ADDING VALUE TO BOM FLOOD PREDICTIONS

(WITHOUT MESSING AROUND WITH MODELS)

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Abstract

The Bureau of Meteorology (BoM) currently provides both real-time and predicted flood height information at a limited number of gauge sites within the Hawkesbury-Nepean basin. The task of value adding, where these flood heights are interpreted and transformed into flood information across the catchment, is the responsibility of the SES.

Operational decisions concerning mobilisation, flood warning announcements and evacuation measures are triggered by flood height information at the gauge sites. Currently, flood levels at other locations within the floodplain (e.g. at road crossings or key infrastructure sites) are extrapolated from the gauged heights using simple "rule-of-thumb" relationships. Unfortunately, the quality of these estimates is limited by the small number of available gauges. In addition, the relationships ignore the unique behaviour of each particular flood and do not vary with the size of the event.

This paper discusses a project initiated by the SES to address the constraints identified above. The outcomes include the implementation of operational tools that allow SES staff to transform real-time BoM predictions into a detailed map of flood information across the catchment. The tools are accessible through a range of software commonly used by SES staff including Microsoft Excel. Although relatively simple in their application, the tools utilise the information produced by complex hydraulic models without requiring the end-user to actually run or understand the models themselves. The tools developed provide improved estimates of flood height information across the floodplain that better reflect the unique behaviour of the flood event.

Key Words: Hawkesbury-Nepean, flood intelligence, flood height prediction, hydraulic model

Introduction

Although the responsibilities of the NSW State Emergency Service (SES) have expanded into the broader area of floodplain management, the responsibility for undertaking flood response operations remains a principal function of the SES. The ability to reliably predict flooding behaviour throughout the floodplain during an actual event allows for informed decisions regarding response actions and the management of available resources (Crowe et. al. 2003).

SES flood warning assessments rely on flood intelligence information derived through the collation and interpretation of flood-related data to estimate or anticipate the corresponding flood impacts in the field. In this context, reliable flood intelligence represents a valuable asset that can assist emergency response managers in both real-time operations and forward planning (Pfister & Rutledge, 2002).

For the Hawkesbury-Nepean floodplain in western Sydney, the SES currently employs a number of techniques to provide flood intelligence. The use of real-time and predicted flood height data is a key component of such intelligence. However this type of data is only available at a limited number of locations within the Hawkesbury-Nepean floodplain.

To overcome this constraint, an innovative flood prediction approach was developed as part of a pilot program for the study area. The technique utilises real-time and predicted flood height data in conjunction with existing hydraulic model results to provide corresponding flood predictions throughout the entire floodplain. The basis of the flood prediction approach is outlined in this paper. The implementation of this technique into operational and planning tools for use by SES officers is also presented.

Flood Intelligence for Flood Warning in the Hawkesbury-Nepean Floodplain

Gissing (2004) emphasises the critical importance of reliable flood intelligence in determining an operational response to flood behaviour and in the preparation of appropriate flood warnings (Flood Bulletins) by the SES. In this context, the accurate translation of river gauge heights into corresponding flood impacts can facilitate the preparation of warnings that can better convey the expected significance of a flood (Pfister & Rutledge, 2002a). The potential consequences can then be better appreciated by SES operational staff (in determining operational actions) and members of the local community (in responding to those actions).

The Bureau of Meteorology (BoM) provides real-time rainfall and flood height data at various locations throughout the Hawkesbury-Nepean floodplain. The BoM also provides flood height predictions at several sites including Penrith (Victoria Bridge), North Richmond and Windsor under the NSW State Flood Plan (refer to Figure 1). For areas between these gauges, the SES have to interpolate likely flood levels and estimate potential impacts through the use of flood intelligence information. Traditionally, this type of intelligence (describing the relationships between gauge heights and corresponding flood effects) has been determined on the basis of past historical flooding and from data derived from modelled design events reported by flood studies and related management studies (Pfister & Rutledge, 2002b).

Hence, during an actual flood event this approach effectively sees SES operational staff applying approximate relationships and 'rules of thumb' which may be interpreted differently by individual staff members to determine flood behaviour in the field. Unfortunately, errors can be introduced into the resulting flood level predictions when the behaviour of a large flood varies significantly from the historical and/or design events on which these rules are based. Furthermore, this type of intelligence associates particular flood heights at gauge locations with flood impacts elsewhere in the floodplain that can then trigger certain response actions by SES staff. This can potentially lead to errors as there is no provision to account for different flood gradients that may be caused by different rates of rise during larger floods.

