115.9	116.0	116.1	116.1	116.3	116.4	117.3
4	Boorga Road	115.6	115.8	116.2	116.8	116.9	117.0	118.1
5	Int. Masonwells and Boorga Roa	N/A	N/A	N/A	N/A	118.8	118.8	119.1
6	Boorga Road	119.4	119.6	120.0	120.3	120.4	120.5	121.4
7	Jones Road	N/A	N/A	N/A	N/A	N/A	111.0	111.3
8	Int. Mancini Dr and Boorga Rd	111.8	111.9	112.2	112.4	112.6	112.7	113.0
9	Smeeth Road	118.9	118.9	118.9	118.9	118.9	119.0	119.4
10	Smeeth Road	117.2	117.5	117.6	117.6	117.7	117.8	118.7
11	Int. Smeeth and Boorga Road	110.3	110.5	110.8	111.2	112.1	112.5	114.8
12	Smeeth Road	114.1	114.2	114.2	114.5	114.6	114.7	116.6
13	Jones Road	117.4	117.4	117.4	117.4	117.5	117.5	118.0
14	McCarthy Road	118.0	118.3	118.4	118.4	118.4	118.4	118.8
15	McCarthy Road	N/A	N/A	119.9	120.0	120.0	120.0	120.4
16	McCarthy Road	119.6	119.8	120.2	120.3	120.4	120.4	121.2
17	Todd Road	110.3	110.4	110.6	110.8	111.0	111.3	113.0
18	Boorga Road	114.4	114.5	114.7	114.9	115.1	115.5	116.0
19	Todd Road	107.6	107.8	108.3	108.5	108.5	108.6	109.5
20	Druitt Road	113.8	113.8	113.9	114.1	114.3	114.3	114.6
21	Drain	N/A	N/A	119.4	119.5	119.6	119.6	119.9
22	Drain	117.4	117.5	117.7	118.0	118.2	118.5	118.8
23	Druitt Road	111.2	111.2	111.2	111.2	111.2	111.3	111.6
24	Int. Lakes and Druitt Road	111.3	111.7	112.2	112.3	112.4	112.4	112.5

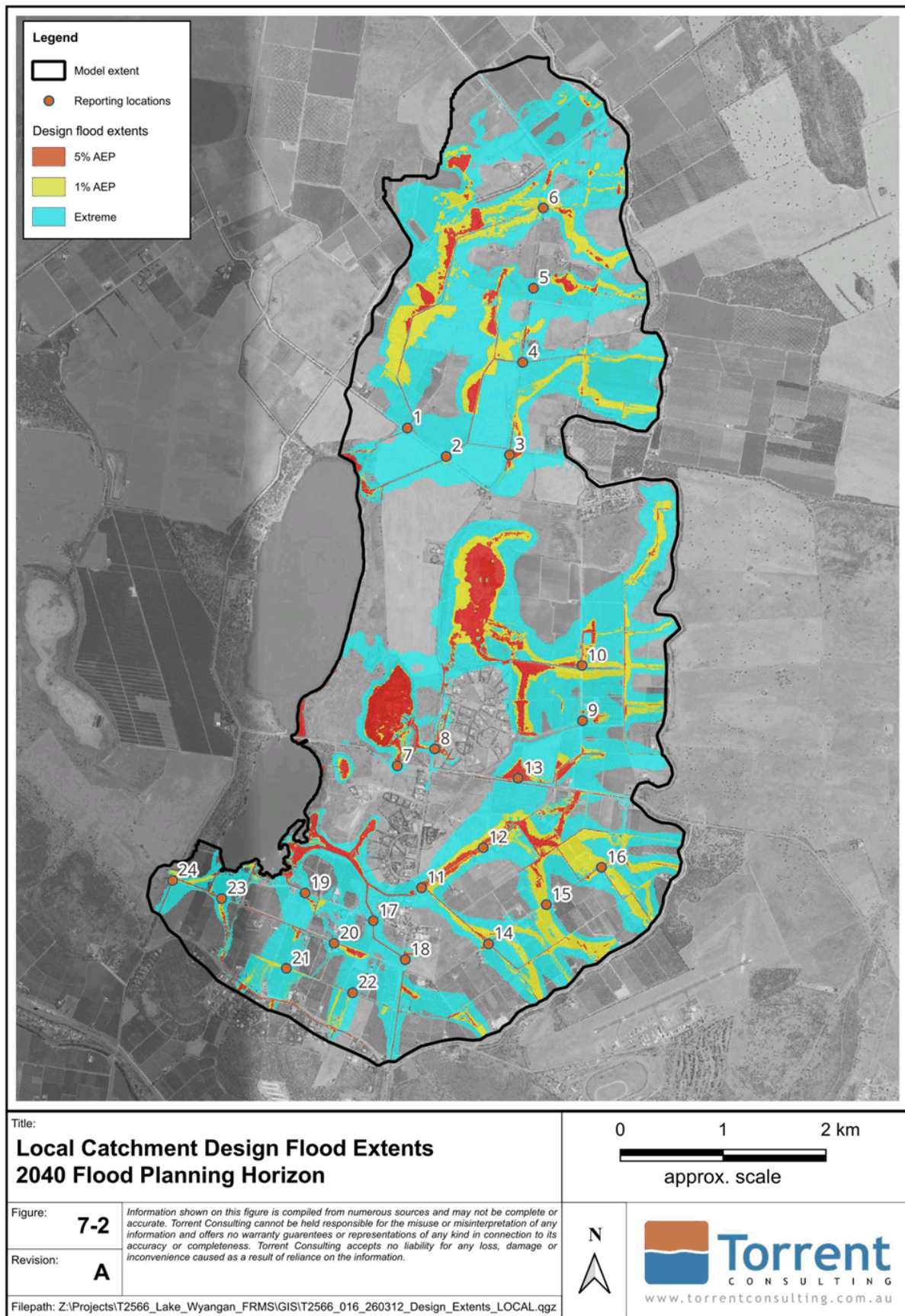


Table 7-5 Combined hazard curves - vulnerability thresholds (AIDR, 2017)

Hazard	Criteria	Description
H1	Depth < 0.3 m and Velocity < 2.0 m/s and Velocity*Depth ≤ 0.3 m ² /s	Generally safe for vehicles, people and buildings
H2	Depth < 0.5 m and Velocity < 2.0 m/s and Velocity*Depth ≤ 0.6 m ² /s	Unsafe for small vehicles.
H3	Depth < 1.2 m and Velocity < 2.0 m/s and Velocity*Depth ≤ 0.6 m ² /s	Unsafe for small vehicles, children and the elderly.
H4	Depth < 2.0 m and Velocity < 2.0 m/s and Velocity*Depth ≤ 1.0 m ² /s	Unsafe for vehicles and people.
H5	Depth < 4.0 m and Velocity < 4.0 m/s and Velocity*Depth ≤ 4.0 m ² /s	Unsafe for vehicles and people. All building types vulnerable to structural damage. Some less robust building types vulnerable to failure.
H6	Depth > 4.0 m OR Velocity > 4.0 m/s OR Velocity*Depth > 4.0 m ²	Unsafe for vehicles and people. All building types considered vulnerable to failure.

The flood hazard mapping shows that, for local catchment flooding, medium to high hazards are generally contained within the drainage channels and within Campell's Swamp and Nericon Swamp up to around the 2% AEP event. Shallow overland flow generally remains at an H1 hazard level. At the 1% AEP shallow depressions, particularly in the northern part of the catchment, were modelled with hazard levels up to H3 due to deeper ponding of water. Hazard levels of up to H3 were modelled along Smeeth Road at the 0.2% AEP event.

At the Extreme Flood event, areas of H4-H5 hazard classification were modelled along the main overland flood flow paths due to flood depths exceeding 2 m, however, velocities remained relatively low, and so H6 hazard conditions were confined to the western end of Smeeth Road and the downstream channel, due to a combination of high depth and velocity (V*D product).

7.2.3 Flood Function

The flood function categories of floodway areas, flood storage areas and flood fringe are defined in the Flood Risk Management Manual: the policy and manual for the management of flood liable land (the manual; DPE 2023) as follows:

- **Floodway** - are generally areas which convey a significant portion of water during floods and are particularly sensitive to changes that impact flow conveyance. They often align with naturally defined channels.
- **Flood Storage** - are areas outside of floodways, are generally areas that store a significant proportion of the volume of water and where flood behaviour is sensitive to changes that impact on the storage of water during a flood.
- **Flood Fringe** - are areas within the extent of flooding for the event but which are outside floodways and flood storage areas. Flood fringe areas are not sensitive to changes in either flow conveyance or storage.

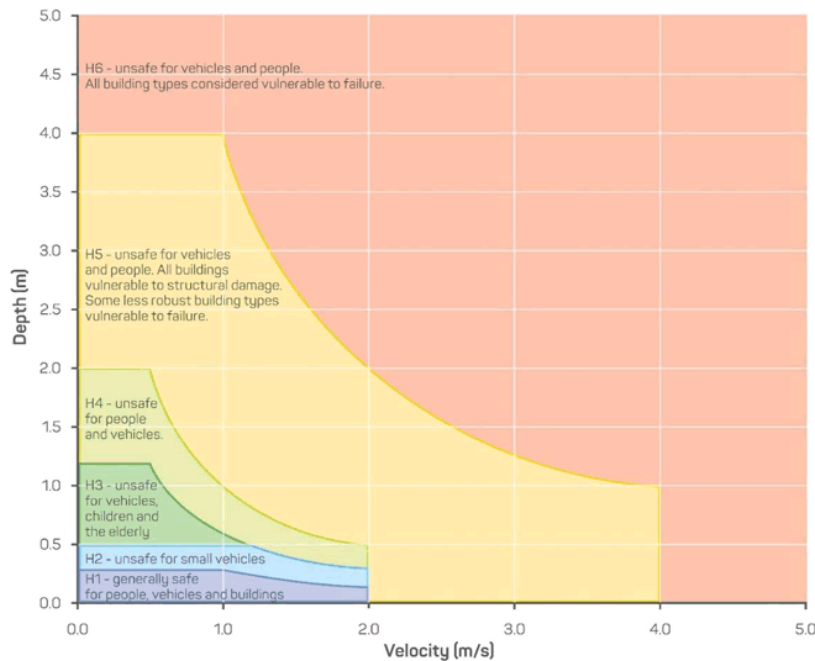


Figure 7-3 General Flood Hazard Vulnerability Curves (AIDR, 2017)

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 Flood Risk Management Manual are essentially qualitative in nature and the 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.

For this study, the multi-criterion approach considering peak flood depths, velocities and the velocity-depth product as described below:

- Floodway is defined as areas where the peak value of velocity multiplied by depth ($V \cdot D$) > $0.2 \text{ m}^2/\text{s}$ ($1.0 \text{ m}^2/\text{s}$ at the Extreme Flood event), with all drainage channels also being considered as floodways;
- Flood Storage comprises areas outside the Floodway where peak depth > 0.5, with all wetland areas also being considered as flood storage; and
- Flood Fringe comprises areas outside the Floodway where peak depth is less than the thresholds for Flood Storage.

8 Conclusions

The Lake Wyangan Flood Study was undertaken to define the historical, existing and potential future climate local catchment and lake storage flood conditions for the township of Lake Wyangan and throughout the surrounding rural. It provides an update of the original study, which was completed in 2012.

Flood behaviour was predicted for a range of design floods based on detailed TUFLOW hydrological and hydraulic modelling developed for the study catchments. Modelling of the local catchment and lake storage flood conditions was validated using flood information for historical events, where available.

The TUFLOW models were used to simulate a range of design events including the 10%, 5%, 2%, 1%, 0.5%, 0.2% AEP and Extreme/PMF events. The potential impacts of climate change, incorporating increased rainfall intensity, was also assessed for implications of managing the future floodplain environment. A suite of detailed design flood mapping has been prepared as a set of appendices to this report.

The outputs of this flood study provide an improved understanding of local catchment and lake storage flood behaviour that will aid in Council's management of flood risk and establish the subsequent Floodplain Risk Management stage of this Study.

9 References

AIDR (2017) Guidelines, Australian Disaster Resilience Handbook 7 Managing the Floodplain: A Guide to Best Practice in Flood Risk Management in Australia.

AWO. (2023). AWO - Australian Water Outlook. <https://www.awo.BOM.gov.au>.

Ball J, Babister M, Nathan R, Weeks W, Weinmann E, Retallick M, Testoni I, (Editors) *Australian Rainfall and Runoff: A Guide to Flood Estimation*, © Commonwealth of Australia (Geoscience

BMT WBM (2012) *Lake Wyangan Flood Study*

BMT WBM (2013) *Lake Wyangan Floodplain Risk Management Study and Plan*

Lee, J.S. (1980): Digital image enhancement and noise filtering by use of local statistics. IEEE Transactions on Pattern Analysis and Machine Intelligence, PAMI-2: 165-168.

