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Construction of the Statewide Digital Terrain Model (DTM) for Tasmania

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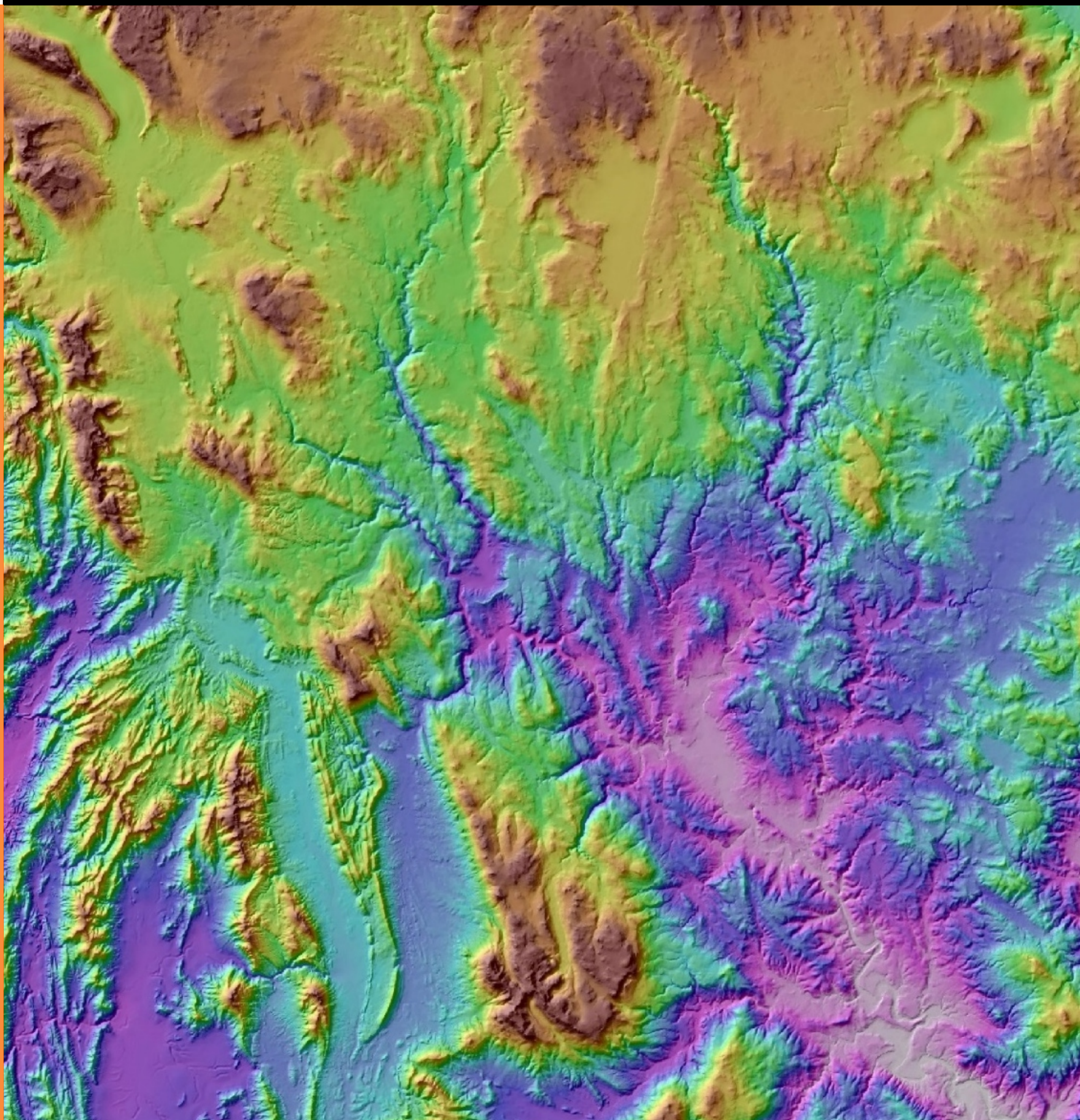

Geological Survey
Technical Report 22

Tasmanian Government

Mineral Resources Tasmania
Department of State Growth

Geological Survey Technical Report 22:

Construction of the Statewide Digital Terrain Model (DTM) for Tasmania

by Claire Kain and Colin Mazengarb

Prepared for the Tasmanian Strategic Flood Mapping Project
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Geological Survey Branch

CONTENTS

FIGURES

1.0 Introduction

This report provides the documentation to support the 10 m Digital Terrain Model (DTM). This DTM was generated by Mineral Resources Tasmania and is current at June 2020.

The need for a new DTM has been driven by the availability of superior datasets, particularly Light Detection and Ranging data (LiDAR), and the need for a more accurate model to support a range of regional-scale geoscience projects, specifically the Tasmanian Strategic Flood Mapping Project. The product discussed here is a 10 m statewide DTM (constructed primarily from LiDAR and 10 m photogrammetric contour data).

The construction of the new DTM has required considerable effort to collate and manually edit input data, as well as significant computer processing time. The product is designed for general use across government and private sectors and will be made freely available. We have designed the DTM in such a way to facilitate upgrades as new data is obtained, or where variations of the model are required for different applications. With improvements in technology and computing power over time, updates to the DTM will become faster, and could evolve to include other types of data, such as spaceborne interferometric synthetic aperture radar (InSAR) data.

We would like to thank those agencies and individuals who contributed data to this project and beta tested the products. We especially thank the custodians of the statewide datasets at Land Tasmania (DPIPWE) for their support.

