Large-scale screening for cost-effective flood risk mitigation projects

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This article will demonstrate the effectiveness of Interferometric Synthetic Aperture Radar (IFSAR) for the identification of flood-prone structures, and the use of that data in planning flood mitigation actions. It will focus on the identification of structures that are particularly prone to repeat flooding. The process for delineating such buildings will be discussed, as well as a process for assigning depth-damage relationships. The discussion will be geared towards areas that do not have LIDAR topographic data or building footprint data available, and therefore need to utilise other resources for this process in a cost-effective manner.

Floods are a major source of damage to structures worldwide, but the degree to which a flood affects a structure is dependent on the location and elevation of the structure in most cases. Identifying the boundaries of a structure and extracting floor elevation data has typically been done using on-site surveying. This method is reliable, but can be costly. In larger metropolitan areas, or in areas where an initial estimate of flood-prone building is desired, remotely sensed data may be useful in identifying areas in need of mitigation.

IFSAR data has been collected for large portions of Australia, and has also been collected for significant portions of the European Union and United States. The ability to use this data to identify building outlines and to estimate the floor elevations of those buildings would thus be invaluable in aiding local authorities in performing initial assessments of flood mitigation opportunities.

Developing a model of any given flood is one part of the equation, but identifying structures that are flood prone is an essential step in developing flood hazard mitigation plans. Mitigation plans frequently require analysis of the cost-benefit ratio of performing certain mitigation actions to structures.

Intermap Technologies has collected digital elevation data for most of eastern New South Wales, Australia, using the Interferometric Synthetic Aperture Radar (IFSAR) technology. The two initial products that come from the IFSAR data are the Digital Surface Model (DSM) and the Orthorectified Radar Image (ORI). The data was collected using Intermap's STAR-4 King Air turboprop plane, flying at an altitude of around 7,010 metres. All of the Australian data is created with a Vertical Datum of AUS Geoid 98 (AHD) and a Horizontal Datum of GDA94. Using two test areas, the town of Bulahdelah and the town of Coomba Park, a process for extracting the structures from the IFSAR data was attempted using ESRI's ArcGIS version 10.

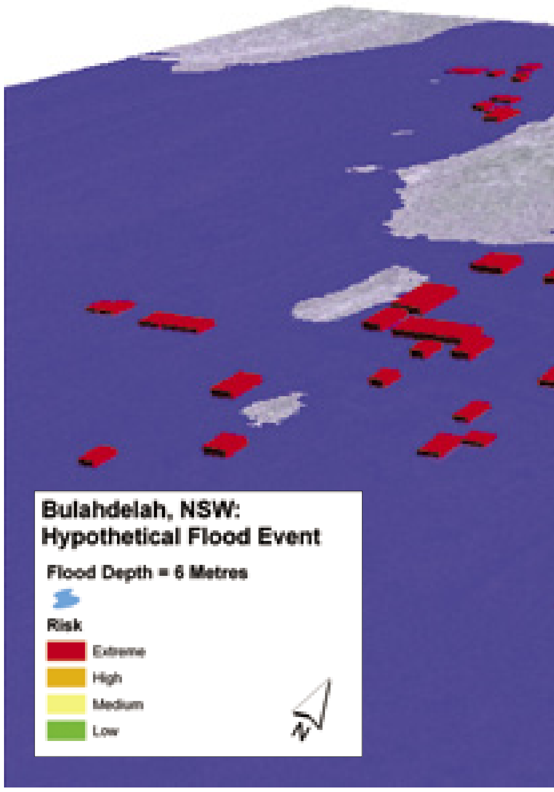
Bulahdelah

For the town of Bulahdelah, only the ORI was used for the structure extraction process. The ORI for this area was acquired using Intermap's high-resolution 270 MHz mode, which generates an image pixel size of 0.62 metres and creates a clearer picture of the ground when compared to Intermap's standard pixel size of 1.25 metres.

