

Regional Floodplain Database:

Floodplain Terrain



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Regional Floodplain Database

Floodplain Terrain

301015-01921 – RP002

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PROJECT 301015-01921 - REGIONAL FLOODPLAIN DATABASE

REV	DESCRIPTION	ORIG	REVIEW	WORLEY- PARSONS APPROVAL	DATE	CLIENT APPROVAL	DATE
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1. INTRODUCTION

1.1 Scope

WorleyParsons Services Pty Ltd (WorleyParsons) has been commissioned by Moreton Bay Regional Council (MBRC) to carry out an investigation into the development of a definitive terrain surface defining the regional floodplain as part of Council's Regional Floodplain Database Project (RFD Project).

The RFD Project involves a three year (three stage) program for the development of comprehensive flood mapping across the Moreton Bay Regional Council Local Government Area. A key focus for the project is the standardisation of methods and procedures so as to ensure consistency in the flood information produced. The Burpengary 'Minor Basin', incorporating Burpengary Creek, Little Burpengary Creek and Deception Bay has been selected as the Stage 1 pilot study catchment for development of these standardised methods and procedures.

WorleyParsons was invited to carry out the following sub tasks as part of the Regional Floodplain Database project:

- *1E – Floodplain Topography (2009 DEM)* – development of a methodology for processing 2009 LiDAR into terrain surfaces for flood modelling, mapping and visualisation.
- *1F – Estuarine Bathymetry* – determination of additional bathymetric requirements.
- *2E – Floodplain Structures (Floodways)* – development of methodologies and datasets defining floodways on major roads.
- *2I – Floodplain Structures (Channels)* – development of methodologies and datasets for describing open stream channels for hydraulic modelling purposes.

Following test application Council will consider extension of the procedures documented herein for Stage 2 of the project which will include detailed flood modelling and mapping for the region.

1.2 Overall Approach

The objective during the completion of the sub projects was to develop methodologies and procedures that provide consistent, suitably formatted elevation data for TUFLOW modellers. To ensure that the methodology was sufficiently flexible to accommodate the creation of other terrain/DEM products, WorleyParsons developed a software tool/system to provide:

- A dramatic improvement in productivity and consistency in setting up TUFLOW models by delivering a wholly integrated model terrain grid containing all necessary "terrain modifiers" by



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layering the various source datasets and “modifiers” (the end user is delivered the final grid directly, rather than a base grid with numerous “modifiers”), TUFLOW Z-Points file, and TUFLOW Material Types file;

- A means of readily accommodating updated elevation data, as new or higher quality elevation information becomes available;
- Consistent elevation data regardless of user (all DEM outputs are derived from common, controlled, and updatable elevation datasets);
- A simple and adaptable means of providing terrain models to varied users (variable resolution, extents, tiling options, and source data inclusion to suit end user requirements, rather than multiple pre-cooked DEM's);
- Efficient storage and generation of DEM's

A schematic diagram of how the tool operates is shown in Figure 1.

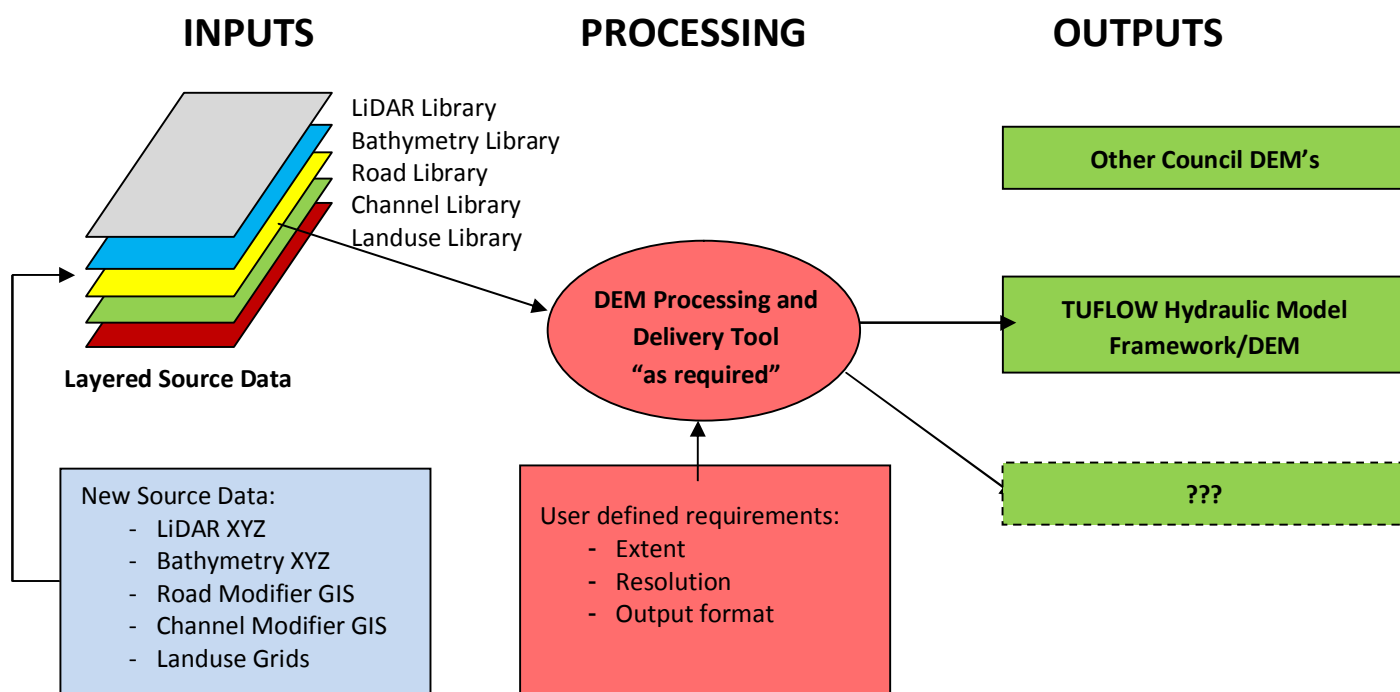


Figure 1 – Schematic Chart of DEM Tool Operation.



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2. DEVELOPMENT OF THE TERRAIN MANAGEMENT TOOL

2.1 Evaluation of alternatives to the custom tool

Alternative approaches to developing the customised DEM management tool were investigated to determine if the effort associated with developing the tool provided significant benefits over existing or traditional approaches.

The table, overleaf, presents a comparison between using ESRI Terrain or a custom developed solution for the purposes of managing and delivering terrain datasets for the Regional Floodplain Database, against a more traditional, “pre-cooked” DEM's approach. Note that not all features used in the comparison were implemented in the DEM tool. The following legend has been used:

- ✗ - not suited
- ✓ - suitable
- ✓✓ - highly suited



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Key Feature	Pre-processed DEM's	ESRI Terrain	Custom Solution
Uses "off the shelf" software with minimal customisation	N/A	✓	✗
Support for varied input file formats and data structures	✓	✓	✓ ✓
Maintaining structure in processed DEM input sources (eg high quality detailed survey delivered as a 12D TIN structure)	✗	✗	✓ ✓
Ability to layer source data using metadata (quality, age, type etc)	✗	✓	✓ ✓
Support for varied output file formats (TINs, grids, XYZ's etc)	✗	✓	✓ ✓
Access to individual source elevation datasets	✗	✓ ✓	✓ ✓
Direct output of TUFLOW data files	✗	✗	✓ ✓
Support for varied output specifications (size, resolution, extent etc)	✗	✓ ✓	✓ ✓
Enforce correct processing of hydraulic terrain modifiers for TUFLOW	✗	✗	✓ ✓
Variety of DEM processing methods	N/A	✓ ✓	✓
Control of DEM processing methods and parameters	N/A	✓	✓ ✓
Ease of Use – End Users	✓	✗	✓ ✓
Ease of Use - Administrators	✓	✓ ✓	✓
Ability to be used outside of Council	✓	✗	✓
Data Management (including efficiency, centralized server)	✗	✓ ✓	✓ ✓
Updating DEM's with new raw terrain data	N/A	✓	✓ ✓
Consistency of delivered data (including minimizing operator error)	✓ ✓	✓	✓
Flexibility of System – ability to be enhanced, altered	✗	✓	✓ ✓



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Processing speed	✓✓	✓	✓
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Given the above clear advantages of developing a custom tool, the DEM Tool was developed.

