

MONITORING THE EXTENT OF FLOODING – BASED ON A CASE STUDY IN QUEENSLAND

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ABSTRACT

“Of droughts and flooding rains” (Dorothea Mackellar 1885-1968, “My Country”). The recent flooding in Queensland affected rural areas, mines, towns and cities including the state capital. Tracking such an event on a day-by day basis raises practical and theoretical issues. While this year’s floods captured world headlines, there is a major flooding event in Queensland about every second year. There are obvious costs resulting from serious flooding, and some can be reduced significantly if the public are reliably informed (whether to evacuate, what property to save, where to evacuate to, what route to take, where to store property). There are also indirect costs to be reduced by the dissemination of reliable information. For example, losses to the tourist industry caused by exaggerated reporting.

The paper explores strategies to provide advice to the public by presenting: available raw imagery leaving users to make an interpretation, processed data with information for probable inundation, processed data overlaid with a quality mask indicating reliability, corrected data using a variety of sources, or combination of existing numerical flood models with topographic information to predict flood extent. The paper addresses various sensor products that can be used, their combination with flood modelling techniques, a historical record of inundations, direct measurements (river gauges, rainfall measurements, sensor webs etc.) and more diffuse inputs (crowd sourcing) to supply the best possible decision support information to the public.

1. INTRODUCTION

In the latter part of 2010, a long-term drought in eastern Australia came to a spectacular end with a period of widespread and continuous rain. This led to flooding over large areas, and the movement of significant floodwaters down the river systems. Over a period of about 3 months, many towns were seriously affected, and large areas of cropland and grazing country were inundated. The exact area of land inundated is still being determined, but is around 8 million ha. It has been estimated that up to 40% of the state of Queensland was affected in some way by the flooding (for example by road access being cut). The inundation of many parts of Brisbane made news worldwide and caused significant personal and financial losses, but it must be remembered that this was not the limit of the event. The town of Rockhampton was crippled by flooding for a period of several weeks before, during and after the Brisbane event.

A major difficulty presented itself as the flooding progressed. There was clearly a predictability in the way the waters progressed down the river systems, but it was difficult to quantify the actual extent of the flooding as it happened. A further difficulty was in communicating to the public which areas were likely to be flooded, and what action they should take.

The paper explores options that may be used to provide timely advice to the public, and identifies the following strategies:

- The available data could be ignored, and not be made available for public use due to low reliability. The available raw imagery could be presented, highlighting those areas giving the spectral response of water, leaving the user to make an interpretation.

- The information can be processed to identify probable areas of inundation. This typically will contain spurious and missing areas, and must be accompanied with metadata and disclaimers.
- The processed data could be further enhanced with a quality mask that indicates areas with probable false positives, and areas where inundation may have been missed.
- An attempt can be made to remove all false positives, and generate the missed areas of inundation from a variety of sources.
- The processed data can be improved with measurements from gauges, webcams or other available real-time sensors
- Existing numerical flood models can be combined with topographic information to help estimate flood extent and depth.

This paper addresses various techniques that can be used, combining modelling techniques, a historical record of inundations, direct measurements (such as river gauges, rainfall measurements, sensor webs etc.) and more diffuse inputs such as reports from members of the public to supply the best possible decision support information to the public.

2. EXISTING TECHNIQUES

Various Earth observation techniques can be used to obtain information about the depth and extend of a flooded area. The reliability of airborne data depend on many factors: spatial resolution, spatial coverage, accuracy and precision, temporal resolution (dependent on orbits of satellites and other sensor platforms), environmental deployment restrictions (determined by the type of the wavelength), etc. In case of emergencies factors such as data availability (especially in the first hours), required expertise and post-processing time are also of critical importance. Commonly optical images are widely available in a

large spectrum of bands, but they are useless in cloudy periods (which is often the case in floods). Satellite Radar is being used worldwide to detect water lying on land surfaces (Brivio 2002; Sokol 2004; Brisco 2009), but the radar images are sometimes difficult to interpret. Furthermore in an area of the size being considered here, it is a very expensive technology for full state coverage. Such a technology could be considered for more detailed investigation in restricted areas and during specific intense flooding events.