1.1 Computing specifications

The data processing was performed primarily on a virtual machine server, owned by Mineral Resources Tasmania. The specifications are as follows:

Processor: Intel Xeon CPU E5-2640 v4, 2.4 GHz
Windows 64 bit OS (Windows 7 Professional)
256 Gb RAM

Software and licences:
ArcGIS Desktop 10.3 and ArcGIS Pro, with Spatial Analyst and 3D Analyst extensions
ListMap web feature service (Tasmanian Government)
R Studio v 1.0.136
Python 2.7.13 and Python 3.6
Whitebox GAT

A series of python scripts were developed to automate the processing operations. These scripts were designed to run within ArcGIS Desktop 10.6 and/or ArcGIS Pro and reference a number of supporting datasets that will be described later in this report.

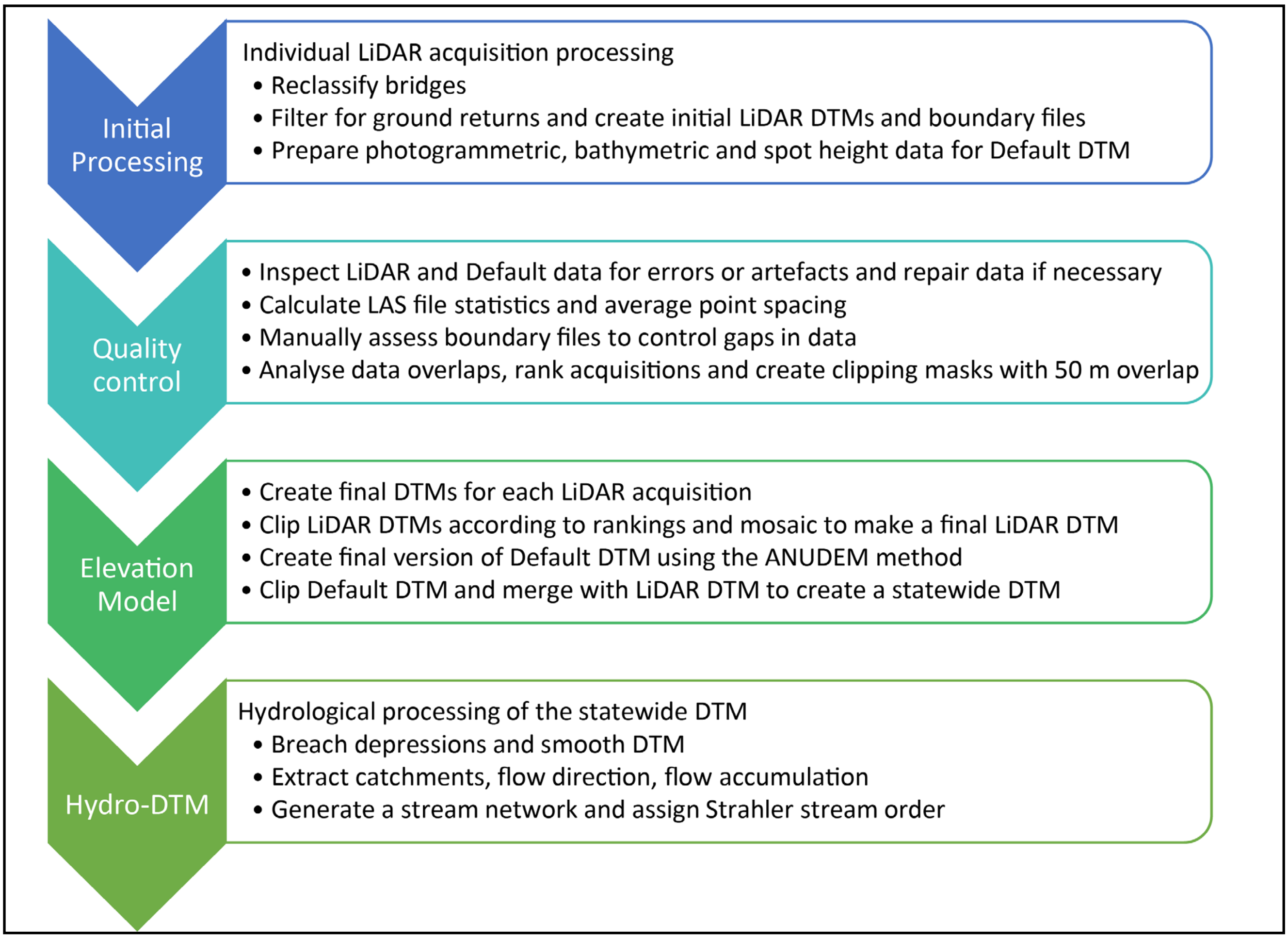

Figure 1. Overview of methodology and processing steps involved in creating the statewide DTM.

1.2 Overview of methodology

There were two primary data types involved in the generation of this DTM: LiDAR data and a Default DTM comprised of primarily photogrammetric contour data, which was used in areas where LiDAR was unavailable. Two separate DTMs were built (one for LiDAR and one for the Default data). These were merged together and then hydrological conditioning was performed on the state-wide DTM. The steps are summarised in Figure 1 and each is described in detail later in the report.

2.0 LiDAR Data Processing

This section documents the methodology for the LiDAR processing component of the statewide DTM. As at June 2020, approximately 60% of Tasmania is covered by LiDAR (Figure 2. The LiDAR data used in this project comes from a large number of surveys undertaken by a range of organisations, such as Forestry Tasmania, local and state government, and Geoscience Australia (Table 1). A total of 176 acquisitions are included, of which 87 were collected specifically for this flood modelling project. Others were collected for a

Commissioned by	Purpose	Number of acquisitions
Flood modelling project	Statewide flood modelling	87
Climate Futures Project	Coastal hazards	1 (multiple locations)
DPAC	Coastal inundation hazard	27
DPIPWE	Land and lake management	14
Forestry Tasmania	Forestry	29
Geoscience Australia	Coastal hazards	3
Meander Valley Council	Local government	1
Metals X	Mining	1
MRT	Geological hazards and mapping	7
Transmission Line operators	Electricity network	2
TIDB	Irrigation	4
Coal Mines Port Arthur	Uncertain	1
Total		**176**

Table 1. Summary of commissioning organisations and survey purpose.

