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# The Use of Rainfall Information in Dam Operations: Uncertainty or Ignorance?

## This Issue





The Queensland Floods Commission of Inquiry into the 2010/2011 flood events released its interim report on 1st August 2011. The report examines a range of issues relating to flood preparedness, including a review of the operation of the dams during flood events. This involved an appraisal of the tools and methods used in forecasting reservoir levels. Here, we draw attention to the key observation that dam operators chose to ignore rainfall forecasts from the Bureau of Meteorology on the grounds that this information was uncertain. Instead they chose to model dam levels on the basis of information that was certain – to be wrong. But first some background and context.

Until recently SunWater Limited, a government-owned bulk water infrastructure developer, has run the flood operations centre for Wivenhoe and Somerset dams on behalf of Seqwater, the statutory authority responsible for bulk water supply to south-east Queensland and owner of the two dams. During a flood event the dam operators control outflows from the dams with reference to a well-documented procedure manual (Manual of Operational Procedures for Flood Mitigation at Wivenhoe Dam and Somerset Dam, Revision 7, November 2009 ("the Operations Manual") - http://resources.news.com.au/files/2011/01/20/1225992/005512-110121-dam-manual.pdf.)

This document lists the objectives of the operation of the dams, in descending order of importance, as

1. Ensure the structural safety of the dams
2. Provide optimum protection of urbanised areas from inundation
3. Minimise disruption to rural life in the valleys of the Brisbane and Stanley Rivers
4. Retain the storage at Full Supply Level at the conclusion of the Flood Event
5. Minimise impacts to riparian flora and fauna during the drain down phase of the flood.

Apart from the obvious overriding objective of ensuring the structural integrity of the dam itself, it can be seen that the dam is expected to serve two contradictory functions. On the one hand it serves as a buffer against drought (and Queensland has been in drought for most of the past 10 years), meaning that it is desirable to keep the dam as full as possible in case future rainfall is low, i.e. at Full Supply Level (Objective 4). On the other hand, the dam was specifically built in the aftermath of the 1974 Brisbane floods to provide a buffer against future floods, meaning that it is desirable to keep it as empty as possible to serve as a storage for flood waters in case of heavy rainfall in the upper catchments of the river (Objectives 2, 3 and 5). Since keeping the dam full and empty are not simultaneously possible, SunWater's engineers had the task of balancing these conflicting objectives.

According to Phil Cummins, a Deputy Commissioner in the Queensland Floods Commission of Inquiry, such ambuguity is true of many locations around the world (The Australian, 19 January 2011) and indeed, in June of this year, in a situation that closely mimics that of the Wivenhoe dam scenario, engineers in the USA were forced to ramp up release rates from dams on the Missouri River in order to create storage space for water from heavy rain and melting snow. These emergency releases flooded communities along a 2,700 km stretch of the river, prompting accusations of mismanagement. In their response the Army Corps of Engineers blamed a set of conflicting congressional mandates and pressure from political leaders up and down the river to manage the water for special interests including recreational boaters, environmentalists and the energy industry (Great Plains Examiner, Bismark-Medan, North Dakota).

In the case of the Wivenhoe Dam, this balancing act has been automated to some extent through the specification of four main Strategies (and several sub strategies) for water releases, depending on the predicted reservoir level. For each Strategy the Operations Manual lists the maximum release rate for the predicted reservoir level, subject to certain other constraints, including downstream river heights and downstream river flow rates.

Indeed according to the Operations Manual, no minimum release is prescribed for any strategy and a zero release would seemingly have been acceptable.

The current revision of the Operations Manual - Revision 7 dated November 2009 - allows the selection of release strategy to be based on the predicted water levels in the dam (based on all available information), whereas the previous revision used actual water levels. This would mean that during an event where the dam levels are rising a particular operating strategy would normally be selected earlier under the current revision than would have been the case formerly. This arises because real time flood modeling based on forecast rainfall will predict a higher dam level when inflows actually reach the dam.

