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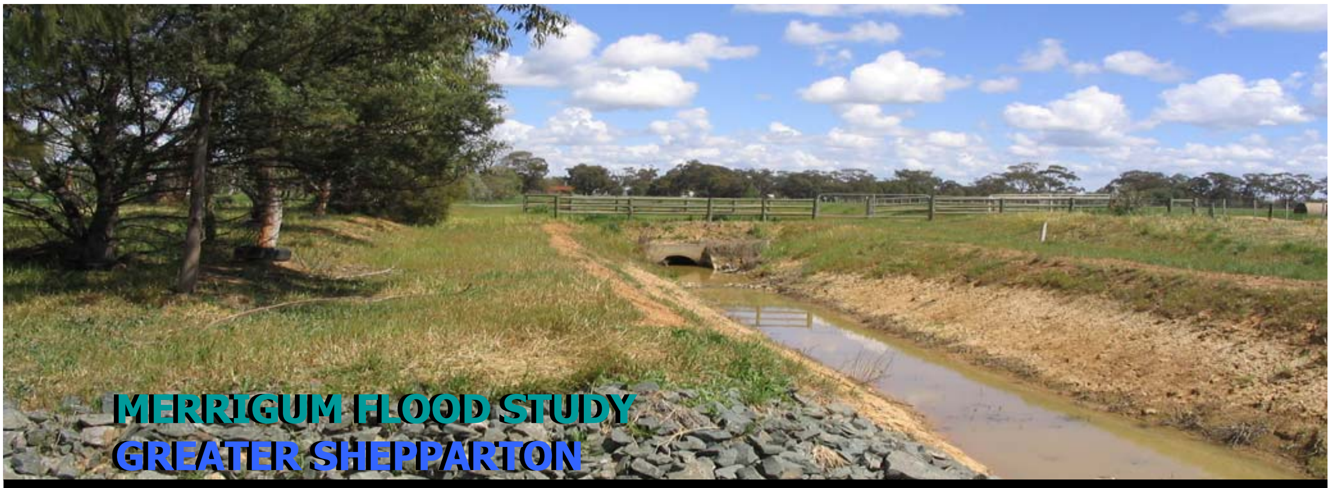

MERRIGUM FLOOD STUDY
GREATER SHEPPARTON

FINAL REPORT

September 2005

GOULBURN BROKEN CATCHMENT MANAGEMENT AUTHORITY

GREATER SHEPPARTON

Merrigum Flood Study

Final Report

Prepared For:	Greater Shepparton City Council
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	Client Reference:	Contract No. 876
	Synopsis:	This report documents hydrologic and hydraulic modelling, results of a community flood questionnaire, damage assessment and inundation mapping for the township of Merrigum, located adjacent to the Mosquito Depression, 24 km west of Shepparton. The report focuses on the determination of flood levels and flood extents within the township and associated floodplain areas for a range of flood events.

REVISION/CHECKING HISTORY

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1 INTRODUCTION

1.1 Background

Greater Shepparton City Council (GSCC) commissioned WBM Oceanics Australia (WBM) to undertake a flood study for the township of Merrigum, with a population of 468 (2001 census), located adjacent to the Mosquito Depression in central Victoria. The objectives of the study were to identify, analyse and document flooding and flood risk at Merrigum.

This report details:

- The project objectives;
- The adopted approach and methodology, including key assumptions; and
- Results of key elements of the investigation, including flood mapping (extent and height), damage assessment and a preliminary assessment of risk treatments.

Commencing June 2004, a draft copy of this report, Merrigum Flood Study (Document R.M6359.001.02.StudyReport.doc), was put on public exhibition. The community were invited to submit comments on the report and associated mapping. Council did not receive any submissions.

1.2 Catchment Description

The township of Merrigum is situated approximately 25 km West of Shepparton, adjacent to the Mosquito Depression. The upstream catchment consists of approximately 228 km^2 of a mix of irrigated and non-irrigated crops, orchards and pastoral land. The Mosquito Depression winds through the catchment as a series of defined ephemeral flow. Generally, drainage of the catchment occurs via the Mosquito Depression Drain. The drain is an earth lined, open trapezoidal channel cut through the depression in the mid 1980's and extended in the early 1990's.

Mosquito Drain Extension Schedule of Works plans at Merrigum (Stage 5) state a design flow of 150 ML/d or 1.8 m^3/s for the drain. This is the flow estimated to result from a 2-year average recurrence interval (ARI) summer design storm of 50mm in 24 hours. Embankments on one or both sides of the drain provide additional flow capacity through the urban areas of Merrigum. The design storm used to determine embankment elevation is stated as the 10-year ARI summer design storm of 75mm in 24 hours.

1.3 Study Area

The Study Area is shown in Figure 1-1. The study area is the area to be hydraulically modelled and mapped using a two-dimensional flood model.

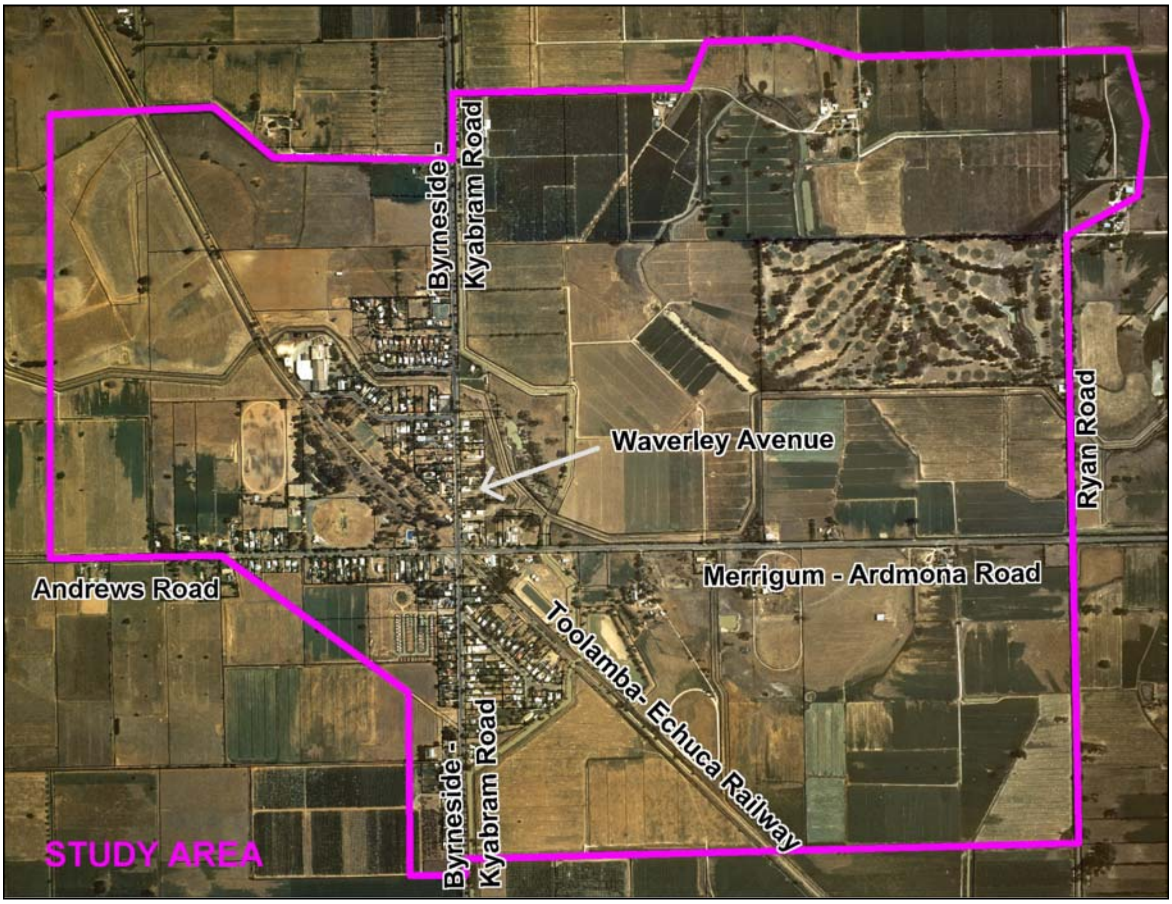


Figure 1-1 Study Area

1.4 History of Flooding

In the past, the community of Merrigum (population 468, 2001 census) has been impacted by flooding from the Mosquito Depression and localised flooding from catchments to the south. Recent events include flooding in 1974 and 1993, which resulted in inundation of roads and properties throughout the town. These events are thought to be relatively frequent events, around a 10-year ARI.

The nature of flooding within the township is influenced by the: very flat grade and meandering nature of the depression; the Railway Line embankment and associated bridge and culverts; and Waverley Avenue culverts. Irrigation channels contained by levee banks affect the flood flow outside of the township. Given the flat slope and sluggish flow, floods in the depression take several days to reach their peak and more to fully drain away.

The construction of the Mosquito drain in the mid 1990's provided improved flow conveyance for frequent flows. However, the design capacity of the drain is nominally 2-year ARI, with sections of the drain with flood embankments having a nominal 10-year ARI summer event capacity at best. The drain has not relieved major flooding originating outside of the depression.

1.5 Study Objectives

The objectives of the study are to identify, analyse and document flooding and flood risk at Merrigum. This will help guide future actions for proactive and reactive management of flooding events by:

- developing maps and tools that can be used for emergency response and planning purposes; and
- identifying appropriate flood mitigation measures to minimise and manage flooding risks in the future.

Key outputs for the study are:

- A GIS database containing:
  - survey data including ground photogrammetric points, generated 200 mm ground contours and a digital elevation model (DEM);
  - survey data of property floor levels, type and condition with property description;
  - 100-year ARI flood level contours;
  - surveyed flood level marks;
  - proposed planning map layers (LSIO, UFZ, FO); and
  - digital ortho photo.
- Project DVD with the above project data in ArcGIS with associated readme file explaining what's on it.
- A set of PDF files of the following:
  - final report and figures;
  - flood inundation maps; and
  - declaration of Flood Level map (No. 540238).
- All flood damage, hydrologic and hydraulic model input files including appropriate readme files.

1.6 Study Approach

A summary of the study methodology is shown schematically in Figure 2.2 and described below.

The general approach adopted for the flood study was to:

- Collate, review and document available flood data at Merrigum including the results of a community flood questionnaire;
- Undertake a flood reconnaissance survey to record historical flood marks identified by the community questionnaire responses as well as identify any additional flood marks through talking to community members;

- Develop a DEM using aerial photogrammetry supplied by GSCC;
- Assess the hydrological characteristics of the Mosquito Depression catchment upstream of Merrigum;
- Undertake hydrologic analyses to determine appropriate design flood hydrographs for the Mosquito Depression catchment and sub-catchments at Merrigum for the 1 in 10, 20, 50, 100 and 500-year average recurrence interval (ARI) events;
- Undertake hydraulic modelling of the main depression flows through Merrigum for the 1 in 10, 20, 50, 100 and 500-year ARI events;
- Quantify flood levels, depths and velocity for a range of flood events at Merrigum;
- Map flooding characteristics including peak flood extent and depth;
- Undertake property type and floor level survey and estimate flood damages at Merrigum;
- Provide an overview of potential flood mitigation options for future investigation; and
- Prepare flood planning maps and GIS databases.

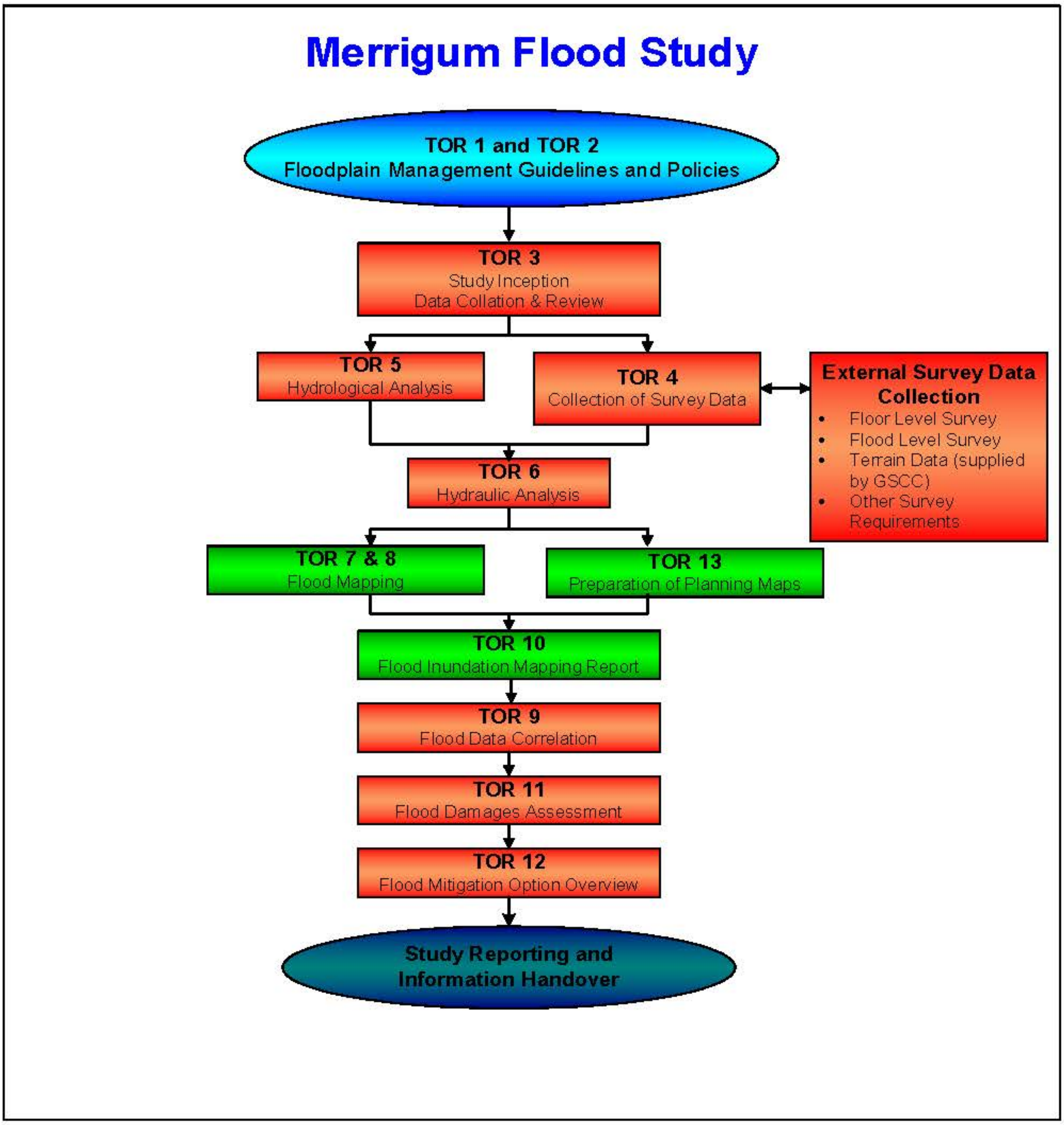


Figure 1-2 Project Task Structure

1.7 Technical Steering Committee

A Technical Steering Committee (TSC) consisting of the members shown in Table 1-1 was established to oversee the project.

Table 1-1 Technical Steering Committee Members

Name of TSC Member	Association
Councillor John Gray (Chairman)	Greater Shepparton City Council
Greg McKenzie and Gordon Cameron	Greater Shepparton City Council
Guy Tierney	Goulburn Broken CMA
Ian Gauntlett	DSE Floodplain Management Unit
Bert Henderson, Mark Lawlor and Greg Pell	Community Representatives
Sam Green and John Owen	Goulburn-Murray Water
Neville Whittaker	Goulburn Valley Water

Meetings held by the TSC throughout the study were used to discuss technical issues and approve key decisions allowing the study to progress. Four TSC meetings were held at Merrigum, typically coinciding with major hold points and technical review as follows:

- 11th June 2003 – Project inception Review. The study methodology was presented and assistance sought for collation of existing data and information;
- 24th October 2003 – TSC Meeting 2. Community flood survey results were presented. Discussion and review of hydrologic preliminary hydraulic modelling results. A methodology for further hydraulic modelling was proposed.
- 24th March 2004 – TSC Meeting 3. Hydrologic modelling results were presented and approved. Preliminary hydraulic modelling and inundation mapping was presented. Deliverables for mapping were proposed.
- 19th May 2004 – TSC Meeting 4. Presentation of the final study results and draft study report to the TSC prior to submission to Council for approval and public exhibition.

2 DATA COLLECTION AND REVIEW

2.1 Existing Data

Members of the TSC gathered the available relevant information for review by WBM. Flood data obtained included previous studies and flood photos held by stakeholders and the Merrigum community. A summary of the information and data sets and their source is presented Table 2-1 and Table 2-2.

Existing data sets collected and reviewed were:

- **Previous investigations and reports** - In general, although there had been previous investigation of flooding characteristics, floodplain management and documentation of historical flooding events for the Mosquito Depression, the work had been relatively broad in nature with little focus on Merrigum itself. A review of previous work is documented in Section 3.2.
- **Survey data** – Availability and reliability of survey data in the depression varied. Downstream of the study area, Keel and Drape spot height and contours from 1906 were available. Patches of laser grade farm survey from 1980 to 2000 was available west of Merrigum in hard-copy format, as were cross-sections surveyed in 1992 prior to construction of the Mosquito Drain. The 1906 Keel and Drape survey compared reasonably well to more recent farm survey.
- **Historical flood data** – Historical flood data at Merrigum was limited. In particular, there was a lack of data on recorded flood flows. The only available flood data included oblique flood photographs taken at ground level, several flood high-water marks and one recorded flow at Merrigum-Ardmona Road in 1993.
- **Rainfall data** – Historical rainfall data for Merrigum was not available. Statistical rainfall data was available from Australian Rainfall and Runoff 1999. Losses for rainfall were available from previous studies and detailed hydrologic model.

Table 2-1 Background Data and Survey Information

Data Type	Source
General Data	
GIS and Digital Cadastral Map Base, 2003	Council
Digital Aerial Photogrammetry, 2D and 3D Feature Survey, QASCO, 2003	Council
Rainfall data (non-historical)	Australian Rainfall and Runoff, 1999
Historical flood data/levels	GBCMA, Council, Community and Historical Society
Mosquito Depression Drain Extension - Schedule of Works, G-MW, 1993 (Plans)	Council
Proposed Mosquito Drain Extension - Cross Sections, RWC, 1992 (Plans)	Council
Mosquito Creek Depression Obstructions, SRWSC, 1982 (Plans)	Council
Mosquito Depression Drainage Course - Removal of Farm Obstructions, RWC, 1989 (Plans)	Council
Data Identified in Study Brief	
Historical Flood information for 1955 and 1975 events	GBCMA
Photography	
March 2000 non-flood colour aerial photography	AAM Survey via Council
Historical flood photos (taken at ground level)	GBCMA, Council, Historical Society, Community
Other Flood Information and Data	
Mosquito Depression RAFTS hydrologic model, SKM, 2002 (Computer Model)	Council
RAFTS, MIKE-11 and TUFLOW hydrologic and hydraulic models and report for the Tatura Flood Study, WBM, 2003 (Computer Model and report)	WBM (project under completion at the time of this report)
Specific Reports	
RWC Deakin Main Drain (RAFTS) Model Development, Murray Basin Consulting Group, 1992	Council

Table 2-2 Additional Background Data Acquired after TSC Meeting 2

Data Type	Source
General Data	
Rodney Irrigation District, SRWSC, 11/03/1907, 1 foot contour plans, 20 chains to one inch, 3 sheets	Council
1 foot contour plans AHD Conversion for Rodney Irrigation District, Council, 1907	Council
Rodney Irrigation District – Parish of Kyabram East, 100mm Contour Plan SRWSC, 1984. Plan no.146598 dated 10/09/1984, Plan no. 146924, dated 01/07/1985 and Plan no. 141375 dated 19/10/1982. Plans show natural surface spot heights in mAHD overlaid on aerial photography.	Council
Farm Plan, Peter and Gail Hemphill - Construction of Irrigation Layout - Final Design, 1:11250, Planright, 28/06/1995. This plan details spot heights in mAHD every 25m and 100mm Contours.	Council
Merrigum Flood Investigation, Locality Plan - Proposed Mitigation Works and Zoning, SRWSC, 21/2/1978, Plan No. 135005 and Longitudinal Section, Plan No 135006	Council - Plan is outside study area
Farm Plan, K.E. and B.A. Argus, Lot 6 and 7, Parish of Kyabram East, 1:15000, Findlay Consulting Group, 30/10/1996	Council
Farm Plan, S. Taig and K. Smidts, Lot 2 of C.A.75 Parish of Kyabram East, 1:15000, Lee Irrigation Design, 8/12/2000	Council - Plan is outside study area
Flows records - Mosquito Depression at Merrigum-Ardmona Rd (limited data recorded between 1992 and 1993)	Thiess Services (Tatura)

2.2 Additional Data

2.2.1 Photogrammetry and DEM

Aerial photography of the study area was flown on 17 November 2000 by QASCO, with photo control survey and data capture completed shortly thereafter. Data capture involved the derivation of spot heights and break lines over the entire Study Area. This data was later processed to develop a DEM of the study area, (Refer to Figure 2-1).