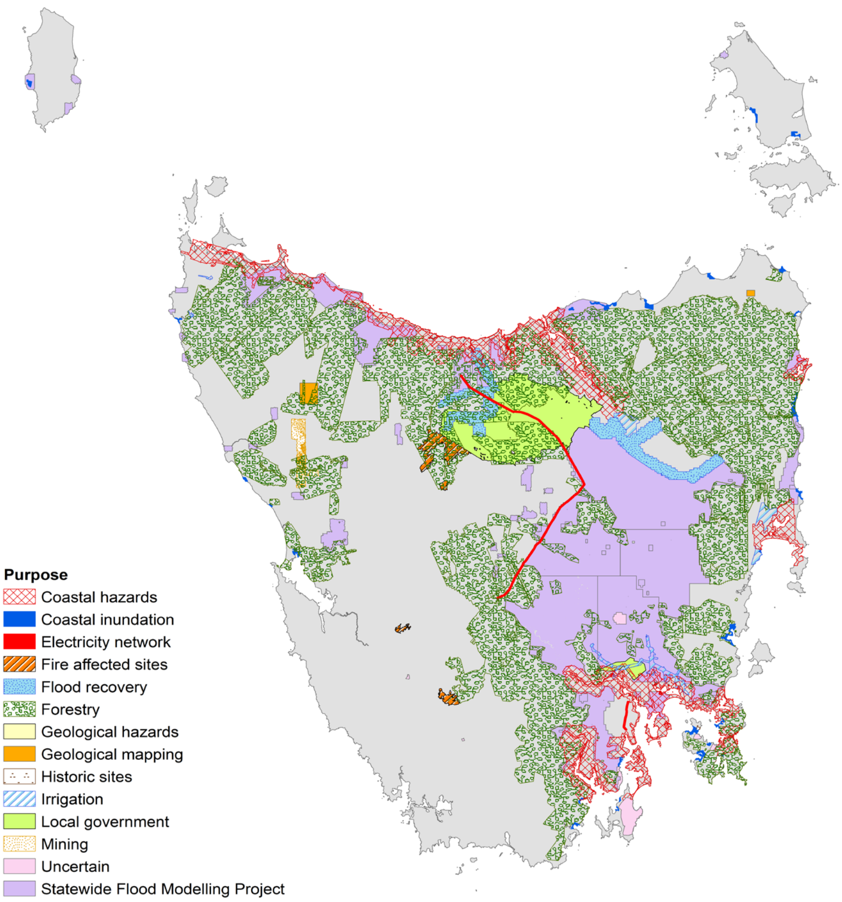

Figure 2. Summary of LIDAR coverage, symbolised by survey purpose.

Year	Number of acquisitions
2008	7
2009	1
2010	2
2011	9
2012	3
2013	13
2014	37
2015	3
2016	6
2017	8
2018	5
Total	**176**

Table 2. Year of data collection.

variety of purposes including forestry, hazards, mapping, mining, irrigation, and infrastructure. The year of collection and number of surveys is given in Table 2. The Department of Primary Industries, Parks, Water and Environment (DPIPWE) is the official custodian of this data and supplied the raw LAS files to MRT for this project. The original data can also be accessed from Geoscience Australia's ELVIS platform (https://elevation.fsdf.org.au/), but these files have not had bridges (re)classified and so differ from the LAS files used here.

2.1 List of supporting files

A number of LiDAR index files have been created during this process, which are referenced in the following sections. These are summarised in Table 3. These files serve as both index files and important inputs within the DTM generation process. In particular, the ranking table and clipping masks control which data takes precedence in the final DTM, in the case of overlapping LiDAR.

File	Description
LiDAR acquisitions index	A polygon shapefile of LiDAR data boundaries, depicting the full coverage of each survey. Attributes include UID, details of survey name, year, commissioning organisation, original purpose, nominal accuracy (v and h) and average point spacing. Note that some details are not available for all surveys. This file is intended as an index and so the boundaries may not be exact.
LAS file index	A polygon shapefile of individual LAS file boundaries for all of Tasmania. Attributes include UID, LAS file name, point count, point spacing, z min and z max.
LiDAR rankings table	An excel table that lists the priority order of surveys (current at April 2020). This hierarchy determines which survey(s) take priority where data overlaps and is a key input for many geoprocessing steps within the DTM creation process.
Clipping masks	A set of polygon shapefiles that represent the area covered by each LiDAR survey in the final DTM.

Table 3. Summary of supporting files that were developed as part of the LiDAR processing workflow.

2.2 Initial Processing

2.2.1 LAS reclassification

The pre-2018 data is in LAS file format and were supplied to us in pre-processed form, with x,y,z coordinates given in the Map Grid of Australia (MGA) Zone 55 projection, relative to the Australian Height Datum (AHD). LiDAR data collected specifically for this project (2018-2019) was supplied in compressed LAS format (zlas) and was decompressed to basic LAS format to allow certain processing tasks.

The LAS files were all received in classified form. However, the level of classification and codes present varied by survey, with some processed to a detailed level (including vegetation and/or buildings, Classes 3-5 and 6 respectively) and others with only ground returns (Class 2) initially classified. The newer LiDAR surveys also include a separate classification for bridges (Class 10). In order to perform hydrological conditioning and generate a stream network from the DTM, it was necessary to ensure that all points representing bridges were properly captured so they could be filtered out.

Firstly, a statewide bridges layer was generated by combining two primary datasets: The LIST Transport layer bridge segments (6445 records in polyline form) and Department of State Growth (DSG) bridge and culvert records (2995 records with width data in spreadsheet form, and 3075 records in point form with no width data). The DSG datasets were joined using a common structure number field, which resulted in a total of 2452 structures with known widths. These were linked to the LIST Transport segments through the Transeg_ID field. A polygon shapefile of bridge footprints was then created for these features. Where no DSG data was available, the LIST transport segments were converted to polygons by applying a buffer, with the buffer width varied according to road type.