From the ORI, simplified polygons were created using the conversion tools based on their 'value'. With the polygons overlaid on the ORI, the general border of the structures was matched up with the polygons and the polygon values of 220 and 221 were decided best fit. The rest of the values were then deleted and the 220 and 221 values were merged to create the first structure shapefile.

Next, the area of each polygon was calculated and any area under seven square metres was deleted from the shapefile. A two-metre buffer was applied to the remaining polygon, with the assumption that many of the smaller polygons that were surrounding the larger polygons were actually parts of the main structure. This buffer would create an overlap of the polygons that were close in geography and, in the next step, 'Feature to Envelope' would create an overlap of those polygons. Once this was completed, all polygons under 40 square metres were deleted; this number was chosen with the assumption that 40 square metres would be an ideal footprint of the structures and also visually best matched the ORI. Any of the remaining polygons that overlapped were merged together, creating single, larger polygons that were to represent the actual structures on the ground. The final shapefile had 545 individual polygons.

For the flood modelling, the structures needed to have their base elevations added to the attribution. For this process, Inter-



and is most likely due to the orthorectification. Because of this shift, some leeway was given to the structure layers agreement with the imagery. 101 polygons were on top of, or within, 13 metres of the structures. A total of 60 structures in the imagery were not accounted for. There were 119 structures that were created with the DSM that were not identified in the imagery; 45 of these polygons appeared to be clusters of trees. There were 21 new structures found and easily identifiable in the ORI, so the amount that was not identified was reduced to 98. The accuracy of this process was around 56%.

One problem that was identified was a 'doubling' of the polygons in areas where the structures were larger than expected or homes were close together. Close to 60 of these doubled structures were counted. These could have been deleted in previous steps; however, to automate this process could possibly delete the structure that is more accurate. The polygon layer was then edited to create the missing structures and delete those polygons that were not needed; 209 polygon structures remained.

map's Digital Terrain Model (DTM) was used. A DTM is a five-metre posted, topographic model of the bare Earth that has had vegetation, structures, and other cultural features digitally removed. In Spatial Analyst, a table with the Zonal Statistics was created for the structure polygons and the mean elevation was calculated. The mean value is added to the attribution as the base floor elevation to each polygon.

For a second visual comparison, the shapefile of the structures was exported as a KML file for viewing in Google Earth (2010 Cnes/Spot Image) and any anomalies were deleted. A total of 31 structures in the imagery were not accounted for. There were 37 polygons that were created with the ORI that were not structures; due to the currency of the ORI, one new structure was found, making the total of actual number 36. The accuracy of this process was around 88%. The polygon layer was then edited to create the missing structures and delete those polygons that were not needed.

Coomba Park

The process for extracting structures in the town of Coomba Park involved using the DSM rather than the ORI. The reason for using the DSM was because Coomba Park is right on the shore of Wallis Lake and, because of this, has a lot of sand surrounding the town. The reflection of the sand has similar values as the structure rooftops within the ORI, making it very time-consuming to identify and correct all of the features. The DSM was chosen to extract the structures because of the specifications: a vertical accuracy of 1 metre root mean squared error (RMSE), a horizontal accuracy of 2 metres RMSE, and 5 metres posted. Within these specifications, the DSM should capture most large structures.

From the DSM, one-metre contours were created and the square metres were calculated for each contour. The smaller contour polygons, usually under 10 square metres, were removed with the assumption that these were usually going to be vegetation that was captured in the data. Areas that were in excess of 500 square metres were deleted; from this process, most remaining contours that had large elevation spikes were visible and used in the next processes.

