Government of **Western Australia**
Department of **Water**

Birrega and Oaklands flood modelling and drainage study

Supporting the Birrega and Oaklands Drainage and Water Management Plan

Securing Western Australia's water future

Water*Science*
technical series

Report no. WST 71
August 2015

Birrega and Oaklands flood modelling and drainage study

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Department of Water

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August 2015

ISSN 1836-2877 (online)
ISBN 978-1-922248-73-2 (online)

Acknowledgements

The Department of Water thanks the following people for their contribution to this publication: Leanne Pearce from the Water Corporation and Simon Rodgers from the Department of Water for assistance with design rainfall and hydrological modelling; Blake Boulton and Monika Balicki from DHI for assistance with hydraulic model construction and review; Martin Daniels and James Wegner from the Water Corporation for review of hydraulic model results; Dave Gossage from the Shire of Serpentine Jarrahdale for photographs and data from historical flood events, and for review of flood extent mapping; Ben Marillier from the Department of Water for assistance with hydraulic modelling, internal model audit and review.

Reference details

The recommended reference for this publication is:

Hall, J 2015, *Birrega and Oaklands flood modelling and drainage study,* Water Science Technical Series, report no. 71, Department of Water, Western Australia.

For more information about this report, contact Joel Hall, Water Science Branch, the Department of Water, Western Australia.

Cover photograph: Kargotich Road near Oaklands Main Drain during the 1987 flood (D. Gossage)

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1 Introduction

1.1 Managing flooding in Western Australia

In Western Australia, the State Government is responsible for the development of appropriate standards and strategic approaches for floodplain management and to ensure that they are applied in a coordinated and integrated fashion. The role involves the provision of expert technical advice by the Department of Water, land-use planning through the Department of Planning and the provision of effective flood emergency response management and planning though the Department of Fire and Emergency Services. The Department of Water is the State Government's lead agency in floodplain mapping and providing floodplain development advice. In accordance with the *Water Agencies Act 1984*, its function is to '*develop plans for and provide advice on flood management'*. The department provides advice on development on floodplains with the objective of promoting the wise use of floodplains while minimising the flood risk and damage. It provides advice to the Department of Planning on land-use planning, to local government on development conditions and to other agencies to ensure appropriate development on floodplains.

1.2 The role of drainage and water management plans

The Western Australian Planning Commission (WAPC), in consultation with local government authorities, has identified as a high priority the need to develop structure plans for areas of urban growth. Structure plans provide guidance for future development and management of environmental issues. A key step in the implementation of a structure plan is the creation of a drainage and water management plan, which identifies planning constraints relating to water issues and embraces water sensitive urban design and best management practices to provide a framework for more site-specific water management plans. The roles and responsibilities associated with the development of water management plans are outlined in the Western Australian Planning Commission's policy document *Better Urban Water Management* (WAPC 2008). The development of drainage and water management plans is the responsibility of the Department of Water.

The Birrega and Oaklands drainage and water management plan (DWMP) was initiated by the Department of Water based on advice from the WAPC. The area (Figure 1), predominantly zoned rural, is coming under increasing pressure for urban development as the state's population expands. The area has flat terrain, high groundwater tables and experiences periodic flooding. A major component of the drainage and water management plan is completion of a **flood modelling and drainage study** for the study area. This requires the development and calibration of hydrologic and hydraulic flood models and subsequent floodplain mapping based on a range of design storm events. The drainage study component involves the simulation of minor and major rainfall events to ascertain pre-development peak flow rates, flood levels and flood storage for key locations at potential development areas within the study area. In addition, detailed floodplain mapping based on the 100 year average recurrence interval flood extent and hydraulic long sections of the major drains are constructed to guide future urban development and drainage design. The

DWMP includes strategies for managing flooding in the catchment as urban development occurs, and is informed by the outcomes of this flood modelling and drainage study.

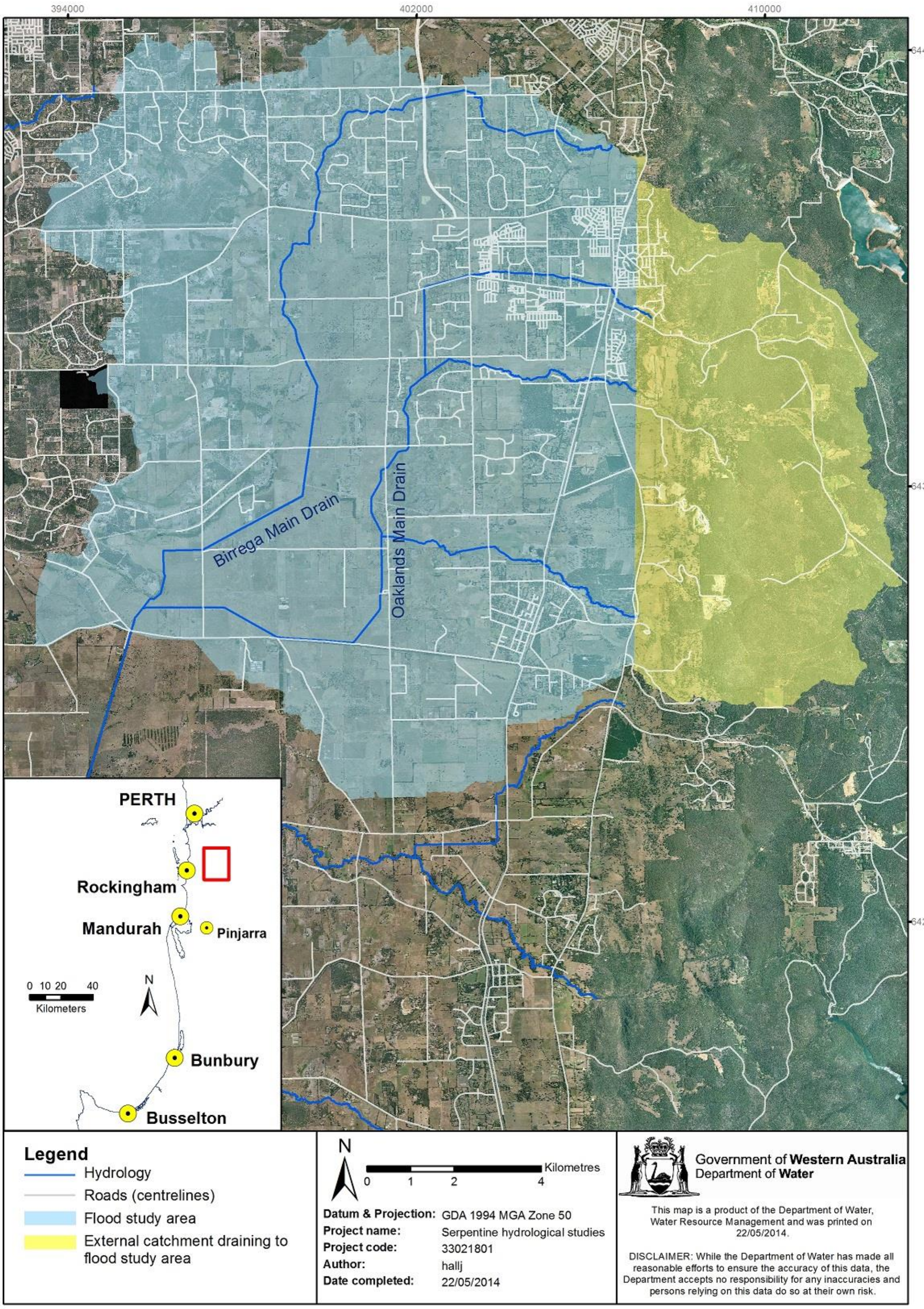


Figure 1-1: *Location of the Birrega and Oaklands catchment displaying the floodplain study area (blue), catchments that contribute flow to the study area (yellow), and significant drainage features*

2 Specification

2.1 Scope

The floodplain and drainage study includes the following components:

1. **Literature review**
2. **Data collection**
3. **Hydrology studies:** to develop the 5, 10, 20, 100, and 500 year average recurrence interval (ARI) design flows for the rivers and watercourses at key locations within the study area. In developing the design flow estimates the following range of techniques will be incorporated:
    a. Flood frequency analysis
    b. Hydrological catchment modelling.

    Outflow hydrographs from catchments external to the modelling area will be calculated using the rainfall-runoff model RORB (Laurenson et al. 2007). Regional RORB parameters developed by the Water Corporation (Pearce, 2006) will be validated for historic flood events using available gauging data. Rainfall intensity frequency duration (IFD) analysis will be undertaken for the internal area of interest. The validated parameters and IFD will be used to generate design hydrographs for inflows from catchments external to the floodplain study area. The methodology for the determination of design rainfall and flow estimates will be documented.
4. **Hydraulic modelling:** this component involves the development of a hydraulic model using digital terrain data for the study area will involve:
    a. developing a suitable hydraulic model for the study area
    b. collecting additional data for stage height and dimension of bridges, crossings, culverts and other structures
    c. using flow gauging information from a flood event for the calibration of the model
    d. using historical flood information for the validation of the hydraulic model
    e. producing 5, 10, 20, 100 and 500 year ARI flood extent mapping for the rivers, watercourses and drains in the study area, including plan and long section drawings of main drains
    f. incorporating a levee break scenario in the 100 year ARI floodplain mapping
    g. producing a detailed sensitivity analysis for the major model parameters and inputs
    h. producing flood animation presentations of various ARI flood events.

    The report will include a section on considerations for drainage design, based on the results of the hydraulic modelling.

2.2 Catchment and drainage

The study covers an area bounded by the Darling Scarp in the east, the Jandakot Mound to the west, the Wungong catchment to the north, and the Serpentine River catchment to the south. The area covers approximately 185 km^2 and most lies on the Swan Coastal Plain west of Rockingham (approximately 20 km south of Perth), with a smaller proportion of the catchment located east of the Darling Scarp (56 km^2). The Swan Coastal Plain is characterised by sandy soils and flat terrain. Land is predominantly zoned rural and rural residential (primarily a combination of beef grazing and lifestyle blocks), with large floodplains incised by deep and narrow rural drains, significant waterlogging in winter and flood risks in some areas. The major hydrological features are shown in Figure 2-1.

Two main drains traverse the catchment – the Birrega Main Drain and the Oaklands Main Drain. The catchment is also incised by many major rural drains (managed by the Water Corporation), and minor rural drains managed by private landholders. The Birrega and Oaklands Main Drains converge in the south-west of the study area where they eventually discharge to the Serpentine Main Drain (downstream of the study area).

Birrega Main Drain

The Birrega Main Drain runs through the entire study area. The drain begins as a minor off-take of the Wungong Brook just downstream of the South-West Highway. The drain is relatively minor (i.e. less than 1m deep) as it travels in a north westerly direction and expands to a large drain at Hopkinson Road (approx. 2m deep and 10m wide). It then flows easterly and then southward, and is a major rural drain for most of the study area (Figure 2-2). The drain expands to a width of 40 m at Mundijong Road. The upper reaches of the Birrega Drain are heavily vegetated and do not have significant levee or spoil banks adjacent to the channel (Figure 2-3). The drain has levee banks of unequal height on the left and right sides downstream of Orton Road. It should be noted that the levee banks are not maintained for flood protection, and are comprised mostly of the spoil in the drainage system that is excavated during maintenance. The term levee bank and spoil bank can be used interchangeably throughout this report. The levees have a series of breaks that allow lateral flow from adjacent channels which link the drain to flood storage areas. A significant levee on the Birrega Main Drain runs 1 km north of Mundijong Road on the western side of the drain. This section of the Birrega Drain alters the natural flow of water around the Jandakot Mound, and is a significant breach-point if flood levels rise to approximately 11 m AHD in this vicinity. A breakout from a large flood event (or failure of this levee) would result in significant flood flows in a westerly direction through north-east Baldivis toward the Peel Main Drain (this occurred during the 1987 flood event). The breakout of large flood events at Duck Pool is a deliberate feature of the Birrega drainage design, as specified in the Public Works Department's Rural Drainage Manual.

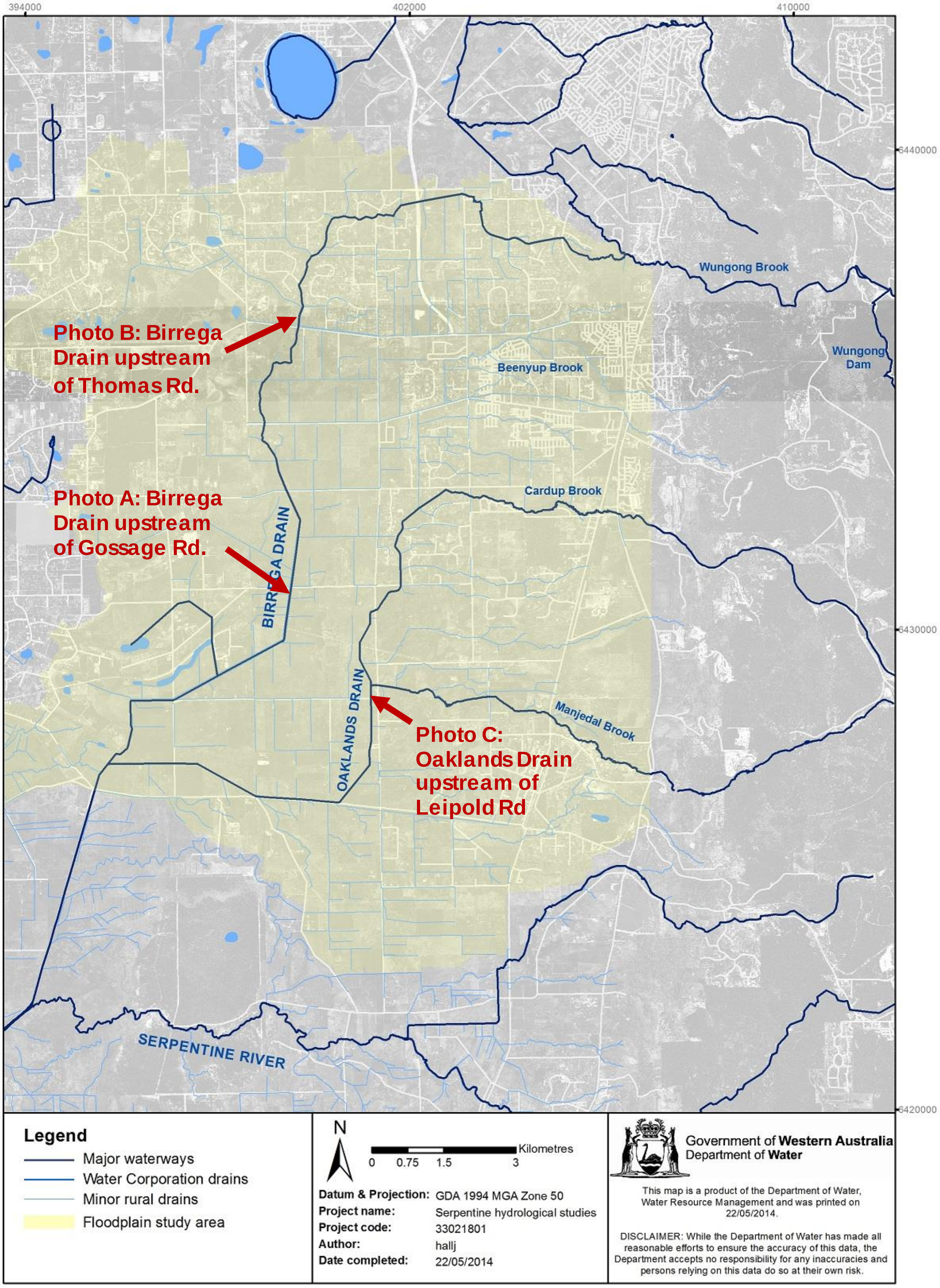


Figure 2-1: *Hydrological features of the floodplain study area*

Figure 2-2: *Birrega Drain upstream of Gossage Road (Photo A)*

Figure 2-3: *Birrega Drain upstream of Thomas Road (Photo B)*

Figure 2-4: *Oaklands Drain upstream of Leipold Road (Photo C)*

Figure 2-5: *Wungong Brook (left) at the confluence marking the beginning of Birrega Drain (right)*

The Birrega Main Drain has a relatively small escarpment catchment. The upper reach of the drain branches form Wungong Brook. At this split-point the Wungong Brook provides an insignificant proportion of flow to the Birrega Drain (very low flows only); the majority of flow is diverted north to the Southern River flowing west of Armadale and into the Canning River at Gosnells (Waugh 1986). The flow that enters Birrega Main Drain is limited by the size of the channel and by a 200 mm culvert located at Wungong Brook (Figure 2-5).

Oaklands Drain

The Oaklands Main Drain receives inflows from catchments with headwaters in the Darling Scarp. Most of the escarpment flows accumulate to Manjedup Brook, Cardup Brook and Beenyup Brook, where they traverse the Swan Coastal Plain in an east-west direction, and discharge laterally to the Oaklands Main Drain. Most of the north-south section of Oaklands Drain has a western levee significantly higher than the eastern levee (Figure 2-4), presumably to capture flows from the escarpment and to provide protection to landholders on the western side of the drain. This drain expands to a width of approximately 25m at its downstream end, where it discharges to the Birrega Drain approximately 600 m north of Mundijong Road.

Rural drainage design

When development is planned within a rural drainage area it is important that drainage issues appropriate to that area are understood, and that planning and design are undertaken to address these issues. The drainage system in the Birrega catchment was designed to alleviate waterlogging during winter to make land viable for agriculture. The rural drains are not designed to give flood protection to all land at all times – some inundation of the land is allowed and expected in large rainfall events (generally above the 2 year ARI). These drains do not provide the protection required for urban development and, in many cases, improvements to the drainage network are required for urban development. Main drains are characterised by deeply incised channels that in some areas have high levees (1–2 m high) to contain flows. These levees are not maintained and most are in poor condition. Flow generally enters the main drains via culverts and laterally flowing channels. During significant events, there are a number of areas where water cannot enter the main drainage channels until the water level in the main drain recedes; water backs up and storage is created adjacent to the drain. Significant volumes of water are stored in large events in natural basins parallel to the Birrega Main Drain. The rural drainage system was designed to completely drain water stored in natural basins within 72 hours of a rainfall event.

Development constraints to rural drainage districts

Most major rural drains in the study area are managed by the Water Corporation. When development is planned within a rural drainage area and Water Corporation is custodian of the drain, it is important that drainage management is undertaken according to guidelines set out by the Water Corporation. This is a major consideration that requires assessment during the flood study and consideration in the development of the DWMP.

A summary of the considerations for urban development can be found in Water Corporation's Development Services Information Sheet No. 59 (Water Corporation 2008). Major points of the summary include:

- It is important that developers, to the satisfaction of the Water Corporation, ensure that the level of service to the rural drainage district is not compromised by the outflow from the development. Development projects need to minimise discharge to rural drains, and take into account their limited capacity. The design of compensating basins and drainage discharge must demonstrate that the functionality of the Water Corporation's drains will not change.

- Flows to any Water Corporation rural drainage system, from a storm event of an average recurrence interval level of protection determined by local government, are not increased as a direct or indirect result of the development. In addition, any naturally occurring storage capacity of the floodplain of existing drains is retained.

- Where additional drainage infrastructure has been provided by the Water Corporation for flood protection purposes to urban areas the design of the internal drainage system for any development must recognise the impact of a major storm event on the flood protection works. Urban areas impacted by flood protection works must be protected from a major flood event by either upgrading that infrastructure to incorporate that event or by providing protection within the development for the impact of the event. The design of the internal drainage system shall identify and incorporate upgrades to existing food protection as required. This will extend to the integrity of levee systems to meet the change in risk from rural to urban land. These requirements are in addition to Australian Rainfall and Runoff (Pilgrim 2001) level of protection requirements for urban developments.

2.3 Flooding mechanisms

The study area is subject to regular winter events resulting from cold fronts moving in a westerly or south-westerly direction across the catchment. Significant events of this nature were observed in June 1945, August 1964, July 1987 and July 1996. During the summer major flooding may occur as a result of significant rainfall from events with tropical origins. The flood in February 1955 was an example of a major summer flood related to the passage of an ex-tropical system through the catchment, and the flood in February 1992 was the result of tropical rainfall from a north-west trough funnelling through to the southern portion of Western Australia. There are several potential flooding mechanisms for the Birrega study area and surrounds. The mechanisms can be broadly categorised as follows:

Groundwater inundation

Groundwater inundation is responsible for extensive flooding during the winter months over much of the study area (see Marillier et al. 2012b). In agricultural areas such inundation is generally discharged via shallow drains over several days. Urban development typically manages such inundation with fill and subsurface drainage infrastructure. Groundwater inundation is not always considered in flood studies; however, in this section of the Swan Coastal Plain, it is likely to contribute to flooding during winter, as it effectively increases the impervious surface area and reduces infiltration capacity. Seasonally inundated areas will produce more runoff than areas with several metres clearance from groundwater. Figure 2-6 shows inundation from the average September groundwater level (1981–2011) throughout the study area, sourced from the Lower Serpentine regional model (Marillier et al. 2012b).

Riverine flooding from escarpment tributaries and main drains

The escarpment catchments in the Birrega study area are small relative to the catchment area located on the Swan Coastal Plain. As such, flooding from tributaries within the Darling Scarp (e.g. Cardup Brook, Manjedal Brook and Beenyup Brook) is relatively minor.

Within the main study area the Birrega and Oaklands Main Drains receive lateral inflows from agricultural drains along their entire reach, and in sufficiently large rainfall events this additional flow may result in flooding adjacent to the drains where gaps in the levee bank or lateral culverts allow discharge.

Historically, large flood events in Wungong Brook would overflow to the Birrega catchment, downstream of the South Western Highway. This occurred in the 1964 flood event, before the construction of the Wungong Reservoir. Prior to construction of the reservoir, the Wungong catchment upstream of the South Western Highway was significantly reduced (approximately 10% of the original catchment), and the likelihood of overflow occurring along this reach of Wungong Brook is negligible.

Localised flooding from catchment rainfall

The main study area experiences localised flooding after prolonged or intense rainfall events. This flooding occurs as a result of infiltration excess runoff or saturation excess runoff; the latter being heavily influenced by landscape position and groundwater levels.

Soils within the study area can be classified into two broad categories: Bassendean Sand and Guildford Clay. The presence of clays throughout the area increases the risk of localised flooding from infiltration excess runoff. Low-lying areas within the study area frequently experience surface ponding, either from groundwater inundation or individual storms.

Levee failure or breakout on the Birrega and Oaklands Main Drains

The western levee banks along the Birrega and Oaklands Main Drains in the event of failure introduce a potential flood hazard to the adjacent landholders. The levees on Birrega and Oaklands drains are not regularly maintained to a standard that would protect from significant flooding, so it is important that the flood modelling includes a ‘levee banks fail’ scenario to examine the potential flood extent.

2.4 Literature review

Murray floodplain development strategy

The Murray floodplain development strategy (GHD 2010), developed for the Murray DWMP, covered the area between the Darling Scarp and the Peel Inlet. The study superseded previous flood studies of the Murray and Serpentine rivers, and storm-surge studies for the Peel-Harvey Estuary. Runoff routing models were developed and calibrated for the Murray River, and a storm-surge model was developed for the Peel Inlet and Harvey Estuary. A coupled one and two-dimensional hydraulic model was developed and calibrated; this included a direct rainfall modelling approach for runoff processes within the study area.

Small dams flood study – regional analysis, Water Corporation (Pearce 2006)

This study developed an approach to estimate peak floods and associated hydrographs between the 50 year ARI and the probable maximum precipitation design flood event for catchment areas between 1 km^2 and 100 km^2. The area of interest was limited to the south-west of Western Australia, in both jarrah forestland and wheat-belt catchments. The report developed a series of equations that could be used to describe the runoff routing parameters k_c and RoC, as a function of catchment area and event rainfall and which could be used in the absence of historical flood data.

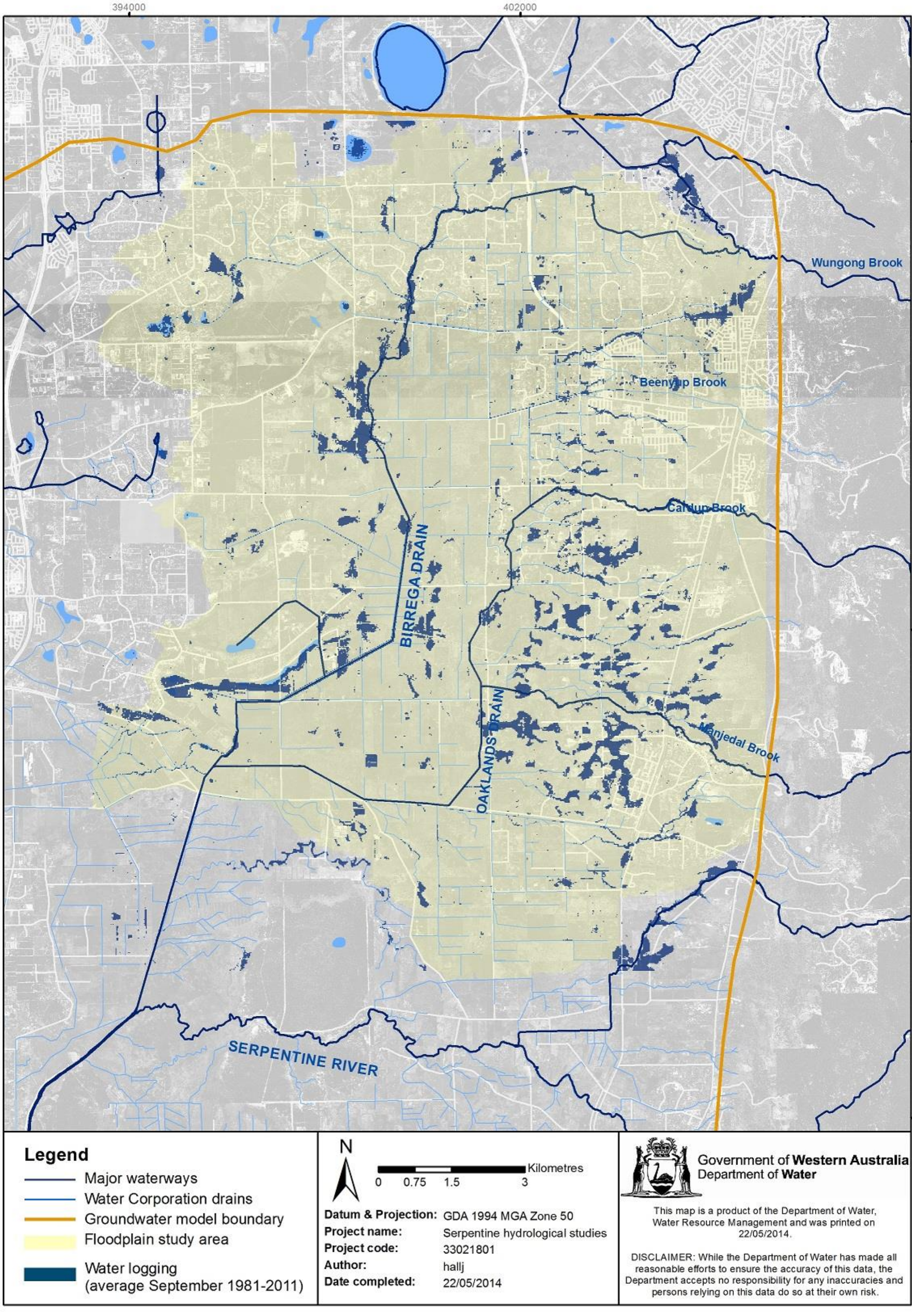


Figure 2-6: *Likely areas of groundwater inundation (Marillier et al. 2012)*

Serpentine hydrological studies, Department of Water (Marillier et al. 2012a, Marillier et al. 2012b, Marillier et al. 2014)

The Serpentine hydrological studies were completed by the Department of Water to support the Serpentine DWMP. The study focuses on development of an integrated surface and groundwater model to provide primarily shallow groundwater information at a regional scale.

Outcomes of the project include provision of groundwater levels, surface water flows, calibrated groundwater and surface water parameter sets and water balances related to current conditions, and several climate, drainage and land development scenarios. Some data and parameter sets investigated and calibrated in the Serpentine hydrological studies are relevant to this study (for example, overland roughness coefficient Manning's '*M'*, or channel Manning's coefficient '*n*'). In addition, inundation mapping from the hydrological studies can be used to set initial water levels for the Birrega floodplain study.

Serpentine River floodplain management study (SKM 2010)

A flood study was undertaken for the Serpentine River through the Serpentine, Baldivis and Karnup areas to review existing mapping and asses the proposed Serpentine Planning Scheme. Hydrologic and hydraulic models were constructed and calibrated, and flood mapping was produced for the 10, 25, 100 and 500 year ARI events. A critical duration was found to be a combination of 24–72 hour duration storms for these areas. The hydraulic model's extent was increased from the previously defined study area to capture the flow behaviour in the upper reaches of the Birrega Main Drain, and the study showed that the Serpentine River downstream of the Birrega Main Drain is overwhelmed in the 100 year ARI flood event. The report estimated that the capacity of the Serpentine River and Birrega Main Drain is greater than the 25 year ARI flood event.

Byford town-site drainage and water management plan (Department of Water 2008)

This document presents results of a floodplain management strategy originally developed by SKM in 2007. The study involved two-dimensional modelling of the Byford catchment and resulted in the identification of floodway and flood fringe areas. The *floodplain management plan* includes structural and non-structural measures for flood mitigation focussed on managing potential flooding impacts on the site and to the immediate neighbouring land and drainage infrastructure. The report lists a series of subdivision storage basins and associated peak discharge areas and detention volumes. Flows, levels and floodway widths at 19 critical locations are listed for the 5 year and 100 year ARI flood events.

Southern River flood study, Water Authority (Waugh 1986)

A runoff routing model was used for the estimation of design floods in the Southern River west of Armadale. The report identified that at the location Birrega Drains splits from Wungong Brook, only a small portion of flow is diverted to Birrega Drain, with the rest diverted north to the Southern River. Wungong Reservoir flood storage effects were analysed as part of this report, and it was calculated that the median storage deficit for the end of winter period is about 13 GL. This equates to just under 100 mm of runoff from its catchment required before spilling would occur. The report stated that the catchment upstream of Wungong Dam will not contribute runoff to flood flows in the downstream reaches at the 1% or greater annual exceedence probability.

Estimation of rare design rainfalls for Western Australia: Application of the CRC-FORGE method (Department of Environment 2004)

This project derived annual design rainfall estimates from an ARI of 1 in 50 to 1 in 2000 and for durations between 24 and 120 hours by use of the application of the CRC-FORGE approach in Western Australia. The methodology was applied annually and seasonally to determine design point rainfalls. Revised areal reduction factors were also derived on annual and seasonal bases to estimate catchment rainfall.

3 Data collection

3.1 Rainfall data

There are a large number of rainfall observation stations in the vicinity surrounding the study area. However, only one station is located within the study area (Byford, BOM reference 509620); which is a relatively new station that has been collecting data since July 2008. Pluviograph data was analysed for stations surrounding the study area. A list of pluviographs used as part of the floodplain development study is shown in Table 3-1, and their locations are displayed in Figure 3-1.

Table 3-1 *Pluviographs used in floodplain development study*

BOM Reference	BOM Context	BOM Name	Easting	Northing	Commence	Cease
509269	Seldom Seen Creek	Gardens	415970	6428114	1/06/1974	-
509270	More Seldom Seen Creek	Ceriani Farm	413286	6430986	1/06/1974	-
509620	Oaklands Drain	Byford	401394	6435561	30/07/2008	-
509232	39 Mile Brook	Jack Rocks	420689	6417699	14/04/1981	-
509295	Serpentine Drain	Dog Hill	392865	6421114	9/06/1983	-
509271	Waterfall Gully	Mt Curtis	413169	6435979	1/06/1974	-
509135	Dirk Brook	Myara Road	411092	6408069	22/07/1971	25/05/1999
009039	Serpentine	Serpentine	406668	6420037	31/12/1905	-
509245	Dirk Brook	Kentish Farm	406011	6412489	1/03/1974	28/05/2001
009023	Jarrahdale	Jarrahdale	410956	6422526	1/01/1900	-
009194	Medina Research Centre	Medina Research Centre	387556	6434310	31/03/1983	-
009044	Wungong Dam	Wungong Dam	411778	6437080	31/12/1911	-
509459	Neerigin Brook	Armadale (P5)	407639	6442549	28/10/1985	-
509387	Dirk Brook	Hopelands Road	397699	6411839	4/04/1979	25/05/1999

3.2 Streamflow data

There are limited streamflow observation stations throughout the study area. Some did not collect the required data or cover the relevant time period. Most relevant data is from catchments on the Darling Scarp, outside the extent of the floodplain study area. These stations are situated at Nerrigen Brook (616044), Serpentine River (614072), Dirk Brook (614005 and 614128) and Gooralong Brook (615073).

Two flow gauging stations located within the study area (Lightbody Road, 614129 and Mundijong Road, 614030) have been operating since 2010. A significant event was recorded on 28 June 2011 (approximately 48 mm over 9 hours) and data used in the calibration of the hydraulic model. The list of flow gauging stations used in the flood study is shown in Table 3-2, and their locations are displayed in Figure 3-2.

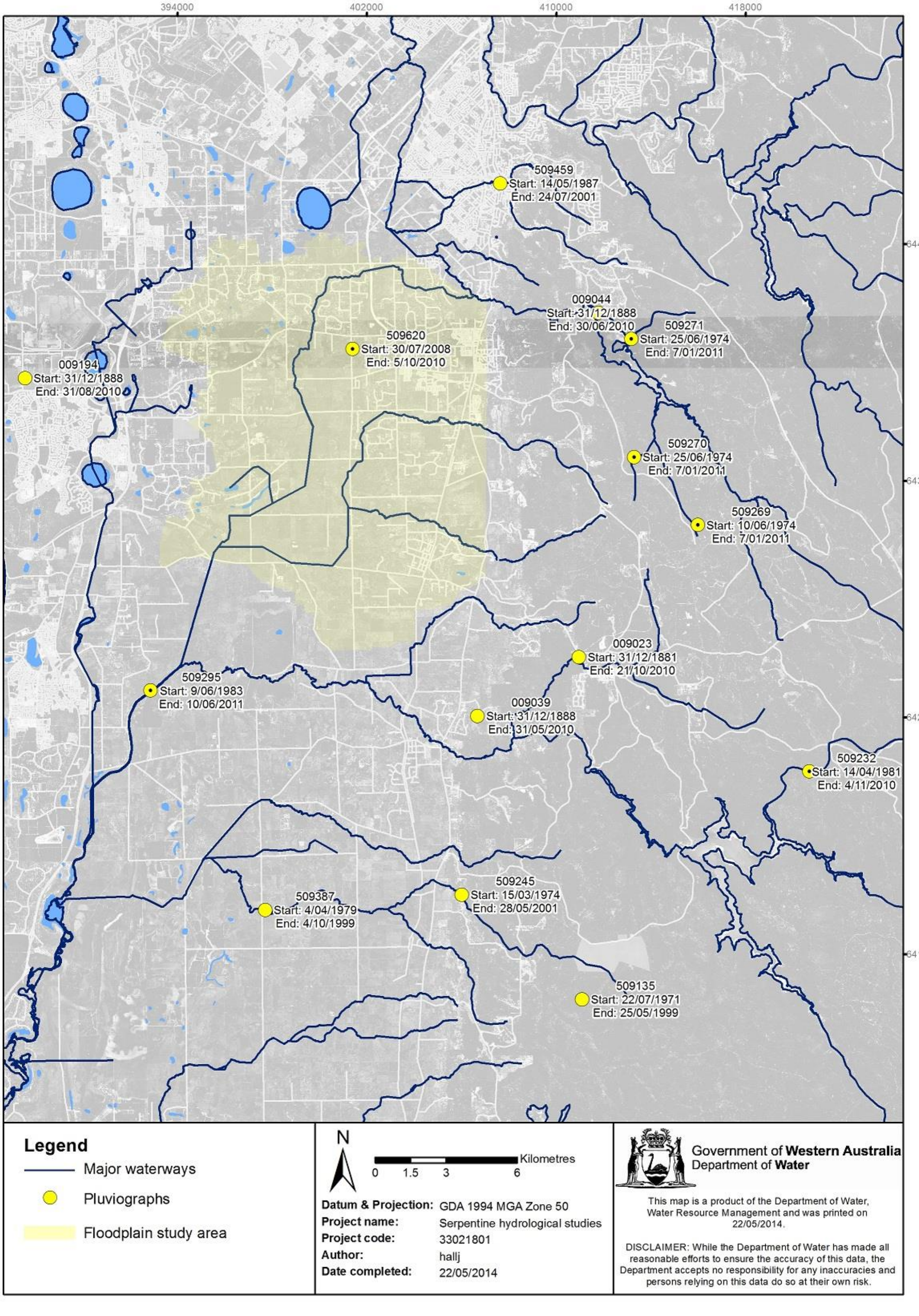


Figure 3-1: *Location of pluviographs used for analysis in the Birrega floodplain study*

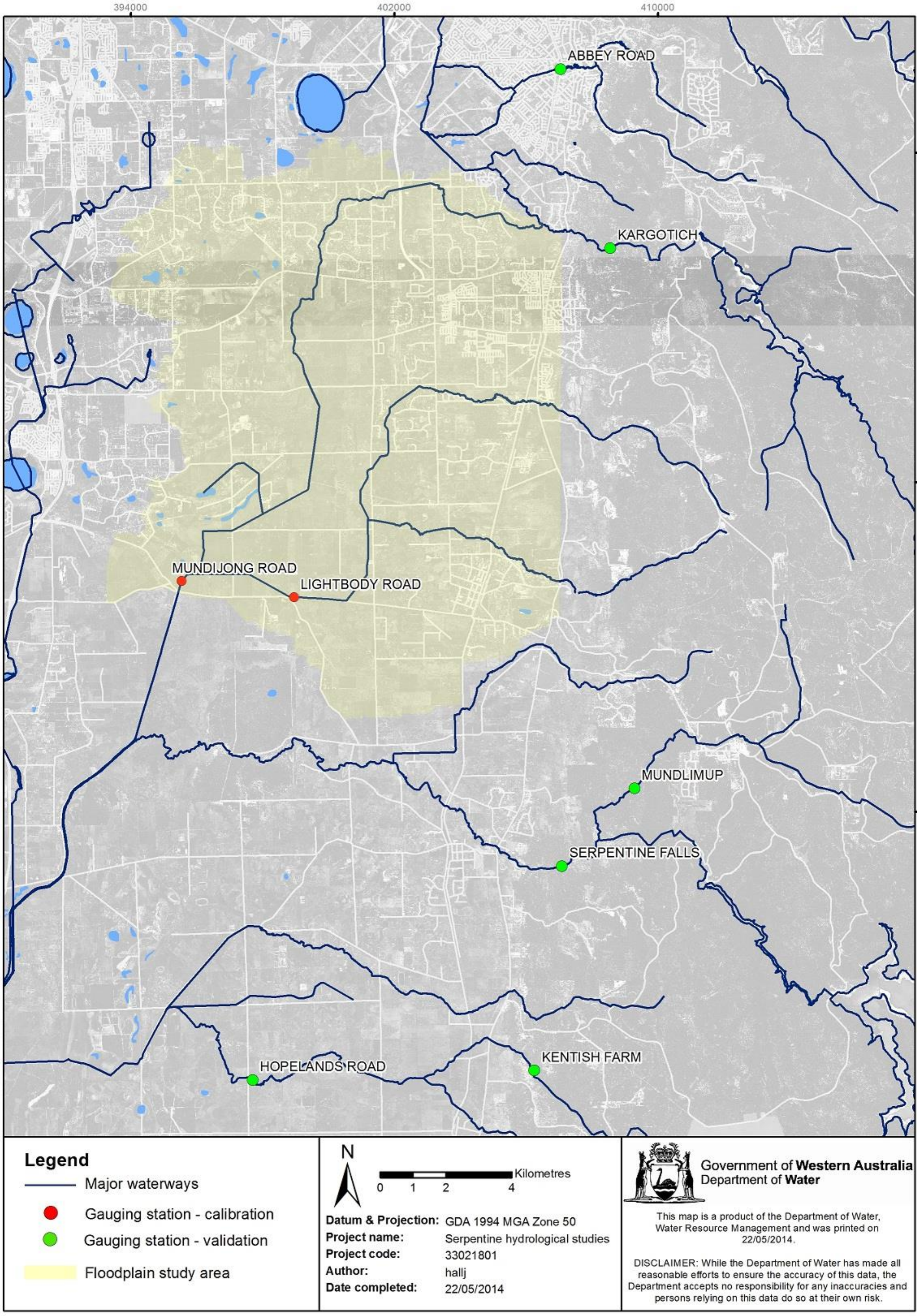


Figure 3-2*: Location of flow gauging stations used in the floodplain development study*

***Table 3-2** Streamflow gauging stations analysed in the study*

Name	Waterway	AWRC reference	Period of record	Catchment area (km^2)
Abbey Road	Neerigen Brook	616044	1985 - 2009	19.83
Kargotich	Wungong Brook	616153	1971 - 2009	10.74
Mundlimup	Gooralong Brook	614073	1951 - 1998	51.04
Serpentine Falls	Serpentine River	614072	1958 - 2001	101.79
Kentish Farm	Dirk Brook	614005	1971 - 2000	35.98
Hopelands Road	Dirk Brook	614028	1979 - 2001	63.88
Mundijong Road	Birriga Drain	614030	2011 - present	248.52
Lightbody Road	Oaklands Drain	614129	2010 - present	132.21

3.3 Terrain data

Light Detection And Ranging (LiDAR) data is available for the proportion of the catchment located on the Swan Coastal Plain. A representation of the extent of the LiDAR coverage is shown in Figure 3-3. These data were captured on 25 February 2008 by Fugro Spatial Solutions Pty Ltd, and have a point density of 1 point per square metre and an accuracy of 0.15 m at 67% confidence. LiDAR was used to develop the bathymetric layer for the 2-D overland flow hydraulic model, to develop the cross-sections of waterways used in the 1-D channel flow hydraulic model, and to develop internal subcatchments for the flood study area.

3.4 Land-use data

Land-use data was developed by the Department of Water for the region, and was based on Landgate cadastre (2008) with DLI aerial imagery (2008), and LiDAR non-ground returns to determine vegetation extent. Land-use data was important for resistance categories in hydraulic modelling and for regional parameterisation of hydrologic models.

3.5 Flood level information

Qualitative and quantitative flood level information was collected in the July 1987 flood event. This included flood levels at various locations within the catchment, location of levee bank breaches, and various photographs documenting the flood extent. Much of the information was from Dave Gossage, Manager of Emergency Services at the Shire of Serpentine Jarrahdale. Flood levels were measured at five locations throughout the catchment, and the flood reportedly breached the levee bank of the Oaklands Drain in three locations and at the Birrega Drain at Duck Pool. Photographs of the extent of flooding along Kargotich Road,

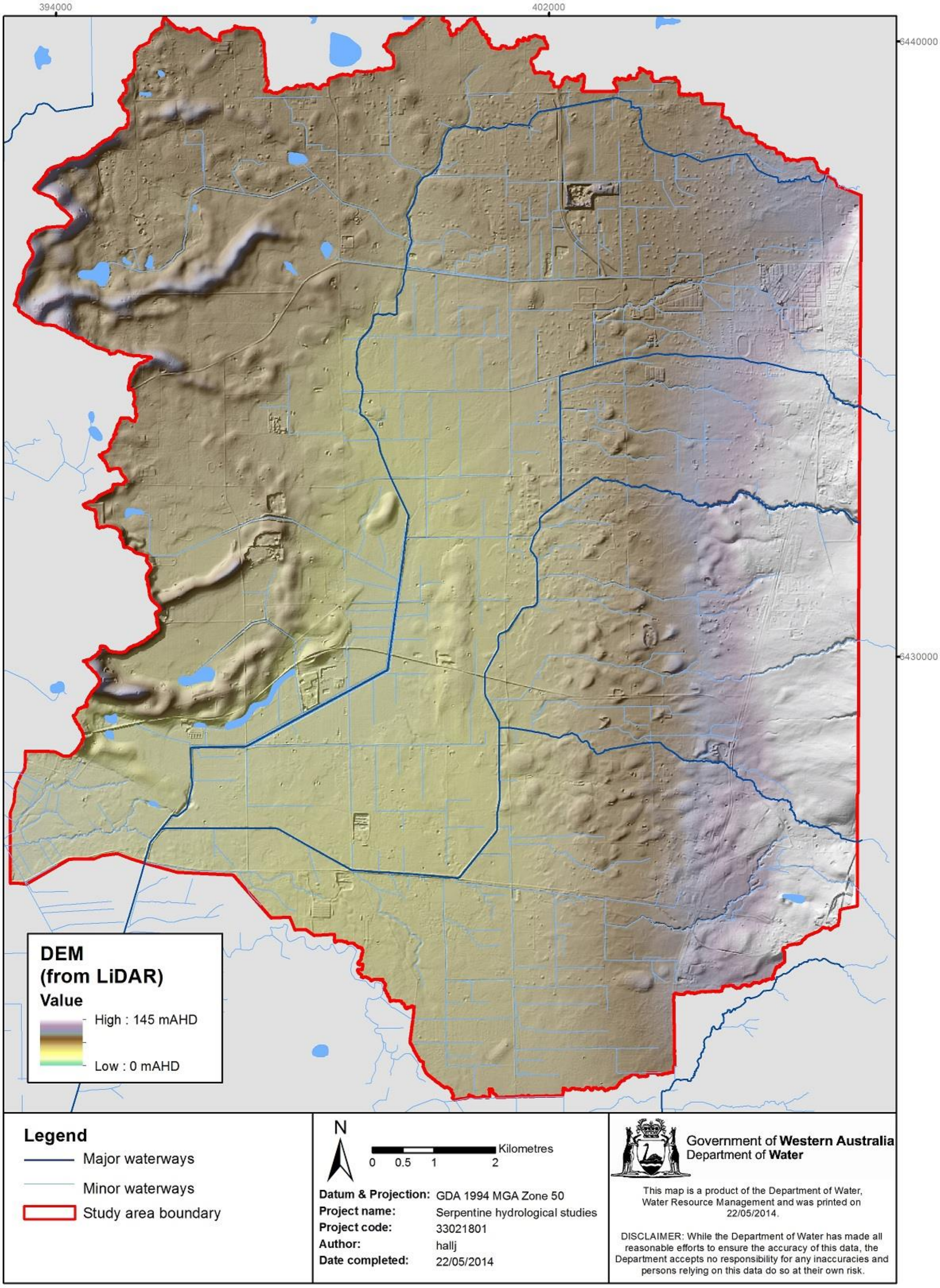


Figure 3-3: *Digital elevation model (DEM) derived from LiDAR data, for the flood study area*

between Gossage and Scott Road are shown in Figure 3-4. The measured flood levels were used by the Water Corporation to interpret the flood extent of the 1987 event at some catchment locations. The flood level and interpreted extent information are shown in Figure 3-5. This information was used to validate the hydraulic model results.


Facing south, Kargotich Road from Scott Road


Corner Kargotich and Bishop Rd, facing south-west


Facing north, from Kargotich Rd rail crossing

Figure 3-4: *Photographs of flooding over Kargotich Road between Gossage Road and Scott Road during the 1987 flood event (D Gossage)*

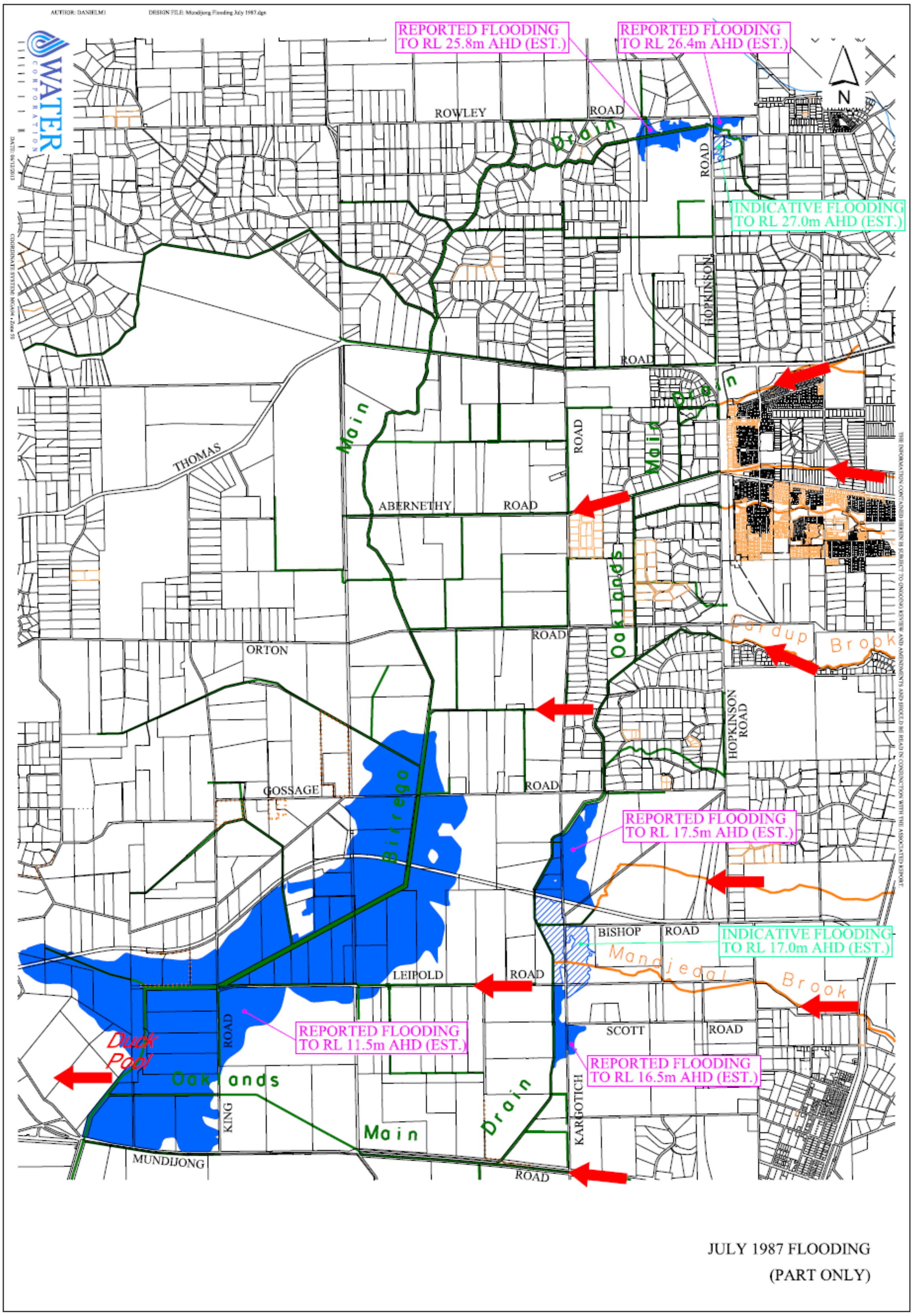


Figure 3-5: *Water level measurements and derived flood extent (part only) mapping for the 1987 flood event (figure courtesy of Water Corporation)*

3.6 Groundwater and surface water interactions

Parts of the Birrega area are prone to very shallow groundwater resulting in regular winter inundation. The Lower Serpentine MIKE SHE model (Marillier et al. 2012b) was developed by the Department of Water to identify areas of groundwater inundation, to provide reliable groundwater level information and estimates of drainage within the study area. The study area experiences partial inundation from groundwater almost every winter, even in dry years, and therefore the interaction between groundwater and surface water must be considered as a component of this flood study. Groundwater levels from the MIKE SHE model can be used to define antecedent conditions for both calibration and design events, effectively identifying areas which should be considered impervious as a result of inundation. Groundwater inundation surfaces used in the flood modelling are detailed in Section 6-4.

3.7 Roads and structures

Culverts, bridges and road elevations were considered in the construction of the hydraulic model, as described in Section 6-4 and Appendix E. More than 50 structures were assessed in the field for inclusion in the hydraulic model. Many of these were too small or overgrown to justify inclusion in the model; however, larger culverts and bridges along the Birrega and Oaklands Main Drains were included explicitly. In many locations the road and drain elevations were modified where appropriate in the model bathymetry to better represent actual levels.