The final bridges layer contained 6139 records, of which 2452 originated from the DSG data and 3687 from the LIST transport segments. All bridge polygons were manually checked against a state hillshade and orthophoto, and the boundaries edited where required to ensure that the bridge footprint was accurate.

The LAS files were then reclassified based on the bridges layer. Points identified as bridges were assigned Class 10, using the ArcGIS function "Set LAS class codes using features". Although some LiDAR acquisitions already had bridges classified, we applied this process to all surveys to make certain that all structures were accurately covered.

Further acquisition-specific details are given in the technical brief that accompanies the LiDAR data drives (Kain 2020 - LiDAR Data Package: File structure and supporting information).

2.2.2 First pass processing and quality assessment

For each acquisition, a LAS dataset was created and then a secondary LAS dataset layer was generated to extract bare-earth points (Class = 2). From this filtered layer, a 10 m DEM, hillshade and slope map were created in raster format to visualise the data. The images were then checked to ensure the landscape was reasonably represented and there were no classification errors.

A polygon boundary file was created for each survey using the ArcGIS 'raster to polygon' function (simplify polygons = FALSE). These files were the basis for the clipping masks, described in Section 2.2.3 and were merged into a single shapefile to create the LiDAR Acquisitions Index (Table 3). They were also used to visually assess data coverage and identify any issues such as flight path underlaps or other gaps in data. The number, size and cause of any data gaps have implications for how the LiDAR data is blended with the background/default DEM, so each boundary file was manually examined and edited to remove waterbodies and small voids (approximately less than 50 m x 50 m). For large lakes and areas of missing data, voids were retained to allow the photogrammetric contour data and/or lake bathymetry to fill the gap during later processing (Figure 3).

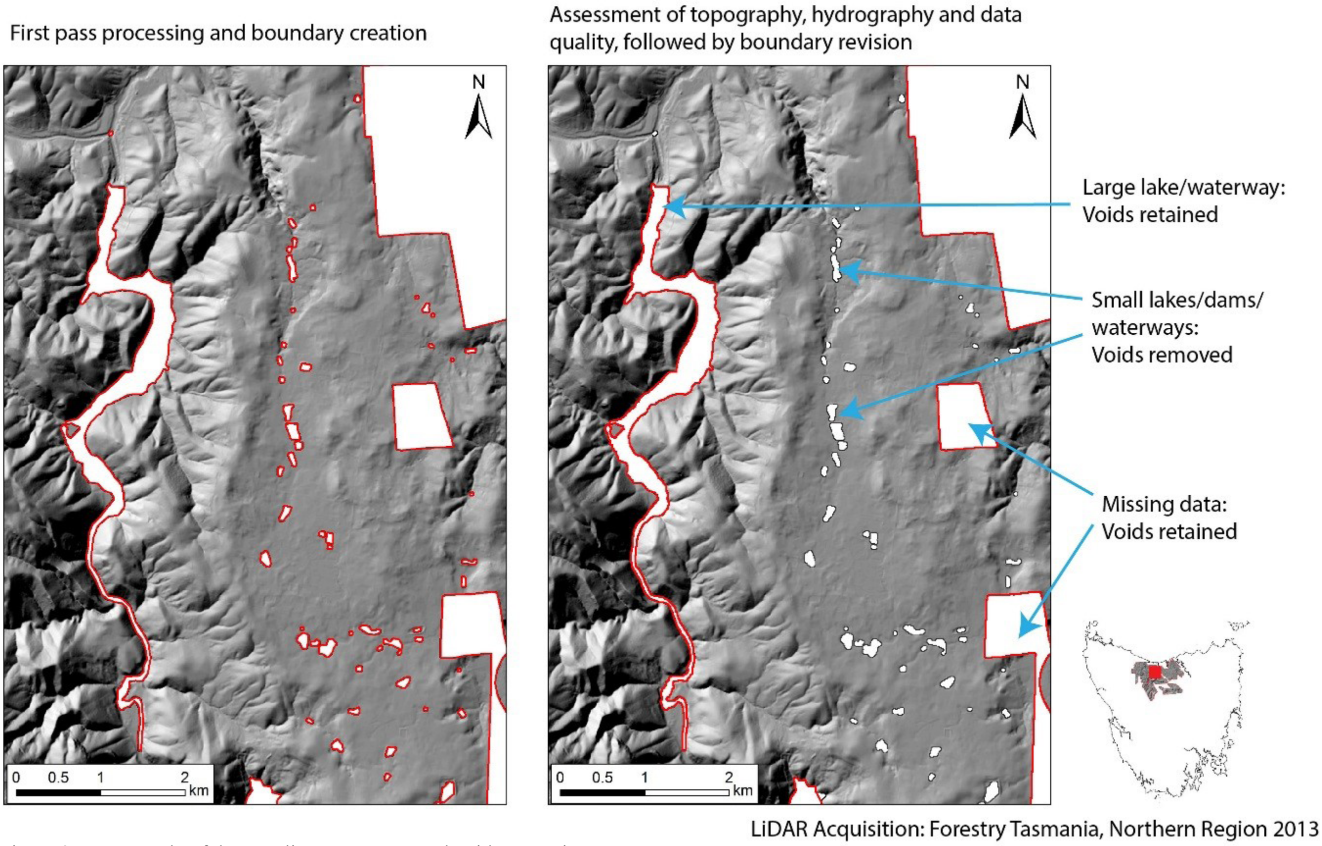

Figure 3. An example of data quality assessment and void processing.

LAS dataset statistics and average point spacing (per LAS file) were also calculated for each acquisition, using the LAS dataset statistics functions in ArcGIS. These outputs were then imported into R to calculate an average point spacing value for each survey to assist when comparing overlapping areas.