An interesting alternative would be the use of Envisat Wide Swath Mode images. These radar images cover the Earth every three days and have a resolution of 250 m. Open water stands out clearly as darker areas in these areas, especially if the surrounding areas are vegetated. Based on change detection, Andreoli and Yesou (2007) showed the possibility to map floods with this satellite product. A complication occurs in built-up areas, where flooded areas contain many corner reflectors, which show up very brightly in radar images. Polarization information can help in such cases but errors are to be expected. Analysis of platforms, sensors, products and their applicability in different disasters is given in Kerle et al 2008 and Zhang and Kerle 2008. In the sections below we will concentrate on the data and technologies used to provide information to the general public for the flood in Queensland.

2.1 Reporting the Flood



Fig 1. Website ABC News, with interactive before/after slider

Quite soon after the flooding in Brisbane a number of geo-information publications were devoted to the information

provision (before, during and after) the flooding. Below is a summary of these recent (mostly popular and professional) publications with the various 'solutions'.

Some impressive aerial photos of the Brisbane floods were published in the ABC News, 17 January 2011 (URL1). The website allows the user to move a slider to gradually between before and after flooding images; see Fig 1 (source: NearMap). Flood level simulations produced interactively in 3D by AAM (in GIM International, 18 January 2011, URL2) do clearly show the impact of the flooding and its temporal dimension via an animation; see Fig 2.

The usefulness of satellite radar data for early warning was reported Linlin Ge of the University of NSW in Spatial Source, 18 January 2011 (URL3) and he motioned the drawback of not having an Australian ground-receiving station: causing several hours of delay in receiving the data: 6 hours to get data from Europe for what could have been 30 minutes. Two more articles mentioned the advantage of radar satellite data in resp. GIM International, 1 February 2011 (URL4) and in Spatial Source, 3 February 2011 (URL5). The cited researcher Albert van Dijk of CSIRO (cooperation TU Vienna) explains how the ESA's Envisat ASAR (Advanced Synthetic Aperture Radar) data is used to monitor the amount of water in the soil (later on relevant for estimating runoff) and also to monitor actual flooding (even in dark or cloudy conditions). The same articles also mention ESA's Sentinel-1 mission, to be launched in 2013, to further improve satellite observations.

Quite a different approach by ESRI Australia is reported in GIM International, 3 February 2011 (URL6): data from social networks (Ushahidi, Flickr, Twitter, YouTube, ...) is used and analyzed to identify problems reported by several persons and put this in the right spatial, temporal and categorical perspective. Finally, Spatial Source, 8 March 2011 (URL7) reports the availability of the first official flood maps released in Queensland; see Fig 3: users can specify their location and switch on and off various layers to analyze the devastations at a specific location.



Fig 2. AAM's 3D Flood Simulation



Fig 3. Interactive map of Queensland Reconstruction Authority

2.2 Dartmouth Mapping

Dartmouth Flood Observatory covers the entire world with flood maps (<http://floodobservatory.colorado.edu/>). It is not continuous mapping and is triggered by press reports on flood events from around the world. It should be assumed that if a flood is minor and not well reported it may not be mapped at all by the Dartmouth group. It is not known at this stage if the time between raw data acquisition and publication of the subsequent flood map products is guaranteed by performance indicators.

The Dartmouth metadata is limited. The actual time and date of the raw data is not immediately available to users and needs to be communicated more clearly. Research has revealed that the Dartmouth product consists of an accumulation of six MODIS images (36 spectral bands) acquired over three days. The spatial resolution is 250m (bands 1-2), 500m (bands 3-7) and 1km (all the rest). The product is published with the last date in the image capture series forming part of the file name. AustraliaNYYYYMMDD.shp where N = one of the 6 zones covering Australia, YYYY = year, MM = month and DD = day. A brief description of processing details quoted from a Dartmouth technical document explains the rationale for combining imagery from six epochs.

