POSITION PAPER REGARDING QUANTITATIVE RISK ASSESSMENT FOR THE HAMPSTEAD HEATH PONDS PROJECT

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EXECUTIVE SUMMARY

Currently dam safety is controlled by the Reservoirs Act, 1975, and there is a "standards based approach" where dams are considered to be "high risk" if lives of 10 or more people are endangered by a reservoir collapse. The future implementation of the Floods and Water Management Act 2010 will alter the definition so that dams are considered to be "high risk" if lives of 1 or more people are endangered.

Quantitative Risk Assessment (QRA) for reservoirs is not currently a statutory requirement. QRA is typically used as best practice for identifying potential failure modes, comparing the risk of reservoir schemes, evaluating the risk of reservoirs prior to, and post, remedial works and prioritising works across a portfolio of reservoirs.

QRA would not normally be undertaken at this stage of the project and was carried out in this instance in response to a request from stakeholders to try to gain an appreciation of the existing risk presented by the Hampstead Heath ponds.

Atkins has undertaken an interim QRA using the latest RARS guidance (2013). Previous studies by CARES/Haycock used the slightly different 2004 Guidance. Both studies confirm that there is a unacceptable risk to life from failure of the ponds during a flood event.

INTRODUCTION

This position paper presents a review by Dr A K Hughes, in his capacity as the currently retained All Reservoirs Panel Engineer for the Hampstead Heath Ponds, on the application of Quantitative Risk Assessment (QRA) for assessment of risks to life presented by the Ponds, taking into account the separate assessment by CARES in 2009 (ref 1) and by Atkins Ltd in 2013 (ref 2).

CURRENT STATUS OF CATEGORISATION OF DAMS

Currently in the UK the risk presented by dams is assessed in accordance with Flood and Reservoirs Safety; An Engineering Guide, 1996, which acts as supporting guidance to the Reservoirs Act 1975. Dams are categorised into four types (Category a to D), depending on the likelihood of a breach causing damage and/or endangering life, with Category A dams having the highest consequence of failure. The assessment of population at risk, made by the Inspecting Engineer under Section 10 of the 1975 Act, is often based on his/her judgement supported by the guidance and any inundation mapping that may be available. Where lives in a community (generally *'considered to be not less than about 10 persons'*) are considered to be endangered, Category A dams are required to be able to safely pass the design flood. The design flood for Category A reservoirs is the Probable Maximum Flood (PMF) and the dam is required to pass the routed outflow of the PMF.

It should be noted that the recently implemented part of the Floods and Water Management Act, 2010, has revised the categorisation of reservoirs to "high risk" and "not high risk". High risk reservoirs are those which endanger the life of at least one person.

This is a standards based approach; if there are lives which can reasonably be seen to be endangered the dams should be designed or modified to "virtually eliminate" the probability of collapse. To avoid failure, the excess water which the dam cannot retain in a flood must be passed safely by a spillway, or over and around the dam, without causing the dam to collapse. To virtually eliminate probability of collapse, the PMF has been used as the benchmark for Category A dams since if this extreme low probability event can be safely accommodated it is reasonable to state that probability of collapse has been virtually eliminated.

We all live with risk all the time in our normal lives. In some other areas of life a more risk based approach has been adopted, where an explicit balance, or trade-off, is made between the probability of endangering life and the cost which may be incurred to reduce or remove that risk. The concept of a tolerable level of risk implies that such a balance can be arrived at. Currently the Inspecting Engineer is relied upon to use his/her judgement as to the risk but not to make an explicit trade-off.

In response to this wider view of risk, methodologies have been in development over the last few years, under the aegis of DEFRA. These methodologies offer a more technical and quantitatively based route to assessing types of failure and probabilities of failure for individual dams. The Interim Guide to Quantitative Risk Assessment for UK Reservoirs was published in 2004. Further developments during its trialing, which exposed some difficulties of application in the absence of significant and often unobtainable data, resulted in the issue of the Guide to Risk Assessment for Reservoir Safety Management in 2013 (RARS).

There is no statutory requirement to apply RARS to the categorisation of dams in the UK as the standards based approach is still current for dams with storage capacity greater than 25,000m^3.

RARS guides the engineer through a process for estimating probabilities of failure of dams from a number of failure modes, including overtopping leading to collapse. This is a screening tool where the probability estimates remain somewhat subjective. To improve the estimates more investigating is required to reduce levels of uncertainty. RARS is for the moment best used for making comparisons between options, since the subjectivity which is necessarily applied commonly does not have a significant impact on the overall outcome.

OVERVIEW OF STUDIES

Both the CARES report and the Atkins report follow a similar process:

- Adopt the currently available hydrological information
- Assess the probability of failure of the embankments/chain of embankments
- Assess how the water released from the ponds affects the downstream catchment in terms of depth and velocity of flow
- Estimate the number of properties at risk and the number of people at risk from the inundation
- Estimate the likely loss of life based on a relationship between the people at risk and the depths and velocity of possible flows.

There are differences in inputs, processes used for the various steps and the outcomes recorded as noted below.

HYDROLOGY

The starting point for any assessment of the probability of failure of dam embankments is the estimation of the flows to which the system is subjected. The basic process is to establish the rainfall intensities and depths for various return periods, and to estimate based on several factors including soil type, slope, vegetation type, how the rain onto the catchment area runs off the land into the pond systems. For each return period assessed hydrographs are calculated which show the flow rate of water into the system over the duration of the flood.

The CARES study relied on hydrographs and modelled flows derived by Haycock (ref 3) and the Atkins study relied on information from the Atkins Assessment of Design Flood report (ref 4).