The ability to better transfer the flood height information at the specific gauge sites to other locations throughout the floodplain was identified as being a potential means of addressing the above limitations.

Objectives of the Present Study

In view of the above, the objective of this study was to provide the SES with a robust mapping system that can quickly give operational staff a clear snapshot, at different times during a flood, of the flood levels likely to be experienced along the Hawkesbury-Nepean floodplain. The mapping system would complement and enhance the existing flood intelligence database and provides the means to define flood level predictions based on gauge flood heights in a consistent manner.

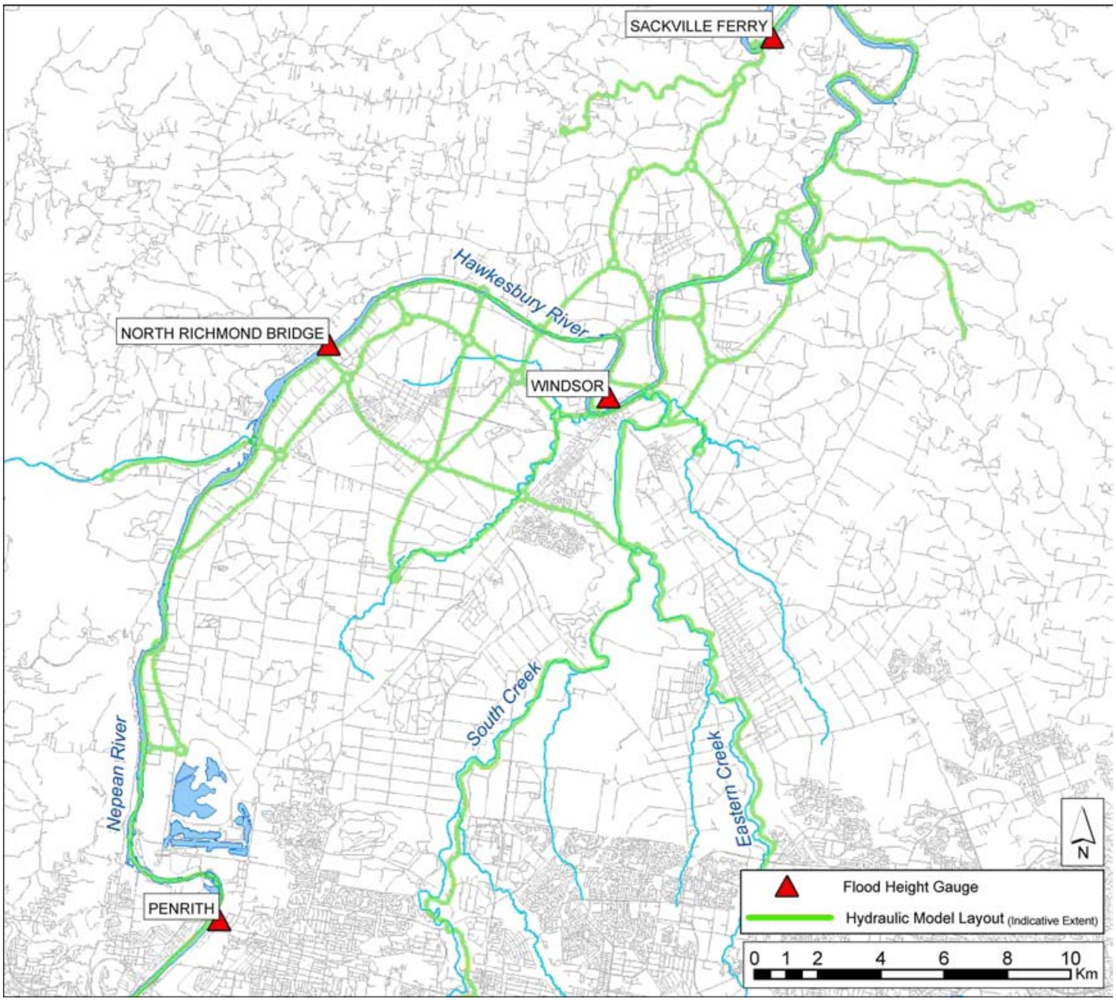

Figure 1: Study Location

To satisfy these objectives, the proposed mapping system would provide:

- an improvement in the accuracy and reliability of flood predictions throughout the floodplain compared to current methods,
- the ability to anticipate the flood behaviour during the rising limb of the event, not just at the peak,
- prediction tools that are easy-to-use, allowing SES staff to interpret the information and trigger the necessary emergency management arrangements,
- flood information that can be readily adapted by SES staff to suit operational and training purposes using standard software packages.

