Shire of Boddington
Floodplain Management Study

FLOOD MODELLING REPORT

The Boddington Shire Council endorsed the *Shire of Boddington Floodplain Management Study* at its meeting on 11 August 2009

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Executive Summary

Sinclair Knight Merz (SKM) was commissioned by the Shire of Boddington to undertake a Floodplain Management Study for an area of the Shire of Boddington, including the Hotham, Bannister and Crossman Rivers. The Boddington Shire Council endorsed the Shire of Boddington Floodplain Management Study at its meeting on 11 August 2009.

A review of available data, previous hydrologic and hydraulic modelling studies was undertaken with the following key findings:

- available terrain information was good quality and fit to purpose for both the hydrologic and the hydraulic assessment;
- good quality rainfall and streamflow data was available for calibration of the hydrologic model;
- no recorded flood levels or previous flood studies were available to calibrate a hydraulic model; and
- anecdotal flooding information was available to verify hydraulic modelling.

The quality of the available information gave confidence that the flood modelling process could be undertaken of a quality suitable for the purpose of the Floodplain Management Study.

A hydrologic model was calibrated to a number of historic rainfall events. This calibration showed the catchment runoff was highly dependent on the antecedent catchment characteristics at the time of the rainfall event. The design rainfall loss parameters were selected based on the calibration and in consultation with Department of Water (DoW). These hydrologic model parameters were validated using a regional flood frequency analysis.

Calibration of the hydraulic model was not possible as there were no previous flood studies or recorded flood levels. A verification of the hydraulic modelling results was undertaken based on anecdotal flooding information collected during the site visit. The hydraulic model was used to prepare flood mapping for the 10, 25 and 100 year average recurrence interval (ARI) events. The critical duration was found to be a combination of 24 and 36 hour duration storms.

The hydraulic modelling results for the 100 year ARI flood event was used as the basis of a flood hazard assessment and development of a floodplain management strategy. The model results were tested using the flood hazard estimation techniques outlined in *SCARM Report 73 (CSIRO, 2000)*.

A floodplain encroachment analysis on flood levels was undertaken to assess the impact of filling areas of the floodplain. This assessment was carried out to ensure proposed development (ie filling, building etc) in the floodplain could be done without increasing 100 year ARI flood levels by more than 150 mm; a criteria required by with DoW.

The flood modelling concluded that flooding of the Hotham, Crossman and Bannister Rivers was generally contained in well defined watercourses. Future development in the catchment needs to manage the additional runoff from impervious areas and the affects of the floodplain fill. The flood hazard mapping showed there were potential conflicts between areas of flood hazard and areas designated rural small holding, rural residential and special residential. There were areas of the floodplain which could be filled to ensure proposed development does not increase flood levels by more than 150 mm.

Recommendations based on these findings were detailed in the separate *Boddington Floodplain Management Strategy* (SKM, 2009).

Glossary

Term	Definition
Average Recurrence Interval (ARI)	The average or expected value of the period between exceedance of a given rainfall intensity or peak discharge. ARI is another way of expressing the likelihood of occurrence of a flood event.
Catchment	The land area draining to a specific location.
Critical Storm Duration	The storm duration which results in the peak discharge or peak flood level at a given location. Longer storms give the critical duration for larger catchments and vice versa.
Eddy Viscosity	Hydraulic model parameter to represent the resistance of a fluid being deformed.
Encroachment	Filling in an area of the floodplain affecting flooding.
Ephemeral	A waterway that does not continuously flow, ie, is dry at sometimes in the year.
Flood	The temporary inundation of land by water that has overtopped the natural or artificial banks of the watercourse.
Flood Frequency Analysis	A statistical analysis to determine the relationship between peak discharge and the likelihood of the occurrence of the peak discharge. This is undertaken based on recorded historical data.
Hydraulic	Term given to the study of water flow in waterways; in particular, the evaluation of flow parameters such as water level and velocity.
Hydrograph	A graph that shows how the discharge or stage/flood level at any particular location varies with time during a flood.
Hydrology (hydrologic)	Term given to the study of the rainfall and runoff process; in particular, the evaluation of peak flows, flow volumes and the derivation of hydrographs for a range of floods.

Term	Definition
Impervious	A surface or area within the catchment where the majority of the rainfall becomes runoff eg roads, carparks and roofs etc.
Link Lags	Links in the hydrologic model that represents the time taken for water to flow down a reach of the river.
Manning’s ‘n’	A parameter that relates to the surface roughness. Used in the Manning’s equation.
Peak Discharge	The maximum flow rate during or following a rainfall event.
Pervious	A surface or area within a catchment where some of the rainfall will infiltrate, resulting in a reduced rate of runoff eg grassed areas, pasture, lawns etc.
Pluviograph	An instrument that automatically records the amount of rainfall as a function of time normally at sub-daily interval.
Resistance	A measure of the surface roughness.
Storm Duration	The period of which the design rainfall occurs in the catchment.

Contents

Figures

Tables

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SKM

1. Introduction

Sinclair Knight Merz (SKM) was commissioned by the Shire of Boddington to undertake a Floodplain Management Study for an area in the Shire of Boddington, located approximately 150 km south-east of Perth. The Floodplain Management Study has two reports; the Flood Modelling Report and the Floodplain Management Strategy Report. The purpose of the Flood Modelling Report is to present the modelling assessment undertaken for the flood modelling. The outcomes of the flood modelling were then used to develop the Floodplain Management Strategy.

The study area includes the towns of Boddington and Ranford and reaches of the Hotham, Bannister and Crossman Rivers. There is expected to be substantial growth in the Boddington Shire due to the imminent opening of a gold mine at the time of the study. The study aims to ensure that this growth follows sound floodplain management principles. The study reviewed the Shire of Boddington Planning Scheme and the Shire of Boddington Local Planning Strategy to assess their alignment with floodplain management principles.

This report details the flood modelling that was undertaken as part of the Floodplain Management Study, under the following headings:

- **Section 2** Review of Available Data;
- **Section 3** Hydrologic Model Development;
- **Section 4** Design Hydrology and Flood Frequency Estimation;
- **Section 5** Hydraulic Model Development;
- **Section 6** Design Event Hydraulics; and
- **Section 7** Conclusions.

1.1 Background

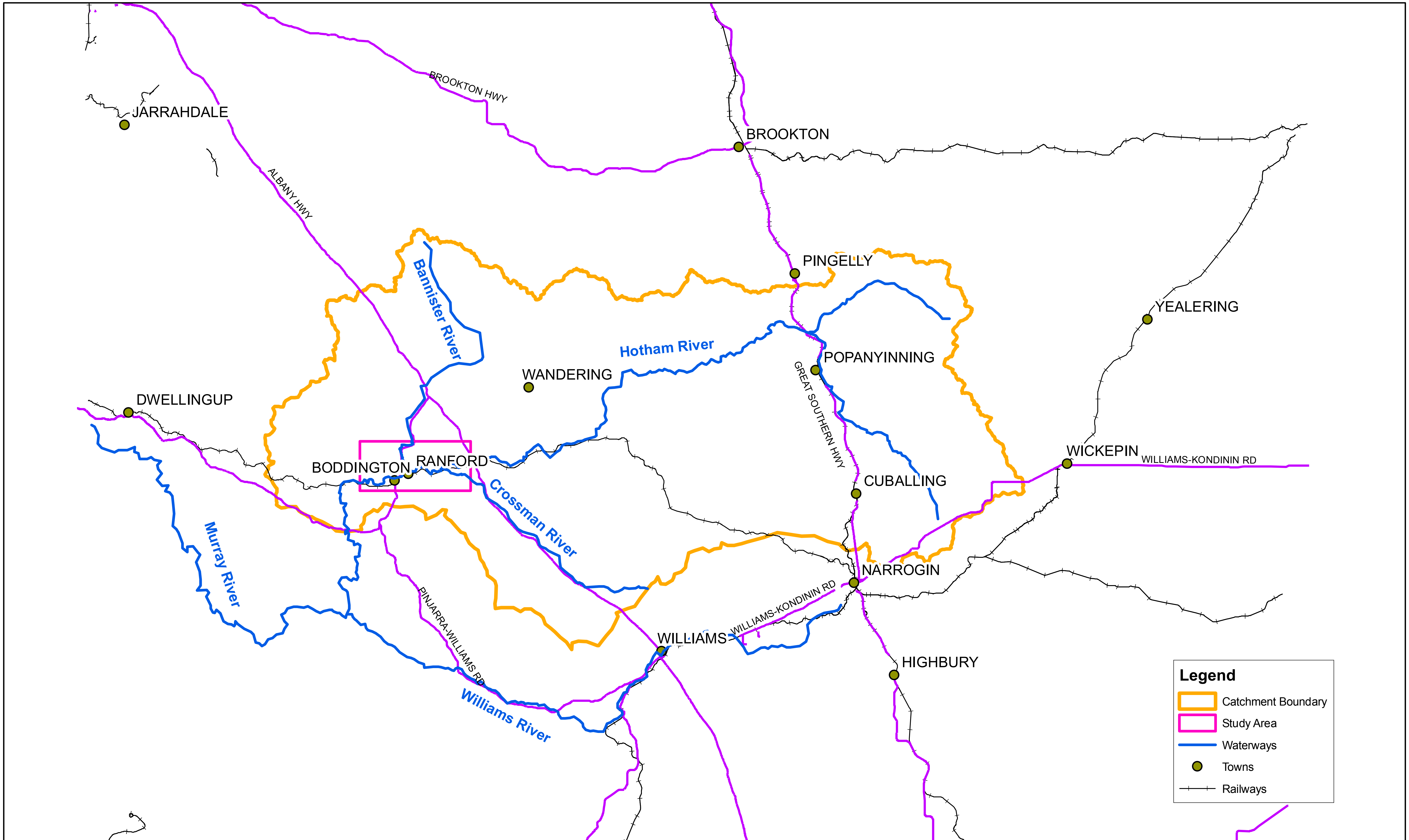
The study area for the Project included the towns of Boddington and Ranford as well as the Hotham, Bannister and Crossman Rivers as shown in **Figure 1-1**. The Hotham River was the largest of the rivers with headwaters to the west of Popanyinning. The catchment of the Hotham River was a combination of forested and rural land uses. The Hotham River flows primarily in a westerly direction where it combines with the Crossman River. The Hotham River continues to flow west and then combines with the Bannister River and then continues west before flowing south to combine with Williams River and then to the Murray River.

The Crossman River has it headwaters north of Williams and flows in a north-westerly direction to combine with the Hotham River. The Crossman River catchment was a combination of forested and rural land uses. The Crossman River is ephemeral with the larger flows predominantly in winter.

The Bannister River has it headwaters north-west of Wandering and flows in a southerly direction to combine with the Hotham River. The Bannister River catchment was a combination of forested and rural uses. The Bannister River is ephemeral with the larger flows predominantly in winter.

The majority of the rainfall for the area was observed in winter however there has been rare summer events experienced as a result of cyclonic activities at the coast. The townships of Boddington and Ranford have experienced flooding in the past.

The Shire of Boddington Local Planning Strategy, which was adopted by the Council on 17 April 2007 and endorsed by the Western Australia Planning Commission on 7 August 2007, provides the strategic land use planning framework for municipality. The Shire of Boddington Planning Scheme is presented in **Figure 1-2**.



BODDINGTON FLOODPLAIN MANAGEMENT STUDY

Figure 1-1 Locality Plan

0 5 10 20 30 40

Kilometres

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Date: 03/07/09
Job No: QE09456

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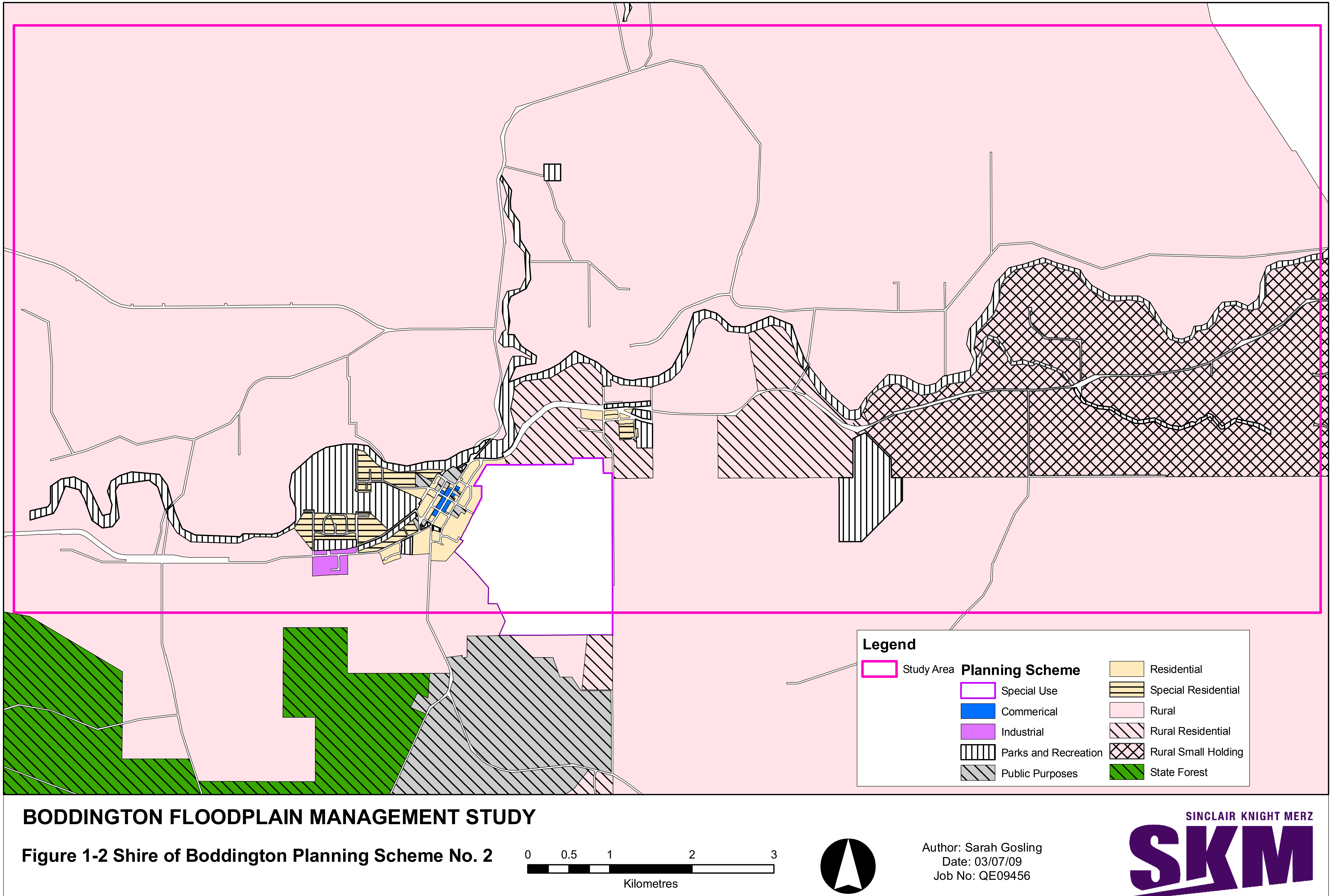

BODDINGTON FLOODPLAIN MANAGEMENT STUDY

Figure 1-2 Shire of Boddington Planning Scheme No. 2

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1.2 Site Investigation

A site visit was undertaken to familiarise the project team with the study area. This was undertaken prior the collection of the terrain data for the project to ensure critical drainage elements were collected in the terrain capture.

Figure 1-3 to **Figure 1-6** are photographs that were collected during the site inspections.

- **Figure 1-3 Study Catchment**

This photograph shows the typical terrain and vegetation of the study area catchment. The catchment is characterised by undulating terrain with a combination of forested and agricultural land.

The agricultural land for the study area was well established and likely to have been similar since the original clearing was undertaken.

Figure 1-4 Boddington Weir

The photograph shows the Boddington Weir which is in the township of Boddington. The weir was constructed in 1981 to provide amenity to the area, catering for fishing and water sports. It was determined that the weir would be full at the time of a flood event.

- **Figure 1-5 Pool in Hotham River**

The photograph shows a pool in the Hotham River. There were a number of shallow pools in the three rivers at the time of the Airborne Laser Scanning (ALS) survey which had the potential to underestimate the conveyance of the rivers. To ensure the full conveyance of the river was captured, survey was undertaken of the river bed and banks in locations where there were pools of water.

- **Figure 1-6 Hotham River Vegetation**

This photograph shows typical vegetation in the rivers of the study area. There are sections of the Crossman, Bannister and Hotham Rivers, which have thick waterway vegetation. It was expected that flow would be high into the upper branches of the vegetation in a flood.

2. Review of Available Data

The following sub-sections detail the data inputs to this study including the sources, quality and spatial location of the data.

2.1 Terrain Information

Three separate sets of terrain information were used for different tasks of this study. Broad contour information was used for catchment delineation for hydrologic modelling. Detailed Airborne Laser Scanning (ALS) survey was collected to build the terrain model used in the hydraulic modelling. The ALS survey cannot penetrate water and therefore does not represent the full conveyance of the river. Cross section survey was used to supplement the ALS survey in areas were there was water at the time of the ALS survey. Developing the terrain information from both ALS and surveyed cross sections provides sound terrain information for flood modelling.

2.1.1 Contour Information

Coarse contour information was used for catchment delineation and general characterisation of the catchment hydrologic conditions such as slope and flow path length. The contour information was provided at a 5 m interval resolution and was considered to be sufficiently accurate for the hydrologic model development. This data was provided by the Department of Water (DoW).

2.1.2 Airborne Laser Scanning Survey

Fugro Spatial Solutions was commissioned by DoW to undertake ALS survey of the study area for the purpose of this investigation. The coverage of the ALS data is presented in **Figure 2-1**. The guaranteed vertical accuracy of the supplied data was ± 0.15 m at 67 % confidence level. Data was supplied in the projection of MGA Zone 50 to the GDA94 datum. A report detailing the data capture and accuracy was supplied by Fugro and is included in **Appendix E**.

2.1.3 Cross Section Survey

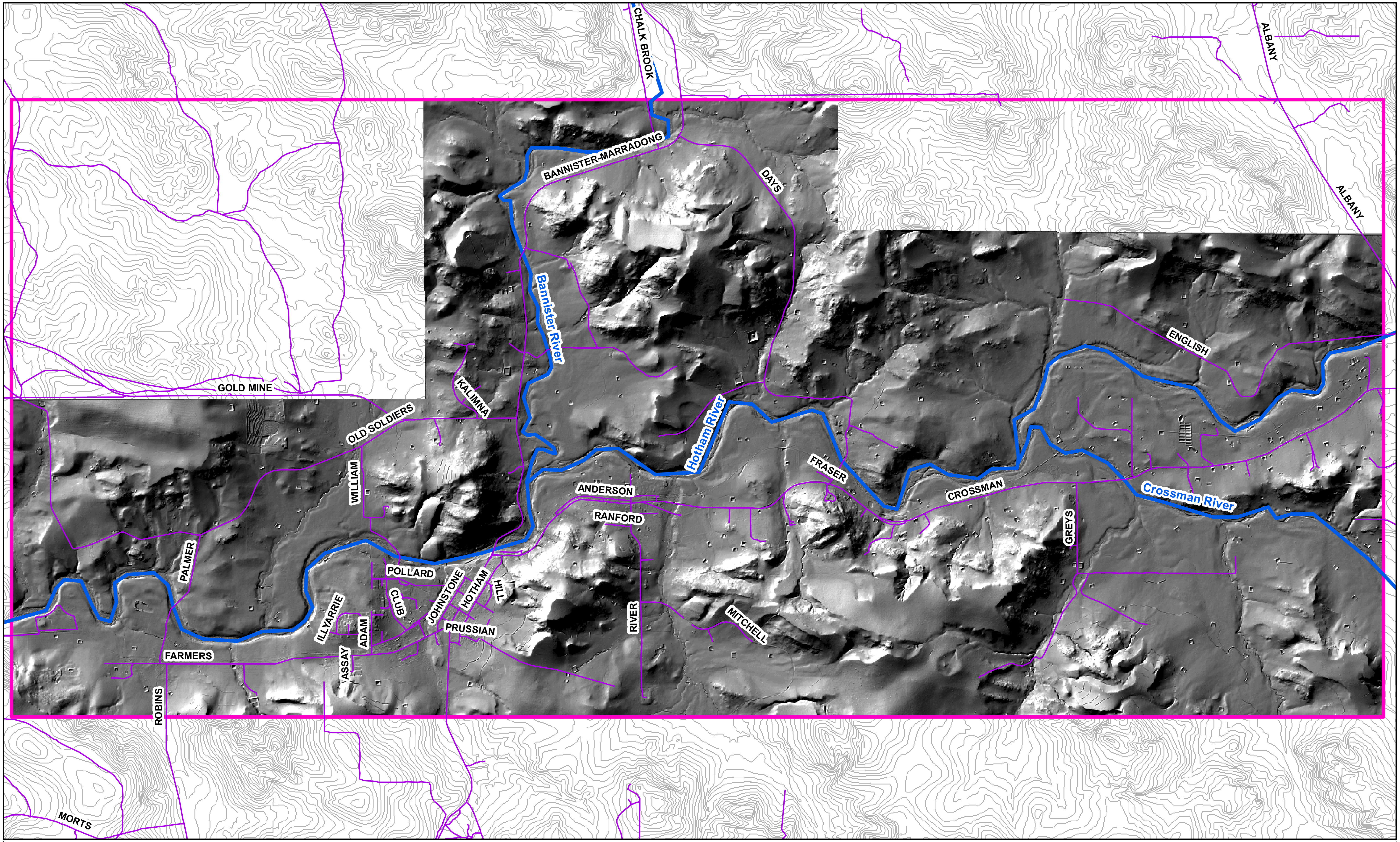
Cross section survey was undertaken by SKM to survey the river bed and banks in a number of locations where there were pools of water when the ALS survey was taken. The survey was undertaken using State survey marks and has +/-20mm accuracy in both horizontal and vertical.