As previously commented upon the Haycock study developed higher flows than the Atkins study for the longer return period events; the reason for this is essentially that Haycock assumed that a greater proportion of any rain falling in a storm would run off the Heath and contribute flow to the system than Atkins did when using the industry standard methodology.

PROBABILITY OF FAILURE

Failure modes

The failure modes of an earth embankment generally fall into a few categories: internal erosion of material as water flows through the body of the dam; external erosion of the dam embankment or foundation due to extended durations of water overtopping the embankment crest and instability of the dam slopes. CARES only reviewed erosion due to overtopping and subsequent breach; this is reasonable as in essence the probability of internal erosion or slope instability is not likely to be significant in relation to overtopping. The Atkins assessment included these failure modes for completeness.

Probabilities estimated
In the CARES study the 2004 Interim Guide is used as the basis for the estimation. It is not clear how the cascade effect is included in the assessment although CARES note that the most significant impact on the failure probability is the probability of the uppermost embankment in the chain collapsing.

The Atkins study uses the RARS 2013 methodology and specifically includes the cascade effects, examining the probabilities of failure of individual ponds for different flood events and combining these appropriately to estimate the failure of the cascades. As for the CARES study, Atkins noted that the most significant effect on the probability of failure is the probability of the uppermost embankment in the chain collapsing.

Although slightly different methodologies have been adopted for the assessments, and the resulting probabilities of failure numbers are not exactly the same, both studies concluded that the estimated probability of failure of the Hampstead heath Ponds are within the unacceptable range.

IMPACT DOWNSTREAM
Both CARES and Atkins produced sophisticated 2D flood models showing how the flows released from failed cascades would spread downstream. The 2D model allows an assessment of extent but more importantly the depth and velocity which are the parameters of the flood flow which most affect likely loss of life. The LISFLOOD model used by Haycock on which CARES based their "persons at risk" and "likely loss of life" is comparable in structure and process to the InfoWorks RS model used by Atkins; InfoWorksRS is widely used in the UK being the modelling suite preferred by the Environment Agency for flood modelling in England and Wales.

Both Atkins and CARES used the current LiDAR data provided by City of London, so the base mapping for both studies is of high quality.

The way in which the breach which releases the water is developed and modelled is dealt with differently in the two studies. The CARES report uses information from Haycock where the breach is instantaneous, thereby releasing the water with great rapidity. In the Atkins study breaches are developed over a period of 1-2 hours, based on the Froelich assessment method, one of the standard breach models.

The CARES report notes that the instantaneous release is likely to result in higher hazard downstream than if a breach develops in a more timed fashion. Clearly there is a significant difference if the breach develops instantaneously or over hours. A slower breach is considered more realistic.

Both CARES and Atkins studies approach the assessment of Population at Risk in a similar way using the same map information about buildings, although the flood envelopes differ due to the differences in input hydrographs and breach modelling as noted above. The Population at Risk were converted to a Likely Loss of Life (LLOL) using the same relationship between Population at Risk and the likely loss of life.

CARES LLOL estimates based on no warning were around 500 however it is unclear what fatality rate was applied to the basement flats and the number of basement flats that were taken into consideration. Atkins LLOL estimate for the PMF and failure of both ponds chains was around 1,400 on the basis that 25% of properties are basement flats and there would be a 100% fatality rate for the inundated basement flats.

It is difficult to compare the estimates in the absence of the details of the number of basement flats and the fatality rate adopted by CARES for inundated basement flats. However, from both studies it is estimated that hundreds, if not thousands, of lives would be lost on failure of the Hampstead Heath Ponds. This is clearly unacceptable in relation to the current guidance.

CONCLUSION
The City of London, as the owner or undertaker for the reservoirs, some of which are currently covered by the 1975 Act, and all of which may be covered by the Flood and Water Management Act 2010, needs to virtually eliminate the probability of collapse. It is noted that eliminating the probability

of collapse will not eliminate flooding downstream from overtopping during extreme events, which could in such events lead to loss of life

As yet the QRA approach is not used for making decisions about whether or not works to dams are required to avoid loss of life, as a threshold approach is currently applied. As such it is not a requirement to quantify the likely loss of life prior to assessing options to virtually eliminate the probability of collapse where lives are reasonably assessed as being at risk.

Risk based approaches such as the QRA are common in other areas of life and DEFRA has been developing the QRA approach since the Interim Guide was published in 2004. However, currently there is no legal requirement for undertaking QRA assessments on reservoirs. Consistent use of the QRA approach over time should improve the reliability and objectivity of the outputs.

Earlier work by Haycock and CARES established that there is a notable probability of collapse of the Hampstead Heath Ponds chains under longer return period storm events and a notable risk to life from such collapse. Atkins has revised the work carried out by Haycock and CARES using current guidance and state of the art methodologies and confirms that there is a notable probability of collapse of the Hampstead Heath Ponds chains under both shorter and longer return period storm events and a notable risk to life from such collapse.

Both CARES and Atkins use the same basic process to attempt to quantify the likely loss of life, although there are differences in inputs and in some details of the guidance between the 2004 and 2013 guides and differences in outputs as a result. Both parties concur that the principal mode of failure of the Hampstead Heath Ponds is erosion due to extended overtopping of the embankments during flood events, and the estimated probabilities of failure are high. In addition, both parties also concur that significant loss of life is estimated upon failure of the ponds, bringing the overall risk of failure into the unacceptable range.

References:

1) CARES (July 2009). Flood Risk Assessment for Three Ponds, Hampstead and Highgate.
2) Atkins (August 2013). Hampstead Heath Ponds Quantitative Risk Assessment – Interim Report.