There are numerous ways in which real-time flood behaviour throughout the floodplain could be obtained by SES operational staff during a flood event. However, in the absence of a detailed (and costly) data collection network, the ability to provide real-time flood predictions that meet the objectives above is difficult to achieve. Available methods that could potentially provide this type of information include:

- real-time modelling
- ‘best estimate’ predictions based on pre-prepared model results.

Methodologies that are based on simulated flood behaviour using real-time numerical modelling for this type of catchment would be technically demanding and expensive. The data requirements, technical responsibilities and computational effort associated with real-time numerical modelling effectively precludes this option for most catchments of this complexity. The technical expertise and training required to administer and operate the necessary models would require additional resources within the SES itself.

Alternatively, flood predictions may be based upon real-time comparisons with simulated design flood behaviour. In these cases, flood predictions are made using existing model results where the simulated event having the "closest" peak or rate of rise (or other such variable) compared to the actual flood is assumed to be representative. However, due to a number of underlying assumptions made when synthesising design storms, the design flood behaviour of the catchment can vary significantly from that experienced during an actual flood event.

The complexity and limitations of the various options outlined above meant that no single approach met the primary objectives of the SES. Hence, an alternative approach was devised based on a compromise between the real-time modelling and 'best estimate' comparison techniques. This alternative approach relates the flood height information (at gauged locations) to the model output obtained from an established, sophisticated set of rainfall/runoff and flood routing models (RORB/RUBICON models) of the Hawkesbury-Nepean system (Figure 1). The outputs from these models inherently contain information describing the flood response of the catchment for a range of storm events (whether design, historical or a combination of both). Importantly, this approach allows SES staff to utilise the information produced by complex hydraulic models without requiring the end-user to actually run or understand the models themselves. The underlying basis of the approach is discussed in the following.

General Methodology

The nature of the hydrology, topography and flood response of the Hawkesbury-Nepean floodplain between Penrith and Windsor readily lends itself to a simplified representation for flood prediction purposes. For example, the gauge at Victoria Bridge (Penrith) provides a good representation of the inflows to the Penrith-Windsor floodplain as it:

- drains approximately 90% of the upstream catchment, and
- has a long (120 year) and reliable historical record and a good rating control.

In comparison, the water level gauge at Windsor has a relatively poor rating. However, it does provide a very good indication of the level of storage within the floodplain and the response of this storage to the inflows from Penrith.

In view of this, the alternative approach of flood prediction relies upon the following information:

- the gauge readings at Penrith and Windsor (either actual or predicted), and
- the predicted peak level at Windsor (provided by the BoM).

Using the existing and proven hydrologic and hydraulic models of the Hawkesbury-Nepean system (PWD, 1996), the results for a number of standard design storms were obtained (for flood events ranging from the 10 year ARI event up to and including the 1000 year ARI event). A series of 250 additional design storms having intermediate ARI's were then randomly generated.

The relationships between the standard design storms, the three variables listed above (gauge heights and predicted peak level) and the simulated flood level at other calculation points in the numerical model were then derived using regression based techniques applied to the random storm events. An allowance was also made to account for the gauge readings being in the rising or falling limbs of the flood hydrograph.

The outcome is a stand-alone statistical model that allows the prediction of flood levels throughout the floodplain for a given set of Penrith/Windsor gauge readings and a predicted peak flood level at Windsor. As the model is driven by inputs from Penrith and Windsor, the output can better reflect the unique nature of a particular flood event.

Model Validation

In order to assess the performance of the above method, the ability of the statistical model to replicate both observed flood behaviour and simulated design flood behaviour was examined.

The statistical model was used to estimate the design flood behaviour of the Hawkesbury-Nepean system for several design storm events having magnitudes between the standard design events used to fit the original model. The statistical model was generally able match the RUBICON levels to within 0.10 m to 0.15 m along the rising limb at most locations along the main river channel.