In any event, predicted reservoir levels depend on expected water inflows into the dam, and that expectation would be based almost entirely upon the rainfall forecast for the catchment area. The Bureau of Meteorology supplies regular 24-hour forecasts of rainfall, and the operators also had access to the Bureau's weather radar, even though the Bureau cautions that in some circumstances the radar can produce poor estimates, either over- or underestimating actual rainfall. Furthermore, there are far fewer rain gauges in the catchment immediately above the Wivenhoe Dam than in other areas, which means that rainfall in that area was not well recorded.

Thus Seqwater claim that there were gaps in the information available on which operational decisions had to be made. This is despite Seqwater having the best rain/runoff gauge of all  - the dam itself!

A 2001 Seqwater report (Feasibility of Making Pre-releases from SEQWC Reservoirs) concluded that the precipitation forecasts were not sufficiently reliable to form the basis of operational decision making for the dam. Thus this less-than-perfect available information was given zero weight, and not used at all to help predict reservoir levels. Effectively a "forecast" of zero rainfall was used to inform decisions about water release strategies. In other words, under the circumstances, it seems that the operators chose a scenario guaranteed to be wrong over a forecast that was likely to be uncertain.

But could incomplete or uncertain forecasts of rainfall prove useful in such complex decision making situations?  Using incomplete information for making decisions is actually quite common.  Handling uncertainty by representing the process as a random variable with the likelihood of outcome given by an associated probability distribution would at least allow the operators to incorporate what is known about future rainfall into the decision process. And indeed the geostatistical technique of kriging is used to interpolate the value of a random variable or field at an unobserved location from observations of its value at nearby locations – a technique that would seem appropriate in the Wivenhoe rainfall problem.

So what could have been a matter of *decision making under uncertainty* (i.e. based on incomplete or sub-optimal information) was replaced by one of *decision making under ignorance*, where it is assumed that nothing is known about the process to even attempt to quantify the risk. This is patently absurd.

Figure 1 compares the forecast and actual rainfall intensities for the Wivenhoe Dam area for the first half of January 2011. Rainfall forecasts corresponded reasonably well with actual average rainfall recorded up until 8th January 2011. Over the next two days the 24-hour forecasts significantly underestimated the average rainfall subsequently recorded as falling in the catchment. On 11th January the situation reversed: the forecast was almost double that actually recorded. Thus extremely heavy rainfall was correctly predicted around the time of the flood, but the intensity of the main peak was underestimated, and its timing was off by around 48 hours.

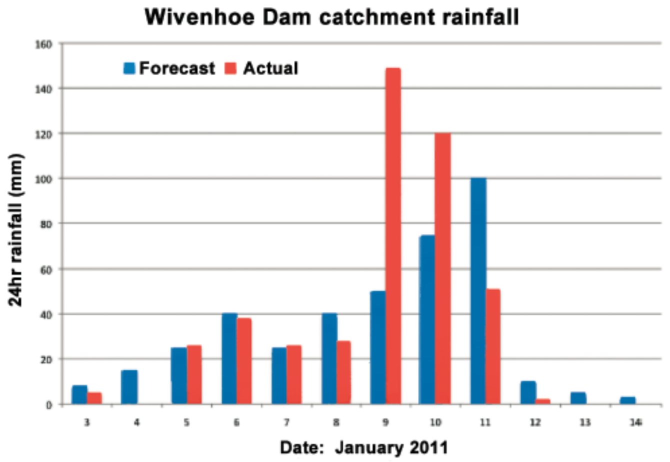


*Figure 1: Forecast and actual rainfall intensities in the Wivenhoe catchment, January 2011. Source: Nicholl, N. (2011). Weather & climate prediction and the Brisbane January 2011 Flood. Presentation at the IUGG 2011 Conference, Melbourne, June-July 2011.*

