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THE OPTIMISATION STUDY OF THE OPERATION OF WIVENHOE DAM

A REVIEW

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ABSTRACT

The Interim Report of the Queensland Flood Commission of Inquiry (2011) recommended that a full and proper review be conducted of the Wivenhoe Manual for the operation of Wivenhoe Dam in its flood control role. Revision 7 of the Manual had standing during the 2011 flood. A class action is directed at the operation of the Dam and compliance with the Manual. The principal issue of claim appears to be whether to consider the best available rainfall forecast in making decisions about releases from the Dam. This paper evaluates this Optimisation Study, and maps the differences between the operations framework advocated by the Optimisation Study, versus the Manual (Revision 7). Positive outcomes from the Optimisation Study are identified. This mapping, however, identifies that, again, the principal issue is whether or not the best available rainfall forecast should guide the decisions on dam releases. The merits of the framework described by Revision 7 versus the framework advocated by the Optimisation Study (Revision 11) on the forecast rainfall factor are discussed. The paper recommends that further work is required in order to return to the Manual the principles of risk management, vital to dealing with uncertainty during large floods.

Keywords: Flooding; risk; uncertainty; dam operations; rainfall forecasts

INTRODUCTION

A major flood on the Brisbane River in 2011 led to the Queensland Flood Commission of Inquiry (QFCI) into several aspects of flood management in Queensland. The principal technical issue concerned whether or not decisions on flood releases from Wivenhoe Dam should have been based on the best available forecasts of future rainfall upstream of the Dam.

The Manual (then at Revision 7 – Seqwater, 2009) for operating the Dam required that the best available rainfall forecasts should be considered when deciding dam releases. The QFCI (2011; p57) found that this requirement of the Manual had not been followed during the January 2011 flood. Government and consultant scientists and engineers proposed that forecast rainfalls could not be considered as these rainfall forecasts were too uncertain. It was further proposed that the way that the Dam was operated, with zero weight given to rainfall forecasts, produced a flood mitigation result close to optimum. The Manual was revised to remove the requirement to consider the best available rainfall forecast when operating the Dam during large floods.

A critical test for deciding this issue was to conduct a model run of what would have happened if the Manual (Revision 7) had been complied with, by using the best available rainfall forecast in making Dam release decisions. This was not attempted by the QFCI, but this insufficiency in the studies completed by the QFCI was covered by specific recommendations from the QFCI that a future technical review be conducted.

Figure 1. Brisbane, Wivenhoe Dam and Somerset Dam

This review was to pay particular attention to:

- The definition of what the 'best forecast rainfall' means;
- How forecast rainfall information is to be used by the flood operations, and how ensemble forecasts can be incorporated into decision-making; and,
- An assessment of the reliability of 24-hour, three-day and five-day rainfall forecasts.

The DEWS (2014) Wivenhoe and Somerset Dam Optimisation Study (WSDOS) was the technical review undertaken in accordance with the relevant recommendations of the QFCI. A diagram of the relevant sites is given at Figure 1.

This paper maps the considerations made by WSDOS in its technical review of important aspects of operating a flood control dam, in the circumstance where the dam is subject to overtopping and dambreak during very large floods. An evaluation of the WSDOS is offered.

MATERIAL AND METHODS

This paper emulates a method used by WSDOS, namely, to compare, on one hand, the flood operations regime favoured by WSDOS, and incorporated into the Manual at Revision 11 (Seqwater, 2013), with, on the other hand, the provisions of the Manual Revision 7 (Seqwater, 2009).

Some points of evaluation are offered, directed at the results of those comparisons.

RESULTS AND DISCUSSION

The control of floods through Wivenhoe Dam is representative of the generic challenges posed by gated, combined water supply and flood mitigation structures that are vulnerable to overtopping and dambreak.

