GRIFFITH CITY COUNCIL

GRIFFITH AERODROME CATCHMENT OVERLAND FLOW FLOOD STUDY

FINAL REPORT

FEBRUARY 2010

Level 2, 160 Clarence Street
Sydney, NSW, 2000

Tel: 9299 2855
Fax: 9262 6208
Email: wma@wmawater.com.au
Web: www.wmawater.com.au

GRIFFITH AERODROME CATCHMENT OVERLAND FLOW FLOOD STUDY

FINAL REPORT

FEBRUARY 2010

Project Griffith Aerodrome Catchment Overland Flow Flood Study	**Project Number** 28077
Client Griffith City Council	**Client's Representative** Duncan McWhirter
Authors Stephen Gray	**Prepared by**
Date 5 FEBRUARY 2010	**Verified by**

Revision	Description	Date
4	FINAL REPORT	Feb-10
3	FINAL DRAFT – Final	OCT-09
2	DRAFT REPORT - Final	OCT-09
1	DRAFT REPORT – Data, Model Establishment and Calibration	JUN 09

GRIFFITH AERODROME CATCHMENT OVERLAND FLOW FLOOD STUDY

TABLE OF CONTENTS

PAGE

LIST OF APPENDICES

LIST OF TABLES

LIST OF FIGURES

LIST OF PHOTOGRAPHS

FOREWORD

The NSW State Government's Flood Policy provides a framework to ensure the sustainable use of floodplain environments. The Policy is specifically structured to provide solutions to existing flooding problems in rural and urban areas. In addition, the Policy provides a means of ensuring that any new development is compatible with the flood hazard and does not create additional flooding problems in other areas.

Under the Policy, the management of flood liable land remains the responsibility of local government. The State Government subsidises flood mitigation works to alleviate existing problems and provides specialist technical advice to assist Councils in the discharge of their floodplain management responsibilities.

The Policy provides for technical and financial support by the Government through four sequential stages:

1. ***Flood Study***
   - Determine the nature and extent of the flood problem.
2. ***Floodplain Risk Management***
   - Evaluates management options for the floodplain in respect of both existing and proposed development.
3. ***Floodplain Risk Management Plan***
   - Involves formal adoption by Council of a plan of management for the floodplain.
4. ***Implementation of the Plan***
   - Construction of flood mitigation works to protect existing development, use of Local Environmental Plans to ensure new development is compatible with the flood hazard.

The Griffith Aerodrome overland flow flood study constitutes the first stage of the management process for this catchment area. WMAwater (formerly Webb McKeown and Associates) has been engaged by Griffith City Council (GCC) to prepare this flood study on behalf of Council's Floodplain Management Committee. The following report documents the work undertaken and presents outcomes that define flood behaviour for existing catchment conditions and proposed management strategies for the aerodrome.

EXECUTIVE SUMMARY

Recent relatively minor flooding in November 2007 highlighted the exposure of the Griffith Aerodrome to flooding events. As such Griffith City Council (GCC), in conjunction with the Department of Environment and Climate Change (DECC), instigated the flood planning process for the aerodrome. This document forms the first step in the flood planning process, that is, the flood study in which existing flood behaviour is defined.

WMAwater Pty Ltd were appointed to carry out the flood study and have carried out a variety of work from site investigation to data collection to model build and design models runs to finally the design and model assessment of various mitigation options.

The aerodrome has a catchment of 10.7 km^2 although only approximately 85% of this area contributes to the developed areas of the aerodrome. When larger rainfalls do occur runoff flows through the golf course, as well as down Remembrance Drive, and into the aerodrome in a dispersed i.e. non-concentrated fashion. Generally the hazard of the flow is low as is both the velocity and depth of the flow also. Some inundation of the aerodrome does occur for all modelled events (smallest modelled event is the 2 year Average Return Interval (ARI) event). During the 1% AEP event a peak flow of approximately 30 m^3/s flows towards the aerodrome.

Flooding damage to the aerodrome occurs, to some extent, for all modelled events and a key feature of the flooding is that it does not tend to worsen dramatically for rarer events. That is the flooding impact is similar for an event that will occur once every ten years and for an event that will occur once every twenty years. The main cost of flooding is no doubt the runway in that consistent flooding is likely to necessitate repair and also because if the runway is damaged by flood waters the aerodrome operations, including commercial passenger air services, will be interrupted. It is difficult to estimate exactly what the dollar per day value of the aerodrome is particularly given less tangible issues such as access to health care/emergency services.

Mitigation options were designed in collaboration with other stakeholders and then run in the model in order to quantify their ameliorative effect. The mitigation works reduced the amount of flood flow entering the aerodrome by approximately 10%. The mitigation run consisted of the following mitigation options:

- Increasing culvert capacity four fold at the culvert which links the eastern side of Remembrance Drive, to the south of the aerodrome to the western side of Remembrance Drive;
- A 10 m wide open channel for the conveyance of flows parallel (on southern side) of Remembrance Drive down to the corner of Kalinda Road and old Aerodrome Road; and
- One metre high levees on the southern edge of the aerodrome with a combined length of approximately 200 m to provide protection and a storage of approximately 25,000 m^3.

If flooding of the aerodrome is to be avoided further mitigation works are now required. Future mitigation runs will need to focus on the following:

- Maximising the use of available upstream storage;

- Ensuring that the levees to the south of the aerodrome (to the east) transition into the levees on the western side of Remembrance Drive complete with a raised Remembrance Drive in order to ensure that flow does not enter the aerodrome area;
- Maximising the conveyance via the improved drain on the southern side of Old Aerodrome Road; and
- Implementing localised flood protection measures on the aerodrome site.

Council must make a decision as to whether or not they want to expend budget on significant capital works and aim for flood protection for the 1% AEP event, or if they are prepared to see the aerodrome flooded more often in exchange for less outlay now.

1. INTRODUCTION

In recent years, small duration heavy intensity rainfall events associated with thunder storms have shown that the Griffith Aerodrome and associated infrastructure are exposed to some potentially destructive, and certainly disruptive, flood risk. In order to quantify the flood risk and then to propose measures which may protect the aerodrome and associated facilities in the event of a flood, Griffith City Council (GCC) have appointed WMAwater to carry out a flood study. The Department of Environment, Climate Change and Water (DECCW) is providing financial assistance towards the flood study.

The main objective of this study is to:

- Define the overland flow flood behaviour within the aerodrome catchment (refer to Figure 1 for the location of the study area). The principle focus is on those buildings that adjoin the aerodrome facility, i.e. hangers and administrative buildings, as well as the runway itself, and
- Preliminary assessment of mitigation measures.

The study seeks to establish suitable hydrologic and hydraulic model tools, demonstrate their capacity to emulate local flood behaviour via calibration/validation (as data allows) and then apply these tools to establish the existing flood risk for a range of design flood event probabilities in conjunction with a range of event durations. Following design flood modelling for the existing conditions, a damages assessment for the aerodrome will be carried out. The above work will establish the flood liability of the aerodrome under exisitng conditions.

The model will then be utilised to test preliminary mitigation measures. Mitigation measures will seek to reduce the degree of inundation of the aerodrome and associated infrastructure and therefore reduce the flood damages associated with an extreme event. Mitigation options could potentially be quite varied however two that spring to mind in this case are detaining flood water upstream of the aerodrome or diverting it prior to its entry into the aerodrome area.

This report details the investigations, results and findings of the Flood Study. The key elements of which include:

- a summary of available data;
- model development;
- calibration of the hydraulic model;
- definition of the design flood behaviour for existing conditions through the analysis and interpretation of model results; and
- testing limited mitigation options.

A glossary of flood related terms is provided in Appendix A.

2. BACKGROUND

Griffith Aerodrome is located on flat terrain at the base of a 10.7 km^2 catchment that drains from the relatively steep Scenic Hill. The Griffith Aerodrome is subject to overland flooding, which has in the past forced the closure of the aerodrome and caused extensive damage to the contents of the aircraft hangers. Inundation of the runway pavement is likely to cause separation of the pavement from the underlying road base, which would be very expensive for Council to repair and which may interrupt air services to Griffith. Some of the worst flood affected hangers are those located to the northwest of the intersection between Remembrance Drive and Airport Road. Those occupying the worst affected hangers have made some ad hoc changes to their immediate surroundings in order to try and reduce the severity and regularity of flooding. The main aerodrome car park is subject to minor flooding and has ponding issues and previous events (November 2007) had floodwaters at the terminal building entrance.

The biggest reputed event at the aerodrome was the 1976 flood with flood waters entering most of the hangers. Flooding was exacerbated by the debris that was reportedly blocking a chicken wire fence on the north west boundary of the golf course causing water to pond waist deep and directing water towards some of the more critical hangers and airport terminal. The fence has since been replaced by a mesh fence with much larger gaps.

As mentioned above significant flooding of the aerodrome occurred in November 2007. Following the November 2007 event GCC did some landscaping works near the entrance to the aerodrome in an effort to ease flooding of vulnerable hangars.

2.1. Study Area

The study area (as shown on Figure 1) comprises the aerodrome site, as well as the catchment area flowing to the aerodrome. The total study area is approximately 10.7 km^2 however approximately 85% of this only flows to the aerodrome. Within the catchment, ground elevations range from approximately 200 mAHD (in the headwaters) to 125 mAHD (at the outlet north of the airstrip). The upper reaches of the catchment are characterised by sparse vegetation and steep slopes. To the south and south-west of the aerodrome runoff from the steep slopes concentrates into relatively well defined gullies and water courses which are then dispersed again at the flatter southern boundary of the aerodrome. To the south east, however, the runoff from the upper reaches is largely sheet flow.

2.2. Previous Studies

A number of flood studies and assessments have previously been undertaken within the Griffith area. However these have covered the broader Griffith area and Murrumbidgee River. A brief overview of the study most pertinent to the current project is provided below.

Griffith Flood Study (Water Studies, 1992) – Reference 1

The 1992 Griffith Flood Study assessed the impact of drainage structures on flooding for Griffith and the nearby towns of Yoogali, Yenda and Hanwood. Hydraulic modelling of the drainage network was undertaken for the 10, 20, 50 and 100 year Average Recurrence Interval (ARI) events. The hydraulic model was calibrated to the March 1989 storm event. The report includes a flood damage assessment which was conducted for the study area.

Contained within the report is a detailed assessment of the 1989 flood event including rainfall recordings, and flood levels. The 1992 Flood Study was used as a source of rainfall data for the current study. Isohyets for 24 and 48 hrs durations are provided for the March 1989 storm event. Water Studies (1992) estimate the 1989 12 hour duration storm event to have a probability of occurrence of 1.2% AEP.

Griffith Flood Study (Patterson Britton and Partners, 2006) – Reference 2

The Flood study examined flood behaviour within the Griffith catchment located south of the current aerodrome flood study catchment. A hydrological (RAFTS) model was established of the catchment. This was used to provide inflows to the hydraulic (RMA-2) models.

The 1989 event was used for hydrologic and hydraulic model calibration. Patterson and Britton (2006) note that the March 1989 event, was "preceded by 2 months of particularly dry weather" and hence adopted high loss values for the hydrologic model.

Overall the study is of minor relevance only to the work undertaken for the aerodrome.

3. AVAILABLE DATA

3.1. Rainfall Information

3.1.1. Historical Rainfall Data

Historical rainfall data was obtained for the known events of March 1989 and November 2007 at a limited number of sites within the study area and surrounds. Further rainfall data which may correspond to the known event that occurred in 1976 has also been presented herein.

Running calibration events requires rainfall data representative of the known flood events. As the study team was unable to identify whether the 1976 event of February 5th represented the remembered 1976 flood event at the aerodrome, the 1989 and 2007 events were used in the calibration process.

3.1.1.1. 1989 EVENT

Data for the 1989 event was sourced from the 1992 Flood Study (Reference 1). The only suitable data that could be found came from the Hanwood gauge which lies approximately 5.7 km from the aerodrome. This data was provided in hourly time steps and indicated a total rainfall depth for the event of 103.4 mm. A comparison with the Airport gauge shows similar overall depth recorded (Airport gauge recorded 95.8 mm). Note that the Airport gauge could not be used due to extremely poor resolution. Table 1 presents the 1989 rainfall data used in the calibration process.

Table 1: 1989 Event – CSIRO Hanwood Pluviograph Rainfall Data

Date and Time	Rainfall (mm)
14/03/1989 1:00 AM	0.0
14/03/1989 2:00 AM	0.0
14/03/1989 3:00 AM	3.0
14/03/1989 4:00 AM	6.1
14/03/1989 5:00 AM	5.3
14/03/1989 6:00 AM	6.9
14/03/1989 7:00 AM	8.4
14/03/1989 8:00 AM	5.1
14/03/1989 9:00 AM	8.1
14/03/1989 10:00 AM	12.9
14/03/1989 11:00 AM	11.7
14/03/1989 12:00 PM	9.1
14/03/1989 1:00 PM	5.6
14/03/1989 2:00 PM	8.4
14/03/1989 3:00 PM	5.8
14/03/1989 4:00 PM	5.1
14/03/1989 5:00 PM	1.0
14/03/1989 6:00 PM	0.0
14/03/1989 7:00 PM	0.3

14/03/1989 8:00 PM	0.3
14/03/1989 9:00 PM	0.0
14/03/1989 10:00 PM	0.0
14/03/1989 11:00 PM	0.0
15/03/1989 12:00 AM	0.3
TOTAL	**103.4**

In order to enable a comparison of the gauged rainfall to design rainfalls Table 4 and Figure 2 are provided. Table 4 presents the IFD data for Griffith as calculated using Reference 3. Figure 2 shows the 1989 rainfall plotted on an Intensity-Frequency-Duration plot (log-log axes and intensity plotted against event duration with average return interval also indicated). This plot allows us to readily make a comparison between the 1989 rainfall event and Griffith design rainfall (Reference 3). As can be seen the 1989 event is a 1% AEP event for the event duration of twelve hours. Note that ideally the plot shown in Figure 2 would be based on pluviograph data (as is the case for the 2007 event plotted in blue). This would certainly have changed how extreme the 1989 event was when considered as a shorter duration event. Unfortunately however the data was only available in hourly resolution. It is noteworthy when comparing the observed and design rainfalls that the critical duration for the Aerodrome catchment is in the order of one to two hours.

3.1.1.2. 2007 EVENT

Data for the 2007 event was sourced from the BoM Griffith Airport Automated Weather Station (AWS) (Station 75041) and was provided at a relatively high resolution. The data is shown in Figure 2 and in Table 2 below.

Table 2: 2007 Event – Griffith Airport AWS - Rainfall Data

Date and Time	Rainfall (mm)
26/11/2007 6:00 PM	0
26/11/2007 6:09 PM	0
26/11/2007 6:16 PM	0.6
26/11/2007 6:23 PM	6.8
26/11/2007 6:31 PM	13
26/11/2007 6:38 PM	1
26/11/2007 7:00 PM	0.2
26/11/2007 7:30 PM	0.4
26/11/2007 8:00 PM	0.2
26/11/2007 8:30 PM	1.8
26/11/2007 9:00 PM	0
26/11/2007 9:30 PM	0
26/11/2007 9:51 PM	0.2
26/11/2007 10:30 PM	0.2
26/11/2007 11:00 PM	1
26/11/2007 11:30 PM	0.6
27/11/2007 12:00 AM	0.2
27/11/2007 12:30 AM	0.4
27/11/2007 1:00 AM	0

27/11/2007 1:30 AM	0
27/11/2007 2:00 AM	0
TOTAL	**26.6**

It is of interest to note that although the 2007 event has a far smaller total rainfall depth than the 1989 event (27 mm versus 103 mm), the 2007 event occurred at a time when there had been a number of rainfall events in the preceding week (total rainfall over preceding five days equalled 14.8 mm) and was also a very high intensity rainfall event. The rainfall event had a maximum intensity of 98 mm/h, at 6:31 pm. Peak intensity for the 1989 event is 13 mm/h (although this is based on hourly sampling). The comparable rate for the 2007 event is 20 mm/h.

With respect to a comparison to design rainfalls the November 2007 event is an approximately 2Y ARI event for the event duration range of 60 to 100 minutes.

3.1.1.3. 1976 EVENT

For completeness we have attempted to secure the rainfall data for the 1976 flood event, the date of occurrence of which is unknown (neither the 1992 or 2006 Griffith Flood Studies reference the 1976 flood event). Unfortunately the relevant gauge (CSIRO Hanwood) has data covering only January to April in 1976. An event is identified and is shown in the table below. The peak rainfall intensity is approximately 55 mm/h and the total depth is 34 mm. So although not as large a rainfall event as the 1989 event with respect to rainfall depth, the identified 1976 event is larger than the November 2007 (although with a lesser peak intensity) and occurs over a similar time frame and so may be expected to have caused flooding at the aerodrome and as such may be the 1976 event which aerodrome users refer to as being the worst on record[1].

Comparing the 1976 event to Figure 2 we see that the event is the worst on record in the range of durations (60 to 100 minutes) likely to be critical for the approximately 11 km^2 catchment, for which durations it is an approximately 5 year ARI event. As such it may be that the 5th February 1976 event found is the event remembered by those at the aerodrome today.

[1] The impact of the event is complicated by the runoff from the Golf Course which collected behind a blocked fence and then was released, acting effectively like a small dam break.

Table 3: 1976 February Rainfall Timeseries

Date and Time	Rainfall Depth (mm)
5/02/1976 2:24	9.4
5/02/1976 2:30	25.2
5/02/1976 2:36	30.2
5/02/1976 2:42	45
5/02/1976 2:48	61.3
5/02/1976 2:54	76.6
5/02/1976 3:00	95.8
5/02/1976 3:06	148.1
5/02/1976 3:12	184.7
5/02/1976 3:18	227.3
5/02/1976 3:24	261.6
5/02/1976 3:30	288.1
5/02/1976 3:36	303.5
5/02/1976 3:42	307
5/02/1976 3:48	308.7
5/02/1976 3:54	309.6
5/02/1976 4:00	311.1
5/02/1976 4:06	313.7
5/02/1976 4:12	314.7
5/02/1976 4:18	316.8
5/02/1976 4:24	321.3
5/02/1976 4:30	323.6
5/02/1976 4:36	324.9
5/02/1976 4:42	327.4
5/02/1976 4:48	328.8
5/02/1976 4:54	329.9
5/02/1976 5:00	332.4
5/02/1976 5:06	333.9
5/02/1976 5:12	334.9
5/02/1976 5:18	336.4
5/02/1976 5:24	337.3
5/02/1976 5:30	339
TOTAL	339

Table 4: Design Rainfall Depths for various events at Griffith

DURATION	1 year	2 year	5 year	10 year	20 year	50 year	100 year
5 mins	4.44	5.89	8.13	9.58	11.42	14.00	16.00
6 mins	4.94	6.56	9.05	10.60	12.70	15.50	17.80
10 mins	6.68	8.85	12.18	14.32	17.00	20.83	23.83
20 mins	9.70	12.83	17.60	20.67	24.60	30.03	34.33
30 mins	11.70	15.50	21.20	24.85	29.60	36.05	41.25
45 mins	13.88	18.30	24.98	29.25	34.80	42.75	48.75
1 hr	15.40	20.30	27.60	32.30	38.30	46.60	53.20
1.5 hr	17.55	23.10	31.35	36.60	43.35	52.65	59.85
2 hr	19.10	25.20	34.00	39.60	46.80	56.60	64.40
3 hrs	21.39	28.08	37.80	43.80	51.60	62.10	70.50
6 hrs	25.74	33.60	44.58	51.42	60.60	72.60	81.60
9 hrs	28.71	37.44	49.50	56.88	66.51	79.65	89.91
12 hrs	31.08	40.44	53.16	61.08	71.28	85.20	96.00
24 hrs	37.68	48.96	64.32	73.68	85.68	102.24	114.96
48 hrs	44.93	58.08	76.32	87.36	101.28	120.48	135.84
72 hrs	48.17	61.85	80.64	92.16	107.28	127.44	143.28

3.2. Historical Flood Level Data

No historical levels are available for survey and subsequent comparison against model results during the calibration/validation process. However, a set of photos were supplied by GCC which document the inundation patterns and provide indicative depths for the November 2007 event. Photo 1 provides an example of the types of photos available.

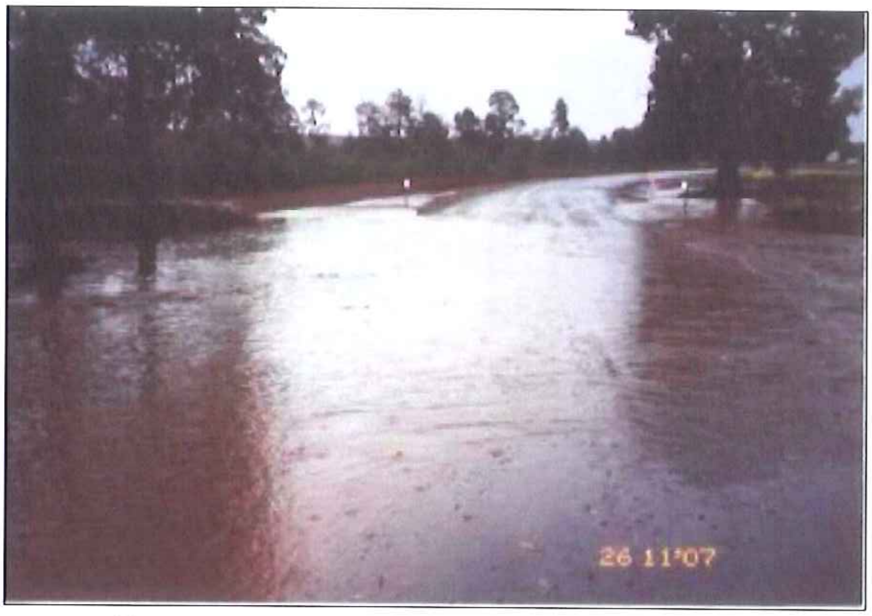


Photo 1: Flooding at entry to Airport Carpark - November 2007

These photos were used in the calibration process to give a broad indication of whether the model represented observed behaviour. Appendix B contains the November 2007 Flood photographs. With the help of Council staff points were digitised in the project's GIS at the photograph locations (refer to Figure 11) and indicative flood depths and velocities estimated from the photo. These were used for comparison with the model results during the calibration process and this information can be reviewed in Section 7.1.

3.3. Topography

GCC have previously obtained Aerial Laser Survey (ALS) for the entire Griffith Region and this data has been made available for the current study. The survey is a low level data set which was captured in 2004 (along with aerial photographs). The ALS provides ground level spot heights from which a Digital Terrain Model (DTM) can be constructed. For well defined points mapped in areas of clear ground, the expected nominal point accuracies (based on a 68% confidence interval) are (vertical accuracy) +/- 0.15 m. When interpreting the above, it should be noted that the accuracy of the ground definition can be adversely affected by the nature and density of vegetation and/or the pressure of steeply varying terrain. The ALS data points were used to create a 1 m and 5 m DTM of the study area. Ground elevations in the TUFLOW model are based on the 5 m grid (Figure 4).