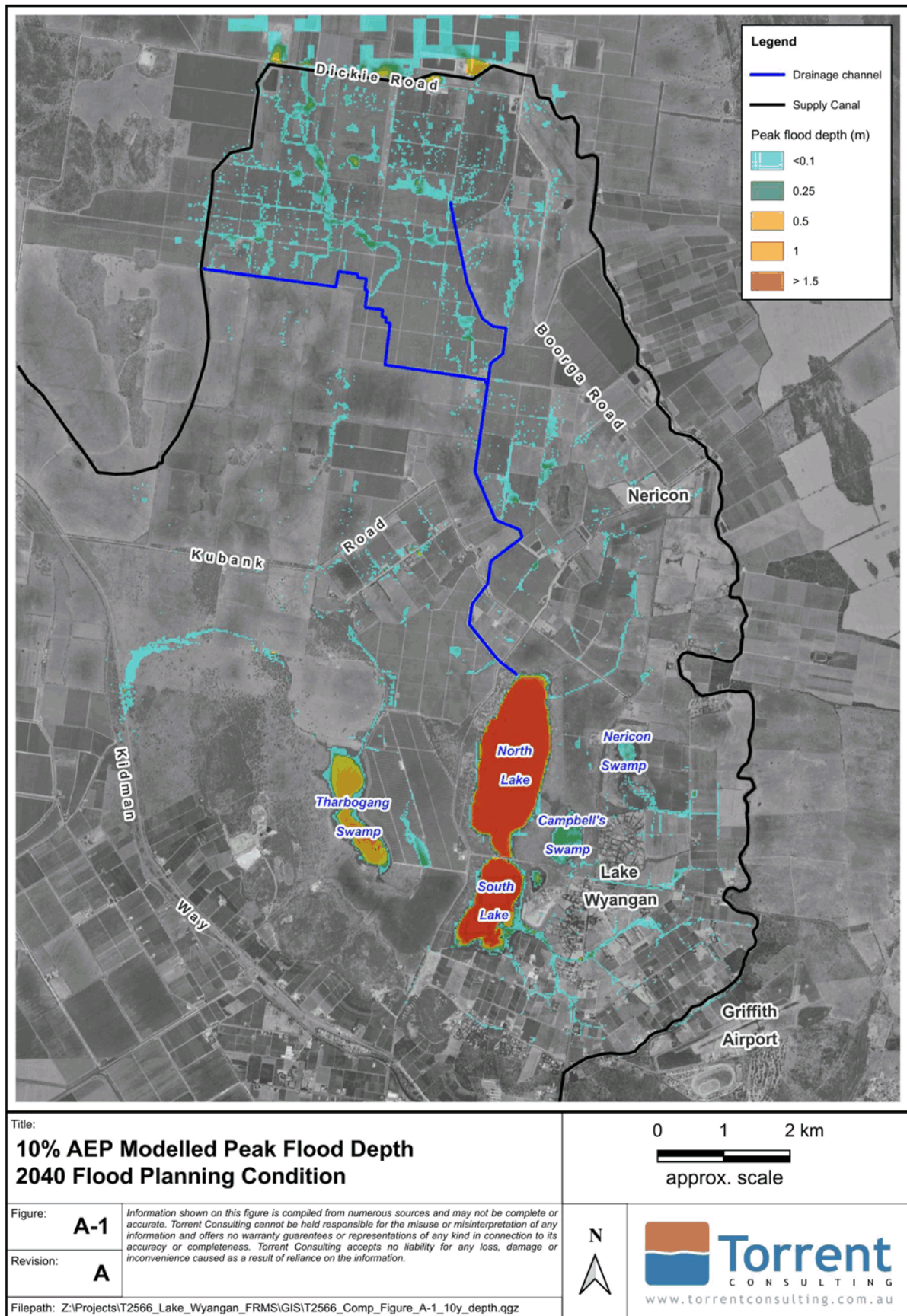
NSW Department of Planning and Environment (2023). *Flood Risk Management Manual*.

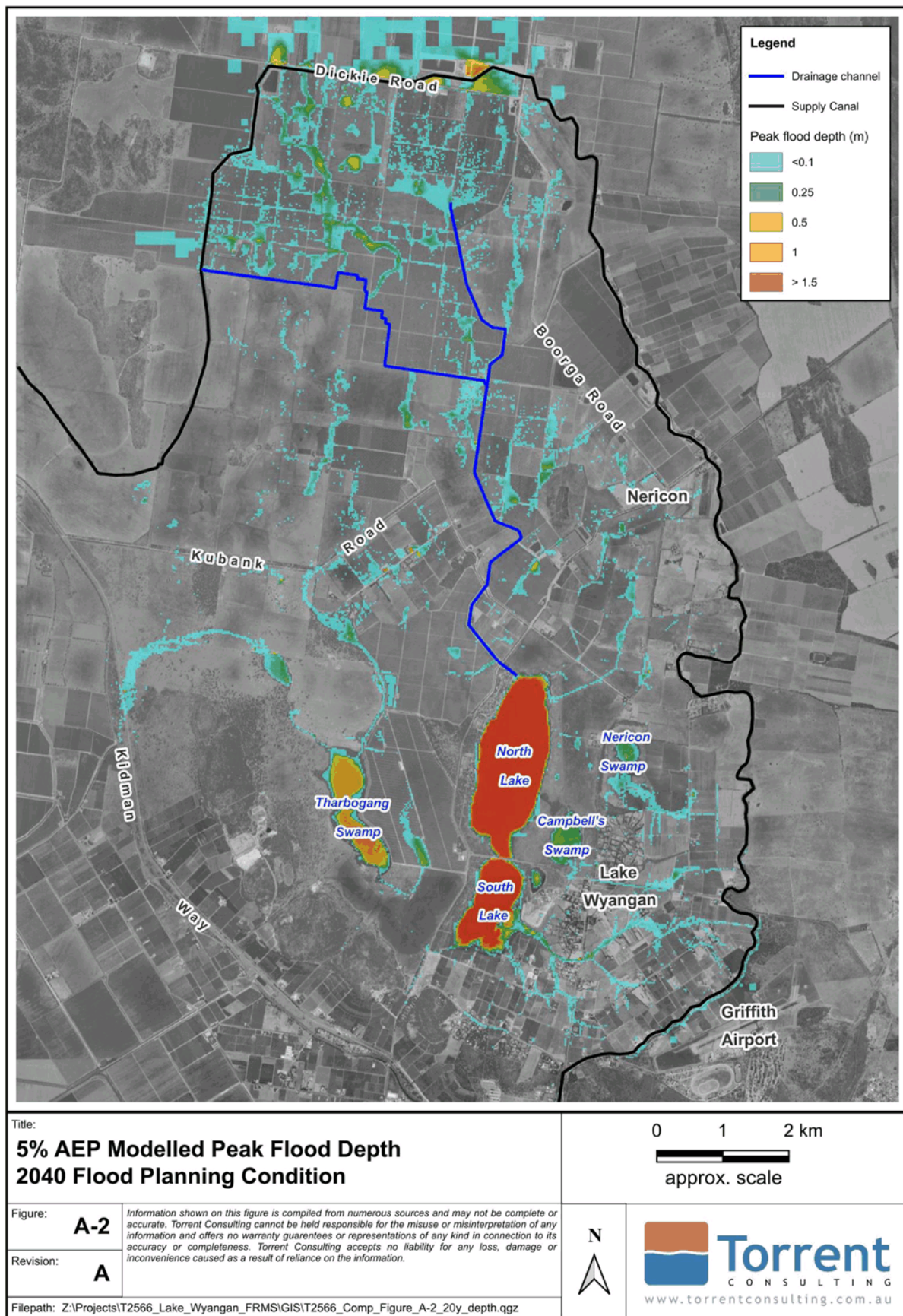
NSW Department of Climate Change, Energy, the Environment and Water 2025. *Digital soil maps for key soil properties over New South Wales, version 2.0, accessed from The Sharing and Enabling Environmental Data Portal* <https://datasets.seed.nsw.gov.au/dataset/22f358d9-e59f-4b00-8089-99aaa8d0f7d0>

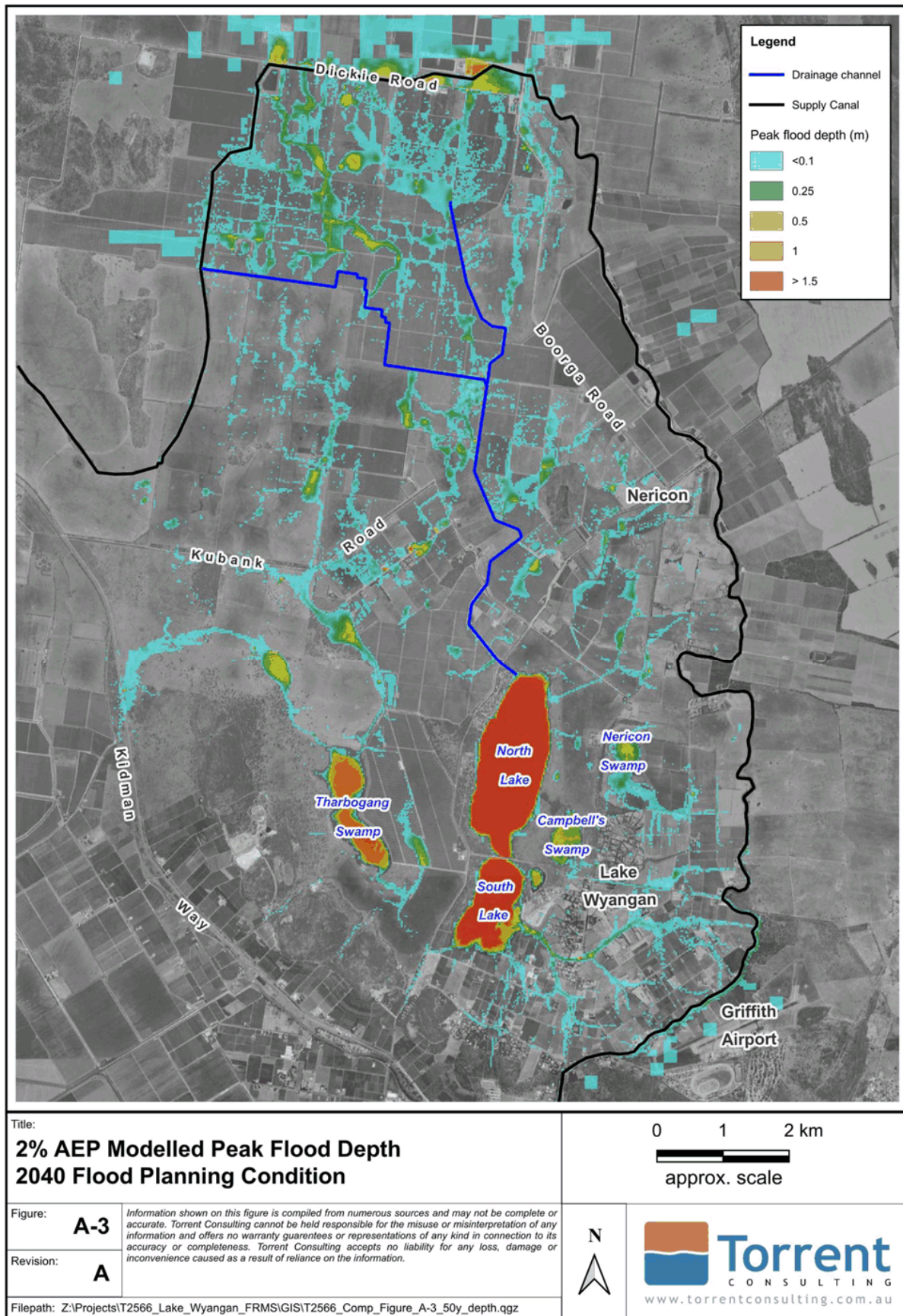
Queensland Department of Environment and Science (DES). *Model for Effluent Disposal using Land Irrigation (MEDLI)*.

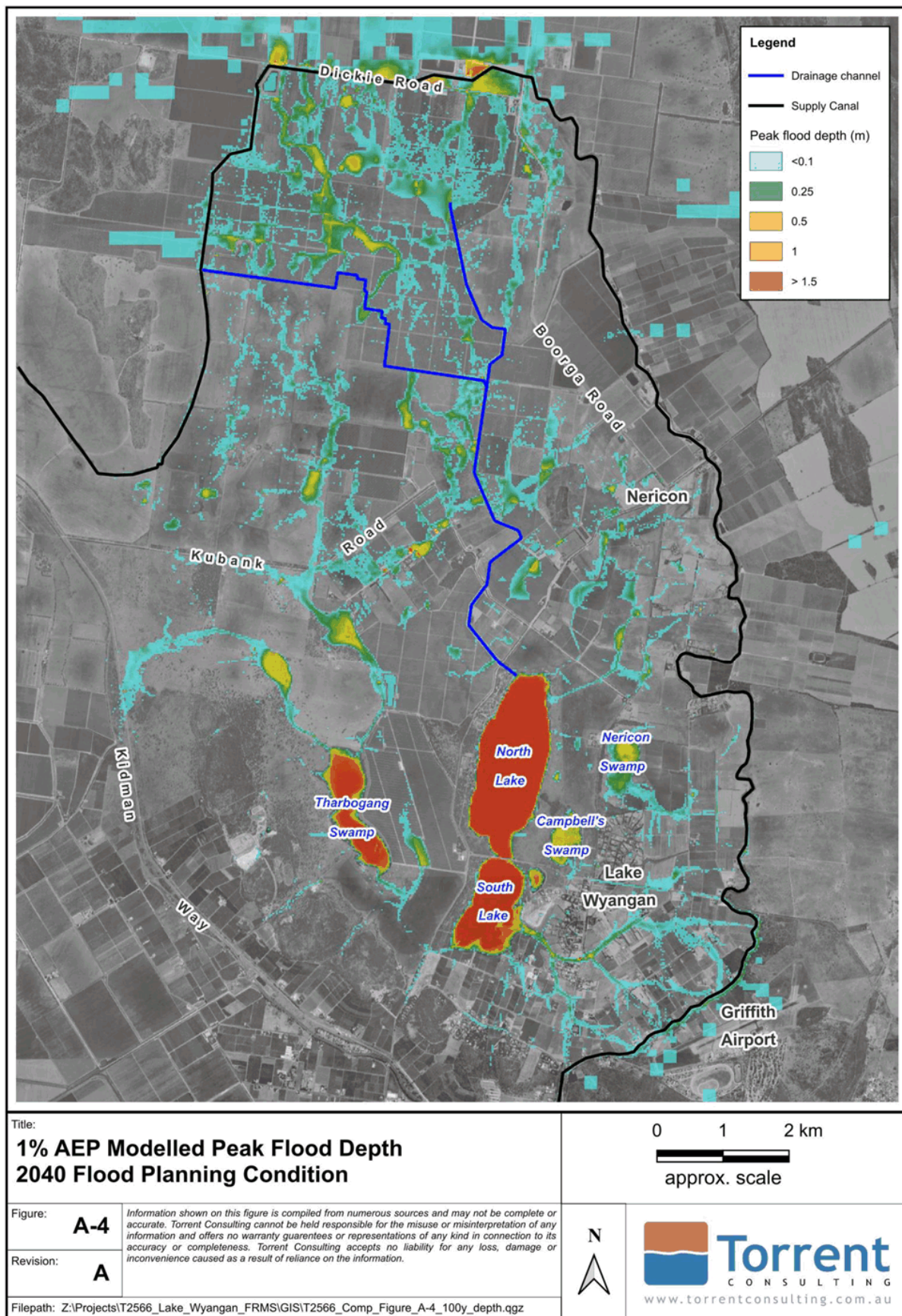
Viscarra Rossel, Raphael; Chen, Charlie; Grundy, Mike; Searle, Ross; Clifford, David; Odgers, Nathan; Holmes, Karen; Griffin, Ted; Liddicoat, Craig; & Kidd, Darren (2014): Soil and Landscape Grid National Soil Attribute Maps - Soil Depth (3" resolution) - Release 1. v4. CSIRO. Data Collection. <https://doi.org/10.4225/08/546F540FE10AA>

