University of Southern Queensland

Faculty of Engineering and Surveying

An Investigation Into The Suitability Of Volunteered Information To Create A Flood Extent Map

A dissertation submitted by

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Abstract

Much flood destruction is due to humans' desire to live near water. Accordingly, there is a need for accurate flood extent maps, so that we may be prepared for repeat flood events. The advent of the internet, coupled with the proliferation of GPS and camera-equipped mobile devices has led to a marked increase in the production of volunteered information. Flood extent mapping may benefit from additional sources of data, which could be provided by these devices.

This project developed the mapping of flood extents from volunteered photography and other available data. The specific objectives were to:

- Research existing flood extent creation methods.
- Collect private media featuring the 2011 Brisbane flood high-water mark.
- Collect a topography Digital Elevation Model (DEM) of the target area.
- Create a series of 3D points from the high-water marks.
- Process collected points to create a TIN model; intersect this with topography TIN model to arrive at extent map.
- Compare and document produced extent map to that released by the Surveying and Spatial Sciences Institute (SSSI).

The online photography site flickr provided the majority of the flood imagery. Most of these marks were able to be collected using RTK GPS. Two topography models were obtained, and three Triangulated Irregular Network (TIN) models created from the collected points. A total of five extent maps were created. This study concluded that volunteered photographs were well suited as a source of additional data to create a flood extent map. It also found that the accuracy of the produced extent map is greatly influenced by the accuracy of the topography DEM used. For best results, the topography DEM should be at least as accurate as the collected data. Advances in photogrammetry software or mobile device-based GPS may greatly automate the collection of flood levels in the future.

University of Southern Queensland

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ENG4111 Research Project Part 1 &
ENG4112 Research Project Part 2

Limitations of Use

Professor Frank Bullen
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Certification

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

Student Name: Philip Temple-Watts
Student Number: W0085542

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Signature

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Date

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Table of Contents

List of Figures

List of Tables

Glossary

DEM	Digital Elevation Model
TIN	Triangulated Irregular Network
AHD	Australian Height Datum
PM	Permanent Mark
Exif	Exchangeable Image File Format
QGIS	Queensland Geographical Information Service
DERM	Department of Environment and Resource Management
SSSI	Surveying and Spatial Sciences Institute

Chapter 1 Introduction

1.1 Project Background

Floods are one of the most destructive natural disasters that threaten us. In recent decades, they have claimed more lives, destroyed more houses, and ruined more fertile land than any other natural hazard (Rodda & Crichton 2011). Many areas on Earth are vulnerable to flooding – anywhere that rain falls is potentially at risk, although rain is not the only cause of floods.

Flooding occurs when water overflows or covers land that is usually dry (National Geographic 2011). There are a number of ways this can happen. The most common cause is excessive rain resulting in rivers or streams overflowing their banks. Coastal flooding occurs due to large storms or tsunamis causing the sea to rush inland (National Geographic 2011).

A flood is classified according to its likelihood of occurring in a particular time period. Of particular interest are once in one hundred-year floods, as these are typically extremely large, destructive events. Statistically, these floods are expected to happen only once per century. In reality however, there is a 1% chance of them occurring in any given year. Recently, floods of this magnitude have been happening worldwide with concerning regularity (National Geographic 2011).

Much flood destruction is as a result of humans' desire to live near water – river valleys and coastal areas are often picturesque. As a result, there is an increasing need for accurate flood modelling and flood extent mapping for past flood events, so we may be prepared for future events. Presently, flood extent maps are created by analysing three sources of data: optical, radar, or river gauge. Optical data includes aerial photography and satellite imagery, on which the flood extent can be seen. Synthetic Aperture Radar uses satellite-mounted radar to distinguish between flooded and dry areas. River gauge water level data can be used to 'flood' a topography model to determine flood extent. With the advent of the internet, and in particular the widespread use of GPS-enabled mobile devices capable of taking photos, there has been a marked increase in the amount of volunteered information being produced. This presents a unique potential source of data to create a flood extent map. Photos containing the high water mark could be used to create a flood model, and by extension an extent map.

1.2 Project Aims and Objectives

1.2.1 Project Aims

This dissertation aims to develop the mapping of flood extents from volunteered photography and other available data. Using the photographic information and river gauge water levels, three flood surface models will be created. A series of flood extent maps will be produced by intersecting the flood surface models with a topography model. These will then be compared to the official flood extent map produced by the Surveying & Spatial Sciences Institute (SSSI), and the results documented.

1.2.2 Project Objectives

The project's objectives are as follows:

(i) Research the methods of establishing flood extents including hydrological modelling and other techniques.

(ii) Collect geo-referenced private media that features the flood high-water mark.

(iii) Undertake appropriate fieldwork to connect each high-water mark to the Australian Height Datum (AHD) to create a series of 3D points.

(iv) Collect topography Digital Elevation Model (DEM) of target area.

(v) Process the series of points to create three Triangulated Irregular Network (TIN) models of flood surface and intersect these with topography DEM to arrive at flood extent maps.

(vi) Compare and document the produced flood extent maps against that established officially by SSSI.

1.3 Scope of the Project

This project does not set out to offer an alternate method of creating a flood extent map. Instead, it aims to assess the suitability of volunteered photographic information as a data source for an existing method. The methodology employed during the project is resource-inefficient relative to existing data-collection methods. Using river gauge data to ‘flood’ a topography model requires only the model, and river gauge water levels. The Floodwarn river height stations in Queensland provide water levels automatically on a regular basis. This project collects volunteered geo-referenced photos (photos taken from a known location, either due to metadata, or user-supplied captions), and uses GPS to derive a water level for each photo. It is conceivable that advances in online mosaicing software could automate collection and processing of volunteered information for this purpose.

1.4 Justification

Hingray et al. (2000) state that worldwide, urbanisation is a growing trend, therefore urban flood hazards are occurring increasingly frequently. Consequently, there is a need for accurate flood models and extent maps, such that cities can be prepared for flood events. The present data sources and methods of creating extent maps have a number of limitations. Optical data must be collected in daylight, and satellite-based images can only be collected whilst a satellite is overhead – this may not coincide with the peak of the flood. Synthetic Aperture Radar (SAR) is a side-mounted microwave radar satellite-mounted system that precisely measures phase and Doppler shift. This allows creation of a synthetic aperture equivalent to the distance the antenna moves while a particular location remains in the beam (McCandless & Jackson n.d.). SAR also suffers the revisit time limitation, as well as being considerably more expensive than optical data. The third common data source/method - using a combination of topography Digital Elevation Models (DEMs) and river gauge tide data suffers from limited data. Volunteered photographic information could provide this last method with much more data. It is conceivable that software could be developed to automate the majority of the process. This project will assess the suitability of using this volunteered information in such a process.

The 3D coordinates collected during this project could be used to calibrate any future studies that apply a flood model to the January 2011 Brisbane flood. The project will also demonstrate a new application for volunteered information.

1.5 Chapter Summary

This project assesses how suitable volunteered photographic information is as input data to create a flood extent map. Present data sources for producing flood extent maps are limited; volunteered photographs may prove ideal to supplement existing sources for one method of extent map creation.

The subsequent chapter is a literature review that examines the existing knowledge relevant to the areas of study for this paper. Key focus topics are: flood model validation and calibration, Digital Terrain Model (DTM) sources, methods for creating flood extent maps, and current sources/uses of volunteered information. This review will provide the necessary knowledge base for the study of volunteered photographic information as a data source to create a flood extent map.

Chapter 2 Literature Review

2.1 History of Flooding in Queensland

Most of the major floods in Queensland occur in summer or early autumn due to tropical cyclones or intense monsoonal depressions (Bureau of Meteorology n.d.). These systems are capable of producing extreme quantities of rainfall in short periods of time. At Bellenden Ker in North Queensland, tropical cyclone "Peter" caused 1,947mm of rain in January 1979 during a 48 hour period. In 1999 cyclone "Rona" produced 1,870mm in 48 hours at the same location (Bureau of Meteorology n.d.).

Prior to 1860 three major floods were reported for the Brisbane/Ipswich regions, with the January 1841 flood having the highest recorded level of 8.43m at Brisbane (Bureau of Meteorology 2010a). A further five major floods inundated Brisbane and Ipswich between 1885 and 1900. In 1891 the Brisbane River peaked at 8.3m, and the Bremer River at 24.5m – its highest recorded level (Centre for the Government of Queensland n.d.). The Bremer River experienced an additional nine major floods between 1900 and 1972. It was not until 1974 however, that Brisbane and Bremer Rivers flooded to 5.45m and 20.7m respectively – the highest levels since 1893 (Bureau of Meteorology 2010b,c). A summary of these flood levels can be found in Figure 2.1 below.

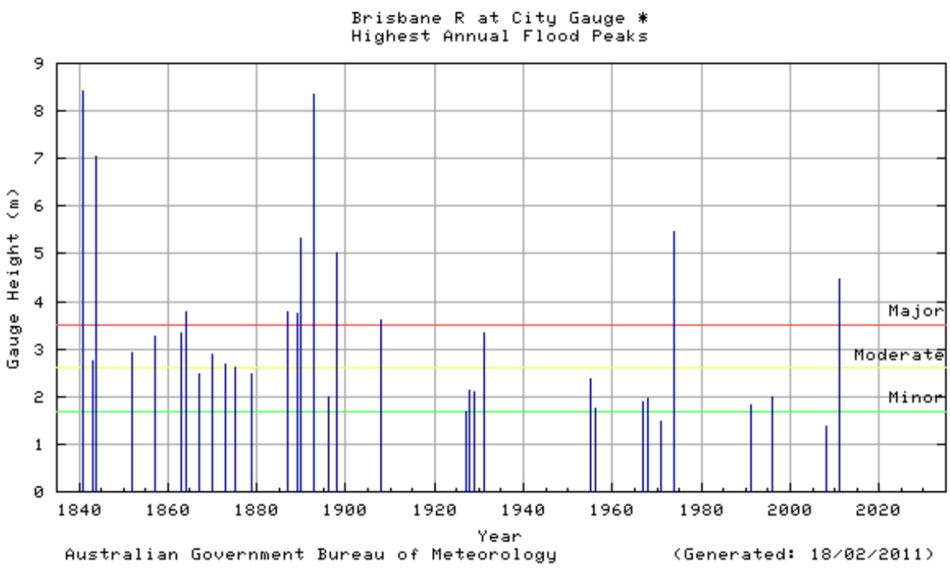

Figure 2.1: Highest Annual Flood Peaks, Brisbane River at City Gauge (BoM 2011b, p. 4)

A couple of photos from the 1974 floods are featured in Figures 2.2-2.3 below.

Figure 2.2: Brisbane City, Monday 28 January 1974 (Sunday Mail 1974)

Figure 2.3: University of Queensland, St Lucia, January 1974 (John Oxley Library 1974)

2.2 Early Warning Systems

"An early warning system is a set of procedures designed to protect human lives and minimise damages to be expected from a flood which exceeds a certain critical level" (Plate 2007). It is made up of a series of related and connected parts: forecasting, turning the forecast into a warning, transmission of the warning to the threatened population, and conversion of the warning into remedial action (UN/ISDR 2004). Floods can be forecast because of the lag between rainfall and transformed flow (which is sensitive to the size of the basin), if the river flow at some point is known in conjunction with a hydrologic model (Hossain & Katiyar 2006). Once an extreme event is forecast, a warning must be generated. This must be in a format appropriate for the threatened population. Once generated, the warning needs to be transmitted in a manner that reaches the target audience. The duly alerted population should then take the necessary remedial action.

The Queensland flood warning network derives its data from a series of rainfall and river height stations (Bureau of Meteorology 2011a). There are two types of rainfall station in use by the Bureau of Meteorology (BoM): Floodwarn and Daily Reporting. The Floodwarn rainfall stations are automated systems designed specifically for flood warning purposes. They are classified either 'manual', reporting every 25 or 50mm of rainfall, or 'automatic', reporting every 1mm of rainfall. Daily reporting rainfall stations consist of manual and automatic stations that report the rainfall received in a 24 hour period to 9am each day (Bureau of Meteorology 2011a). Finally, Floodwarn river height stations have both manual and automatic varieties. They report river levels whenever the water reaches a threshold height, and at regular intervals thereafter.

The Bureau of Meteorology's Flood Warning Centre receives the data provided by these stations, and uses it in hydraulic models to produce river height predictions (Bureau of Meteorology 2010b). In the event of an expected flood, the Flood Warning Centre issues warnings to radio stations, Councils, emergency services and various other agencies involved in flood response activities (Bureau of Meteorology 2010b). This enables threatened persons to take appropriate action and minimise risk and hazard.

