ABSTRACT
On 20 May 2009 a complex low pressure system developed off the Queensland coast that caused major flooding across the New South Wales (NSW) north and mid-north coast in the ensuing days. Heaviest rain occurred over Wednesday to Saturday 20 to 23 May, when falls in the range of 500 to 600 millimetres were recorded at several locations.

The numerical weather prediction models gave a good early indication of this event which presented the Bureau of Meteorology (Bureau) an opportunity to issue early Severe Weather Warnings and Flood Watches for the NSW State Emergency Service (SES) and public ahead of the flood producing rainfall. The event also saw a series of smaller low pressure systems impact the NSW coast, notably in the Bellinger and lower catchments of the Clarence and Macleay Rivers. To provide sufficient warning lead time for these rivers the hydrologists used short term rainfall forecasts from the meteorologists that were incorporated in the flood modelling.

In response to the Flood Watch the SES deployed 83 personnel from other areas of the state to assist local staff. Later, Flood Warnings triggered the evacuation of several thousand people from flood affected areas.

This paper will discuss the meteorological and hydrological aspects of the event as well as provide a background to the delivery of these warning services to the SES, media and public.

INTRODUCTION
For several locations along the NSW north and mid-north coast the May 2009 floods were the highest since March 2001, when a deep low pressure system located near Ballina caused major flooding in the area. Improvements to numerical weather prediction models and the application of forecast rain in hydrological flood forecasting models since 2001 led to earlier identification of the potential seriousness of the flood threat. This in turn provided the Bureau with the opportunity to provide the SES and public with targeted early warning of major flooding through a range of warning products.

The heaviest rain in NSW occurred over Wednesday to Saturday, 20 to 23 May 2009. Major flood peaks occurred from Friday to Sunday 22 to 25 May. The SES was first advised of the potential for flooding in the previous week, on Friday 15 May. Severe Weather Warnings and Flood Watches were issued to the public from Tuesday 19 May. The Bureau and SES also issued
a joint media release on Tuesday 19 May that urged residents in northeast NSW to prepare for heavy rain, flooding, damaging winds and coastal erosion – see http://www.bom.gov.au/announcements/media_releases/nsw/20090519.shtml.

**BUREAU WARNING SERVICES FOR FLOODING**

When severe flood producing weather is predicted, there are a range of products available to the community to allow them to best prepare for floods and other hazards that may be associated with the event. The current warning products for flooding include:

1. **Severe Thunderstorm Warnings.** These are short-term warnings, typically giving 1 to 2 hours notice, for thunderstorms which can cause local flash flooding, lightning, hail and destructive winds, including tornadoes. Flooding from thunderstorms generally affects a smaller area compared to the large scale weather systems. Occasionally bands of thunderstorms can reoccur over the same area and generate enough runoff volume to cause main river flooding at downstream locations. In NSW about 83% of severe thunderstorms are preceded by a warning. Around 15-20% of warnings are verified with a reported severe thunderstorm.

2. **Severe Weather Warnings.** These are issued for large (synoptic) scale weather events, such as deep low pressure cells or major frontal systems, which may cause flooding, damaging winds and damaging surf and tidal flooding along coastal zones. Such systems often affect large areas. The Bureau usually provides 24 hours warning of these unless the event is expected to be particularly significant and longer notice may be provided. Warnings are issued for all or part of a weather forecast district, for example, the NSW Northern Rivers, which can be a broader area than that covered by a Flood Watch or Warning. All areas included in a Severe Weather Warning have a risk of flooding even if they are not included in the Flood Watch or Warning, which is a more geographically targeted product – see 3 and 4 below.

3. **Flood Watches.** In NSW Flood Watches target catchment areas with a 70% or greater chance of flooding based upon matching catchment wetness with forecast rain. The targeted catchments are also included in the Severe Weather Warnings, which usually cover a broader area and also include warnings for other hazards that are listed above. In NSW about 80% of Flood Warnings are preceded by a Flood Watch. On average, there is a 70% chance that main river flooding will occur after a Flood Watch has been issued.

