Flood Contingency Planning During Construction on Reservoir Embankments

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SYNOPSIS This paper describes work done to provide quantitative assessments of flood risk and flood risk mitigation options during construction works for a number of reservoir embankments operated by United Utilities. Hydraulic modelling using ISIS V3.5 and hydrological analysis using methods from the Flood Estimation Handbook (FEH) (Institute of Hydrology, 1999) were utilised to derive reservoir stage rise profiles for a range of flood events and storm durations. The effectiveness of flood mitigation and emergency response measures was assessed, both as advance works and emergency response measures. A decision tree to inform the site emergency plan was developed; this translates model analyses into a practical site protocol.

INTRODUCTION

In order to comply with current safety guidance the operators of Category A Reservoirs are required ensure that overflow facilities are able to safely pass the probable maximum flood storm event or the 10,000 year flood if overtopping of the embankment is tolerable (ICE 1996). In a number of cases recent inspections of dams belonging to United Utilities under the Reservoirs Act (1975) have shown that the construction of new overflow facilities are required to achieve this standard. In the cases considered, the construction of new spillway arrangements being carried out under AMP5 requires excavation of the embankment, exposing the clay core, which increases the risk that flood water overtopping might compromise embankment stability.

Work was therefore undertaken to:

1. Identify the standard of protection provided by existing overflow facilities.
2. Provide indicative lead times for reservoir stage rise up to spillway activation and embankment overtopping.

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3. Provide case specific preventative actions for mitigation, of which reservoir drawdown is the primary tool.
4. Test the effectiveness of emergency response options.

The United Utilities Impounding Reservoir team have undertaken these analyses for seven reservoirs within the AMP5 framework. An analysis of the most downstream reservoir, in a cascade of four will be presented in this report. That reservoir will be designated “NYB”.

RESERVOIR CASCADE MODELLING

Catchment Hydrology

Catchment parameters were obtained using the FEH CD ROM V3 and refined using GIS inspection with reference to additional data sources including DTM topography, OS mapping, aerial photography, digital soil mapping and site inspection. Specific modification was made to Standard Percentage Runoff and Base Flow Index calculation where Class 4 soil type was identified within the reservoir catchment, as recommended by Davison (2005).

Catchment runoff was modelled for a range of return period rainfall events using the Revitalised Flood Hydrograph (ReFH) model. This method is calibrated for events up to 1:150 years, beyond this the ReFH model hydrographs were scaled to match peak flow provided by the Flood Estimation Handbook Rainfall Runoff Model which is considered to be more appropriate for higher return periods. No sites had a gauged record suitable for the calibration of model parameters and no catchments were suitable for the use of statistical (pooled) maximum flow analysis.

Computational Hydraulic Model

A fully hydrodynamic 1d methodology, using ISIS Software was utilised. Model schematisation comprised reservoir storage units connected by multiple hydraulic structures including; weirs, orifices, gates, scour valves open channels and culvert reaches. Bywash facilities were modelled using a simplified abstraction method, which routes flow, up to a stated bywash capacity, from selected sources using a logic rule system. Bywash capacity was assessed using a separate, standalone models. This method enhanced model convergence and run time in the cascade model with no loss of accuracy.

The hydraulic modelling methodology allowed a fully integrated representation of a reservoir cascade to be modelled. Figure 1 below shows a generic schematisation for a two reservoir cascade. Features unique to each reservoir were integrated into this basic arrangement.