4 Flood frequency analysis

4.1 Introduction

A flood frequency analysis (FFA) using flow gauging data for selected catchments inside and near the Birrega catchment was completed to estimate peak flows for a range of flood frequencies. The two main drains (Birrega and Oaklands), which are the largest contributors to flow in the study area were ungauged until 2010, and a flood frequency analysis could not be performed on the gauges on these waterways due to lack of sufficient data. The flood frequency data was compared with results of rainfall-runoff and routing models for various flood events. The analysis provides confidence in the adopted results of the hydrological modelling using regional parameterisation, and gives a basis for altering the hydrological model's regional parameters to comply more closely with local data.

4.2 Methodology

Flood frequency analysis was carried out on the peak annual flow data series. Although it was recognised that rainfall could be broadly divided into summer ex-tropical cyclonic events and winter low pressure system events, the lack of data for the gauged catchments in the region made this approach impractical (only one major summer event was recorded at most flow gauges in February 1992). The flood frequency analysis was completed using the six gauging stations listed in Table 3-2, and shown in Figure 3-2.

The annual maximum flows were extracted from the gauged record. Only flows after development of the dams were analysed (post-1979 for Kargotich when the Wungong Dam was completed, and post-1961 for Serpentine Falls when the Serpentine Dam was completed).

Hydrographs were inspected for completeness, and flow gauging stations were discussed with the regional hydrographer for some insight into the accuracy or problems that various gauging structures have measuring extreme flows either presently or historically. The program Flike V4.50 (Kuczera 2001) was used to fit Log Normal, Log Pearson type III (LPIII) and Generalised Extreme Value distributions to the annual data series. LPIII distribution was the closest fit to the data in all cases, and was used for subsequent analysis.

4.3 Results

A summary of the flood frequency results for all flow gauging stations is shown in Table 4-1. Serpentine Falls and Nerrigen Brook have significantly higher peak flood flows than the other sites. Although the Serpentine Dam was completed in 1961, there were significant dam overflows/releases in year's before 1975, so only the post-1975 years were used in the flood frequency analysis.

Table 4-1 *Flood frequency analysis for design flows at selected gauges*

Annual recurrence interval (ARI) (1 in y)	Nerregin Brook Abby Road (616044) (m^3/s)	Dirk Brook Hopelands Road (614028) (m^3/s)	Dirk Brook Kentish Farm (614005) (m^3/s)	Wungong Brook Kargotich (616153)* (m^3/s)	Gooralong Brook Mundlimup (614073) (m^3/s)	Serpentine Serpentine Falls (614072)** (m^3/s)
5	5.4	11.1	5.6	1.9	6.9	9.8
10	8.4	13.4	6.9	2.6	9.3	12.9
20	12.9	15.7	8.3	3.6	12.1	16.6
50	22.3	18.8	10.2	5.1	16.7	22.5
100	33.4	21.1	11.8	6.5	21.0	27.8
200	49.7	23.5	13.5	8.2	26.1	34.1
500	83.6	26.8	15.9	10.9	34.6	44.2

* Analysis results without the inclusion of the 1992 summer event
** Results for post 1975 only (no overflows from Serpentine Dam)

The ARI for the larger events at each of the stations are shown in Table 4-2. The 1987 event produced a 20–50 year ARI flow in most catchments. The Hopelands Road gauging station recorded an ARI of 3 years for the 1987 event, which was unusual given that the upstream gauging station (Kentish Farm), recorded a 50 year flow for the same event. The only significant summer event recorded at all sites was in February 1992. Flood frequency analysis indicated a large variation in ARI for the 1992 event at the various sites, which is likely to be due to the isolated nature of the storm: for example, rainfall station 9194 recorded 230 mm rain for this event whereas 9232 recorded only 27 mm. The flow gauging station at Kargotich (616153) had only 38 years of data, and the most significant event was the 1992 summer event. This event was an outlier on the FFA, as it resulted in extreme rainfall on the Wungong catchment. The FFA for Kargotich was run with the absence of the 1992 event.

Table 4-2 *ARI values from flood frequency analysis at selected gauges and events*

Event	Nerregin Brook Abby Road (616044) ARI (1 in y)	Dirk Brook Hopelands Road (614028) ARI (1 in y)	Dirk Brook Kentish Farm (614005) ARI (1 in y)	Wungong Brook Kargotich (616153)* ARI (1 in y)	Gooralong Brook Mundlimup (614073) ARI (1 in y)	Serpentine Serpentine Falls (614072)** ARI (1 in y)
1964	-	-	-	-	74	-
1967	-	-	-	-	28	-
1987	44	3	50	52	17	44
1963	-	-	-	-	12	-
1968	-	-	-	-	10	-
1988	10	37	12	12	8	16
1974	-	-	19	-	7	-
1992	16	3	3	-	2	10

* Analysis results without the inclusion of the 1992 event
** Results for post 1975 only (no dam overflows)

The flows recorded in the flood frequency analysis for Serpentine falls were compared with the estimated flow at the South-Western Highway in the SKM report (2010). The South-Western Highway is located 2 km downstream of the Serpentine Falls gauging station, and the catchment at the South-Western Highway is approximately 6 km^2 larger (6% larger) than the Serpentine Falls catchment. There was significant difference in the magnitude of flows for the 100 year ARI event calculated from the Serpentine Falls FFA in this study compared to the peak flows calculated from the previous studies (Table 4-3). It should be noted that the FFA for Serpentine Falls is likely to be an underestimate, as only the post-1975 flows have been analysed, and rainfall events were much more frequent and intense pre-1975. The RORB modelling for the Serpentine Falls catchment (using intensity-frequency-duration data for the 100 year rainfall event and validated for the 1987 event) estimates a peak flow of 49 m^3/sec for the 100 year event: also much lower than those estimated in previous studies. There is a large discrepancy between the hydraulic flood level at the South Western Highway and the recorded flow at Serpentine Falls gauging station. The flows in the previous studies were calibrated against a flood height at the South Western Highway Bridge for the 1987 event – and the SKM study estimated this flow peaked at approximately 80 m^3/s – however the measured flow at Serpentine Falls for the 1987 event was 27 m^3/s. The gauging station at Serpentine Falls had a good flow structure and high flow measurements were likely to be accurate (K Firth pers. comm. 2011). This analysis is supported by the Mundlimup flood frequency analysis. The previous Serpentine flood studies (WAWA 1990; SKM 2010) did not include flood frequency analysis at the Serpentine Falls or Mundlimup gauging stations.

Table 4-3 *100 year ARI flow at locations in the Upper Serpentine River*

Location	Study	100yr ARI peak discharge estimate (m^3/sec)
South Western Highway	SKM, 2010	166
South Western Highway	WAWA, 1990	118
Serpentine Falls	current (FFA)	28
Serpentine Falls	current (RORB)	49

The flow gauging station at Kargotich on the Wungong Brook collected data post-1985, and extrapolation to the large events is not likely to be reliable. LPIII fitted curves and annual data are plotted in Appendix A. The results of the flood frequency analysis were compared to design floods peaks, and are discussed further in Section 5-3.

5 Hydrology studies

The hydrology studies generated flow hydrographs at the edge of the flood study for flow input to the hydraulic model (Figure 1-1). Rainfall-runoff and routing techniques were used to generate the hydrographs for the catchment east of the South Western Highway (which was the eastern border of the hydraulic flood model domain). The hydrographs were derived from the modelling software package RORB (Laurenson et al. 2007). RORB is an interactive non-linear distributed runoff and streamflow routing program. The catchment is subdivided into a number of subareas and represented by a network of routing reaches. The non-linear storage routing procedure was used to combine the routed flow through the various routing reaches within the catchment. RORBWin Version 6.15 was used in this project.

Due to the limited station data in the escarpment catchments to adequately calibrate RORB models for each of the catchments that flow into the study area, RORB models were parameterised using a regional method for estimating the main parameters (k_c and *RoC*) developed by the Water Corporation for the south-west of Western Australia (Pearce 2006 and Pearce 2011). The regional parameter values were verified using the available gauging station data and adjustments made where necessary.

Runoff generation within the flood study area was simulated within the hydraulic model using a direct rainfall approach (explained in detail in Section 6), so RORB hydrographs were not developed for the internal hydraulic model domain.

The hydrologic modelling approach used to develop design hydrographs for the hydraulic model is outlined below:

1. Delineate subcatchments spatially for rainfall-runoff modelling, both within the Birrega catchment and in surrounding catchments used to validate regional RORB parameters.
2. Develop a series of RORB models.
3. Calculate regional parameters (these are a function of the catchment areas and event rainfall depths).
4. Validate the RORB output with regional parameters using actual output for historical events. Comment on the validation, and adjust the regional parameters if necessary.
5. Generate rainfall intensity frequency duration (IFD) plots for the area. Apply areal reduction factors to determine catchment design IFDs. Apply temporal series for IFD data.
6. Calculate critical design flows at each of the gauging stations, and compare to the flood frequency analysis results.
7. If design peaks are very different from flood frequency analysis results, adjust regional parameter relationships accordingly.
8. Use the adjusted relationships for the design hydrology for all catchments in the Birrega study area. Generate design hydrographs for the 5, 10, 20, 100 and 500 year ARI events; for 6, 12, 24, 36, 48 and 72 hr durations.

5.1 RORB regional parameter validation

RORB catchment delineation

The subcatchments used in the RORB analysis were selected using the ArcHydro extension from ESRI's ArcGIS. Flow accumulation and catchment delineation techniques were used to accurately delineate the subcatchments. RORB subcatchments are displayed in Figure 5-1.

Catchments were subdivided upstream of the gauging stations into at least three subareas of less than 30 km^2. The flooding effects of regulating the upper catchment of the Birrega Drain by the Wungong Reservoir were analysed in the Southern River flood study (Waugh 1986). It was demonstrated that the weir is unlikely to overspill in a large flood event. Hence, flows upstream of the Wungong Reservoir are not considered in the hydrology studies.

Four separate RORB models were constructed to validate the RORB regional parameters:

- The Dirk Brook RORB model, which includes the Hopelands Road (614028) and Kentish Farm (614005) flow-gauging stations.
- The Serpentine RORB model, which includes the Serpentine Falls (614072) and Mundlimup (614073) flow-gauging stations.
- The Nerrigen Brook RORB model, which includes the flow-gauging station at Abby Road (616044).
- The Wungong Brook RORB model, which includes the flow gauging station at Kargotich (616153).

The RORB catchment files are presented in Appendix B.

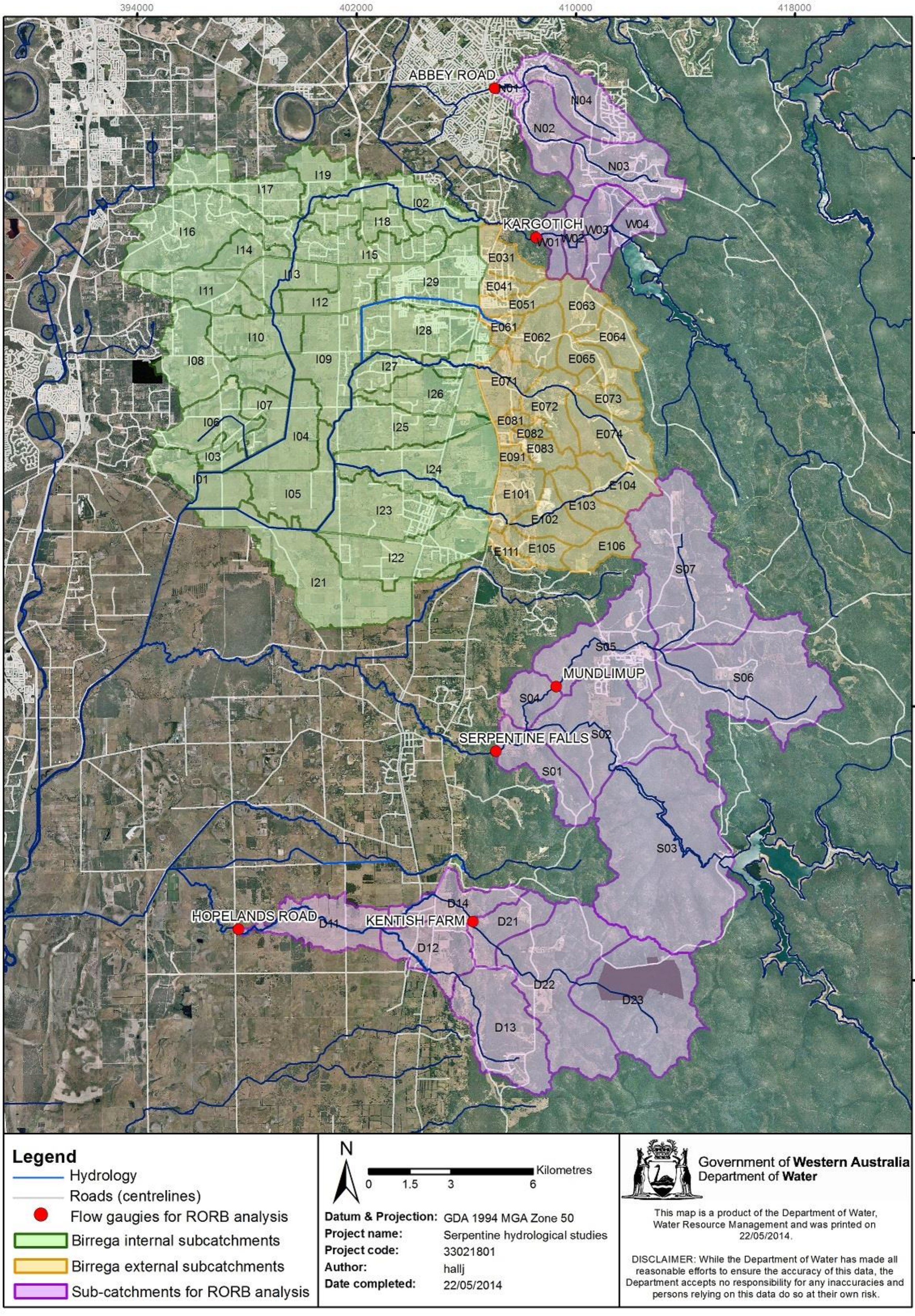


***Figure 5-1**: Gauges for RORB regional hydrology validation and RORB subcatchments*

Regional parameter calculations

Pearce (2006) demonstrated strong correlations between catchment area, extent of clearing, and appropriate values of k_c. Pearce derived values for k_c were based on catchment area and extent of clearing using the following relationships:

- Foothills/coastal plain: $k_c = 1.07 * A^{0.76}$
- Fully forested in Darling Range: $k_c = 0.49*A^{0.76}$
- 50% or more clearing in Darling range: $k_c = 0.22*A^{0.76}$

Where A = area in km^2.

This relationship was derived (and is valid) only for catchments < 100 km^2 in the south-west of Western Australia.

For the Birrega flood study there were several RORB subcatchments located on the Darling Scarp. The categories proposed by Pearce (2006) were further divided to represent more divisions of catchment clearing. The adjusted values are presented in Table 5-1.

Table 5-1 Adjusted kc values for the Birrega Flood model

Level of clearing	Equivalent to	kc
0-10% cleared	Fully forested	$0.49*A^{0.76}$
10-25% cleared	-	$0.40*A^{0.76}$
25-40% cleared	-	$0.31*A^{0.76}$
40-60% cleared	50% Cleared	$0.22*A^{0.76}$
60-85% cleared	-	$0.13*A^{0.76}$
Foothills	Foothills	$1.07*A^{0.76}$

A constant value of k_c was applied to each catchment. The relationship between catchment area and k_c is displayed in Figure 5-2, and the list of the RORB catchments and associated k_c values are shown in Appendix B.

Pearce (2011) estimated values of runoff coefficient (*RoC*) for foothills, 50% cleared catchments, and fully forested catchments. These were also re-categorised to produce 5 levels of clearing in order to better represent the runoff from partially cleared catchments. Linear regression was used to categorise 60–85% cleared, 10–25% cleared and 25–40% cleared categories.

A constant value of *RoC* was applied to each catchment, and the relationships are plotted in Figure 5-3. It should be noted that the work to produce the regional parameterisation for *RoC* focused on 50 and 100 year ARI events only, and these relationships were reviewed and adjusted for the smaller events modelled in the Birrega study. This was considered appropriate; as Pearce (2006) states that whenever possible any available local runoff data should be incorporated and cross-checked with the regional data. This will be discussed further in Section 5-3. A list of values of *RoC* for each RORB subcatchment, and for each rainfall event, is presented in Appendix B.

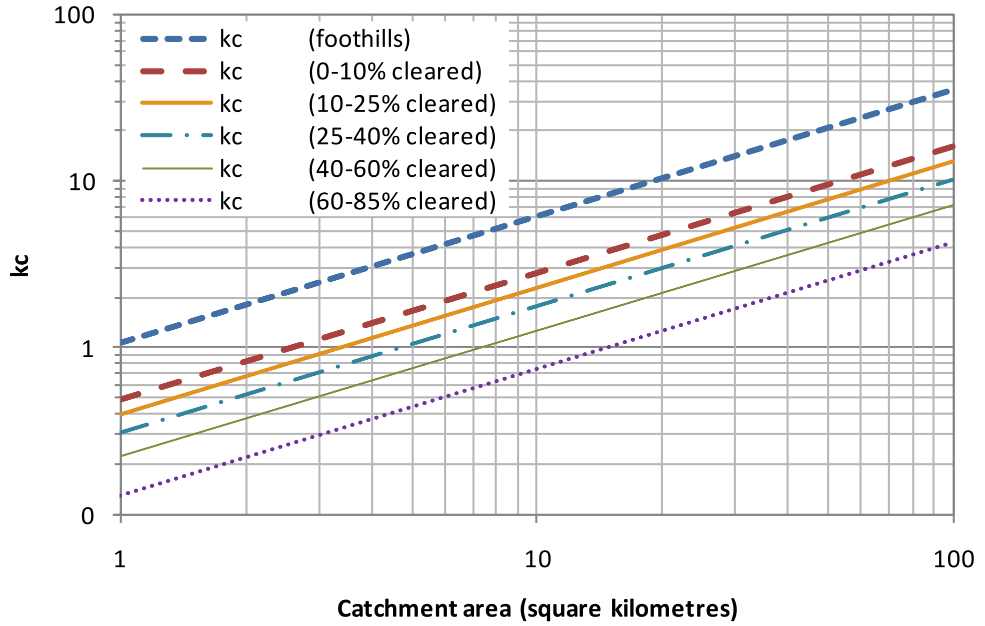


***Figure 5-2:** Relationship between k_c and catchment area for the RORB regional parameters (Pearce 2006)*

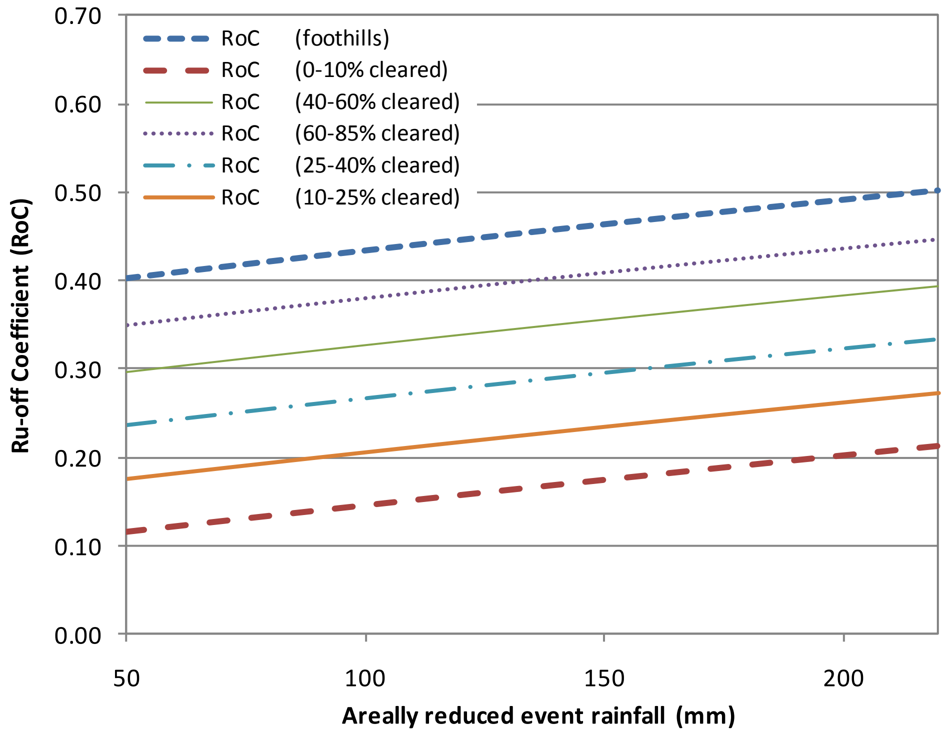


***Figure 5-3:** Relationship between runoff coefficient (RoC) and areally reduced rainfall for the RORB regional parameters (Pearce 2006)*

Common practice in RORB modelling is to set the *m* parameter to the value of 0.85. Pearce (2006) noted that a value of 0.85 appeared to adequately define the degree of non-linearity of south-west Western Australian catchments. This value was adopted for all validation and design runs of the hydrologic models.

Baseflow

Baseflow rates were calculated in accordance with the Water Corporation's document, *Baseflow seasonality in south-west Western Australia* (Kinkela 2011). The document recommends baseflow contributions for large to extreme design floods in south-west Western Australia. A *design baseflow under peak factor* was used to calculate baseflow magnitude at any given timestep, and a constant factor of 0.291 was used for all design events < 200 year ARI, and a factor of 0.129 was used for flows ≥ 200 year ARI. This means that all values from RORB modelling were multiplied by 1.291 to account for baseflow in the < 200 year ARI events by 1.129 to account for baseflow in the ≥ 200 year ARI events.

Verification results

The peak discharge rates predicted using the regional method were verified by comparing with available streamflow data for the largest recorded rainfall events in each of the RORB catchments. This corresponded to the rainfall events in July 1987, July 1988, and February 1992. Comparisons of the peak flows from the calculated versus observed events, the time to peak and the event volumes are shown in Table 5-2.

Table 5-2 *Results of the verification of the RORB regional parameters*

Flow gauge	Units	1987 event				1988 event				1992 event			
		Hydrograph		*Error*		Hydrograph		*Error*		Hydrograph		*Error*	
		Calc.	Obs.	*Abs.*	*%*	Calc.	Obs.	*Abs.*	*%*	Calc.	Obs.	*Abs.*	*%*
Nerrogin Brook, Abby Road (616044)													
Peak flow	m^3/s	21.8	22.0	*-0.2*	*-1.0*	10.3	7.8	*2.5*	*31.8*	14.7	14.4	*0.3*	*1.9*
Time to peak	hours	13.5	13.5	*0.0*	*0.0*	10.0	11.5	*-1.5*	*-13.0*	14.5	15.0	*-0.5*	*-3.3*
Volume	ML	654	704	*50*	*-7.1*	469	517	*-48*	*-9.3*	125	322	*-197*	*-61.3*
Dirk Brook, Hopelands Road (614028)													
Peak flow	m^3/s	10.2	10.0	*0.2*	*2.0*	15.2	15.6	*-0.4*	*-2.8*	4.0	4.1	*-0.1*	*-3.0*
Time to peak	hours	20.5	21.0	*-0.5*	*-2.4*	21.0	21.5	*-0.5*	*-2.3*	24.0	20.0	*4.0*	*20.0*
Volume	ML	828	1000	*-175*	*-17.4*	1140	1390	*-250*	*-18.1*	294	120	*174*	*145*
Dirk Brook, Kentish Farm (614005)													
Peak flow	m^3/s	8.3	8.4	*-0.1*	*-1.3*	7.5	7.4	*0.1*	*1.3*	2.2	2.1	*0.1*	*2.5*
Time to peak	hours	8.5	11.5	*-3.0*	*-26.1*	12.0	18.0	*-6.0*	*-33.3*	18.0	15.0	*3.0*	*20*
Volume	ML	402	614	*-212*	*-34.5*	428	622	*-194*	*-31.1*	80	45	*35*	*77.8*
Wungong Brook, Kargotich (614005)													
Peak flow	m^3/s	6.4	6.0	*0.4*	*6.8*	3.1	3.6	*-0.5*	*-15.2*	7.1	8.7	*-1.6*	*-18.3*
Time to peak	hours	14.5	15.0	*-0.5*	*-3.3*	9.5	21.0	*-11.5*	*-54.8*	14.0	15.0	*-1.0*	*-6.7*
Volume	ML	224	235	*-10*	*-4.4*	144	250	*-106*	*-42.4*	120	59	*61*	*103*
Serpentine River, Serpentine Falls (614072)													
Peak flow	m^3/s	27.5	26.6	*0.9*	*3.3*	-	-	*-*	*-*	10.1	13.1	*-3.0*	*-23*
Time to peak	hours	21.5	15.5	*6.0*	*38.7*	-	-	*-*	*-*	20.5	16.0	*4.5*	*28.1*
Volume	ML	1680	1930	*-259*	*-13.4*	-	-	*-*	*-*	548	309	*239*	*77.5*
Gooralong Brook, Mundlimup (614073)													
Peak flow	m^3/s	14.8	12.3	*2.5*	*20.3*	8.5	7.3	*1.1*	*15.6*	3.7	4.4	*-0.6*	*-14.3*
Time to peak	hours	19.0	14.0	*5.0*	*35.7*	12.5	25.5	*-13.0*	*-51.0*	19.5	16.0	*3.5*	*21.9*
Volume	ML	854	667	*187*	*28.1*	549	741	*-191*	*-25.8*	170	171	*-1*	*-0.4*

Time series charts displaying the rainfall-runoff relationships for observed and RORB predicted flows are presented in Appendix B. The regional parameters performed reasonably well when comparing to the observed flows. There were some issues with the performance of the regional parameters which included:

- For a 2-burst event (such as the July 1987 event), the flow peak from the first burst would typically be overpredicted by RORB model, and the second burst under-predicted (Figure 5-4). This is due the catchment being wetter at the beginning of the second burst, resulting in a larger runoff coefficient. This was not accounted for in the regional parameterisation method, as a constant value of *RoC* was applied for each storm.

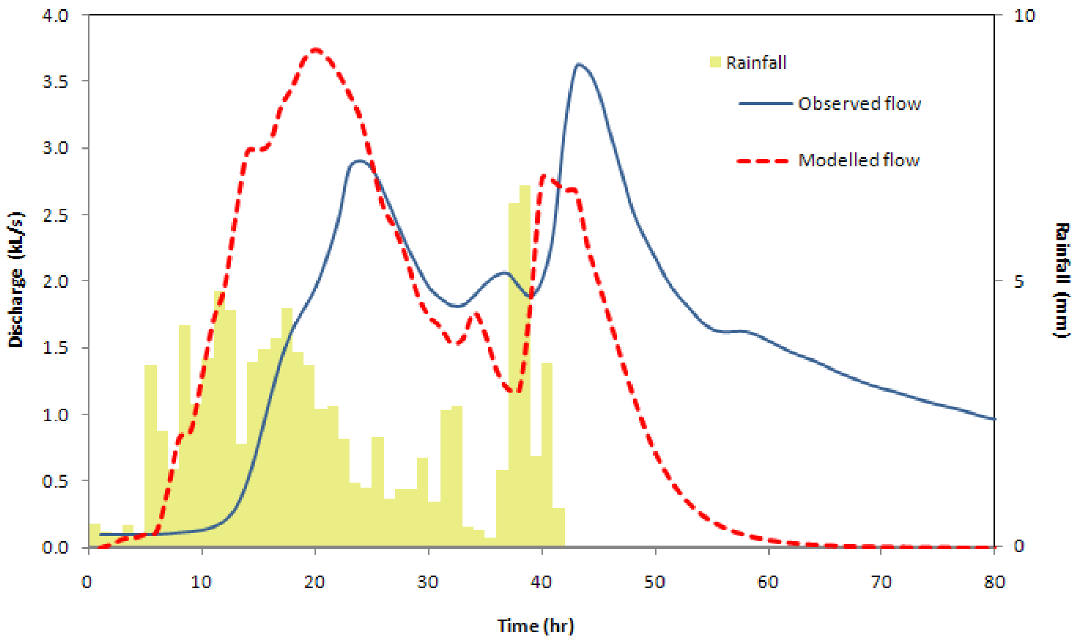


***Figure 5-4**: An example of a 2 burst event showing the overprediction of the hydrograph at the first burst, and an underprediction in the second burst (1987 event at Kargotich, Wungong Brook - 616153)*

- Although the peaks of the events generally matched quite well, the tails were generally underpredicted by the RORB models – as baseflow was included as a constant proportion of the surface flow at each timestep (Figure 5-5).

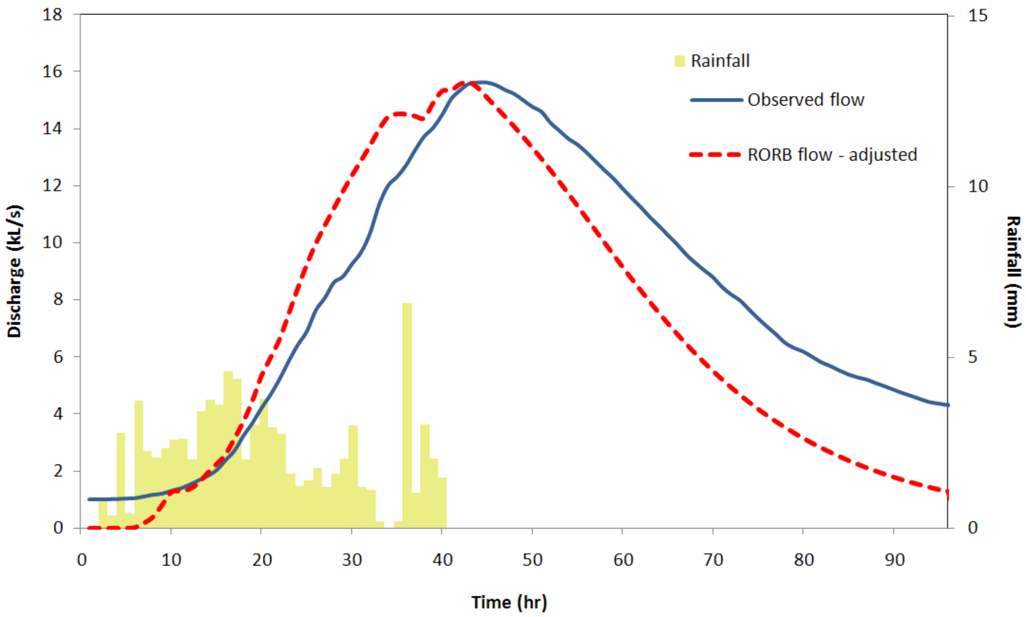


***Figure 5-5:** An example of underprediction of the baseflow from the RORB regional parameterisation (1988 event, Hopelands Road, Dirk Brook - 614028)*

- The 1992 flood required the addition of a large initial loss (generally between 40 and 100 mm) for the flood peaks to match. This led to a good fit for flood peaks but the value of k_c from the regional parameterisation was generally too large to fit the rapid recession of the hydrograph (Figure 5-6). The regional parameters are probably not appropriate for summer events.

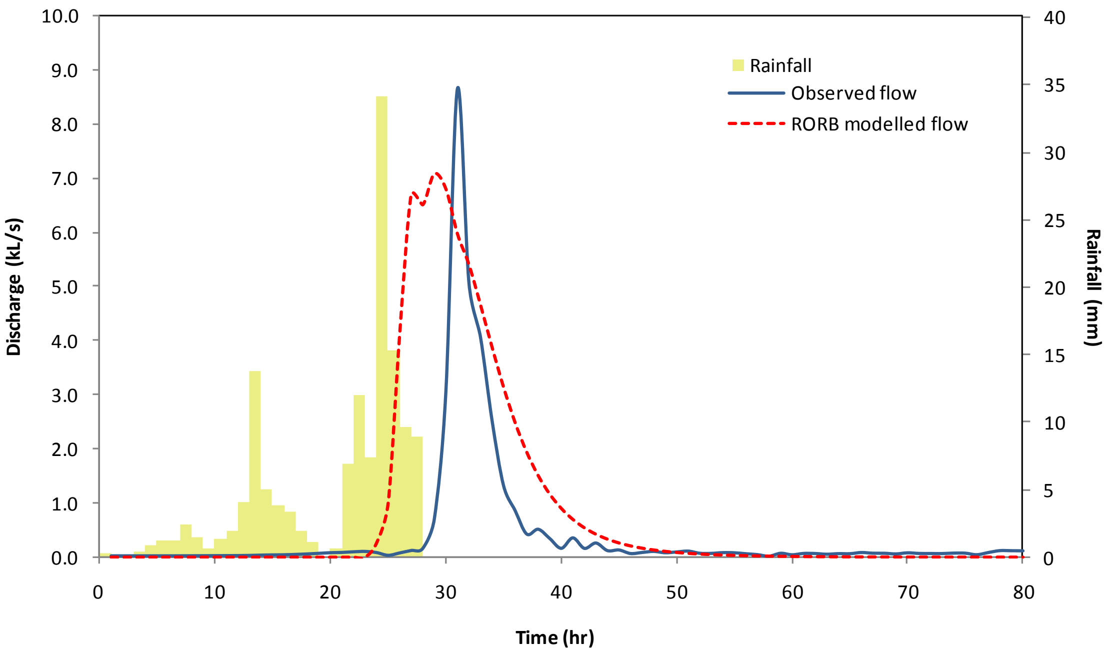


***Figure 5-6:** An example summer event predicting a larger flow recession and volume and requiring a large initial loss of 60 mm in this case (1992 event, Kargotich, Wungong Brook - 616153)*

Based on the results of the validation, the use of the regional parameters was deemed appropriate for the design flood estimation for annual flow events. However, adjustments were made to the regional parameters for the smaller events (5, 10 and 20 year ARI); this is discussed in Section 5-3.

5.2 Design rainfall

Design rainfall depth

Design intensity frequency duration (IFD) information was calculated using the methods outlined in Australian Rainfall and Runoff (Pilgrim 2001) and CRC Forge (DoE 2004). AUS-IFD was used to generate IFD data for all events of ARI 5–50 years, with durations less than or equal to 24 hours. AUS-IFD is a program which calculates the design average rainfall intensities and temporal patterns for any location in Australia, and is located on the Bureau of Meteorology Website (http://www.bom.gov.au). The procedure for the calculation of rainfall intensity is described in Chapter 2 of Australian Rainfall and Runoff (AR&R; Pilgrim 2001).

WA-CRC Forge was used to derive the rainfall depth for the 50–500 year ARI events for durations > 24 hours (only events of 24–72 hour duration are available from the CRC Forge database). The WA CRC-Forge '*EXTRACT*' computer program has been produced to facilitate the extraction of large rainfalls from the Western Australian database (Department of Environment 2004).

For events of less than 24 hours duration and greater than 50 year ARI, an interpolation of values based on the relative magnitude of the design event to the 50 year 24 hour event was used to derive the rainfall depth for the 100–500 year ARI events. Events of duration > 24 hr and < 50 year ARI were interpolated using the same technique.

Design rainfall depths and intensities are shown in Table 5-3. A plot of event rainfall versus event duration is shown in Figure 5-7, and a probabilistic plot of annual exceedence versus event rainfall (on a log scale) is shown in Figure 5-8. Both plots show a consistent smooth response for all event durations and ARI categories. Therefore the IFD information is considered suitable to use in the design hydrology.

Table 5-3 *Rainfall IFD data used in modelling*

ARI	5	10	20	50	100	200	500	ARI	5	10	20	50	100	200	500
duration	Event rainfall (mm)							duration	Rainfall intensity (mm/hr)						
6 hr	50	56	64	77	88	101	122	6 hr	8.4	9.3	10.7	13	15	17	20
12 hr	65	72	82	99	113	130	157	12 hr	5.4	6.0	6.8	8.2	9.4	11	13
24 hr	84	94	106	124	142	164	197	24 hr	3.5	3.9	4.4	5.2	5.9	6.8	8.2
36 hr	93	104	118	137	156	177	212	36 hr	2.6	2.9	3.3	3.8	4.3	4.9	5.9
48 hr	100	112	126	147	166	188	223	48 hr	2.1	2.3	2.6	3.1	3.5	3.9	4.6
72 hr	111	124	140	164	185	207	242	72 hr	1.5	1.7	1.9	2.3	2.6	2.9	3.4

values taken from CRC Forge (DoE 2004)
values taken from ARR (Pilgrim 2001)
interpolated values

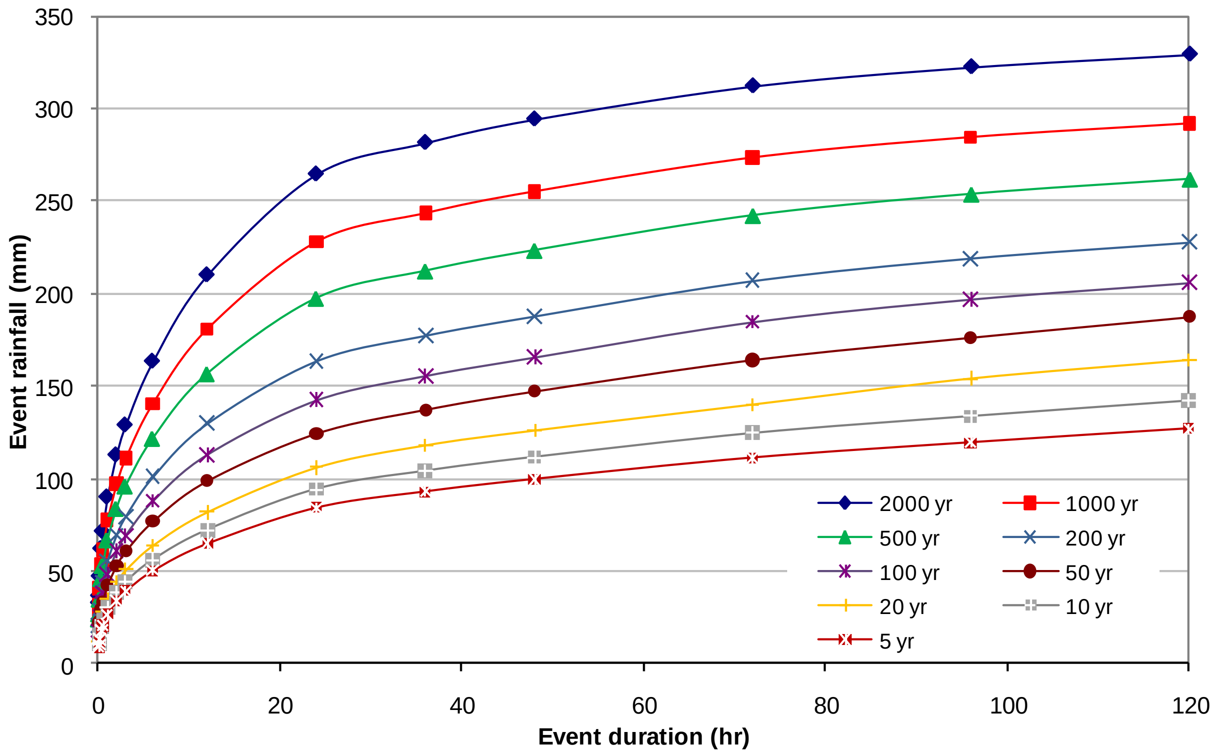


Figure 5-7: *Rainfall IFD data plotted with event duration versus event rainfall*

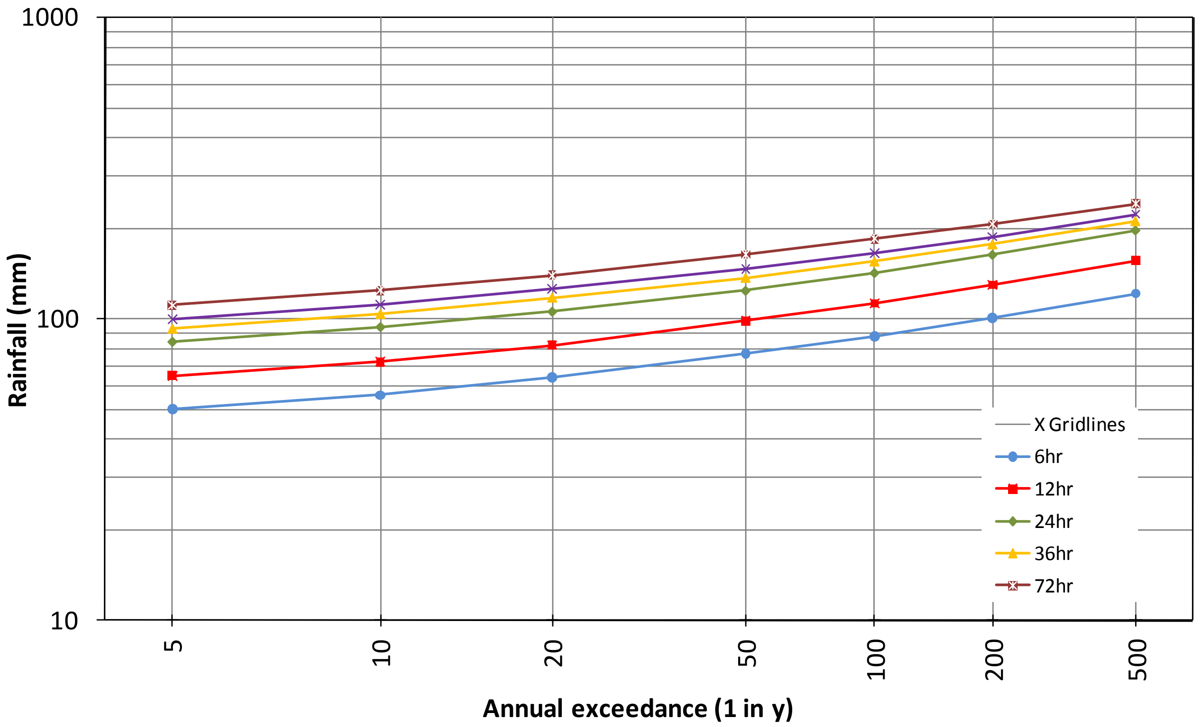


Figure 5-8: *Rainfall IFD probabilistic plot for annual exceedence versus log event rainfall*

Temporal patterns

Temporal patterns were applied to the rainfall depth data. Temporal patterns of rainfall adopted can have major effects on the critical duration and maximum peak discharge of computed design floods.

The methodology used to calculate design temporal patterns is described in Book II Section 2 of AR&R. The method provides a separate temporal pattern for events with ARI <30 years and events with ARI > 30 years. The temporal patterns for the design rainfall events are shown in Table 5-4.

Table 5-4 *Design rainfall temporal pattern*

	Temporal pattern for events <30 yr ARI							Temporal pattern for events >30 yr ARI						
Duration	6hr	12hr	18hr	24hr	36hr	48hr	72hr	6hr	12hr	18hr	24hr	36hr	48hr	72hr
Timestep	0.5hr	0.5hr	1hr	1hr	2hr	2hr	4hr	0.5hr	0.5hr	1hr	1hr	2hr	2hr	4hr
1	9.1	13.8	15.4	13.9	15.2	14.1	33.1	9.1	11.4	13.1	11.6	12.9	11.7	27.0
2	18.3	27.0	28.1	26.4	10.5	28.4	16.7	16.1	21.6	22.8	21.2	9.3	22.8	14.4
3	4.2	8.5	10.3	8.7	28.9	8.5	10.5	5.4	7.3	9.2	7.4	23.4	7.3	9.5
4	30.6	4.3	3.8	7.1	7.4	6.0	7.8	25.3	4.4	4.4	6.4	7.0	5.7	7.5
5	12.9	6.7	8.9	4.6	6.1	6.4	5.4	12.0	6.0	8.4	4.8	6.1	5.7	5.9
6	6.4	5.5	2.5	7.0	5.5	5.3	6.9	6.9	5.2	3.3	6.7	5.8	5.3	7.1
7	4.3	4.2	7.3	3.7	3.9	4.8	2.7	5.3	4.6	7.3	4.0	4.6	5.0	3.5
8	5.3	4.9	5.6	5.6	4.8	3.4	4.3	6.1	4.8	5.9	5.6	5.3	3.9	5.0
9	3.3	3.7	2.5	3.1	1.7	1.0	1.3	4.6	4.2	3.4	3.7	2.6	1.6	2.1
10	2.3	1.6	3.0	3.6	1.0	1.1	1.7	3.5	2.3	3.7	4.1	1.7	1.7	2.5
11	1.9	1.8	4.4	2.6	2.0	2.1	2.1	3.1	2.5	4.9	3.3	2.9	2.7	2.9
12	1.4	1.4	2.0	2.2	2.5	1.3	0.3	2.6	2.1	2.9	2.9	3.4	1.9	0.9
13	0.0	3.1	1.4	1.9	3.6	0.8	0.7	0.0	3.6	2.3	2.6	4.4	1.4	1.4
14	0.0	2.7	1.7	1.6	2.9	4.1	0.5	0.0	3.3	2.6	2.3	3.8	4.5	1.2
15	0.0	2.3	1.1	1.4	1.1	1.5	0.6	0.0	2.9	1.9	2.1	1.8	2.1	1.4
16	0.0	2.0	0.8	1.2	0.7	2.4	3.4	0.0	2.7	1.4	1.9	1.3	3.0	4.2
17	0.0	1.2	0.7	1.0	1.4	0.9	1.1	0.0	1.9	1.4	1.6	2.3	1.5	1.9
18	0.0	0.9	0.5	0.6	0.8	1.8	0.9	0.0	1.6	1.1	1.1	1.4	2.5	1.6
19	0.0	0.4	0.0	0.9	0.0	0.7	0.0	0.0	0.7	0.0	1.5	0.0	1.2	0.0
20	0.0	1.1	0.0	0.3	0.0	2.8	0.0	0.0	1.8	0.0	0.5	0.0	3.3	0.0
21	0.0	1.0	0.0	0.5	0.0	0.6	0.0	0.0	1.7	0.0	0.9	0.0	1.2	0.0
22	0.0	0.7	0.0	0.9	0.0	0.6	0.0	0.0	1.2	0.0	1.6	0.0	1.3	0.0
23	0.0	0.7	0.0	0.5	0.0	0.7	0.0	0.0	1.3	0.0	1.0	0.0	1.3	0.0
24	0.0	0.5	0.0	0.7	0.0	0.7	0.0	0.0	0.9	0.0	1.2	0.0	1.4	0.0

Areal reduction factors

During a rainfall event, rainfall depths vary across the catchment. The rainfall intensities calculated in Section 5.3 represent rainfall at multiple points in space; however, application of this point rainfall would overestimate the total volume of rainfall if applied uniformly over the catchment. This effect is most pronounced for shorter duration events, and less pronounced for longer duration rainfall events that occur over multiple days. To account for this variation of rainfall across a catchment, and areal reduction factor (ARF) is derived and applied to rainfall depths used for design flood estimates.

Two sets of areal reduction factors were calculated for the Birrega floodplain development strategy. This included:

- a set for the escarpment catchments, to be used in the RORB modelling to derive hydrographs at the edge of the Birrega floodplain study area. This corresponded to an area of 72 km^2
- a set for the internal catchment of the Birrega floodplain study area. This was used for the rain-on-grid modelling and for the development of the internal RORB design hydrographs and corresponded to a catchment area of 176 km^2.

The adopted ARFs for the Birrega floodplain development strategy were derived for Western Australia calculated from the WA CRC-Forge and are shown in Table 5-5.

Table 5-5 *Areal reduction factors (ARF) and ARF adjusted event rainfall*

	Duration	176 km^2 area for hydraulic study area ARI (1 in yr)							72 km^2 catchment for RORB external catchments ARI (1 in yr)						
	(hr)	5	10	20	50	100	200	500	5	10	20	50	100	200	500
Rainfall (mm) non adjusted	6	50	56	64	77	88	101	122	50	56	64	77	88	101	122
	12	65	72	82	99	113	130	157	65	72	82	99	113	130	157
	24	84	94	106	124	142	164	197	84	94	106	124	142	164	197
	36	93	104	118	137	156	177	212	93	104	118	137	156	177	212
	48	100	112	126	147	166	188	223	100	112	126	147	166	188	223
	72	111	124	140	164	185	207	242	111	124	140	164	185	207	242
Rainfall intensity (mm/hr) non adjusted	6	8.4	9.3	11	13	15	17	20	8.4	9.3	11	13	15	17	20
	12	5.4	6.0	6.8	8.2	9.4	11	13	5.4	6.0	6.8	8.2	9.4	11	13
	24	3.5	3.9	4.4	5.2	5.9	6.8	8.2	3.5	3.9	4.4	5.2	5.9	6.8	8.2
	36	2.6	2.9	3.3	3.8	4.3	4.9	5.9	2.6	2.9	3.3	3.8	4.3	4.9	5.9
	48	2.1	2.3	2.6	3.1	3.5	3.9	4.6	2.1	2.3	2.6	3.1	3.5	3.9	4.6
	72	1.5	1.7	1.9	2.3	2.6	2.9	3.4	1.5	1.7	1.9	2.3	2.6	2.9	3.4
Areal reduction factor (ARF)	6	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.87	0.87	0.87	0.87	0.87	0.87	0.87
	12	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.89	0.89	0.89	0.89	0.89	0.89	0.89
	24	0.91	0.91	0.91	0.92	0.92	0.92	0.92	0.93	0.93	0.93	0.93	0.94	0.94	0.94
	36	0.94	0.94	0.94	0.94	0.95	0.95	0.95	0.95	0.95	0.96	0.96	0.96	0.96	0.96
	48	0.95	0.95	0.96	0.96	0.96	0.96	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.98
	72	0.97	0.97	0.98	0.98	0.98	0.98	0.99	0.98	0.98	0.98	0.99	0.99	0.99	0.99
Rainfall (mm) ARF adjusted	6	42	47	53	64	73	84	102	44	49	56	67	76	88	106
	12	56	62	71	85	98	112	135	58	64	73	88	101	116	140
	24	77	86	97	114	131	150	182	78	88	99	116	133	153	185
	36	87	98	111	130	147	168	202	89	99	113	131	149	170	204
	48	95	107	121	141	159	181	216	96	108	122	143	161	183	218
	72	108	121	137	161	181	204	239	109	122	138	162	182	205	240
Rainfall intensity (mm/hr) ARF adjusted	6	7.0	7.8	9	11	12	14	17	7.3	8.1	9.3	11	13	15	18
	12	4.7	5.2	5.9	7.1	8.1	9	11	4.8	5.4	6.1	7.3	8.4	9.7	12
	24	3.2	3.6	4.0	4.7	5.4	6.3	7.6	3.3	3.7	4.1	4.8	5.5	6.4	7.7
	36	2.4	2.7	3.1	3.6	4.1	4.7	5.6	2.5	2.8	3.1	3.7	4.1	4.7	5.7
	48	2.0	2.2	2.5	2.9	3.3	3.8	4.5	2.0	2.2	2.5	3.0	3.4	3.8	4.5
	72	1.5	1.7	1.9	2.2	2.5	2.8	3.3	1.5	1.7	1.9	2.2	2.5	2.8	3.3

The values for areally reduced design rainfall depth are compared against previous studies in the Serpentine region in Table 5-6.

***Table 5-6** Design rainfall for the Birrega floodplain development study compared with previous Serpentine floodplain studies*

Duration (hr)	10 yr ARI			20 yr ARI			100 yr ARI		
	current study	WAWA (1990)	SKM (2010)	current study	WAWA (1990)	SKM (2010)	current study	WAWA (1990)	SKM (2010)
6	47	51	-	53	62	-	73	80	-
12	62	66	-	71	81	-	98	105	-
24	86	89	77 - 93	97	108	91 - 111	131	141	118 - 144
36	98	104	-	111	127	-	147	165	-
48	107	116	-	121	141	-	159	184	-
72	121	132	103 - 131	137	161	124 - 157	181	210	158 - 201

Design rainfall depths calculated for this study generally agree with those used in the SKM (2010) study, but are smaller than those used in the WAWA (1990) study, particularly for the larger events and longer durations. This is likely to be because the SKM and current study used CRC Forge data as a basis for the larger events, and as a basis for extrapolation to longer duration events. CRC Forge produces smaller design rainfall depths than the ARR method in the south-west of WA.