“Cloud shadows on land and terrain shadows may exhibit spectral signatures in the MODIS bands used that are nearly identical to that of clear water. To remove cloud shadows, our approach evolved with experience: from a 4 scene set including two days and two scenes per day (Terra, morning, and Aqua, afternoon), to also employing a 3 day, 6 scene set in regions where such noise is a problem. In this approach, cloud shadows are removed by requiring 3 "water" classifications for each pixel to be accepted as water in the final product. Cloud shadows are largely removed, because their positions change over a three day interval. Only three, in any order, of the 6 images show water: intermittent cloud cover is partially removed also by this approach, which fills coverage between clouds, and while at the same time removing noise caused by cloud shadows. Terrain shadows also move from morning to afternoon and may be partially removed, but some deeply shadowed land areas in mountainous terrain remain misclassified as water”. (Brakenridge 2011).

The false positives caused by terrain shadows are mitigated by the methodology but are not completely removed. The six epoch model approach removes many of the false positives caused by cloud shadows but includes a risk of introducing false negatives (no water mapped where water does exist) where flood waters move rapidly across the landscape. Introduced false negatives may negatively impact public safety therefore the Dartmouth data should not be used for decision making that may affect public safety.

Infrared absorption is a key tool used for water classification. The extract from the Dartmouth technical document refers to the link between clear water and the infrared band 7. The level of absorption in infrared bands reduces with increasing turbidity making spectral classification more difficult. High levels of sediment carried by floodwaters may potentially affect the classification by introducing false negatives. As rapidly moving floodwaters (example Brisbane’s highly turbid floodwaters) will have a higher sediment load than less dynamic floodwaters (example Victoria’s relatively clear floodwaters) the risk of mapping false negatives is multiplied by the turbidity factor associated with the rapid movement of water across the landscape combined with the Dartmouth methodology

requirement for at least three of the six epochs to be mapped as water to be accepted as water.

The Dartmouth mapping does have the potential to reduce false negatives due to intermittent cloud cover. If cloud only covers the water for three of the six epochs it will be mapped correctly as water. The single epoch Landsat mapping does not have this ability.

A comparison of the Dartmouth flood mapping relative to a raw Landsat 5 image for the same date can be seen in Figs 4 and 5 below. It is apparent that there are considerable false negatives in the example shown. One possible reason for these false negatives could be the dynamic nature of the flood footprint over the three days of MODIS image capture included in the Dartmouth product. There were four MODIS images captured prior to the Landsat 5 image capture and two after 7 bands, 30m spatial resolution Band 6, 120m spatial resolution). The fifth MODIS image in the series would have been captured only about thirty minutes after the Landsat 5 image was captured.

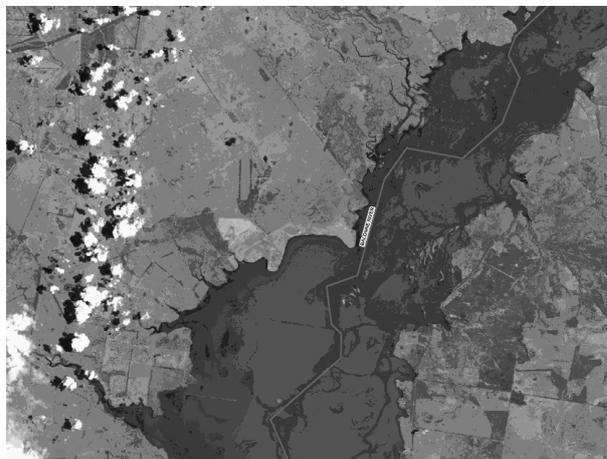


Fig 4. A Landsat 5 image taken on the 5th of January 2011 showing the flood extent of a section of the Balonne River.

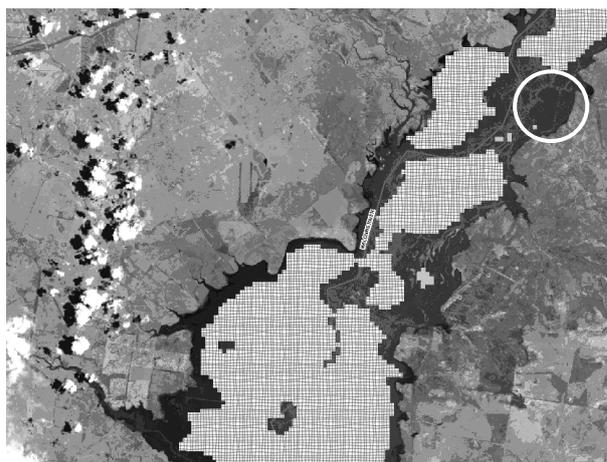


Fig 5. A Dartmouth product derived from MODIS imagery captured over a three day period from 3rd - 5th of January 2011 (Note the circled false negative).