2.3 Types of Flooding

A flood is 'the temporary covering by water of land not normally covered by water' (EU Floods Directive 2007, p. 29). Various flood types include: flash floods, coastal floods, urban floods, river floods and pluvial floods. A flash flood is "a flood that rises and falls quite rapidly with little or no advance warning, usually as the result of intense rainfall over a relatively small area" (American Meteorological Society 2000). A coastal flood occurs when the coast is flooded by the sea. This is usually caused by severe storms whose wind creates high waves (FLOODsite Consortium 2008). Urban areas can be inundated by flash floods, coastal floods, or river floods, however urban flooding is also a specific flood type. It occurs when high intensity rainfall causes drainage and sewerage systems to overflow. Pluvial floods are also referred to as ponding. Merriam-Webster (2011) defines pluvial as 'resulting from the action of rain'. A pluvial flood therefore, occurs when more rainwater enters a water system than can be managed and controlled. They are similar to urban floods, but without the sewage systems, and in more rural areas (FLOODsite Consortium 2008). 'Riverine flooding occurs when heavy rainfall causes relatively high water levels in rivers or creeks to overtop the banks' (Northern Territory Government 2007). The primary focus of this study relates to riverine flooding in urban areas.

2.4 Urban Flood Modelling

There has been a significant amount of research done towards the creation of flood models, and associated topics. Much of the work between 1999 and 2005 focused on creating models that were tested in rural areas (Ervine & Macleod 1999; Bates & DeRoo 2000; Bates & Horritt 2001). A number of these models were later utilised to predict flood inundation levels in urban areas (Bates & DeRoo, 2000; Yu & Lane 2006). A 1D model measures flood levels in the channel, whereas a 2D model measures flood depth for the extent of the floodplain.

Gallati and Braschi (cited in Haider et al. 2003, pg. 129) undertook pioneering work in 1990 by applying a simplified 2D depth-averaged model to the Florence flood. The obtained results were close to the available data, with the model showing good behaviour (Gallati et al. cited in Soulis 1992, p. 632).

Haider et al. (2003) felt that in the face of an increase in the incidence of floods, there was a need to apply the most recent hydraulic models to the problem of urban flooding. It was found that a 2D model provided water levels close to measurements. Mignot, Pacquier and Haider (2006) found that with calibration, for the city of Nimes, France, a 2D model could predict flood levels with a standard deviation of about 50cm. A coupled dynamic 1D-2D model (ESTRY-TUFLOW) was compared to a simplified 1D-2D model (LISFLOOD-FP) using data from the 2005 Carlisle flood. It was found that the dynamic model was more robust, with changes in calibration values resulting in less deviation from actual water levels (Fewtrell et al. 2011).

One limit to raster-based flood models is the resolution of cells used in the model – if they are too small the computational requirements became restrictive (Haider et al. 2003). Yu and Lane (2006) investigated the effect of model cell size for models applied to urban areas, and concluded that even small variations in model resolution have significant effects on inundation extent. Accordingly, as processing power increases, using progressively smaller cell sizes will be a viable option.

2.5 Flood Model Validation / Calibration

Bates (2004) noted that ‘until recently’, primarily bulk flow measurements made up the validation data for hydraulic models. Many models can be made to fit this data, giving good results, but with a wide range of input values for common parameters. Therefore, lack of distributed validation data is the cause of equifinality. Finally, remotely sensed data is one possible solution to this problem.

Henry et al. (2006) focused on the new capabilities of the ASAR sensor of the Envisat (Environmental Satellite). It was found that the data allowed flood damage maps to be promptly produced, often hours after data acquisition. These could then be used for flood model validation.

Di Baldassarre, Schumann and Bates (2009) compared two resolutions of remotely sensed imagery to produce flood extent maps, which were then used as validation data for a raster-based inundation model. They encountered equifinality and concluded that there is a need to move from binary, i.e. wet/dry maps, to uncertain flood extent maps or ‘possibility of inundation maps’.

Another source of calibration data for flood models is distributed flood water levels. Werner, Blazkova and Petr (2005) determined that constraining model uncertainties using distributed floodplain level observations allows for greatly improved reliability of flood inundation modelling in urban areas. Mason, Bates and Dall' Amico (2009) found that using water surface elevations along flood boundaries as calibration data afforded faster production of flood extent maps due to restricting the input parameters. However upon evaluation, the modelled uncertainty map was found to be significantly different to the observed flood extent. This was attributed to the simplicity of the flood model employed.

A large series of distributed water levels were collected for the flood of Carlisle, UK, in January 2005. This afforded a unique opportunity for flood model validation. Neal et al. (2009) capitalised on this, and assessed the LISFLOOD-FP model. They noted a root mean squared error (RMSE) value of 0.28m for maximum water level.

2.6 DTM Sources

Urban flood modelling requires digital terrain models (DTMs) of high resolution and accuracy (Mason et al. 2007). DTMs can be produced from a number of different data sources. These include:

- Elevation contour maps
- GPS survey
- Interferometric synthetic aperture radar (IfSAR)
- Light detection and ranging (LiDAR)

Casas et al. (2006) analysed the effects of DTM data sources on the reliability of a 1D hydraulic flood model. It was found that a DTM derived from a 5m contour map was the least accurate, in the order of 50% error for estimation of the area of inundated floodplain. The GPS-based and laser-based (LiDAR) models allowed for significantly more accurate results with errors of 8% and 1% respectively. Sanders (2006) drew similar conclusions upon analysing a series of on-line DEMs: LiDAR provided the most accurate results, followed by IfSAR. One point to note is that airborne IfSAR based data is really a digital surface model (DSM) rather than a DTM, so that features such as buildings and bridges are resolved. Therefore, further processing is required to produce a DTM. IfSAR DEMs may also be prone to radar speckle contamination, adding noise or undulations to surfaces that would otherwise be flat (Sanders, 2006).

LiDAR data collected for the purposes of flood modelling was found to have a vertical accuracy of between 7 and 14cm RMSE, dependent on post-processing method (Gomes Pereira & Wicherson 1999). Horizontal accuracy was found to be +/- 5cm (Environmental Agency, cited in Marks & Bates 2000).

Sanders (2006) noted that IfSAR data had a horizontal and vertical accuracy of 3m and +/-2.5m (RMSE) respectively. Casas (2006) made the observation that with GPS, 'the final data quality achieved depends on the accuracy of the survey equipment and the density and distribution of measured points.' A similar concept is of course true for elevation contour maps. The contour interval and scale of the map will determine its accuracy.

A method for producing a DTM suitable for urban flood modelling using fused LiDAR and digital map data was outlined by Mason et al. (2007).

2.7 Creating Actual Flood Extent Maps

The primary goal of flood mapping is to identify areas that are flooded or not flooded. This process consists of two steps – (1) determining wet/dry areas before and during a flood event, and (2) comparing these areas to determine which areas were flooded. Three main data sources are used to map flood extents: optical data, radar data, and topographic and river gauge data (Wang 2002a).

Optical data include aerial photographs and satellite data (such as from a Landsat Thematic Mapper (TM) sensor). Thanks to different reflectance responses of dry and wet or water surfaces, aerial photographs and TM data can easily distinguish between surfaces (Wang 2002a). Wang (2002a) also concluded that using TM data for flood extent mapping is:

1) Reliable and accurate;
2) Simply applied: geo-reference two TM images, identify wet/dry areas, and compare before/after imagery;

3) Efficient and cost-effective.

There are limitations to using TM data however. As a satellite has a fixed orbit pattern, its revisit time (the time taken between subsequent collection of data from the same location) may mean data is collected long after a flood has receded. The revisit time for the Landsat 7 satellite is 16 days (Satellite Imaging Corporation n.d.). The limited spatial resolution of TM data may be too coarse for identifying small flooded areas, particularly in vegetated, commercial, or residential areas. Additionally, the TM sensor does not penetrate vegetation well, so flooding may not be reliably detected under the canopy (Wang 2002b). Finally, both TM data and aerial photography must be collected during the day and will not penetrate cloud cover.

The same basic principle to determine flood extent i.e. detection and comparison of wet/dry surfaces before and during a flood applies also to extent mapping when using radar data. The key advantage in using SAR data over optical data is the ability of radar microwave to penetrate cloud cover and forest canopies (depending on wavelength) (Wang 2002a). Because current SAR sensors are satellite-mounted, this system suffers from the same revisit time limitation as TM data. In addition, the data is expensive – in the order of 5-8 times more than TM data covering the same area (Wang 2002a).

Finally, using topography DEMs and river gauge data is perhaps the simplest of the three methods. It involves getting river levels before a flood, and during its peak for each gauge, and then flooding a DEM – once with the pre-flood levels, and once with peak levels. The inundated areas can then be compared to determine existing bodies of water, and flood extent (Wang 2002a). Advantages of using this data include: 1) Data is reliable and accurate, 2) Methodology is simple, efficient, and economical, and 3) The data is easily updated. Its limitations include: only being able to map areas that have flood gauges, and it is sensitive to the accuracy of the input DEM (Wang 2002a).

2.8 Volunteered Information/Social Networking

Goodchild (2007) defines volunteered geographic information (VGI) as spatial information collected voluntarily by private citizens. Geo-tagged images submitted by individuals to the web may therefore be considered VGI. Goodchild (2007) outlines some popular examples of VGI, including: Wikimapia <http://wikimapia.org>, Flickr <http://www.flickr.com/>, and OpenStreetMap < http://www.openstreetmap.org/>. Wikimapia lets anyone with an internet connection select an area of the Earth's surface, and provide it with a description. Flickr allows users to upload photos and tag them with a latitude and longitude. Finally, OpenStreetMap is 'an editable map of the whole world, which is being built largely from scratch, and released with an open content license' OpenStreetMap (2011).

Social networking also played a major role in keeping people informed during the Brisbane January 2011 flood. Ushahidi are a non-profit tech company that specialises in developing free and open source software for information collection, visualisation and interactive mapping (Ushahidi 2011). Crowdmap is an on online interactive mapping service, based on the Ushahidi platform (Crowdmap 2011). It offers the ability to collect information from cell phones, news and the web, aggregate that information into a single platform, and visualise it on a map and timeline. The Australian Broadcasting Corporation launched QLD FLOOD CRISIS MAP – a crowdmap of the Queensland floods in January 2011 (ABC 2011). This crowdmap allowed individuals to send flood-related information via email, text message, Twitter, or via the website itself (ABC 2011). This information was then available to anyone with an internet connection. The Courier Mail also provided a similar service, but only allowing people to submit photos, via email (Courier Mail 2011).

The social networking service Twitter <www.twitter.com> allowed people to post and receive short text based updates about the flood in real time. Photos and videos were also able to be attached to these updates. Similarly, the website Facebook <www.facebook.com> allowed groups such as the Queensland Police Service to provide flood information updates to anyone who browsed to their Facebook page (Queensland Police Service 2011). Finally, YouTube <www.youtube.com> provided a forum for people to connect and inform through the use of user-generated and contributed videos.

Chapter 3 Methodology

3.1 Introduction

To assess the suitability of volunteered photos to create a flood extent map, it was necessary to separate this project's study into three main sections of work. These are: data collection, data processing, and results analysis. Firstly, the data collection stage was broken down into three tasks: obtaining geo-referenced private media featuring the flood high-water mark, collecting 3D coordinates for each mark, and obtaining topography DEM of target area. Secondly, the data processing stage involved processing the series of coordinates to obtain a TIN of the flood surface, and extrapolating this onto the topography DEM to derive a series of extent maps. Finally, the resulting maps were compared to the one produced by the SSSI.

3.2 Study Area

The chosen study area was located in the lower Brisbane River and Oxley catchments and bounded by the extent of the collected river gauge and photographic data. These catchments cover a combined area of 1,453km^2. Their dominant land uses are urban, native bush, grazing and rural residential. They are highly modified, urbanised catchments with riparian vegetation having been cleared from most waterways. There is a large volume of stormwater runoff into the waterways during and after storm events, and population growth is a major pressure on both catchments (Healthy Waterways 2011a, b).

The study area covers an area of 159.54km^2. This area was selected as it offered the highest concentration of suitable flood imagery. Figure 4, overleaf, shows the area in detail.