5.3 Design hydrology

The areally reduced IFD rainfall data and temporal patterns were imported as a design template to RORB. Since the magnitude of the design rainfall altered the value of *RoC*, a value for *RoC* was calculated for each of the design events. These values are displayed in Appendix D.

The design hydrology was then calculated by simulating each catchment model using the design IFD data and the calculated values of k_c and *RoC*. The critical duration (CD) storm was determined for each ARI event. The CD storm was the event duration which produced the highest peak discharge, and was generally between 24 and 72 hours.

Comparing design flows to flood frequency analysis results

Because of the small number of catchments analysed in the Water Corporation's Small Dams Study to determine the regional parameterisation methodology, additional flood frequency data from other catchments and studies should be used to provide better confidence in the adopted results (Pearce 2006).

The design hydrographs were compared with flood frequency analysis results for the 5, 10, 20, 50, 100, 200 and 500 year ARI events at the six flow gauging stations. The peak flow rates calculated by RORB were generally larger than those calculated in the FFA, particularly for the smaller events (5 to 20 year ARI). However, as the regional parameters were designed with a focus on 50 and 100 year ARI events, it is not surprising that the regional parameters do not match closely for smaller events. The RORB design flows agree more closely with the 50–100 year ARI flows though in most cases RORB produces larger peak flow rates. The 200–500 year flows are predicted to be larger from the RORB modelling in half of the catchments. A high level of uncertainty is associated with FFA for the 200–500 year events as they are extrapolated from 30–60 years of data, and relatively large discrepancies between RORB and FFA results for the rare event floods are to be expected.

Adjustments to regional parameters

Due to the consistent overprediction of the RORB models compared to the FFA results, particularly for the 5, 10 and 20 year ARI events, the RORB regional parameters were adjusted so that the design hydrographs better matched the FFA results.

Pearce (2006) notes that site-specific information must be used to review the results from regional parameterisation; in particular for *RoC*, where any available local runoffs should be incorporated and crosschecked whenever possible.

The regional parameters produced much larger flows for the 5, 10 and 20 year ARI events, and moderately higher values for the 50 and 100 year ARI events. Therefore, the following adjustments were made to the regional parameters datasets:

- *RoC* was multiplied by a factor of 0.6 for the 5 year ARI events
- *RoC* was multiplied by a factor of 0.7 for the 10 year ARI events
- *RoC* was multiplied by a factor of 0.8 for the 20 year ARI events
- *RoC* was multiplied by a factor of 0.9 for the 50 year ARI events

The adjusted regional parameters are shown in Appendix D. The design hydrology was re-run for each of the catchment models using the design IFD data and the adjusted regional parameters. Results are summarised in Table 5-7.

Table 5-7 *Comparison of design events derived from flood frequency analysis with those derived from RORB design rainfall events and adjusted regional parameterisation. 'CD' refers to the critical duration storm.*

Annual recurrence interval (1 in yr)	Nerregin Brook Abby Road (616044) (m^3/s)			Dirk Brook Hopelands Road (614028) (m^3/s)			Dirk Brook Kentish Farm (614005) (m^3/s)			Wungong Brook Kargotich (616153) (m^3/s)			Gooralong Brook Mundlimup (614073) (m^3/s)			Serpentine Serpentine Falls (614072) (m^3/s)		
	FFA	RORB*	CD	FFA	RORB*	CD	FFA	RORB*	CD	FFA	RORB*	CD	FFA	RORB*	CD	FFA	RORB*	CD
5	5	8	36hr	11	12	48hr	6	6	48hr	2	4	48hr	7	8	48hr	10	15	48hr
10	8	11	36hr	13	17	48hr	7	8	48hr	3	5	48hr	9	13	48hr	13	22	48hr
20	13	14	36hr	16	23	72hr	8	11	48hr	4	7	48hr	12	16	48hr	17	30	48hr
50	22	17	36hr	19	29	36hr	10	13	72hr	5	8	48hr	17	19	36hr	22	36	36hr
100	33	23	24hr	21	38	24hr	12	18	72hr	6	12	48hr	21	26	48hr	28	49	72hr
200	50	28	24hr	24	41	24hr	13	20	72hr	8	13	48hr	26	29	72hr	34	54	72hr
500	84	36	24hr	27	52	24hr	16	25	48hr	11	16	24hr	35	38	48hr	44	69	36hr

*RORB flows in this table have baseflow added, this uses a BUPF of 0.291 for flows < 200 year ARI and 0.129 for flows ≥ 200 year ARI

Using the adjusted regional parameters, there is a much closer match between the RORB modelling and the FFA at each of the flow gauging stations. The RORB 100 year events remain larger at four of the six gauging stations but this is not unexpected as the IFD rainfall is based on a long-term rainfall series, whereas the FFA was based on the previous 30–40 years of data in most cases, and a disproportionately small number of significant events have occurred over this period.

Design hydrology for external catchments

The design hydrology was run for all external and internal RORB subcatchments (Figure 5-1), using the adjusted regional parameters. Hydrographs were produced for the 5, 10, 20, 50, 100, 200 and 500 year ARI events for the 6, 12, 18, 24, 36, 48 and 72 hour storm durations.

The results for the peak flow rates and critical storm durations for the design hydrographs discharging to the western boundary of the study area are shown in Table 5-8.

Table 5-8 *Peak flows and critical durations for external RORB catchments*

Location	5yr ARI		10yr ARI		20yr ARI		50yr ARI		100yr ARI		200yr ARI		500yr ARI	
	m^3/s	CD	m^3/s	CD	m^3/s	CD	m^3/s	CD	m^3/s	CD	m^3/s	CD	m^3/s	CD
E01	4.6	48hr	6.2	48hr	9.2	48hr	10.6	48hr	14.4	48hr	15.7	48hr	16.8	48hr
E02	3.8	48hr	5.0	48hr	7.4	48hr	8.4	48hr	11.5	48hr	12.5	48hr	13.4	48hr
E03	3.0	12hr	4.1	12hr	5.5	12hr	6.1	12hr	8.0	12hr	8.4	12hr	10.0	12hr
E04	1.7	12hr	2.3	12hr	3.1	12hr	3.4	12hr	4.4	12hr	4.6	12hr	5.5	12hr
E05	2.0	12hr	2.5	12hr	3.5	12hr	4.0	12hr	5.1	12hr	5.3	12hr	6.4	12hr
E06	8.7	12hr	11.6	12hr	16.8	12hr	18.2	12hr	24.4	12hr	26.7	48hr	31.5	24hr
E07	6.9	48hr	9.9	48hr	13.3	48hr	15.8	48hr	20.6	48hr	22.4	48hr	24.8	24hr
E08	3.9	12hr	5.3	12hr	7.0	12hr	7.9	12hr	10.1	12hr	10.6	12hr	12.6	12hr
E09	1.1	12hr	1.5	12hr	2.0	12hr	2.2	12hr	2.9	12hr	3.0	12hr	3.6	12hr
E10	5.5	48hr	7.3	48hr	11.1	48hr	12.7	48hr	17.5	48hr	19.2	48hr	20.5	48hr
E11	1.2	12hr	1.6	12hr	2.2	12hr	2.4	12hr	3.1	12hr	3.3	12hr	3.8	12hr

Examples of the hydrographs for RORB catchment E07 (which represents the flow in Manjedal Brook upstream of the South Western Highway Bridge) are displayed in Figures 5-9 and 5-10. The critical duration for the 100 year ARI event at this location is 24 hours.

The peak discharge rates derived from the RORB design flows were compared to modelled peak discharge rates for the 5 and 100 year ARI events in the Byford region, modelled by GHD as part of the Byford DWMP (Department of Water 2008). The results are shown in Table 5-9.

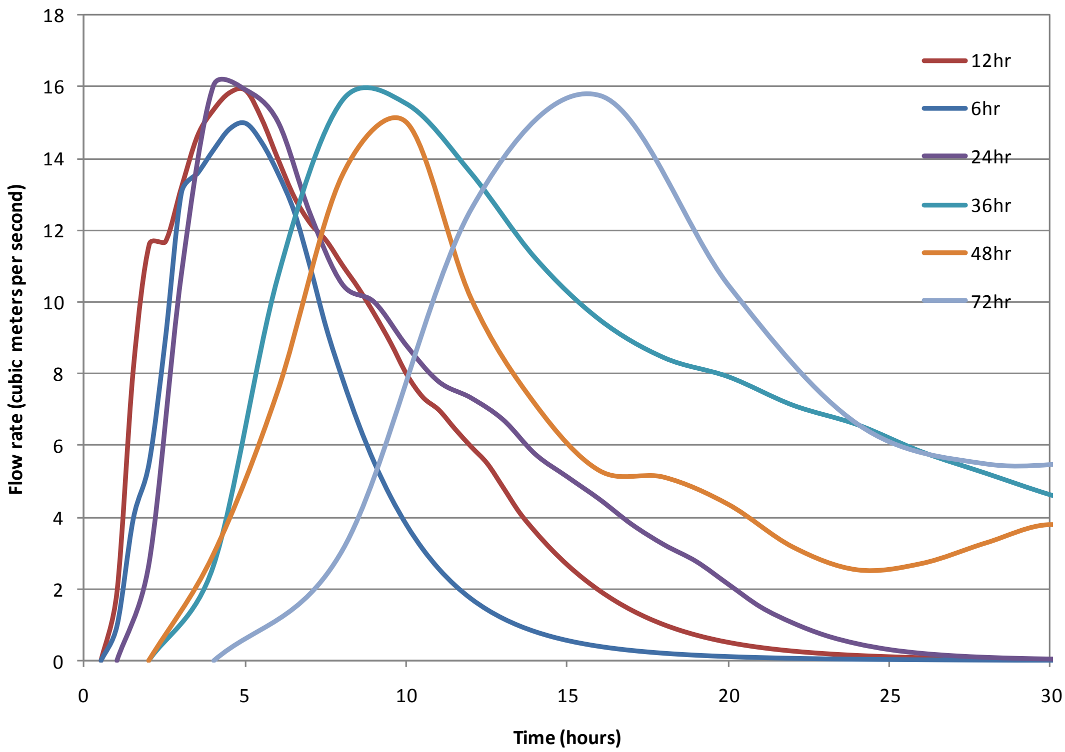


Figure 5-9: *RORB design flow estimation for flow at Manjedal Brook and South-Western Highway (upstream; RORB subcatchment E10), 100 year ARI event event with varying durations*

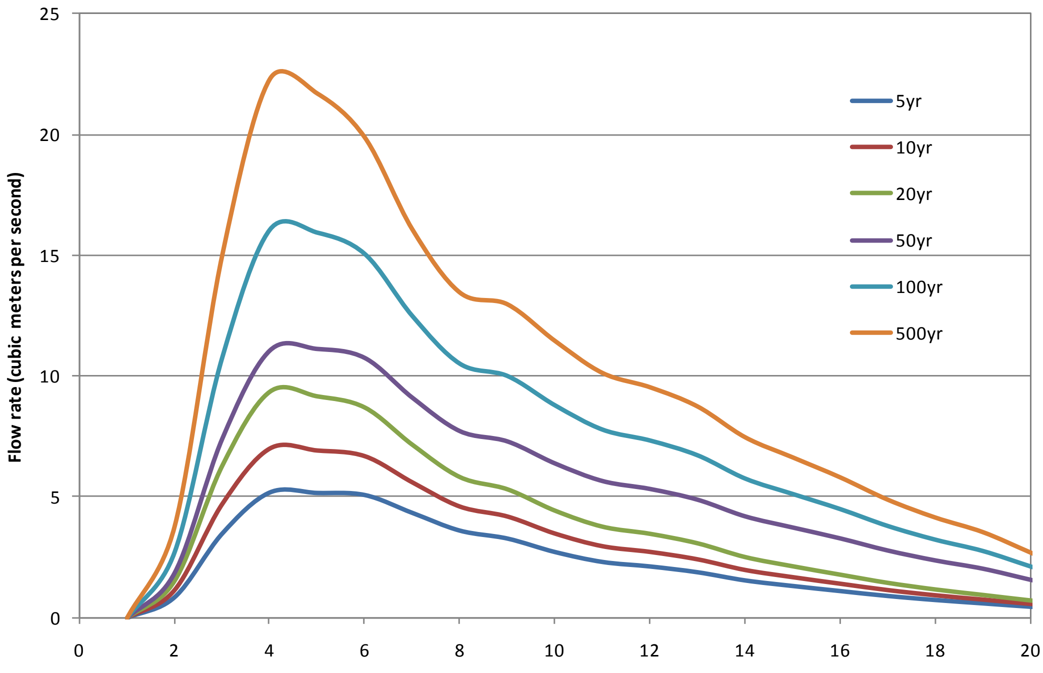


Figure 5-10: *RORB design flow estimation for flow at Manjedal Brook and South-Western Highway (upstream; RORB subcatchment E10), 24 hour event with varying ARI*

Table 5-9 Comparison of peak discharges calculated in the current study and the previous flood study completed for the Byford DWMP

Description of the location	Byford DWMP (DoW, 2008)			current study		
	Location ID	5yr ARI peak flow (m^3/sec)	100yr ARI peak flow (m^3/sec)	Location ID	5yr ARI peak flow (m^3/sec)	100yr ARI peak flow (m^3/sec)
Oaklands drain d/s of George Road (n)	1	5.5	10.2	E04+E05	4.2	11.7
Beenyup Brook d/s South Western Hwy	8	8.1	31.2	E06	5.4	26.8
Cardup Brook d/s South Western Hwy	18	5.8	23.5	E07	8.0	22.7

The estimates for peak flows for the 5 and 100 year ARI events in the current summary were generally smaller than for the Byford DWMP study, but within 30% of one another. The discrepancy in flow rate is likely to be due to the differences in adopted k_c and *RoC* parameters for the two studies.

Climate change

The influence of climate change on design rainfall was not considered as part of this study. There is a high level of uncertainty associated with the outputs of global climate models (GCMs), and climate projections are not available at the subdaily time step for many of the datasets available in the Coupled Model Intercomparison Project archives. In this respect, it is difficult to modify rainfall IFDs and temporal patterns based on the results of GCMs. The Bureau of Meteorology and Engineers Australia are currently reviewing AR&R1987, and future editions may address the influence of climate change.

6 Hydraulic modelling

6.1 Introduction

A hydraulic flood model for the Birrega and Oaklands study area was used to develop flood extent mapping, detailed floodplain mapping, and long sections of main drains. The model was calibrated to a recorded event, and the calibrated model was used to simulate the 5, 10, 20, 100 and 500 year ARI design events for 6, 12, 24, 36, 48 and 72 hour durations. A sensitivity analysis was performed to determine the effect of changes in key parameters to flood peaks and volumes.

6.2 Selection of an appropriate hydraulic model

There are many methods and techniques for developing hydraulic flood models. When developing a flood model, decisions are required as to the most appropriate model architecture. This includes the choice of appropriate model dimension, inflow generation technique, requirement of a steady-state or a transient state solution and appropriate software package. The selection of an appropriate model set-up depends on the physical characteristics of the study area and the required outputs of the model, which relate to the objectives of the study.

Selection of model dimension

The Birrega and Oaklands flood model requires flood extent mapping for the entire catchment area within the Swan Coastal Plain (i.e. not only for the major drains). Due to the large extent of potential flooding and the complex nature of the channel network, a 2-dimensional modelling approach is required to undertake floodplain mapping sufficiently. The study area is, for the most part, extremely flat with deep, narrow main drains incising the floodplain (i.e. the Birrega and Oaklands drains). These drains are extremely important in the hydraulic conveyance of flood flows through the catchment, and cannot be adequately represented by the 2-dimensional grid (a 20 m grid is required for adequate run-times in an area this large, which is too coarse to adequately capture the hydraulic properties of these narrow drains which are approximately 10–20 m wide). Therefore the drainage channels were represented by a 1-dimensional flood model, and the overall model was an integrated 1- and 2-dimensional flood model. Bridges and culverts were also represented in the 1-dimensional model.

Selection of inflow generation technique

There are two possible techniques for generating inflows within the modelling domain:

1) **Distributed hydrograph technique:** This approach involved the application of inflow hydrographs (generated from hydrological modelling) to selected model 2-dimensional model cells (or 1-dimensional model boundaries)

2) **Direct rainfall technique:** Application of direct rainfall (also known as rainfall-on-grid) to all cells in the 2-dimensional grid, and the runoff is routed within the hydraulic model.

The Birrega / Oaklands model used a combination of these two techniques: the hydrograph technique was used to generate flows from the catchments upstream of the Darling escarpment (east of the South-Western Highway) and the direct rainfall technique was used within the hydraulic modelling domain. Reasons for selecting a direct rainfall approach within the hydraulic modelling domain included:

- Cross catchment flow is facilitated in the model using the direct rainfall technique. In flat catchments, flow can cross a catchment boundary during higher rainfall events. This is difficult to represent in a traditional hydrological model.
- The direct rainfall approach replaces hydrological modelling in the modelling domain. This approach can provide a superior representation of drainage elements, particularly where the catchment is mostly ungauged, and regional hydrological parameters are uncertain or unavailable.
- The direct rainfall approach provides a high definition of flow behaviour in a catchment since overland flow is incorporated directly. This level of definition is required in this project for understanding flood flows and floodplain mapping for potential urban development areas.

The main limitations to the direct rainfall approach include:

- Direct rainfall is a relatively new technique, and this approach is sometimes still treated with some suspicion. Therefore caution and detailed checking are needed in its application.
- Detailed model calibration is required.
- The approach requires high quality digital terrain information. For the Birrega Study LiDAR information suitable for use in direct rainfall studies is available for the Swan Coastal Plain.
- The shallow flows generated in the direct rainfall approach may be outside the typical range where Manning's roughness parameters are applied.
- The model grid size will affect the flood extent and magnitude, and the flow paths. Therefore, the same grid should be used in model calibration and in scenario simulations. This can limit some projects.
- There are significant increases in model run times.

By applying direct rainfall over a portion of the catchment (i.e. the Swan Coastal Plain) and using flow hydrographs for the remainder (the Darling Scarp), the model utilises the benefits of both traditional hydrological models and the direct rainfall approach. By limiting the size of the 2-D domain, model run times are reduced, but flows over the 2-D domain do not need to be defined separately. While this approach still requires two separate models, it reduces the assumptions associated with the application of flows within the 2-D domain. This is important for the Birrega region, as there are limited studies on the Swan Coastal Plain to parameterise hydrological models.

It is important when using direct rainfall models to use a constant-sized grid for model calibration and for design scenarios, as changing the grid size can alter the flood flows due to the changing resolution of smaller flow-paths which affect flood timing (particularly in the upper catchments). It may be necessary to stamp a preferred flow path into the model grid, particularly with respect to smaller flood events, to represent road kerbs, gutters or important drains. This was done at key locations in the Birrega model and described in Section 6.4.

More information on the direct rainfall approach can be found in the recent Australian Rainfall and Runoff Revision Project 15: Two Dimensional Modelling in Urban and Rural Floodplains (Engineers Austraila 2012), and in Rehman (2011), who was involved in the development of the rainfall-on-grid modelling technique and has done significant research and analysis on this technique over the past decade.

6.3 Hydraulic model development overview

MIKE Flood, a numerical computer modelling platform from the Danish Hydrological Institute (DHI) was used to develop the hydraulic model. The model consists of integrated 1-D channel and 2-D overland flow mechanisms. A description of the DHI software is given in DHI (2007). The 2012 version of the MIKE Flood software was used. Thy hydraulic model was developed using two modelling components:

1) **MIKE 21** was used to simulate the overland flow. MIKE 21 uses time-dependent non-linear equations of continuity and conservation of momentum which are solved by implicit finite difference techniques over either a rectangular grid or flexible mesh. The Birrega model uses the rectangular grid configuration. Model inputs for MIKE 21 include surface topography, rainfall, evapotranspiration/infiltration, inflows from the escarpment catchments, and parameters representing surface roughness, eddy viscosity, and flooding and drying depths.

2) **MIKE 11** was used to simulate the 1-dimensional flow in the major drainage pathways, and through culverts, bridges and weirs. In the Birrega model, MIKE 11 was configured to provide a fully dynamic solution to the complete nonlinear Saint Venant equations for flow. Inputs to the MIKE 11 model included a model network, cross-sections, boundary conditions, culvert and weir dimensions, and parameters representing channel and culvert roughness.

The two model components are linked using a MIKE Couple file to produce an integrated MIKE Flood model. The MIKE Couple file for the Birrega model included two types of couple to link the MIKE 11 and MIKE 21 models:

- **Lateral links:** enabling simulation of overbank flow from river channel to flood plain. These were included on the left and right hand levees of the Birrega and Oaklands drains to represent water spilling from the floodplain into the drains, or water overtopping the drains and spilling onto the floodplain.
- **Standard links:** used where one or more MIKE 21 cells are linked to the end or beginning of a MIKE 11 river branch. These were included to represent the inflows from the floodplain to drains which connected to the Birrega and Oaklands Main Drains.

The model was optimised to minimize grid-size whilst maintaining adequate run-times. A 20m rectangular grid was used, and a constant timestep of 0.25 seconds was required to produce a stable model. The parameters incorporated in the set-up of the MIKE 11, MIKE 21, and MIKE Flood components of the Birrega model are shown in Table 6-1.

Table 6-1 *Parameters for the MIKE 21, 11 and Flood models*

Mike 21 parameters	
Time step (sec)	0.25
Grid size (m)	20
Grid configuration	rectangular
No active grid cells	463706
Simulation period (days)	4
Source points	9
Flooding depth (m)	0.001
Drying depth (m)	0.00025
Eddy viscosity (m^2/s)	3
Resistance (Mannings M)	variable (Table 6-4)
Mike 11 parameters	
Resistance (Mannings n)	0.048
Wave approximation	Fully dynamic
Main channels modelled	3
Inflow channels modelled	23
Number of culverts/bridges	22
Number of h points	2438
Number of Q points	2402
Mike Flood parameters	
Standard links	25
Lateral links (No. cells)	1016

6.4 2-D model construction

Model domain and boundary

The model domain is described in Section 1, and covers an area 13.9 km (east-west) by 17.4 km (north-south), corresponding to 694 x 873 model cells. There were in total 463 706 active MIKE 21 cells in the model domain (i.e. not including 'land cells' or 'delete values'). The domain contains a single wetted boundary on the eastern edge of the model – this is the location that any break-out from the Birrega Drain would flow to. The wetted boundary has a constant water level boundary condition of 6.0 m. The extent of the hydraulic model domain and boundary are shown in Figure 6-1.

Topography

The MIKE 21 model was constructed using a fixed 20 m x 20 m grid. The grid was developed using bilinear interpolation from the 1.0 m LiDAR data, which was manually modified to better represent overland flow paths. Manual modifications to the grid included:

- **Levee banks:** These were modified to match the actual levels of the levees on both the Birrega and Oaklands drains. This was necessary because the 20 m grid is larger than the width of the levees, and the interpolated cells which contained the levee would be assigned a level that is lower than that of the levee bank. This will cause water in the model to 'break-out' before the actual levee bank height is reached.

- **Road levels:** Some major roads in the model domain are raised and water builds up behind the roads in a large rainfall event (the roads act in a similar manner to the levee banks). In this instance the actual level of the road needs to be assigned to model cells containing the road. These included Thomas Road, Hopkinson Road, Rowley Road and Mundijong Road.

- **Standard links:** The topography was altered at the locations of the standard links so that the value in the topographical grid was equal to the lowest point in the MIKE 11 cross section. This was necessary to ensure numerical stability in the MIKE Flood model.

- **Bridges:** Most bridges and large culverts were removed from the topography. Bridges were assessed to determine whether they would be likely to affect the flood flows (i.e. whether they are likely to overtop). If a bridge was likely to affect the flood flows, it was included explicitly in the MIKE 11 model (see Section 6.4).

Rainfall

Rainfall was applied directly to the 2-D model domain uniformly across all model grids that were not 'land cells' or 'couple cells'. Derivation of the rainfall IFD data used in the design simulations was outlined in Section 5.2.

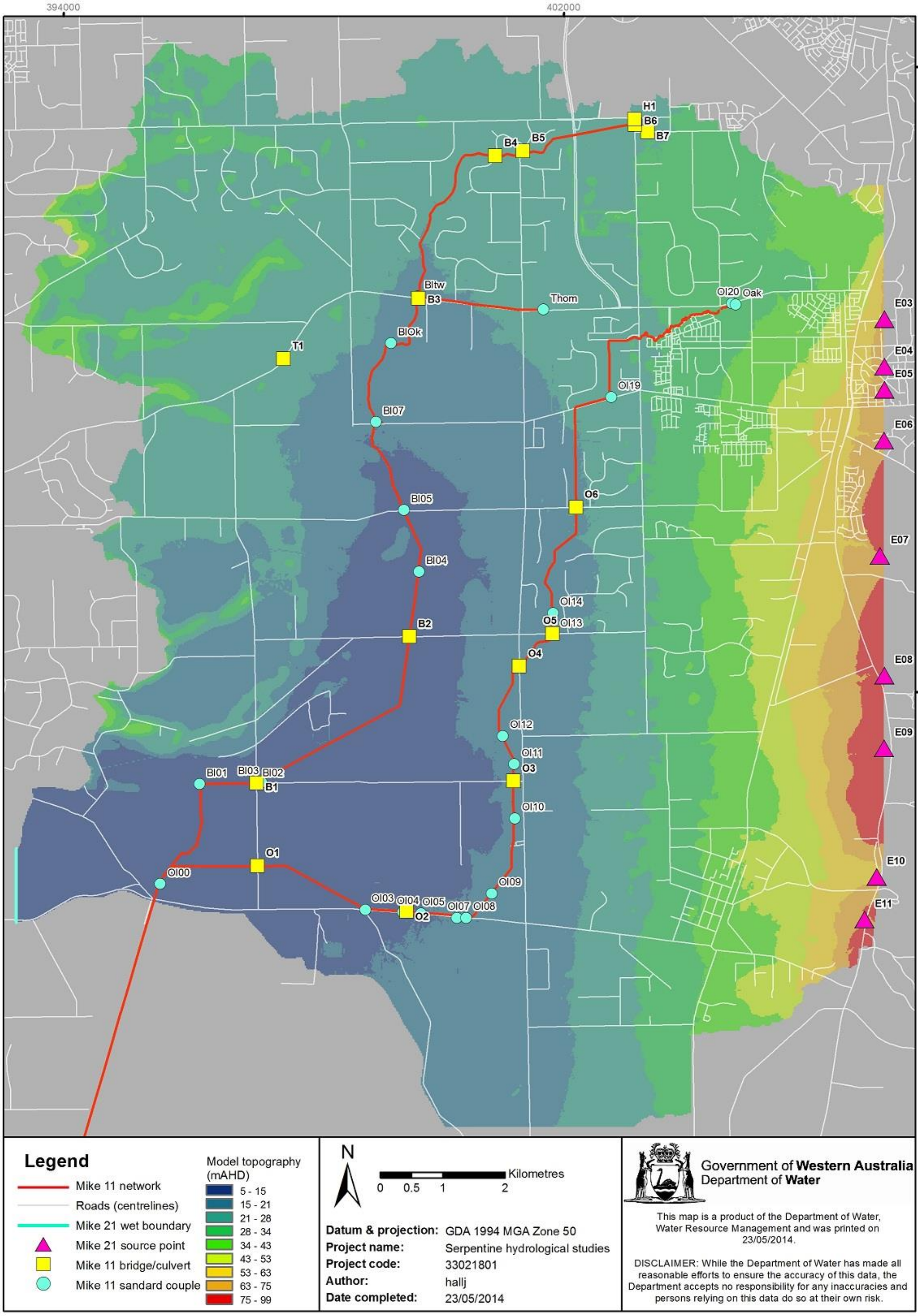


Figure 6-1: *Model domain, topography, structures and inflows*

Losses

As rainfall becomes runoff, catchment water losses occur due to processes like interception, infiltration, evapotranspiration and storage. The amount of loss is dependent on many factors such as vegetation type, soil type, initial saturation levels and catchment topography. There are three methods to incorporate losses in direct rainfall models:

- **Rainfall loss models:** These models apply losses by removing a portion of the rainfall applied to the model. Rainfall loss models are limited as they can only apply losses while the rain falls. The main advantage of this technique is that it lumps all loss processes into a single loss value, and negates the requirement for extra data necessary for 2-D or integrated groundwater loss techniques (e.g. spatial representation of groundwater data, soil data, vegetation data).

- **2-D loss models:** These models remove water from the 2-D domain rather than from the rainfall being applied to the 2-D domain. This means that runoff is exposed to potential losses while it is being routed thought the 2-D domain. The main advantage of this model is that it can provide a better representation of the physical system and fully utilise the benefit of 2-D runoff routing. The nature of the 2-D model allows evapotranspiration and infiltration to be defined based on the area of inundation. Its main disadvantage is that it requires significantly more information than a rainfall loss model. This information includes spatial definition of parameters for infiltration, areas of groundwater inundation, and initial inundation values.

- **Integrated groundwater models**: These models effectively extend the loss methods to the next level of detail beyond a 2-D loss model, and involve linking a groundwater model to the 2-D surface water model. In rainfall loss and 2-D loss models, there is an inherent assumption that any water that has entered the groundwater system is effectively removed from the surface runoff whereas an integrated groundwater model is not limited by this assumption. This assumption is generally not critical in most flooding applications as the groundwater processes are substantially slower than the surface water component.

All three loss models were trialled. The integrated groundwater model option was assessed as there was an available integrated surface water and groundwater MIKE SHE model for the Serpentine region (Marillier et al. 2012a and b). A local area model of the Serpentine MIKE SHE model, constructed for the Birrega and Oaklands hydraulic model domain, incorporated the top layer of the groundwater model and the unsaturated zone parameters from the Serpentine MIKE SHE model. The local area model had a 20 m grid, and was trialled to include overland flow processes only (only a 2-D model). It was found that model run-times were not feasible using this technique, due to limitations of the overland flow solver in the MIKE SHE engine (version 2011).

The rainfall loss model and the 2-D loss model were compared in the calibration process, using recorded flow gauging data from a rainfall event in June 2011. Model calibration is discussed in detail in Section 6-5. The calibration process found that the 2-D loss model provided a more accurate calibration and realistic representation of flow processes in the Birrega and Oaklands hydraulic model domain. Therefore, it was necessary to provide spatially explicit input files soil-type (to model infiltration rate), groundwater inundation and initial water depth to incorporate the 2-D loss model processes. Evapotranspiration and canopy interception were considered negligible over the four day period that the model was simulated and were not considered in the loss model (evapotranspiration is < 2 mm/day in the winter period, and canopy interception is minimal as the catchment is predominantly cleared).

Infiltration

Infiltration is a major loss in the conversion of rainfall to runoff on the Swan Coastal Plain, which is characterised by well-drained sands and little topographical relief. Soil-mapping was sourced from the Department of Agriculture's database and document *Soil-landscape mapping in south-western Australia* (Schoknecht et al 2004). The 2-D model domain comprises mostly Bassendean and Pinjarra soils, with minor areas of Forrestfield soils close to the Darling Scarp. The Bassendean and Pinjarra soils comprise sands or sandy loams, which are medium to well-drained. However, there are clay phases within the Pinjarra and Bassendean units (commonly referred to as Guildford Clays) which are likely to have much lower vertical hydraulic conductivities. The phase mapping units in the soil-landscape mapping unit hierarchy were used to locate clay and sandy surface soils in the model domain. Likely infiltration rates (saturated vertical hydraulic conductivity) for sandy soils range from 50 to 500 mm/day, and for the clay phases infiltration rates are likely to be less than 50 mm/day. Infiltration rates were refined during the model calibration process and rates of 70 mm/day for the sand phase and 5 mm/day for the clay phase were used in the hydraulic model. The clay and sand phases of the 2-D model domain are shown in Figure 6-4.

Antecedent groundwater conditions are also likely to affect the flood magnitude. Field observations and groundwater modelling results show large areas of inundated land during winter months. Inundated areas will have no infiltration capacity (almost all of the rainfall in these areas will be converted to runoff), so to calculate overall runoff for the model domain it was necessary to 1) define the extent of the inundated area for the calibration event, and 2) to develop an inundation extent for design model simulations.

The south-west of Western Australia experiences a strong seasonal variation in catchment wetness. Results from the Serpentine hydrological studies (Marillier et al. 2012b) show that groundwater levels are generally lowest April–May (when there is very limited surface inundation), and highest September–October. Major winter rainfall events are most likely to occur in July so it is unlikely that a significant rainfall event would occur when the groundwater level is at a maximum. The average maximum July groundwater level (1980–2010) was used in design simulations. The sensitivity of the magnitude of the flood event to the groundwater level was analysed in Section 6-8, 'Sensitivity analysis'.

The results of the Serpentine MIKE SHE modelling (Marillier et al. 2012a, b) were used to develop groundwater inundation maps for both the calibration and design events. Figure 6-2 shows the 28 June 2011 inundation extent which was used in the calibration simulation and Figure 6-3 shows the inundation extent from the average maximum July groundwater level; this was used in design simulations. In both cases, infiltration in the inundated areas (and the infiltration in the land cells) was set to 0 mm/day.

Initial conditions

Direct rainfall models incorporate some element of depression storages within the model. The use of raw digital terrain data can lead to overestimating depression storage and underestimating hydraulic conductivity. This problem is particularly pronounced in catchments subject to small magnitude, short-burst duration design rainfall where the rainfall volume is relatively low (e.g. the five year six hour events).

To increase the hydraulic connectivity, a technique known as 'pre-wetting' is used. Pre-wetting is the application of a rainfall burst to a DEM with the purpose of filling unconnected depressions in the DEM. Once the runoff excess has drained, the water level results of the final time step are then used in subsequent runs.

Pre-wetting was completed by simulating a 'hot-start' scenario, and using the results at the end of this scenario as the initial conditions for the 2-D and 1-D model. The hot-start was simulated with 40 mm of rainfall in a nine hour period and then allowed to drain for a further three days. This storm was simulated using the rainfall pattern and magnitude from the event on 24 June 2011 at the Dog Hill rainfall gauging station (BoM Ref. 509295). A period of four days drainage was allowed so that baseflow conditions would remain post-simulation to reflect the Water Corporation's conditions that event floodplain storage would drain within 72 hours.

The initial water depth (the water remaining at the end of the hot-start simulation) used in calibration and design simulations is shown in Figure 6-5. The initial water depth in the main channels simulated in the 1-D model is discussed in Section 6-5.

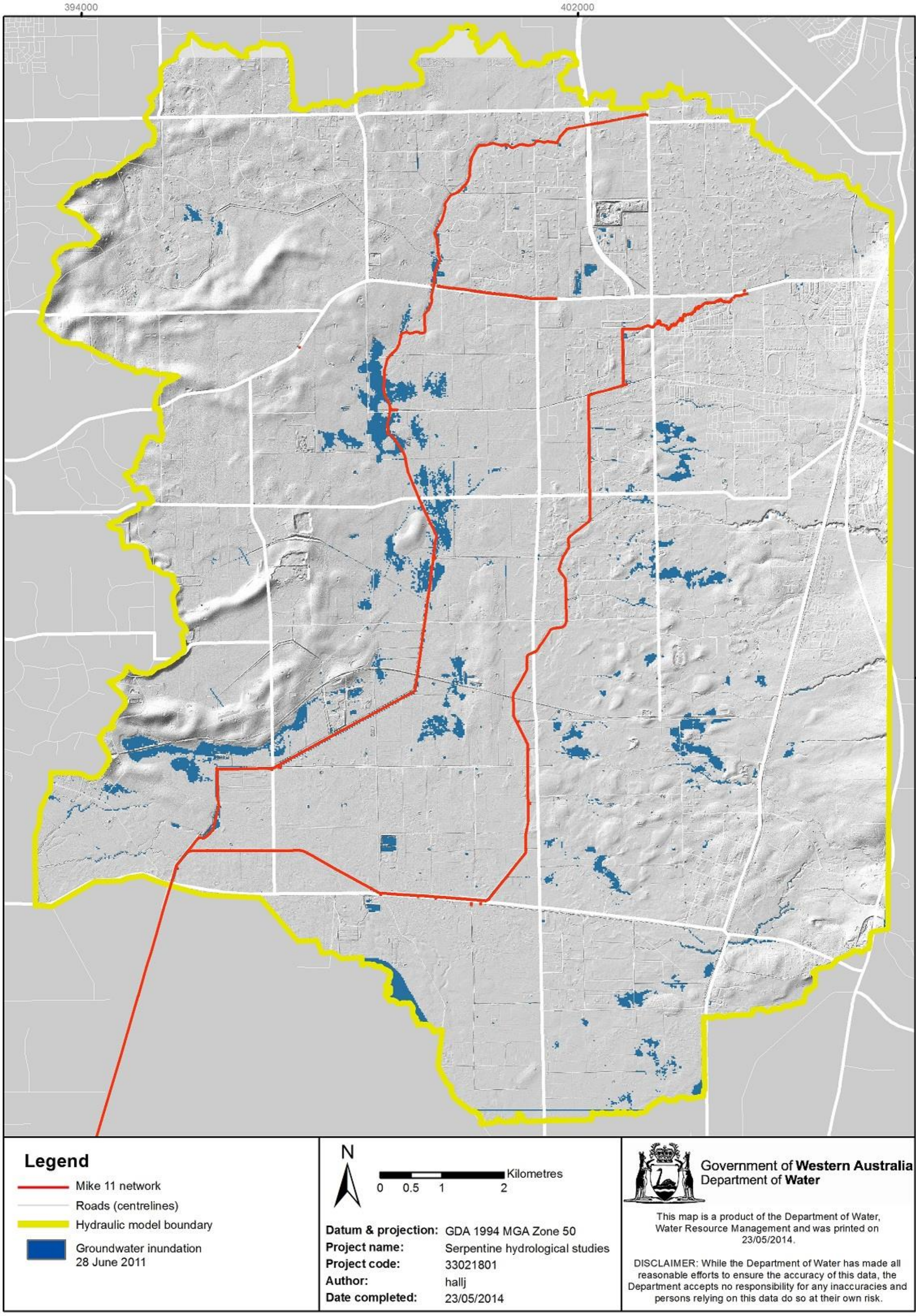


Figure 6-2: *Model inundation for June 2011 calibration event*

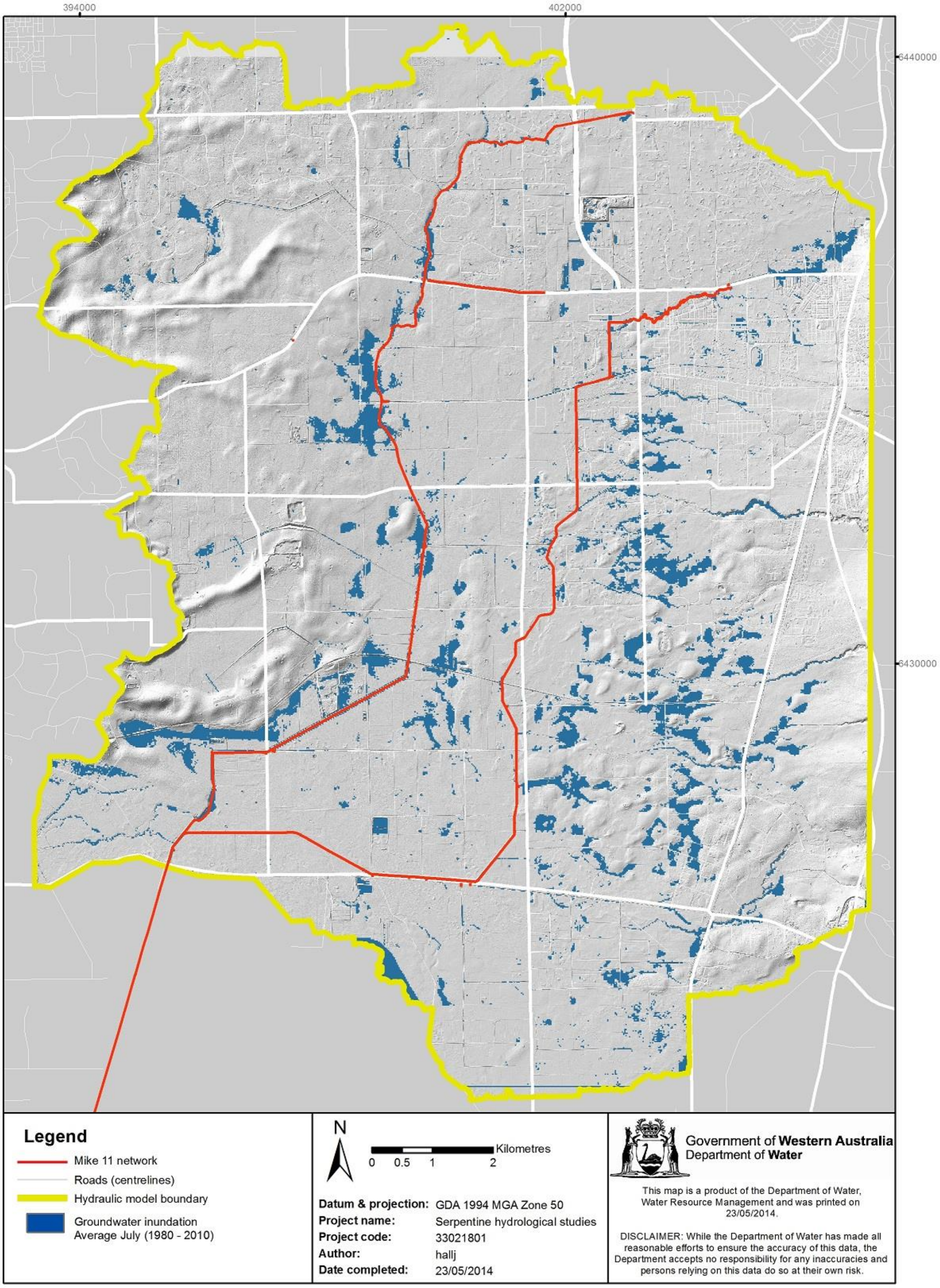


Figure 6-3: *Model inundation for design events*

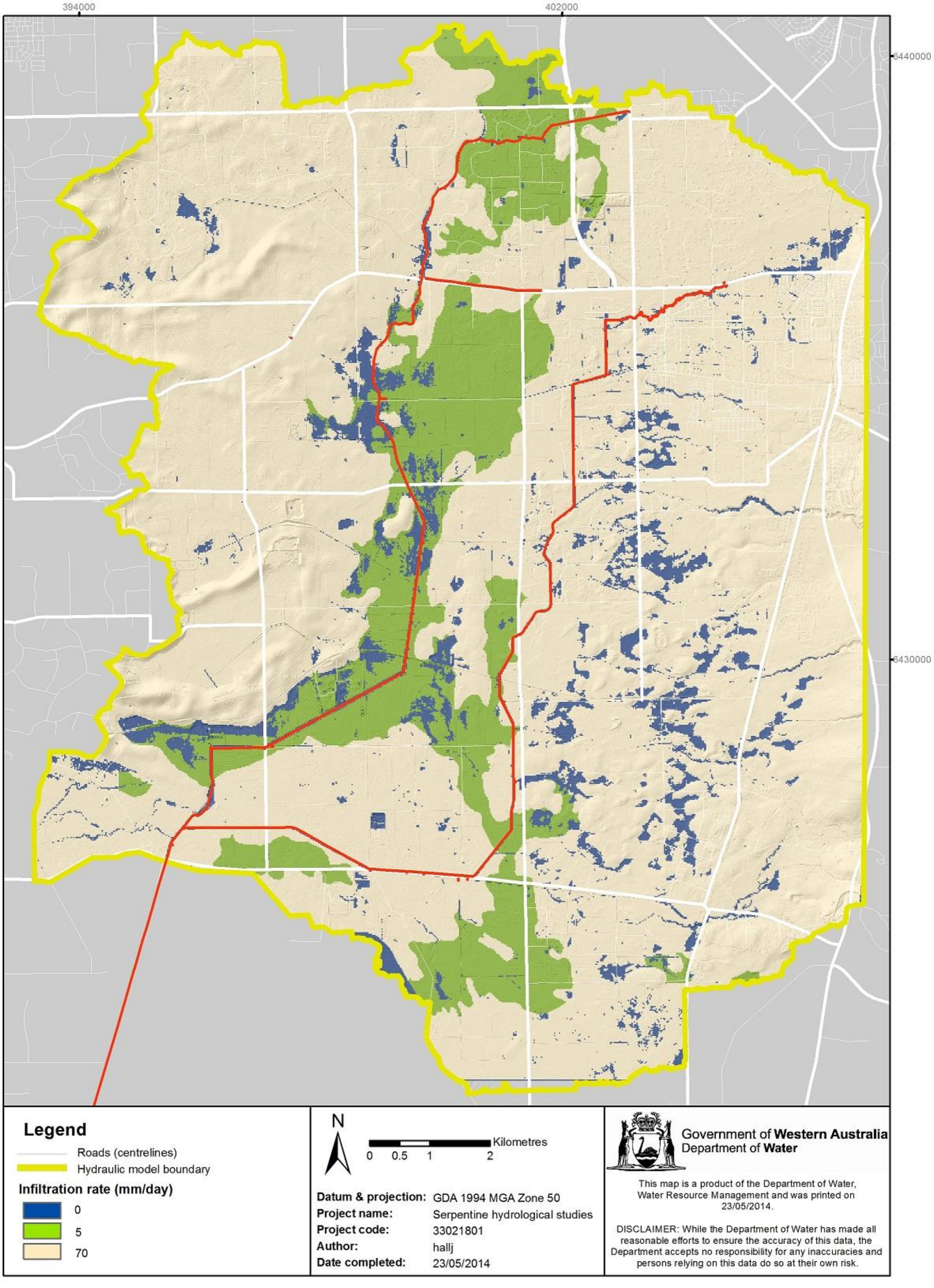


Figure 6-4: *Model infiltration rate, accounting for soil type and groundwater inundation*

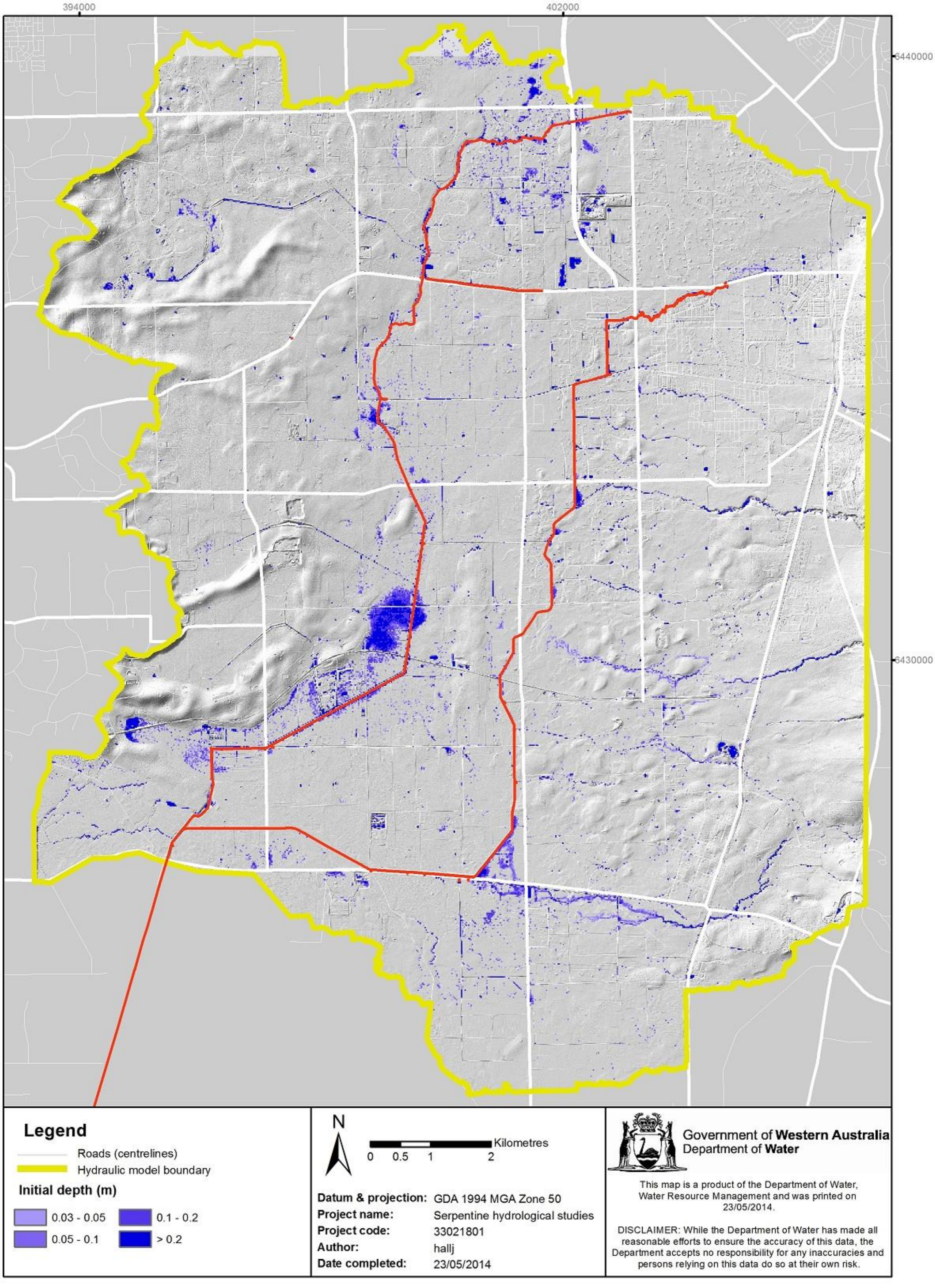


Figure 6-5: *Initial water depth for model runs*

Inflows from escarpment catchments

The MIKE 21 model included 'source points' at nine locations along the eastern boundary of the model; these represent inflows from the waterways with headwaters upstream of the escarpment. An inflow point at Wungong Brook was not included because it was concluded that an insignificant volume of flood flow from Wungong Brook would enter the Birrega Drain as the high flows are directed towards Southern River. Inflow hydrographs were calculated in the design hydrology section (Section 5-3), and a set of model inflows was simulated for the 5, 10, 20, 50, 100 and 500 year ARI events, for the 6, 12, 24, 36, 48 and 72 hour durations. The location of the MIKE 21 source points are shown in Figure 6-1, and examples of the inflow hydrographs for the 100 year 24 hr event are shown in Figure 6-6.

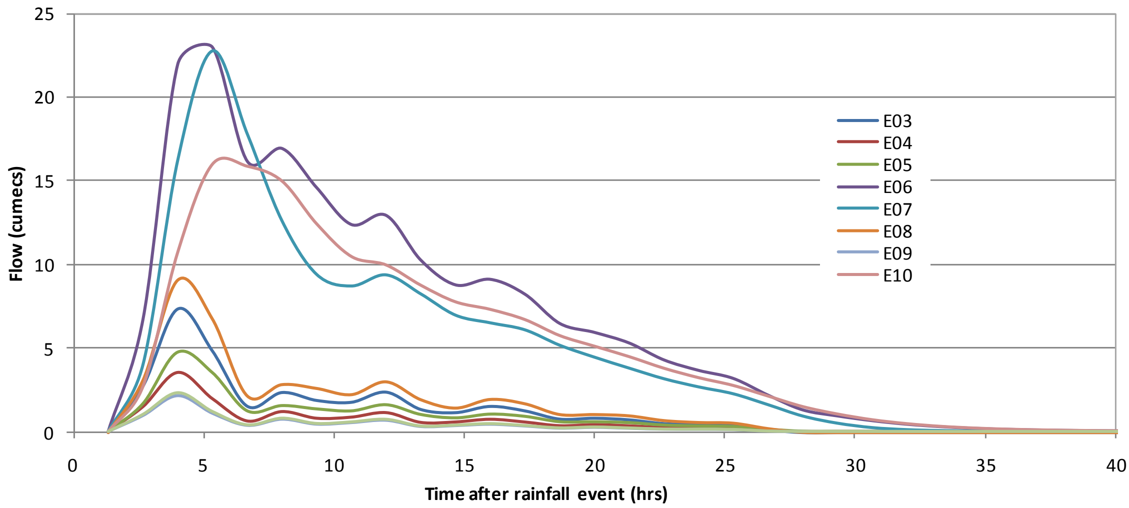


Figure 6-6: *Model inflows from escarpment catchments for the 100 year 24 hr design event*

6.5 1-D model construction

MIKE 11 is used to simulate 1-D channel flow in the Birrega model. It is a one-dimensional model and consists of a set of nodes along a river reach, each with a series of properties. Water will flow from node to node, and nodes are linked together to form the river network. Nodes contain physical properties such as river cross-section geometry, floodplain topography, channel and floodplain roughness and/or structure geometry. Time-series data can be stored at the nodes, including boundary conditions (like Q-h, flow time-series, constant head) or calibration data. The MIKE 11 simulation file for the Birrega model requires four data editors: a river network editor, a cross-section editor, a boundary file editor and a hydraulic parameter editor.