2.1.4 Structures

There was a number a number of crossings of the rivers which were survey as part of the study. **Table 2-1** outlines the deck levels for the crossing of the Hotham, Bannister and Crossman Rivers.

- **Table 2-1 Structures**

Crossing	Deck Height (m AHD)
Palmer Street	200.7
Williams Street	203.3
Bannister - Marradong Rd (Bannister River)	212.1
Chalk Brook Road	214.0
Bannister - Marradong Rd (Hotham River)	208.9
Days Rd	209.6
Crossman Rd	215.3



BODDINGTON FLOODPLAIN MANAGEMENT STUDY

Figure 2-1 Airborne Laser Scanning Survey Coverage

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2.2 Previous Hydrologic and Hydraulic Studies

There were no previous hydrologic or hydraulic studies undertaken in the Boddington area. There was some anecdotal evidence including photographs of previous flooding. This anecdotal evidence was incorporated in this study.

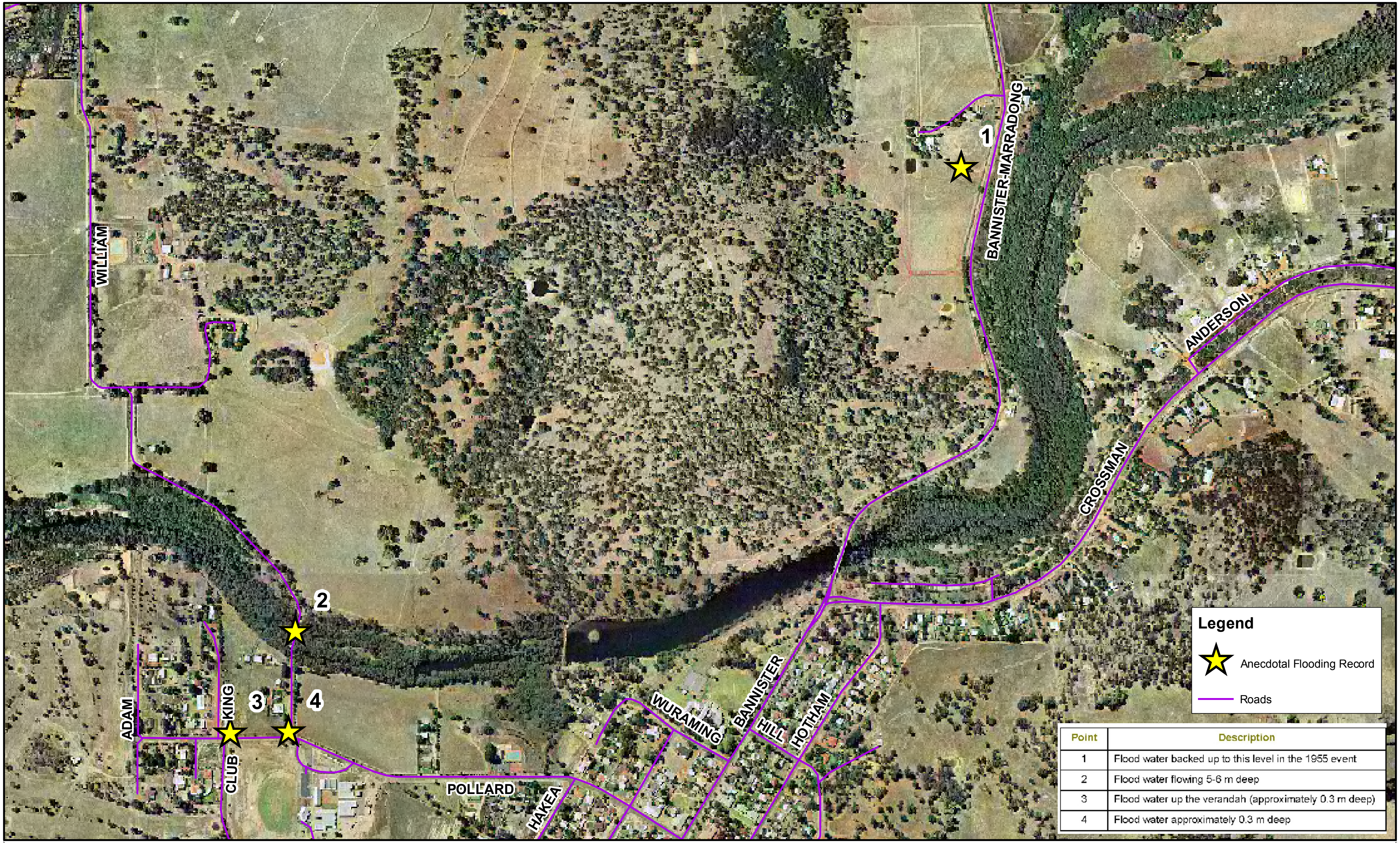
The Hotham River combines with the Williams River to become the Murray River. The Murray River Flood Study was completed in 1984 and was reviewed in 1999. This study included the estimation of peak discharge for the 100 year ARI event for the Murray River.

2.3 Anecdotal Flood Evidence

There has been a history of flooding in the Boddington area. Anecdotal flooding information was collected from a number of residents as part of the site visit. There were a number of points that residents remember flooding for the 1955 event. These are outlined in **Table 2-1** and shown in **Figure 2-2**. These points were captured with a hand held GPS. Accurate survey of these anecdotal flood levels would be helpful to compare to modelled results.

- **Table 2-2 Anecdotal Flooding Information**

Point	Description	Source
1	Flood water backed up to this level in the 1955 event	Gwen Matsen (pers. comm.)
2	Flood water flowing 5-6 m deep	Charlie Firns (pers. comm.)
3	Flood water up the verandah (approximately 0.3 m deep)	Tom Hardie (pers. comm.)
4	Flood water approximately 0.3 m deep	Charlie Firns (pers. comm.)



Point	Description
1	Flood water backed up to this level in the 1955 event
2	Flood water flowing 5-6 m deep
3	Flood water up the verandah (approximately 0.3 m deep)
4	Flood water approximately 0.3 m deep

BODDINGTON FLOODPLAIN MANAGEMENT STUDY

Figure 2-2 Anecdotal Flooding Information

0 0.25 0.5
Kilometres

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2.4 Rainfall Data

Rainfall data was available across the catchment and in the surrounding area in the form of both daily rain gauge and pluviograph data. Pluviograph rainfall data is collected on a sub-daily resolution. There were 31 rainfall gauges in the area however, there were three pluviographs selected for use in the study based on the location, length and quality of record. Daily rain gauging was also used in the study to compared total rainfall depths for large known historic flood events prior to pluviographs information. **Figure 2-3** and **Table 2-2** presents the rainfall gauges used in the study and for details of all rainfall gauges in the area refer to **Appendix B**.

▪ **Table 2-3 Rainfall Gauges**

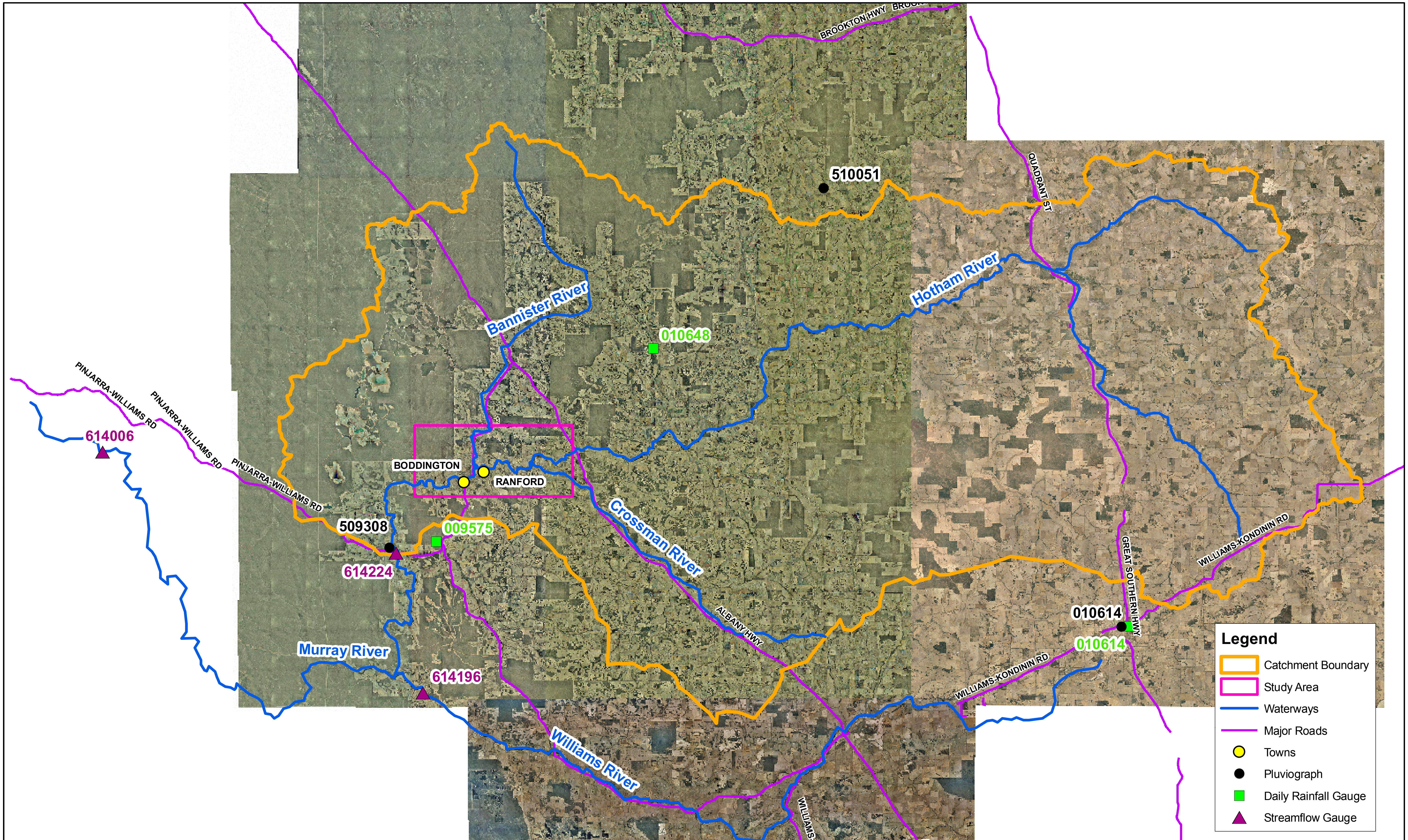
Site	Name	Type	Source	Start	Cease
009575	Marradong	Daily	BOM	1897	2007
010648	Wandering Comparison	Daily	BOM	1887	2003
010614	Narrogin	Pluviograph	BOM	1963	2005
509308	Marradong Rd Bridge	Pluviograph	DOW	1975	2007
510051	Dattening	Pluviograph	DOW	1977	2001

2.5 Streamflow Data

Streamflow data was available in the catchment of the study area and the surrounding area. There were 29 streamflow gauges in the area however there were three selected for use in the study based on the location, length and quality of record. The three stream flow gauges are shown in **Figure 2-3** and outlined in **Table 2-3**. These gauges were suitable for use in the flood frequency analysis and calibration of the hydrologic model.

▪ **Table 2-4 Streamflow Gauges**

Gauge No.	Gauge Name	Catchment Area (km^2)	Period of Record	No. of Years
614196	Saddleback Rd Bridge (Williams River)	1,408	1966-2007	41
614224	Marradong Rd Bridge (Hotham River)	3,969	1966-2007	41
614006	Baden Powell (Murray River)	6,758	1940-2007	67



BODDINGTON FLOODPLAIN MANAGEMENT STUDY

Figure 2-3 Rainfall & Streamflow Gauge Locations

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Kilometres

Author: Sarah Gosling
Date: 03/07/09
Job No: QE09456

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2.6 Summary of Existing Information

The following is a summary of the key findings from the previous information:

- terrain information was good quality and fit to purpose for both the hydrologic and the hydraulic assessment;
- good quality rainfall and streamflow data was available for calibration of the hydrologic model;
- no recorded flood levels or previous flood studies in the Boddington Area were available to calibrate the hydraulic model; and
- anecdotal flooding information was collected to verify the hydraulic modelling.

3. Hydrologic Model Development

Hydrologic modelling for the Boddington Floodplain Management Study was developed using the RAFTS hydrologic modelling software package. This section details the development of the RAFTS model.

RAFTS is a computer hydrologic model used for the development of design discharge hydrographs where design rainfall is input to the model. The model estimates runoff from catchment parameters including catchment roughness, slope, impervious area, link lags and catchment storage multipliers. All inputs to the RAFTS hydrologic modelling are presented in **Appendix A**.

3.1 Catchment Delineation

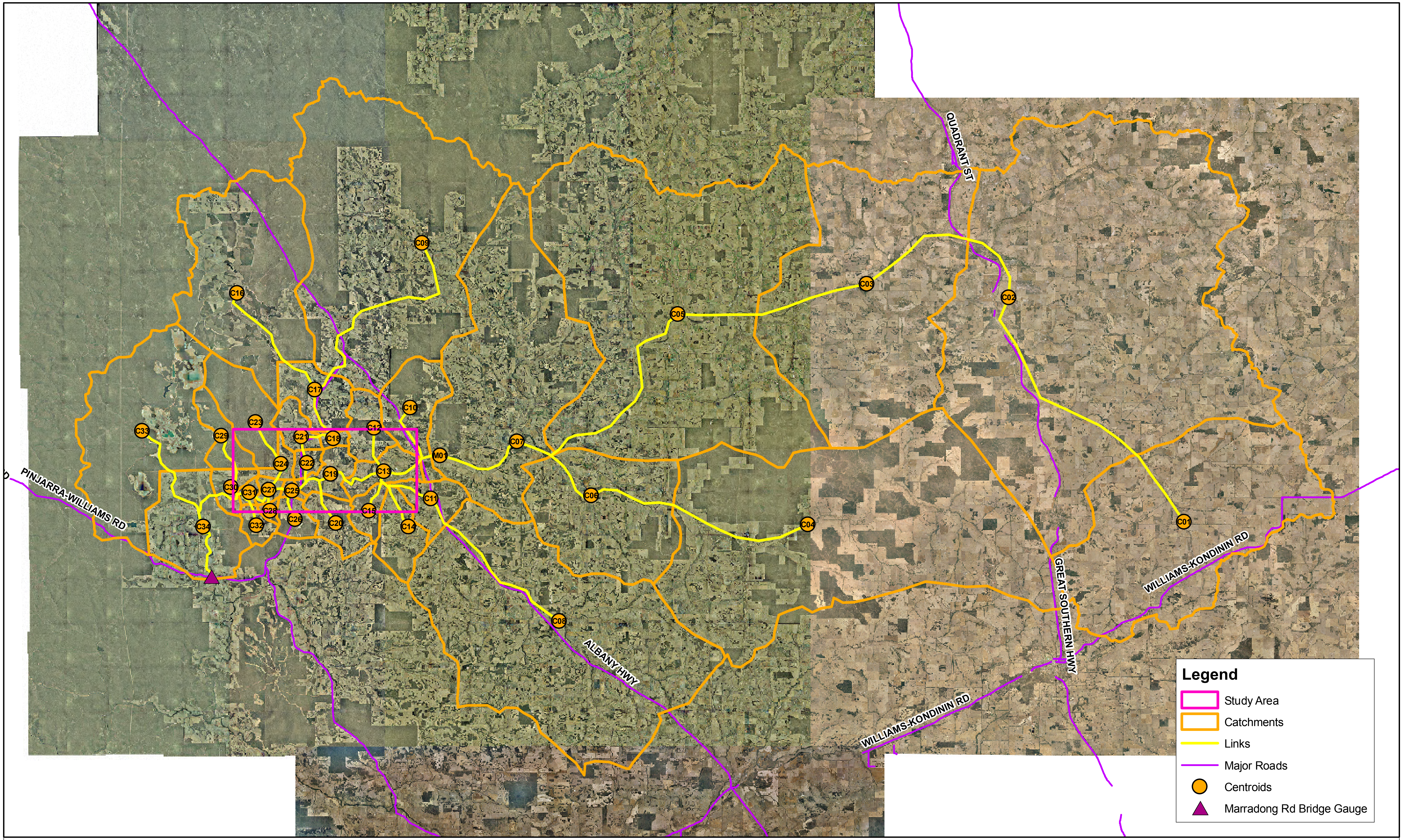
The catchment delineation for the Boddington Floodplain Management Study was undertaken using the following information:

- 5 m interval contour mapping;
- waterway spatial information (DoW); and
- aerial photography.

Figure 3-1 illustrates the catchment plan for the Boddington Floodplain Management Study. The figure shows the catchment boundary and subcatchment delineation. This figure also illustrates the catchment centroid and links that were used for the hydrologic modelling.

3.2 Subcatchment Areas

The catchment was divided into a number of subcatchments and converted into spatial data using ArcGIS, shown in **Figure 3-1**. The GIS was used to determine the subcatchment areas. The total catchment area to the Marradong Road bridge gauge was 3,969 km^2 and 3,762 km^2 to the downstream extent of the study area. For a full summary of the subcatchment areas, refer to **Appendix A**.



BODDINGTON FLOODPLAIN MANAGEMENT STUDY

Figure 3-1 Catchment Plan

0 2.5 5 10 15 20 25
Kilometres

Author: Sarah Gosling
Date: 03/07/09
Job No: QE09456

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3.3 Catchment Slope

A digital terrain model (DTM) of the study area catchment was developed for the 5 m interval contour data. The DTM was developed as a terrain grid with a resolution of 25 m. The DTM was interrogated to create a grid of the terrain slope. This slope grid was used to calculate the average catchment slope. The average catchment slopes for the subcatchments range from 2.5 to 12 %. For a full summary of the subcatchment slopes refer to **Appendix A**.

3.4 Impervious Catchment Area

Impervious areas are roofs, roads and other hardstand areas. These create different hydrologic response than pervious areas such as pasture and forests. As only a very small proportion of the catchment was impervious, this area was excluded from the assessment and was considered to be pervious.

3.5 Manning's n Values

RAFTS models the affect of the surface roughness on the flow characteristics using the Manning's 'n' parameters. The Manning's n values adopted for the various land uses in study area are presented in **Table 3-1** and are based on reference material from the RAFTS manual.

Table 3-1 Manning's n Values – Hydrologic Modelling

Land Use	Manning's n
Forested	0.15
Rural	0.08

3.6 Link Lags

Link lagging was used in the RAFTS model to allow for the travel time of flow through a waterway. The link lagging was set as a simple time lag between each subcatchment. Lag times were established by dividing the routing distance by typical stream flow velocities for the given catchment slope. Typical stream flow velocities were based on values in the Queensland Urban Drainage Manual (QUDM) and are believed to be acceptable for use in WA.

Table 3-2 Stream Velocities for Catchment Areas (QUDM, Table 5.05.4)

Type of Country	Average Slope of Catchment Surface (%)	Approximate Velocity of Stream (m/s)
Flat	0 to 1.5	0.3
Rolling	1.5 to 4	0.7
Hilly	4 to 8	0.9
Steep	8-15	1.5
Very Steep Rocky Mountains	>15	3.0

SKM

For the purposes of this study, link lags were only important for upper catchments located outside the hydraulic modelling boundary. Within the hydraulic modelling boundary, the hydraulic model routes flows implicitly. Total hydrographs for these catchments were exported from the RAFTS model to correspond with the upstream boundary of the study area.

For catchments contained within the boundary of the hydraulic model, only local hydrographs were exported from the RAFTS model. Local hydrographs report only flow developed in a subcatchment.

3.7 Calibration

The primary calibration parameter in the RAFT hydrologic model are rainfall losses. The calibration of the hydrologic model was undertaken for the Marradong Road Bridge Gauge (614244) which has a period of record from 1966 to present. The largest recorded events for the Marradong Road Bridge gauge (614224) are presented in **Table 3-3**.

- **Table 3-3 Largest Flow Event Marradong Road Bridge Gauge (614224)**

Date of Event	Flow (m^3/s)	Approx ARI[1] (years)
30/06/1983	268	18
27/06/1967	237	14
31/07/1996	219	12
22/01/1982	191	9
2/08/1974	162	7

1 - Approximate ARI from regional FFA (**Section 4.6**)

The events were compared to the available pluviograph rainfall data over the catchment. Pluviograph rainfall data is collected at a sub-daily resolution which allows for the more accurate representation of the patterns and intensity of the rainfall event than daily rainfall data. The pluviograph rainfall data covered the catchment for the period from 1975 to 1998. The following events were selected to undertake hydrologic calibration:

- June 1983;
- July 1996; and
- January 1982.

Pluviograph rainfall data was used for three gauges across the catchment. The following gauges were used for the historic rainfall events:

- 010614 Narrogin – Upper Catchment;
- 510051 Dattening – Mid Catchment;
- 509308 Marradong Rd Bridge – Lower Catchment

The three events selected represent the variation of catchment antecedent conditions. The June 1983 event was a winter storm with some rainfall prior to the event, the July 1996 event was a winter storm which had significant rainfall prior to the event. Finally, the January 1982 event was a summer storm with no rainfall preceding the event. This was expected to give large variation in rainfall losses as the level of saturation in the catchment varies significantly depending on when the rainfall event occurred. Assessing a range of events showed the range of possible rainfall losses to be expected.

