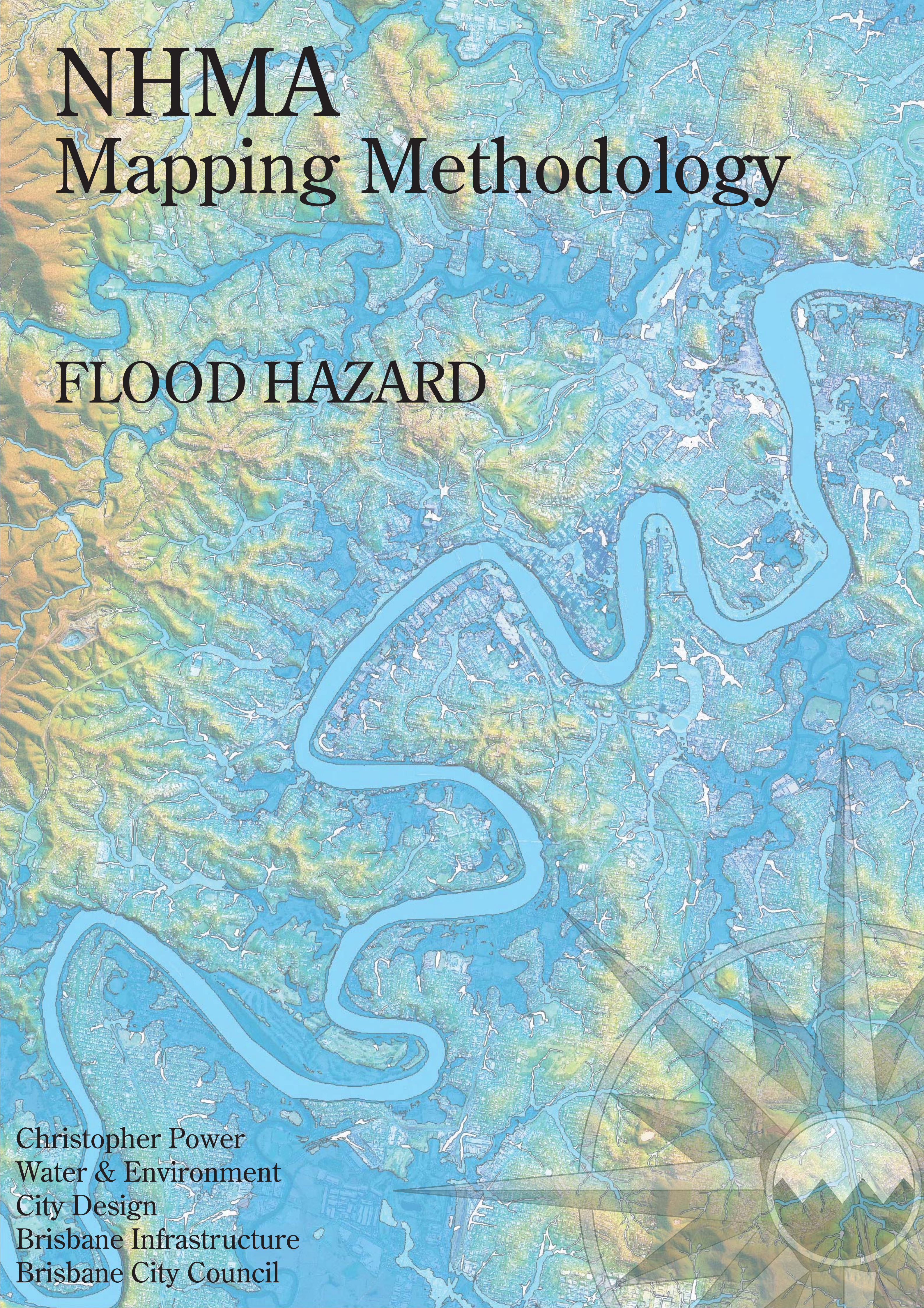
NHMA
Mapping Methodology

FLOOD HAZARD



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A GIS/Map Algebra Option for NHMA Mapping (Flood Hazard)

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Introduction

Brisbane City occupies the lower reaches of the Brisbane River Valley, which is characterised by steep, hilly terrain in the west (Taylor Range), which defines the catchments of numerous suburban creeks that wind through largely urbanised foothills and ridges, and subsequently broad, low lying flood plains. The myriad of suburban creeks creates complex drainage patterns that present a wide range of possible flood scenarios. In order to undertake disaster mitigation planning in relation to flood hazard in the city, it is essential to identify areas of potential inundation by flood waters.

While flood scenarios for the river itself, and most of the major creeks, have been expertly modelled by professional hydrological engineers, the extent and complexity of the City's drainage network means that it may take some time (and considerable resources) to formally model every potential flood hazard area in Brisbane. With this in mind, water resource managers in Brisbane commissioned a project to investigate the possibility of finding a GIS based solution in order to quickly and efficiently map the full extent of flood hazard potential as overland flow paths. This work is not intended to reproduce the accuracy of formal flood modelling, but to provide a tool where formal modelling is not practical or unavailable.

The project uses spatial data for a variety of flooding scenarios: storm surge, river, creek and local flooding, as well as overland flow path flooding are examined. River, creek and local flooding are required under the Natural Hazard Management Area mapping scheme set out in the Brisbane City Plan 2000, and overland flow path flooding is also included, although it is likely to play a less pivotal role in a town planning sense. The *Draft Flood Code* 1 defines overland flow paths as streams with a contributing catchment area of less than 30 hectares, while waterways are said to begin once the contributing catchment area exceeds 30 hectares.