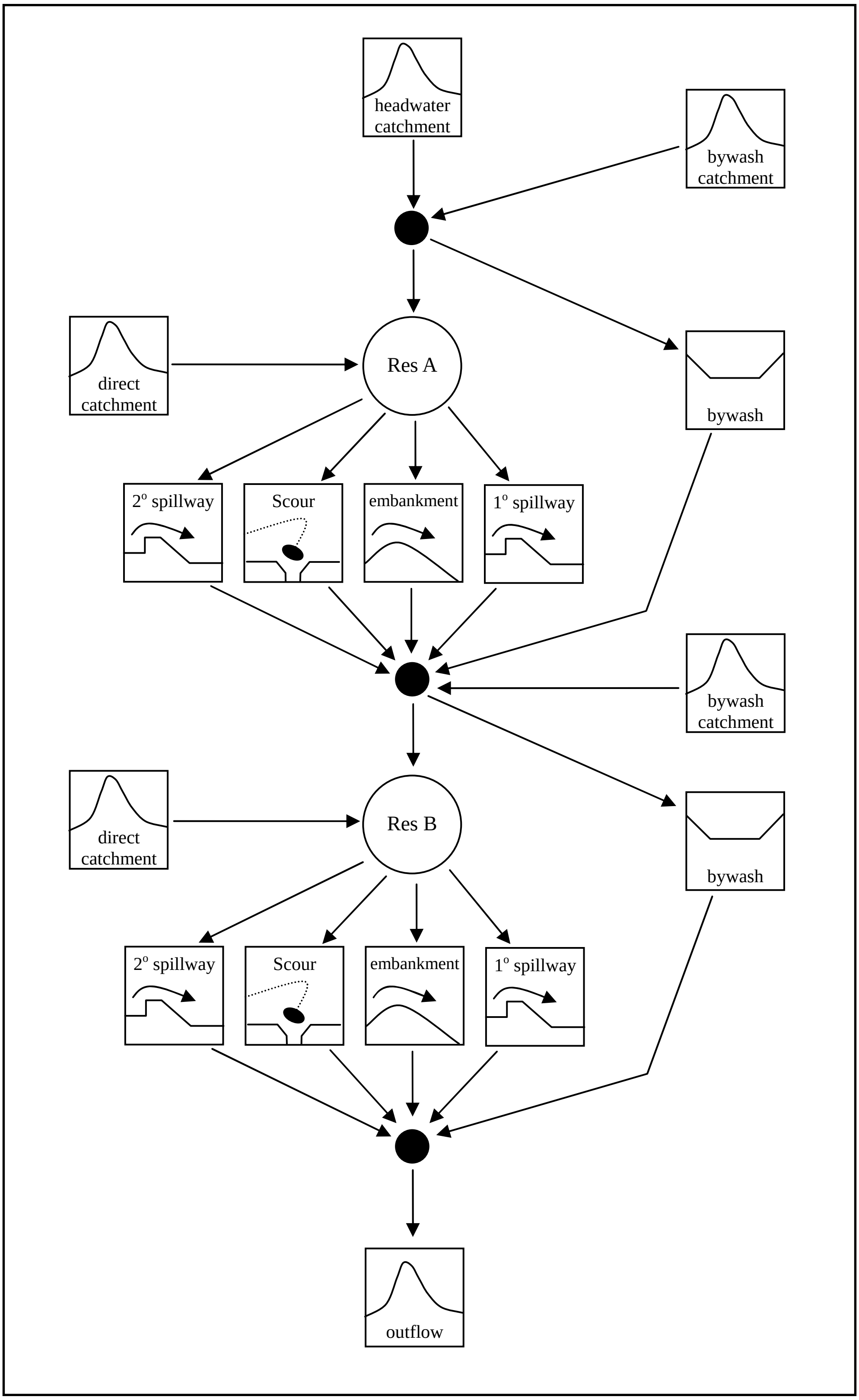

Figure 1. Generic 1d Reservoir model schematisation.

Model input data was based on best the available sources including: topographic and bathymetric survey, LiDAR altimetry, physical model outputs, site inspection and design / as built drawings.

Hades software from MWH was used to validate the model results for key model components and Infoworks CS was used to provide rating curves for any control structures with parameters outside the Isis operational range such as steep culverts.

Model Scenarios

The hydraulic model was used to optimise proposed scenarios for flood risk mitigation.

For all model scenarios under consideration each return period simulation was run using a storm duration optimisation tool. This makes batched model runs for rain storm durations within a defined range using the Brent hill climbing algorithm (Press *et al* 1986). Model diagnostics show stage and flow for each duration at a predetermined location. This allows the critical storm duration, which results in maximum stage or flow, to be established.