Network

The MIKE 11 network consisted of the two major drainage channels (Birrega and Oakland drains), a minor drainage channel (Thomas Road drain), and 20 small inlet channels (< 50 m long) to represent the rural drainage channels that convey water to the Birrega and Oaklands drains at low and medium flows where the levee banks of the main drains are not overtopped. An important road culvert on Thomas Road was also entered explicitly in the MIKE 11 network. The MIKE 11 network and the location of all inflow points to the Birrega and Oaklands drains are shown in Figure 6-1.

Cross sections

The river cross-section data comprises both raw and processed data. The raw data describes the physical shape of a cross-section using (x, z) coordinates. For much of the model, the coordinates were obtained using the MIKE 11 GIS extension. MIKE 11 GIS is an extension to ESRI's ArcMap, which takes advantage of ArcMap's many GIS functionalities and provides a number of useful tools in relation to MIKE 11 modelling. MIKE 11 GIS allows for the automatic sampling of cross-sections using the LiDAR data. This allows for many cross-sections to be applied to the MIKE 11 model without requiring large amounts of survey data (Figure 6-7). The LiDAR was flown in late summer so most waterways in the model domain were dry at the time. It was important to ensure that levee heights for the Birrega and Oaklands Drains were correct, and cross sections were edited to ensure the left and right channel markers corresponded to the maximum height of the levee bank. Set-up options and parameters used in the MIKE 11 cross section file are shown in Table 6-2.

Table 6-2 *Set-up options for the MIKE 11 cross section file*

Setup parameter	Value
Radius type	Total area, hydraulic radius
Resistance type	Relative resistance
Resistance value	1
Level selection method	Equidistant
Number of levels	50
Markers	1,3: Left/Right, 2: Lowest

Bridges and culverts

Bridges and culverts were entered explicitly into the MIKE 11 model using the 'Weir/Culvert" method. The bridges were initially assessed to decide whether they would impinge on the natural flow of the drain. In many cases, bridges were built with a clearance above the level of the surrounding levee banks so flow would overtop the levee bank before being significantly affected by the bridge structure; in these cases the bridges were not included in the model. Nine bridges and four important culverts along Birrega and Oaklands drains were explicitly included in the model. Photos of each of these bridges/culverts and their corresponding representation in MIKE 11 are shown in Appendix B. In addition, included in the model were nine culverts where water drains laterally from the floodplain to the Birrega and Oaklands Drains. Long sections of the Birrega and Oaklands Drains and the locations of each of the bridges included in the model are shown in Figures 6-8 and 6-9.

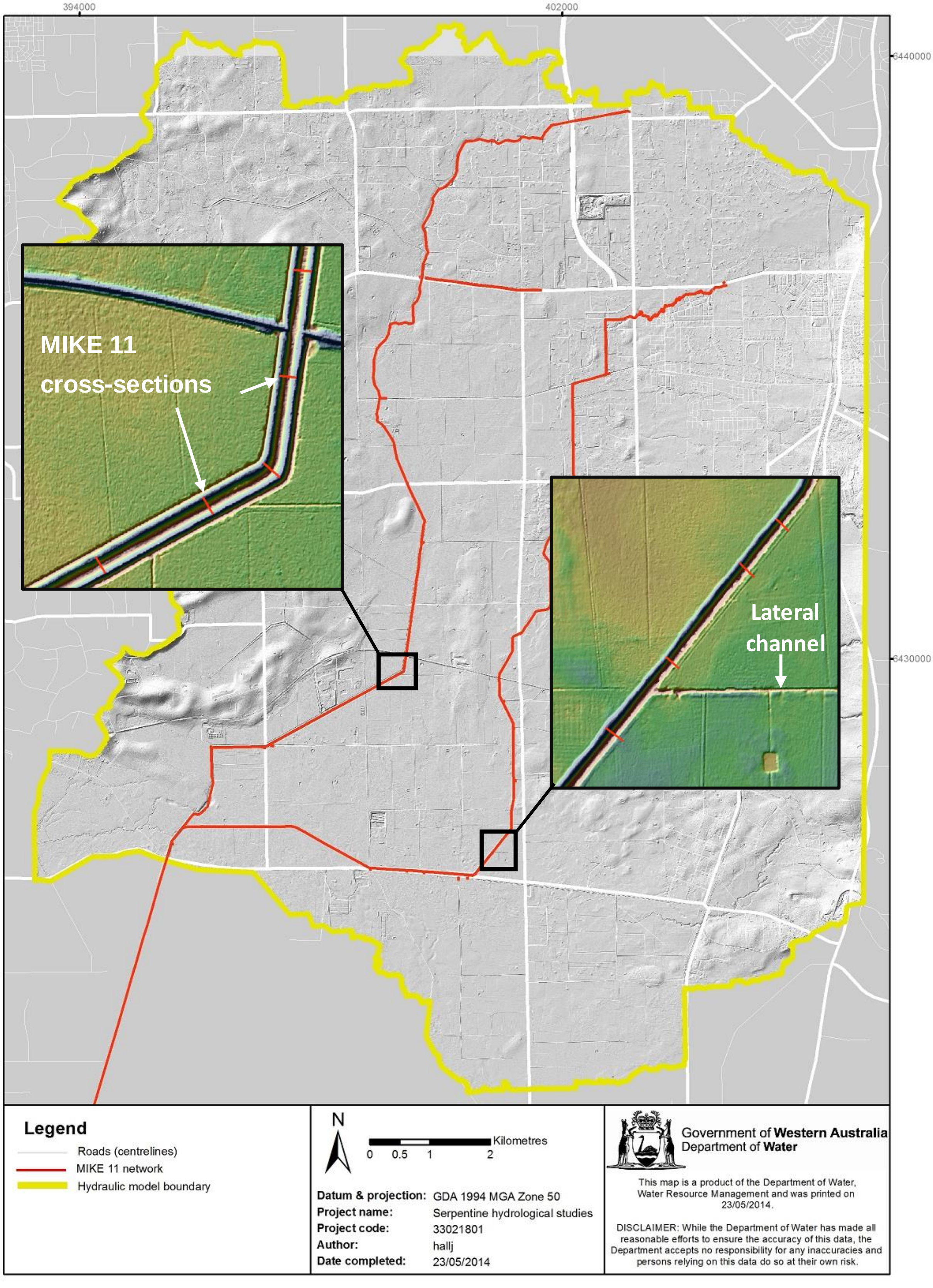


Figure 6-7: *MIKE 11 cross-sections and network set-up*

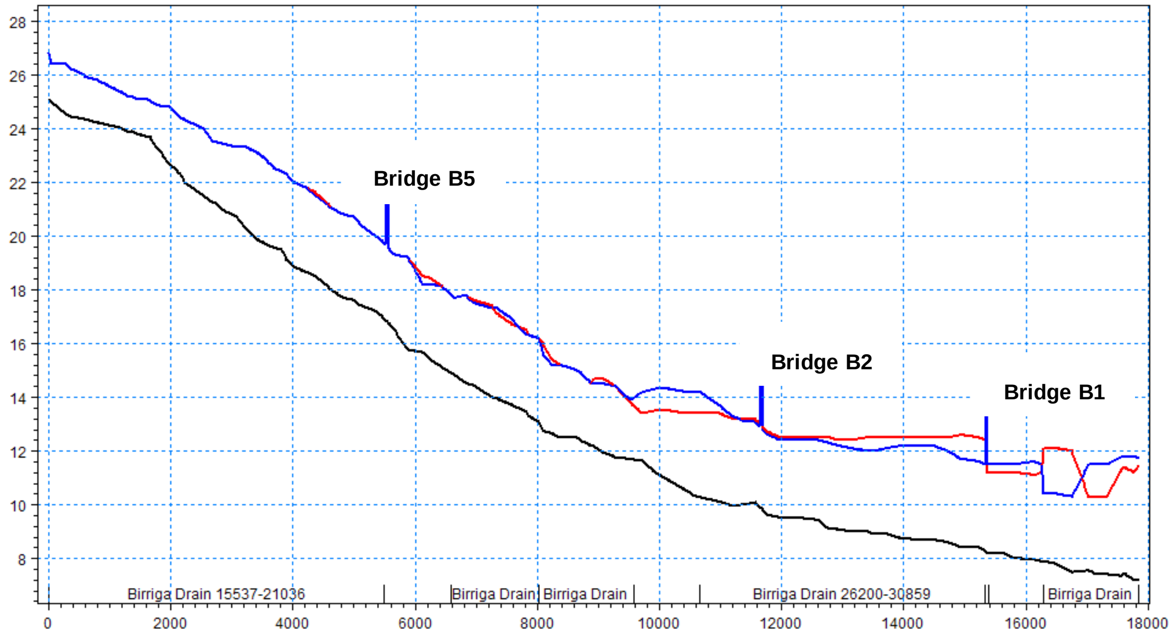


Figure 6-8: *Longitudinal section of the Birrega Drain. Red line denotes the left bank level, and the blue line denotes the right bank level.*

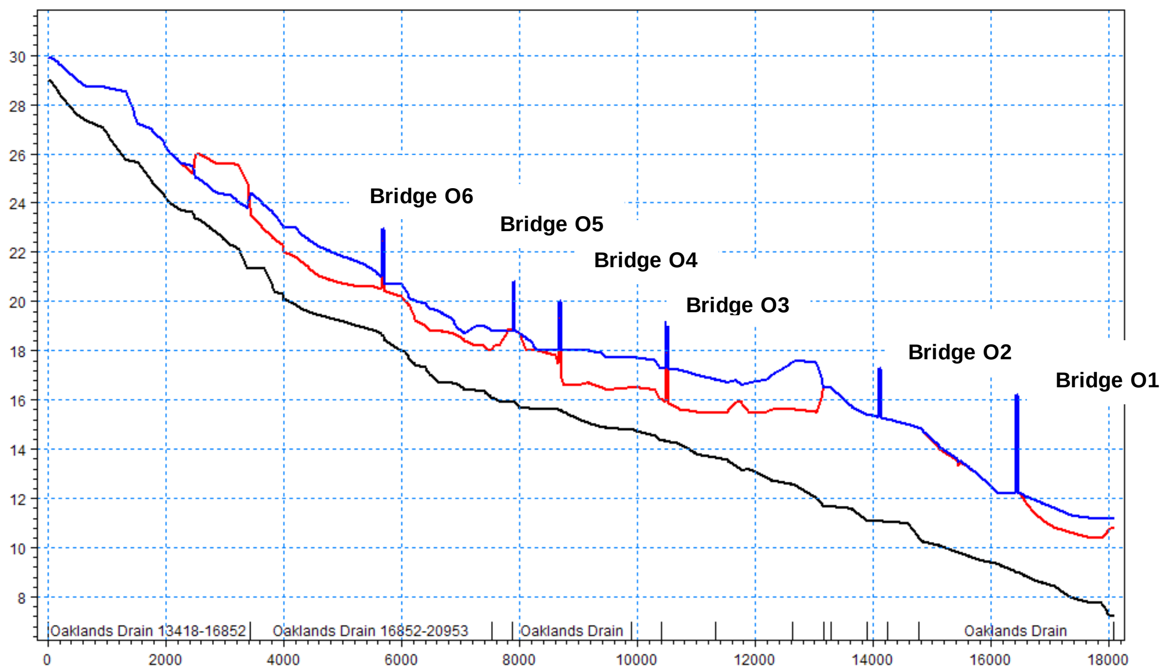


Figure 6-9: *Longitudinal section of Oaklands Drain upstream of the confluence with Birrega Drain. Red line denotes the left bank level, and the blue line denotes the right bank level.*

Initial conditions

An initial water level in the 1-D waterways was necessary to simulate baseflow conditions. The initial level was taken from the model 'hot-start' described in Section 6-4. The hot-start was simulated with 40 mm of rainfall in a nine hour period and then allowed to drain for a further three days (as described above). This storm was simulated using the rainfall pattern and magnitude from the event on 24 June 2011 at the Dog Hill rainfall gauging station (BoM Ref. 509295). The water depth in each of the main drainage channels at the end of the hot-start simulation used as the initial conditions in the calibration and design events is generally between 5 and 50 cm, and is shown in Figure 6-10 (Oaklands Drain) and Figure 6-11 (Birrega Drain).

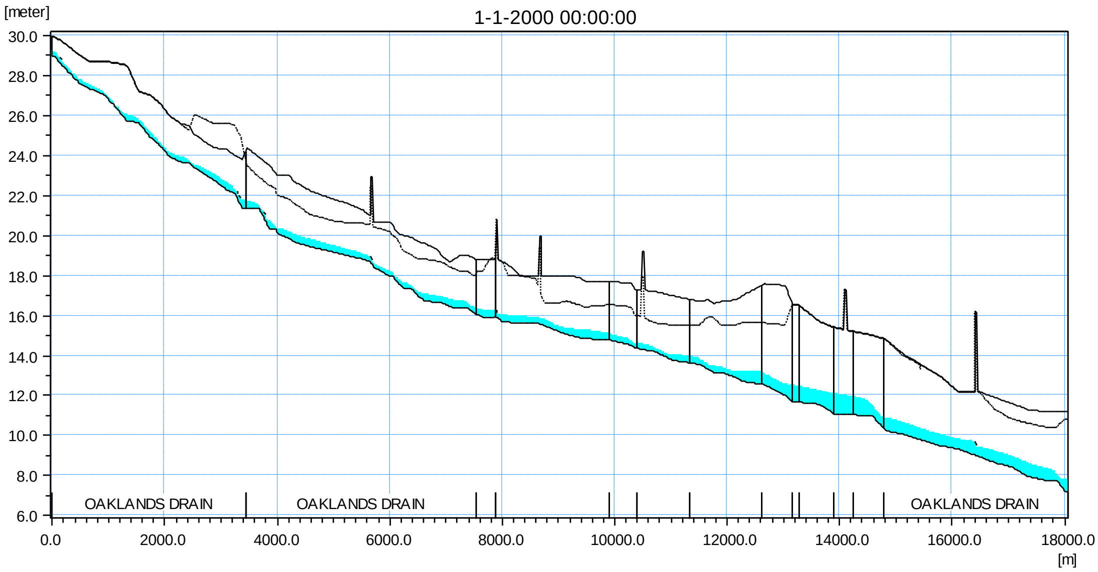


Figure 6-10: *Initial drain level for the Oaklands Drain*

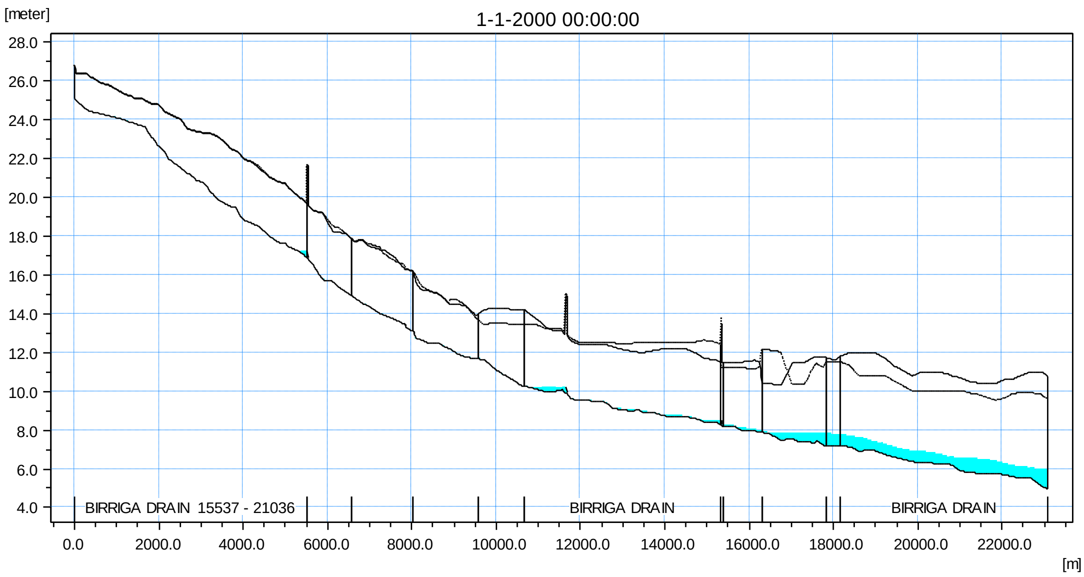


Figure 6-11: *Initial drain level for the Birrega Drain*

6.6 Model calibration

As mentioned in Section 6.4, model calibration is a necessary requirement when using the direct rainfall approach. This is because the direct rainfall approach is relatively new to the industry so the method has very little published research, and no guidance for the configuration of losses for uncalibrated models. Furthermore, there are limitations to the approach (such as the behaviour of very shallow flows with respect to Manning's values, and the effect that the grid size has on flow behaviour) which make each direct rainfall model unique, and therefore the requirement for calibration important. In undertaking a calibration the limited number of parameters to alter include:

- Roughness parameters (Manning's 'M' or 'n')
- Parameters associated with losses (Runoff coefficient for rainfall loss models, and infiltration/interception rates for 2-D loss models)
- Grid resolution.

Grid resolution was set at 20 m, and not altered in the calibration process. It was important that the same grid (size and configuration) was used for calibration, design and scenario simulations, as altering the grid size of direct rainfall models can affect the calibration results. There were two flow gauges installed within the Birrega area, which included a flow gauging station on the Birrega Drain downstream of the confluence with the Oaklands Drain (Mundijong Road, 616030) and a flow gauging station on the Oaklands Drain (Lightbody Road, 616029).

The Mundijong Road flow gauging station represented the flow at the downstream end of the modelling domain. The gauging stations were installed in 2010, and no significant flow events that could be used for model calibration were recorded in that year. In 2011 there was a series of independent rainfall events in June and July. The largest of these was on 28 July, when in an 8 hour period 40.2 mm of rainfall was recorded at the Byford gauge (9620) and 50.4 mm of rainfall at the Dog Hill gauge (9295). Although this was not a large flood event, it corresponded approximately to a 5 year ARI rainfall event, and was large enough to warrant calibration for modelling purposes.

This event corresponded to a maximum flow rate of 30 m^3/s at Mundijong Road (614130), and of 19 m^3/s at Lightbody Road (614129). For this particular event, the rainfall at Byford (9620) and the corresponding outflows at Mundijong Road (614130) and Lightbody Road (614129) gauging stations are shown in Figure 6-12. The rainfall loss method and 2-D loss methods described in Section 6.4 were trialled in the calibration process.

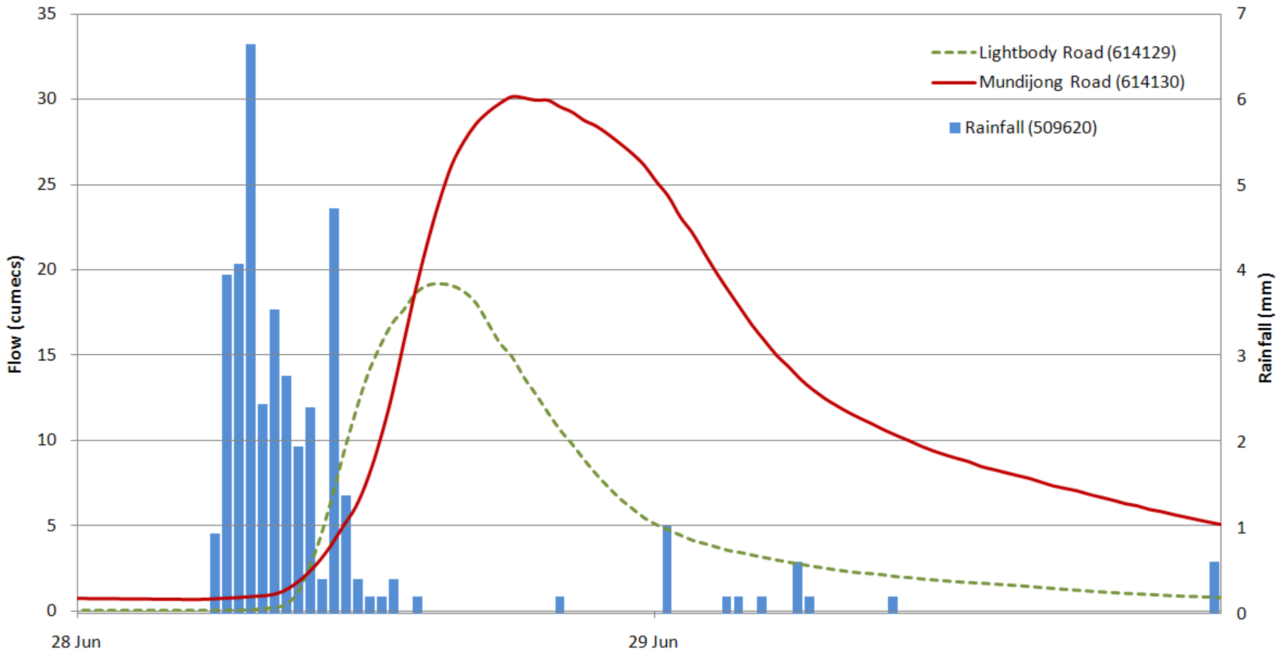


Figure 6-12: *Rainfall (for gauge 509620) and measured runoff at Lightbody Road (614129) and Mundijong Road (614130) for the rainfall event on 28 June 2011*

Rainfall loss method

The rainfall loss method applied losses by removing a portion of the rainfall applied to the model. As described in Section 6.4, the main advantage of this technique is that it lumps all loss processes into a single loss value, and negates the requirement of extra data necessary for 2-D or integrated groundwater loss techniques (e.g. spatial representation of groundwater data, soil data, vegetation data). A runoff coefficient of 0.24 was calculated for the calibration event – this figure was derived using the technique described in Section 5, assuming the foothill land use on the Swan Coastal Plain and a 5 year ARI rainfall event.

The results of this calibration are shown in Figure 6-13a. The calibration shows a poor correlation between observed and modelled flows at both flow gauging locations. The flow peak is underpredicted, the timing of the peak is overpredicted, and the total event volume is overpredicted at Lightbody Road (614129) and underpredicted at Mundijong Road (614130). It is evident that the rainfall loss model does not reflect catchment routing processes required to calibrate the model. There are various options to improve the calibration of the rainfall loss model, which include 1) adjusting the coefficient of runoff, or 2) by introducing a temporally varying rainfall loss. Increasing the coefficient of runoff is likely to eventually match the flow peak at one of the two rainfall gauges; however, this will generate a large error in the other flow gauging station, and large errors in the event volumes and timing of the peaks will remain.

Introducing a temporally varying rainfall loss model is likely to eventually improve the calibration though there is no justification (documentation or literature) for the changes required to the rainfall time series to match the flow events. It was therefore decided that the 2-D loss method would be applied to the Birrega model.

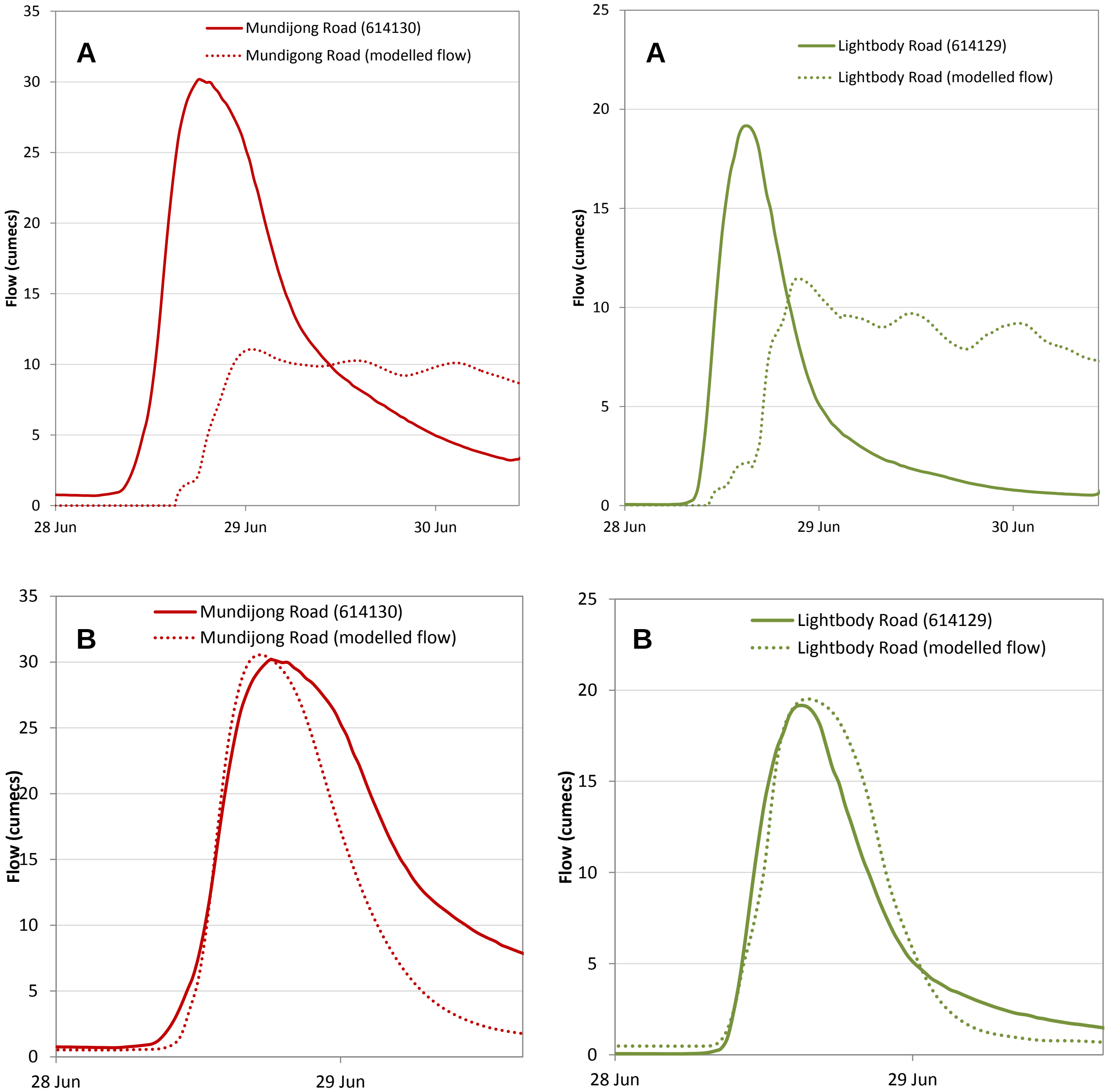


***Figure 6-13:** Results for the test calibration using a) the rainfall loss method and b) the 2-D loss method*

2-D loss method

2-D loss models remove water from the 2-D domain, rather than from the rainfall being applied to the 2-D domain. The main advantage of this model is that it can provide a better representation of the physical system and fully utilise the benefits of 2-D runoff routing, though it requires extra data and information, including spatial definition of parameters for infiltration, areas of groundwater inundation, and initial inundation values (Figures 6-2 to 6-5).

The rainfall loss method was calibrated by adjusting infiltration loss and parameters for the sandy soils and for the clayey soils within reasonable bounds until the flood hydrographs were matched as closely as possible.

The 2-D loss model showed a much better correlation between observed and modelled hydrographs, with the magnitude of the peak within 0.5 m^3/s at both locations (Figure 13b). The timing of the peak was also closely matched at both locations. The volume of the flood hydrograph was <1% of the observed volume at Lightbody Road but there was more event volume observed at the Mundijong Road location than was predicted by the flood model, which was confined to the falling limb of the hydrograph. This is likely to be due to groundwater, or baseflow, which is expressed in the observed data but is not replicated in the modelled data (as the MIKE FLOOD model has no method of simulating groundwater flow into channels). As the objective of the project focuses on peak flows, this was acceptable for the Birrega project.

Table 6-3 shows the calibration results for peak flow, total event volume and time to peak at Lightbody Road (614029) and Mundijong Road (614030) gauging stations for the rainfall loss model and 2-D loss model. Based on the results of the calibrations, the 2-D loss model was used to set-up all design simulations.

Table 6-3 *Calibration statistics for 2-D loss and rainfall loss methods*

Location	Series	Peak flow (m^3/s)	Volume (ML)	Time to peak (hrs)
2D loss model				
Lightbody Road	Observed	19.2	830	16.5
(614029)	Modelled	19.5	831	17.0
	Difference	*-1.8%*	*-0.2%*	*-3.0%*
Mundijong Road	Observed	30.2	2079	19.5
(614030)	Modelled	30.5	1542	18.5
	Difference	*-1.1%*	*25.8%*	*5.1%*
Rainfall loss model				
Lightbody Road	Observed	19.2	830	16.5
(614029)	Modelled	11.1	1026	23.0
	Difference	*42.1%*	*-23.7%*	*-39.4%*
Mundijong Road	Observed	30.2	2079	19.5
(614030)	Modelled	11.5	994	26.0
	Difference	*61.9%*	*52.2%*	*-33.3%*

6.7 Model validation

Water level information collected by the Shire of Serpentine Jarrahdale on behalf of the Water Corporation during the 1987 flood event was used to validate the Birrega Model. The event was simulated and peak water levels from the model were compared to measured peak water levels at key locations in the catchment (Figure 6-14).

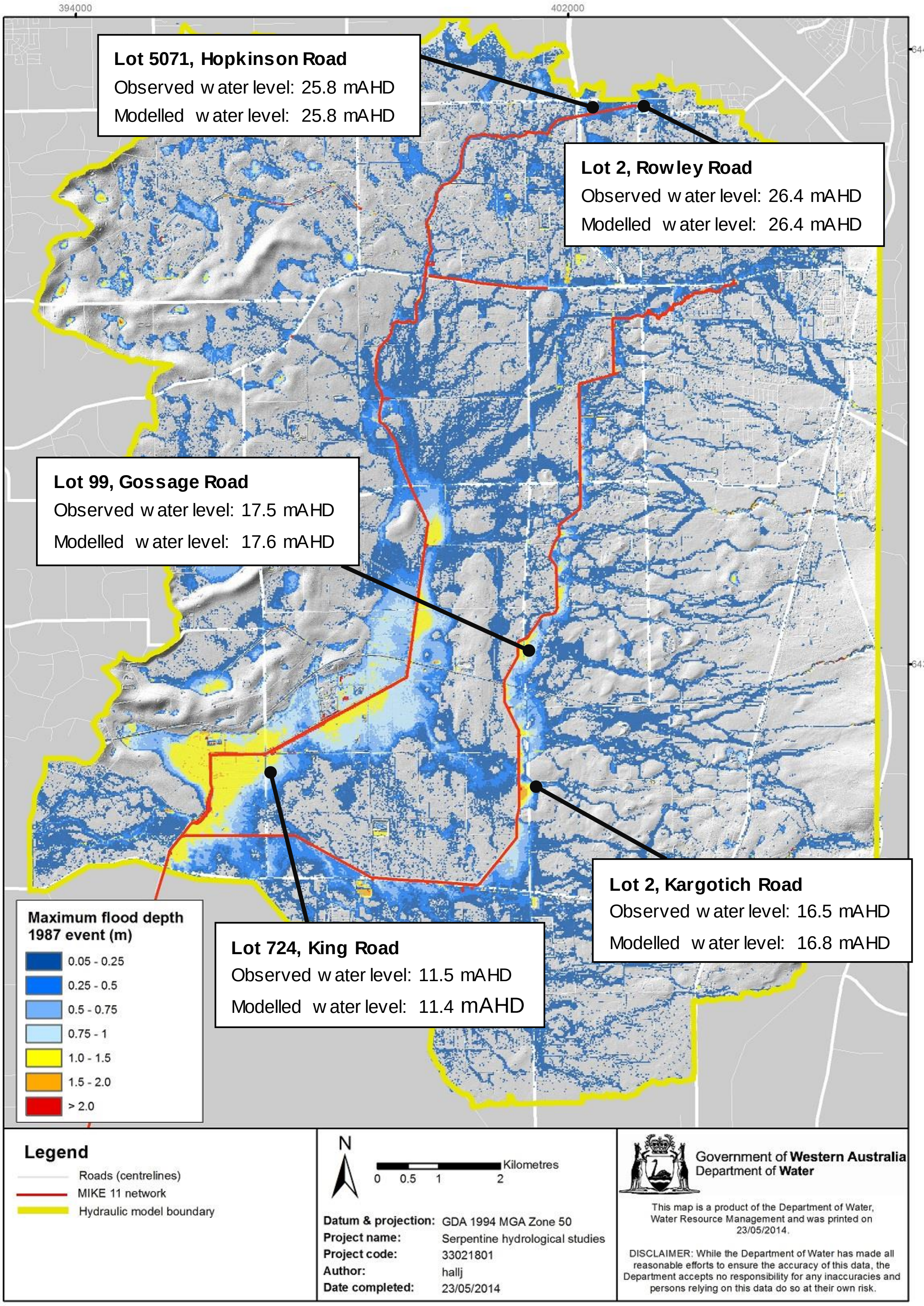


Figure 6-14: *Observed versus modelled water levels at key locations for the 1987 flood event*

The model peak water levels are similar to measured peak water levels. In four locations (Lot 724 King Road, Lot 99 Gossage Road and Lot 5071 Hopkinson Road, and Lot 2 Rowley Road) the water levels match to within 0.1 m. At the other locations(Lot 2 Kargotich Road) the model over predicted by 0.3 m. This is likely to be due to the failure of the Oaklands Levee Bank during the 1987 flood event. The failure occurred during the event adjacent to Scott Road and resulted in significant loss in bank height (D Gossage, pers. comm.). This would result in observed water levels being lower than modelled water levels, as the model did not account for this levee failure for the 1987 event.

The model predicted the overtopping of the Oaklands Levee at the observed locations, and the overtopping of the Birrega Drain at Duck Pond. The model results were checked by Dave Gossage of the Shire of Serpentine Jarrahdale (the emergency response officer at the time of the 1987 flood event), who was satisfied that the model's flood extent and depth accurately depicted the conditions during this event (D Gossage, pers. comm.).

The results of the model validation provide a greater level of confidence in the model's performance at accurately predicting the flood depth and extent of large flood events (50 to 100 year ARI).

6.8 Sensitivity analysis

Sensitivity testing of inputs and parameter values provides an understanding and resolves the importance of the input/parameter on the model result. The Birrega model calibration is satisfactory (see Sections 6-6 and 6-7), so there is some confidence in the model's ability to reproduce accurate flood levels and flows. The 2-D modelling guidelines (Engineers Australia 2013) recommend that, when using the direct rainfall method, sensitivity testing should specifically include losses, model roughness and variations in inputs.

The Birrega model was not solely driven by direct rainfall as it had inflows from catchments upstream of the Darling escarpment, therefore sensitivity to rainfall and to inflows was explored and compared. A 20% increase and decrease in inflows and in rainfall was modelled to explore input sensitivity analysis. Model losses are related to infiltration and inundation, and a sensitivity analysis was undertaken for both of these parameters. For infiltration, the soil parameters were increased and decreased by 20%. For inundation sensitivity, the model was simulated using no inundation (summer conditions), and average September inundation (peak groundwater conditions). Manning's values for high and low sensitivity were taken from Chow (1959). Table 6.4 displays the parameters that were used for the sensitivity analysis, in both high and low sensitivity set-up. All sensitivity analyses were simulated for a 100 year ARI, 12 hour design flood event.

Results of the sensitivity analysis were compared at two locations within the model to represent two spatial scales. They were compared at the outlet of the catchment (Birrega Drain at Mundijong Road), which has a total contributing area of 240 km^2, and for a 6 km^2 catchment within the Swan Coastal Plain (Figure 6-16). This subcatchment on the Swan Coastal Plain receives no inflows from the escarpment, and is not influenced by the hydrograph inflows. The results of the sensitivity analysis are shown in Figures 6-17 and 6-18.

Table 6-4 *Set-up parameters for sensitivity analysis*

	Used in model		Sensitivity - HIGH		Sensitivity - LOW	
Roughness sensitivity	Mannings		Mannings		Mannings	
Land use	n	M	n	M	n	M
Road reserve	0.022	45.0	0.02	62.5	0.024	41.7
Urban	0.059	17.0	0.08	13.3	0.150	14.3
Rural living	0.038	26.0	0.03	40.0	0.045	22.2
Cleared	0.045	22.0	0.03	40.0	0.050	20.0
Native vegetation	0.059	17.0	0.04	28.6	0.070	14.3
Channels (n)	0.048	20.8	0.04	25.0	0.055	18.2
Inundation sensitivity	Inundation (%)		Inundation (%)		Inundation (%)	
Inundation surface	Average June		Average September		None	
% of active cells inundat	6.55%		7.80%		0.43%	
Infiltration sensitivity	Infiltration rate		Infiltration rate		Infiltration rate	
Soil type	mm/day		mm/day		mm/day	
Clay	5		6		4	
Sand	70		84		56	
Water	0		0		0	
Inflow sensitivity	Inflows m^3/s		Inflows m^3/s		Inflows m^3/s	
Darling scarp inflows (9 source locations)	From hydrology studies		+20%		-20%	
Rainfall sensitivity	Event rainfall (12hr)		Event rainfall (12hr)		Event rainfall (12hr)	
	10yr ARI	100yr ARI	10yr ARI	100yr ARI	10yr ARI	100yr ARI
Rainfall sensitivity	62	98	74	118	50	78

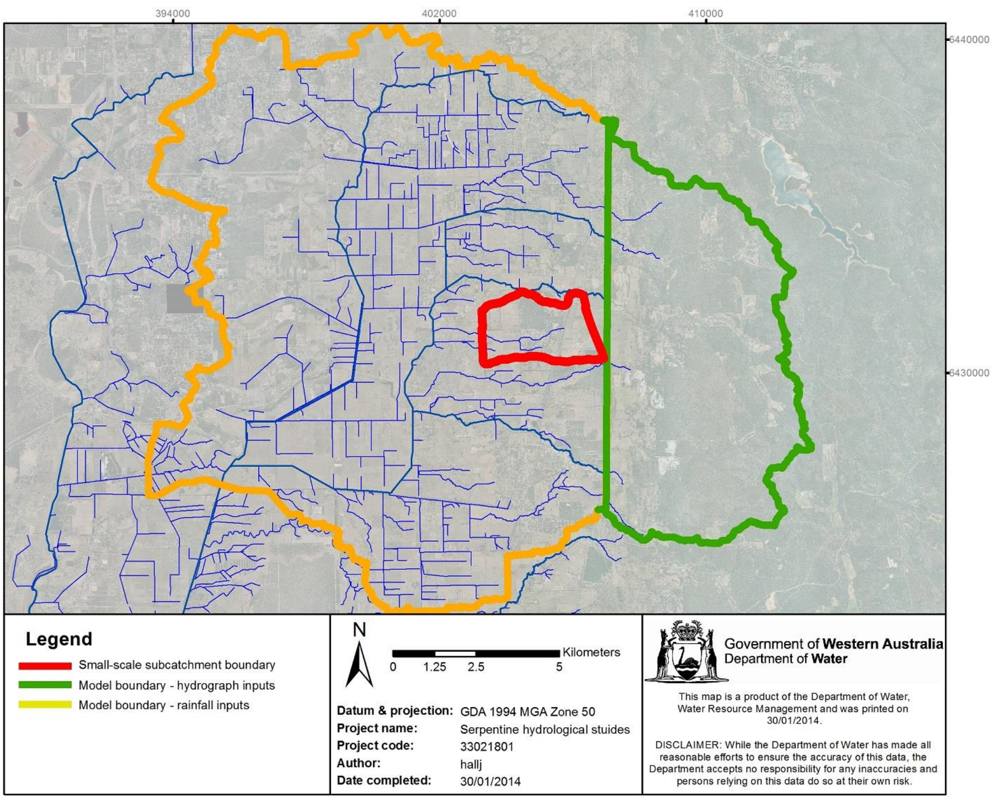


Figure 6-16: *Small-scale and large-scale catchments used in the sensitivity analysis*

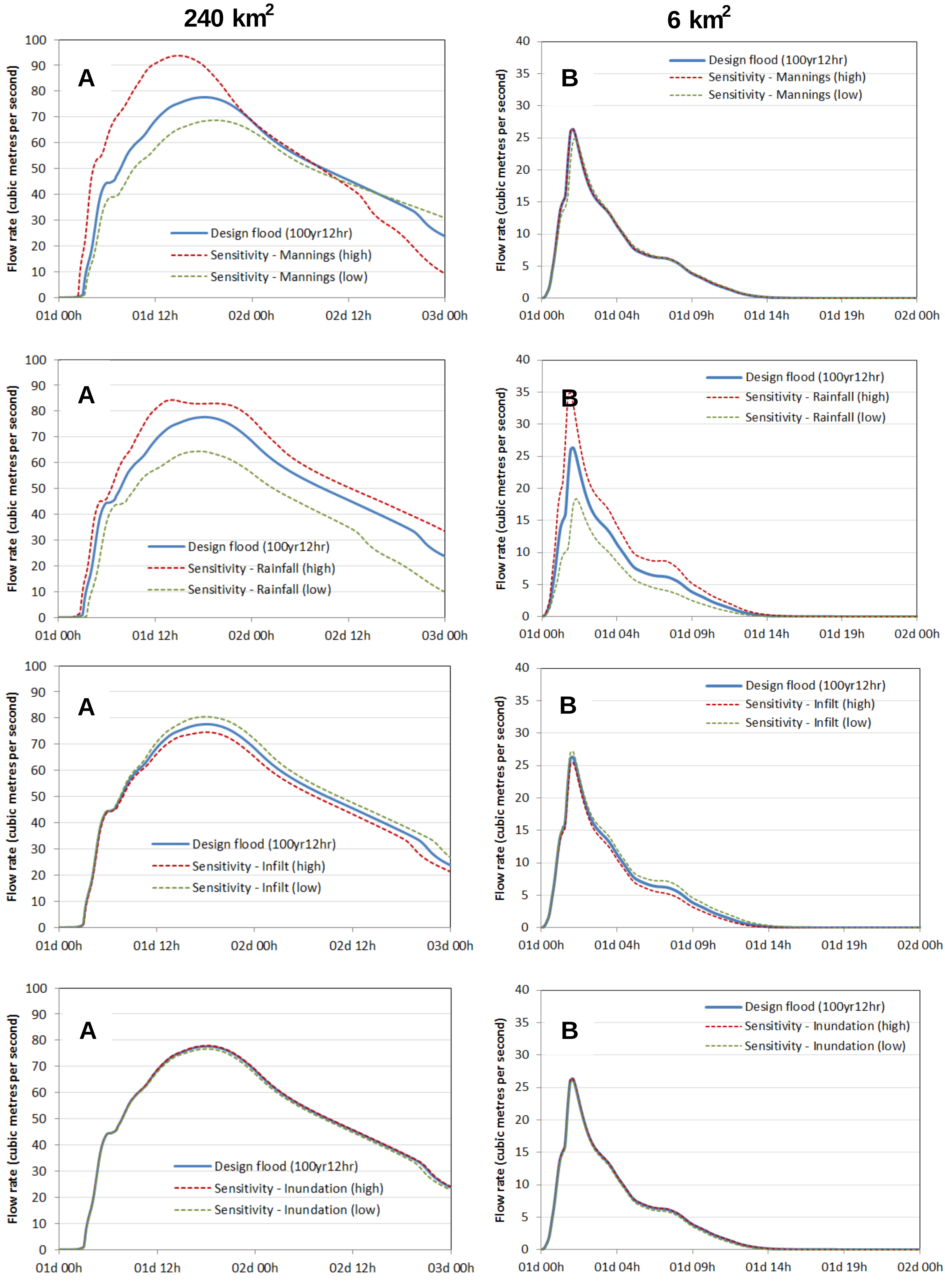


***Figure 6-17:** Sensitivity analysis results for a) large-scale, and b) small-scale catchment flooding for a 100 year 12 hr design flood event*

At the large scale, the model is most sensitive to Manning's roughness and rainfall. At the small scale the model is most sensitivity to rainfall but not sensitive to Manning's roughness. The model is much more sensitive to channel roughness than overland roughness. The overland Manning's parameter receives quite a lot of attention in direct rainfall modelling, as Manning's is depth dependent, and the very shallow depths generated using the direct rainfall technique result in Manning's parameters outside of the typical range used within the model. It is often recommended that depth-dependent Manning's parameters are used in direct rainfall modelling (Engineers Australia 2012). As the model was relatively insensitive to overland Manning's, a depth-dependent overland Manning's option was not explored further in this project. The model is less sensitive to soil infiltration, and relatively insensitive to inundation.

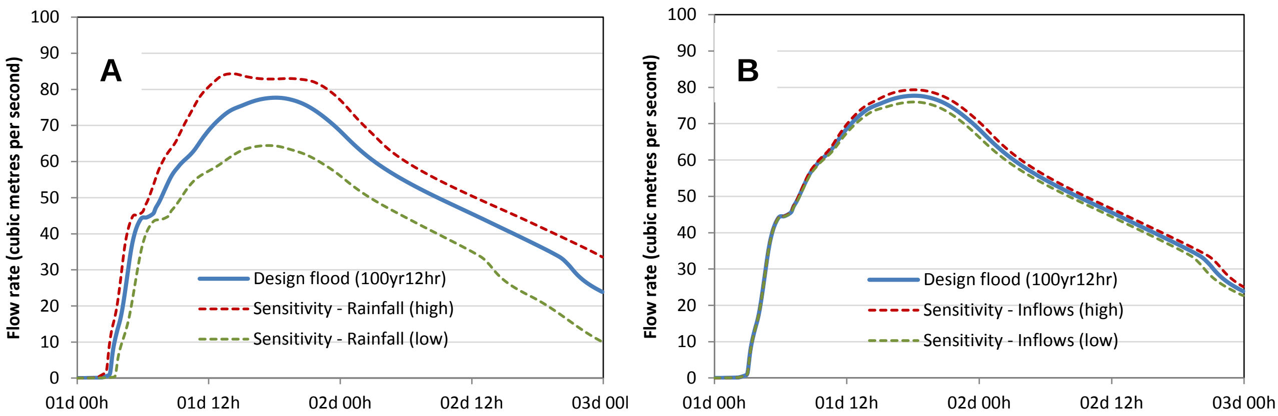


***Figure 6-18:** Input sensitivity analysis for a) rainfall inputs, and b) hydrograph inflows*

Figure 6-18 shows the input sensitivity and compares the sensitivity of hydrograph inflows to direct rainfall inputs at the outlet of the model. The model is much more sensitive to rainfall, which is not surprising given that most of the catchment area is driven by rainfall inputs.

It should be noted that, although sensitivity is explored at two locations and catchment scales, the model sensitivity relative to the different parameters and inputs will be likely to be dependent on a number of factors, including catchment size, the location of the point of interest, and flood event size and duration. Further exploration of site-specific sensitivity is recommended for studies concerning a particular subregion within the model domain.

6.9 Comparison to traditional hydrograph techniques

The direct rainfall method was compared to a traditional hydrological modelling method for the 100 year ARI, 24 hr duration flood event. A RORB model was developed consisting of 9 catchment nodes, 5 junction nodes and 14 links for a 7 km^2 subcatchment within the 2-D model domain. A subcatchment that was not influenced by hydrograph inflows, flood storages or regulating structures was selected. Comparisons of the results of the traditional hydrological model and the 2-D direct rainfall model show a very good fit for the shape, volume of the hydrograph, as well as the magnitude and timing of the peak flow (Figure 6-

19). The runoff coefficient of 0.45 used in the RORB model was recommended in a regionalisation study for the Swan Coastal Plain (Pearce 2006; 2011), and the K_c value was derived through calibration. A K_c value of 1.2 is similar to those used in flood studies for 7 km^2 catchments in adjacent escarpment studies on the Swan Coastal Plain (SKM 2010), and is considered appropriate for this subcatchment of this area. This process provides greater confidence in using the direct rainfall approach on events of magnitudes larger than the calibration events. It shows that the hydrographs produced by the direct rainfall technique are similar to those that would be derived if a traditional hydrograph-based approach was used.

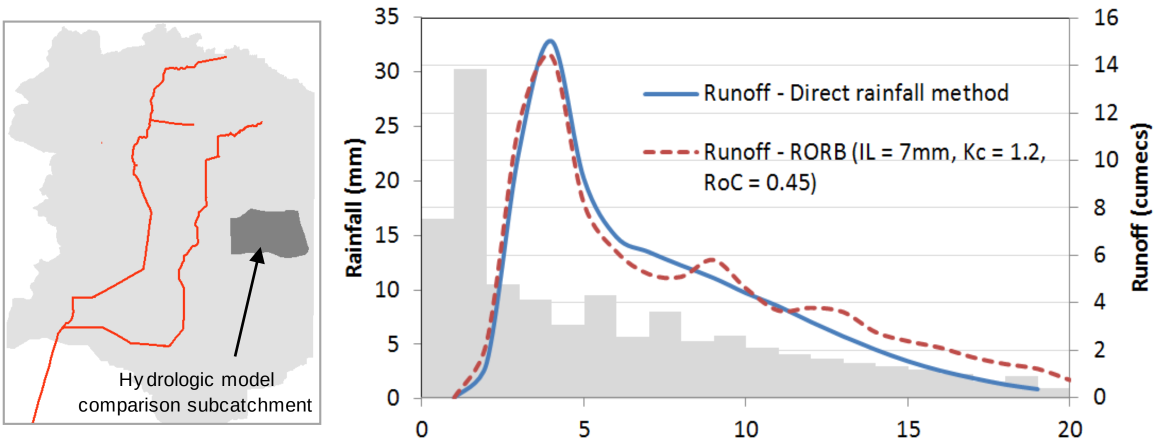


Figure 6-19: *Direct rainfall comparison to traditional hydrology technique (RORB)*

6.10 Mass balance

A mass balance was performed on a selection of model runs of various event sizes and durations. In all cases, the relative mass balance error was within 1%, which is suitable for hydraulic flood models (a threshold of 5% is recommended by Engineers Australia (Engineers Australia 2012)).

Table 6-5 shows the mass balance for all components of the model for the 100 year ARI 24 hr design flood event. The mass balance error, or the result of the continuity balance, is the sum of the outflow minus the sum of the inflows minus the storage change in the model. A continuity balance of zero means that there is no numerical mass balance error in the model. In the example shown in Table 6-5, the continuity balance is 3805 kL, which corresponds to 0.02% of the total model inputs, and is well within the range of the recommended threshold.

***Table 6-5** Mass balance results for the 100 year ARI 24 hr design flood event*

Component	Total volume	units
A: Initial volume in model area	**280**	ML
B: Final volume in model area	**5396**	ML
MIKE 11 inflow	6667	ML
Inflow sources	2157	ML
Open boundaries inflow	27	ML
Hydrology processes (rainfall and infiltration)	11754	ML
Water level correction	737	ML
C: Total inflow	**21342**	ML
MIKE 11 outflow	15587	ML
Outflow sinks	0	ML
Open boundaries outflow	636	ML
D: Total outflow	**16223**	ML
E: Continuity balance = Out - In = (B+D) - (A+C)	**-4**	ML
Relative defecit (water balance error)	**-0.02%**	**%**

6.11 Model limitations and recommendations

The application of the model should be constrained by the limitations inherent in the modelling process. The calibration of a flood model does not ensure that it will accurately represent flood depth, extent and flows at all locations within the hydraulic model domain. The Birrega model is a regional model with a spatial resolution of 20 m. Model results interpreted at smaller scales (i.e. subdivision or lot scales) will have some inherent structural limitations that users need to be aware of. These include:

- **Grid resampling issues:** These can result in underestimating road elevations, generally in the order of 0.1–0.3 m, and can cause water to overtop roads at modelled elevations lower than what would actually occur. Some major roads were 'stamped' into the grid – that is, the grid was manually modified to reflect the actual level of the road's centreline to avoid this issue though many minor roads within the modelling domain were not modified. Grid resampling can also remove small-scale flow paths. This is generally not a major issue in large flood events (as the small-scale flow paths are generally inundated) but it can result in overestimating floodplain storage, and underestimating the flood recession.