GIS mapping targets for this project include:

- Formally Modelled Flood Areas (Q100 flooding)
- Approximated inundation boundaries modelled using a GIS/map algebra method (described here).

Approximated inundation boundaries are further separated according to the following criteria:

- < 30Ha (overland flow paths)
- > 30Ha (Natural Hazard Management Areas)
- > 400Ha (Major Creek Flooding)

Background

Initial investigations into this problem centred on a geometric proposal. In this context, spatial analysts and hydrological engineers applied buffers to linear drainage lines extracted from a triangulated five metre digital elevation model (DEM). The approach was to determine buffer widths using a combination of accumulated area and slope averages ie.

$$Y = \frac{C_A}{10\sqrt{S} \times \left[\left(0.035 \times (C_A^{1/2.5}) \right)^{5/3}\right]} + \frac{1}{\tan\theta}$$

Where: Y = the total inundation buffer width (metres)
C_A = the catchment area (hectares)
S = slope class
θ = Individual catchment slope for the node (degrees)

A problem with this method is that overland flow paths can not always be found to occupy symmetrical channels and therefore any approach focussed on buffered centrelines is very likely to produce anomalous results. Take the example of a creek that has cut its way into the bottom of a spur or ridge. These are common geographical features, which more usually exhibit one high bank coupled with a flood plain on the opposite side. In this scenario, a buffered centreline is likely to contain a significant height difference in cross section.

Further, the use of a triangulated digital elevation model (DEM) based on LiDAR returns will almost certainly generate a spurious linear drainage network. As LiDAR pulses are absorbed by water bodies (resulting in data gaps) the triangulation operation can be expected to result in the linear drainage network zigzagging from one side of a water body to the other (particularly where there is significant riparian cover and overhang). A related problem occurs inside building footprints (also data gaps in LiDAR ground return data), particularly on low slopes, where the use of facets skews the results returned from drainage network extraction operations.

Overview

The method employed by the project team was a map algebra solution consisting of a combination of readily available algorithms, which were originally combined in order to model leaf litter transport in bushland areas as part of an accumulated fuel model for bushfire managers.

This section provides a conceptual overview of the process employed for the purpose of defining natural hazard management areas (NHMA – Flooding) as outlined by the Queensland State Planning Policy 1/03 Mitigating the Adverse Impacts of Flood, Bushfire and Landslide.

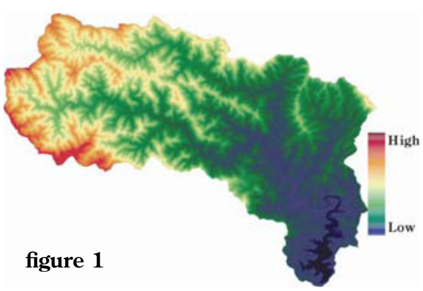


figure 1

figure 2

The first step was to generate a DEM suited to hydrological functions. This was achieved using the minimum curvature algorithm with 25% tension (ER Mapper). This returns a DEM which effectively trains subsequently generated drainage networks to the middle third of creek and river water bodies, and eliminates the zigzag effect apparent in LiDAR based TINs by conforming data interpolated for LiDAR gap areas to surrounding elevation trends and reducing the need to introduce breaklines. Figure 1 shows a section of the DEM generated for the project covering the Moggill Creek catchment. This data is used as an input to a single direction accumulated flow algorithm such as described by O'Callaghan and Mark (1984). The project team considered the use of multi-direction flow algorithms (eg. Seibert and McGlynn, 2007), however as the out put is required to be converted to binary data and subsequently used as a source file input to a cost distance algorithm, the single direction flow algorithm was implemented via the RUNOFF module in the Clark Labs, Idrisi Andes Software. Figure 2 shows the output of this operation after the data is truncated to eliminate flow networks with less than 30Ha contributing area.

Once a byte/binary source file is prepared it is input to the cost distance operation, which is implemented via the COST module in Idrisi Andes using the cost-grow algorithm and selecting the "use friction" option. In this operation the friction multiplier is generated using a slope (percent) raster, which is combined with elevation using a range of techniques including normalised ration and weighted linear combination (WLC) depending on the stage of model development. Slope (figure 3.) is used exclusively of elevation for primary creek flooding, while the slope/elevation combinations are employed for flow paths with low contributing area.

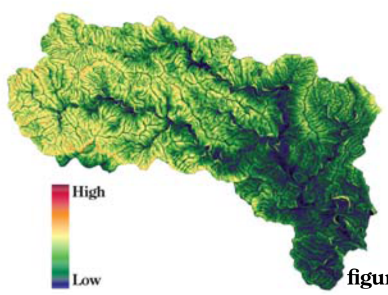


figure 3

After running the cost-grow algorithm (in unrestricted passes), a raster surface is returned, which forms the bases of subsequent mapping operations. A Gaussian filter is applied to this data (shown as figure 4) in order to reduce noise. The raster is then threshold classified according to calibrated flow path widths (using calibration data generated during phase 1) and converted to polylines (figure 5).