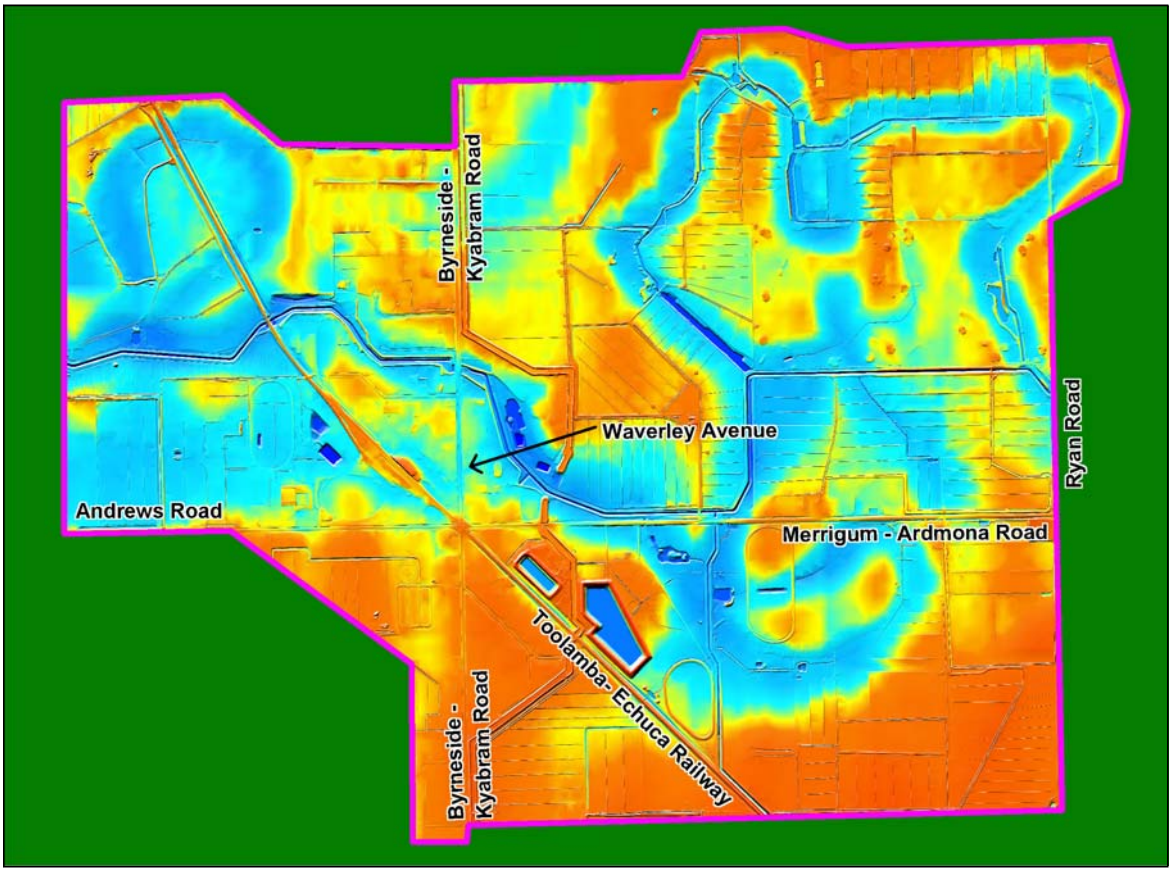


Figure 2-1 Merrigum Study Area DEM

2.2.2 Site Inspection of Floodplain Obstructions

On Friday 24 September 2003 Messrs Greg McKenzie of Greater Shepparton City Council and Guy Tierney of Goulburn Broken Catchment Management Authority inspected the Mosquito Depression from Merrigum to upstream of Tatura. A table, locality plan and photographs documenting the obstructions were collected. A summary of the obstructions photographed and their locations is contained in Appendix B.

The aim of the inspection was to correlate the degree of retardation in the depression downstream of Tatura compared with the degree of retardation in the catchment upstream of Tatura. The information was then used to derive flows at Merrigum from flows at Tatura (WBM, 2004), as discussed in Section 3.5.2. The derived flows were used to verify the hydrologic model results.

Downstream of Tatura, the site inspection found approximately 15 obstructions in the Mosquito depression. This is significantly fewer than the number of obstructions found upstream of Tatura (Refer to Appendix B).

2.2.3 Survey

LICS Pty Ltd undertook survey of buildings in Merrigum. Details surveyed included general data such as building type, size and condition, as well as floor levels. Floor levels were collected for 215 buildings and general data for an additional 3 buildings in Merrigum. The majority of buildings in

Merrigum are residential, with a small number of commercial and industrial. Details of the survey and data included in the GIS database are as follows:

- Floor levels were surveyed by conventional levelling to AHD. Levels were tied-in to at least 2 Bench Marks at an accuracy of +/- 0.05m;
- The levels were linked to street addresses and collated in a database for GIS purposes;
- Ground levels for each floor level were surveyed where applicable;
- Construction material, condition and size of building were noted; and
- Co-ordinates for each building level were generated by plotting on the digital orthophoto or by using GPS (GPS accuracy of +/- 1m in GDA94).

2.3 Data Gaps

Data Gaps identified by the study are as follows:

- Poor historical flow data;
- Lack of digitised and ground survey downstream of the study area; and
- Toolamba - Echuca Railway Line culvert dimensions and invert levels located to the south of Merrigum near the racetrack. Aerial photography indicates a culvert is located under the railway line but due to difficult site access, the culvert dimensions could not be confirmed. A nominal diameter of 300mm has been assumed, which will not affect flood levels in the hydraulic model as the culvert only serves to allow water in the Mosquito Depression to backup through the low lying area.

2.4 Community Consultation

Whilst broad community consultation was not an objective of the study, community information was sought via a flood questionnaire and reconnaissance survey of historical flood marks. A brief community information sheet and the flood questionnaire was prepared by WBM and distributed by Council.

The aim of the community flood questionnaire and information sheet was to:

- gain interest and support from the community;
- inform the community of the purpose of the study and the community's role in providing input to the project; and
- collect information and data regarding historical floods and flooding characteristics.

Consultation was achieved by:

- mail-out distribution of the flood questionnaire and information sheet to gather information from residents regarding their knowledge of historical flooding characteristics; and

- flood reconnaissance survey involving individual interviews with respondents and survey of flood marks at their property.

Copies of all material produced as part of community consultation activities and a copy of the flood questionnaire and information sheet are provided in Appendix A.

2.4.1 Results of Community Questionnaires

Approximately 50 residents in Merrigum and surrounding areas responded to the questionnaire. The results of the questionnaire are summarised in Table 2-3. A more detailed summary of the questionnaire results is contained in Appendix A.

Table 2-3 Results of Flooding Questionnaire

No	Question	Yes	No	Other	Response
1	Are you aware of historical flooding in Merrigum?	37	13	0	
2	If yes when did the flood(s) occur (year)?	36	13	1	1954, 1955, 1956, 1974, 1982, 1993
3	Was your property affected by floodwaters?	20	22	8	
4	Did floodwaters enter any buildings on your property?	9	33	8	
5	If yes, in what year(s)?	9	39	2	1955,1974,1982, 1993
6	Are you able to show us how high the flood levels rose?	18	26	6	
7	Can you provide information on flooding in other areas of the district?	15	32	3	
8	Are you aware of any other people who may have knowledge of flooding but no longer reside in the area? How can they be contacted?	12	35	3	
9	Do you have any photos/videos of flooding that could be borrowed for copying? (If yes please attach details)	38	8	4	

Maps, contained in Appendix A, illustrate the results and distribution of the following aspects of the questionnaire:

- The distribution of responses throughout the study area;
- The distribution of properties affected by flooding;
- The extent of available anecdotal information; and
- Availability of historical flood marks for survey.

3 HYDROLOGY

3.1 Objective

The objective of the hydrology was to generate design hydrographs for a range of flood events (10, 20, 50, 100 and 500 ARI) at Merrigum for input to a hydraulic model used to simulate flood behaviour for a range of flood events.

Hydrologic analysis involved simulation of hydrological behaviour using an existing rainfall runoff (RAFTS) model of the upstream catchment. Confirmation of the resulting flows was undertaken using an area weighted catchment multiplier applied to flows at Tatura (refer to Tatura Floodplain Management Plan report, WBM 2004).

Key tasks for the hydrologic analysis were:

- Review available data including the RAFTS model of the Mosquito Depression, rainfall and rainfall losses;
- Simulate design rainfall events for a range of return periods and durations using RAFTS;
- Verify the performance of the RAFTS model by comparing the estimated peak flow to that derived from translation of flows from Tatura (i.e. weighted catchment multiplier method); and
- Derive design flood hydrographs using RAFTS for a range of return periods.

3.2 Review of Available Data

A review of available reports, studies and hydrologic models was undertaken and is documented below.

In 1992, the RWC commissioned the development of a catchment runoff (RAFTS) hydrologic model of the Mosquito Depression extending from upstream of Tatura to downstream of Tongala. The model, consisting of 43 sub-catchments contains storages, areas of ponding and diversions. Wetlands are modelled on the East branch upstream of Tatura and in the upper Byrneside-Merrigum catchment, which contributes to flows in the depression at Merrigum upstream of the Railway Line. The model includes a diversion from the depression approximately 5 km downstream of Tatura out of the catchment into the Rodney Main Drain system. The out of catchment diversion takes low flows up to 240 ML/d or 2.8 m^3/s.

The 1992 RWC report found flows in the depression "sluggish" and noted that works (such as culvert enlargements) were under way to ensure that flow along the depression is not unduly inhibited. It also documented design storms losses for both 'Summer' and 'Winter' pre-storm catchment loss conditions. Rainfall data was based on Australian Rainfall and Runoff (ARR) Intensity Frequency Duration (IFD) data. A lack of available flow data was noted in the report.

A RAFTS model upstream of Tatura only was developed and refined SKM in 1994 and again in 2000. The number of sub-catchments was increased from 8 to 16 and the model was used to determine flows and flow frequency. A quasi 2-dimensional MIKE-11 model for Tatura was also developed. It should be noted that the Tatura RAFTS model does not contain floodplain storage and wetlands included in the overall Mosquito Depression RAFTS model.

In 2003/2004, WBM used the SKM Tatura RAFTS and MIKE-11 models to develop design flood hydrographs at Tatura to input into a fully two-dimensional hydraulic model (TUFLOW). Design storm events and losses used were for worst-case ‘Winter’ pre-storm catchment loss conditions. The hydrographs were input into a TUFLOW model of Tatura to model the complex series of depressions, storages and obstructions.

The modelling found that man-made weirs, bridges and other structures on the floodplain had a significant effect on the shapes of the hydrograph at Tatura. The storage and routing effects in the contributing branches of the Mosquito Depression, which meet approximately 5km upstream of Tatura, vary greatly. Flood peak attenuation in the southern arm was found to be significant while flows in the east arm into Tatura were almost fully throttled.

3.3 Data Gaps

There is very little information available on recorded flood flows, rainfall and documented flood levels at Merrigum. As part of this study, considerable effort was made to search for and document available flood photography and flood levels in Merrigum via the community flood questionnaire, and subsequent flood reconnaissance survey of flood marks. Agencies contacted to find additional historical flow data were Thiess Services, SKM and DSE.

No data was available from DSE (Ian Gauntlett) or SKM (Mani Manivasakan). It was noted that SKM has records for Curlott Gauge, located 15km downstream of Merrigum, but that the flows are not relevant to this study as the gauge is not rated outside the main channel and there are inflows from several drains downstream of Merrigum, contributing to the total gauge flow.

Leon Tepper of Thiess Services in Tatura provided the following historical flows measured for the Mosquito Depression over the period of 1992 and 1993:

- 573 ML/d (6.6 m^3/s) on 6/10/1993 at Merrigum-Ardmona Road; and
- 569 ML/d (6.6 m^3/s) on 8/10/1993 at Merrigum-Ardmona Road.

Advice provided with the above data was that G-MW was capable of diverting flows from the mosquito drain between Merrigum-Ardmona Road and Merrigum Township. It is not clear how much flow or even how the diversion can be achieved. In addition, it is not clear whether the flows measured by Thiess include all the flows in the depression (i.e. bypass flows north of Merrigum-Ardmona Road) or only flows crossing the Merrigum-Ardmona Road. Hence, the recorded flows may not be the same flow as experienced at Merrigum. Clarification of this issue was sought from Thiess and G-MW, but at the time of writing was unresolved.

3.4 Hydrologic Modelling Approach

Given the limited historical flow information available to undertake historical data analysis (eg. flood frequency analysis of flood flows), it was necessary to rely on hydrological modelling techniques to simulate catchment behaviour.

3.4.1 RAFTS Simulation of Design Storm Events

The RAFTS model at Merrigum is an overall model for the depression. It consists of the Mosquito Depression upstream of Tongala including East and West Branches. The total catchment area at Merrigum is 228 km^2 and is modelled in RAFTS by 19 sub-catchments.

Upstream of Merrigum, there is significant floodplain storage in the Depression. The model has major storages referred to as Doctors, Goulburn, Lake Boga and Lake Bartlett, and wetlands upstream of Tatura and in the catchment to the south of Merrigum or upper Byrneside-Merrigum catchment. A schematic of the model is presented in Figure 3-1. Note that low flows of up to 240 ML/d or 2.8 m^3/s are diverted out of the depression 5 km downstream of Tatura to the Rodney Main Drain labelled in the schematic as RDNY MD node.

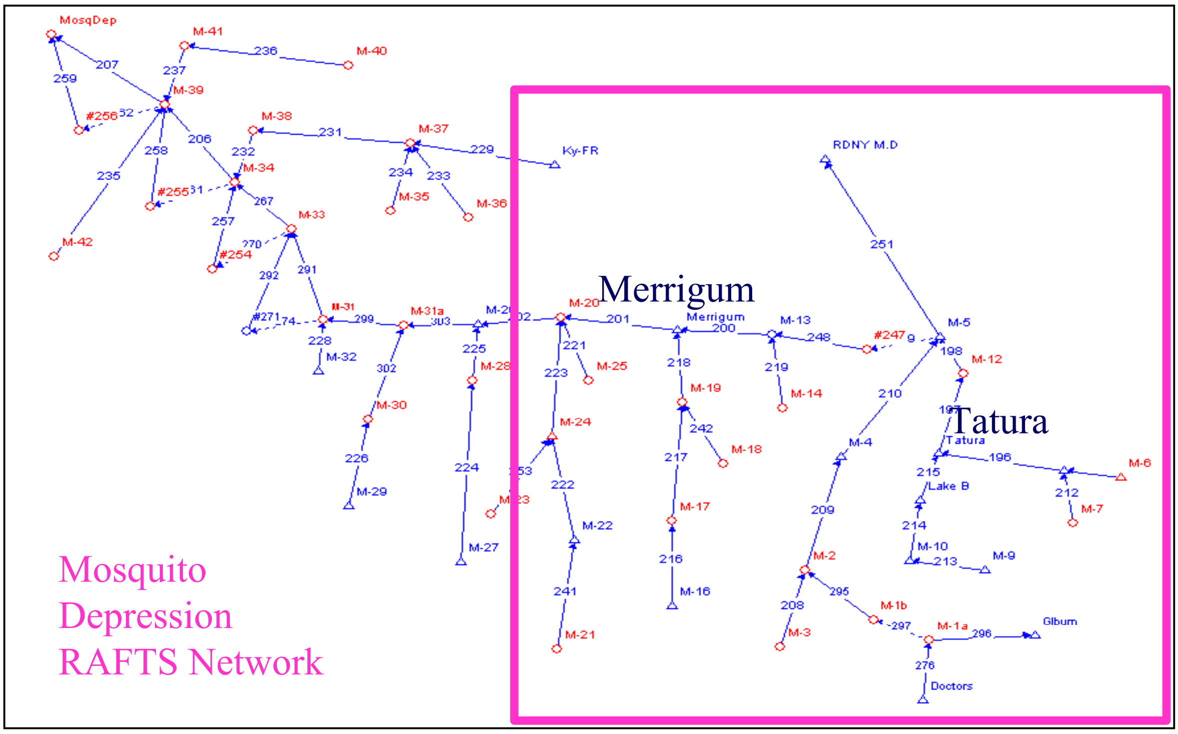


Figure 3-1 Mosquito Depression RAFTS Model Network

3.4.2 Rainfall Intensity and Losses

Rainfall intensities for the 10 and 100-year ARI events modelled in RAFTS are shown in Table 3-2. The storms were based on intensity frequency duration (IFD) parameters and storm patterns from Australian Rainfall and Runoff (AR&R, 1999). The parameters are consistent with those used for the Tatura Floodplain Management Plan (WBM 2004). The critical storm duration for the Mosquito Depression catchment at Merrigum is 36 hours.

An initial/continuing rainfall loss model and parameters were provided with the hydrologic RAFTS model.

The model was run with a statistical 100-year ARI storm. Due to lack of evidence on seasonality of floods, it was determined that one set of rainfall losses be adopted for the catchment. As a result, higher or 'summer' losses for pre-storm conditions were selected for several reasons. Firstly, historical May 1974 and October 1993 flood events, which will be used to compare and verify the hydraulic modelling occurred in drier months. Secondly, there are no historical 'winter' events to verify using lower or 'winter' pre-storm condition losses, which means there is a risk of lower losses having an unknown effect on the flood peak. Thirdly, the ability of RAFTS to accurately model storage effects in the depression between Merrigum and Tatura is not known. Adopting higher losses will partly compensate for this. This is particularly important in the Mosquito depression as there is very little fall available and floodplain and storage does affect the flood hydrograph shape peak significantly.

Table 3-1 Rainfall Depth and Losses for Merrigum Catchment

Storm ARI (1 in x years)	Average Intensity (mm/h)	Initial Loss #1 (mm)	Initial Loss #2 (mm)	Continuing Loss #1 (mm/h)	Continuing Loss #2 (mm/h)	Excess Rain #1 (mm)	Excess Rain #2 (mm/h)
100 yr 36 hr	3.656	40	25	1.2	1.2	70.197	81.897
10 yr 36 hr	2.385	40	25	1.2	1.2	29.826	42.126

Where: #1 are Non-Irrigated areas and #2 are Irrigated areas

Note: approximately half of the catchment upstream of Merrigum is irrigated and half is non-irrigated.

3.5 Verification of Hydrologic Model

Table 3-2 compares the peak 100-year ARI flow estimate at Tatura from the overall RAFTS model and the TUFLOW model at Tatura. The flow estimates are very similar, which indicates that there is sufficient storage inbuilt in the overall RAFTS model upstream of Tatura. Downstream of Tatura the performance of the RAFTS model must be verified by other means. (Refer to Section 3.5).

Table 3-2 Comparison of Modelled 100-year ARI Peak Flows at Tatura

Flow Location	RAFTS Overall model Peak Flow (m^3/s)	Tatura TUFLOW model Peak Flow (WBM 2004) (m^3/s)
Tatura	8.8	8.7

Through discussions with GBCMA, a suitable method was developed to verify the results of the hydrologic model using a catchment multiplier applied to flow estimates at Tatura. The flow estimates for Tatura are those derived from the Tatura TUFLOW hydraulic model (WBM 2003).

The multiplier is an area-weighted factor, which effectively translates flows from Tatura to Merrigum. The multiplier takes into account a range of factors, including the characteristics of the contributing catchment and possible timing effects, and was derived based on the following:

- An empirical or common translation factor applied to catchments in Victoria; and
- A catchment inspection to draw similarities between the catchment storage characteristics of the two main depression branches leading to Tatura, and the catchment at Merrigum.

3.5.1 Empirical Catchment Multiplier Factor

The initial estimate of the catchment multiplier was derived as the ratio of the total catchment area contributing to Merrigum to the total catchment area at Tatura, raised to the power of 0.7 as follows:

- Factor = $(A_{Merrigum}/A_{Tatura})^{0.7}$

where A = Catchment Area (km^2) and Q= Flow Rate (m^3/s)

- $Q_{Merrigum} = Q_{Tatura}$ x Factor

The factor was then refined to take into account the characteristics of the contributing catchments and possible timing effects.

3.5.2 Catchment Characteristics and Catchment Multiplier

Messrs Greg McKenzie of GSCC and Guy Tierney of GBCMA inspected the Mosquito Depression catchment on Friday 24 September 2003. The aim of the inspection was to quantify the degree of flood retardation in the catchment based on the number of retarding structures and other mechanisms. (Refer to Section 2.2.2).

Following a review of the site inspection report and available waterway obstruction plans, the catchment was subsequently visited by WBM.

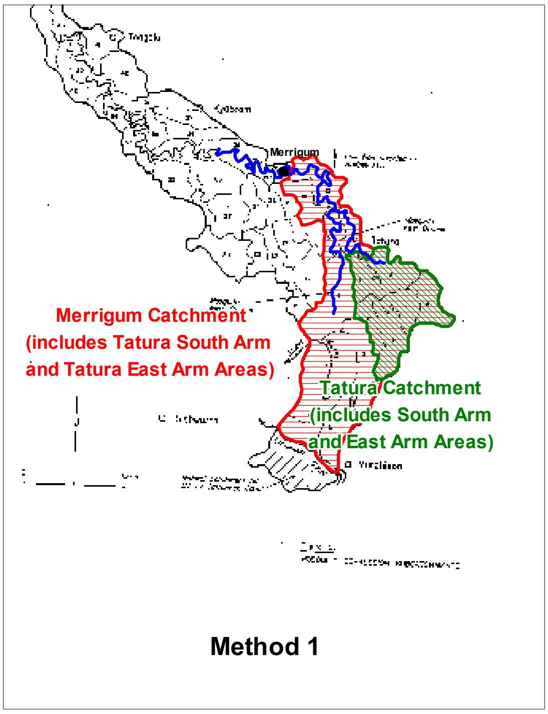
The hydraulic assessment of the Tatura catchment (SKM 2000) indicates that flood attenuation upstream of Tatura is caused by the combination of agricultural levees, roads and rail embankments. Also contributing to attenuation in the catchment are storages upstream of Tatura and in the upper Byrneside-Merrigum catchment. These storages are in the RAFTS hydrologic model, and are referred to as Doctors, Goulburn, Lake Boga and Lake Bartlett, as well as a number of wetlands.

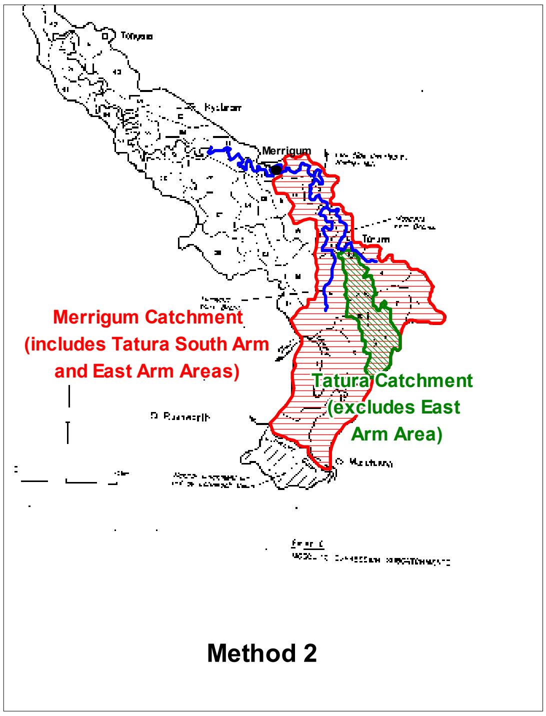
VicTopo topographic plans indicate that there is natural flood storage in the depression between Tatura and Merrigum shown as swamp areas, which could provide significant storage of flows.

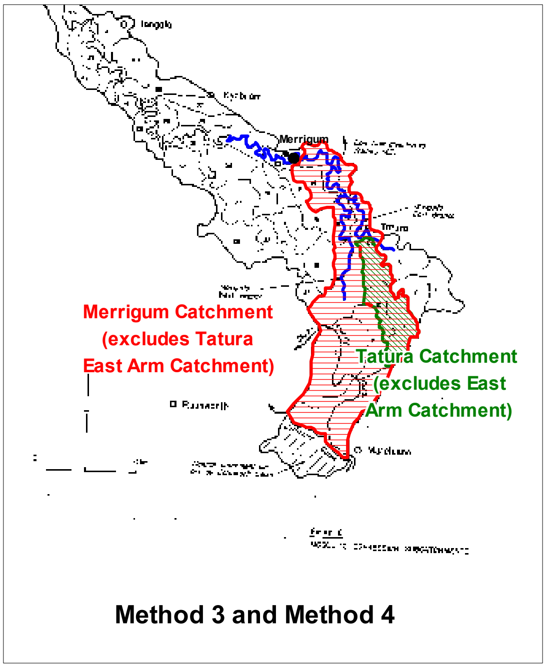
The attenuation of flows experienced in the East Arm upstream of Tatura will be in excess of natural floodplain effects downstream. In conclusion, the attenuation of the peak flood flow between Tatura and Merrigum is most similar to the Tatura South Arm catchment given the combination of natural floodplain storage and some obstructions. The recommended catchment multiplier for the Merrigum catchment is therefore based on the Tatura South Arm catchment.