- **Road culverts were not explicitly modelled in many locations**. This can cause an overestimated flood extent upstream of some roads in some parts of the model. To partially overcome this issue, major bridges and culverts in the Birrega and Oaklands drains were modelled explicitly, and where there were significant culverts or bridges on roads outside the Birrega and Oaklands drain's the DEM was generally modified to allow the transfer of water from one side of a road to another (however, in these cases, conveyances may be over predicted due to the 20 m grid). In the Birrega catchment, many of the small culverts (< 400 mm) are blocked, and it is likely that many more will block in a flood event. It is impossible to know which will remain free-flowing during a large flood event. The assumption inherent in the modelling process is that all minor road culverts block at the start of the flood event (a common assumption in many 2-D modelling projects).

It was not practical to explicitly model all road culverts within the Birrega domain (there are hundreds) or to stamp all minor roads into the grid. Unfortunately, it is difficult to quantify the extent of the errors caused by these model simplifications. To partially overcome this issue David Gossage from the Shire of Serpentine Jarrahdale verified the flood extent for the 1987 event (see Section 6-7). It is recommended that proponents looking to undertake finer-scaled flood modelling within the Birrega Domain contact the Shire of Serpentine Jarrahdale to discuss historical flooding for their sites and surrounding lands.

The direct rainfall approach is relatively new to the industry and is sometimes treated with suspicion. To overcome this a series of detailed quality assurance processes were performed, including detailed model calibration, validation, sensitivity analysis, comparison to traditional hydrograph techniques and a mass balance check. This process was recommended in the recently published 2-D modelling guidelines (Engineers Australia 2012). A review of the hydrology was undertaken by Leanne Pearce of the Water Corporation, and a detailed peer review of the hydraulic model was undertaken by DHI. The model was found to be fit for purpose.

The floodplain mapping is suitable to be viewed at a scale of 1:5000. If a higher resolution is required, a more detailed flood study is recommended. As a result of the structural limitations of the Birrega flood model, the results are likely to be unsuitable for calculating:

- detailed flood extent, depth and storage at a lot scale
- detailed flows through roads (culverts) at a lot scale.

If lot-scale results are required by development proponents or other stakeholders, it is recommended that the Birrega model be used to assist finer grid-scale modelling where development is planned.

7 Model results

Design floods were simulated using the hydraulic model for the 5, 10, 20, 100 and 500 year ARI events, for durations of 6, 12, 24, 36, 48 and 72 hr. An additional 100 year ARI 'levee fail' (LF) scenario was simulated for all durations, assuming that the western bank along the Oaklands Main Drain and both banks along the Birrega Main Drain were absent.

Model results are presented in this section in several forms, which include:

- **Flood extent mapping:** Simulated maximum levels and flood extent for the 5, 10, 20, 100 and 500 year ARI events are presented in Appendix F.
- **Detailed floodplain mapping:** Detailed mapping of simulated maximum levels and flood extent based on the combined maximum of the 100 year and 100 year LF scenarios is provided on request by the Department of Water.
- **Main drain long-sections:** Long-sections illustrating peak flood levels and discharge for the Oaklands Main Drain and sections of the Birrega Main Drain are described in Section 7.3 and are provided in Appendix G.

Results are reported for the entire hydraulic model domain. Note that some locations within the Byford region have been developed and drainage works undertaken since the model's topographic LiDAR dataset was flown, and as such any flooding reported in this area should be disregarded.

7.1 Flood extent mapping

Floodplain extent and critical duration were calculated for each of the design events. The flood extents for the 5, 10, 20, 100, 100 levee fail and 500 year ARI events are shown in Appendix F. They represent the model results of the maximum levels for the combined 6, 12, 24, 36, 48 and 72 hour events. The results are taken directly from the model outputs and are displayed at a 20 m grid. No further interpolation or smoothing of the results for the flood extent mapping has been done as part of this project (other than for the 100 year ARI event for the detailed floodplain mapping).

7.2 Detailed floodplain mapping

Detailed floodplain mapping was prepared for the 100 year ARI event, using a combination of the maximum modelled flood levels for all duration events, including levee failure scenarios.

Methodology

Floodplain mapping involved post-processing a combination of MIKE 21 results to a single spatial dataset. A total of 12 design runs were used to develop a composite maximum flood level based on a combination of six event durations, the levee fail scenario, and the standard 100 year event. The maximum flood level modelled for each grid cell was calculated from the gridded MIKE 21 results files and the maximum of these grids was calculated to work out an overall maximum flood depth. Note that this does not give a flood level for a given point in time but rather the maximum potential flood level for a given location for the 100 year event.

The grid was converted to a water level surface, resampled to 1 m grid, and subtracted from the LiDAR to produce an indicative flood depth at a 1 m grid. The floodplain extent was then mapped manually at a scale of 1:2500 by tracing inundated areas. A maximum depth threshold of 0.05 m was used to eliminate very shallow areas of flooding. Small disconnected areas of ponding (< 1000 m^2) were not included in the floodplain mapping. However, larger disconnected areas were included as a separate category 'ponded areas'. These areas do not convey flow through the study area but, in some cases, accumulate large volumes of water.

Flood level contours were derived using the same gridded results datasets. Flood contours were generated in ArcGIS and manually edited for consistency and readability. Final floodplain mapping was formatted and quality controlled by GIS technicians. The datasets were used to produce a series of A1 maps at 1:5000 scale covering the study area.

An overview of the floodplain mapping for the 100 year event is shown in Figure 7-1, and detailed floodplain mapping is provided by the Department of Water on request. Note that the mapping did not extend to the west of the Birrega Main Drain, as this mapping was undertaken as part of the north-east Baldivis flood modelling exercise (Marillier 2014).

7.3 Main drain long-sections

Long-sections of the Oaklands Main Drain and Birrega Main Drain were developed using results from MIKE 11 (Appendix G). Results were extracted from all design runs, and the maximum discharge and stage were determined for each Q and H point within the channel network. Note that the levee failure scenarios were not used in the development of long-section diagrams.

The long-sections provide results at key locations along the main drains and show channel geometry. The left and right bank geometries are shown in more detail to illustrate the discharge/inflow points along the main channels. Where the design peak stage is above a bank's height, the water may discharge from the main channel to the surrounding floodplain, depending on the relative flood levels. The main channels also receive inflows from the floodplain where there are low points in the levee bank.

The long-section for **Oaklands Main Drain** shows the following:

- The Oaklands Main Drain is predicted to overtop between Malarkey Road and Kardan Road in the 5, 10, 20, 100 and 500 year events. The drain has only a small capacity in this region.

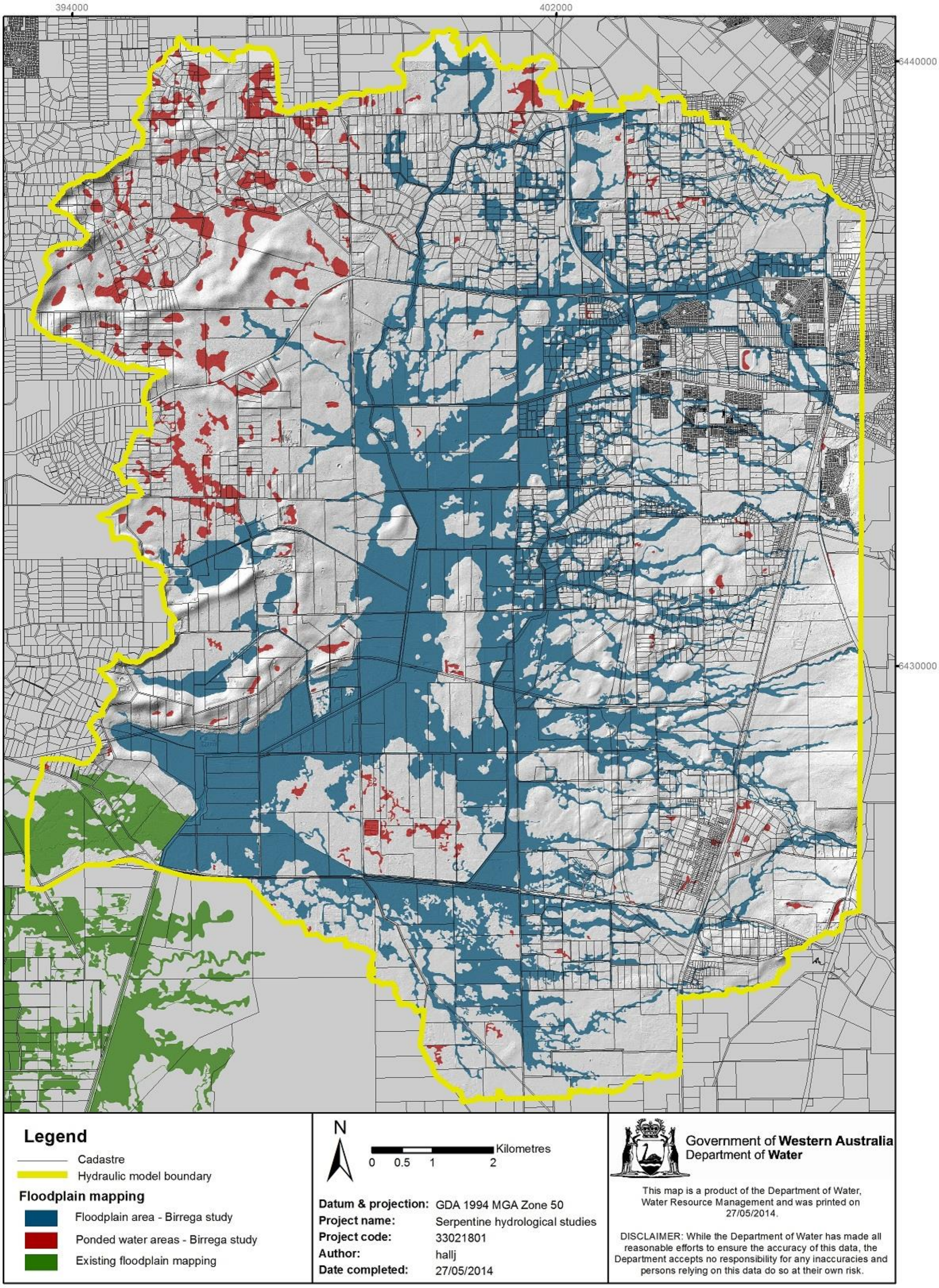


Figure 7-1: *Detailed 100 year ARI floodplain mapping and ponded areas*

- The drain is not predicted to overtop between Kardan Road and Hopkinson Road.
- Between Abernethy Road and Mundijong Road, the drain has a right bank that is significantly higher than the left bank. The left bank is predicted to overtop during all modelled flood events in this reach. The right bank will overtop at discrete locations for the 100 year and 500 year events including Orton Road, in line with Scott Road and upstream of King Road, and between Orton Road and Gossage Road in the 20 year ARI event.

The long-section for the **Birrega Main Drain** shows the following:

- The 900 mm culvert at Hopkinson Road is at capacity in the 50–100 year ARI events, and significantly limits the downstream flow.
- The Birrega Main Drain is not predicted to overtop in the 5, 10 and 20 year ARI events between Hopkinson and Thomas Road.
- The drain overtops at Tonkin Highway but is not predicted to overtop between Kargotich and Thomas roads in the 100 and 500 year ARI events, and is predicted to overtop Thomas Road only in the 500 year event.
- The Birrega Main Drain overtops at various locations between Thomas Road and Mundijong Road in the 100 and 500 year events. The drain is predicted to breach at Duck Pond (chainage approx. 17500 m) in the 50 year, 100 year and 500 year events. This will cause overflow to the North East Baldivis catchment.

Peak discharge from the lower end of the Birrega Main Drain was modelled as 81.9 m^3/s in the 100 year event.

7.4 Considerations for drainage design within the study area

The outcomes of this flood modelling completed for this study highlight several considerations when planning drainage design and urban development within this area. Although this modelling does not attempt to make prescriptive statements about drainage design or urban development, it aims to identify major flood hazards, and potential issues associated with urban development. It is recommended that any development or drainage design on the western side of the Oaklands Main Drain within the study area considers the following:

- **The potential for failure of the levee banks on the Birrega and Serpentine Main Drains**: This study indicates that levee overtopping is possible in large (>50 year ARI events), and with areas of levee failure possible before overtopping (the levee banks are not maintained and so are in poor condition in many locations). Therefore all developments west of Oaklands Main Drain or adjacent to the Birrega Main Drain downstream of Orton Road should be considered at risk of levee failure during large flood events.

- **The capacity of Birrega and Oaklands Main Drains to convey drainage water without influencing downstream landholders**: The regular breaks and lateral culverts in the drains mean that additional discharge to the drain upstream could result in increased downstream flooding.

- **The importance of floodplain storage**: The Birrega and Oaklands catchments contain large areas of floodplain storage which help mitigate peak flood flows and total flood volumes. Consideration of the floodplain storage should be taken into account in the development process – as reducing or eliminating these storage areas will probably result in additional discharge to the main drains, which in turn could result in more extensive downstream flooding or levee bank overtopping.

Although none of these considerations prohibit development within the study area, they may require that more land is set aside for storage and retention of flood water compared with areas with more capacity for infiltration, less floodplain storage or steeper hydraulic gradients.

8 Conclusions

A flood model was developed for the Birrega Drain catchment north of Mundijong Road to help develop the Serpentine Drainage and Water Management Plan. The catchment area is approximately 240 km^2, but the study area was confined to the Swan Coastal Plain (approximately 185 km^2). The model used hydrograph inputs for the areas east of the Darling escarpment and direct rainfall as inputs to the hydraulic model domain. The rainfall runoff model RORB was used to develop the inflow hydrographs, and validated regional parameters were used to develop the RORB models.

An integrated 1-D 2-D hydraulic model was constructed using DHI's software package MIKE FLOOD. 2-D modelling was used to model the floodplain areas and to rout the flows resulting from the direct rainfall inputs, and the 1-D modelling was used to accurately depict flows in the Birrega and Oaklands Main Drains (including explicitly modelling a series of culverts and bridges). The direct rainfall technique was suited to the project, as the study area is very flat and traversed by drains of various sizes where cross catchment flows are common. As the direct rainfall technique is relatively new to the industry, a series of techniques for model quality assurance was undertaken including: model calibration, validation, sensitivity analysis, and comparison to traditional hydrograph modelling techniques (in accordance with the Engineers Australia 2-D Modelling Guidelines). The model was successfully calibrated to a 2011 flood event (approximately 5–10 year ARI) at two gauging locations, and peak levels were within 2% of one another at both locations. The model was validated using flood levels measured during the 1987 flood event (50–100 year ARI).

This flood study assessed the pre-development site conditions. Design rainfall events were simulated using the model for flows for the 5, 10, 20, 100, and 500 year average recurrence interval (ARI) events, for durations of 6, 12, 24, 36, 48 and 72 hours. A levee failure scenario was simulated for the 100 year design events, assuming that the western levee banks on the Birrega and Serpentine Main Drains were removed. The outputs of the study include flood extent mapping, detailed 100 year floodplain mapping, and long-sections of the Peel, Serpentine and Birrega Main Drains.

The hydraulic model construction and calibration was reviewed by DHI, the hydrologic inputs and rainfall IFD reviewed by Water Corporation, and the results for the model reviewed by Water Corporation and the Shire of Serpentine Jarrahdale. All parties were satisfied that the model was fit-for-purpose.

Modelling indicated that widespread shallow inundation would occur over much of the study area in a 100 year ARI event. The most extensive inundation was located adjacent to the Birrega Main Drain and east of the Oaklands Main Drain where the hydraulic capacity and grade of the drains limit discharge from the catchment. Flow velocities within the study area were generally very low. The Birrega Main Drain is predicted to overtop in the 50, 100 and 500 year events at Duck Pond (north of Mundijong Road), and flow toward the Peel Main Drain through North-East Baldivis.

Several important considerations may affect the suitability of the Birrega and Oaklands area for urban and industrial development. These do not prohibit development but are likely to influence the feasibility of development from a technical and financial perspective. It is recommended that future drainage design within the study area considers the following:

- the potential for failure of the Birrega and Oaklands levee banks
- the capacity of the main drains to convey drainage water without influencing downstream landholders
- the importance of pre-development floodplain storage in reducing flood peaks and volumes.

The results presented in this study should be used to inform future development and drainage design within the study area.

Appendix A - Flood frequency analysis plots

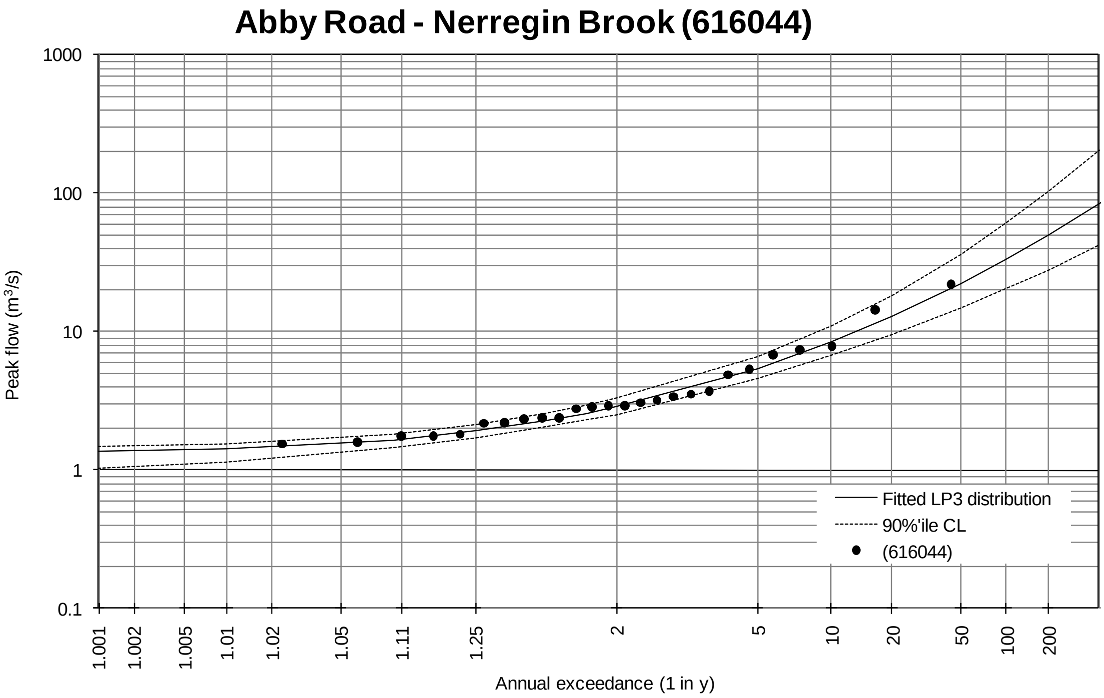


Figure A-1: *Flood frequency analysis for Abby Road, Nerregin Brook (616044)*

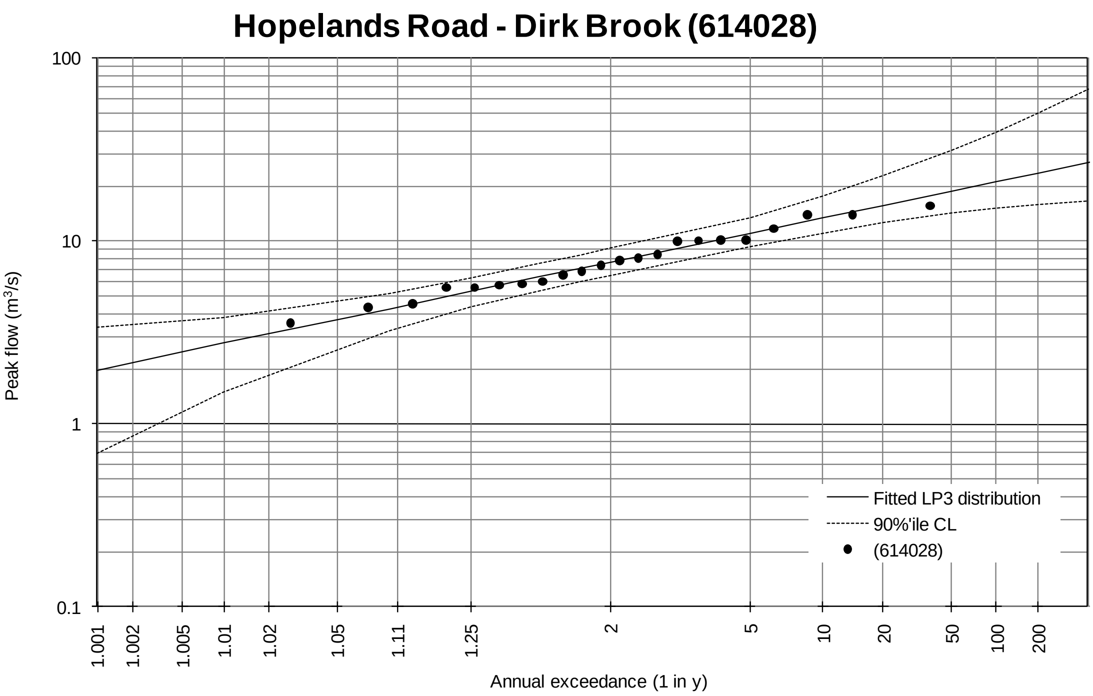


Figure A-2: *Flood frequency analysis for Hopelands Road, Dirk Brook (614028)*

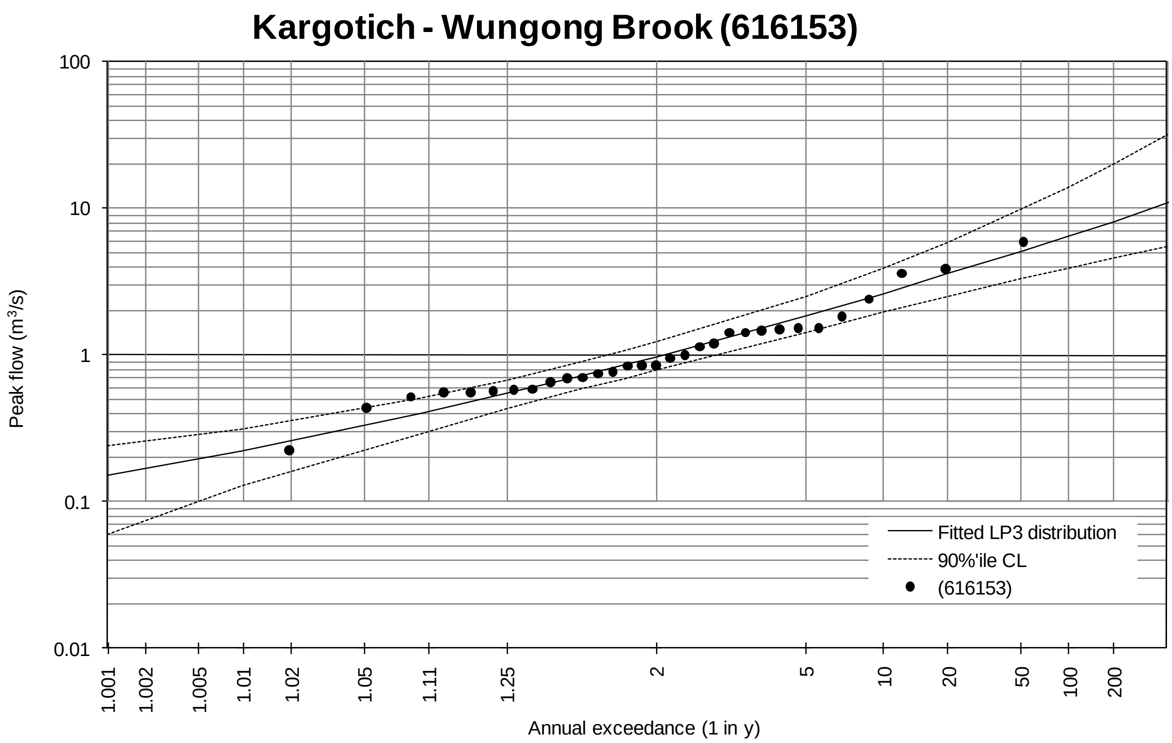


Figure A-3: *Flood frequency analysis for Kargotich, Wungong Brook (616153)*

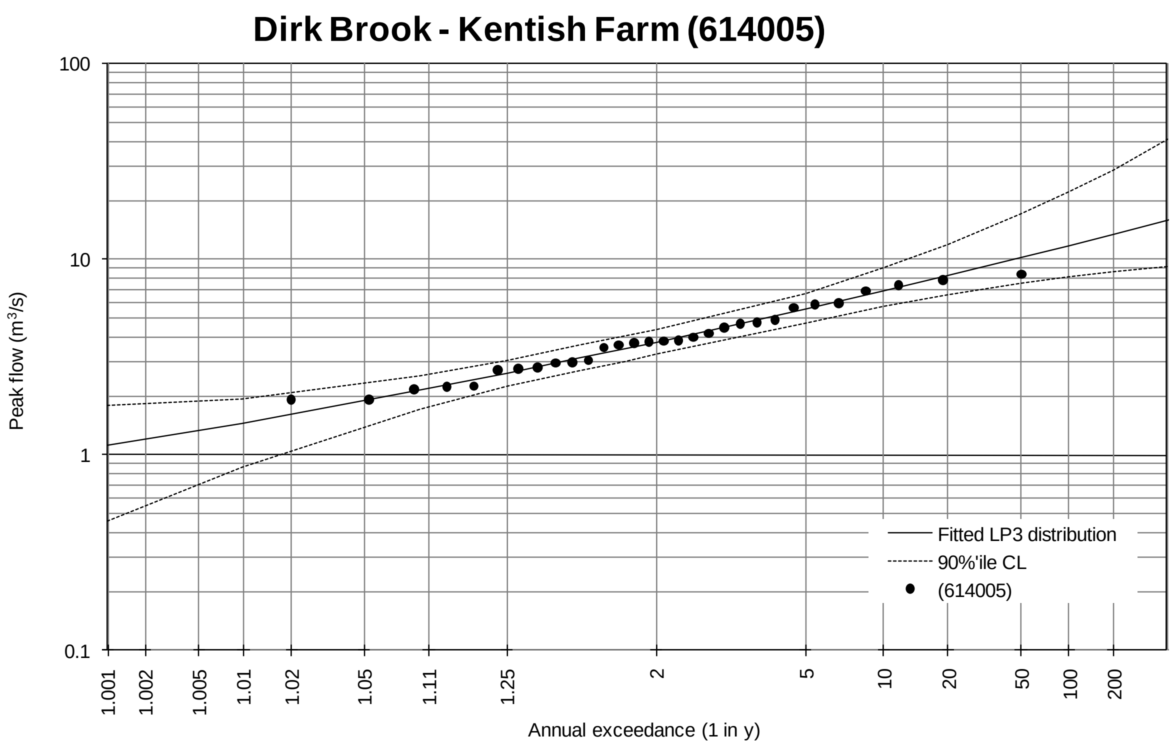


Figure A-4: *Flood frequency analysis for Kentish Farm, Dirk Brook (614005)*

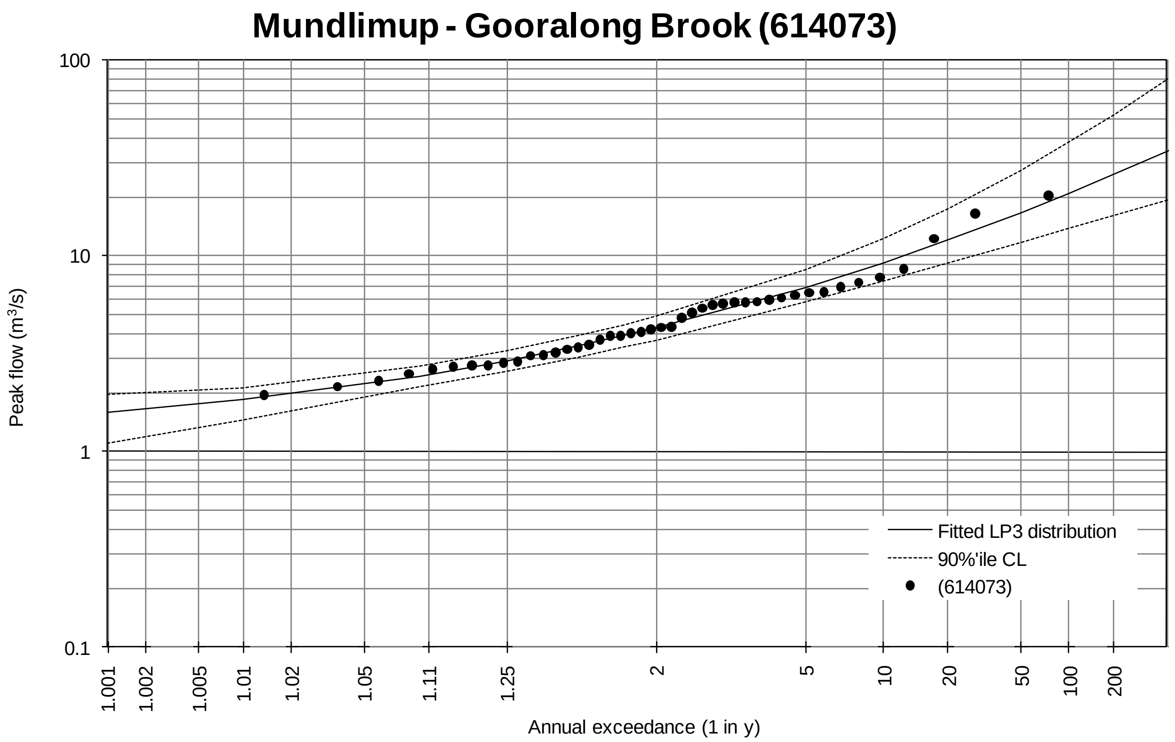


Figure A-5: *Flood frequency analysis for Mundlimup, Gooralong Brook (614073)*

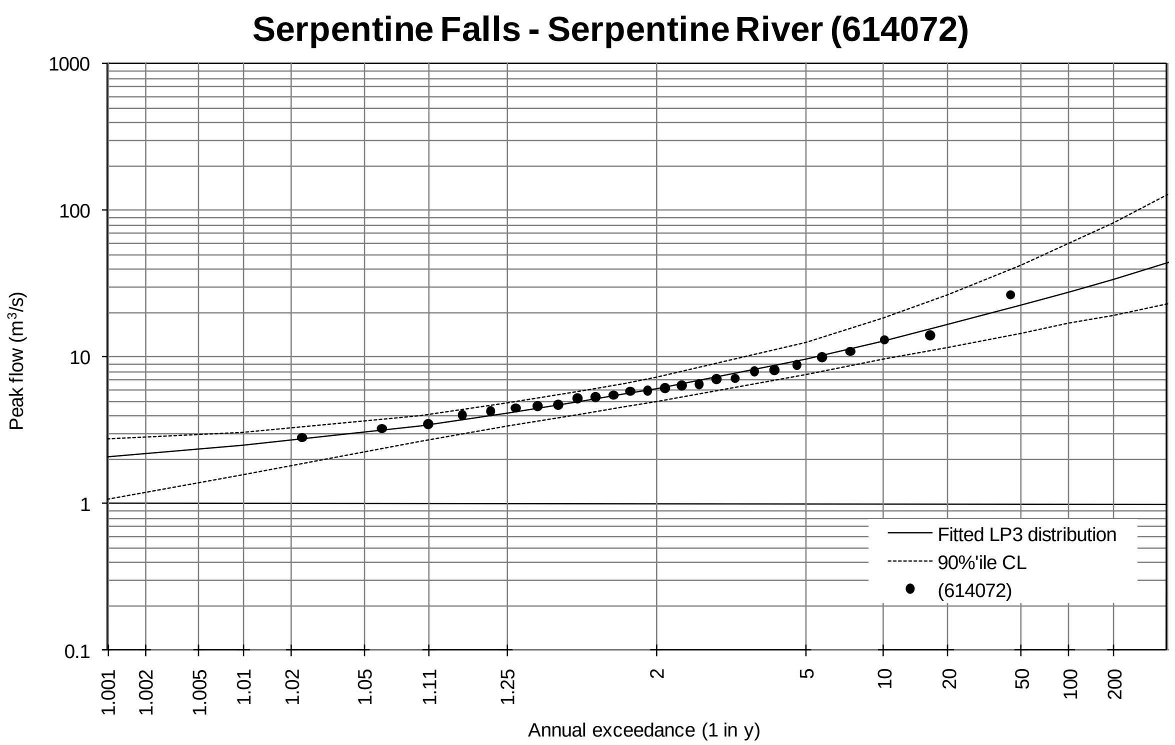


Figure A-6: *Flood frequency analysis for Serpentine Falls, Serpentine River (614072)*

Appendix B - Regional RORB parameters and models

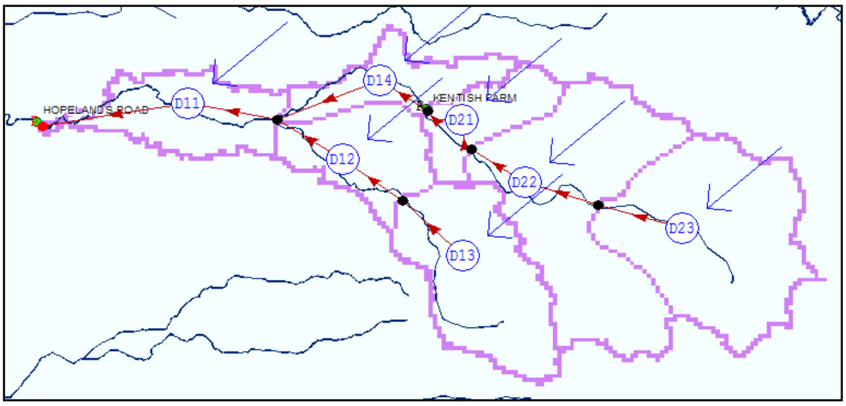
Table B-1: *Regional runoff concentration (RoC) values for validation catchments in the Birrega Flood study*

Event	Event rainfall (mm)	ARI-RoC Factor	RoC (foothills)	RoC (0-10% cleared)	RoC (10-25% cleared)	RoC (25-40% cleared)	RoC (40-60% cleared)	RoC (60-85% cleared)
Nerregin 509271 - 1987 event	126	0.9	0.40	0.15	0.20	0.25	0.31	0.36
Nerregin 509459 - 1987 event	107	0.9	0.39	0.14	0.19	0.24	0.30	0.35
Nerregin 509271 - 1988 event	96	0.8	0.35	0.11	0.16	0.21	0.26	0.30
Nerregin 509459 - 1988 event	91	0.8	0.34	0.11	0.16	0.21	0.26	0.30
Nerregin 509271 - 1992 event	177	0.7	0.34	0.13	0.18	0.22	0.26	0.30
Nerregin 509459 - 1992 event	140	0.7	0.32	0.12	0.16	0.20	0.24	0.28
Serpentine 509232 - 1987 event	157	0.8	0.37	0.14	0.19	0.24	0.29	0.33
Serpentine 509245 - 1987 event	100	0.8	0.35	0.12	0.17	0.21	0.26	0.30
Serpentine 509232 - 1992 event	27	0.6	0.23	0.06	0.10	0.13	0.17	0.20
Serpentine 509245 - 1992 event	84	0.6	0.25	0.08	0.12	0.15	0.19	0.22
Serpentine 509232 - 1988 event	79	0.7	0.30	0.09	0.14	0.18	0.22	0.26
Serpentine 509245 - 1988 event	79	0.7	0.30	0.09	0.14	0.18	0.22	0.26
Dirk Brook 509387 - 1987 event	65	0.6	0.25	0.08	0.11	0.15	0.18	0.22
Dirk Brook 509245 - 1987 event	93	0.6	0.26	0.09	0.12	0.16	0.19	0.23
Dirk Brook 509135 - 1987 event	105	0.6	0.26	0.09	0.13	0.16	0.20	0.23
Dirk Brook 509387 - 1992 event	65	0.6	0.25	0.08	0.11	0.15	0.18	0.22
Dirk Brook 509245 - 1992 event	84	0.6	0.25	0.08	0.12	0.15	0.19	0.22
Dirk Brook 509135 - 1992 event	36	0.6	0.24	0.06	0.10	0.14	0.17	0.20
Dirk Brook 509387 - 1988 event	65	0.9	0.37	0.11	0.17	0.22	0.27	0.32
Dirk Brook 509245 - 1988 event	79	0.9	0.38	0.12	0.17	0.23	0.28	0.33
Dirk Brook 509135 - 1988 event	87	0.9	0.38	0.12	0.18	0.23	0.29	0.34
Dirk Brook 509245 - 1974 event	54	0.8	0.32	0.09	0.14	0.19	0.24	0.28
Dirk Brook 509135 - 1974 event	39	0.8	0.32	0.09	0.14	0.18	0.23	0.27
Wungong 509271 - 1987 event	128	0.9	0.41	0.15	0.20	0.25	0.31	0.36
Wungong 509459 - 1987 event	110	0.9	0.40	0.14	0.19	0.25	0.30	0.35
Wungong 509271 - 1988event	96	0.7	0.30	0.10	0.14	0.18	0.23	0.26
Wungong 509459 - 1988 event	91	0.7	0.30	0.10	0.14	0.18	0.22	0.26

Table B-2: *k_c values for validation catchments in the Birrega Flood study*

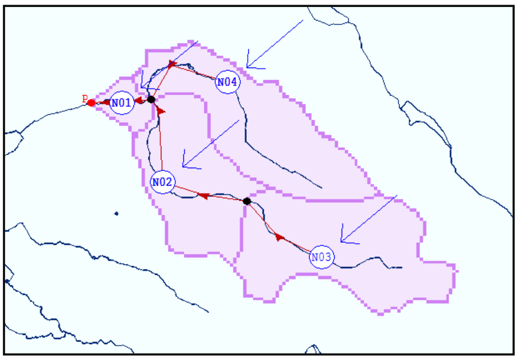
ID	Area	Category	Forrest Coef.	k_c
D01	27.90	Foothills	1.07	13.43
D02	35.98	10-25% cleared	0.40	6.09
N01	19.83	40-60% cleared	0.22	2.13
S01	50.75	0-10% cleared	0.49	9.69
S02	51.04	10-25% cleared	0.40	7.94
E02	10.74	10-25% cleared	0.40	2.43

Dirk Brook RORB model (Hopelands Road and Kentish Farm)



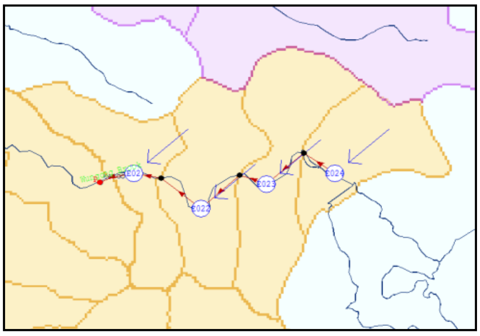

```
Dirk Brook
1
1, 1.750,  -99                              ,Reach 7 node 13          Sub-area D23, Reach  - Generate rainfall
excess h'graph and route downstream
5, 1.950,  -99                              ,Reach 6                  Reach  - Route running h'graph downstream
2, 1.950,  -99                              ,Reach 5 node 11          Sub-area D22, Reach  - Generate rainfall
excess h'graph, add to running h'graph, and route downstream
5, .700,  -99                               ,Reach 11                 Reach  - Route running h'graph downstream
2, .700,  -99                               ,Reach 12 node 4          Sub-area D21, Reach  - Generate rainfall
excess h'graph, add to running h'graph, and route downstream
7.1                                         ,                         PRINT
5, 2.000,  -99                              ,Reach 4                  Reach  - Route running h'graph downstream
2, 2.000,  -99                              ,Reach 3 node 6           Sub-area D14, Reach  - Generate rainfall
excess h'graph, add to running h'graph, and route downstream
3                                           ,                         Store running hydrograph
1, 1.700,  -99                              ,Reach 10 node 9          Sub-area D13, Reach  - Generate rainfall
excess h'graph and route downstream
5, 1.700,  -99                              ,Reach 9                  Reach  - Route running h'graph downstream
2, 1.700,  -99                              ,Reach 8 node 7           Sub-area D12, Reach  - Generate rainfall
excess h'graph, add to running h'graph, and route downstream
4                                           ,                         Add running h'graph to last stored
h'graph
5, 2.850,  -99                              ,Reach 2                  Reach  - Route running h'graph downstream
2, 2.850,  -99                              ,Reach 1 node 3           Sub-area D11, Reach  - Generate rainfall
excess h'graph, add to running h'graph, and route downstream
7.1                                         ,                         PRINT
0
C Sub Area Data
C Areas, km**2, of subareas A,B...
  15.346,   16.403,    4.232,    4.743,   10.586,
   5.977,    6.591,
 -99
C Impervious Fraction Data
0,  -99                                     ,No impervious areas in system
```

Nerrogin RORB model (Abby Road)



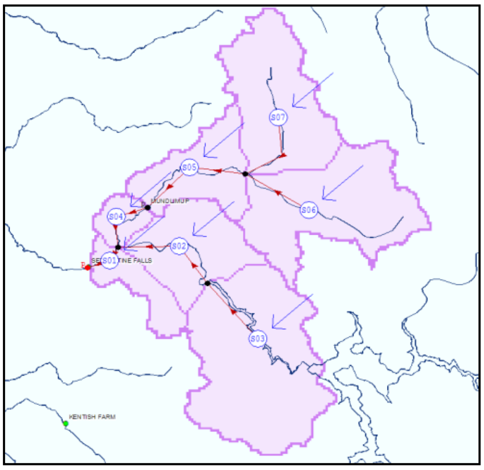

```
Nerrogin Brook
1
1, 1.700,  -99                              ,Reach 4 node 7                Sub-area N03, Reach  - Generate rainfall
excess h'graph and route downstream
5, 1.600,  -99                              ,Reach 5                       Reach  - Route running h'graph downstream
2, 1.600,  -99                              ,Reach 6 node 5                Sub-area N02, Reach  - Generate rainfall
excess h'graph, add to running h'graph, and route downstream
3                                           ,                              Store running hydrograph
1, 2.200,  -99                              ,Reach 3 node 4                Sub-area N04, Reach  - Generate rainfall
excess h'graph and route downstream
4                                           ,                              Add running h'graph to last stored
h'graph
5, .600,  -99                               ,Reach 2                       Reach  - Route running h'graph downstream
C , sub-area N01, Reach Nerrogin Brook
2, .600,  -99                               ,Reach 1 node 1                Sub-area N01, Reach  - Generate rainfall
excess h'graph, add to running h'graph, and route downstream
C ,
C , save
C , print for the gauging station
7.1                                         ,                              PRINT
0
C  Sub Area Data
C  Areas, km**2, of subareas A,B...
   7.263,    5.184,    6.603,    0.782,
  -99
C  Impervious Fraction Data
0,  -99                                     ,No impervious areas in system
```

Wungong RORB model (Kargotich)



```
Wungong Brook
1
1, .400,  -99                               ,Reach 2 node 8                Sub-area E024, Reach  - Generate rainfall
excess h'graph and route downstream
5, .600,  -99                               ,Reach 3                       Reach  - Route running h'graph downstream
2, .600,  -99                               ,Reach 4 node 6                Sub-area E023, Reach  - Generate rainfall
excess h'graph, add to running h'graph, and route downstream
5, .800,  -99                               ,Reach 5                       Reach  - Route running h'graph downstream
2, .800,  -99                               ,Reach 6 node 4                Sub-area E022, Reach  - Generate rainfall
excess h'graph, add to running h'graph, and route downstream
5, .325,  -99                               ,Reach 7                       Reach  - Route running h'graph downstream
2, .325,  -99                               ,Reach 1 node 2                Sub-area E02, Reach Wungong Brook -
Generate rainfall excess h'graph, add to running h'graph, and route downstream
7.1                                         ,                              PRINT
0
C Sub Area Data
C Areas, km**2, of subareas A,B...
   2.251,    3.300,    2.747,    2.437,
  -99
C Impervious Fraction Data
0,  -99                                     ,No impervious areas in system
```

Serpentine RORB model (Serpentine Falls and Mundlimup)



```
Serpentine_River_Catchment
1
1, 2.800,  -99                                  ,Reach 2 node 8              Sub-area S07, Reach  - Generate rainfall
excess h'graph and route downstream
3                                               ,                            Store running hydrograph
1, 2.900,  -99                                  ,Reach 3 node 9              Sub-area S06, Reach  - Generate rainfall
excess h'graph and route downstream
4                                               ,                            Add running h'graph to last stored
h'graph
5, 2.350,  -99                                  ,Reach 4                     Reach  - Route running h'graph downstream
2, 2.350,  -99                                  ,Reach 5 node 6              Sub-area S05, Reach  - Generate rainfall
excess h'graph, add to running h'graph, and route downstream
7.1                                             ,                            PRINT
5, 1.100,  -99                                  ,Reach 6                     Reach  - Route running h'graph downstream
2, 1.100,  -99                                  ,Reach 1 node 3              Sub-area S04, Reach  - Generate rainfall
excess h'graph, add to running h'graph, and route downstream
3                                               ,                            Store running hydrograph
1, 2.770,  -99                                  ,Reach 7 node 11             Sub-area S03, Reach  - Generate rainfall
excess h'graph and route downstream
5, 2.350,  -99                                  ,Reach 8                     Reach  - Route running h'graph downstream
2, 2.350,  -99                                  ,Reach 9 node 4              Sub-area S02, Reach  - Generate rainfall
excess h'graph, add to running h'graph, and route downstream
4                                               ,                            Add running h'graph to last stored
h'graph
5, .750,  -99                                   ,Reach 10                    Reach  - Route running h'graph downstream
2, .750,  -99                                   ,Reach 11 node 12            Sub-area S01, Reach  - Generate rainfall
excess h'graph, add to running h'graph, and route downstream
7.1                                             ,                            PRINT
0
C Sub Area Data
C Areas, km**2, of subareas A,B...
  18.413,   21.813,   10.817,    3.108,   29.485,
  12.609,    5.549,
 -99
C Impervious Fraction Data
0,  -99                                         ,No impervious areas in system
```

Appendix C - Validation plots for regional RORB parameters

Abbey Road – Nerrigen Brook (616044)

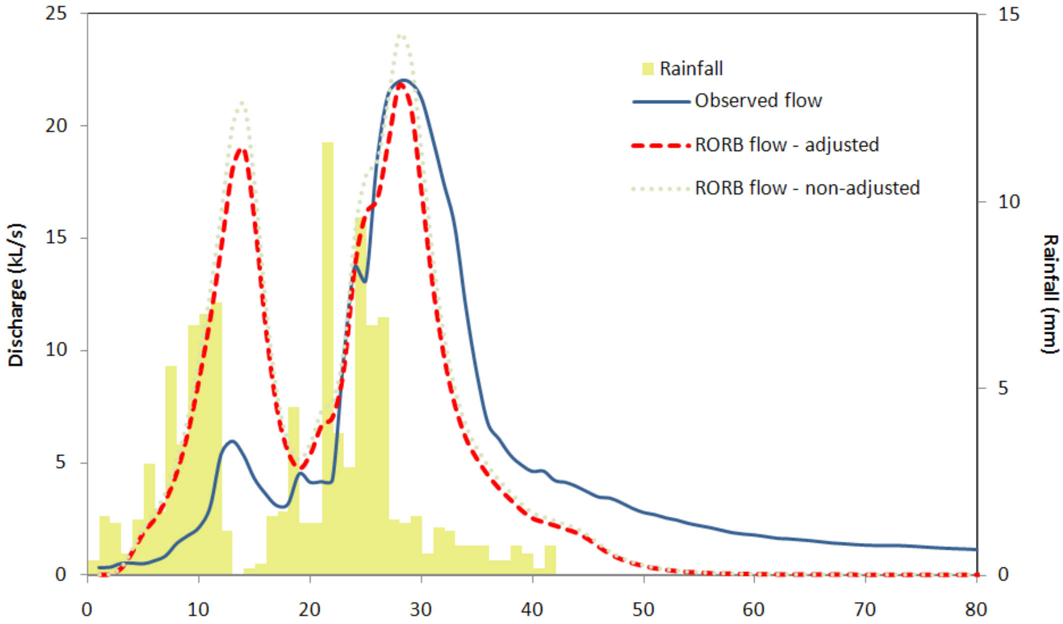


Figure C-1: *1987 event (27/07/1987), Abby Road, Nerrigen Brook (616044)*

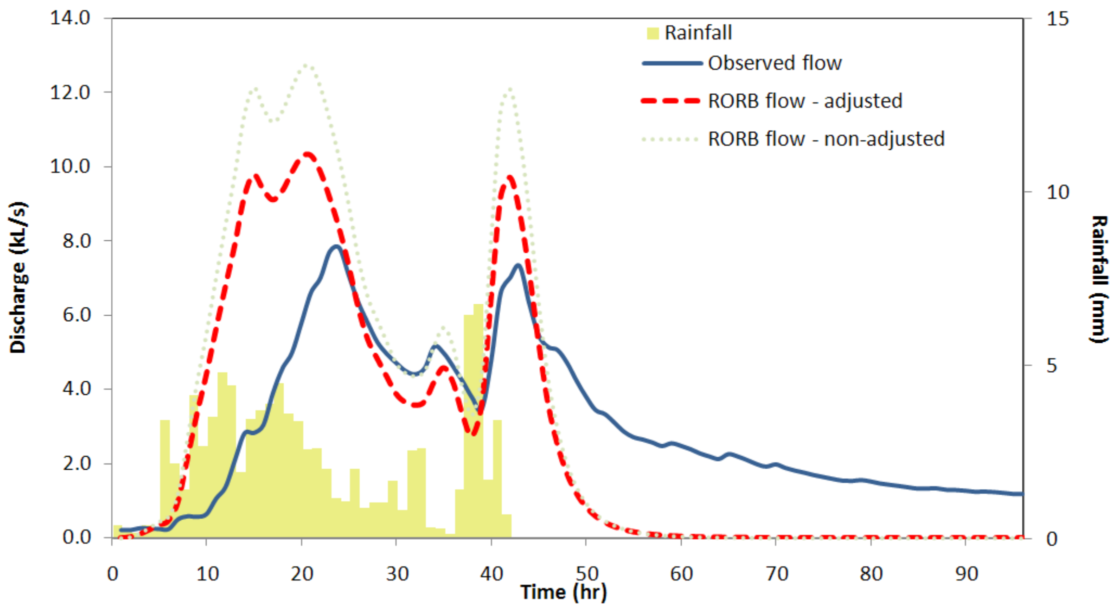


Figure C-2: *1988 event (23/07/1988), Abby Road, Nerrigen Brook (616044)*

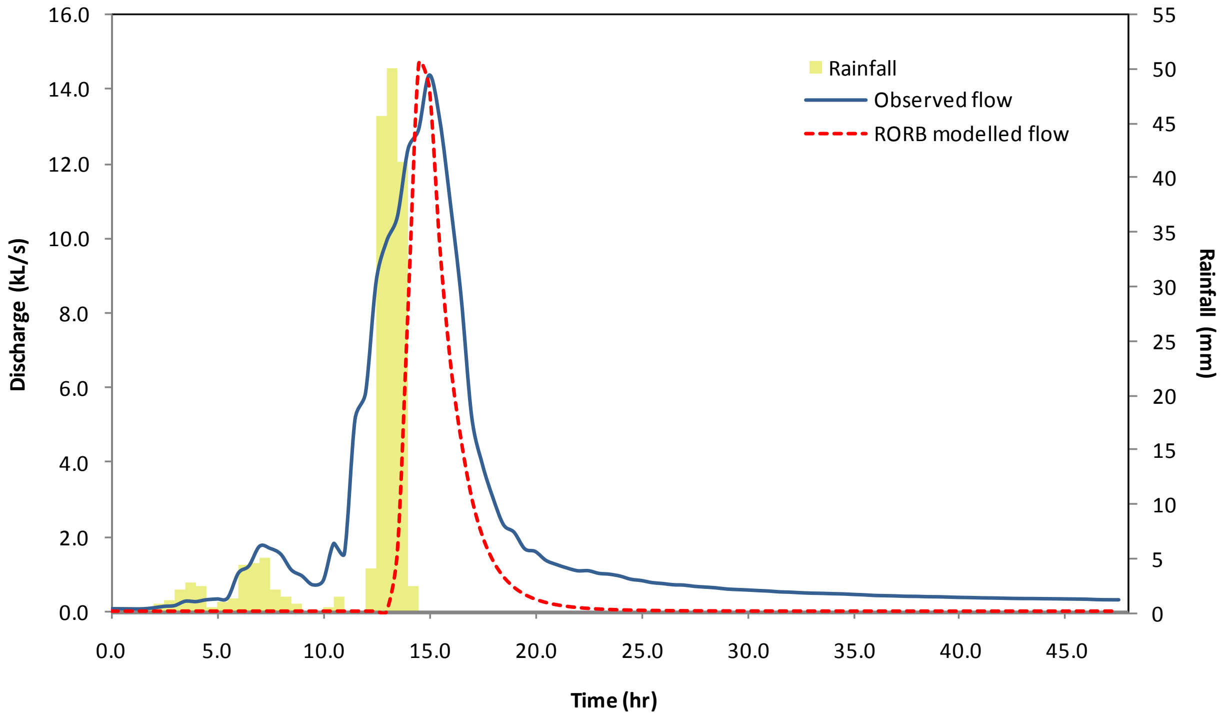


Figure C-3: *1992 event (8/2/1992), Abby Road, Nerrigen Brook (616044), 123 mm initial loss used in validation*