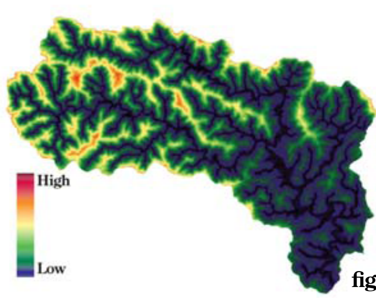


figure 4

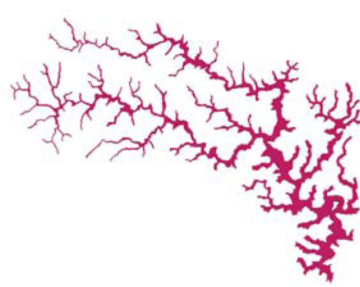


figure 5

The general concept (summarised in figure 6) is quite straight forward, however a number of details need to be defined more precisely. The definition of source using the flow direction output alone is not suitable for all flood scenarios and therefore requires alterations and additions according to topographic circumstances. For example the accurate definition of low lying flood planes using a single direction flow

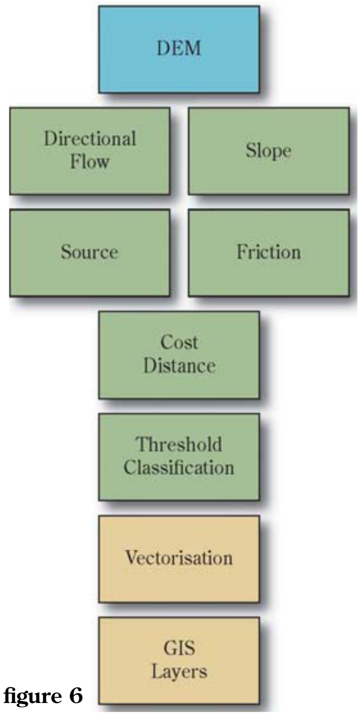


figure 6

algorithm produces anomalous results because the action of water in this situation is not confined to a single dominant direction, hence the occurrence of river and tidal deltas as well as lagoons and marshlands. This was one of the driving arguments for the introduction of multi-directional flow algorithms, and there remains scope to introduce this through subsequent iterations of this application.

Similarly, the use of slope as a friction multiplier has some drawbacks, which need to be accounted for. In particular areas where waterflows have produced marked primary channelisation as high steep embankments that are overtopped during floods require additional modifications to source files in order to provide more accurate results. These issues have facilitated the introduction of a multi-stage source file development process. In general this approach entails defining the cost distance source in four stages:

- Low lying flood plains
- Steep bank channelisation with high contributing area and secondary channelisation (high bank)
- Flow paths without secondary channelisation
- Overall connectivity

Digital Elevation Model

As the digital elevation model (DEM) is the only input to this process it is essential that specialists take some time to achieve the best results as possible. As mentioned previously triangulated models are not the most suitable option. Care should be taken to examine DEMs proposed for this application as by far the majority of models are created in this way due to the expedience of production. Should a triangulated DEM by the only alternative, then it is important that break lines be introduced particularly at water bodies. Ideally, the invert levels of culvert should be entered into the data in order to reduce the effects of pit filling algorithms required by the first stage of the directional flow generation operation, however this should be not practicable the process includes a pit fill error removal contingency. In general terms the DEM should be detailed and high resolution especially when applied in urban areas. The best results are achieved when using LiDAR based models (with a pulse density of 1-2m) interpolated via splines or kriging (making sure to use reasonable tension where break lines are not available or practicable). In this instance the minimum curvature interpolation option available through ER Mapper was implemented using 25 % tension. The data was gridded in 4m cells and stored as 4-bit IEEE data in .ers format.

Source Development

An initial accumulative directional flow algorithm is applied to a pit filled version of the DEM producing lineal flow paths as raster data, which can be classified according to contributing area. This raster is then used to produce lineal raster flow path data in the following classes;

- 1250Ha +
- 400 – 1250Ha
- 30 – 400Ha
- 2 – 30Ha

Using a 4m DEM prepared for the Bulimba Creek Catchment, the Idrisi runoff module produces a data range of -1 - 7593551.08, which translates into an overall contributing area of 12 150Ha. The square root of this data is calculated in order to handle the data using the 4-bit IEEE format. The data is then truncated at 35, 137, 500 and 885 in order to accommodate the four contributing area classes. These files were then converted to Integer/Binary for use as individual source files for Idrisi cost-distance functions.

All rasters were generated using identical parameters to the DEM in terms of cell size, data type, projection, datum etc., which facilitates ease of map algebra operations for most platforms and software environments.

Friction Development

The primary data used for source development is a slope surface (percent) generated using standard slope algorithm applied to the 4m Bulimba Creek Catchment DEM.

Friction surfaces for flowpaths with lower contributing areas are constructed from three inputs – elevation, slope and a normalised ratio of these two rasters (NRAT). The final friction surface is implemented as the WLC of elevation, slope and the NRAT result as (elevation x 0.2) + (slope x 0.65) + (((NRAT+1) x 100) x 0.15). This raster is denoted with the postscript "_ESN", and provides a more controlled growth pattern during the cost distance operation (i.e. reduces the influence of slope when necessary).

Note: the formula used to produce the NRAT is (elevation – slope) / (elevation + slope)

Model Development

Primary Creek Flooding

The initial raster produced in order to map primary creek flooding is a straight forward elevation class based on the average height of the flood plain. This involves the user querying the DEM in order to define the optimal flood plain elevation remembering to include a meter for inundation in the final threshold value. Figure 7 shows the result of extracting values less than 3m from the DEM.