The stages of flood control for such structures are at least three in type:

- Within Bank Flooding – damages can arise for the conditions of the banks, for the crops of rural enterprises, and for traffic flows over low level river crossings, for example. Where the forecast rainfall indicates that only minor flooding is expected to eventuate, these damages can be mitigated by absorbing the flood inflow behind the Dam wall, allowing Dam releases that maintain a downstream flood level below the bankfull level;
- Overbank or Floodplain Flooding – here the Dam is operated to mitigate and minimise the flooding of properties and households;
- Overtopping and Dambreak flooding – here the Dam is operated so as to prevent any failure of the dam and the losses to life and property that may be caused by a dambreak wave on downstream communities.
  This phase to the operations of the Dam is often described as 'protecting-the-dam', but, in flood control terms, the phase is directed at preventing the flooding from the dambreak wave that accompanies Dam failure.

Table 1. Comparison of Flood Control Compartments in the Wivenhoe Manual Revisions 7 & 11

Type of Flooding	Revision 7		Revision 11	
	Descriptor	Levels	Descriptor	Levels
Within Bank	W1	< 68.5m	WR	< [FSL+1.5m][1]
Floodplain	W2 & W3	68.5 to 74m	WU	[FSL+1.5m] to74m
Dambreak	W4	> 74m	WS	> 74m (or > 75m[1])

Notes: 1. WSDOS looked at variations of levels, and at rules for changing levels within a single control option, eg, by varying the FSL. This is a difference across the two Revisions

Wivenhoe Dam used flood levels to control when the operations of the Dam were to move from one control regime to another. The volumes between these control levels have herein been termed compartments, which have been given the descriptors shown in Table 1.

Under Revision 7, the W1 compartment below RL 68.5m has the intent not to submerge the bridges downstream of the Dam prematurely. The W2 and W3 strategies operate in the compartment between RL 68.5 and RL 74m, with intents to limit the flow to within non-damaging flows, 3500 cumecs at Lowood and 4000 cumecs at Moggill respectively. W4 is the strategy for which the primary intent switches from flooding effects at downstream locations to the intent of the safety of the dam, while still limiting downstream effects as much as possible.

Under Revision 11, the WR strategy has a release plan focussed on the bridges (as per W1), WU has a release plan focussed on (non-damaging) flood levels at Moggill (as per W3), and WS has a release strategy focussed on the structural safety of the Dam (as per W4).

The primary focus of this evaluation is a comparison of the rules of Revisions 7 & 11 pertaining to the Floodplain Flooding control regime. The comparison includes the rules requiring the operations to enter into this W3 (Revision 7) or WU (Revision 11) regime, and those pertaining to leaving this regime to enter into the W4 (Revision 7) or WS (Revision 11) regimes. The evaluation thus is focused upon the threat of a rising flood, whether that rise is the first or second or even third peak in that flood.

Table 2 lists the 'conditions' (the Revision 7 term) pertaining to the flood control operations within the W3 compartment. Opposite that are listed the 'principles' (the Revision 11 term) embedded into the controls of floods reaching the WU compartment of the Dam storage. Additional material from the respective Revisions of the Manual are added to allow best comparison.

Inspection of the comparisons made in the table show important similarities. For serial 1, there will only be a difference if the FSL is changed from RL 67m as FSL was set with Revision 7. Similarly at serial 2 of the Table, both operational regimes set 4000 cumecs as a desirable flow limit at Moggill but then further allow that limit to be exceeded if necessary. Serials 3 and 4 also provide a primary purpose for W3 (Revision 7) and WU (Revision 11), with a lower priority aim using wordings that are not dissimilar or not dissimilar in effect.

Table 2. Comparison of Conditions (rev 7) and Principles (rev 11 in Wivenhoe Dam Manual

