VICROADS

Princes Highway East Duplication – Kilmany Section

Hydrology and Hydraulic Investigations Report

February 2018

V4000_010

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1. INTRODUCTION

1.1 Objectives

The Princes Highway East Duplication Project (hereafter referred to as the, *highway duplication*) between Traralgon and Sale is being undertaken by VicRoads for the purpose of improving the traffic flow and road safety. The section of Princes Highway that is located between the towns of Rosedale and Kilmany from the Maffra-Rosedale Road and the Sale-Cowwarr Road, is scheduled to be the next section of the Highway to be duplicated and is the focus of this study.

Engeny Water Management (Engeny) has been engaged by VicRoads to complete a detailed hydrological and hydraulic study for the various major waterway crossings for this section of the highway duplication. The highway duplication works within the study area are presented in Figure 1.1.

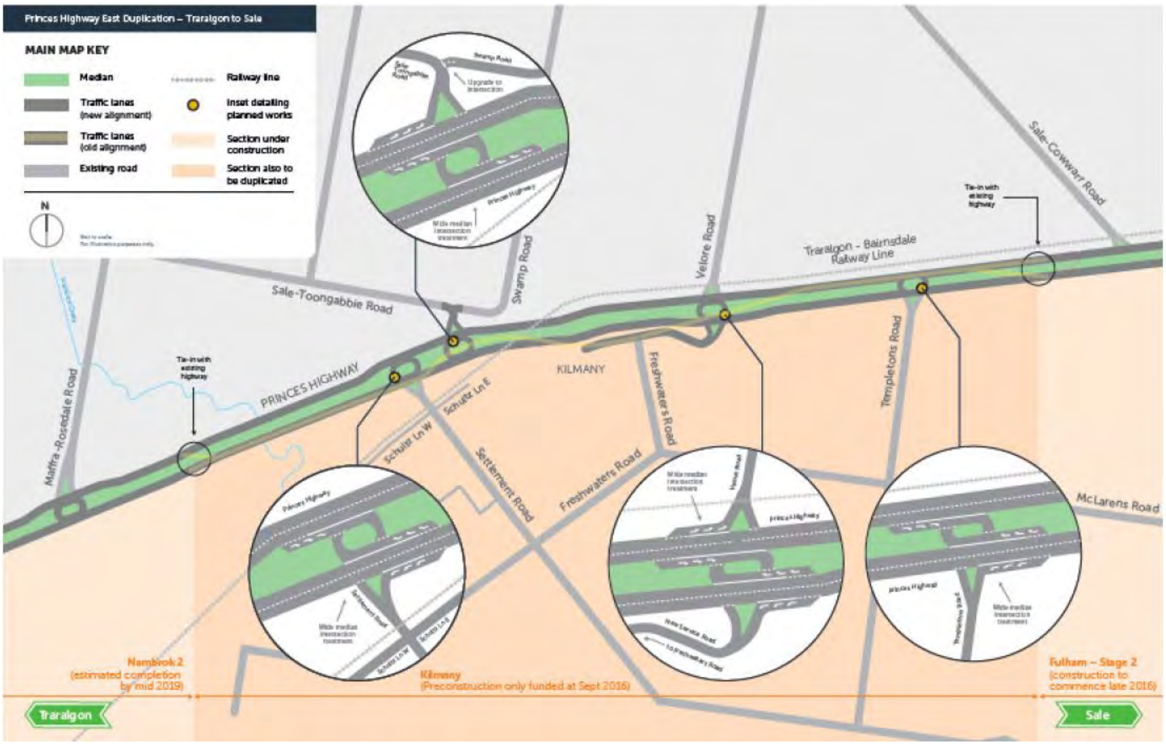


Figure 1.1 Princes Highway Duplication works: Maffra-Rosedale Rd to Sale Cowwarr Rd (source: VicRoads)

The primary objectives for this study was as follows:

- Estimate existing flooding conditions at the highway duplication
- Inform the VicRoads reference design regarding road surface levels and the configuration of major waterway structures

- Inform VicRoads' design and construct project partners with respect to the hydraulic requirements for the various road crossing designs during that stage of the project.

1.2 Scope

The scope for this study was as follows:

- Review previous relevant hydrological and hydraulic studies
- Liaise with the relevant authorities to confirm hydraulic performance criteria and any design requirements
- Review of historical hydrological information, including streamflow and rainfall data
- Estimate design event hydrographs using RORB hydrological models for the 1 %AEP event
- Input design hydrographs into a one dimensional (1D) and two dimensional (2D) TUFLOW hydraulic model to determine existing conditions flooding (extents, depths, etc.)
- Provide commentary on the potential impact of undertaking the duplication works through this area
- Recommend road levels and waterway structures that could be implemented to achieve the hydraulic design criteria
- Undertake hydraulic modelling under developed conditions to confirm the recommended road levels and waterway structures.

1.3 Authorities

1.3.1 Context

The Princes Highway East Duplication Hydrology and Hydraulic Investigation is situated within the Wellington Shire Council (WSC) municipal area and within the West Gippsland Catchment Management Authority (WGCMA) waterway management area. The study area also contains a number of irrigation channels and drains that are part of the Macalister irrigation district, which is administrated by Southern Rural Water (SRW). The aforementioned authorities have an interest in the duplication project from a surface water perspective. Within the study area, the management of drainage and flooding is shared between the WGCMA and SRW as summarised in Table 1.1.

Table 1.1 Management of drainage and flooding in the study area

Drainage/Floodplain element	Authority	Comment
Waterway structures (e.g. culverts) crossing the Princes Highway	VicRoads	Owned and managed by VicRoads in consultation with SRW.
Minor Road cross drainage	SRW	Cross drainage associated for all minor roads in the area forms part of the Macalister Irrigation District.
Gippsland No 2 drain (Nambrok Creek)	SRW	-
Gippsland No 3 drain	SRW	-
All irrigation channels	SRW	-
Floodplain	WGCMA	-

1.3.2 Hydraulic performance criteria

Hydraulic performance criteria were provided by the authorities for the purposes of informing the hydraulic design. These are presented in Section 6.

2. DATA

2.1 Summary of data

The data presented in Table 2.1 was used to inform this study.

Table 2.1 Data summary

Data	Source	Use
2007-08 SRW Ninety Mile Beach LiDAR	WGCMA	Used as the basis for the digital elevation model (DEM) used for the definition of catchments for the hydrologic model.
Survey DEM	SGSC	Used to verify and augment the LiDAR data at a number of locations
October 2014 Aerial (.ecw)	DELWP	Used to inform impervious fraction for the hydrological model and roughness selection for the hydraulic model
Planning zones (.tab)	DELWP	Used to inform the preliminary impervious fraction selection for the hydrological model and roughness for the hydraulic model.
Rainfall data	Bureau of Meteorology	Used for the calibration of the RORB hydrological model.
Chapter 17 Surface Drainage of Irrigation Areas: Part I, Principles	SRW	Used for the calibration of the RORB hydrological model.
VicRoads structure data (.pdf) (SN2890, SN2893, SN2894)	VicRoads	Used to inform structure representation within the hydraulic model.
Irrigation channel details (050905.tif)	SRW	Used to inform channel and structure representation within the hydraulic model.
VicRoads preliminary highway duplication design. Typical cross sections.	VicRoads	-
Site survey (29210-lis--es-01.dgn)	VicRoads	Used to augment the LiDAR DEM adopted for the hydraulic modelling.
VicRoads road design surface (759-pf-a-3ds-01.dgn)	VicRoads	Used to augment the LiDAR DEM adopted for the hydraulic modelling under developed conditions.

2.2 Relevant studies

The following hydrological/hydraulic studies were reviewed as part of this study:

- Traralgon East to Kilmany EES and Draft PSA Surface Water Assessment Report (GHD, 2011)

  The surface water assessment was undertaken by GHD on behalf of VicRoads as part of the Environmental Effects Statement (EES) for the Princes Highway Duplication, Traralgon East to Kilmany. The report presented an assessment of catchment values, surface water and ground water quality, stream flows and floodway capacity and provided recommendations on waterway structural requirements to preserve beneficial uses of the existing waterways. Catchment flows estimated by the Surface Water Assessment are compared to the estimates from this study in Section 4.6.

- Latrobe River Flood Study (Cardno, 2015)

  The Latrobe River Flood Study was undertaken by Cardno on behalf of the WGCMA for the purposes of mapping a range of design flooding events including the 100 year ARI (1 % AEP). Whilst the hydrological model definition and associated flow estimates were not directly translatable to this study, the flood mapping outputs were used to inform the interaction between the downstream boundary of the hydraulic model and the Latrobe River.

2.3 Digital Elevation Model (DEM)

The 2007-08 SRW Ninety Mile Beach LiDAR data, which was provided by the WGCMA, was used on this project as follows:

- To inform catchment and flow path definition for the RORB hydrological model
- As the underlying Digital Elevation Model (DEM) for the 1D/2D TUFLOW hydraulic model.

The LiDAR data was provided as a 1 metre surface grid with horizontal and vertical accuracies as follows:

- Vertical accuracy of ±0.10 m
- Horizontal accuracy of ±0.35 m.

Figure 2.1 shows the DEM for the area modelled using the 1D/2D TUFLOW hydraulic model.

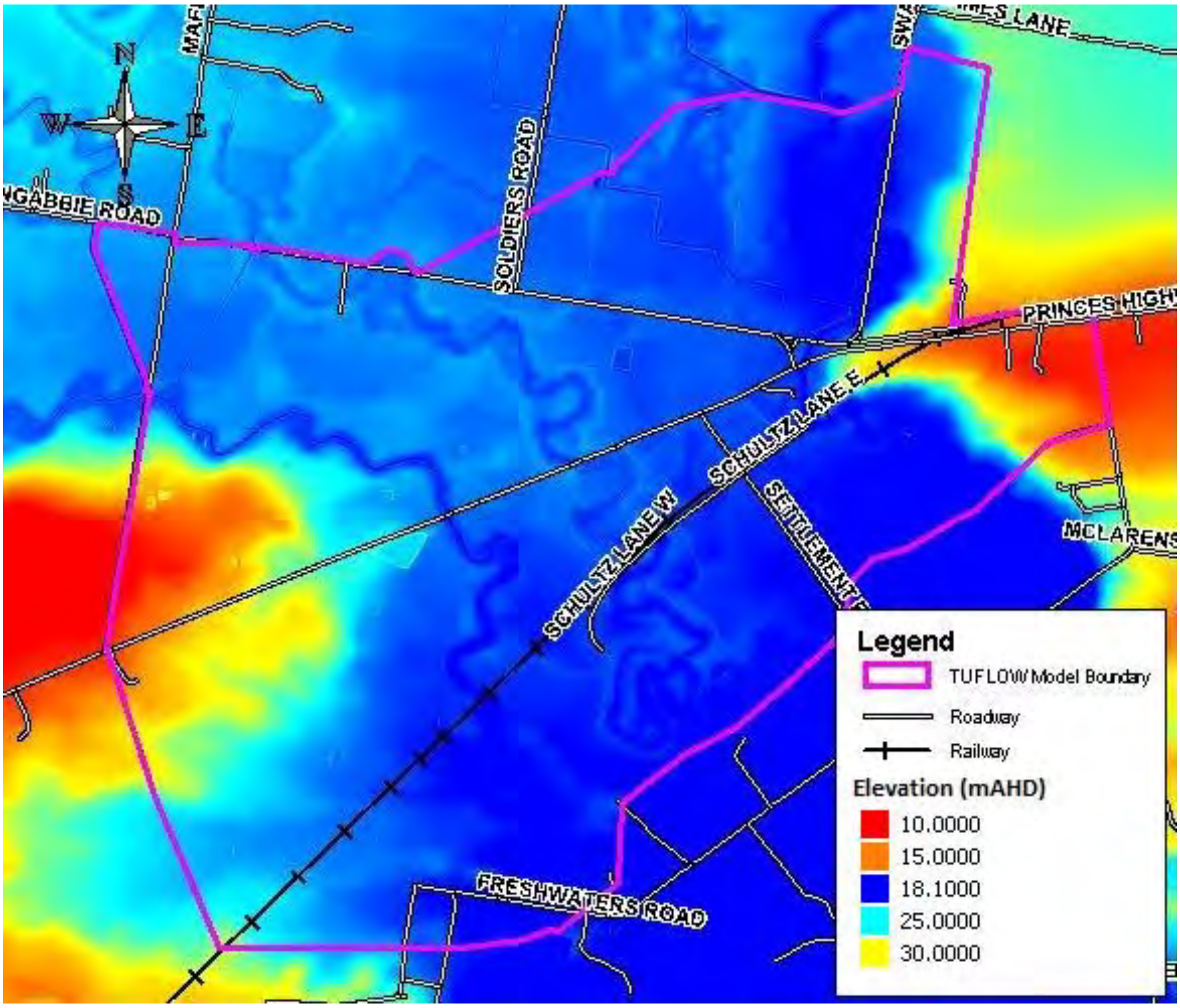


Figure 2.1 DEM used for TUFLOW model

2.4 Site visit

A site visit was undertaken by Engeny staff on the 5th of July 2017, which included photographing and measuring major waterway structures. Where possible this information was used to inform the hydraulic modelling. Figure 2.2 - Figure 2.9 present photographs taken during the site visit.

Figure 2.2 SRW irrigation channel and sluice gate at Morris Road

Figure 2.3 Morris Road crossing of SRW irrigation channel

Figure 2.4 Gippsland Drain No. 3 crossing at the Princes Highway

Figure 2.5 Gippsland Drain No 3 crossing at the railway

Figure 2.6 Private crossing immediately downstream of the railway on Gippsland Drain No 3

Figure 2.7 Nambrok Denison Drain 4-1 crossing of the Princes Highway

Figure 2.8 Princes Highway crossing on Gippsland Drain No 2 (Nambrok Creek)

Figure 2.9 View south towards the Princes Highway on Swamp Road

2.5 Rainfall gauges

Various rainfall gauges were investigated within Kilmany and surrounding areas in order to determine their suitability for calibration of the RORB hydrological models. Figure 2.10 presents the locations of rainfall gauges in the region.

To calibrate the RORB model the following rainfall information is typically required:

- Pluviograph gauge data - rainfall recorded at 6 minute intervals that is used to determine the temporal distribution of historical rainfall events
- Daily rainfall gauge data – rainfall recorded at 24 hour intervals (9am every morning) that is used to determine the total rainfall depth and spatial distribution of historical rainfall events.

Ideally, pluviograph gauges should be selected that are within the catchment that is being modelled. Where this is not possible, pluvoigraph gauges from outside of the catchment can be used, however the correlation of this data to recorded streamflow data will decrease with increasing distance from the catchment.