2.2 Terrain Generation Theory

2.2.1 Overview

The DEM tool uses a layered “library” of source elevation datasets from which appropriate data is extracted, and used to incrementally build the DEM. The general, base datasets are the thinned ground points (ASCII XYZ) from the 2009 LIDAR tiles. The tool collects the ground points required to build the user specified DEM, and assigns elevations to each cell accordingly. The tool then uses the bathymetry datasets (as ASCII XYZ points) to assign elevations (overlay) to those cells within a ‘bathymetry extent’ GIS polygon layer. The tool then uses the terrain modification datasets, to update the elevations of those cells influenced by the modifiers on the output DEM, delivering a fully integrated DEM.

2.2.2 MBRC Source Elevation Data

The primary data sources for elevation information are the 2009 LiDAR data and 2009 bathymetry data. Localised or purpose specific terrain updates or modifiers representing, channel lines, road crossing lines, bathymetry updates etc are also likely to be used. These updates can be in a number of formats such as 3D points and 3D lines.

The source data for constructing DEM's can be summarised as follows:

- **Base Elevation Data:**

The base elevation data forms the bulk of the elevation dataset at a specific point in time (ie the time the data was captured). It consists of:

- LIDAR ground elevations (XYZ points – 2009 LiDAR)
- Bathymetry (commonly as XYZ ASCII points, or occasionally as a structured 12D DEM)

- **Local scale Elevation Updates (or terrain modifiers):**

The local elevation updates consist of, generally, local scale enhancements or additions to the base datasets. They may provide more detail or accuracy than the base data in certain regions (eg detailed survey), or may be used to specify hydraulically significant terrain features (such as top of banks, road crossings, thalweg lines, controls etc), or may provide updates reflecting changes to the terrain since the base data was captured (eg development or channel survey).



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Some of the terrain modifiers may only be applicable to certain DEM uses (eg for modelling purposes versus mapping purposes).

The local terrain updates may come in a number of formats such as (note that not all formats have been incorporated into the tool):

- 3D lines/polylines
- Separate spot heights (not implemented)
- Structured TIN DEMs (not implemented)
- Structured Grid DEMs (not implemented)

Local terrain updates may be applied in a variety of ways:

- Insert (add update data to base data)
- Overlay (update base data with interpolated values from update data)
- Replace (replace base data points in the area of interest with those from the update data)

2.2.3 Assigning Elevations

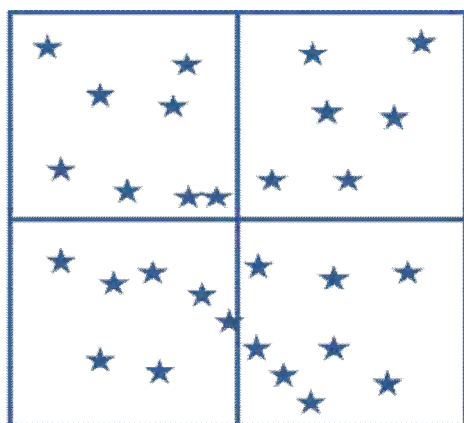
In generating the DEM, the tool uses the most suitable approach to assign elevations to each cell, based on the relative density of source elevation data points in each cell. In general, there are three relationships between the source data density (resolution) and the output DEM cell size:

1. Source data *much greater* resolution than DEM cell size – “high relative resolution”
2. Source data *much lower* resolution than DEM cell size – “low relative resolution”
3. Source data of similar resolution to DEM cell size

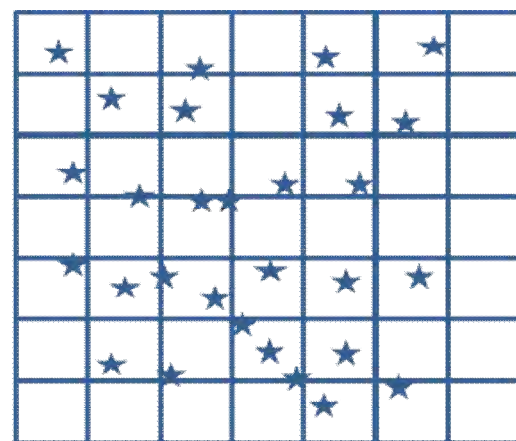
Figure 2 shows relationships 1 and 2 (above), pictorially. The source data is the same in both cases (stars), however, the relative density (number of data points per cell) of the data in the left hand case is higher than that in the right.



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High “Relative Resolution” Source Data



Low “Relative Resolution” Source Data

Figure 2 – Source Data Resolution Greater than Output DEM Cell Size (LEFT), and Source Data Resolution Less than Output DEM Cell Size (RIGHT).

2.2.3.1. Source Data Resolution Greater Than Output DEM Cell Size

The grid on the left of Figure 2 shows a situation where, for the four DEM cells shown, there are many source elevation data points in each cell. In this case, traditional approaches such as Krigging, spline interpolation, inverse distance etc are not suitable to define the elevation in the cell as they are predominantly used when determining the elevation at a point from sparse source data. Each point in the cell was considered to contribute equally to the elevation of the cell, and therefore, a simple averaging approach was used. Trials were undertaken with a variety of spatial and weighted averaging but these failed to improve on a sample average when compared to the TIN representation of the points (see below).

2.2.3.2. Source Data Resolution Less Than Output DEM Cell Size

The grid on the right of Figure 2 shows a situation where, for the DEM cells shown, there are often only 1 or 2 source elevation data points in each cell, with some cells not containing any data points. In this case, Krigging, spline interpolation, and inverse distance approaches are suitable, however, a localised triangulation of the source data and interpolation from the triangular faces will yield better results.

2.2.3.3. Dynamic Approach to Elevation Assignment

The tool processes each cell of the output DEM separately. The number of source data points in each governs whether the averaging approach or TIN interpolation approach is used. The number of



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source elevation points at which the tool transitions from TIN interpolation to point averaging was set to 5. In this sense, it assigns elevations to each cell of the DEM using the most suitable approach, depending on the relationship (relative resolution) between the density of source data versus the output DEM resolution. This is shown in Figure 3 where the blue cells are assigned elevations by averaging the source data points, whilst the white cells are assigned an elevation by interpolating from the TIN surface at the centroid of the cell.

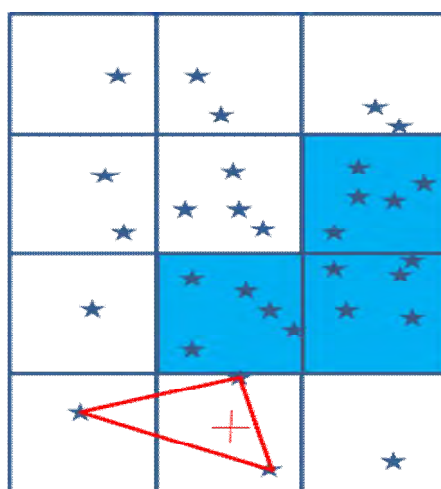


Figure 3 – Output DEM Cell Elevations Assigned Using The Most Suitable Approach For Each Cell.