3.5.3 Catchment Multiplier Translated Flows

Peak flows at Merrigum have been determined below by translating modelled peak flows at Tatura using four different catchment multipliers or area-weighted factors. Four factors were calculated to demonstrate the sensitivity of the calculations to the underlying assumptions. The factors are discussed in more detail below. A diagram of the catchments used in each of the four methods is illustrated in Figure 3-2.







Catchment Sub-Areas used for Catchment Multiplier Methods 1 to 4

Where:

$$\text{Catchment Multiplier} = \frac{\text{Merrigum Catchment Area (sq. km)}}{\text{Tatura Catchment Area (sq. km)}}$$

Figure 3-2 Catchment Multiplier Method

Method 1

An initial area weighted factor of 2.5 was derived from a ratio of the total catchment area at Merrigum, the total catchment at Tatura and a power factor of 0.7. This method yields a lower bound estimate of 22 m^3/s as the total catchment area at Tatura yields a lower peak flow per km^2 than the Tatura south arm catchment alone. Hence, translation to the total catchment at Merrigum also yields a low flow.

Method 2

Based on the results of the Site Inspection, the Tatura South Arm represents flow behaviour in the depression better than the Tatura East Arm. Methods 2 uses flows from the Tatura South Arm only but translates these to a catchment at Merrigum which includes the Tatura East Arm. This yields a flow peak of 40 m^3/s an overestimate of peak flow at Merrigum as the Tatura East Arm catchment contributes very little to the peak.

Method 3

Method 3 improves on Method 2 by simply removing the Tatura East Arm catchment from the total Merrigum Catchment. This method yields the preferred catchment multiplier and flow of 38 m^3/s for Merrigum.

Method 4

Method 4 provides an upper bound estimate of 46 m^3/s by increasing the power factor from 0.7 to 0.8.

The summary of results for each method are summarised in Table 3-3.

Table 3-3 Summary of Translated Flows using Catchment Multiplier Method

Method used to derive 'Catchment Multiplier'	Peak Flow Q_{Tatura} (m^3/s)	Catchment Multiplier or Area Weighted Factor	Factored Flow $Q_{Merrigum}$ (m^3/s)	Comment
Method 1 - Use Tatura total catchment area and flow and apply to Merrigum catchment	8.8 (Overall RAFTS model) 8.7 (Tatura TUFLOW model)	2.46 $=(228/63)^{0.7}$	22 =2.46 x 8.7	Empirical Method – Lower-bound estimate
Method 2 – Apply Tatura South Arm area and flow upstream of Tatura to Merrigum catchment	8.2 (Overall RAFTS model -Tatura South Arm Only) 9.8 (Tatura MIKE11 model- South Arm)	4.13 $=(228/30)^{0.7}$	40 =4.13 x 9.8	Overestimates peak flow at Merrigum
Method 3 – Apply Tatura South Arm area to Merrigum catchment excluding Tatura East Arm area	9.8 (Tatura MIKE11 model – Tatura South Arm Only)	3.85 $=(206/30)^{0.7}$	38* =3.85 x 9.8	Preferred method of estimation
Method 4 – As per method 3, increase area power ratio from 0.7 to 0.8 for upper-bound estimate	9.8 (Tatura MIKE11 model - South Arm Only)	4.67 $=(206/30)^{0.8}$	46* =4.67 x 9.8	Upper-bound estimate

*Peak flow estimate excludes Tatura East Branch contribution. The East Branch contributes 1 to 2 m^3/s, which is effectively cancelled out by up to 2.5m^3/s diverted from the depression downstream of Tatura into the Rodney Main Drain.

3.6 Results of Hydrologic Modelling

Design flow peaks, times to peak and hydrographs for the 10, 100 and 500-year ARI events are shown in Table 3-4, Figure 3-5, Figure 3-4 and Figure 3-3. The inflow for the Byrneside-Merrigum catchment and part of the Harston-Merrigum catchment at Merrigum is also shown. The critical duration storm for all events is 36 hours resulting in maximum peak flow.

The estimated 100-year ARI peak flow from the RAFTS model at the Merrigum upstream study boundary is $38m^3/s$ from Table 3-4. This estimate is supported by a peak flow estimate of $38m^3/s$ calculated using Method 3 in Table 3-3. The similarity of these estimates provides confidence in the flow estimates produced by RAFTS.

Table 3-4 RAFTS Design Peak Flows and Time to Peak

Flow Location	Catchment Area (km^2)	10-year ARI Peak Flow (m^3/s)	100-year ARI Peak Flow (m^3/s)	500-year ARI Peak Flow (m^3/s)	Time to Peak Flow (hrs)
Tatura (downstream)	62.5	4.4	8.8	15.0	29
Merrigum (upstream study boundary)	263.6	14	38	59	118
Byrneside Merrigum catchment (upstream of Railway Line)	33.7	5.2	13	18	26
Harston Merrigum sub-catchment (downstream of Railway Line)	8.4	1.4	3.8	6.1	40

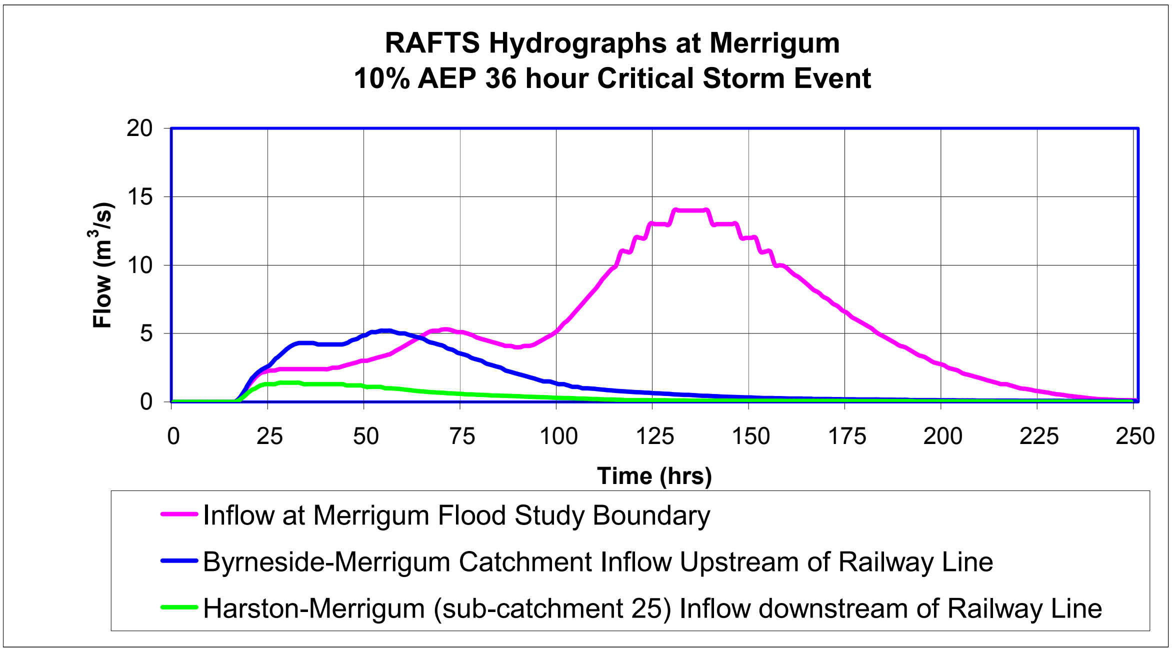


Figure 3-3 10-year ARI Hydrographs at Merrigum

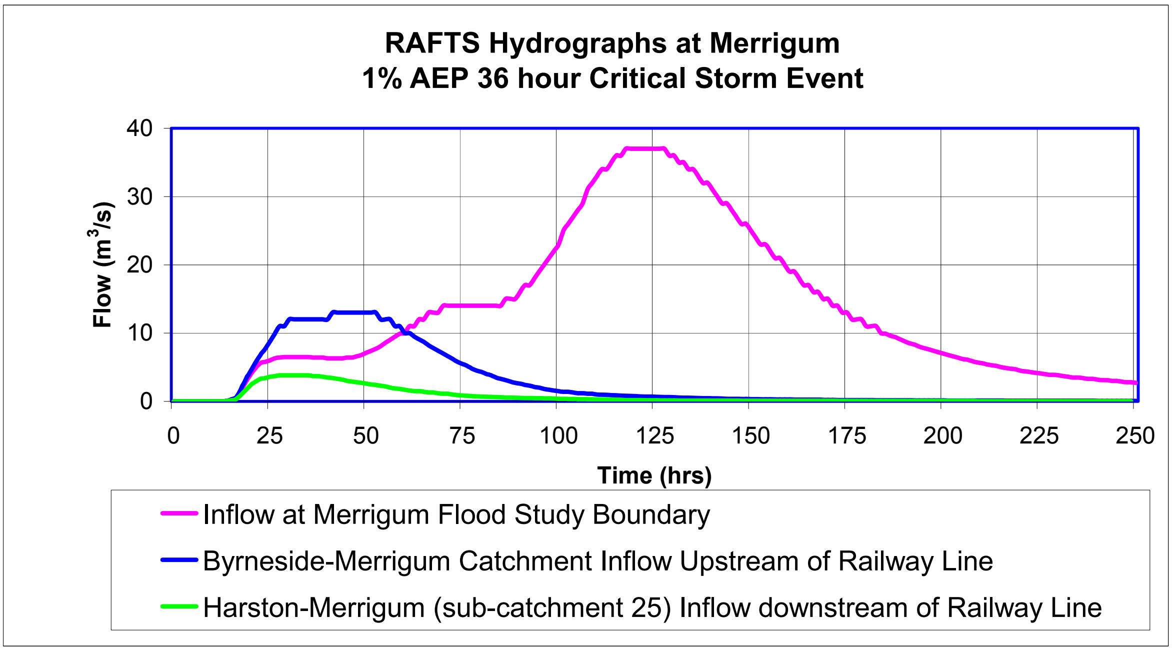


Figure 3-4 100-year ARI Hydrographs at Merrigum

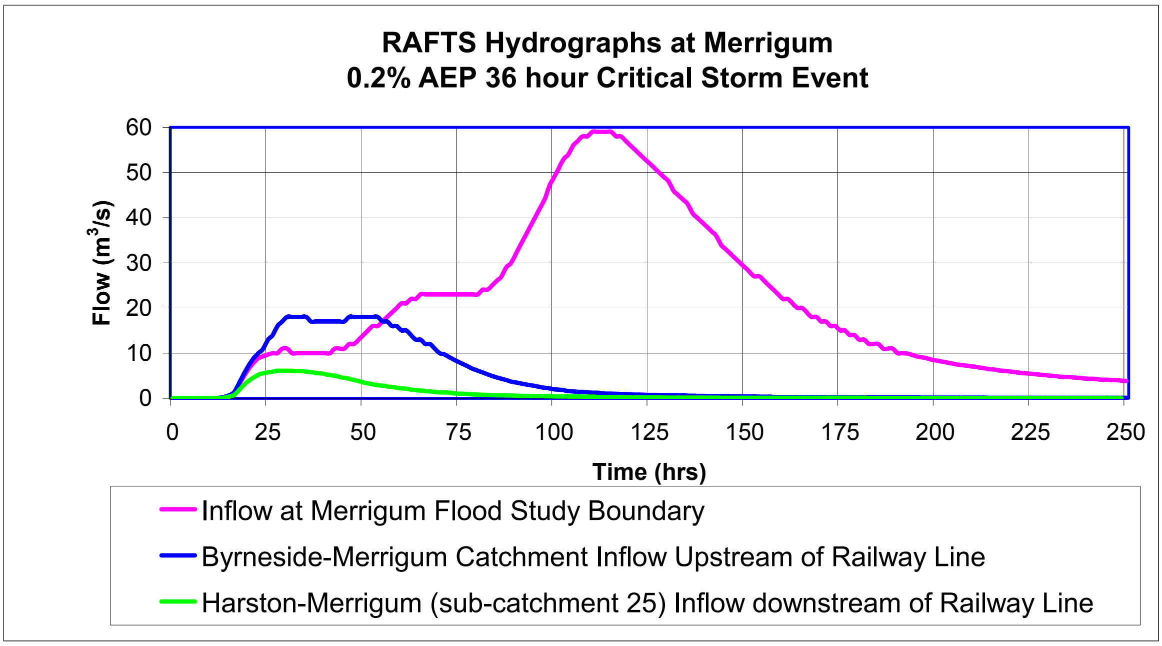


Figure 3-5 500-year ARI Hydrographs at Merrigum

3.7 The Probable Maximum Flood

Detailed analysis and derivation of the PMP was not considered necessary, as an order of magnitude of the flood depth is sufficient to determine the consequences.

The Probable Maximum Precipitation (PMP) rainfall depth, which will result in the Probable Maximum Design Flood (PMF) was estimated using an empirical relationship as follows:

- $PMP = 138.5 - 4.055\sqrt{Area} + 450.5\sqrt{^{50}I_{72}}$ (1 see note below)

The relationship gives an approximate total rainfall depth of 690mm for a 36 hour critical duration storm distributed over the catchment upstream of Merrigum.

Given that an extreme magnitude flood (in the order of 500-year ARI event or greater) was expected to inundate almost the entire study area, the incremental flooding consequences for a PMF at Merrigum may not be much greater than for the 500-year ARI flood. Through discussions with the TSC, it was agreed that hydraulic modelling and mapping of the PMF was not required.

[1] The approach adopted for determining the PMF was based on the method outlined by Dr R.Nathan in the technical paper entitled *A Quick Method for Estimating Probable Maximum Precipitation in the Tropical and South East Region of Australia.* This approach describes simple algorithms for a number of regions throughout Australia that can be applied to gain an indicative estimate of the PMP.

4 HYDRAULIC ANALYSIS

4.1 Objective

The objective of the hydraulic analysis was to develop a hydraulic model that could simulate the behaviour of the Merrigum floodplain for a range of flood events (10, 20, 50, 100 and 500 ARI). The key tasks for the hydraulic analysis were to:

- Select suitable hydraulic modelling software and modelling approach;
- Develop a hydraulic model capable of simulating the flood behaviour of the Merrigum floodplain;
- Simulate the 10, 20, 50, 100 and 500 ARI design flood events and produce flood level and velocity data; and
- Where possible, verify the performance of the hydraulic model by comparing the estimated flood levels to known flood marks.

4.2 Hydraulic Modelling Approach

To accurately model the complex characteristics associated with flooding of Merrigum, it was essential that a two-dimensional (2D) hydraulic modelling approach be adopted. It was also important that the chosen software have the ability to:

- Model one-dimensional (1D) channel networks outside of the immediate study. In this way, all major controls beyond the immediate study area could be accurately simulated; and
- Model the effects of culverts and other hydraulic control structures within the 2D modelling domain, regardless of the adopted grid resolution.

To achieve this, the chosen model needed the ability to dynamically link 1D elements with the 2D modelling domain. WBM's proprietary software, TUFLOW, has this capability and was endorsed by the TSC for use in this study.

4.3 Hydraulic Model Development

4.3.1 Model Resolution

One of the key considerations in establishing a 2D hydraulic model relates to the selection of an appropriate grid size. Grid size, or model resolution, must be balanced in consideration of the goals of the study and computation efficiency. Accordingly, the grid resolution must be selected to provide a suitable compromise of the following:

- The grid resolution must be fine enough to provide sufficient representation of the modelling domain to accurately simulate the physical characteristics the study area; and
- The grid resolution must result in a model with number of elements that will not result in unrealistically long run times. Model run times of greater than 10 hours are generally not considered practical.

WBM chose a cell size of 4 metres for the Merrigum Study Area. A 4m grid size over the study area, with appropriate 1D elements, provided an excellent definition of land shape, key controls and waterways, while also keeping model run times to within realistic limits.

4.3.2 Model Layout

The area encompassed by the model is bounded in the north near Manley Road, the east near Ryan Road, in the south near Fenaughty Road and in the west by near Dunbar Road. The layout of the TUFLOW model for the simulation of flood flows in Merrigum is illustrated in Figure 4-1.

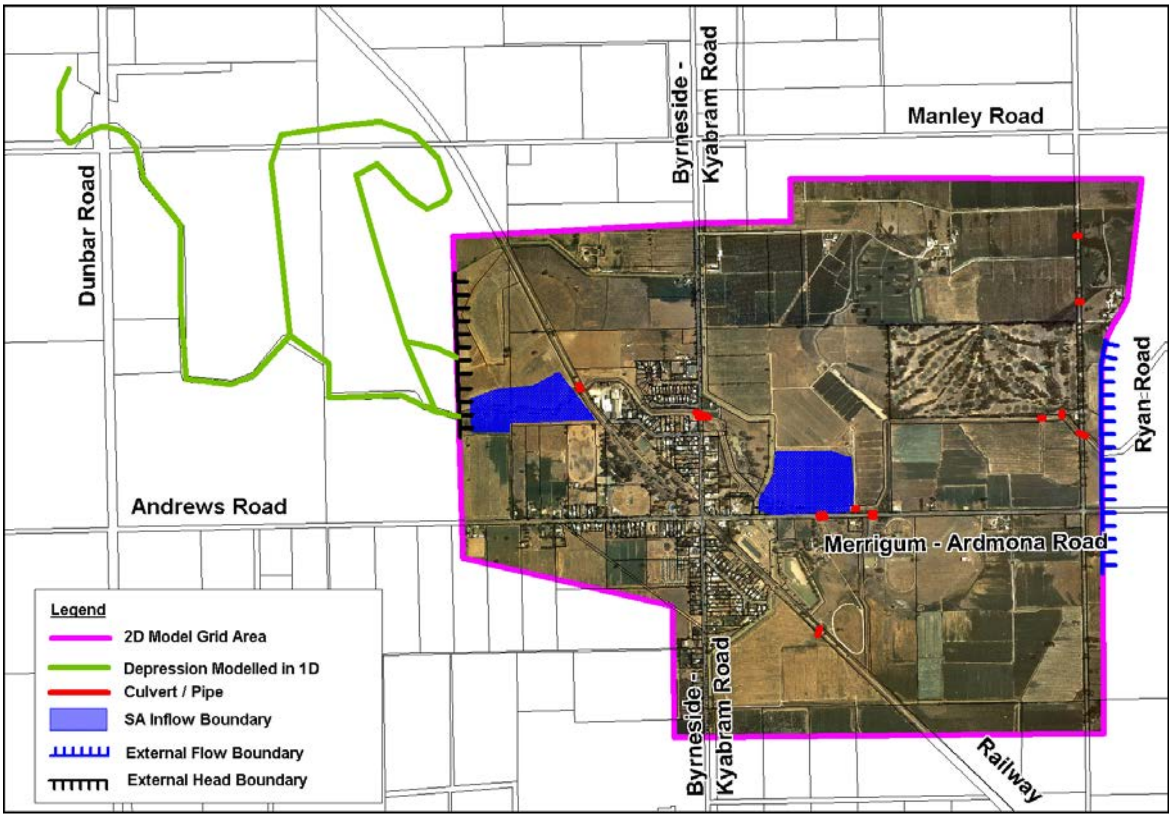


Figure 4-1 2D Hydraulic Model Layout

Design drainage data was used to develop the underground pipe and culvert network within the TUFLOW hydraulic model. The segment of Depression extending downstream from the edge of town to Dunbar road was modelled in 1D. The 1D network was formulated using cross section data extracted from Mosquito Depression Drain design drawings and available contour plans.

It should be noted that although the TUFLOW model has been developed to include some areas outside the Study Area, the results from these areas are affected by boundary effects, and therefore cannot be supplied. The modelling of these areas has been undertaken for the sole purpose of obtaining accurate results at the edges of the study area.

Roughness parameters for the model (Table 4-1) were developed using a combination of data from the GSCC planning scheme, aerial photography and field inspections carried out by WBM. Manning's Roughness Coefficient (n) distribution for the model area is shown in Figure 4-2.

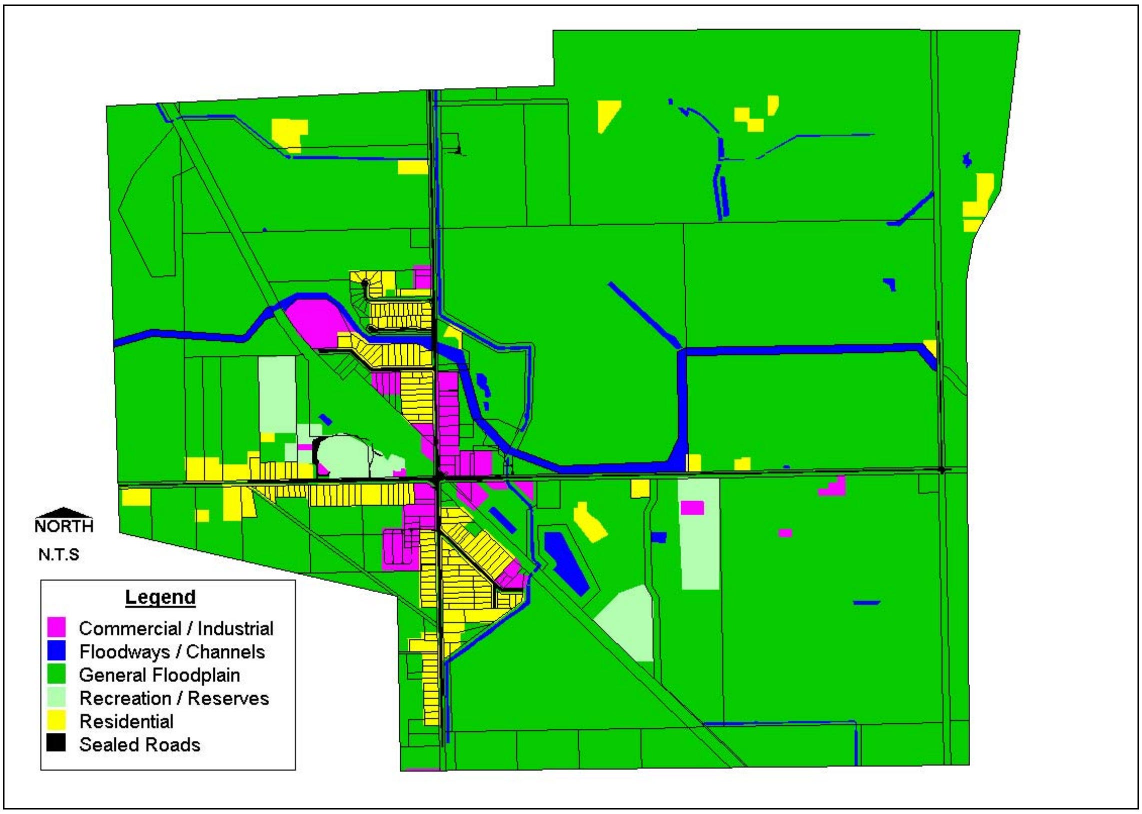


Figure 4-2 Manning's 'n' Distribution

Table 4-1 presents the key Manning's 'n' coefficients used in the model.