	Strategy W3 from Revision 7		Strategy WU from Revision 11
1	Wivenhoe Storage Level predicted to be between 68.5m and 74m AHD		If Lake Level is >[FSL+1.5m] – MUST change to WU If predicted Lake Level is judged likely to reach [FSL+1.5m] – MAY change to WU
2	Maximum release should not exceed 4000m^3/s		Select a target flow at Moggill that includes Wivenhoe Dam releases. The permitted range for the target flow is between 2000m^3/s and 4000m^3/s, or between 2000m^3/s and the predicted peak of the downstream inflows.
3	The primary consideration is protecting urban areas from inundation		This Strategy focuses on limiting inundation of urban areas while protecting the safety of the Dam.
4	Lower level objectives are still considered when making decisions on water releases. Objectives are always considered in order of importance	**iii** **iv**	While the Lake Level is below FSL+3m, the Release Plan may be adjusted in order to maintain the trafficability (of two nominated bridges). Above this level, releases may only be made with the objective of keeping these bridges open if it is considered that this makes only a minor difference to the release rates chosen. Endeavour to schedule releases to provide reasonable advance warning of bridge closures to Agencies responsible for closure of bridges, and give regard to both community safety and minimising community disruption.
	Notes: **1.** The intent is to limit flow at Moggill to less than the upper limit of non-damaging flows downstream – (stated to be 4000m^3/s flood)	**i**	The Release Plan should aim to maximise releases without exceeding the target flow at Moggill. The permitted range for the target flow is between 2000m^3/s and 4000m^3/s, or between 2000m^3/s and the predicted peak of the downstream inflows.
	2. When this is not possible, the flow at Moggill is to be kept as low as possible	**ii**	If downstream inflows are greater than the target flow, aim to minimise releases in periods when downstream inflows are predicted to exceed the target flow.
	3. The control regime is moved to W4 when: Wivenhoe Storage Level predicted to exceed RL 74.00m		The control regime is moved to WS: If the Predicted Lake Level is judged very likely to reach EL 74m – **MUST change to WS**
	4. When determining dam outflows within all strategies, peak outflow should generally not exceed peak inflow	**v**	Provided the above principles are applied, it is permissible for releases to exceed the predicted peak inflows above Wivenhoe Dam.

WSDOS (s3.2) offers the summary that ***the fundamental operational philosophy of the Flood Manual is not significantly different from what it was in 2011.***

A survey of the differences may indicate if this is a fair summary of the comparison.

A first difference is in the nature and use of predictions. Revision 7 required or allowed decisions to be taken if particular forecasts were made. Revision 7 set out that those forecasts ***are to be made using the best forecast rainfall and streamflow information available at the time*** (p22). This is the case with Revision 7, even where Revision 7 recognises ***the limitations on being able to obtain accurate forecasts of rainfall during flood events*** (p3).

The incorporation into the operations Manual for Wivenhoe of the risk management approach to operations appears to have been one of the measures directed in the mid-2000s at reducing the vulnerability of Wivenhoe Dam to overtopping and dam breach. This reflected initiatives taken in the USA following major floods in western and middle states in 1997, leading to the National Academies' ***'Uncertainty Imperative'*** (NRC, 2006; p14).

As NRC explained, ***there is a confluence of compelling reasons … to transition to a new paradigm for hydrometeorological prediction, one in which uncertainty information is considered an integral and essential component of all forecasts***.

The US had developed the Advance Release methodology - deciding releases on the most probable with allowance for maximum impacts on parties (Faber, 2003) - and Adaptive Management and Anticipatory Engineering (Faber, 2001) - using a three step progressive [1. Decide, 2. Monitor & Update, 3. Adjust (mitigating wrong decisions and false alarms)] decision-making process - for responding to the risks with uncertainty in rainfalls (Schultz et al, 2010; pp40&76). The USACE came from a position of not being allowed by law to use forecast information when operating dams (NRC,2006; p20,36), to new solutions to the 1997 situations that now require the use of Forecast-Based Operations, by law. Archival studies for cases of false alarms with major events have not found any cases, experts opining that the largest events are readily seen coming, and are too large to change quickly (USACE, 2002; pp7-11).

The developments have spread to other countries – such as Canada hydropower industry (Weber et al, 2006 – '*an uncertain forecast is preferable to complete ignorance about future hydrologic events*'), Taiwan flood alerts (Hsiao et al, 2013 – *'almost perfect'* with tracking but '*systematic over-forecasting of rainfalls on windward side*' of mountainous regions), and Australia (GMW, 2011 - the use of *'reliable'* four-day rainfall forecasts for deciding pre-releases from gated-spillway dams in the Murray-Goulburn system).

