Water London Borough of Camden December 2014

Independent Review of Hampstead Heath Ponds Project

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Executive Summary

Consultants Atkins have designed the upgrading works for the Highgate and Hampstead chains of ponds. The proposals have been developed over a long process of design stages and consultation with users of the Heath and local residents. City of London is now seeking planning permission from the London Borough of Camden. A considerable number of objections to the scheme have been received by the planning authority. AECOM have been asked to review the proposed scheme, and comment on some key points contained in the objections. The Scope of the review is given by 5 questions from the Client, which summarise the key objection points, and are listed below. Further technical content is given within the body of the report.

1) Whether the proposed project is technically appropriate and necessary in the context of legislation and current best practice guidance, within the context that the Council understands that while legislation may only require the City of London to improve the three ponds designated as reservoirs we accept that there may be benefits in a project that considers all ponds within both the Highgate and Hampstead chains.

The legislative context is that, in addition to the duty of care under Common Law, other potentially conflicting pieces of legislation are relevant to the Ponds Project: the Reservoirs Act 1975, the Floods and Water Management Act 2010, and the Hampstead Heath Act 1871.

The matter of interpretation of the law raises a question of which of the conflicting legal requirements (preservation under the Hampstead Heath Act, or reservoir safety under the Reservoirs Act) takes precedence. The measures taken to resolve the apparent conflict between the Acts are to fulfil the purpose of reservoir safety as defined under the Reservoirs Act, while accommodating the interests expressed in preservation of the Heath as much as is practicable, together with scaling down the proposed works to make use of the ability of some of the dams to withstand occasional limited overtopping.

From review of the documents submitted, it is clear that the current arrangements are wholly inadequate to safely accommodate even a relatively frequent flood event without putting the dams at risk of failure. We find that the project is technically appropriate and necessary to bring the risk to life from breach of the dams by extreme flood events to within an acceptable standard as set out in current guidance (Institution of Civil Engineers, 1996[1]) (see section 2.4). The flood standard applied from the ICE guide is Category A, i.e. a case “where a breach could endanger lives in a community”. Atkins has used this standard as the rationale for the scheme and basis of design of the upgrading works, and we fully agree with this categorisation and the need to accommodate the corresponding design flood.

We fully agree with the approach taken that considers all the ponds within the Highgate and Hampstead chains, rather than only those that fall under the Reservoirs Act 1975. This ensures that the non-statutory reservoirs are not still vulnerable to failure, allows mitigating measures to be targeted at most appropriate sites rather than only at the statutory reservoirs, enables “softer” engineering solutions to be incorporated in the design to minimise the impact on the landscape characteristics of the Heath allowing the proposed works to align more closely with the aims of the Hampstead Heath Act, and will ensure full compliance when the relevant parts of Floods and Water Management Act 2010 are implemented.

In response to comments from objectors, a risk assessment has been carried out for the scheme, and this has verified the assignment of Category A in quantitative terms by deriving the likely range of fatalities attributable to breach of the dams during flood. The Risk Assessment also allows the risk posed by the ponds to be expressed in relation to tolerable limits of risk to society, based on accepted guidance (Health and Safety Executive, 2001[2], Environment Agency, 2013[3]) (see section 5.3). Although not recognised in current reservoir guidance, revisions to the ICE Floods and Reservoir Safety Guidance, 4th edition[1] due for issue shortly, allow a risk-based approach as an alternative to the existing standards-based approach. This guidance will be adopted as best practice by the dams and reservoirs community on publication. The Risk Assessment carried out is dependent on various assumptions that could be varied, but overall it is regarded as technically sound in presenting a broad

[1] *Floods and Reservoir Safety*, ICE, 1996

[2] *Reducing Risk, Protecting People*, HSE, 2001

[3] *Guide to risk assessment for reservoir safety management*, Defra/Environment Agency, 2012

evaluation. It shows that the risk currently posed by the ponds is clearly in the “Unacceptable” zone, i.e. the combination of probability of failure and the number of fatalities likely to arise from breach failure of the dams is unacceptably high, and that the proposed works are necessary and proportionate in relation to the reduction in risk achieved.

2) Written confirmation that the modelling methodology and assumptions underpinning the project are suitable, reasonable and have been applied appropriately. We propose that this is determined through a site visit and a two to three hour workshop (both with the applicant and Council officers), during which the approach to the work will be presented. For the avoidance of doubt, we do not require separate modelling to that already undertaken to be produced.