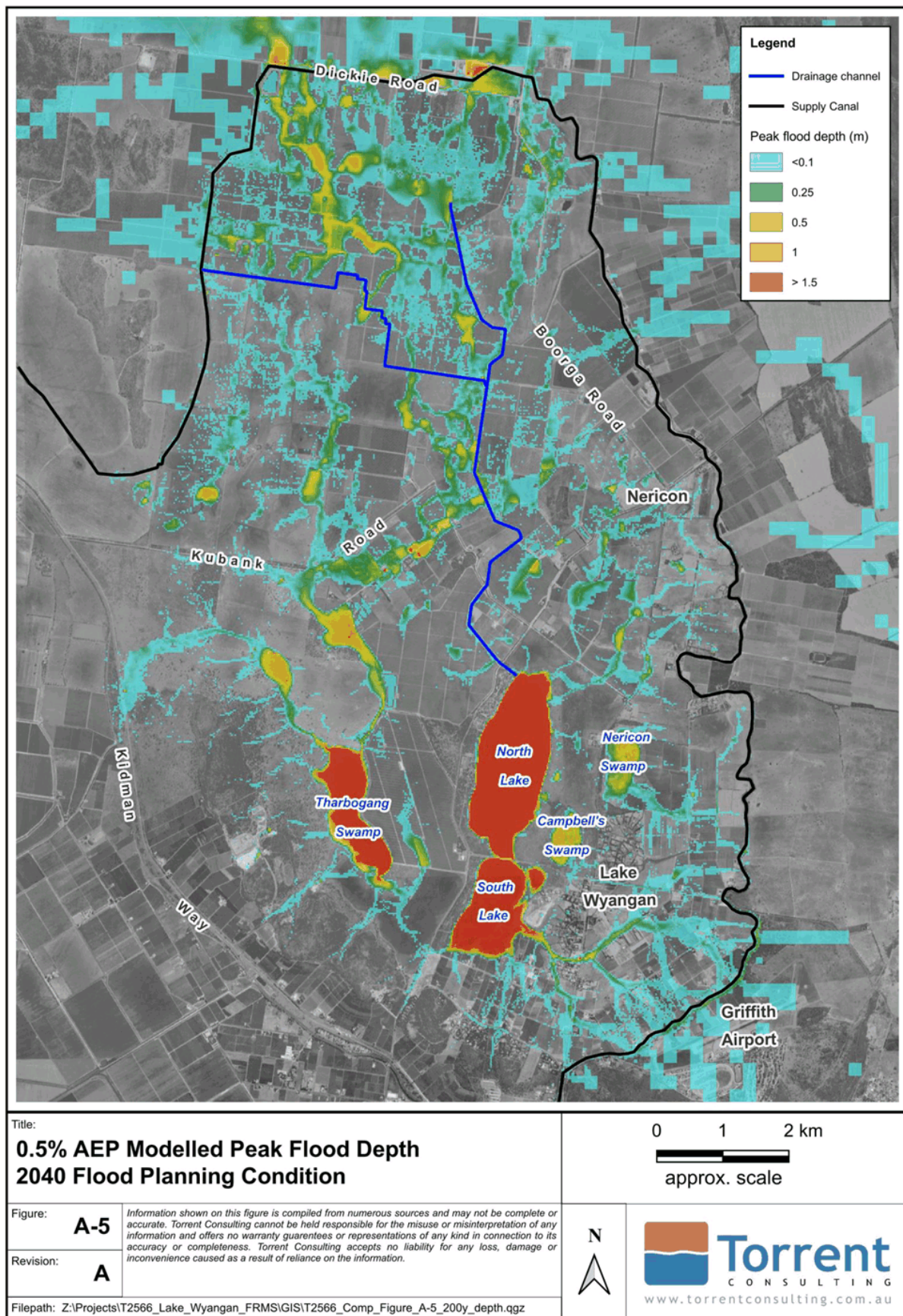
Appendix A Lake Wyangan / Tharbogang Swamp Design Flood Mapping