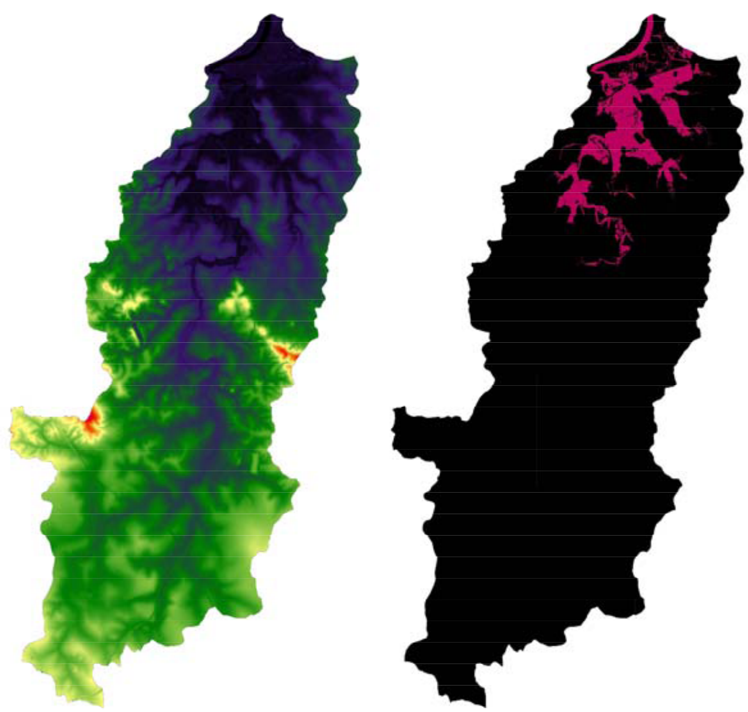


figure 7. Values < 3m are extracted from a detailed DEM

This raster is saved as Boolean data (i.e. 0 and 1) for subsequent inclusion in the final primary creek flooding class.

Cost Distance Analysis

Figure 8 shows the cost distance analysis dialogue for Idrisi Andes. Using the settings shown, the integer/binary 885 source file is set as source with the percent slope surface employed as friction.

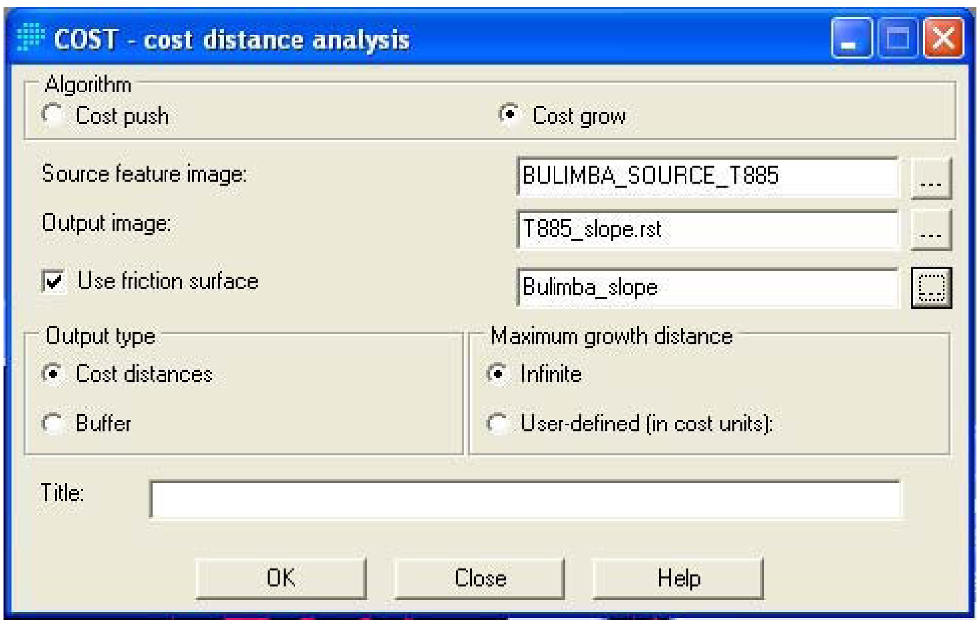


figure 8. Idrisi Cost module

This operation may take an hour or so to complete depending on processing capacity. It is not recommended to undertake these operations on standard PCs. Using Dual Xeon 3.06GHz processors and 3Gb RAM, This operation completed in Just under an hour. The time taken is also area dependant so when processing very large areas it is recommended that the operator use catchment boundaries to create smaller rasters (if necessary).

The result returned from this operation is shown in figure 9. Also shown in figure 9 is the result of extracting all values < 140.

figure 9. > 1250Ha contributing area source with slope friction and a 140 threshold value