As the tool varies its approach to elevation assignment based on the relative density of the source data, it has been called a “Dynamic Elevation Assignment Approach”.

2.2.4 Performance of the DEM Tool

2.2.4.1. DEM Tool Accuracy

The approach discussed above will give the best representation of the terrain surface for any given output DEM cell size by virtue of the ‘dynamic elevation assignment approach’. It is the cell size of the output DEM will govern the overall ‘accuracy’ of the DEM.

For example, a 5m cell size will approximate a 25m² area by a single, flat terrace. There is likely to be significant discrepancy between a TIN surface derived from the LiDAR (at approximate 0.3m spacings there would be 280 odd data points in a 5m cell) and a 5m DEM. If, however, a 0.3m cell (0.09m² area) size was used, it would be expected that there would be a much lower discrepancy between the two surfaces. If the cell size was “infinitely small”, the gridded surface would be same as the TIN surface.



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Whilst a TIN will give the best absolute approximation of the terrain surface using LiDAR source data, a grid prepared to suit the context of how the data is used will be adequate, if prepared using the 'dynamic elevation assignment' approach.

2.2.4.2. Dynamic Processing Method Comparison

A number of options for assigning elevations to each cell of a gridded DEM from LiDAR datasets were investigated, and formed the basis of developing the dynamic terrain assignment approach used in the DEM tool:

- Assigning from TIN interpolation at the cell centroid only,
- Averaging TIN interpolations at a number of locations in the cell (centroid plus 4 midpoints between the centroid and each cell corner),
- The adopted approach (TIN interpolation at the centroid where there are less than 5 LiDAR datapoints in the cell, or averaging if there are more than 5).

Figure 4 shows a comparison between a profile extracted from 5m DEM's developed using the above methods and from the LiDAR TIN surface. 5m DEM's were selected to match the predominant 5m cell size of the TUFLOW models used in the RFD project. To provide a reasonable comparison to the LiDAR TIN, the 5m gridded DEM cell centroids have been used to prepare a "smooth" profile, rather than a "stepped" profile usually extracted from gridded DEM's.



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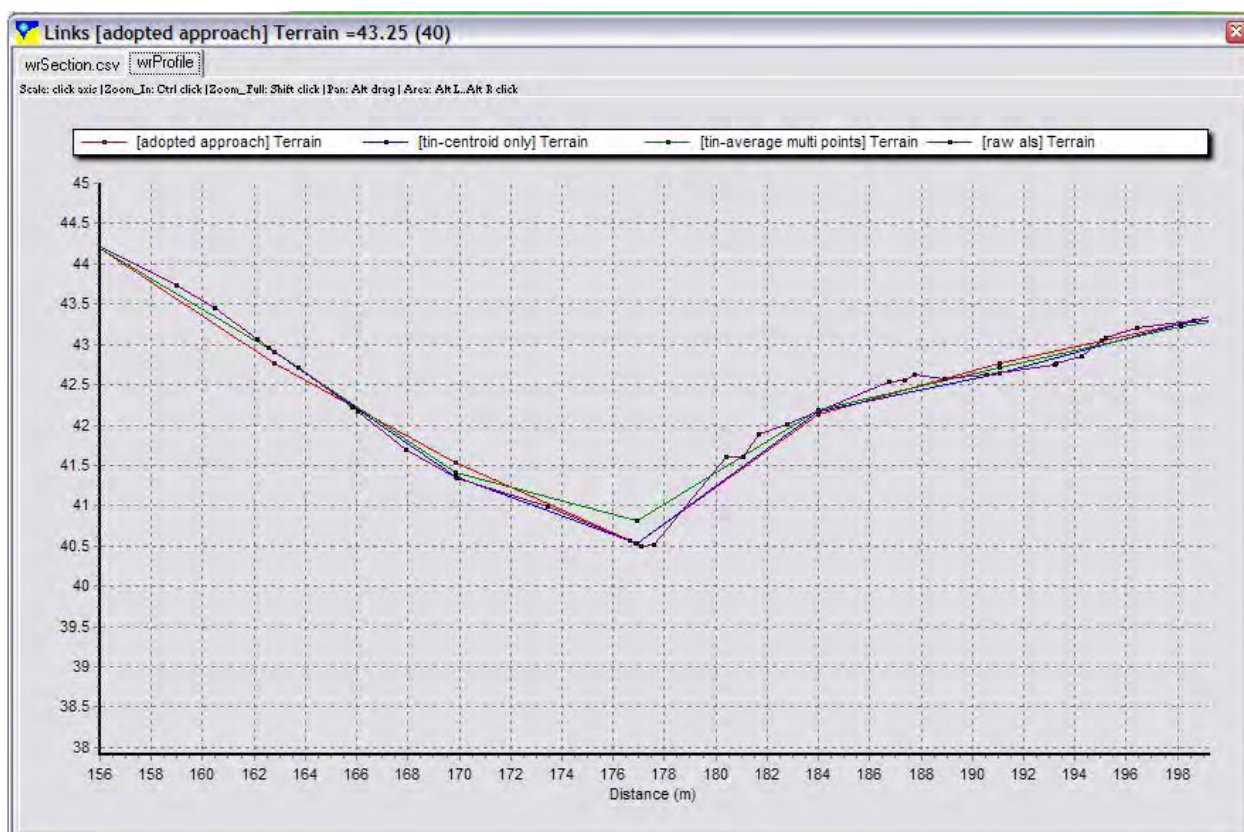


Figure 4 – Comparison of 5 DEM's generated using various elevation assignment approaches.

It is clear from Figure 4 that there is minimal difference between the methodologies, except that the TIN surface multi point averaging routine has not defined the channel bottom as well as the other approaches.

2.2.5 Terrain Modification

The facility to modify the output DEM, to ensure specific hydraulic controls are incorporated into the output DEM, was included in the DEM Tool. The output DEM can be modified in a TUFLOW compatible format (along stepped diagonals) by ensuring that any cell within the specified distance of the modifier line (the line "width") was included in the modification process.

The tool was structured to accommodate two types of modification, as follows:

- *Nodal Elevation Line* – 3D GIS polylines (user defined widths) where nodal values are read from the LiDAR data and linear interpolation applied between nodes, and



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- *User Specified Line* - 3D GIS polylines (user defined widths) where the start and end values of the line are specified by the user, with linear interpolation applied along the line.

Terrain modifiers are applied as a final “layer” to the DEM output process with channel modifiers following road modifiers.

2.3 Addressing TUFLOW Modeller Requirements

2.3.1 General Hydraulic Modeller Terrain Requirements

TUFLOW hydraulic modellers generally use terrain information to:

- Resample and assign elevations to each cell of the grid model
- Visualise/inspect the terrain to gain an understanding of regional and local topography to assist in developing suitable model networks
- Interrogate results and verify modelled flow behaviour against physical (terrain) constraints or drivers
- Potentially map the model results in post processing and analysis tasks

Issues to consider in developing DEM's for flood modellers include:

- Usable file size constraints imposed by hardware and software
- Required DEM resolution (the raw LIDAR is likely to provide far more detail than can be utilised by the modeller in their coarser model network)
- Suitability of DEM in describing hydraulic features of terrain
- Incorporating terrain modifiers into the DEM or providing separate modification files
- Provision of DEM's in suitable formats. Modellers may desire DEM's in different formats depending on the tools they are using to develop their TUFLOW models (eg ESRI, MapInfo, SMS, XP, ISIS, waterRIDE etc).
- Allow for rotated model grids
- Access to DEM's (server location, software tools and expertise required to extract and combine DEM's, service provided by GIS department)



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2.3.2 TUFLOW Requirements, Limitations, and Traditional Elevation Assignment

Through discussions with Phillip Ryan of BMTWBM, Brisbane, and subsequent discussion with Bill Syme of BMTWBM, we understand that TUFLOW samples (inspects) an external DEM (12D ASCII TIN or Vertical Mapper grid) to generate elevations for its internal structure. These elevations can then be altered or overridden using external terrain modification files.