The operators use a computer-based modeling tool, the real time flood model, to provide predictions of the reservoir water level. In fact two levels are generated: a 'with forecast' prediction (i.e. incorporating the Bureau's rainfall forecasts), which is tracked in a blue line in Figure 2 (this chart is the one modeled at 8 pm on 9 January 2011), and a 'without forecast' prediction (i.e. assuming zero rainfall), which is tracked as the red line. This chart shows, for the first time, the model's 'with forecast' prediction suggesting that the level of the lake would exceed 74.0 m, the tipping point for moving to a strategy where the primary consideration is the protection of the dam. This strategy, according to the manual, has no upper limit on the maximum release rate of water from the dam. But the red line, the 'without forecast' prediction remains well below the 74.0 m mark, meaning that a completely different strategy was followed. By neglecting to use all the available information (however incomplete) available to them the dam operators made sub-optimal decisions.

Risk Frontiers' submission to the Commission includes a discussion on the use of uncertain data in decision making around the operation of the dam. Specifically, we suggested that decisions in the face of uncertainty be based on a probabilistic approach, which could be tested and implemented using Monte Carlo simulation or stochastic modeling. We also advocated taking account of variability in spatial and temporal (as in Figure 1) patterns of rainfall forecasts, as well as improving the accuracy of forecasts as more information becomes available. The latter process is known as iterative "Bayesian updating". Finally we suggested that all this information, including the inherent uncertainty that it carries with it, be used as input into a hydrological model to determine the relative rate of reservoir level rise, and the associated impacts of various water release rates on downstream flow heights. This, we believe, could prove vital to reassessing appropriate dam operating strategies.

The Commission agrees with our view and suggested (Recommendation 2.12) that the design hydrology be reviewed. In particular, it recommends:

- using a stochastic or Monte Carlo or probabilistic approach
- taking into account observed variability in temporal and spatial patterns of rainfall, and
- taking into account observed variability in relative timings of inflows from the dams and downstream tributaries.

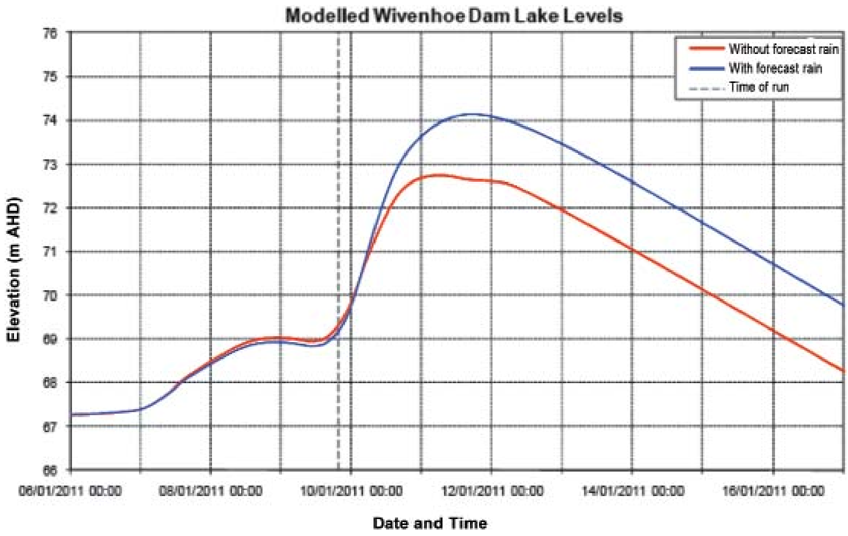


*Figure 2: Modeled Wivenhoe dam lake levels – 8 pm on 9 January 2011. Source: Queensland Floods Commission of Inquiry Interim Report (August 2011) http://www.floodcommission.qld.gov.au/__data/assets/pdf_file/0008/8783/QFCI-Interim-Report-Chapter-2-Dams.pdf page 56*

**For futher information contact:** Dr Rob van den Honert. Email: rob.vandenhonert@mq.edu.au

# Risk Frontiers' Response to the National Disaster Insurance Review (NDIR)

The National Disaster Insurance Review (NDIR) was initiated following widespread flooding in many parts of Queensland and Victoria in late 2010 and early 2011. It is concerned with the availability and affordability of insurance in respect of riverine flood. Our submission written at the request of the NDIR Panel is limited to only a few of the many questions raised in the Issues Paper.