The nearest pluviograph gauges with a period of record covering the key streamflow events is Glenmaggie Weir Station (85034) which is approximately 18 km from the study catchment and the East Sale Station (85072) which is approximately 21 km east of Central Gippsland Drain No 2 (CGD2).

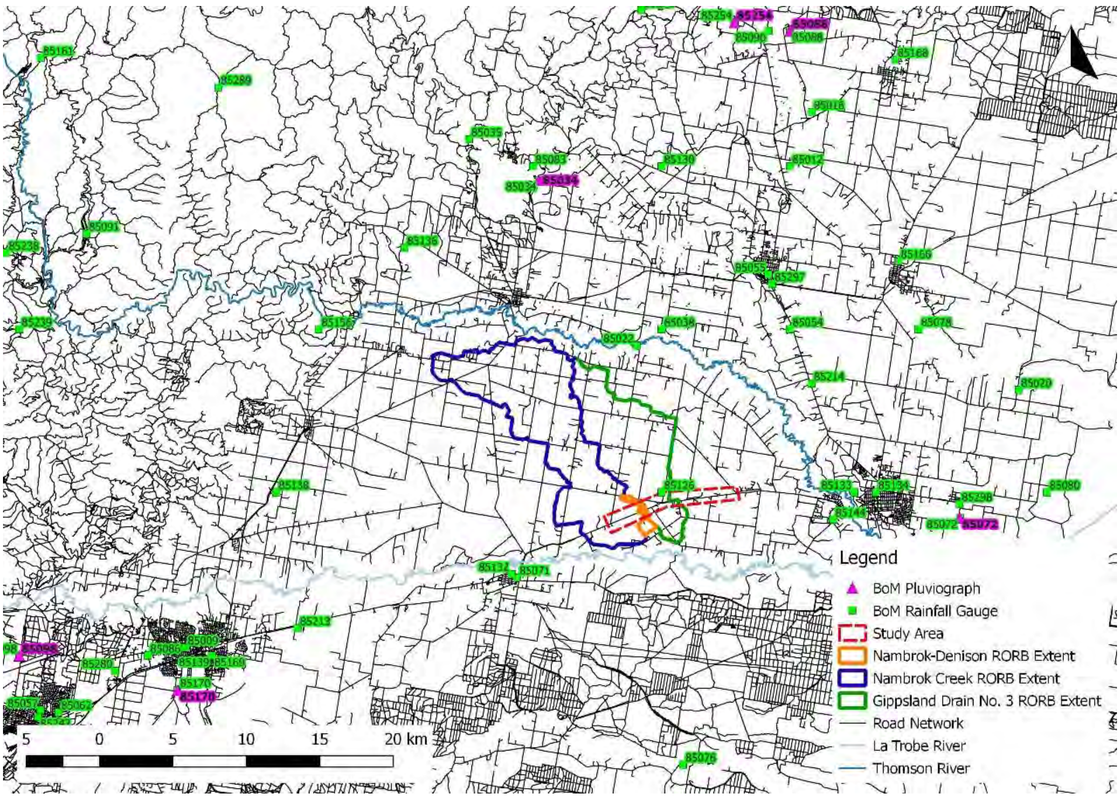


Figure 2.10 Streamflow gauging station and rainfall stations

2.6 Stream flow gauges

The ARR 2016 recommended approach to hydrological modelling is to adopt historical streamflow data for calibration, where this data is available. Ideally, streamflow data from within the study catchment is to be used for calibration. Where this is not possible, streamflow data from a neighbouring catchment can be used, providing the catchment has similar characteristics to the catchment of interest.

The locations of available streamflow gauges relative to the study catchments are presented in Figure 2.11, with key information on each gauge summarised in Table 2.2.

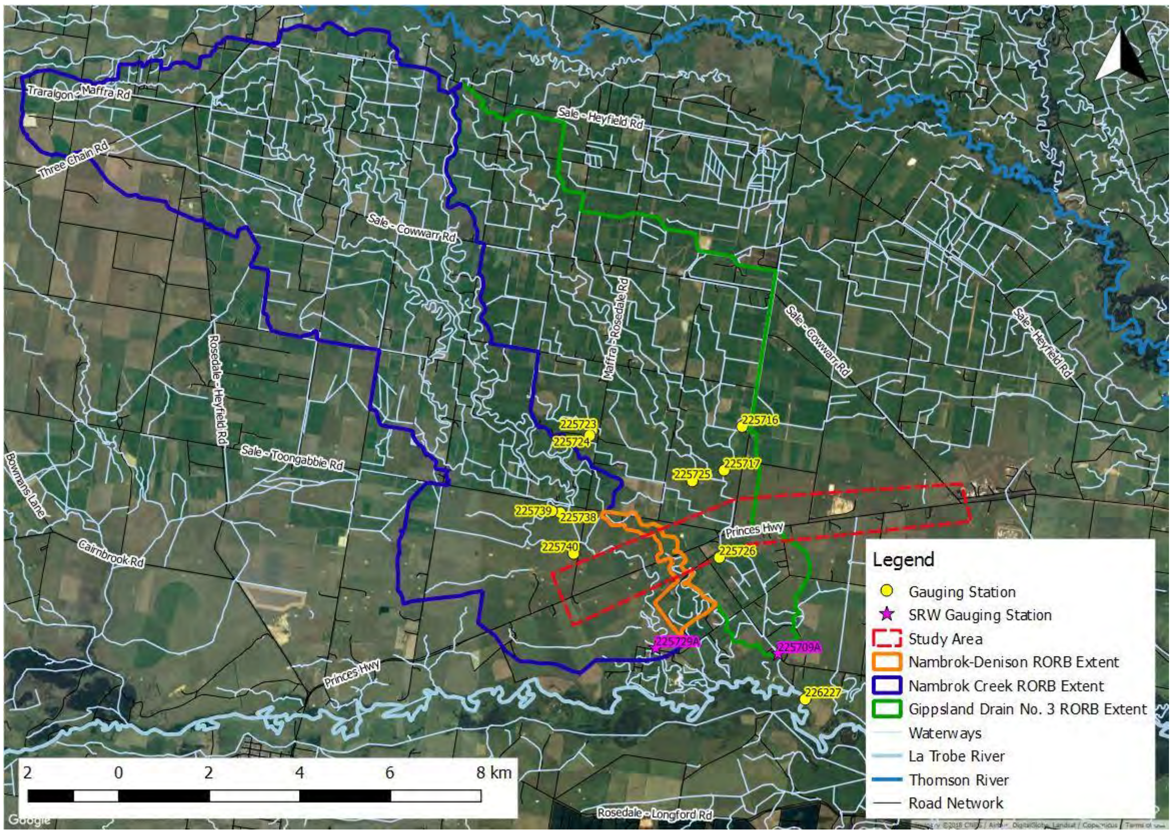


Figure 2.11 Streamflow gauge locations

Table 2.2 Streamflow gauge information

Site ID	Site Name	Site Start Date	Site Cease Date	Comments
225709A	CG3 AT KILMANY SOUTH	23/07/1997	31/12/2013	Supplied by SRW in December 2017 Partial data set of daily flow volumes.
225716	CENTRAL GIPPSLAND 1/2 DRAIN 3 @ DROP STRUCTURE (RD500)	24/02/1980	4/02/2004	Missing Data (07/1991 - 06/2000)
225717	CENTRAL GIPPSLAND 2/3 DRAIN @ US OF DRAIN 3 (RD 500 M)	24/02/1980	15/04/2005	Missing Data (07/1991 - 06/2000)
225723	CENTRAL GIPPSLAND DRAIN NO 1/3 @ D/S 11/4/1 JUNCTION	29/05/2000	13/02/2004	Short data series
225724	CHANNEL O/FALL 11/4/1 U/S JUNCTION CG DR 1/3	29/05/2000	15/04/2005	Short data series
225725	CENTRAL GIPPSLAND DRAIN NO 3 D/S O/FALL 11/1	26/05/2000	15/04/2005	Short data series
225726	CENTRAL GIPPSLAND DRAIN NO 3 D/S RAILWAY LINE	29/05/2000	15/04/2005	Short data series
225729A	CG2 AT FRESHWATER ROAD	30/07/1999	31/12/2013	Supplied by SRW in December 2017 Partial data set of daily flow volumes.
225738	CENTRAL GIPPSLAND DRAIN NO 2 @ SALE-TOONGABBIE ROAD	28/05/2002	15/04/2005	Short data series
225739	CENTRAL GIPPSLAND DRAIN NO 2/2 @ DESSENTS	28/05/2002	15/04/2005	Short data series
225740	CENTRAL GIPPSLAND DRAIN NO 2 U/S TINAMBA-ROSEDALE ROAD	16/05/2002	15/04/2005	Short data series
226227	LATROBE RIVER @ KILMANY SOUTH	16/12/1976	13/06/2017	On LaTrobe River ; ~20 yr data GAP

Whist there are a number of gauges located within the study catchments, these gauges have small periods of record that do not cover any of the larger flood events (recorded on the Latrobe River) that would typically be used for model calibration. Whilst the gauge on the Latrobe River has a reasonable period of record, it is not suitable for model calibration, as it has vastly different and more complex catchment characteristics compared to the study catchments. Based on a review of the publicly available information, no streamflow gauges were identified as being suitable for model calibration.

Additional flow data timestep from gauging stations (225709A and 225729A) was supplied by SRW. However the data was limited to a daily timestep and no correlating water level data was available (to determine if the irrigation channels had overtopped during any recorded storm event), these streamflow gauges were identified as unsuitable for model calibration. Consequently, an alternate method as discussed in Section 4 was used to calibrate the hydrological models.

3. CATCHMENT

3.1 Overview

Within the study area, the highway duplication follows a ridge line before dropping down into the Central Gippsland Drain No. 2 (Nambrok Creek) and Central Gippsland Drain No. 3 floodplain at approximately 700 metres east of the Maffra-Rosedale Road before rising out of the floodplain east of Swamp Road and following another ridge line out of the study area. The alignment of the highway duplication within the study area in the context of the upstream catchments is presented in Figure 3.1.

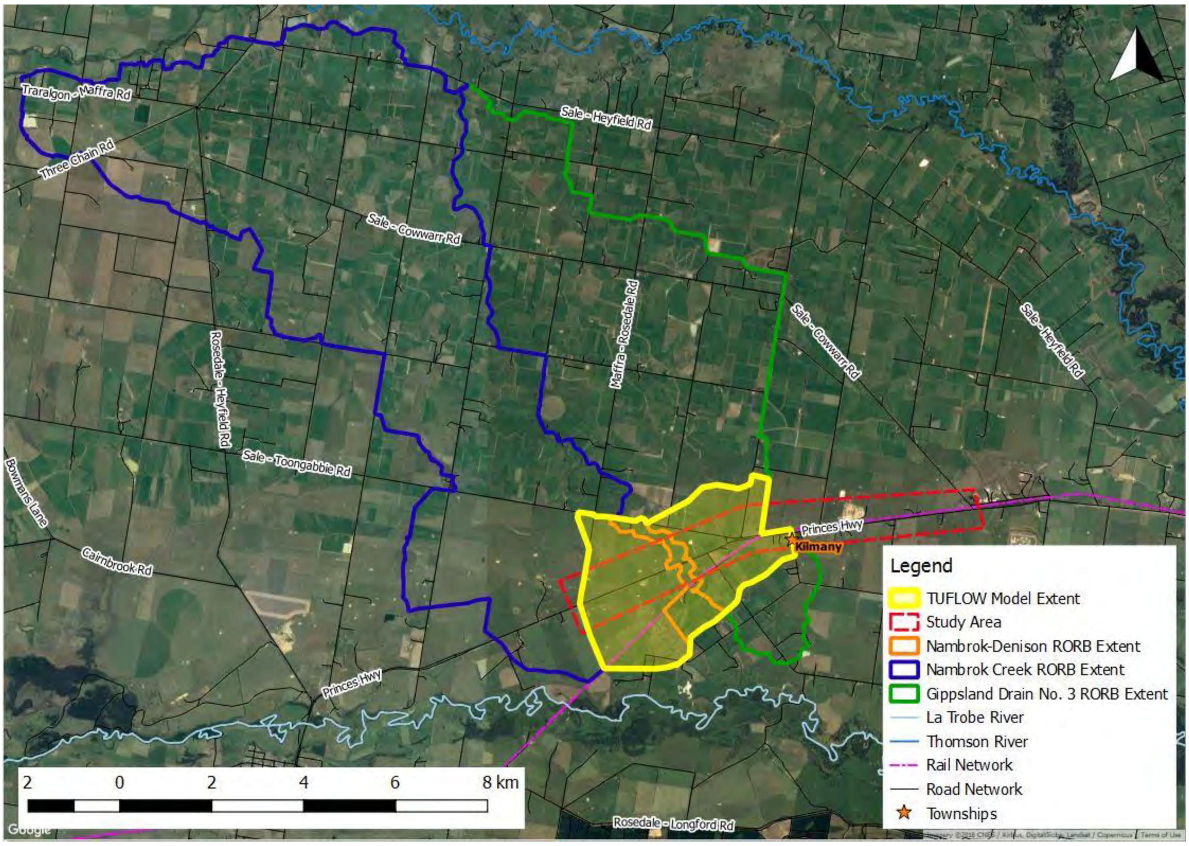


Figure 3.1 Catchment locations

For the purposes of this study, the hydrological and hydraulic investigations were focussed on the major waterways and their associated catchments. The Central Gippsland Drain No 2 and No 3 combined catchment areas are approximately 120 km^2 of predominantly rural land that range in elevation between approximately 65 m AHD and 14 m AHD. Both catchments are criss-crossed by the irrigation channels, which form part of the Macalister irrigation district. The terrain is undulating in the upper reaches of the catchment but becomes very flat towards the southern end of the catchment, where the Princes Highway is located. In this area surface gradients are generally less than 1 %.

The northern catchment boundary of the 74.1 km^2 Central Gippsland Drain No 2 (CGD2) catchment is located on a ridge that is situated approximately 600 m south of the Thomson River. Flows generated within the catchment discharge in a south-westerly direction before crossing the Princes Highway and the Gippsland Railway Line before ultimately discharging into the Latrobe River which is located approximately 3 km south of the Princes Highway.

The catchment boundary of the 44.2 km^2 Central Gippsland Drain No 3 (CGD3) is located on a levee bank near the Heyfield-Sale Road, approximately 1 km south of the Thomson River. Catchment flows also follow a generally south-westerly alignment before crossing the Princes Highway and the Gippsland Railway Line and ultimately discharging to the Latrobe River. This catchment's delineation was verified against documents provided by SRW, which state that the "Central Gippsland Drain 3 has a catchment of 44 square kilometres" (SRW, *Surface Drainage of Irrigation Areas: Part I, Principles*).