4. **Flood Warnings.** These are issued for 175 locations across NSW when river levels are expected to exceed their locally defined minor flood level. These locations and their warning requirements are listed in the NSW State Flood Plan - see http://www.ses.nsw.gov.au/topics/2271.html. Warnings contain predictions of river levels and times when these levels are expected to occur. Across NSW around 74% of river level predictions are within 0.3 metres of observed levels.

In NSW Severe Thunderstorm and Severe Weather Warnings are sent directly to the media, while Flood Watches and Warnings are distributed to the local media via the SES regional headquarters,
which add local information and advice to these products. All Bureau warning products are published on www.bom.gov.au within a few minutes of issue.

MAY 2009 SEVERE WEATHER EVENT
The severe weather was caused by a complex low pressure system that formed off the Queensland Coast. The event saw a series of smaller low pressure systems impact the coast, most notably in the lower catchments of the Macleay and Clarence Rivers shown in Figure 1 below.

The event was characterised by periods of severe weather, with heavy rainfall the most notable. Shorter episodes of damaging wind gusts were evident as small low pressure centres passed across the coast and the large swells generated by the event saw water levels peak above the Highest Astronomical Tide.

The highest rainfall over the 4 day event was 595 millimetres, recorded in the Bellingen Valley.

Figure 1
Grafton Radar Image
1am EST Friday
22 May 2009

A series of small low pressure cells caused a continuous influx of moisture causing very heavy rainfall in the lower Clarence valley for some 6 to 9 hours on Thursday (21/5/09) night. The radar image is about 1.5 hours into this period. Highest rain recorded during this period was 150 mm at Lilydale, 30 km west of Grafton. Flood Warnings for Grafton were upgraded to major at 10:45 pm Thursday night.

RAIN - FORECAST AND RECORDED
Overall, the forecast rain estimates from the numerical weather prediction models for the May 2009 floods, shown in Figure 2, were very good. However, the models did not capture some of the heavier totals that extended further south into the Macleay and Manning River valleys. Recorded rain is shown in Figure 3 for comparison.
During the developing stages of the flood, a senior meteorologist was assigned to the NSW Flood Warning Centre to provide regular updates of forecast rain based on new model runs and radar imagery that were incorporated into hydrological models. Regular briefings were also provided by the Bureau to the SES State and regional staff and to the State Emergency Management Committee.

One of the challenges in this and similar events is highlighting short periods of heightened threat with a broad warning. The nature of such systems means that severe weather is generally transient and depicting such information within warnings can be difficult.

Figure 2
Total Forecast Rain for 20 to 23 May 09

Figure 3
Total Recorded Rain for 20 to 23 May 09

FLOOD WARNINGS – EXCEED, REACH AND PEAK
During the developing stages of a flood the Bureau’s Flood Warnings for NSW contain the standard phrase “at this stage it is not possible to predict the flood peak because of uncertainty over how much more rain will fall”. Initial predictions will be for river levels to “exceed” a certain height at a designated time. These predictions will be revised as heavy rain continues to fall during the event. There may also be additional predictions for the river to “reach” a higher level when using forecast rain values or if the rainfall appears to be easing. The term “peak” is only used for river level predictions when the Bureau is fairly confident that rainfall has eased and the worst is over.

Feedback from public meetings held after the 2001 floods indicated people were confused by frequent changes in river level predictions that can occur during the developing stages of a flood. People also questioned low initial predictions for downstream locations, when significant flooding was already occurring in the upper parts of the catchment. Although it is not possible to predict the peak at the onset of heavy rainfall, the Bureau undertook to keep these changes to a minimum by using, where possible, forecast rain values in hydrological models to give early indications of likely maximum river levels (McKay 2001). In NSW the Bureau also has a policy of not revising river level predictions downwards unless absolutely certain. Experience has shown that more often than not such changes were followed by another upward revision when more rain fell. Late downward changes to predictions near the peak of a flood can also confuse the public, even if they appear high, as the appropriate emergency response should already have been undertaken by this time. This approach was developed in consultation with the NSW SES.