This internal structure is based on a 9 node sampling of elevations for each cell. However, only 5 points are used in TUFLOW's hydraulic solution. The central node governs the hydraulic storage of the cell (red on Figure 1), whilst the midside nodes control flow into and out of a cell (blue on Figure 1). The corner nodes are not used in the hydraulic calculations but form part of the reporting framework. This is represented in Figure 1.

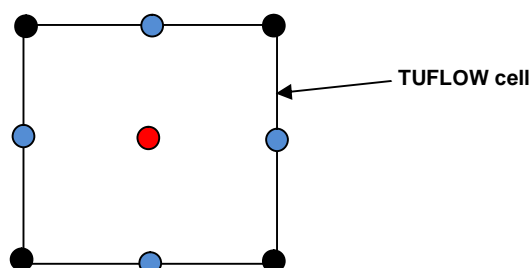


Figure 5 – TUFLOW Internal Elevation Points for a Cell

TUFLOW samples the elevations for these 9 points directly from a gridded DEM (ie the elevation value of the cell the point is in), or from a TIN surface at the point. For any model, the resolution of the elevation data versus the resolution of the model becomes important.

For fine scale models (where the resolution of these 9 points is similar to that of the source data, or the source data is coarser than the model framework), the elevations assigned from a TIN would be a good representation of the source data (as shown in Figure 6).

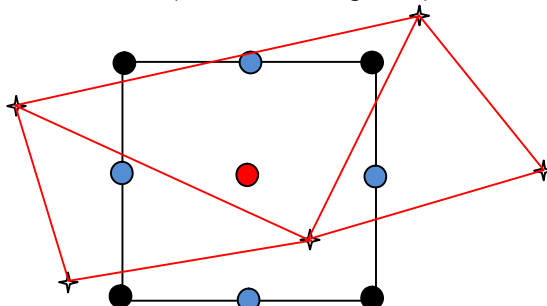


Figure 6 – Assignment of TUFLOW node elevations using coarser scale TIN source data

For larger scale models (where a single cell may contain many source elevation data points), the elevation assigned is dependent on the structure of the source DEM. If a TIN DEM is used, TUFLOW will assign elevations from the triangle in which each point resides. If a gridded DEM is used,



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TUFLOW will assign elevations from the cell each point resides in. This may lead to the assignment of an elevation that does not represent the general terrain covered by the model grid cell and has the potential to be skewed by “noise” in the source datasets. This is shown in Figure 7 where only 3 elevation points are used from a TIN DEM and only 1 cell is used from a gridded DEM, yet each TUFLOW cell contains many source elevation data points.

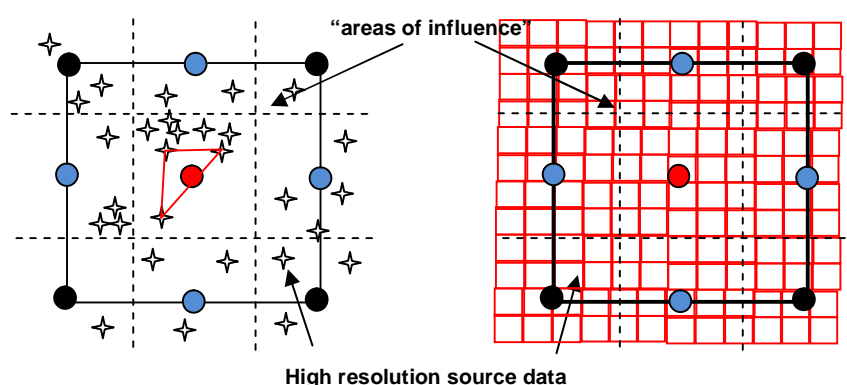
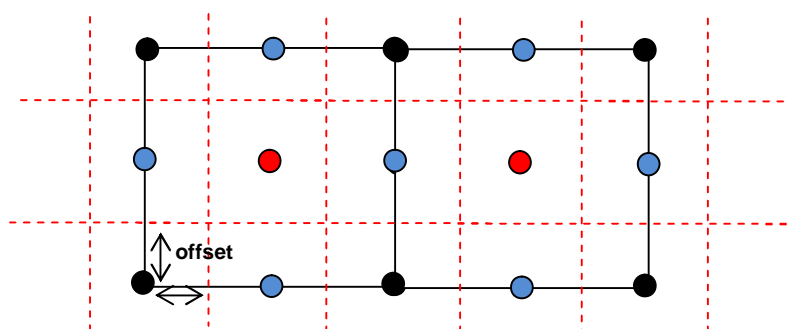


Figure 7 – Assigning TUFLOW cell elevations from a TIN (left) and gridded (right) DEM – Fine Scale Source Data.

An alternative approach would be to use the dynamic elevation assignment approach to derive an elevation for each node based on the relative density of points that reside within each node’s “area of influence”.

Given that TUFLOW uses 5 elevation points in its hydraulic solution, the most efficient source dataset is a gridded DEM of twice the resolution (four times the disk space) of the TUFLOW model that is offset by one quarter of a cell (coinciding with the “area of influence” lines on Figure 2), would eliminate the aforementioned problems. Herein, this is referred to as the “TUFLOW sub-grid”. This is shown, dotted, in Figure 8, below.





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Figure 8 – Offset “2x2” grid (dotted in red) used to assign elevations to TUFLOW internal nodes

The TUFLOW sub-grid would be created using the dynamic elevation assignment discussed in section 2.2.3. The grid would be offset from the coordinates used to create the TUFLOW model (or the TUFLOW model would be offset from the “2x2” grid when it is created).

When terrain modifiers (roads and channels) are used in the process, they are overlayed onto the TUFLOW sub-grid using the width specified in the modifier file but ensuring a minimum connectivity between the sides of TUFLOW cells, thus guaranteeing a continuous flow path or obstruction.

The modified TUFLOW sub-grid is then used to create the TUFLOW Z-Point file which can also be clipped to a supplied GIS polygon to minimise the resulting file size.



3. SUB TASK 1E – FLOODPLAIN TOPOGRAPHY (2009 DEM)

3.1 Role of 2009 LIDAR Data

The 2009 LIDAR data provided by Emergency Management Queensland (EMQ) forms the base dataset for the DEM tool. EMQ provided two ASCII XYZ datasets: all ground points, and thinned ground points. The metadata for the thinned ground points indicated that data points were removed if they were redundant (ie did not alter the triangulated TIN surface). Given that this dataset was approximately 1/3 the size of the unthinned dataset, this was used as the base elevation dataset for the tool.

3.2 2009 LIDAR Quality

An investigation into the quality of the 2009 LIDAR dataset (ie how well it represents the terrain) was carried out by comparing spot heights derived from detailed ground survey to the LIDAR triangulated surface, at a number of locations in the floodplain:

- *Old Bay Rd, Burpengary* – detailed survey of a combination of road surface, and heavily vegetated (trees - bush land) areas. 176 survey points regarded as “bush land”, and 104 regarded as roadway.
- *Maine Terrace, Deception Bay* – detailed survey of a combination of road surface and heavily vegetated (trees - bush land) areas. 219 survey points regarded as “bush land”, and 62 regarded as roadway.

The aim of the investigation was not to assess the quality of the LIDAR data capture itself, as this was assumed to be of high quality given the scale of the EMQ project, but to determine how well the LiDAR data represents the terrain in a number of specific situations: namely clear, relatively flat areas such as along roads; and densely vegetated areas, such as bush land.