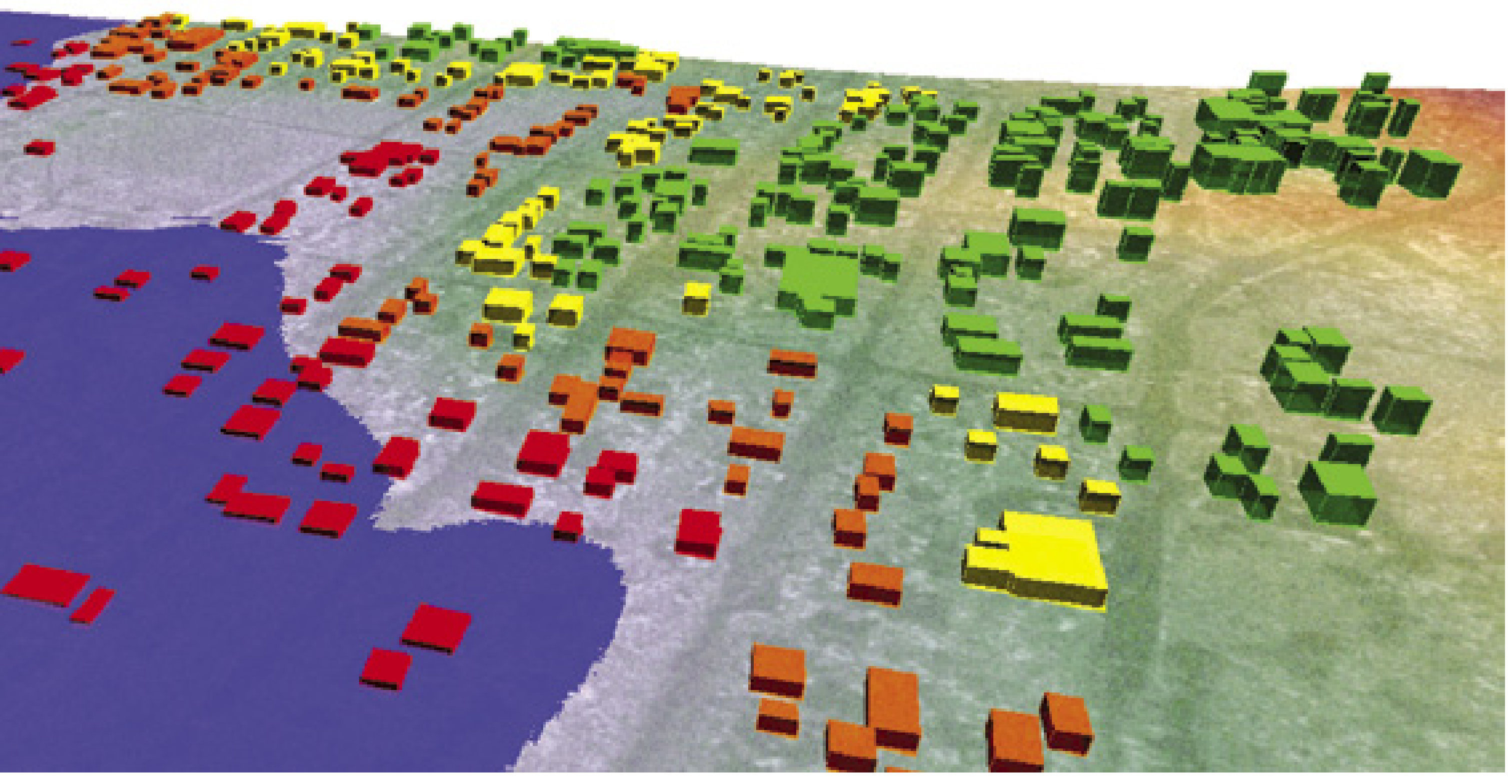
Like the buffering process that was done in the town of Bulahdelah, the same was done in Coomba Park; two-metre buffers were created around the remaining polygons in order to combine the smaller polygons with the larger ones. The polygons that were less than 40 square metres were then removed and a centre-point shapefile was made from the remaining features. Points were created because the shapes of the contours are organic looking and do not represent a man-made structure. From the points, a 7-metre buffer was created and then the 'Feature to Points' function was used around the buffers; this function creates a square shape around the circles and nicely represents a man-made structure.