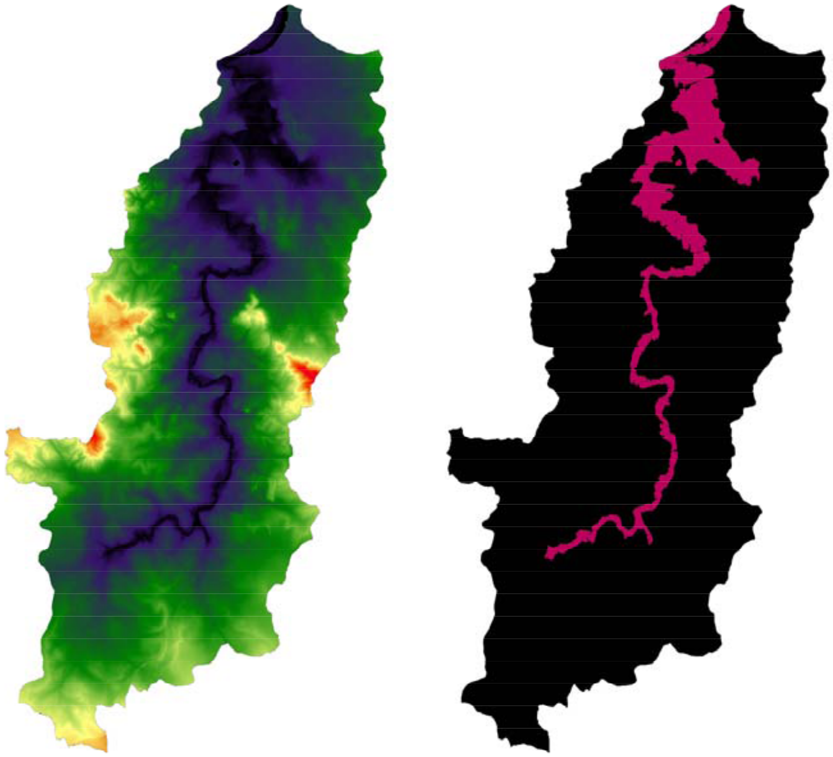
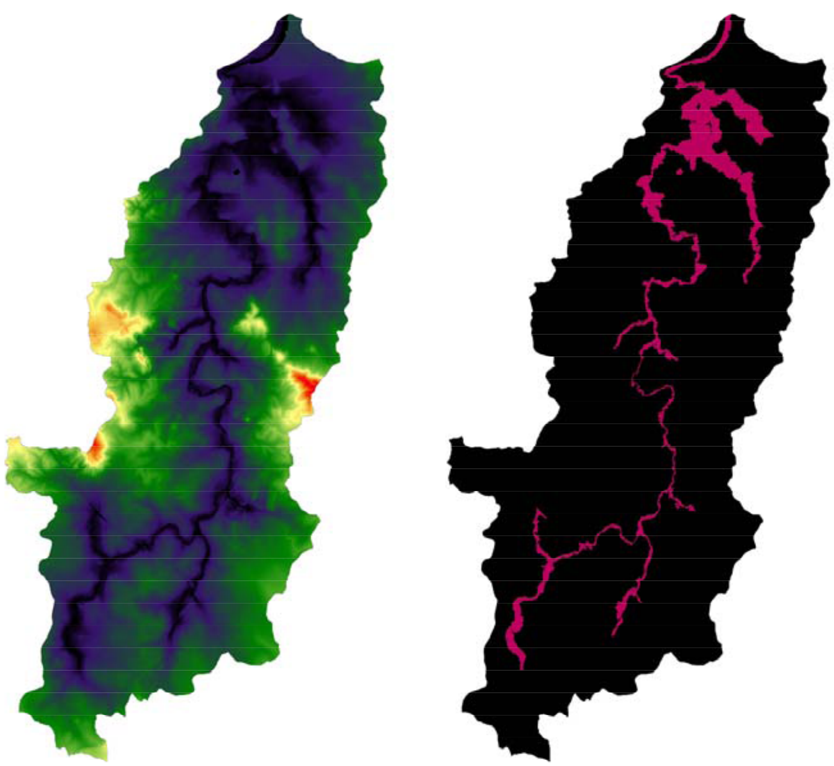


figure 10 (below) shows the result of generation a cost distance surface using the 400Ha source file and slope as friction. In this instance a data threshold value of 65 is used.



The three classified rasters generated by these means are combined to produce the primary creek flooding class. Figure 11 shows the result of the combination.

figure 11

The result of this operation can now be converted to vector data for further processing. The Second class of natural hazard management area is produced in two stages using both slope and the ESN data outlined earlier. Firstly a cost distance raster is prepared using the 137 source and the ESN raster as friction. This data is threshold classified to extract data less than 100 and converted to an integer/binary Boolean surface for use as a source file for the next step. Figure 12 shows the results of this operation.

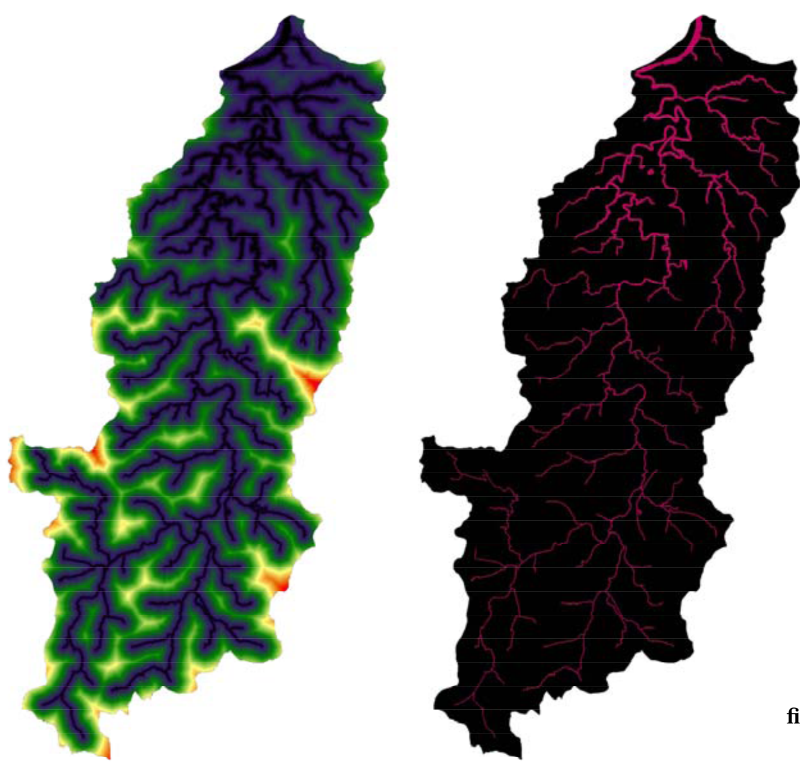


figure 12

The source file created from the 137/ESN cost distance operation is returned to an additional cost distance operation, this time using slope as friction. This step overcomes problems associated with steep embankments containing data growth during the cost distance operation. Figure 13 shows the result of using the source file created from the previous step (ESN) now using slope as friction and a threshold classified value of 10.