Hopelands Road – Dirk Brook (614028)

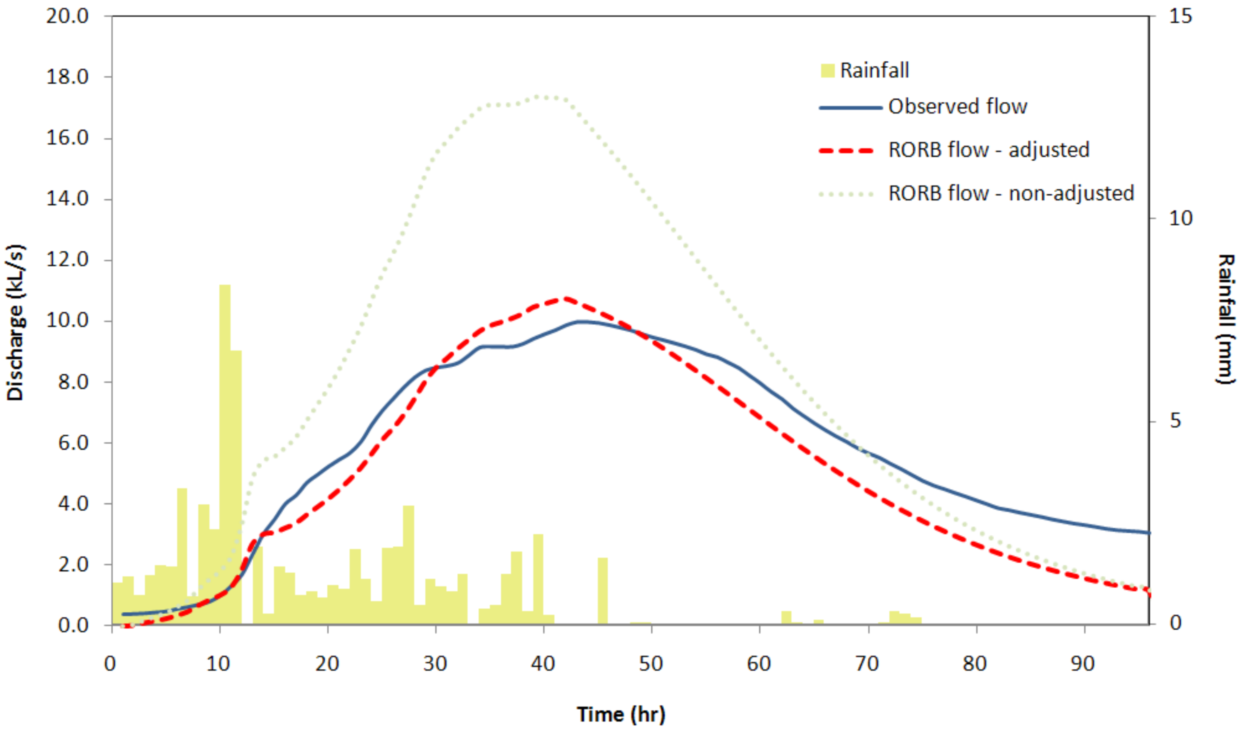


Figure C-4: *1987 event (27/07/1987), Hopelands Road, Dirk Brook (614028)*

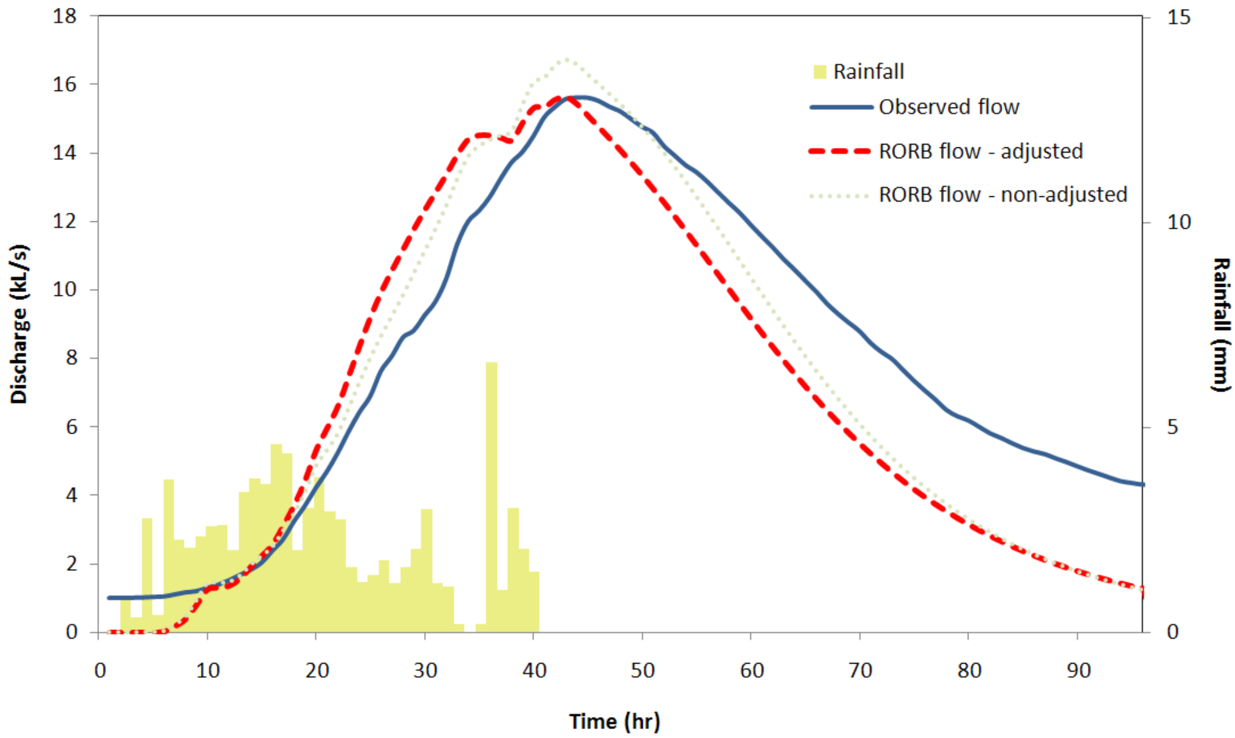


Figure C-5: *1988 event (23/07/1988), Hopelands Road, Dirk Brook (614028)*

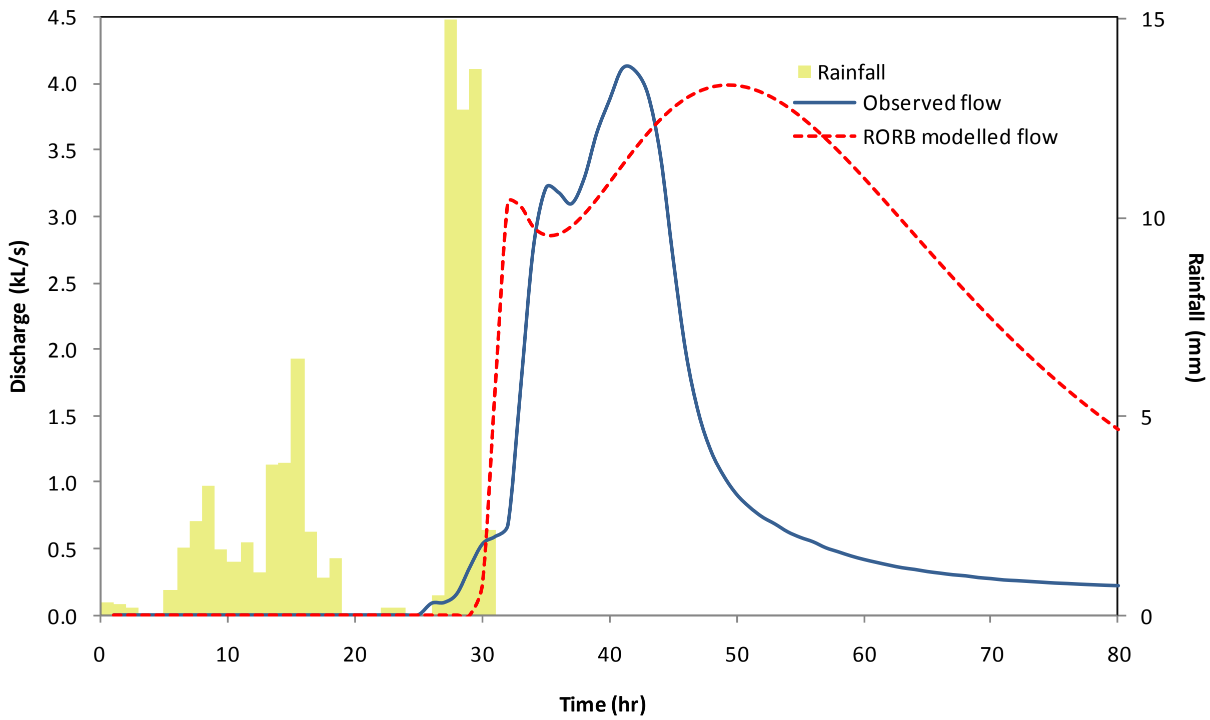


Figure C-6: *1992 event (8/2/1992), Hopelands Road, Dirk Brook (614028), 70 mm initial loss used in validation*

Kargotich – Wungong Brook (616153)

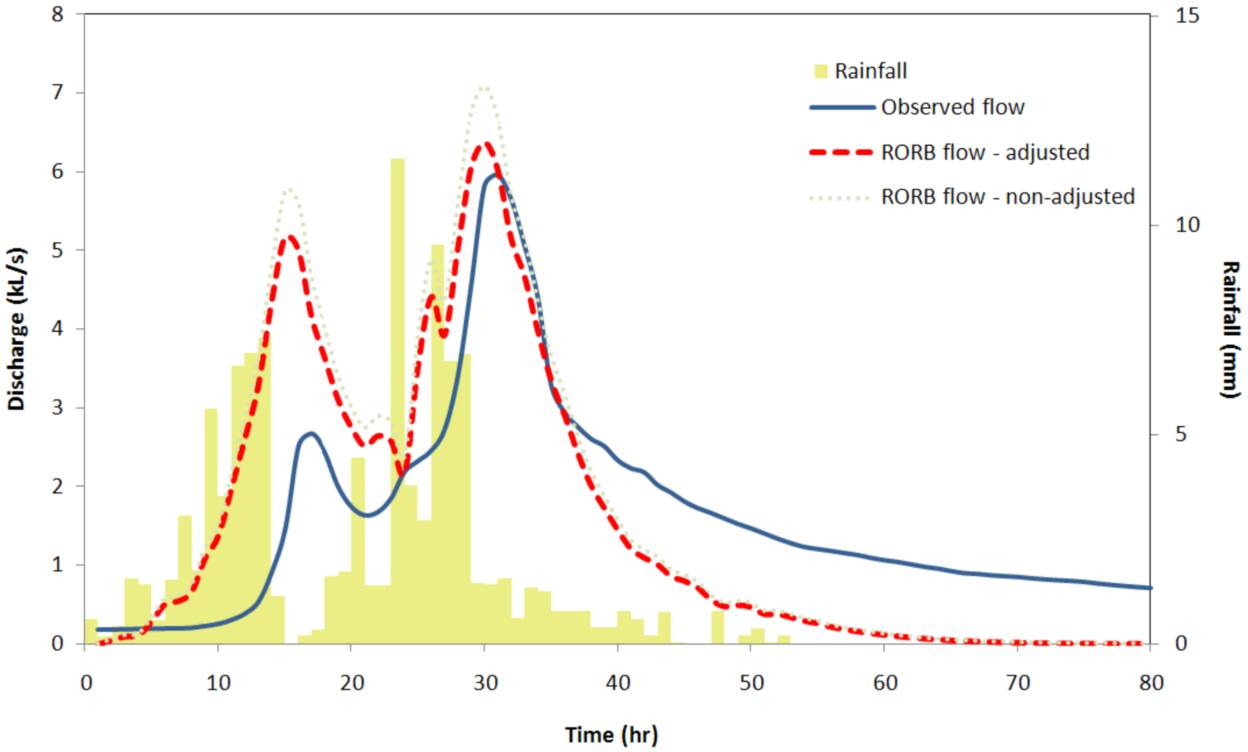


Figure C-7: *1987 event (27/07/1987), Kargotich, Wungong Brook (616153)*

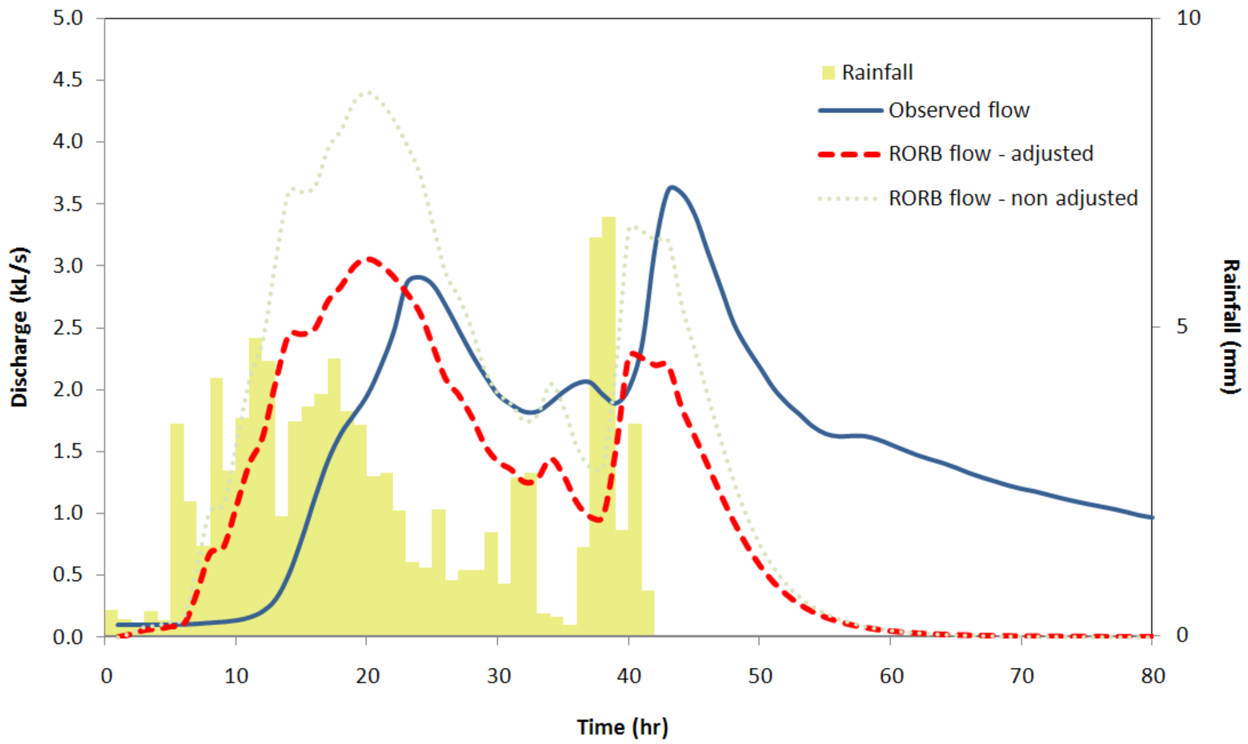


Figure C-8: *1988 event (23/07/1988), Kargotich, Wungong Brook (616153)*

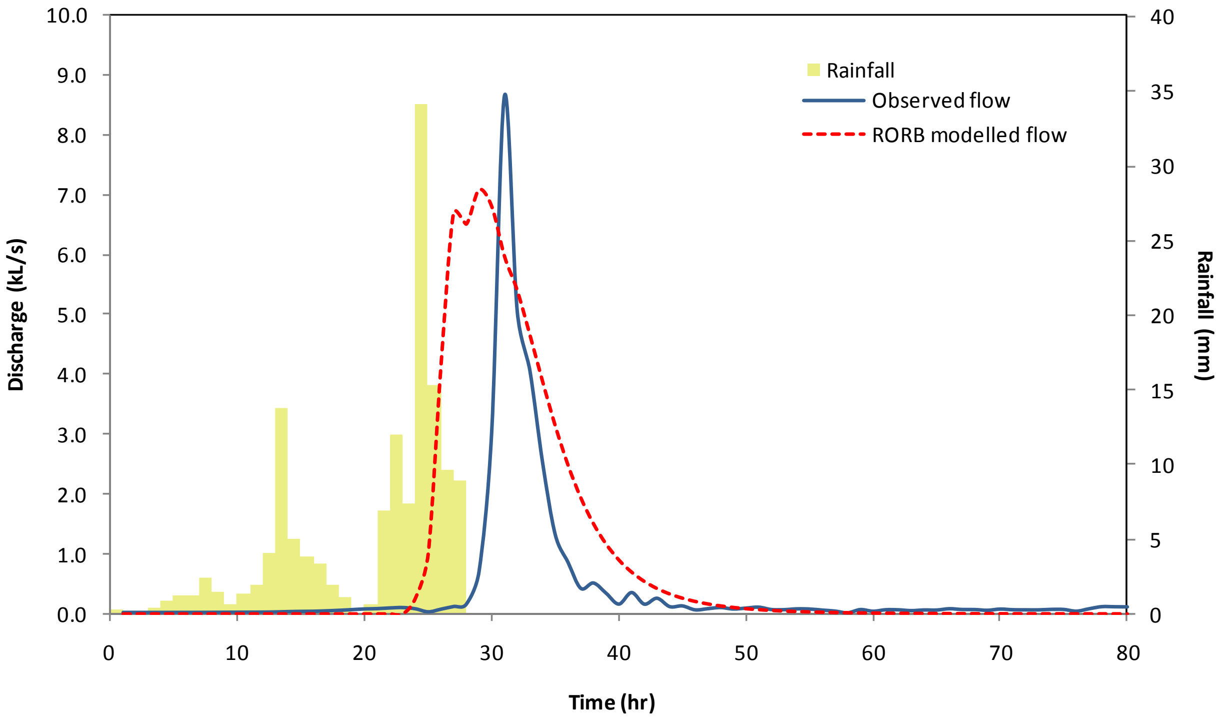


Figure C-9: *1992 event (8/2/1992), Kargotich, Wungong Brook (616153), 60 mm initial loss used in validation*

Kentish Farm – Dirk Brook (614005)

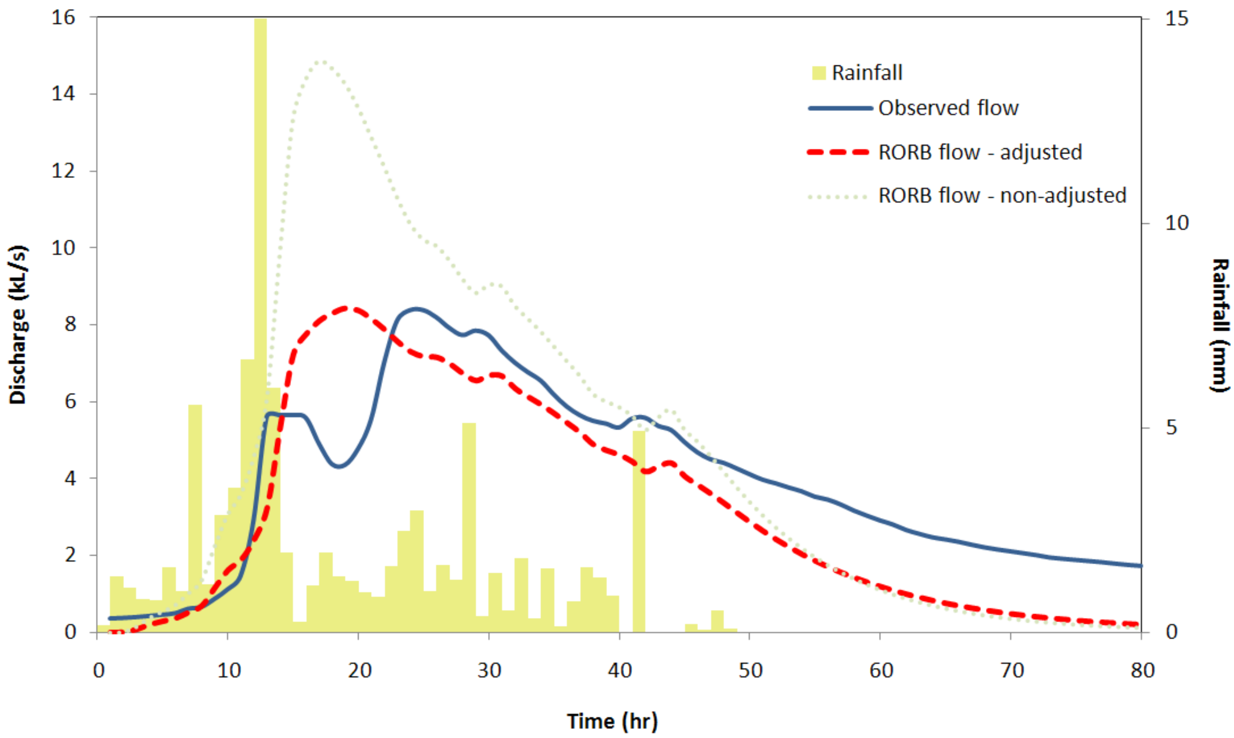


Figure C-10: *1987 event (27/07/1987), Kentish Farm, Dirk Brook (614005)*

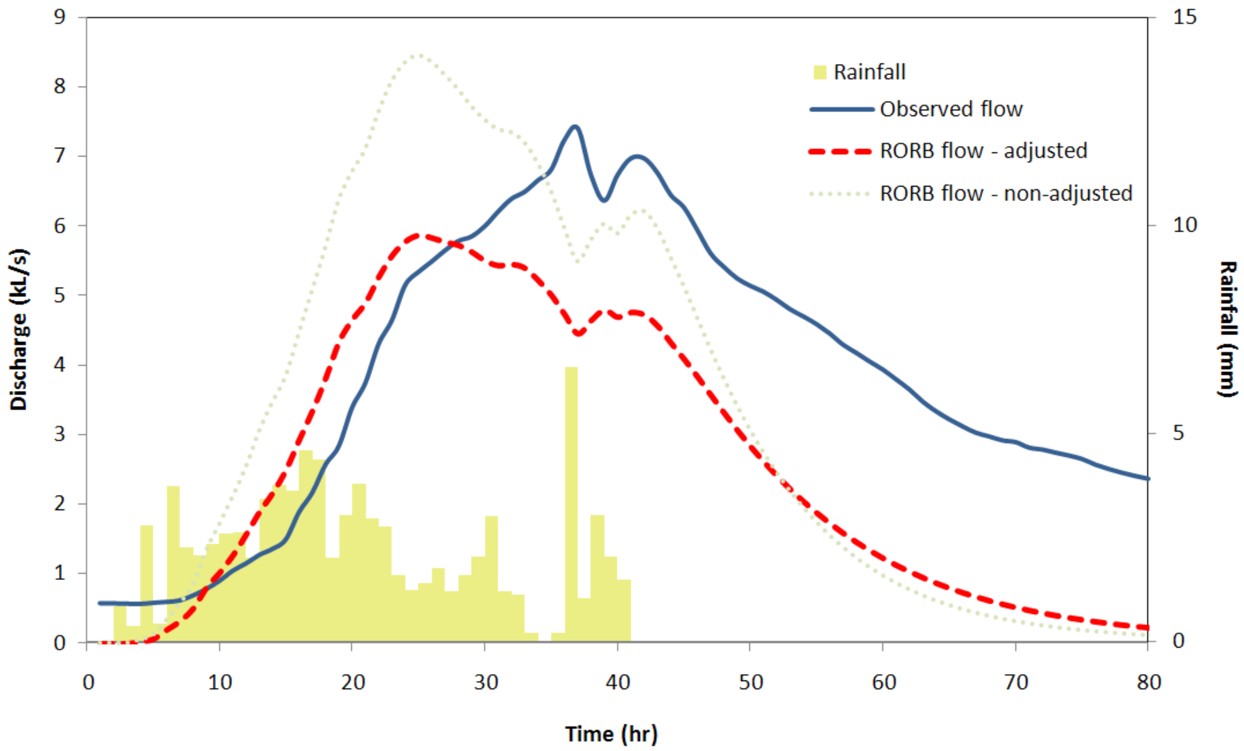


Figure C-11: *1988 event (23/07/1988), Kentish Farm, Dirk Brook (614005)*

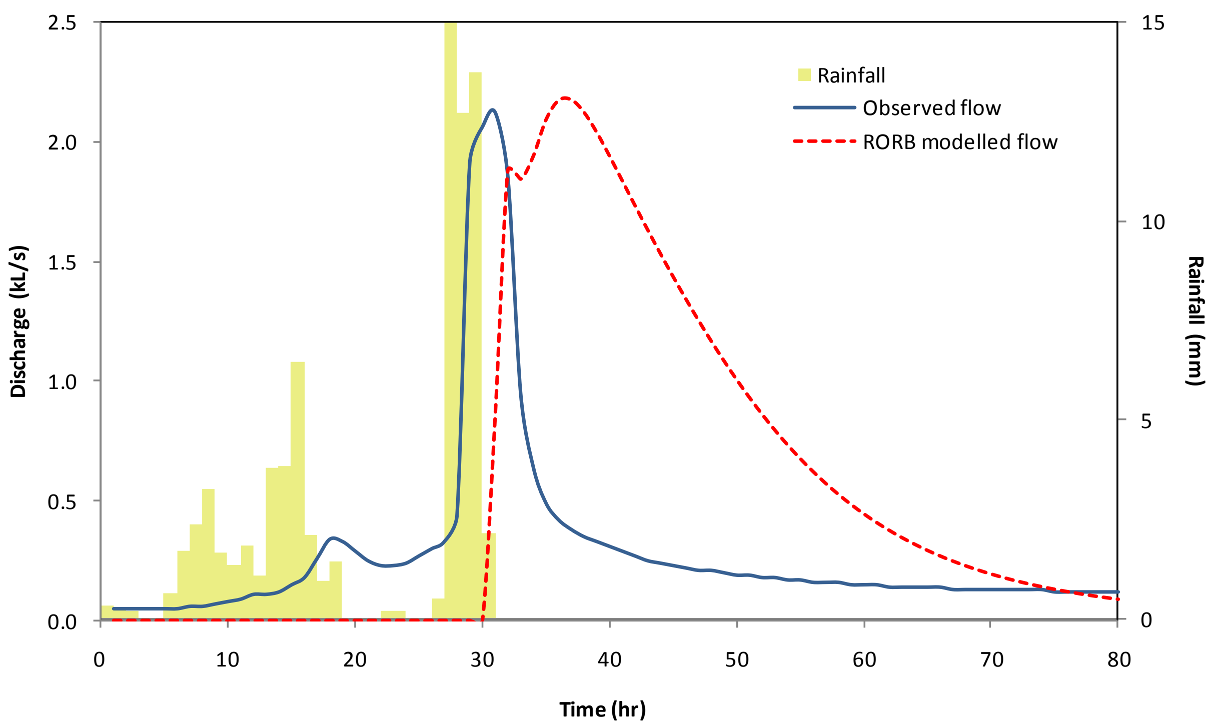


Figure C-12: *1992 event (8/2/1992), Kentish Farm, Dirk Brook (614005), 70 mm initial loss used in validation*

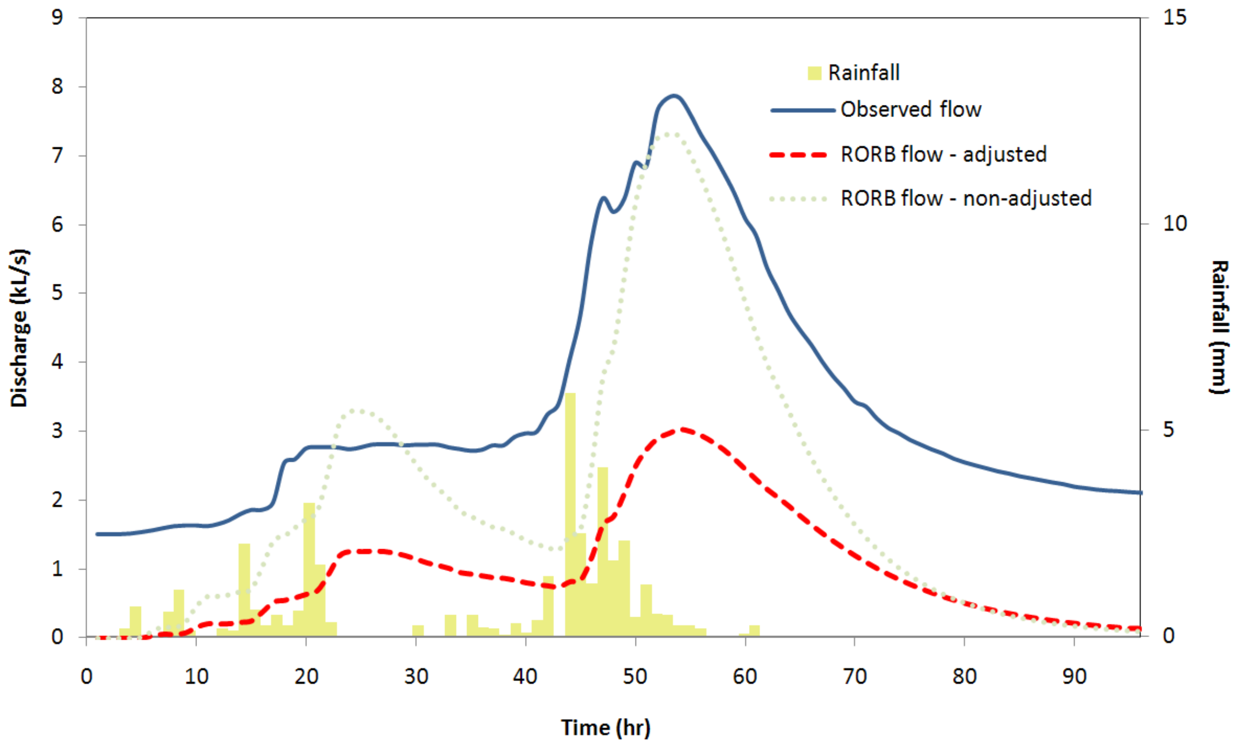


Figure C-13*: 1947 event (18/07/1974), Kentish Farm, Dirk Brook (614005)*

Mundlimup – Goorolong Brook (614073)

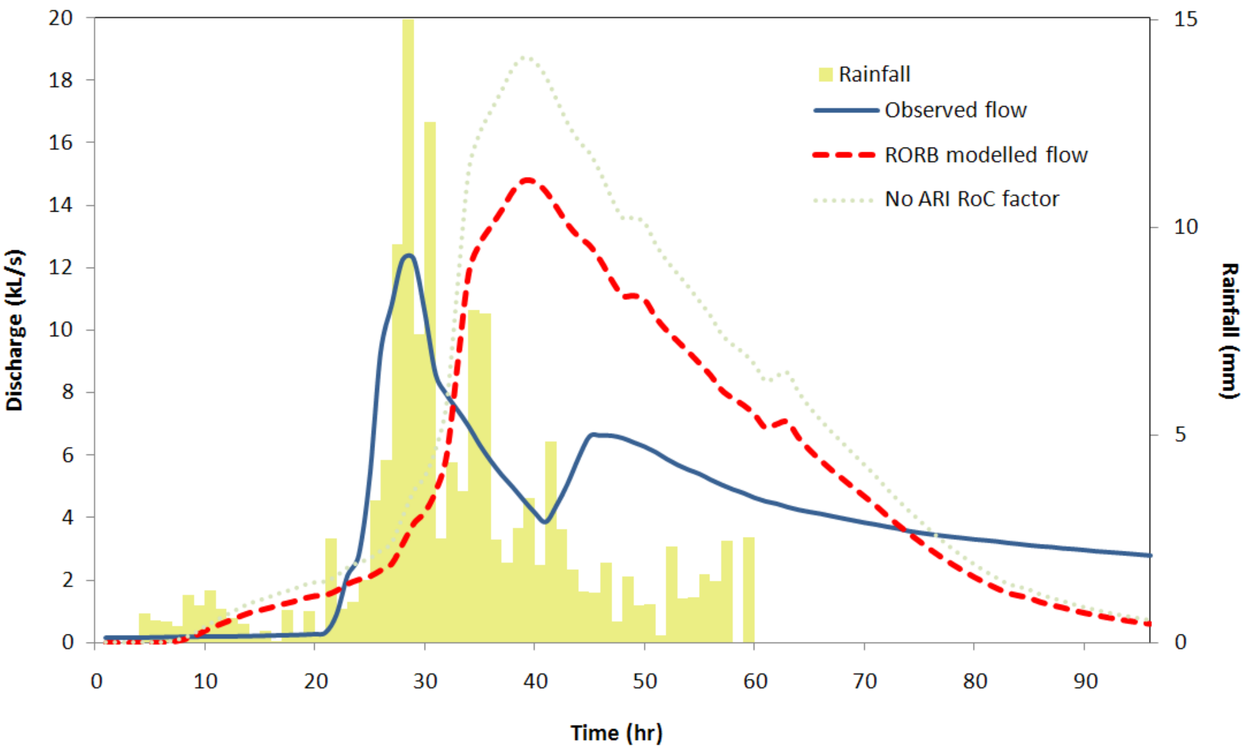


Figure C-14*: 1987 event (27/07/1987), Mundlimup, Goorolong Brook (614073)*

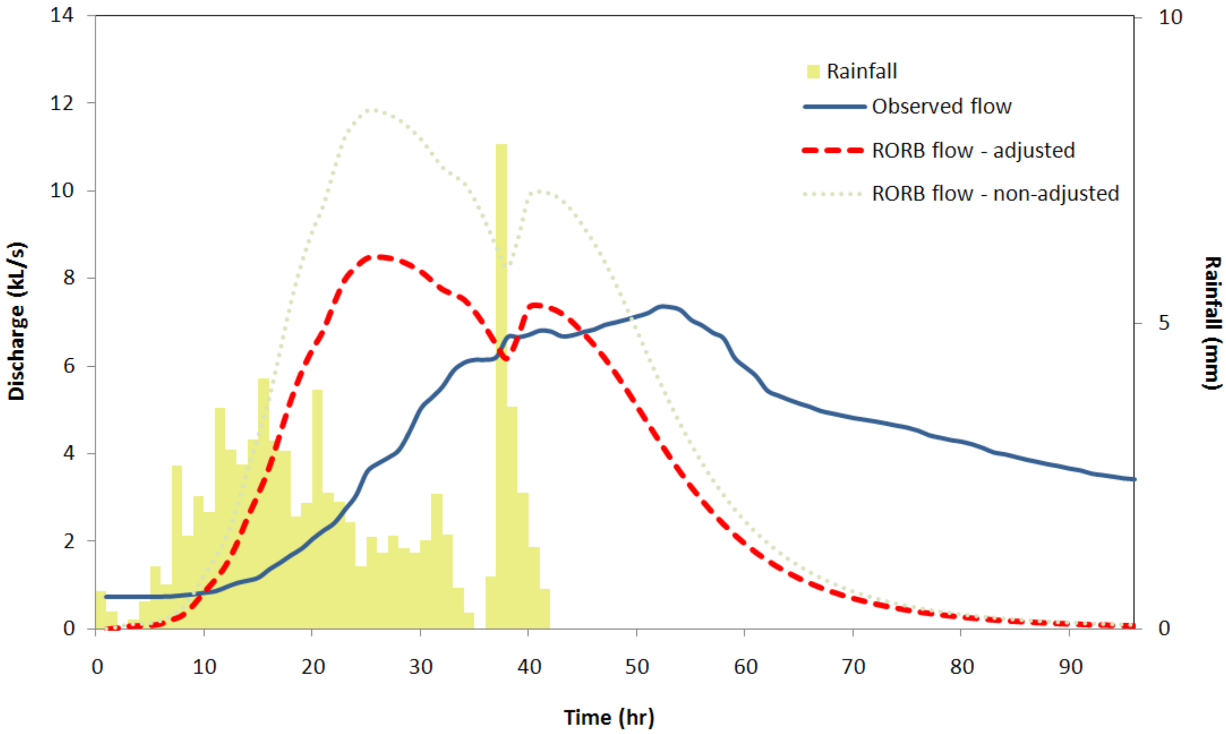


***Figure C-15:** 1988 event (23/07/1988), Mundlimup, Goorolong Brook (614073)*

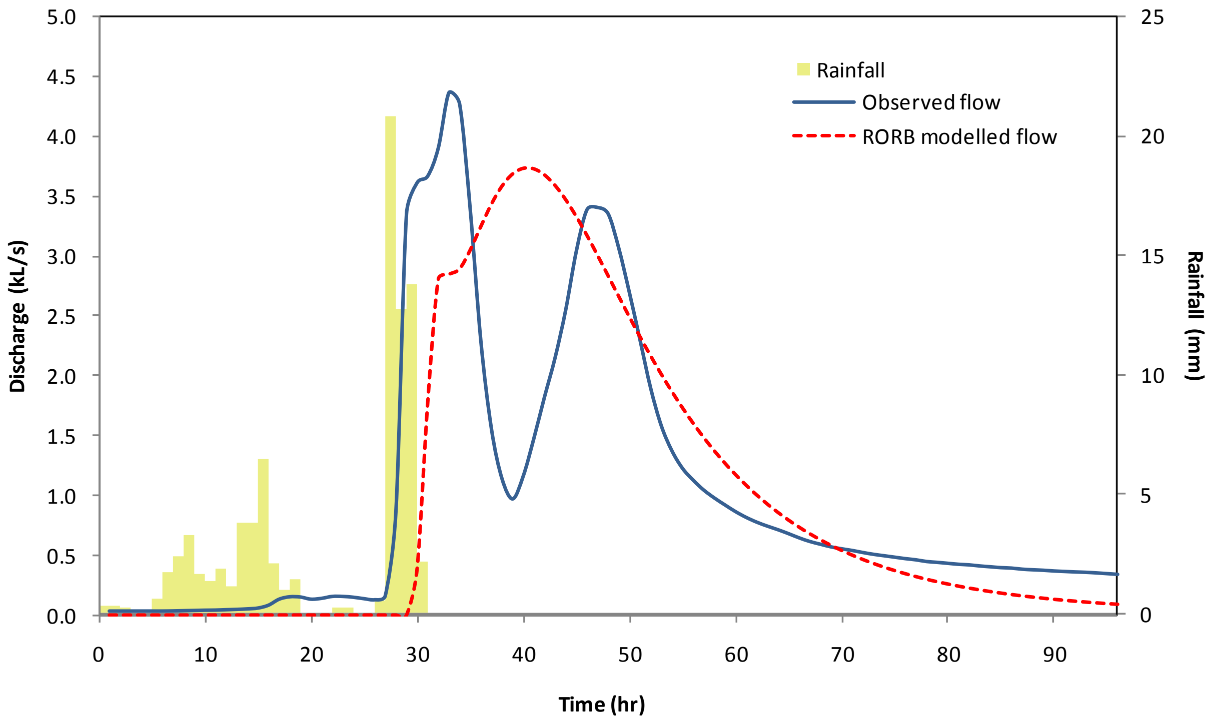


***Figure C-16:** 1992 event (8/2/1992), Mundlimup, Goorolong Brook (614073), 65 mm initial loss used in validation*

Serpentine Falls – Serpentine River (614072)

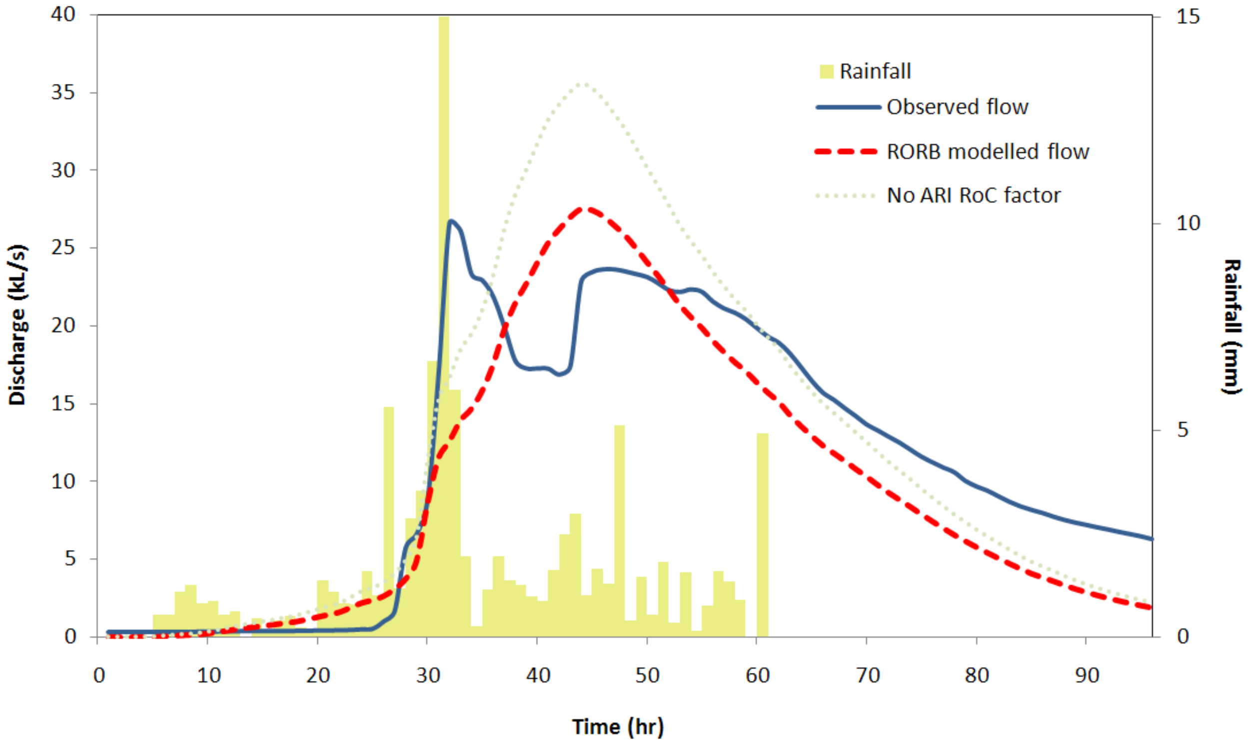


***Figure C-17**: 1987 event (27/07/1987), Serpentine Falls, Serpentine River (614072)*

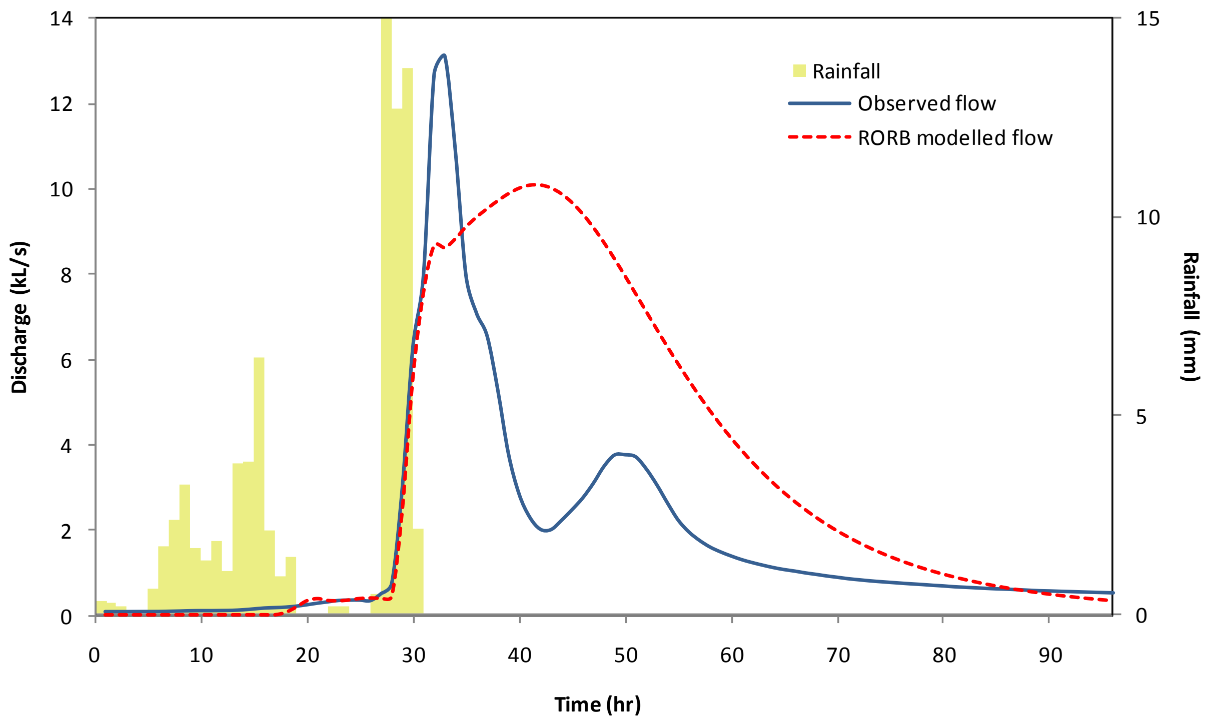


***Figure C-18**: 1992 event (8/2/1992), Serpentine Falls, Serpentine River (614072), 40 mm initial loss used in validation*

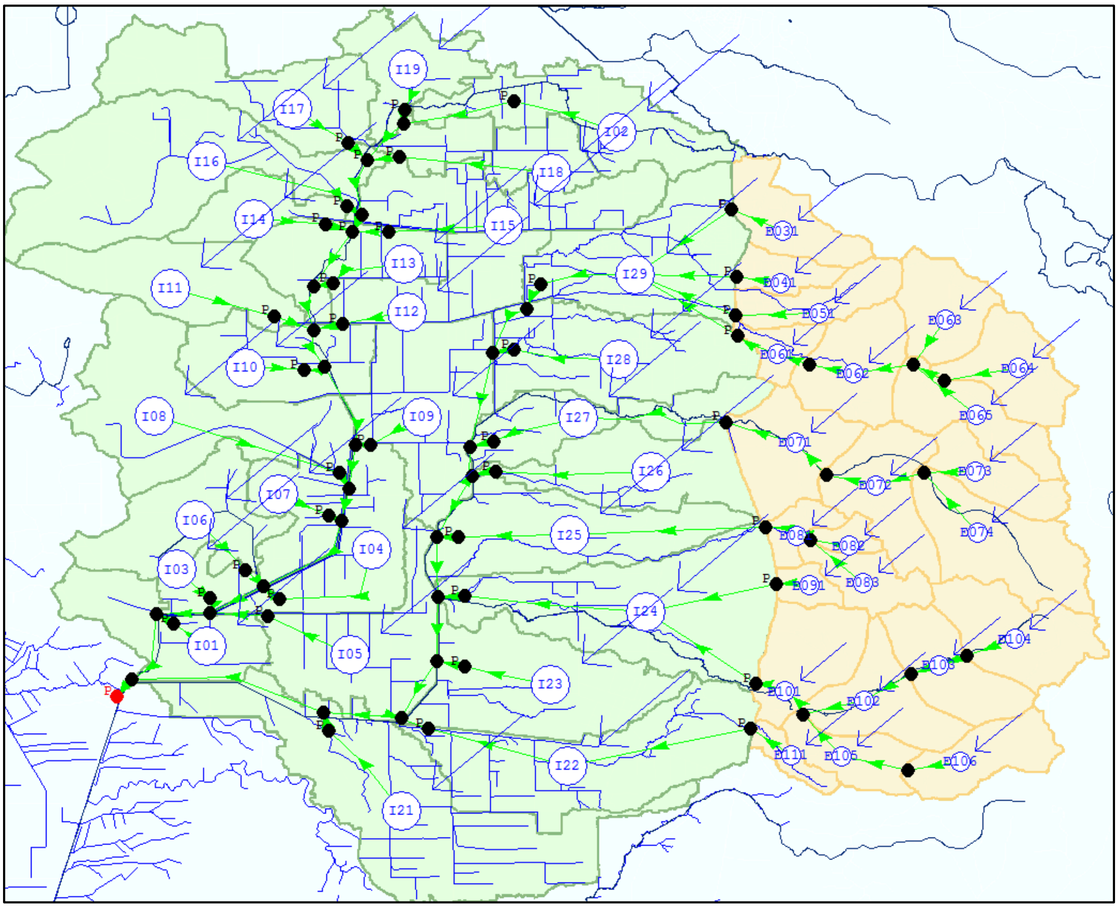
Appendix D - Parameters and RORB model set-up

Table D-1: *Adjusted regional runoff concentration (RoC) values for the Birrega catchment*