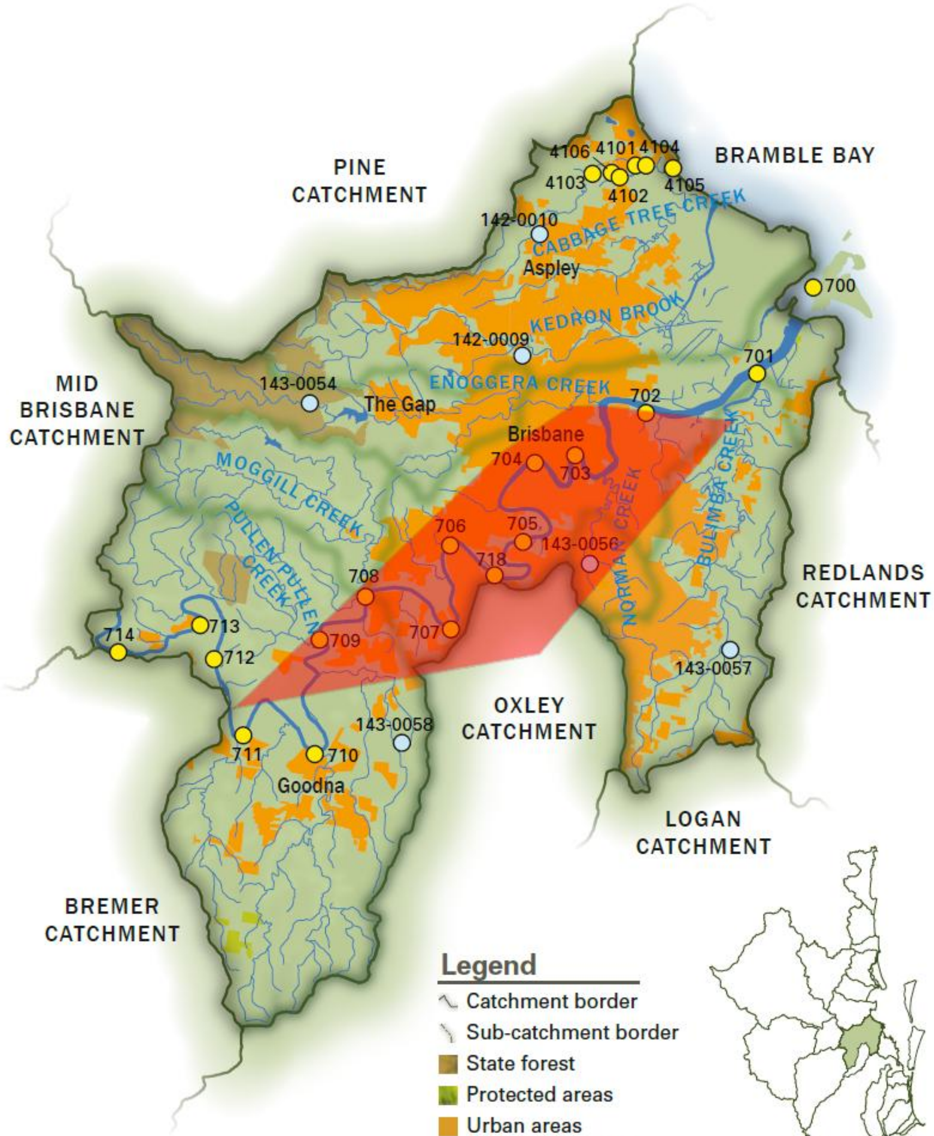

Figure 3.1: Study Area (adapted from (Healthy Waterways 2011a))

3.3 Data Collection

3.3.1 Collect private media featuring the flood high-water mark.

The first step of the data collection stage was to obtain private media that clearly feature the high-water mark of the January 2011 Brisbane flood. It was a requirement that these media be geo-referenced, so that their location could be readily identified. The flood peaked at 4am on the 13th of January 2011. Some areas experienced non-riparian peaks due to local rainfall before this time. Consequently, in order to ensure the media features the peak flood levels, they will need to have been produced after 4:00am on the 13th. This was established from Exif metadata time-stamps. Where Exif tags were not present (or it was clear they were incorrect) only photos that did not feature bodies of floodwater were selected.

The vast majority of media was obtained from the online photography website flickr http://www.flickr.com. The social networking site Facebook http://www.facebook.com also provided useful results. Finally, one image was sourced from Picasa Web http://picasaweb.google.com/. tumblr http://www.tumblr.com, photobucket http://photobucket.com, and the image search functionality of Google http://www.google.com.au, Bing http://www.bing.com, AltaVista http://au.altavista.com, and Yahoo http://search.yahoo.com were also searched, but did not provide any useable images not already discovered with flickr and Facebook. In order to produce a TIN with enough detail for any patterns to be evident, it was determined a minimum of 30 points would need to be collected. Therefore, a minimum of 30 photos showing the high-water mark were required. A total of 51 geo-referenced images were collected. After discounting duplicate shots of the same scene, 43 unique images remained. Three sets of before and after photos can be found in Figures 3.2-3.7. The remainder of photos can be found in Appendix B.

Figure 3.2: McIlwraith Croquet Club, Auchenflower, January 2011 (Bannerman 2011a)

Figure 3.3: McIlwraith Croquet Club, Auchenflower, July 2011

Figure 3.4: Munro St, St Lucia, January 2011 (Sparshott 2011b)

Figure 3.5: Munro St, St Lucia, July 2011

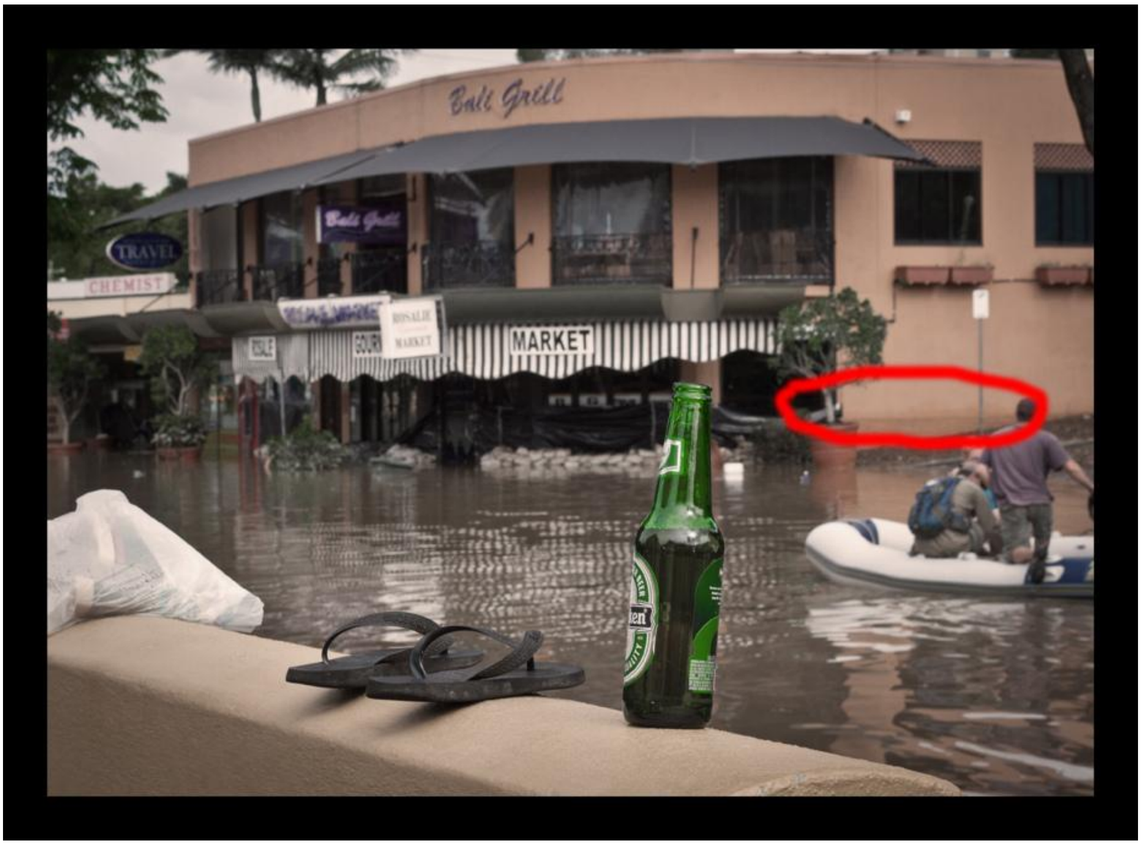

Figure 3.6: Agars Rd, Baroona, January 2011 (McIntosh 2011)

Figure 3.7: Agars Rd, Baroona, July 2011

3.3.2 Undertake fieldwork to connect each mark to the AHD.

A Trimble R8 GPS receiver with TSC2 controller and TDL 3G cellular modem utilising VRS corrections was used in RTK mode to collect 3D coordinates for each high-water mark. This equipment can be seen in Figure 3.8 below.

Figure 3.8: GPS Equipment

VRS or Virtual Reference System provides real-time network modelled corrections to RTK roving receivers. The VRS corrections employed for this study were using the CMR (Compact Measurement Record) protocol, broadcast via NTRIP (Networked Transport of RTCM via Internet Protocol). The NTRIP protocol is designed to stream GNSS data over the internet. Ultimate Positioning provided access to their VRS network corrections. A test using two permanent marks (PM) with known coordinates showed the system was operating with sub-centimetre accuracy in the horizontal, and within 0.13m in the vertical. This vertical difference can be attributed to variations in the employed geoid models. See Appendix C for details.

This GPS setup was used to successfully collect a total of 31 points including the two PMs. A list of these and their coordinates appears in Table 3.1.

Table 3.1: High-water mark coordinates

Name	Northing	Easting	Elevation	Feature Code
NetR5 50	6964864.734	504105.535	14.033	Base
knm-10443	6956657.563	494542.643	51.531	2
knm-55918	6956692.724	493841.907	60.906	2
auc-bowls	6960701.098	499612.955	2.212	50
bell-pharm	6951233.266	488999.706	11.838	50
city-coro	6960407.65	499791.196	3.757	50
ffield-7-11	6957269.814	502445.219	5.014	50
jin	6954191.314	493555.141	13.46	50
mil-eagle	6961416.475	499977.1	4.651	50
mil-heu	6962087.368	500670.584	6.049	50
mil-qmas	6962176.94	500833.422	7.747	50
nfm-153syd	6961933.881	504987.215	2.264	50
nfm-colespk	6961913.862	504666.323	3.041	50
nfm-ferry	6962335.441	505017.039	3.03	50
nfm-liquid	6961771.777	504599.393	2.876	50
nfm-welsby	6961978.965	504774.58	2.498	50
rock-650	6952507.502	502033.69	9.215	50
rock-hjs	6951693.511	501636.286	9.051	50
rock-pub	6952465.061	501995.453	5.38	50
ros-agars	6961913.052	499687.255	5.262	50
ros-nash	6962060.96	499685.89	6.083	50
sher-chancellor	6954924.998	498782.679	8.038	50
sher-hall	6954737.027	498558.463	9.174	50
sth-corv2	6960810.475	501570.115	4.201	50
sth-qpac	6961016.392	502018.53	5.298	50
stl-bellevue	6958832.248	499602.131	11.269	50
stl-eric	6959061.569	501189.672	5.797	50
stl-munro	6958932.462	500595.09	3.893	50
tar-per-sign	6959133.1	498968.429	7.035	50
tar-shell	6959116.408	499400.33	6.797	50
tar-sir-fred	6958802.643	500237.53	7.044	50
tar-west	6958670.401	498933.558	6.018	50

A number of locations were unsuitable for GPS collection – the receiver was unable to gain or maintain initialisation for the selected collection time of 5 minutes. In a number of cases, reconstruction efforts meant that the high-water marks were no longer accessible, or the surface in question had been demolished. For 15 of the points, a total station was utilised to transfer a level to a location that could be reliably collected with

GPS. The horizontal displacement of the furthest point was approximately 15m. The levels were transferred to locations with a ground level below the high-water mark, such that the resulting points would not be underground. This was only done in locations where there was minimal vertical elevation change in the area, to avoid possible variations in water heights.

The collected data was imported into Trimble Geomatics Office (TGO), checked for consistency, and then exported to an AutoCAD DWG file.

This data was then supplemented with peak water level records from Queensland Flood Warning River Height Stations for the January flood period. AHD heights of the stations were obtained from the Bureau of Meteorology website at http://www.bom.gov.au/hydro/flood/qld/networks/section6.shtml. Water heights were then added to these AHD levels to arrive at final water levels. This data was then exported to another AutoCAD DWG file.

A third AutoCAD DWG file containing only the river gauge data was also exported.