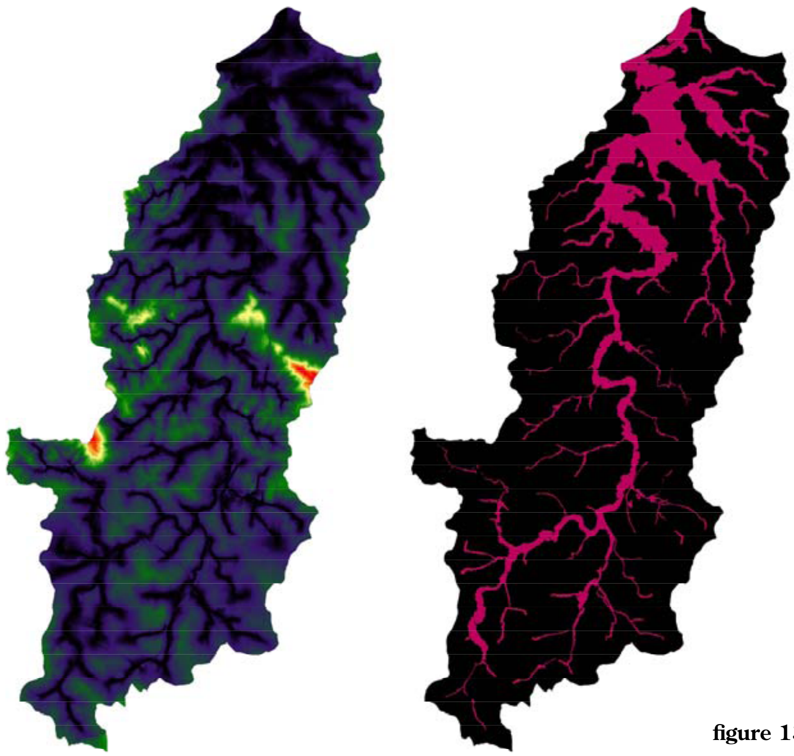
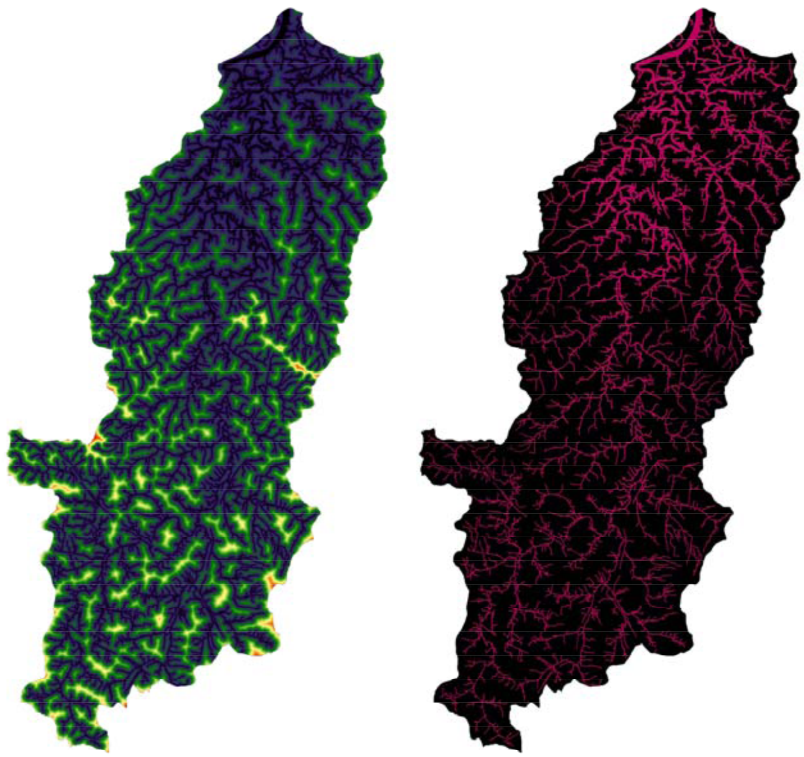


figure 13

The result of this operation is essentially the NHMA class, which can now be converted to vector data for further processing.

The third class is the overland flow path class. This class is minor overland flow i.e. flow paths with a contributing area of 30Ha or less. These flow paths generally create minimal secondary channelisation and are considered to produce water volumes that may be adequately handled by storm water piping. These flow paths often traverse built up areas without defined channelisation and have therefore been mapped in a single ESN cost distance operation. Figure 14 (see over) shows the result of a cost distance operation using the 35 data, with ESN friction and a threshold classification value of 100.

figure 14. > 30Ha source with ESN friction and a threshold value of 100



The result of this operation provides the third class of overland flow path and can now be converted to vector data for further processing.

Cost Distance Analysis Summary

component	Contr. Area	Friction	Source	Threshold	Class
1	Flood plain	N/A	N/A		Creek flood
2	1250 Ha +	slope	885	140	Creek flood
3	400 Ha +	slope	500	65	Creek flood
4	30 Ha +	ESN	137	100	NHMA
5	30 Ha +	Slope	137	10	NHMA
6	1.96 Ha +	ESN	35	100	OFP

Vector Operations

NHMA classes that have been converted from raster format require additional handling in order to produce vector data that is not unnecessarily cumbersome in a GIS environment.