This area has areas of heavy vegetation and it was clear that many of the supposed structures were not in the right location and an extra step needed to be done. Coomba Park is a smaller town and the homes do not tend to be far from the roads, so obtaining a road shapefile would be ideal, however, there was not one available.

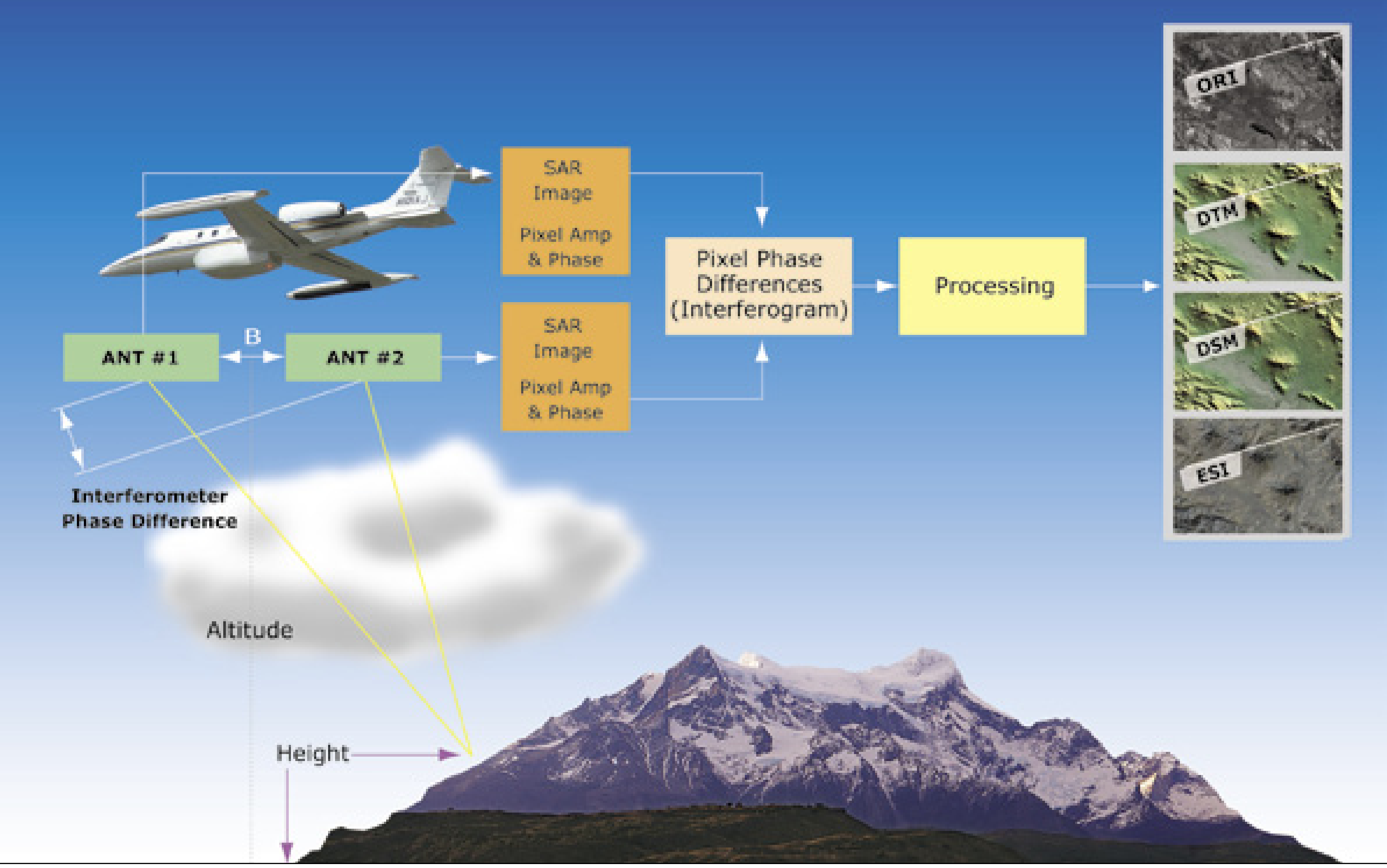
In Coomba Park, the ORI was used to create a roads layer. Since the roads had values much different than that of the sand, it was easier to extract them. This process was done much like Bulahdelah when selecting polygon values. The values from 20 through 40 were kept and the others were deleted, leaving road-like patterns. A new polyline shapefile was created and the roads were digitised by following the pattern. Using the 'Select by Location' function, all of the structures within 40 metres of the newly-created roads shapefile were kept and the rest were deleted, leaving 280 structures.