3.3.3 Collect topography DEM of target area.

The target area was determined from the coverage afforded by the series of coordinates collected during the previous task. An initial comparison was completed using the South East Queensland 25m digital elevation model (DEM) sourced from the Department of Environment and Resource Management (DERM). Two excerpts from the metadata state:

> "ANUDEM version 4.6.2 was used to produce a 25 metre floating point grid. Source digital data were contours and drainage (scanned repromats) from AUSLIG 1:100000 mapsheets with a 20 metre contour interval for most areas. Drainage lines were pointed in the direction of flow. A hillshade of the DEM was used to identify errors in source drainage and contour data that were previously missed. The errors, including wrongly directed drainage and wrongly labelled contours, were fixed though some errors may remain." "The accuracy of this DEM depends on the accuracy of the source data and the error of ANUDEM`s interpolation. The average accuracy of

AUSLIG's 1:100000 source data is + or - 25 metres in the horizontal position of well defined detail and + or - 5 metres in elevation for most mapsheets" (Department of Environment and Resource Management 2010a).

The accuracy for mapsheet 9543 (Brisbane) was not specifically noted. The dataset that obtained useful results was a 10m contour map. The metadata states:

"This data is extracted from a dataset covering 90% of Queensland that consists of contour features generated from the Space Shuttle Radar Terrain Model (SRTM) 3 second DEM with a ten metre contour interval. The radar used by the SRTM does not penetrate thick vegetation and in such areas the contours generated represent the top of the canopy rather than bare earth while in lightly vegetated areas the contours represent bare earth. In a worst case scenario, the accuracy in heavily vegetated areas may be +-16m in the vertical, while in open areas it may be as good as +-5m. This data is suitable for use in 1:50000 mapping and seamlessly integrated with the 10 metre contours generated from the orthophotography DEMs and the 5 contours captured by photogrammetry, form a continuous dataset of 10 metre contours across the entire state" (Department of Environment and Resource Management 2010b).

This dataset was sourced from the Queensland Government Information Service (QGIS) and is based on AHD.

3.4 Data Processing

3.4.1 Create extent maps from TIN models created from collected points.

ArcCatalog 10 was used to assign GDA94/MGA zone 56 coordinate systems to the AutoCAD files. A new project was created in ArcMap 10, and four triangulated irregular network (TIN) models created – one from the 10m contour topography data, one from the river gauge data, one from combined river gauge and GPS data, and one from only the river gauge data. ArcMap's surface difference function was then used to compute where the two TINs intersected. This process was undertaken for each of the three flood TIN/topography TIN pairs. These then formed a series of extent maps.

3.5 Results Analysis

3.5.1 Compare and document produced flood extent maps to SSSI map.

The SSSI extent map was created using aerial flood imagery that was flown over a number of days between the 13th to 15th January and pre-flood aerial imagery (Department of Environment and Resource Management 2011).

> "This line was verified against digital elevation models and contours (LiDAR). It was measured against 1000 observed flood points taken from aerial photography and 100 surveyed debris marks. The line was captured by Spatial Information Officers using MapInfo GIS software. The completeness of the data is dependent on image quality and the ability to identify feature detail. Inaccuracies may exist particularly in the Brisbane CBD area due to high rise buildings, areas of heavy vegetation along the river banks and also low lying flat areas such as near the mouth of the Brisbane River" (Department of Environment and Resource Management 2011).

Each of the produced extent maps and the official one were rasterised with a 5m grid. The raster datasets were then reclassified such that the inundated areas stored a value of 1, and the dry areas had a null data value. The total number of cells in each of the produced maps was noted. The SSSI extent map was then used as a baseline to determine the accuracy of the other maps. A raster minus operation was calculated between the SSSI map and each of the produced maps to determine the common area between each pair. The non-common area was then also calculated. The ratio between the number of non-common and common cells in each pair gave a quantifiable metric that allowed for simple selection of the most accurate map.

3.6 Summary

This section has outlined the methods that were undertaken to successfully assess how suitable volunteered photographic information is to derive a flood extent map for a recent flood. A series of photos were found, coordinates collected, and a number of flood surface models created. These surface models were then intersected with two topography models, and processed to form raster maps. The raster maps were differenced, and the results compared to the SSSI flood extent map. These results may be found in the following chapter.

Chapter 4 Results

4.1 Introduction

A series of flood extent maps were created as per the steps outlined in the previous chapter. These extent maps were then compared to the SSSI map. The 25m topography DEM heights were compared to the reported river gauge heights. Finally, the 10m topography DEM was checked for accuracy using the collected GPS points. The results of these comparisons appear here.

4.2 25m DEM

The first TIN intersection was undertaken between a 25m DEM of South East Queensland, and the TIN compiled from only the river gauge data. The resulting extent map can be seen in Figure 4.1, below:

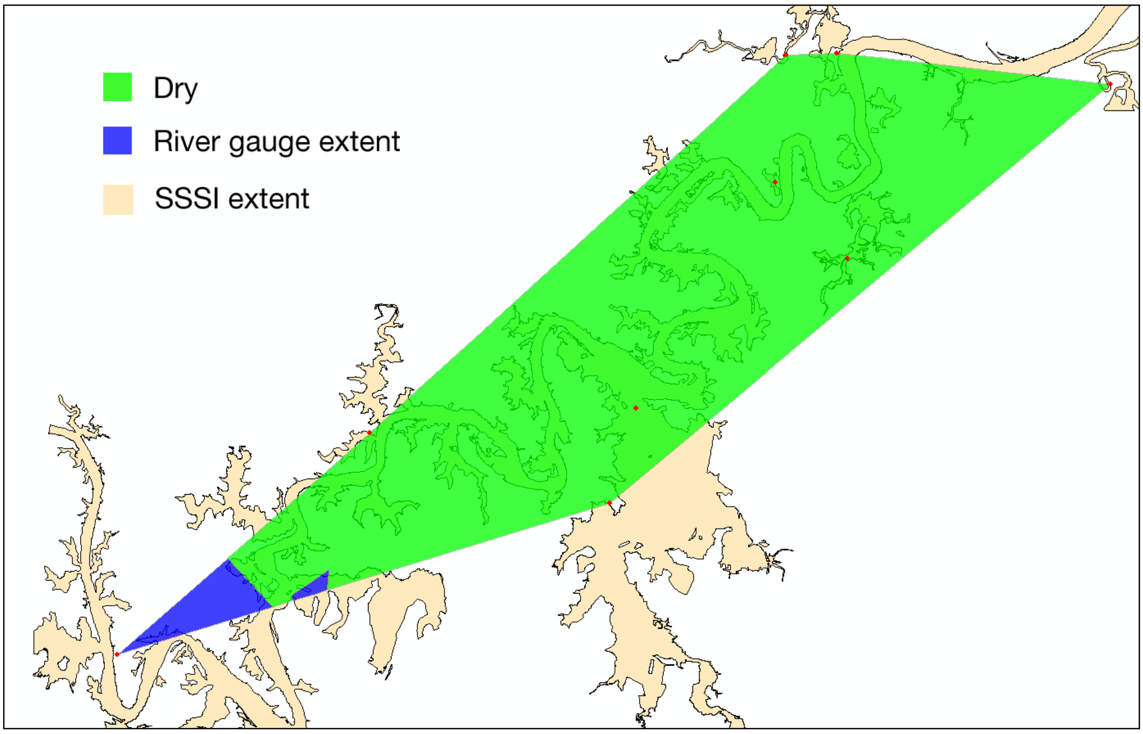

Figure 4.1: 80,000:1 25m River Gauge Extent Map

This initial result can be seen to grossly underestimate the inundation extent. The river gauge data covers an area of 4,589,182 cells. A raster difference with the official extent map reveals that within this area, 1,300,333 cells were inundated, or approximately 30%. The river gauge data suggests that 142,956 cells or 3% were inundated. In addition, Figure 4.1, above, shows that the reportedly inundated area is also quite inaccurate. The correctly modelled area was made up of 23,485 cells. Therefore, only 16.43% of the inundated cells were correctly identified, or 83.57% were reportedly wet when they were in fact dry. In order to determine the cause of these poor results, a comparison of elevations of the river gauges with elevations of the same horizontal locations on the DEM was undertaken. The results can be seen in Table 4.1, below.

Table 4.1: 25m DEM vs. River Gauge Heights

Gauge No	Water	DEM	Delta
40812	17.87	15.505	2.365
540192	12.9	22.025	-9.125
540071	9.33	41.4	-32.07
540274	9.27	37.35	-28.08
540198	4.455	19.55	-15.095
540130	2.73	15.59	-12.86
540286	2.75	12.9	-10.15
540132	3.27	25.12	-21.85
540129	1.28	10.2	-8.92

Only at one of the river gauges did the recorded water level lie above the topography model's elevation. It was concluded that the 25m DEM was not of sufficient accuracy to provide meaningful results from the river gauge data.

Another TIN intersection (see Figure 4.2) was completed using combined river gauge and GPS data to see if there would be any significant differences. This data covered an area of 6,372,241 cells. A total of 156,867 cells were modelled to be inundated. Of these, only 42,170 were actually under water during the January flood event. This equates to an error of 73.12%, or 26.88% of cells being correctly identified. Whilst this is a markedly improved result over the river gauge data, it is still much worse than expected.

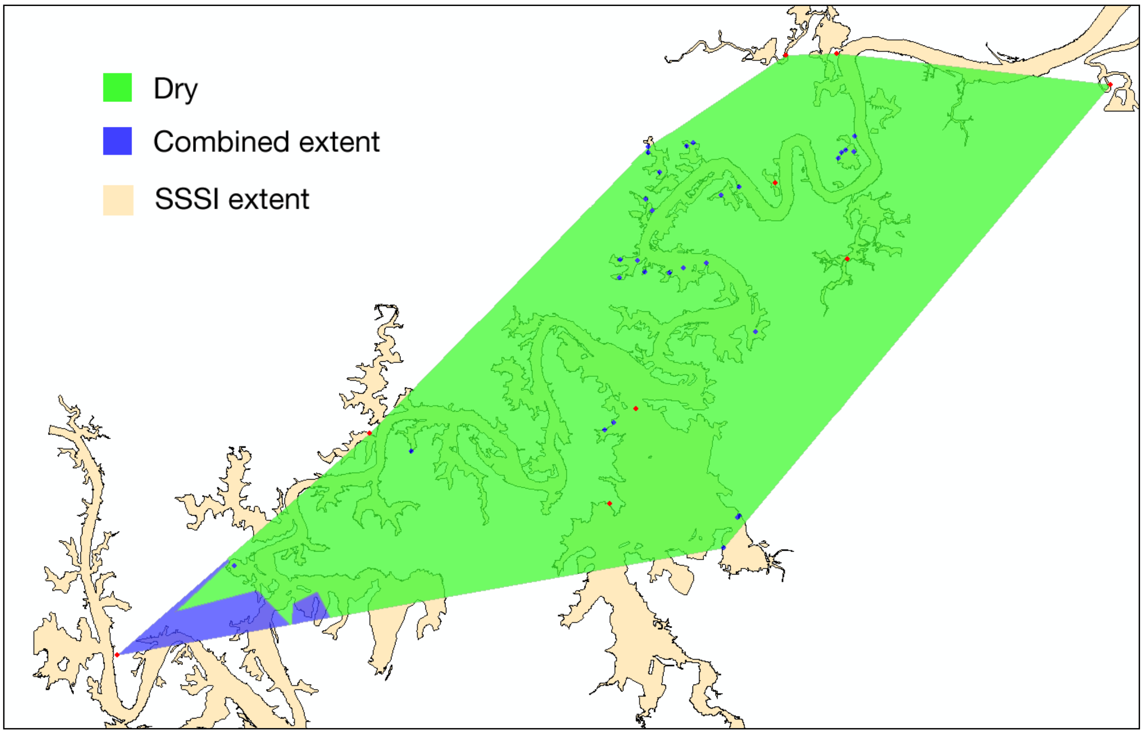

Figure 4.2: 80,000:1 25m Combined Extent Map

4.3 10m DEM / River

The second round of modelling undertaken with 10m contour data provided much better results. The river gauge-based TIN intersected with a TIN based on 10m contours produced an extent map as seen below in Figure 4.3:

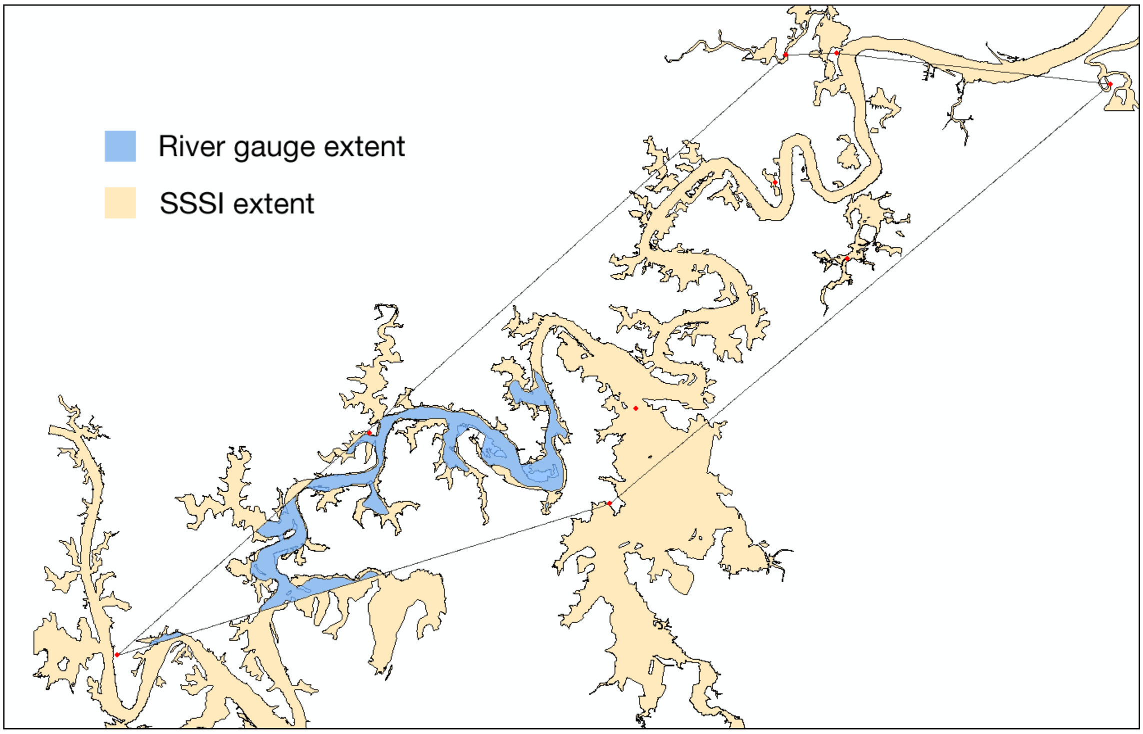

Figure 4.3: 80,000:1 10m River Gauge Extent Map

While offering markedly improved results, it can be seen that the map only shows any inundation for approximately half the area for which there is data. An inspection of elevations at common locations between the two TIN models reveals the lowest elevation in the topography TIN model is 10m. This is because the lowest contour in the dataset is at 10m. All the river gauge peak water levels in the North-East half of the model fall below a height of 10m; therefore, none of this area shows as inundated.

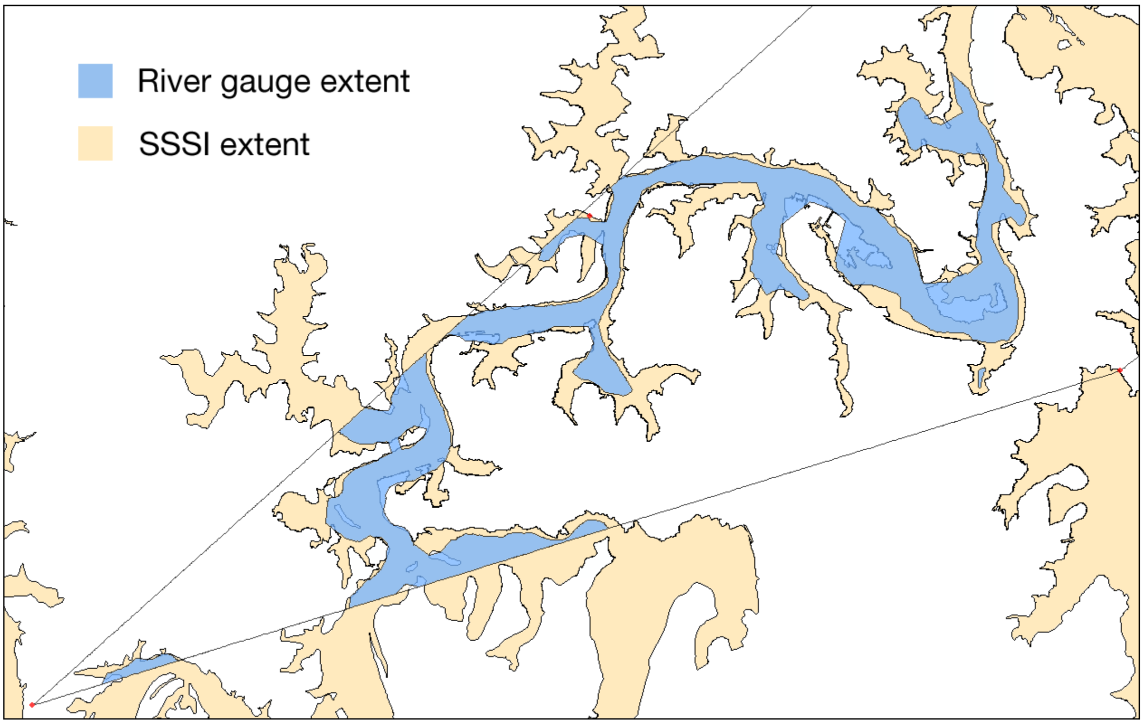

Figure 4.4: 40,000:1 10m River Gauge Extent Map

The 40,000:1 map in Figure 4.4 shows the inundation extent in greater detail. It can be seen that the modelled inundation extent is largely coincident with that of the official extent. The river gauge inundation extent raster contained 294,303 cells. 31,919 of these were located in dry areas, resulting in an overestimated inundation area of 10.85%. Additionally, it can be seen that the computed map underestimates inundation extent in some locations.

4.4 10m DEM / GPS

The extent map created using a TIN model derived from only the collected GPS points also suffered from limited coverage due to insufficient accuracy of the topography DEM, as can be seen in Figure 4.5. Its coverage is slightly reduced compared to the river gauge extent map: 270,500 cells vs. 294,303. This is because the data extents are different between the two flood surface TIN models. The inundation extents also accordingly cover different areas.

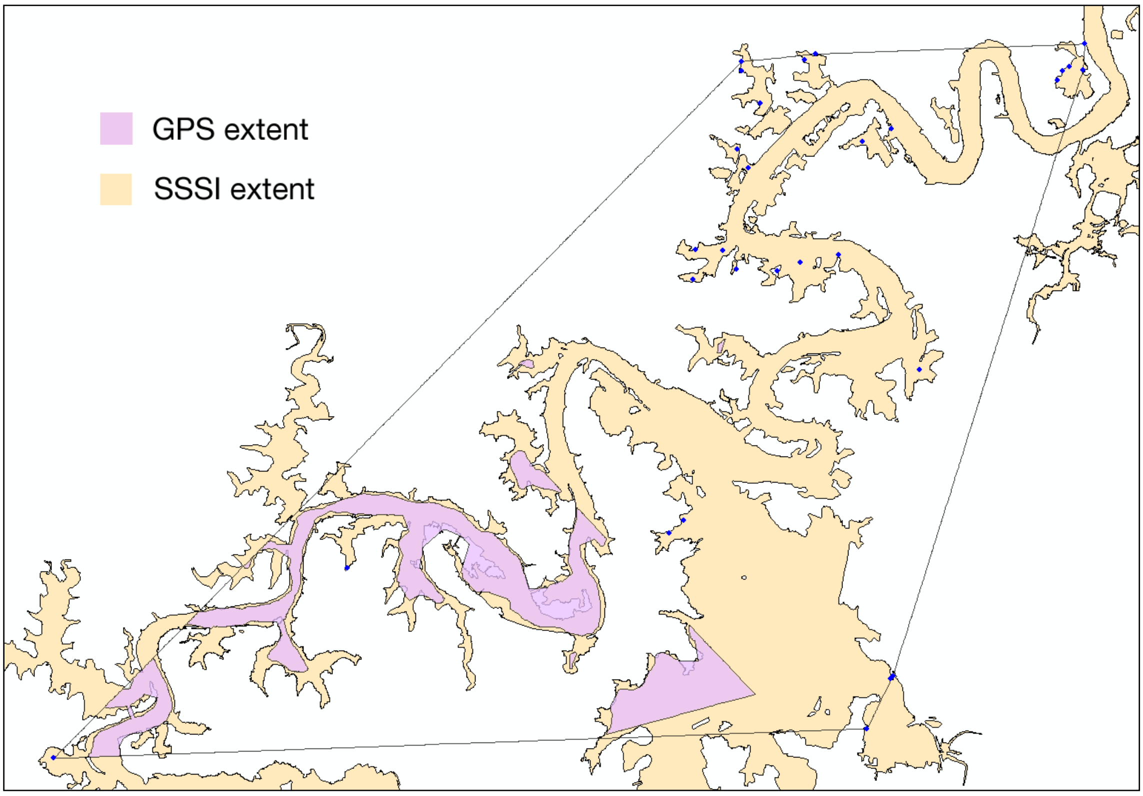

Figure 4.5: 50,000:1 10m GPS Extent Map

There were 24,918 cells incorrectly inundated, resulting in an error of 9.21%. The GPS-based extent map also underestimates the inundation extent relative to the SSSI extent, as can be seen in greater detail in Figure 4.6 below.

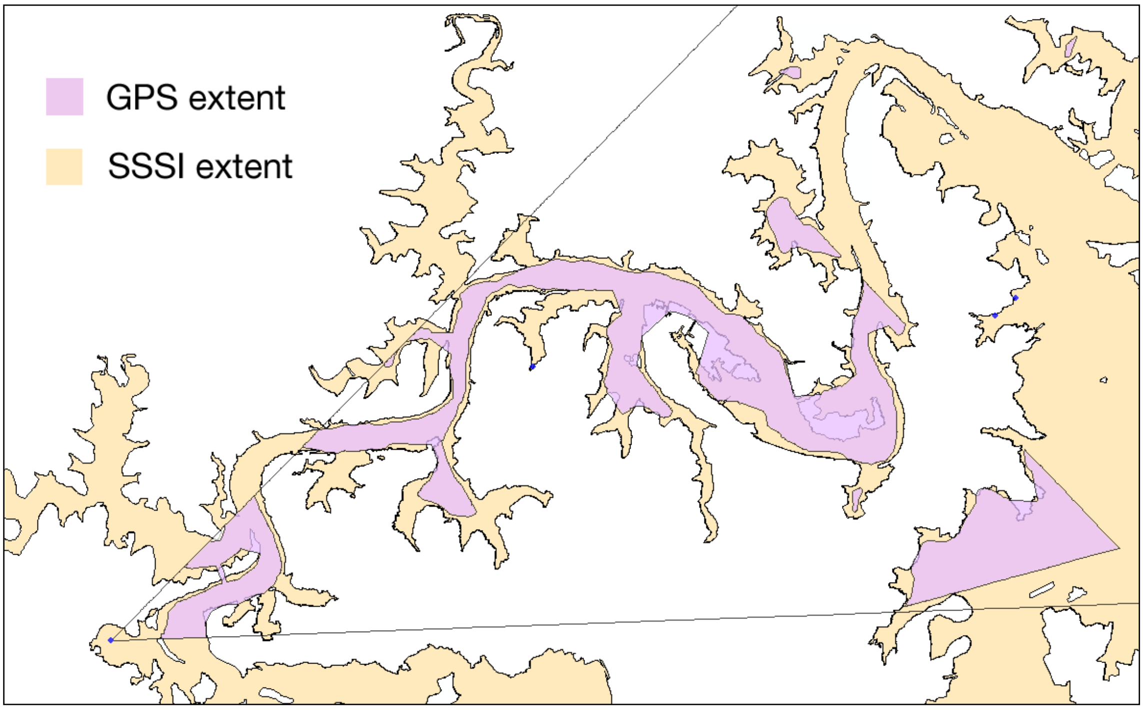

Figure 4.6: 40,000:1 10m GPS Extent Map

4.5 Combined /10m

Finally, the river gauge and GPS data was combined to create another TIN model, and through intersection with the topography TIN, another extent map was produced. The results of this are shown in Figure 4.7.