The established DTM was reviewed for completeness and where necessary additional survey to augment this data set has been requested. This survey was required in order to detail features such as:

- Features constructed after 2004 which are likely to have a large impact on flood behaviour, for example the new levee on western end of runway, new drain on western and northern end of runway;
- Smaller drains and berms which are not well defined by the ALS data;
- Dalton Park levee on southern side;
- Invert levels which are obscured from accurate interpretation via ALS because of heavy vegetation; and
- Precise floor levels for buildings so that the damages assessment can be carried out.

The requested survey data for this project are indicated on Figure 3.

3.4. GIS Layers

A number of spatial data sets covering the study area were made available by GCC. The following data sets have been utilised in this study:

- Cadastre;
- Drainage layers;
- Aerial photography based on the 2004 ALS project;
- ALS data; and
- Vegetation layers.

All GIS data has been provided in a MapInfo/ARCGIS compatible form.

4. ADOPTED MODELLING APPROACH

The key purpose of this study was to develop a detailed flood model in the vicinity of Griffith Aerodrome to define flood behaviour and assess proposed mitigation options to alleviate flood risk. The modelling approach is designed to achieve this objective. To achieve this a TUFLOW model was established of the study area.

The suggested modelling approach was initially to establish a Watershed Bounded Network Model (WBNM) hydrological model. WBNM is a widely used lumped conceptual hydrologic model. The hydrological model was to be used in conjunction with a hydraulic model (TUFLOW, a 1D/2D fully dynamic fixed grid based model). Direct rainfall was to be applied to the aerodrome precinct only.

Following some preliminary hydraulic modelling, in which test rainfalls were applied directly to a 5 m grid resolution model, it was found that the majority of water entering the aerodrome vicinity was doing so as dispersed sheet flow, not as concentrated gully/stream flow. The modelling approach was subsequently revised for the following reasons:

- Flow developed in WBNM (or any other typical hydrologic modelling application) is introduced to a 2D hydraulic model via a discharge boundary or source point. Both of these methods require some relatively discrete description of the location of the flow in order to work. As much of the flow is sheet flow, this cannot easily be done; and
- If there was uncertainty regarding the way flow was entering the 2D domain, then for some length downstream of the input location in the 2D model there would likely be uncertainty regarding the validity of results. This was at cross-purposes, however, with the point of having split hydraulic/hydrological domains (i.e. minimising the hydraulic area).

It became apparent that not only could a 2D solution work, where rainfall was applied directly as rainfall excess to the hydraulic grid, but that it was far preferable to the initially proposed approach in that it better suited the study area and gave more accurate results. As such this revised methodology, which is elaborated upon further in the ensuing sections, was employed.

TUFLOW model calibration/validation was conducted using the 1989 and 2007 events. The calibrated/validated hydraulic model was then used to assess the flood levels for the 10%, 5%, 2%, 1%, 0.5% AEP and 2 and 5 year ARI and Probable Maximum Flood (PMF) design events. The established model was modified to represent a set of proposed mitigation options developed in consultation with study stakeholders. The impact of proposed options on flood behaviour was then assessed.

5. HYDROLOGIC MODELLING

5.1. Introduction

Applying direct rainfall in the hydraulic model has been adopted as the hydrological modelling approach in this study. In the direct rainfall approach, rainfall minus losses, is applied directly, as a depth, to grid cells in the 2D hydraulic model domain, which is then routed hydraulically.

This approach has many advantages over more traditional hydrological modelling techniques such as lumped conceptual modelling (RAFTS, RORB, WBNM etc). However, associated with this method are a number of potential pitfalls, which in order to avoid require stringent checking and an emphasis on the calibration and verification process.

Advantages of the direct rainfall approach are:

- There is no need to define sub-catchments. However, the catchment area (in total) needs to be defined;
- There are no storage routing exponents or other hydrological model specific parameters to establish/calibrate;
- Results are implicitly high resolution and spatial, i.e. readily mapped; and
- There is no need to define a location in the 2D hydraulic model where the hydrograph is to be applied and hence none of the typical issues with boundary conditions are required to be dealt with.

Disadvantages of the direct rainfall approach are:

- Applications tend to be far more complicated than standard hydrological modelling and with complication comes an increased potential to err;
- If the DTM exaggerates surface depression a significant portion of the rainfall volume may be retained in the catchment (de-facto losses) and hence downstream hydrographs are unrealistically small with respect to both peak flow and overall volume and also timing is late. It is noteworthy that all of these issues are non-conservative in design;
- Models can take a long time to run because of a large number of active (wet) grid cells;
- Stability can be an issue particularly when bathymetry is non-smooth; and
- Mass balance errors can occur.

Losses applied to the rainfall are discussed in the section below. However, other parameters which are relevant to the hydrology are also relevant to the 2D hydraulic model (through which they are implemented) and as such will be discussed in the hydraulic modelling section (Section 6).

5.2. Model Configuration

Preliminary modelling, in which test rainfalls were applied directly to a 5 m version of the model, found that the majority of water entering the aerodrome vicinity was doing so as dispersed sheet flow, not as concentrated gully/stream flow. The modelling approach was subsequently revised, and direct rainfall applied to the entire study area (Figure 4 shows the direct rainfall extent). The rainfall was applied to every cell in the model as opposed to concentrating it in low points. The rainfall was applied to the model as a rainfall vs time boundary. Initial and continuing losses were removed prior to the rainfall being applied to the model. Different rainfall hyetographs were applied depending on whether the area was classified as impervious or pervious (based on aerial photos).

5.3. Model Calibration

5.3.1. Calibration/Validation Losses

Two hydrologic model parameters were adjusted as part of the calibration process: initial and continuing losses.

The initial and continuing losses adopted for both the 1989 and 2007 events are presented in Table 5. Smaller initial losses were used for the 2007 as there had been rain the in the preceding days.

Table 5: Calibration Events - Losses

Event	Initial Loss (mm)	Continuing Loss (mm/h)
March 1989	5	2
November 2007	2	1

5.3.2. Design Losses

Losses used were chosen based on previous experience in western NSW and also taking into account the recommendations of Reference 3. The values used are an initial loss of 15 mm and a continuing loss of 2.5 mm per hour. No losses were applied to impervious surfaces.

5.3.3. Pervious/Impervious Surface Mapping

Losses were applied depending on whether the surface was classified as pervious or impervious. Impervious surfaces within the study area include roads, buildings and the airport runway. Pervious surfaces were anything not defined as being impervious ie. ground, and vegetated areas. Figure 7 shows the impervious and pervious regions.

6. HYDRAULIC MODEL CONFIGURATION AND CALIBRATION

6.1. Introduction

A model of the study area was developed in TUFLOW. TUFLOW is widely used in Australia and internationally for assessing flood behaviour and hydraulic hazard. TUFLOW is a finite difference numerical model which is capable of solving the depth averaged shallow water equations in both the one and two dimensional domains. The model consists of a 2D grid defining the ground elevations within the study area with 1D branches defining subgrid features including the pipe network, channels, culverts and the critical outflow subways. The extent of the TUFLOW model is defined by the study area boundary. The TUFLOW model configuration is shown in Figure 4 and Figure 5. The model extent is such that the downstream boundary conditions do not impact on the model results in the area of interest.

6.2. Build Elements

6.2.1. Model Grid

Preliminary runs, including calibration/validation runs were undertaken using a 5 m grid model informed by a 5 m DTM. The 5 m grid model took approximately 24 hours in order to run a five hour rainfall event. Given the long run times of the 5 m resolution, modelling of design and mitigation runs was undertaken using a 10 m grid cell model (informed by the same 5 m DTM). The 10 m resolution model's performance was significantly improved over the 5m resolution model whilst results remained the same.

6.2.2. Boundary Conditions

The TUFLOW model contains no upstream boundaries as no inflows were introduced to the model but instead were developed based on the direct rainfall approach.

The TUFLOW model downstream boundaries consist of:

- Two subways (the locations of which are shown in Figure 4). Each subway is modelled as a one-dimensional element and links to an upstream cell which is within the model domain. The downstream end of the subway is not connected to the 2D domain and therefore acts as an inlet controlled outflow from the model. This means that the subway has a capacity to discharge flow out of the model domain limited only by the inlet capacity of the subway. The subways were modelled as 1 m diameter and 50 m long pipes with a slope of 1%. Pipe dimensions came from field observations by the surveyors. The 50 m length is an estimate as is the 1% slope. Given that the subways are well downstream of the aerodrome and given that preliminary runs indicated that the canal is overtopped before water levels at the upstream end of the siphon backwater onto the aerodrome it was considered that exact subway representation would not be critical to the accuracy of model results;
- For larger events flow will overtop the levees of the channels at the downstream end of

the study area. As such a downstream water level boundary is also implemented on the downstream face of the eastern bank which defines the main irrigation channel (see yellow line in Figure 4). The average height of the eastern face of the main channel is approximately 125.5 mAHD. The boundary water level has been set at 124.5 mAHD. As such again the boundary is inlet controlled which is appropriate.

The boundaries as described above were used for all scenarios modelled barring the sensitivity runs which examined how aerodrome inundation is impacted by higher downstream water levels (which are likely to retard outflows). For the sensitivity runs (discussed further in Section 6.4) only the water levels downstream of the subways were changed (set at 1.5 mAHD above the subway downstream invert level).

6.2.3. Roughness

Roughness was assigned to the model domain on the basis of land use. Land use was interpreted using aerial photography supplied by Council. Various categories were defined and these were:

- Bitumen;
- Dense vegetation;
- Farms;
- Medium density vegetation;
- Sparse vegetation; and
- Buildings.

Roughness values used for the various land uses are shown both in Table 6 and Figure 6.

6.2.4. Implemented Structures

Various structures, as shown in Figure 4 and Figure 5, were incorporated into the 2D modelling domain. A list of structures included in the model is provided below:

- Two subways flowing beneath the main irrigation canal and the main outflow points for the study area;
- Pits and pipes for six south-north airstrip crossings (sub-surface);
- Various other assorted pipe/pits as shown on Figure 4; and
- The culvert crossing Remembrance Drive at the junction with Airport Road. This culvert transfers flow from east of Remembrance Drive to a drain (on south side of Old Aerodrome Road) which flows further west.

6.2.5. Breaklines

A number of significant hydraulic features, which are likely to impact on the flow behaviour, exist within the catchment. Hydraulic features are particularly important due to the flat nature of the topography through out much of the catchment. Breaklines were used throughout the study area in order to define hydraulic controls not well represented in the 5 m DTM used to inform the model grid.

Figure 4 depicts the breaklines utilised in the model. The key benefit of using the breakline is that high resolution height data for significant hydraulic features (such as levees as represented in the 1 m DTM) can be utilised in conjunction with the coarser 5 m DTM for modelling purposes.

Significant hydraulic features include:

- Dalton Park Racecourse;
- Speedway;
- Golf course;
- Remembrance Drive;
- Airport Road;
- Drain feature on southern side of Airport Rd;
- Irrigation canal at northern edge of study area;
- Levee/drain configuration to south of irrigation canal;
- Small open channels on perimeter of runway for collection/transfer of stormwater; and
- Levee on northern side of Airport Rd.

6.3. Model Calibration / Validation

Calibration is a key element of the modelling process but can be a challenge when there is a lack of data. During the calibration process, observed rainfall data is used as an input to the model. The model results are then compared to observed flood levels. In an application such as this key model parameters would be roughness and losses, and these are varied until there is reasonable agreement between the observations and model performance. In the calibration set the key deficiency is the lack of flood observations for the herein reported upon project. The interpreted depth/velocity observations from the November 2007 photo set are not accurate with respect to either location or magnitude.

Model calibration was nevertheless undertaken using data for the November 2007 event.

The final roughness values arrived at are shown in Table 6. These same factors were then used for hydraulic modelling of the design flood events. Note that typically in a calibration process the roughness is a key parameter which can be adjusted in order to achieve a match between observed and modelled flood events. The initial roughness values are informed by experience and reference to texts such as Chow (1959) and then manipulated in order to enhance the calibration. Due to the lack of data in this instance however this was not done. Instead roughness values remained as per initial settings. It is of interest to note that in this study, given the low flow velocities, the values used for roughness are less important than they might normally be, as flood flows of low velocity are relatively insensitive to roughness values used. Nevertheless the sensitivity of model results to values of roughness used was tested and this is reported on in the ensuing section.

Table 6: Adopted Manning's 'n' roughness values

Description	Manning's 'n' value
Roads and airport runway	0.02
Dense vegetation	0.08
Farms	0.06
Medium vegetation	0.06
Sparse vegetation or bare ground	0.04

6.4. Sensitivity Runs

Sensitivity runs are carried out in order to improve confidence in model results. If it can be shown that the selection of precise model parameter values has a lesser impact on model results then more confidence can be held in model predictions regardless perhaps of a lack of a full model calibration/validation process.

The two sensitivity runs undertaken examine the impact of changing the:

- Downstream tail water level at the model's boundary. The value used in all design runs is 124.5 mAHD. For the sensitivity runs this value was increased by 1.5 m; and
- Changing the applied roughness values. For the sensitivity runs the roughness values were increased by 20% on values as indicated in Table 6.

7. RESULTS

7.1. Calibration Results and Model Check

7.1.1. March 1989 Event

Model results (peak flood depth) for the 1989 event (for which no calibration data exists) are shown in Figure 8 and Figure 9. With no observed flood marks to compare results to little can be said about this event except that, in the modelling of it, certainly the result is comparable to what was generally observed to have occurred at the aerodrome during the event, i.e. widespread inundation.

7.1.2. November 2007 Event

Figure 10 and Figure 11 depict the peak flood depths for the November 2007 event and these are also summarised in Table 7. As stated previously the calibration data available for the November 2007 event are photographs. To aid the interpretation of results, the approximate photograph locations have been digitised and indicative depths and velocities estimated for these locations. Council staff then confirmed that the locations digitised by WMA were accurate. Estimated flood depths were then compared to the model results.

In general the modelled depths and velocities corresponded with the observed depths and indicative velocities supplied by Council. Where large discrepancies exist it may be that this is indicative of where the model omitted highly localised effects, for example, constrictions between buildings. The points at which the largest discrepancies exist are points 8, 16, 19 and 24 and for all of these points modelled depths are lower than estimates and also the velocity results are incongruous (fast moving flow is barely moving in the model). In such cases it may be that the model is unable to resolve localised impacts due to building blockage/constriction of flow paths.

Table 7: Comparison of Estimated Observed Depth and Modelled Depth -2007 Event

Photo Number	Estimated Observed Depth (m)	Modelled Depth (m)	Indicative Observed Velocity	Indicative Modelled Velocity (m/s)
1	Left side of photo – 0.2 - middle of road – 0.03	0.06	Fast Moving	0.60
2	0.15	0.09	slow moving	0.50
3	0.1	0.11	Fast Moving	0.41
4	0.1	0.15	Very Fast Moving	0.71
5	0.1	0.12	Slow Moving	0.34
6	0.2-0.3	0.13	Ponding -still	0.31
7	0.05-0.1	0.07	Fast moving	0.59
8	0.2	0.08	Fast moving	0.13
9	0.2-0.25	0.13	Slow Moving	0.56
10	0.2-0.3	0.21	Ponding -still	0.12
11	0.3	0.29	Very Fast Moving	0.47
12	0.3-0.35	0.24	Ponding	0.17
13	0.1-0.15	0.09	Fast moving	0.60
14	0.1-0.15	0.14	Slow moving	0.48
15	0.05-0.1	0.07	Slow moving	0.41
16	0.3-0.4	0.14	Slow Moving	0.28
17	0.1	0.18	Slow Moving	0.47
18	0.15-0.2	0.15	Slow Moving	0.23
19	0.2	0.05	Fast Moving	0.06
20	0.1	0.03	Slow moving	0.07
21	0.1-0.15	0.15	Fast moving	0.53
22	0.2	0.11	Slow Moving	0.47
23	0.1	0.07	Slow moving	0.33
24	0.25	0.10	Ponding	0.28
25	0.1	0.15	Slow moving	0.21
26	0.1-0.15	0.11	Slow Moving	0.52

7.1.3. Mass Balance Check

To improve confidence in the model results a mass balance has been carried out in which all volumetric inputs to the model (rainfall, initial water level etc) are compared to all volumetric outputs of the model (outlet discharge, and standing water at end of simulation). Agreement of within ±10% (i.e. 10% mass is created/lost) is typically considered acceptable.

The mass balance check was carried out for the 1% AEP 1 hour event, although the model was run for eight hours in total in order to allow some water to drain out of the modeol. Run statistics are provided below which demonstrate that the mass balance check verifies that the model is running in a stable fashion.

Inputs:

Inflow Total = 386,785 m^3

Outputs:

Outflow Total = 279,711 m^3 (72.3% of inflow)

Total volume of water in model after eight hours run time = 106,673 m^3 (27.6% of inflow)

Error:

$$Error = \frac{Inflow - Outlow}{Inflow} \times 100 = 0.1\%$$

Note the flow remaining in the model is collected around the downstream canal and to some degree is a function of the fact that the aerodrome drainage system is not actually connected to the downstream "boundary" except for large overtopping flows. As such it is expected that a relatively large volume of water should remain in the model at the end of the run.

7.2. Design Flood Results

7.2.1. Verification of Model Results

In an attempt to improve confidence in results the 1% AEP peak flow for the 10.7 km^2 catchment was estimated using the Probabilistic Rational Method from Australian Rainfall and Runoff (2001). Whilst the PRM is not applicable to a location as far west in NSW as Griffith the hope was that it would provide some context for model results. The calculated 1% AEP peak flow (based on the PRM) is 17 m^3/s whilst the modelled peak flow for the 1% AEP event (taken at the runway) is 42 m^3/s. Comment is made on the comparison in Section 8.

7.2.2. Sensitivity Testing

Sensitivity results shown below in Table 8 indicate that:

- Model results at the aerodrome are insensitive to the amount of flow moving through the subways. An increase in tail water at the subways, which would have resulted in less discharge through the subways for a given upstream water level, did not change flood depth results at the sample point locations; and
- Model results at the sample point locations are highly insensitive to roughness settings and this is expected given the very low velocity of the flow.

Both results increase confidence in the accuracy of the results.

Table 8: Sensitivity Results for the 1% AEP event

ID #	Surveyed Floor Level (mAHD)	1% AEP Event Flood Depth (m)	High Tail Water[2] Flood Depth (m)	Impact (m)	High Roughness[3] Flood Depth (m)	Impact (m)
1E	133.09	0.04	0.04	0.00	0.04	0.00
1W	133.00	0.07	0.07	0.00	0.06	0.00
2	133.09	0.09	0.09	0.00	0.09	0.00
3	133.02	0.10	0.10	0.00	0.10	0.00
4	133.12	0.14	0.14	0.00	0.14	0.00
5	133.08	0.20	0.20	0.00	0.20	0.01
6	133.10	0.18	0.18	0.00	0.19	0.01
7	133.36	0.19	0.19	0.00	0.19	0.01
8	133.24	0.19	0.19	0.00	0.20	0.01
9	133.36	0.07	0.07	0.00	0.07	0.00
10	131.89	0.10	0.10	0.00	0.10	0.00
11	132.63	0.03	0.03	0.00	0.04	0.01
12	132.66	0.03	0.03	0.00	0.04	0.01
13	133.14	0.03	0.03	0.00	0.03	0.00
14	133.75	0.01	0.01	0.00	0.01	0.00
15	133.59	0.10	0.10	0.00	0.10	0.00
16	133.67	0.05	0.05	0.00	0.05	0.00
17	133.31	0.02	0.02	0.00	0.02	0.00
18	133.19	0.11	0.11	0.00	0.11	0.00
19	132.66	0.04	0.04	0.00	0.05	0.01
20	132.80	0.02	0.02	0.00	0.03	0.01
21	132.59	0.03	0.03	0.00	0.03	0.00
22	132.39	0.00	0.00	0.00	0.00	0.00
23	131.96	0.03	0.03	0.00	0.03	0.00
24	131.79	0.04	0.04	0.00	0.04	0.00
25	131.90	0.08	0.08	0.00	0.08	-0.01
26	133.48	0.09	0.09	0.00	0.09	0.00
27	133.48	0.06	0.06	0.00	0.06	0.00
28	132.00	0.00	0.00	0.00	0.00	0.00
29	129.94	0.17	0.17	0.00	0.17	0.00

7.2.3. Design Results

All durations (15 minute to 72 hour) were run and the 60 minute storm was found to be critical for all modelled events except for the PMF, for which the critical duration was found to be 30 minutes.

Peak depth maps for the 2Y ARI, 5Y ARI, 10%, 5%, 2% and 1% AEP events are presented in Figure 12 to Figure 17. Figure 18 shows the hazard for the 1% AEP event and the provisional

---

[2] Tail water level increased by 1.5 m
[3] Roughness increased by 20%

hydraulic categories are shown in Figure 19. Figure 20 shows the 0.5% AEP flood depth and the same is then shown in Figure 21 for the PMF.

Further, in order to more readily compare the results, Table 9 presents flood depths for a variety of events at aerodrome buildings. To find the location of the points correlate the ID # with the point on Figure 3.

7.3. Damages

7.3.1. Introduction

Flood damages estimates are typically used in benefit cost ratio analysis for proposed mitigation works in order to assess the viability of the works and it is for this purpose that flood damages are to be assessed in this study.

Typically flood damages are calculated for residential property as it tends to be the protection of residential property that is the primary focus of flood mitigation works funded under state and commonwealth flood mitigation programs. In this case however some quite specialised assets/property are flood liable and as such the calculation of flood damage becomes more complex and perhaps less certain than it might be in other projects.

Also this case is complicated by the centrality of the aerodrome to the region. The aerodrome's business activities, particularly with respect to the facilitation of domestic air travel, are integrated into other local businesses activities. Another complication of the damages costing is the fact that the runway provides essential services which can be difficult to quantify in monetary terms and an example of such a service is emergency medical access.

7.3.2. Key Aerodrome Assets Assessed

The damages assessment is undertaken for a total of 29 "assets". The majority of these are buildings on the aerodrome used by a variety of tenants for a variety of commercial/recreational purposes. Two facilities to be distinguished from the other "assets" are the airport terminal building and the runway.