Underlying our response is the belief that the problem with which the Review has been charged is poorly framed. The fundamental question that needs to be addressed is not the insurability of flood risk but how best to deal with the legacy of poor land-use planning decisions that has left some home owners in locations now designated as flood prone. How to reduce this exposure should be the explicit policy objective.

In short, we are uncertain as to whether government intervention in the private insurance market is warranted and thus, rather than propose a possible structure of a Flood Insurance Pool (FIP) or its financing, we suggest necessary attributes of any such scheme for it to be workable. We also pose some problems that need to be resolved before implementing such a scheme. We reproduce these key concerns here:

1. To the degree that insurance can be a partial solution to the land-use planning problem, we concur with the NDIR Panel in advocating risk-based premiums: unless there is a market signal that clearly acknowledges the real risk – however this be funded – there will be little incentive on the part of home owners or various levels of government to encourage mitigation practices and reduce the overall level of risk.
2. Insurance should be seen as a means of risk transfer; it is not a substitute for risk management. And so any proposal for a FIP taken up by government must over time act to reduce the numbers of homes at risk to flooding. There must be a mechanism in place to remove or retrofit flooded homes in order to reduce vulnerability to future floods.
3. We draw attention to the absence of a simple solution to defining eligibility for a FIP. In the parlance of the NDIR Issues Paper, an *engineering threshold*, that depends on a simple metric such as the extent of flooding for a given Average Recurrence Interval (e.g. the 1 in 100 year flood) will not work as it deals only with the frequency of flooding at ground level and is not a true measure of risk. We return to this point in later discussion.
4. A *price threshold*, based on the non-flood premium also seems problematic, but a flood-risk premium based on a modelled loss, for example, using Risk Frontiers' proprietary FloodAUS loss model, which is already being used by insurers and reinsurers to price flood risk, may be feasible.
5. Notwithstanding points 3 and 4 above, there will exist a boundary within which most insurers will want to avoid doing business. We suggest that the National Flood Information Database and FloodAUS together as suitable tools for determining this *threshold of materiality*.
6. One way to avoid poor outcomes is to make any FIP a minimalist programme that encourages homeowners to buy further insurance from the private market and provides opportunities for insurers to provide such cover. Possible ways of achieving a desirable degree of parsimony are to have high, but not unaffordable, rates, high deductibles and low total, first tranche cover analogous to the $100,000 limit used by the Earthquake Commission in New Zealand. Other ways are to include coverage restrictions, such as no additional living

expense, sub-limits (or no cover) for food spoilage, etc.

7. Any Pool introduced will need to create a mechanism for funding large losses or deficits that may arise in particular years on particular catchments – Brisbane, Northern New South Wales or the Hawkesbury-Nepean – or large losses in successive years. Funding this deficit should have a pre-determined priority ranking that includes contributions from those within the pool, local councils, insurers and Federal government. For very large losses, a bond issue by the FIP might be necessary to amortise large payments or a succession of large payouts over several years.
8. In our view, local councils must share in these costs in order to incentivise risk-informed land-use planning practices.
9. There needs to be a shared responsibility on the part of home-owners and the various levels of government to reduce the risk. Incentives need to be aligned. Providing recovery grants following a disaster, as is the current policy, maintains the status quo and only increases the risks.
10. The above conditions will render irrelevant the artificial distinction between damage due to flash flooding and riverine flood.