3.2.1 Old Bay Road, Burpengary

The LIDAR data showed a general trend of underestimating the ground level along the *roadway* by an average of -0.13m when compared to the detailed survey. However, this was relatively consistent with a standard deviation of 0.02m and Root Mean Squares (RMS) error of 0.13m. The closest point was -0.07m lower than the detailed survey with the greatest difference being -0.17m lower.

In the *heavily vegetated* areas, the LiDAR showed an average overestimation of the ground surface by an average of 0.08m. However, the differences were much more variable than along the roadway with a standard deviation of 0.23m, RMS error of 0.24m, and a minimum and maximum difference of -1.23m and 1.05m, respectively.

Taken as a whole, the LiDAR data had an average difference of less than 0.01m, with a standard deviation of 0.21m, and RMS error of 0.21m.



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Figure 9 shows a thematic map of the difference in ground elevations between the LiDAR (interpolated from a TIN surface) and the detailed survey spot heights.



Figure 9 – Terrain Difference: LiDAR TIN Surface MINUS Detailed Survey – Old Bay Rd

3.2.2 Maine Terrace, Deception Bay

The LiDAR data showed a general trend of slight overestimation of the ground level along the roadway by an average of 0.02m when compared to the detailed survey. Again, this was relatively consistent with a standard deviation of 0.02m and RMS error of 0.03m. The closest point was -0.02m lower than the detailed survey with the greatest difference being 0.09m higher.

In the *heavily vegetated* areas, the LiDAR showed an average overestimation of the ground surface by an average of 0.18m. Again, the differences were much more variable than along the roadway with a standard deviation of 0.10m, RMS error of 0.21m, with a minimum and maximum difference of -0.02m and 0.55m, respectively.

Taken as a whole, the LiDAR data had an average difference of 0.15m, with a standard deviation of 0.11m and RMS error of 0.19m.

Figure 10 shows a thematic map of the difference in ground elevations between the LiDAR (interpolated from a TIN surface) and the detailed survey spot heights.



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Figure 10 – Terrain Difference: LiDAR TIN Surface MINUS Detailed Survey – Maine Terrace

3.2.3 Discussion

From these limited comparison datasets, the LiDAR data seems to provide fairly consistent elevation data in open, hard surface areas such as roads. There is a degree of variability in accuracy of the LiDAR data in the heavily vegetated areas. However, it is worth noting that the density of the LiDAR points is significantly higher in the open areas, which in turn provides a 'better' TIN surface from which to calculate the differences.

In regard to hydraulic modelling at the scale suitable for this project, these variations in accuracy should be balanced by the overall accuracy associated with the model cell size and assignment of suitable hydraulic roughness in the densely vegetated areas.

The land use layer could be used as a means of categorising the likely accuracy of the LiDAR data.



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4. SUB TASK 1F – ESTUARINE BATHYMETRY

4.1 General Approach

Council provided bathymetric datasets for the following rivers:

- Pine River (2005)
- Burpengary Creek (2009)
- Caboolture (2009)
- Bribie Gardens (2007)
- Pacific Harbour (2007)

These datasets were provided as either 3D points (DXF files) or processed DEM's. Prior to incorporation into the DEM tool as bathymetric datasets, the 3D points were exported to ASCII XYZ files.

A “bathymetry extent” polygon layer was developed using the outline of the bathymetry, LiDAR extent, and Councils “waterways” layer. This extent layer facilitates the exclusion of those LiDAR data points inside the polygon, to ensure that there is no overlap between LiDAR and bathymetric survey data points during the elevation assignment process.

In processing the bathymetric data, the DEM tool will dynamically clip any LiDAR points inside the clipping polygon from the “working points dataset”, insert bathymetric points to the working set, then triangulate to provide a seamless transition between LiDAR and bathymetry.

4.2 Suggested Methodology

If full hydro survey data is available, then the bathymetric data can be imported directly into the DEM Tool. Part of this process will be adjusting the “waterways” layer to ensure that the waterways extent layer acts as a valid clipping polygon to the LiDAR data, otherwise a clipping polygon GIS file will have to be created.

If no hydro survey data is available, then the channel modification procedure (refer section 6) should be used to an acceptable downstream limit. This limit can be determined using judgement by an experienced hydraulic modeller, and will vary between different rivers and waterways. The modeller could use tools such as:

- Aerial photography coincident with the LiDAR data capture to assess water body size/capacity,
- Extraction of cross section profiles from elevation models to assess likely channel shape and localised geomorphology which will govern the likely conveyance within the channel



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As the waterway increases in size and width, the channel geometry will become more important to adequately model the conveyance capacity of the channel and hydro survey will need to be commissioned. The limit of this is likely to be in the vicinity location where significant lengths of waterway channel have been omitted from the LiDAR dataset (ie where the LiDAR “picked up” the water surface).



5. SUB TASK 2E – FLOODPLAIN STRUCTURES (FLOODWAYS)

5.1 General Approach

Council's roadways GIS layer was used to identify those sections of road that are subject to flooding (ie floodways) in the PMF event. Some of these sections of road were then investigated to determine the variability (or 'noise') in the LiDAR datasets along the roadway. This investigation showed that the variation in elevation was generally less than +/- 0.02m about the average line. This was considered acceptable within the overall accuracy of the LiDAR data and hence, the sole use of the LiDAR data to develop the floodways lines was considered acceptable.

Floodways lines were developed as terrain modification GIS lines (refer section 2.2.5), suitable for direct incorporation into the tool. The LiDAR serves as an external GIS reference to be incorporated into the RFD.

3D GIS lines were created along the centreline of each floodway, representing the highest point across the road or the hydraulic control. Each line was specified as a "Nodal Elevation Line". As such, the positioning of each node was selected using a thematic view of the TIN derived from the LiDAR datapoints. In this manner, the roadway was "smoothed" using informed judgement to minimize the small amount of noise discussed above, whilst ensuring that the key crest heights were captured.

This approach was found to provide suitable modification of the output DEM and was quite efficient to implement. We do not foresee any significant obstacles to "rolling out" this approach for all catchments.

5.2 Suggested Methodology

Each roadway defined in Councils GIS layer that resided within the broad scale modelling PMF extent should be investigated. Thematically mapping a TIN of the LiDAR data will allow a line to be manually drawn along the roadway, placing nodes at key high elevation points in the TIN. With the TIN structure visible, one can readily distinguish between elevation points that represent the road surface and artefacts of the triangulation process including triangulation across the road.

Using "Nodal Elevation Lines" ensures that the elevations are extracted from the LiDAR data to provide a smooth modification line.



6. SUB TASK 2I – FLOODPLAIN STRUCTURES (CHANNELS)

6.1 General Approach

Council's 'channels' GIS layer was used as a basis for locating all channels. These lines were then compared against a thematically mapped TIN of the 2009 LiDAR data. From this comparison, it became evident that Council's GIS layer did not necessarily accurately reflect the alignment of each channel. Consequently, this layer was used as a guide, and a procedure developed for preparing channel modification lines.

Channel lines were developed as terrain modification GIS lines (refer section 2.2.5), suitable for direct incorporation into the DEM tool. The LiDAR serves as an external GIS reference of channel locations to be incorporated into the RFD.

3D GIS lines were created along the centreline of each channel. Each line was specified as either a "Nodal Elevation Line", or as a "User Specified Line", depending on the adequacy of channel definition in the LiDAR TIN.

A key requirement of a TUFLOW model is that the thalweg of each channel presents a realistic flowpath towards the downstream end of the channel. Channel modifier lines serve as a means of ensuring that the channel is incorporated into the TUFLOW model and not "missed" due to the size and location of the TUFLOW model cells.

Where the LiDAR data provided a good representation of the channel geometry, "Nodal Elevation Lines" were used to ensure that the channel was represented in the TUFLOW model cells, and that the channel thalweg decreased in elevation moving downstream. Appropriate channel widths were assigned using the thematically mapped LiDAR data as a guide.