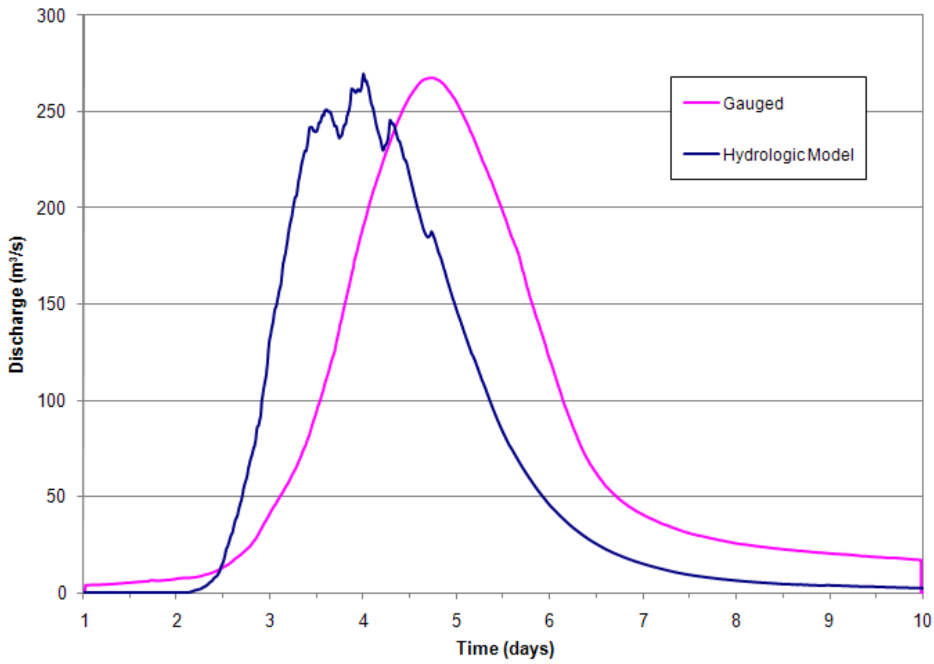
The calibration of the storm events was undertaken primarily to determine the rainfall losses however, sensitivity to other parameters including Manning's 'n' and link lags were also assessed in the calibration.

The July 1996 event was a winter event which had a significant amount of baseflow. It is important to separate catchment response from baseflow to determine loss parameters. The gauged and baseflow separated hydrograph was provided by DoW as shown in **Figure 3-3**.

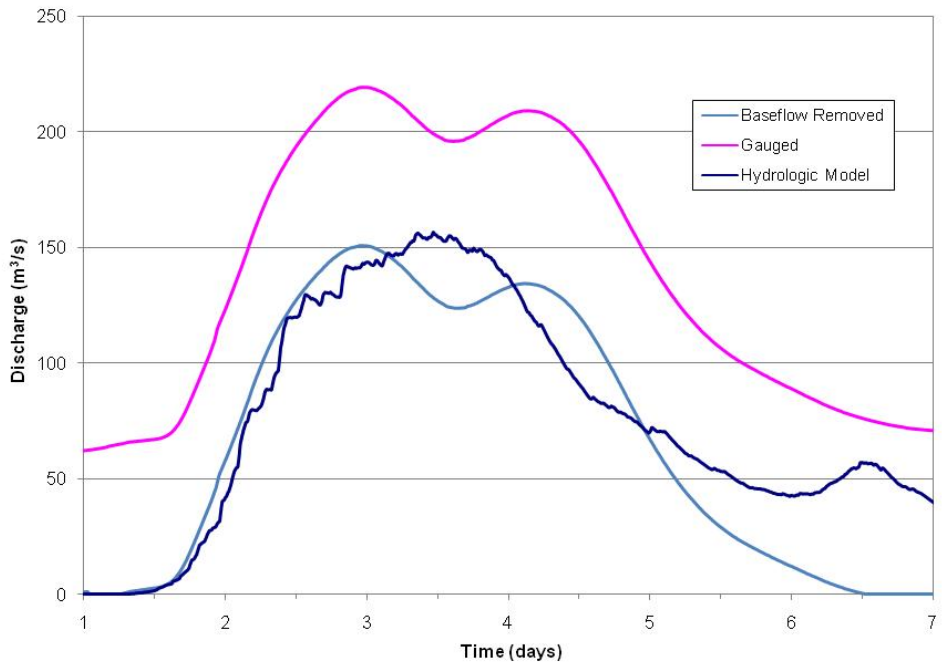
Table 3-4 presents the rainfall losses for each storm event and **Figure 3-2** to **Figure 3-4** shows the calibration at the Marradong Road Bridge Gauge (614224).

- **Table 3-4 Calibration of Rainfall Losses**

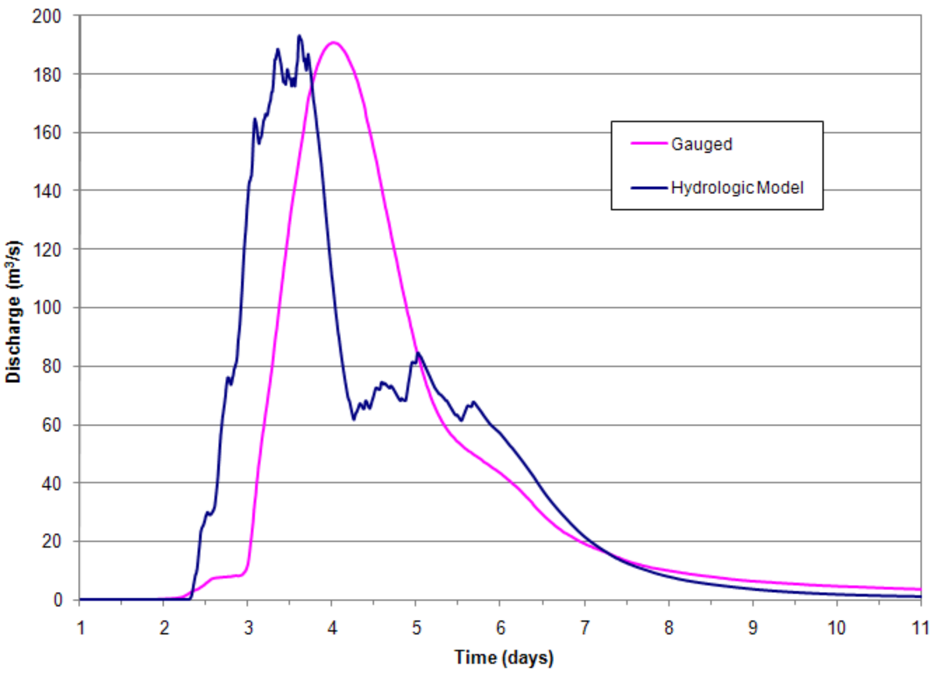
Date of Event	Forest		Rural	
	Initial Loss (mm)	Continuing Loss (%)	Initial Loss (mm)	Continuing Loss (%)
June 1983	45	90	30	71
July 1996	10	82	5	72
Jan 1982	150	85	110	65



▪ **Figure 3-2 June 1983 Event Calibration**



▪ **Figure 3-3 July 1996 Event Calibration**



- **Figure 3-4 January 1982 Event Calibration**

The calibration showed a wide range of loss parameters due to the antecedent catchment characteristics. The calibration showed that larger rainfall depths which historically occurred in summer, likely as a result of cyclonic activity, resulted in smaller peak discharges due to the dry nature of the catchment. Rainfall events which occurred in winter had smaller rainfall depths however produce larger peak discharges due to the saturated nature of the catchment.

This finding was confirmed with DoW. It meant that care was required when developing design flood events for the catchment. The design flood events would be significantly under or over estimated if the seasonality of the rainfall and catchment conditions were not taken into account.

3.8 Validation

Anecdotal flood information was gathered as part of the study, as outlined in **Section 2.3**, which suggested the 1955 flood was a large event. There was no gauged pluviograph rainfall data for the event however an analysis was undertaken of the daily rainfall data for that period. An analysis in the hydrologic model was attempted based on the daily rainfall data for the 1955 event, however without the appropriate representation of rainfall pattern and intensity from a pluviograph there was limited confidence in the peak discharge estimate predicted. Therefore, an analysis of the total rainfall depths was undertaken.

The 1955 event total rainfall depth was compared to the recorded events of 1983, 1996 and 1982 as shown in **Table 3-5**.

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- **Table 3-5 Rainfall Total Comparison**

Site	Name	3-Day Rainfall Total (mm)			
		June 1983	July 1996	Jan 1982	Feb 1955
010614	Narrogin	83	58	138	205
010648	Wandering Comparison	80	49	151	201
009575	Marradong	97	73	167	251

This table shows that the 1955 event had a significantly higher rainfall depth than the other recorded historic events. The 1955 event was a summer event and calibration showed summer events result in very high initial losses. Therefore, the Average Recurrence Interval (ARI) of the rainfall would not translate to the ARI of the flood event due the antecedent catchment conditions, as discussed in **Section 3.7**. It was not possible to determine the ARI of the 1955 flood event, however it was considered to be a significant event due to the large and widespread rainfall. However of the 200 mm of rainfall in the 1955 event it was estimated there would be approximately 100 mm of runoff generating rainfall. This would be comparable to the 100 year ARI rainfall as presented in **Figure 4-1.** For this reason, it was considered appropriate to compare the anecdotal evidence of the 1955 event to the predicted 100 year ARI flood event hydraulic results (as discussed in **Section 5.9**).

4. Design Hydrology and Flood Frequency Estimation

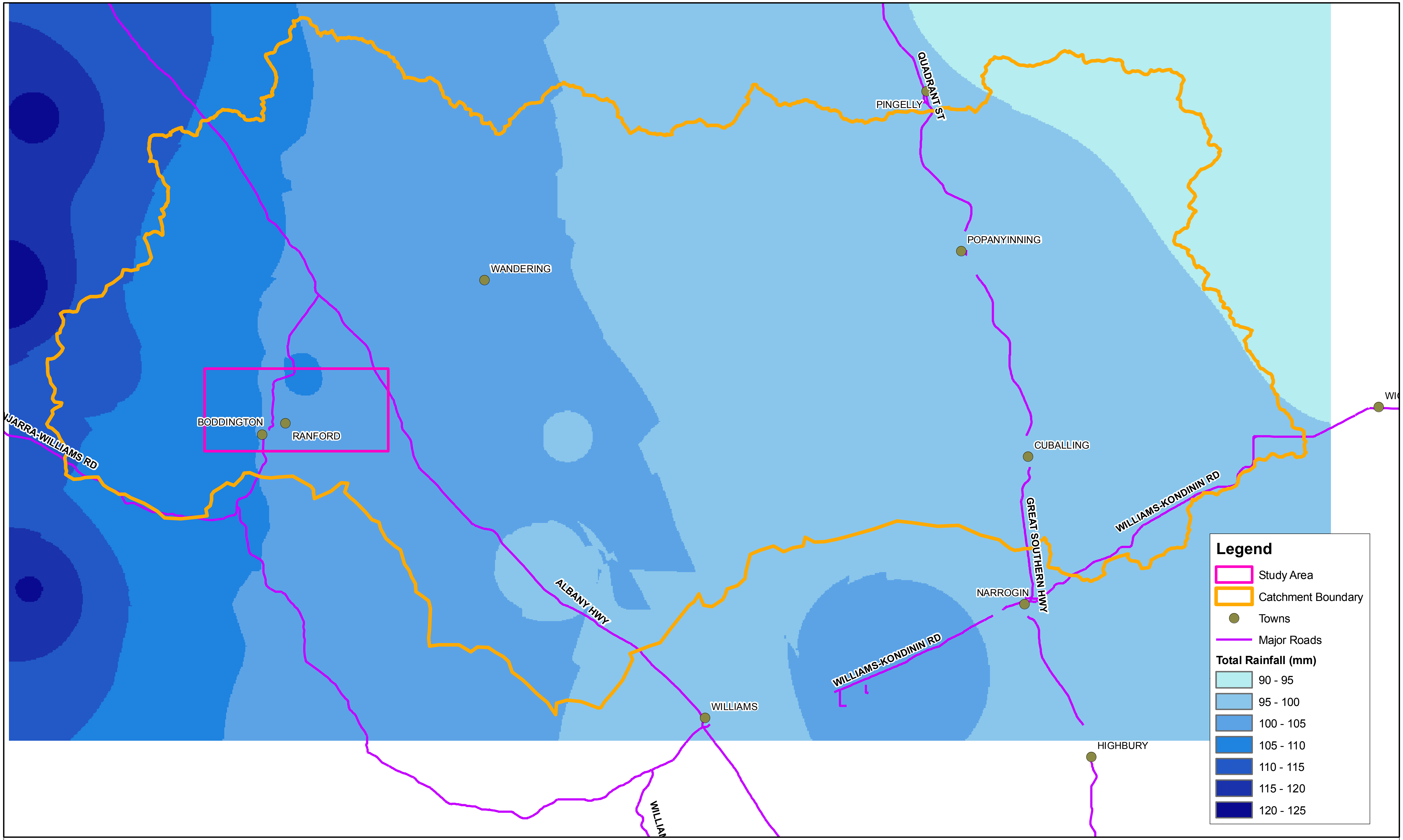
Design events were simulated for a range of ARI events including;

- 10 year;
- 25 year; and
- 100 year.

4.1 Design Rainfall Depths

Design rainfall depths were derived using the WA CRC-Forge Extract application developed by the WA Department of Environment, 2004. This program uses the CRC-Forge Method for the development of design rainfall depths in Western Australia. The WA CRC-FORGE EXTRACT computer program has been produced to facilitate the extraction of large rainfalls from the Western Australian database, in a format commonly used for hydrologic design.

An assessment was undertaken to determine the variability in design rainfall depths across the catchment. **Figure 4-1** presents the variability in rainfall across the catchment for the 100 year ARI rainfall event for the storm duration of 24 hours. The results indicates there was variation in rainfall across the catchment. The design rainfall depths reduced from west to east across the catchment, design rainfall depths in the east of the catchment are up to 15 % lower than in the west. As a result, spatially varying rainfall depths were adopted for the hydrologic modelling to represent this variation.



BODDINGTON FLOODPLAIN MANAGEMENT STUDY

Figure 4-1 Rainfall Spatial Variation - 100 Year ARI Event 24 hr Duration

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4.2 Design Temporal Patterns

Design temporal patterns from *Australian Rainfall and Runoff, Book 2 (Institution of Engineers, Australia, 2000)* were adopted for the development of design discharge hydrographs. The study area was located within Zone 8.

4.3 Areal Reduction Factor

During a rainfall event, rainfall depths vary across a catchment. The rainfall intensities calculated using the CRC-Forge method represent the 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, convection based rainfall events and less pronounced for longer duration rainfall events that occur over multiple days. To account for this variation of rainfall across a catchment, an areal reduction factor was derived and applied to rainfall depths used for design flood estimates.

The adopted areal reduction factors for the Boddington catchment were based on the revised areal reduction factors (ARFs) derived for Western Australia calculated from WA CRC-Forge and are shown in **Table 4-1**.

- **Table 4-1 Western Australia Annual Areal Reduction Factors**

Storm Duration (hours)	ARI (Years)		
	10	25	100
24	0.846	0.846	0.846
36	0.875	0.875	0.875
48	0.892	0.892	0.892
72	0.912	0.912	0.912

4.4 Design Rainfall Losses

The rainfall losses adopted for Boddington Floodplain Management Study were based on the calibration to recorded historic flood events (**Section 3.7**), regional flood frequency analysis **(Section 4.6**) and in consultation with the DoW. It was agreed the most appropriate representation of the catchment to assume the rainfall losses of a winter event. Although the winter events produce less rainfall then the recorded summer events, they result in much greater discharges as described in **Section 3.8**.

The rainfall losses chosen were varied for each ARI and land use types. The adopted design rainfall losses for the hydrologic modelling are presented in **Table 4-2**.

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▪ **Table 4-2 Design Rainfall Losses**

ARI (Years)	Forest		Rural	
	Initial Loss (mm)	Continuing Loss (%)	Initial Loss (mm)	Continuing Loss (%)
100	10	85	5	70
25	20	85	10	70
10	20	85	10	70

4.5 Sensitivity Analysis

A sensitivity analysis was conducted on the design rainfall losses, Manning's n and lag times. The sensitivity found the model results were not particularly sensitive to Manning's n or the lag times. The results were sensitive to the rainfall losses.

The range of rainfall losses considered in the sensitivity analysis was determined through consultation with DoW. This sensitivity analysis was important to understand the variation in antecedent catchment conditions based on the seasonality of rainfall.

The result of the sensitivity analysis for rainfall losses is shown in **Table 4-3**.

▪ **Table 4-3 Sensitivity of Design Rainfall Losses**

Forest		Rural		Peak Discharge Marradong Rd Bridge Gauge (614224) (m^3/s)		
Initial Loss (mm)	Continuing Loss (%)	Initial Loss (mm)	Continuing Loss (%)	100 Year ARI	25 Year ARI	10 Year ARI
10	90	5	70	608	449	349
10	85	5	65	738	546	424
10	80	5	60	869	642	500
10	75	5	50	1,103	818	638

The sensitivity analysis showed results were sensitive to the rainfall losses selected and therefore a validation of the rainfall losses to a flood frequency analysis was undertaken.

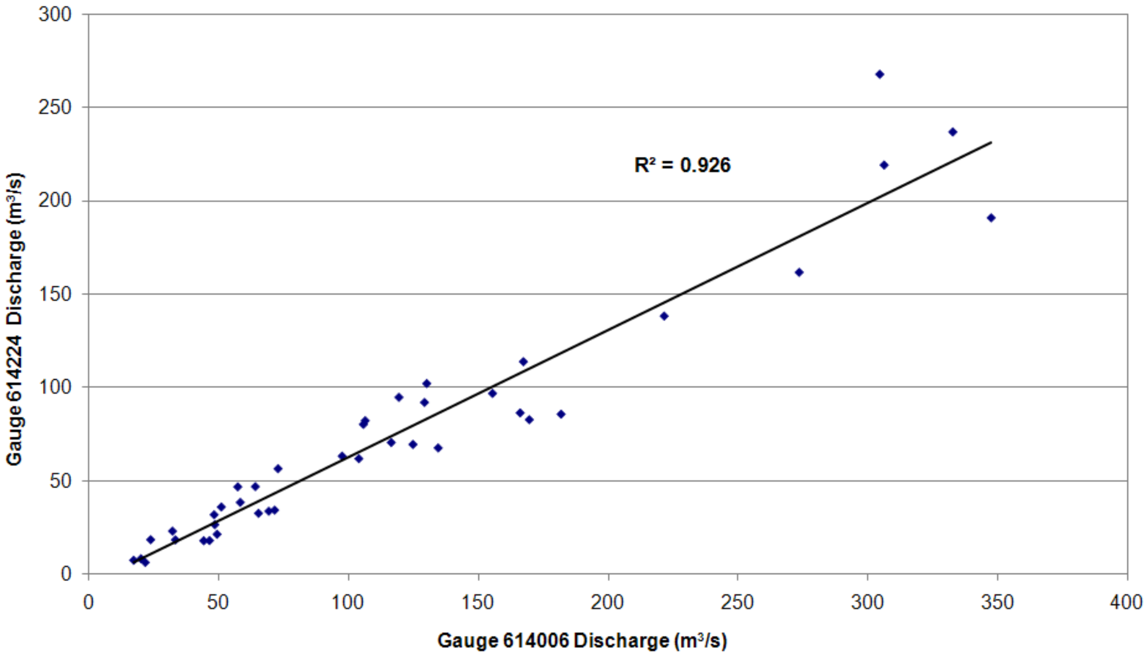
4.6 Flood Frequency Analysis

A flood frequency analysis (FFA) was undertaken to validate the outcomes of the model calibration and the resolve the outcomes of the sensitivity analysis. The FFA was undertaken using the three gauges in the catchment with suitable record. These gauges are outlined in **Table 4-4**.

▪ **Table 4-4 Streamflow Gauges for FFA**

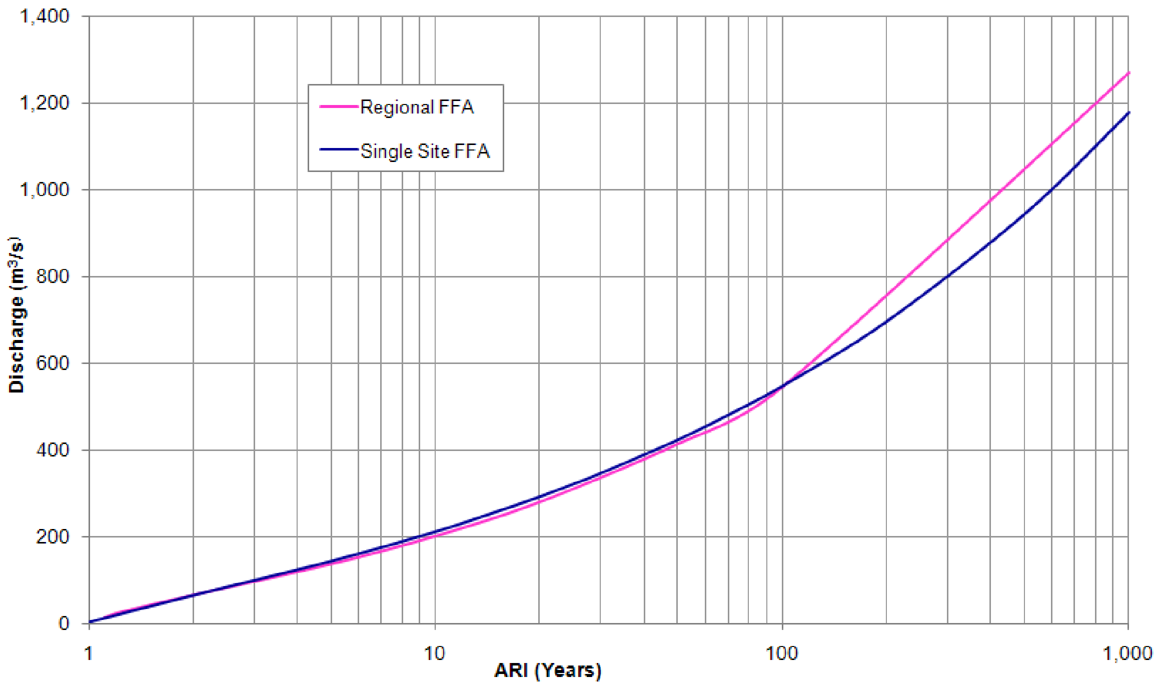
Gauge No.	Gauge Name	Catchment Area (km^2)	Period of Record	No. of Years
614196	Saddleback Rd Bridge (Williams River)	1,408	1966-2007	41
614224	Marradong Rd Bridge (Hotham River)	3,969	1966-2007	41
614006	Baden Powell (Murray River)	6,758	1940-2007	67

The Marradong Road Bridge gauge (614224) and the Baden Powell gauge (614006) were compared and found to have a very strong correlation, as shown in **Figure 4-2**. The Baden Powell gauge (614006) was used to extend the period of record of the Marradong Road Bridge gauge (614224) from 1966 back to 1940. This resulted in an additional 26 years of streamflow data and added confidence to the FFA.