Event	Areally reduced rainfall (mm)	RoC factor	RoC (foothills)	RoC (60-85% cleared)	RoC (40-60% cleared)	RoC (25-40% cleared)	RoC (10-25% cleared)	RoC (0-10% cleared)
			Adjusted regional parameters					
500yr 6h design	101	1.0	0.43	0.38	0.33	0.27	0.21	0.15
500y 12h design	134	1.0	0.45	0.40	0.35	0.29	0.23	0.17
500y 18h design	162	1.0	0.47	0.42	0.36	0.30	0.24	0.18
500y 24h design	185	1.0	0.48	0.43	0.37	0.31	0.25	0.19
500y 36h design	204	1.0	0.49	0.44	0.39	0.32	0.26	0.20
500y 48h design	218	1.0	0.50	0.45	0.39	0.33	0.27	0.21
500y 72h design	240	1.0	0.51	0.46	0.40	0.34	0.28	0.22
200yr 6h design	83	1.0	0.42	0.37	0.32	0.26	0.20	0.14
200y 12h design	111	1.0	0.44	0.39	0.33	0.27	0.21	0.15
200y 18h design	134	1.0	0.45	0.40	0.35	0.29	0.23	0.17
200y 24h design	153	1.0	0.47	0.41	0.36	0.30	0.24	0.18
200y 36h design	183	1.0	0.48	0.43	0.37	0.31	0.25	0.19
200y 48h design	205	1.0	0.49	0.44	0.39	0.33	0.27	0.21
200y 72h design	234	1.0	0.51	0.45	0.40	0.34	0.28	0.22
100yr 6h design	80	1.0	0.42	0.37	0.31	0.25	0.19	0.13
100y 12h design	106	1.0	0.44	0.38	0.33	0.27	0.21	0.15
100y 18h design	128	1.0	0.45	0.40	0.34	0.28	0.22	0.16
100y 24h design	146	1.0	0.46	0.41	0.35	0.29	0.23	0.17
100y 36h design	174	1.0	0.48	0.42	0.37	0.31	0.25	0.19
100y 48h design	195	1.0	0.49	0.43	0.38	0.32	0.26	0.20
100y 72h design	223	1.0	0.50	0.45	0.40	0.34	0.28	0.22
50yr 6h design	71	0.9	0.38	0.33	0.28	0.22	0.17	0.12
50y 12h design	94	0.9	0.39	0.34	0.29	0.24	0.18	0.13
50y 18h design	113	0.9	0.40	0.35	0.30	0.25	0.19	0.14
50y 24h design	129	0.9	0.41	0.36	0.31	0.26	0.20	0.15
50y 36h design	154	0.9	0.42	0.37	0.32	0.27	0.21	0.16
50y 48h design	172	0.9	0.43	0.38	0.33	0.28	0.22	0.17
50y 72h design	197	0.9	0.44	0.39	0.34	0.29	0.23	0.18
20yr 6h design	60	0.8	0.33	0.28	0.24	0.19	0.15	0.10
20y 12h design	80	0.8	0.34	0.29	0.25	0.20	0.16	0.11
20y 18h design	95	0.8	0.35	0.30	0.26	0.21	0.16	0.11
20y 24h design	109	0.8	0.35	0.31	0.27	0.22	0.17	0.12
20y 36h design	129	0.8	0.36	0.32	0.27	0.23	0.18	0.13
20y 48h design	144	0.8	0.37	0.33	0.28	0.23	0.19	0.14
20y 72h design	164	0.8	0.38	0.33	0.29	0.24	0.19	0.15
10yr 6h design	52	0.7	0.28	0.25	0.21	0.17	0.12	0.08
10y 12h design	69	0.7	0.29	0.25	0.22	0.17	0.13	0.09
10y 18h design	83	0.7	0.30	0.26	0.22	0.18	0.14	0.10
10y 24h design	94	0.7	0.30	0.26	0.23	0.18	0.14	0.10
10y 36h design	112	0.7	0.31	0.27	0.23	0.19	0.15	0.11
10y 48h design	124	0.7	0.31	0.28	0.24	0.20	0.15	0.11
10y 72h design	141	0.7	0.32	0.28	0.25	0.20	0.16	0.12
5yr 6h design	47	0.6	0.24	0.21	0.18	0.14	0.10	0.07
5y 12h design	63	0.6	0.25	0.21	0.18	0.15	0.11	0.07
5y 18h design	78	0.6	0.25	0.22	0.19	0.15	0.12	0.08
5y 24h design	84	0.6	0.26	0.22	0.19	0.15	0.12	0.08
5y 36h design	100	0.6	0.26	0.23	0.20	0.16	0.12	0.09
5y 48h design	111	0.6	0.26	0.23	0.20	0.16	0.13	0.09
5y 72h design	126	0.6	0.27	0.24	0.20	0.17	0.13	0.10

Table D-2: *Adjusted k_c values for validation catchments in the Birrega Flood study*

ID	Area	Category	ForrestCoef.	k_c
E01-	2.76	25-40% cleared	0.31	0.67
E02-	10.74	10-25% cleared	0.40	2.43
E03-	2.73	40-60% cleared	0.22	0.47
E04-	1.26	40-60% cleared	0.22	0.26
E05-	2.26	25-40% cleared	0.31	0.58
E06-	13.65	10-25% cleared	0.40	2.92
E07-	14.80	25-40% cleared	0.31	2.40
E08-	3.52	40-60% cleared	0.22	0.57
E09-	0.77	40-60% cleared	0.22	0.18
E10-	18.95	10-25% cleared	0.40	3.74
E11-	0.83	40-60% cleared	0.22	0.19
I01	4.78	Foothills	1.07	3.51
I02	6.17	Foothills	1.07	4.27
I03	1.42	Foothills	1.07	1.40
I04	4.97	Foothills	1.07	3.62
I05	6.34	Foothills	1.07	4.35
I06	5.45	Foothills	1.07	3.88
I07	3.04	Foothills	1.07	2.49
I08	9.27	Foothills	1.07	5.81
I09	7.16	Foothills	1.07	4.78
I10	5.05	Foothills	1.07	3.67
I11	5.39	Foothills	1.07	3.85
I12	4.22	Foothills	1.07	3.20
I13	4.35	Foothills	1.07	3.27
I14	2.39	Foothills	1.07	2.07
I15	5.91	Foothills	1.07	4.13
I16	12.00	Foothills	1.07	7.07
I17	6.69	Foothills	1.07	4.54
I18	3.62	Foothills	1.07	2.85
I19	3.40	Foothills	1.07	2.71
I21	14.10	Foothills	1.07	8.00
I22	9.44	Foothills	1.07	5.90
I23	7.83	Foothills	1.07	5.11
I24	10.88	Foothills	1.07	6.56
I25	7.02	Foothills	1.07	4.71
I26	5.38	Foothills	1.07	3.84
I27	4.56	Foothills	1.07	3.39
I28	7.56	Foothills	1.07	4.98
I29	7.66	Foothills	1.07	5.03




```
Berriga RORB Model
1
1, 1.100,  -99        ,Reach 98 node 104     Sub-area E064, Reach  - Generate rainfall excess h'graph and route downstream
5, .450,  -99         ,Reach 101             Reach  - Route running h'graph downstream
3                     ,                      Store running hydrograph
1, .950,  -99         ,Reach 100 node 103    Sub-area E063, Reach  - Generate rainfall excess h'graph and route downstream
4                     ,                      Add running h'graph to last stored h'graph
3                     ,                      Store running hydrograph
1, 1.600,  -99        ,Reach 99 node 105     Sub-area E065, Reach  - Generate rainfall excess h'graph and route downstream
4                     ,                      Add running h'graph to last stored h'graph
5, .950,  -99         ,Reach 102             Reach  - Route running h'graph downstream
2, .950,  -99         ,Reach 103 node 101    Sub-area E062, Reach  - Generate rainfall excess h'graph, add to running h'graph, and route downstream
5, .750,  -99         ,Reach 104             Reach  - Route running h'graph downstream
2, .750,  -99         ,Reach 4 node 1        Sub-area E061, Reach  - Generate rainfall excess h'graph, add to running h'graph, and route downstream
7.2                   ,                      PRINT
E06_discharge
5, 2.500,  -99        ,Reach 95              Reach  - Route running h'graph downstream
3                     ,                      Store running hydrograph
1, 1.200,  -99        ,Reach 3 node 7        Sub-area E051, Reach  - Generate rainfall excess h'graph and route downstream
7.2                   ,                      PRINT
E05_discharge
5, 2.500,  -99        ,Reach 12              Reach  - Route running h'graph downstream
4                     ,                      Add running h'graph to last stored h'graph
3                     ,                      Store running hydrograph
1, .940,  -99         ,Reach 2 node 8        Sub-area E041, Reach  - Generate rainfall excess h'graph and route downstream
7.2                   ,                      PRINT
E04_discharge
5, 2.600,  -99        ,Reach 11              Reach  - Route running h'graph downstream
4                     ,                      Add running h'graph to last stored h'graph
3                     ,                      Store running hydrograph
1, 1.000,  -99        ,Reach 1 node 9        Sub-area E031, Reach  - Generate rainfall excess h'graph and route downstream
7.2                   ,                      PRINT
E03_discharge
5, 2.100,  -99        ,Reach 10              Reach  - Route running h'graph downstream
4                     ,                      Add running h'graph to last stored h'graph
2, 2.600,  -99        ,Reach 16 node 20      Sub-area I29, Reach  - Generate rainfall excess h'graph, add to running h'graph, and route downstream
7.2                   ,                      PRINT
I29_discharge
5, .200,  -99         ,Reach 25              Reach  - Route running h'graph downstream
5, 1.600,  -99        ,Reach 34              Reach  - Route running h'graph downstream
3                     ,                      Store running hydrograph
1, 2.450,  -99        ,Reach 17 node 21      Sub-area I28, Reach  - Generate rainfall excess h'graph and route downstream
7.2                   ,                      PRINT
I28_discharge
5, .200,  -99         ,Reach 26              Reach  - Route running h'graph downstream
4                     ,                      Add running h'graph to last stored h'graph
5, 2.080,  -99        ,Reach 35              Reach  - Route running h'graph downstream
3                     ,                      Store running hydrograph
```

```
1, 1.900,  -99                  ,Reach 106 node 109    Sub-area E074, Reach  - Generate rainfall excess h'graph and route
downstream
3                               ,                      Store running hydrograph
1, 1.300,  -99                  ,Reach 105 node 110    Sub-area E073, Reach  - Generate rainfall excess h'graph and route
downstream
4                               ,                      Add running h'graph to last stored h'graph
5, 1.000,  -99                  ,Reach 107             Reach  - Route running h'graph downstream
2, 1.000,  -99                  ,Reach 108 node 107    Sub-area E072, Reach  - Generate rainfall excess h'graph, add to
running h'graph, and route downstream
5, 1.000,  -99                  ,Reach 109             Reach  - Route running h'graph downstream
2, 1.000,  -99                  ,Reach 5 node 2        Sub-area E071, Reach  - Generate rainfall excess h'graph, add to
running h'graph, and route downstream
7.2                             ,                      PRINT
E07_discharge
5, 2.300,  -99                  ,Reach 96              Reach  - Route running h'graph downstream
2, 2.100,  -99                  ,Reach 18 node 22      Sub-area I27, Reach  - Generate rainfall excess h'graph, add to
running h'graph, and route downstream
7.2                             ,                      PRINT
I27_discharge
5, .200,  -99                   ,Reach 27              Reach  - Route running h'graph downstream
4                               ,                      Add running h'graph to last stored h'graph
5, .800,  -99                   ,Reach 36              Reach  - Route running h'graph downstream
3                               ,                      Store running hydrograph
1, 2.900,  -99                  ,Reach 19 node 23      Sub-area I26, Reach  - Generate rainfall excess h'graph and route
downstream
7.2                             ,                      PRINT
I26_discharge
5, .200,  -99                   ,Reach 28              Reach  - Route running h'graph downstream
4                               ,                      Add running h'graph to last stored h'graph
5, 1.300,  -99                  ,Reach 37              Reach  - Route running h'graph downstream
3                               ,                      Store running hydrograph
1, .660,  -99                   ,Reach 110 node 112    Sub-area E082, Reach  - Generate rainfall excess h'graph and route
downstream
3                               ,                      Store running hydrograph
1, 1.100,  -99                  ,Reach 111 node 113    Sub-area E083, Reach  - Generate rainfall excess h'graph and route
downstream
4                               ,                      Add running h'graph to last stored h'graph
5, .360,  -99                   ,Reach 112             Reach  - Route running h'graph downstream
2, .360,  -99                   ,Reach 6 node 3        Sub-area E081, Reach  - Generate rainfall excess h'graph, add to
running h'graph, and route downstream
7.2                             ,                      PRINT
E08_discharge
5, 3.700,  -99                  ,Reach 97              Reach  - Route running h'graph downstream
2, 2.600,  -99                  ,Reach 20 node 24      Sub-area I25, Reach  - Generate rainfall excess h'graph, add to
running h'graph, and route downstream
7.2                             ,                      PRINT
I25_discharge
5, .200,  -99                   ,Reach 29              Reach  - Route running h'graph downstream
4                               ,                      Add running h'graph to last stored h'graph
5, 1.400,  -99                  ,Reach 38              Reach  - Route running h'graph downstream
3                               ,                      Store running hydrograph
1, 1.000,  -99                  ,Reach 113 node 119    Sub-area E104, Reach  - Generate rainfall excess h'graph and route
downstream
5, .550,  -99                   ,Reach 120             Reach  - Route running h'graph downstream
2, .550,  -99                   ,Reach 114 node 117    Sub-area E103, Reach  - Generate rainfall excess h'graph, add to
running h'graph, and route downstream
5, 1.100,  -99                  ,Reach 115             Reach  - Route running h'graph downstream
2, 1.100,  -99                  ,Reach 116 node 115    Sub-area E102, Reach  - Generate rainfall excess h'graph, add to
running h'graph, and route downstream
3                               ,                      Store running hydrograph
1, 1.600,  -99                  ,Reach 119 node 122    Sub-area E106, Reach  - Generate rainfall excess h'graph and route
downstream
5, 1.300,  -99                  ,Reach 118             Reach  - Route running h'graph downstream
2, 1.300,  -99                  ,Reach 117 node 120    Sub-area E105, Reach  - Generate rainfall excess h'graph, add to
running h'graph, and route downstream
4                               ,                      Add running h'graph to last stored h'graph
5, .500,  -99                   ,Reach 121             Reach  - Route running h'graph downstream
2, .500,  -99                   ,Reach 8 node 5        Sub-area E101, Reach  - Generate rainfall excess h'graph, add to
running h'graph, and route downstream
7.2                             ,                      PRINT
E10_discharge
5, 2.600,  -99                  ,Reach 14              Reach  - Route running h'graph downstream
3                               ,                      Store running hydrograph
1, .500,  -99                   ,Reach 7 node 4        Sub-area E091, Reach  - Generate rainfall excess h'graph and route
downstream
7.2                             ,                      PRINT
E09_discharge
5, 2.600,  -99                  ,Reach 13              Reach  - Route running h'graph downstream
4                               ,                      Add running h'graph to last stored h'graph
2, 3.400,  -99                  ,Reach 21 node 25      Sub-area I24, Reach  - Generate rainfall excess h'graph, add to
running h'graph, and route downstream
7.2                             ,                      PRINT
I24_discharge
5, .200,  -99                   ,Reach 30              Reach  - Route running h'graph downstream
4                               ,                      Add running h'graph to last stored h'graph
5, 1.600,  -99                  ,Reach 39              Reach  - Route running h'graph downstream
3                               ,                      Store running hydrograph
1, 1.900,  -99                  ,Reach 22 node 26      Sub-area I23, Reach  - Generate rainfall excess h'graph and route
downstream
7.2                             ,                      PRINT
I23_discharge
5, .200,  -99                   ,Reach 31              Reach  - Route running h'graph downstream
4                               ,                      Add running h'graph to last stored h'graph
5, 1.900,  -99                  ,Reach 40              Reach  - Route running h'graph downstream
3                               ,                      Store running hydrograph
1, 1.000,  -99                  ,Reach 9 node 6        Sub-area E111, Reach  - Generate rainfall excess h'graph and route
downstream
7.2                             ,                      PRINT
E11_discharge
5, 3.500,  -99                  ,Reach 15              Reach  - Route running h'graph downstream
2, 2.700,  -99                  ,Reach 23 node 27      Sub-area I22, Reach  - Generate rainfall excess h'graph, add to
running h'graph, and route downstream
7.2                             ,                      PRINT
I22_discharge
5, .200,  -99                   ,Reach 32              Reach  - Route running h'graph downstream
4                               ,                      Add running h'graph to last stored h'graph
5, 1.000,  -99                  ,Reach 41              Reach  - Route running h'graph downstream
3                               ,                      Store running hydrograph
1, 2.800,  -99                  ,Reach 24 node 28      Sub-area I21, Reach  - Generate rainfall excess h'graph and route
downstream
7.2                             ,                      PRINT
I21_discharge
5, .200,  -99                   ,Reach 33              Reach  - Route running h'graph downstream
4                               ,                      Add running h'graph to last stored h'graph
5, 3.300,  -99                  ,Reach 42              Reach  - Route running h'graph downstream
3                               ,                      Store running hydrograph
1, 1.600,  -99                  ,Reach 45 node 49      Sub-area I19, Reach  - Generate rainfall excess h'graph and route
downstream
7.2                             ,                      PRINT
I19_discharge
5, .200,  -99                   ,Reach 64              Reach  - Route running h'graph downstream
```

```
3                        ,                    Store running hydrograph
1, 4.200, -99            ,Reach 44 node 50    Sub-area I02, Reach - Generate rainfall excess h'graph and route
downstream
7.2                      ,                    PRINT
I02_discharge
5, 2.600, -99            ,Reach 63            Reach - Route running h'graph downstream
4                        ,                    Add running h'graph to last stored h'graph
5, 1.000, -99            ,Reach 67            Reach - Route running h'graph downstream
3                        ,                    Store running hydrograph
1, 1.600, -99            ,Reach 46 node 48    Sub-area I17, Reach - Generate rainfall excess h'graph and route
downstream
7.2                      ,                    PRINT
I17_discharge
5, .200, -99             ,Reach 65            Reach - Route running h'graph downstream
4                        ,                    Add running h'graph to last stored h'graph
3                        ,                    Store running hydrograph
1, 2.500, -99            ,Reach 47 node 51    Sub-area I18, Reach - Generate rainfall excess h'graph and route
downstream
7.2                      ,                    PRINT
I18_Discharge
5, .200, -99             ,Reach 66            Reach - Route running h'graph downstream
4                        ,                    Add running h'graph to last stored h'graph
7                        ,                    PRINT
Oakford US
5, 1.200, -99            ,Reach 68            Reach - Route running h'graph downstream
3                        ,                    Store running hydrograph
1, 3.300, -99            ,Reach 49 node 52    Sub-area I16, Reach - Generate rainfall excess h'graph and route
downstream
7.2                      ,                    PRINT
I16_discharge
5, .200, -99             ,Reach 69            Reach - Route running h'graph downstream
4                        ,                    Add running h'graph to last stored h'graph
5, .500, -99             ,Reach 84            Reach - Route running h'graph downstream
3                        ,                    Store running hydrograph
1, 2.700, -99            ,Reach 48 node 53    Sub-area I15, Reach - Generate rainfall excess h'graph and route
downstream
7.2                      ,                    PRINT
I15_discharge
5, .200, -99             ,Reach 71            Reach - Route running h'graph downstream
4                        ,                    Add running h'graph to last stored h'graph
3                        ,                    Store running hydrograph
1, 1.400, -99            ,Reach 50 node 54    Sub-area I14, Reach - Generate rainfall excess h'graph and route
downstream
7.2                      ,                    PRINT
I14_discharge
5, .200, -99             ,Reach 70            Reach - Route running h'graph downstream
4                        ,                    Add running h'graph to last stored h'graph
7                        ,                    PRINT
Oakford DS
5, 1.500, -99            ,Reach 85            Reach - Route running h'graph downstream
3                        ,                    Store running hydrograph
1, 1.300, -99            ,Reach 53 node 55    Sub-area I13, Reach - Generate rainfall excess h'graph and route
downstream
7.2                      ,                    PRINT
I13_discharge
5, .200, -99             ,Reach 72            Reach - Route running h'graph downstream
4                        ,                    Add running h'graph to last stored h'graph
5, .900, -99             ,Reach 86            Reach - Route running h'graph downstream
3                        ,                    Store running hydrograph
1, 2.400, -99            ,Reach 52 node 56    Sub-area I12, Reach - Generate rainfall excess h'graph and route
downstream
7.2                      ,                    PRINT
I12_discharge
5, .200, -99             ,Reach 73            Reach - Route running h'graph downstream
4                        ,                    Add running h'graph to last stored h'graph
3                        ,                    Store running hydrograph
1, 2.800, -99            ,Reach 51 node 58    Sub-area I11, Reach - Generate rainfall excess h'graph and route
downstream
7.2                      ,                    PRINT
I11_discharge
5, .200, -99             ,Reach 74            Reach - Route running h'graph downstream
4                        ,                    Add running h'graph to last stored h'graph
5, .800, -99             ,Reach 87            Reach - Route running h'graph downstream
3                        ,                    Store running hydrograph
1, 1.300, -99            ,Reach 54 node 59    Sub-area I10, Reach - Generate rainfall excess h'graph and route
downstream
7.2                      ,                    PRINT
I10_discharge
5, .200, -99             ,Reach 75            Reach - Route running h'graph downstream
4                        ,                    Add running h'graph to last stored h'graph
5, 1.600, -99            ,Reach 88            Reach - Route running h'graph downstream
3                        ,                    Store running hydrograph
1, 2.000, -99            ,Reach 55 node 57    Sub-area I09, Reach - Generate rainfall excess h'graph and route
downstream
7.2                      ,                    PRINT
I09_discharge
5, .200, -99             ,Reach 76            Reach - Route running h'graph downstream
4                        ,                    Add running h'graph to last stored h'graph
5, .700, -99             ,Reach 89            Reach - Route running h'graph downstream
3                        ,                    Store running hydrograph
1, 3.300, -99            ,Reach 56 node 60    Sub-area I08, Reach - Generate rainfall excess h'graph and route
downstream
7.2                      ,                    PRINT
I08_discharge
5, .200, -99             ,Reach 77            Reach - Route running h'graph downstream
4                        ,                    Add running h'graph to last stored h'graph
5, .900, -99             ,Reach 90            Reach - Route running h'graph downstream
3                        ,                    Store running hydrograph
1, .900, -99             ,Reach 59 node 61    Sub-area I07, Reach - Generate rainfall excess h'graph and route
downstream
7.2                      ,                    PRINT
I07_discharge
5, .200, -99             ,Reach 78            Reach - Route running h'graph downstream
4                        ,                    Add running h'graph to last stored h'graph
5, 2.100, -99            ,Reach 94            Reach - Route running h'graph downstream
3                        ,                    Store running hydrograph
1, 3.500, -99            ,Reach 62 node 62    Sub-area I04, Reach - Generate rainfall excess h'graph and route
downstream
7.2                      ,                    PRINT
I04_discharge
5, .200, -99             ,Reach 80            Reach - Route running h'graph downstream
4                        ,                    Add running h'graph to last stored h'graph
3                        ,                    Store running hydrograph
1, 2.300, -99            ,Reach 61 node 63    Sub-area I06, Reach - Generate rainfall excess h'graph and route
downstream
7.2                      ,                    PRINT
I06_discharge
5, .200, -99             ,Reach 79            Reach - Route running h'graph downstream
4                        ,                    Add running h'graph to last stored h'graph
5, 1.000, -99            ,Reach 91            Reach - Route running h'graph downstream
3                        ,                    Store running hydrograph
```