An approximately 1.5 km^2 catchment was delineated for the purposes of calculating inflows to the 1D/2D TUFLOW hydraulic model. This area is part of the CGD2 catchment but separated from the wider catchment flows by levee banks and is only connected to CGD3 upstream of the Princes Highway during major flooding events (exceeding the 5 % AEP event). Stormwater flows from this catchment are conveyed to the Nambrok-Denison 4-1 irrigation channel which is controlled by a series of sluice gates and does not freely drain.

Modelled flood extents from the Victorian Flood Database and the Latrobe River Flood study were reviewed to inform whether the Latrobe River or Thomson River contributed to catchment flows during flooding events. Based on the review of these data sources it was determined that flows from the Thomson River and Latrobe River do not discharge into the study area for the 1 % AEP event.

3.2 Existing waterway structures

Table 3.1 presents a description of the existing waterway structures that cross the Princes Highway within the study area.

The location ID's correspond to the labels in Figure 3.2.

Table 3.1 Existing waterway structures

Location ID	Drain / Channel	Structure	Comment
1	Minor culvert west of CGD2	450 mm W x 300 mm H	-
2	CGD2	1 no 1520 dia Siphon 3 no. 1830W x 1600 H RCBC 3 no. 914 dia RCP	Multi-level structure. Further description provided in Section 5.3.
3	Minor structure west of Nambrok-Dennison Irrigation Channel	450 mm dia Siphon	-
4	Nambrok-Dennison Irrigation Channel	838 mm RCP	-
5	Minor culvert east of Nambrok-Dennison Irrigation Channel	375 mm RCP	-
6	Sale-Toongabbie Road	375 mm RCP	Connects floodplain north of Princes Highway
7	CGD3	5 no. 1219 mm W x 813 mm H RCBC	-
8	Minor culvert east of CGD3	375 mm RCP	-
9	Minor culvert east of CGD3	300 mm RCP	-

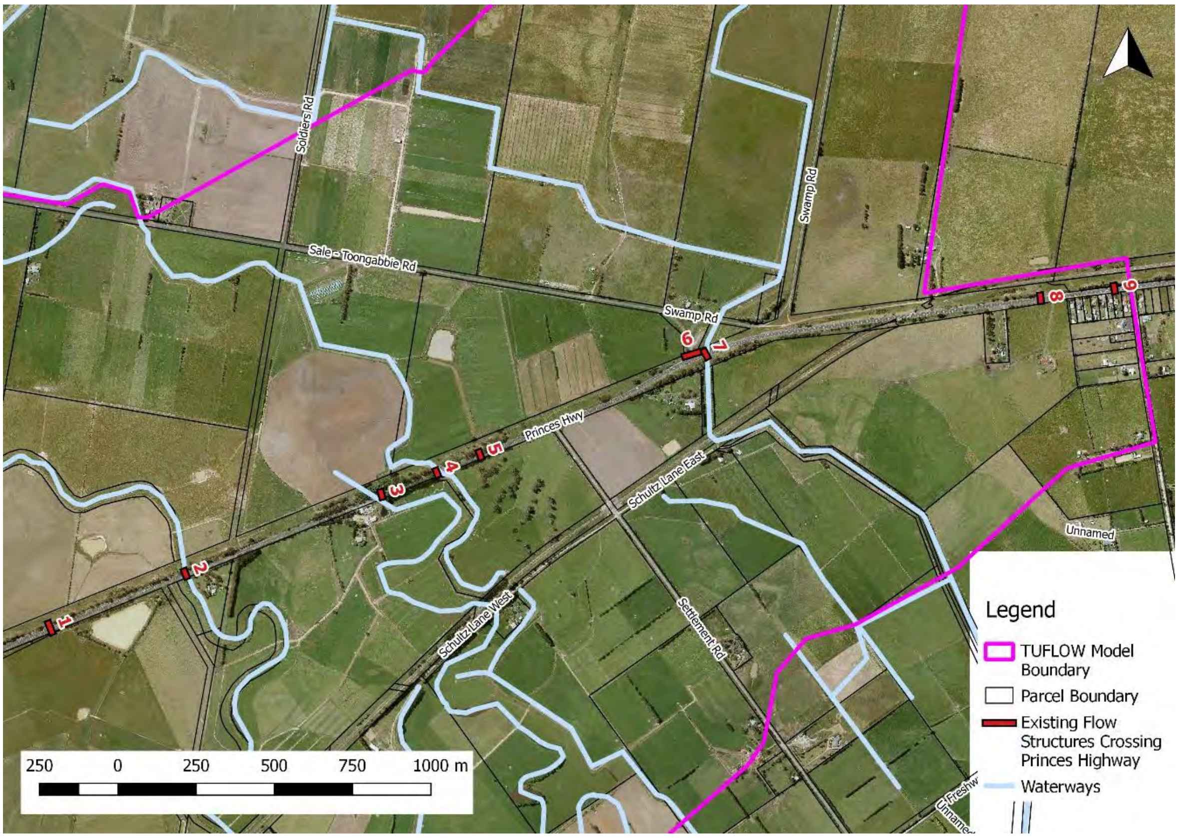


Figure 3.2 Existing flow structures crossing Princes Highway

4. RORB HYDROLOGICAL MODELLING

4.1 Methodology

Diverted RORB models were developed for the CGD2, CGD3 and Nambrok-Denison 4-1 irrigation channel catchments for the purpose of estimating inflow hydrographs for the 1D/2D TUFLOW hydraulic model. A combination of rainfall-excess hydrographs and routed hydrographs for waterways were used as inputs for the TUFLOW model. RORB modelling was undertaken to create design inflow hydrographs for the 1 % AEP storm event.

The following summarises the adopted methodology:

- Catchment, subarea, node and reach delineation using the LiDAR DEM and fraction impervious definition using aerial photography (image date October 2014).
- Estimation of RORB model parameters by matching the estimated 20 % AEP flood flow and volume predicted by RORB for the CGD3 to the design capacity of that drain, as reported in *Chapter 17 Surface Drainage of Irrigation Areas: Part I, Principles* (Rural Water Commission of Victoria, 1988).
- RORB Monte Carlo simulations to determine design flood quantiles for the 1 % AEP event based on the approach described in AR&R 2016 Book IV chapter 3.
- Sensitivity analysis of the adopted k_c value and loss parameters to RFFE estimates and regional equations.

Engeny believes that the modelling methodology that has been devised is consistent with the recommendations of the Australian Rainfall and Runoff (AR&R) Guidelines (November 2016), and has adopted the revised Intensity-Frequency-Duration (IFD) data, rainfall temporal patterns and model parameters as a basis for the hydrological modelling.

4.2 Model definition

4.2.1 Catchment and sub-catchment delineation

CGD2, CGD3 and the Nambrok-Denison 4-1 irrigation channel RORB model catchment and sub-catchment (sub-area) boundaries were delineated with consideration given to the following information:

- the DEM generated from available LiDAR (Jan 2008 SRW) and contours from the DEM
- land use identified in the Victorian Planning Scheme

- property boundaries
- aerial photography (image date Oct 2014)
- SRW drainage asset locations.

RORB model layouts were developed with consideration given to the predicted 1 % annual exceedance probability (AEP) overland flow paths. Given the complexity of the terrain it was decided to inform RORB subarea and reach definition using a rain-on-grid Graphical Processor Unit (GPU) 2D TUFLOW model. A depth plot from the GPU 2D TUFLOW model run is presented in **Appendix A**.

Where appropriate, land use types with different impervious fractions were separated into different sub-areas in order to reduce the effect of averaging runoff volumes across a sub-area. Sub-area reach and node layouts for each of the three RORB models are presented in **Appendix B**.

4.2.2 Fraction Impervious Definition

Victorian planning scheme zones were used in conjunction with recommended fraction impervious (FI) values from Melbourne Water Flood Mapping Guidelines (November 2016) and the available aerial photography (October 2014) as a basis for assigning FI values.

Table 4.1 provides the normal range of fraction impervious values provided in the Melbourne Water Flood Mapping Guidelines (November 2016) for each land use, as well as the value adopted by Engeny. Where the Melbourne Water Flood Mapping Guidelines have not provided a normal range, the Melbourne Water Music Guidelines (2016) normal range has been provided *in italics*, where available. While these values have been applied in most zones there are areas where alternative FI values have been applied with review of the aerial photography as validation.

Table 4.1 Fraction impervious values for planning scheme zones

Planning Scheme Zone	Zone Code	Normal Range (MW Guidelines)	Adopted RORB FI Value
Farming Zone	FZ	*0.05 – 0.1*	0.1
Public Conservation and Resource Zone	PCRZ	0.1	0.1
Public Park and Recreation Zone	PPRZ	0.05 – 0.20	0.1
Public Use Zone – Service and Utility	PUZ1	0.05 – 0.10	0.1
Public Use Zone – Education	PUZ2	0.60 – 0.80	0.7

Planning Scheme Zone	Zone Code	Normal Range (MW Guidelines)	Adopted RORB FI Value
Public Use Zone – Transport	PUZ4	0.60 – 0.90	0.5
Public Use Zone – Local Government	PUZ6	0.50 – 0.90	0.7
Road Zone – Category 2	RDZ2	0.50 – 0.80	0.6
Special Use Zone	SUZ1	0.50 – 0.80	0.6
Township Zone	TZ	*0.40 – 0.70*	0.6

4.2.3 Catchment storages

Whilst there are no formal detention basins located within the study catchments, based on discussions with SRW, properties utilising irrigation water within the Macalister irrigation district are understood to generally have been designed to detain stormwater using embankments and pipe outlets. Additionally, in some locations roads act as detention storages by holding back flow and releasing it downstream through culverts or bridges at an attenuated rate. A GPU 2D TUFLOW model was used to identify the location of significant catchment storages which were then modelled in the existing conditions RORB model.

The large detention storages located upstream of the Princes Highway on both CGD2 and CGD3 within the respective RORB models enabled verification of the TUFLOW results with the RORB model.

Figure 4.1 presents the locations of the storages that were modelled in RORB.

Additional storage throughout the catchment were accounted by adjusting model parameters as part of the calibration process (discussed in Section 4.4).

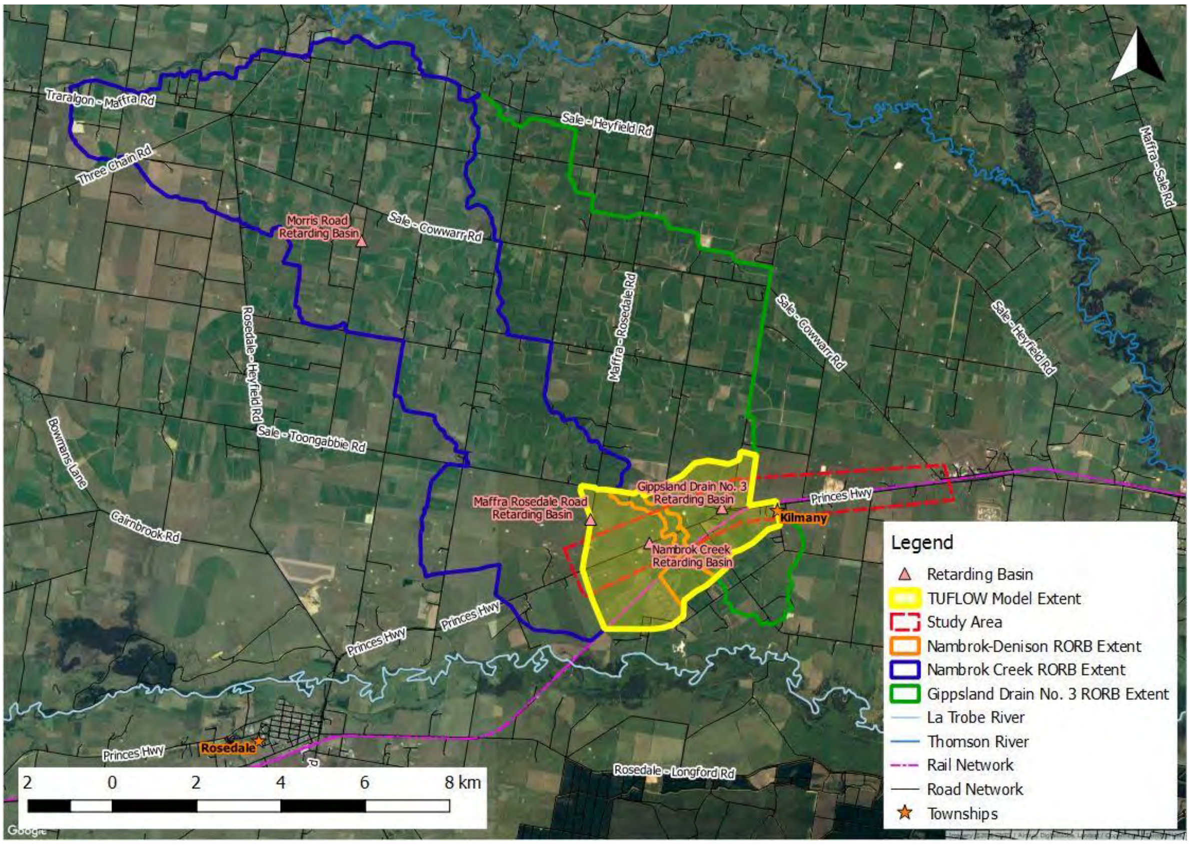


Figure 4.1 RORB model boundaries and storage locations

4.3 Model parameters

4.3.1 Summary

The RORB hydrological models adopted an initial loss/continuing loss approach, 2016 AR&R temporal patterns and uniform rainfall spatial pattern:

Land use within the entire Kilmany catchment was apportioned to one of two categories:

- rural largely previous areas
- low density residential areas.

Table 4.2 provides a summary of the final parameters utilised to run each of the three RORB models respectively. Section 4.4 provides discussion on the adopted k_c value.

Table 4.2 RORB models parameter specification

Parameter	Nambrok Creek	Nambrok-Denison Irrigation Channel	Gippsland Drain No. 3
k_c	87.25	10.35	54
m	0.8	0.8	0.8
Initial Loss	16 mm	16 mm	16 mm
Continuing Loss	0.5 mm/hr	0.5 mm/hr	0.5 mm/hr

4.3.2 Intensity-Frequency-Duration (IFD) Data

AR&R 2016 IFD data for the study area was sourced from the Bureau of Meteorology using the online 2016 Rainfall IFD request system.

4.3.3 Temporal Rainfall Patterns

2016 AR&R temporal patterns were adopted for all RORB models. AR&R 2016 states that point temporal patterns should be used for catchments less than 75 km^2. All study catchment areas were smaller than 75 km^2 therefore point temporal patterns were adopted.