Extracts in Table 2 from Revision 11 speak of predictions having to be ***'likely'*** or ***'very likely'***. This is different to Revision 7, which requires only the ***best forecast available***, whatever is its likelihood or its accuracy. Figure 2 describes the requirement made by Revision 11 for ***likely*** and ***very likely*** (or more precise) predictions, versus the requirement of Revision 7 for only the best forecast from estimates expected to be inaccurate and unreliable.

WSDOS, in supporting the Revision 11 approach, uses the fact that the rainfall forecasts are inaccurate to dismiss the use of these forecasts until research and / or modelling is able to make more accurate forecasts:

BOM had previously advised Seqwater circa 2006 (QFCoI 2011) and reiterated in 2010 (via email), that their short to medium term (0 to 48hr) prediction of rainfall for the objective use in flood forecasting models had at times considerable error or uncertainty in the prediction of the location, amount and timing of rainfall events at the scale of the Wivenhoe catchment.

… forecast models still cannot be relied upon to capture the development of rainfall events at extended timescales. In particular, the forecast models will have less skill (or accuracy) at the catchment scale relevant to dam operations for higher rainfall intensities.

While forecasts may indicate that a heavy rainfall event is possible, forecasts should only be taken as a guide and cannot be relied upon with any significant certainty (WSDOS 4.1.5.2).

Revision 7, in contrast, has used the fact that the rainfall forecasts are inaccurate to justify the requirement that the best rainfall forecast available be used.

This appears to be a fundamental divergence in philosophy. The WSDOS does not appear to appreciate, and may not have appreciated, this divergence.

A second difference is the use of judgment. The extracts from Revision 11 require that predictions be ***judged likely*** and ***judged very likely*** to achieve trigger criteria. In Revision 7, the forecasts are triggered directly from modelling using the best available rainfall forecast. Both revisions found scope for discretion to be applied, but Revision 7 did not give discretion to use or not use the best available rainfall forecast rationale – Revision 11 is using judgment to determine whether the best available forecast rationale (or another rationale) should be used.

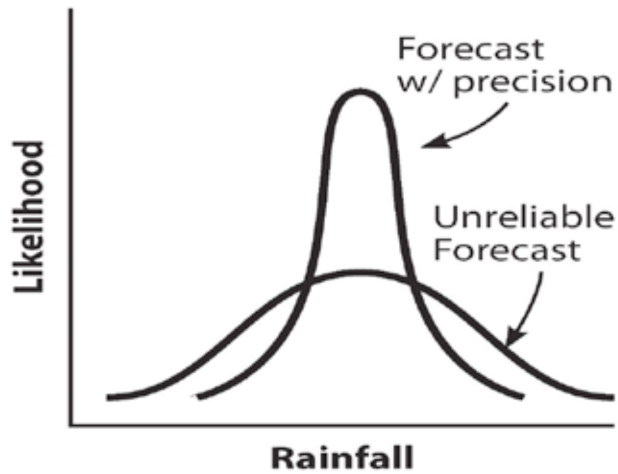


Figure 2. Reliable Accurate Forecast vs an Unreliable, Inaccurate Forecast

WSDOS explains the use of judgment to decide to use rainfall forecasts (WSDOS 4.3).

For accurate hydrologic modelling of flood flows in the Brisbane River, the best estimate of rainfall depth, timing and spatial distribution down to a 5 km grid is required. … this can be problematic using observed rainfall data but the uncertainty is magnified when applying forecast rainfall. Numerical weather prediction models operate on much coarser grids and do not provide the resolution of depth, timing and spatial distribution required for accurate estimates of future flows. It is this area of flood operations that requires the highest degree of professional judgment. Engineers and hydrologists typically liaise with meteorologists from BoM but ultimately, it is the task of the engineer / hydrologist to judge the suitability to apply meteorological forecast rainfalls to the hydrologic models.

A key to explaining the differences in approach between Revisions 7 vs 11 may be the differences in the disciplines from which each Revision of the Manual was derived.