A second potential reason for the false negatives could be high turbidity levels in the water failing to trigger the spectral response for clear water expected by the Dartmouth team. The Landsat 5 scene exhibits signs of turbidity – lighter blues and

aqua colours – as opposed to clearer water that is shown as deeper dark blue colours.

A third potential reason for the false negatives could be cloud cover over flooded areas of clear water for more than three of the six epochs captured.

Over the sample site provided in Figs 4 and 5 there are no obvious false positives in the Dartmouth mapping.

2.3 Landgate Mapping

Landgate flood mapping uses MODIS data exclusively and is limited to Australia (<http://www.landgate.wa.gov.au>). It can be purchased on a user defined periodic basis. The Landgate group capture Australia wide coverage from the morning overpass (circa 10:30) of the Terra satellite and the afternoon overpass (circa 13:30) of the Aqua satellite on a daily basis.

It is unlikely the time between raw data acquisition and publication of the subsequent flood map products is guaranteed by performance indicators. Currently the processing is dependent on a single part time officer who only works three days per week. As a result there can be a delay of up to five days from data acquisition to provision of the derived flood map product. The Landgate data has better metadata than the Dartmouth data, and is available on a twice daily basis with the date and time of the satellite overpass being well documented.

No attempts have been made to combine satellite image epochs to remove cloud shadow or terrain shadow errors as in the Dartmouth methodology but additional spectral classification of the raw data has been done to improve the cloud mask data that comes with the MODIS products. The Landgate flood mapping also utilises historical data from their extensive MODIS derived flood mapping archive to assist in reduction of mapping errors. The Landgate algorithm also includes the use of a DEM as explained in an e-mail message from Mario Ferri, Senior Research Officer, Satellite Remote Sensing Services Landgate, 65 Brockway Road Floreat WA 6014:

“A mask is created on two topographic attributes obtained from the DEM at 90m resolution (SRTM) and resampled to the same resolution of 250 meters of MODIS: the slope and profile convexity. This mask is obtained by considering two thresholds, one for each of the two attributes. In fact it is considered very unlikely the existence of a surface water or a flood when the surface has a relatively excessive slope or when it shows a certain convexity. The use of such a mask significantly reduces misclassification due mainly to the ambiguity water/shadows”

Looking at Figs 6 and 7, it appears that the six epoch Landgate combined dataset has less false negatives than the standard Dartmouth product. The Landgate dataset seems to map the turbid water better than the Dartmouth dataset in this sample site while some areas of the clearer water are not mapped as well as the Dartmouth product.

As with the Dartmouth mapping the Landgate dataset has no obvious false positives over the selected sample site. There are still considerable false negatives and the possible reasons for these are the same as those outlined for the Dartmouth mapping.

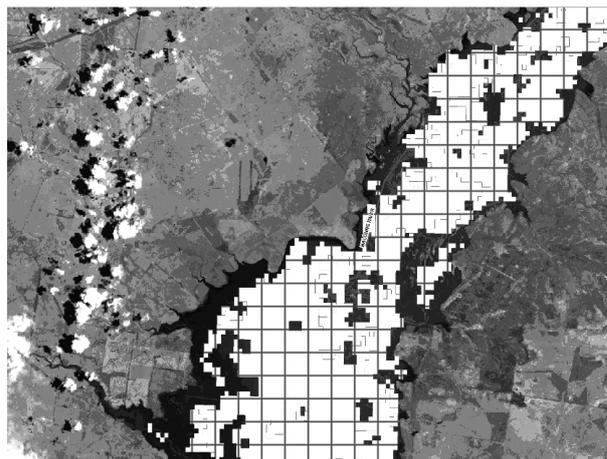


Fig 6. Merged six epoch Landgate product created to enable direct comparison with the standard Dartmouth six epoch combined product.