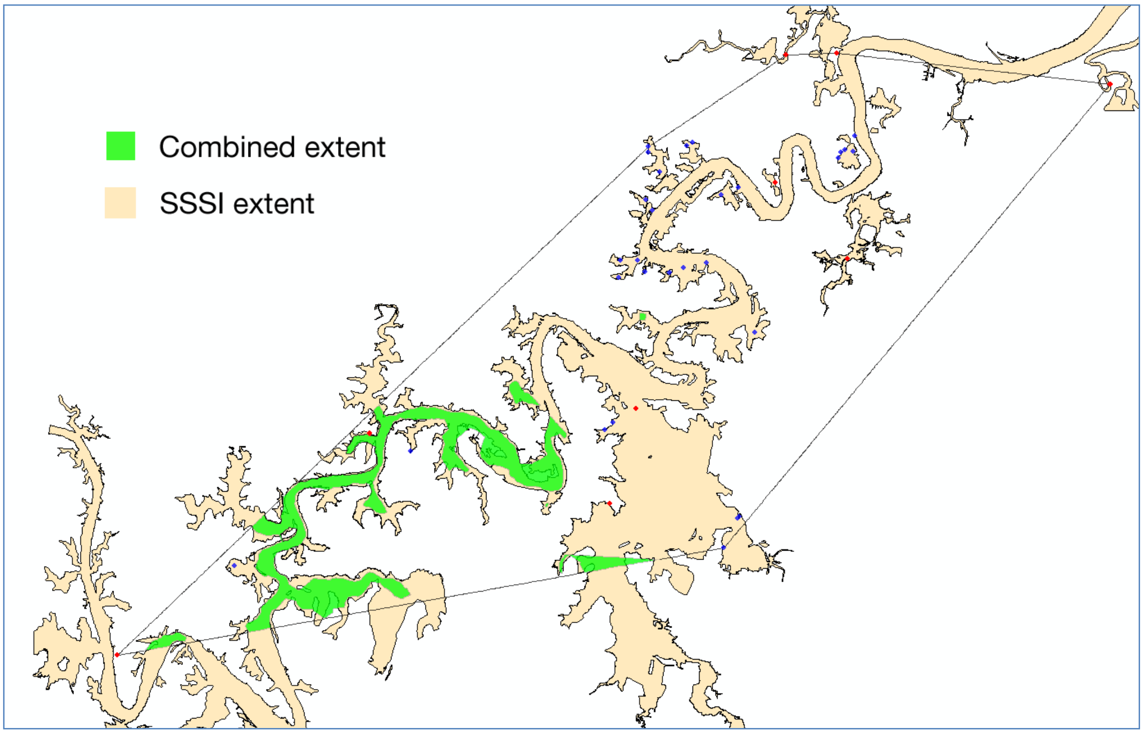

Figure 4.7: 80,000:1 10m Combined Extent Map

It too suffers from limited coverage due to insufficiently accurate topography data. Of the three extent maps that were based on 10m contour topography data, the combined data shows the largest inundation extent. It consists of 359,090 inundated cells, compared to 270,500 for the GPS map, and 294,303 for the river gauge map.

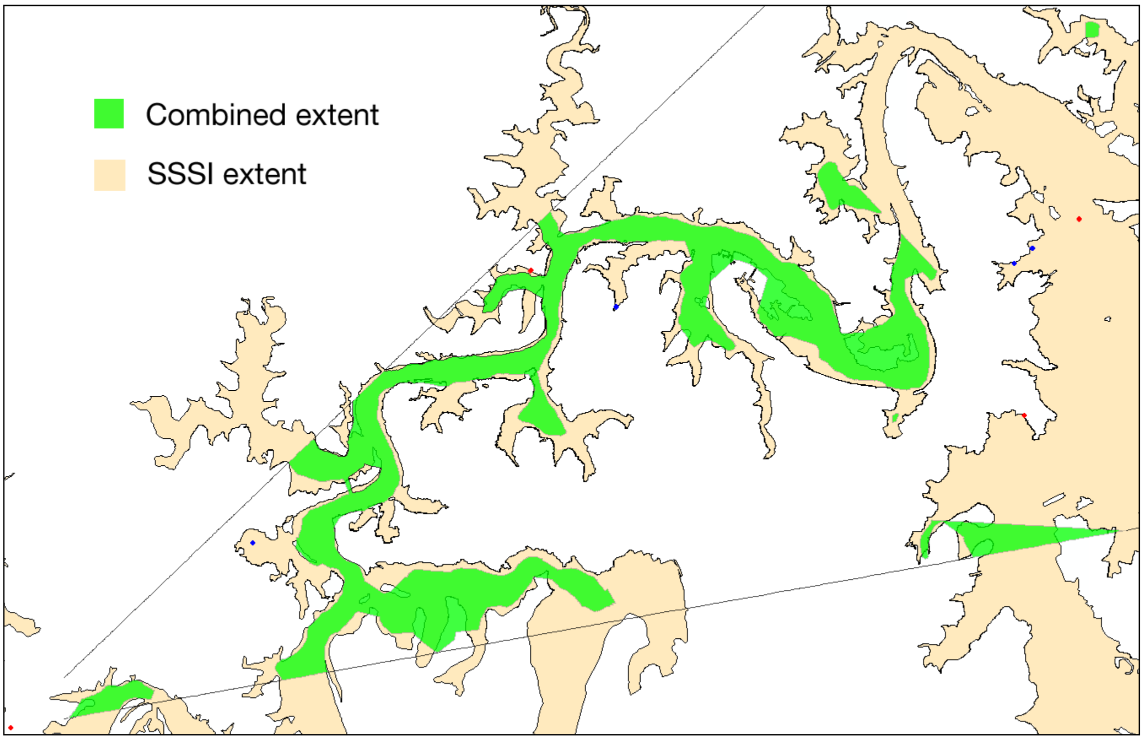

Figure 4.8: 40,000:1 10m Combined Extent Map

Figure 4.8 above, shows more clearly the modelled inundation extent. It both over and underestimates the inundation extent in differing areas. A total of 316,720 / 359,720 cells were correctly identified as inundated. This corresponds to an error of 11.80%.

4.6 10m / Comparison

Figure 4.9, overleaf, shows the three computed extent maps overlaid onto the SSSI one. The differences in coverage are apparent. The GPS map covers the least area, followed by the river gauge map, and the combined map has the most coverage. These differences can largely be accounted for by the location of the collected data points. The GPS points bounded the smallest physical area where the topography had an elevation of more than 10m. As can be seen in Figure 4.9, overleaf, the combined data has the outermost extents.

For areas of common coverage, there is little in the way of differences, except in the western half of the image. Both the GPS and the combined maps slightly underestimate the extent relative to the river gauge map. The other large variation between the GPS and combined extent maps is the presence of a large inundated area in the South-East of the GPS map that does not appear in the combined map. This is due to the river gauge point at the northern tip of this area. It has an elevation of 9.27m, which means that in the combined TIN model, the whole area falls below the 10m limit of the topography DTM. It was expected that adding more data to the flood surface model would give a better result; however this was not the case, due to insufficiently accurate topography data. Without access to topography data with similar accuracy to that of the collected points, it is not possible to properly assess the suitability of the data beyond a proof of concept level.

Even without accounting for the topography data induced differences in inundation extent between the maps, the combined extent map still shows the greatest inundation extent. If the large aforementioned area in the GPS extent map were included in the combined map, the difference in inundation extents would be even greater.

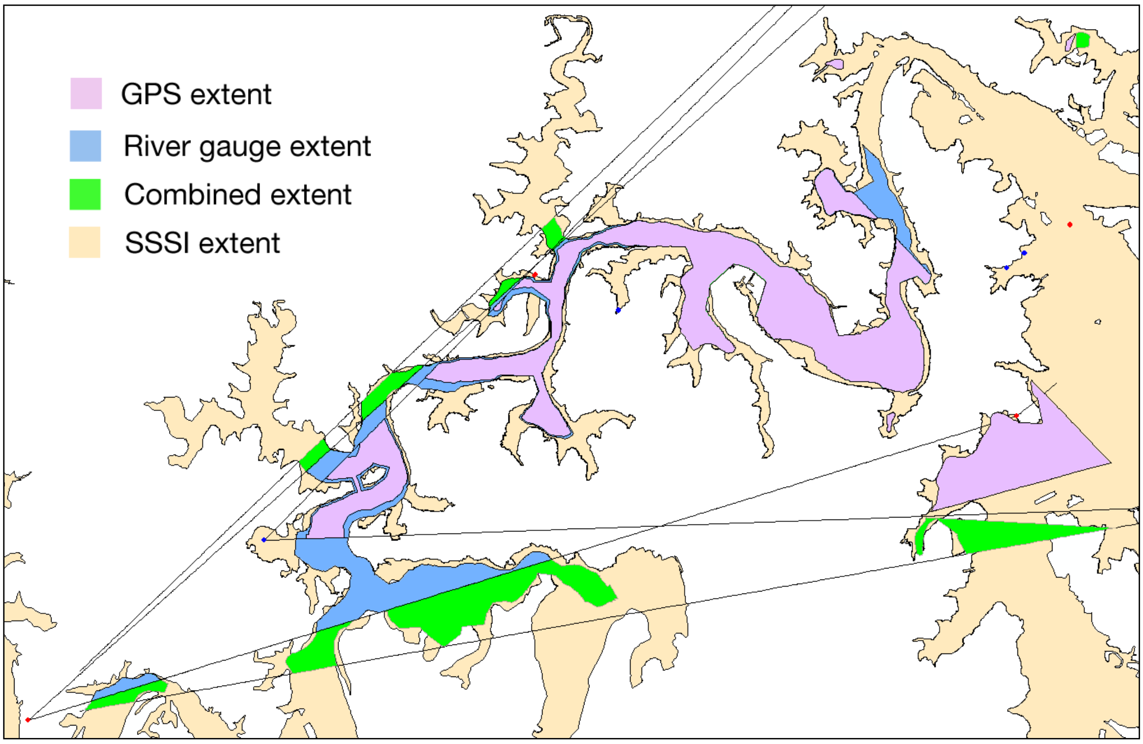

Figure 4.9: 40,000:1 10m Compiled Extent Maps

In terms of absolute accuracy, the GPS-based extent map gives the best result, with the inundation extent overestimated by 9.21%. The river gauge-based map is the next most accurate, with an error rate of 10.85%. Finally, the combined extent map showed the least accurate result, with an error of 11.80%. It is difficult to draw conclusions about the suitability of each source of data from the differences in overestimation of inundation extent, because these differences are largely due to the limited accuracy of the topography data.

4.7 Accuracy Assessment of 10m Topography DEM

The topography levels at the collected points can be determined with knowledge of the antenna heights used during GPS collection. The expected accuracy of these levels is +/-0.1m as this is the observed accuracy of the GPS system used. Table 4.2, below, shows a comparison of collected topography heights vs. DEM topography heights for common locations. The expected accuracy of the topography DEM ranges from +/-5m in open areas, to +/-16m in heavily vegetated areas (Department of Environment and Resource Management 2011).

Table 4.2: Collected vs. Topography DEM Heights

Feature	Topography	Feature	"Antenna"	Ground	Delta
bell-pharm	20	11.838	4.007	7.831	-12.169
jin	20.81	13.46	1.5	11.96	-8.85
rock-hjs	10	9.051	0.42	8.631	-1.369
rock-650	10	9.215	0	9.215	-0.785
rock-Pub	10	5.38	3.91	1.47	-8.53
sher-hall	12.11	9.174	1.6	7.574	-4.536
ffield-7-11	10	5.014	1.335	3.679	-6.321
stl-eric	10	5.797	1.955	3.842	-6.158
stl-munro	10	3.893	3.337	0.556	-9.444
tar-sir-fred	13.22	7.044	0.17	6.874	-6.346
tar-west	20	6.018	1.13	4.888	-15.112
tar-shell	10	6.797	2.07	4.727	-5.273
tar-per-sign	10	7.035	1.17	5.865	-4.135
city-coro	10	3.757	2.965	0.792	-9.208
auc-bowls	10	2.212	3.374	-1.162	-11.162
mil-eagle	10	4.651	2.555	2.096	-7.904
ros-nash	10	6.083	0.405	5.678	-4.322
ros-agars	12.35	5.26	0.755	4.505	-7.845
mil-heu	15.48	6.049	0	6.049	-9.431
sth-cordelia	10	4.201	1.077	3.124	-6.876
sth-qpac	10	5.298	0.46	4.838	-5.162
nfm-liquid	10	2.876	0.6	2.276	-7.724
nfm-colespk	10	3.041	0.135	2.906	-7.094
nfm-welsby	10	2.498	0.31	2.188	-7.812
nfm-153syd	10	2.264	0.795	1.469	-8.531
nfm-ferry	10	3.03	0.046	2.984	-7.016

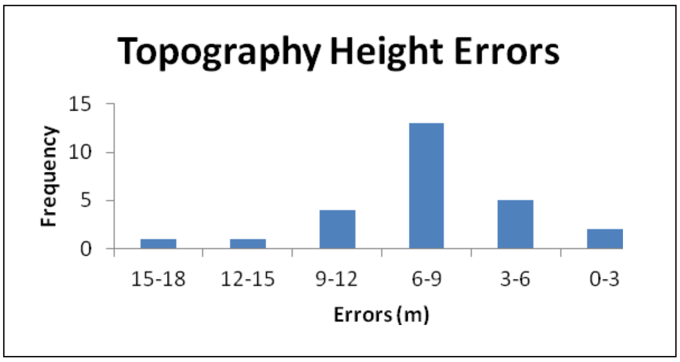

Figure 4.10: 10m Topography Height Errors

A histogram of the topography height error values, see Figure 4.10, shows the majority of values fall within the 6-9m range. The least accurate value showed an error of 15.112m. This is consistent with the expected accuracy of the model.