The principal components of the modelling are the derivation of inflow flood hydrographs (hydrological modelling) based on the catchment characteristics and flood routing (hydraulic modelling) using the dam and reservoir characteristics. Downstream inundation modelling, with and without dam failure has also been carried out as part of the Risk Assessment, requiring assumptions to be made for time for development of dam breach, and fatality rate of the population at risk. We have reviewed the methodology and assumptions adopted.

For flood assessment and routing, hydrology used for assessment of the Probable Maximum Flood (PMF) design flood and less severe floods has followed standard procedure with a specific adjustment for run-off from compacted areas of the heath, which we consider valid. The hydraulics used for overflow arrangements follows standard modelling considerations using industry standard hydraulic modelling software and is within normal limits of accuracy. The assumptions made are suitable, reasonable and applied appropriately.

For the Risk Assessment, the dams’ tolerance to overtopping has followed standard guidance. The conclusions appear possibly conservative when compared with their behaviour in the 1975 flood, but are acceptable and are entirely valid for floods approaching the PMF design flood.

The time for development of dam breach has been assigned on the basis of judgement as longer than the range given by standard breach formulae, so the breach peak discharges may correspondingly represent the low end of the possible range.

The fatality rate from dam-break and concurrent natural floods has been given special consideration in view of the large number of basement properties, and a valid range has been derived. It should be noted that the estimated of loss of life may be underestimated as it does not include potential loss of life related to transport infrastructure, i.e. users of roads, underground and train lines within the area at risk.

For the Risk Assessment, the methodology follows the latest guidelines. The assumptions made are by necessity limited in relation to the large number of parameters that could be varied to allow for uncertainties. The overall application is appropriate and the outcome is a valid representation within the range of uncertainty inherent in risk assessment studies.

We confirm that the methodologies used to determine flood inflows to the ponds, and the modelling undertaken to route the floods through the ponds, assess spillway capacities, overtopping flows, and determine downstream inundation extents and fatalities follow industry best practice, and are suitable, reasonable, and appropriate for use to design the upgrading works.

3) Whether a sufficient range of alternatives to address the dam safety hazard have been assessed to an appropriate level of detail to justify being discounted.

A wide range of alternatives has been addressed in considerable detail in the reports on successive stages, including Part 4 of the Planning, Design and Access Statement and the Preferred Options Report.

Further consideration has been given to a general alternative of “systems that require human interaction” (such as gated spillways) is noted in Appendix C of the Preferred Options Report. It is our view that any such active systems are not appropriate, would not constitute best practice, and would not provide the level of protection that the public at risk downstream is entitled to reasonably expect. A passive system is the only way to reliably achieve the required reduction in risk.

The range of alternatives considered is wide-ranging and sufficient. The reasons for discounting these alternatives are stated in the relevant documents with an appropriate level of detail being given for this purpose.

Regarding the nature of the proposed works, the required flood is accommodated by a combination of increased temporary storage and supplementary overflow capacity, providing a passive system that does not rely on human intervention during a flood event.

We consider a sufficient range of alternatives have been considered, and that those alternatives have rightly been constrained to a passive solution.

The process of consultation has been sufficiently thorough and wide-ranging, although it has to be borne in mind that there is a disproportionate amount of representation of the views of stakeholders who use and enjoy the Heath, compared with those living or working downstream who are potentially at substantial risk from dam failure, but generally unaware of the risk.

4) Whether the applicant's claims that the scheme will neither alter the ponds interaction with the Thames Water drainage network nor increase the potential for surface water flooding downstream under all operating conditions (including overtopping and spillway activation) are sufficiently evidenced and reasonable.

The submission includes sufficient evidence in the form of hydrographs showing discharge from the ponds into the Thames Water drainage network and discharging over ground for a range of return period floods to illustrate that the peak flows and volumes (over a given time period) will reduce under the proposed arrangements. The proposed works will therefore reduce the contribution from the Heath to downstream surface water flooding. Although this is not the primary aim of the project, the proposed works will provide some benefit in terms of flood alleviation.

5) Whether the comments made by the third party identifies any reasonable concerns about the technical content or considerations of the submission which should be addressed by the applicant by way of further submission, prior to planning permission being able to be recommended to be granted (should this be the officer level recommendation to Development Control Committee (DCC)). In this case it would need to be apparent that the submission is so deficient in some respect that the conclusions (points 1-4 above) cannot be guaranteed without the provision of further information at this stage. Please clearly denote the precise information (if any) that would be required to satisfy 1-4.