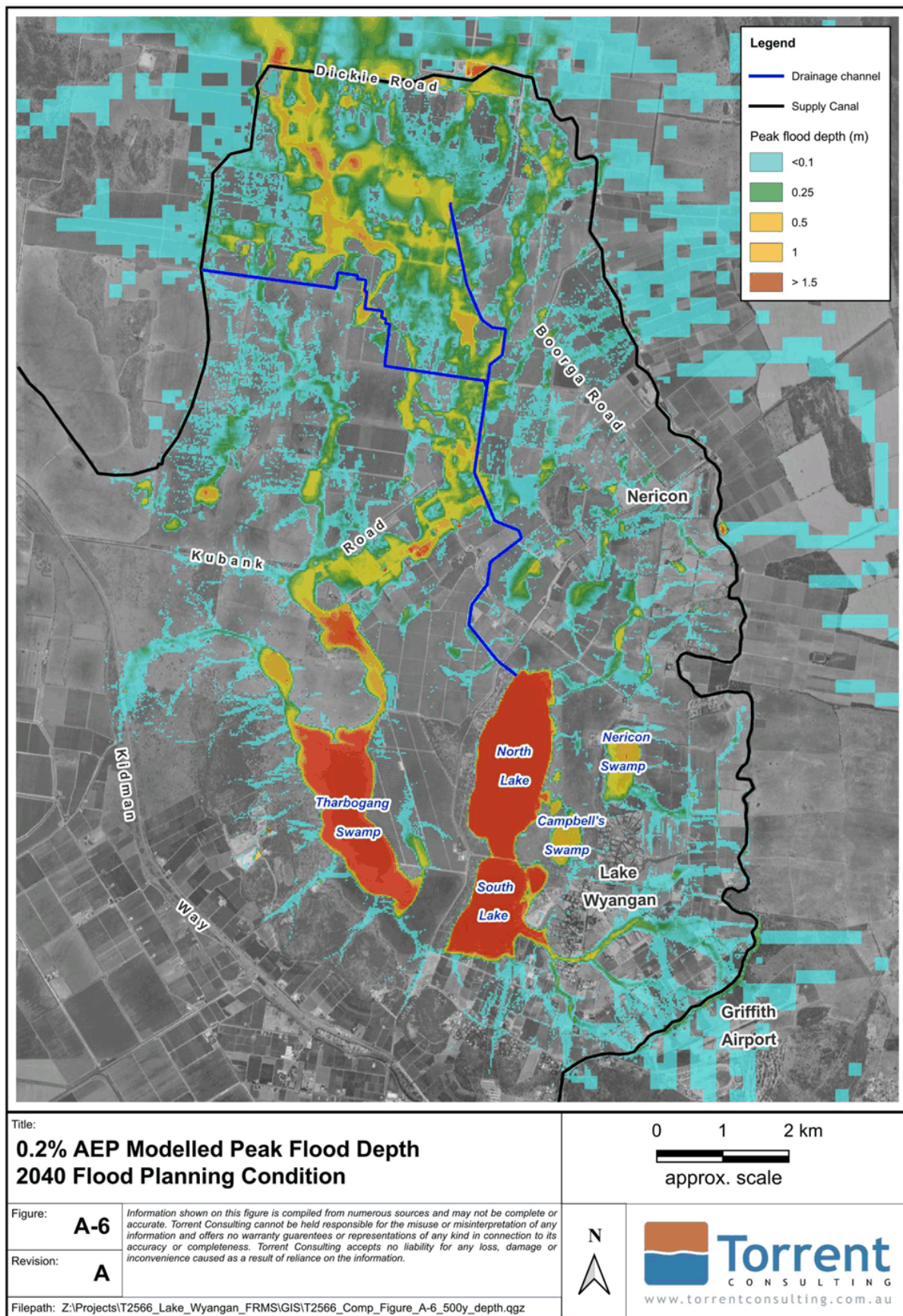


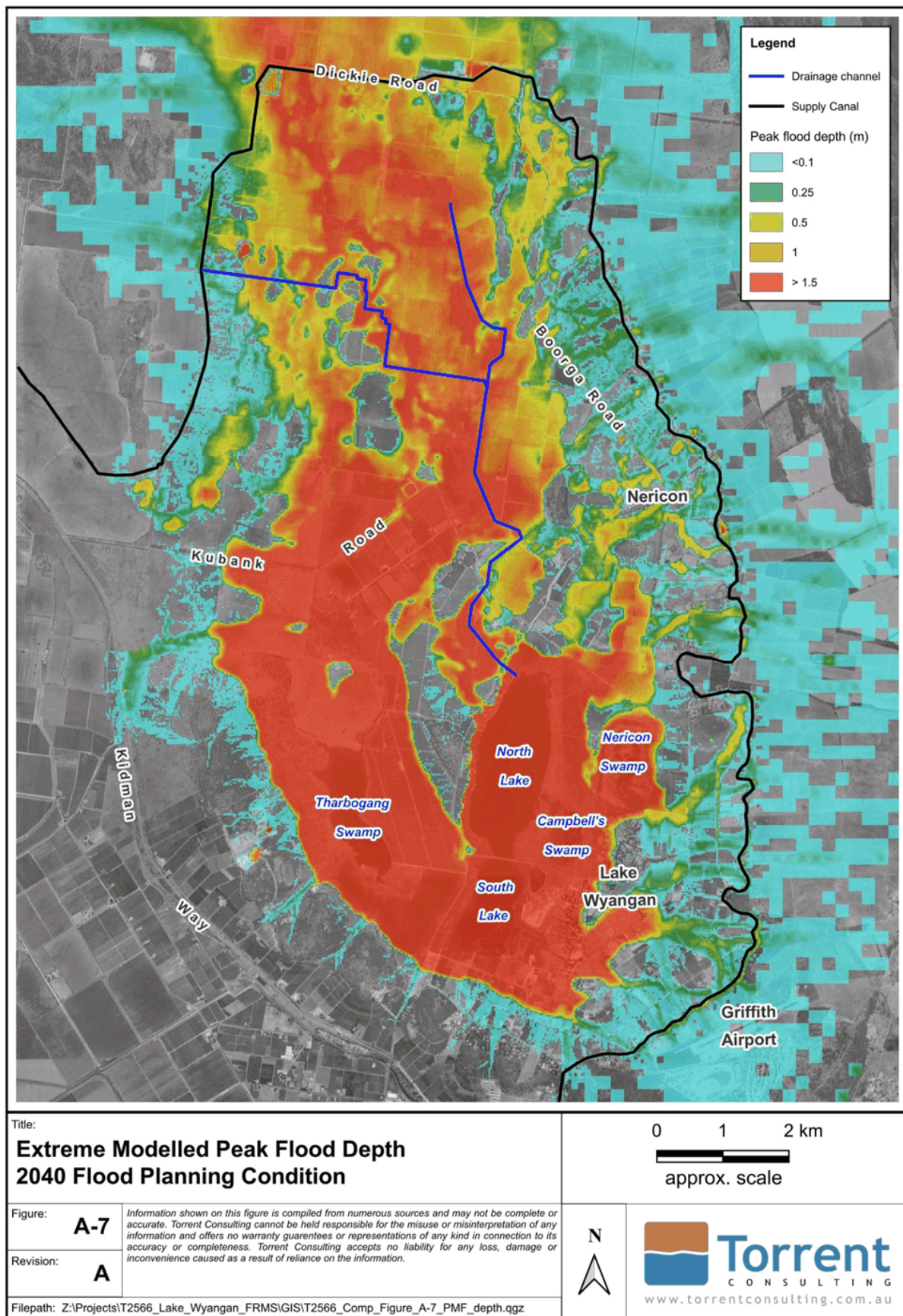


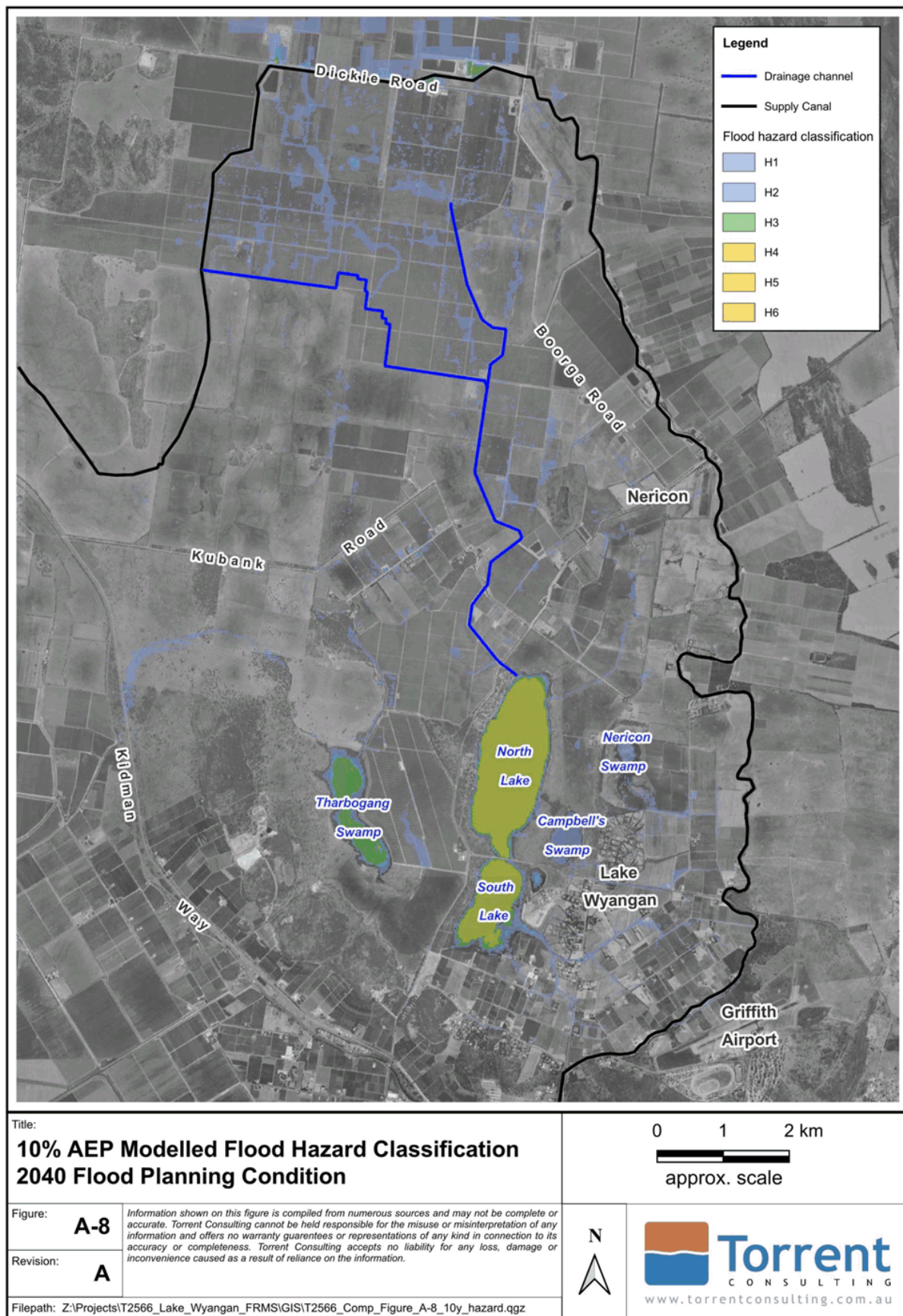


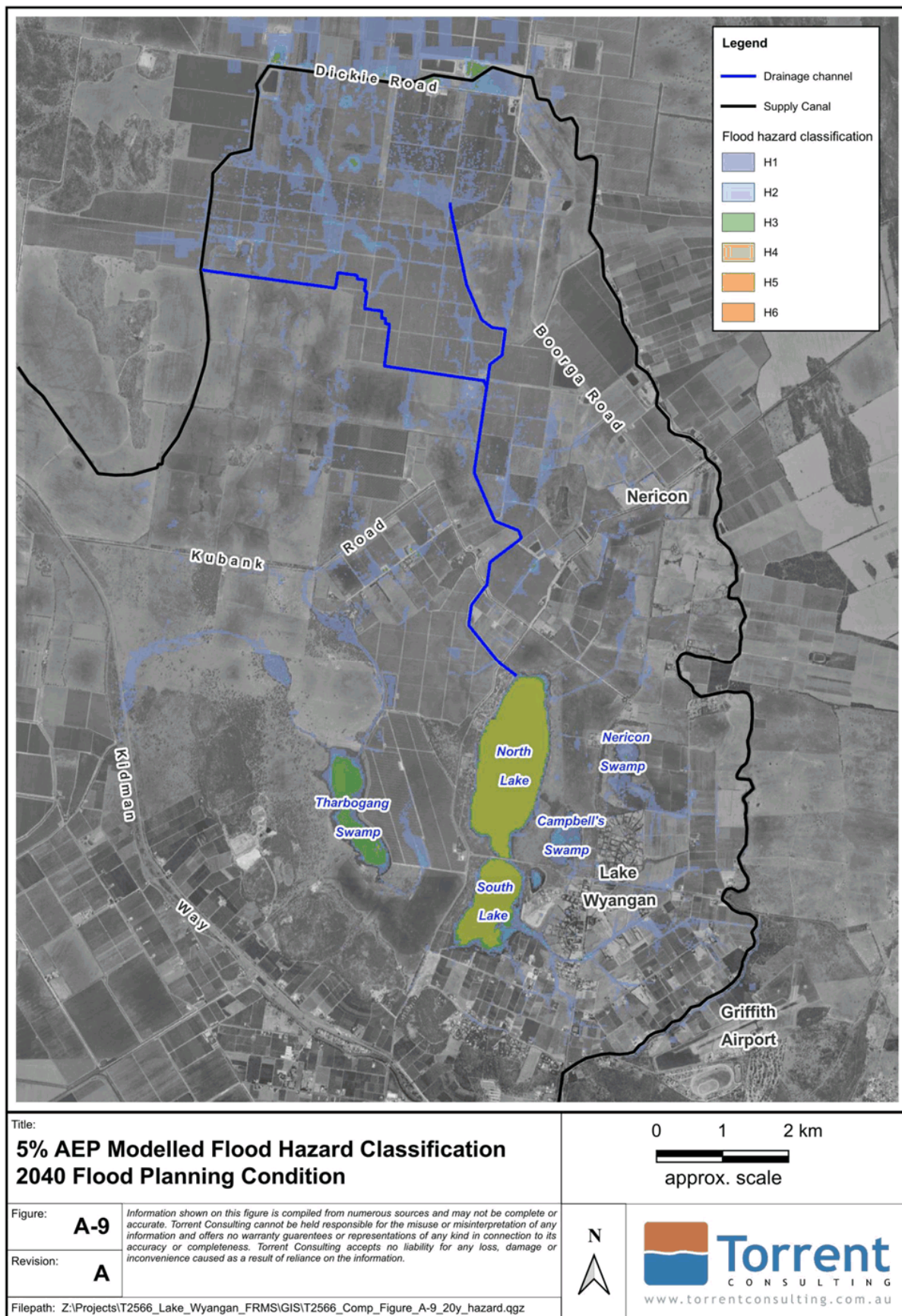


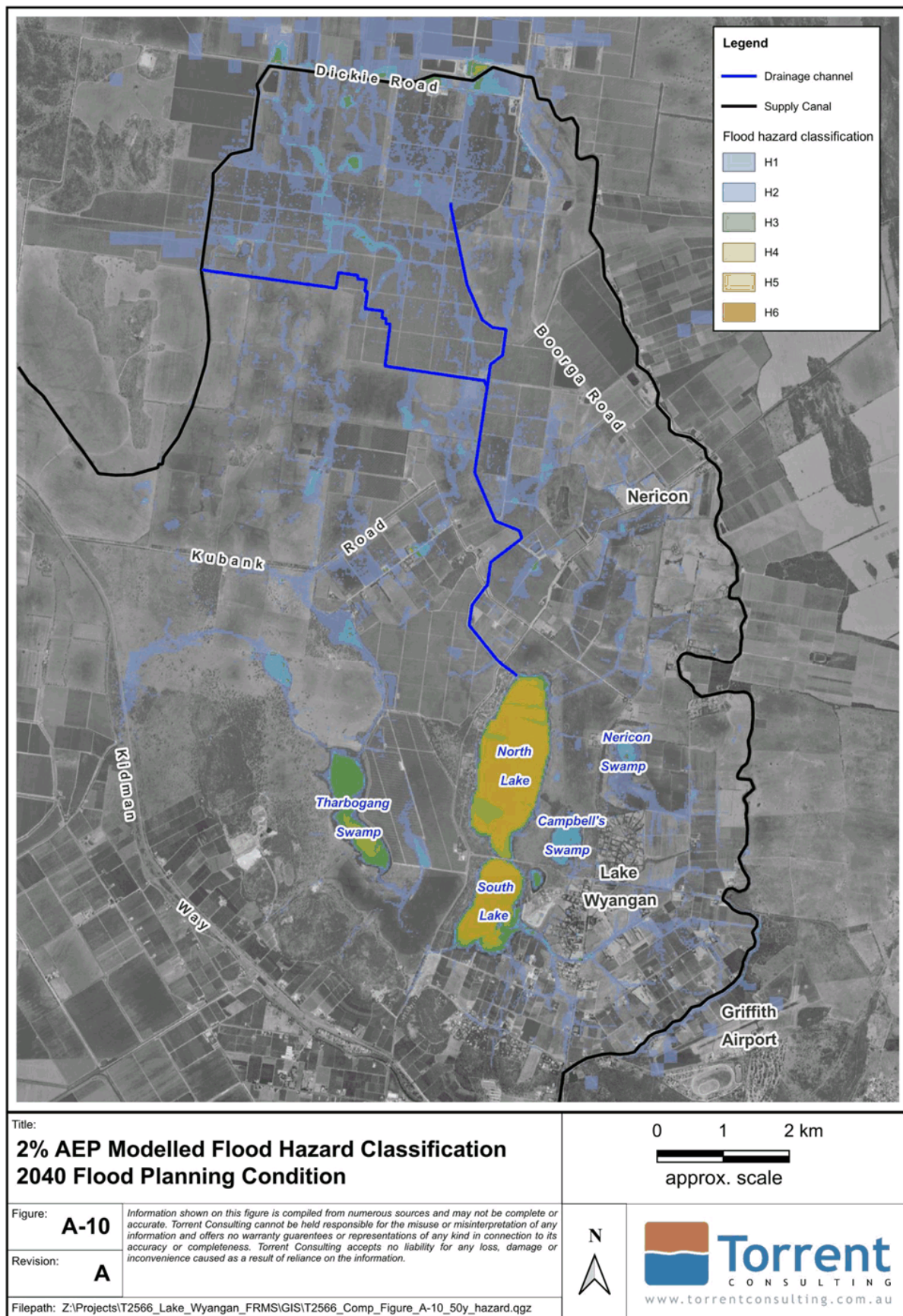