Table 9: Flood Depths at Aerodrome Buildings for Various Design Events

		Flooding Depth (m)									
		ARI Event		AEP Event							
ID #	**Floor Level (mAHD)**	**2Y**	**5Y**	**10%**	**5%**	**2%**	**1%**	**0.5%**	**PMF**	**2007**	**1989**
1E	133.09	0.02	0.02	0.03	0.03	0.04	0.04	0.05	0.29	0.03	0.02
1W	133.00	0.02	0.03	0.05	0.06	0.06	0.07	0.08	0.32	0.04	0.03
2	133.09	0.02	0.04	0.07	0.07	0.08	0.09	0.10	0.36	0.05	0.04
3	133.02	0.01	0.03	0.08	0.09	0.09	0.10	0.12	0.43	0.06	0.03
4	133.12	0.01	0.04	0.10	0.11	0.12	0.14	0.16	0.47	0.09	0.05
5	133.08	0.04	0.08	0.16	0.17	0.18	0.20	0.22	0.57	0.14	0.10
6	133.10	0.03	0.08	0.14	0.16	0.17	0.18	0.21	0.55	0.12	0.09
7	133.36	0.03	0.06	0.15	0.16	0.17	0.19	0.21	0.58	0.13	0.09
8	133.24	0.02	0.07	0.15	0.16	0.18	0.19	0.22	0.55	0.13	0.10
9	133.36	0.00	0.02	0.03	0.04	0.06	0.07	0.08	0.35	0.03	0.02
10	131.89	0.04	0.05	0.08	0.08	0.09	0.10	0.11	0.34	0.07	0.06
11	132.63	0.01	0.02	0.02	0.02	0.03	0.03	0.05	0.37	0.02	0.02
12	132.66	0.01	0.01	0.02	0.02	0.03	0.03	0.05	0.33	0.02	0.01
13	133.14	0.01	0.02	0.02	0.02	0.02	0.03	0.04	0.37	0.02	0.02
14	133.75	0.00	0.00	0.00	0	0	0.01	0.02	0.32	0.00	0.00
15	133.59	0.04	0.05	0.07	0.08	0.09	0.10	0.12	0.48	0.06	0.06
16	133.67	0.02	0.02	0.03	0.04	0.04	0.05	0.07	0.41	0.03	0.03
17	133.31	0.00	0.00	0.00	0.01	0.01	0.02	0.03	0.30	0.00	0.00
18	133.19	0.05	0.06	0.09	0.09	0.1	0.11	0.12	0.39	0.07	0.07
19	132.66	0.01	0.01	0.02	0.03	0.03	0.04	0.06	0.38	0.01	0.01
20	132.80	0.01	0.01	0.01	0.02	0.02	0.02	0.04	0.29	0.01	0.01
21	132.59	0.01	0.01	0.02	0.02	0.03	0.03	0.04	0.35	0.02	0.02
22	132.39	0.00	0.00	0.00	0	0	0.00	0.00	0.24	0.00	0.00
23	131.96	0.01	0.01	0.02	0.02	0.02	0.03	0.03	0.28	0.02	0.01
24	131.79	0.00	0.01	0.02	0.02	0.03	0.04	0.06	0.45	0.01	0.01
25	131.90	0.01	0.02	0.06	0.07	0.07	0.08	0.10	0.46	0.05	0.03
26	133.48	0.04	0.05	0.08	0.09	0.09	0.09	0.10	0.29	0.07	0.06
27	133.48	0.03	0.04	0.05	0.05	0.05	0.06	0.06	0.25	0.04	0.04
28	132.00	0.00	0.00	0.00	0	0	0.00	0.00	0.11	0.00	0.00
29	129.94	0.05	0.09	0.14	0.15	0.16	0.17	0.19	0.48	0.13	0.10
MEAN	**132.81**	**0.02**	**0.03**	**0.06**	**0.06**	**0.07**	**0.08**	**0.09**	**0.38**	**0.05**	**0.04**

In order to ascertain what type of damage was likely to occur should unheralded significant flooding occur at the aerodrome, a number of aerodrome tenants were telephoned and subjected to a questionnaire. An example of the questionnaire is shown below in Table 10.

The survey process found that the financial risk for aerodrome tenants, due to flooding, was small. Most respondents, when asked to reflect on what might be inundated in the event of flooding, could not identify any particular high value assets at risk. The main response consisted of small power generators, welders and computers. Aircraft were also mentioned however given that flood depths on the aerodrome are shallow (and velocities low) no damage to these could be expected in anything but the largest of flood events.

Besides the commercial properties on the aerodrome and their contents the other chief asset is the runway. There are two aspects to the runway in the damage calculation. The first is the runway as a tangible asset with a replacement value and also repair costs. The second is the runway as the chief element of a functioning aerodrome which is a commercial entity as well as a vital community service. Pin pointing the exact value of the runway, based on the second perspective, is difficult, as it involves the affixing of monetary value to intangibles such as safety and also because it involves quantifying the multiplier impact of aerodrome activities with respect to the local economy. Regardless of the difficulty however an estimate is required to be made for utilisation in damage calculations.

Table 10: Example Damages Questionnaire

Questionaire for airport users		
	Name	Joe Smith
	Company	Flying Company
	Address/Hanger location	PO Box 666
	Contact details	NA
	Questions	Answers
1	What type of business?	Agricultural Spraying
2	What type of equipment is in the building?	Planes, 4 PC's, chemicals on racks, Welders (x3), Tools
3	What is the building floor area?	60 sq meters
4	How long have you been in this building?	15 years
5	Have you been flooded before? If so when?	8/9 years and had no flooding
6	If you have been flooded before how deep was the water and do you have a photo/flood mark?	x
7	If you have been flooded before what was the estimated damage cost	x
8	How much do you estimate damages at if you were flooded to 0.1m or 0.5m?	Computers/ Electrical Equipment (0.5m delay)
9	If you were given warning could you get some items up off the floor	Yes
10	How many hours a day is someone in the building? And what times?	6am - 9pm sometimes. Seasonal. Usually someone

Given the very low depths of flooding experienced on the aerodrome, and the very small changes in modelled depth for large changes in event probability, the damages assessment will not utilise relationships based on depth. Rather lump sum values will be used in the estimation process. This is appropriate as the damages to a hangar are unlikely to vary for a flood with a depth of 0.10 m versus 0.15 m.

7.3.3. Damages Assessment Assumptions

For the assessment it is assumed an inundation event occurs as soon as the modelled depth exceeds 0.00 m. Although it may be argued that an inundation depth of 0.01 m indicates very minor inundation wave action caused by vehicles etc may exacerbate such levels.

The cost of damages to any hangar inundated are estimated to be $25,000. This is based on the survey and the assumption that inundation will result in damages to computer assets, generators and welding equipment and cause at least one week's loss of operations.

The cost of runway damage, from a repair perspective, is assumed to be $30,000, per inundation event.

The cost of runway damage, from an interruption to aerodrome activities perspective, is assumed to be $200,000. This presumes that the value of the runway to the local economy is $10,000,000 per year and that an inundation event results in a lost week of operations.

8. DISCUSSION

8.1. Calibration

The calibration data available is limited and as such the calibration/validation process in this study is necessarily augmented. A lack of calibration data for such a site is typical, particularly since the catchment is relatively free from residents. With the data that was available however a check has been made and it appears that the results strongly correlate to the observed behaviour. This is particularly the case near the end of Remembrance Drive, the location from which flood flows tend to move into the aerodrome, i.e. the modelled behaviour strongly matches observations of typical flood behaviour at the site.

The attempt to check the peak flow for the site identified in the modelling via PRM calculation is not successful. It may be that the shape of the catchment, which approximates a semi-circle, tends to accentuate the peak flow. Certainly, whilst it is normal for flow from a partially developed area to exceed the flow from a PRM estimate since the PRM estimate is meant for "rural" or undeveloped areas, having the modelled peak flow exceed the PRM estimate by a factor of 2.5 was unexpected. Given that the PRM is not applicable so far west the comparison does have less validity than it otherwise might.

8.2. Mass Balance Check

The mass balance check indicates that the model is running in a stable fashion and flood results indicated in plots are certainly not exaggerated or underestimated due to mass loss/generation. As stated previously the fact that approximately 25% of the applied input is left on the grid at the end of the run is not alarming as aerodrome drainage is not connected (sub-surface) to any outlet and so flow can only leave the model domain by flowing over downstream roads and through the subway or over the canal.

8.3. Design Flood Results

Results indicate then that buildings on the aerodrome are inundated in all modelled events, albeit not to any great depth. Mean depth is 0.02 m in the case of the 2Y ARI event and 0.10 m in the case of the 0.5% AEP event. This change in inundation depth between an event expected to happen once every two years (on average) and the other which is expected to happen once every 200 years (on average) is indicative of the topography at the aerodrome. Large expanses of flat area mean that for an increased quantity of runoff the increase in flood depth is minimal.

From Figure 3 it can be seen that ID number 24 corresponds to the airport terminal and Table 9 above indicates that the floor level at the terminal is 131.79 mAHD. Results indicate that the airport terminal will be inundated in all modelled events except the 2 year ARI event, albeit to very shallow depths (depth in the 1% AEP event is 0.04 m).

The velocity of the flow is generally low and this result is best seen in the hazard map (Figure 18) which indicates that all areas of the study area experience low hazard flood flow only during the 1% AEP event.

Figure 17 shows the flood extent for the 1% AEP event as well as the depth. What is also shown is the amount of flow (peak flow in m^3/s) at different locations in the study area. So for example it is indicated in Figure 17 that immediately upstream of the speedway 10 m^3/s is flowing in the watercourse which lies on the eastern side of Remembrance Drive.

Figure 17 is useful as it describes succinctly the challenge that exists in devising mitigation schemes which might keep the aerodrome flood free for all but events in excess of, for example, the 1% AEP event. The challenge is that 30 m^3/s is flowing into an approximately 200 m wide space the centre of which is approximated by the location of the intersection between Remembrance Drive and Old Aerodrome Road. Either ensuring that the flow never arrives, diverting it once it does arrive or adapting to being flood liable are the mitigation options that seem relevant in this instance. This issue is further discussed in Section 9.

Figure 18 presents the hazard categorization of 1% AEP design flood results for the aerodrome. The criteria used to generate the plot is that criteria given in Reference 4. The noteworthy result is of course that very little high hazard flow exists on the aerodrome (restricted to deeper areas of the downstream drainage system). This result is down to the shallowness of the flow as well as the lack of slope on the aerodrome and hence flow velocity.

Figure 19 presents the hydraulic categorisations for the 1% AEP design result. Hydraulic categories defined are floodway (red) and flood storage (green). Each of these categories is defined by the criteria as found in Reference 4 and further explained below:

- Flood ways are defined as those drainage elements that convey a large proportion of the flow and in which blocking would cause significant re-distribution of flow. Areas defined as flood ways in Figure 19 include the drain running parallel to Old Aerodrome Road (on the southern side), the drains that convey flow from the aerodrome to the north and through the irrigation canal, and the main flow path parallel to Remembrance Drive; and
- Flood storage areas are defined in Reference 4 as being those areas outside flood ways which if completely filled may cause significant flood afflux and an increase in the downstream flow magnitude. In the case of Figure 19 flood storage areas are defined as being those areas which are within the 1% flood extent but which are not classified as floodway.

9. MITIGATION MEASURES

9.1. Introduction

Results shown in the attached figures and also in Section 7.2 and Table 9 indicate the flood liability of the aerodrome. In all modelled design events buildings are inundated to varying depths (including the runway) and for events larger than the 10% AEP flow is crossing the runway. As such, Griffith Aerodrome is flood liable and requires some form of flood mitigation in order to relieve its' flood liability or works to, at the very least, protect critical property/infrastructure from regular inundation. A key issue is the runway tarmac as flood damage to this could be costly as well as causing significant disruption to aerodrome operations.

As briefly discussed in Section 8.3 the main issue is well highlighted by Figure 17 which shows that approximately 30 m^3/s (in the 1% AEP event) flows into the aerodrome at approximately the location of the intersection of Remembrance Drive and Old Aerodrome Road. Immediate mitigation options which suggest themselves are retardation and diversion. These mitigation elements and alternatives are discussed below.

9.2. Retardation

A common solution to flooding is to retain flow upstream, that is, to use a retardation pond. A retardation pond will ideally fill with flood waters and then release a relatively small flow over an extended period of time, greatly reducing the downstream peak flow as well as flood volume. As identified during the site visit for this study, there are some existing basins upstream of the aerodrome, particularly on the drainage line which runs approximately parallel to Remembrance Drive on the eastern side. Note that the existing basins are detention basins in that the outlet is elevated (at top water level) and the basins will, following an event, empty slowly through seepage and evaporation.

There are two significant issues with implementing retardation as a mitigation solution for Griffith Aerodrome. The first issue is providing, cost effectively, an appropriate amount of retardation volume. The second issue is that flow entering the aerodrome is not overly concentrated. In some areas it is in fact sheet flow. As such in order to capture a good portion of the overall volume, further earth works may be required in order to direct flow into the basin or alternatively many basins will need to be built.

Possible options include:

- Utilising existing basins on the eastern side of Remembrance Drive more effectively and formalising their role in the stormwater system;
- Building a number of basins within the Golf Course grounds; and
- Retrofitting retardation basins into the Dalton Park and Speedway locations.

In testing the retardation basin strategy it will be necessary to run longer duration design events, in order to test volume issues adequately, and also it will be necessary to make some assumption regarding the starting volume of the basins. Assuming that the retardation basins are free draining (can empty without need for pumping over a 24 hour period) it will be suitable to assume that the basins are empty at the beginning of the design flood event.

Some preliminary calculations find that 100,000 m^3 of volume (equates to approximately half of the volume moving into the aerodrome during the 1% AEP event) can be obtained by a series of 20 retarding basins which are 60 m square, and have a mean depth of 1.25 m. The total area required will be approximately 11 ha.

In summary retarding the flood flow can be an effective measure in many instances, particular when the focus of the flood behaviour is a downstream area. The volume that is required to be retained in this instance, for the 1% AEP event, is relatively large and will necessitate some extensive and expensive capital works as well potentially significant easement/land purchases. Should Council wish to pursue this mitigation element the following work will be required:

- Identify sites for basins which are suitable with respect to
    - Location (proximity to water course as well as potential storage capacity);
    - Availability; and
    - Cost.
- Make a decision as to the goal flood protection level, i.e. the 1% AEP event or other smaller event;
- Run the model for the desired AEP event for all durations, analyse and present results and then report.

For the first of these work items WMA can identify the flow paths that these basins should lie on. As to land availability and cost issues it may be best for Council/DECCW to address these. The design AEP can be selected by Council/DECCW and certainly WMAwater can, if Council wish, provide advice in this regard.

9.3. Diversion

Diversion as a mitigation strategy would seek to push flood waters away from the aerodrome and to an alternative location which will not be overly impacted by the diverted flow. The water required to be diverted is that flow coming from the golf course and down Remembrance Drive and in the 1% AEP event this amounts to a peak flow of 30 m^3/s.

To convey a peak discharge of 30 m^3 will require a square shaped 10 m wide channel flowing at a depth of 1 m with a bed slope of 1%. Additionally delivering 30 m^3/s to the intersection of Old Aerodrome Road and Kalinda Street may require ongoing downstream capital works in order to convey the flows without exacerbating existing flooding issues.

A strategy which employed retardation in conjunction with diversion may prove to be the most desirable solution.

9.4. Alternative Mitigation Strategies

An alternative, or perhaps complementary activity, to upstream works which seek to divert or detain flood waters, are works which seek to minimise the harm of the floodwaters to the aerodrome. The very nature of the flooding at the aerodrome, which is low hazard non-concentrated dispersed flow, lends itself to passive strategies of coping with the flood waters. Works might include the following:

- Formalising drainage paths through the airport in order to control which areas become inundated;
- Creating a higher capacity pipe and open channel system to drain the aerodrome so that flooding does not persist. A key point would be connecting this system to the subway that flows beneath the main canal. Note that the current drainage system for the runway runs to an infiltration basin upstream of the canal[4];
- Creating a system of bunds that protect properties, but not access routes, from floods up to the 1% AEP flood event; and
- Focus development at the Aerodrome on maintaining levels of flood storage.

Low bunds can be used on the site because flood depths are relatively low for the 1% AEP event at a mean peak depth of 0.08 m and maximum peak depth, at one of the buildings, of 0.20 m. Velocities are also low with a mean value of approximately 0.3 m/s and a peak value of 0.8 m/s (see Table 7).

9.5. Mitigation Run A

Mitigation options have been developed in conjunction with the study stakeholders and tested via the established hydraulic model. Run A consists of the following options (locations are pointed out in Figure 22) :

- A 1 m high levee (relative to surrounding ground levels) at the southern/south-east side of the airport terminal which functions as a retardation basin. The capacity of this is approximately 25,000 m^3;
- A four fold increase in the capacity of the culvert which flows beneath Remembrance Drive immediately south of the intersection with Old Aerodrome Road; and
- A diversion channel which runs along the existing alignment of a swale on the southern side of Old Aerodrome Road. The diversion channel has a width of 10 m and a depth, relative to existing ground height, of 1 m.

Figure 22 shows the flood extent and depth for Run A. As can be seen, the works have not prevented inundation at the aerodrome (also see Table 11 below).

---

[4] As this is an important point it must be highlighted, i.e. current drainage arrangements for the aerodrome mean that runoff collected in the drainage channel to the north of the runway will be detained upstream of a minor dirt road which is itself approximately 100 m upstream of the Main Canal.

Table 11: Mitigation Impact for Aerodrome Buildings

ID #	Surveyed Floor Level	1% AEP Event	1% Mitigation Option A	Impact[5]
	(mAHD)	Flood Depth (m)	Flood Depth (m)	(m)
1E	133.09	0.04	0.02	0.02
1W	133.00	0.07	0.05	0.02
2	133.09	0.09	0.14	-0.05
3	133.02	0.10	0.15	-0.05
4	133.12	0.14	0.19	-0.05
5	133.08	0.20	0.24	-0.04
6	133.10	0.18	0.21	-0.03
7	133.36	0.19	0.21	-0.03
8	133.24	0.19	0.21	-0.02
9	133.36	0.07	0.03	0.03
10	131.89	0.10	0.10	0.00
11	132.63	0.03	0.07	-0.04
12	132.66	0.03	0.03	0.00
13	133.14	0.03	0.05	-0.02
14	133.75	0.01	0.01	-0.01
15	133.59	0.10	0.04	0.06
16	133.67	0.05	0.02	0.03
17	133.31	0.02	0.01	0.00
18	133.19	0.11	0.10	0.01
19	132.66	0.04	0.02	0.03
20	132.80	0.02	0.06	-0.03
21	132.59	0.03	0.02	0.01
22	132.39	0.00	0.01	-0.01
23	131.96	0.03	0.05	-0.03
24	131.79	0.04	0.02	0.02
25	131.90	0.08	0.07	0.02
26	133.48	0.09	0.04	0.06
27	133.48	0.06	0.02	0.03
28	132.00	0.00	0.02	-0.02
29	129.94	0.17	0.20	-0.03

In viewing the above results it can be seen that due to the mitigation works there has been a redistribution of flows which has in some cases caused flood levels to increase. One of the chief elements of this redistribution is the levee implemented at the northern edge of the Golf Course. This has forced more water toward Remembrance Drive and then increased the flow moving from the vicinity of Remembrance Drive into the aerodrome itself. This shows that if more water is to be pushed towards Remembrance Drive that it is important to ensure that there is capacity at Remembrance Drive to take this water somewhere else other than the aerodrome, otherwise

[5] A positive impact denotes a reduction in peak flood level due to the mitigation work whilst a negative impact indicates that the flood depth has actually increased. Note a flood depth increase will result due to a redistribution of flood flows.

building inundation may be exacerbated. It also demonstrates the inadequacy of the approximately 25,000 m^3 storage at the south east corner of the aerodrome in Run A and the need to raise Remembrance Drive at the intersection of Old Aerodrome Road in order to ensure flow is diverted to the west and the improved drain effectively.

10. CONCLUSIONS

Either further mitigation works are considered for implementation, including potentially expensive capital works, and/or the design standard of flood protection works must be reduced. This is a decision for Council and DECCW with WMAwater being available to provide input as required.

Options which are recommended for further runs are as follows:

- Adopt a design standard for flood works which puts the focus on nuisance flooding alone, i.e. the two and five year ARI events for example;
- Implement retardation basins downstream of Pioneer Park, on the golf course, at the speedway and to the south east of the airport terminal building;
- Implement the diversion channel along the southern side of Old Aerodrome Road;
- Formalise flow paths through the aerodrome and implement bunds to protect buildings from inundation; and
- Improve drainage from the aerodrome site to reduce the duration of flooding, including an improvement of drainage on the western end of the runway where extension works have recently been completed.

11. ACKNOWLEDGEMENTS

This study was carried out by WMAwater and funded by Griffith City Council and the Department of Environment, Climate Change and Water. The assistance of the following in providing data and guidance to the study is gratefully acknowledged:

- Griffith City Council; and
- Department of Environment, Climate Change and Water.

12. REFERENCES

1. Water Studies Pty Ltd. Griffith Flood Study, June 1992.

2. Patterson Britton and Partners. Griffith Flood Study, August 2006. Issue No. 3.

3. Pilgrim H (Editor in Chief), Australian Rainfall and Runoff – A Guide to Flood Estimation Institution of Engineers, Australia, 1987.