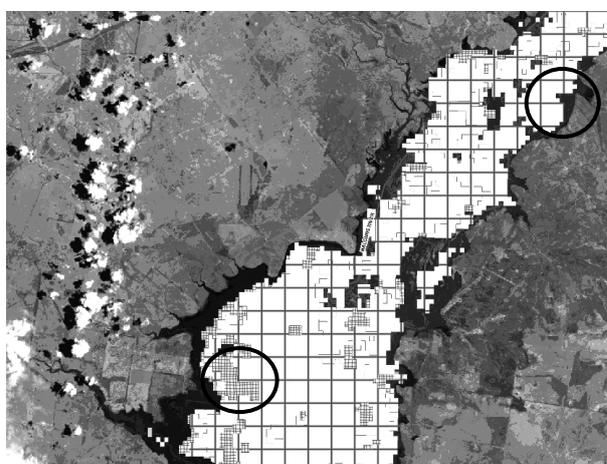


Fig 7. Landgate data overlaid on top of the Dartmouth data (Note the circled areas, where a positive in one set of data shows as a negative in the other).

3. LIMITATIONS

General limitations associated with flood mapping are outlined in the following two sections while limitations and some advantages specific to both systems are discussed under their respective headings.

3.1 False positives

Fire scars, cloud shadows, terrain shadows and land forms such as certain bare rocks, and moist black soils emit a spectral response that is difficult to distinguish from flood water. Difficulty separating these elements from flood waters increases proportionally with the level of turbidity in the flood waters. It is difficult to solve for the elements listed that are ephemeral by nature but the consistent elements such as terrain shadows and dark bare rocks can be excluded where appropriate by mapping their locations. However, if an area is consistently showing as a positive while the flood develops, time series analysis could be used to eliminate that area.

It is embarrassing, but not potentially dangerous to publish areas of “inundation” that turn out to be hilltops. The risk in publishing data with these errors is a loss of user confidence in the mapping. This may be allayed to some extent by complete and simply communicated disclosure of known errors.

3.2 False negatives

Inundated areas under cloud cover cannot be mapped by a sensor that uses visible and infrared parts of the electromagnetic spectrum. Clouds completely reflect these wavelengths therefore any water beneath a cloud cannot be mapped by a sensor above the cloud. This is the major cause of false negatives in mapping during flood events.

There is also potential for false negatives to be mapped in areas with dense forest cover and also in city areas where the footprint of buildings above the flood line exceeds the water footprint between the buildings. The high reflectance values from concrete and roofing materials tends to “burn out” the absorption properties of the water signature. The relatively high reflectance of dense forest compared to clear water has a similar “burn out” effect although not as significant as the much brighter reflectance from buildings.

This is more serious than the false positive, as it may lead to bad decision making – leading to people travelling into flood regions, or failing to evacuate areas downstream.

4. STRATEGIES

In any solution, the level of confidence in the data will necessarily vary geographically. It will be necessary to indicate this on the face of any maps that are presented to the public (or to any non-expert users).

One possible approach is to use a different colour and shading pattern depending on the confidence. e.g. it might be that areas of known inundation are shown in brown, but if there is some doubt, it may be a cross hatched brown (with an appropriate legend).

4.1 Eliminating False Positives

This is probably the easiest of the technical fixes, but unfortunately, it is also the least important.

It may be possible generate a binary mask that in effect states that “floods can occur in this area”. Using a DEM it may be possible to exclude areas that theoretically cannot flood unless they surpass previous long term records. The indicated flood polygons are then just intersected with this region, and the result will have some false positives removed. Some false positives will remain – in particular, moist/wet black soil areas and perhaps the basalt wall near Charters Towers or similar (really dark rock with little slope/terrain shadows). This approach is problematic, because the criterion for land being floodable is difficult to determine. In fact if this could be done with any accuracy, the building regulations would be modified to use it.

In order to avoid removing true positives, there must be a buffer around the floodable area, but the extent of that buffer is also difficult to determine. Too wide a buffer will lead to the acceptance of false positives again. Nevertheless, it is better to accept some false positives than to remove a real positive.

4.1.1 Service

An alternative approach is a service that does a “reasonability test” on the individual flood polygons. For example, a flood polygon that indicates a region on the side of a hill, with dry ground below it is probably spurious. So, use the DEM for this

purpose and next check the classification of the (lower) neighbouring areas.