4.3.4 Spatial Rainfall Patterns

Uniform spatial patterns were adopted for each catchment model.

4.3.5 Initial and Continuing Loss Model

The RORB models adopted an initial loss/continuing loss model approach, in accordance with the recommendations of AR&R 2016.

4.3.6 Accounting for Rainfall Pre-Burst

The initial losses for rural areas provided on the AR&R data hub are for full storms (abbreviated as IL_s). The IFD data provided by the BoM is for rainfall bursts only and not full storm rainfall depths. To account for this, IL_s was reduced to an initial loss relevant to the burst (IL_b) using Equation 4-4 from AR&R 2016 (IL_s-$IL_{preburst}$=IL_b) using the median pre-burst depth data from the data hub.

4.4 Model Calibration and Validation

4.4.1 Peak Flow Estimation

Due to the lack of suitable gauging station flow data, the RORB model was initially calibrated using flows generated using the Regional Flood Frequency Estimation method. The resultant flow outputs were modelled in TUFLOW and presented for discussion with SRW, VicRoads and the WGCMA. The resultant flood extents were considered to be significantly larger than the anecdotal record and it was reasoned that the RORB model had not sufficiently accounted for the storage provided properties and roads within each catchment. SRW subsequently provided documentation (*Surface Drainage of Irrigation Areas: Part I, Principles*) describing the design basis for sizing the Macalister Irrigation District drainage network which was subsequently used to undertake calibration of the RORB models.

The design basis for sizing drains in the Macalister Irrigation District, including CGD3 and CGD2 is summarised as follows:

- Drains sized to convey a 5 year ARI event (20 % AEP)
- The 5 year ARI event was considered to be a 24 hour storm with a total depth of 84 mm.

Further information provided in the reference document identified that the volume of this event in CGD3 is 2500 ML at the Freshwater Road (gauging station 225729A). The reference document reports:

The hydrographs for 80 storms over twenty years were analysed, both in volume and peak flow rates…

Whilst the flow record available for this study was insufficient to provide independent verification for the above estimate, given the lack of alternative data it was deemed appropriate to use the above for calibration of the RORB hydrological model.

The RORB hydrological model was calibrated using the 20 % AEP event, 24 hour duration as follows:

- Flow capacity of CGD2 at the Freshwater Road gauging station was estimated based on the available terrain data and design drawings
- Modification of RORB routing parameter k_c to achieve a peak flow and total hydrograph volume equivalent to the design channel capacity
- Modification of the continuing loss value to achieve a hydrograph volume of approximately 2500 ML.

The RORB model initial loss depth of 16 mm was chosen based on the AR&R 2016 data. The reference document discusses initial losses within the context of seasonal periods and irrigation cycles (assumed to comprise 5 days watering, 10 days drying across the summer period) and estimates that initial losses are up to 21 mm in summer after a period of 10 days drying (table 17.2). It was therefore considered that the 16 mm initial loss recommended by the data hub was an appropriate value.

To achieve the required hydrograph volume the continuing loss was reduced to 0.5 mm/hr (comparative to an original rural loss value of 2.7 mm/hr). AR&R 2016 discusses adjustments to continuing loss during longer storm events as a result of reduced soil infiltration over time. A review of aerial imagery notes a general lack of deep-rooted vegetation throughout the region which may further reduce continuing loss of storms (due to a lack of preferential pathways for infiltration from deep root zones). Based on these factors, the adopted continuing loss of 0.5 mm/hr was considered as potentially applicable to the catchment area.

4.4.2 Estimation of the RORB Routing Parameter k_c

Model calibration and verification was undertaken through adjustment of the k_c value such that peak flows within the CGD3 catchment approximately matched the estimated peak flow within the irrigation channel during the 24 hour, 5 year ARI event.

Estimation of k_c values for the other two RORB catchments, CGD2 and Nambrok – Denison Irrigation Channel, was undertaken via consideration of the relationship between the routing parameter (k_c) and the Average Flow Distance (d_{av}). Catchments with similar k_c/d_{av} relationships will exhibit similar runoff responses. Given the similarities in grade and land use (fraction impervious values) between all three catchments, the k_c/d_{av} ratio for Gippsland Drain No 3 was used to calculate the k_c values for the other two catchments. Table 4.3 provides a summary of the k_c and d_{av} values correlating to each catchment.

Table 4.3 Comparison of the k_c and d_{av} values for each catchment

Catchment	k_c	d_{av}	k_c/d_{av}
Nambrok Creek	87.25	15.85	5.5
Nambrok-Denison Irrigation Channel	10.35	1.88	5.5
Gippsland Drain No. 3	54.0	9.81	5.5

Various studies (Pearse et al, 2002; Yu, 1989 and CRCCH) have determined the expected k_c/d_{av} relationship for RORB hydrological models which have been summarised in Table 4.4. The k_c/d_{av} relationship calculated for the RORB hydrological models completed for this project are notably higher than those recorded by the various studies. However, it is noted that the k_c values adopted have been estimated with due consideration for the distributed storages throughout the study catchment which largely have not been modelled explicitly. Consequently, Engeny believes that the k_c values adopted within this study are appropriate.

Table 4.4 Summarised k_c/d_{av} relationships for RORB hydrological models

Group	Victorian (Pearse, 2002)	Yu, 1989	CRCCH
Expected	1.25	0.96	1.14
Low (-1 SD in log)	0.75	0.47	0.61
High (+1 SD in log)	2.07	1.94	2.13

4.5 Flow comparison

The original flow estimates calculated using Regional Flood Frequency Estimation (RFFE) and associated calculation methods are presented in **Appendix C.**

Table 4.5 provides a comparison of the peak flows at the upstream boundary of the TUFLOW model, as modelled through calibration of RORB flows to irrigation channel design flows and to RFFE flow values respectively. Peak flows from the RFFE method are significantly higher than those from the irrigation channel verification method. The difference is attributed to the RFFE method not accounting for the extensive network of distributed storages that exist within the Macalister Irrigation District. Consequently, the RFFE peak flows were considered to have overestimated peak flows and the alternative approach using the drainage design documentation considered to be a more appropriate flow estimate.

Table 4.5 Comparison of the 1 % AEP peak flows observed at upstream boundary of the TUFLOW hydraulic model

Catchment	Peak Flow at upstream boundary of TUFLOW model (m^3/s)	
	Adopted Method	RFFE Estimation Method
CGD2	36	72
CGD3	22	52

The EES Surface Water Assessment Report (GHD, 2011) estimated flows for Nambrok Creek and Gippsland Drain No. 3 using the probabilistic or 'rural' Rational method (AR&R 1987). Catchment areas and peak flows estimated at each catchment's outlet by the Surface Water Assessment Report and this study are presented in Table 4.6 for comparison.

Table 4.6 1 % AEP peak flow comparison

Waterway	Engeny, 2017		GHD, 2011	
	Catchment (km^2)	Peak Flow (m^3/s)	Catchment (km^2)	Peak Flow (m^3/s)
Nambrok Creek	74.1	**35.1**	90	**61.6**
Gippsland Drain No. 3	44.2	**20.1**	51.6	**41.3**

The data presented in Table 4.6 highlights the following:

1. The catchment areas estimated by GHD (2011) are higher than estimated for this study and reported in, *Surface Drainage of Irrigation Areas: Part I, Principles*. The difference reflects the challenges of estimating the contributing catchment areas in flat terrain that is crossed by roads and levee banks which can direct flow in and out of the catchment. It is considered that the catchment areas estimated in this study are more accurate as they have been based on analysis of flow paths identified by a rain on grid 2D GPU TUFLOW model.

2. Peak flow estimates are 50 % to 60 % of the values estimated by GHD (2011). The difference in peak flows are considered to be attributable to the difference in catchment areas, along with Engeny's model accounting for localised catchment storage through the k_c parameter and select storages which have been explicitly modelled.

4.6 RORB design flow estimation

4.6.1 Monte Carlo approach

The design event approach, in which all parameters other than rainfall are input as fixed values, is the traditional approach to design flood estimation that has been used in Australia for many decades. The design event approach assumes 'AEP neutrality', that is, that the resulting flood has the same annual exceedance probability as its causative rainfall. To ensure 'AEP-neutrality' considerable effort is made in selecting the fixed parameters.

Joint probability techniques that attempt to mimic 'mother nature' by considering the variability of modelling inputs can offer improvements to the traditional design event approach. The application of joint probability approaches is incorporated into ARR 2016 and is recommended as more defensible than the design event approach.

In developing the joint probability framework particular attention was given to ensuring that the inputs and the manner in which they are incorporated are consistent with Book 8 of ARR2016.

4.6.2 Summary of Results

The design event peak flows from the hydrographs that were used as inputs to the TUFLOW hydraulic model are presented in Table 4.7. The Nambrok – Dennison Irrigation Channel has not been reported on as it is not critical for determining infrastructure size or peak flood levels.

Table 4.7 Summary of median peak flows, critical durations and temporal patterns at upstream boundary of the TUFLOW hydraulic model

AEP	CGD2			CGD3		
	Flow (m^3/s)	Duration	Temporal Pattern	Flow (m^3/s)	Duration	Temporal Pattern
1 %	36	48 hr	30	22	36 hr	22

The 1 % AEP critical duration hydrographs for CGD2 (Nambrok Creek) and CGD3 at the upstream boundary of the TUFLOW hydraulic model are presented in Figure 4.2.

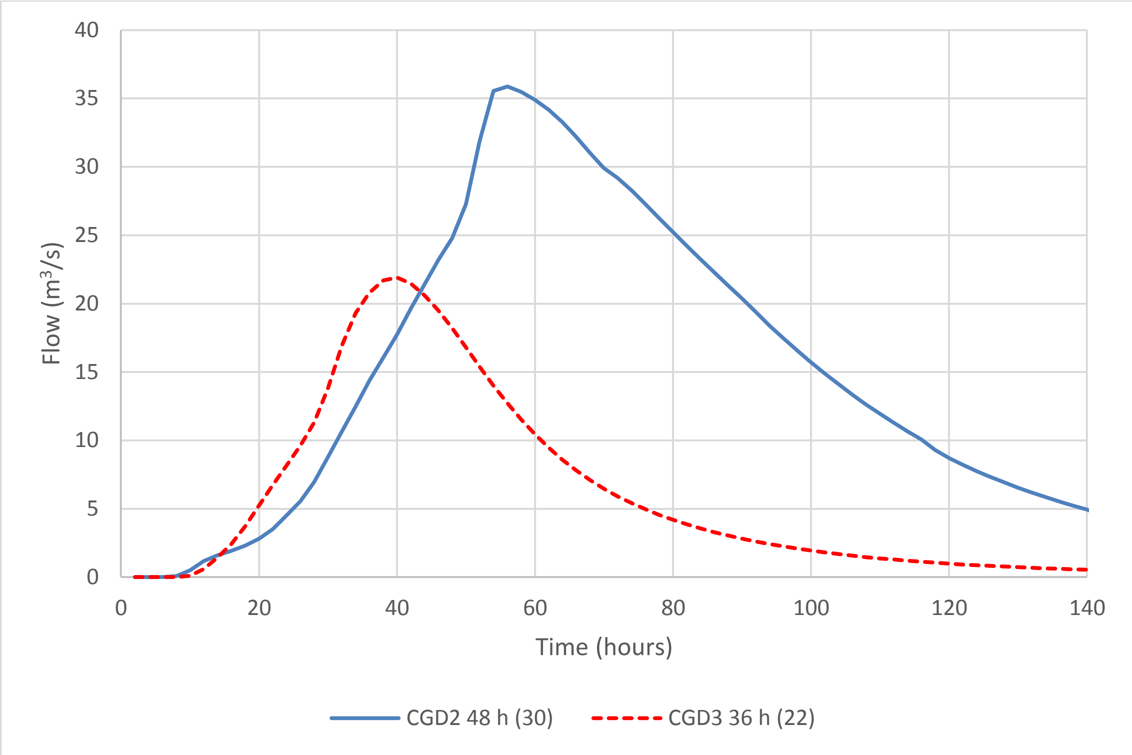


Figure 4.2 Critical 1 % AEP hydrographs for Nambrok Creek and Gippsland Drain No.3 at the upstream boundary of the TUFLOW hydraulic model

In the absence of suitable streamflow data within the study catchment for use in model calibration, there is inherent uncertainty associated with design flow estimation. However, Engeny has used the best available information and the approach recommended by the latest industry guidelines (AR&R 2016) to estimate design flows, which is considered appropriate for the purposes of this study.

5. FLOOD MODELLING

5.1 Methodology

Engeny developed a one-dimensional and two-dimensional (1D/2D) hydraulic model for the Nambrok Creek, the Nambrok – Denison Irrigation Channel and Gippsland No.3 Drain, in order to estimate existing and design flooding conditions at the Princes Highway.

Modelling was undertaken with the hydrodynamic software package, TUFLOW, using the latest version of the software available at the project start date: TUFLOW.2016-03-AE-w64 (iDP). The TUFLOW model boundary covers an area of approximately 12.2 km^2. **Appendix E** presents the developed conditions TUFLOW model boundary and key input layers.

5.2 TUFLOW Model Setup

Table 5.1 provides a summary of the key model parameters.

Table 5.1 TUFLOW model parameters

Model Parameter	Value	Comment
Grid Size	6 m	CGD2, CGD3 and associated channels were modelled in the 1D domain.
DEM	1 m LiDAR grid	2007-08 SRW Ninety Mile Beach LiDAR Project data.
DEM	Survey	Provided by VicRoads and used to augment the LiDAR data where it was available.
DEM	Road Design Surface	Provided by VicRoads and used to augment the LiDAR data under design conditions.
2D time step	1 second	-
1D time step	0.25 seconds	-
Inflows	2d_bc (QT inflow) and 2d_sa ALL	Routed Nambrok Creek and Gippsland Drain No.3 hydrographs (QT) and rainfall excess hydrographs (2d_sa ALL) for local catchment inflows
Downstream boundary	HQ (b ~ 0.005)	Slope determined via inspection of DEM and varies at different locations.

Table 5.2 presents a summary of the adopted Manning's roughness values.

Table 5.2 Adopted Manning's roughness values

Manning's n (roughness)	Description
0.035	Open paddock
0.06	Open paddock with moderate trees
0.09	Paddock with high density trees
0.03	Road / carpark
0.035	Open channels (Nambrok Creek, Central Drain & Gippsland Drain No.3)

5.3 1D HEC-RAS Model Verification

1D HEC-RAS hydraulic models were created for the purposes of informing head/flow/storage relationships for informal storages that were identified within the catchment and modelled using the RORB hydrological model. Models were also created to develop a head loss table for the Princes Highway waterway structure on Nambrok Creek and to verify the 1D/2D TUFLOW hydraulic model results at Gippsland Drain No 3. Figure 5.1 presents the 1D HEC-RAS representation of the waterway structure on the Princes Highway at the Nambrok Creek crossing, showing the 3 no. box culverts, 3 no. pipes and siphon.