2.2.3 Ranking and masking overlapping data

Because the LiDAR acquisitions were obtained by varying organisations and for varying purposes, significant overlap is present in places. The boundary polygons for each acquisition were added to a map in ArcGIS and queried using the Find Overlapping Features add-in tool that was created by the NOAA Biogeography Branch(1). In isolated areas, up to four overlapping acquisitions were mapped.

The survey statistics and year of capture were used to develop an acquisition hierarchy according to data quality. This hierarchy was then saved as an excel table (LiDAR Rankings Table, described in Table 2) that acts as a master list that is called by many of the DTM geoprocessing scripts. In general, newer surveys take precedence over older data. Where surveys of the same year were overlapping, nominal accuracy and calculated point spacings were used to determine the appropriate ranking.

A set of clipping masks were generated to control the area covered by each survey in the final DTM. These boundaries were created by sequentially clipping each survey boundary by higher-ranked overlapping boundaries (leaving a 50 m overlap where possible) (Figure 4).

1. http://www.arcgis.com/home/item.html?id=968e6a55a11640d2b9cfa211104d3811

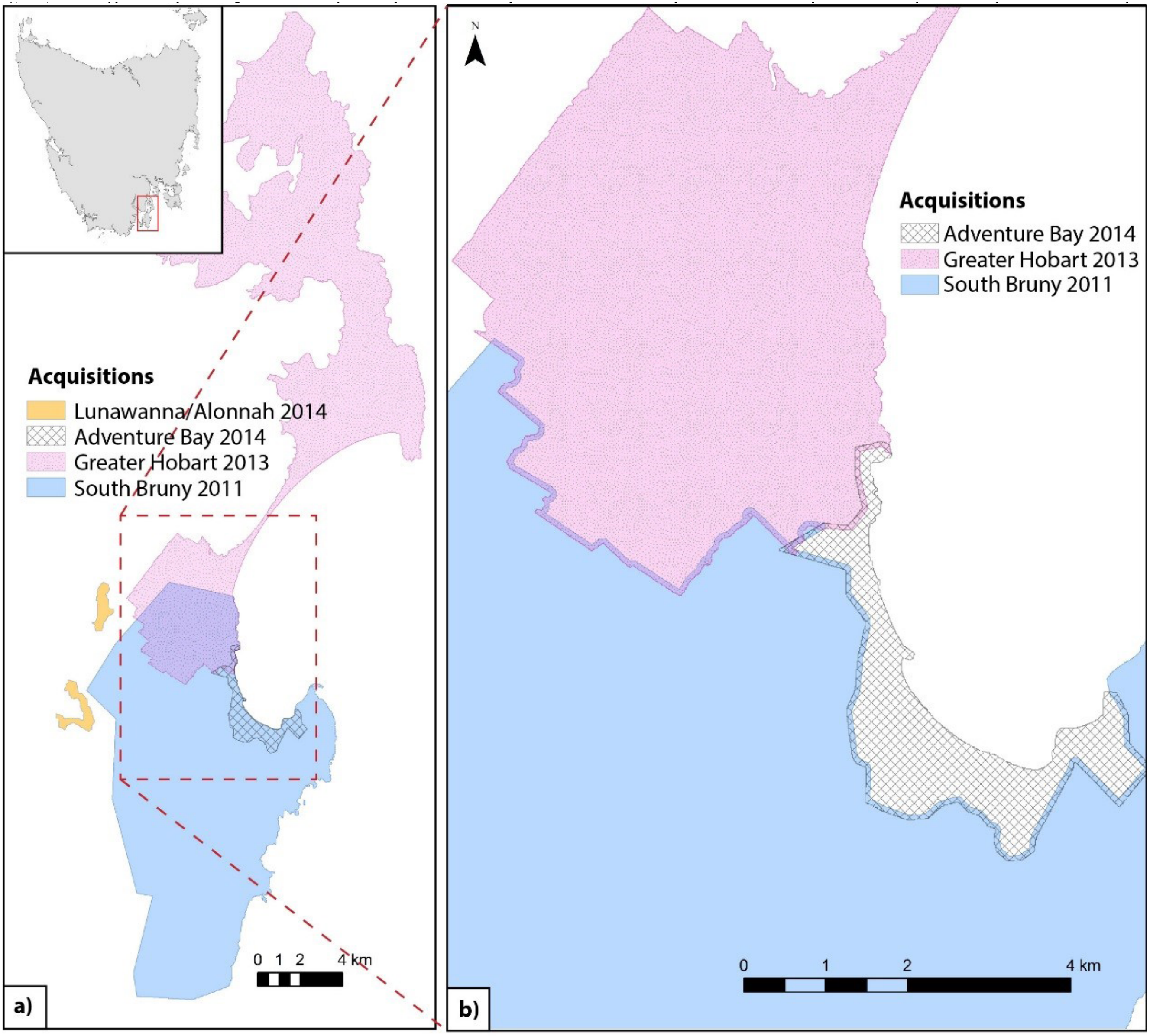

Figure 4. Example of clipping 3 acquisitions around Bruny Island. a) Original extent of the contributing acquisitions. b) Clipped boundaries of the three overlapping acquisitions. Note the 50 m overlap zone, which was maintained to minimise any edge effects at the joins.

A small number of surveys have been completely superseded by newer data and are not included in the final DTM. A series of 'walk', 'buffer' and 'erase' functions were used to create the clipping masks.

2.3 Creation of final LiDAR DTM

A final set of LiDAR DTMs were created for each acquisition, using the LAS dataset to raster function, with a linear void interpolation operator. The snap raster environment setting was also used to ensure the cells of each individual DTM were aligned. This process created a set of 10 m DTMs that had no data gaps.