Revision 11, and WSDOS which supports this Revision, come to the issues through the principles of deterministic hydrology. It is against the standards of this discipline to enter uncertain data into a model as the model then can only produce uncertain results. This discipline cannot employ the rainfall forecasts because the forecasts are uncertain. Faced with the advantages and disadvantages of using the rainfall forecasts, disarmed by the absence of any hydrologic method for reliably using the uncertain forecasts, Revision 11 leaves it to the judgment of the operators to decide whether and to what extent, if at all, the rainfall forecasts will be used.

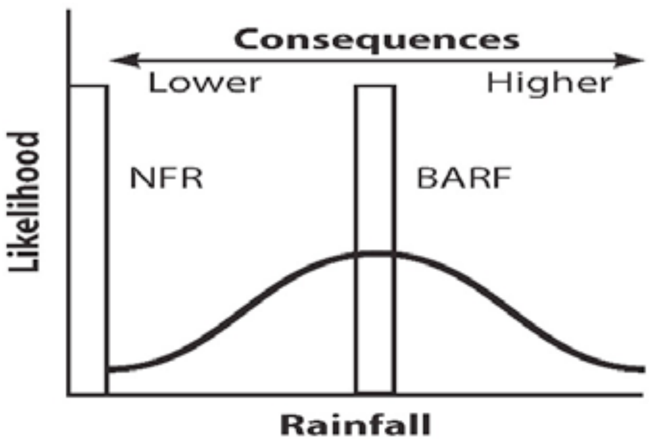


Figure 3. Plots of Advantages and Disadvantages of the DHM rationale versus the RM rationale

Revision 7 also came to the same point using hydrology. But then the analysis to support decision making, in the face of these uncertain rainfall forecasts, is transferred over to the discipline of risk management. Note that Figure 2 incorporates the parameter 'likelihood' in the deterministic analysis. Risk management may be more powerful in analytical and decision-making terms because it uses 'likelihood' in combination with 'consequences' to analyse for a good decision (see top of Figure 3).

Risk Management (RM) provides the methodology with which to best operate within an uncertain environment. In this circumstance, RM advises the practitioner to use three rules - similar to those rules described in Faber (2003) and Schultz et al (2010):

1. Make an original decision based on the forecasts derived from hydrologic modelling that used the best available rainfall forecast (BARF) – 'best' is the most probable rainfall in risk terms, but discretion can be used here;
2. Make some provision for the most dangerous rainfall, that is, deviations of rainfall from the most probable rainfall that would generate greater danger (or consequences, in risk management terminology);
3. Monitor actual rainfalls, continuously, for any deviation from the best rainfall forecast, and amend decisions in response to any such significant discrepancy as well as to any change in the best available rainfall forecast.

Figure 3 may explain the advantages and disadvantages of each approach, the Deterministic Hydrologic Modelling approach (hence DHM) that bars all forecasts of further rainfall, and the Risk Management (RM) approach using the BARF forecast.

Advantage 1:
BARF is more likely to be more Accurate

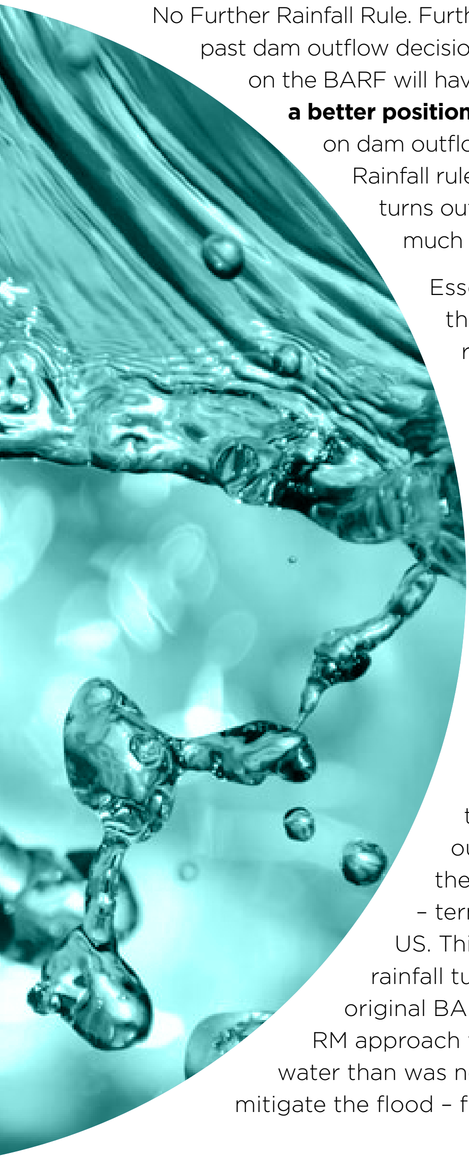
Advantage 2:
BARF is in better position for a Worst Case