Situations where the LiDAR data did not provide a good representation of the channels included:

- Dense tree cover above the channel,
- Narrow sections of the channel with data point triangulation from one bank to the other, and
- Under roadways (eg culverts and bridges).

Examples of the above are shown on Figure 11.



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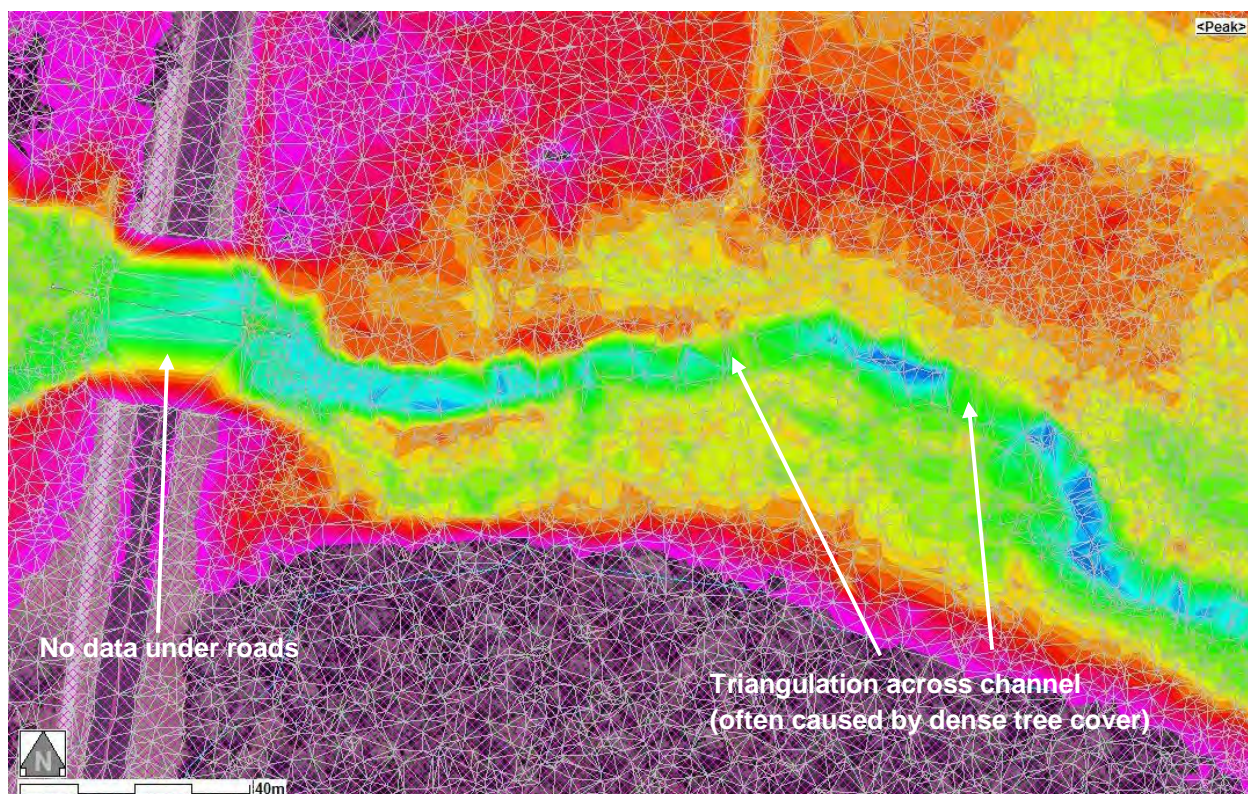


Figure 11 – Thematic Mapping of Triangulated LiDAR data points - Examples of LiDAR Deficiency in Defining Channels.

In each of the above cases, judgement is required to infer channel behaviour from upstream and downstream sections where the LiDAR data is adequate. Given the highly complex and variable nature of this judgement, it was considered that the most efficient and accurate way of modifying channels was for a hydraulic modeller (ie a person who understands river hydraulics and flow conveyance) to manually draw the GIS modifier lines.

In creating these lines, the modeller could infer a reliable channel alignment at any location by investigating upstream and downstream reaches, and by examining the triangulation of the LiDAR datapoints. In many cases, a combination of GIS modifier line types were required, along with a varying width in different parts any given channel.

For example, Figure 12 shows modification lines for the LiDAR data shown in Figure 11. In this case the channel low points have been captured in the LiDAR data for the nodes of the *solid* lines and these elevations would be used to overlay grid elevations along the length of the line using “Nodal Elevation Lines”.



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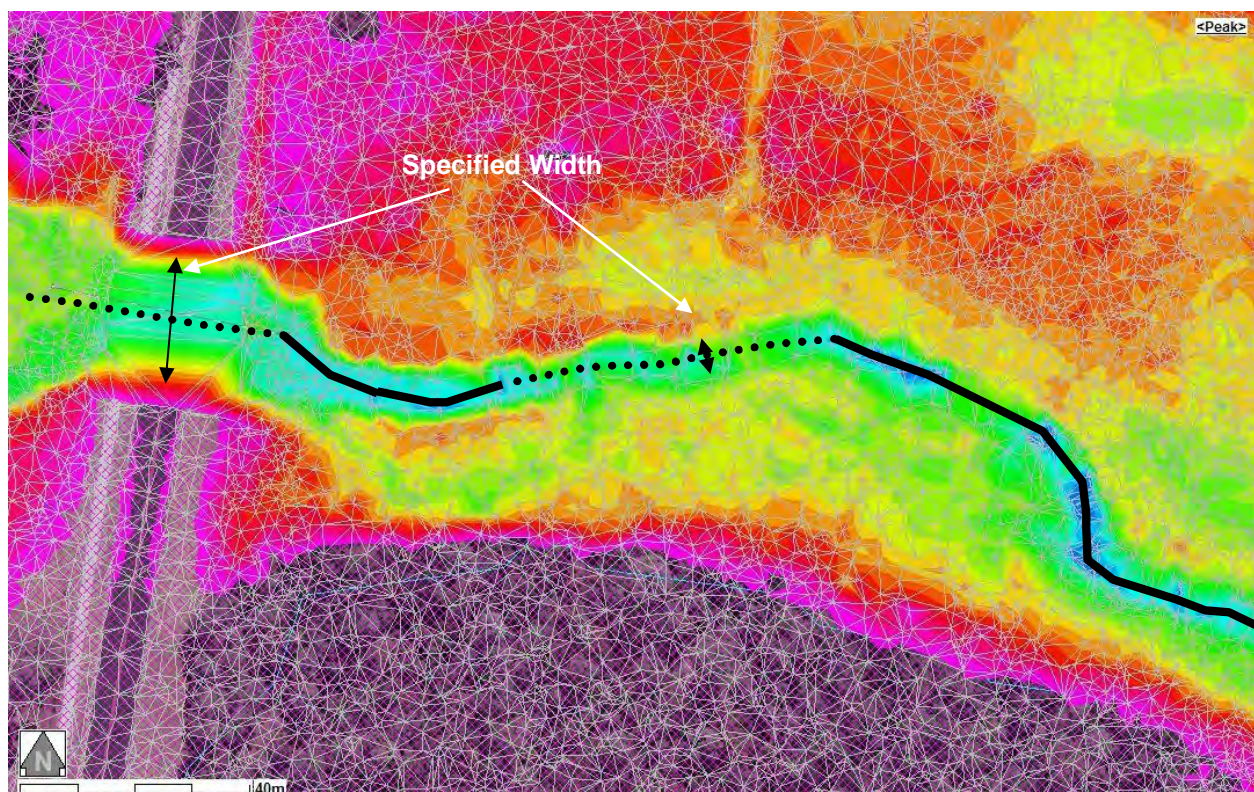


Figure 12 – Example Modification of a section of channel: Solid lines are “Nodal Elevation Lines”, Dotted lines are “User Specified Lines”.