In this instance .dxf vector files were ex ported from ER Mapper's native .erv format after having used this software to create vectors from the three Boolean raster classes outlined earlier. The conversion process adopted here comprises:

- Export to .dxf
- Import to TNTmips .rvc format
- Application of line densification filter using bi-cubic splines
- Application of line simplification filter using minimum distance thinning
- Import to MapInfo's .tab format
- Error detection and editing
- Amalgamation of data, creation of tabular structure and population of database.

Data Translations

This process employs a range of commercially available algorithms implemented via various software packages. This requires a significant degree of data translation between propriety formats. In general the translations schedule is as follows:

- DEM as .ers to Idrisi .rst (cost distance analysis)
- .rst to (ER Mapper) .ers (threshold classification)
- .ers to .erv (Er Mapper native vector format) (raster to vector conversion)
- .erv to (AutoCAD).dxf (export format)
- dxf to (TNTmips) .rvc (vector filtering)
- .rvc to .(MapInfo) .tab (GIS processing, error detection and analysis)

Although it is acknowledged that the range of software employed for this project could be reduced, the focus has been on using the most efficient and effective algorithms available and it should be noted that the project team found no single application package contains all of the modules required for this project.

Vector Filtering

In order to present GIS ready data without the characteristic "steps" often associated with vectorised raster data. A series of carefully selected vector filters have been applied. This not only gives the data more realistic curves, but also simplifies and optimises the data so that it is not cumbersome in the GIS environment. Figure 15 shows the influence of these filters.

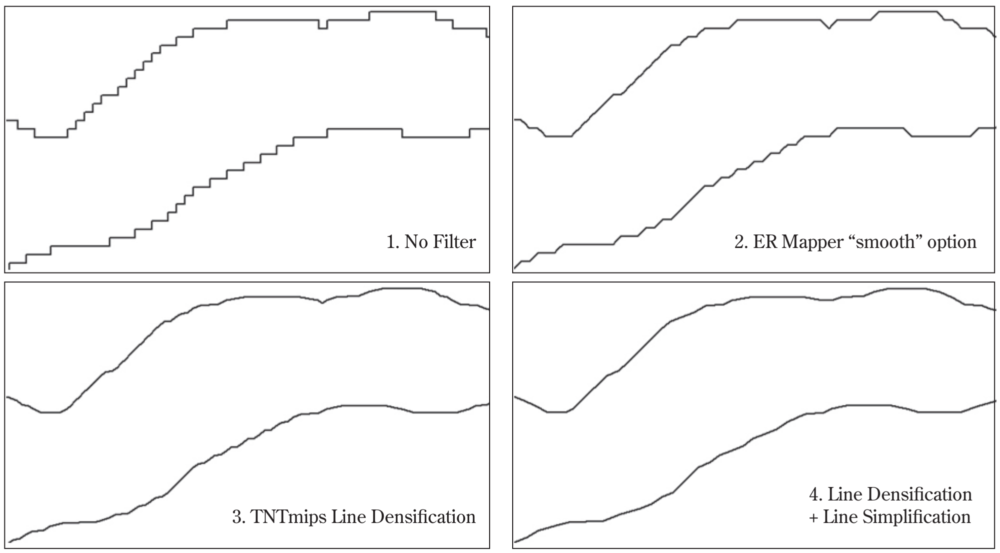


figure 15

The ER Mapper "smooth" option is selected during the initial raster to vector conversion (accessed vial the ER Mapper toolbar – Process – Raster to Vector data conversion) and subsequent filters are implemented via TNTmips. The TNTmips relational environment may take a little getting used to; however the following provides an outline of the process.

figure 16

Once the data is imported to the .rvc format, the vector filters were accessed via the Main toolbar – Geometric – Filter… This opens the Vector Filter dialogue (figure 16), select the target object created at the import stage and choose "Line Densification". This opens the Line Densification dialogue. In this window, select the Cubic BSpline option, set the tolerance to 25.00 and click "run".

This requires the user to create a new object, which should be placed inside the .rvc created at the import stage. This new object should be post scripted with "LD25" denoting the type of filter used and the tolerance set.

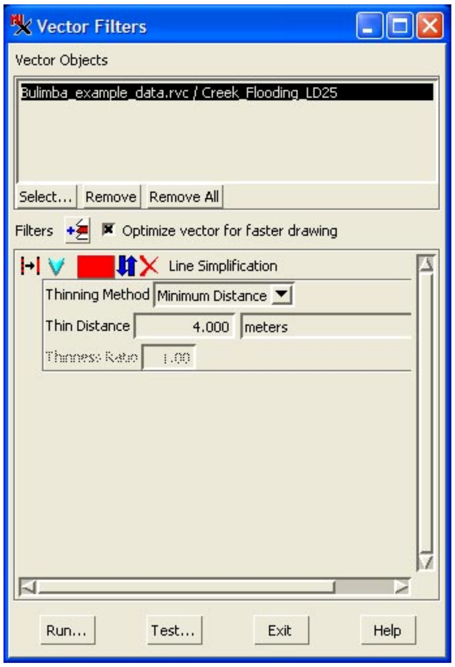


figure 17

Once this process completes (usually very fast) remove the vector object and filter from the vector filter dialogue. Then select the newly created object (_LD25) and select the Line Simplification option to open the relevant dialogue (figure 17). Here select the "Minimum Distance" option, set the thin distance to 4 metres and click "run". Create the new object in the same .rvc file with the post script "LS4".