These favourable comparisons are not unexpected as the test storms use the same spatial and temporal rainfall patterns. However, observed flood events can exhibit storm patterns that are markedly different to those used to generate design storms. The ability of the model to reproduce observed flood behaviour therefore offers a good independent assessment of overall model performance.

Using observed levels at Windsor and Penrith, the model predictions were compared to recorded flood heights at North Richmond for a number of flood events. An example of the model results for the March 1978 event is shown in Figure 2. For the key portions of the hydrograph, the comparisons indicate that the absolute error in the predictions was typically in the order of 0.3m to 0.4m. The predicted levels at North Richmond were found to be consistently higher than the corresponding observed levels.

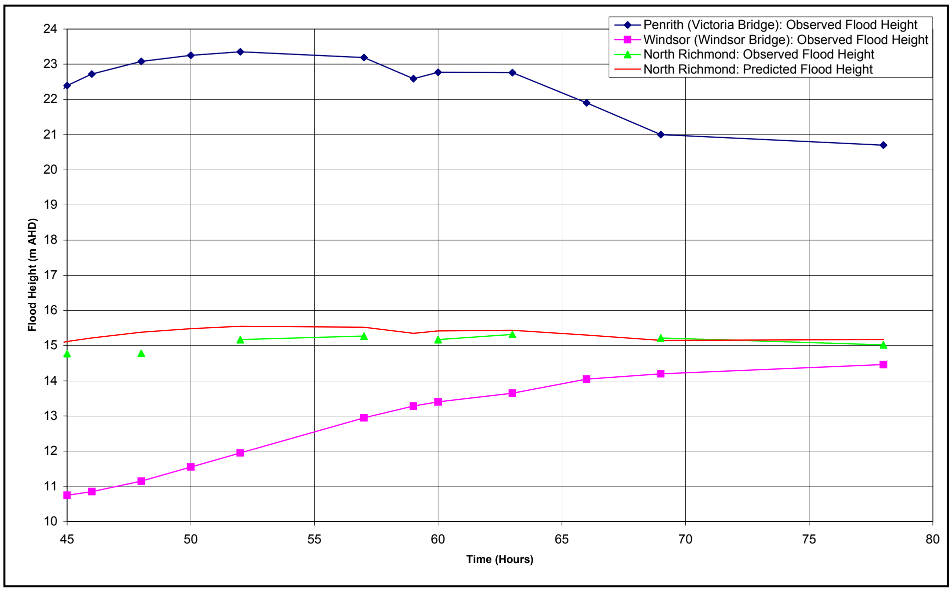

Figure 2: Comparison of Model Performance – March 1978 Event

As expected, the model performance for locations outside of the interpolation domain between Windsor and Penrith showed poorer comparisons. For some tributaries, similarly poor comparisons were also noted. However, these trends are more likely due to the lack of a distinct correlation between the flood level in the tributary and corresponding flood levels at both Penrith and Windsor.

Current Implementation

A pilot version of the flood prediction model has been written using Visual Basic within Microsoft Excel. This approach allows the software to be easily distributed and operated by SES personnel in a familiar, user-friendly system. The software has been structured to facilitate integration by SES staff with other Windows based (COM compliant) software as required in the future. Presently, the outputs from the statistical model are being integrated into the SES GIS system to facilitate mapping of predicted flood levels and inundation extents.

During an actual flood operation, SES staff would be required to input some basic data such as the gauge heights for the Penrith and Windsor gauges (as forecasted by the BoM or actual readings). These values are currently entered via a user-friendly interface that has been implemented in Microsoft Excel (Figure 3).

The output provided by the software provides two main types of flood information for each run:

- predicted flood heights valid at the time of the actual or forecast input gauge heights, and
- predicted peak flood heights at these locations.

This information is produced at locations corresponding to the grid points used in the hydraulic model of the Hawkesbury-Nepean system downstream of Warragamba Dam. The current version of the software displays the output in various formats including:

- A table showing the input parameters used for the listed predictions.
- A summary table indicating predicted flood information at key locations.
- A detailed table containing flood predictions at each gridpoint in the system.

An example is shown in Figure 4. Future extensions to the current version can readily be implemented subject to the particular requirements of the SES. For example, a table showing key infrastructure (roads, bridges etc.) and the predicted level of inundation at these locations could also be provided.