We have requested and received clarification from Atkins on some matters of the technical content that were not available in the documents listed, but was available in detail as part of their assessments and calculations. This detailed information has some limitations, but together with inference that we have drawn from it, brings the technical content and considerations to a sufficiently complete state to fully address key comments made by the third party.

Considering the objections to the scheme, reported in Section 6, it is our opinion that none of these objections raise reasonable concerns about the scheme. The assertion that the project is based on an illogical interpretation of risk is addressed by the Risk Assessment carried out. As explained in Section 1.3, as an alternative to the "standards-based" approach, new ICE guidance (*Floods and Reservoir Safety, 4th edition)*, when published, provides for an alternative "risk-based" approach. This procedure has been followed by Atkins to produce their QRA report, which was prepared in response to comments from objectors. We have used the outcome of this procedure to evaluate the proportionality of the proposed scheme, which is a measure of the cost of the scheme against the value of saving lives and avoiding damages. This is reported in Section 5.5. The result of this confirms logically that the works are entirely proportionate with the reduction in societal risk, and there is no supporting reason to reduce the scale of the works to accommodate any less than the proposed design flood.

Having received clarification from Atkins on some matters of the technical content, we consider that no further submission by the applicant is necessary prior to planning permission being able to be recommended.

Capabilities on project:
Water

1 Introduction and Legislative Context

1.1 Background

Consultants Atkins have designed the upgrading works for the Highgate and Hampstead chains of ponds. The proposals have been developed over a long process of design stages and consultation with users of the Heath and local residents. City of London is now seeking planning permission from the London Borough of Camden. A considerable number of objections to the scheme have been received by the planning authority, and it is understood that the Heath and Hampstead Society, who have been part of the consultation process, intend to call for a judicial review.

AECOM has been appointed by the London Borough of Camden (the planning authority), to undertake an independent review of the proposed upgrading works to the ponds on Hampstead Heath, which are owned and operated by the City of London. The upgrading works are required to address the flood risk to downstream residents posed by the ponds. AECOM have been asked to review the proposed scheme, and comment on some key points contained in the objections. The Scope of the review is given by 5 questions from the Client, which summarise the key objection points

1.2 Legislative context

The ponds on Hampstead Heath represent both an asset and a liability to their owners, The City of London Council. In addition to the duty of care under Common Law, other potentially conflicting pieces of legislation are relevant to the Ponds Project: the Reservoirs Act 1975, the Floods and Water Management Act 2010, and the Hampstead Heath Act 1871.

The Hampstead Heath Act 1871 was enacted in order to ensure the preservation of the Heath's natural aspect. The Act seeks to preserve the "*natural aspect and state"* of the Heath and grants powers to the Council "*to drain, level and improve the Heath …..with a view to the use thereof for purposes of health and unrestricted exercise and recreation*".

The Reservoirs Act 1975 was introduced in order to protect against loss of life from the uncontrolled escape of water from reservoirs, and applies to all reservoirs that impound more than 25,000 m^3. Three of the ponds fall above this threshold. The Floods and Water Management Act 2010, when implemented, brings substantial amendments to the Reservoirs Act 1975, and lowers the volume threshold to reservoirs holding more than 10,000 m^3, and will encompass reservoir cascades that contain in total more than 10,000 m^3. The remaining ponds will fall under this legislation.

The matter of interpretation of the law raises a question of which of the conflicting legal requirements (preservation under the Hampstead Heath Act, or reservoir safety under the Reservoirs Act) takes precedence. This legal point remains unresolved and enquiries made by Atkins to government have received a response that this would be a matter for the courts. The measures taken to resolve the apparent conflict between the Acts are to accommodate the interests expressed in preservation of the Heath as much as is practicable, together with scaling down the proposed works to make use of the ability of some of the dams to withstand occasional limited overtopping.

1.3 Floods and Reservoirs

Hydrological studies undertaken for the ponds on Hampstead Heath indicate they are not capable of withstanding a significant flood event without overtopping with the attendant risk of failure, and therefore pose a risk to the downstream population. It is important to understand that the flooding caused by failure of a dam, whilst usually of a much lower probability, is in most cases significantly greater and more sudden than a natural flood.