▪ **Figure 4-2 Gauge 614224 and 614006 Correlation**

A regional FFA was undertaken using the Generalised Extreme Value (GEV) method with the three gauges including the extended Marradong Road Bridge gauge (614224). A single site FFA, also using the GEV method, was undertaken on the Marradong Road Bridge gauge (614224), including the extended period of data, to validate the regional FFA. The results of the FFA are presented in **Figure 4-3**.



■ **Figure 4-3 Regional and Single Site FFA Marradong Rd Bridge Gauge (614224)**

The regional FFA and the single site FFA showed a strong correlation. The regional FFA was undertaken on 67 years of recorded stream flow data, which gives confidence up to a 100 year ARI flood event.

The hydrologic model results with the selected rainfall loss parameters were compared to the regional FFA as shown in **Table 4-5**.

■ **Table 4-5 FFA Validation Marradong Rd Bridge Gauge (614224)**

ARI (Years)	Peak Discharge (m^3/s)	
	Hydrologic Model	Regional FFA
100	635	547
25	433	315
10	326	203

The results show the selected design rainfall losses predicted flows higher than the regional FFA. This was agreed with DoW to be appropriate for use in the hydraulic modelling, as this approach will give a conservative result. The design rainfall losses outlined in **Table 4-2** were adopted for the study.

4.7 Hydrologic Modelling Results

The 100 year ARI flood event was modelled for a range of storm durations in order to determine the storm duration that resulted in the peak discharge. **Table 4-6** shows the hydrologic model results for the 100 year ARI flood event from 18 to 72 hour storm durations at five locations. From this modelling it was predicted the 24 and 36 hour storms were critical for the study area. This was considered to be appropriate due to the catchment size and average catchment slopes.

Table 4-6 100 year ARI Flood Event Modelled Peak Discharge

Storm Duration (hours)	Peak Discharge (m^3/s)				
	Hotham River (U/S extent study area)	Hotham River (D/S extent study area)	Hotham River – Marradong Rd Bridge Gauge	Crossman River (U/S extent study area)	Bannister River (U/S extent study area)
18	439	563	576	123	113
24	**466**	612	624	**126**	**116**
36	451	**619**	**635**	115	106
48	418	571	590	109	98
72	402	548	564	96	88

4.8 Hydrologic Outputs

The outputs of the RAFTS model were created for use in the hydraulic model. Outputs are in two forms, local and total hydrographs. Total hydrographs for the catchments outside of the hydraulic modelling boundary were exported from the RAFTS model to correspond with the upstream boundary of the study area. For catchments contained within the boundary of the hydraulic model, only local hydrographs were exported from the RAFTS model. Local hydrographs report only flow developed in a subcatchment. Within the hydraulic modelling boundary, the hydraulic model routes flows implicitly. The type of hydrograph exported for each catchment is listed in **Appendix A**.

5. Hydraulic Model Development

5.1 Adopted Modelling Approach

MIKE21 is a hydraulic modelling software package (version 2007) developed by the Danish Hydraulics Institute (DHI). MIKE is a two-dimensional model which is used to predict flooding. The MIKE21 model represents the study area topography as a terrain grid, with the following parameters input to the model to define flow behaviour:

- design inflow time series;
- terrain roughness (entered as Manning's roughness); and
- eddy viscosity.

5.2 Model Area

A hydraulic model area, including the Boddington township, was designated by DoW and adopted for the purpose of the study. ALS survey data was obtained for the area. The adopted hydraulic model extent is shown in **Figure 5-1**.

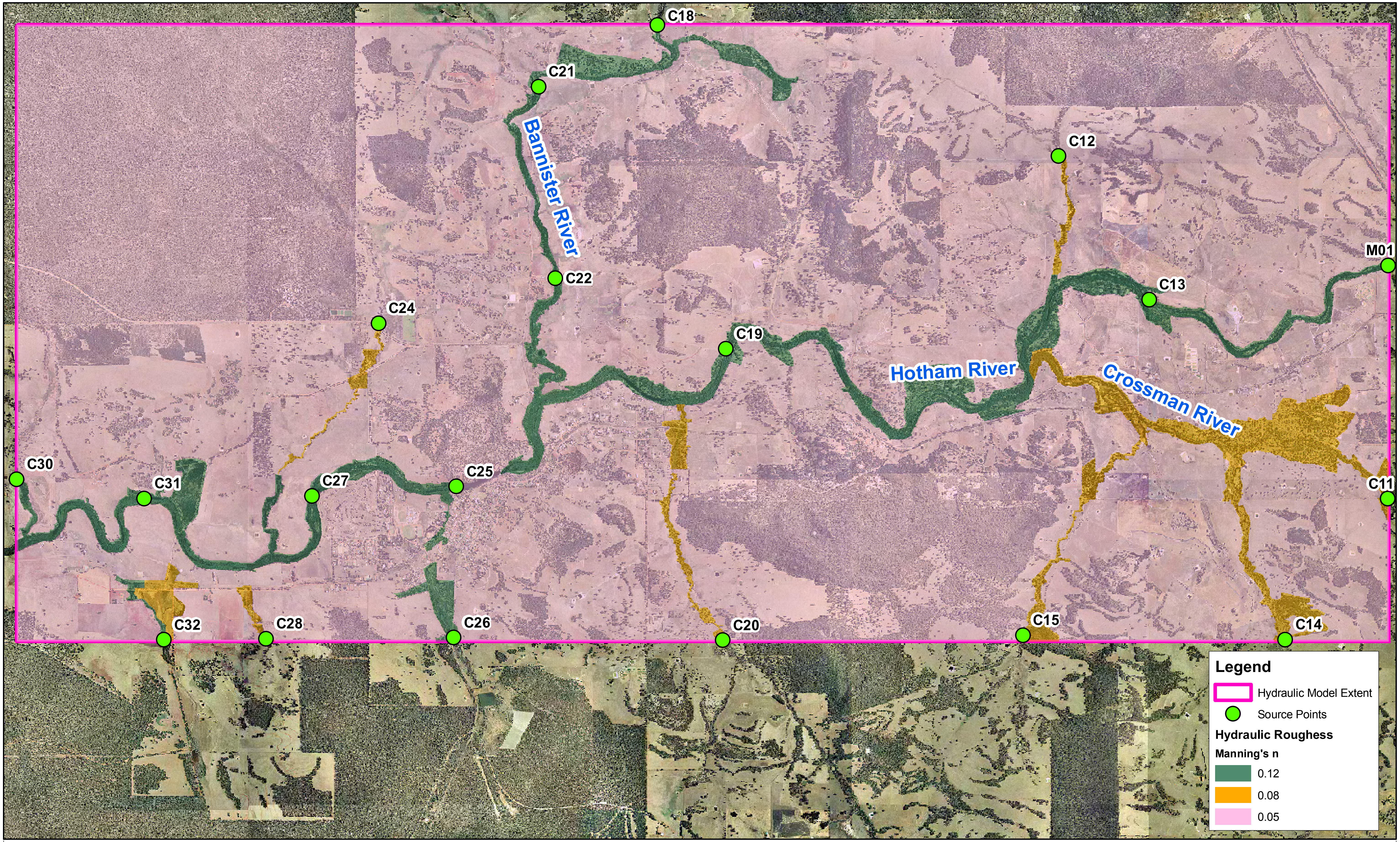
5.3 Terrain Development

ALS survey data was collected for the study area by Fugro Spatial Solutions as described in **Appendix E**. This terrain information was provided as a 1 m resolution grid of elevation data points based on the quality controlled output of the laser scanning process.

There were a number of standing water pools in the study area waterways when the ALS survey was undertaken. As the ALS survey cannot penetrate water, there was the potential to underestimate the conveyance of the river (ie the area available for water to flow is underestimated) as the river bed is not accurately captured. Therefore cross section survey of the river bed and banks was undertaken. The survey was combined with the ALS survey 1 m resolution grid to give a terrain model, which appropriately represented the waterways and floodplain.

An optimisation process was undertaken to select the appropriate grid resolution to use in the hydraulic modelling. From this, a regular grid of 9 m resolution was adopted for input to the hydraulic modelling. The 9 m resolution grid was selected in order to maximise runtime efficiency and maintain adequate definition of the terrain.

In the conversion from a 1 m to 9 m grid resolution, terrain detail is lost through averaging of terrain. To prevent this loss of detail and ensure that waterways and significant features were accurately represented in the model terrain, the 1 m grid was used to define the waterways and significant floodplain features. Using GIS Spatial Analysis tools the detail of the 1 m grid through these areas was reprojected onto the 9 m grid and to ensure critical features were not lost from the modelling.



BODDINGTON FLOODPLAIN MANAGEMENT STUDY

Figure 5-1 Hydraulic Model Extent & Parameterisation

0 0.5 1 2 3
Kilometres

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5.4 Model Parameters

5.4.1 Manning's Roughness

The terrain roughness represented by Manning's 'M' was a critical parameter of the hydraulic modelling as it affects flow of water through the waterways and floodplain. A Manning's 'M' roughness was determined using aerial photography of the study area and knowledge gained from the site visit.

The inspection of the waterways during the site visit and anecdotal flood evidence suggested that the Manning's roughness would be high in the waterways. Preliminary hydraulic modelling using HEC-RAS was undertaken to determine the sensitivity of flood inundation extent to the roughness. HEC-RAS is a hydraulic modelling software package developed US Army Engineering Corp which is used to predict flooding.

As discussed in **Section 3.8**, the 1955 flood event observations were compared to the 100 year ARI flood event hydraulic results. The HEC-RAS model determined that high roughness would be required to generate flood inundation extents similar to that of the 1955 event.

Table 5-1 presents the Manning's 'M' values, equivalent Manning's 'n' value and description in *Open Channel Hydraulics (Chow, 1959)*. **Figure 5-1** shows the selected roughness for the study area.

- **Table 5-1 Manning's Roughness**

Land Use	Description	Manning's 'M'	Manning's 'n'
Densely vegetated	Waterways with heavy stands of timber, a few down trees, flood stage reaching branches	8.3	0.12
Forested	Medium to dense brush	12.5	0.08
Rural	Scattered brush and heavy weeds	20	0.05

5.4.2 Eddy Viscosity

A uniform eddy viscosity of 0.12 was applied across the full model area. This value was recommended by the model developers for a grid resolution of 9 m. The model results were reviewed to ensure the value was predicting reasonable flow patterns and response.

5.5 Baseflow

In order to more accurately model a winter storm in which the river system contains some baseflow, the hydraulic model was run using a "hotstart". A hotstart allows flow with momentum, to be present within the hydraulic model at the start of the model run. For the Boddington model, an initial flow of 20 m^3/s was included using the hotstart. This baseflow was selected based on the recorded streamflow at Marradong Road Bridge gauge (614224).

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5.6 Hydraulic Structures

The site visit identified a number of bridges and culverts in the study area. Culverts capacities were considered to be relative minor when compared to the expected flood flows and were therefore excluded from the hydraulic assessment.

Hydraulic structures were not explicitly modelled in this assessment. Bridges were represented in the model as openings in the terrain to allow water to flow through. This representation of the structures is considered to have minimal impact on the overall result of the hydraulic model. The 100 year ARI flood event overtops the Bannister-Marradong Road Bridge.

The weir has been represented in the terrain for the hydraulic model. The weir has been assumed to be full at the start of the design flood event.

5.7 Hydrologic Inputs

Inflows to the hydraulic model were developed using the hydrologic model, as outlined in **Section 4.8**. The boundary inflow locations in the hydraulic model were consistent with the hydrologic catchment delineation. Internal model inflows were introduced to the hydraulic model into the stream or drainage line nearest to the subcatchment centroid identified in the hydrologic model. The model inflow points (source points) are presented in **Figure 5-1**.

5.8 Calibration

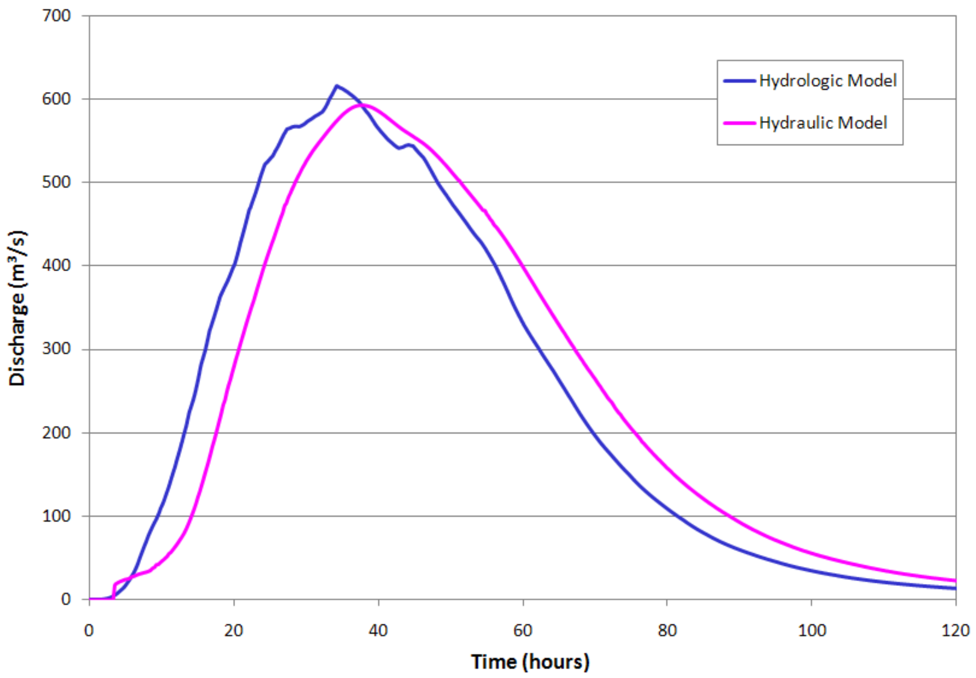
Calibration of the hydraulic model was not possible as there were no recorded flood levels for the historic flood events. There was however anecdotal evidence of inundation extents for historical flood events this is discussed in **Section 5.9**.

5.9 Validation

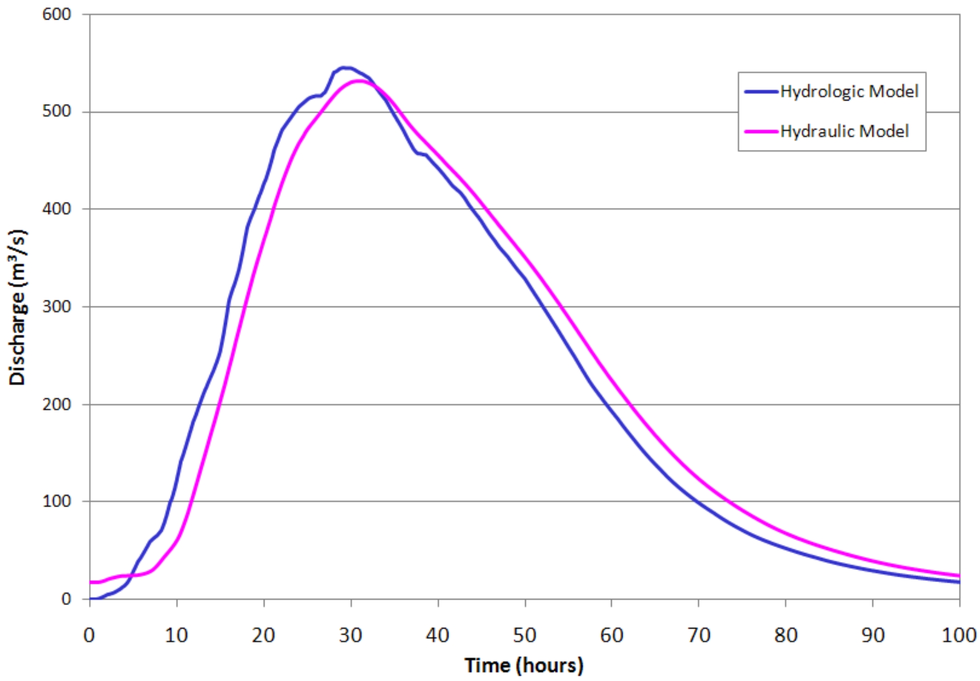
Validation of the hydraulic model was undertaken by two methods:

- comparison on the hydrologic and hydraulic model hydrographs; and
- comparison to anecdotal flood evidence.

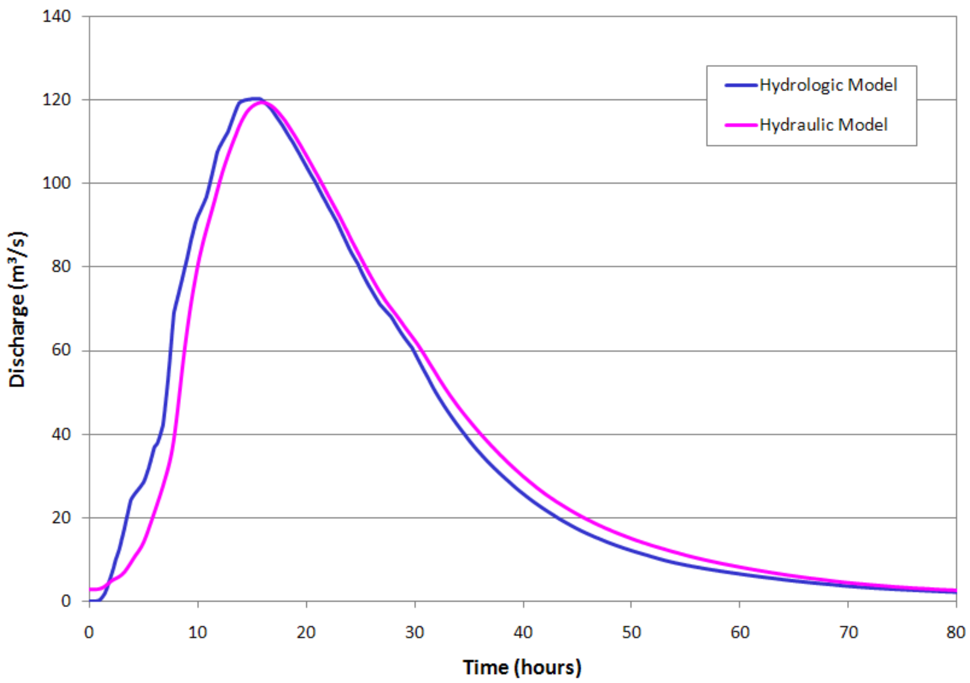
Hydrographs were extracted from the hydrologic and hydraulic models at a number of locations to compare peak discharges and timing of the hydraulic model. **Figure 5-2** to **Figure 5-4** shows a comparison of the hydrologic model and hydraulic model hydrographs for the 100 year ARI flood event.