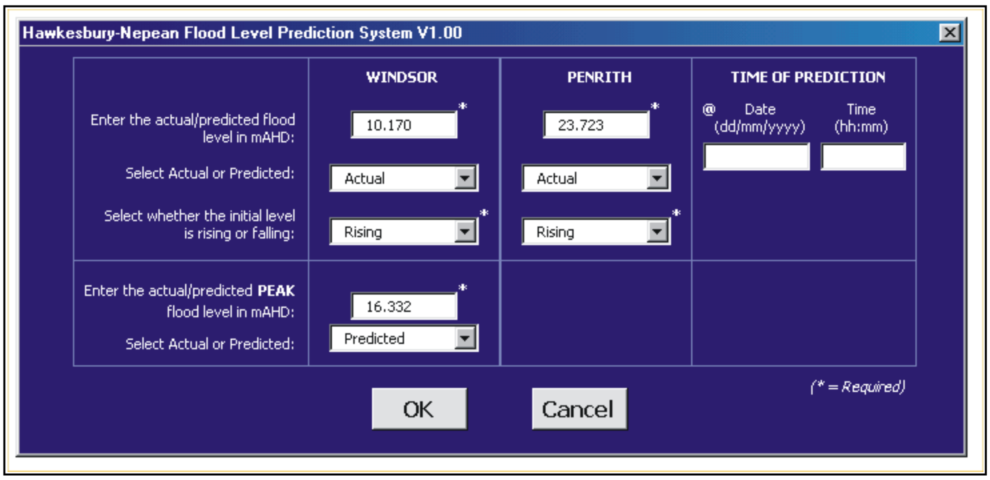

Figure 3: User Interface for Flood Prediction System

Pred 28-04-2003 091407

Hawkesbury-Nepean Flood Prediction System

INPUT DATA:

	Flood Level (mAHD)	Actual or Predicted	Date	Time
Windsor	10.2	Actual	28/04/2003	09:14:07
Penrith	23.7	Actual	28/04/2003	09:14:07

Peak at Windsor	16.3

Prediction Based on Rising Limb Estimates

FLOOD PREDICTIONS: KEY SUMMARY

River	Location	Predicted Level @ 28/04/2003 09:14:07 (m AHD)	Predicted Peak Flood Level (m AHD)	Gauge Level (m)
Nepean River				
	Victoria Bridge	23.7	25.4	*Heights (mAHD)*
	Penrith Weir	22.9	24.6	*converted*
	Penrith Lakes	22.6	24.5	*to gauge heights*
	Jacksons Lane	21.2	23.3	*in this column*
	Devlins Road	17.9	19.5	
Hawkesbury River	Yarramundi	16.6	17.7	
	North Richmond	15.5	16.8	
	Freemans Reach	12.4	16.4	
	Argyle	11.3	16.4	
	Windsor Bridge	10.2	16.3	
	South Creek	10.0	16.3	
Additional Sites	TBA			
	TBA			

FLOOD PREDICTIONS: ALL LOCATIONS

Location	Predicted Level @ 28/04/2003 09:14:07 (m AHD)	Predicted Peak Flood Level (m AHD)	MGA Easting (m)	MGA Northing (m)
PORTAL1	28.0	29.9	281535	6259037
F4BRIDGE	25.5	27.1	283496	6261477
REGENT3	25.2	26.9	283163	6262369
PANTHERS1	24.6	26.3	283669	6263084
REGATTA1	24.1	25.7	285035	6263118
VICTORIA	23.7	25.4	285713	6263475
DSVICBR	23.7	25.3	285706	6263798
PENRITHWR	22.9	24.6	284642	6264015
BELOWWEIR	22.8	24.6	285743	6264150
PEACH1	22.7	24.5	285801	6264414
QUARRY	22.6	24.5	285546	6264896
QUARRYBR1	22.3	24.3	285013	6265138
JACKSONSFD	21.2	23.3	283416	6264135
MCCANNS1	21.1	23.3	283115	6265424
BONNIEVALE	20.9	23.1	281808	6265919
JACKSONSLN	20.5	22.6	282130	6267044
MINNA1	19.5	21.4	283382	6269136
YELLOWROCK	18.8	20.5	282092	6270107
FRAZERSCK	17.9	19.5	282079	6271131
MILLDAM1	18.2	19.9	282889	6272593
DEVLINSRD	17.9	19.5	282941	6274054
RIVERSIDE1	17.0	18.2	283615	6275848
KOORINGAL	16.6	17.7	284772	6276535
SHAWSIS	16.7	17.9	285213	6277968
YMUNDI1	16.6	17.7	286844	6278737
RICHHILL	16.3	17.5	286540	6280323
CLARKESIS	16.3	17.5	286517	6280756
POWERLINES	16.0	17.2	287011	6281332
NTHRICH1	15.5	16.8	288528	6282113
THORNHAMPK	15.4	16.8	288963	6282748
EDWARDS1	14.7	16.5	290498	6284010