Bywash Analysis

Bywash operation was modelled for selected antecedent scenarios including inlet gate setting and structure blockage. These situations were investigated independently and in combination with various drawdown scenarios. However for development of site flood contingency guidance it was shown that bywash fully blocked was the most conservative option, and subsequent drawdown analysis was undertaken under this assumption.

Drawdown Analysis

On the NYB site the following options were considered:

1. NYB Reservoir drawn down 2.5m
2. NYB drawn down 5m
3. NYB drawn down 5m plus upstream reservoir drawn down 2m

This work provided the standard of service afforded by the existing overflow facilities for given a drawdown situation as well as the rate and volume of possible embankment overflow under storm events of greater magnitude than that capacity. Figure 2 shows that standard of protection increases linearly with drawdown of NYB Reservoir, with the maximum drawdown of 5m resulting in an estimated 1:300 year standard of protection. The introduction of drawdown on the reservoir immediately upstream, provided a large increase in standard of protection up to approximately 1:600 years. However the supply cost implications for this scenario were considered excessive and the 5m drawdown on NYB was carried forward as the preferred option. Further mitigation options were therefore seen to be required for the occurrence of storm events above the 1:300 year standard.

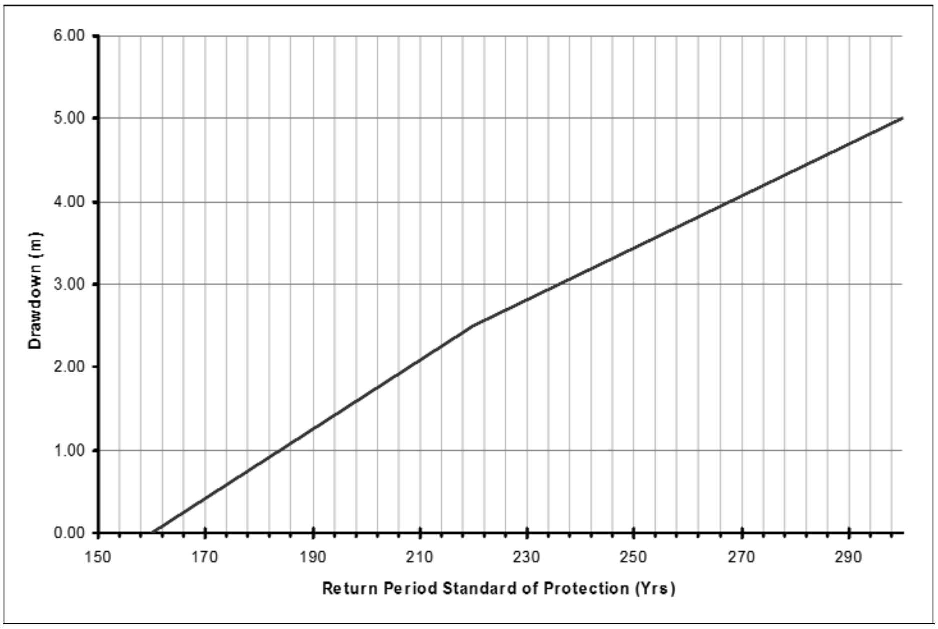

Figure 2. Standard of protection afforded by drawdown at NYB

Weir crest reduction
It was suggested that reduction of the existing spillway weir crest might increase the capacity of that structure and provide enhanced flood safety during construction. Physical modelling analysis (MWH 2008) has identified that the control point on the overflow is in fact found at the access bridge culvert downstream of the weir, so the option resulted in only minor improvement in standard of protection. However it also was noted that the reservoir bywash outfalls into the weir tumble bay. Under bywash active scenarios, modelling showed that reduction of the weir crest in fact caused reverse flow from the tumble bay into the reservoir, and an increase in flood risk. It was however recommended that the action should be retained as a case specific emergency response option, if full blockage of the NYB by-wash is identified during a flood event, then flood risk to the embankment may be mitigated somewhat by an emergency reduction of the existing spillway weir level

Site Alert Status
The preferred option draw down depth was sub divided into four alert phases (green, yellow, amber and red) of equal depth. Appropriate responses were determined for reservoir stage breaching each alert level. These included call outs, emergency drawdown and abstraction, preparation for overflow spillway activation, and preparation for site inundation.