The above strategy resulted in improvements in flood predictions for the May 2009 flood compared to 2001 in terms of reduced changes to predictions, warning lead times and accuracy shown in Table 1.

<table>
<thead>
<tr>
<th>Location / Flood</th>
<th>Number of Changes to Predictions Before Peak</th>
<th>Warning Lead Time to within 0.3 m of peak</th>
<th>Accuracy of Final Peak Prediction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kempsey 2001</td>
<td>8</td>
<td>13.5 hours</td>
<td>N.A. (faulty gauge) 0.3 m high</td>
</tr>
<tr>
<td>2009</td>
<td>5</td>
<td>21 hours</td>
<td>0.1 m high</td>
</tr>
<tr>
<td>Lismore 2001</td>
<td>4</td>
<td>6 hours</td>
<td>0.02 m high</td>
</tr>
<tr>
<td>2009</td>
<td>3</td>
<td>16 hours</td>
<td></td>
</tr>
<tr>
<td>Grafton 2001</td>
<td>6</td>
<td>20 hours</td>
<td>0.25 m high</td>
</tr>
<tr>
<td>2009</td>
<td>4</td>
<td>27 hours</td>
<td>0.4 m high</td>
</tr>
<tr>
<td>Bellingen 2001</td>
<td>9</td>
<td>6.5 hours</td>
<td>0.1 m high</td>
</tr>
<tr>
<td>2009</td>
<td>5</td>
<td>11.5 hours</td>
<td>0.02 m high</td>
</tr>
</tbody>
</table>

Table 1 – Flood Warning Performance Comparisons 2001 and 2009 Floods

There was some public debate over the 2009 Grafton forecast being too high. To provide the SES with the required 24 hours notice of major flood peaks this forecast was made during the
evolution of the flood when heavy rain was still falling and there was still a fair degree of uncertainty over future rain and catchment runoff rates. While the Bureau aims to have its predictions as accurate as possible, its overriding concern is to provide the SES and community with the earliest possible notice of major flooding that may involve evacuation.

**THE FUTURE**

Benchmarking against international services, the Bureau of Meteorology is well placed to provide high quality flood warning services. A single agency containing both operational meteorologists and hydrologists allows for very close working relationships to be developed and consistent messages to be transmitted to the SES and community.

As the Bureau embarks on the installation of a new weather forecast system in 2010, new capabilities arise that will allow more information to be supplied to hydrologists, the general public, emergency services, government agencies and private industry. This opens new opportunities for mitigating the damage from flooding but also requires careful consideration of the way new information can be provided.

This coupled with advancements in the way radar data is linked to computer models heralds new opportunities for both the Bureau and all users of rainfall data. Additional and higher quality real-time rain and river data is also coming online as the result of the Bureau’s Modernisation and Extension of Hydrologic Monitoring Systems Program.

Further research is being undertaken by the Bureau to advance the use of these improved rainfall forecasts in hydrological modelling. The Bureau is also looking to upgrade its hydrological modelling platform.

The challenge remains to provide useful information in a timely fashion while remaining nimble enough to provide real-time updates as the weather unfolds. The Bureau’s focus will remain on delivering high quality and flexible services and continuing to build our relationships with emergency services.

**CONCLUSION**

The May 2009 floods saw the combination of meteorological and hydrological forecasts used to provide the SES and public with warnings that were issued well in advance of major flooding. With these longer warning lead times, the SES was able to effectively mobilise their resources to assist the affected communities.

**TAKE HOME MESSAGE**

Be proactive with flood warnings. If it’s for certainty you wait, it’s usually too late.

**REFERENCES**