The design of this reasonability test will be quite subtle, but can be refined, based on its success in practice. The advantage is that, even though a piece of ground is detected to be a false positive, if it becomes involved in a true inundation later, it will not be missed. From personal conversations with the Landgate team their methodology does something similar but in reverse, discarding false positives due to terrain shadows based on their archive of previously inundated areas and distances from rivers, creeks and lakes.

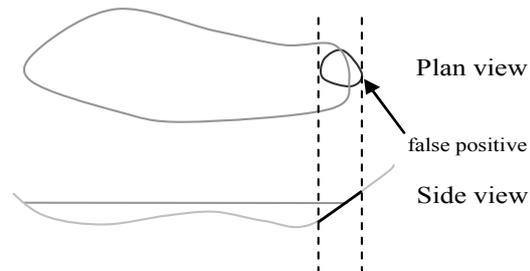


Fig 8 A false positive (in black) on one occasion may be part of a true inundation at another date.

In Fig 8, a service that detects a spurious area because it is on a hillside would correctly remove the region marked in black, but on another occasion, the area marked in blue would be correctly detected. (In practice, the soil type that lead to the original false positive may cause the region of inundation to be over-estimated in that area, but that is a relatively minor problem). This approach would rely on an easily accessible elevation model of reasonable resolution. For example, if a DEM is to be used, it would have to have at least several poles in the smallest of inundation polygons to be processed. The MODIS 250m pixels may be well matched with the 30m DEM from Geoscience Australia.

4.2 Correcting False Negatives

This is a more important, but far more difficult operation.

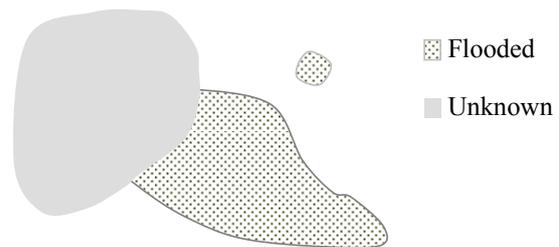


Fig 9 Missing data shown by metadata

Metadata Approach: One common reason for missing information is that cloud cover obscures the flooded area. Optical satellites are therefore severely compromised when it comes to flood mapping. It is important that this is not presented to the public as though the area is dry. At a minimum, there should be a blank on the map (Fig 9), showing a lack of information.

A possible improvement might be to fill the unknown region with older data, which may still be useful (Fig 10).

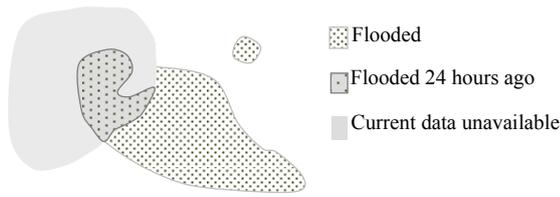


Fig 10 3 Showing older data where current information is unavailable (this is similar to the Dartmouth decision process but they see a varying “water” signature as possible cloud shadow and therefore remove it)

A further possible improvement is similar to the ‘DEM-neighbour’ approach when removing false positives. Use the DEM for unknown area and in case this is on hill-top/side and higher than neighbour area (known to be dry), then quite likely that this unknown area is also dry. However, if an unknown area is on the valley/low side of neighbours that are known to be wet, then quite likely that this unknown area is also wet.

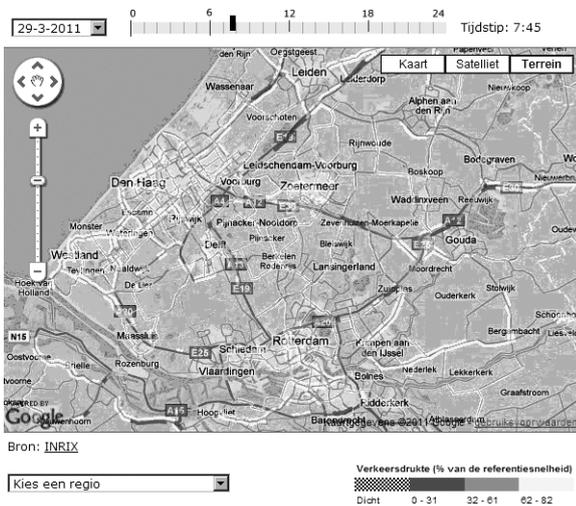


Fig 11 Real time-traffic movement data (moving mobile phones): colour indicates delay (or blockage)

4.3 Alternative Data Sources

Given the large distances involved, Satellite data remains an attractive option, but many other sources of information are available.