Calculation of Lead times

The modelled reservoir stage hydrograph was analysed to provide the rate of reservoir stage rise from the initial drawn down state, to spillway activation and then embankment overtopping. Storm duration analysis was again applied to determine the storm profile that caused the fastest stage rise response. Figure 3 below shows the stage profiles of critical storm event at NYB Reservoir with alert phases. This plot is typical in that all extreme storm events require the operation of the existing overflow and pose risk to any works therein. However events in the order of 1:300 year rarity cause embankment overtopping and flood risk to the construction works. Contingency is required for this situation which might include management of flow over specific sections of embankment.

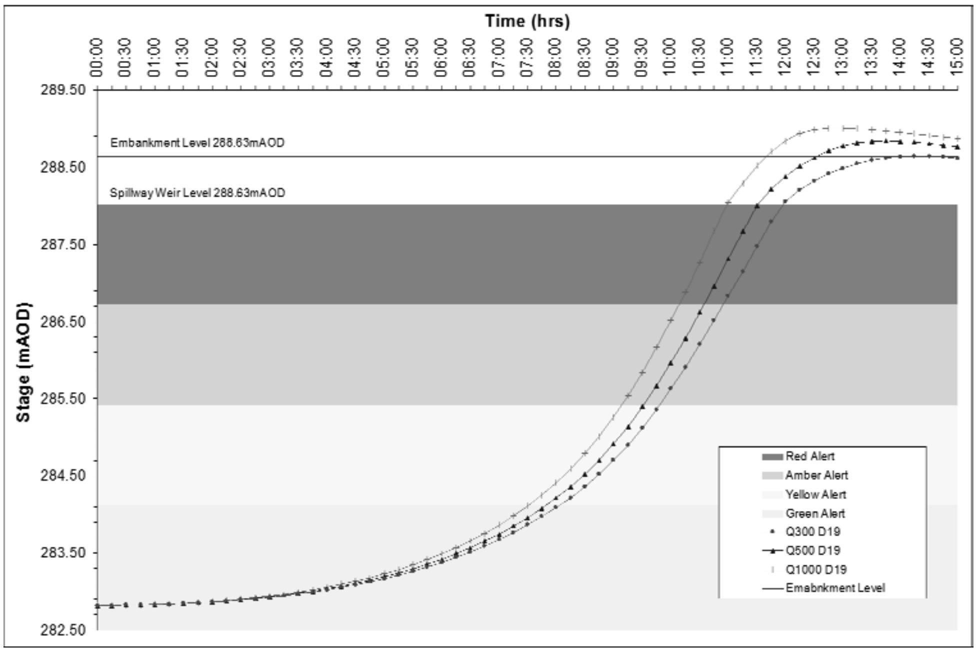

Figure 3. Reservoir stage profile with flood alert phases.

Previous physical modelling analysis (MWH 2008) has also shown that spillway flows in excess of 15m³/s cause capacity of the chute to be exceeded, and surcharge spilling onto the embankment downstream face. This flow rate was occurs at water levels of 288.3mAOD in the reservoir and represents a further. Flood alert threshold beyond those presented in Figure 3. Contingency measures are required to be available to ensure that this surcharge does not have any hazardous interaction with construction works.

Flood lead times for the preferred option are presented in Table 1 below.