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1, 3.000,  -99                              ,Reach 57 node 64        Sub-area I05, Reach  - Generate rainfall excess h'graph and route
downstream
7.2                                         ,                        PRINT
I05_discharge
5, .200,  -99                               ,Reach 81                Reach  - Route running h'graph downstream
4                                           ,                        Add running h'graph to last stored h'graph
3                                           ,                        Store running hydrograph
1, .700,  -99                               ,Reach 60 node 65        Sub-area I03, Reach  - Generate rainfall excess h'graph and route
downstream
7.2                                         ,                        PRINT
I03_discharge
5, .200,  -99                               ,Reach 82                Reach  - Route running h'graph downstream
4                                           ,                        Add running h'graph to last stored h'graph
5, 1.000,  -99                              ,Reach 92                Reach  - Route running h'graph downstream
3                                           ,                        Store running hydrograph
1, 1.200,  -99                              ,Reach 58 node 66        Sub-area I01, Reach  - Generate rainfall excess h'graph and route
downstream
7.2                                         ,                        PRINT
I01_discharge
5, .200,  -99                               ,Reach 83                Reach  - Route running h'graph downstream
4                                           ,                        Add running h'graph to last stored h'graph
5, 1.700,  -99                              ,Reach 93                Reach  - Route running h'graph downstream
4                                           ,                        Add running h'graph to last stored h'graph
5, .000,  -99                               ,Reach 43                Reach  - Route running h'graph downstream
7                                           ,                        PRINT
Outflow
0
C Sub Area Data
C Areas, km**2, of subareas A,B...
   3.013,    2.830,    3.104,    3.564,   13.640,
   2.264,    1.259,    2.732,    7.660,    7.560,
   4.944,    2.310,    3.853,    3.693,    4.560,
   5.380,    0.643,    1.883,    0.994,    7.020,
   4.113,    3.293,    3.386,    2.700,    2.117,
   3.344,    0.767,   10.880,    7.830,    0.834,
   9.440,   14.100,    3.400,    6.170,    6.690,
   3.620,   12.000,    5.910,    2.390,    4.350,
   4.220,    5.390,    5.050,    7.160,    9.270,
   3.040,    4.970,    5.450,    6.340,    1.420,
   4.780,
 -99
C Impervious Fraction Data
0,  -99                                     ,No impervious areas in system
```

Appendix E - Bridge dimensions for Oaklands and Birrega Main Drains

Note: Bridge and culvert bases were taken from LiDAR data and not surveyed. This gives an estimated vertical accuracy of the invert levels of ± 30cm. Elevations of the culverts were modified to introduce slope to the culverts (approx. 20 cm)

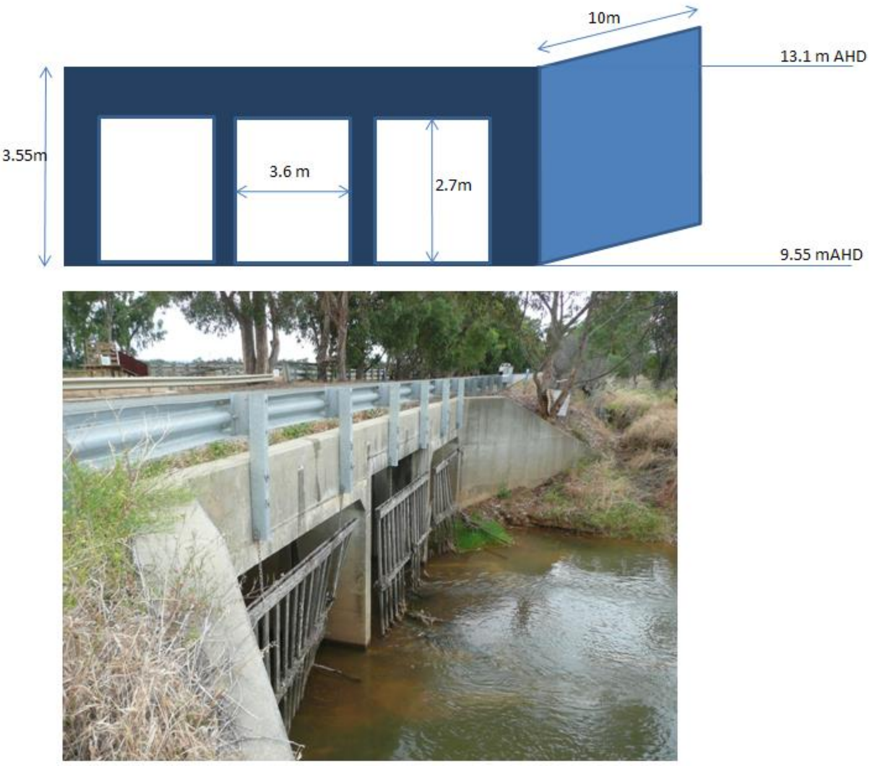


Figure E-1: *Bridge O1, DZ014325, Oaklands Main Drain, King Road*

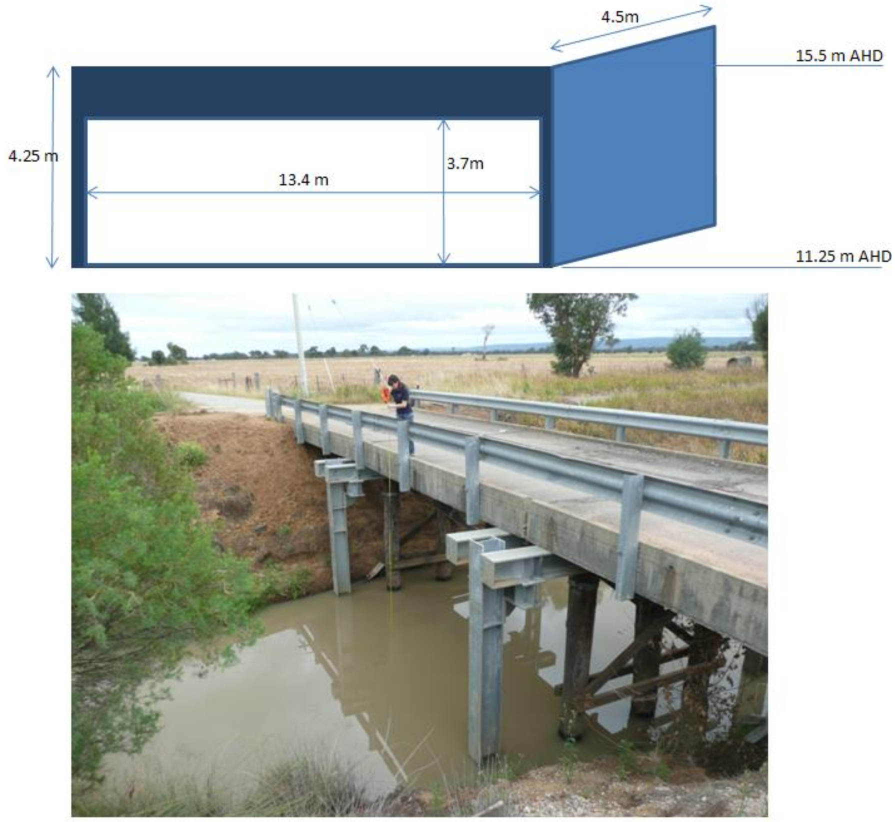


Figure E-2: *Bridge O2, DZ013625, Oaklands Main Drain, side road*

Figure E-3: *Bridge O3, DZ013626, Oaklands Main Drain, Leipold Road*

Figure E-4: *Bridge O4, DZ013627, Oaklands Main Drain, Kargotich Road*

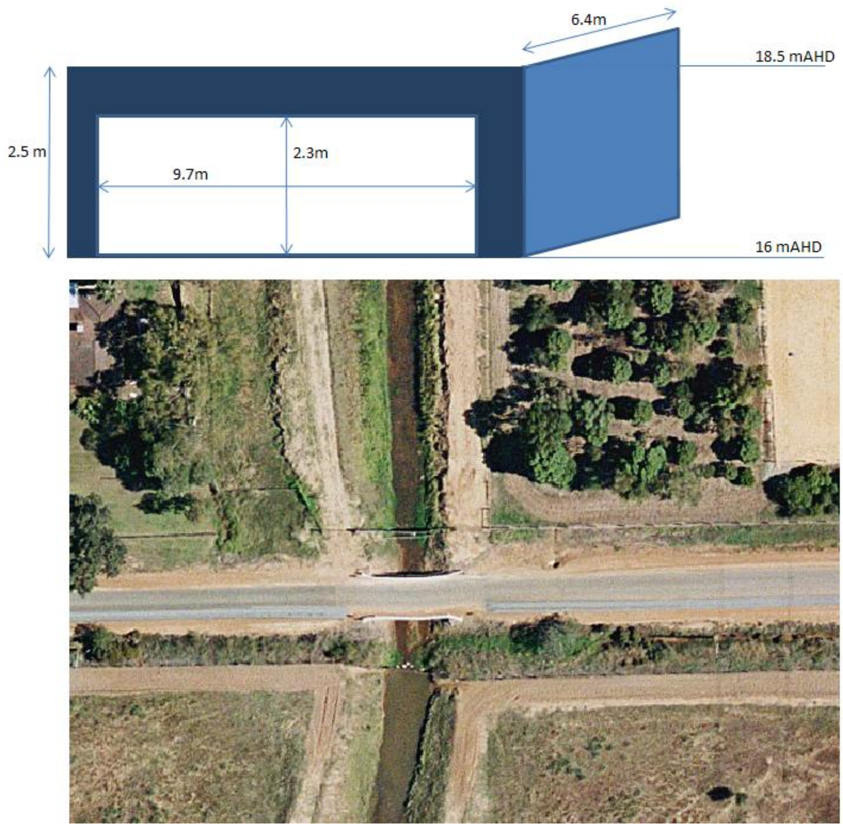


Figure E-5: *Bridge O5, DZ013628, Oaklands Main Drain, Gossage Road*

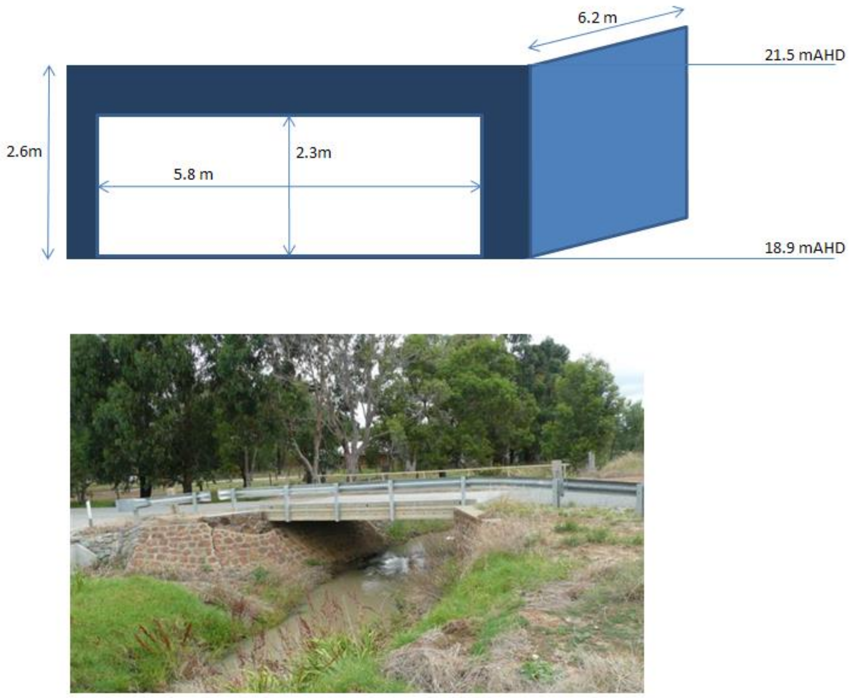


Figure E-6: *Bridge O6, DZ014287, Oaklands Main Drain, Orton Road*

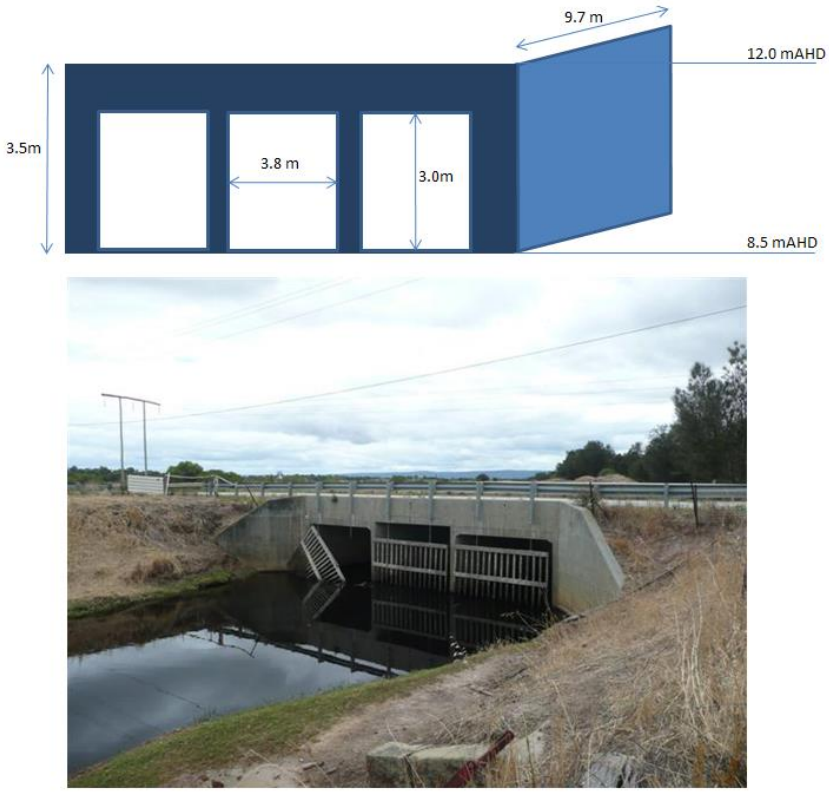


Figure E-7: *Bridge B1, DZ014325, Birrega Main Drain, King Road*

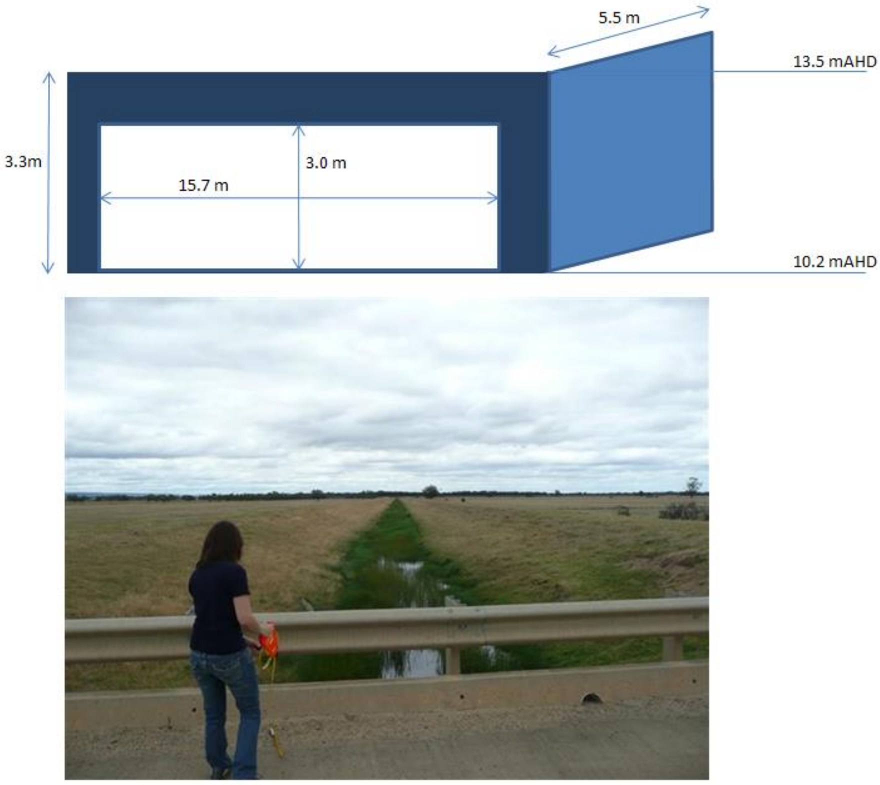


Figure E-8*: Bridge B1, DZ013629, Birrega Main Drain, Gossage Road*

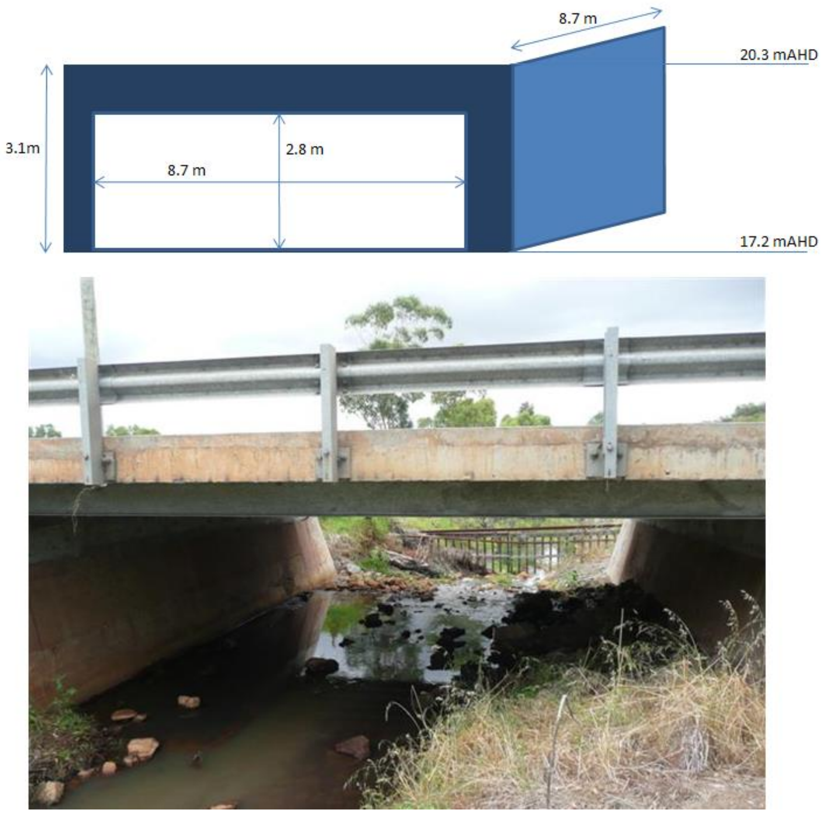


Figure E-9: *Bridge B9, Oakford, Birrega Main Drain, Thomas Road*

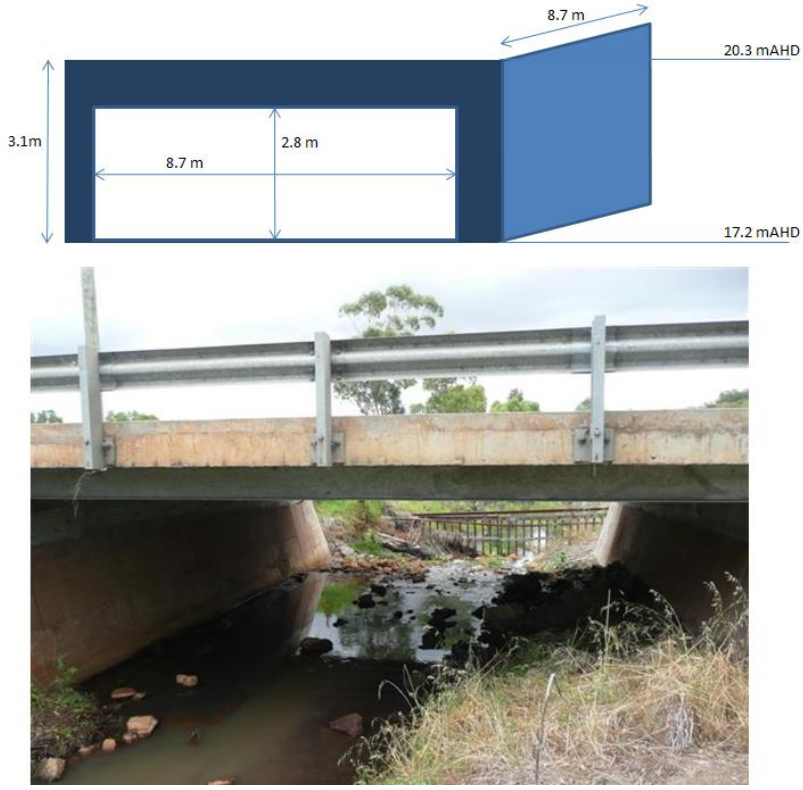


Figure E-10: *Bridge B4, Country Road, Birriga Main Drain*

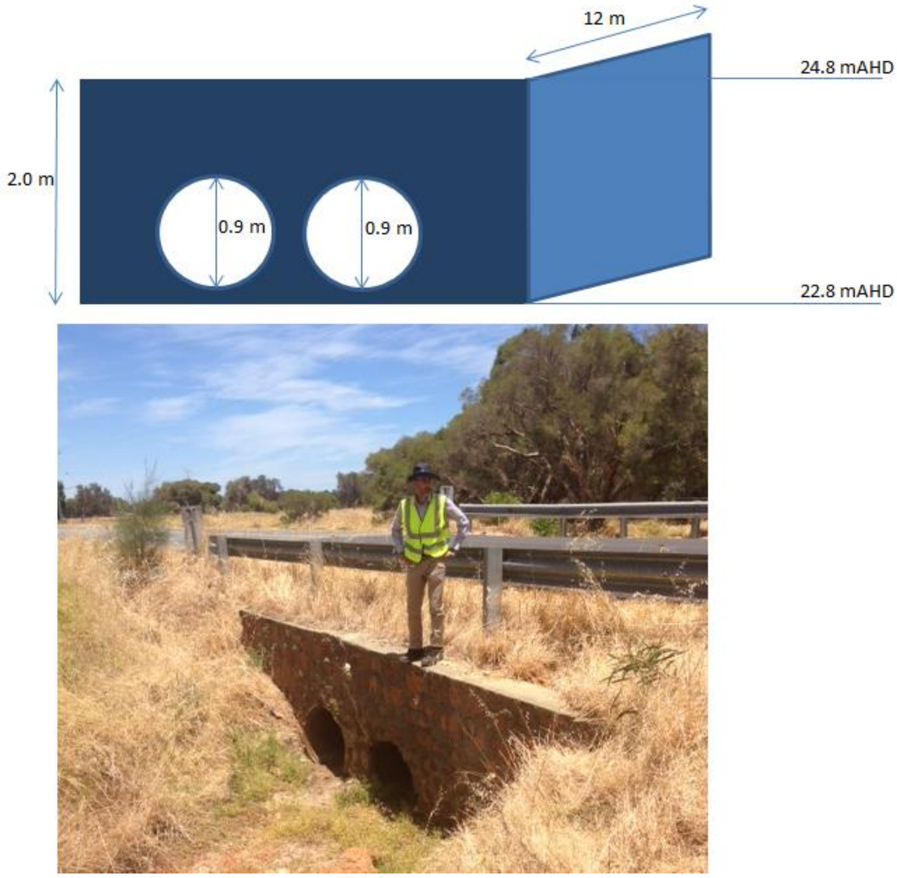


Figure E-11: *Bridge B5, Kargotich Road, Birriga Main Drain*

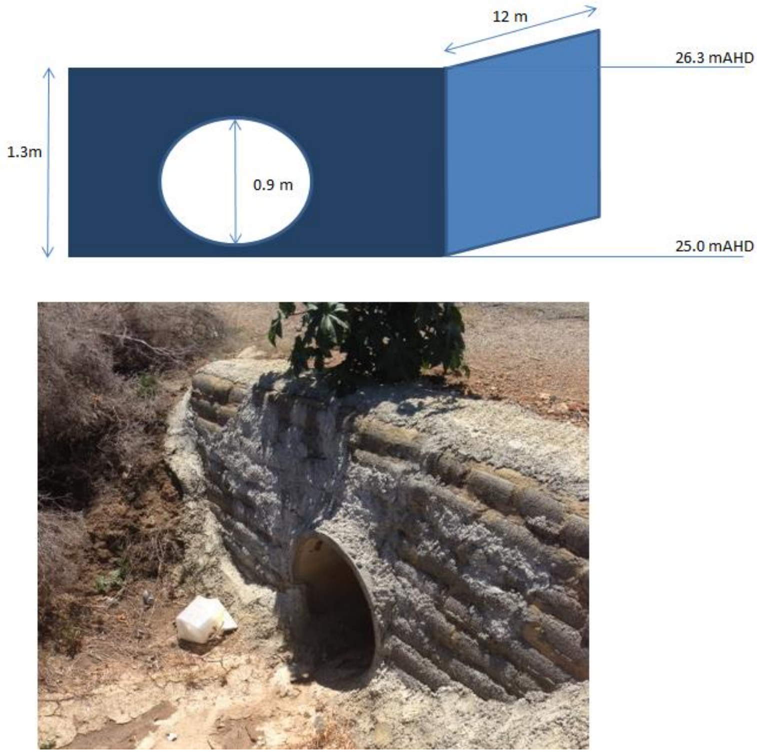


Figure E-12: *Bridge B6, Hopkinson Road, Birriga Main Drain*

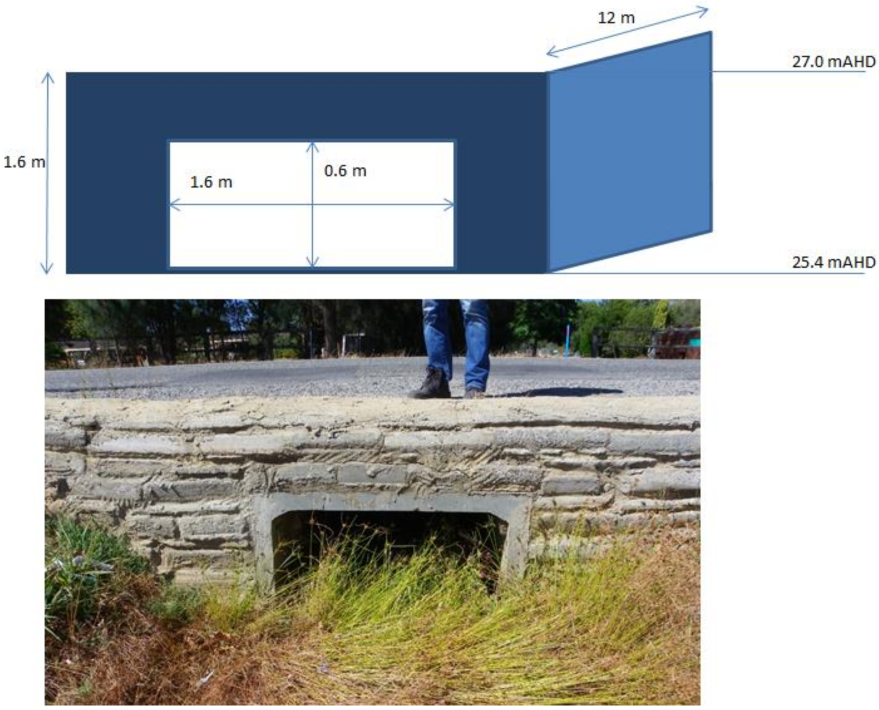


Figure E-13: *Bridge B7, Rowley Road, Birriga Main Drain*

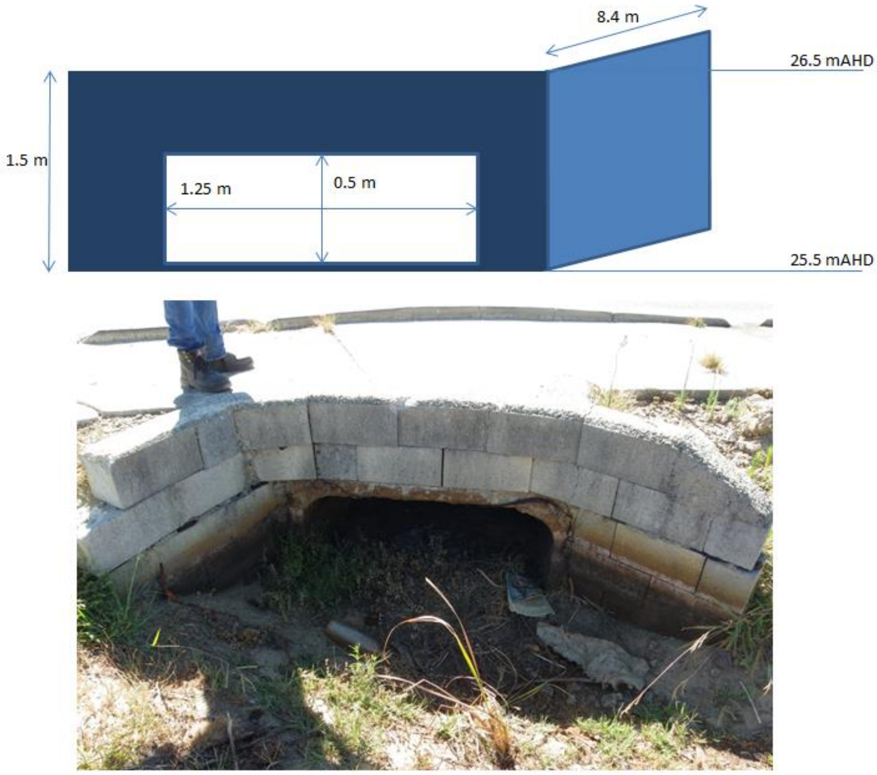


Figure E-14: *Culvert H1, Hopkinson Road, Birriga Main Drain*

Appendix F - Flood extent for 5, 10, 20, 100, 100 levee fail and 500 year ARI events

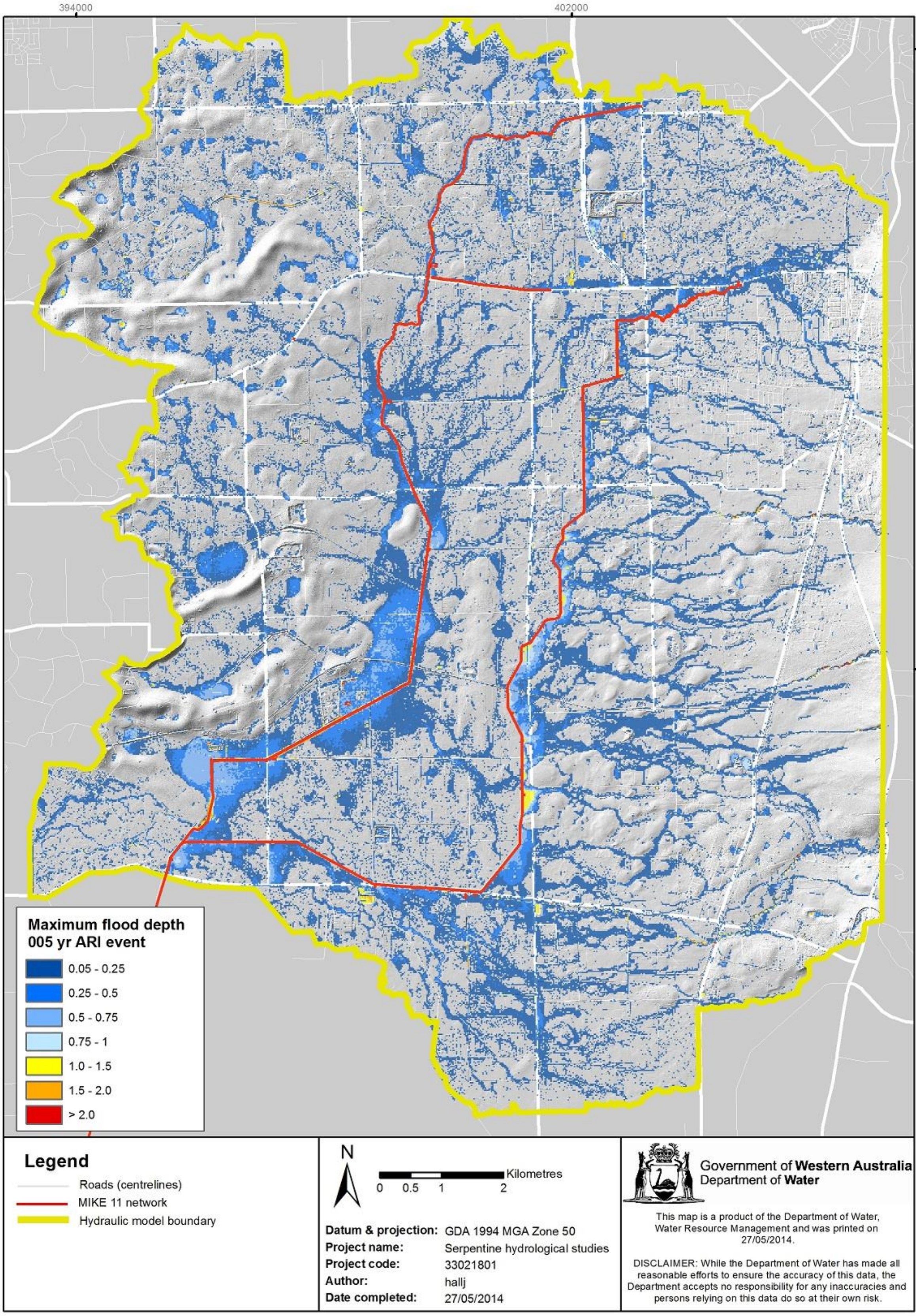


Figure F-1: *Floodplain mapping for the 5 year ARI event*

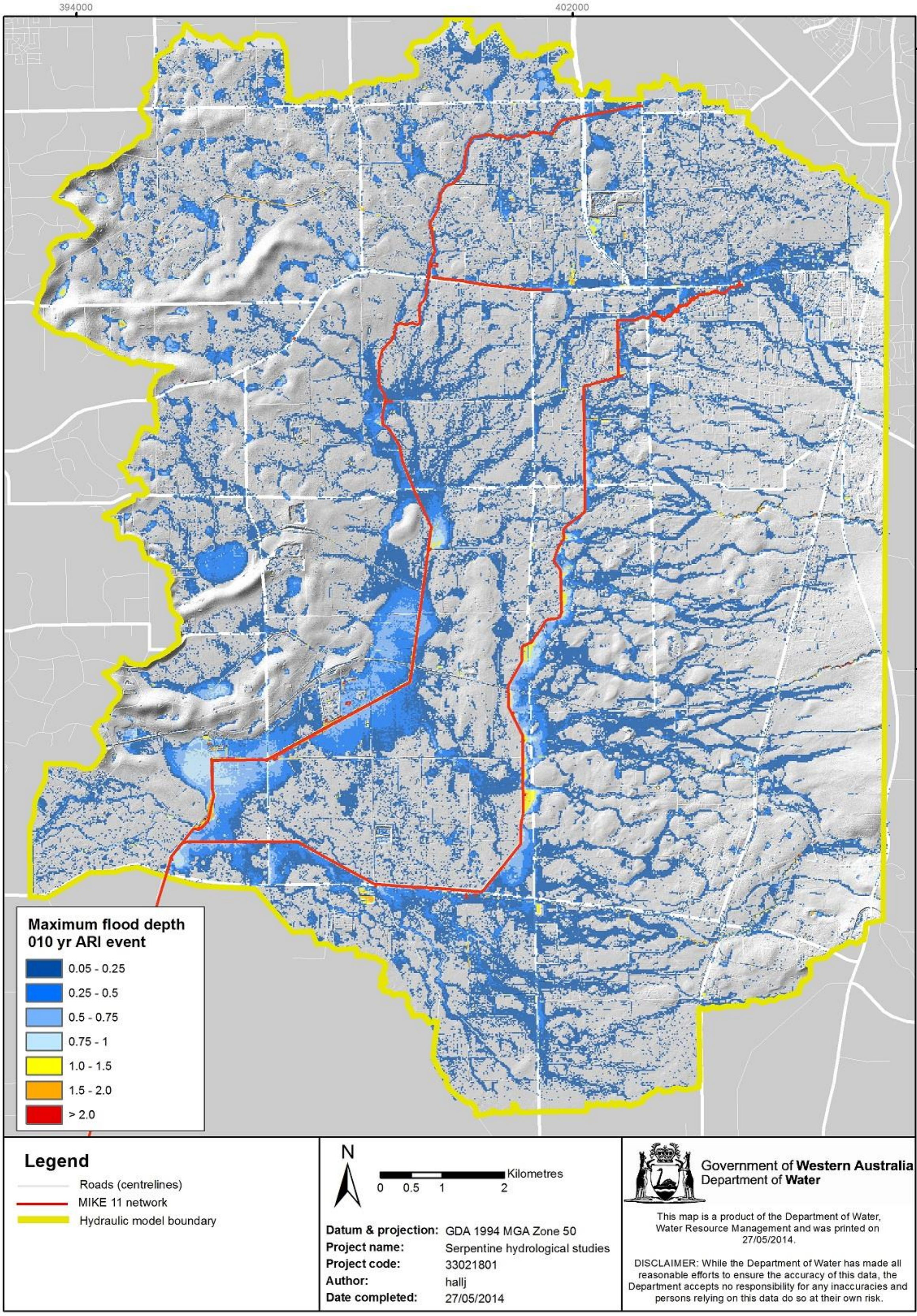


***Figure F-2**: Floodplain mapping for the 10 year ARI event*

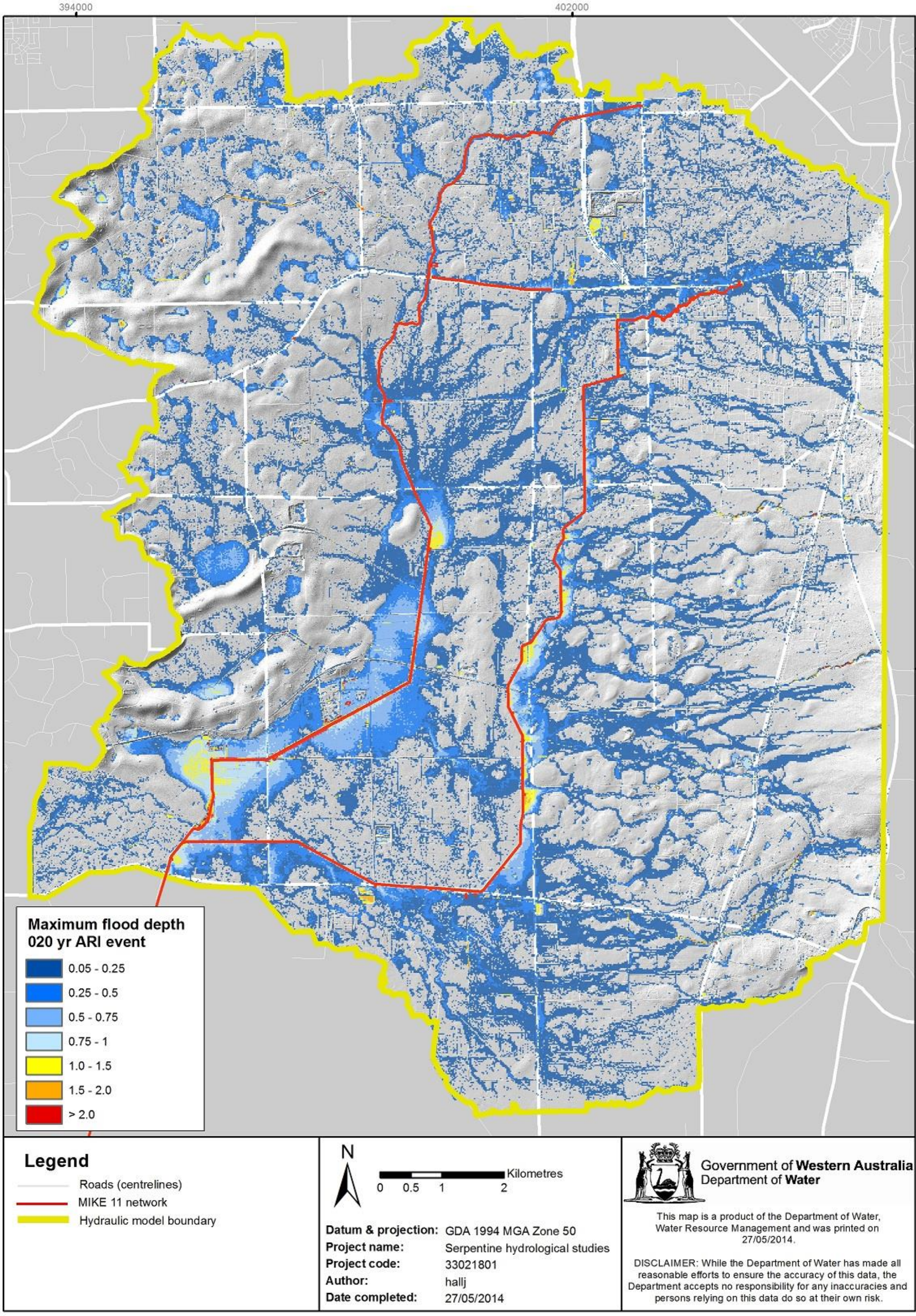


Figure F-3: *Floodplain mapping for the 20 year ARI event*

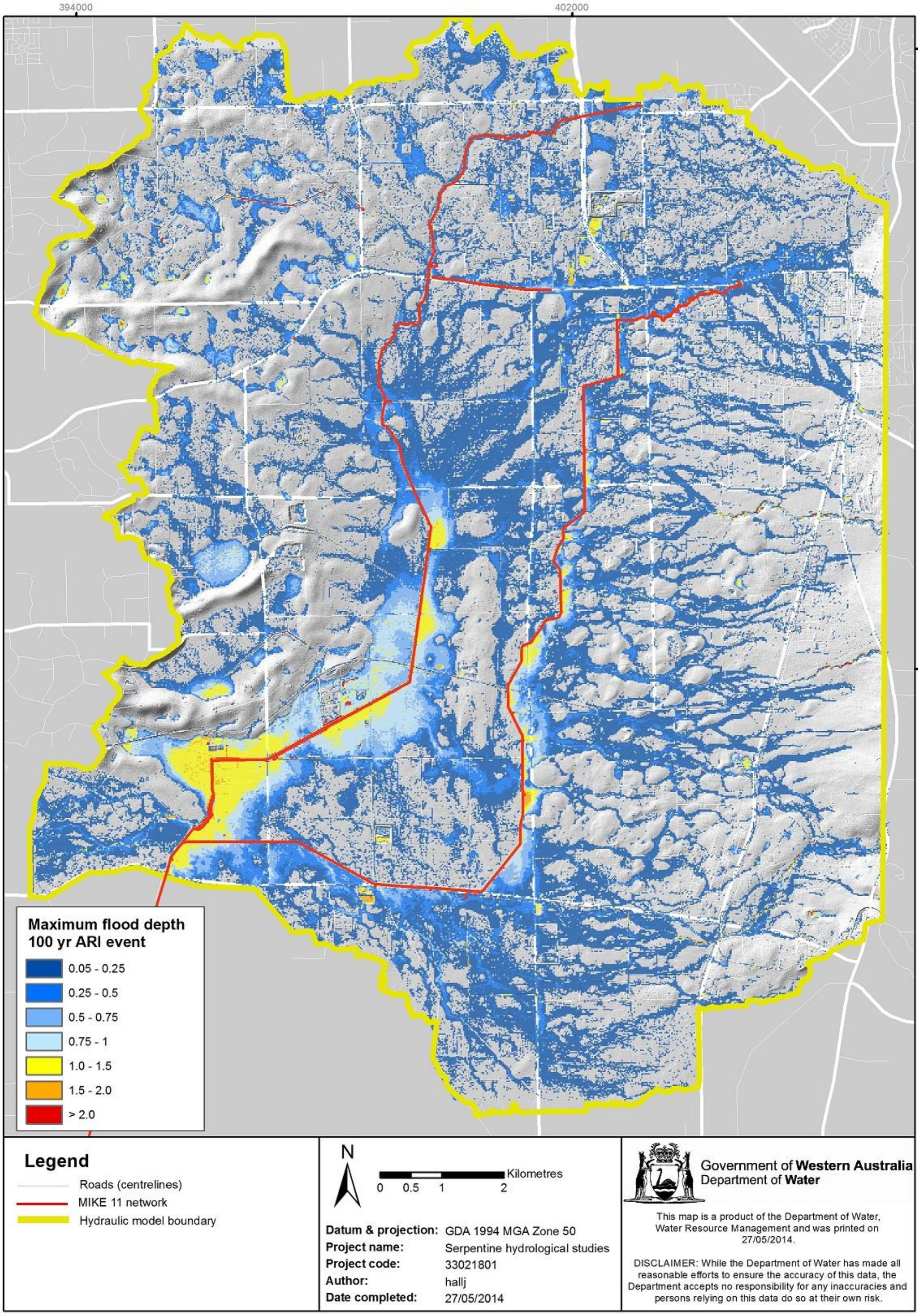


Figure F-4: *Floodplain mapping for the 100 year ARI event*

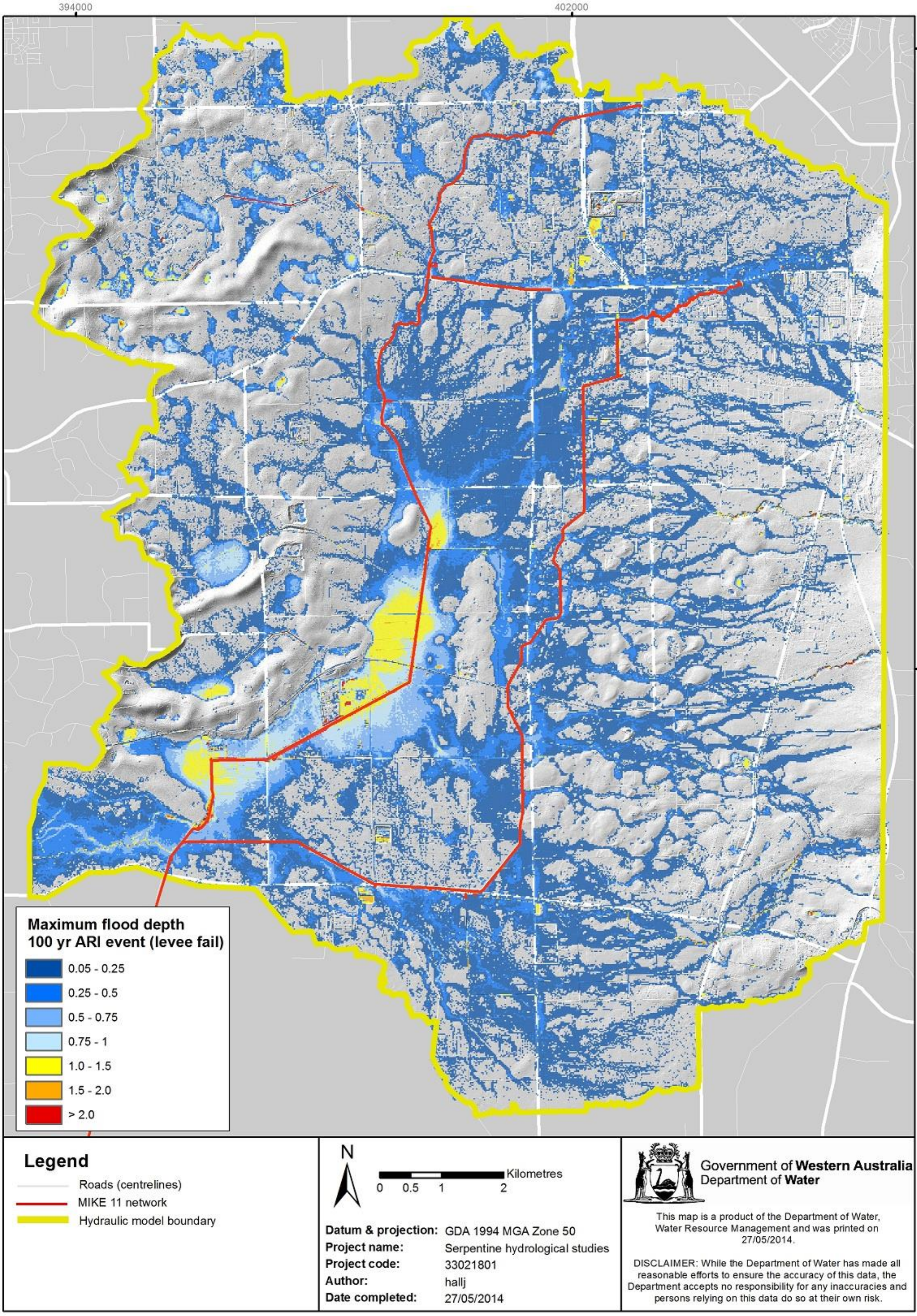


***Figure F-5**: Floodplain mapping for the 100 year ARI levee fail event*

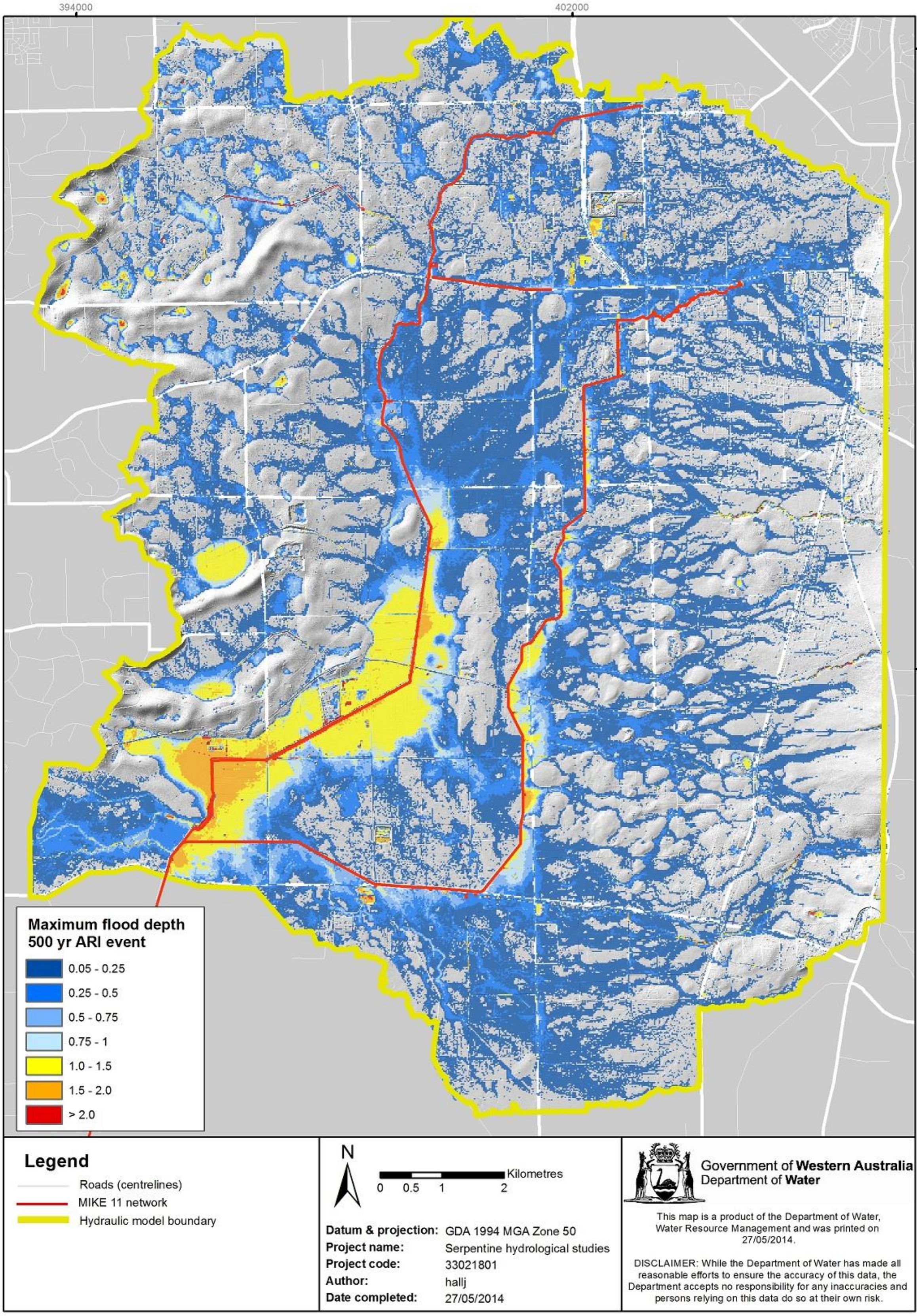
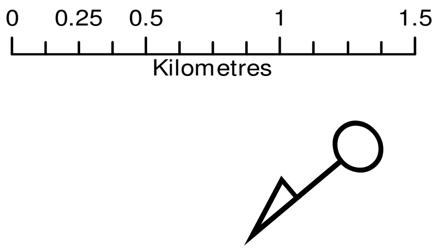
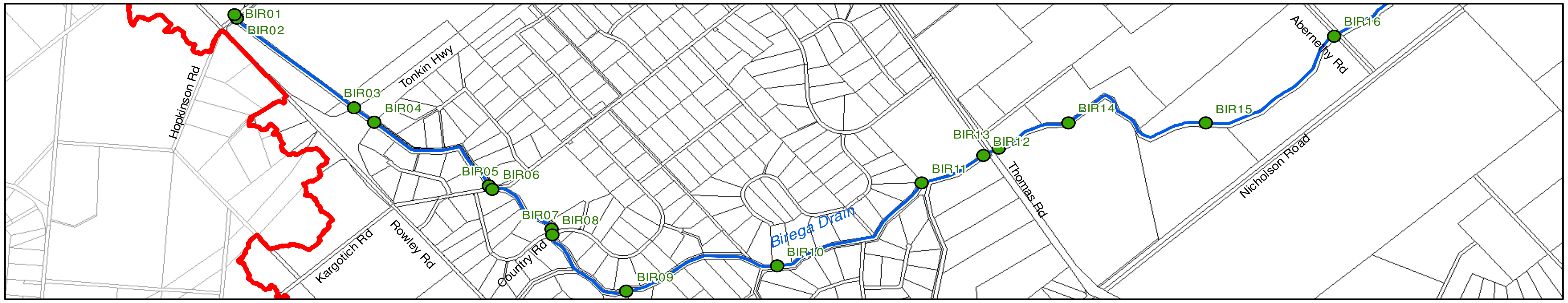


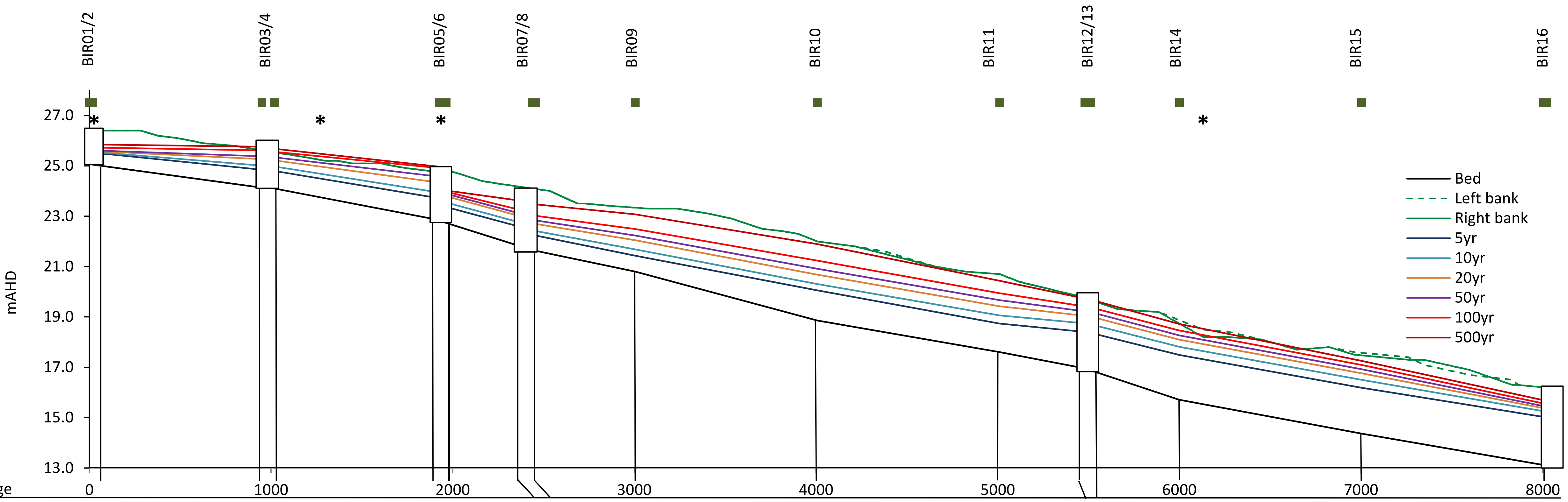
Figure F-6: *Floodplain mapping for the 500 year ARI event*

Appendix G - Long-sections for Birrega and Oaklands Main Drains

Vertical Datum: AHD
Horizontal Datum: GDA 94
Projection System: MGA Zone 50







Size (mm)	1 x 900		4 x 1200mm		2 x 900mm		2 x 1500mm					8700mm x 2800mm				9600mm x 3200mm
Chainage (m)	0	18	950	1018	1926	1964	2438	2458	3000	4000	5000	5479	5513	6000	7003	8004
Left bank level (mAHD)	26.12	26.40	24.84	24.79	23.71	23.37	22.45	22.23	21.43	20.05	18.74	18.40	18.37	17.49	16.19	15.03
Right bank level (mAHD)	26.21	26.40	25.01	24.97	23.94	23.55	22.62	22.41	21.68	20.31	19.06	18.74	18.71	17.81	16.50	15.26
5 year ARI HGL (mAHD)	26.31	25.53	25.26	25.22	24.34	23.79	22.87	22.69	22.05	20.68	19.42	19.05	19.01	18.10	16.76	15.38
10 year ARI HGL (mAHD)	26.32	25.56	25.38	25.34	24.57	23.89	22.98	22.83	22.23	20.91	19.66	19.22	19.19	18.27	16.93	15.46
20 year ARI HGL (mAHD)	26.35	25.59	25.61	25.56	24.91	23.97	23.13	23.01	22.49	21.24	19.94	19.42	19.38	18.46	17.10	15.56
50 year ARI HGL (mAHD)	26.42	25.61	25.76	25.68	24.97	24.02	23.55	23.47	23.08	21.89	20.44	19.73	19.68	18.72	17.26	15.70
100 year ARI HGL (mAHD)	26.04	25.73	25.65	25.58	24.30	24.25	23.23	23.21	22.51	21.17	19.86	19.40	19.36	18.43	17.08	15.55
500 year ARI HGL (mAHD)	26.15	25.85	25.80	25.71	24.52	24.47	23.60	23.58	23.02	21.78	20.35	19.73	19.69	18.72	17.27	15.70
Invert level (mAHD)	25.09	24.14	24.14	24.10	22.85	22.73	21.66	21.63	20.80	18.85	17.61	16.96	16.88	15.71	14.37	13.12
5 year ARI flow (m^3/s)	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.99	2.45	2.78	2.80	7.67	7.67	7.90	10.30
10 year ARI flow (m^3/s)	1.07	1.07	1.06	1.46	1.61	1.61	1.60	1.60	2.01	3.91	4.34	4.38	11.35	11.35	11.72	12.91
20 year ARI flow (m^3/s)	1.23	1.23	1.63	2.73	2.89	2.89	2.89	2.89	4.13	6.90	7.38	7.44	15.63	15.62	16.26	14.26
50 year ARI flow (m^3/s)	1.24	1.24	2.05	3.39	3.53	3.53	3.53	3.53	5.55	9.26	9.86	9.88	18.63	18.63	19.50	14.96
100 year ARI flow (m^3/s)	1.29	1.29	3.21	5.05	4.59	4.12	4.12	4.12	7.97	13.28	14.05	14.07	22.17	22.16	23.20	15.65
500 year ARI flow (m^3/s)	1.38	1.38	5.62	8.30	5.01	4.18	4.22	4.22	14.55	23.95	25.21	25.21	29.54	29.14	26.97	18.16

* indicates flooding during a 100yr storm event

Birrega Drain - Hopkinson Road to Abernethy Road

LONGITUDINAL SECTION

Pre-development HGLs & flows

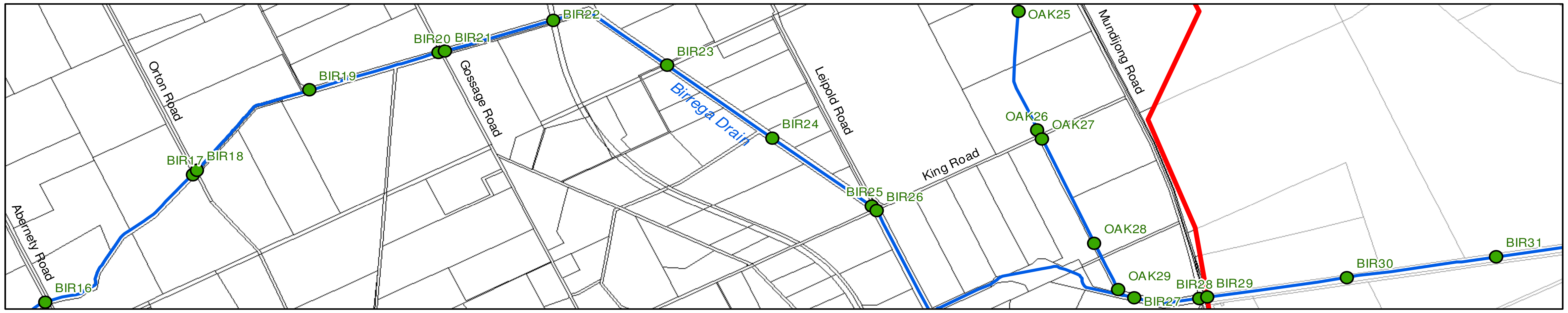
Figure E-1

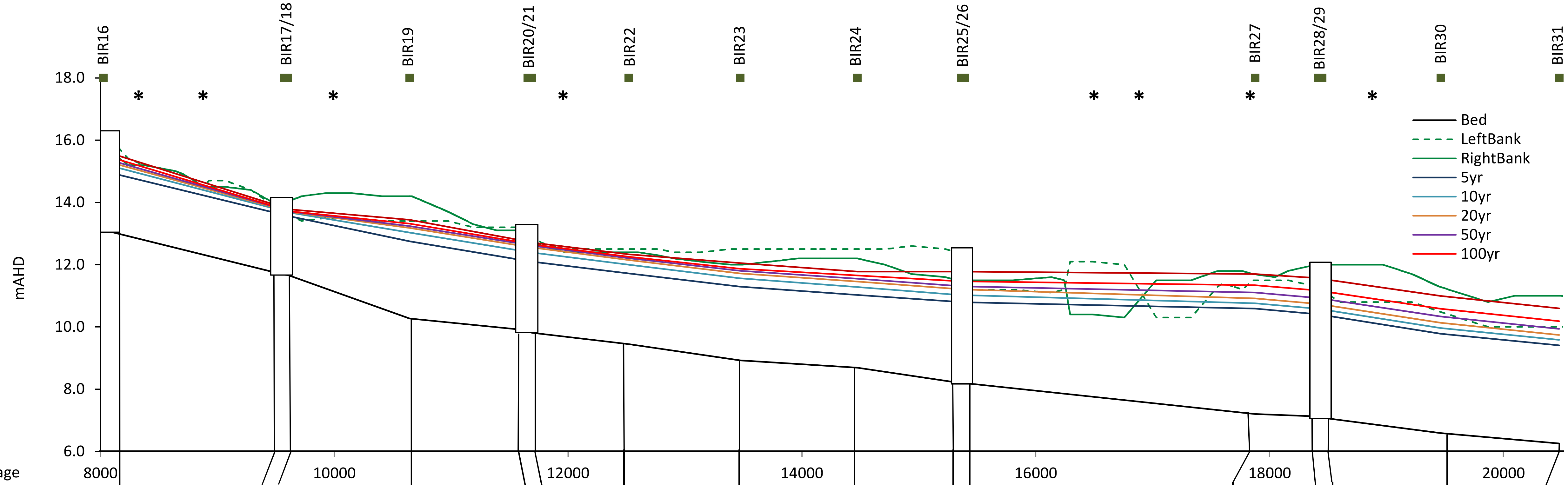
Author: J. Hall

Date: 22/04/2014

The Department of Water acknowledges the following datasets and their custodians in the analysis of data and production of the maps: Water Corporation Pipes, Water Corporation, 2009; Cadastre, Landgate, 2013.

Vertical Datum: AHD
Horizontal Datum: GDA 94
Projection System: MGA Zone 50





Chainage (m)	8023	9570	9603	10645	11655	11690	12517	13471	14474	15361	15394	17875	18414	18449	19465	20477
Left bank level (mAHD)	16.20	13.70	13.63	13.40	14.99	12.91	12.50	12.50	12.50	11.20	11.20	11.50	11.26	11.18	10.48	10.00
Right bank level (mAHD)	16.20	13.98	14.03	14.20	14.89	12.81	12.40	12.00	12.20	11.50	11.50	11.69	12.00	12.00	11.28	11.00
5 year ARI HGL (mAHD)	15.01	13.60	13.56	12.75	12.12	12.10	11.72	11.29	11.02	10.80	10.79	10.59	10.41	10.39	9.78	9.41
10 year ARI HGL (mAHD)	15.24	13.73	13.68	13.03	12.41	12.39	12.00	11.56	11.28	11.02	11.02	10.76	10.58	10.56	9.97	9.58
20 year ARI HGL (mAHD)	15.35	13.76	13.71	13.18	12.58	12.55	12.15	11.72	11.46	11.21	11.21	10.92	10.74	10.72	10.13	9.74
50 year ARI HGL (mAHD)	15.42	13.77	13.72	13.24	12.64	12.61	12.21	11.81	11.55	11.31	11.30	11.11	10.93	10.91	10.33	9.94
100 year ARI HGL (mAHD)	15.53	13.78	13.72	13.32	12.68	12.66	12.26	11.87	11.65	11.47	11.47	11.34	11.17	11.15	10.58	10.19
500 year ARI HGL (mAHD)	15.66	13.84	13.78	13.45	12.74	12.71	12.33	12.05	11.78	11.78	11.78	11.70	11.57	11.54	10.99	10.59
Invert level (mAHD)	13.12	11.68	11.67	10.27	9.89	9.81	9.45	8.93	8.69	8.19	8.19	7.20	7.12	7.08	6.59	6.26
5 year ARI flow (m^3/s)	10.30	10.24	10.24	16.48	16.44	16.43	16.39	16.31	17.87	17.86	17.86	35.18	42.43	42.43	42.40	42.37
10 year ARI flow (m^3/s)	12.91	12.90	12.62	21.68	21.59	21.59	21.51	21.38	23.91	23.90	23.90	37.74	48.23	48.23	48.18	48.14
20 year ARI flow (m^3/s)	14.26	14.33	13.38	24.83	24.72	24.71	24.61	24.43	29.14	29.13	29.13	41.06	53.92	53.91	53.88	53.85
50 year ARI flow (m^3/s)	14.96	15.11	13.70	26.19	26.09	26.09	25.86	25.64	25.24	31.64	31.63	44.04	61.20	61.20	61.18	61.16
100 year ARI flow (m^3/s)	15.65	15.59	13.90	28.17	28.15	28.15	26.70	26.39	25.90	34.73	34.32	45.47	71.26	71.26	71.21	71.17
500 year ARI flow (m^3/s)	18.16	16.51	14.22	32.20	32.18	32.18	27.27	26.84	26.18	45.93	44.19	45.80	91.43	91.43	91.35	91.29

* indicates flooding during a 100yr storm event

Birrega Main Drain - Abernethy Road to Mundijong Road

LONGITUDINAL SECTION

Pre-development HGLs & flows

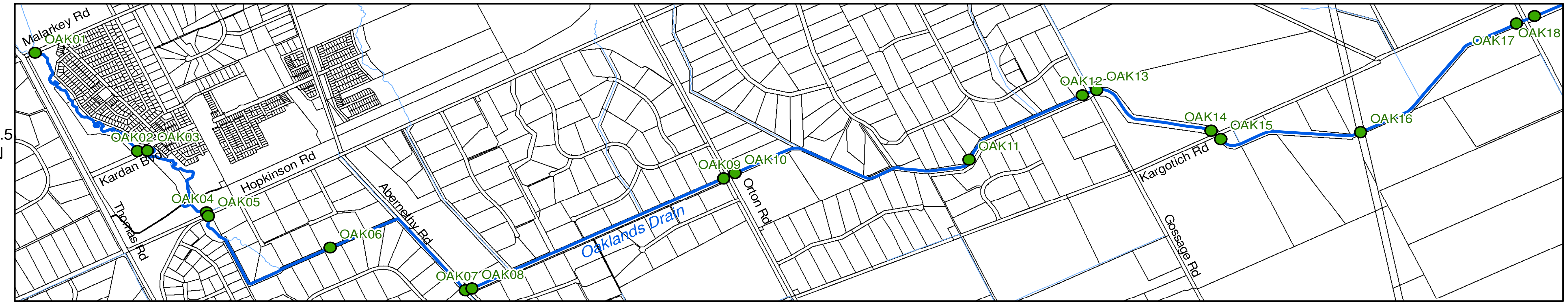
Figure E-2

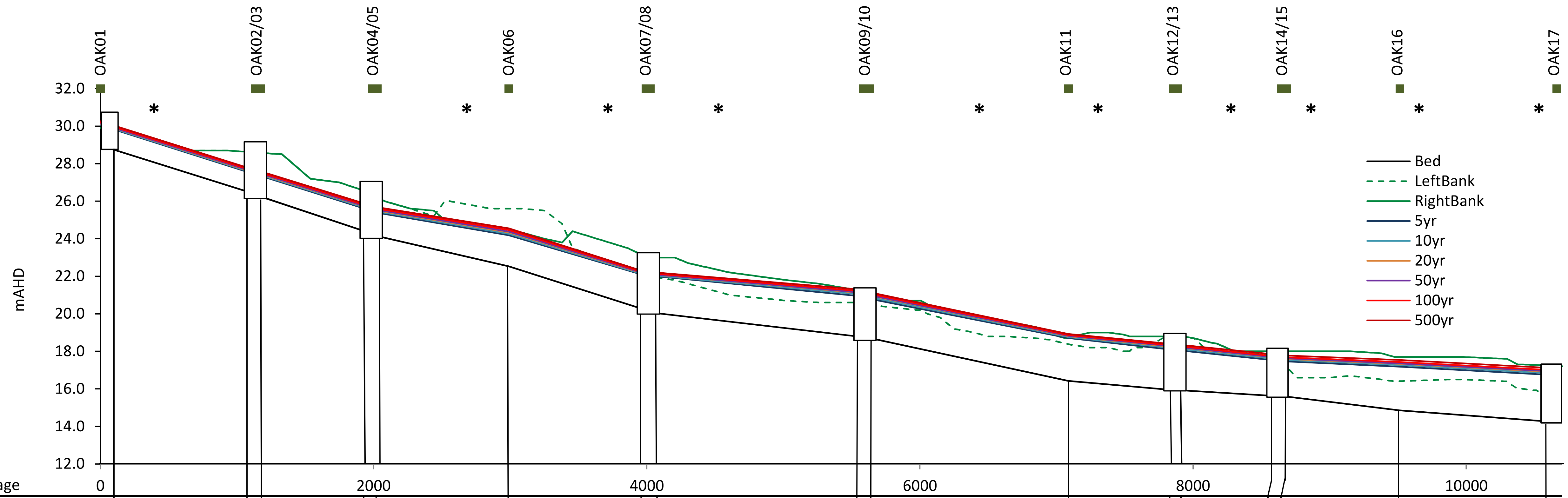
J.Hall
Date:22/4/2014

The Department of Water acknowledges the following datasets and their custodians in the analysis of data and production of maps: Water Corporation Pipes, Water Corporation, 2009; Cadastre, Landgate, 2013

Vertical Datum: AHD
Horizontal Datum: GDA 94
Projection System: MGA Zone 50

0 0.25 0.5 1 1.5
Kilometres





Chainage (m)	0	1132	1171	1991	2000	2990	3992	4026	5582	5634	7087	7854	7887	8646	8683	9514	10663
Left bank level (mAHD)	29.90	28.60	28.58	26.36	26.21	25.60	22.15	21.98	20.55	20.51	18.38	18.83	18.80	17.50	17.50	16.41	15.68
Right bank level (mAHD)	29.90	28.60	28.58	26.36	26.21	24.35	23.05	23.00	21.15	21.04	18.73	18.80	18.80	18.00	18.00	17.70	17.22
5 year ARI HGL (mAHD)	30.06	27.43	27.36	25.47	25.39	24.18	22.03	22.03	20.93	20.79	18.71	18.08	18.06	17.49	17.46	17.18	16.73
10 year ARI HGL (mAHD)	30.09	27.47	27.40	25.53	25.45	24.26	22.07	22.06	21.02	20.89	18.77	18.17	18.14	17.56	17.54	17.26	16.81
20 year ARI HGL (mAHD)	30.12	27.51	27.45	25.58	25.51	24.34	22.11	22.10	21.10	20.97	18.81	18.23	18.21	17.62	17.60	17.33	16.89
50 year ARI HGL (mAHD)	30.14	27.54	27.47	25.61	25.54	24.38	22.13	22.12	21.12	21.00	18.83	18.26	18.24	17.65	17.62	17.36	16.92
100 year ARI HGL (mAHD)	30.19	27.59	27.53	25.67	25.60	24.47	22.17	22.17	21.20	21.07	18.87	18.31	18.29	17.70	17.68	17.43	16.99
500 year ARI HGL (mAHD)	30.25	27.66	27.60	25.74	25.68	24.56	22.23	22.23	21.28	21.14	18.92	18.39	18.36	17.80	17.78	17.54	17.10
Invert level (mAHD)	28.97	26.38	26.25	24.26	24.14	22.52	20.20	20.07	18.76	18.71	16.42	15.94	15.93	15.60	15.59	14.85	14.23
5 year ARI flow (m^3/s)	6.80	6.63	6.62	6.51	6.49	6.31	10.53	10.52	10.67	16.81	11.79	16.49	16.49	16.45	16.44	12.19	16.19
10 year ARI flow (m^3/s)	7.41	7.26	7.25	7.16	7.14	7.05	12.85	12.69	11.31	18.62	12.32	18.11	18.11	18.03	18.03	13.71	17.73
20 year ARI flow (m^3/s)	8.11	7.96	7.95	7.94	7.93	7.91	14.27	13.93	11.85	19.79	12.69	19.45	19.45	18.88	18.86	15.12	19.27
50 year ARI flow (m^3/s)	8.43	8.41	8.41	8.39	8.39	8.34	14.82	14.36	12.02	20.29	12.82	20.09	20.09	19.19	19.18	15.70	19.88
100 year ARI flow (m^3/s)	9.51	9.48	9.48	9.46	9.46	9.40	15.70	15.04	12.81	22.11	13.09	21.61	21.61	19.90	19.87	16.70	21.53
500 year ARI flow (m^3/s)	10.96	10.93	10.92	10.90	10.90	10.84	16.50	15.68	14.57	24.99	13.34	24.13	24.12	21.75	21.66	18.20	25.01

* indicates flooding during a 100yr storm event

Oaklands Main Drain - Malarkey Road to Leipold Road

LONGITUDINAL SECTION

Pre-development HGLs & flows

Figure E-3

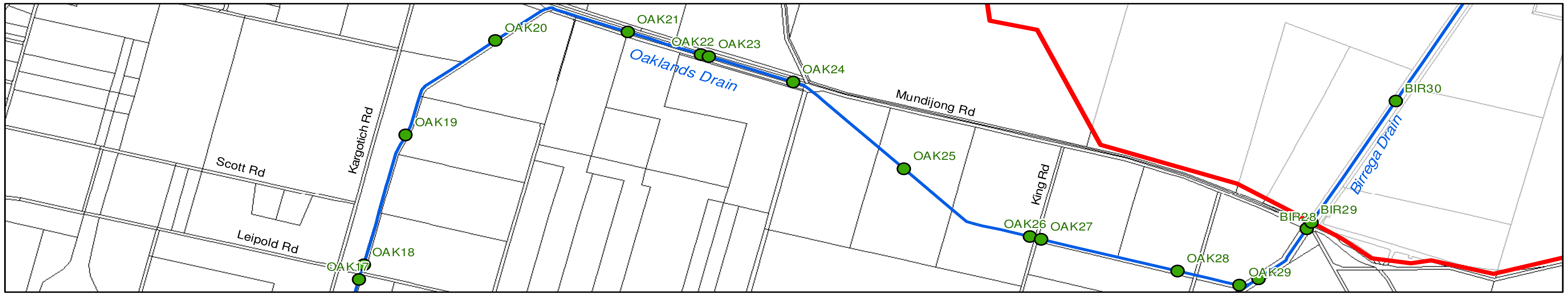
Author: J. Hall
Date: 22/04/2014

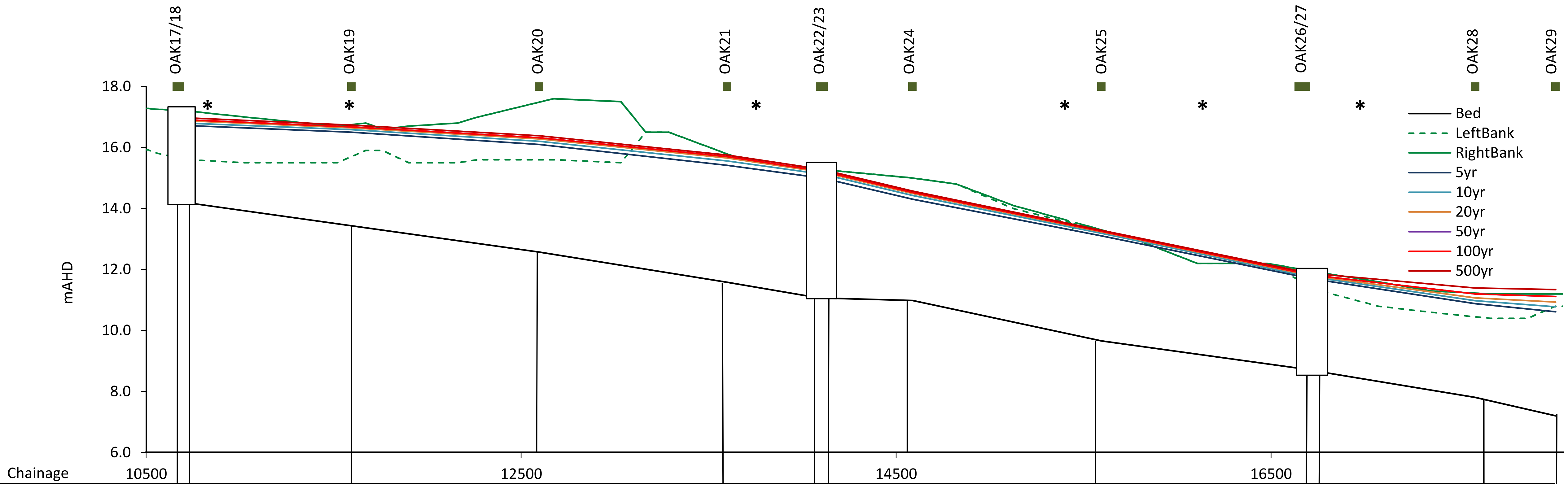
While the Department of Water has made all reasonable efforts to ensure the accuracy of this data, it accepts no responsibility for any inaccuracies and persons relying on this data do so at their own risk

The Department of Water acknowledges the following datasets and their custodians in the analysis of data and production of the maps: Water Corporation Pipes, Water Corporation, 2009; Cadastre, Landgate, 2013

Vertical Datum: AHD
Horizontal Datum: GDA 94
Projection System: MGA Zone 50

0 0.25 0.5 1 1.5
Kilometres





Chainage (m)	10663	10682	11594	12597	13598	14093	14113	14587	15595	16648	16686	17588	18017
Left bank level (mAHD)	15.68	15.65	15.70	15.60	15.79	15.30	15.30	15.00	13.27	11.66	11.54	10.45	10.80
Right bank level (mAHD)	17.22	17.21	16.75	17.49	15.79	15.30	15.30	15.00	13.30	12.02	11.98	11.23	11.20
5 year ARI HGL (mAHD)	16.73	16.73	16.50	16.10	15.42	15.01	14.99	14.31	13.10	11.78	11.73	10.88	10.61
10 year ARI HGL (mAHD)	16.81	16.81	16.58	16.20	15.56	15.13	15.12	14.43	13.19	11.84	11.78	10.98	10.78
20 year ARI HGL (mAHD)	16.89	16.88	16.65	16.28	15.65	15.20	15.18	14.49	13.23	11.88	11.82	11.07	10.93
50 year ARI HGL (mAHD)	16.92	16.91	16.68	16.32	15.70	15.24	15.21	14.52	13.25	11.91	11.85	11.20	11.12
100 year ARI HGL (mAHD)	16.99	16.98	16.73	16.39	15.75	15.29	15.27	14.57	13.29	11.95	11.89	11.39	11.35
500 year ARI HGL (mAHD)	17.10	17.09	16.82	16.49	15.79	15.32	15.30	14.61	13.32	12.03	11.97	11.73	11.71
Invert level (mAHD)	28.97	26.38	26.25	24.26	24.14	22.52	20.20	20.07	18.76	18.71	16.42	15.94	15.93
5 year ARI flow (m^3/s)	16.19	16.26	29.00	27.50	36.31	36.29	36.29	36.28	39.33	40.66	40.21	25.73	36.61
10 year ARI flow (m^3/s)	17.73	17.89	30.74	27.53	39.16	39.14	39.14	39.14	42.38	43.80	43.07	27.12	43.23
20 year ARI flow (m^3/s)	19.27	19.54	32.14	27.58	40.64	40.62	40.62	40.62	43.94	45.92	44.97	28.26	49.41
50 year ARI flow (m^3/s)	19.88	20.20	32.52	27.60	41.47	41.45	41.45	41.45	44.78	46.75	45.63	28.74	52.56
100 year ARI flow (m^3/s)	21.53	21.99	33.77	27.70	43.35	42.65	42.65	42.64	46.02	48.21	46.94	29.83	57.61
500 year ARI flow (m^3/s)	25.01	25.94	35.94	29.06	47.17	43.17	43.17	43.18	47.03	50.61	49.12	31.83	65.35

* indicates flooding during a 100yr storm event

Oaklands Main Drain - Leipold Road to Birrega Drain Confluence

LONGITUDINAL SECTION

Pre-development HGLs & flows

Figure E-4

Author: J. Hall
Date: 24/04/2014

The Department of Water acknowledges the following datasets and their custodians in the analysis of data and production of the maps: Water Corporation Pipes, Water Corporation, 2009; Cadastre, Landgate, 2013

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