Table 4-1 TUFLOW Manning's 'n' Coefficients

Land use	Manning's n
Commercial / Industrial	0.30
Floodways / Channels	0.035
General Floodplain	0.045
Recreation / Reserves	0.035
Residential	0.20
Sealed Roads	0.02

4.3.3 Model Boundary Conditions

Flows for the model boundary conditions were provided as part of hydrological assessment, Section 3.6. Inflows to the Merrigum model occur as external flow boundary conditions (i.e. runoff from areas outside the model domain). The key inputs to the model, as referred to in the hydrological assessment, are:

- Merrigum (upstream study boundary);
- Byrneside Merrigum catchment (upstream of Railway Line);
- Harston Merrigum sub-catchment (downstream of Railway Line).

The Byrneside and Harston flow boundaries represent runoff from their respective catchments. The total flows from these catchments were distributed directly over the Mosquito Depression as sub-area rainfall boundaries (SA boundaries), as shown in Figure 4-3. This approach was adopted as the study was principally concerned about flooding from the Mosquito Depression, not local catchments. The flows from these catchments peak much earlier and are much smaller in magnitude than flows in the Mosquito Depression (i.e. the Merrigum Inflow Boundary), hence the adopted approach has no impact on peak flood levels in the Depression.

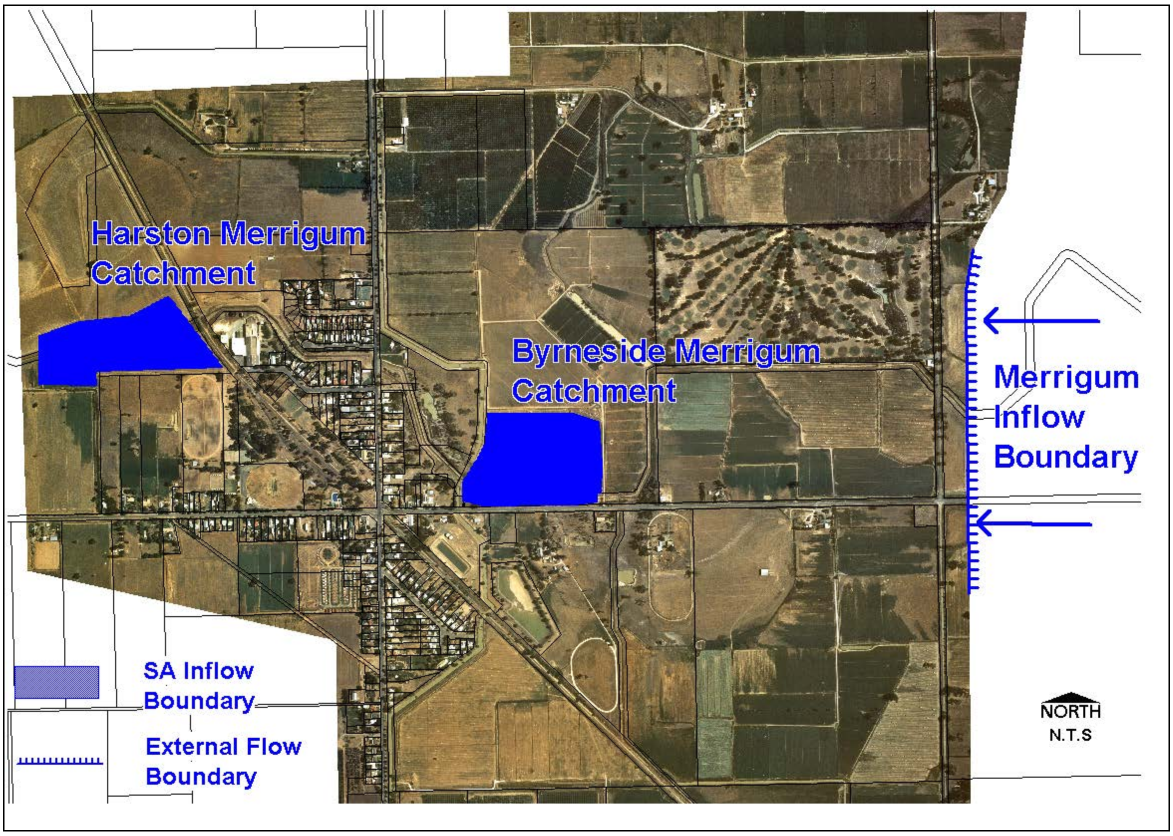


Figure 4-3 Boundary Condition Configuration

The downstream boundary condition on the 1D section of the model, near Dunbar Road, was adopted as a stage-discharge curve. The curve was developed using an approximated cross-section from available contour information, as well as typical ground slopes in the area. Sensitivity testing showed that peak water levels in the 2D study area were largely independent of the water level adopted near Dunbar Road

4.4 Structures

Structural details, dimensions, locations and levels for Structures in the depression were obtained from site visits and from existing plans (Mosquito Creek Depression Obstructions, SRWSC 1982, and Mosquito Depression Drain Extension - Schedule of Works, G-MW, 1993). Additional ground survey of structures was not required.

Road embankments, drain embankments and overflow sills form key hydraulic controls on the floodplain. These features are represented in the 2D hydraulic model by 'z-lines' (or break-lines). The levels on the z-lines are taken directly from the 3D string data contained in the photogrammetry survey. This modelling approach ensures the greatest level of accuracy in representing these features.

Minor flow obstructions and hydraulic structures (including the local underground pipe drainage network) were not included in the hydraulic model. They were not included as their effect on overall model performance and the resulting flood levels was considered negligible.

4.5 Design Event Modelling

Design event modelling was carried out in a two-stage process. Firstly, the standard discreet return period events used in the Tatura Floodplain Management Plan study were run (i.e. the 10, 20, 50, 100 and 500-year ARI flood events). These events were mapped and used to determine the number of properties inundated vs. ARI, as summarised in Table 6-4. The second stage was to select (if required) a number of additional events to provide a sound distribution of maps over the key areas of flood water rise in respect to property inundation.

Considering the relatively linear distribution of affected property floors for each ARI, as well as the relatively small difference in flood height between successive ARI flood events, it was agreed that the second stage was not required.

5 FLOOD DATA CORRELATION

It was agreed with the TSC to compare the modelled 10-year ARI Annual Rainfall modelled flows and flood levels to the available flow and flood mark information for the October 1993 flood event. The 1993 flood event was believed to be in the order of a 10-year ARI. In the absence of detailed flow and flood mark survey, the comparison formed an approximate verification of the hydrologic and hydraulic modelling results.

5.1 Comparison of Modelled and Recorded Flows

A comparison of modelled 10-year ARI flood flows at Merrigum and the flow recorded at Merrigum-Ardmona Road in 1993 are shown in Table 5-1.

Table 5-1 Comparison of Modelled and Recorded Flow at Merrigum

Flood Event and Location	RAFTS Peak Flow (m^3/s)	Historical Peak Flow (m^3/s)
100-year ARI at upstream study boundary	38	NA
10-year ARI at upstream study boundary	14	NA
October 1993 recorded at Merrigum-Ardmona Road	NA	6.6

The recorded flow at Merrigum-Ardmona Road for the 1993 event was 6.6 m^3/s. It is not clear whether this flow included all the flow in the depression (i.e. bypass flows north of Merrigum-Ardmona Rd) or only flows crossing the Merrigum-Ardmona Road. It was also suggested that G-MW was capable of diverting flows from the Mosquito drain between Merrigum-Ardmona Road and Merrigum Township. As a result, 6.6 m^3/s may not be the same flow as that experienced at Merrigum.

Even if it is assumed that some flow in 1993 bypassed the reading at the Merrigum-Ardmona Road, modelling suggests that the event is unlikely to be more extreme than a 10-year ARI event. This suggestion is also supported by the comparison of recorded flood levels (Refer to Section 5.2).

5.2 Comparison of Modelled and Recorded Flood Levels

Table 5-2 and Figure 5-1 compare the October 1993 flood marks to modelled 10-year ARI flood levels. The flood levels east of Waverley Avenue near the CFA building are approximately 107.57m (0.14m higher than modelled levels), while immediately downstream (to the west of Waverley Avenue), there is level of 107.67 (0.03m lower than the modelled levels). It is interesting to note that:

- The downstream flood mark is higher than the upstream marks. This illustrates the uncertainty associated with anecdotal flood mark levels.
- As a consequence of the 1993 flood, in 1994 embankments were added to the floodway between Waverley Avenue and the railway. Embankment heights were set at 500 mm above the 1993 flood levels. The results of the hydraulic modelling suggest that the addition of the embankment could be increasing flood levels in the 10-year ARI flood event higher than

those experienced in 1993. This helps explain some of the difference between the 10-year ARI modelled event and the 1993 flood marks.

As a general observation, the discrepancy between modelled and flood mark levels is still within the accuracies that can be expected given changed floodplain conditions since 1993, the photogrammetric DEM accuracy (i.e. ± 0.10 to 0.15m), and the uncertainty in recalling anecdotal flood level marks and associated inaccuracies in their survey (± 0.05m).

In addition to the 1993 flood marks, some flood marks for the May 1974 flood event were recorded as part of the flood reconnaissance survey. Table 5-3 and Figure 5-2 compare the 1974 flood marks to the modelled 10-year ARI flood levels. Table 5-3 illustrates a greater variation between flood marks and modelled levels, ranging from –0.21 to +0.21m. The higher degree of variation is expected given:

- There have been significant changes to the floodplain since that time (eg Drain modifications including the addition of embankments following the 1993 flood; whole-farm plan changes).
- There is greater uncertainty in the community recalling flood level marks from 1974.
- It is thought that the 1974 event was concentrated in local catchments to the south of Merrigum, not the main Mosquito Depression catchment. This is supported by the 1974 flood marks south of the Merrigum-Ardmona Road, where the hydraulic modelling does not show any inundation (i.e. differences = 9,999 on Figure 5-2).

As part of sensitivity testing the hydraulic model, the flow required in the hydraulic model to produce the 1993 flood level at the CFA building was estimated. Using the results of the model at Waverley Avenue, the estimated flow to replicate the flood mark level was 9 m^3/s. Note that 9 m^3/s is an estimate but still exceeds the 6.6 m^3/s recorded at Merrigum-Ardmona Road in 1993 event (Refer to Section 3.3). This supports the belief that the recorded flow at Merrigum-Ardmona Road in 1993 was not the same as the actual flow in Merrigum itself.

Table 5-2 Flood Mark and Level Comparison - October 1993 and modelled 10-year ARI Peak Flood Levels

Historical Peak Flood Level (mAHD)	Modelled 10-year ARI Peak Flood Level (mAHD)	Difference between Modelled and Historical Peak (m)
108.04	107.99	-0.05
107.63	107.76	0.13
107.67	107.65	-0.03
107.58	107.71	0.13
107.57	107.72	0.15
107.54	107.72	0.18
107.50	107.64	0.14

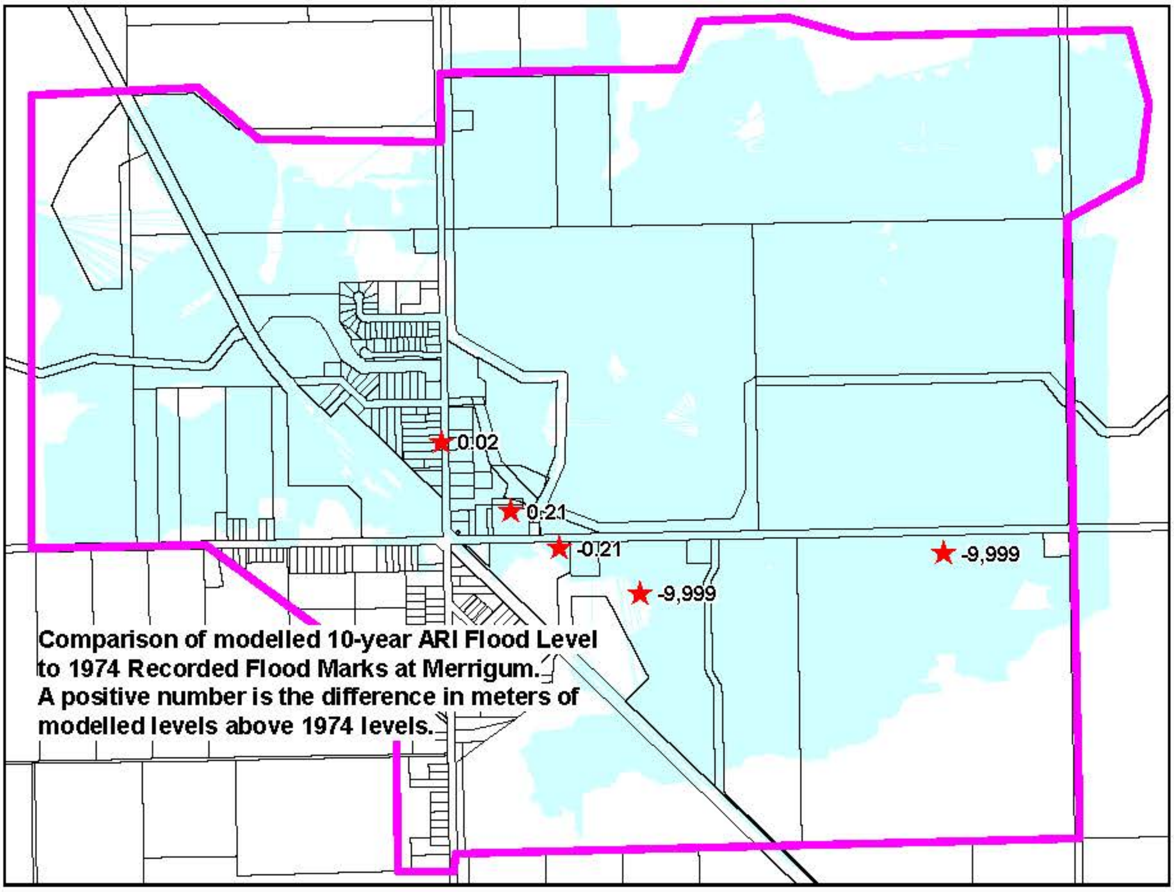


Figure 5-2 Comparison of Modelled 10-year ARI Peak Flood Levels and May 1974 Flood Marks*

** Note: A difference of -9,999 denotes that the surveyed flood mark is outside the modelled flood extent.*

Table 5-3 Flood Mark and Level Comparison - May 1974 and modelled 10-year ARI Peak Flood Levels

Historical Peak Flood Level (mAHD)	Modelled 10-year ARI Peak Flood Level (mAHD)	Difference between Modelled and Historical Peak (m)
107.69	107.71	0.02
107.51	107.72	0.21
107.94	107.73	-0.21

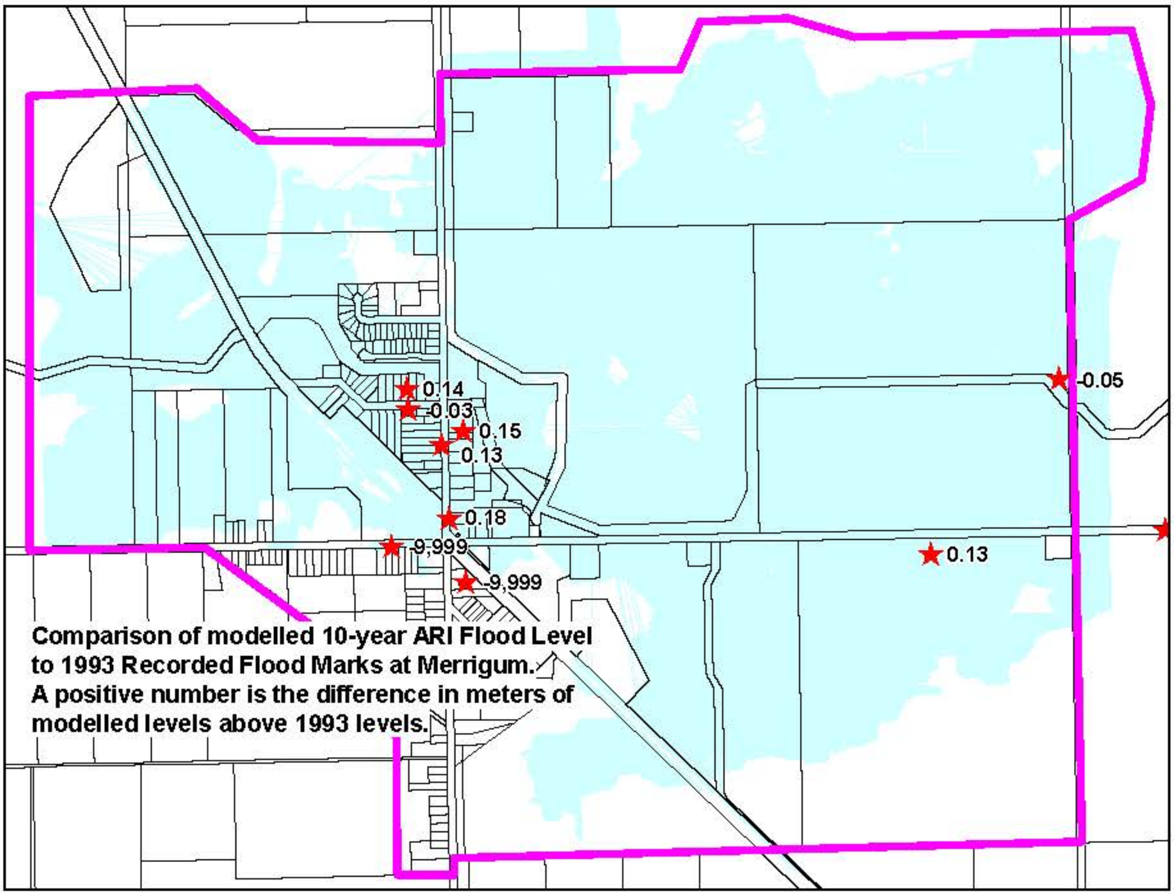


Figure 5-1 Comparison of Modelled 10-year ARI Peak Flood Levels and October 1993 Flood Marks*

** Note: A difference of 9,999 denotes that the surveyed flood mark is outside the modelled flood extent.*

6 FLOOD DAMAGE ASSESSMENT

Flood damage assessment is an important component of floodplain management as it enables an understanding of the magnitude of assets under threat from flooding. The method adopted for flood damage assessment at Merrigum is ANUFLOOD. The method is described in more detail in the following sections.

6.1 Damage Curves

Flood damage assessment using ANUFLOOD involves use of building floor and flood level information in conjunction with ANUFLOOD residential stage damage curves. Residential stage-damage ANUFLOOD curves are from the RAM (Rapid Appraisal Method) report (NRE, 2000). Non-residential ANUFLOOD stage-damage curves are from a journal paper titled “Flood Damage Estimation – A review of urban stage-damage curves and loss functions” (Smith, 1994). For comparison purposes, damages have also been estimated using the RAM method but are not discussed in any detail here.

ANUFLOOD has 15 non-residential stage damage curves. For each building size (small, medium and large), there are 5 curves representing 5 value classes. As only 3 value classes, poor, average and good are considered for Merrigum, averaging the 2 lowest and the 2 highest curves have reduced the number of ANUFLOOD curves. Similarly, the number of non-residential ANUFLOOD damage curves has been reduced from 15 to 9.

Factors were then applied to ANUFLOOD curves as per Table 6-1. The source of the factors is also shown in brackets.

Table 6-1 Summary of Factors applied to ANUFLOOD Curves for Merrigum

Building Type Curve	CPI Factor ($2000 to $2004)	Re-assessment Factor for Potential Damages	Community Flood Preparedness Factor
Residential	1.15 (ABS)	2.5 (DLWC, 2003)	0.7 (RAM)
Non-Residential	1.15 (ABS)	1.6 (NRE, 2000)	0.7 (RAM)

The CPI Factor is based on Australian Bureau of Statistics (ABS) CPI data, and indexes the curves to 2004 dollars.

The potential damages Re-assessment Factors are used to alter damages according to recommendations from NRE and DLWC. It is widely recognised and documented in the RAM (NRE, 2000) that the ANUFLOOD curves underestimate flood damages. To address this issue, the RAM recommends increasing both residential and non-residential curves by a factor of 1.6. Most recently NSW DLWC has re-assessed ANUFLOOD residential stage-damages curves and is applying a factor of 2.5. The DLWC re-assessment factor is based on preliminary data analysed from a study commissioned by DLWC and undertaken by “Risk Frontiers”.

The Community Flood Preparedness Factor is derived from RAM report recommendations. The factor converts potential damages to actual damages. Given that the Merrigum community will be relatively prepared with more than 12 hours warning time, a factor of 0.7 has been used.

Figure 6-1 shows adjusted ANUFLOOD potential damages for residential above floor flooding. Table 6-2 and Table 6-3 show potential and adjusted actual damages estimated for Merrigum respectively.