4. NSW Government. Floodplain Development Manual, 2005.

Figures

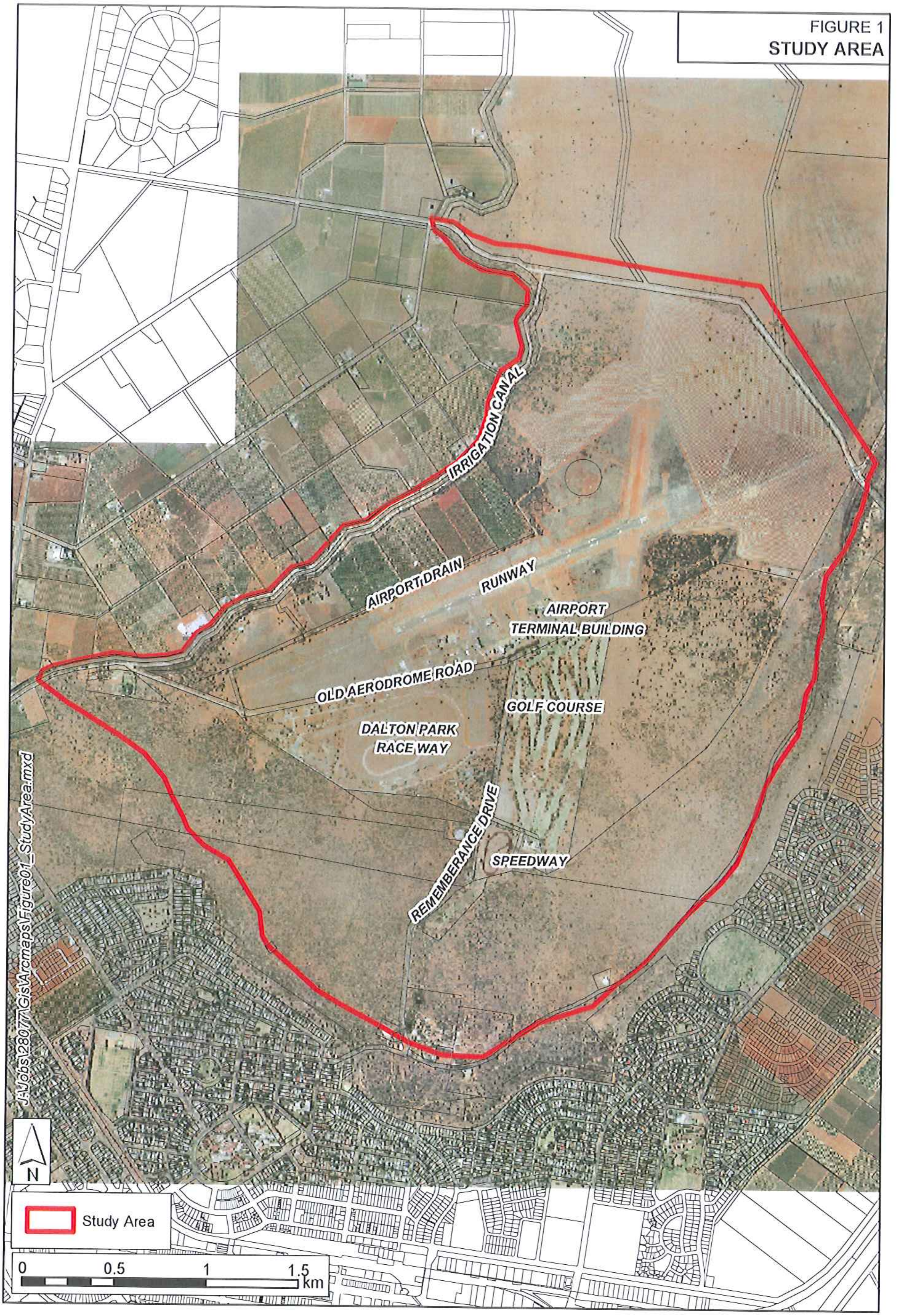
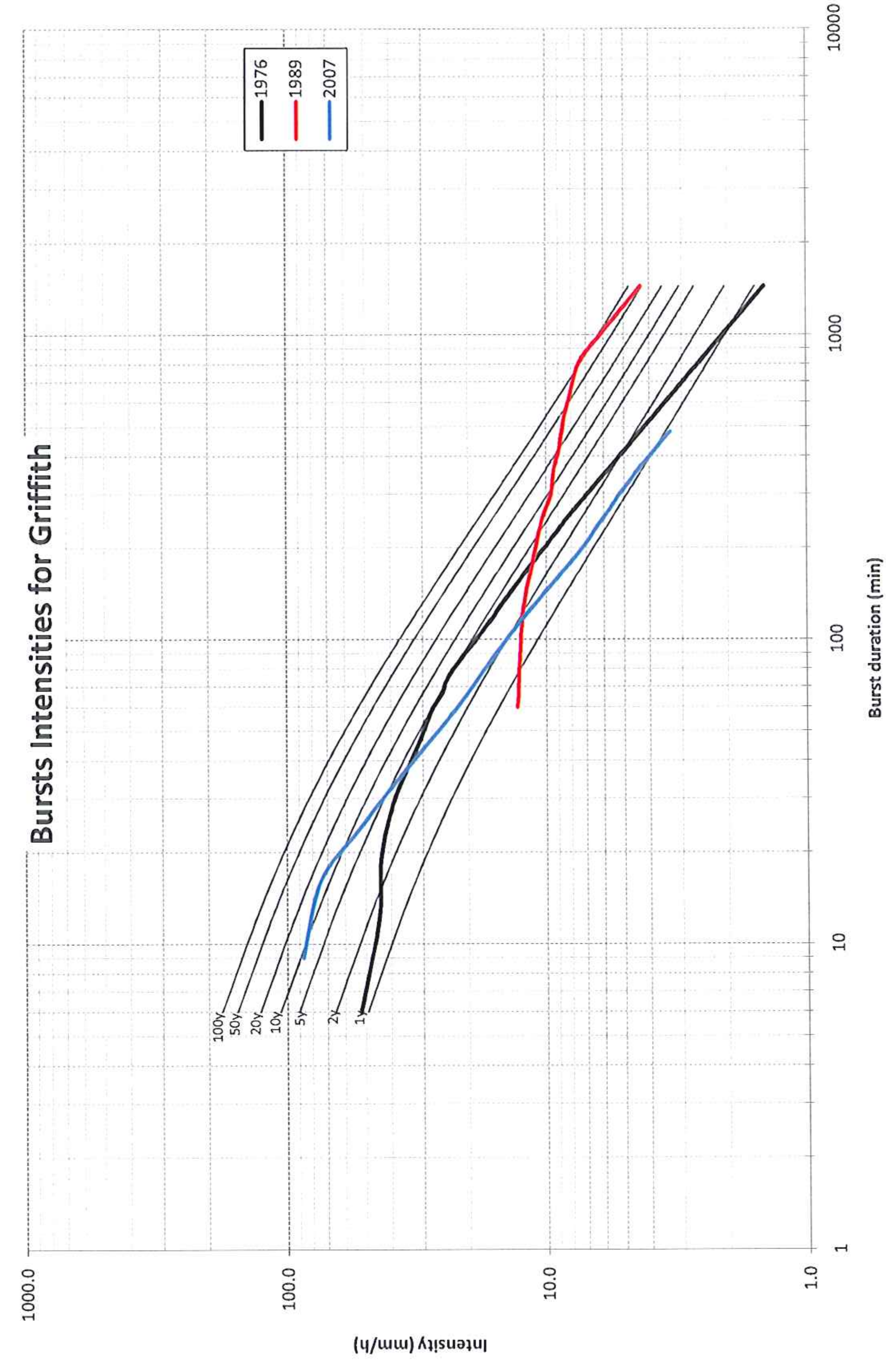


FIGURE 1
STUDY AREA
IRRIGATION CANAL
AIRPORT DRAIN
RUNWAY
AIRPORT
TERMINAL BUILDING
OLD AERODROME ROAD
GOLF COURSE
DALTON PARK
RACE WAY
REMEMBERANCE DRIVE
SPEEDWAY
J:\Jobs\28077\Gis\Arcmaps\Figure01_StudyArea.mxd
N
Study Area
0
0.5
1
1.5
km

FIGURE 2
IFD PLOT OF OBSERVED EVENT RAINFALL



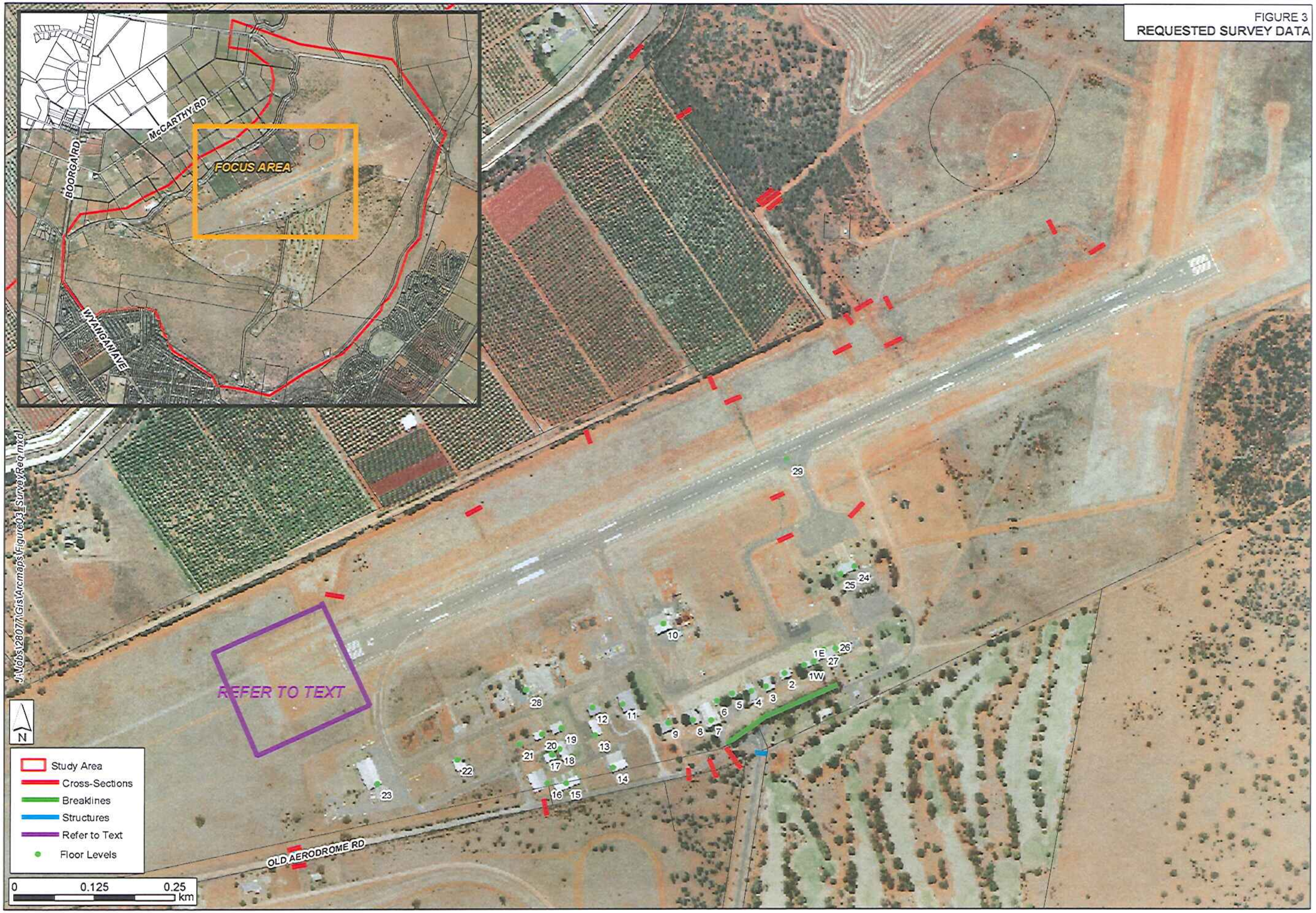


FIGURE 3
REQUESTED SURVEY DATA
McCARTHY RD
BOORGA RD
WYANGAN AVE
FOCUS AREA
REFER TO TEXT
OLD AERODROME RD
1E
1W
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
Study Area
Cross-Sections
Breaklines
Structures
Refer to Text
Floor Levels
0
0.125
0.25
km
N
J:\Jobs\128077\Gis\Arcmaps\Figure03_SurveyReq.mxd

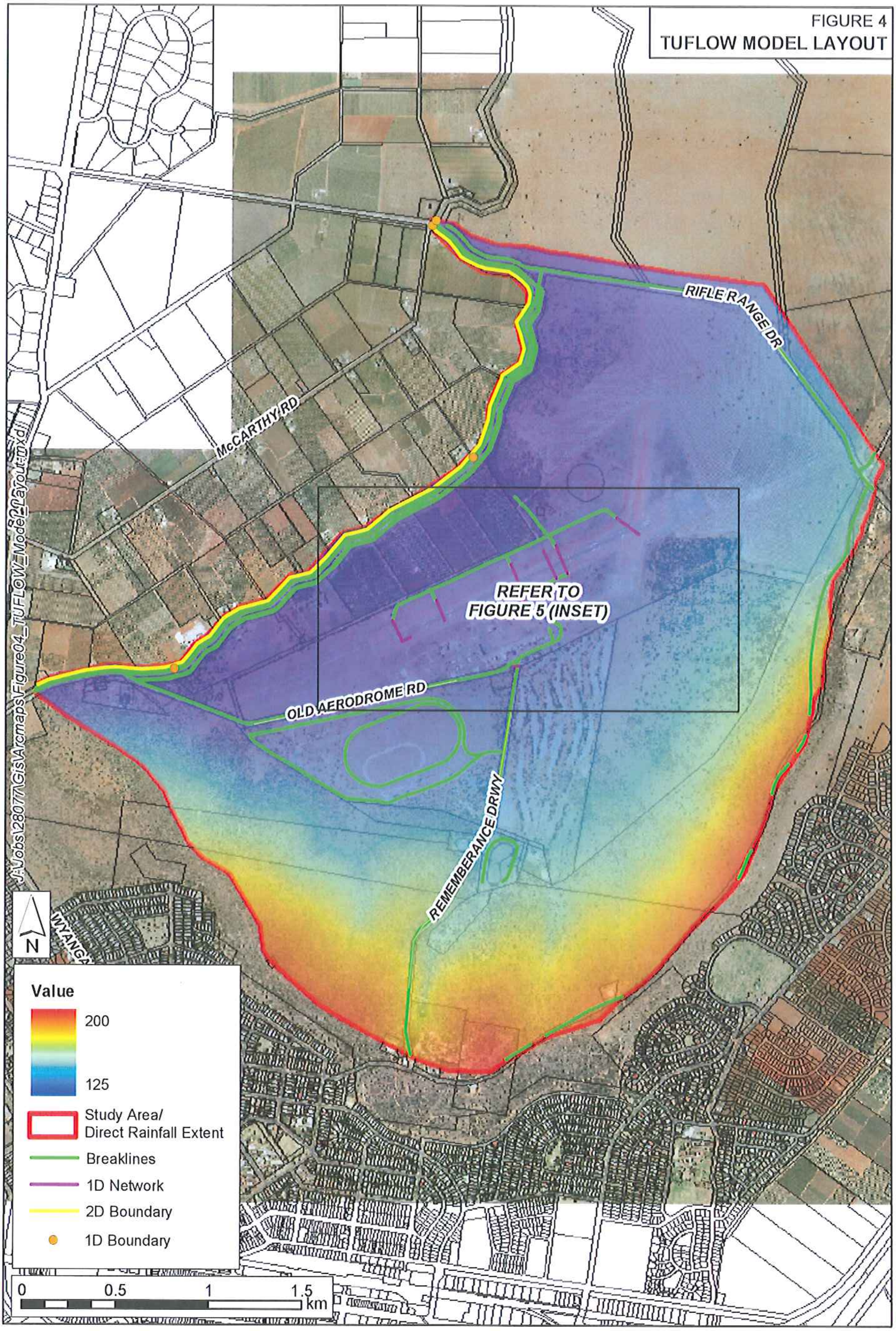


FIGURE 4
TUFLOW MODEL LAYOUT
RIFLE RANGE DR
McCARTHY RD
REFER TO
FIGURE 5 (INSET)
OLD AERODROME RD
REMEMBERANCE DRWY
J:\Jobs\128077\Gis\Arcmaps\Figure04_TUFLOW_Model_Layout.mxd
N
Value
200
125
Study Area/
Direct Rainfall Extent
Breaklines
1D Network
2D Boundary
1D Boundary
0
0.5
1
1.5
km

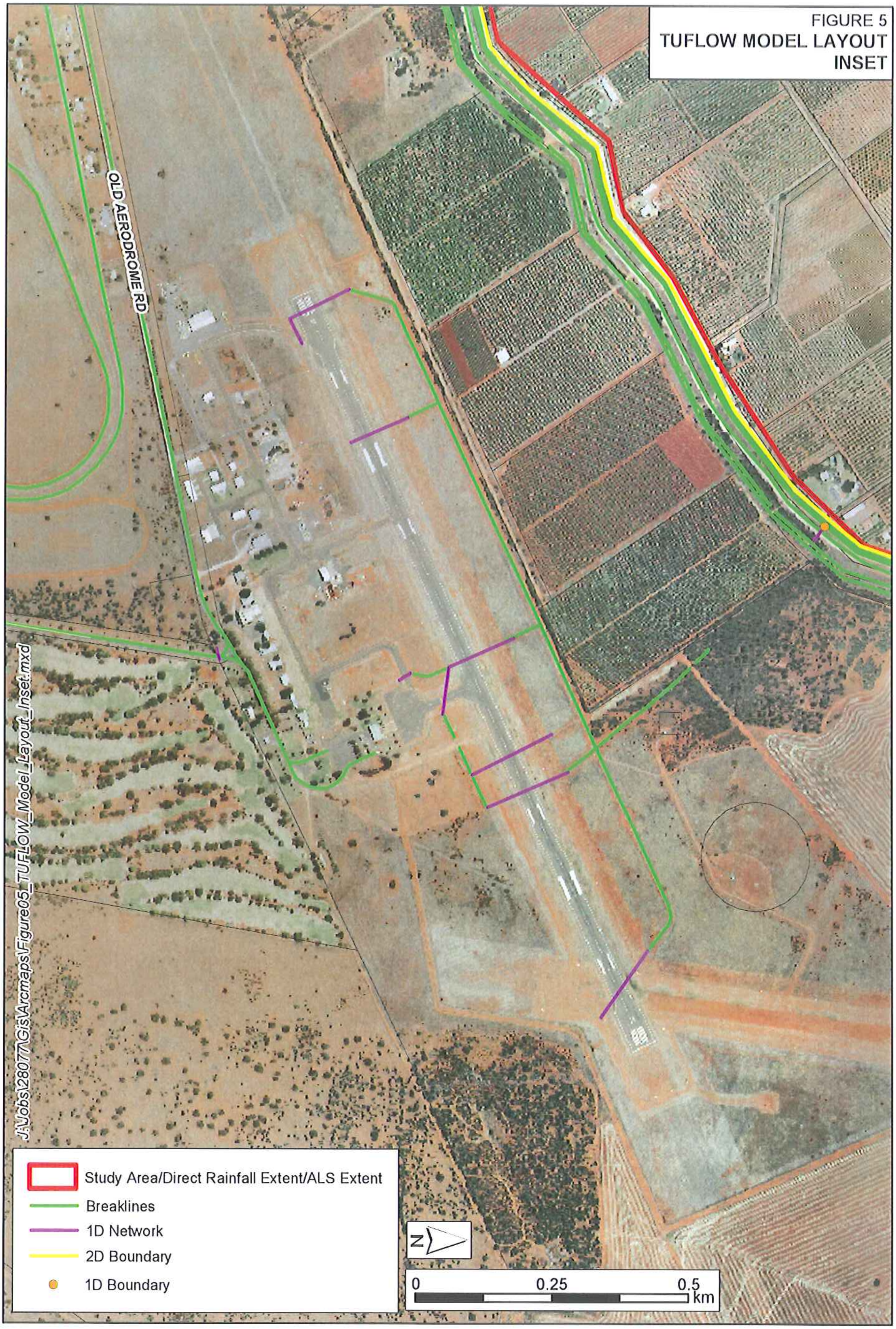


FIGURE 5
TUFLOW MODEL LAYOUT
INSET
OLD AERODROME RD
J:\Jobs\28077\Gis\Arcmaps\Figure05_TUFLOW_Model_Layout_Inset.mxd
Study Area/Direct Rainfall Extent/ALS Extent
Breaklines
1D Network
2D Boundary
1D Boundary
N
0
0.25
0.5
km

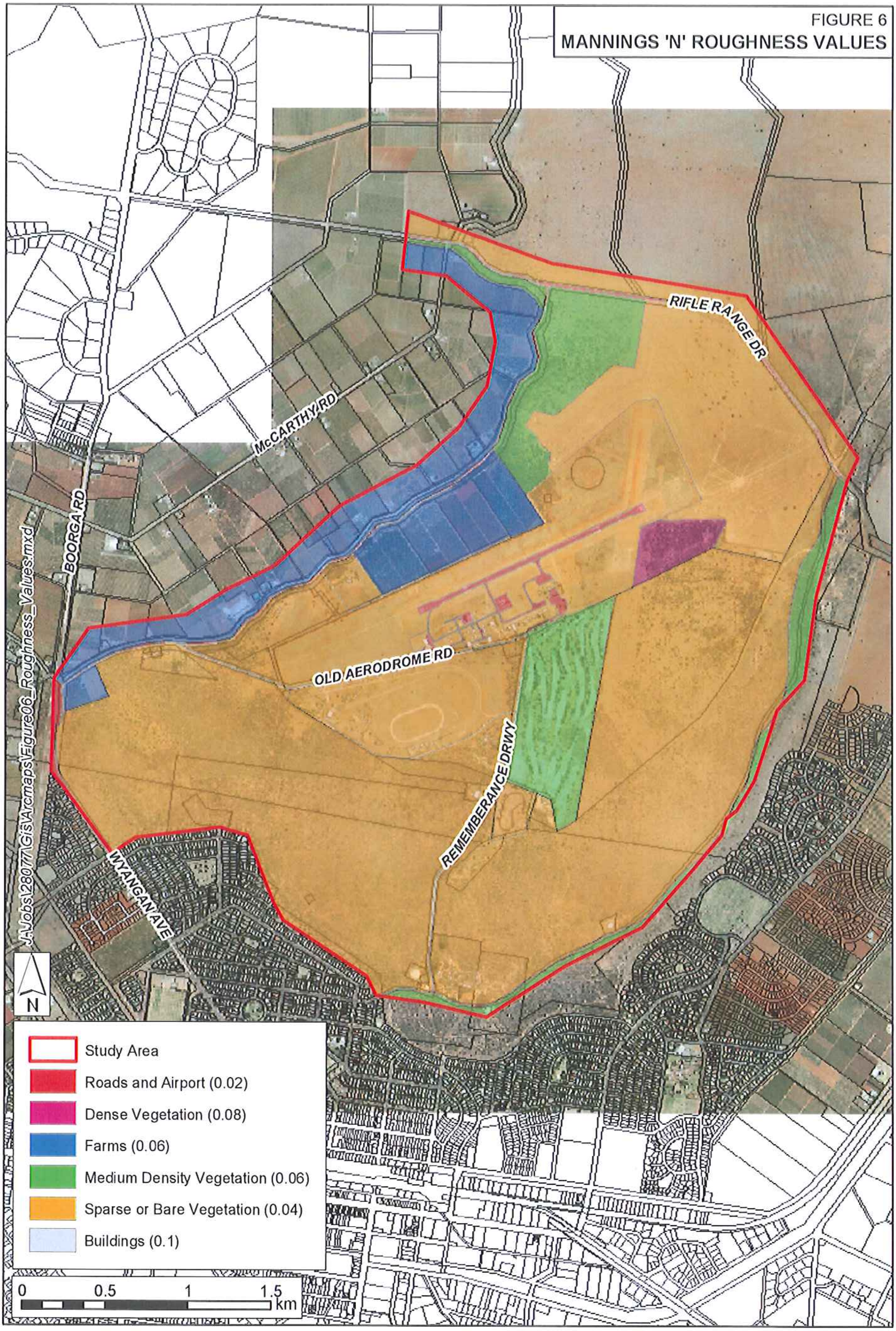


FIGURE 6
MANNINGS 'N' ROUGHNESS VALUES
RIFLE RANGE DR
McCARTHY RD
BOORGA RD
OLD AERODROME RD
REMEMBERANCE DRWY
WYANGAN AVE
J:\Jobs\28077\Gis\Arcmaps\Figure06_Roughness_Values.mxd
N
Study Area
Roads and Airport (0.02)
Dense Vegetation (0.08)
Farms (0.06)
Medium Density Vegetation (0.06)
Sparse or Bare Vegetation (0.04)
Buildings (0.1)
0
0.5
1
1.5
km