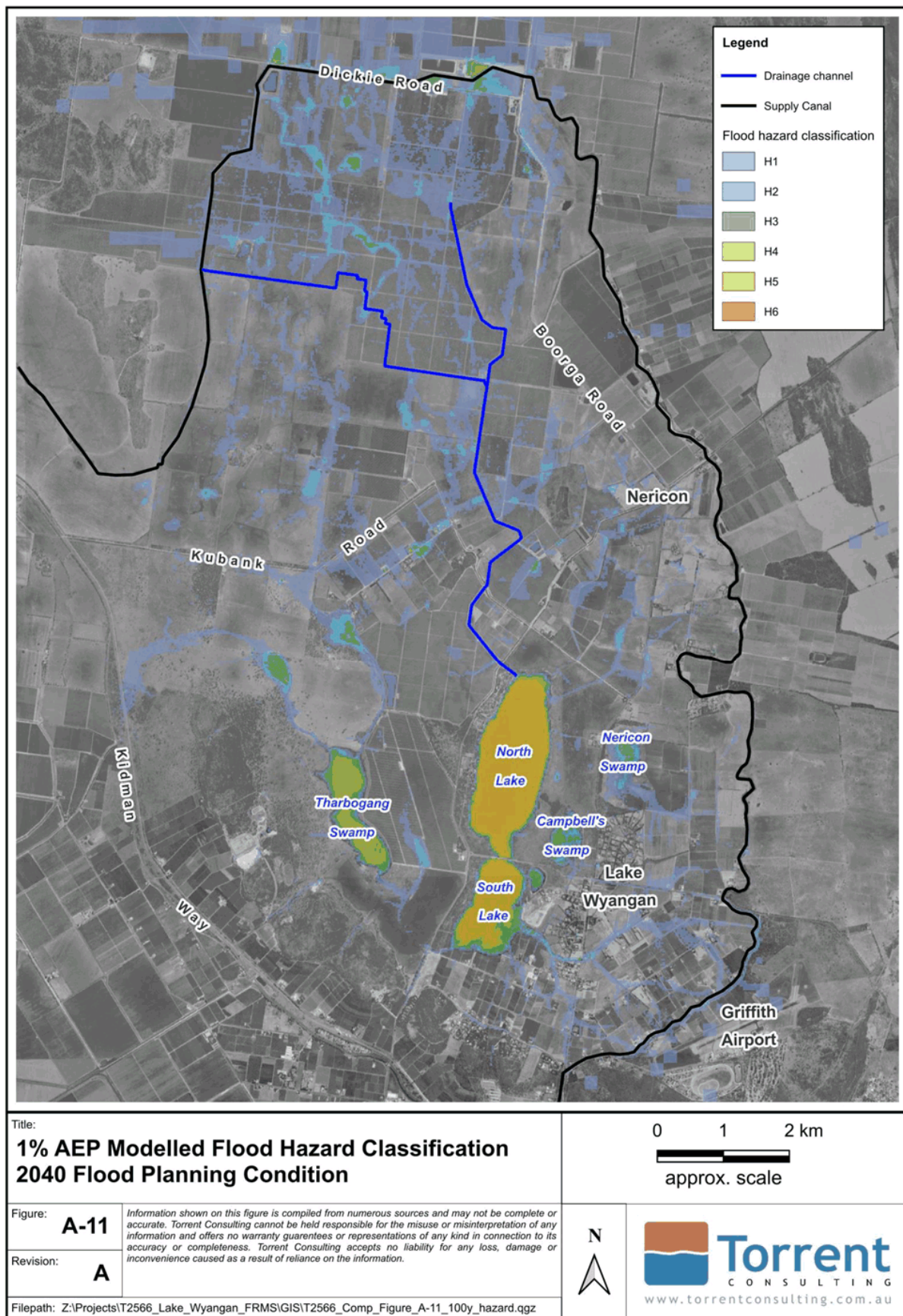


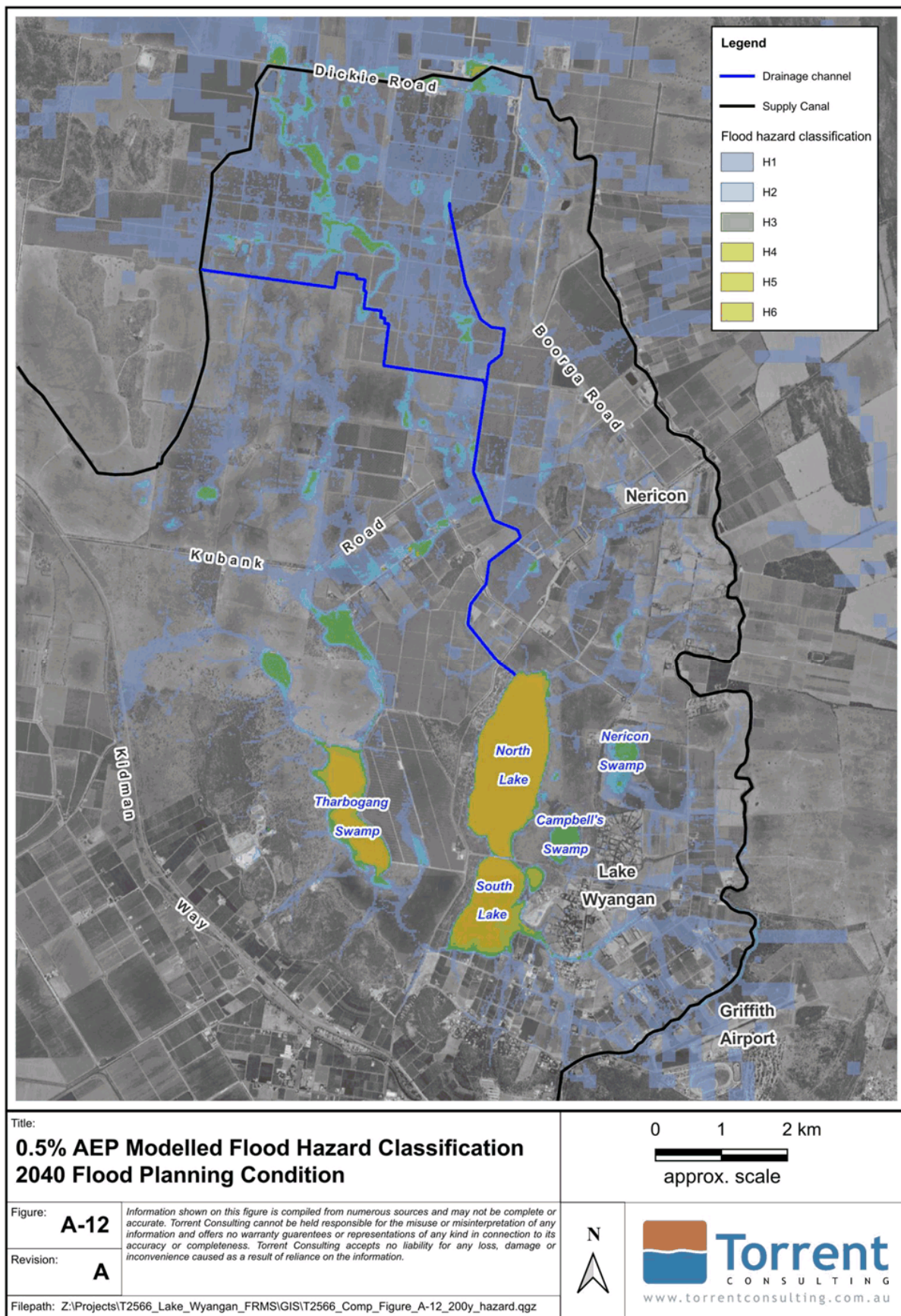


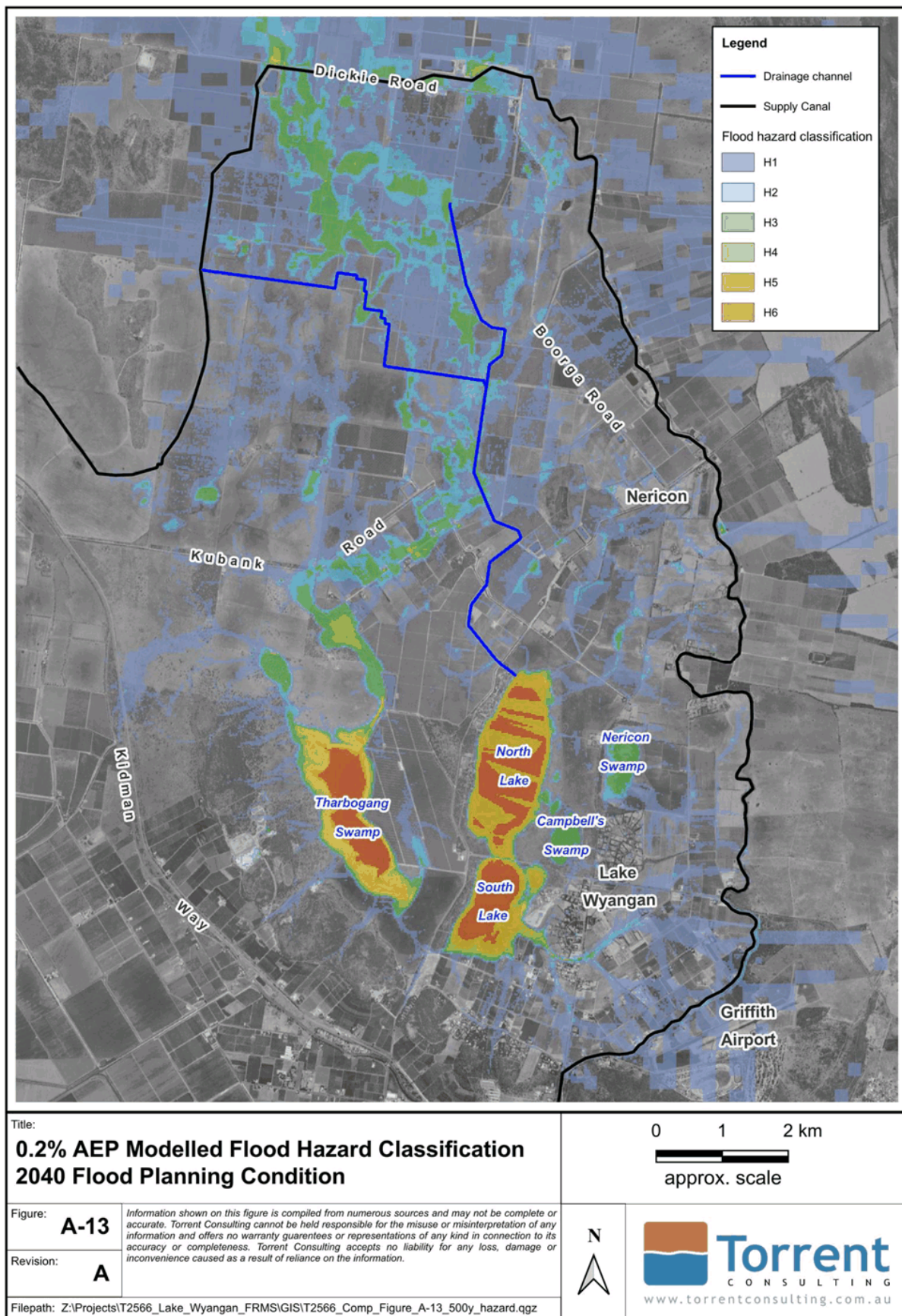


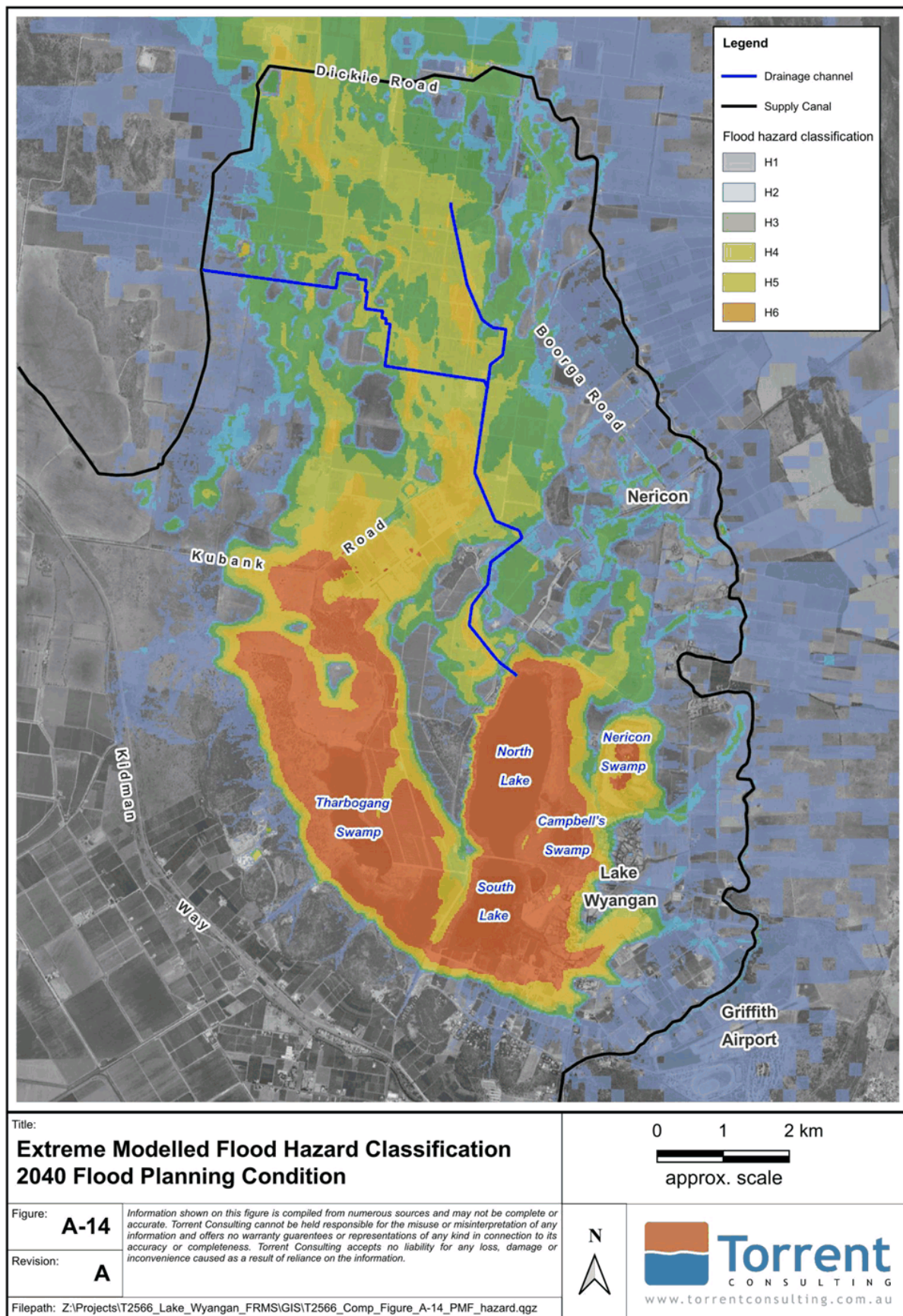