For the *dotted* lines, the LiDAR data does not reflect the channel dimensions and, hence, “User Specified Lines” were used to provide a linear transition in thalweg elevation between the upstream and downstream end of the line. There would also be a distinct change in the specified channel width associated with each modifier line between the upstream modifier line (left hand side of the figure) to those lines downstream of the roadway.

This approach was found to provide suitable modification of the output DEM and was quite efficient to implement. We do not foresee any significant obstacles to “rolling out” this approach for all catchments.

6.2 Suggested Methodology

By examining the channels GIS layer with a thematic backdrop of the LiDAR TIN surface (including display of the TIN structure), a distinction between those sections of each channel that are adequately represented by the LiDAR data points and those that are not can be readily determined. Modification



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lines can then be drawn as either “nodal elevation lines” or “user specified lines” to ensure a constantly decreasing flow path along the channel.

We recommend creation of new channel GIS lines, as the existing GIS layer was not found to be suitable (insufficiently accurate in location and node spacing) for modification.



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7. MBRC DEM TOOL

The MBRC DEM Tool is a standalone Windows 32 bit application which can be run on any Windows platform and the more memory available, the better the capacity for processing large DEMs.

7.1 Data Structure

The tool relies on a number of datasets covering the LiDAR point tiles, bathymetry point files, road and channel terrain modifier files, and landuse grids. Each of these datasets typically consists of a number of files stored in separate library folders. Two additional cosmetic GIS layers can be included to enhance the map display. The tool relies on an INI file to point to the various folders and files.

The data schema is setup around a main folder which contains the application and associated INI file, and the cosmetic GIS layers. The data libraries are sub-folders of the main folder, and it is suggested that one or more separate sub-folders be setup for DEM output.

ALS Library:

This folder contains the set of LiDAR thinned ground point tiles converted from ASCII xyz files to a compact binary exyz format. An associated catalog file (*text csv format*) contains the list of tiles, their extents, source, year and number of points.

Source ASCII files are imported from any location into the library using the Admin tools. The files are converted as they are imported with the filenames remaining the same (*except for the .exyz extension*) and the catalog is updated automatically.

Additional associated files include:

- a mif/mid GIS layer of the tiles which is created automatically from the catalog. This file is used to display the tiles on the map and has the same filename as the catalog file with '-tiles' added as a suffix.
- a GIS layer (*shp or mif/mid*) with the same filename as the catalog containing a bounding polygon for the LiDAR data can be added manually to the folder. The bounding polygon in this file can be created by amalgamating the tile polygons, created manually, or created from the clipping polygon used deliver the LiDAR points. This layer is used to clip concave sides of TIN DTM tiles that cross over the boundary and to eliminate DEM cells outside the boundary from hole filling. The file should contain only a single polygon and must not include multi parts.

Bathymetry Library:

In a similar manner to the ALS library, the bathymetry library contains binary point files (*.exyz format*) for all areas where bathymetry has been undertaken along with an automatically created catalog file. The source files are imported in a similar manner to the ALS files. Each bathymetry file should be accompanied by a GIS file (*shp or mif/mid*) with a single non-multipart polygon defining the clipping



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boundary for the bathymetry points. This polygon is used to remove LiDAR points before adding in the bathymetry points prior to TINing the surface. Islands within the boundaries of the bathymetry should have the LiDAR points on the island included in the bathymetry file. The bathymetry polygon file must have the same filename as the bathymetry points.

Road Library:

The road library contains shape files of 3D polylines that are used to modify grid cells as part of the DEM processing. Their purpose is to ensure hydraulic controls such as roads across flowpaths are correctly defined in the DEM grid. A tool is available to import pre-prepared 2D polyline files that are converted to the 3D polylines by reference to the TIN DTMs, or to end point elevations within the 2D file. A catalog is also automatically created. Each polyline can include a width field which is used when the lines are draped over the grid to modify the elevation value of affected cells. Each 2D file to be imported should rely on only one method, either the TIN DTMs or the end point values for elevations. The two methods cannot be mixed in the same source file.

Channel Library:

The channel library is similar to the road library except that its purpose is to ensure flowpaths are contiguous and meet flood modelling requirements. The channel modifiers are run after any road modifiers.

Landuse Library:

The landuse library contains raster grids representing landuse classes for the purpose of defining a roughness or material grid for the flood modelling. The grids are imported in a similar manner to the LiDAR data and are automatically converted from ASCII grids to a binary format (*Idrisi .rst*). A catalog is also created automatically.

One additional file that is required is a landuse classification file. This is a CSV file listing all the landuse values and their associated attributes. At present the file should contain an integer field for 'Value', a character field for 'Class' and a character field for 'Per/Imp'. It should contain a header line followed by an entry for each landuse class to be found in all the landuse grid tiles. The classification file must be placed manually into the landuse folder.

7.2 Operation

For the tool to run, it requires an INI file, 'MBRC_DEM_Tool.ini' which includes a number of keys pointing to the various libraries and catalog files. A typical INI file is as follows:

```
[ADMN]
AlsFolder=ALS Library
AlsCatFile=XYZ_Library.cat
BathFolder=Bathymetry Library
BathCatFile=Bath_Library.cat
RoadFolder=Road Library
```