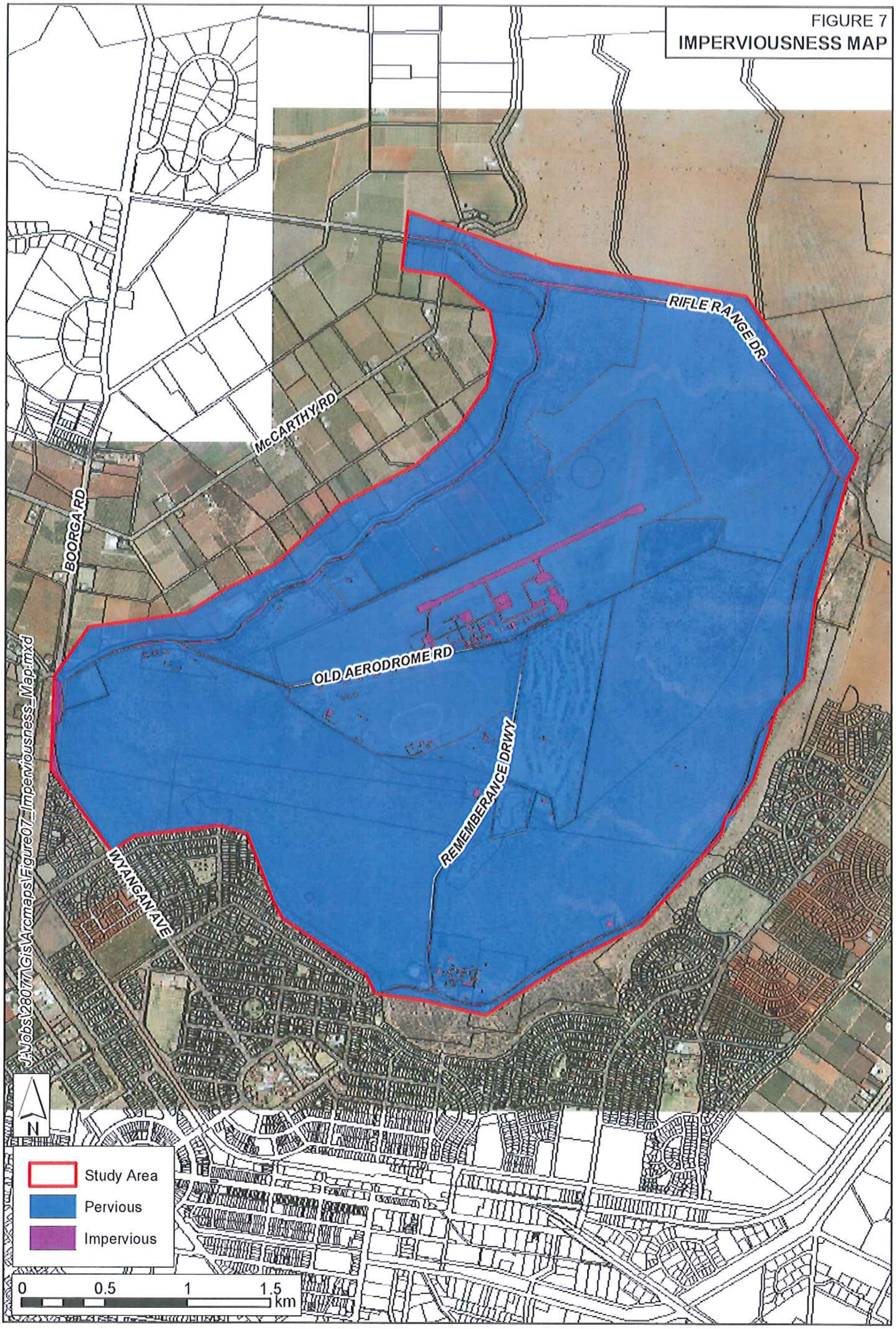
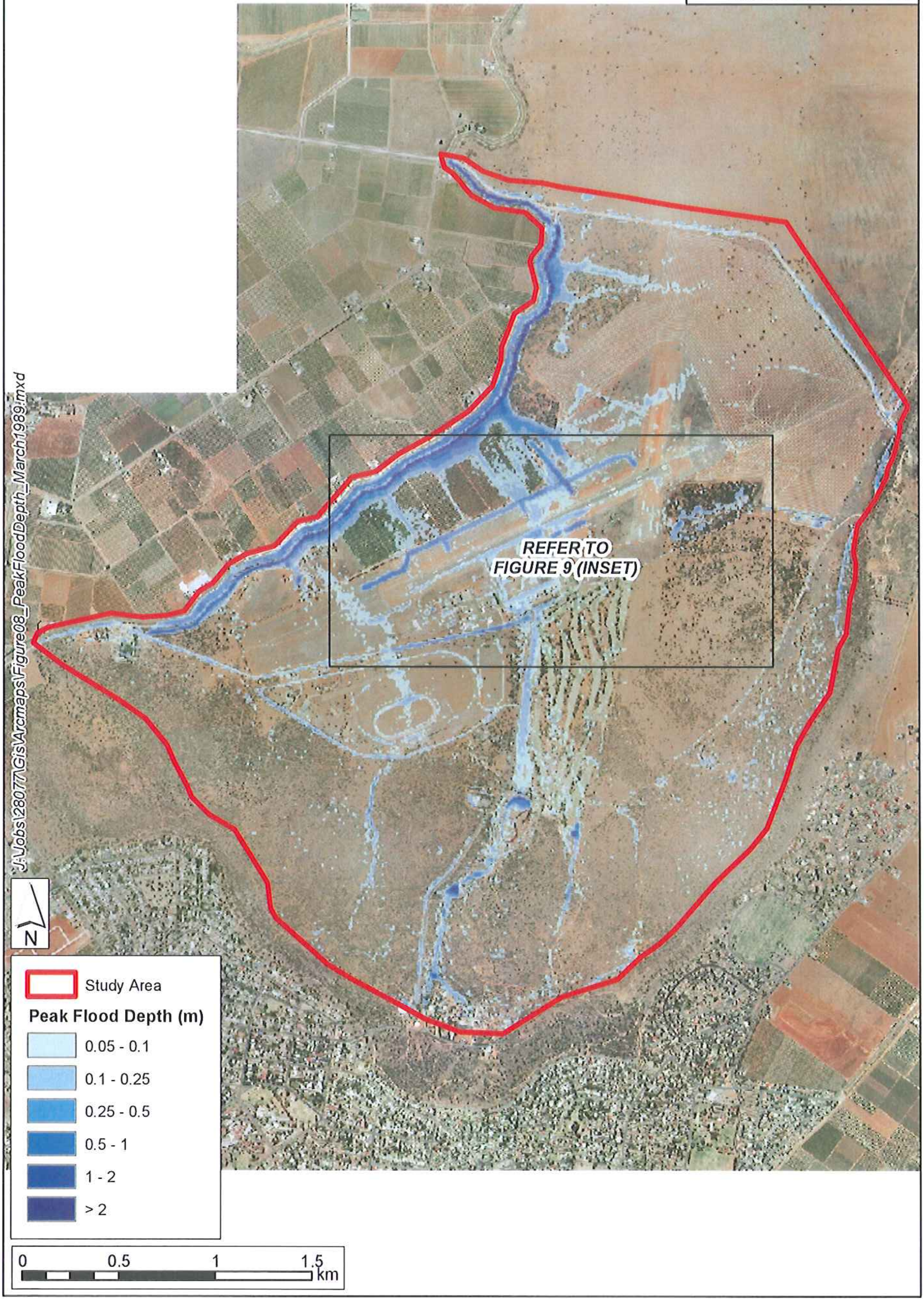


FIGURE 7
IMPERVIOUSNESS MAP
RIFLE RANGE DR
McCARTHY RD
BOORGA RD
OLD AERODROME RD
REMEMBERANCE DRWY
WYANGAN AVE
J:\Jobs\28077\Gis\Arcmaps\Figure07_Imperviousness_Map.mxd
N
Study Area
Pervious
Impervious
0
0.5
1
1.5
km

FIGURE 8
PEAK FLOOD DEPTH
MARCH 1989 EVENT



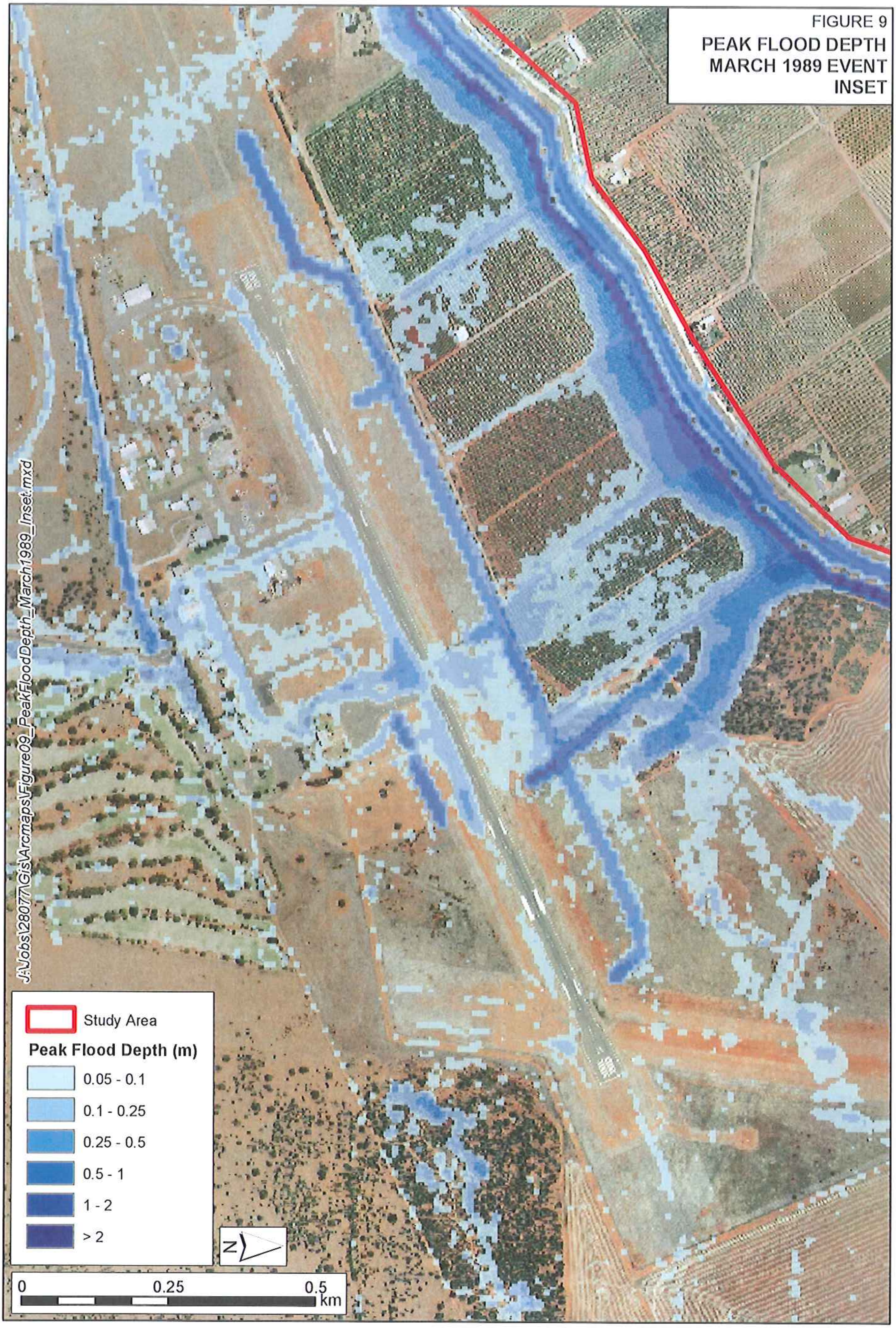
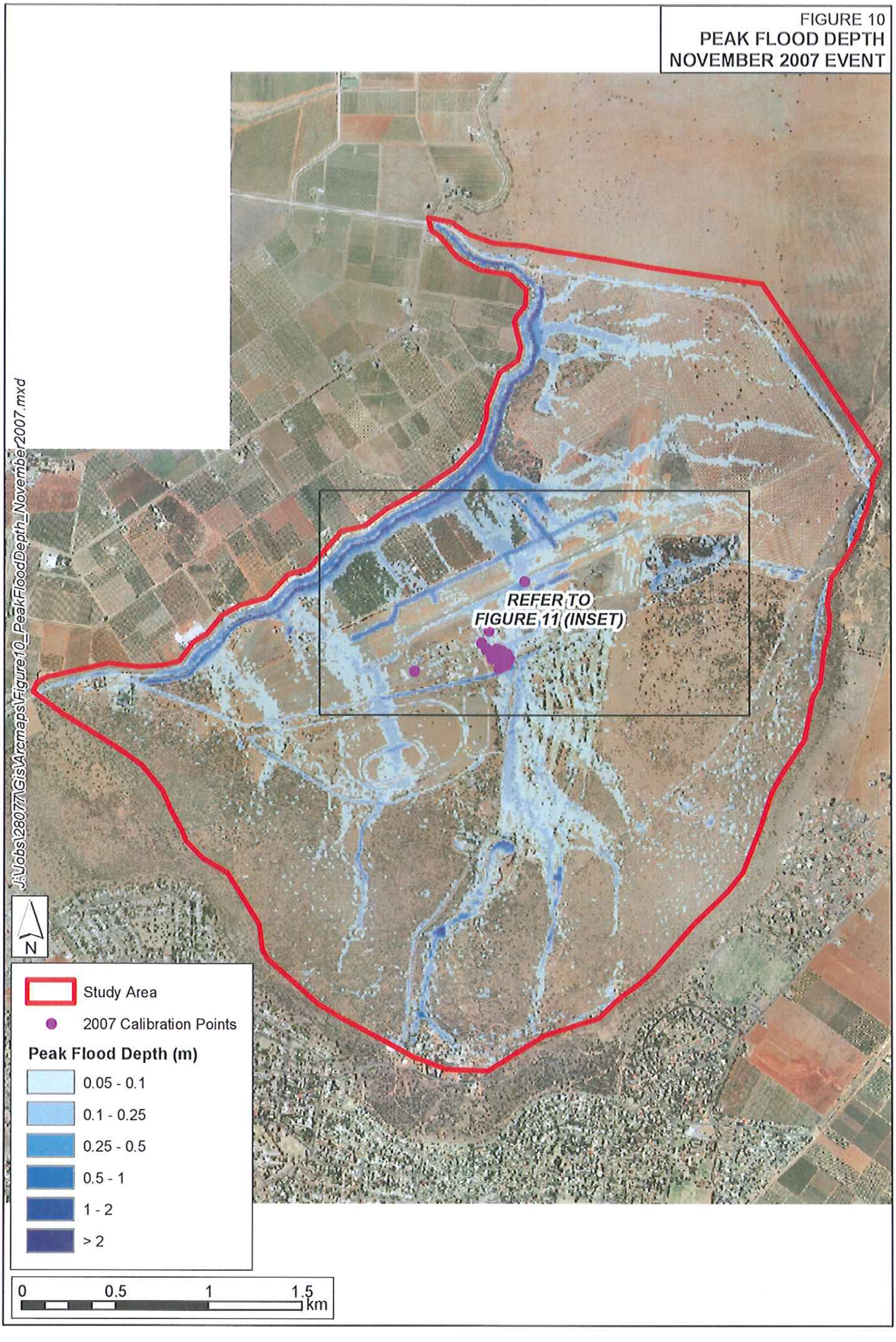


FIGURE 9
PEAK FLOOD DEPTH
MARCH 1989 EVENT
INSET
J:\Jobs\28077\Gis\Arcmaps\Figure09_PeakFloodDepth_March1989_Inset.mxd
Study Area
Peak Flood Depth (m)
0.05 - 0.1
0.1 - 0.25
0.25 - 0.5
0.5 - 1
1 - 2
> 2
N
0
0.25
0.5
km

FIGURE 10
PEAK FLOOD DEPTH NOVEMBER 2007 EVENT



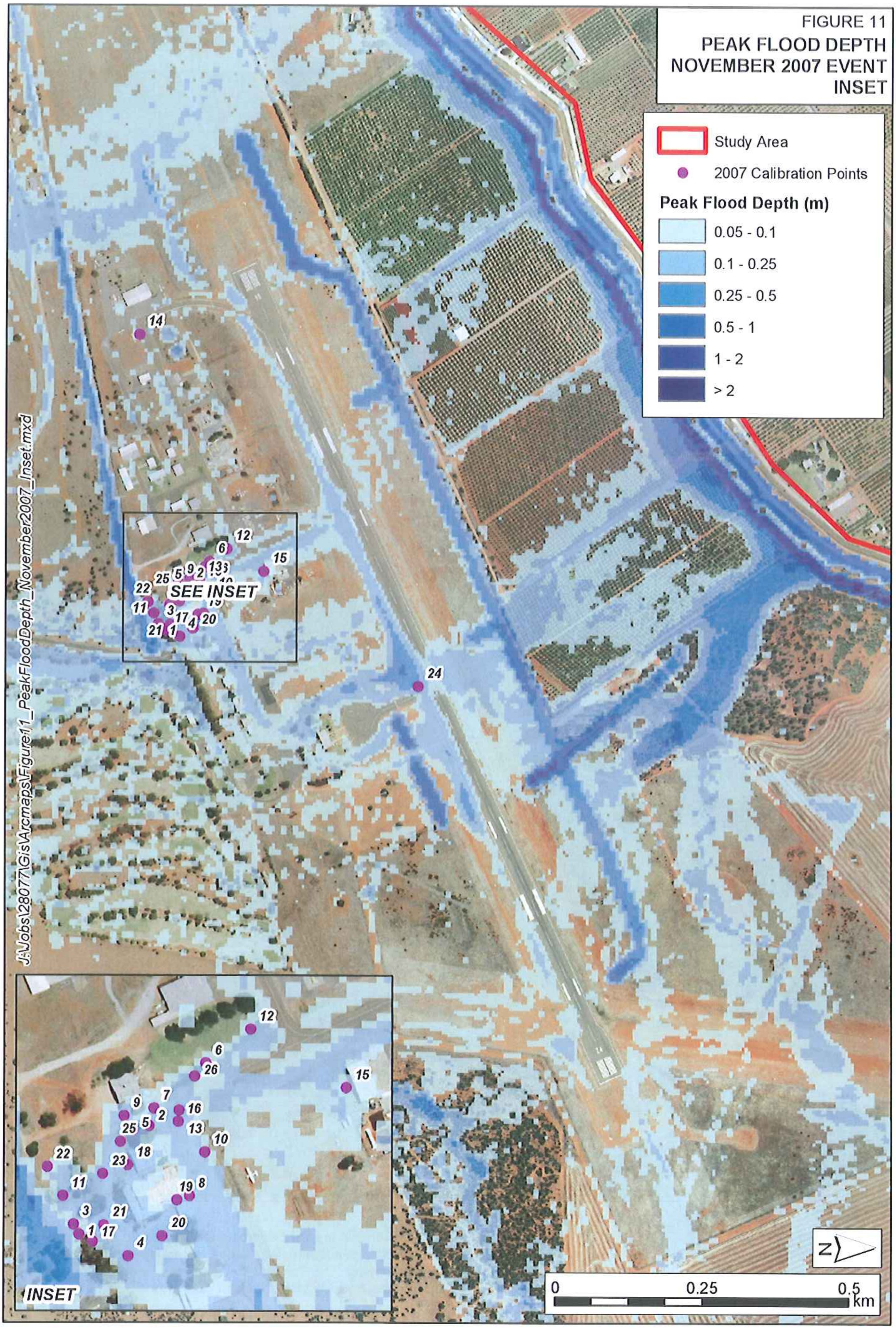
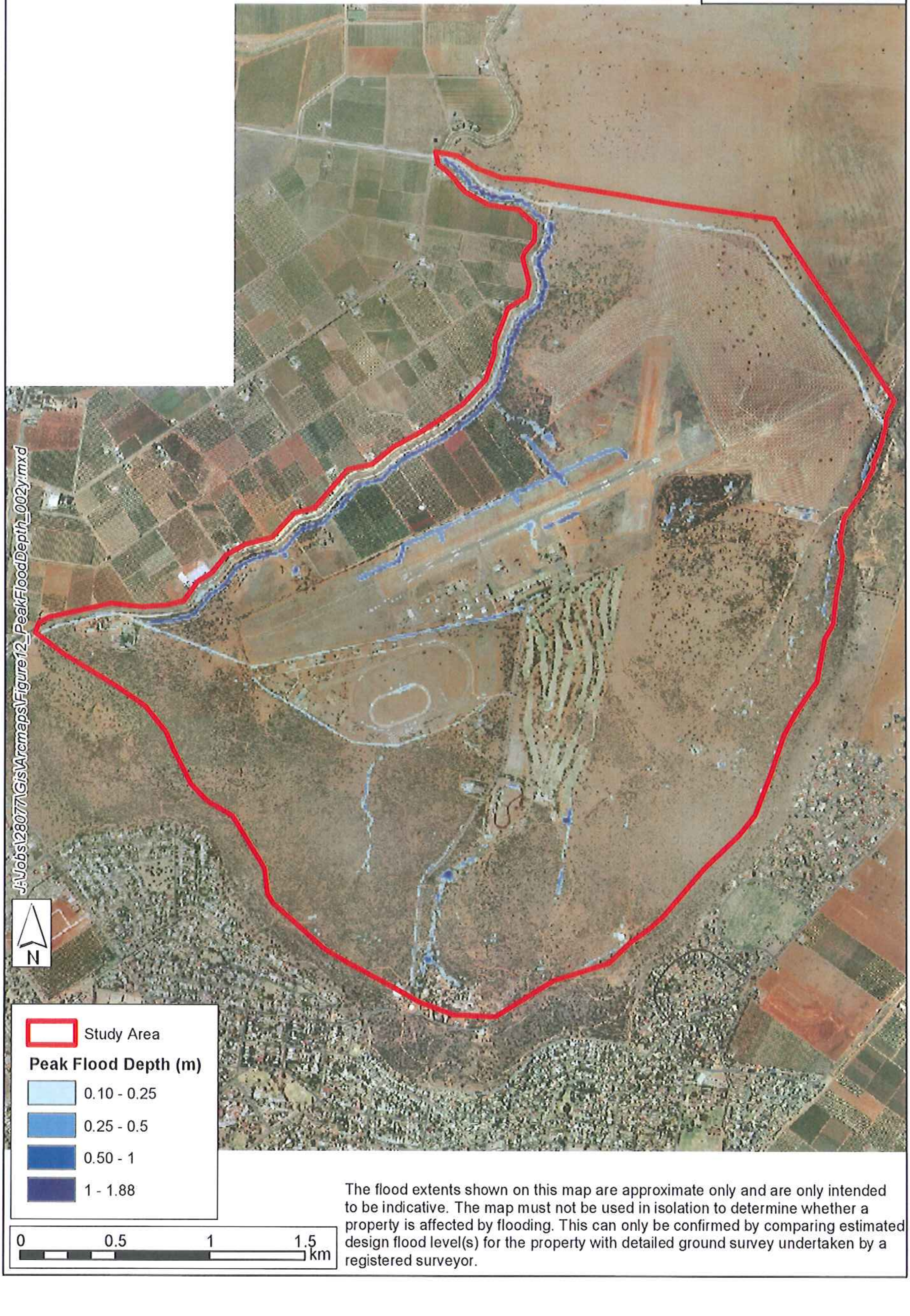