But in order to provide a tool that is suitable for use on a construction site, under extreme storm conditions, the reservoir stage hydrograph analysis was developed into a decision tree (Figures 4a and 4b). This is intended to provide a clear template for site flood contingency protocol. The procedure directs site staff to record the time at which reservoir stage moves from green to yellow alert status. Continual monitoring of reservoir level is stipulated in all non green alert situations. By recording the time at which sequential alert phases are reached a rate of rise is established, which can be categorised relative to modelled storm events. This provides an estimated time remaining until spillway activation, and to embankment overtopping by fitting observed stage rise to modelled reservoir stage profiles.

Table 1. Alert thresholds for the NYB reservoir with time remaining until spillway flow under the 5m drawdown scenario.

Alert Status	**Reservoir Level (mAOD)**		**Modelled time to overtopping (hh:mm)**		
	from	**to**	1:1000 yr event	1:500 yr event	1:300 yr event
Embankment Overtopping	288.6	-	-01:05	-01:20	-02:00
Spillway Active	287.8	-	00:00	00:00	00:00
Red	286.6	287.8	00:35	00:45	00:50
Amber	285.3	286.6	01:05	01:20	01:30
Yellow	284.1	285.3	01:35	02:00	02:20
Green	282.8	284.1	NA	NA	NA