- **Figure 5-2 Comparison of Hydrologic and Hydraulic Models – Hotham River (C31)**



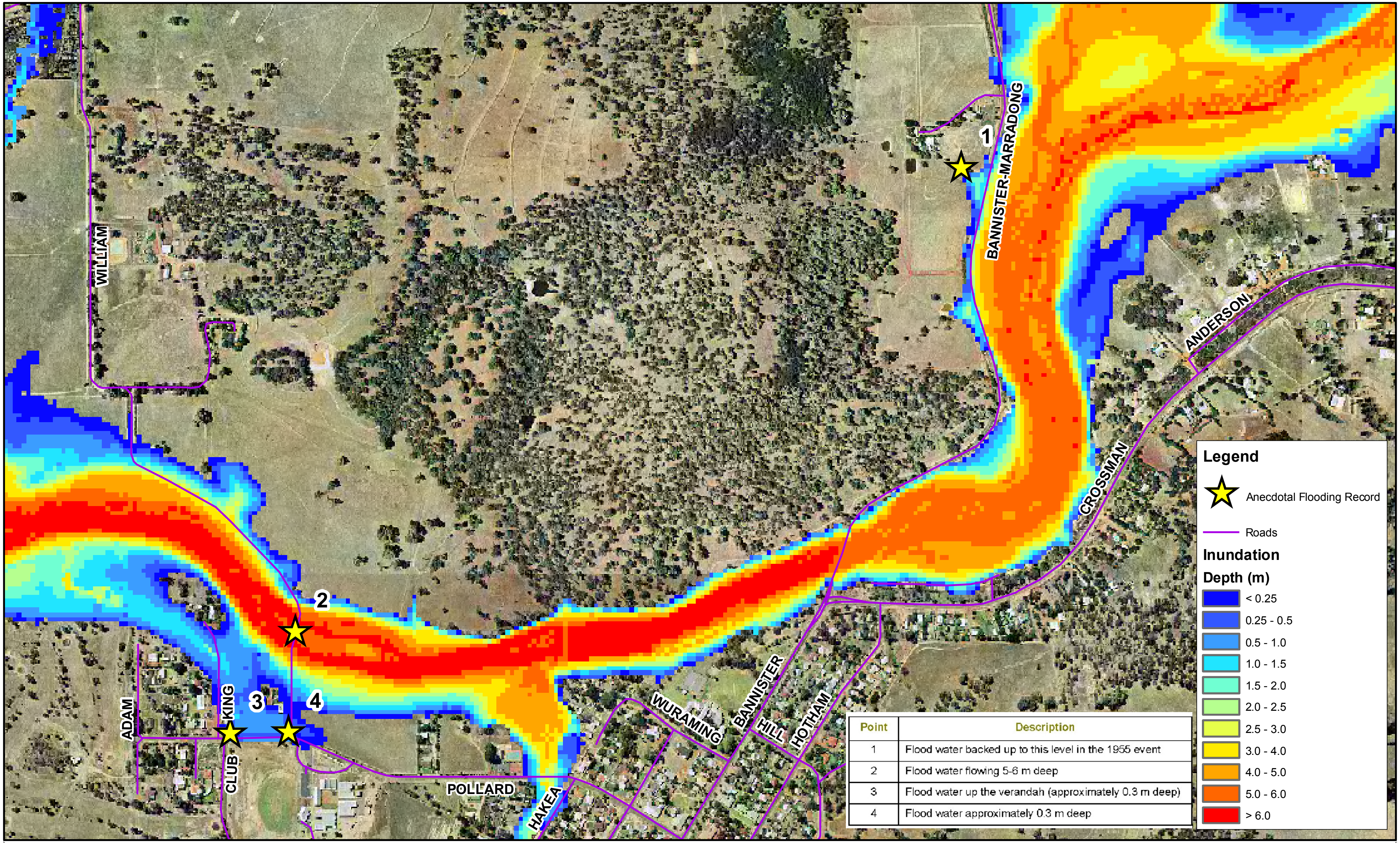
- **Figure 5-3 Comparison of Hydrologic and Hydraulic Models – Bannister River (C22)**



▪ **Figure 5-4 Comparison of Hydrologic and Hydraulic Models – Hotham River (C19)**

The results show a very strong comparison between the hydrologic and hydraulic modelling for both peak discharge, timing and flood volume. This indicates the hydrologic model has sufficient allowance for internal subcatchment storage and appropriate routing parameters.

Validation to anecdotal records was undertaken for this study as inundation extent mapping for previous floods or recorded flood levels were not available. Anecdotal reports of previous flooding were obtained from long term residents of the area as discussed in **Section 2.3**. Hydraulic model results for the 100 year ARI flood event showed that the predicted inundation extent was similar to the inundation extent reported for the 1955 event. The locations for the comparison of the hydraulic modelling results are shown in **Figure 5-5**.



Point	Description
1	Flood water backed up to this level in the 1955 event
2	Flood water flowing 5-6 m deep
3	Flood water up the verandah (approximately 0.3 m deep)
4	Flood water approximately 0.3 m deep

BODDINGTON FLOODPLAIN MANAGEMENT STUDY

Figure 5-5 Anecdotal Floooding Information Comparison to 100 Year ARI Event

0 0.25 0.5

Kilometres

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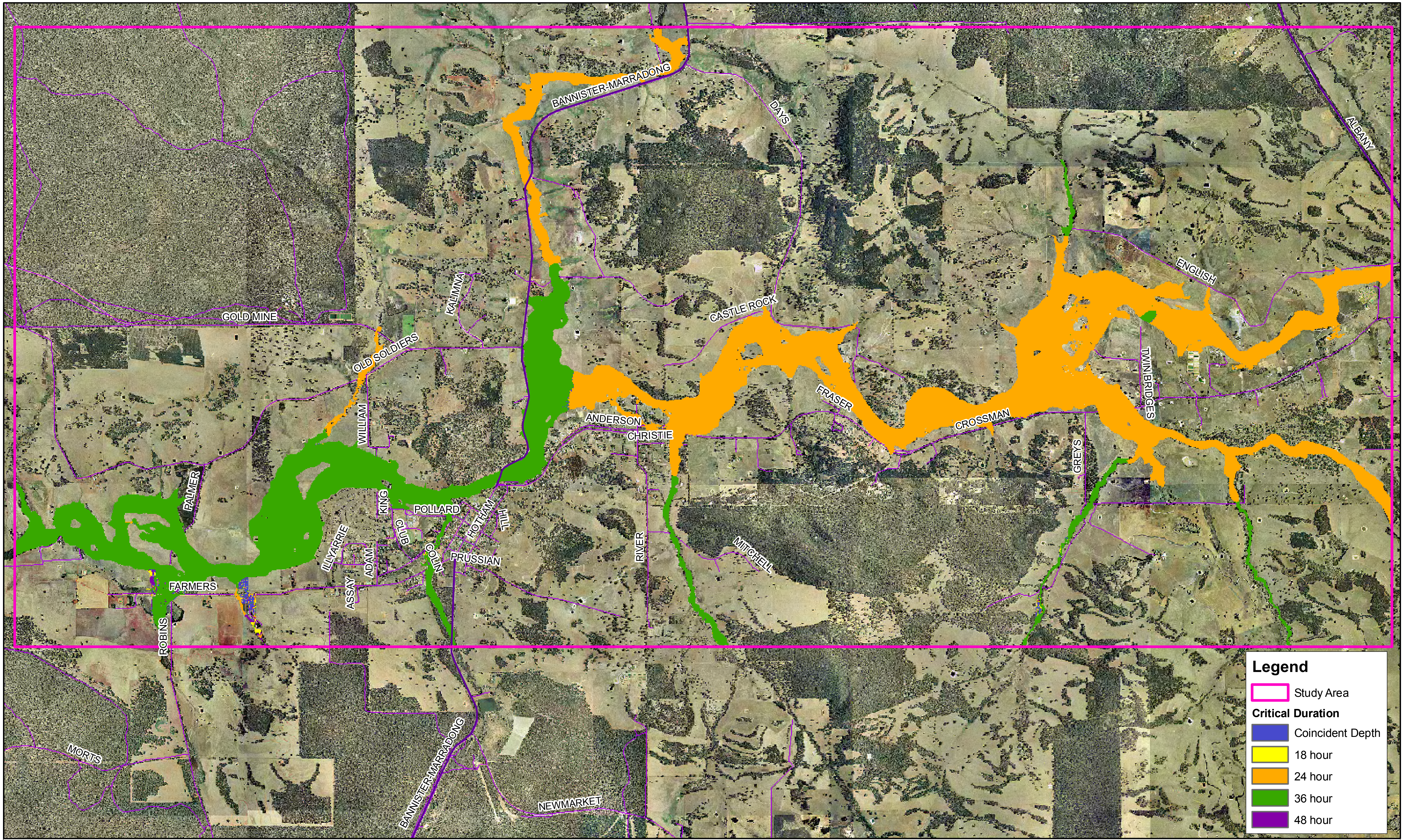
6. Design Event Hydraulics

Design event hydraulic model runs were undertaken utilising design event hydrology outlined in **Section 4**. The model runs were conducted for 10, 25 and 100 year ARI flood events.

6.1 Critical Duration Storm Events

For this study, the critical storm duration was deemed to be the storm event that caused the deepest flooding depth. The hydrologic modelling predicted the peak discharge was from a combination of 24 and 36 hour storm durations. Preliminary hydraulic model runs were conducted to establish the storm events that delivered the critical flood depth within the hydraulic model area. The hydraulic model was run for durations from 18 to 48 hours. The 24 and 36 hour storm event was found to be critical for the majority of the study area.

In the upper parts of the study area near the confluence of the Hotham and Crossman Rivers and in the upper parts of the Bannister River, the 24 hour storm was the critical event. The 36 hour event was found to be critical for the lower parts of the study area and for the majority of the small streams entering the catchment from the south. **Figure 6-1** illustrates the variation in critical duration across the study area.



BODDINGTON FLOODPLAIN MANAGEMENT STUDY

Figure 6-1 100 Year ARI Event Existing Conditions Critical Duration

0 0.5 1 2 3
Kilometres

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6.2 Existing Conditions

The design event hydraulics were modelled for the range of return periods from the 10 year to the 100 year ARI flood events. Peak flood depth and velocity results for all modelled ARIs were extracted and these are presented in **Appendix C** for existing conditions.

6.3 Description of Flooding Regime

The flooding from the Hotham, Crossman and Bannister Rivers is generally contained in well defined channels. Flooding was predicted to be more widespread at the confluence of the Hotham and Crossman as well as the confluence of the Hotham and Bannister Rivers. Widespread flooding is also predicted downstream of the Boddington town site where the Hotham River meanders from King Road to the downstream boundary of the study extent.

6.4 Flood Impacted Properties

The 100 year ARI flood was mostly contained in the well defined channels. There were a limited number of flood affected properties in the study area. There were some houses which are predicted to be affected by the 100 year ARI flood event and a number of houses were predicted to be surrounded by flood waters in the 100 year ARI flood event.

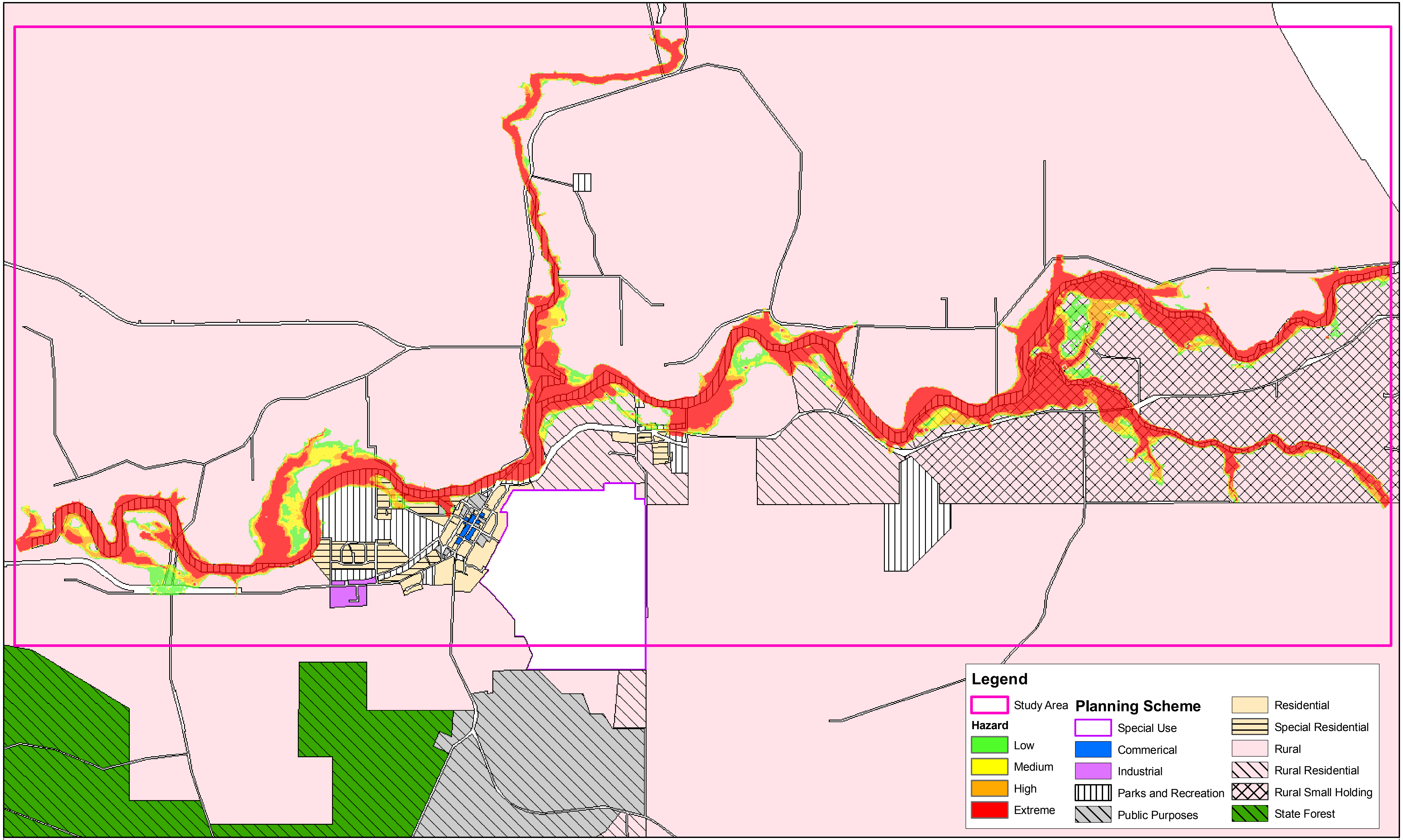
Shallow flooding and flood impacted properties are discussed further in the *Boddington Floodplain Management Strategy Report (SKM, 2009)*.

6.5 Flood Hazard Assessment

The hydraulic model results for the 100 year ARI flood event, as shown in **Figure 6-2**, was used as the basis of a flood hazard assessment and development of options for floodplain management. The model results were tested using the flood hazard estimation techniques outlined in *SCARM Report 73 (CSIRO, 2000)*. 'Hazard' is a function of the flood depth and velocity.

Flood hazard mapping was generated from the hydraulic modelling results using the project GIS. The GIS analysis was based on the results of peak 100 year ARI flood depth and velocity. This is a conservative analysis because it assumes that peak flood depth is coincident with the peak flood velocity. Experience with using this methodology has found that it does not exaggerate flood hazard and gives sound results. Further details of this analysis are presented in the *Boddington Floodplain Management Strategy Report (SKM, 2009)*. The flood hazard results are also presented in **Appendix D**.

The existing conditions results have been compared to the current planning scheme of the area as shown in **Figure 6-2**.



BODDINGTON FLOODPLAIN MANAGEMENT STUDY

Figure 6-2 100 Year ARI Event Flood Hazard Map and Boddington Planning Scheme

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6.6 Developed Conditions

A floodplain encroachment analysis was undertaken to assess the potential areas of the floodplain which may be filled as part of future development. The criteria, decided in consultation in the DoW, to be applied was that filling of the floodplain could only increase 100 year ARI flood level by a maximum of 150 mm. The potential areas of floodplain fill were developed in consultation with the DoW. The floodplain encroachment analysis areas is shown in **Figure 6-3**.

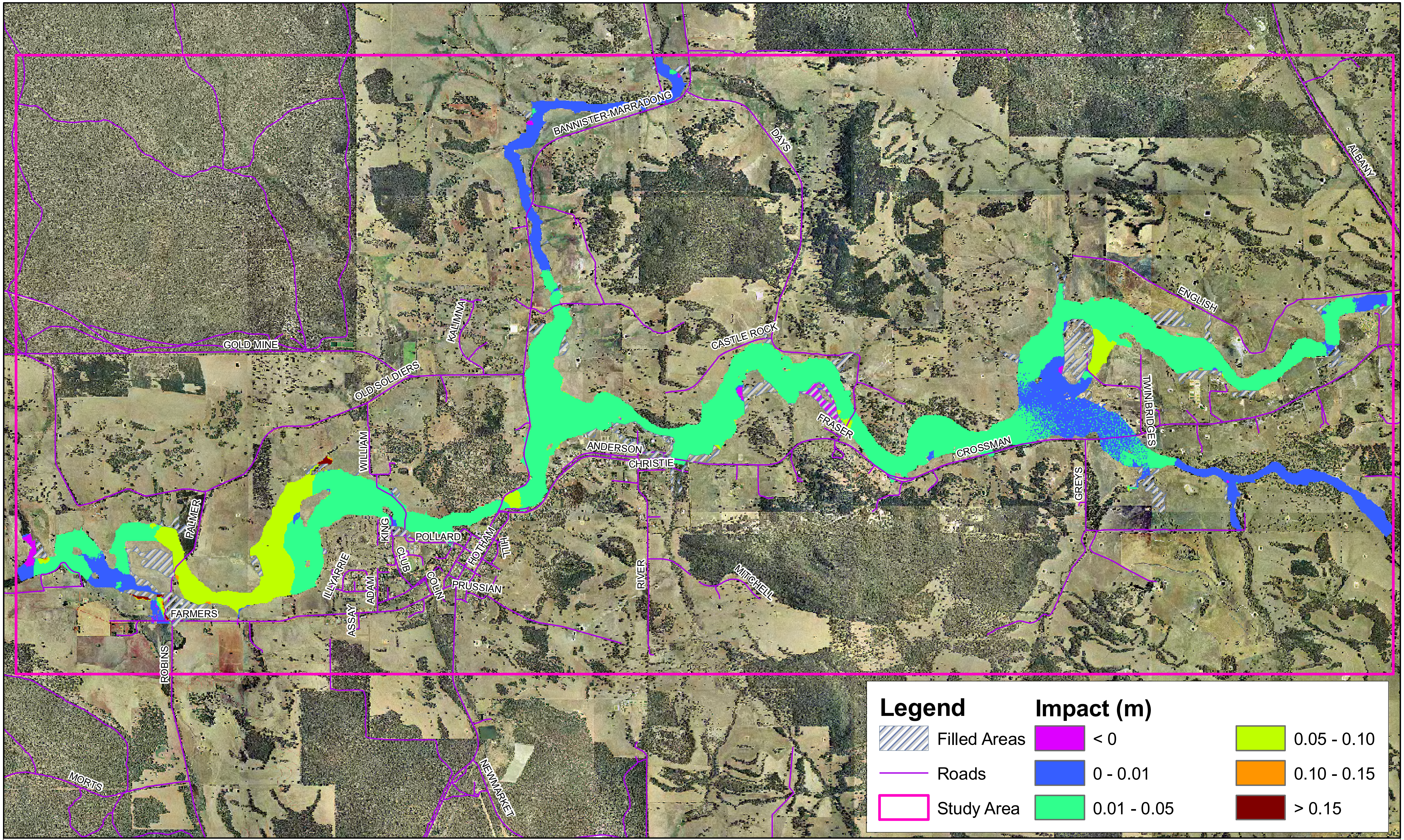
It was assumed that local stormwater management will be implemented for any development approved in the Boddington area and therefore, peak discharges are maintained at existing conditions once developed. This is discussed further in the *Boddington Floodplain Management Strategy Report (SKM, 2009)*.

The existing conditions hydraulic model was updated to include the potential areas of encroachment into the floodplain. **Figure 6-3** presents the results of encroachment analysis for the 100 year ARI event.

Full results of developed conditions hydraulic modelling are presented in **Appendix E**.

The areas of potential floodplain development identified in the encroachment analysis does not imply these areas are approved for filling by the Shire of Boddington. Areas where floodplain development is potential acceptable is presented in the *Boddington Floodplain Management Strategy Report (SKM, 2009)*. Filling areas of the floodplain requires Shire approval and it should be noted that other planning issues, such as environmental and ecological considerations, may also need to be addressed.

It should also be noted the increase in flood levels due to floodplain filling was not maximised to the full 150 mm criteria as part of the encroachment analysis. It would be inappropriate to maximise the developable area (utilise the full 150 mm allowance) without full knowledge of developments that may have significant regional benefit to the community (eg. new bridges, roads, tourism facilities, etc).



BODDINGTON FLOODPLAIN MANAGEMENT STUDY

Figure 6-3 100 Year ARI Event Developed Conditions Floodplain Encroachment Analysis

0 0.5 1 2 3
Kilometres

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6.7 Discussion

The critical duration for the study area was a combination of 24 and 36 hour duration event. The Rivers were generally contained in well defined channels. There were some areas which had breakouts that were activated in the 100 year ARI flood event. This occurred at the following locations:

- at the confluence of the Hotham and Crossman Rivers;
- at the confluence of the Hotham and Bannister Rivers; and
- at bends in the Hotham River near Castle Rock Road, Palmer Road, William Road and Anderson Road.

Figure 6-2 shows potential clashes between the Planning Scheme and the predicted flooding for 100 year ARI flood event. Flooding was predicted in the upper reaches of the Hotham River and at the confluence with the Crossman River which is designated Rural Small Holding. There was flooding predicted at the confluence of the Hotham and Bannister River, which is designated as rural residential. Flooding was also predicted for the Hotham River in the town of Boddington, which is designated special residential. Other predicted flooding occurs in areas designated as rural.

A floodplain encroachment analysis was undertaken to assess the impacts from filling areas of the floodplain. This encroachment analysis determined areas in which filling could occur without increasing 100 year ARI flood levels by more than 150 mm. **Figure 6-3** shows the potential areas of floodplain filling for the Boddington area.

7. Conclusions

The following conclusions have been developed based on the results of the flood modelling analysis described within this report. Recommendations based on these findings are detailed in the separate *Boddington Floodplain Management Strategy* (SKM, 2009).