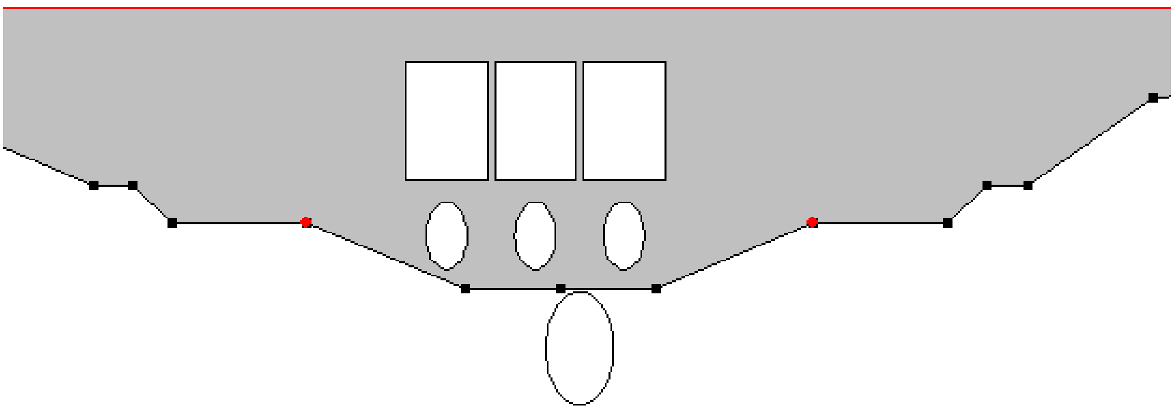


Figure 5.1 Princes Highway at Nambrok Creek 1D HEC-RAS representation

5.4 Existing Conditions Flood Modelling Results

5.4.1 Water surface levels

Existing conditions flood depth maps for the modelled design event are presented in **Appendix F**. The modelled existing conditions peak water surface levels (WSL) upstream of the Princes Highway at key locations are presented in Table 5.3. The modelling predicts that during the 1 % AEP flood event, the road within the vicinity of CGD3 is expected to overtop. No overtopping of the road is expected at CGD2 or the Nambrok – Denison Irrigation Channel.

Table 5.3 Modelled peak water surface levels upstream of the Princes Highway

Description	CGD2	Nambrok – Denison Irrigation Channel	CGD3
	m AHD	m AHD	m AHD
1 % AEP Peak WSL	17.25	17.05	16.7
Existing Princes Highway road crest	17.52	17.53	16.44

6. HYDRAULIC DESIGN

6.1 Objectives

Design conditions flood modelling was undertaken for the purposes of determining hydraulic infrastructure required for the proposed duplication of the Princes Highway at Kilmany.

The hydraulic infrastructure determined by this study represents an arrangement that achieves the hydraulic design criteria (section 6.2). Alternative arrangements could be adopted but the effectiveness of these solutions would need to be demonstrated using the TUFLOW hydraulic models.

6.2 Hydraulic design criteria

The following hydraulic design criteria were provided by the project stakeholders:

6.2.1 VicRoads design criteria

- 1 % AEP flood immunity for the road. The proposed road should provide 300 mm freeboard from the peak 1 % AEP flood level to the road shoulder.
- 600 mm freeboard to the soffit of proposed bridges.
- No allowance for blockage of cross culverts

6.2.2 WGCMA design criterion

The duplication project should not result in a change to hydraulic conditions (including water levels and velocities) outside of the VicRoads Right of Way (ROW) boundary. In the context of the flood modelling this was considered to be specifically referring to an increase in flood levels or flow velocity outside the ROW.

6.2.3 SRW design criterion

The duplication project should not reduce the capacity of any irrigation channel or drain associated with the Macalister Irrigation District.

6.3 Design basis

6.3.1 Preservation of existing structures

CGD2 and CGD3

The existing major waterway structures that cross the Princes Highway at CGD3 and CGD2 control the depth of flooding upstream and downstream of the highway. It was

VicRoads preference to retain the existing structures at both CGD2 and CGD3 by bridging across each structure and filling between the existing structures and the road crest. A bridge with 600 mm freeboard above the 1 % AEP flood level was adopted for the duplicated section of the carriageway. Plan and section diagrams of this arrangement at CGD3 are presented in Figure 6.1 and Figure 6.2.

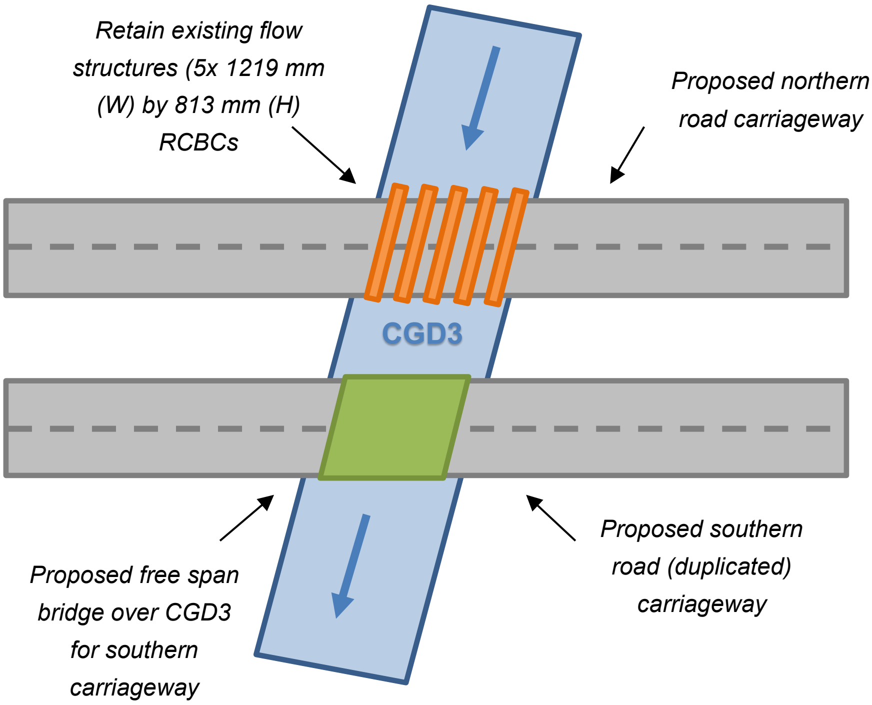


Figure 6.1 Plan view of proposed structure arrangement at CGD3

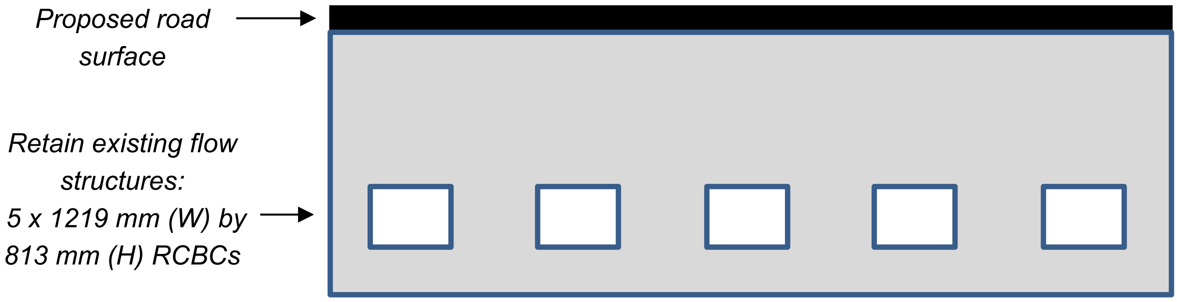


Figure 6.2 Section view of northern road carriageway at CG3

Should an alternative design proposal specify the replacement of these structures with new structures, the design must demonstrate that hydraulic conditions can be achieved for a range of design storm events between the 20 % AEP and 1 % AEP.

6.3.2 Replacement of existing structures

Nambrok-Dennison Irrigation Channel

An 838 mm RCP currently conveys irrigation flows across the Princes Highway and does not provide significant conveyance during flood events.

The proposed design replaces this structure with a longer culvert in order to extend through the duplicated highway. This structure was upsized to a 900 mm RCP to account for additional friction losses associated with the longer culvert lengths.

Sale – Toongabbie Road

To facilitate the interchange of flows between the floodplain west of the CGD3 and the CGD3 the existing 375 mm RCP located under the Sale-Toongabbie Road (refer to location 6 in Section 3.2) was replaced with a 1200 mm wide by 450 mm high RCBC.

Additional Locations

Minor culverts conveying flows across and around the Princes Highway were also replaced at various locations with lengthened or upsized culverts to span the width of the proposed road embankment and connect new irrigation channels parallel to the Highway. Section 6.4 details the specifications of the modelled replacement structures.

6.3.3 Additional structures

The flood modelling found that overtopping of the Princes Highway at CGD3 occurs for existing conditions (refer to section 5.4). The duplicated highway crest level at this location is significantly higher than the existing road, therefore additional culverts were required to prevent increases in water levels occurring upstream of the alignment. Two 1800 mm wide by 600 mm high RCBCs were required to convey flows through the duplicated highway embankment.

An additional 1050 mm RCP was also required to convey floodplain flow through the duplicated highway west of the CGD3. A 450 mm RCP was also added on Settlement Road, to facilitate east-west floodplain flow south of the Princes Highway.

6.3.4 Culvert design blockage

Consideration for the application of blockage factors to cross culverts was given in accordance with the recommendations of the 2013 Austroads Guidelines (Chapter 5B Section 3.7.4) and in consultation with VicRoads. A 0 % blockage factor was considered appropriate for designing culverts crossing the Princes Highway duplication at Kilmany given the structure acts as a detention basin and oversizing structures to account for blockage would result in increased water levels downstream.

The risk of blockage to Princes Highway structures was considered on a structure by structure basis and was generally considered low despite the relatively small diameter of the proposed and existing cross culverts for the following reasons:

- The upstream catchment is flat and contains minimal woody debris. Grass and other non-woody vegetation is considered to be the main source of debris.
- The presence of upstream structures that would intercept debris that does occur during a flood event prior to it reaching the Princes Highway.

Consideration was given to the provision of debris deflectors and grills for cross culverts to reduce blockage risks. However it was determined that given the likely debris source these structures would not provide a significant reduction in the blockage risk.

6.4 Proposed hydraulic infrastructure

Design conditions flood depth and flood afflux (design conditions peak water level minus existing conditions peak water level) maps for the 1 % AEP flood event are presented in **Appendix G**. The afflux maps demonstrate that the proposed design does not significantly impact upstream and downstream hydraulic conditions outside the VicRoads ROW with the exception of small pockets of positive afflux located adjacent to the proposed road embankment and in the Nambrok-Dennison Irrigation Channel. Afflux at these are locations is attributable to the removal of table drains which currently run parallel to the highway. The construction of table drains to the required design standard for longitudinal drainage should mitigate these local increases in water level.

The afflux maps show a reduction in the peak 1 % AEP flood level both upstream and downstream of the Princes Highway. This result is a function of the relative stage-discharge relationships of the existing highway and the proposed duplication.

Table 6.1, Table 6.2 and Table 6.3 presents waterway structures modelled or the design conditions flood modelling. The tables present bridges and culverts located under the Princes Highway (Table 6.1, Table 6.2 respectively) and culverts located under adjacent minor roads. A layout plan showing the location of each structure is provided in **Appendix H**.

Table 6.1 Design bridges for the Princes Highway

Location	Comment
CGD2	Single span bridge - northern carriageway
CGD2	Single span bridge filled below the soffit level to the existing culverts – southern carriageway
CGD3	Single span bridge - southern carriageway only
CGD3	Single span bridge filled below the soffit level to the existing culverts – northern carriageway

Table 6.2 Design culvert for the Princes Highway

ID / Location	Dimensions	Upstream Invert	Length	Comment
A (West of CGD2)	450 mm x 300 mm RCBC	19.68 m AHD	50 m	Lengthened existing culvert to span widened road embankment
B (Siphon, west of Nambrok – Denison Irrigation Channel)	450 mm RCP	17.20 m AHD	48 m	Lengthened existing siphon to span widened road embankment
C (Nambrok – Denison Irrigation Channel)	900 mm RCP	15.8 m AHD	66.5 m	Replaced existing 838 mm RCP
D (east of Nambrok – Denison Irrigation Channel)	450 mm pipe	16.44 m AHD	63 m	Replaced existing 375 mm RCP
F (Highway culvert, west of CGD3)	1050 mm pipe	15.94 m AHD	69.5 m	New culvert to facilitate north-south flows across the highway
H (CGD3)	2 x 1800 mm x 600 mm RCBC	15.5 m AHD	18.5 m	Additional flow structures at CGD3 to mitigate existing overtopping of road. Existing flow structures will also be retained.

Table 6.3 Design culvert structures for local roads adjacent to the Princes Highway

ID / Location	Dimensions	Upstream Invert	Length	Comment
E (Settlement Road culvert)	375 mm pipe	16.6 m AHD	29 m	Connects floodplain south of the Princes Highway
G (Sale – Toongabbie Road culvert)	1200 mm x 450 mm RCBC	15.7 m AHD	22 m	Connects floodplain north of the Princes Highway. Replaces existing 375 mm RCP.
I (Private driveway culvert)	300 mm pipe	32.1 m AHD	11.5 m	Replacement of existing culvert which connects irrigation channel south of highway

7. CONCLUSIONS

RORB hydrological modelling was undertaken for the Kilmany catchment for the purposes of estimating routed hydrographs and rainfall-excess inflows to the 1D/2D TUFLOW hydraulic model. Flows were estimated for the 1 % AEP event. Three separate RORB models were developed for Nambrok Creek, the Nambrok – Denison Irrigation Channel and Central Gippsland Drain No 3, to estimate routed inflows and rainfall excess inflows for the 1D/2D TUFLOW model. The hydrological modelling was undertaken using 2016 AR&R rainfall IFD data, temporal patterns and losses. Monte Carlo simulations were undertaken to determine flood quantiles for each modelled duration to account for aleatory variability, in accordance with AR&R 2016 guidelines.