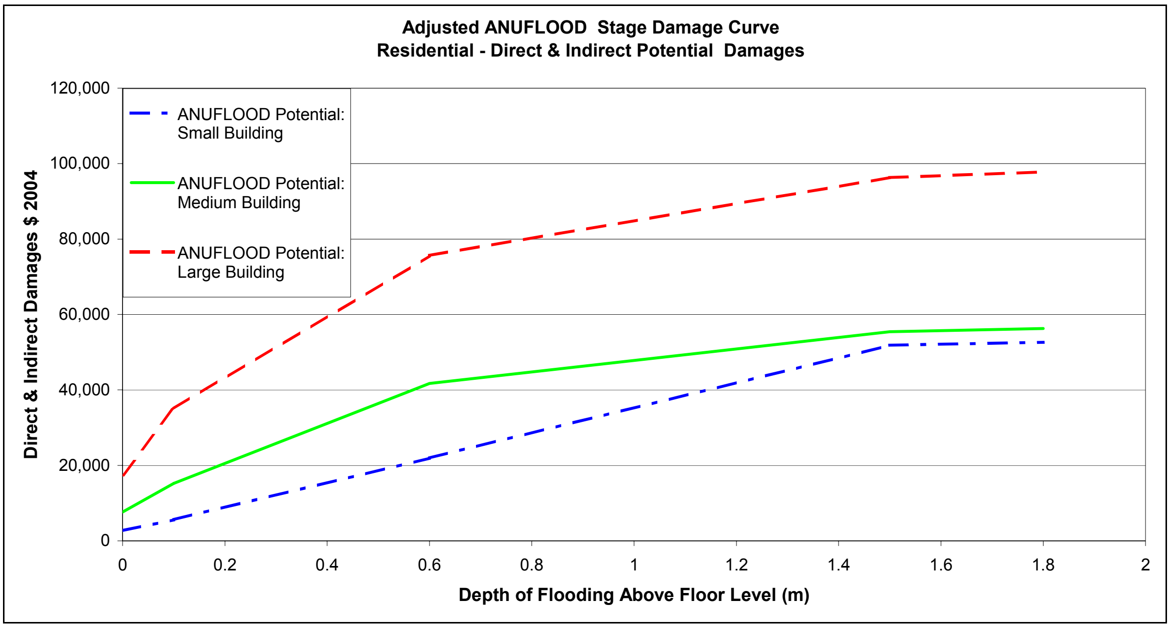


Figure 6-1 Residential Stage Damage Curve for Merrigum

Table 6-2 ANUFLOOD Potential Residential Damages at Merrigum

Flood Height Above Floor Level (m)	Potential Residential Damages - Direct and Indirect ($2004)		
	Poor Condition	Fair Condition	Good Condition
0.0	$ -	$ -	$ -
0.1	$ 2,000	$ 4,000	$ 9,000
0.6	$ 6,000	$ 10,000	$ 20,000
1.5	$ 13,000	$ 15,000	$ 26,000
2.0	$ 14,000	$ 16,000	$ 27,000

Table 6-3 Adjusted ANUFLOOD Actual Residential Damages at Merrigum

Flood Height Above Floor Level (m)	Actual Residential Damages - Direct and Indirect ($2004)		
	Poor Condition	Fair Condition	Good Condition
0.0	$ -	$ -	$ -
0.1	$ 3,500	$ 7,000	$ 15,800
0.6	$ 10,500	$ 17,500	$ 35,000
1.5	$ 22,800	$ 26,300	$ 45,500
2.0	$ 24,500	$ 28,000	$ 47,300

6.1.1 Above Floor Level Flooding

Floor level and natural surface data (Refer to Section 2.2.3) was compared to flood levels generated by TUFLOW to determine the depth of property inundation. The comparison indicates above floor level inundation of a significant number of properties. In total, of the 215 floor levels surveyed, 73 were inundated above floor level by the modelled 1 in 100-year ARI event. It should be noted that this damage assessment is for flooding resulting from the main Mosquito Depression only and does not include properties that may be inundated by flooding from local catchments.

The number of properties inundated above floor level in each event is shown in Table 6-4.

Table 6-4 Number of Properties Inundated Above Floor Level

Design Flood Event (1 in x-year ARI)	10	20	50	100	500
Number of Buildings Inundated above Floor Level	7	17	35	50	73

Figure 6-2 shows the 100-year ARI design flood extent and location of surveyed property floor levels marked in black. Red markers indicate the 100-year ARI flood level is above the floor level at that location. Green markers indicate a floor level above the 100-year ARI flood level. Figure 6-3 indicates the flood extent and flood affected properties for the 10-year ARI design flood.

6.1.2 Below Floor Level Flooding

Damages outside buildings are not included in the standard stage damage curves used. Such damages may include damage to fences, driveways, lower level laundries and outdoor equipment. To account for this, an estimate of "ground damages" was made as a function of ground level inundation. A sliding scale has been used from $0 to $1000 with $1000 being the maximum. The full $1000 damage is experienced once the flood level has reached the floor level of the building. The sliding scale works on the difference between the ground level and the floor level (i.e. a ground level of 1m, floor level of 2m, flood level of 1.5m receives ground equipment damages of $500).

Ground damages for inundated properties without floor level information have been assumed equal to the average ground damages cost for properties where floor level surveys have occurred.

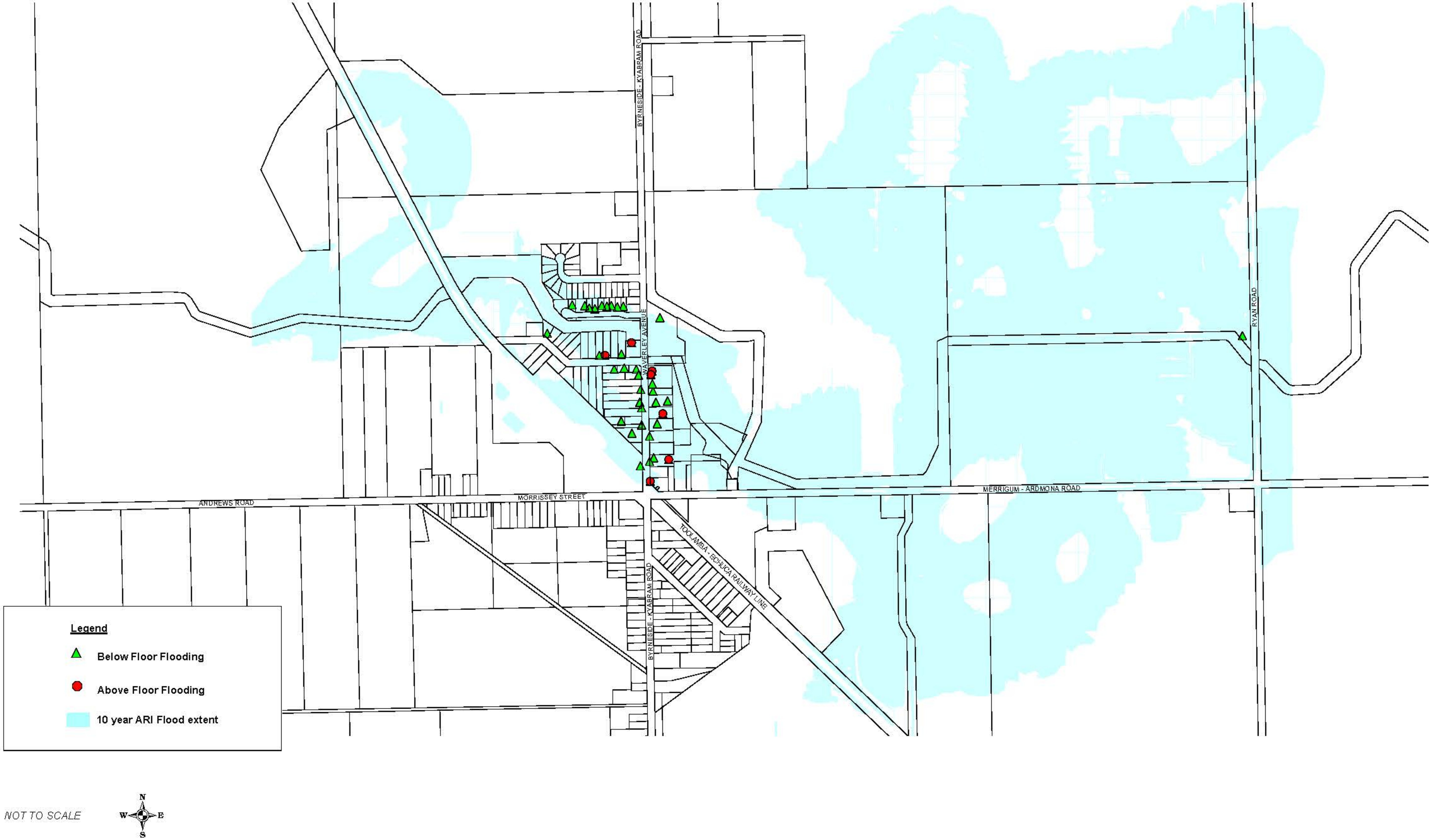


Figure 6-3 Distribution of Above and Below Floor Inundation - 10 year ARI Event

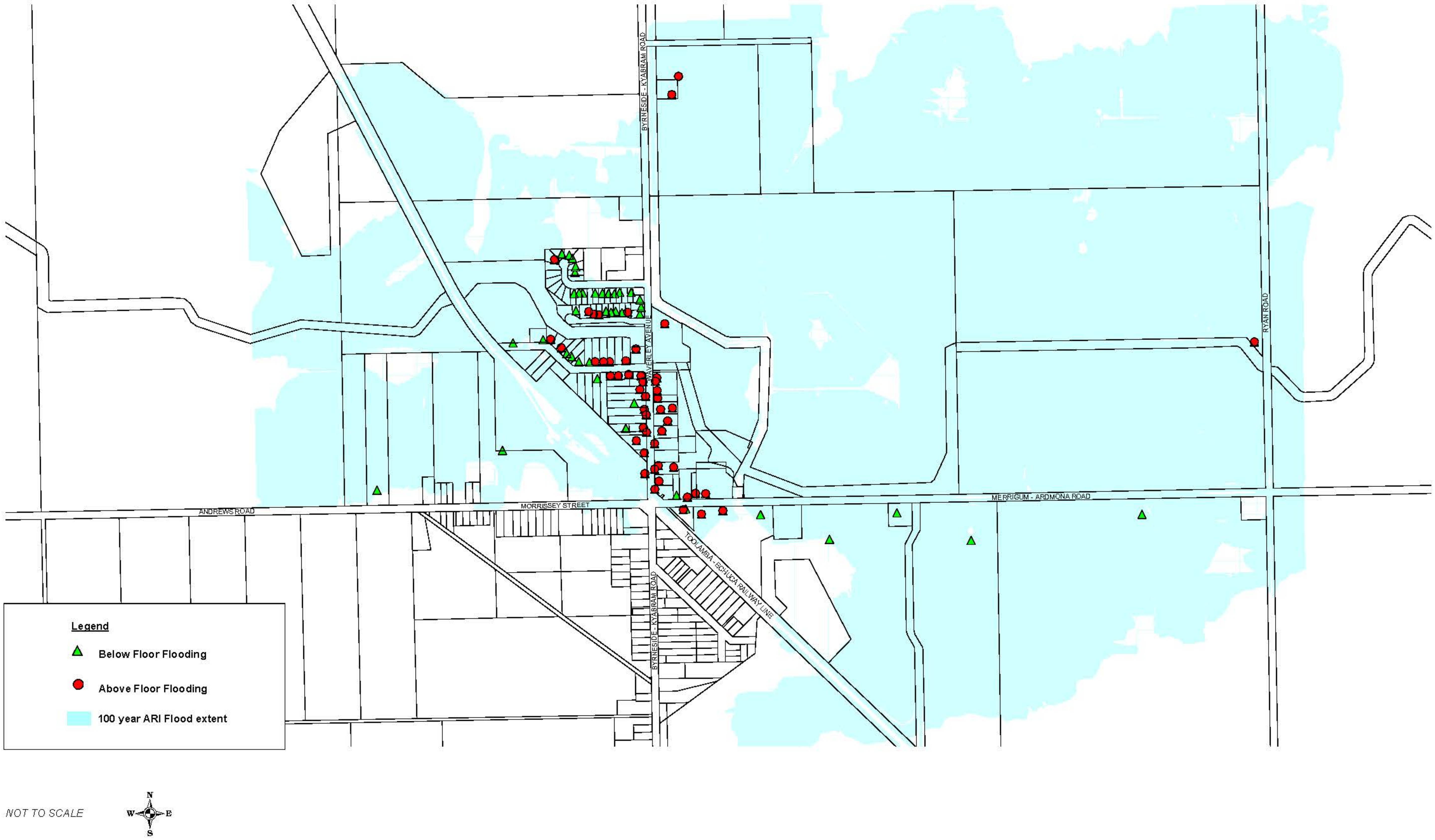


Figure 6-2 Distribution of Above and Below Floor Inundation - 100 year ARI Event

6.1.3 Estimated Damages

Flood damages were estimated using the ANUFLOOD method for the 10, 20, 50 and 100-year ARI design flood events. The Average Annual Damage (AAD) estimate due to flooding at Merrigum is $92,000. For comparison purposes, the RAM estimate of AAD is $257,000. Given that ANUFLOOD uses a more comprehensive methodology than RAM, an estimate of $92,000 AAD should be adopted for Merrigum.

It has been assumed that damages will occur only for greater than 1 in 2-year ARI events, i.e. a 1 in 2.5-year ARI event.

Numbers of buildings inundated above floor levels for a specified depth increment are indicated in Table 6-5. The damage curve for the existing condition is presented in Figure 6-3.

Table 6-5 Above Floor Level Inundation by Depth Increment

Above Floor Inundation Depth (m)	Number of Floor Levels Inundated			
	10-year ARI	20-year ARI	50-year ARI	100-year ARI
0.0 – 0.10	4	8	12	17
0.10 – 0.60	3	9	22	32
0.60 – 1.50	0	0	1	1
> 1.50	0	0	0	0

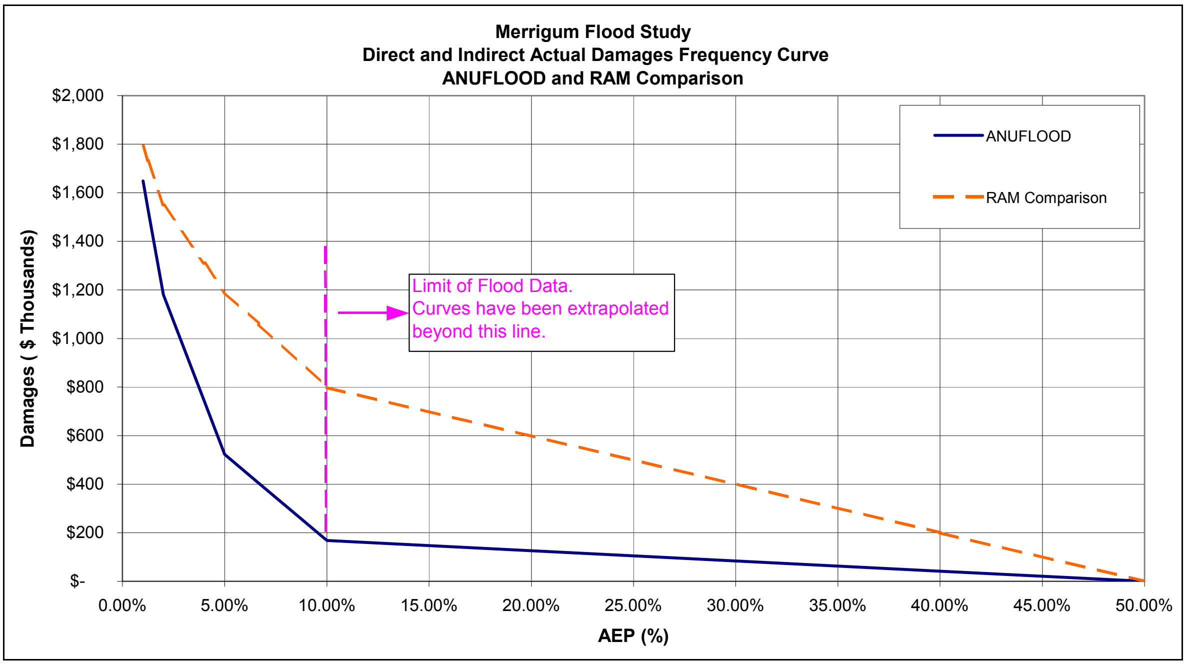


Figure 6-4 ANUFLOOD Damages Curve

7 MAPPING

7.1 Inundation Mapping

Inundation mapping of flood events at Merrigum has been undertaken as follows:

- A combined flood extent plot for the 10, 20, 50, 100 and 500-year ARI modelled flood events;
- Depth mapping for the 1 in 100-year ARI event. Peak flood elevations in m AHD linked to proposed gauge sites have been included with comments on access at road crossings; and
- Depth mapping for the 1 in 10-year ARI event. Peak flood elevations in m AHD linked to proposed gauge sites have been included with comments on access at road crossings.

The floodplain at Merrigum is extremely flat, and as can be expected, velocities were generally less than 0.1 m/s and in the depression less than 0.5 m/s. In consultation with the TSC, it was agreed that mapping velocities was not required.

The map set has been produced in A1 sheet size in both hardcopy and PDF format. Examples of each map are presented in A3 size in Appendix D. All flood extents have been produced digitally for use in Councils and GBCMA ArcGIS.

7.2 Planning Map

A flood planning map for Merrigum, indicating the extent of Urban Floodway Zone (UFZ), Land Subject to Inundation (LSIO) and Floodway Overlays (FO) has been prepared in A1 format, with a reduced copy presented in Appendix E. The basis of the planning map overlays were:

- LSIO is derived from the 1 in 100-year ARI flood extent as modelled in TUFLOW;
- FO and UFZ have been delineated according to depth of flow modelled for the 1 in 100-year ARI event; and
- Declared Flood Level isolines in approximately 0.1m increments, based on the modelled 1 in 100-year ARI peak flood level.

Given the slow nature of flows i.e. velocities up to 0.2 m/s on the floodplain, 0.2 to 0.5 m/s in the natural depression, and up to 1.0 m/s in the confined and straightened sections of trapezoidal drain, velocity was not considered when delineating floodway.

The approximate depth of flow in floodway is 1.5 to 2m generally following the main depression and trapezoidal drain. Depth of flow on the floodplain varies but is generally less than 0.5m.

8 FLOOD MITIGATION OPTION OVERVIEW

8.1 Option Assessment

This section contains preliminary discussion of potential flood management and flood mitigation measures appropriate to Merrigum.

Table 8-1 lists potential flood mitigation options. Both structural and non-structural options are considered. Those items marked * may already be in use or are not an effective or practical solution for Merrigum and may be removed.

Table 8.1 Potential Flood Mitigation Options

Type	Option	Comment on Suitability
Structural	Flood Levees	Yes
	Floodplain Modification	No
	Purchase and Relocation	Yes
	Individual Property Flood-proofing	Yes
	Floodwalls	Yes
	Floodways	No
	Removal of Obstructions	Yes
	Channel Improvement*	No (Implemented)
	Flood Storage*	No (prohibitive scale)
	Diversions*	No (not possible)
Non - Structural	Flood Insurance	Yes
	Floodplain Education Programs	Yes
	Flood Warning System	Yes
	Information and Data Collection (e.g. gauges)	Yes
	Planning Scheme Amendments	Yes
	Land Use Planning*	No (Implemented)
	Regulation and enforcement*	No (Not Applicable)

Previous experience has shown that, based on a matrix style assessment of the remaining mitigation measures against the likely economic benefits and environmental and social effects, the following ranking will typically occur:

1 Levees

2 Flood Warning System

3 Floodplain Education Programs

4 Planning Scheme Amendments

5 Individual Property Flood-proofing

6 Flood Insurance

7 Purchase and Relocation

8 Floodways

9 Floodplain Modification (lowering of roads etc.)

10 Floodwalls

A brief discussion of the key measures follows below.

8.1.1 Levees

Given the vast amount of storage available on the floodplain and that the majority of floodplain around the town is inundated to some degree already, a levee or other flood proofing option for the town may offer a quick solution without resulting in significant increase in hardship or damages to those outside the levee. An appropriate design recurrence interval could be selected from the 10-year ARI to the 100-year ARI protection based on the findings of a hydraulic investigation and cost benefit analysis.

8.1.2 Flood Warning System

A flood warning and dissemination system to residents would help reduce flood damages at Merrigum. The system would require co-operation of residents who are informed and understand what to do in the event of a flood warning being issued.

Advance flood warnings can be used outside of urban areas to allow stock to be moved to high ground and crops to (potentially) be harvested. Within the urban areas, preparations should be made to close temporary gaps in levee banks and arranging supplies of sandbags for the construction of temporary levees if necessary. Residents can move valuable items above anticipated flood levels, as well as obtain food and other vital supplies.

Monitoring and linking flood levels at Tatura to flood levels at Merrigum would formulate one possible flood warning system. A review of flood warning arrangements should be undertaken in conjunction with a review of Council's MEMP, including pre and post-flood procedures.

8.1.3 Floodplain Education Program

Public education is very effective at reducing flood damages. This is particularly so where: awareness of floods in the community is high; people are prepared and know what to do in the event of a flood; and there is sufficient time for belongings to be moved above the anticipated flood level.

If selected as a mitigation option, Council should clarify in a program the actions, aims and proposed date of implementation. The program could involve other agencies, such as VICSES and may include the following:

- Display of maps in public places indicating when and where to evacuate;
- Public education evenings;
- Advertising and posters on what to do in a flood;
- School flood education programs; and
- Distribution of flood information brochures.

Information on a brochure would include:

- Types of flooding at Merrigum
- Flood risk and damage figures
- How to prepare for a flood
- What to do during a flood
- What to do after a flood

Other useful flood education resources are:

- A sample brochure, prepared recently for the Greater Shepparton City Council, contained in Appendix B.
- VICSES produces a flyer titled “How to stay safe during floods”.
- More detailed information on flood preparation, safety and recovery is available in the Emergency Management Australia publication titled "A Personal Handbook of Flood Activities - What to do before, during and after.".

8.1.4 Planning Scheme Amendments

Flood planning levels should be adopted based on the modelled 100-year ARI flood level plus appropriate freeboard. A minimum freeboard of 300 mm will be required to adequately cater for wave and wind action and local flooding effects. Given the greenhouse effect and associated climate change, more extreme weather is predicted for Australia and therefore a higher freeboard may be worth considering.

8.1.5 Individual Property Flood-proofing

Individual property flood proofing may be a good choice for properties outside of the main township or where the benefits of selected flood mitigation options for the town may not be felt.

8.1.6 Flood Insurance

Flood insurance will not mitigate flooding or flood damages. It will however provide some relief to residents from the economic burden and stress resulting form damage to property. This option is currently not available.

8.1.7 Purchase and Relocation

There are potentially 7 residences flooded frequently (less than 10-year ARI protection) that could be suitable for purchase and/or relocated using this option. Alternatively, buildings may be raised (if possible) to provide additional floor level protection. The condition and construction materials of each building would need to be considered to ascertain the suitability of this option.

8.1.8 Floodways

The floodway through Merrigum is an excavated open trapezoidal channel. Increasing the channel's capacity would have an impact on more frequent flood events, but increasing the capacity is limited due to lack of space through the town and very flat grades. The results of this flood study show that the floodway capacity through Merrigum is less than a 10-year ARI event. For rare events, including the 100-year ARI flood, an enlarged floodway would not be of significant benefit.

8.1.9 Floodwalls

This form of flood protection is costly and would work best for any large buildings or industries that would benefit significantly by flood proofing the site.

8.1.10 Floodplain Modification

Due to the flat nature of the floodplain, there is very little energy available to allow the floodwaters to pass quickly. Structural measures involving channel improvements and installing culverts are therefore not able to offer a solution in terms of flood mitigation. Lowering of roads may be of some benefit although the majority of roads are only slightly elevated above the floodplain. The channels that criss-cross the floodplain have the greatest effect on flooding behaviour. Modification to the channels is most likely to have the greatest impact on flooding.

8.1.11 Removal of Obstructions

Replacing a small section of the No. 7 irrigation channel with a siphon, just north of Palmer Crescent and adjacent to Waverley Avenue, may help drain areas east of Waverley Avenue and north of Merrigum. The effect of this option on the urbanised areas west of Waverley Avenue and at the Railway Line would require hydraulic modelling if this option is were selected as part of a floodplain management plan.

8.1.12 Data Collection - Hydrographic Gauge

We strongly recommend Council install a hydrographic gauge and monitor levels in future floods as a way of verifying the modelling work and calibrating the gauge.

A suitable location for a hydrographic gauge has been indicated upstream of Channel No. 7 siphon near Merrigum-Ardmona Road.