The conclusions were:

- terrain information was good quality and fit to purpose for both the hydrologic and the hydraulic assessment;
- good quality rainfall and streamflow data was available for calibration of the hydrologic model;
- no recorded flood levels or previous flood studies were available to calibrate the hydraulic model;
- anecdotal flooding information was collected to validate the hydraulic modelling;
- flooding of the Hotham, Crossman and Bannister Rivers was generally contained in well defined channels, with floodplain flooding at the river confluences;
- development in the catchment needs to control hydrology through managing the additional runoff from impervious areas and the affects of the floodplain fill;
- the flood hazard analysis showed there were potential conflicts between areas designated rural small holding, rural residential and special residential and the flooding expected in the 100 year ARI event; and
- potential areas of floodplain development were identified by the DoW and this filling predicted to increase 100 year ARI flood levels by less than the 150 mm criteria and thus considered acceptable with regard to major flooding.

8. References

CSIRO (2000), *SCARM Report 73: Floodplain Management in Australia: Best Practice Principles and Guidelines*. CSIRO Publishing.

Department of Environment, Western Australia (2000), *WA CRC-Forge.*

Department of Natural Resources and Water (2007), *Queensland Urban Drainage Manual (QUDM)*, Volume 1. Department of Natural Resources and Water.

Institution of Engineers Australia (1987), *Australian Rainfall and Runoff: a Guide to Flood Estimation. Vol. 2*. The Institution of Engineers, Australia.

SKM (2009), *Boddington Floodplain Management Strategy Report.*

Ven Te Chow (1959), *Open Channel Hydraulics*. McGraw-Hill Book Company Inc.

Appendix A Hydrologic Key Inputs

Node Name	x_orig	y_orig	Total Area [km2]	Second Sub Catchment Flag	% Impervious	Area Catch 1 Pervious [km2]	Area Catch 2 Impervious [km2]	Pervious Catchment Mannings 'n'	Impervious Catchment Mannings 'n'	Percentage Impervious Catch 1 [%]	Percentage Impervious Catch 2 [%]	Slope Catch 1 Pervious [%]	Slope Catch 2 Impervious [%]	Losses Perv	Losses Imperv	Local Hydrograph	Total Hydrograph
C01	528003.24196	6368219.35040	268.9	0	0%	268.9	0.001	0.07	0.15	0.001	0.001	2.59	2.59	Pasture_IL_PL	Forest_IL_PL	0	0
C02	512795.68071	6387718.08576	709.9	1	0%	684.9	25.000	0.07	0.15	0.001	0.001	2.83	2.83	Pasture_IL_PL	Forest_IL_PL	0	0
C03	500479.38815	6388877.59973	321.3	1	0%	311.3	10.000	0.07	0.15	0.001	0.001	3.87	3.87	Pasture_IL_PL	Forest_IL_PL	0	0
C04	495377.47430	6367991.63794	448.4	1	0%	303.4	145.000	0.07	0.15	0.001	0.001	4.46	4.46	Pasture_IL_PL	Forest_IL_PL	0	0
C05	484085.69297	6386255.47478	496.8	1	0%	446.8	50.000	0.07	0.15	0.001	0.001	4.95	4.95	Pasture_IL_PL	Forest_IL_PL	0	0
C06	476590.19491	6370504.64204	124.3	1	0%	112.3	12.000	0.07	0.15	0.001	0.001	5.58	5.58	Pasture_IL_PL	Forest_IL_PL	0	0
C07	470130.96652	6375189.40474	237.8	1	0%	202.8	35.000	0.07	0.15	0.001	0.001	6.80	6.80	Pasture_IL_PL	Forest_IL_PL	0	0
C08	473803.63270	6359637.79573	347.9	0	0%	347.9	0.001	0.07	0.15	0.001	0.001	5.46	5.46	Pasture_IL_PL	Forest_IL_PL	0	0
C09	461906.90355	6392428.99553	337.7	1	0%	162.7	175.000	0.07	0.15	0.001	0.001	7.01	7.01	Pasture_IL_PL	Forest_IL_PL	0	0
C10	460897.78111	6378129.83918	37.3	1	0%	27.3	10.000	0.07	0.15	0.001	0.001	9.27	9.27	Pasture_IL_PL	Forest_IL_PL	1	0
C11	462672.79691	6370241.42185	19.5	0	0%	19.5	0.001	0.07	0.15	0.001	0.001	8.32	8.32	Pasture_IL_PL	Forest_IL_PL	0	1
C12	457752.27183	6376382.64737	18.2	1	0%	12.2	6.000	0.07	0.15	0.001	0.001	8.12	8.12	Pasture_IL_PL	Forest_IL_PL	1	0
C13	458603.36883	6372606.01788	16.8	0	0%	16.8	0.001	0.07	0.15	0.001	0.001	5.78	5.78	Pasture_IL_PL	Forest_IL_PL	1	0
C14	460743.64118	6367796.71784	23.4	1	0%	21.4	2.000	0.07	0.15	0.001	0.001	6.91	6.91	Pasture_IL_PL	Forest_IL_PL	1	0
C15	457298.57064	6369186.87220	10.4	1	0%	7.9	2.500	0.07	0.15	0.001	0.001	7.76	7.76	Pasture_IL_PL	Forest_IL_PL	1	0
C16	445858.53232	6388078.76806	164.7	1	0%	14.7	150.000	0.07	0.15	0.001	0.001	6.86	6.86	Pasture_IL_PL	Forest_IL_PL	0	0
C17	452627.73832	6379708.79231	28.0	1	0%	26.0	2.000	0.07	0.15	0.001	0.001	9.49	9.49	Pasture_IL_PL	Forest_IL_PL	0	0
C18	454204.46333	6375460.08283	3.5	1	0%	3.0	0.500	0.07	0.15	0.001	0.001	9.29	9.29	Pasture_IL_PL	Forest_IL_PL	0	1
C19	453974.16235	6372377.40922	14.1	1	0%	10.6	3.500	0.07	0.15	0.001	0.001	8.67	8.67	Pasture_IL_PL	Forest_IL_PL	1	0
C20	454447.37555	6368124.93539	17.3	1	0%	15.8	1.500	0.07	0.15	0.001	0.001	8.30	8.30	Pasture_IL_PL	Forest_IL_PL	1	0
C21	451424.66249	6375629.98893	11.8	0	0%	11.8	0.001	0.07	0.15	0.001	0.001	10.49	10.49	Pasture_IL_PL	Forest_IL_PL	1	0
C22	451950.83048	6373348.39491	5.5	1	0%	4.5	1.000	0.07	0.15	0.001	0.001	7.85	7.85	Pasture_IL_PL	Forest_IL_PL	1	0
C23	447492.18992	6376869.21477	35.7	1	0%	0.0	35.738	0.07	0.15	0.001	0.001	6.83	6.83	Pasture_IL_PL	Forest_IL_PL	1	0
C24	449702.59193	6373277.64686	5.7	0	0%	5.7	0.001	0.07	0.15	0.001	0.001	7.64	7.64	Pasture_IL_PL	Forest_IL_PL	1	0
C25	450636.15279	6370940.15750	2.3	0	0%	2.3	0.001	0.07	0.15	0.001	0.001	10.94	10.94	Pasture_IL_PL	Forest_IL_PL	1	0
C26	450895.95104	6368465.01366	9.9	1	0%	4.9	5.000	0.07	0.15	0.001	0.001	7.52	7.52	Pasture_IL_PL	Forest_IL_PL	1	0
C27	448613.72613	6371009.26719	4.4	0	0%	4.4	0.001	0.07	0.15	0.001	0.001	3.88	3.88	Pasture_IL_PL	Forest_IL_PL	1	0
C28	448728.07729	6369171.84438	2.5	1	0%	2.0	0.500	0.07	0.15	0.001	0.001	12.34	12.34	Pasture_IL_PL	Forest_IL_PL	1	0
C29	444499.88376	6375698.86129	16.8	1	0%	0.0	16.843	0.07	0.15	0.001	0.001	7.26	7.26	Pasture_IL_PL	Forest_IL_PL	1	0
C30	445339.71050	6371244.72484	10.0	1	0%	9.3	0.700	0.07	0.15	0.001	0.001	11.77	11.77	Pasture_IL_PL	Forest_IL_PL	1	0
C31	446935.04997	6370771.53515	3.1	0	0%	3.1	0.001	0.07	0.15	0.001	0.001	5.47	5.47	Pasture_IL_PL	Forest_IL_PL	1	0
C32	447560.50233	6367933.92454	7.5	1	0%	4.8	2.700	0.07	0.15	0.001	0.001	10.29	10.29	Pasture_IL_PL	Forest_IL_PL	1	0
C33	437660.16404	6376115.39392	147.2	1	0%	25.2	122.000	0.07	0.15	0.001	0.001	7.86	7.86	Pasture_IL_PL	Forest_IL_PL	0	0
C34	442942.84282	6367804.59720	60.1	1	0%	47.1	13.000	0.07	0.15	0.001	0.001	7.59	7.59	Pasture_IL_PL	Forest_IL_PL	0	0
M01	463466.07129	6373992.15338	0.0	1	0%	0.0	0.000	0.07	0.15	0.001	0.001	0.10	0.10	Pasture_IL_PL	Forest_IL_PL	0	1

SKM

Appendix B Rainfall & Streamflow Gauges

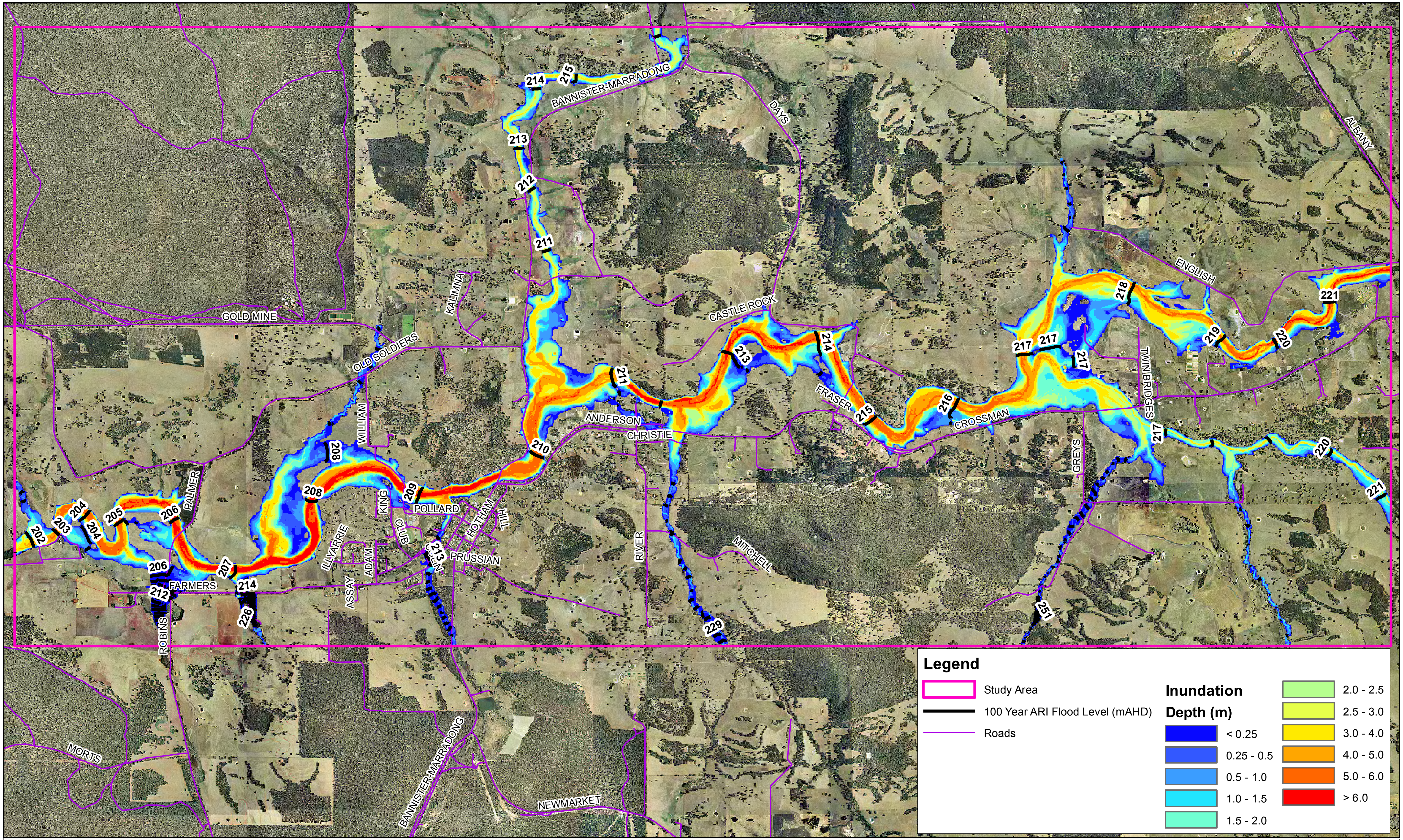
Table B-1 Rainfall Gauges

Site	Name	Type	Source	Start	Cease
009507	Bannister	Daily	BOM	1884	2007
009509	Boddington Shire	Daily	BOM	1915	2007
009538	Dwellingup Forestry	Daily	BOM	1934	2007
009575	Marradong	Daily	BOM	1897	2007
009742	Bannister North	Daily	BOM	1963	1979
009769	Culford	Daily	BOM	1967	2007
010538	Cuballing Post Office	Daily	BOM	1911	2007
010540	Kenilworth TU	Daily	BOM	1906	1967
010624	Wynrock	Daily	BOM	1912	1972
010626	Pingelly	Daily	BOM	1890	2007
010648	Wandering comparison	Daily	BOM	1887	2003
010655	Williams	Daily	BOM	1885	2007
010658	Wonnaminta	Daily	BOM	1905	2007
010678	Landscape Hill	Daily	BOM	1907	1963
010687	Wandering Brook	Daily	BOM	1945	1981
010772	Popanyinning	Daily	BOM	1917	1941
010876	Caernarvon park	Daily	BOM	1976	2007
010888	Dwarda Downs	Daily	BOM	1982	2007
010907	Thornton Park	Daily	BOM	1971	1987
510054	Tutanning	Daily	DOW	1980	1987
509216	Mt Wells	Daily	DOW	1974	1992
010614	Narrogin	Pluviograph	BOM	1963	2005
009742	Bannister North	Pluviograph	BOM	1963	1979
009538	Dwellingup	Pluviograph	BOM	1953	2002
11581	Mt Saddleback	Pluviograph	DOW	1975	1998
11588	Tunnell Rd	Pluviograph	DOW	1975	1998
11589	Bee Farm Rd	Pluviograph	DOW	1975	1998
11583	Saddleback Rd Bridge	Pluviograph	DOW	1975	2007
11964	Bannister River - Culford	Pluviograph	DOW	1984	1999
11585	Marradong Rd Bridge	Pluviograph	DOW	1975	2007
11931	Dattening	Pluviograph	DOW	1977	2001

Table B-2 Streamflow Gauges

AWRC Reference	AWRC Waterway Name	AWRC Name	From	To
609009	NORTHERN ARTHUR RIVER	LAKE TOOLIBIN	1977	2007
609010	NORTHERN ARTHUR RIVER	LAKE TOOLIBIN INFLOW	1978	2007
609013	LAKE TOOLIBIN	BOOLOO	1982	1984
609029	LAKE TOOLIBIN BYPASS	BELOW DIVERTOR	1999	2006
609037	LAKE TOOLIBIN DRAIN INFLOW	CALM DRAIN EAST	2000	2007
609038	INFLOW LAKE TOOLIBIN	CALM DRAIN WEST	2000	2007
612021	BINGHAM RIVER	STENWOOD	1978	1999
614006	MURRAY RIVER	BADEN POWELL WTR SPOUT	1952	2007
614008	HOTHAM RIVER TRIB.	FALLS FARM	1982	1995
614011	MOORADUNG BK TRIB	TUNNEL ROAD	1975	1998
614012	MOORADUNG BK TRIB	BEE FARM ROAD	1975	1998
614041	WURAMING	YARRAGIL TRIB	1985	2000
614042	CHALK BROOK	POSSUM SPRING	1983	1984
614044	YARRAGIL BROOK	YARRAGIL FORMATION	1955	2007
614045	SWAMP OAK BROOK TRIB	CHADOORA	1984	1998
614046	YARRAGIL BROOK TRIB	YARRAGIL NORTH	1984	1991
614047	DAVIS BROOK	MURRAY VALLEY PLNTN	1954	2002
614055	DWELLINGUP BROOK	FORTESCUE DW05	1985	1987
614057	YARRAGIL BROOK TRIB	4L SUB CATCHMENT	1987	1999
614105	HOTHAM RIVER	PUMPHREY'S BRIDGE	1995	2007
614106	HOTHAM RIVER	BODDINGTON	Not Rated	
614123	CHALK BROOK	QUINDANNING ROAD	1959	1997
614124	BELL BROOK	QUINNDANNING ROAD	1967	1972
614125	CROSSMAN RIVER	RIVENDALE	2007	2007
614126	14 MILE BROOK	CONGILIN	2007	2007
614135	DWELLINGERUP BROOK	EAST BRANCH	1960	1976
614196	WILLIAMS RIVER	SADDLEBACK ROAD BRIDGE	1966	2007
614224	HOTHAM RIVER	MARRADONG ROAD BRIDGE	1966	2007
615222	DALE RIVER SOUTH	BROOKTON HIGHWAY	1966	1999

Appendix C Existing Conditions Hydraulic Modelling Results



BODDINGTON FLOODPLAIN MANAGEMENT STUDY

Figure C-1 100 Year ARI Flood Event Inundation Map Existing Conditions

0 0.5 1 2 3
Kilometres

Author: Sarah Gosling
Date: 03/07/09
Job No: QE09456

SINCLAIR KNIGHT MERZ
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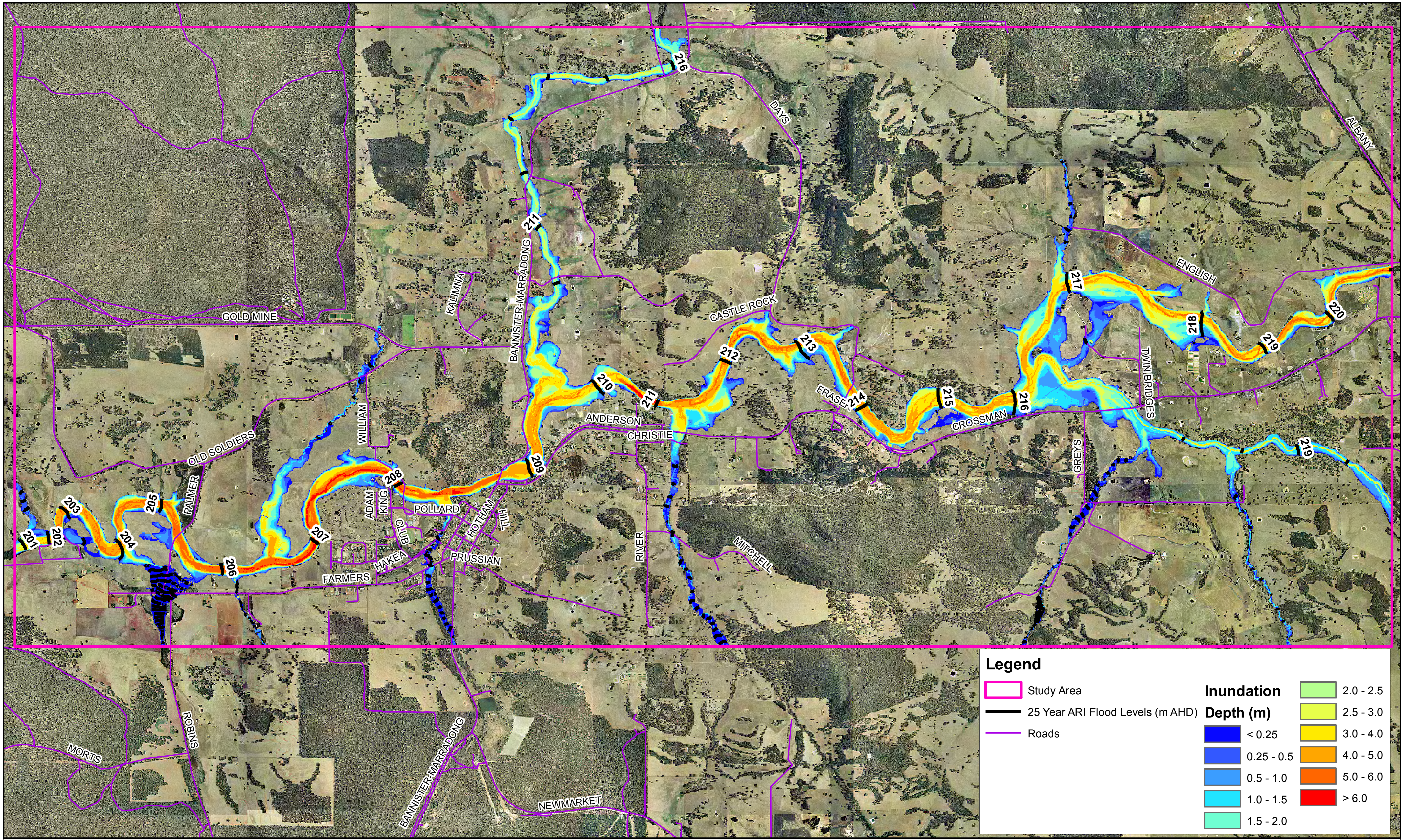