The DTMs were then clipped using the clipping masks described in Section 2.2.3, resulting in a set of trimmed DTMs with an overlap of 50 m between abutting acquisitions. Clipping was performed using the ArcGIS 'extract by mask' function.

A final mosaic step was performed to generate a single LiDAR DTM for the state (Figure 5). The 'mosaic to new raster' function was used, with a blend operator. In most cases, a smooth seam was achieved between abutting acquisitions.

3.0 Other (non-LiDAR) Data Processing

This section documents the methodology used for the areas of the State not covered by LiDAR, referred to here as the "Default DTM".

The original official DEM issued by DPIPWE (LIST Tasmania 25 metre Digital Elevation Model) was initially produced over 20 years ago and at 25 m resolution. As the objective of this process was to create a 10 m DTM, a new 10 m Default DTM was constructed using the ANUDEM method (ANU, 2008; Hutchinson, 1989; Hutchinson et al., 2011).

3.1 Methodology using ANUDEM

ANUDEM is a spline based interpolator that produces raster and is well suited for modelling natural

Figure 5. Final LiDAR DTM. This was then merged with the background, Default DTM to create a statewide model.

landscapes. The ANUDEM method has a number of additional controls that can be imposed on the output model. The hydrological enforcement option is particularly useful where elevation control is poor, such as on large flood plains or when mapping terrain beneath large artificial lakes.

The Default DTM was created using the Topo2Raster tool within the Spatial Analyst Extension for ArcGIS Desktop, which is based on the ANUDEM method. The Topo2Raster was used within Model Builder (a graphical programming environment within ArcGIS) where an iterator function called each tile in turn, added a buffer and used this as the processing extent input parameter for Topo2Raster. Tiles were then mosaiced to create a single, statewide model.

Large dam structures were specifically excluded in order to assist the hydrological enforcement method to interpolate along submerged valleys. Some stream networks were digitised from old maps in areas that are now submerged by artificial lakes to further assist this process. Bathymetry was also supplied by Hydro Tasmania for some lakes (Figures 6 and 7).

3.2 Issues encountered during processing

A number of issues were encountered during the processing of the Default DTM. As a rule of thumb, a 10 m resolution DTM using primarily photogrammetric contours collected for 1:25 000 scale maps may be regarded as pushing the limit of resolution. This is particularly evident when viewing a slope angle DTM derivative where a form of interpolation oscillation (waveforms) can be seen on those slopes where the spacing of contours exceeds the resolution of the raster model. In this instance, cells overlying contour lines have slightly lower slope values than the intervening areas. Although the Topo2Raster tool has some parameters to control this, and despite some experimentation, it was impossible to eliminate this effect. However, we consider this issue to be of minor importance and one that is of diminishing importance as more LiDAR datasets are collected.

Artefacts have also been discovered along the boundaries of some tiles. It is to be expected that there will be some difference in elevation values where tiles overlap, especially where controlling data are limited, such as across large flood plains and lakes. Despite the use of the blend method for areas of overlap it was impossible to remove artefacts, even when the overlap distance was set to 1 km. In most instances the problem is outside of urban areas.

Some errors in input data were also identified. In particular, the lake bathymetry required significant manual editing and position correction to ensure the contours matched the surrounding data. Additionally, a small number of incorrect spot heights were discovered, which appear in the final Default DTM as localised mounds or hollows.

4.0 Merging LiDAR and Default DTMs

The default DTM raster is a statewide layer with a 10 m cell size, which was clipped to the coastline boundary. A mask was generated with a 50 m internal buffer from the total LiDAR boundary, which was then used to clip the default DEM. This buffer provided an overlap zone across which to blend the LiDAR and default DEM and generate a seamless output. This clipping process resulted in a thin path of Default DTM pixels being left around the coastline where LiDAR data

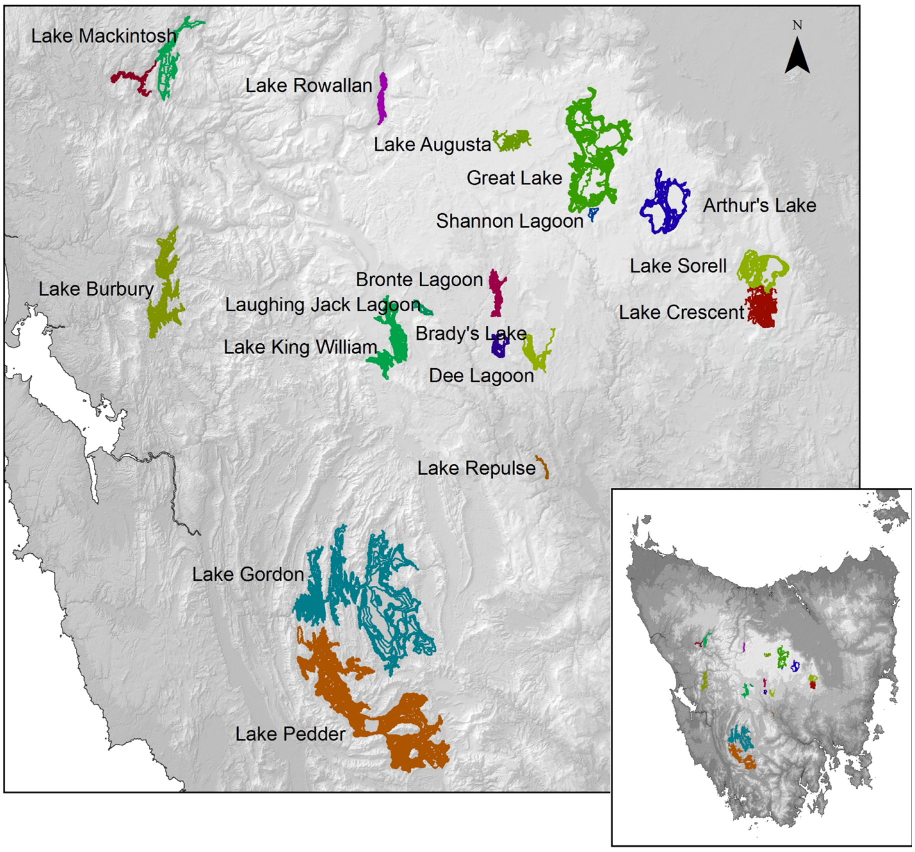

Figure 6. Overview of the Hydro Tasmania bathymetry files and lake locations.