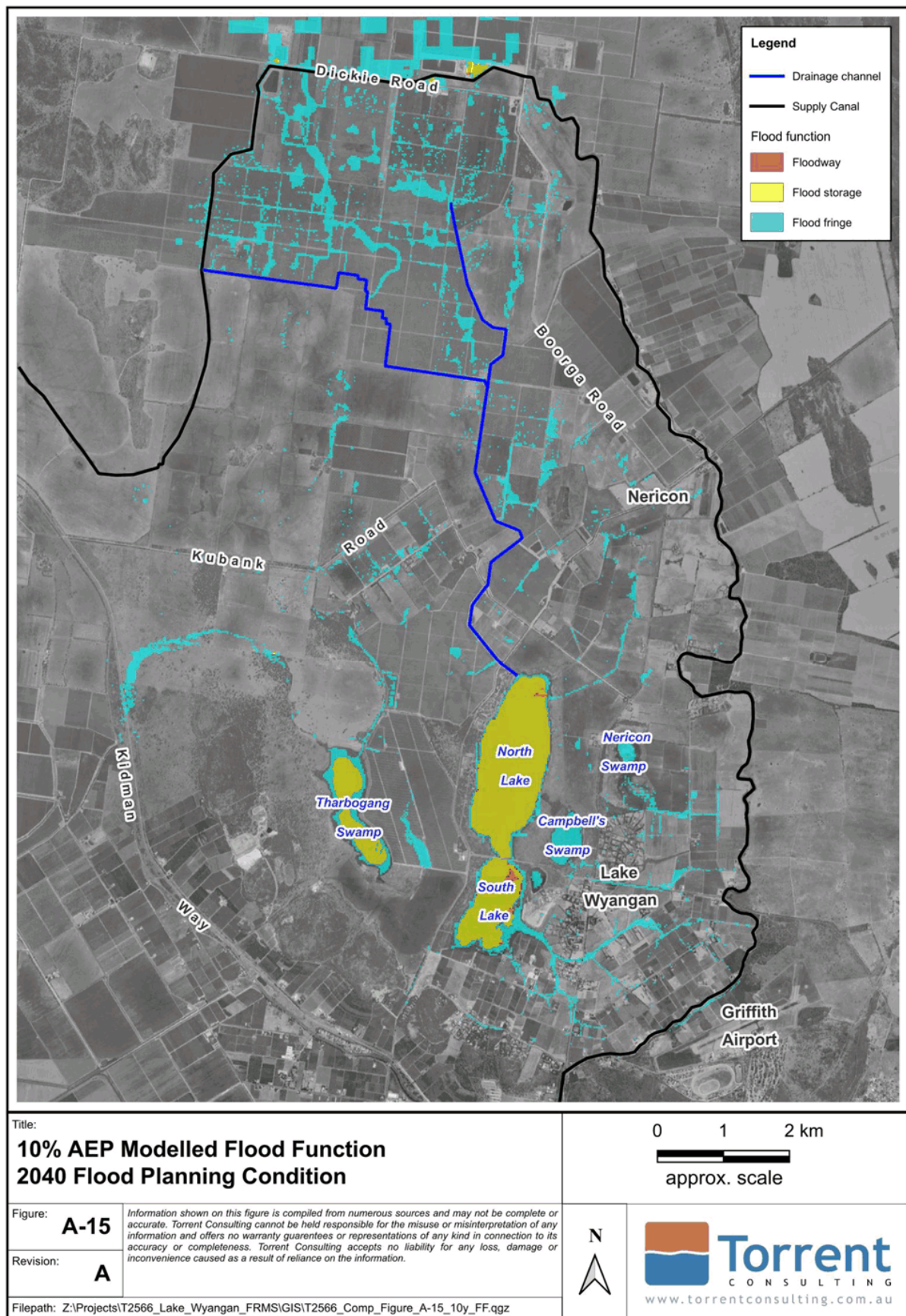


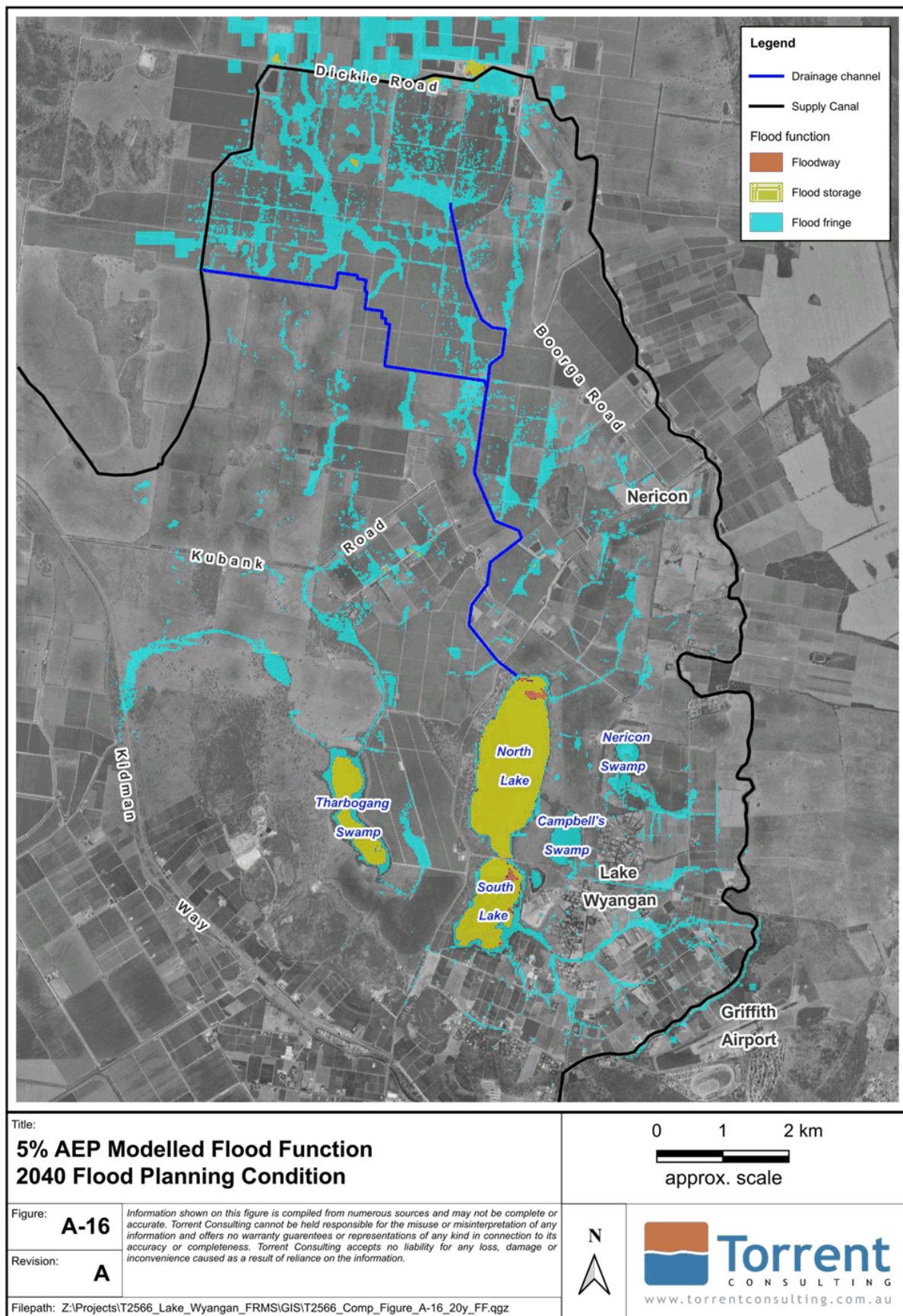


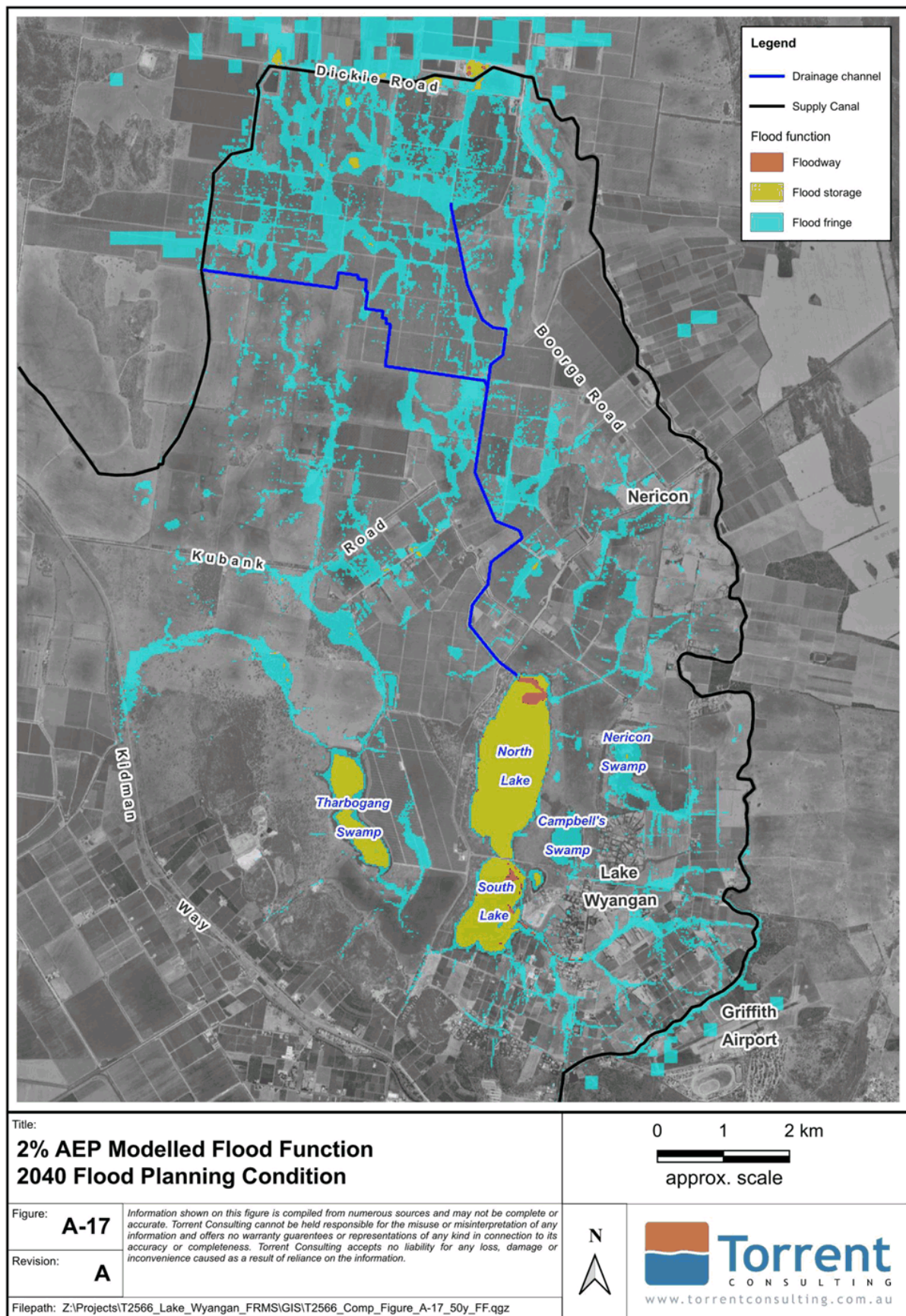


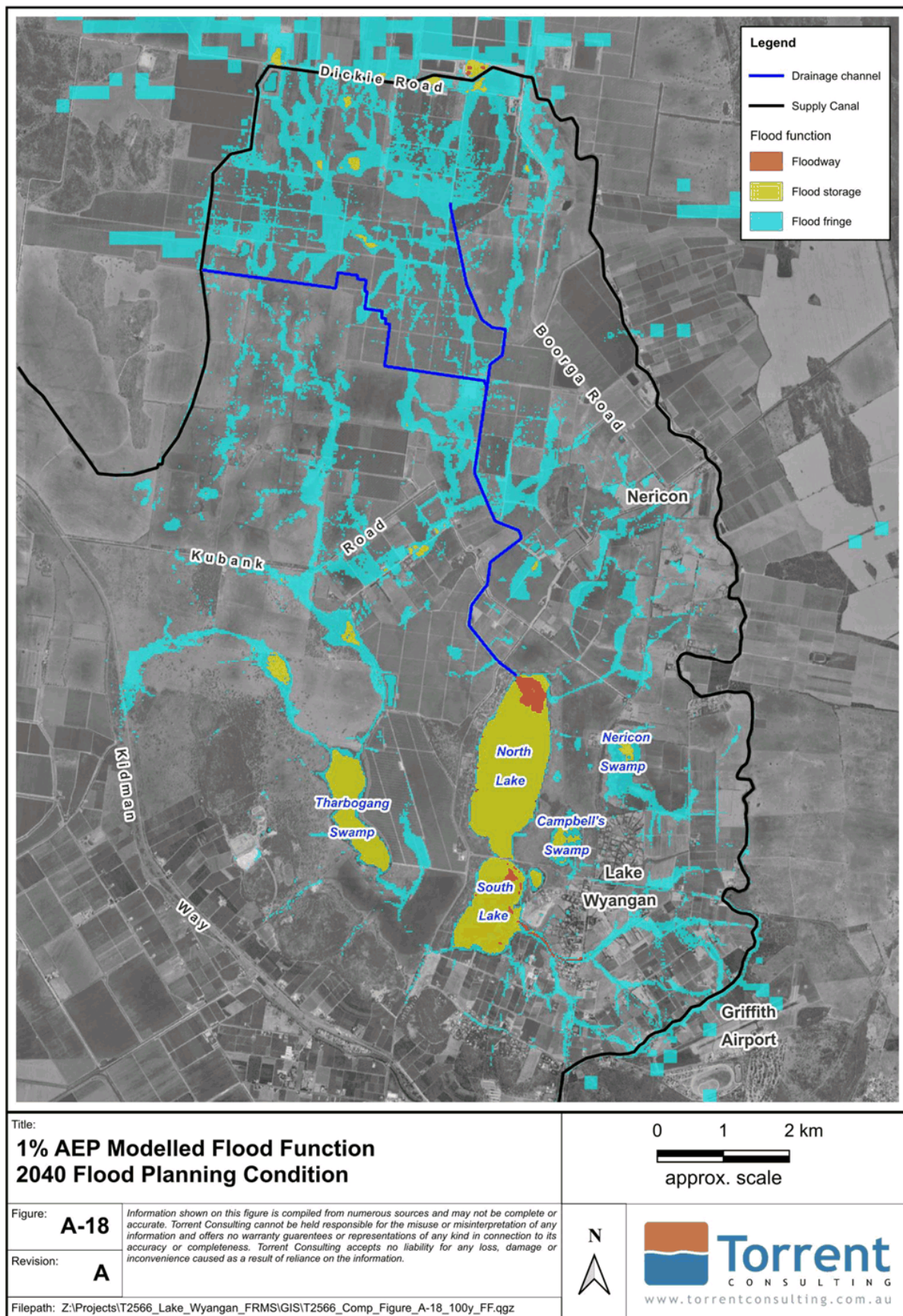


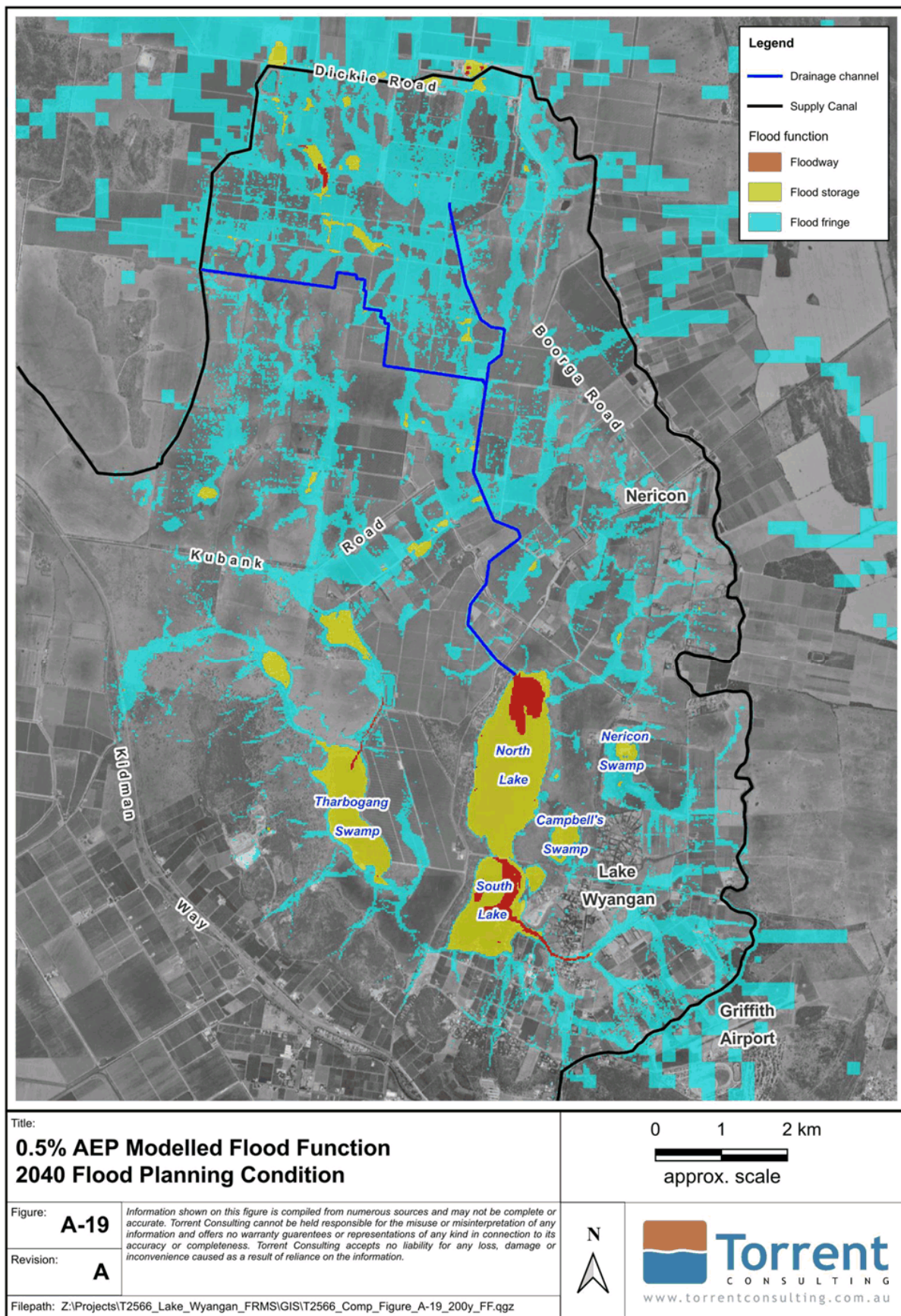