BODDINGTON FLOODPLAIN MANAGEMENT STUDY

Figure C-2 25 Year ARI Flood Event Inundation Map Existing Conditions

0 0.5 1 2 3
Kilometres

Author: Sarah Gosling
Date: 03/07/09
Job No: QE09456

SINCLAIR KNIGHT MERZ

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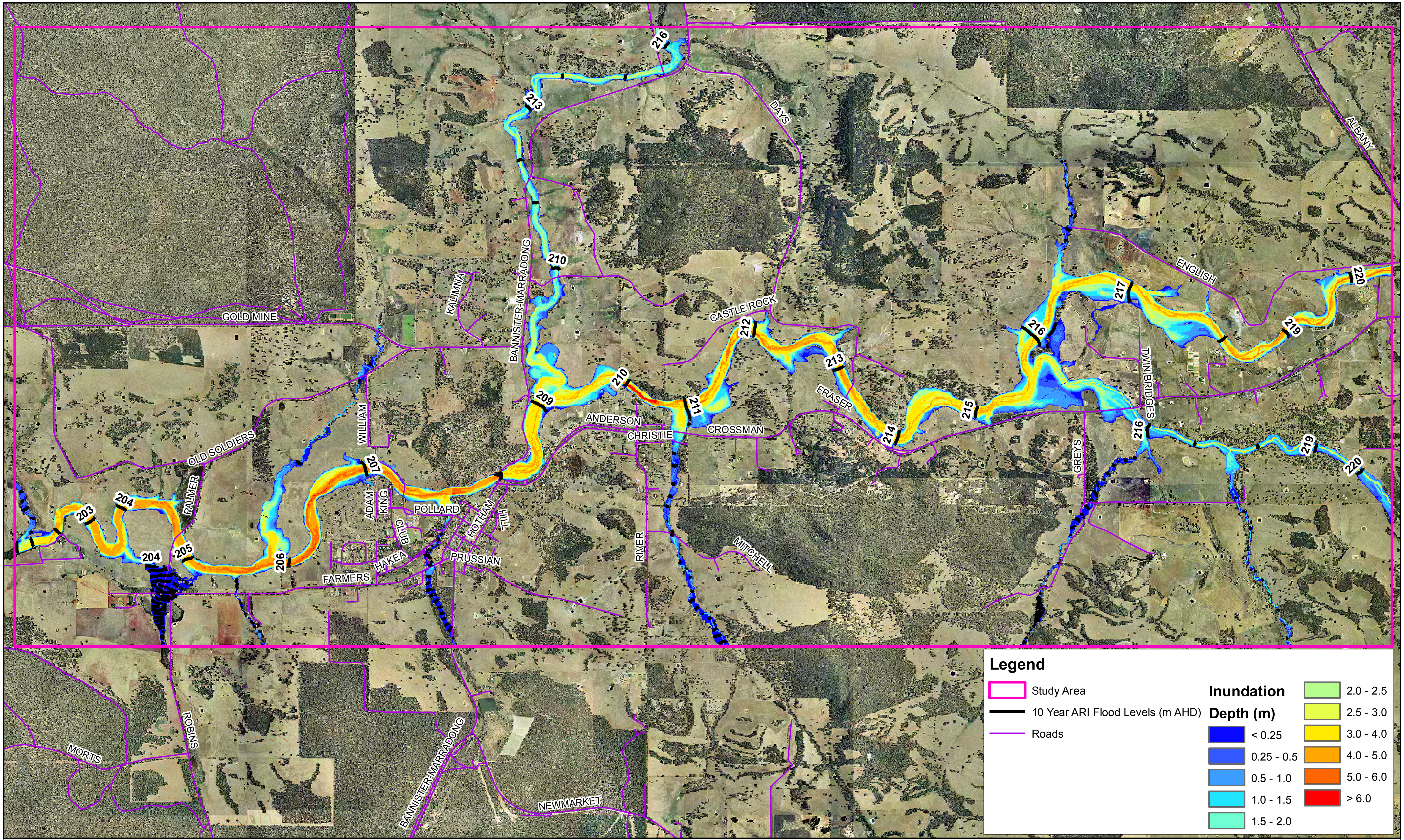

BODDINGTON FLOODPLAIN MANAGEMENT STUDY

Figure C-3 10 Year ARI Flood Event Inundation Map Existing Conditions

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Kilometres

Author: Sarah Gosling
Date: 03/07/09
Job No: QE09456

SINCLAIR KNIGHT MERZ

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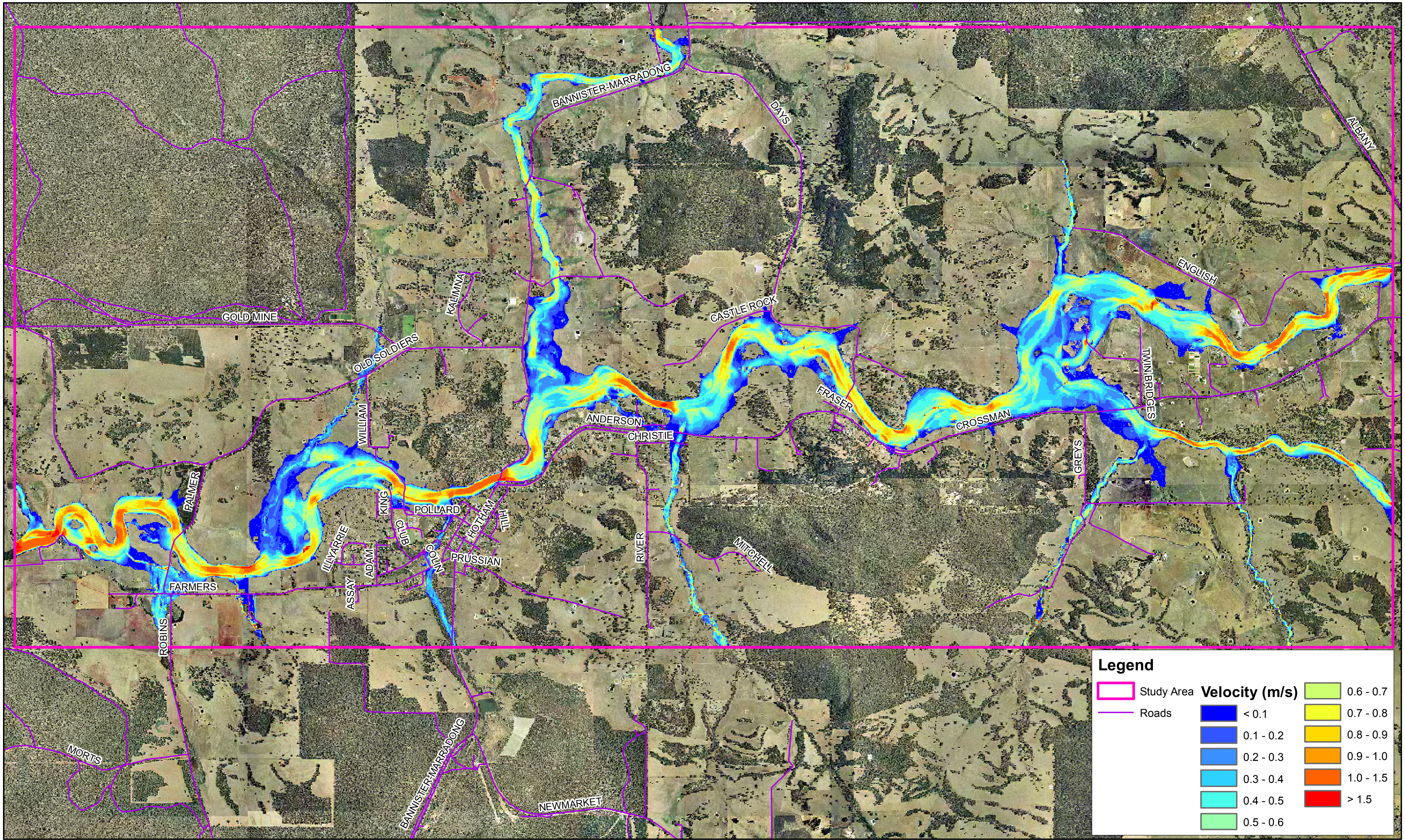

BODDINGTON FLOODPLAIN MANAGEMENT STUDY

Figure C-4 100 Year ARI Flood Event Velocity Map
Existing Conditions

0 0.5 1 2 3
Kilometres

Author: Sarah Gosling
Date: 03/07/09
Job No: QE09456

SINCLAIR KNIGHT MERZ

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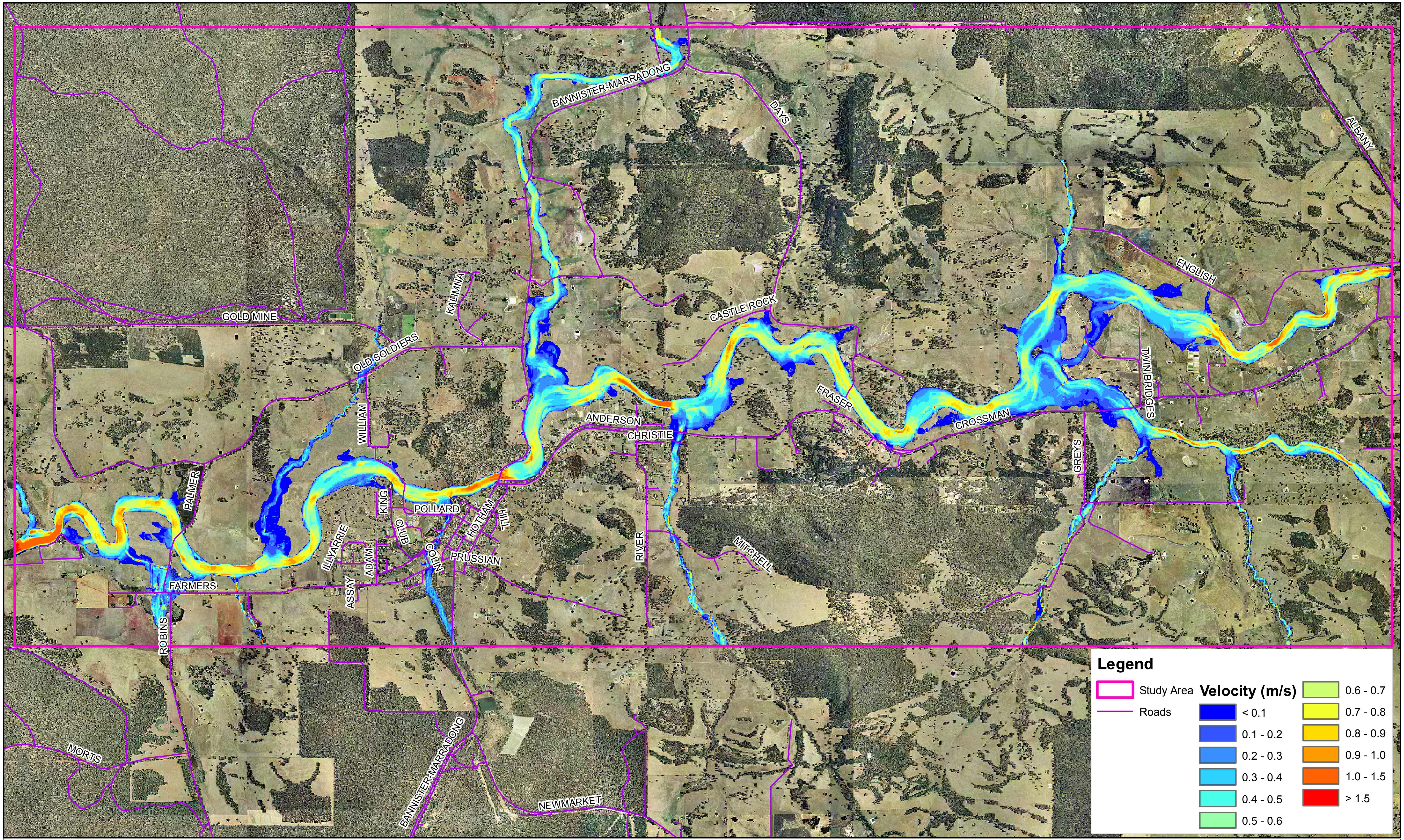

BODDINGTON FLOODPLAIN MANAGEMENT STUDY

Figure C-5 25 Year ARI Flood Event Velocity Map Existing Conditions

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Kilometres

Author: Sarah Gosling
Date: 03/07/09
Job No: QE09456

SINCLAIR KNIGHT MERZ

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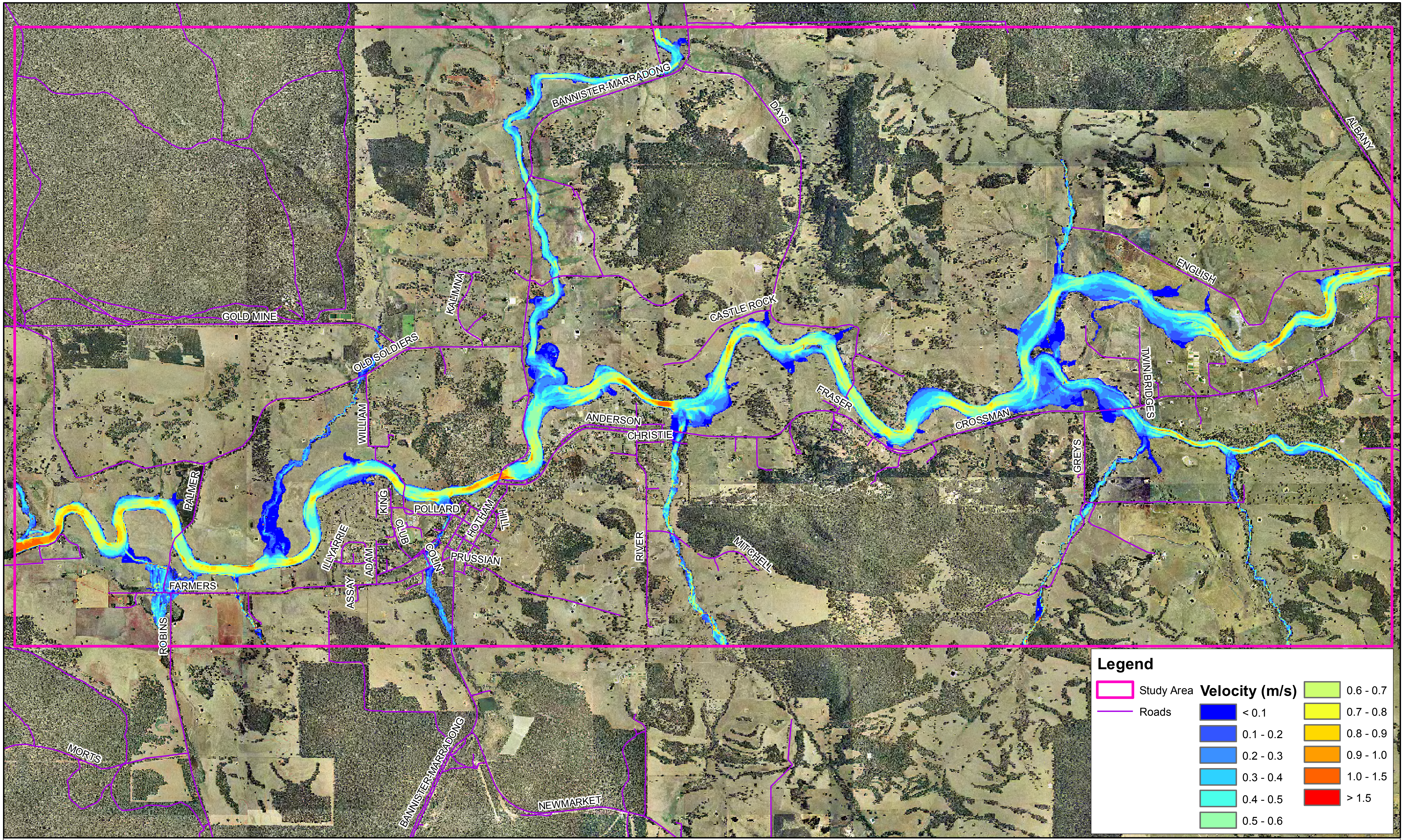

BODDINGTON FLOODPLAIN MANAGEMENT STUDY

Figure C-6 10 Year ARI Flood Event Velocity Map Existing Conditions

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Kilometres

Author: Sarah Gosling
Date: 03/07/09
Job No: QE09456

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SKM

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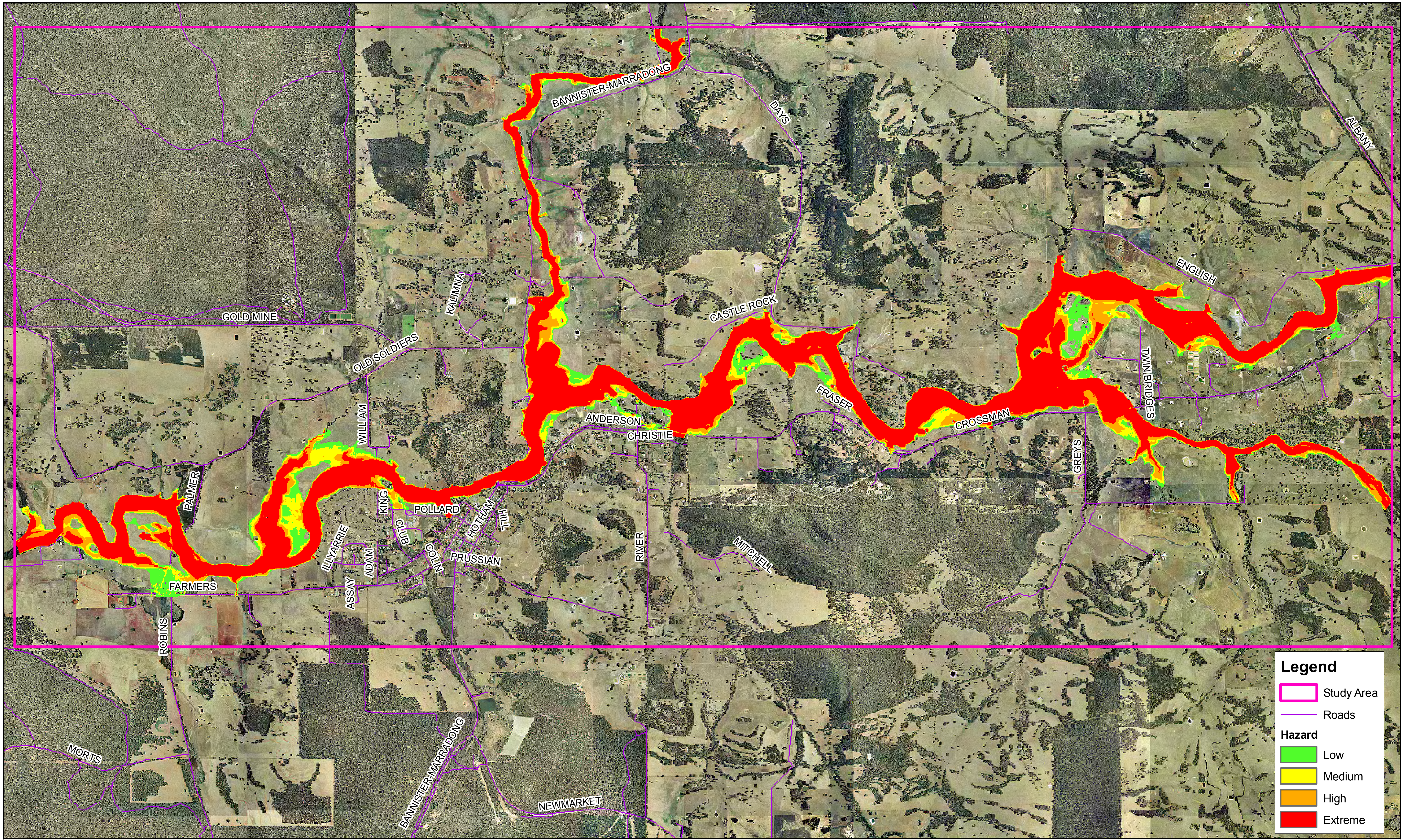
Appendix D Flood Hazard Analysis



BODDINGTON FLOODPLAIN MANAGEMENT STUDY

Figure D-1 100 Year ARI Event Flood Hazard Map

Author: Sarah Gosling
Date: 03/07/09
Job No: QE09456

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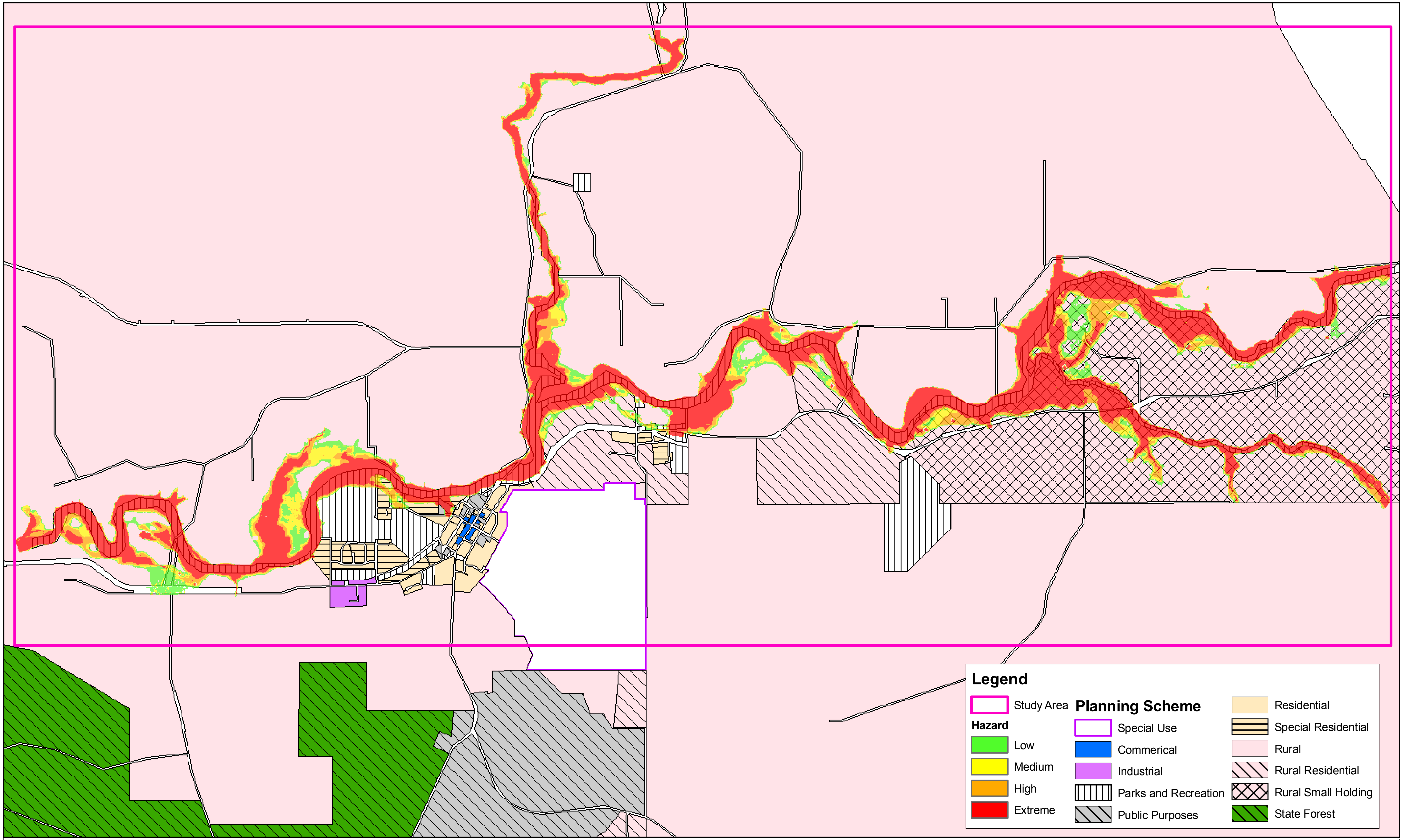