- Direct Measurement: It would be ideal to have a network of autonomous sensors reporting on inundation heights, especially on critical locations. Some possibilities include: rain gauge and stream gauge data and acoustic sensors at low points on critical roads.
- Road reports: Major roads, freeways etc are monitored for traffic flow purposes. If these cameras show flooding, the depth can be estimated and fed into the information base.
- Crowd Sourcing: Reports from members of the public, from emergency service vehicles, from survey vehicles (such as those used by Google Earth for “street view” capture) etc. could be collated and used – automatically or with expert user guidance.
- Data mining: Incoming calls at municipalities, alarm numbers, fire department

- Mobile GPS phone movements: Many people travelling by car, train, bike, etc have mobile phones and there are large archives with historic and real-time mobile phone movements (especially the GPS-mobile phones are providing relatively good quality positional info); e.g. Vodafone/TomTom cooperate with their users to use the real-time movement data of the individuals to monitor traffic jams (and to be able to provide better route planning advice) (fig. 11). If there is no movement on a road (where there is normally movement), this is a strong indication that the road is blocked (potentially due to flooding). Could a mobile phone then act as a de-facto flood EPIRB for trapped motorists?
- Direct Investigation: Vehicles can be dispatched for the purpose of checking and determining flood levels. (Workplace Health and Safety issues arise if sending staff into dangerous conditions).

4.4 Modelling and Interpolation

Floods are notoriously unpredictable, but over local areas known water heights can be used to estimate extent of inundation.

4.5 Forecasting

Based on past flood records, a known river height and rate of increase can be used to forecast what areas are likely to be flooded in the near futures. Conversely, the same procedure could be used to fill in the gaps in the current inundation maps.

5. OUTPUTS

The aim is to provide the public with effective decision support information to assist in making personal decisions:

- Should I do nothing and wait?
- Should I attempt to sandbag or build embankments?
- Should I evacuate?
- If evacuating, where to? and by what route?

Making a clear map of the current inundation easily available is of great use to the public, and the public can be allowed to interpret that map at least in relation to their home. Typically, a person in a rural area (particularly if flood-prone) will be aware of stream flow directions, and knowledge of the conditions upstream will give a warning, if not explicit advice. In urban areas, the public do not have the same connection to the land, and may not have a similar awareness (Many people in the Brisbane area were unaware that their homes had been badly flooded in 1974).

Beyond the basic production of areas of current inundation, there are several other services that can be provided:

- Estimates of roads that are currently impassable to various classes of vehicles.
- Automatic calculation of routes based on current road data (Mioc and Lian 2008).
- Predictions of inundation extent in the near future, or more realistically, risk estimates of future inundation.
- A detailed history (archive) of the development of earlier floods, to assist with the estimates of future flood courses.
- Animations of the progression of earlier floods (in a form similar to the current inundation maps).

6. CONCLUSIONS AND FUTURE RESEARCH

This paper has presented a description of the problems encountered in reporting making available to the public information about the floods of 2010 to 2011 in Queensland. Existing techniques were highlighted, and promising techniques identified.

It is clear that the available techniques are improving day by day. It is also clear that a knowledge of previous flood events (such as the Brisbane flood of 1974) can be of use to the public if no more immediate information is available. A definitive and detailed map of the 2010/2011 flood event is being produced.

The outstanding question is how these techniques can be automated and/or proceduralised in order that the most useful and timely information can be provided to the public as a future flood event happens. It would be ideal if presentations such as those shown in section 2.1 were available as the flood event unfolds, rather than 4 days to a week later.