Figure 4: Typical Outputs

Future Directions

Based on the results obtained to date, there are several opportunities to build upon the approach described above to further enhance the existing flood intelligence for the Hawkesbury-Nepean floodplain. Potential directions include:

Improvements to the Statistical Model: The introduction of the North Richmond gauge as an additional predictor variable would be expected to improve the quality of the flood predictions. Similarly, the incorporation of additional intermediate design events would improve the accuracy of the original methodology. There is also the potential to allow for corrections for those areas where the model is found to consistently over-estimate/under-estimate flood levels.

Mapping Outputs: Work is currently underway to translate the numerical output of the statistical model into corresponding maps of flood levels and depths across the floodplain. These mapping outputs could then be readily imported into any of the GIS platforms used by the SES.

Portability of Software Engine: In it's current form, the prediction engine is accessed via an Excel spreadsheet. However, the structure of the software is being modified to provide the SES with open access to the software outputs. Ultimately it is anticipated that the prediction engine will be accessible from any COM compliant Windows applications (such as the Microsoft Office suite).

Conclusions

For planning purposes and during flood response operations, the SES currently uses both real-time and predicted flood height information at a limited number of gauge sites within the Hawkesbury-Nepean basin. To complement and enhance existing flood intelligence based on this information, a statistical model has been prepared, that relates the flood heights at Penrith and Windsor to the simulated behaviour throughout a 60km reach of the river system. These relationships have been derived from existing results obtained from sophisticated hydrologic and hydraulic models of the Hawkesbury-Nepean floodplain.

Effectively, the method allows the SES to easily access the pre-existing information produced by complex numerical models in a consistent manner. This information is then used to translate the available flood height information into a representation of the flood surface across the floodplain. The approach has been validated against both historical floods and design events. The performance of the method is considered to be suitable for both planning and operational purposes.

The process of value-adding to available flood height information in this manner provides SES personnel with a consistent and reliable means of anticipating likely flood impacts in the field. The application of the prediction engine itself is relatively simple and the outputs are in a form that can be readily accessed and interpreted by a range of common software packages.

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Author Biography

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Mark is a Director of Webb, McKeown & Associates with over 15 years experience in flood, floodplain and stormwater management studies. Mark is currently a Sydney Division representative of Engineers Australia National Committee on Water Engineering which is overseeing the review of Australian Rainfall and Runoff. He is a past Chair of the Sydney Division of the Water Panel, and was Chair of the most recent Hydrology and Water Resources Symposium organising committee. Mark specialises in runoff routing modelling and has considerable experience in hydrologic investigations involving flood frequency and joint probability analyses.

He has been project manager for several major studies for the Hawkesbury River Floodplain for Sydney Catchment Authority, and more recently, for the Hawkesbury-Nepean Flood Management Advisory Committee.

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Steve Opper has 28 years experience in emergency management, and for the last 16 years he has been as a full time officer of the NSW SES and has worked as an Executive Officer for the Southern Highlands and Lachlan Divisions, as the State Equipment Manager, as a Planning and Research Officer and as the State Planning Coordinator in which he managed the Hawkesbury-Nepean project within the SES. He is currently the Director of Emergency Risk Management and supervises the SES's planning, risk management, community education and public information processes. He has been involved in the management of floods at the local field level, and in both regional and state operation centres. He holds the Disaster Services Administration Certificate from Emergency Management Australia (EMA) and has completed a number of specific emergency management training courses offered by that organisation (EMA). Steve also holds a Graduate Certificate in Applied Management from the Australian Institute of Police Management and has been awarded the National Medal for emergency service to the community.

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Peter Cinque is a senior regional manager in the SES and has prime responsibility for ensuring that the SES is ready for flooding in the Hawkesbury-Nepean River valley. This valley has possibly Australia's most serious flood threat in terms of the potential numbers of people having to evacuate and the volume of damage which severe flooding can generate.

Peter has over 30 years experience as both a volunteer member and staff member of the SES.

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