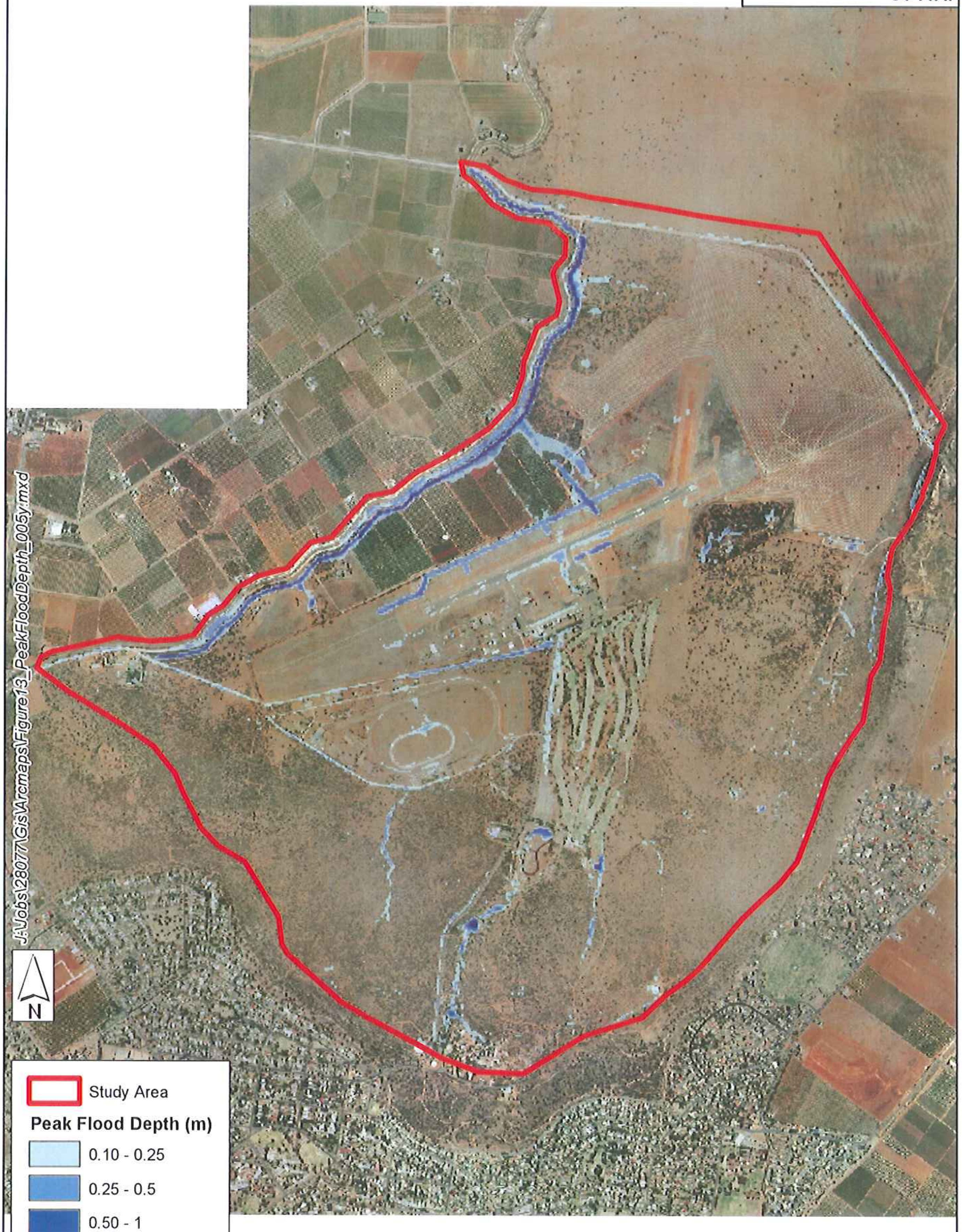
FIGURE 11
PEAK FLOOD DEPTH
NOVEMBER 2007 EVENT
INSET

FIGURE 12
PEAK FLOOD DEPTH
2Y ARI



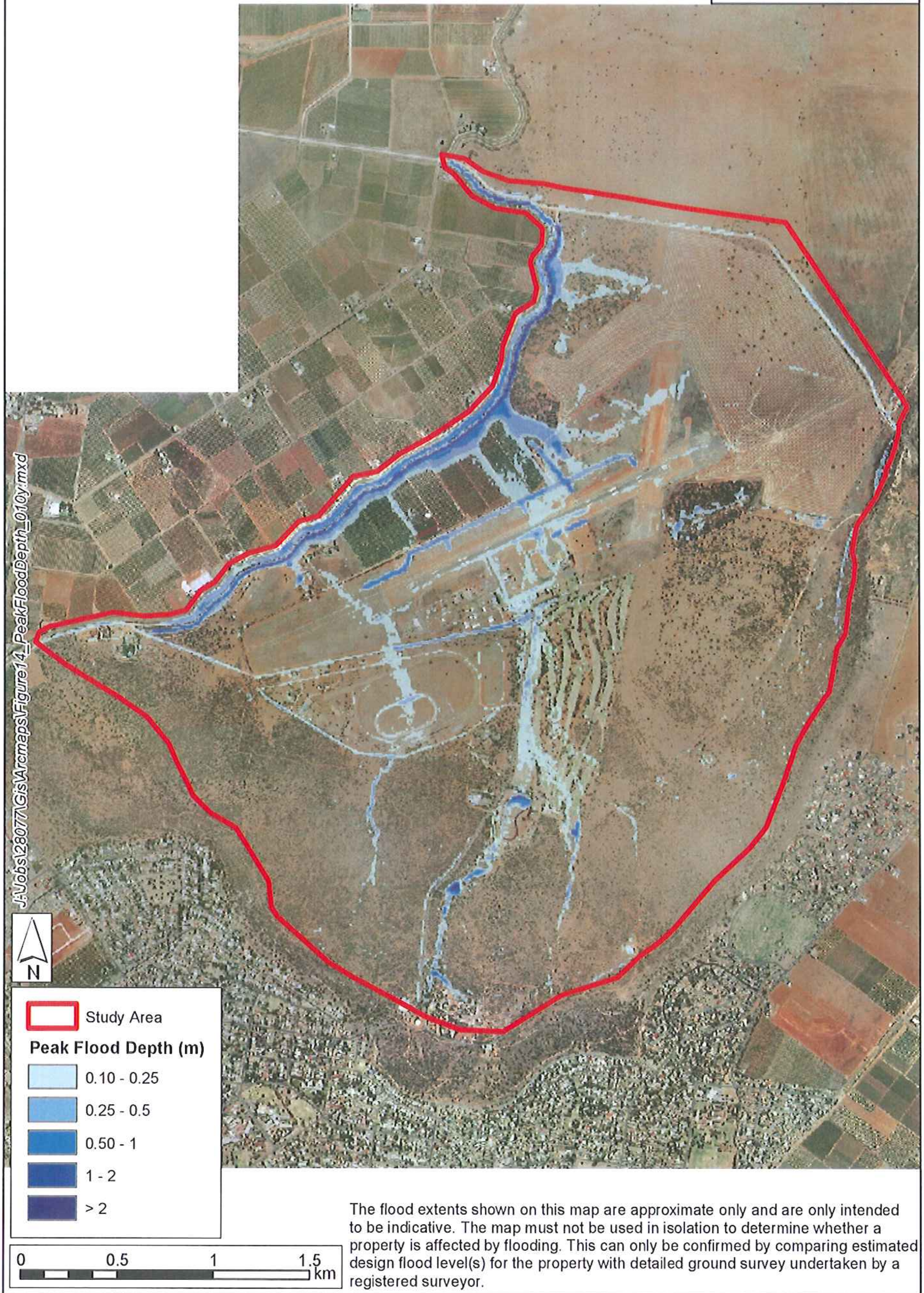
The flood extents shown on this map are approximate only and are only intended to be indicative. The map must not be used in isolation to determine whether a property is affected by flooding. This can only be confirmed by comparing estimated design flood level(s) for the property with detailed ground survey undertaken by a registered surveyor.

FIGURE 13
PEAK FLOOD DEPTH
5Y ARI



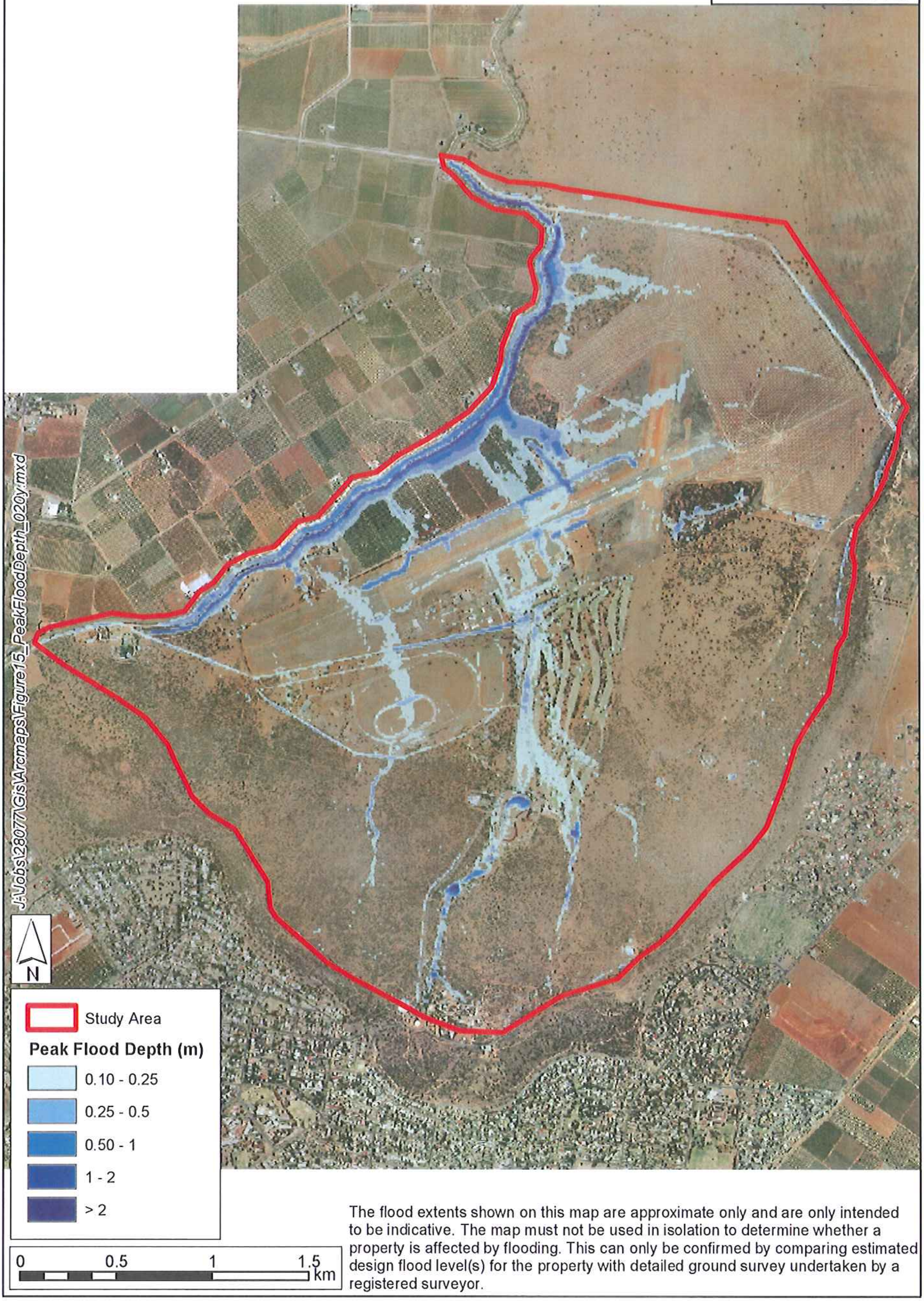
The flood extents shown on this map are approximate only and are only intended to be indicative. The map must not be used in isolation to determine whether a property is affected by flooding. This can only be confirmed by comparing estimated design flood level(s) for the property with detailed ground survey undertaken by a registered surveyor.

FIGURE 14
PEAK FLOOD DEPTH
10% AEP



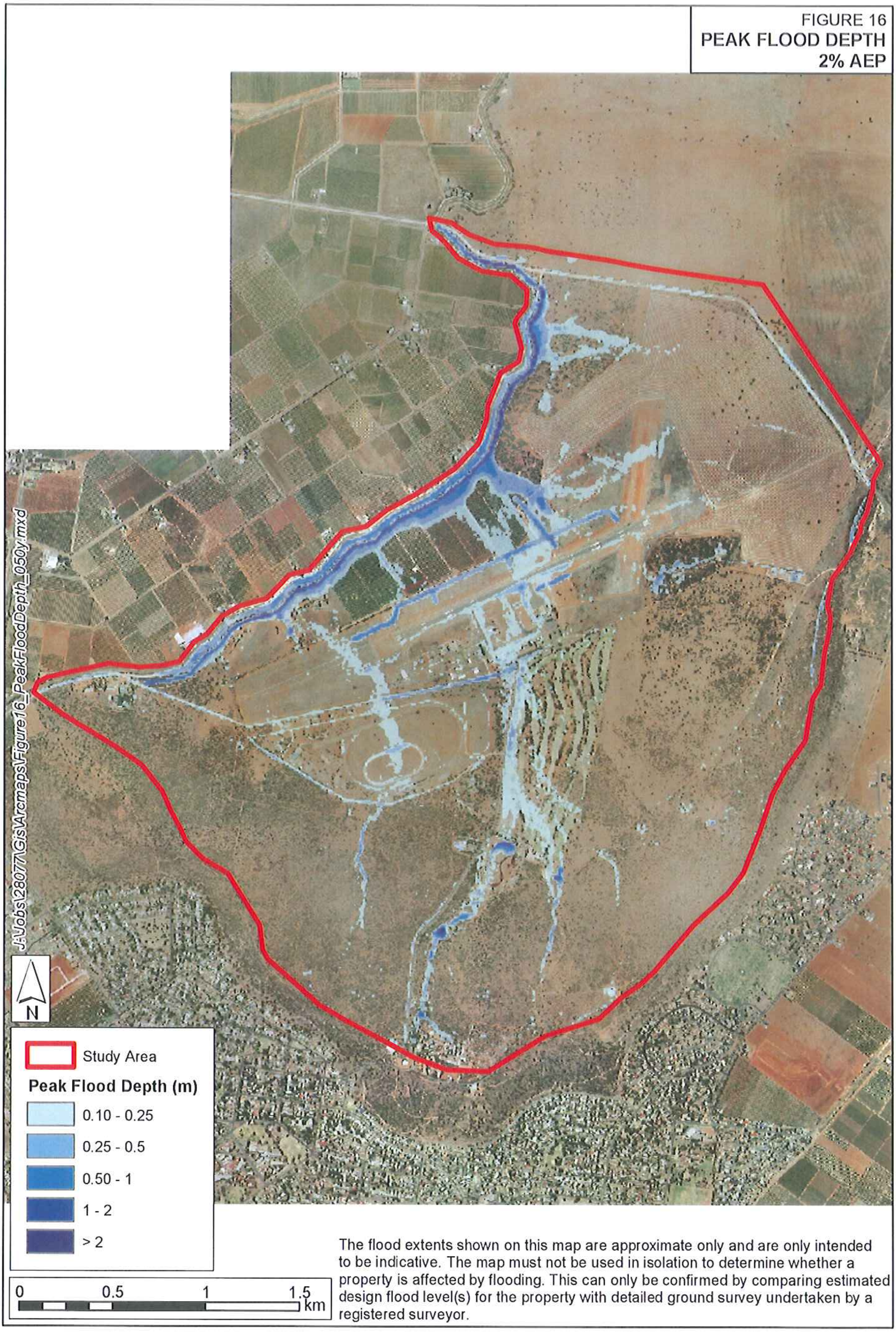
The flood extents shown on this map are approximate only and are only intended to be indicative. The map must not be used in isolation to determine whether a property is affected by flooding. This can only be confirmed by comparing estimated design flood level(s) for the property with detailed ground survey undertaken by a registered surveyor.

FIGURE 15
PEAK FLOOD DEPTH
5% AEP



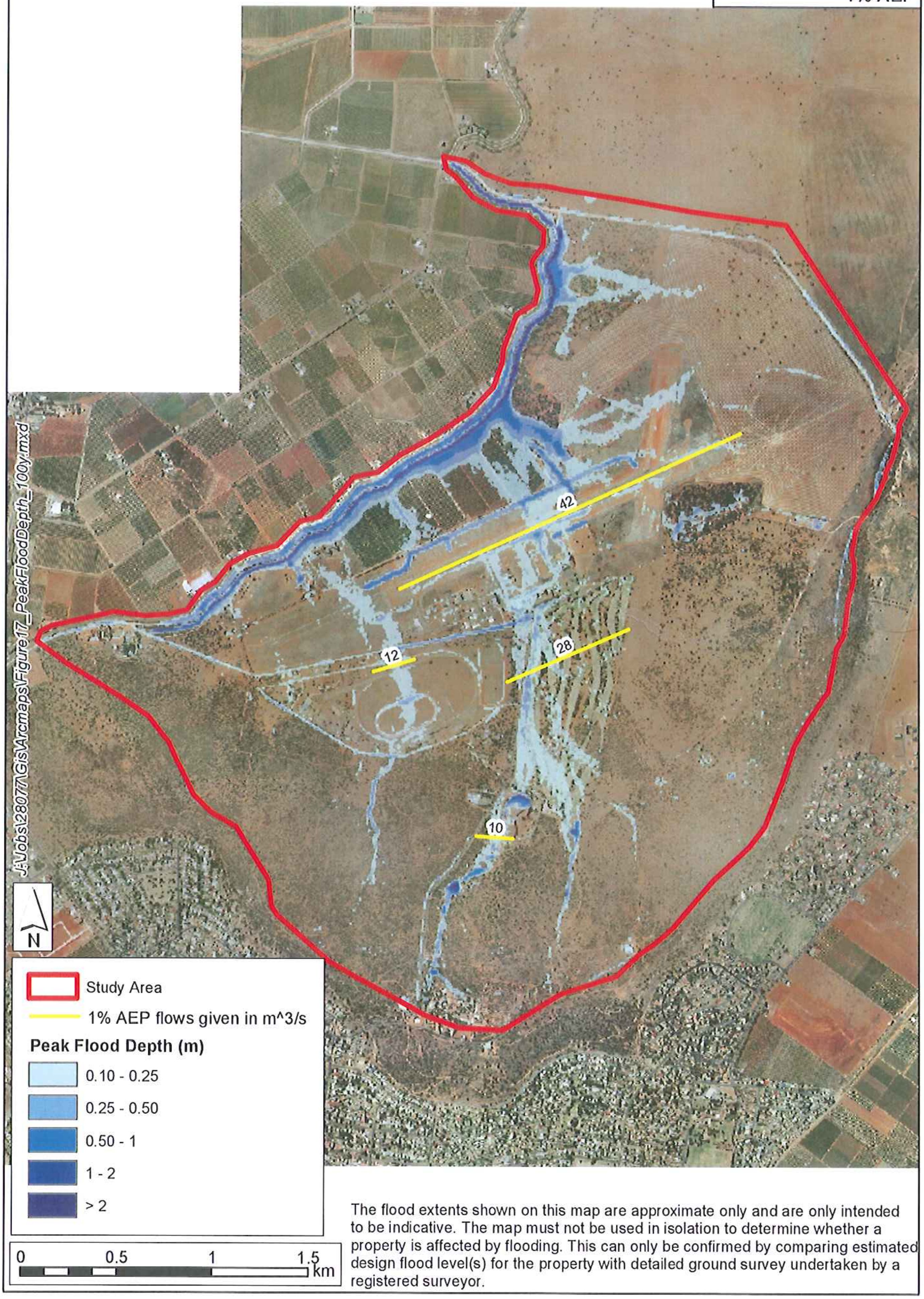
The flood extents shown on this map are approximate only and are only intended to be indicative. The map must not be used in isolation to determine whether a property is affected by flooding. This can only be confirmed by comparing estimated design flood level(s) for the property with detailed ground survey undertaken by a registered surveyor.

FIGURE 16
PEAK FLOOD DEPTH
2% AEP



The flood extents shown on this map are approximate only and are only intended to be indicative. The map must not be used in isolation to determine whether a property is affected by flooding. This can only be confirmed by comparing estimated design flood level(s) for the property with detailed ground survey undertaken by a registered surveyor.

FIGURE 17
PEAK FLOOD DEPTH
1% AEP



The flood extents shown on this map are approximate only and are only intended to be indicative. The map must not be used in isolation to determine whether a property is affected by flooding. This can only be confirmed by comparing estimated design flood level(s) for the property with detailed ground survey undertaken by a registered surveyor.