4.8 Conclusion

This chapter has provided an overview of the comparisons between the two topography models and the three generated flood surface models, as well as an assessment of the accuracy of the 10m model. The initial comparisons found that using the 25m topography DEM provided results much worse than expected. Subsequent comparisons using a 10m DEM gave vastly improved results. Using the 10m topography model the three produced flood surface models showed similar error levels. The topography model was still found to be the limiting factor however. This will be discussed further in the following chapter.

Chapter 5 Discussion

5.1 Introduction

The results of this study raised one large issue, namely, the impact of the accuracy of the topography DEM relative to that of collected data when creating an extent map. The impacts of future technology improvements should also be considered. These points are discussed in this chapter.

5.2 Resource Limitations

The greatest limiting factor for this study was the accuracy of the topography data. The most accurate freely available topography data covering the study area was composed of 10m contours generated from the SRTM 3 second DEM collected between December 2008 and March 2010. The vertical accuracy of this data ranged from +-5m to +-15m in heavily vegetated areas. The most significant limitation of the data was the lowest contour being at 10m. As a result, the collected high-water marks with heights below this level do not model as inundated, when they should have. This problem affected approximately 80% of the data collected.

Significantly more accurate LiDAR-derived topography data that covers the study area is available. Whilst the expected accuracy of the data is not published on the DERM product webpage, the data is available as 0.25m contours. LiDAR-based products typically have vertical accuracies of +-0.1m (AAM n.d.). LiDAR-based topography data would have been ideal; however coverage of the required area is priced at approximately $1300. Budget limitations prevented purchase of the data.

The more accurate topography data would have provided much more useful results. Firstly, all the collected high-water mark data would have registered as being above the topography, so a significantly greater area could have been assessed. Additionally, the full forty collected data points would have provided results, rather than the approximately eight that formed the TIN over the reportedly inundated area. This would have allowed concrete conclusions to be drawn about the reasons for the differences in results for common areas between the three produced extent maps. Without having topography data that is at least as accurate and precise as the collected points, it is difficult to know the full effect of adding additional points to the flood surface TIN model. If the topography model is not of sufficient precision to capture small changes in elevation within an area, then there will be no benefit to adding additional flood surface points to that area as the resulting extent map will not differ. With topography data of such low accuracy relative to that of the collected points, this study to a large extent ends up assessing the accuracy of the topography data.

Using more accurate LiDAR-based topography data would have allowed for a much better assessment of the suitability of the high-water mark data to create a flood extent map. It is difficult to quantify any possible improvement in results without having access to the data, however comparing the results from using the 25m DEM to those from using 10m contours may provide some indication. Using the 25m DEM topography data resulted in errors of 83.57% and 73.12% for the river gauge, and combined data respectively. Using the topography data composed of 10m contours resulted in errors of 10.85% and 11.80% respectively. This is a markedly improved result.

The other majorly limited resource was geo-referenced photos featuring the high-water mark. Approximately forty-five hours were spent searching for imagery. This yielded forty suitable photos. Many photos that featured what may have been the high-water mark were either taken in an unspecified location, or it could not be verified they were taken after the flood peak. Difficulties were encountered when attempting to collect points at approximately one third of the photo locations. Access to a number of construction sites was denied, which prevented data collection. One of the photos featured a high-water mark on the UQ Aquatic Centre. This building had been demolished before collection could be undertaken. Lastly, a number of locations were not suited to GPS collection owing mostly to overhead vegetation or buildings. Where the surrounding topography had little to no vertical variation, points were collected where the GPS could maintain initialisation. For locations where there was significant vertical variation, it was planned that a PM search would be undertaken, and the points collected with a total station. For the locations that were searched, there were very few PMs with both heights and accurate coordinates. Time limitations prevented connecting to these as they were mostly a considerable distance from the photo locations, in areas with limited parking.

5.3 Future Improvements

Currently, iPhone 3GS A-GPS is only accurate to on average +/-9m RMSE in the horizontal and +-10.6m in the vertical in ideal conditions (Zandbergen 2009). Other GPS implementations in mobile cellular devices offer similar levels of accuracy. This is of insufficient accuracy to model flood surface heights. It is possible that in the future, vertical accuracies of mobile phone-based GPS may improve to the point where flood surface heights may be able to be captured directly within a reasonable margin. This seems unlikely however; as there is little demand for sub 0.1m vertical accuracy in a consumer mobile cellular device.

The other possibility for automated collection of flood surface heights from volunteered data is to use photos as in this study, but to import them into photo mosaicing software like Microsoft Photosynth. The Synth functionality of this application is 'good for capturing different sides or details of an object' (Microsoft 2011). Photosynth works by analysing multiple photos of the same area. An interest point detection and matching algorithm is applied to each photograph. Specific features are identified by this process. The program can determine which face of an object a photo belongs on by analysing the position of matching features within each photo. Bundle adjustment is the process of identifying the 3D position of a series of features, as well as the angle and position from which each photo was captured. This is accomplished by analysing the differences in the relationships between the features (distance, angle, etc.). The process is extremely computationally intensive, but only needs to be performed once on each set of photos. A 3D point cloud is the output of this first stage. A 3D model may then be generated from this point cloud.

Assuming adequate Photosynth coverage of the subject area of a volunteered photo, it could be integrated into the Photosynth model, and 3D coordinates for the high-water mark could then be derived. Some LiDAR systems include a digital camera that will map a colour to each point. This LiDAR imagery may be suitable for use as input into a Photosynth-style system such that coverage of large areas could be obtained at reasonable cost. Conventional aerial photography could also potentially be used for this purpose. If an image is geo-referenced, then its approximate location within the imagery is known, and it could be integrated into the model.

5.4 Summary

To conclude, the accuracy of the topography DEM is of great importance when creating a flood extent map via the methods used in this study. Future improvements in either mobile phone-based GPS, or advances in photogrammetry software, may allow the collection of flood surface heights to become greatly automated.

Chapter 6 Conclusions

6.1 Conclusions

All of this project's objectives were successfully achieved. The methods of establishing flood extents including hydrological modelling and other techniques were researched. Flood extents are typically established using optical data, SAR data, or 'flooding' a topography DEM with water levels. 51 geo-referenced private photos featuring the flood high-water mark were successfully collected. After discounting multiple photos of the same location, 43 photos remained. 29 of these proved suitable for collection via GPS, and were connected to the AHD. Two topography DEMs of differing accuracy were obtained from DERM. Both the DEMs and the GPS points were processed to create a series of TIN models. Each flood surface model was then intersected with the topography models to create a number of extent maps. These were then compared to the official extent map produced by SSSI.

This project set out to assess the suitability of volunteered information to create a flood extent map, or supplement existing data to create one. It found that volunteered photographs featuring the high-water mark could be used as data source, and offered a level of accuracy limited by the accuracy of the system used to collect the data. Finding sufficient suitable photos however, is a very time consuming process not guaranteed to produce results. Moreover, not all photo locations were suited to GPS collection, which would have necessitated additional time and resources to capture the data. There is also one major caveat. The accuracy and precision of the topography DEM should be similar to that of the system used to collect the coordinates of each high water mark. If this is not adhered to, the results are likely to be misleading.

6.2 Further work

It is recommended that the surface models from this study be intersected with a more accurate topography model, such as one based on LiDAR data. Results from this would allow for a better assessment of the suitability of volunteered photographs to create a flood extent map.

Future advances in photogrammetry systems may make the GPS-based coordinate collection stage unnecessary, allowing for coordinates to be derived directly from submitted geo-referenced photos. It is also possible that photos may even become unnecessary, as mobile phone-based GPS systems mature, allowing great enough accuracy to be able to directly capture flood levels to within reasonable margins.

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Appendices

Appendix A – Specification

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG4111/4112 Research Project
PROJECT SPECIFICATION

FOR: **Philip Arthur TEMPLE-WATTS**

TOPIC: AN INVESTIGATION INTO THE SUITABILITY OF PHOTOGRAPHIC VOLUNTEERED INFORMATION TO DETERMINE FLOOD EXTENTS

SUPERVISOR: A/ Prof. Kevin McDougall

PROJECT AIM: This project seeks to assess the suitability of volunteered (photographic) information to determine flood extents for the Brisbane 2011 flood, through the production of a DEM derived from submitted photos.

PROGRAMME: **(Issue A, 21 March 2011)**

1) Obtain flood photos from a series of sites along expected flood extents.
2) Connect to existing level control, rectify photos, and determine flood levels.
3) Produce a DEM using data gathered during 2).
4) Extrapolate DEM and compare to official flood extents map.
5) Submit an academic dissertation on the research.

AGREED: ____________________(Student) ________________________(Supervisor)

Date: / 03 / 2011 Date: / 03 / 2011

Examiner/Co-examiner: ___________________

Appendix B – High-water Mark Photos

Following are a series of original flood photos, followed by the same scenes at the time of data collection, with the exception of the Coronation Drive point, which was collected in July 2011, but not photographed until October 2011.

Figure B.1: UQ Aquatic Centre, University of Queensland, St Lucia, January 2011 (Agamid 2011b)

Figure B.2: UQ Aquatic Centre, University of Queensland, St Lucia, July 2011

Figure B.3: Cnr Blackwood & Hall St, Sherwood, February 2011 (Prior 2011b)

Figure B.4: Cnr Blackwood & Hall St, Sherwood, July 2011

Figure B.5: Eagle Tce, Milton, January 2011 (Palmer 2011b)

Figure B.6: Eagle Tce, Milton, July 2011

Figure B.7: Merthyr Ferry Terminal, Merthyr Rd, New Farm, January 2011 (Jacques 2011b)

Figure B.8: Merthyr Ferry Terminal, Merthyr Rd, New Farm, July 2011

Figure B.9: Sydney St, New Farm, January 2011 (Jacques 2011a)

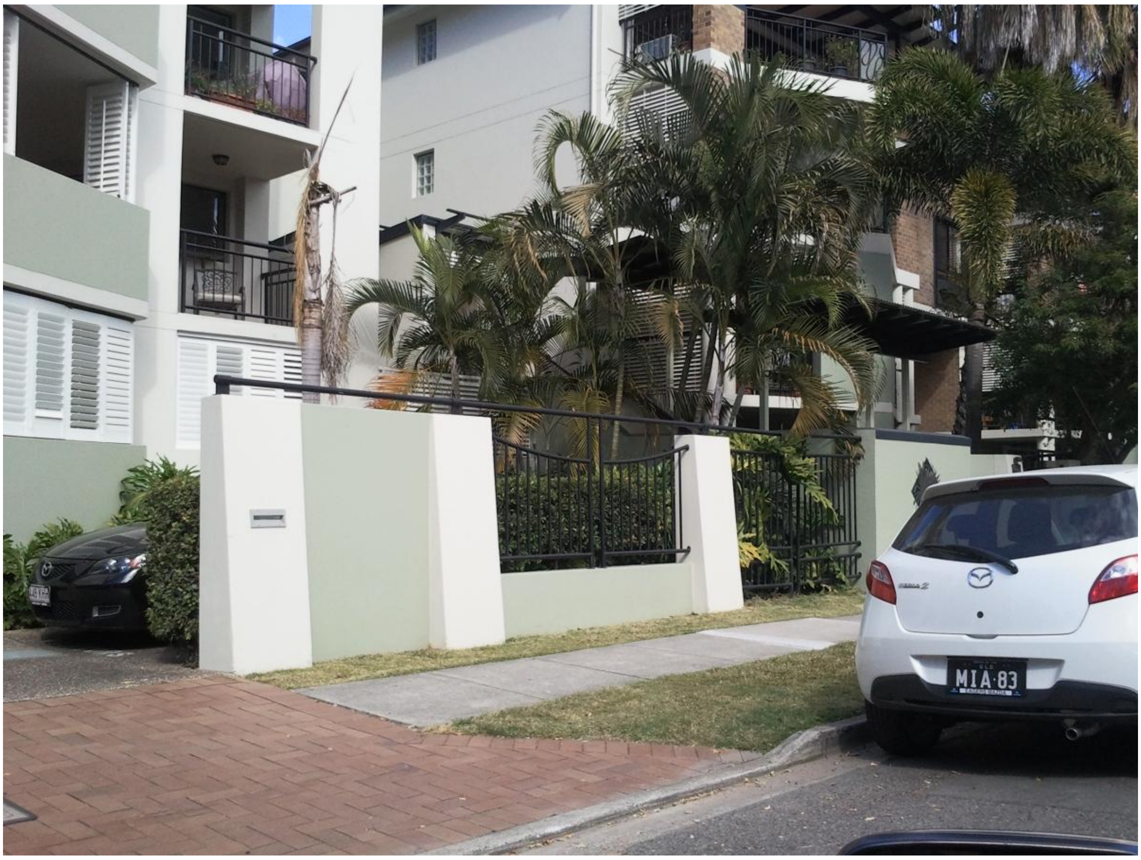

Figure B.10: Sydney St, New Farm, July 2011

Figure B.11: Westerham St, Taringa, January 2011 (daisy.meow 2011)