The gauge must be located sufficiently upstream of the irrigation channel siphon constriction to ensure hydraulic drawdown will not affect gauge readings. The site is readily accessible, but in the event of Merrigum-Ardmona Road being impassable, access through an alternate route is required.

9 CONCLUSION AND RECOMMENDATIONS

The following recommendations to Council, in order of highest to lowest priority, have been made as a result of this flood study. The recommended actions are to:

- Update council planning schemes and maps to reflect the results from the study;
- Adopt and declare flood planning levels based on the 100-year ARI flood level plus freeboard where appropriate;
- Update Council MEMP including pre and post-flood procedures;
- Install a hydrographic gauge for flood level and flood flow monitoring;
- Undertake mitigation modelling to determine the impact of a number of possible mitigation measures; and
- Prepare and disseminate flood information to the residents of Merrigum.

10 REFERENCES

Institution of Engineers Australia, 1998, *Australian Rainfall and Runoff – a Guide to Flood Estimation*, Reprinted Edition, Volume 1, 1998 and Volume 2, 1987.

SKM, 2000, *Mosquito Depression East Arm Catchment Modelling, hydraulic Assessment Report*, Goulburn-Murray Water, November 2000.

WBM, 2004, *Tatura Floodplain Management Plan,* Greater Shepparton City Council, (This work is in progress).

R Nathan, 1999, *A Quick Method for Estimating Probable Maximum Precipitation in the Tropical and South East Region of Australia*, Water 99 Joint Congress-Brisbane Australia 6-8 July 1999, Handbook and Proceedings, Volume 2.

Read, Sturgess and Assoc. Consulting Economists, 2000, *Rapid Appraisal Method (RAM) for floodplain management,* Department of Natural Resources & Environment Victoria, May 2000.

NRM (2002) *Guidelines on Determination of Tangible Flood Damages,* NRM QLD, 2002.

Department of Infrastructure, Planning and Natural Resources, *Floodplain Management Guideline No. 4, Residential Flood Damage Calculation*, February 2004.

APPENDIX A: COMMUNITY CONSULTATION DOCUMENTATION

Public Notice

The Greater Shepparton City Council has embarked on a process to develop a Floodplain Management Plan for Merrigum. The plan will help guide future activities associated with the floodplain, including ways to minimise and manage flood risks to the local community and surrounding areas. As the first part of this process, consultants have been commissioned to undertake a flood study in consultation with the community, Council and other key stakeholders. The study will include the preparation of detailed flood inundation maps of the Merrigum Township, which can be used to facilitate emergency response to flood situations, including evacuation.

An understanding of the nature and extent of flooding in the Township is vital as an input to the flood management process. In this regard, the Greater Shepparton City Council is seeking assistance from the local community to provide relevant information on historical flooding characteristics in Merrigum.

The community's assistance will initially be sought via the distribution of a letter and questionnaire to the residents of Merrigum within the study area. The questionnaire will provide an opportunity for residents to document their experience with previous flooding events.

Members of the community, who do not reside in the Merrigum study area and would like to contribute to this important study, are encouraged to do so by providing written submissions to:

Manager of Environmental Development
Greater Shepparton City Council
90 Welsford Street
Shepparton, 3630

Dear Resident

Merrigum Flood Study

To develop a better understanding of flooding in the township of Merrigum, the Greater Shepparton City Council has commissioned engineering consultants, WBM Oceanics Australia, to undertake the Merrigum Flood Study. The study area encompasses the township and some areas adjacent to the Merrigum township (see plan on page 2).

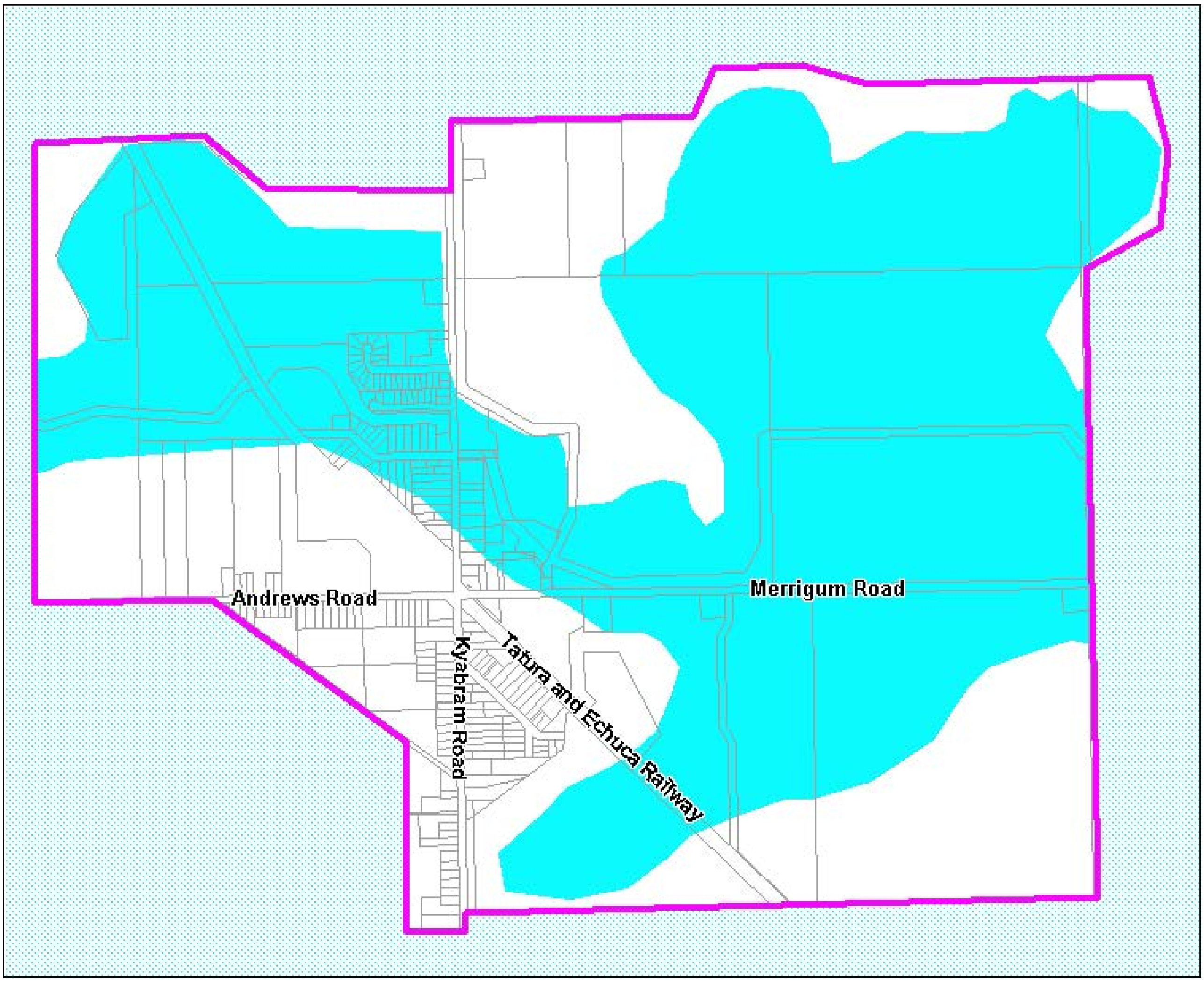
This letter and the attached questionnaire are to inform you of the study process and to seek your comments and views on flooding in the area. To ensure quality results are obtained from the study, please assist us by completing the questionnaire provided.

Study Aims

In the past, the Merrigum community has been impacted by flooding associated with surplus flows that cannot be conveyed by the township's floodways and stormwater drainage infrastructure. Recent studies and assessments have identified that a number of buildings and properties located adjacent to major flow paths and depressions may be subject to inundation. This study will collate existing information and use it, along with new information and the latest technology, to improve the understanding of flooding in Merrigum.

This project will incorporate a strategy to co-ordinate and encourage communication between residents, landholders and the project's Technical Steering Committee. Local community representatives on the Technical Steering Committee are; Mark Lawlor, Greg Pell and Bert Henderson. The study will provide the Council and the community with a set of flood maps for use in emergency management and response situations for the whole of the study area. A preliminary investigation into flood mitigation measures will also be carried out to determine the likely effectiveness of various methods in reducing the impacts of flooding on the community.

Waverley Avenue Flooding 1993



Study Area For Merrigum Flood Study

Note: The extent of flooding shown on this map reflects existing flood overlays for the town. Part of this study's scope is to review these overlays and update them using the most recent data and modelling techniques.

Flooding at corner of Judd & Waverley Avenues - 1993

GREATER SHEPPARTON

Merrigum Flooding Questionnaire

This questionnaire seeks information from local residents regarding historical flood events in the Merrigum flood study area. Your recollections of historical floods will provide valuable information to assist in the investigations. Thank you for your contribution.

Please provide attachments or sketches to answer questions in greater detail (if necessary).

Name ____ Date __________________

Address ____

Telephone Number ____

Other Contract Information ____

How long have you lived at this address? ____________________________________

How long have you lived in the district? _____________________________________

In the period of time you have lived at this address:

1. Are you aware of historical flooding in Merrigum? Yes No

2. If Yes, in what year(s) did the flood(s) occur? __________________________________

3. Was your property affected by floodwaters? Yes No

4. Did floodwaters enter any buildings on your property? Yes No

5. If Yes, in what year(s) ? ____

6. Are you able to show us how high the flood levels rose? Yes No

7. Can you provide information on flooding in other areas of the district? Yes No

8. Do you have any photos/videos of flooding that could be borrowed for copying? (If yes please attach details) Yes No

9. Are you happy to be contacted to discuss the information you have provided here? Yes No

10. If you are aware of other community members who may be able to contribute to this study, please ask them to contact the Council on 5832 9700.

Please feel free to add any further comments or sketches

Privacy Statement: The information that you provided will be used solely for the purposes of assisting in the development of the Merrigum Flood Study. As a result of the information provided you may be contacted by an employee of the consultants and/or the council.

Thank you for your assistance.

Please return before 7th August, 2003, using the enclosed self addressed envelope.

WBM OCEANICS AUSTRALIA

GREATER SHEPPARTON

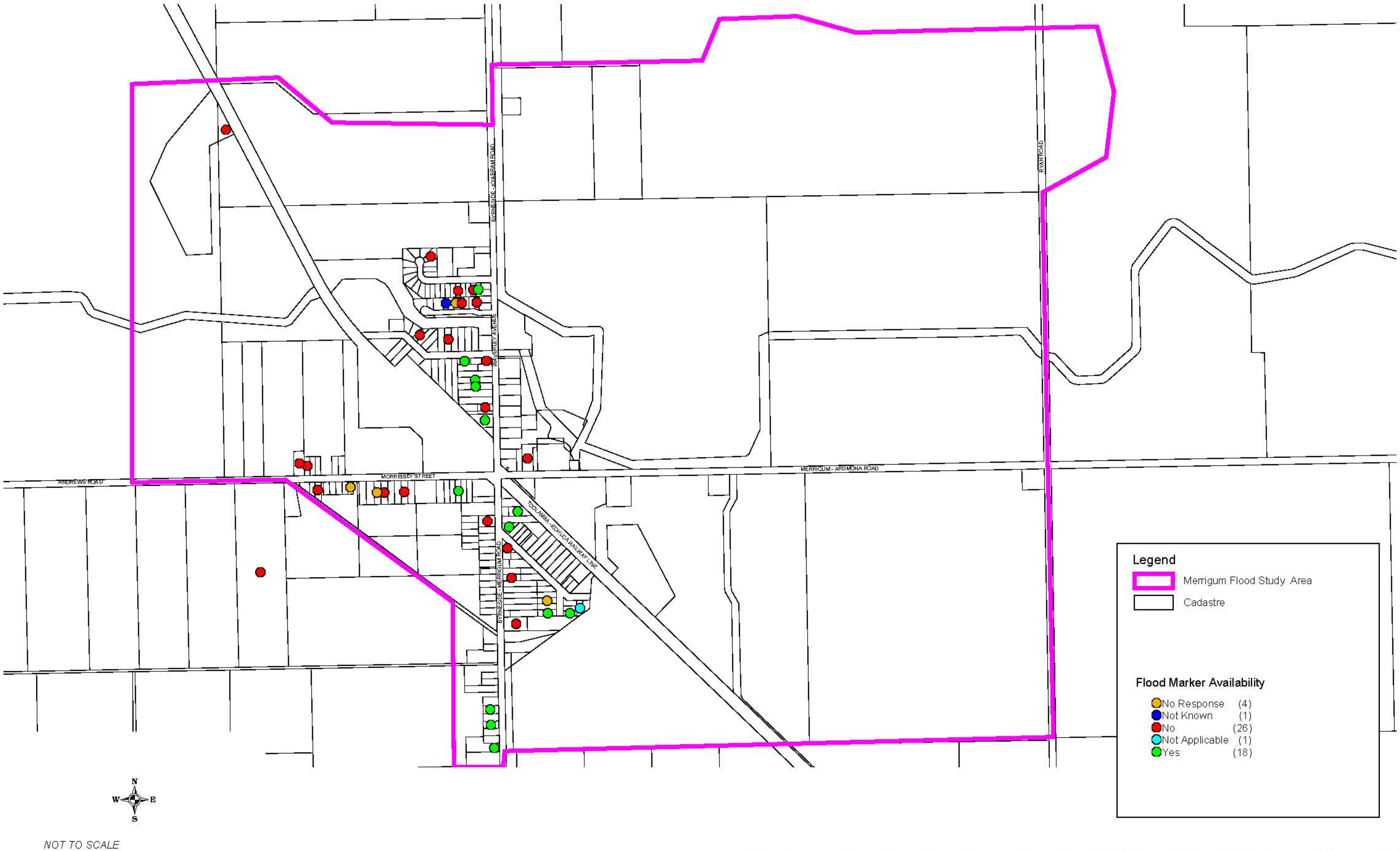
Table A1: Detailed Summary of Merrigum Flooding Questionnaire

Questions

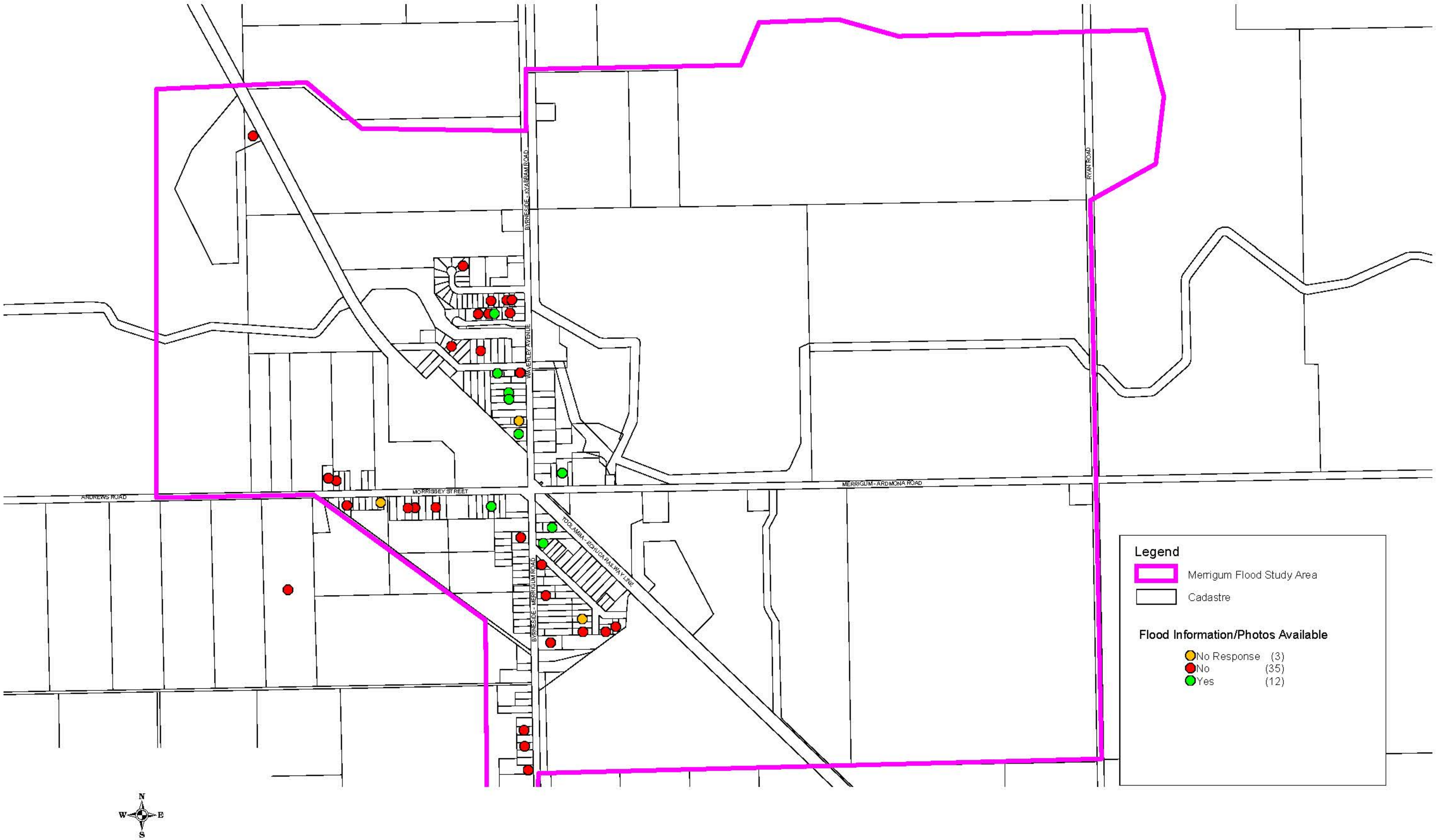
1. Are you aware of historical flooding in Merrigum?
2. If yes when did the flood(s) occur (year)?
3. Was your property affected by floodwaters?
4. Did floodwaters enter any buildings on your property?
5. If yes, in what year(s)?
6. Are you able to show us how high the flood levels rose?
7. Can you provide information on flooding in other areas of the district?
8. Are you aware of any other people who may have knowledge of flooding but no longer reside in the area? How can they be contacted?
9. Do you have any photos/videos of flooding that could be borrowed for copying? (If yes please attach details)

			Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Other
Response Number	Total Years at Address	Total Years in Merrigum	Are you aware of historical flooding in Merrigum?	If yes when did the flood(s) occur (year)?	Was your property affected by floodwaters?	Did floodwaters enter any buildings on your property?	If yes, in what year(s)?	Are you able to show us how high the flood levels rose?	Can you provide information on flooding in other areas of the district?	Are you aware of any other people who may have knowledge of flooding but no longer reside in the area? How can they be contacted?	Do you have any photos/videos of flooding that could be borrowed for copying? (If yes please attach details)	Comments
1	19	19	y	1993	n	n	0	na	n	n	y	
2	8	20	y	1993	n	n	0	n	n	n	n	
3	all life	all life	y	1993	n	n	0	y	y	n	n	Wasting money
4	2	2	y	1992-93	?	?	0	?	?	n	y	
5	11	11	y	1993	y	n	1993	n	n	n	y	
6	6	12	y	1993	y	y	1993	n	n	n	y	
7	60	60	y	1974-1983-1993	y	y	1974-1993	n	n	y	y	
8	2	2	n									
9	49	49	y	1974-1993	y	n		y	y	y	y	Flood photos Andrews & Dunbars Rd
10	1.5	1.5	n					n	n	n	n	
11	36	48	y	1974-1993	y	y	1993	n	n	n	y	
12	0.75	0.75	n									
13	3	20	n		n	n		n	y	y	y	
14	1	1	y	1993	n	n		n	n	n	n	
15	25	33	y	1993	n	n		y	n	n	n	
16	4	4	n		n	n		n	n	n	y	
17	4.5	4.5	y	1993	y			n	n	n	y	see photo in brochure
18	0.1	0.1	n		?	?		n	n	n	y	
19	14	14	n		y	y	1993	y	n	n	y	see notes
20	18	38	y	1974-1993	n	n		n	n	n	y	
21	6		n		n	n		n	n	n	y	
22	18	25	y	1993	y	n		y	n	n	y	
23	65	78	y		y	y	1993	y	y	y	y	flooded under parts of house included photos scanned
24	3	22	n		?	n		n	n	n	y	
25	20	21	y	1993	n	n		y	y	n	y	
26	40	38	n		y	n		y	y	n		natural depression through Merrigum
27	26	30	y	1974	y	n		n	n	n	y	
28	24	52	y	1974-1993	y	n	1993	y	y	y	y	videos of 1974
29	2	22	n		n	n		n	n	n	y	
30	17	17	y	1993	n	n			n	n	n	
31	27	57	y	1955-1974-1993	n	n		n	n	n	y	
32	0.1	39	n					n	n	n	y	
33			y	1974-1993	y	n		n	n	y	y	
34	13	15	y	1974-1993	y	y	1993	y	n	y	y	
35	3	4	n		n	n		n	n	n	y	
36	16	40	y	1954-1974-1993	n	n		y	n	n	n	Cnr Wilson Ave
37	27	50	y	1956-1974-1993	n	n		y	n	y	y	photos supplied. See notes on form
38	46	46	y	1974-1993	y	n		y	y	n	y	CFA captain
39	19	19	y	1974-1993	y	n		n	n	n	n	see notes
40	2.5	2.5	y	1993	n	n		n	n	n		
41	13	30	y	1974-1993	n	n		n	y		y	see photos & Notes
42	23	54	y	1955-1974-1982-1993	y	y	1955-1982-1993	y	y	y	y	see photos & Notes
43	28	56	y	1955-1974-1993	n	n		n	n	n	y	Since Mossquito channel flooding is unknown
44	65	70	y	1955-1974-1993	y	y	1974-1993	y	y	y	y	has photos
45	32	54	y	1956-1984-1993	n	n		y	y	n	y	Was captain of FB
46	1	1	y	1993				n	n	n	y	
47	25	37	y	1993	y	y	1993	y	y	y	y	flooded due to railway line
48	19		y	1993	n	n			y	n	y	see notes
49	10	10	y	1993	n	n		n	n	n	y	street impassable
50	18	40	y	1993	y	n		y	y	y	y	see attached photos
Total			37 Yes	36 - date 1 - no date	20 Yes	9 Yes	11 - date	18 Yes	15 Yes	12 Yes	38 Yes	
			13 No		22 No	33 No		26 No	32 No	35 No	8 No	