Flood modelling using a 1D/2D TUFLOW hydraulic model was undertaken to estimate the extent of existing conditions flooding, the existing flood immunity of the Princes Highway, and the potential implications for making changes to the waterway structures at Nambrok Creek and Gippsland Drain No.3. The following conclusions were drawn based on the results of the existing conditions flood modelling:

1. Overtopping of the Princes Highway occurs at one location for the 1 % AEP event; at Central Gippsland Drain No. 3.

2. VicRoads planned highway duplication works include widening and raising the elevation of the highway. The planned works will change flooding conditions upstream and downstream of the highway without the implementation of the appropriate mitigation measures.

Flood modelling was undertaken to estimate the extent of flooding under design conditions using a design road surface provided by VicRoads. The following conclusions were drawn based on the results of the design conditions flood modelling:

1. The proposed duplication requires modification of the existing hydraulic structures and the addition of new hydraulic structures to satisfy the hydraulic objectives. A description of the hydraulic infrastructure required is presented in Section 6.4.

2. Irrigation channels infilled as a result of the widened and raised road embankment should be re-established in adjacent locations to prevent increases in flows across properties upstream of the highway.

3. Upgrades to minor culverts crossing the highway and the Sale – Toongabbie Road will be required as part of works to facilitate continued conveyance of overland flows which may otherwise be obstructed by the proposed road embankment.

8. RECOMMENDATIONS

It is recommended that the hydraulic infrastructure identified by this report is adopted for the road design. Alternative hydraulic infrastructure arrangements may be acceptable but should be tested using the TUFLOW hydraulic model to demonstrate compliance with the hydraulic design criteria.

9. QUALIFICATIONS

a. In preparing this document, including all relevant calculation and modelling, Engeny Water Management (Engeny) has exercised the degree of skill, care and diligence normally exercised by members of the engineering profession and has acted in accordance with accepted practices of engineering principles.

b. Engeny has used reasonable endeavours to inform itself of the parameters and requirements of the project and has taken reasonable steps to ensure that the works and document is as accurate and comprehensive as possible given the information upon which it has been based including information that may have been provided or obtained by any third party or external sources which has not been independently verified.

c. Engeny reserves the right to review and amend any aspect of the works performed including any opinions and recommendations from the works included or referred to in the works if:

   (i) Additional sources of information not presently available (for whatever reason) are provided or become known to Engeny; or

   (ii) Engeny considers it prudent to revise any aspect of the works in light of any information which becomes known to it after the date of submission.

d. Engeny does not give any warranty nor accept any liability in relation to the completeness or accuracy of the works, which may be inherently reliant upon the completeness and accuracy of the input data and the agreed scope of works. All limitations of liability shall apply for the benefit of the employees, agents and representatives of Engeny to the same extent that they apply for the benefit of Engeny.

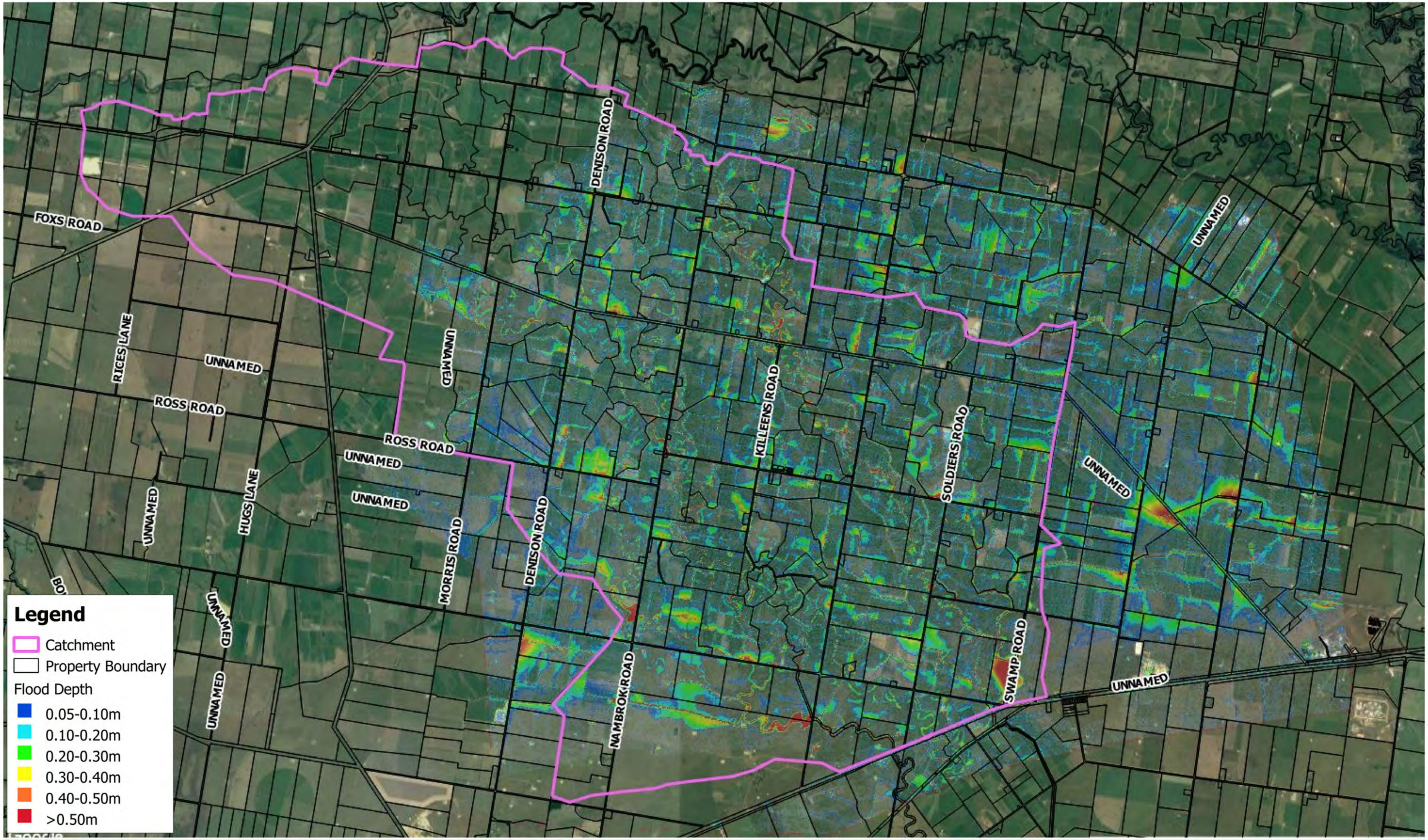
e. This document is for the use of the party to whom it is addressed and for no other persons. No responsibility is accepted to any third party for the whole or part of the contents of this report.

f. If any claim or demand is made by any person against Engeny on the basis of detriment sustained or alleged to have been sustained as a result of reliance upon the report or information therein, Engeny will rely upon this provision as a defence to any such claim or demand.

g. This report does not provide legal advice.

APPENDIX A

GPU TUFLOW Model Flow Path Identification Results



ENGENY
WATER MANAGEMENT

vicroads

1200 0 1200 m

Map Projection: Tranverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

Data Source: DELWP: VicMap - Sep 2016

Kilmany hydrology and hydraulics assessment

GPU 1% AEP Max Flood Depths

Job Number: V4000_010
Revision: 1
Drawn:
Checked:
Date: 25/9/2017

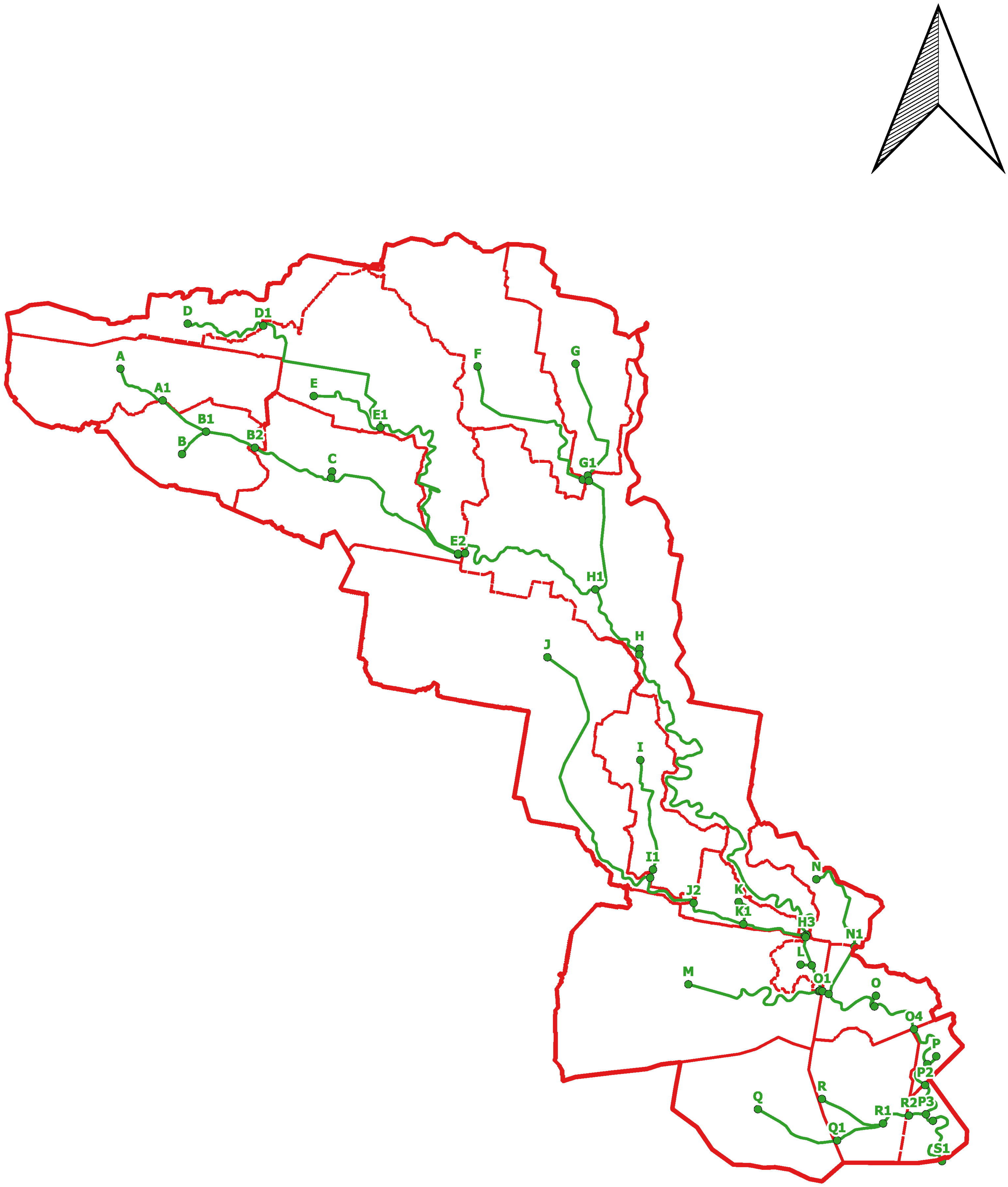
APPENDIX B

RORB Model Layouts

Nambrok Creek

Nambrok – Denison Irrigation Channel

Gippsland Drain No 3.



Legend

- RORB Model Boundary
- RORB Node
- RORB Reach
- RORB Subarea

ENGENY WATER MANAGEMENT

vicroads

1180.68 0 1180.68 m

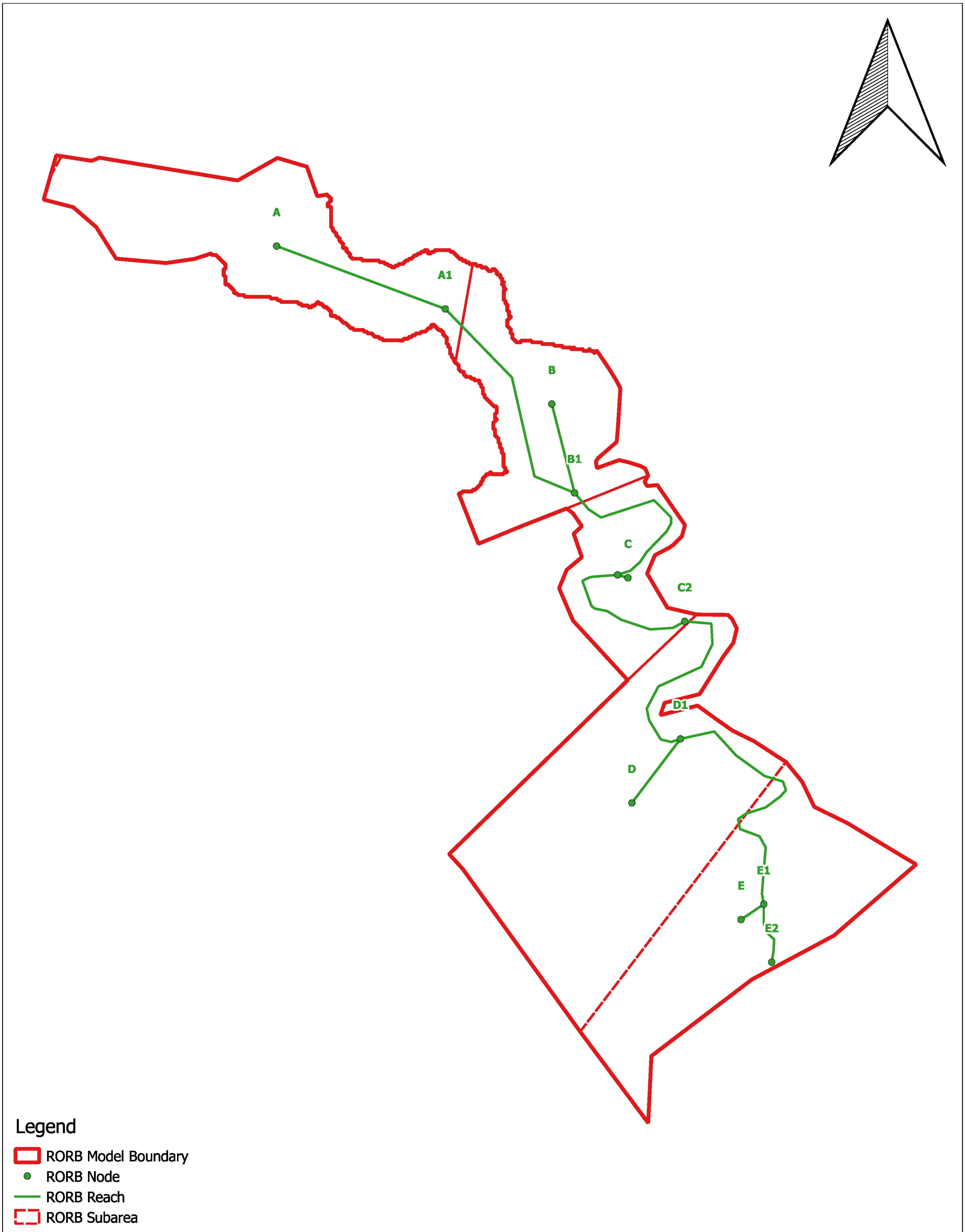
Scale in metres (1:75,000 @ A3)