FIGURE 18
HAZARD CATEGORISATION
1% AEP

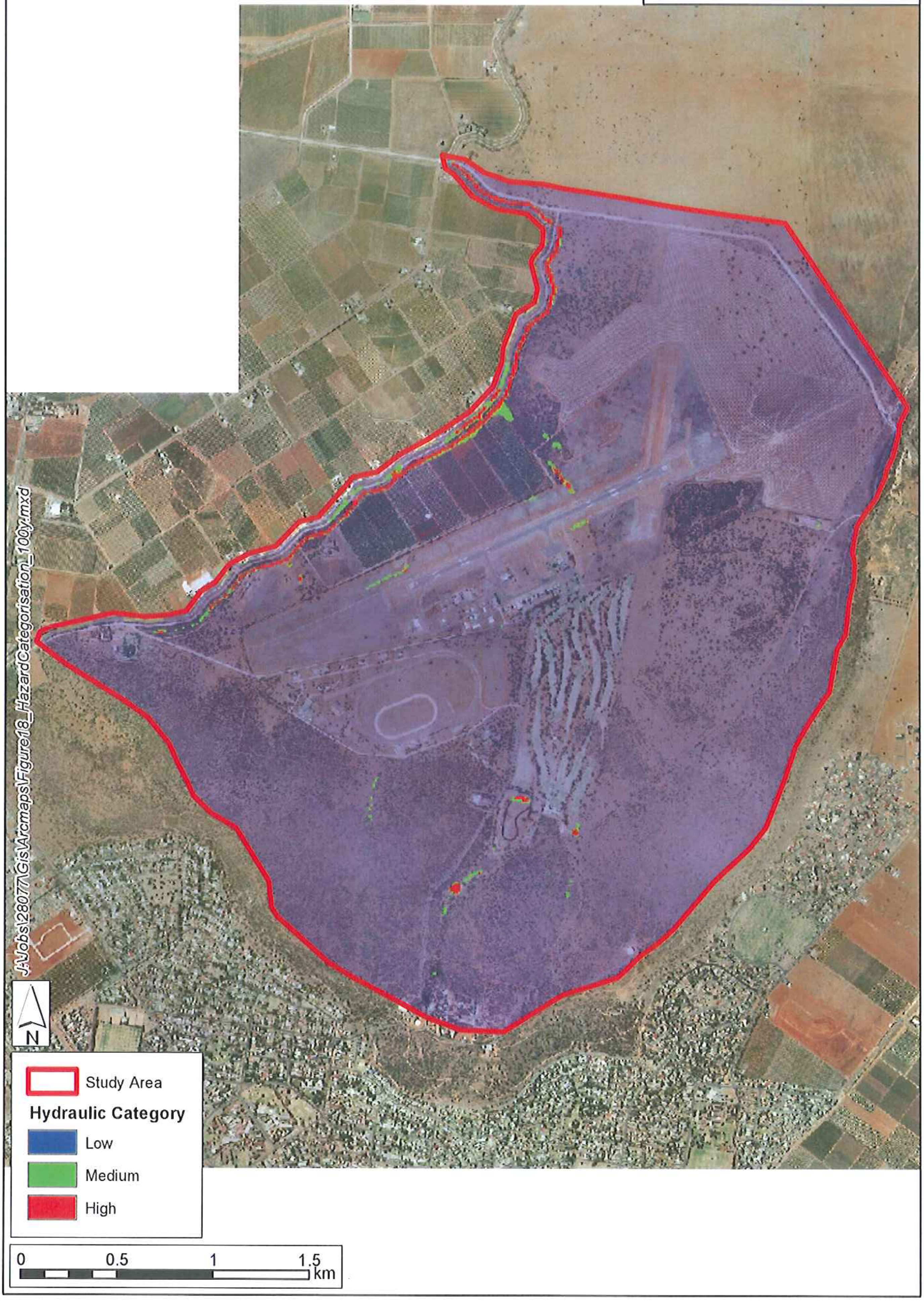


FIGURE 19

PROVISIONAL HYDRAULIC CATEGORIES

1% AEP

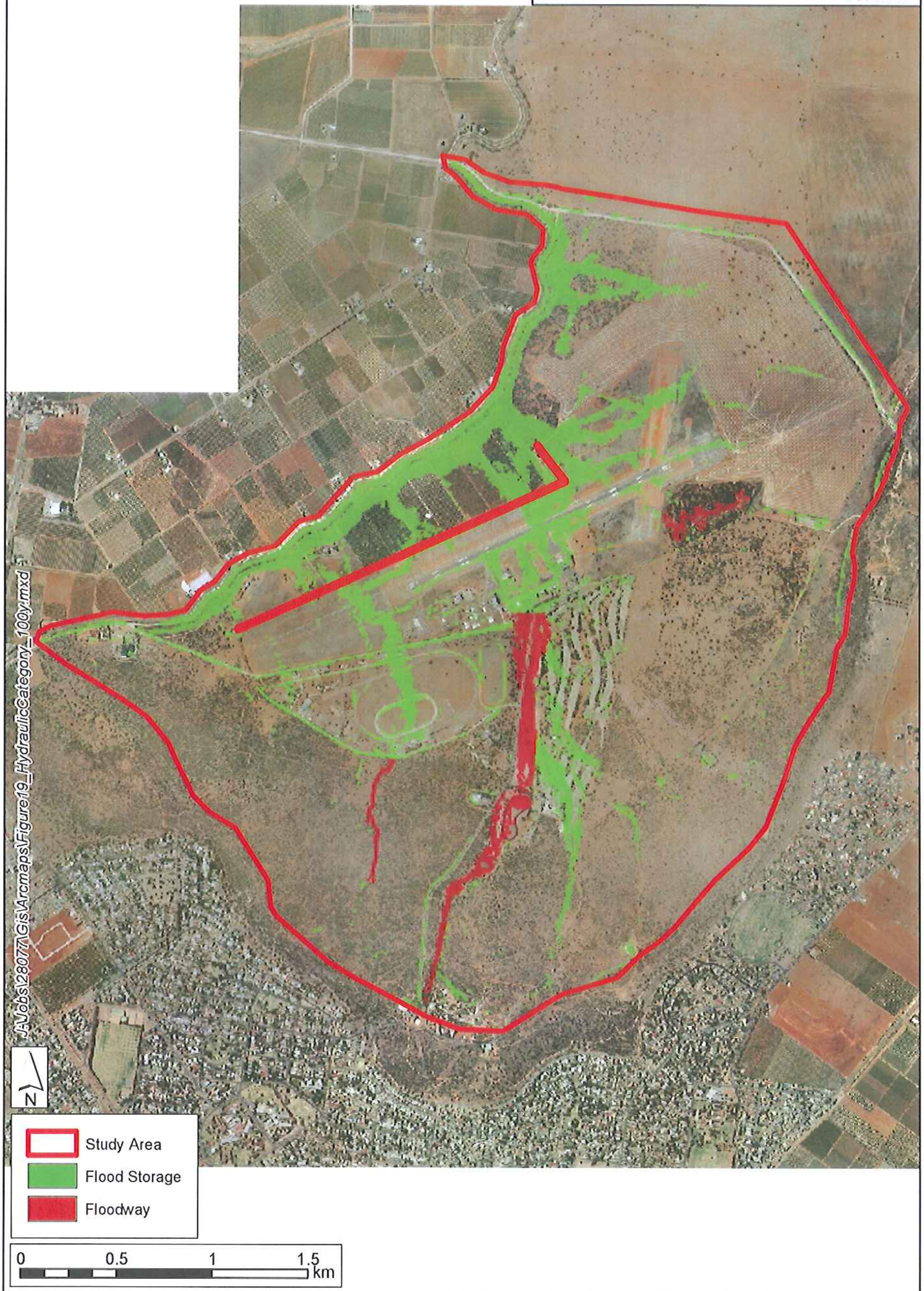
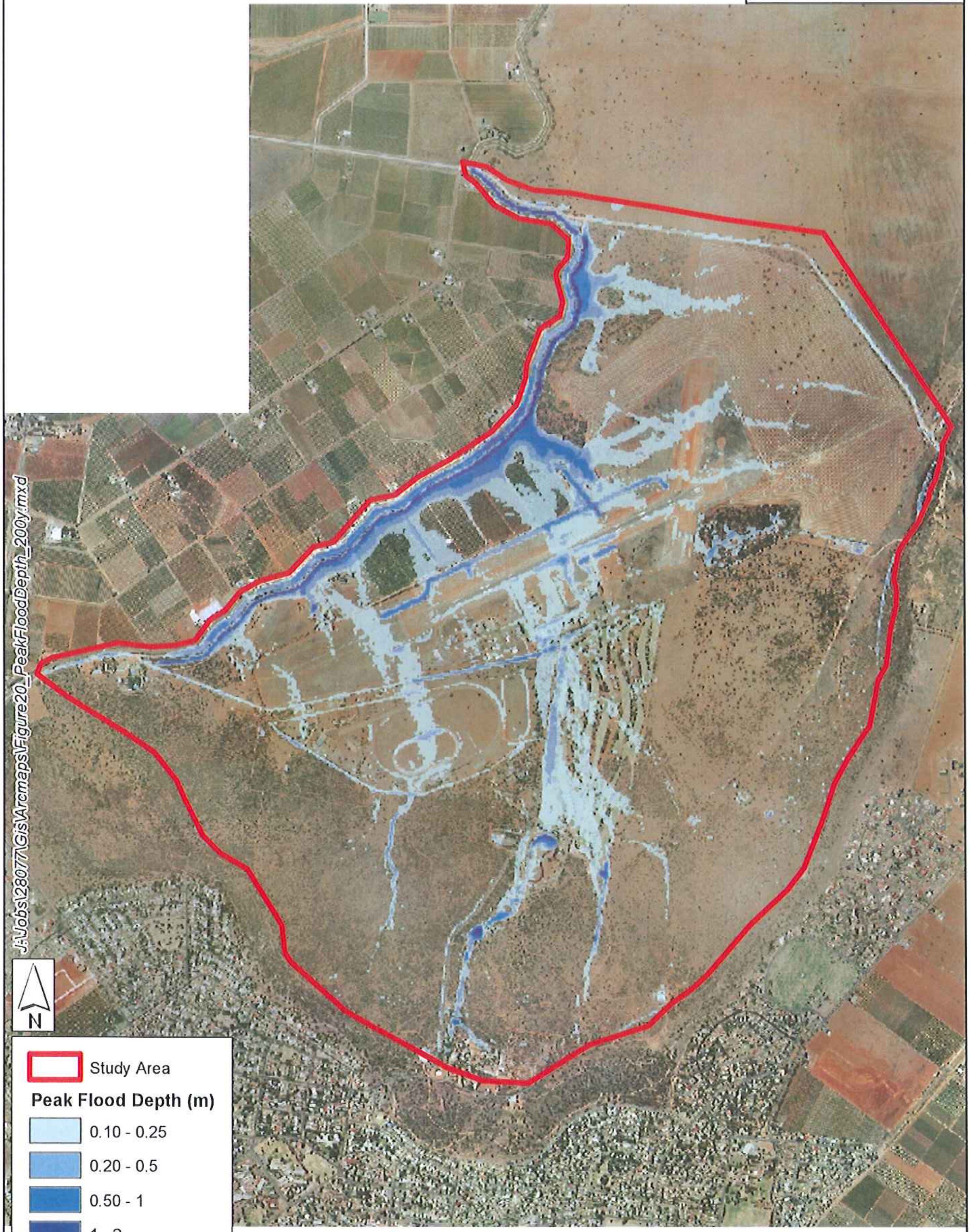
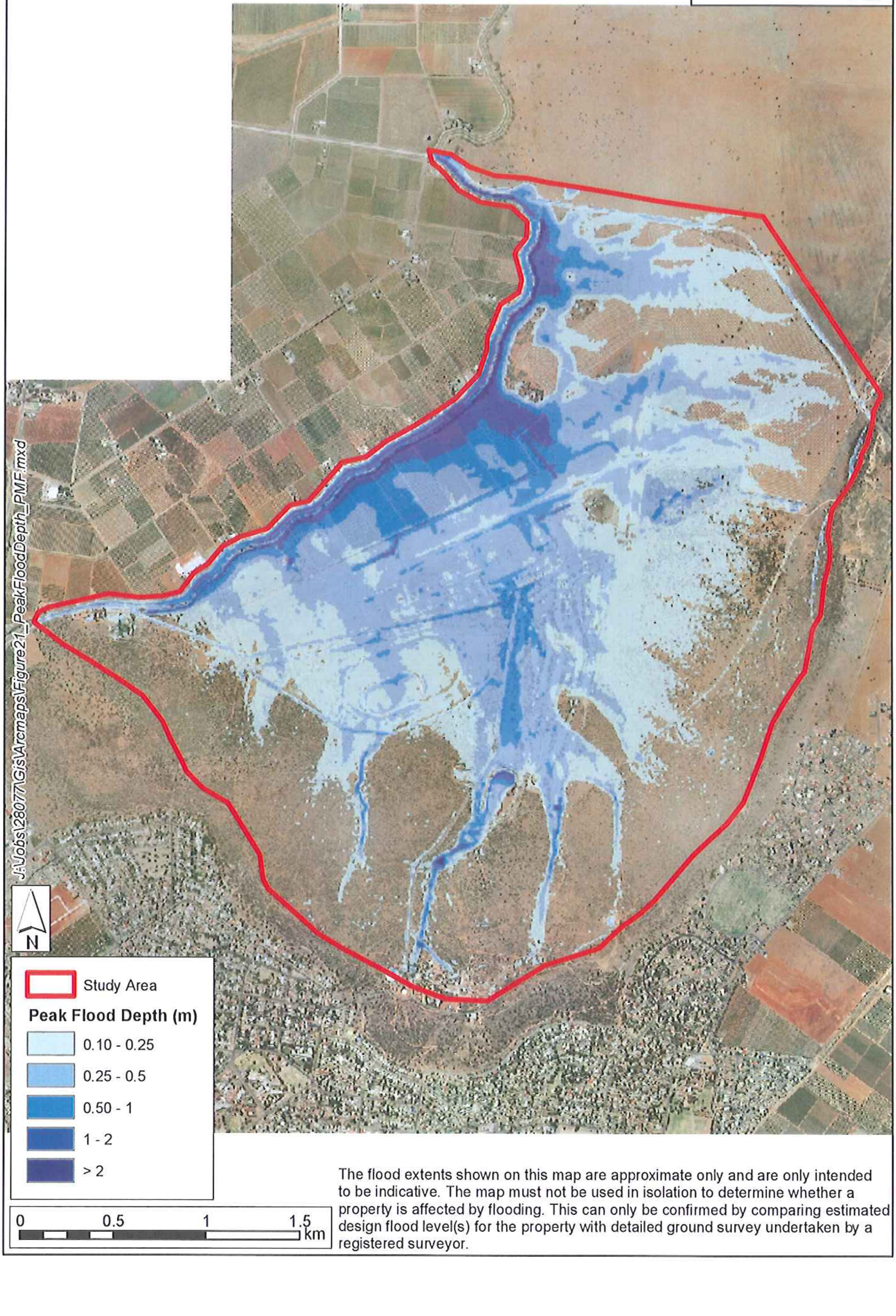


FIGURE 20
PEAK FLOOD DEPTH
0.5% AEP



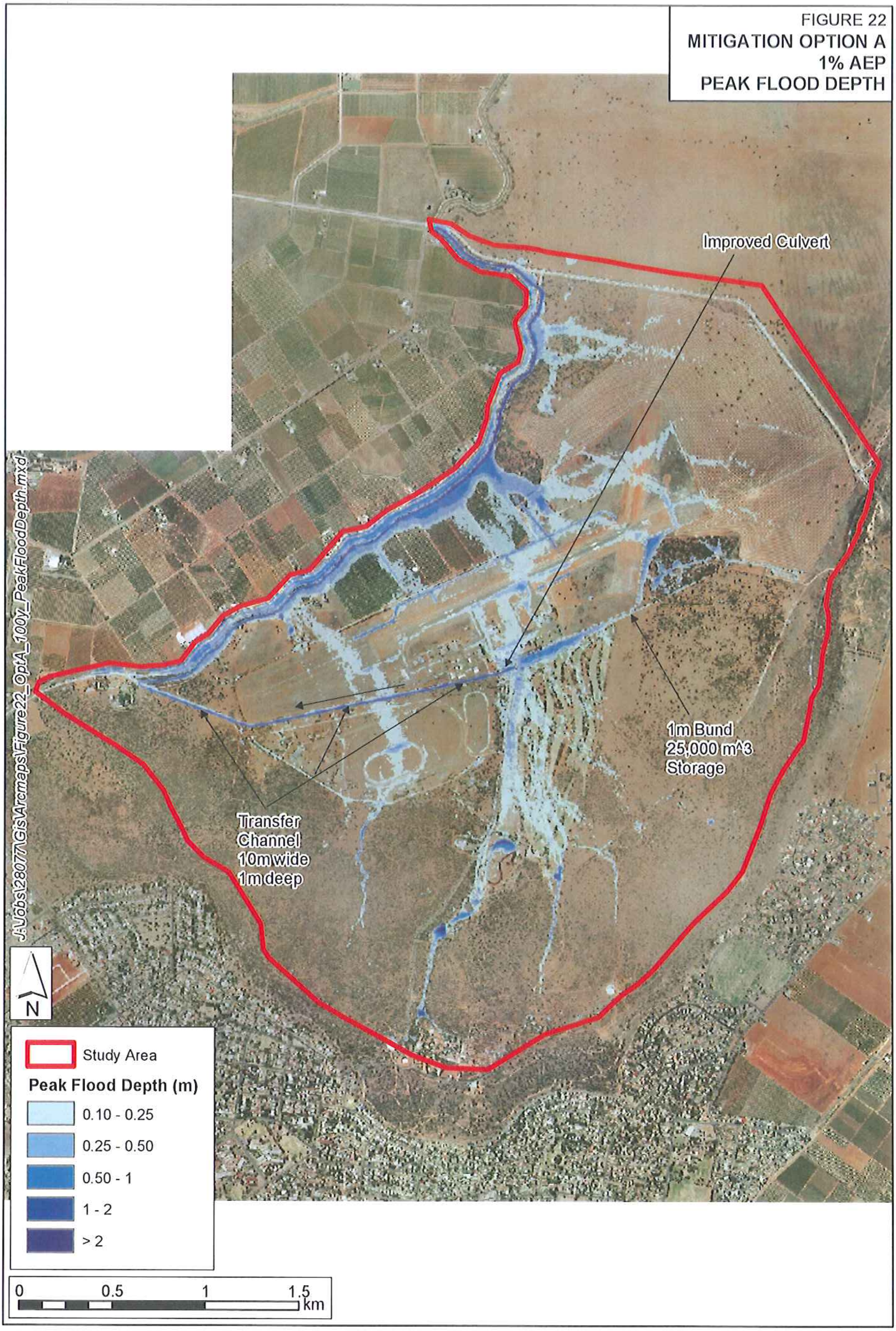
The flood extents shown on this map are approximate only and are only intended to be indicative. The map must not be used in isolation to determine whether a property is affected by flooding. This can only be confirmed by comparing estimated design flood level(s) for the property with detailed ground survey undertaken by a registered surveyor.

FIGURE 21
PEAK FLOOD DEPTH
PMF



The flood extents shown on this map are approximate only and are only intended to be indicative. The map must not be used in isolation to determine whether a property is affected by flooding. This can only be confirmed by comparing estimated design flood level(s) for the property with detailed ground survey undertaken by a registered surveyor.

FIGURE 22
MITIGATION OPTION A 1% AEP PEAK FLOOD DEPTH



Appendix A

APPENDIX A: GLOSSARY

Taken from the Floodplain Development Manual (April 2005 edition)

acid sulfate soils	Are sediments which contain sulfidic mineral pyrite which may become extremely acid following disturbance or drainage as sulfur compounds react when exposed to oxygen to form sulfuric acid. More detailed explanation and definition can be found in the NSW Government Acid Sulfate Soil Manual published by Acid Sulfate Soil Management Advisory Committee.
Annual Exceedance Probability (AEP)	The chance of a flood of a given or larger size occurring in any one year, usually expressed as a percentage. For example, if a peak flood discharge of 500 m^3/s has an AEP of 5%, it means that there is a 5% chance (that is one-in-20 chance) of a 500 m^3/s or larger event occurring in any one year (see ARI).
Australian Height Datum (AHD)	A common national surface level datum approximately corresponding to mean sea level.
Average Annual Damage (AAD)	Depending on its size (or severity), each flood will cause a different amount of flood damage to a flood prone area. AAD is the average damage per year that would occur in a nominated development situation from flooding over a very long period of time.
Average Recurrence Interval (ARI)	The long term average number of years between the occurrence of a flood as big as, or larger than, the selected event. For example, floods with a discharge as great as, or greater than, the 20 year ARI flood event will occur on average once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event.
caravan and moveable home parks	Caravans and moveable dwellings are being increasingly used for long-term and permanent accommodation purposes. Standards relating to their siting, design, construction and management can be found in the Regulations under the LG Act.
catchment	The land area draining through the main stream, as well as tributary streams, to a particular site. It always relates to an area above a specific location.
consent authority	The Council, government agency or person having the function to determine a development application for land use under the EP&A Act. The consent authority is most often the Council, however legislation or an EPI may specify a Minister or public authority (other than a Council), or the Director General of DIPNR, as having the function to determine an application.
development	Is defined in Part 4 of the Environmental Planning and Assessment Act (EP&A Act). **infill development:** refers to the development of vacant blocks of land that are generally surrounded by developed properties and is permissible under the current zoning of the land. Conditions such as minimum floor levels may be imposed on infill development. **new development:** refers to development of a completely different nature to that associated with the former land use. For example, the urban subdivision of an area previously used for rural purposes. New developments involve rezoning and typically require major extensions of existing urban services, such as roads, water supply, sewerage and electric power.

	redevelopment: refers to rebuilding in an area. For example, as urban areas age, it may become necessary to demolish and reconstruct buildings on a relatively large scale. Redevelopment generally does not require either rezoning or major extensions to urban services.
disaster plan (DISPLAN)	A step by step sequence of previously agreed roles, responsibilities, functions, actions and management arrangements for the conduct of a single or series of connected emergency operations, with the object of ensuring the coordinated response by all agencies having responsibilities and functions in emergencies.
discharge	The rate of flow of water measured in terms of volume per unit time, for example, cubic metres per second (m^3/s). Discharge is different from the speed or velocity of flow, which is a measure of how fast the water is moving for example, metres per second (m/s).
ecologically sustainable development (ESD)	Using, conserving and enhancing natural resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be maintained or increased. A more detailed definition is included in the Local Government Act 1993. The use of sustainability and sustainable in this manual relate to ESD.
effective warning time	The time available after receiving advice of an impending flood and before the floodwaters prevent appropriate flood response actions being undertaken. The effective warning time is typically used to move farm equipment, move stock, raise furniture, evacuate people and transport their possessions.
emergency management	A range of measures to manage risks to communities and the environment. In the flood context it may include measures to prevent, prepare for, respond to and recover from flooding.
flash flooding	Flooding which is sudden and unexpected. It is often caused by sudden local or nearby heavy rainfall. Often defined as flooding which peaks within six hours of the causative rain.
flood	Relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or local overland flooding associated with major drainage before entering a watercourse, and/or coastal inundation resulting from super-elevated sea levels and/or waves overtopping coastline defences excluding tsunami.
flood awareness	Flood awareness is an appreciation of the likely effects of flooding and a knowledge of the relevant flood warning, response and evacuation procedures.
flood education	Flood education seeks to provide information to raise awareness of the flood problem so as to enable individuals to understand how to manage themselves an their property in response to flood warnings and in a flood event. It invokes a state of flood readiness.
flood fringe areas	The remaining area of flood prone land after floodway and flood storage areas have been defined.
flood liable land	Is synonymous with flood prone land (i.e. land susceptible to flooding by the probable maximum flood (PMF) event). Note that the term flood liable land covers the whole of the floodplain, not just that part below the flood planning level

	(see flood planning area).
flood mitigation standard	The average recurrence interval of the flood, selected as part of the floodplain risk management process that forms the basis for physical works to modify the impacts of flooding.
floodplain	Area of land which is subject to inundation by floods up to and including the probable maximum flood event, that is, flood prone land.
floodplain risk management options	The measures that might be feasible for the management of a particular area of the floodplain. Preparation of a floodplain risk management plan requires a detailed evaluation of floodplain risk management options.
floodplain risk management plan	A management plan developed in accordance with the principles and guidelines in this manual. Usually includes both written and diagrammetic information describing how particular areas of flood prone land are to be used and managed to achieve defined objectives.
flood plan (local)	A sub-plan of a disaster plan that deals specifically with flooding. They can exist at State, Division and local levels. Local flood plans are prepared under the leadership of the State Emergency Service.
flood planning area	The area of land below the flood planning level and thus subject to flood related development controls. The concept of flood planning area generally supersedes the "flood liable land" concept in the 1986 Manual.
Flood Planning Levels (FPLs)	FPL's are the combinations of flood levels (derived from significant historical flood events or floods of specific AEPs) and freeboards selected for floodplain risk management purposes, as determined in management studies and incorporated in management plans. FPLs supersede the "standard flood event" in the 1986 manual.
flood proofing	A combination of measures incorporated in the design, construction and alteration of individual buildings or structures subject to flooding, to reduce or eliminate flood damages.
flood prone land	Is land susceptible to flooding by the Probable Maximum Flood (PMF) event. Flood prone land is synonymous with flood liable land.
flood readiness	Flood readiness is an ability to react within the effective warning time.
flood risk	Potential danger to personal safety and potential damage to property resulting from flooding. The degree of risk varies with circumstances across the full range of floods. Flood risk in this manual is divided into 3 types, existing, future and continuing risks. They are described below. **existing flood risk:** the risk a community is exposed to as a result of its location on the floodplain. **future flood risk:** the risk a community may be exposed to as a result of new development on the floodplain. **continuing flood risk:** the risk a community is exposed to after floodplain risk management measures have been implemented. For a town protected by levees, the continuing flood risk is the consequences of the levees being overtopped. For an area without any floodplain risk management measures, the continuing flood risk is simply the existence of its flood exposure.

flood storage areas	Those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood. The extent and behaviour of flood storage areas may change with flood severity, and loss of flood storage can increase the severity of flood impacts by reducing natural flood attenuation. Hence, it is necessary to investigate a range of flood sizes before defining flood storage areas.
floodway areas	Those areas of the floodplain where a significant discharge of water occurs during floods. They are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flows, or a significant increase in flood levels.
freeboard	Freeboard provides reasonable certainty that the risk exposure selected in deciding on a particular flood chosen as the basis for the FPL is actually provided. It is a factor of safety typically used in relation to the setting of floor levels, levee crest levels, etc. Freeboard is included in the flood planning level.
habitable room	**in a residential situation:** a living or working area, such as a lounge room, dining room, rumpus room, kitchen, bedroom or workroom. **in an industrial or commercial situation:** an area used for offices or to store valuable possessions susceptible to flood damage in the event of a flood.
hazard	A source of potential harm or a situation with a potential to cause loss. In relation to this manual the hazard is flooding which has the potential to cause damage to the community. Definitions of high and low hazard categories are provided in the Manual.
hydraulics	Term given to the study of water flow in waterways; in particular, the evaluation of flow parameters such as water level and velocity.
hydrograph	A graph which shows how the discharge or stage/flood level at any particular location varies with time during a flood.
hydrology	Term given to the study of the rainfall and runoff process; in particular, the evaluation of peak flows, flow volumes and the derivation of hydrographs for a range of floods.
local overland flooding	Inundation by local runoff rather than overbank discharge from a stream, river, estuary, lake or dam.
local drainage	Are smaller scale problems in urban areas. They are outside the definition of major drainage in this glossary.
mainstream flooding	Inundation of normally dry land occurring when water overflows the natural or artificial banks of a stream, river, estuary, lake or dam.
major drainage	Councils have discretion in determining whether urban drainage problems are associated with major or local drainage. For the purpose of this manual major drainage involves: • the floodplains of original watercourses (which may now be piped, channelised or diverted), or sloping areas where overland flows develop along alternative paths once system capacity is exceeded; and/or

- water depths generally in excess of 0.3 m (in the major system design storm as defined in the current version of Australian Rainfall and Runoff). These conditions may result in danger to personal safety and property damage to both premises and vehicles; and/or
- major overland flow paths through developed areas outside of defined drainage reserves; and/or
- the potential to affect a number of buildings along the major flow path.

mathematical/computer models

The mathematical representation of the physical processes involved in runoff generation and stream flow. These models are often run on computers due to the complexity of the mathematical relationships between runoff, stream flow and the distribution of flows across the floodplain.

merit approach

The merit approach weighs social, economic, ecological and cultural impacts of land use options for different flood prone areas together with flood damage, hazard and behaviour implications, and environmental protection and well being of the State's rivers and floodplains.