Note that the DHM approach, by using predictions based only on actual rainfall recorded to date, is effectively adopting a forecast of No Further Rainfall (NFR) – thus the DHM approach can be plotted on Figure 3 at the zero point (or NFR) on the rainfall forecast axis. Note also that, where any DHM model run is undertaken while it is raining, or when water remains in untipped rainfall buckets at the start of the model run, the probability that the NFR forecast may actually occur is also zero.

Figure 3 supports the following evaluation of the advantages and disadvantages of the RM approach over the DHM approach.

Firstly, whatever the uncertainty of forecasts, RM is using the most probable rainfall forecast. The best available rainfall forecast [BARF] is more probable than the zero rainfall or No Further Rainfall [NFR] rule used in a DHM approach. BARF is also more probable than any forecast made by an operator using professional judgment.

Secondly, the decisions based on the best available rainfall forecast (the most probable forecast) will be in **a better position** than decisions based on the No Further Rainfall rule to adjust dam outflows when the actual rainfall is less than the BARF but closer to the BARF than to the No Further Rainfall Rule. Further, and most importantly, past dam outflow decisions that were made based on the BARF will have placed the operations in **a better position** than past decisions made on dam outflows based on the No Further Rainfall rule, when the actual rainfall turns out to be higher and very much higher than the BARF.



Essentially, decisions based on the RM approach will have released more flow from the dam than decisions based on the DHM approach. Thus there will be more of the flood mitigation compartment still available with which to deal with the forecast runoff from the greater than forecast rainfall.

The disadvantage of the RM's use of the best available rainfall forecast, however, occurs when the actual rainfall turns out to be much less than the original BARF forecast – termed 'false alarms' in the US. This is because, when actual rainfall turns out to be less than the original BARF, decisions based on the RM approach will have released more water than was necessary to control and mitigate the flood – flood heights downstream of the dam will be higher than necessary.

This leads to the third advantage held by the RM approach over the DHM approach.

The third advantage of the RM approach, then, its most important advantage, is that RM's other advantages over the DHM approach are greater where the flooding and the flood damage is greater, and its disadvantages compared with DHM occur where the flooding and the flood damage is relatively less.

WSDOS has shown this third advantage to be the case, and explain this advantage, by empirically studying a large suite of flood situations and passing them all through Wivenhoe Dam. WSDOS, however, may only have done this in a qualitative or indirect fashion, and may have presented the evidence only by accident.

The accident arrived in the results from simulations and modelling of two other flood control practices. These two practices, like the advanced and increased releases from the RM approach based on BARF, would increase the flood storage compartment behind the dam. These practices were:

- Increasing the targeted flow limits downstream at Moggill, and,
- Increasing the flood mitigation compartment behind the wall by reducing the water supply compartment (WR) or the Save-the-Dam compartment (WS).

For the practice of increasing downstream target flows, WSDOS concludes (5.1):

> ***For very large floods, flood mitigation performance can be improved by increasing downstream target flows during flood operations with a view to preserving the flood mitigation storage for longer. This approach carries with it the risk of flooding houses unnecessarily if the expected large flood does not eventuate.***

Regarding the practice of increasing the flood mitigation compartment, WSDOS has based its conclusions on a study reported by Seqwater (2014) (5.2, pp xxvii):

> ***The modelling indicates that any increase in flood storage achieved under the eight alternatives (including the Base Case) based on operations under the 2013 Flood Manual offers little benefit (and may create a dis-benefit) for minor and low end moderate floods but larger potential benefits for high end moderate and major floods. This is because the additional flood storage created in Wivenhoe Dam is not fully utilised (needed) in the smaller floods.***