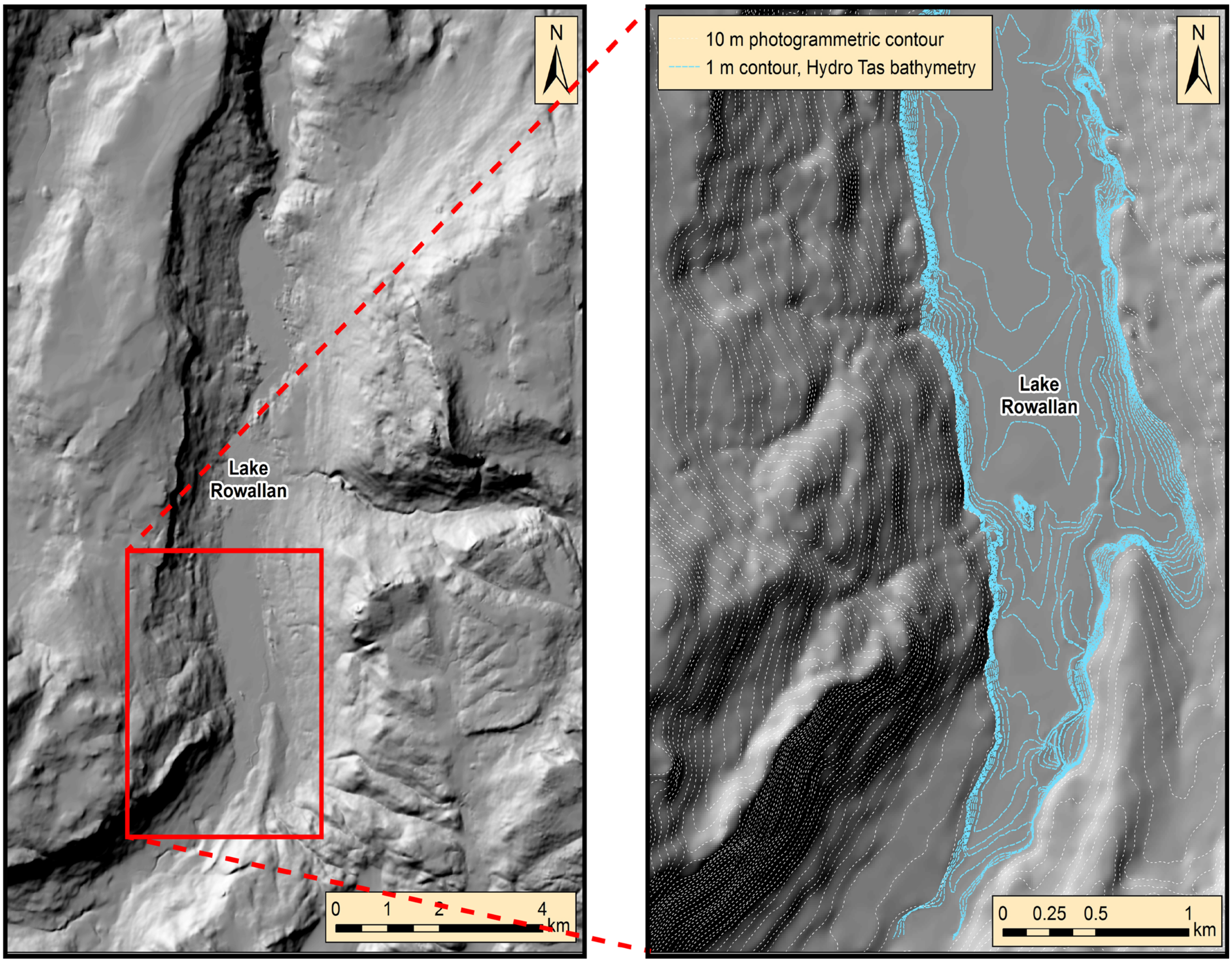

Figure 7. An example of the bathymetry supplied by Hydro Tasmania for Lake Rowallan.

was present, which if left to blend with the LiDAR in the mosaic would result in poor data quality at the coastal margins. A manual mask was generated to remove these erroneous pixels prior to mosaicking the two DTMs.

Initially, the LiDAR and Default DTMs were mosaicked using the ArcGIS 'mosaic to new raster' function, using the blend operator. However, the result was not seamless, particularly in cases where there was a large difference in elevation between the LiDAR data and the Default data in the overlap zone. Consequently, a script was developed to calculate a simple weighted average across the overlap zone, by first performing a Euclidian distance calculation from the Default DTM edge of the overlap zone, and then applying a conditional evaluation to perform the weighted average based on the distance raster. This process produced a much smoother result.

5.0 Hydrological Processing

This section outlines the process that has been applied (to date) to hydrologically correct the statewide DTM and to generate a draft stream network for the flood model. A number of hydro-processing tools were trialled before settling on Whitebox Tools. Details of the processing steps and tools is presented in Table 4. The processing involved a number of intermediate steps, each of which resulted in a separate statewide output that can be made available if desired. Initial processing was done across the entire state in one iteration, but some outputs were compromised. The state was then broken into 6 catchment areas: Northeast, Southeast, Northwest, Southwest, King Island and Flinders Island (Figure 8). These boundaries were drawn along catchment boundaries, as per the CFEV catchments layer available on LISTMap and processing was largely performed using Whitebox GAT. Whitebox uses its own raster format (.dep and .tas), which necessitated ongoing file conversions between ESRI or ASCII grid rasters and the Whitebox format. The stream network will be manually cross checked and edited to ensure it is correct. We will also need to inspect and flatten waterbodies. Following this process, we expect to burn the stream network into the DTM and produce a final hydrologically enforced DTM.