BODDINGTON FLOODPLAIN MANAGEMENT STUDY

Figure D-2 100 Year ARI Event Flood Hazard Map and Boddington Planning Scheme

Author: Sarah Gosling
Date: 03/07/09
Job No: QE09456

SINCLAIR KNIGHT MERZ

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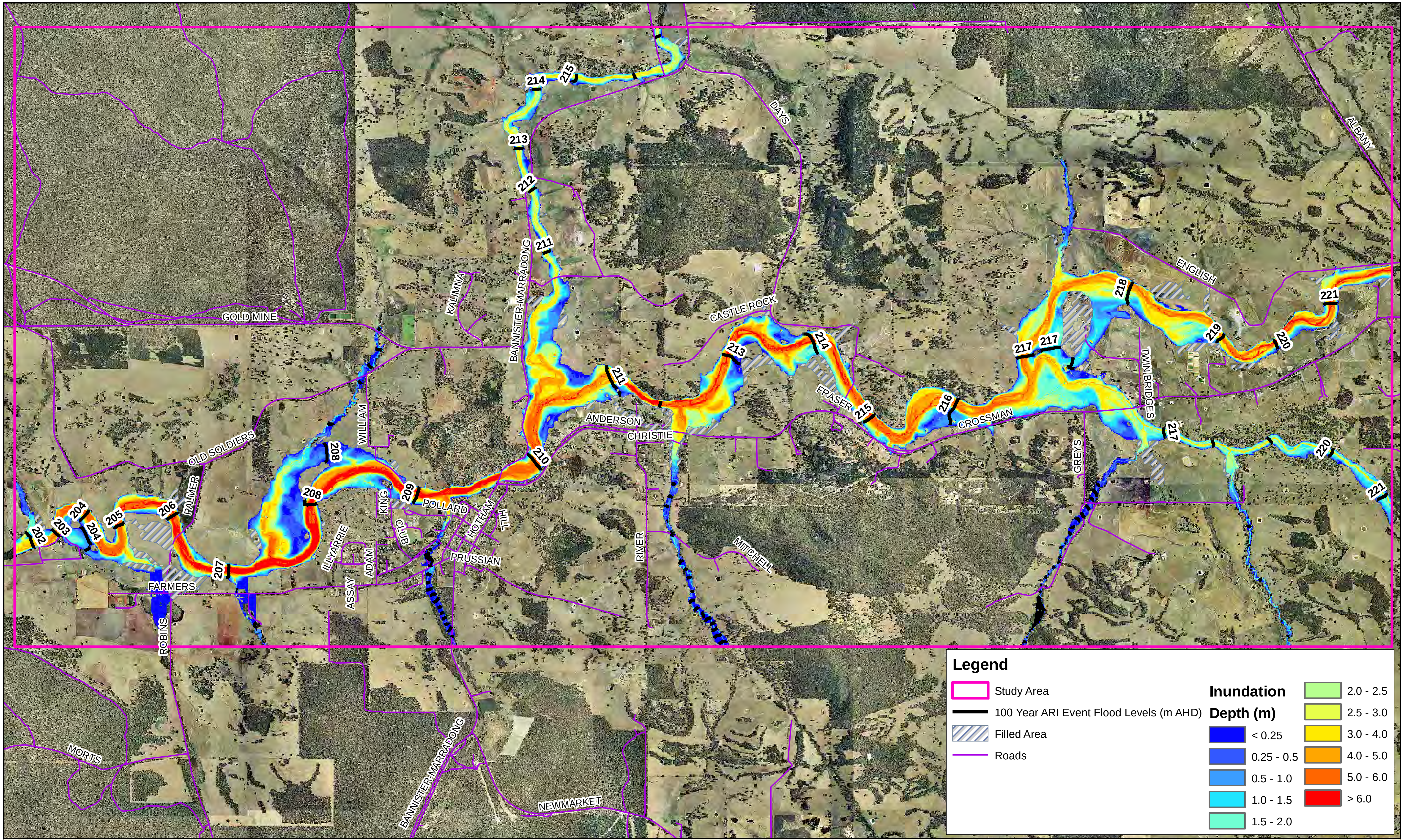
Appendix E Developed Conditions Hydraulic Modelling Results



BODDINGTON FLOODPLAIN MANAGEMENT STUDY

Figure E-1 100 Year ARI Flood Event Inundation Map
Developed Conditions

0 0.5 1 2 3
Kilometres

Author: Sarah Gosling
Date: 03/07/09
Job No: QE09456

SINCLAIR KNIGHT MERZ
SKM

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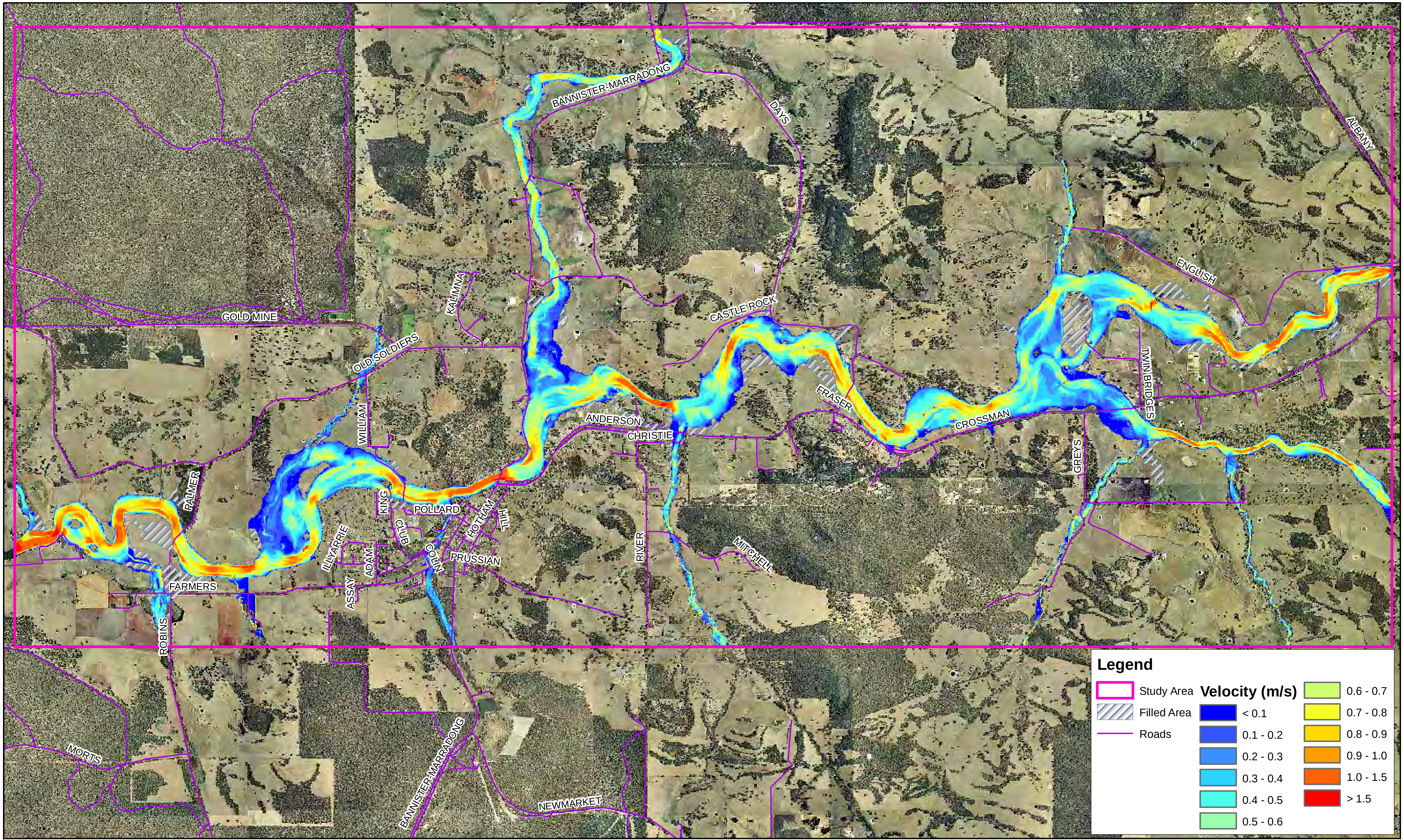

BODDINGTON FLOODPLAIN MANAGEMENT STUDY

Figure E-2 100 Year ARI Flood Event Velocity Map
Developed Conditions

Author: Sarah Gosling
Date: 03/07/09
Job No: QE09456

SINCLAIR KNIGHT MERZ
SKM

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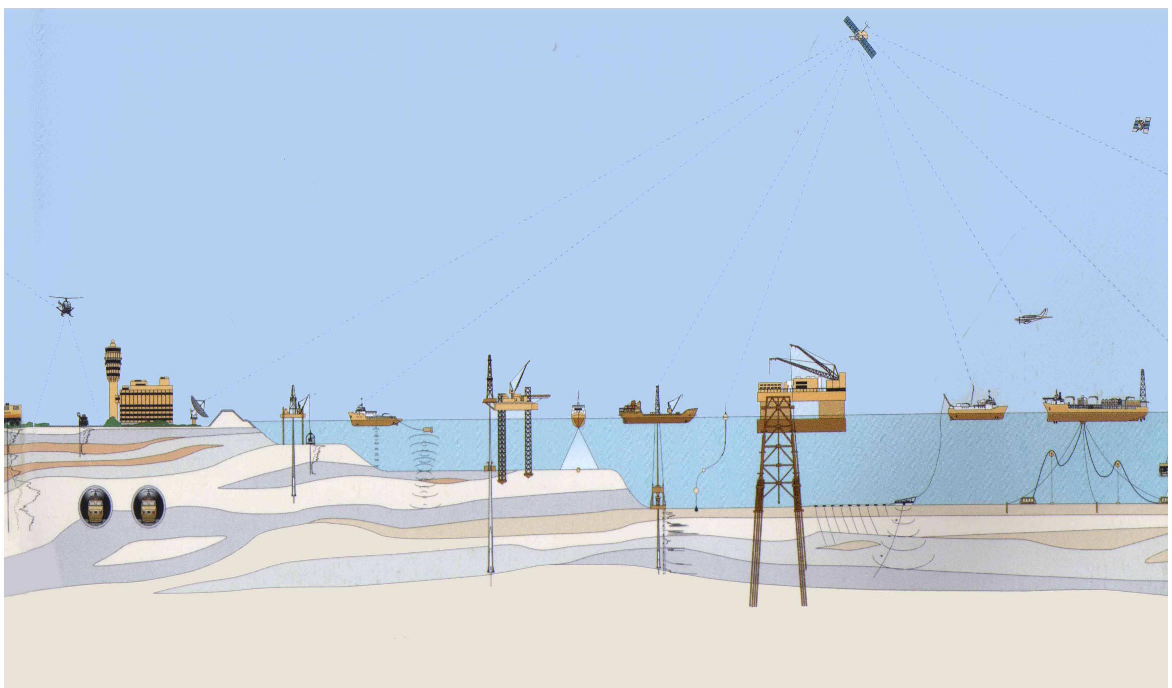
Appendix F ALS Data Capture & Processing Report: FUGRO

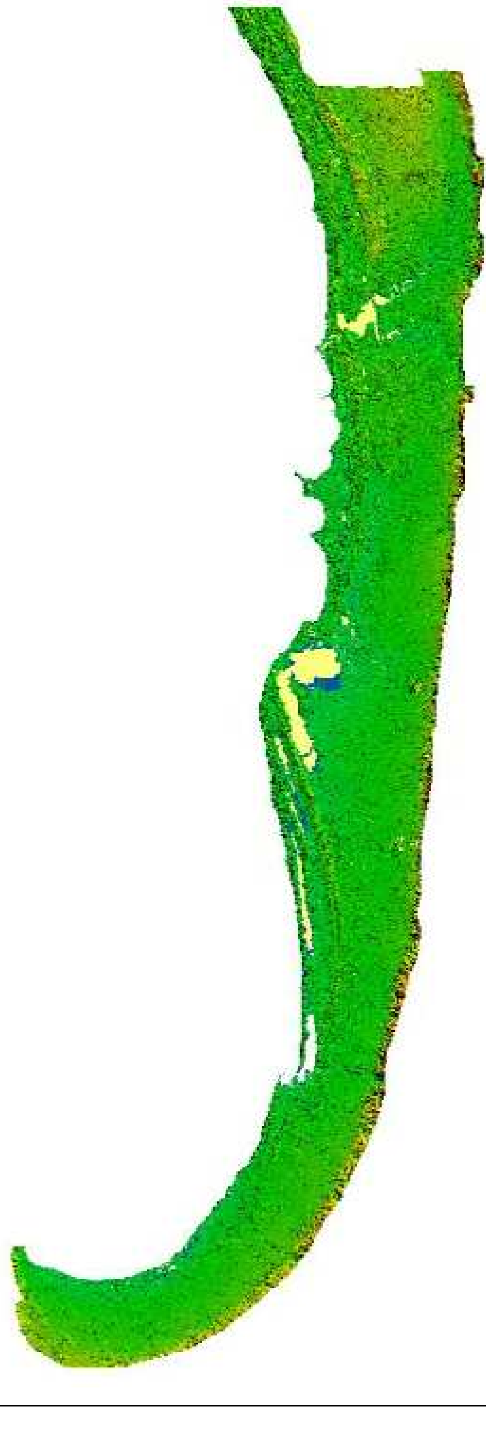
METADATA REPORT
FOR
DEPT OF WATER WA

J221571 ARMADALE – DUNSBOROUGH
NORTH METRO & 3 TOWNS
LIDAR SURVEY

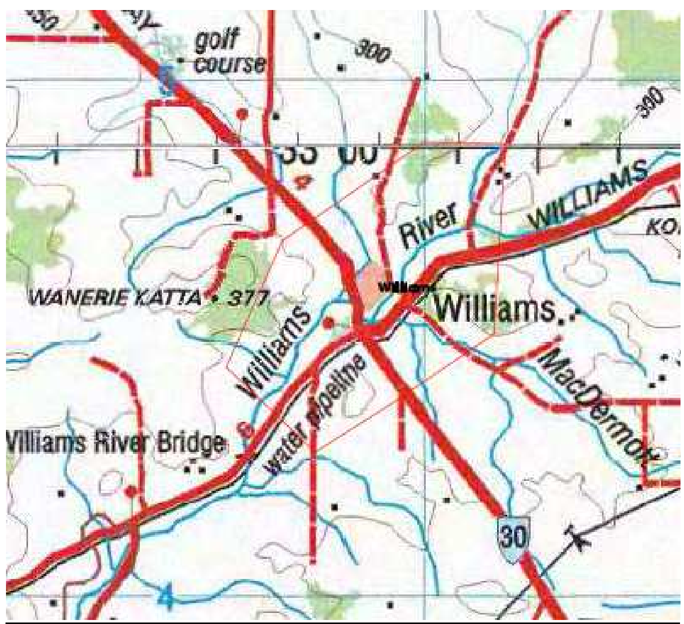


Client:	**Dept of Water - WA**
Job Number:	**J221571**
Project Name:	**Armadale to Dunsborough Lidar Survey**
Report Prepared by:	**M. Bench**
Date:	**25th August 2008**
***Aerial Lidar Survey*:**	
Sensor:	The Leica ALS50 II MPIA airborne laser sensor.
Flying Height:	**2170m**
Point Density:	**1 point per square metre**
Date of Capture:	25th Feb 2008
Navigation mode:	GPS based
Positioning model:	DGPS and Precise Point Positioning (PPP)
Accuracy:	0.15m at 67% confidence
Processes:	
Airborne Survey:	Leica ALS50 II MPIA (Multi Point In Air) laser scanner on board fixed wing aircraft
Ground Control:	ALS data georeferenced to GDA94, MGA Zone 50 and elevations reduced to the Australian Height Datum (AHD) via the Ausgeoid98 model.
Geodetic Validation:	Proving of the airborne lidar survey for interior and exterior orientations.
Orthorectified Imagery:	Not requested for this survey.
Accuracies:	According to ASPRS (American Society of Photogrammetry and Remote Sensing) standards: +/- 0.15m vertical accuracy at 67% confidence level (or 1δ)
Reference Systems:	• Datum: GDA94; AHD • Projection: MGA50 • Reference Pt: k
Delivery:	Elevation data was delivered on portable hard disk drive storage media: • On one 160Gb HDD ESRI BIL file data supplied on: • One 160Gb HDD

Survey Areas:




Mine
377
300
uarries
bandoned)
MARRADONG
14
5
6
Crossman
250
Darnminning Pool
quarry
Wal
390
golf
course
Ranford
Moollaman
Farmers Crossing
BODDINGTON
335
TIMBER
RESERVE
BANNISTER
golf
course
300
360
rocky
outcrop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MacDermott
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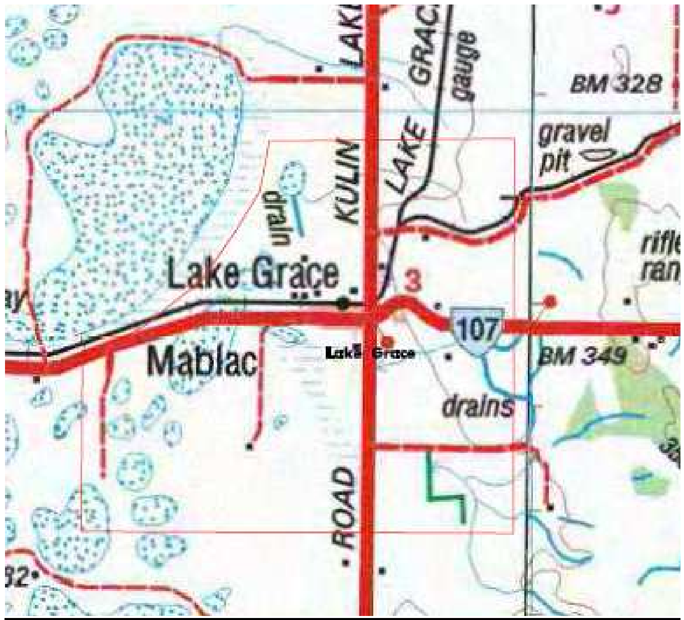
30
4



Date Acceptance: Unless otherwise agreed, the acceptance period for any work performed by Fugro Spatial Solutions shall be ninety (90) days, after which the work shall be deemed as accepted. This assurance applies only to unaltered original work as provided to the Client by Fugro Spatial Solutions.

Any supplied data is to be used only for the purpose for which it was commissioned and in accordance with the terms of engagement. Use of any supplied data for purposes other than those stated is entirely at the risk of the Client.

Appendix G DoW Recommendation

Department of Water
Government of Western Australia

Your ref:
Our ref: WT4717
Srod23.doc
Enquiries: Simon Rodgers (6364 6923)

Mr Gary Sherry
Chief Executive Officer
Shire of Boddington
PO Box 4
Boddington WA 6390

Dear Mr Sherry

Shire of Boddington - Floodplain Management Study by Sinclair Knight Merz

The Department of Water (DoW) has reviewed the two SKM reports that form the Shire of Boddington Floodplain Management Study:

- Flood Modelling Report (3 July 2009)
- Floodplain Management Strategy (3 July 2009)

The DoW considers the approach and methodology adopted for determining the design flow and flood level information is acceptable for the Hotham River and its tributaries.

The recommended Floodplain Management Strategy is consistent with current best practice. The DoW recommends that your Council adopt the recommendations of the Floodplain Management Study to guide future land planning and development proposals and to incorporate the strategy into your Town Planning Scheme.

The DoW in carrying out its role in floodplain management, will continue to support your Shire by providing advice and recommending guidelines for development on floodplains with the object of minimising flood risk and damage.

Yours faithfully

Rick Bretnall

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