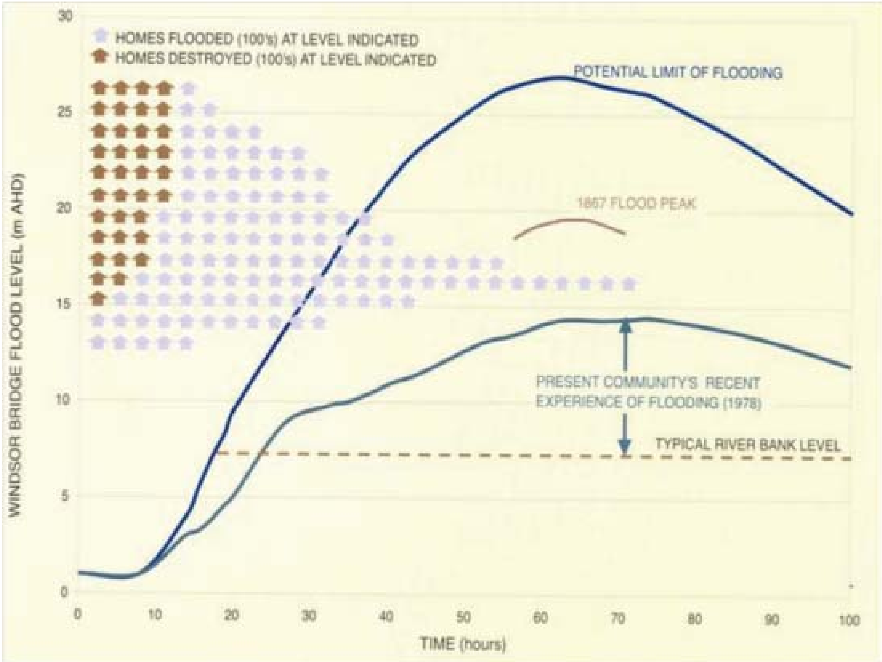


*Figure 1: Figure taken from a 1997 study for the Hawkesbury-Nepean Flood Management Advisory Committee[1].*

Some catchments pose particular risks. As has been pointed out already, the 1-in-100 year flood extent (or that of any other Average Recurrence Interval (ARI)) is not a measure of risk but of the frequency of flooding. It says nothing about likely damage that is primarily a function of water depth above floor level or how this will vary for other flood scenarios. What will happen in smaller or bigger floods? An insurer needs to know this in order to rate risks properly, a fact often ignored by local councils.

It is not sensible to compare the risk for increasing water depths beyond the notional 1-in-100 year flood extent for the Hawkesbury-Nepean, say, with many other inland river catchments. For the latter, the difference in water depth between the 1-in-100 year flood and the maximum possible flood (the PMF may be less than 1 meter; in the case of the Hawkesbury-Nepean, it is 9 m!) Figure 1 shows how numbers of properties at risk in that catchment increase for small changes in flood level.

There has been considerable recent development and in-fill housing in this area since 1997.

Unfortunately many Local Councils, particularly in Queensland, and notwithstanding the fact that flood modelling studies have been paid for by public monies, consider divulging flood information not to be in their interests. As we have seen, Mother Nature has little respect for the sensibilities of Councillors and the next flood will reveal the exposure. Flood mapping needs to be widely disseminated.

Lastly, we draw attention to the fact that while an individual homeowner is naturally concerned about the risk to his or her home, an insurer or reinsurer has to deal with the totality of losses that may encompass entire communities over several different catchments. Correlated flooding on multiple catchments need to be considered. In other words, assessing riverine flood risks is not a simple actuarial problem, it requires knowledge of the hazard.

[1] Achieving a Hawkesbury-Nepean Floodplain Management Strategy, 1997. A report prepared by the Hawkesbury-Nepean Flood Management Committee.

**For more information contact:** John McAneney
Email: john.mcaneney@mq.edu.au

Risk Frontiers' full report is available at www.riskfrontiers.com


## Risk Frontiers' Seminar Series 2011 - Provisional Programme:

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  Kevin Roche
- *Recent earthquakes: what does this mean for Probabilistic Seismic Hazard Assessment*
  Paul Somerville
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  Brain Ashe
- *Global Food Security*
  Rade Musulin


**Risk Frontiers, Dept of Environment & Geography, Room 817, Building E7A, Macquarie University,**
**Phone: +61-2-9850 9683 Facsimile: +61-2-9850 9394, Email: riskfrontiers@mq.edu.au Website: www.riskfrontiers.com**