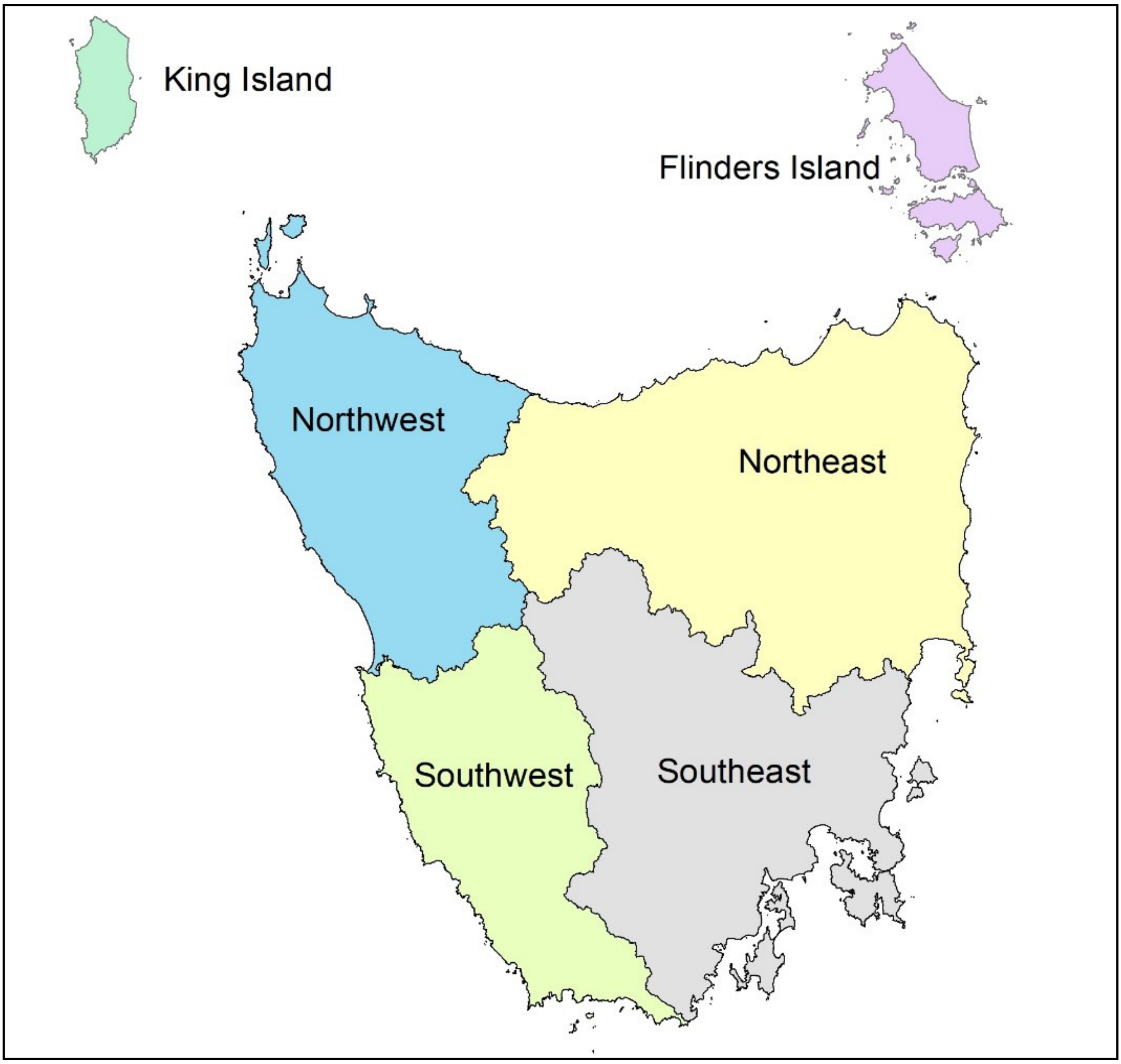

Figure 8. Boundaries of the processing areas for the stream network generation process.

Process	**Tool**
Breach depressions in the DTM	Whitebox - Breach depressions least cost
Generate D8 flow direction raster using output from (1)	Whitebox - D8 flow pointer
Generate flow accumulation raster using output from (3)	Whitebox - D8 flow accumulation
Extract stream network from outputs of (2) and (3)	Whitebox – Stream extraction, channelization threshold 500 (i.e. 500 cells = 5 000 m2)
Calculate Strahler order using outputs from (2) and (4)	Whitebox – Horton-Strahler stream order
Convert Strahler ordered stream raster (5) to vector format	ArcGIS Pro – Raster to polyline
Smooth vector stream lines (6)	ArcGIS Pro – Smooth line (PAEK algorithm, tolerance = 50)
Interpolate z values to the Strahler-ordered stream network (6) and (7), using outputs from (1)	ArcGIS Pro – Interpolate shape, using the breached DTM as the input surface.
Calculate z values for the stream network nodes in (8)	ArcGIS Pro – Calculate geometry, z values for the start and end of each line segment

Table 4. List of processing steps and tools used to generate the stream network.

6.0 Conclusions

The need for a new DTM for Tasmania has been driven by improvements in data, particularly LiDAR, and for a new model to use as an input to upcoming state projects and the Tasmanian Strategic Flood Mapping project in particular. The final outputs are intended to be freely and publicly available.

We would like to thank various agencies and individuals for contributing to this project by supplying data and/or testing the preliminary products. Special thanks go to Land Tasmania (DPIPWE), who are the custodians of Tasmania's elevation datasets.

7.0 References

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