Based on observations of what people in Brisbane (and this includes two of the authors of this paper) needed on the Tuesday prior to the flood peaks was rapid access to flood level data mapped over their property, linked to TV & radio estimates of how far over or below that level the peak was expected. Vectorising the 74 flood line and making it available via Google Earth would have been one solution. Also ESRI products such as the one shown in Fig 3 (see also URL6) could have been published from several federal, state and local government servers to avoid network traffic issues. Flood maps were produced and made available by the Brisbane City Council, but were in a raster format and this helped to bring down their site.

Around the world, bureaus of meteorology have been making available websites which show the extent of currently falling rain, and, while they clearly display false negatives and false positives, they are extremely useful to the public and popular. A line of research is indicated to attempt to provide some similar presentation of an evolving flood situation.

7. REFERENCES

Andreoli, R. and H. Yesou (2007). "Large scale change detection techniques dedicated to flood monitoring using ENVISAT wide swath mode data. " *Geoscience and Remote Sensing Symposium, 2007. IGARSS 2007, IEEE International*, pp 2382 - 2385, doi:10.1109/IGARSS.2007.4423321

Brakenridge, G R. (2011) "Technical Description, DFO-GSFC Surface Water Mapping Algorithm" <http://floodobservatory.colorado.edu/Tech.html> (accessed April 2011)

Brisco, B. (2009). "A semi-automated tool for surface water mapping with RADARSAT-1." *Canadian Journal of Remote Sensing* 35(4): 336-344.

Brivio, P. A. (2002). "Integration of remote sensing data and GIS for accurate mapping of flooded areas." *International Journal of Remote Sensing* 23(3): 429-441.

Kerle, N, S. Heuel and N. Pfeifer, 2008, Real-time data collection and information generation using airborne sensors, in Zlatanova and Li (eds) *Geospatial Information Technology for emergency response*, Taylor and Francis, pp. 43-74

Mioc, D., F. Anton and G. Lian (2008). *On-line Street Network Analysis for Flood Evacuation Planning, Remote Sensing and GIS Technology for Monitoring and Prediction of Disasters*. Nayak and S. Zlatanova. Heidelberg, Springer Verlag: 219-242.

Sokol, J. (2004). "Case studies demonstrating the hydrological applications of C-band multipolarized and polarimetric SAR." *Canadian Journal of Remote Sensing* 30(3): 470-483.

URL1. Brisbane floods: before and after. In ABC News, 17 January 2011, <http://www.abc.net.au/news/infographics/qld-floods/beforeafter.htm>

URL2. Modelling Aids Brisbane Flood Crisis. In GIM International, 18 January 2011, http://www.gim-international.com/news/id5416-Modelling_Aids_Brisbane_Flood_Crisis.html?utm_source=Newsletter&utm_medium=email&utm_campaign=20110118+-+GIM

URL3. Australia needs eye in the sky to help with floods, says professor, In Spatial Source, 18 January 2011, <http://www.spatialsource.com.au/2011/01/18/article/Australia-needs-eye-in-the-sky-to-help-with-floods-says-professor/SYMV OQFMMM>

URL4. Satellite Data to Improve Flood Forecasting, In GIM International, 1 February 2011, http://www.gim-international.com/news/id5457-Satellite_Data_to_Improve_Flood_Forecasting.html?utm_source=Newsletter&utm_medium=email&utm_campaign=20110201+-+GIM

URL5. Satellite Data to Improve Flood Forecasting, In Spatial Source, 3 February 2011, <http://www.spatialsource.com.au/2011/02/03/article/Satellite-Data-to-Improve-Flood-Forecasting/BSZWTMOKZR.html>

URL6. Mapping and Analysis for Australia Floods, In GIM International, 3 February 2011, http://www.gim-international.com/news/id5468-Mapping_and_Analysis_for_Australia_Floods.html?utm_source=Newsletter&utm_medium=email&utm_campaign=20110208+-+GIM

URL7. First official flood maps released in Queensland. In Spatial Source, 8 March 2011, <http://www.spatialsource.com.au/2011/03/08/article/First-official-flood-maps-released-in-Queensland/BOPJTYDQCE.html> and official government website <http://www.qldreconstruction.org.au>

Zhang, Y and N. Kerle, 2008, Satellite remote sensing for near-real time data collection, Real-time data collection and information generation using airborne sensors, in Zlatanova and Li (eds) *Geospatial Information Technology for emergency response*, Taylor and Francis, pp. 75-102