Map Projection: Tranverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

Kilmany Hydrology and Hydraulics Assessment

Nambrok Creek RORB Model Layout

Job Number: V4000_010
Revision: 2
Drawn:
Checked:
Date: 25/9/2017



196.872 0 196.872 m

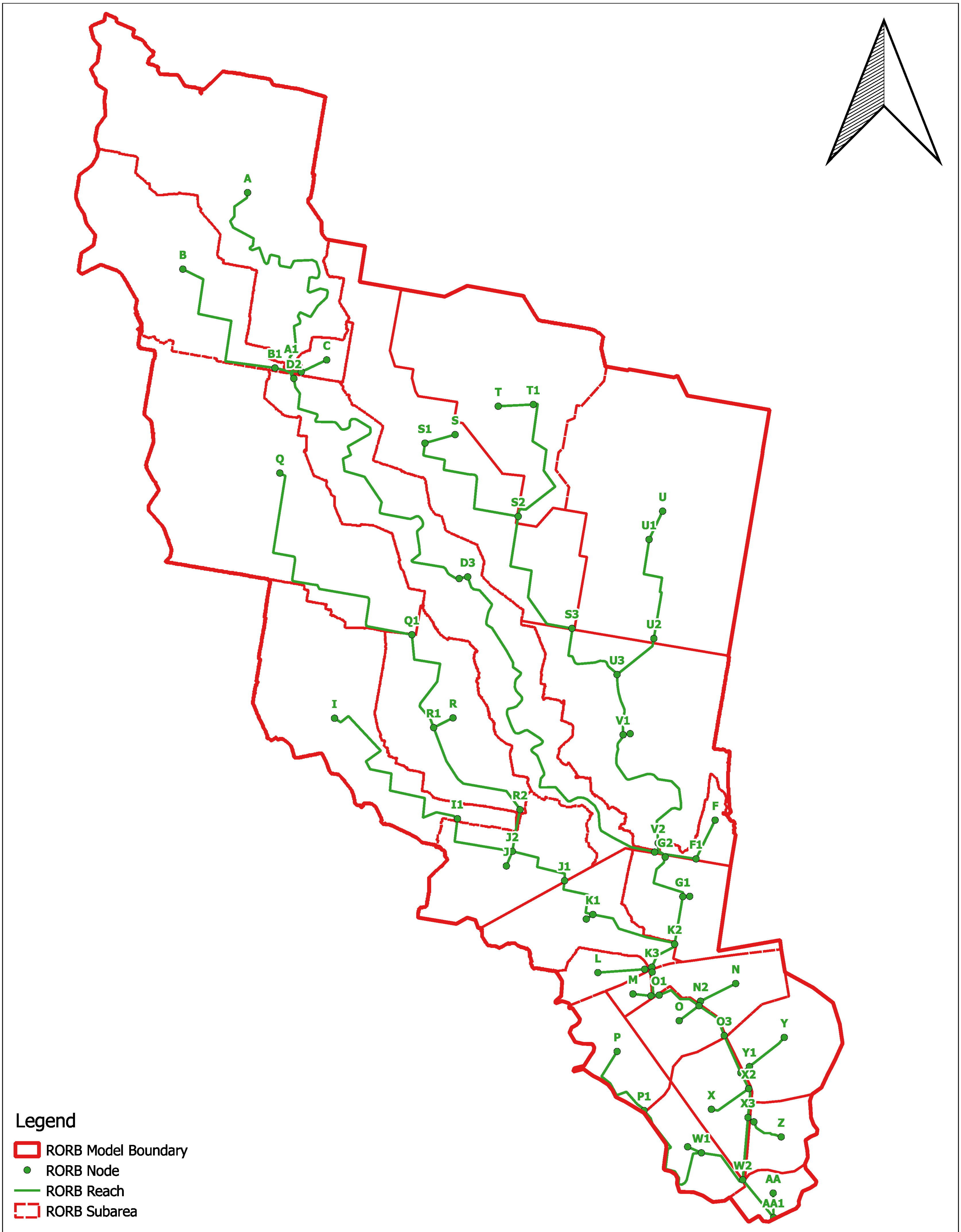
Scale in metres (1:12,500 @ A3)

Map Projection: Tranverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

Kilmany Hydrology and Hydraulics Assessment

Nambrok-Denison Irrigation Channel
RORB Model Layout

Job Number: V4000_010
Revision: 2
Drawn:
Checked:
Date: 25/9/2017



500 0 500 m

Scale in metres (1:45,000 @ A3)

Map Projection: Tranverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

Kilmany Hydrology and Hydraulics Assessment

Gippsland Drain No.3 RORB Model Layout

Job Number: V4000_010
Revision: 3
Drawn:
Checked:
Date: 10/1/2018

APPENDIX C

RORB RFFE Parameter Estimation

C.1.1. Regional Flood Frequency Estimation

Flow estimations for each catchment were undertaken using the Regional Flood Frequency Estimation (RFFE) methodology for the values for the catchment. Appendix Table C. 1 presents the expected flood quantiles for each catchment.

Appendix C presents RFFE values for each catchment and for a range of AEP events.

Appendix Table C. 1 1 % AEP RFFE flood quantiles by catchment

Catchment	Expected Quantiles (m^3/s)	5 % CL (m^3/s)	95 % CL (m^3/s)
Nambrok Creek	110.0	50.7	243.0
Nambrok – Denison Irrigation Channel	13.6	6.30	29.6
Gippsland Drain No. 3	79.4	36.4	175.0

The RFFE flood quantiles and AR&R 2016 recommended loss parameters were used as a basis for validating the k_c value for each catchment. Validation involved adjusting the k_c value so that the flood quantiles estimated by the 'natural conditions' RORB models approximately matched the RFFE estimates.

C.1.2. Routing parameter validation

In the absence of suitable calibration data an assortment of industry regional equations were used to estimate the appropriate k_c value for each catchment and validate the k_c parameter estimated using the RFFE flood quantiles. Appendix Table C. 2 presents a summary of each regional equation, the resulting k_c and 1 % AEP flows (estimated using the Monte Carlo approach) for each catchment. 'Natural' conditions RORB models that did not contain retarding basins were used for this exercise.

Appendix Table C. 2 Comparison of RFFE k_c estimate to regional equation estimates of k_c

Equation	Formula	Nambrok Creek Catchment		Nambrok – Denison Irrigation Channel Catchment		Gippsland Drain No. 3 Catchment	
-	-	k_c	Monte Carlo (m^3/s)	k_c	Monte Carlo (m^3/s)	k_c	Monte Carlo (m^3/s)
Victoria (MAR<800 mm) – Equation 3.22, ARR (Book V)	$K_c = 0.49 \times A^{0.65}$	8.05	205	0.64	22	5.17	172
Victoria (MAR>800 mm) – Equation 3.21, ARR (Book V)	$K_c = 2.57 \times A^{0.45}$	17.84	106	3.1	8	13.14	72
Victoria Data (Pearse et al, 2002)	$K_c = 1.25 \times D_{av}$	19.89	96	2.35	9	10.69	87
Australia Wide Dyer (1994) data (Pearse et al, 2002)	$K_c = 1.14 \times D_{av}$	18.14	105	2.14	10	9.75	94
Australia Wide Yu (1989) data (Pearse et al, 2002)	$K_c = 0.96 \times D_{av}$	15.27	120	1.8	11	8.21	110
Matched to RFFE flow estimates	n/a	17	106	1.0	16	11	85

As presented in Appendix Table C. 3 the 'verified' k_c values match very closely to k_c values estimated by the regional prediction equations. Whilst a poor match was achieved to the Victoria (MAR<800 mm) equation, the mean annual rainfall for the study area is 750 to 800 mm, and it is likely that the Victoria (MAR>800 mm) equation is more representative of the region.

Further investigation to determine an appropriate k_c value was conducted, which involved considering the relationship between the routing parameter (k_c) and the Average Flow Distance (d_{av}). Catchments with similar k_c/d_{av} relationships will exhibit similar runoff responses. Studies (Pearse et al, 2002; Yu, 1989 and CRCCH) have determined the expected k_c/d_{av} relationship for RORB hydrological models which have been summarised in Appendix Table C. 3.

Appendix Table C. 3 Summarised k_c/d_{av} relationships for RORB hydrological models

Group	Victorian (Pearse, 2002)	Yu, 1989	CRCCH
Expected	1.25	0.96	1.14
Low (-1 SD in log)	0.75	0.47	0.61
High (+1 SD in log)	2.07	1.94	2.13

Appendix Table C. 4 presents the k_c/d_{av} relationships for each catchment and demonstrates that the k_c/d_{av} ratio for the Nambrok Creek and Gippsland Drain No. 3 catchments are close to the expected values predicted by the equations and the Nambrok – Denison Irrigation Channel ratio is towards the lower end of the estimated range.

Appendix Table C. 4 Comparison of k_c/d_{av} relationships for each catchment

Catchment	k_c	d_{av}	k_c/d_{av}
Nambrok Creek	17	15.91	1.07
Nambrok-Denison Irrigation Channel	1	1.74	0.57
Gippsland Drain No. 3	11	8.55	1.29

Based on the above analysis and the characteristics of each catchment the following can be inferred:

1. The study catchments are expected to exhibit similar runoff responses and should therefore have similar k_c/d_{av} ratios; and,

2. A higher k_c/d_{av} ratio will likely represent catchment flows better given the extent of catchment storage that has not been fully accounted for in the RORB model.

APPENDIX D

RFFE by catchment

D.1.1. Central Gippsland Drain No. 2 catchment

Flow estimates were calculated based on the details provided in Appendix Table D. 1 and produced flow estimates shown in Appendix Table D. 2.

Appendix Table D. 1 RFFE input parameters – CGD2

Detail	Value
Latitude at Outlet (degree)	-38.1316
Longitude at Outlet (degree)	146.8834
Latitude at Centroid (degree)	-38.1698
Longitude at Centroid (degree)	146.8262
Catchment Area (km^2)	74.10

Appendix Table D. 2 RFFE flow estimates – CGD2 RORB model

AEP (%)	Expected Quantiles (m^3/s)	5 % CL (m^3/s)	95 % CL (m^3/s)
50	12.9	6.26	26.6
20	26.8	13.4	53.7
10	40.1	19.9	81.3
5	56.5	27.5	117.0
2	84.1	39.6	180.0
1	110.0	50.7	243.0

D.1.2. Nambrok-Denison Irrigation Channel Catchment

Flow estimates were calculated based on the details provided in Appendix Table D. 3 and produced flow estimates shown in Appendix Table D. 4.

Appendix Table D. 3 RFFE input parameters – Nambrok-Denison Irrigation Channel

Detail	Value
Latitude at Outlet (degree)	-38.123
Longitude at Outlet (degree)	146.896
Latitude at Centroid (degree)	-38.1149
Longitude at Centroid (degree)	146.8882
Catchment Area (km^2)	1.52

Appendix Table D. 4 RFFE flow estimates – Nambrok-Denison Irrigation Channel

AEP (%)	Expected Quantiles (m^3/s)	5 % CL (m^3/s)	95 % CL (m^3/s)
50	1.73	0.84	3.53
20	3.51	1.78	6.95
10	5.17	2.59	10.4
5	7.17	3.52	14.7
2	10.5	4.99	22.2
1	13.6	6.30	29.6

D.1.3. Central Gippsland Drain No. 3 catchment

Flow estimates were calculated based on the details provided in Appendix Table D. 5 and produced flow estimates shown in Appendix Table D. 6.

Appendix Table D. 5 RFFE input parameters – CGD3 RORB model

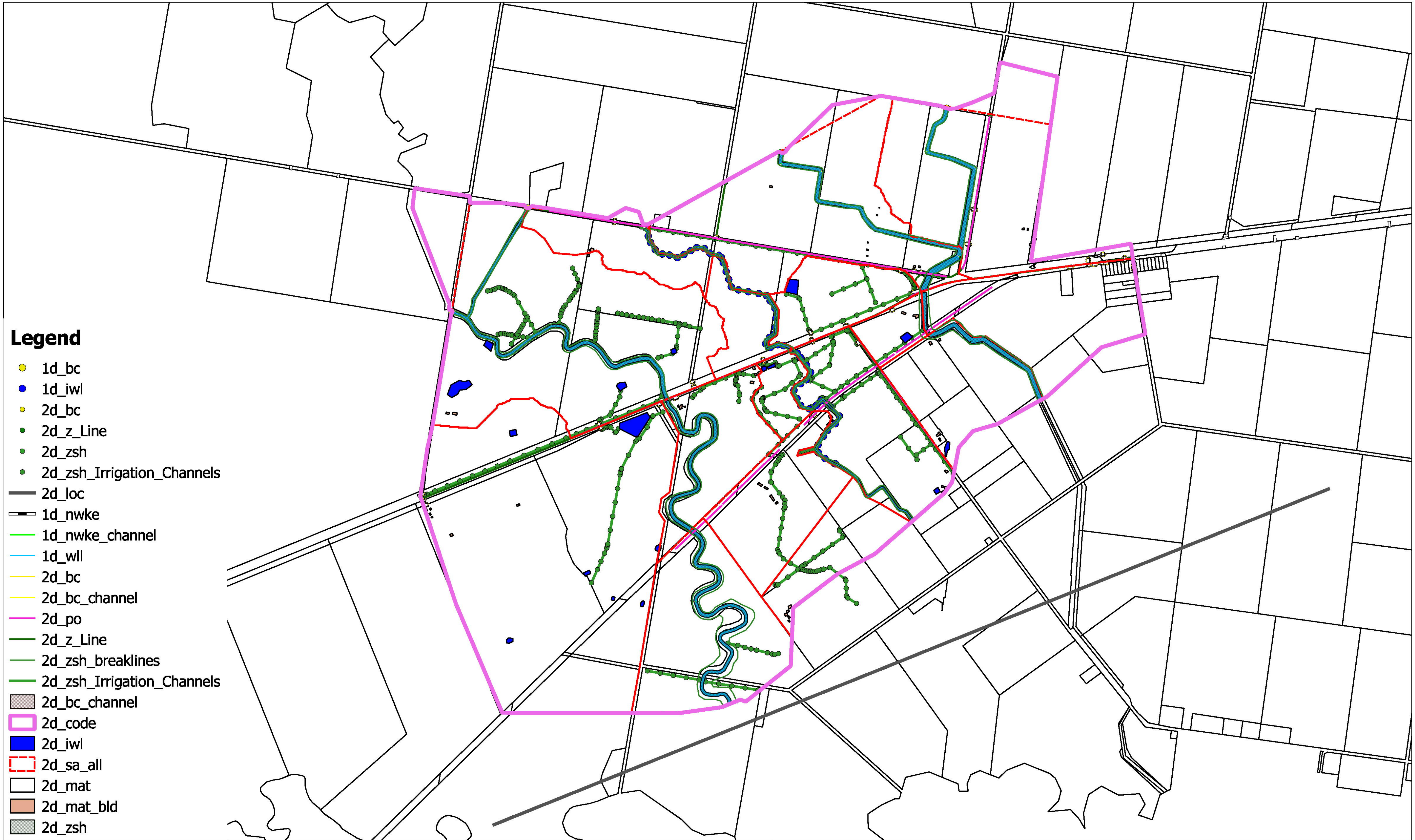
Detail	Value
Latitude at Outlet (degree)	-38.119
Longitude at Outlet (degree)	146.902
Latitude at Centroid (degree)	-38.0691
Longitude at Centroid (degree)	146.8713
Catchment Area (km^2)	37.56