Summarily, regarding Revision 11, WSDOS states:

Any decision to change the flood operations strategies in the 2013 Flood Manual requires consideration of the trade-offs between flood mitigation, water supply security and disruption caused by bridge submergence and for each location trade-offs between:

- ***Increased flooding from minor and lower end moderate floods, and***
- ***Reduced flooding in high end moderate and major floods***

The decision to revert from the DHM based Revision 11 back to the RM based Revision 7 will have that effect. For any flood that will fully utilise the flood mitigation storage in Wivenhoe Dam, the RM approach will forecast this outcome sooner. Earlier warning allows the RM based operations to affect higher dam releases undertaken much earlier in the flood event. This in turn will tend to empty the flood storage (that is, increase the storage available for the developing flood) more than the DHM approach which will still be regarding the flood as minor or low-moderate.

The empirical study by WSDOS, using a deterministic model from the hydrology discipline, has arrived at the pattern of advantages and disadvantages of the DHM versus the RM approaches to operating flood control dams, by an empirical study of a large number of flood cases. The same pattern to flood outcomes is immediately and directly available from the theoretical constructs in a different discipline, namely, the discipline of Risk Management.

Unfortunately, however, neither the QFCI nor WSDOS may have gone to this Risk Management discipline with the uncertainty-rainfall-forecasts problem. Despite the recommendation of the QFCI that the use of rainfall forecasts be investigated, WSDOS has not carried out this investigation, but has left the ***simulations to test the robustness of relying on rainfall forecasts as suggested in the QFCI Interim Report recommendation 2.13.2*** to ***targeted research*** on ***the potential for advanced or increased releases in response to…imminent flood event rainfall forecasts***. WSDOS also wanted to limit the processes that it developed to ***processes that would be accepted and supported by experts*** (4.1.5.3 and 5.3).

While the first rule of RM – base decisions on the most probable rainfall – may not have attracted reported study during the WSDOS, the second rule has received good attention. The second rule of RM is to make some provision for the worst case. For a flood event at Wivenhoe, the worst case is an event where the actual rainfall becomes significantly greater than the original best available rainfall forecast (BARF).

McMahon (2012) gave an example of such a provision that could be added to the operating rules, namely, of using the bank-full capacity of the Brisbane River as soon as the first indication is received that the flood event may reach RL74.0m behind the Dam. WSDOS terms this provision the Rural Bypass Strategy, and takes the form of a decision to abandon efforts to mitigate low level flooding effects, such as the flooding of rural land and drowning of low level crossings. The effect of the second rule of RM is reduced by the absence of the first rule of the RM approach, which would provide an earlier trigger for the use of the Rural Bypass Strategy.

CONCLUSIONS

The WSDOS appears to be dependent on the capabilities of the discipline of hydrology. This discipline does not have the methodology to deal with the problem of uncertainty for decision-making when controlling a flood through a Dam vulnerable to overtopping and dambreak failure. The discipline for solving the uncertainty problem is the Risk Management discipline.

Revision 11 of the Manual and the DHM rationale appear to be concerned with what to do with inaccurate rainfall forecasts, while Revision 7 and the RM approach quickly accept that the rainfall forecasts are inaccurate, and gets on with the concern of how best to control whatever rainfall actually falls.

In 2009, engineering authorities in the Queensland Government established a Flood Manual for operating Wivenhoe Dam that appears to have been based upon the discipline of Risk Management. This Manual was identified as Revision 7. Current Revisions of the Manual appear to have lost important aspects of the RM approach to dealing with the uncertainty in rainfall forecasts. This loss appears to be due to the failure of the QFCI, and of the WSDOS study recommended by QFCI, to address this issue using the Risk Management discipline, to actually evaluate the RM control regime that may not have been employed during the 2011 flood.

The RM approach may not be recovered by the Wivenhoe Flood Manual until some authority conducts a study that tests what the flood levels in Brisbane would have been if the Revision 7 of the Manual had been followed with respect to the rainfall forecasts provided during the January 2011 Brisbane River flood.

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