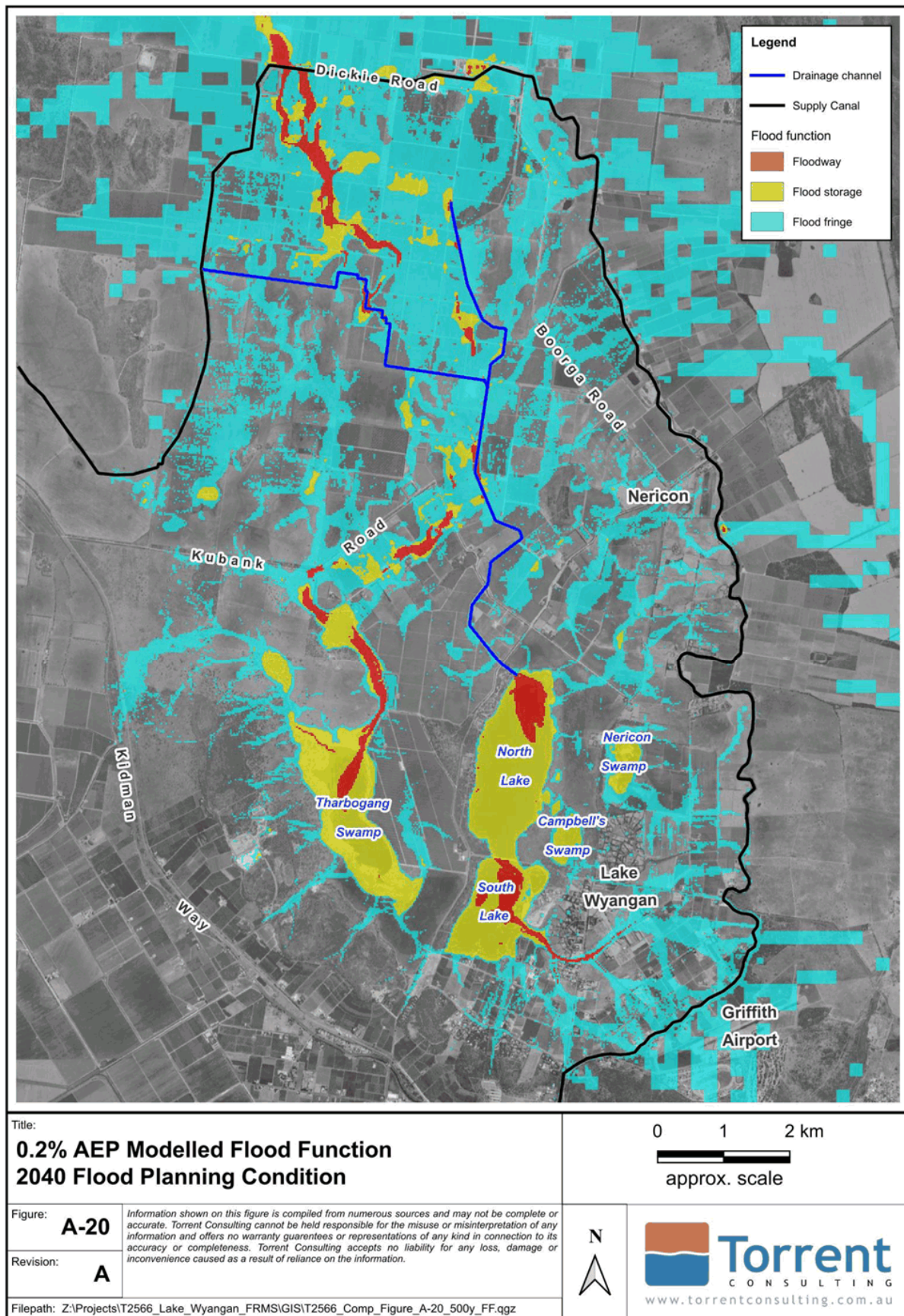


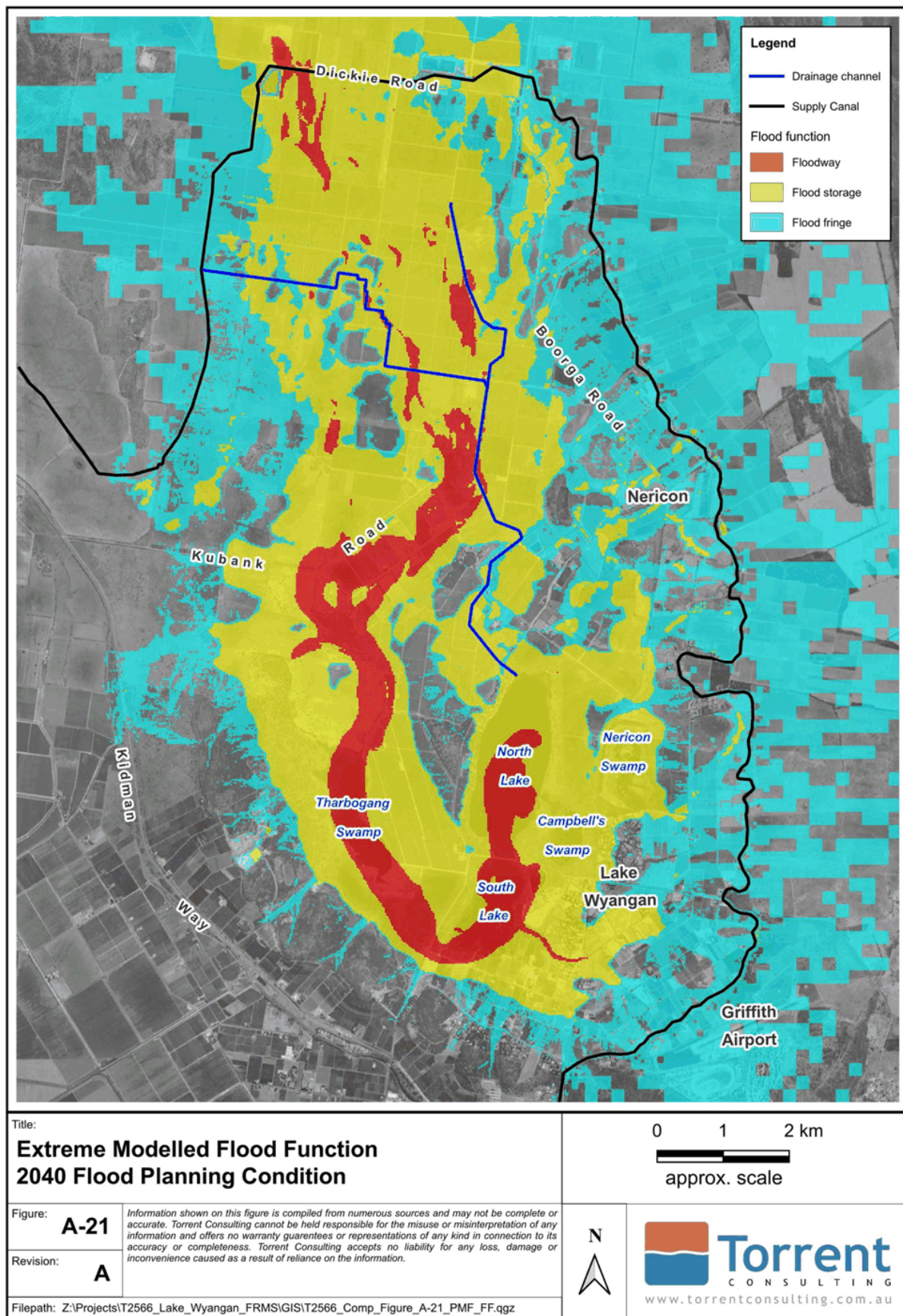


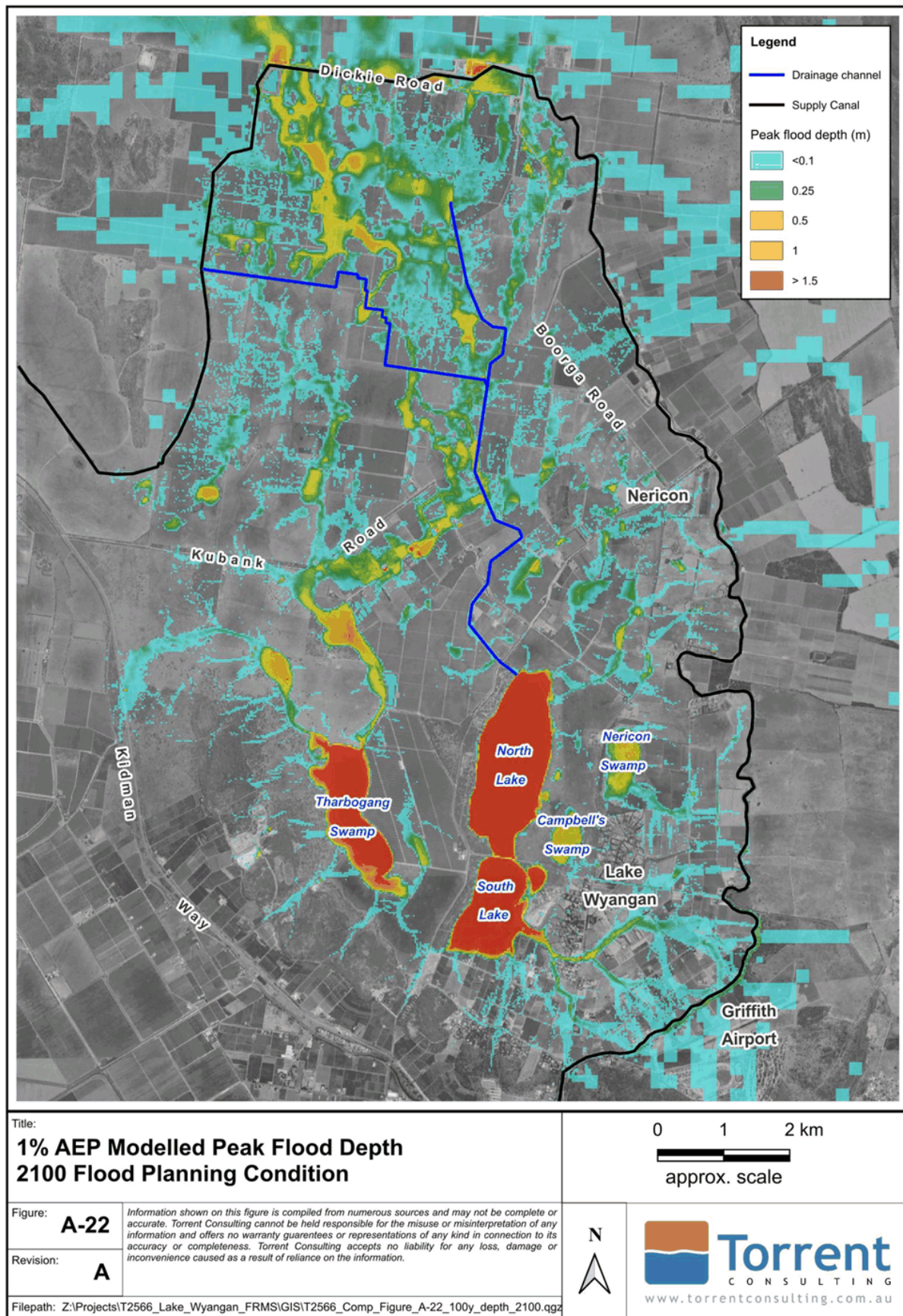


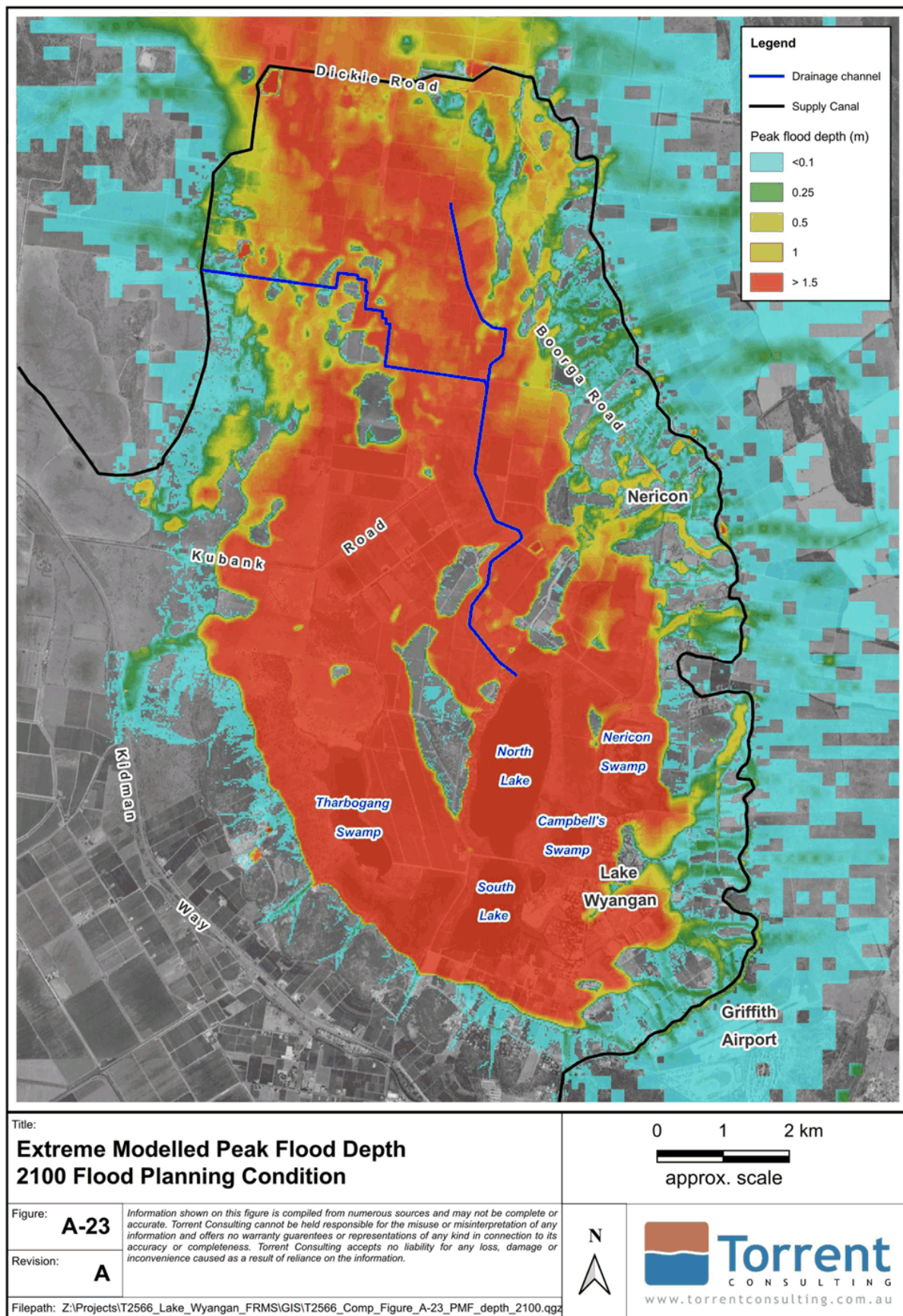


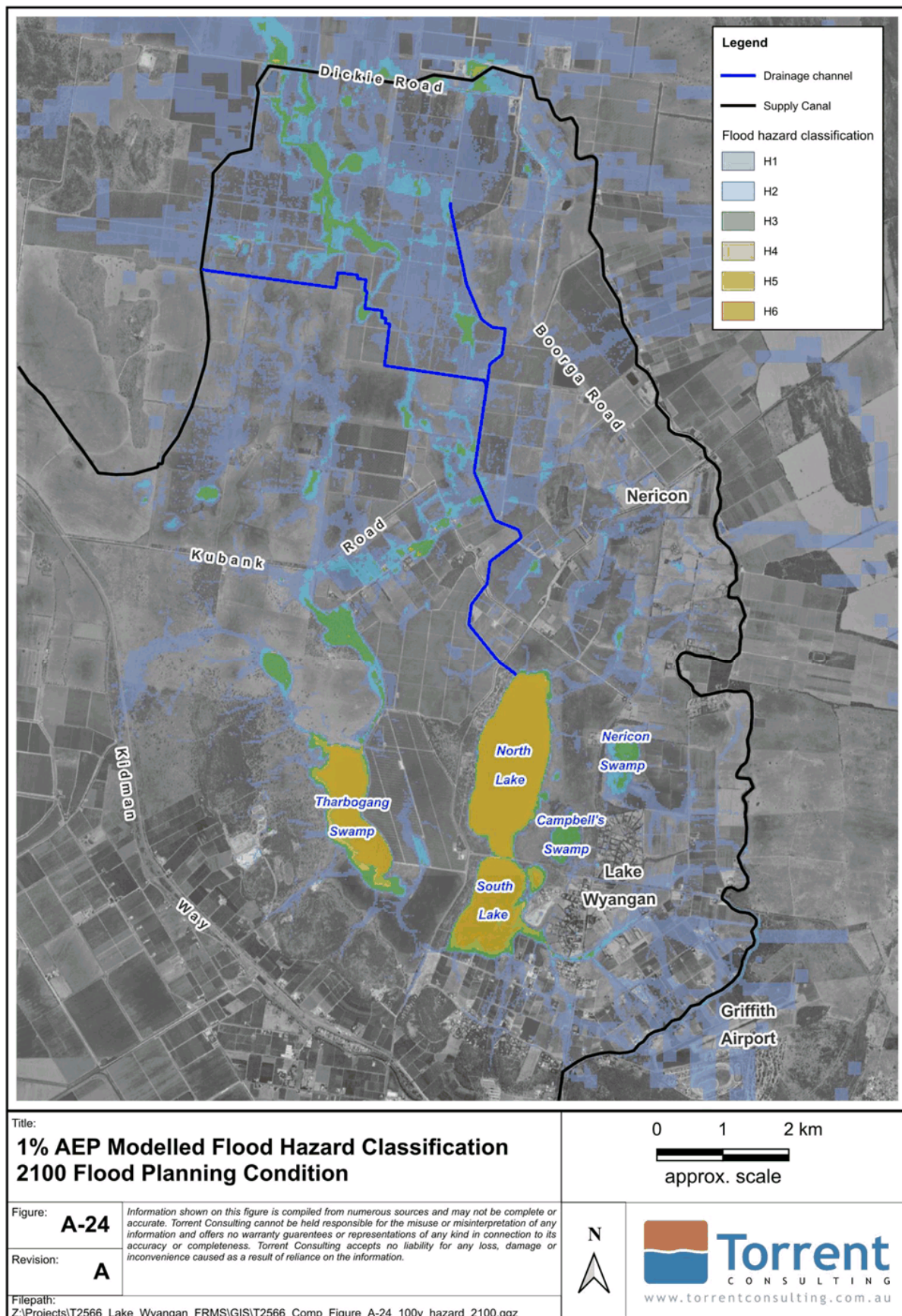