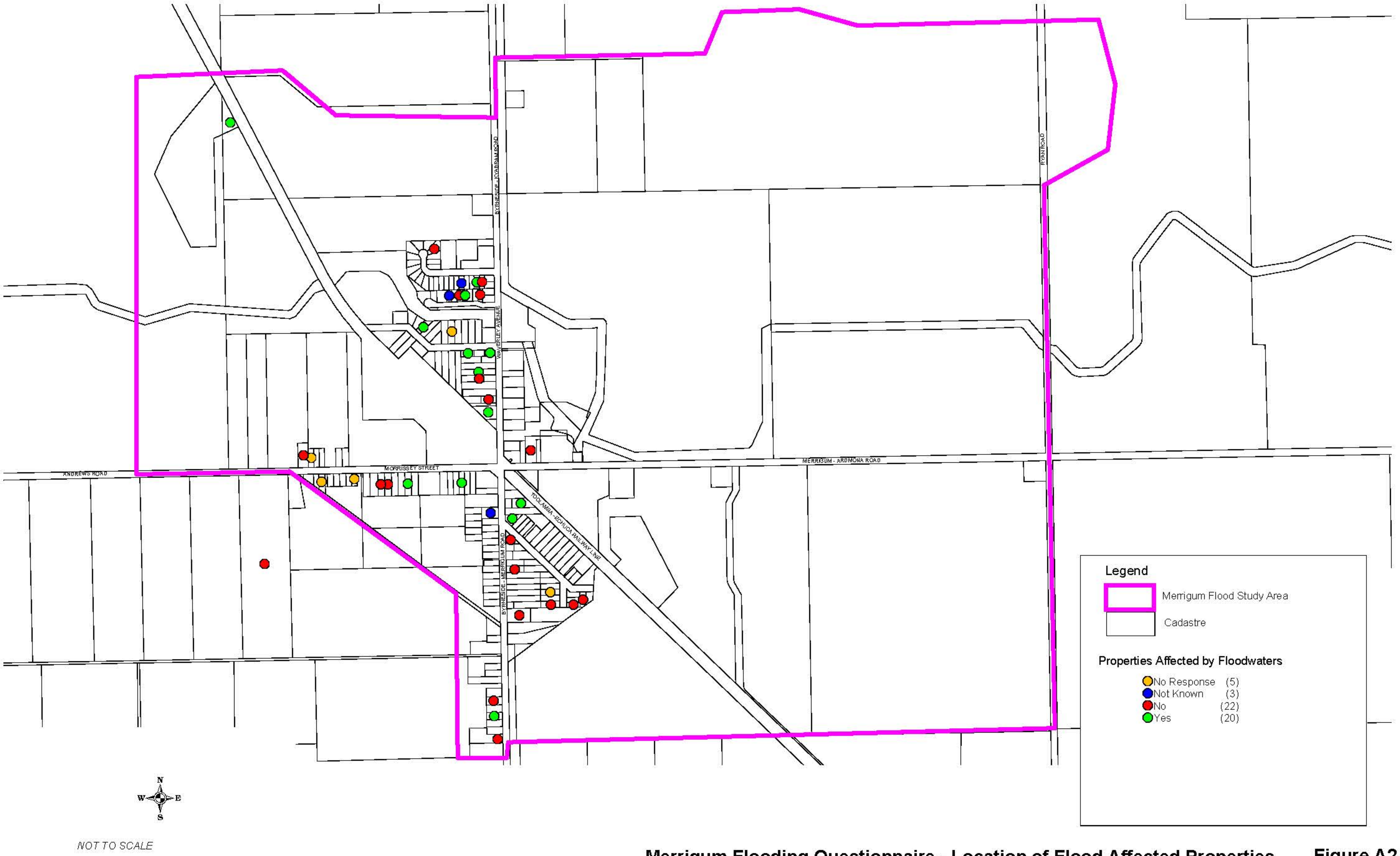
WBM OCEANICS AUSTRALIA



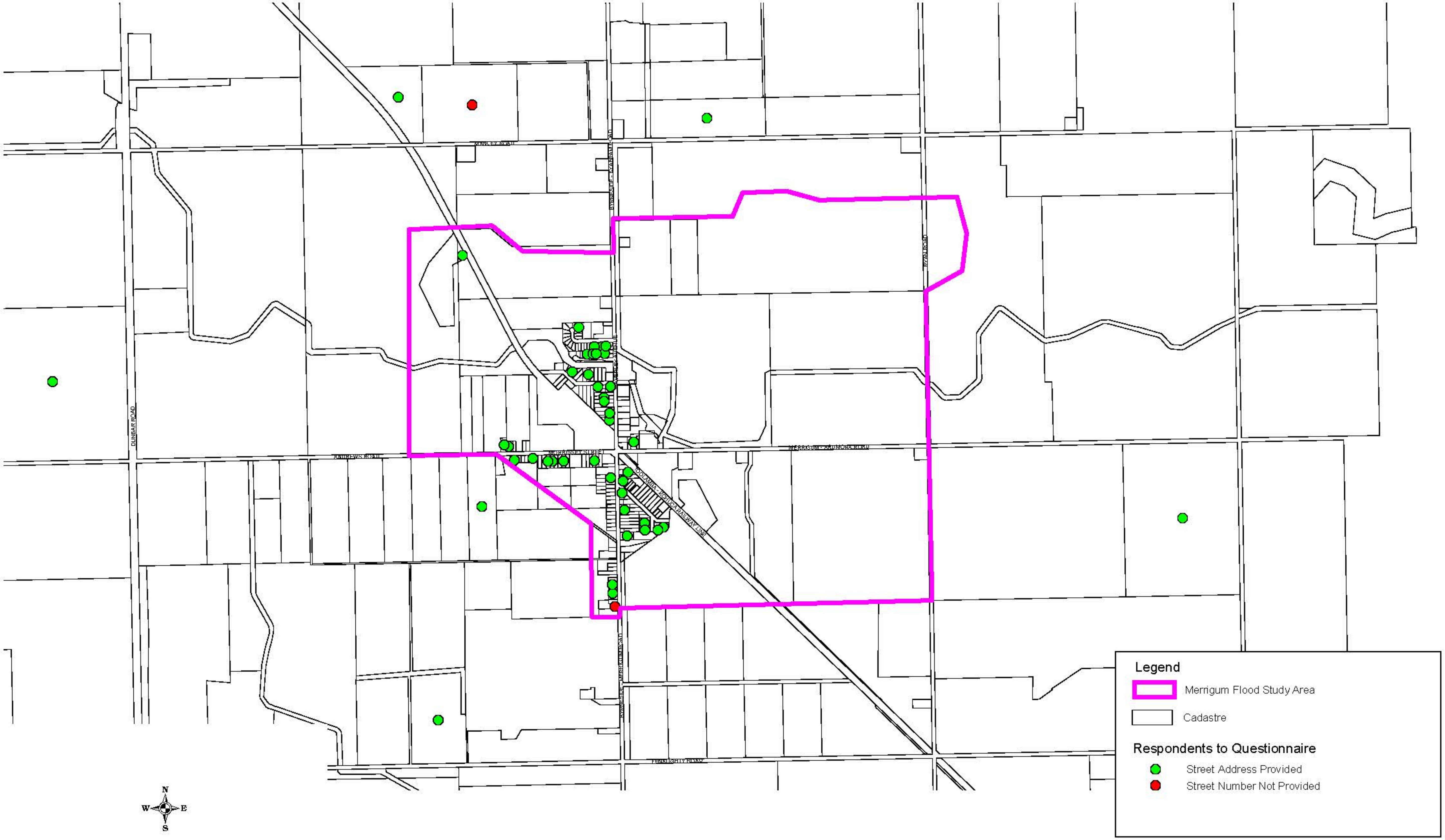
Merrigum Flooding Questionnaire - Availability of Flood Marks Figure A4



Merrigum Flooding Questionnaire - Availablity of Flood Data/Photos **Figure A3**



Merrigum Flooding Questionnaire - Location of Flood Affected Properties **Figure A2**



NOT TO SCALE

Merrigum flooding Questionnaire - Distribution of Respondents **Figure A1**

APPENDIX B: FLOODPLAIN OBSTRUCTIONS

A description of photographs is presented in Tables 1 and 2 respectively. Figures 1 and 2 are labelled with photo and site numbers. Figure 1 shows the location of obstructions Upstream of Tatura and Figure 2 shows those located downstream Tatura.

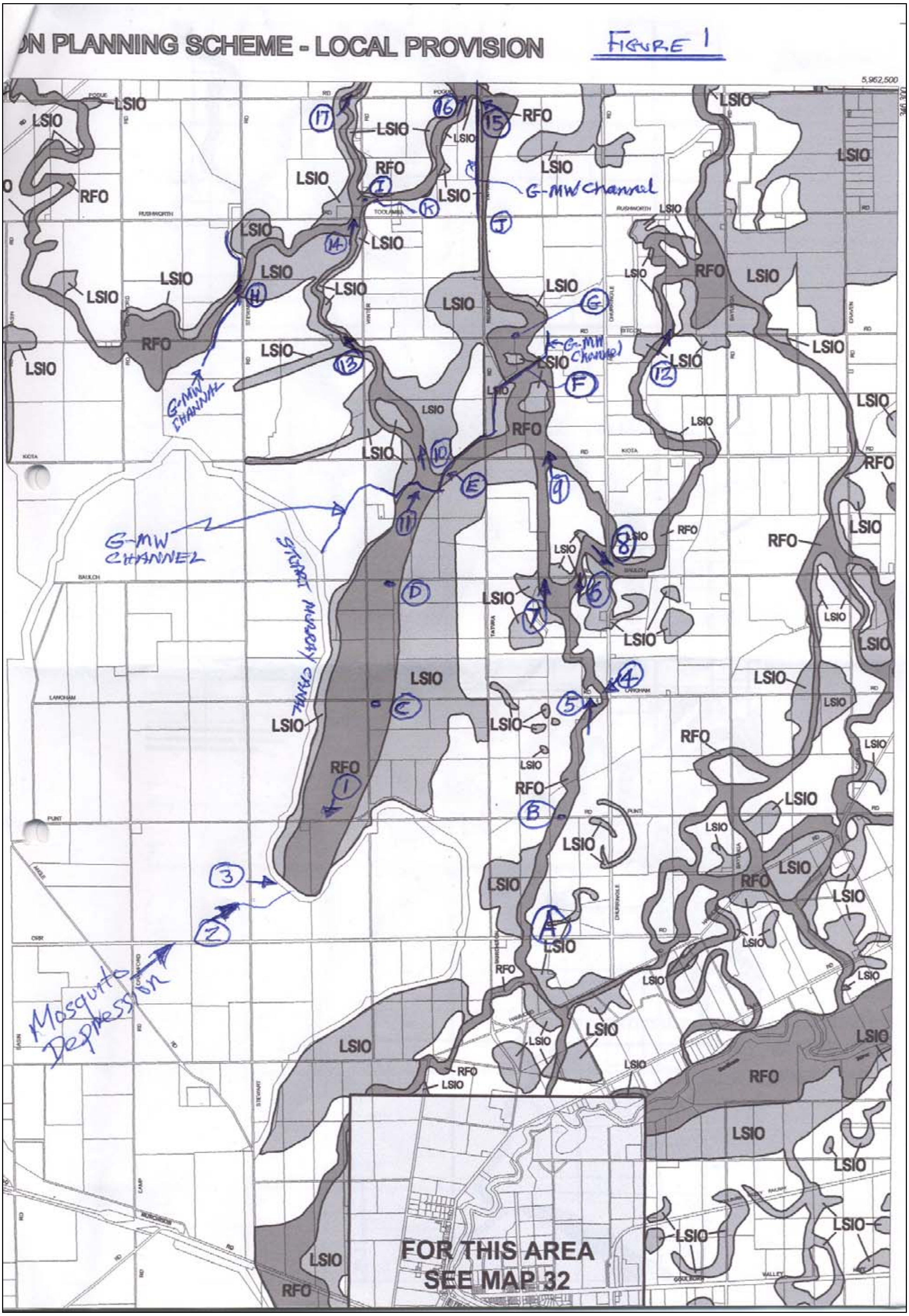
TABLE 1 – Floodplain Obstructions A to R

Site No.	Description
A	Orr Road about 450mm above depression with a single 600mm box culvert. This is tributary depression drainage a localised catchment.
B	Punt Road ditto as for Site A, but has a single 600mm pipe culvert.
C	Langham Road doesn't exist and the Mosquito Depression is in natural state
D	Baulch Road doesn't exist and the Mosquito Depression is in natural state
E	Small 450mm subway pipe culvert through G-MW divert flows via anabranch system which rejoin downstream of Pogue Road.
F	G-MW channel crosses the anabranch channel – Channel has two subways, 1x600mm and 1x450mm pipes.
G	Wide shallow depression downstream of Bitcon Road.
H	G-MW channel crosses a localised tributary depression, which drains, into the Mosquito Depression. The Channel has a 600mm subway pipe culvert.
I	Winter Road is low lying with sunken 6 box culverts.
J	Toolamba Rushworth Road east of the Murchison-Tatura Road is sealed and 450 above an ill-defined anabranch.
K	A depression which heads west (see planning map) doesn't appear to operated given a high ridge of land coupled by a farm channel.
L	It was though that a G-MW Channel crosses the Mosquito Depression. At this location. G-MW today (15/10/03) confirmed no channel exist at this location it is merely a property boundary.
M	Winter Road - Six box culverts over Mosquito Depression.
N	Winter Road is high in this location and not likely to flood greatly
O	See Photo 30
P	New channel has been formed to straighten the Mosquito Depression.
Q	Winter Road – 3 box culverts road is low-lying
R	The eastern and southern arm depression is blocked by a G-MW channel. G-MW stated that the channel has been syphoned under this depression, which is 125 metres long.

TABLE 2 –Floodplain Obstructions 1 - 29

Photo No.	Description
1	Low level road across over mosquito depression floodway, small culvert for low flow
2	Mosquito Depression upstream of Stuart Murray Canal (major embankment)
3	Mosquito Depression piped under the Stuart Murray Canal by two 900mm dia pipes.
4	Sealed road over a tributary depression. Road some 1.5 metres above depression invert. Single 900mm pipe structure.
5	Ditto – as per 4 but looking downstream.

Photo No.	Description
6	Tributary depression with road some 600mm above depression.
7	Tributary depression with road some 450mm above depression which is "ill-defined"
8	Tributary depression crosses sealed road which is low-lying
9	Wide shallow depression with road some 450mm above general depression level
10	Kiota Road (sealed) crossing the Mosquito depression about 1.0m above depression. Six 1.2x0.9m box culverts installed (one is placed lower for low flow).
11	A large G-MW Irrigation Channel crosses the Mosquito Creek. G-MW advised it contains two 1.5m dia pipe. However another head wall adjacent to that shown in photo suggests an additional pipe.
12	Bitcon Road crosses a tributary depression. The road is about 300mm above depression level.
13	Bitcon Road (sealed and low-lying) crosses the Mosquito Depression. Six 1.2x0.9m box culverts installed (one is placed lower for low flow).
14	Toolamba-Rushworth Rd (sealed) crosses the Mosquito Depression. Six 1.2x0.9m box culverts installed (one is placed lower for low flow). Note a local catchment enter from the west (see comment H in Table 2).
15	Photo looking west across Murchison Tatura Road at a G-MW Channel with a single pipe siphon (size not ascertained).
16	Pogue Road crosses an anabranch of Mosquito Depression. Road is low-lying about 300 to 450 above depression water flowing under road but no culvert visible.
17	Pogue Road (sealed) crosses the Mosquito Depression. Six 1.2x0.9m box culverts installed (one is placed lower for low flow).
18	Girgarre East (sealed) crosses the Mosquito Depression. Six 1.2x0.9m box culverts installed (one is placed lower for low flow).
19	Winter Road crosses the Mosquito Depression. Six 1.2x0.9m box culverts installed (one is placed lower for low flow).
30	Pyke Road crosses the Mosquito Depression. Six 1.2x0.9m box culverts installed (one is placed lower for low flow).
20	Railway bridge over Mosquito Depression with large opening (3x1.8m openings).
21	Downstream of the Southern and Eastern arms on Pyke Road. Road some 1.5 metres above depression with 2x600mm pipe culverts.
22	As for 21
23	Midland Hwy bridge crossing the Mosquito Depression
24	Midland Hwy bridge crossing the depression that leaves Tatura
25	The depression of the eastern and southern arm
26	3 box culverts in Winter Road – Mosquito Depression original. Note low flow is now captured via a cutting – refer to comment at site "P" in Table 2.
27	Ford Road crosses the Mosquito Depression. Five 900mm pipe and one box culvert installed for low flow. Road is low lying aiding weir flow.
28	G-MW channel is syphoned under the Mosquito Depression (at least 100m length)
29	Stewarts Road Culverts crosses the Mosquito Depression. Ditto of other crossing downstream to Merrigum offering little obstruction to flooding.



WBM OCEANICS AUSTRALIA

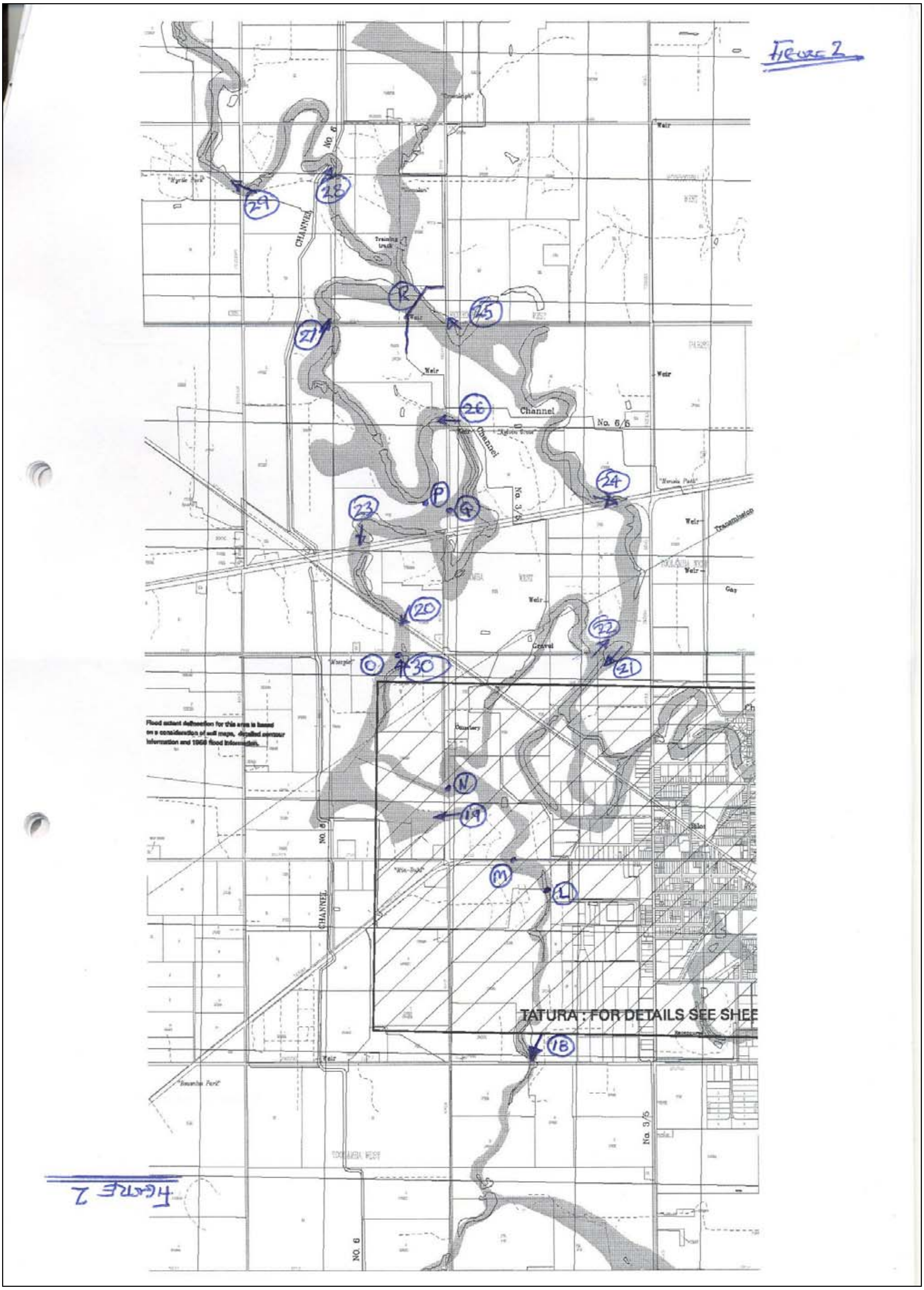
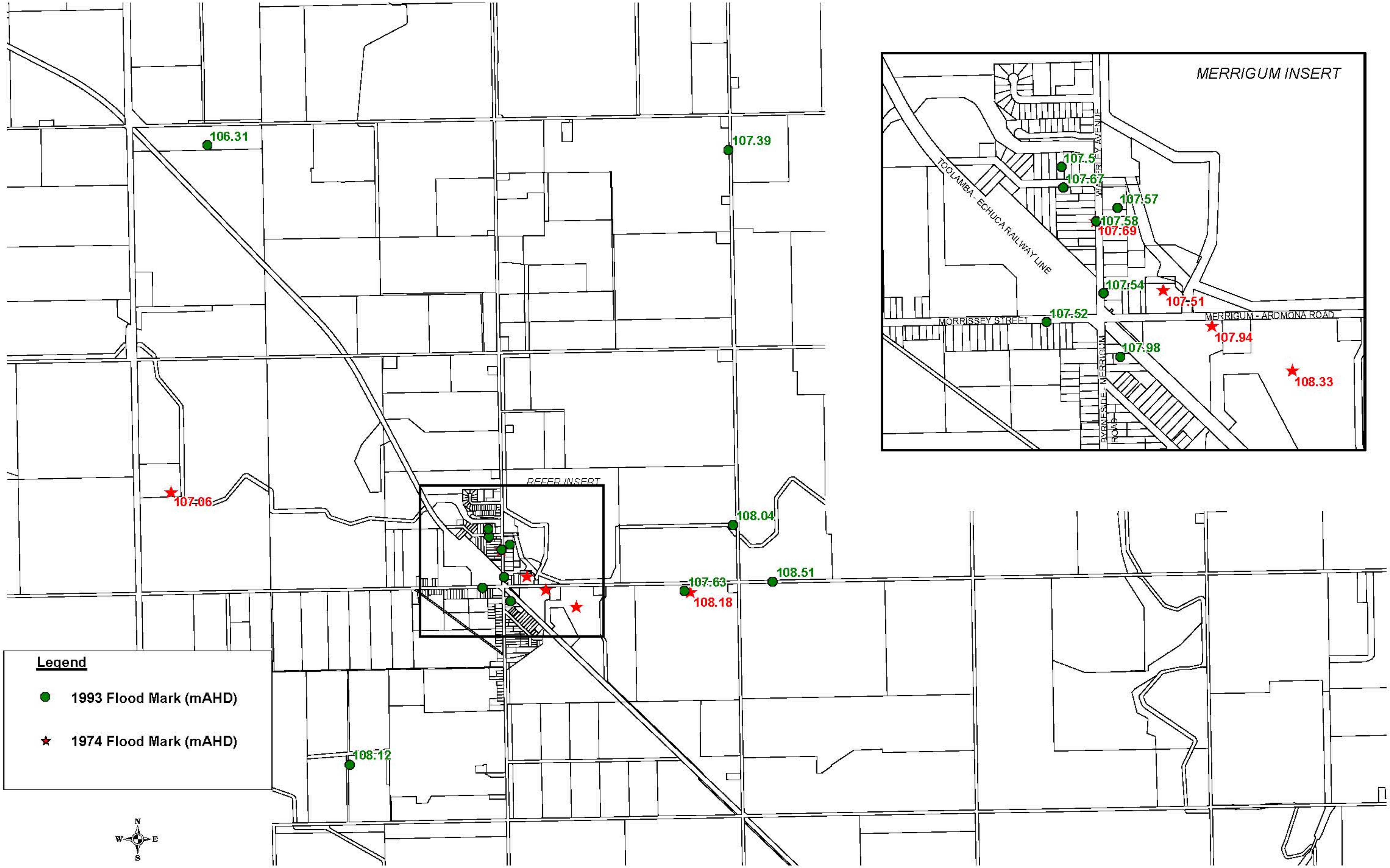