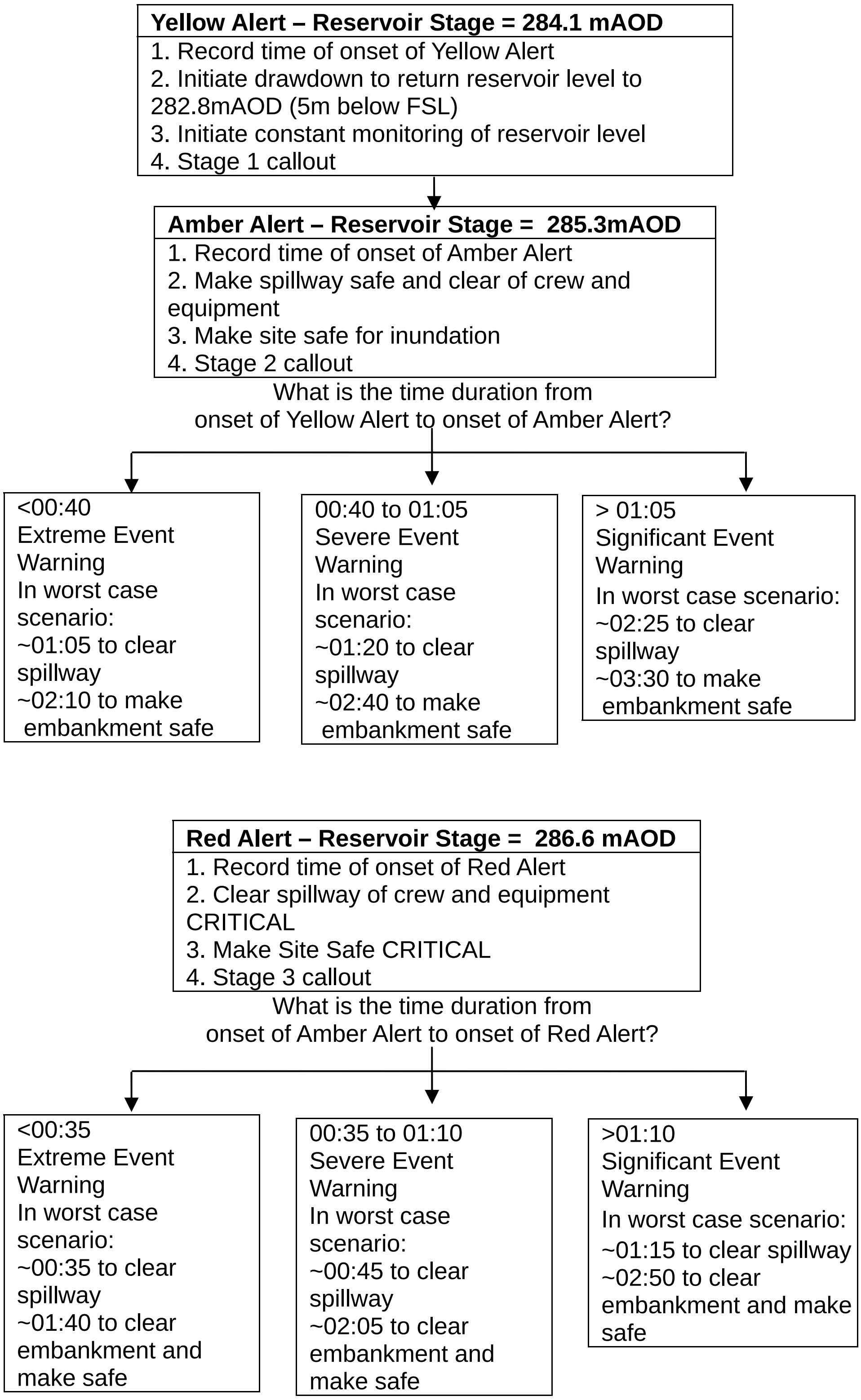

Figure 4a. Decision Tree for Yellow, Amber and Red Alerts

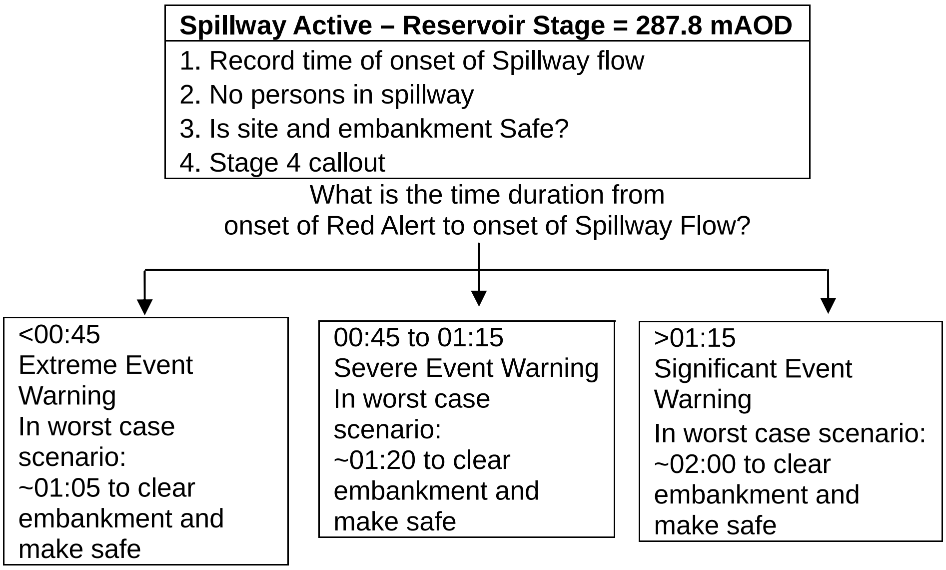

Figure 4b. Decision Tree for Spillway Active

CONCLUSIONS

The latest industry standard hydraulic modelling and catchment hydrology methodologies were applied to provide data for the analysis of flood risk during different phases of construction works on impounding reservoir embankments. The effectiveness of a number of flood risk mitigation scenarios was tested, and the analysis was provided to contractors for the development of an effective site flood contingency plan.

The work provided indicative lead times over a range of storm event severity. The most extreme event considered was the 1:1000 year event which showed a delay of 01:35 hh:mm from the onset of stage rise to spillway activation, and 02:40 hh:mm from stage rise until embankment overtopping. The model results were used to develop a user friendly site protocol that guides the user through using observed stage rise in the reservoir to estimate the time remaining to the onset of key flood risk situations.

The current analysis utilises modelled flood events up to the 1:1000 year rarity. A key requirement for contractors working on impounding reservoir embankments is that contingency is in place for all flood events. Rather than considering events by their annual return period it was recommended that events should be categorised by their effect, such as overflow activation, spillway chute capacity exceeded and embankment overtopping. Specific actions are required for all of these situations. This work has shown a method for presenting flood events in this way.

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