The merit approach operates at two levels. At the strategic level it allows for the consideration of social, economic, ecological, cultural and flooding issues to determine strategies for the management of future flood risk which are formulated into Council plans, policy and EPIs. At a site specific level, it involves consideration of the best way of conditioning development allowable under the floodplain risk management plan, local floodplain risk management policy and EPIs.

minor, moderate and major flooding

Both the State Emergency Service and the Bureau of Meteorology use the following definitions in flood warnings to give a general indication of the types of problems expected with a flood:

minor flooding: causes inconvenience such as closing of minor roads and the submergence of low level bridges. The lower limit of this class of flooding on the reference gauge is the initial flood level at which landholders and townspeople begin to be flooded.

moderate flooding: low-lying areas are inundated requiring removal of stock and/or evacuation of some houses. Main traffic routes may be covered.

major flooding: appreciable urban areas are flooded and/or extensive rural areas are flooded. Properties, villages and towns can be isolated.

modification measures

Measures that modify either the flood, the property or the response to flooding. Examples are indicated in Table 2.1 with further discussion in the Manual.

peak discharge

The maximum discharge occurring during a flood event.

Probable Maximum Flood (PMF)

The PMF is the largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation, and where applicable, snow melt, coupled with the worst flood producing catchment conditions. Generally, it is not physically or economically possible to provide complete protection against this event. The PMF defines the extent of flood prone land, that is, the floodplain. The extent, nature and potential consequences of flooding associated with a range of events rarer than the flood used for designing mitigation works and controlling development, up to and including the PMF event

	should be addressed in a floodplain risk management study.
Probable Maximum Precipitation (PMP)	The PMP is the greatest depth of precipitation for a given duration meteorologically possible over a given size storm area at a particular location at a particular time of the year, with no allowance made for long-term climatic trends (World Meteorological Organisation, 1986). It is the primary input to PMF estimation.
probability	A statistical measure of the expected chance of flooding (see AEP).
risk	Chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. In the context of the manual it is the likelihood of consequences arising from the interaction of floods, communities and the environment.
runoff	The amount of rainfall which actually ends up as streamflow, also known as rainfall excess.
stage	Equivalent to "water level". Both are measured with reference to a specified datum.
stage hydrograph	A graph that shows how the water level at a particular location changes with time during a flood. It must be referenced to a particular datum.
survey plan	A plan prepared by a registered surveyor.
water surface profile	A graph showing the flood stage at any given location along a watercourse at a particular time.
wind fetch	The horizontal distance in the direction of wind over which wind waves are generated.

Appendix B

Flooding Photos – November 2007

Photograph 1

Photograph 2

Photograph 3

Photograph 4

Photograph 5

Photograph 6

Photograph 7

Photograph 8

Photograph 9

Photograph 10

Photograph 11

Photograph 12

Photograph 13

Photograph 14

Photograph 15

Photograph 16

Photograph 17

Photograph 18

Photograph 19

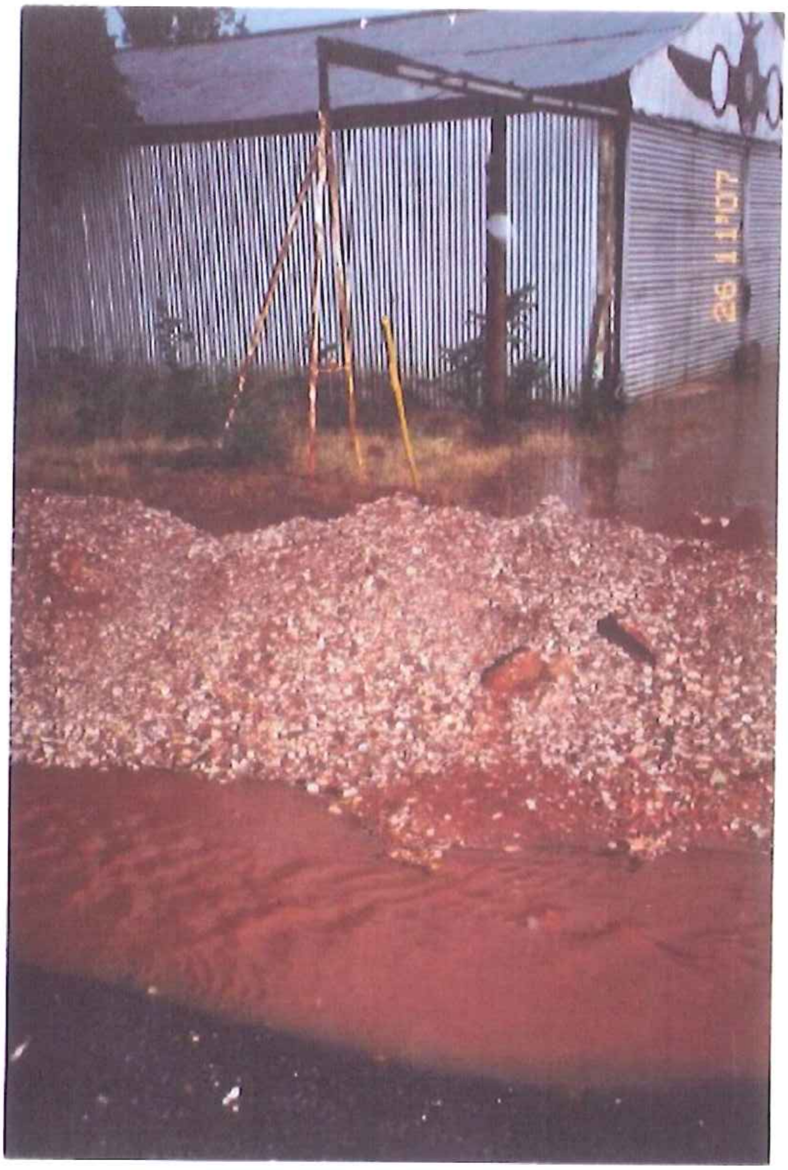
Photograph 20

Photograph 21

Photograph 22

Photograph 23

Photograph 24



Photograph 25

Photograph 26

Appendix C

Survey Brief

28077_090512_sg

13 May 2009

Attention: **Quoting Surveyor**

Re: Survey to facilitate Griffith Aerodrome Catchment Overland Flooding Study

PREAMBLE

Griffith City Council (GCC) has commissioned WMAwater (WMA) to undertake an overland flooding study of Griffith Aerodrome. The wider study area is shown in the attached Figure 1. Most data for the study is provided via Airborne Laser Survey (ALS). There is however a requirement to pick up details of topography which have changed since the date of ALS survey and also which are not able to be resolved by ALS.

The following Brief documents the detailed survey requirements of the project.

SCOPE OF WORK

The approximate location of the cross-sections required are shown in Figure 2. In some instances, data other than cross-sections are required (break lines, structure details, and floor levels). Note that the locations of cross-sections to be surveyed are shown in red. Break lines required are shown in green. Where invert levels and structure dimensions are required is shown via blue lines. Note that survey items located at or adjacent to road crossings are to provide details of the drainage structures and road levels in accordance with the General Specifications presented later in this document. The area described by a rectangle to the left of Figure 2 is where recent runway extension work has recently been carried out. Within this vicinity fresh runway has been laid, a levee has been constructed (small semi-circular bund) to the west of the runway extension and a small length of drain has also been dug (linking to

Webb, McKeown & Associates Pty Ltd (trading as WMAwater) **ABN 50 366 075 980**

DIRECTORS
M K Babister BE(Hons), MEngSc, GradDipMgt, MIEAust
G L Hurrell BSc, BE(Hons), MIEAust
R W Dewar BSc(Hons), MEngSc, MAIG, MIEAust

ASSOCIATES
M J Chadwick BE(Hons), MEngSc
E J Askew BE(Hons), MIEAust
S D Gray BE, MEng

Level 2, 160 Clarence St, SYDNEY NSW 2000
Phone: 02 9299 2855 Fax: 02 9262 6208
Email: enquiry@wmawater.com.au
Website: wmawater.com.au

existing drain to north of runway). Details required are: six points defining the start, end and internal location of top of bund, a single cross-section running from west to east along centre of runway to beginning of old runway extent, alignment of new drain and a single cross-section defining its capacity (at most upstream point).

Cross-sections surveyed will need to be taken in accordance with the general specifications of this Brief.

General Specifications

Preparation of the surveyed cross-section data should conform to the following specifications:

- Each surveyed point should include a survey code. The point coding shall readily identify the feature being surveyed.
- For watercourses, the locations of each surveyed cross-section should correspond as close as is practicable to the lines as indicated. However the location of the section can be moved to eliminate excessive vegetation clearing.
- The labelling of sections should follow a consistent protocol and clearly indicate which branch of the system the cross-section belongs to. Any labelling should be clearly marked and explained.
- Cross sections should be taken approximately perpendicular to the watercourse and are to include details of the streambed profile below the water surface and the overbank area to a width of approximately 10 m from top of bank. A representative photograph (or photographs) should be taken to show the terrain along the surveyed line and immediately upstream and downstream of each section.
- Where sections include culverts or bridge waterway crossings, the following information is needed:
  < *Culvert dimensions:* u/s and d/s inverts, length, height, width (or diameter), and section along the top of road.
  Bridge dimensions: bridge waterway details and section along top of road.

An appropriate photograph and diagram at any culvert or bridge showing these details is required on an A4 sheet. An example diagram is provided in Figure 3 (or you can just label the digital photograph accordingly). At these locations (i.e. at creek/channel crossings), there will need to be additional cross-sections surveyed both upstream and downstream of the structure. These cross-sections should be located approximately 10m away from the crossing or at a section which is representative of the typical watercourse upstream and downstream of the crossing.

- Excessive vegetation or other obstructions that are likely to restrict flood flows should be marked on the plans and photographed.

ADDITIONAL SURVEY NOTES

- All survey data is to be reduced to Australian Height Datum (AHD) and Map Grid of Australia (MGA94) co-ordinates. Heights should be given in metres AHD to 2 decimal places (e.g. 2.65 m) and distance in metres to 1 decimal place.
- Sections should show the distances relative to a zero point on the left bank looking downstream.
- Within the creeks, it is preferable to take more levels up the sides of the channel rather than to inadequately define a section. Data points should be taken at any significant change in grade.
- If property access issues are deemed to be an issue in completing this work, then please contact Duncan McWhirter at Griffith City Council on 69628113.
- The surveyor is to follow all DECC/Council protocols for entering private property and the relevant Occupational Health and Safety requirements for working in traffic.

DELIVERY OF DATA

Cross sections should be provided in digital form (on a CD or via email). An overall plan is to be provided showing all the data points, section names, floor level of buildings surveyed,and notes etc. Preferred digital formats include 12D or CivilCAD. A textfile should be returned with the ASCII listing of each section in the specified format (see Figure 4 attached). Note that the order of the points as listed should define the cross-section as if viewed from left to right looking downstream. Details of bridges/culverts can be provided as per Figure 3 or a suitably annotated photograph.

Could you please respond (email or fax) by COB Friday 29th May 2009 with a fixed priced quote and timeframe to undertake the above survey tasks.

If you have queries regarding any of the information requested above, please do not hesitate to contact me on (02) 9299 2855 or via email at gray@wmawater.com.au.

Regards,

Steve Gray

Associate

Appendix D

Damages Survey Forms

Questionnaire for airport users

Name	Gerard Peter Higgins
Company	Skycroppers
Address/Hanger location	PO BOX 761 Griffith NSW 2680
Contact details	6964 1919
Figure 3 ID number	28

	Questions	Answers
1	What type of business?	Agricultural Spraying
2	What type of equipment is in the building?	Planes, 4 PC's, chemicals on racks, Welders (x3), Tools
3	What is the building floor area?	60 sq. meters
4	How long have you been in this building?	15 years
5	Have you been flooded before? If so when?	8/9 years and had no flooding
6	If you have been flooded before how deep was the water and do you have a photo/flood mark?	x
7	If you have been flooded before what was the estimated damage cost?	x
8	How much do you estimate damages at if you were flooded to 0.1m or 0.5m?	Computers/ Electrical Equipment (0.5m delay)
9	If you were given warning could you get some items up off the floor?	Yes
10	How many hours a day is someone in the building? And what times?	6am - 9pm sometimes. Seasonal. Usually someone
11	If you were given warning how quickly could someone get to the hanger to move equipment off the ground?	Always someone there so irrelevant
12	Is there equipment currently on the ground which could be raised permanently?	Yes. Welders, PC's

Name	Mr. Ed Dowling and Shane McNaul
Company	Edsal Pty. Ltd. And Globe Promotions Pty. Ltd.
Address/Hanger location	Thompson Air PO BOX 1845 Griffith NSW 2680
Contact details	6964 9487 / 0427 649 487
Figure 3 ID number	11

	Questions	Answers
1	What type of business?	Aerial application and survey
2	What type of equipment is in the building?	Computers, Aircraft, Utes, Tools (Drill presses, Grinders), Maintanence machinery
3	What is the building floor area?	60m x 94m (so 5640 sq. meters)
4	How long have you been in this building?	14 years
5	Have you been flooded before? If so when?	Not in all 14 years
6	If you have been flooded before how deep was the water and do you have a photo/flood mark?	x
7	If you have been flooded before what was the estimated damage cost?	x
8	How much do you estimate damages at if you were flooded to 0.1m or 0.5m?	≈ $13 million
9	If you were given warning could you get some items up off the floor?	Yes
10	How many hours a day is someone in the building? And what times?	5am - 7pm
11	If you were given warning how quickly could someone get to the hanger to move equipment off the ground?	1 hour
12	Is there equipment currently on the ground which could be raised permanently?	No

Name	Mr Rhett Heffernan
Company	Combined Airwork Pty. Ltd.
Address/Hanger location	PO BOX 2264 Griffith NSW 2680
Contact details	6962 3469
Figure 3 ID number	23

	Questions	**Answers**
1	What type of business?	Aerial Spraying
2	What type of equipment is in the building?	Planes, Trucks, Computers, Specialised Equipment
3	What is the building floor area?	900 sq. meters or more
4	How long have you been in this building?	6 years
5	Have you been flooded before? If so when?	No, but its been close to flooding. Last time this happened was the last time it rained, maybe 6 months ago.
6	If you have been flooded before how deep was the water and do you have a photo/flood mark?	x
7	If you have been flooded before what was the estimated damage cost?	x
8	How much do you estimate damages at if you were flooded to 0.1m or 0.5m?	≈ $50,000 (for specialised equipment damage)
9	If you were given warning could you get some items up off the floor?	Yes
10	How many hours a day is someone in the building? And what times?	8am - 6pm (sometimes later)
11	If you were given warning how quickly could someone get to the hanger to move equipment off the ground?	10 minutes
12	Is there equipment currently on the ground which could be raised permanently?	No

Name	Gerry Wilcox
Company	Riverina Rotor Work Pty. Ltd.
Address/Hanger location	PO BOX 1456 Griffith NSW 2680
Contact details	6964 9433 / 0427 874 233
Figure 3 ID number	22

	Questions	Answers
1	What type of business?	Helicopters
2	What type of equipment is in the building?	Helicopters, Trucks, Computers
3	What is the building floor area?	18m x 12m (so 216 sq. meters)
4	How long have you been in this building?	11 years
5	Have you been flooded before? If so when?	Not in all 11 years
6	If you have been flooded before how deep was the water and do you have a photo/flood mark?	x
7	If you have been flooded before what was the estimated damage cost?	x
8	How much do you estimate damages at if you were flooded to 0.1m or 0.5m?	Not too bad (vehicles and helicopters relatively unaffected). Maybe $30,000
9	If you were given warning could you get some items up off the floor?	Yes
10	How many hours a day is someone in the building? And what times?	Daylight hours (varies)
11	If you were given warning how quickly could someone get to the hanger to move equipment off the ground?	30 minutes
12	Is there equipment currently on the ground which could be raised permanently?	No

Name	Peter Schofield Little
Company	
Address/Hanger location	1 Ortella Street, Griffith NSW 2680
Contact details	6962 2200
Figure 3 ID number	15

	Questions	Answers
1	What type of business?	Aircraft Storage (sounds like this is a personal investment not a business venture)
2	What type of equipment is in the building?	Aircraft (x3), Angle Grinders, Drills (not many though) and NO computers
3	What is the building floor area?	10m x 40m (so 400 sq. meters)
4	How long have you been in this building?	Since 2003
5	Have you been flooded before? If so when?	No
6	If you have been flooded before how deep was the water and do you have a photo/flood mark?	x
7	If you have been flooded before what was the estimated damage cost?	x
8	How much do you estimate damages at if you were flooded to 0.1m or 0.5m?	Could damage the engines on at least 2 of the aircraft
9	If you were given warning could you get some items up off the floor?	Could fly aircraft out
10	How many hours a day is someone in the building? And what times?	A few hours, usually someone around
11	If you were given warning how quickly could someone get to the hanger to move equipment off the ground?	Would need 3 people (to fly the aircraft), maybe 30 minutes
12	Is there equipment currently on the ground which could be raised permanently?	No

Name	Robert Milne Robilliard
Company	
Address/Hanger location	PO BOX 173 Griffith NSW 2680
Contact details	6962 4689 (disconnected) / 0428 693 983
Figure 3 ID number	7

	Questions	Answers
1	What type of business?	Aerial Spraying
2	What type of equipment is in the building?	Aeroplanes, Computers, Tools to maintain aeroplanes
3	What is the building floor area?	60ft x 120ft (so 18m x 37m or 657 sq. meters)
4	How long have you been in this building?	Since 1988
5	Have you been flooded before? If so when?	3 times (only since roads and drains changed)
6	If you have been flooded before how deep was the water and do you have a photo/flood mark?	Yes they have photos. A few inches deep
7	If you have been flooded before what was the estimated damage cost?	Cleaning carpet, undermines tiles
8	How much do you estimate damages at if you were flooded to 0.1m or 0.5m?	Carpet, tools rusting
9	If you were given warning could you get some items up off the floor?	Maybe, if someone was there (have been given warning previously and have used sandbags. But other times they've been away or its flooded at night and they couldn't do anything)
10	How many hours a day is someone in the building? And what times?	In drought, 20 hours/week
11	If you were given warning how quickly could someone get to the hanger to move equipment off the ground?	??? Live a few miles away
12	Is there equipment currently on the ground which could be raised permanently?	No

Name	Mr Dennis Couch
Company	Griffith Aero Club
Address/Hanger location	PO BOX 1447 Griffith NSW 2680
Contact details	6964 1666
Figure 3 ID number	26

	Questions	Answers
1	What type of business?	Air Agriculture
2	What type of equipment is in the building?	Planes, Computers, Office Equipment
3	What is the building floor area?	Unsure, just large
4	How long have you been in this building?	Since 1980's
5	Have you been flooded before? If so when?	Last time it rained
6	If you have been flooded before how deep was the water and do you have a photo/flood mark?	Yes (have already given to council)
7	If you have been flooded before what was the estimated damage cost?	Just had to clean carpet
8	How much do you estimate damages at if you were flooded to 0.1m or 0.5m?	?
9	If you were given warning could you get some items up off the floor?	Previously were given warning and sandbags to prevent water (so in answer to this, yes, I think)
10	How many hours a day is someone in the building? And what times?	Only a few hours
11	If you were given warning how quickly could someone get to the hanger to move equipment off the ground?	?
12	Is there equipment currently on the ground which could be raised permanently?	Maybe, unsure

The woman seemed unsure about a lot of the questions

Name	Maurice Leslie Makeham and Jennifer Makeham
Company	
Address/Hanger location	40 Doolan Crescent, Griffith NSW 2680
Contact details	6964 2899
Figure 3 ID number	20

	Questions	Answers
1	What type of business?	(Personal use I think)
2	What type of equipment is in the building?	Aeroplane, Boat
3	What is the building floor area?	She didn't know
4	How long have you been in this building?	3 or 4 years
5	Have you been flooded before? If so when?	Not in all that time
6	If you have been flooded before how deep was the water and do you have a photo/flood mark?	x
7	If you have been flooded before what was the estimated damage cost?	x
8	How much do you estimate damages at if you were flooded to 0.1m or 0.5m?	None (they have concrete floors and they hose out the hanger on occasion)
9	If you were given warning could you get some items up off the floor?	
10	How many hours a day is someone in the building? And what times?	
11	If you were given warning how quickly could someone get to the hanger to move equipment off the ground?	
12	Is there equipment currently on the ground which could be raised permanently?	