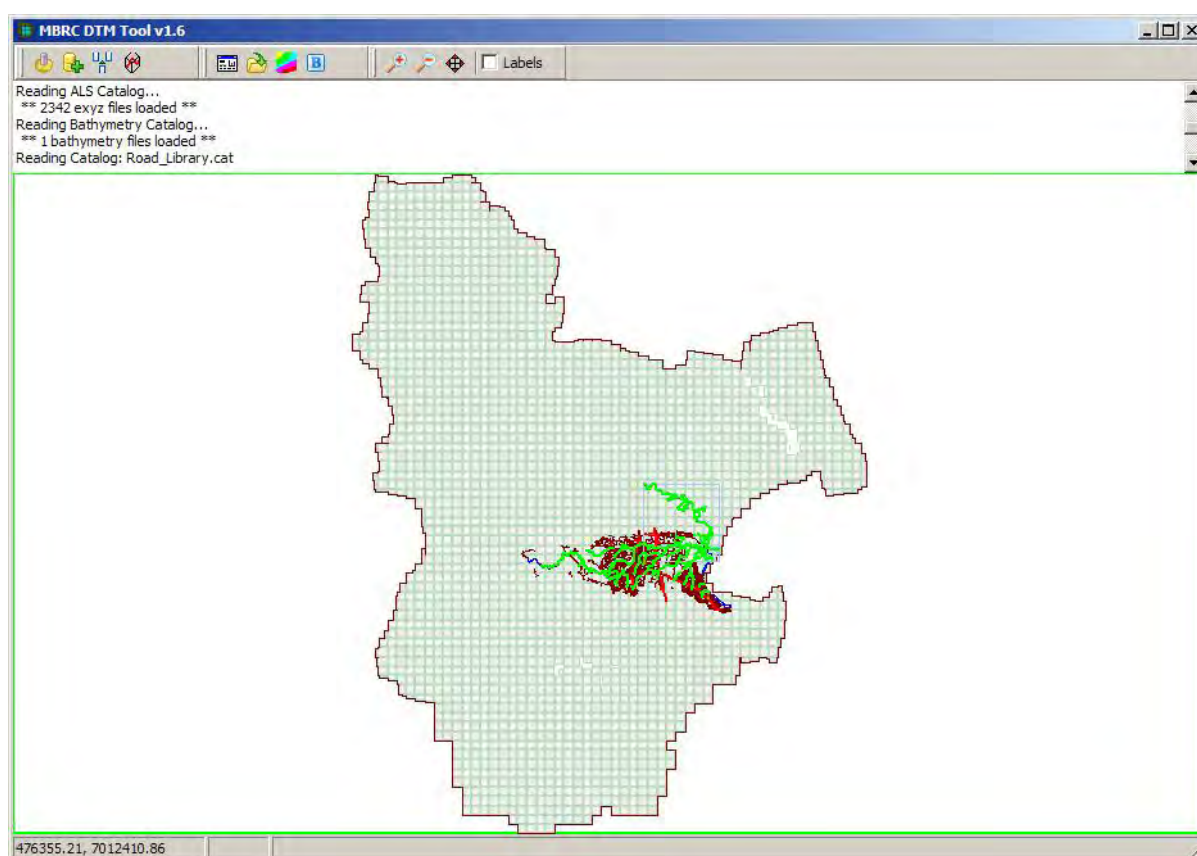

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RoadCatFile=Road_Library.cat
ChannelFolder=Channel Library
ChannelCatFile=Channel_Library.cat
LanduseFolder=Landuse Library
LanduseCatFile=Landuse_Library.cat
LanduseClassFile=Landuse_Classification.csv
waterGisFile=DCDB_WaterWays.shp
roadGisFile=DCDB_RoadWays.shp

The two cosmetic GIS layers, waterGisFile & roadGisFile can be any GIS layers suitable for enhancing the map display and helping with identifying locations. They can be left blank if not required.

7.3 Main Interface

Once the application and data files have been successfully setup, operation of the tool is fairly simple and intuitive. The interface consists of toolbar row, a log of activity, the map display, and a status bar.





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There are three toolbars:

Admin Tools: This toolbar is normally hidden and can be turned on by pressing <Ctrl><Alt><A>.

- The 1st button on this toolbar allows the INI file to be reviewed and edited if necessary.
- The 2nd button forces the catalogs to be updated from the list of files in the library folders.
- The 3rd button allows LiDAR, bathymetry and landuse data to be imported.
- The 4th button converts 2D structured polyline files into 3D shapefiles for use as terrain modifiers. These files are written to the same folder as the 2D source files and have to be moved or copied into their respective library folders. Their catalog will also have to be created manually by using the 2nd button.

DEM Tools:

- The 1st button is used to initiate a DEM request by opening a dialog where the user can specify the requirements for a DEM and the steps to be processed.
- The 2nd button allows a previously created DEM specification to be re-opened for further processing or altering of the grid cell size, thus saving the time it takes to generate the TIN tiles.
- The 3rd button allows any previously created DEM to be thematically displayed on the map.
- The 4th button enables a variety of source files to be used to batch process a number of DEM datasets.

Map Tools:

These tools allow zooming and panning of the map and the display of ALS tile filenames. Note that moving the mouse over the map will display MGA coordinates on the status bar and clicking on the map will identify the tile name and the number of points it contains.

7.4 DEM Dialog

The DEM dialog is used to create a specification for the creation of a DEM. The user should enter the coordinates for the bottom left corner of the desired DEM, the width, the height and the cell size, then click the 'Apply Changes' button. This will calculate the rows, columns and top right coordinate and setup the TIN tiles. The green edit fields are read only.

The array of TIN tiles can be altered but the tiles should be checked to ensure all are OK before proceeding. The tile overlap is used to allow thin edge triangles around the TIN tiles to be clipped out and to ensure there is sufficient coverage of the TIN over its portion of the DEM grid. The higher the cell size, the higher the overlap should be.



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MBRC DTM Tool DTM Scope

Columns: 2400
Width: 12000
Rows: 1600
Height: 8000
Cell Size: 5
BL X: 465000
BL Y: 6990000
TR X: 477000.00
TR Y: 6998000.00

Select format / steps
☒ Base DEM GRID 26.880Mb
☐ Thin ALS TIN points

TUFLOW Model Files
☐ TufLOW DEM Grid
☐ TufLOW Z Point File
☐ TufLOW Material Grid
☐ TufLOW Mat Point File
☐ Use Terrain Modifiers

TufLOW Model Boundary Polygon: [Folder icon]

Apply Changes & Set TIN Tiles

Base filename: Test.asc [Folder icon] [OK] [Cancel]

TIN Tiles: 2 wide x 2 high Tile overlap (m): 20 [Check Tiles]

Tile ID	BL X	BL Y	Width	Height	Pts OK
C1R1	465000.00	6990000.00	6000	4000	OK
C1R2	465000.00	6994000.00	6000	4000	OK
C2R1	471000.00	6990000.00	6000	4000	OK
C2R2	471000.00	6994000.00	6000	4000	OK

The next task is to select the steps to be undertaken from the check boxes and the selections produce the following output:

Base DEM Grid generates the DEM as defined in ASCII (*.asc) and waterRIDE (*.wrr) formats. This grid is not required for any of the TufLOW model outputs.

Thin ALS TIN points can be used to reduce the number of points (*usually 10% to 30% depending on the topography*) when no prior thinning has been undertaken.



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Tuflow DEM Grid generates a DEM suited to the subsequent creation of the Z points file. This is also stored in ASCII and waterRIDE formats as for the base grid.

TuflowZ Point File generates a MIF/MID 2D Z points file for use in a Tuflow model. The output will be clipped to a polygon specified in the edit box below. A Tuflow grid must exist from a prior run for this DEM specification or be checked for this run.

Tuflow Material Grid generates a grid of material types to match the base DEM specification. Note this can be a time consuming process where the source landuse grids have a small cell size.

Tuflow Mat Point File generates a MIF/MID material point file which will be clipped to any specified polygon. A Tuflow material grid must exist from a prior run for this DEM specification or be checked for this run.

Use Terrain Modifiers will apply the road then the channel modifier lines to the grids prior to further use for point files or DEM output.

Tuflow Boundary Polygon. Open a MIF/MID or SHP file for use as a clipping boundary for the Tuflow points files. Only the first polygon in this GIS file will be used and it should not be multipart. Note in the case of batch process with a GIS layer of catchment polygons, these boundaries will be used as clipping polygons. The grids are not clipped by this polygon.

Built-In Processes. In addition to the above steps that are selectable, several additional processes are included:

- TIN tiles are created automatically and are saved in waterRIDE *.wrb format. Once created, these tiles can be re-used for subsequent processing on the same DEM specification, including changing the cell size.
- Hole filling of the DEM grids is automatically undertaken prior to terrain modification and saving of the grids. The holes can arise when TIN tile boundaries cross through sparse data point areas such as farm dams and lakes and the overlap is not sufficient to completely include the lake inside one or other of the TINs.
- Tuflow LOC File. This MIF/MID file is automatically created when a Tuflow grid is included.
- The log of the process is also saved as the BaseName.log in the case of a single run and the name of the source file.log for a batch run.

Finally identify a name and location to save the results. This filename is used as a base name for all output as shown in the following example:

Base name	Test.asc
DEM specification	Test.spec
Base DEM Grid	Test.asc, Test.wrr
TIN Tiles	Test.C#R#.wrb (C# represents the column No. & R# the row No.)
TuflowDEM Grid	Test.TFG.asc, Test.TFG.wrr
Tuflow Z Point File	Test.TFG -2dZPts.mif



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Tuflow Material Grid	Test.rst
Tuflow Mat Point File	Test-MT2dPts.mif

Note that associated files are also created: MID with MIF, CFG2 with WRR, CFG and WRX with WRB, and RDC with RST.

The waterRIDE grids (*.wrr) also contain a layer indicating the number of points used for each cell. A value of 5 or less indicates that the TIN was used to estimate the elevation, a value of -9 indicates that the cell is outside the ASL boundary and a value of -1 indicates that the cell was in a hole and has been filled.