Figure B.12: Westerham St, Taringa, July 2011

Figure B.13: Heussler St, Milton, January 2011 (Palmer 2011a)

Figure B.14: Heussler St, Milton, July 2011

Figure B.15: Q-Masters, Milton, January 2011 (Wack the barn pimp 2011)

Figure B.16: Q-Masters, Milton, July 2011

Figure B.17: 893 Brunswick St, New Farm, January 2011 (Surplice 2011b)

Figure B.18: 893 Brunswick St, New Farm, July 2011

Figure B.19: Welsby St, New Farm, January 2011 (Storm Jury 2011)

Figure B.20: Welsby St, New Farm, July 2011

Figure B.21: Nash St, Rosalie, January 2011 (Palmer 2011c)

Figure B.22: Nash St, Rosalie, July 2011

Figure B.23: Johnstone St, Sherwood, January 2011 (Prior 2011c)

Figure B.24: Johnstone St, Sherwood, July 2011

Figure B.25: Eric Freeman Boathouse, UQ, St Lucia, January 2011 (Agamid 2011c)

Figure B.26: Eric Freeman Boathouse, UQ, St Lucia, July 2011

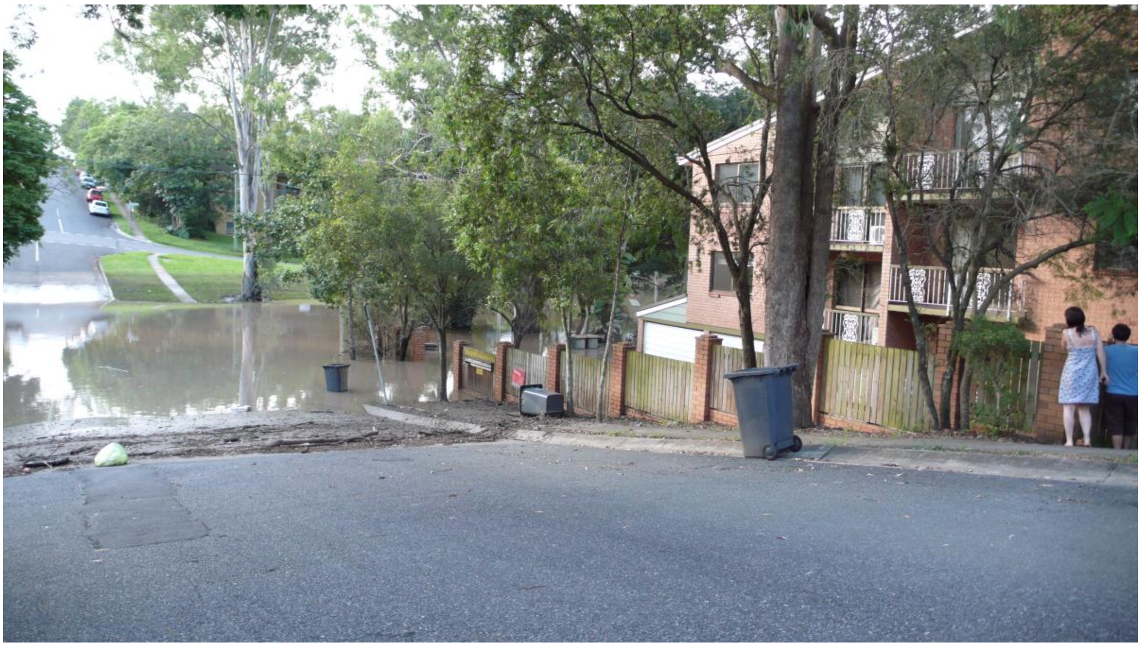

Figure B.27: Bellevue Terrace, St Lucia, January 2011 (Agamid 2011a)

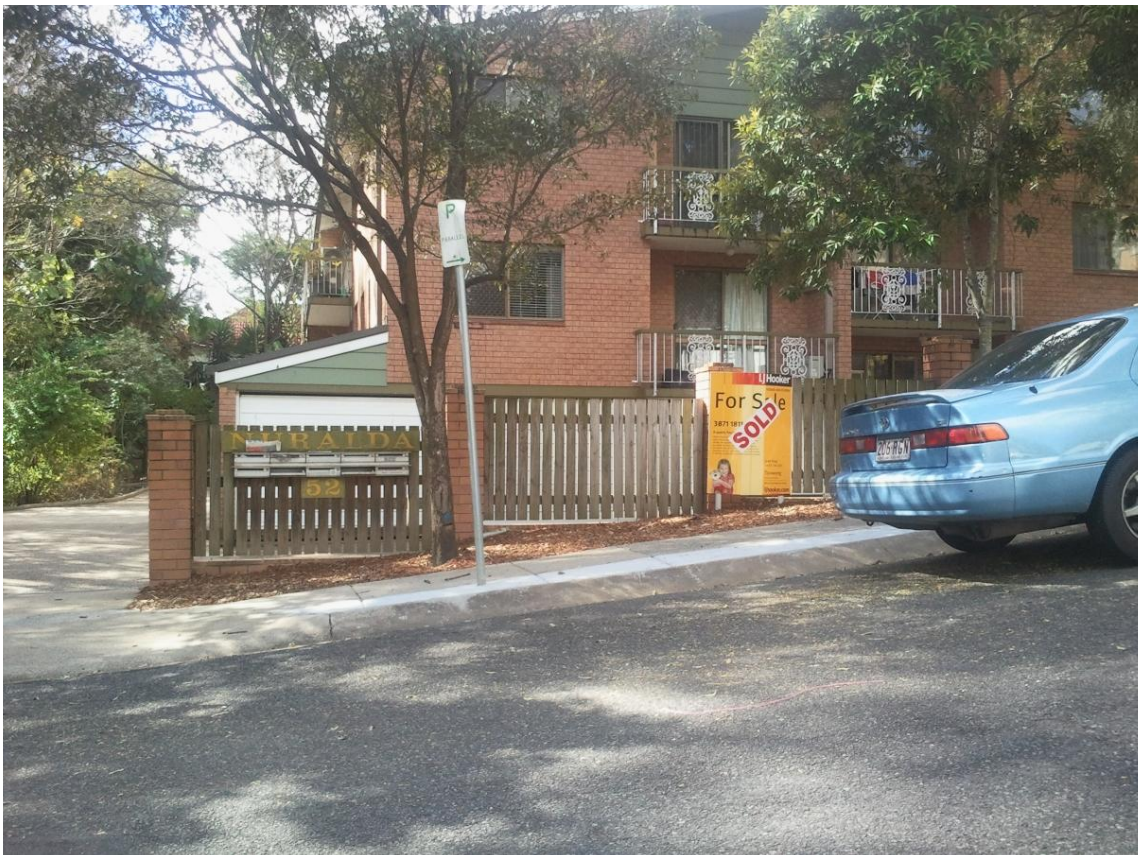

Figure B.28: Bellevue Terrace, St Lucia, July 2011

Figure B.29: Sir Fred Schonell Drive, St Lucia, January 2011 (Sparshott 2011a)

Figure B.30: Sir Fred Schonell Drive, St Lucia, July 2011

Figure B.31: Shell, Gailey Rd, Taringa, January 2011 (Brisbane Area Flood Photos & Info 2011)

Figure B.32: Shell, Gailey Rd, Taringa, July 2011

Figure B.33: Bellbowrie Pharmacy, Bellbowrie, January 2011 (Prior 2011a)

Figure B.34: Terry White chemists (formerly Bellbowrie Pharmacy), July 2011

Figure B.35: Arrabri Ave, Jindalee, January 2011 (Clifford 2011)

Figure B.36: Arrabri Ave, Jindalee, July 2011

Figure B.37: Hungry Jacks, Granard Rd, Rocklea, January 2011 (Kenneth Au 2011)

Figure B.38: Hungry Jacks, Granard Rd, Rocklea, July 2011

Figure B.39: Beaudesert Rd, Rocklea, January 2011 (Tang 2011b)

Figure B.40: Beaudesert Rd, Rocklea, July 2011

Figure B.41: Tramore St Pub, Rocklea, January 2011 (Tang 2011a)

Figure B.42: Tramore St Pub, Rocklea, July 2011

Figure B.43: Fairfield Rd, Fairfield, January 2011 (Manchester 2011)

Figure B.44: Fairfield Rd, Fairfield, July 2011

Figure B.45: Cordelia St, South Brisbane, January 2011 (Fish Fidler 2011)

Figure B.46: Cordelia St, South Brisbane, July 2011

Figure B.47: QPAC, Southbank, January 2011 (Giant Rider 2011)

Figure B.48: QPAC, Southbank, July 2011

Figure B.49: Coles car park, Merthyr Rd, New Farm, January 2011 (Surplice 2011a)

Figure B.50: Coles car park, Merthyr Rd, New Farm, July 2011

Figure B.51: Perrin Park, Josling St, Toowong, January 2011 (Bannerman 2011c)

Figure B.52: Perrin Park, Josling St, Toowong, July 2011

Figure B.53: Coronation Drive, Brisbane City, January 2011 (Bannerman 2011b)

Figure B.54: Coronation Drive, Brisbane City, October 2011

Appendix C – GPS Accuracy Check

Table C.1 PM vs. GPS Coordinates

Point	Easting	Northing	Elevation
knm-10443	494542.643	6956657.563	51.531
knm-55918	493841.907	6956692.724	60.906
PM-10443	494542.649	6956657.565	51.395
PM-55918	493840	6956692	60.78
	ΔEasting	ΔNorthing	ΔElevation
PM-10443	-0.006	-0.002	0.136
PM-55918	1.907	0.724	0.126

PM 10443 confirmed the horizontal accuracy to within 0.01m and vertical accuracy to approximately 0.13m as seen in Table C.1. The vertical accuracy was slightly lower than expected, so PM 55918 was also checked. It showed similar vertical accuracy, so the differences were attributed to differing geoid models. The horizontal accuracy of PM 5591 is poor because its coordinates were scaled from a digitised map.

Horizontal			
Datum	GDA94		
Latitude	27°30' 49.5440" S	Longitude	152°56' 41.0693" E
Easting	494542.649	Northing	6956657.565
Zone	56		
Order	1st ORDER	Class	CLASS A
Adjustment Name	JINDALEE 1KM DENSIFICATION AUG 2000	Fixed By	GPS
Prominent Feature	NO		
Vertical			
Height	51.395	Datum	AHD
Order	4th ORDER	Class	Class A
Fixed By	GPS	Origin	JINDALEE 1KM DENSIFICATION AUG 2000
Geoid/Ellipsoid Separation(N)	41.512		
Model	AUSGEOID98 INTERPOLATED		

Figure C.1: PM 10443 Coordinate Details

Horizontal			
Datum	GDA94		
Latitude	27°30' 48.4140" S	Longitude	152°56' 15.4571" E
Easting	493840.000	Northing	6956692.000
Zone	56		
Order	NO ORDER	Class	NO CLASS
Adjustment Name	DIGITIZED DCDB COORDS BY CABOOLTURE LSC	Fixed By	SCALED
Prominent Feature	NO		
Vertical			
Height	60.780	Datum	AHD D
Order	4th ORDER	Class	Class C
Fixed By	SPIRIT LEVELLING	Origin	7584
Geoid/Ellipsoid Separation(N) Model	0.000		

Figure C.2: PM 55918 Coordinate Details