Appendix Table D. 6 RFFE flow estimates – CGD3 RORB model

AEP (%)	Expected Quantiles (m^3/s)	5 % CL (m^3/s)	95 % CL (m^3/s)
50	9.02	4.38	18.6
20	18.9	9.47	37.9
10	28.4	14.1	57.8
5	40.2	19.5	83.6
2	60.2	28.3	129.0
1	79.4	36.4	175.0

APPENDIX E

TUFLOW model layout



ENGENY
WATER MANAGEMENT

vicroads

500 0 500 m

Map Projection: Tranverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

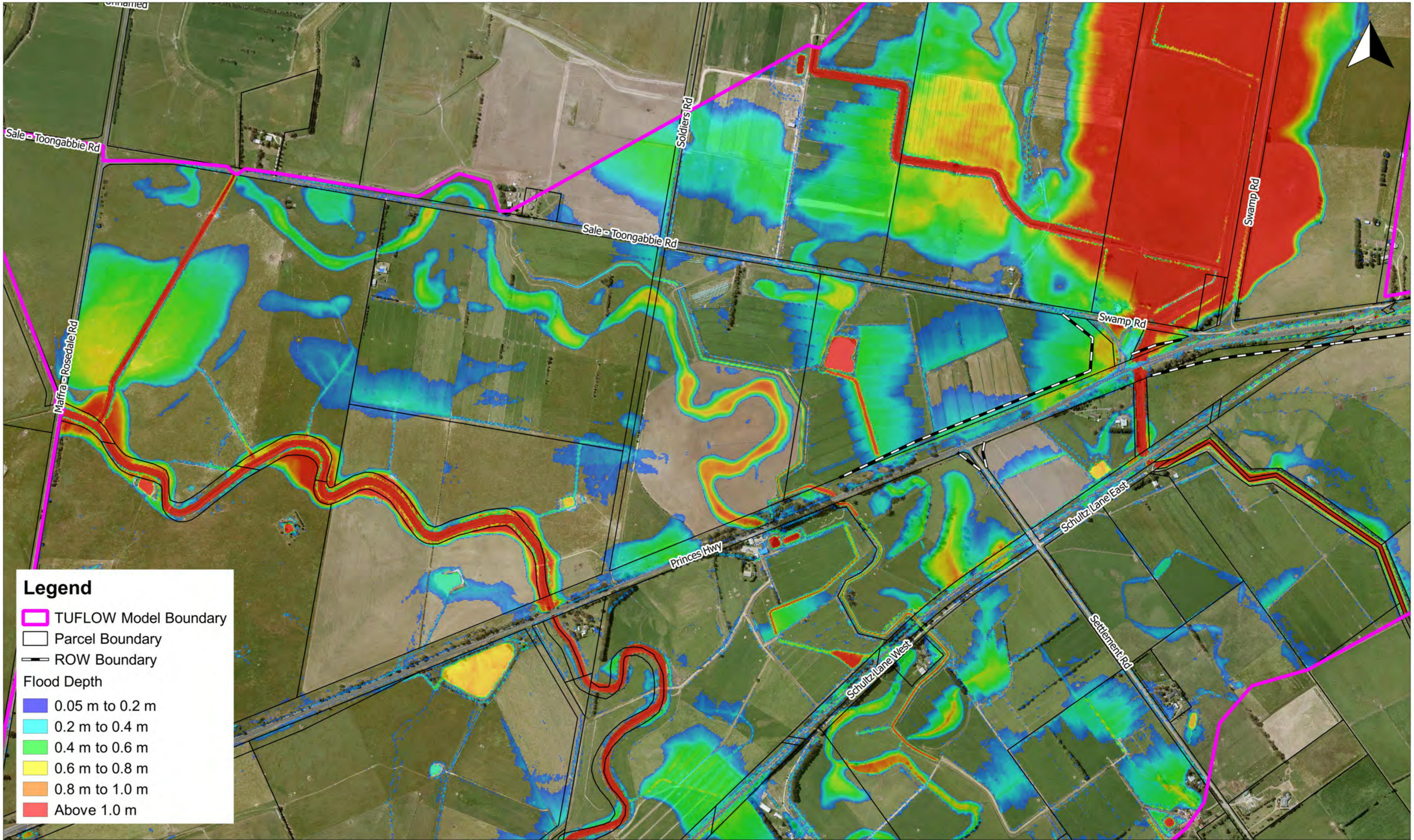
Kilmany Hydrology and Hydraulics Assessment

TUFLOW Model Input Layers

Job Number: V4000_010
Revision: 0
Drawn:
Checked:
Date: 25/9/2017

APPENDIX F

Existing Conditions Flood Depth Plots



200 0 200 400 m

At A3 1:12,500

Map Projection: Tranverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

ENGENY WATER MANAGEMENT

vicroads

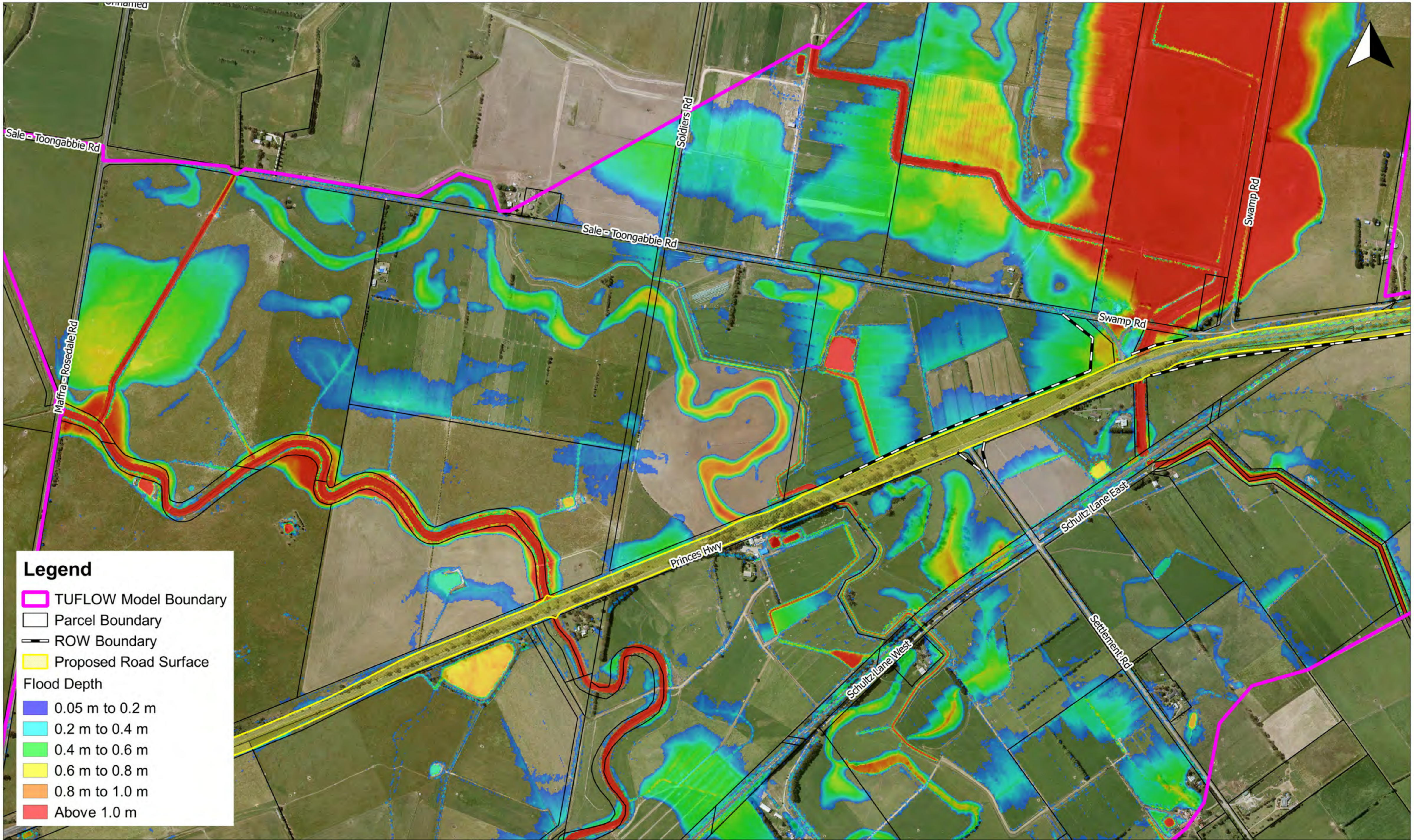
Kilmany Hydrology and Hydraulics Assessment

1% AEP Existing Conditions Flood Depth

Job Number: V4000_010
Revision: 3
Drawn:
Checked:
Date: 6/2/2018

APPENDIX G

Design Conditions-Flood Depth Plots



200 0 200 400 m

At A3 1:12,500

Map Projection: Tranverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

Kilmany Hydrology and Hydraulics Assessment

1% AEP Design Conditions
Flood Depth

Job Number: V4000_010
Revision: 0
Drawn:
Checked:
Date: 6/2/2018

ENGENY WATER MANAGEMENT

vicroads

200 0 200 400 m

At A3 1:12,500

Map Projection: Tranverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

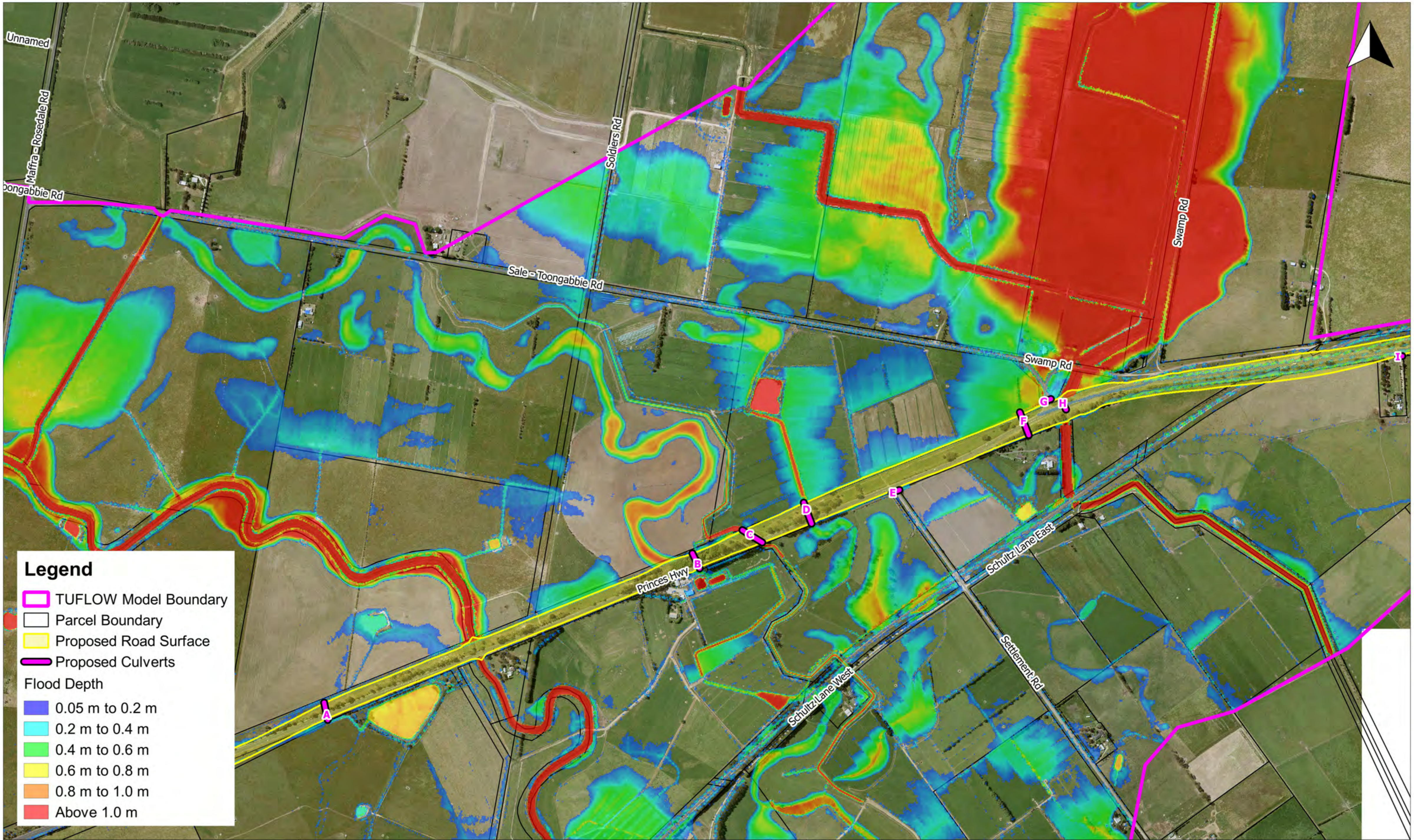
Kilmany Hydrology and Hydraulics Assessment

Flood Difference (Afflux) Plot
Design Conditions minus Existing Conditions

Job Number: V4000_010
Revision: 0
Drawn:
Checked:
Date: 6/2/2018

APPENDIX H

Layout of Proposed Culvert Crossings



ENGENY WATER MANAGEMENT

vicroads

200 0 200 400 m

At A3 1:12,500

Map Projection: Tranverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

Kilmany Hydrology and Hydraulics Assessment

Layout Plan
Proposed Culverts
1 % AEP Design Conditions

Job Number: V4000_010
Revision: 0
Drawn:
Checked:
Date: 6/2/2018