The elevation was added to the attribution in the same process that was done for the town of Bulahdelah. The same Intermap DTM product was used in acquiring the elevations.

For this second visual comparison, the shapefile of the structures was exported as a KML file for viewing in Google Earth (Image 2010 Digital Globe) and any anomalies were deleted. A 13-metre shift was present in the Google Earth imagery



The IFSAR data collection process.



It is understood that there are many functions in ArcGIS that can replicate similar features. The steps taken in these processes were used because of their simplicity and speed. This was also the first attempt at a feature extraction from the ORI and DSM so it should be assumed that there can be many improvements to the process in the future.

There is also a potential public policy or privacy component to this analysis, since individual structures are identified, and any such remotely-sensed analysis should be performed in the context of local regulations and customs on such matters.

Using the data for mitigation analysis

Once the building footprints and elevations have been extracted, it is then possible to compare the elevations to the water surface elevations of relevant floods. Typically, structures that flood most often will be the most cost effective to mitigate. However, there are nuances to the cost-benefit analysis process.

Modern flood analysis data is typically available in spatial format for use in GIS systems. The most useful type of spatial flood analysis data is 3-D water surface elevation coverage for the flooded area. A good quality mitigation analysis requires several flood return periods to be analysed against the structure data. Commonly, the 2-year, 5-year, 10-year, 50-year, and 100-year flood events are available, or may be developed. Depending on the flood characteristics of the area, it may also be possible to interpolate intermediate flood elevations if only a low frequency and high frequency flood are available, though this is not the preferred method.

Figure 1. demonstrates the data extracted from the process described earlier in this article. Depending on the flood elevations, broad-scale decisions could begin to be made for this area, based on this information. For example, if the flood elevation of a 10-year flood event was approximately eight metres, then about 35% of the structures identified would be flood-prone in that event. Similar analyses could be performed for additional flood events. For the purposes of this article, fictional floods have been used for the demonstration of the techniques. Normally, actual flood elevation data would be used.

Depth-damage curves for residential and commercial structures are available from a wide variety of sources, and at many levels of detail. For example, some resources provide differentiation between damage suffered by one-story and two-story homes. Some resources also provide estimates of contents damage as well as structural damage. Readers are directed to their local source of such information. Many local, state, and national authorities have developed depth-damage curves specific to their locations.

Using a generic set of depth-damage curves, annualised loss estimates were developed for the community above. Figure 2. shows the number of structures affected to various damage levels by the fictional floods. The data behind this allows any individual structure to be identified and the level of damage in any given flood event, and on an annualised basis, to be determined. This data is exceptionally useful in determining which structures will suffer more damage, or more catastrophic damage, in various flood events. This data can be attributed to the structures in a GIS platform and used to perform numerous spatial analyses.