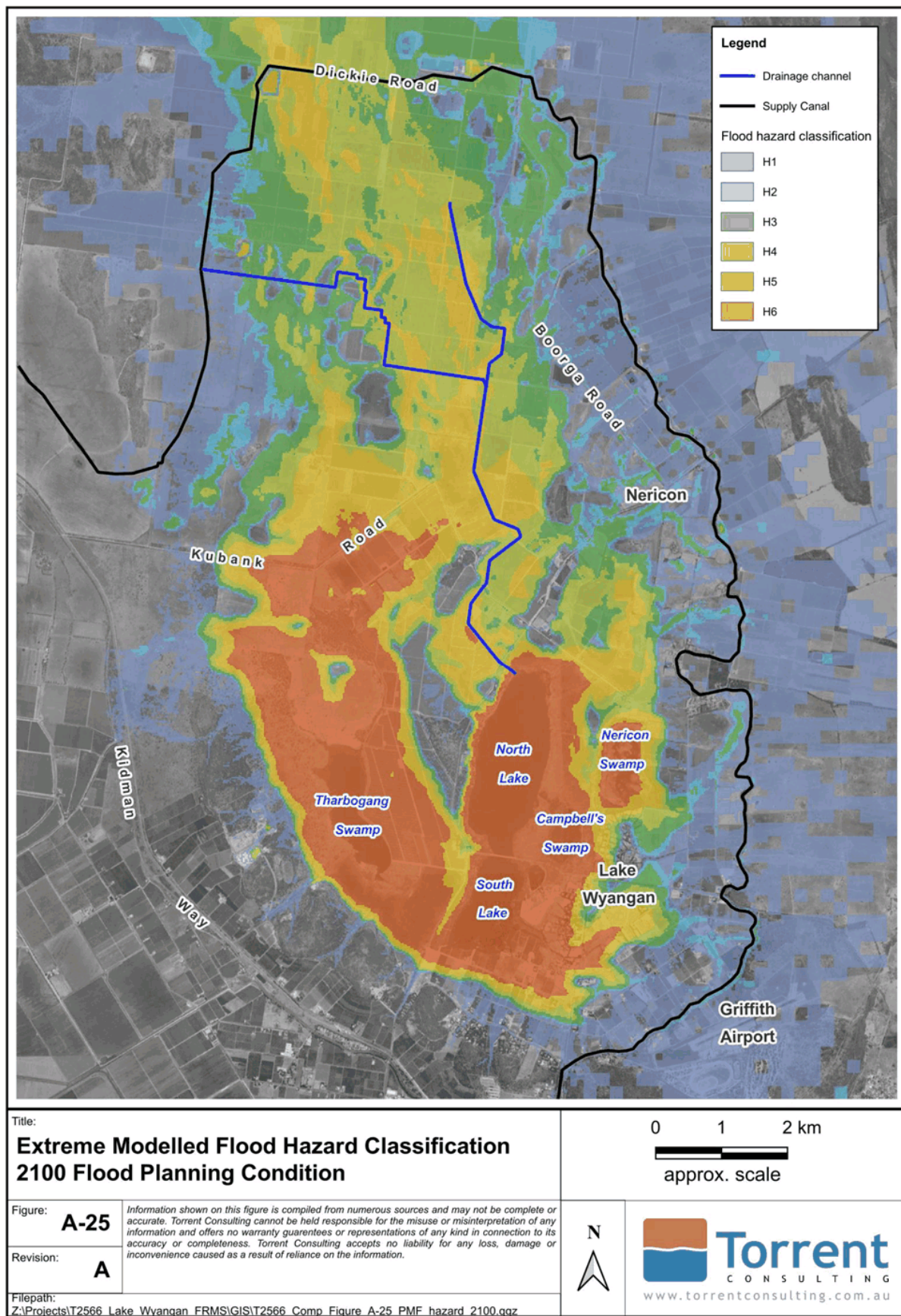


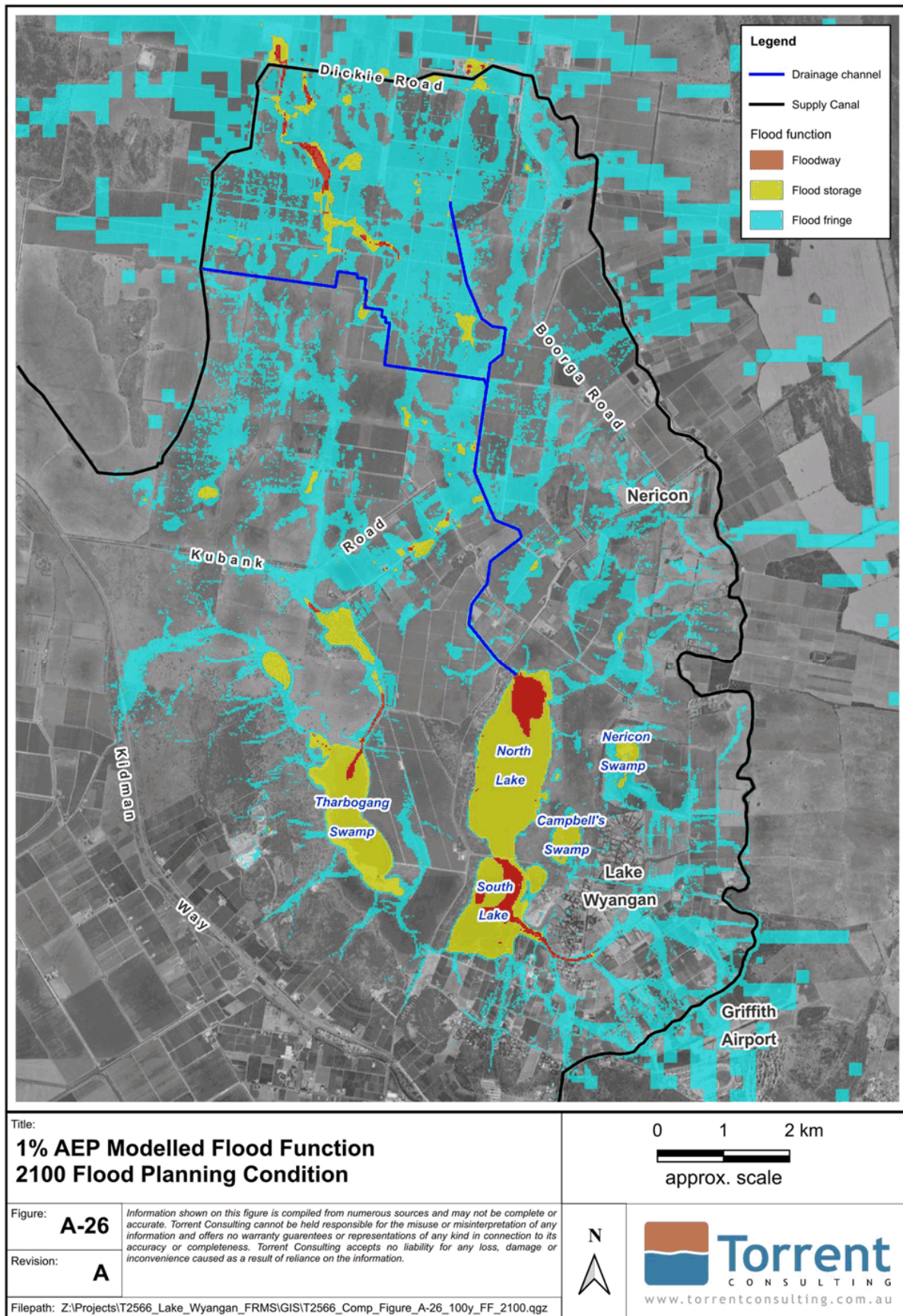


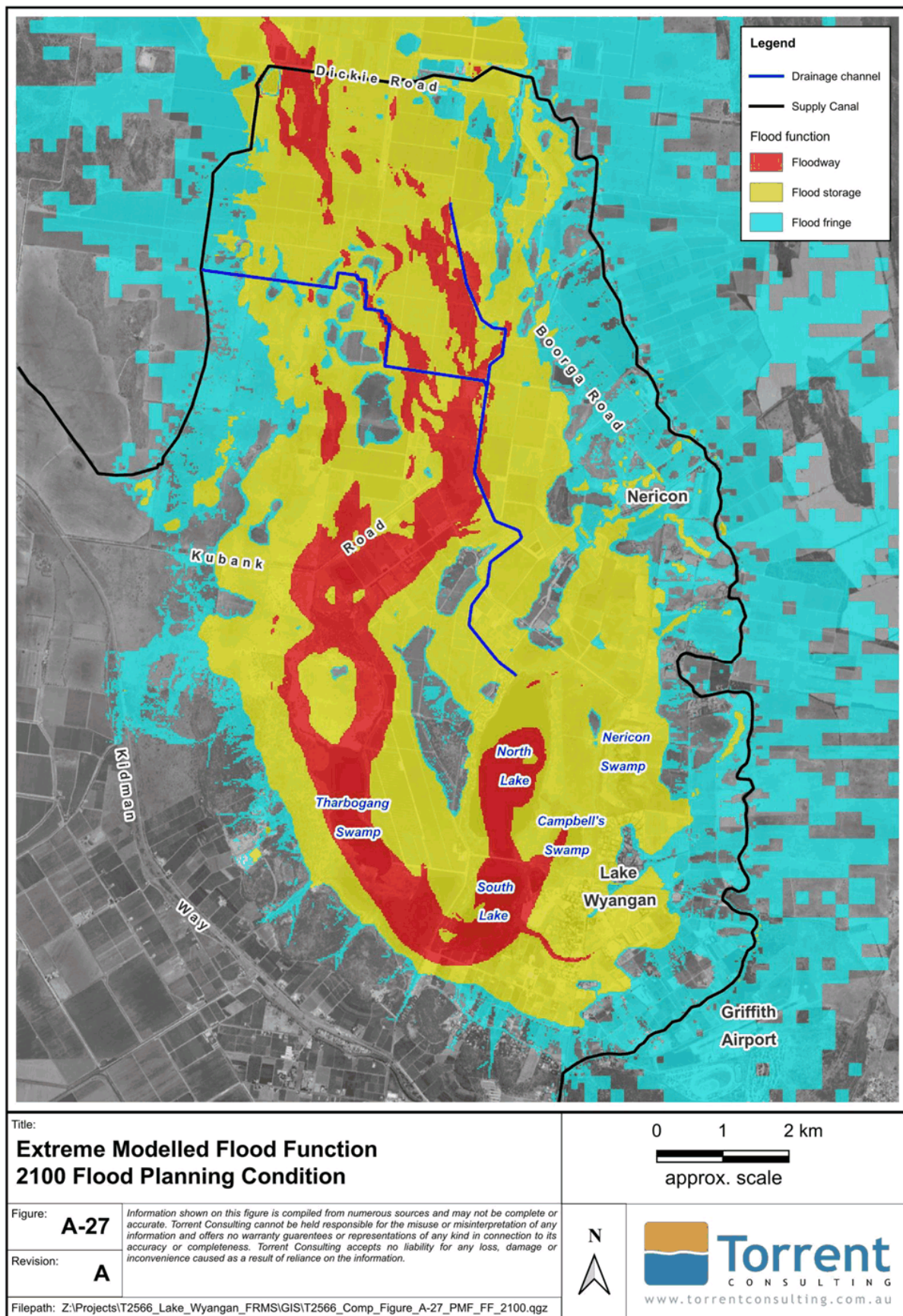












Appendix B Local Catchment Flood Mapping