Export the (_LS4) object to MapInfo format for further processing. Repeat the process for all classes.

Editing Vector Objects in MapInfo

The MapInfo platform has been utilised for removing overlaps between classes, aggregating vector objects into a single table and setting tabular data structures. Any part of the Overland flow class objects that are overlapped by either the NHMA class or the Creek Flooding class are removed using (from the MapInfo main toolbar)

- Query – Select all from Overland_Flow_LS4
- Objects – Set Target
- Query – Select all from NHMA_LS4
- Objects - Erase.

Repeat this operation remove Overland Flow objects overlapped by Creek Flooding objects as well as NHMA objects overlapped by Creek Flooding. Set all table structures to a single character field (15) and update the column with the data class i.e. (Overland Flow, NHMA and Creek Flooding), before appending all data to a single table. Figure 18 gives a graphic representation of these operations.

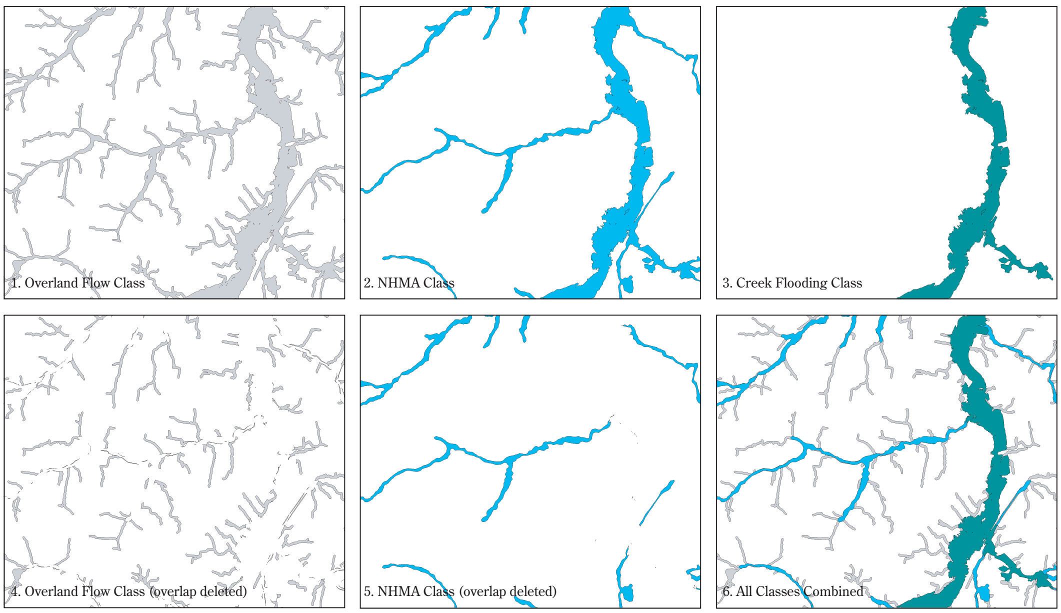


figure 18

Error Detection and Further Editing

The primary source of error for this process comes from pit filling algorithms required to produce accumulated directional flow data. While this is necessary in order to develop contributing area classes, the error that some times results needs to be accounted for. The process has, up to this point, proceeded with very little manual interrogation of data, however as with any computer generated mapping, there remains a need for human inspection, evaluation and error rectification. In this instance comprehensive evaluation has identified that deviation from actual drainage lines occurs where lineal obstructions such as roads and railways traverse drainage lines and the LiDAR data filter used to separate ground and non-ground strikes has (quite understandably) not correctly identified the presence of stormwater infrastructure. This highlights the need for comprehensive GIS data, as a table of culverts and bridges rendered as polygon objects with invert levels included (eg. GCCC) would provide a reasonably simple 'fix' for this problem by allowing spatial analysts to enter invert levels for the obstructions into the DEM. As these data were unavailable (from BCC), a manual error detection and rectification process was adopted.

Figure 19 gives examples of the pit filling errors. Note that the drainage line has been forced to traverse the Freeway (Nathan) via the University Road underpass

figure 19

Manual editing conducted with the aid of aerial photography, as well a storm water infrastructure and 0.5m contour data allows a skilled analyst to accurately reinstate the correct drainage lines. This process also provides a good opportunity for QA.

Conclusion

The business objective for this project was to provide mapping for potential flood hazard areas. While it is acknowledged this method does not use absolute volumes and associated flood levels calculated to the millimetre, the method relies on the terrain itself to tell its own story. The relevance of this of course, is that the terrain is a very good indicator of flood potential as flood events contribute significantly to terra-formation. Drainage plains and flood plains provide a reasonably simple target for mapping and coincide quite well with formally modelled flood inundation maps.

It can be seen from this methodology outline that mapping potential flood hazard in this way provides a practicable and cost effective means to achieve a good result across quite large areas. The method does not require the resources of formal flood modelling and can be combined with tradition flood inundation outputs in order to supplement existing modelled areas (fill in the gaps). GIS data produced also provides tools for evaluating and/or identifying model priorities. Figure 20 shows the utility of the data for mapping flow path depths in order to identify flow paths with well defined channelisation and capacity for flood water conveyance.

figure 20. Depth Mapping

When all is said and done the method provides comprehensive coverage quickly and at a fraction of the cost of traditional flood modelling. While there remains scope for refinement, the method produces sound results as GIS layers that are suitable for planning purposes.