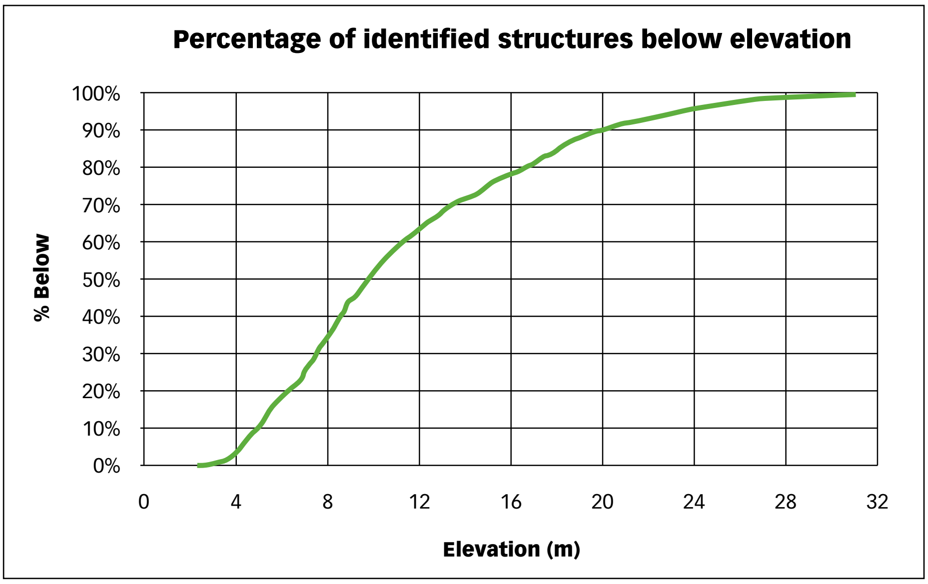


Figure 1.

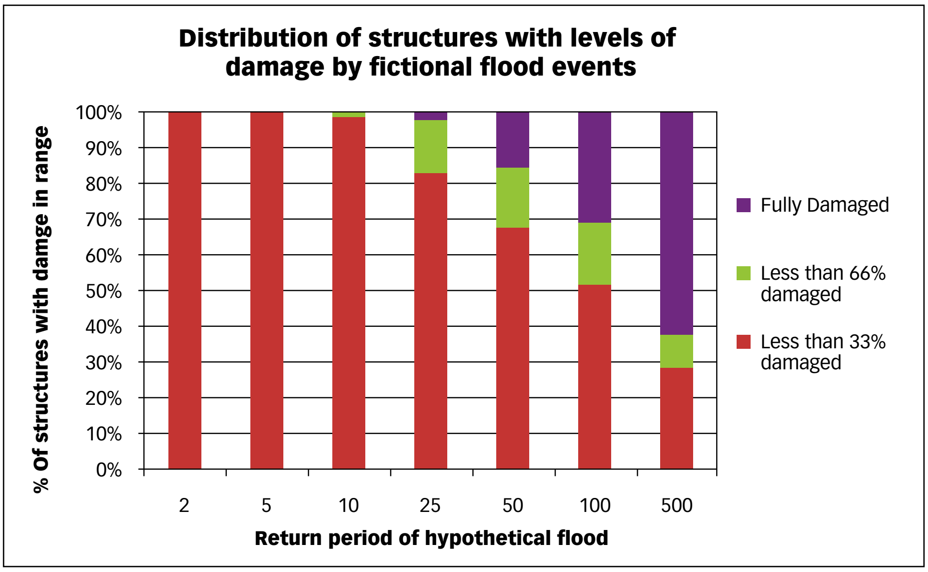


Figure 2.

Conclusion

Additional testing is being performed on the methods described above for the identification of structure footprints and elevations using IFSAR data. Initial results are promising. The data produced to date is useful in flood mitigation planning analyses, and allows structure-by-structure level screening for cost-benefit and flood depth-damage analyses. ■

This article is based on a presentation given by the authors at the Tamworth 2011 51st Annual Floodplain Management Authorities Conference in February 2011. Kea M. Beiningen, GISP, CFM, is a project manager and GIS specialist with the risk management group at Intermap Technologies, and Michael DePue, PE, CFM, PBS&J, is a vice president with Atkin's Floodplain Hazards Management Group. He is a registered professional engineer and a certified floodplain manager (CFM).