Figure 2
Weir
Channel
No. 6/5
CHANNEL
NO. 6
No. 3/5
Transmission
Gravel
Cemetery
Training track
TATURA : FOR DETAILS SEE SHEE
29
28
R
25
27
26
24
P
Q
23
20
22
21
O
30
N
19
M
L
18
Figure 2

APPENDIX C: FLOOD MARK SURVEY MAP

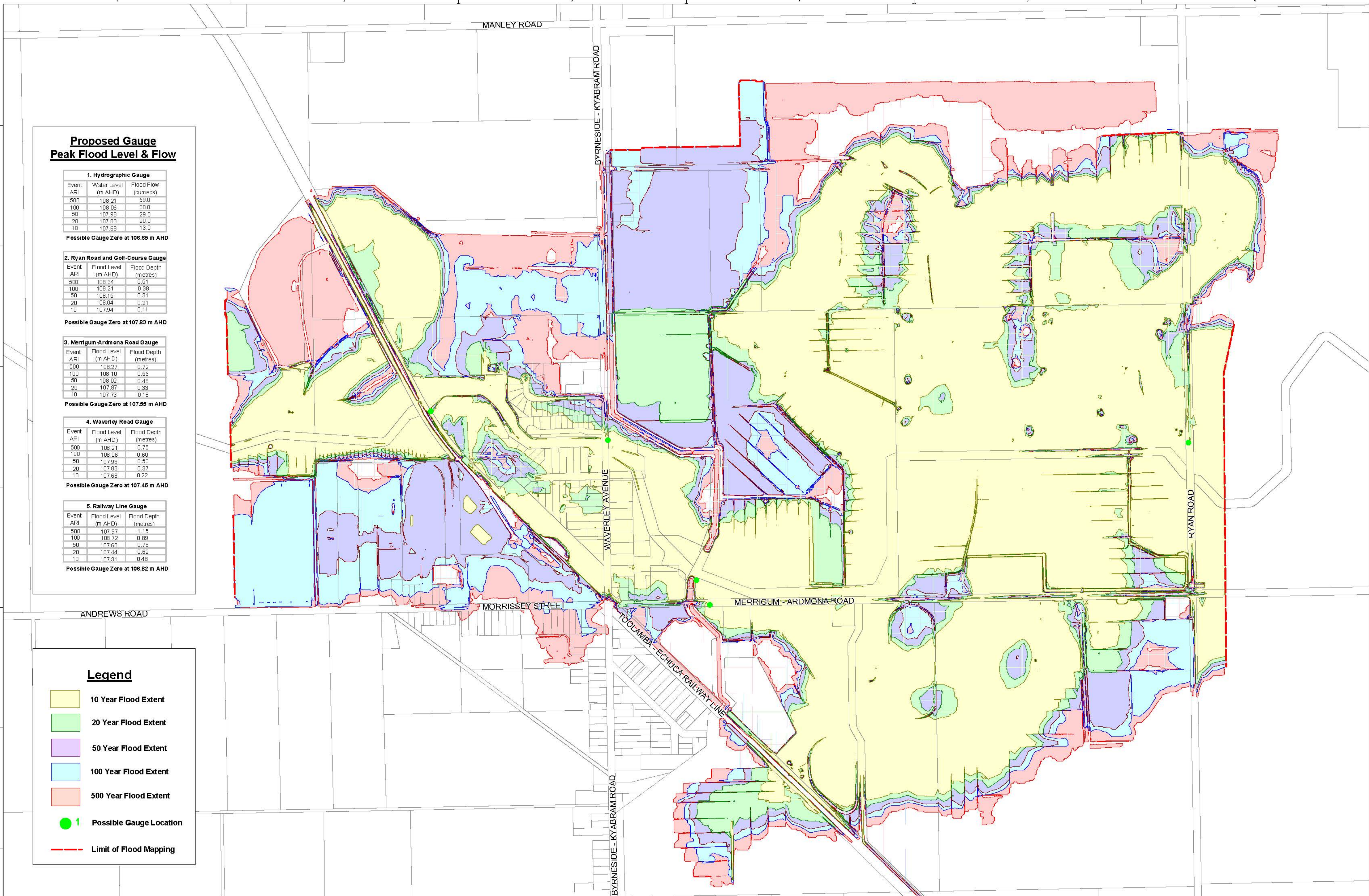


NOT TO SCALE

Distribution of Historical Flood Marks for the Mosquito Depression at Merrigum

Figure C-1

APPENDIX D: FLOOD INUNDATION MAPS



Proposed Gauge Peak Flood Level & Flow

1. Hydrographic Gauge		
Event ARI	Water Level (m AHD)	Flood Flow (cumecs)
500	108.21	59.0
100	108.06	38.0
50	107.98	29.0
20	107.83	20.0
10	107.68	13.0

Possible Gauge Zero at 106.65 m AHD

2. Ryan Road and Golf-Course Gauge		
Event ARI	Flood Level (m AHD)	Flood Depth (metres)
500	108.34	0.51
100	108.21	0.38
50	108.15	0.31
20	108.04	0.21
10	107.94	0.11

Possible Gauge Zero at 107.83 m AHD

3. Merrigum-Ardmona Road Gauge		
Event ARI	Flood Level (m AHD)	Flood Depth (metres)
500	108.27	0.72
100	108.10	0.56
50	108.02	0.48
20	107.87	0.33
10	107.73	0.18

Possible Gauge Zero at 107.55 m AHD

4. Waverley Road Gauge		
Event ARI	Flood Level (m AHD)	Flood Depth (metres)
500	108.21	0.75
100	108.06	0.60
50	107.98	0.53
20	107.83	0.37
10	107.68	0.22

Possible Gauge Zero at 107.45 m AHD

5. Railway Line Gauge		
Event ARI	Flood Level (m AHD)	Flood Depth (metres)
500	107.97	1.15
100	108.72	0.89
50	107.60	0.78
20	107.44	0.62
10	107.31	0.48

Possible Gauge Zero at 106.82 m AHD

Legend

- 10 Year Flood Extent
- 20 Year Flood Extent
- 50 Year Flood Extent
- 100 Year Flood Extent
- 500 Year Flood Extent
- 1 Possible Gauge Location
- Limit of Flood Mapping

NORTH

0 150 300m

Scale 1 : 5000 A1 sheet

Australian Map Grid GDA 94, MGA Zone 55

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PREPARED BY	I. Nolle	25/05/04
CHECKED	M. Turnley	25/05/04
AUTHORISED BY		

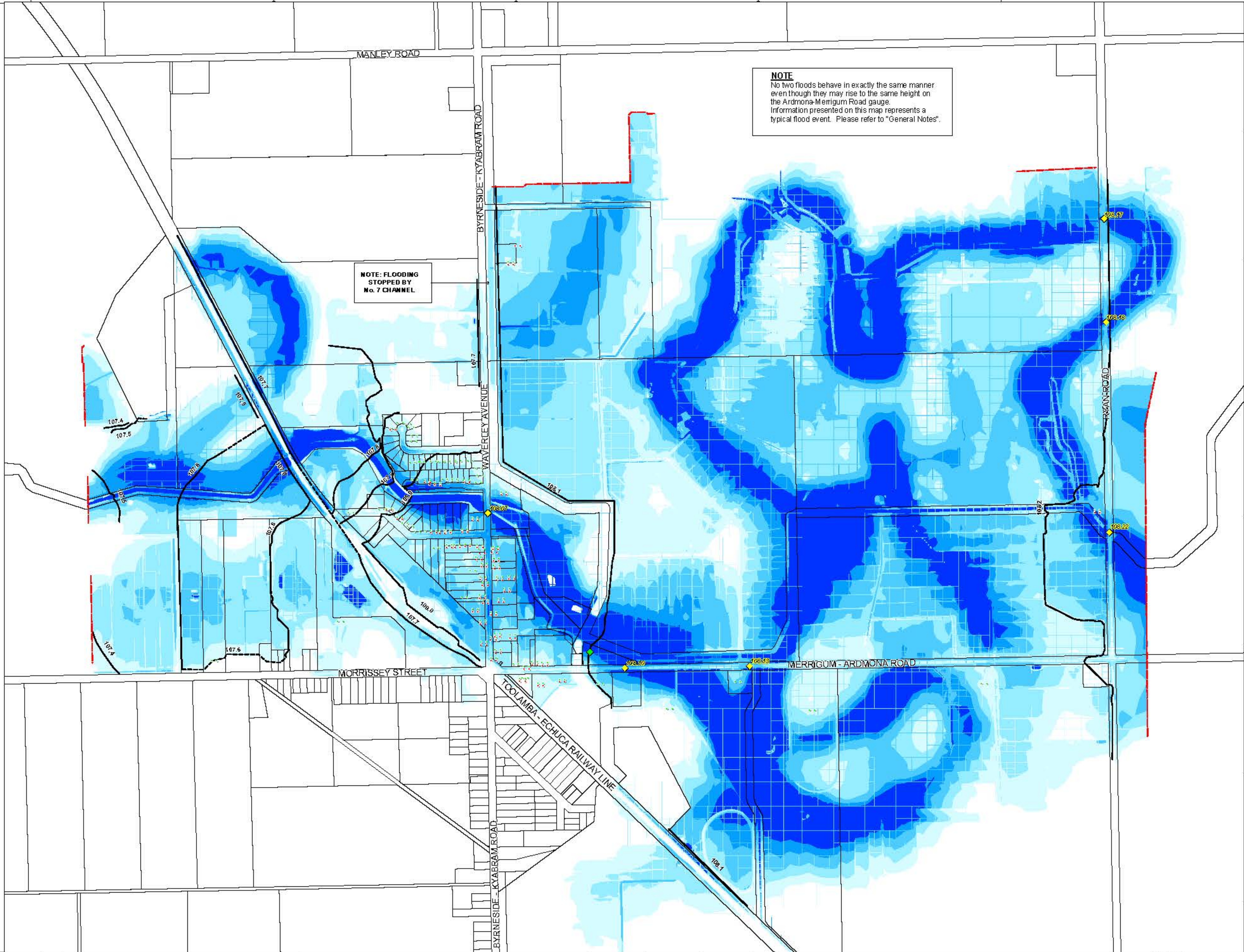
Mosquito Depression at Merrigum Combined Flood Extent Map

PROJECT MANAGER

CORRESPONDENCE NUMBER R.M6359.001.00

SHEET NUMBER 1 OF 1

DRG NO. *Merrigum - 001*



LEGEND

Flood Depth

- 0.00 to 0.25m
- 0.25 to 0.50m
- 0.50 to 0.75m
- 0.75 to 1.00m
- 1.00 to 3.50m
- Building Inundated above Floor
- Building Floor not Inundated
- 107.4 Flood Level Contour (m AHD)
- Limit of Flood Mapping
- Flood Level (m AHD) / Flood Depth (m)
- Proposed Gauge Location

GENERAL NOTES

1. WBM Oceanics Australia has prepared this document in accordance with the instructions of the Greater Shepparton City Council and the Goulburn Broken Catchment Management Authority, for their specific use.

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5. Cadastral and topographic information have been supplied by Greater Shepparton City Council.

6. This map has been prepared using the best available data and computer modelling and mapping techniques. The accuracy of this map however, is not absolute and reflects only the accuracy of the data and techniques used.

7. WBM Oceanics Australia does not warrant that this map is definitive nor free of error and does not accept liability for any loss caused or arising from reliance upon information provided herein.

REVISIONS			
E			
D			
C			
B			
A			
	DATE	REMARKS	APPD

NORTH

0 150 300m

Scale 1 : 5000 A1 sheet

Australian Map Grid GDA 94, MGA Zone 55

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WBM OCEANICS AUSTRALIA

GOULBURN BROKEN CATCHMENT MANAGEMENT AUTHORITY

GREATER SHEPPARTON

PREPARED BY	I. Nolle	24/06/04
CHECKED	M. Tumley	24/06/04
AUTHORISED BY		

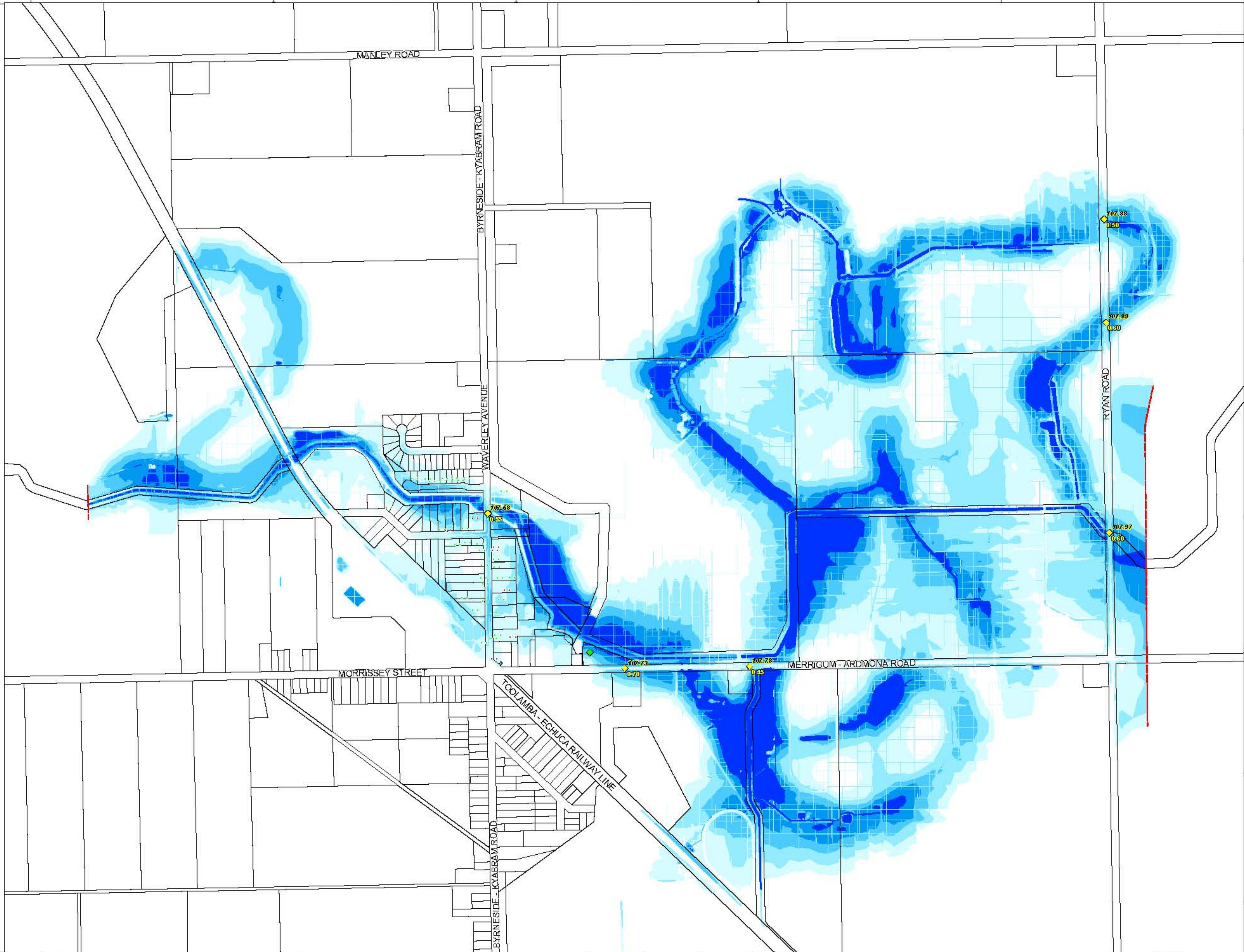
Mosquito Depression at Merrigum
100 Year ARI Flood Depth Map

(108.06 mAHD at Proposed Merrigum Gauge)

R.M6359.001.00

1 OF 1

Merrigum - 002



LEGEND

Flood Depth

- 0.00 to 0.25m
- 0.25 to 0.50m
- 0.50 to 0.75m
- 0.75 to 1.00m
- 1.00 to 3.50m
- Building Inundated above Floor
- Building Floor not Inundated
- 107.4 Flood Level Contour (m AHD)
- Limit of Flood Mapping
- Flood Level (m AHD) / Flood Depth (m)
- Proposed Gauge Location

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NORTH

0 150 300m

Scale 1 : 5000 A1 sheet

Australian Map Grid GDA 94, MGA Zone 55

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PREPARED BY	I. Nolle	25/05/04
CHECKED	M. Tumley	25/05/04
AUTHORISED BY		

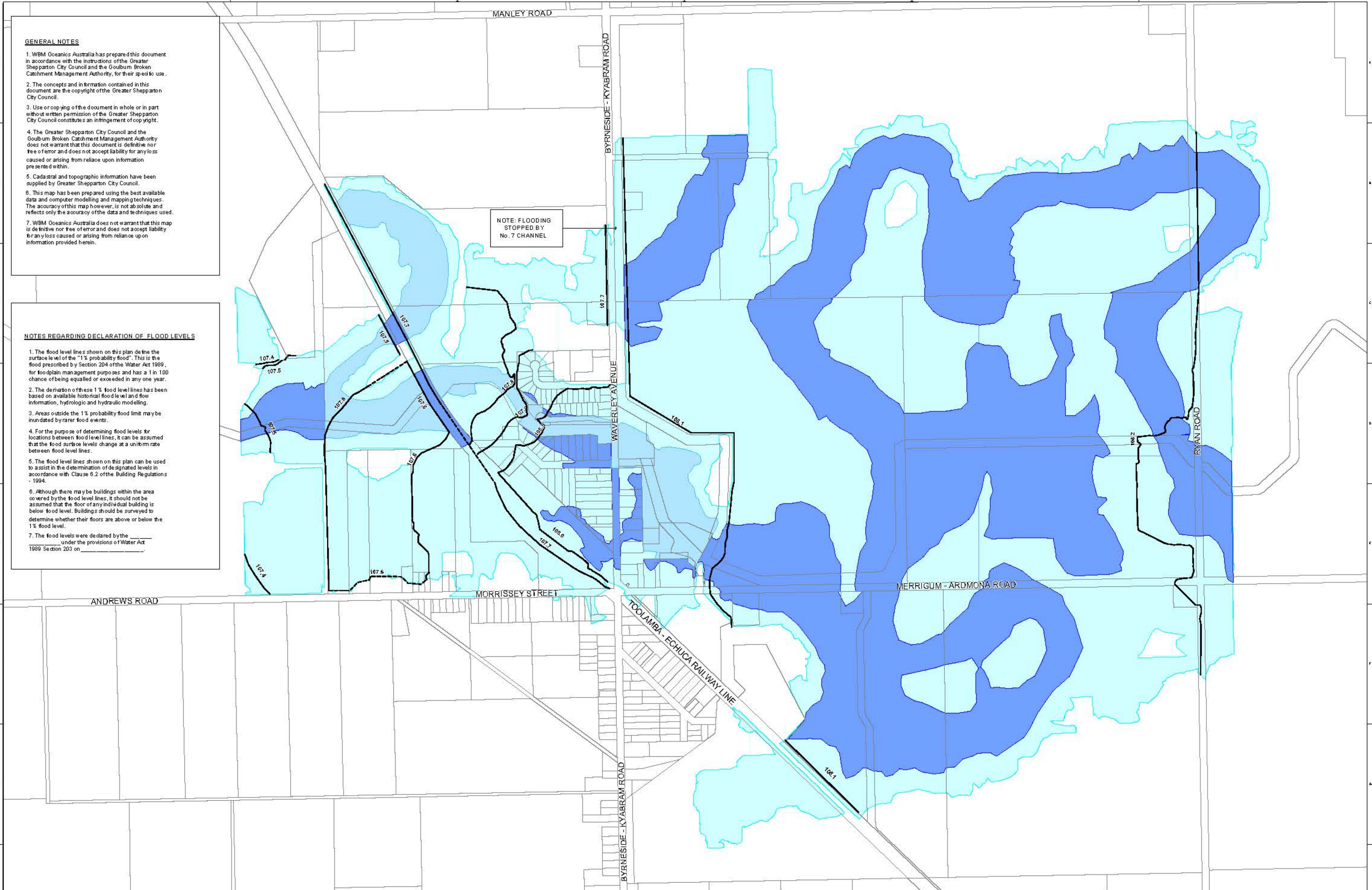
Mosquito Depression at Merrigum
10 Year ARI Flood Depth Map
(107.68 mAHD at Proposed Merrigum Gauge)

R.M6359.001.00

1 OF 1

DRG NO. **Merrigum - 003**

APPENDIX E: FLOOD LEVEL AND PROPOSED PLANNING MAP



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NOTES REGARDING DECLARATION OF FLOOD LEVELS

1. The flood level lines shown on this plan define the surface level of the "1% probability flood". This is the flood prescribed by Section 204 of the Water Act 1989, for floodplain management purposes and has a 1 in 100 chance of being equalled or exceeded in any one year.

2. The derivation of these 1% flood level lines has been based on available historical flood level and flow information, hydrologic and hydraulic modelling.

3. Areas outside the 1% probability flood limit may be inundated by rarer flood events.

4. For the purpose of determining flood levels for locations between flood level lines, it can be assumed that the flood surface levels change at a uniform rate between flood level lines.

5. The flood level lines shown on this plan can be used to assist in the determination of designated levels in accordance with Clause 6.2 of the Building Regulations - 1994.

6. Although there may be buildings within the area covered by the flood level lines, it should not be assumed that the floor of any individual building is below flood level. Buildings should be surveyed to determine whether their floors are above or below the 1% flood level.

7. The flood levels were declared by the _______ __________ under the provisions of Water Act 1989 Section 203 on ____________________.

Legend

- PROPOSED LSIO
- PROPOSED UFZ
- PROPOSED FO
- 107.60 FLOOD LEVEL (mAHD)

NORTH

0 150 300m

Scale 1 : 5000 A1 sheet

Australian Map Grid GDA 94, MGA Zone 55

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OCEANICS AUSTRALIA

GOULBURN BROKEN CATCHMENT MANAGEMENT AUTHORITY

GREATER SHEPPARTON

PREPARED BY	I. Nolla		25/06/04
CHECKED	M. Turnley		25/06/04
AUTHORISED BY			

Merrigum
Mosquito Depression
Declaration of Flood Levels

SHEET NUMBER 1 OF 1

DRG NO. **540238**