A reservoir will accommodate a flood by discharging flow over a spillway arrangement and by using the temporary storage afforded by the volume between the spillway level and crest level (dependent on the surface area of the reservoir and the height between the spillway and crest). If together, these features of the dam and reservoir are inadequate to accommodate a flood, the dam will overtop. Should the dam be formed from an earth embankment, as is the case for all the ponds on Hampstead Heath, there is then a risk of the embankment material being eroded by the overtopping flow, resulting in a breach of the dam. Depending on the geometry of the dam and the resistance of the embankment material, breach can occur in a very short space of time – in some cases a matter of minutes. The entire contents of the reservoir are then discharged through the breach, resulting in extremely high flows and velocities downstream which can be significantly greater and more sudden than a natural flood. Failure of a dam can therefore present an extremely high risk to life, and if the area downstream of the dam is highly populated, result in a significant number of fatalities.

For this reason, reservoirs over a certain volume are subject to formal legislation to ensure their safety. The Reservoirs Act (1930), and the superseding Reservoirs Act (1975) were born out of a number of dam failures that resulted in significant loss of life. The Act currently applies to reservoirs that hold over 25,000 m^3 of water, and three of Hampstead's ponds fall under this legislation. For reservoirs that fall below the current volume threshold, best practice is to apply the same standards [CIRIA Report R161, 1996], but is not mandatory. The Act specifies the frequency of supervision and inspection of dams by qualified engineers appointed to the relevant Panels on the advice of the ICE. Inspecting engineers are empowered to make recommendations in the interests of safety which carry the force of law. They can also make other recommendations to the owner which do not carry the force of law, but are to ensure good maintenance and asset management. Since the legislation was introduced, there have been no fatalities due to dam failures, but there have been a number of incidents, one of the most recent being at Ulley dam (Rotherham), where the safety of the dam and downstream population and infrastructure have been at risk, avoided only by urgent intervention.

Guidance supporting the legislation to ensure the safety of reservoirs during a flood event is set out in *Floods and reservoir safety, 3rd edition"*, published by the Institution of Civil Engineers in 1996. Whilst the guide is not mandatory, significant divergence from it could place a reservoir owner at risk of being found negligent in the event of an incident. The guide uses a "standards based" approach, giving a design flood of a specified severity that the reservoir must be able to safely accommodate without risk of failure, based on the consequence of failure in terms of loss of life and damage.

A "risk based" approach has been adopted in revisions to the ICE guidance currently in preparation[4], as an alternative to the current "standards-based" approach, for determining the flood that needs to be accommodated to achieve a degree of safety proportionate to the circumstances at the reservoir. This approach draws on the methodology set out in the recent Defra/EA publication: *Guide to risk assessment for reservoir safety management*, 2013. The aim of this approach is to ensure that proposed works reduce the risk to society to a tolerable level, and that the scale of the works is proportionate to the risk. This is examined further in Section 5.

[4] *Floods and Reservoir Safety,* 4th Edition, in preparation

2 Assessment of floods on Hampstead Heath

2.1 Current standards

Three of the ponds on Hampstead Heath fall under the Reservoirs Act 1975. These ponds should comply with the flood standards set out in guidance accompanying the Act: *Floods and Reservoir Safety*, 3rd edition, published by the Institution of Civil Engineers, as discussed in Section 1.3. The flood standard applied from the ICE guide is Category A, i.e. a case "where a breach could endanger lives in a community", and on review we fully agree with this categorisation and the need to accommodate the corresponding design flood.

The approach taken by the designers is to apply these standards to all the ponds on the Heath, in order to ensure non-statutory reservoirs are not still vulnerable to failure, to allow mitigating measures to be targeted at most appropriate sites rather than only at the statutory reservoirs, and to enable "softer" engineering solutions to be incorporated in the design. We fully agree with this approach, which in addition, will ensure compliance when the relevant parts of Floods and Water Management Act 2010 are implemented.

For the Hampstead Heath ponds, where there are a large number of people at risk downstream, the relevant design flood is the Probable Maximum Flood. In their current arrangement, the hydrological studies reviewed below indicate the Hampstead Heath Ponds cannot safely accommodate this flood without overtopping and subsequent risk of failure.

2.2 Hydrological studies

The ponds on Hampstead Heath have been the subject of a number of hydrological studies to determine the flows generated over the catchment and reaching the ponds in the event of a flood. Previous studies were undertaken by Haycock (2006, 2010), and more recently by designers Atkins (2013). Each approached the analysis in a different way. Haycock constructed a distributed hydrological model, which routed rainfall input through or over the soil, portioning flows into groundwater, accounting for groundwater discharges and then routing the remaining surface flow through the drainage network. This bespoke approach is unusually complex and sophisticated for a project of this type. More usually, the methods recommended in the ICE guide (3rd and 4th edition) are followed to generate extreme flood hydrographs for reservoirs, with the use of the standard rainfall-runoff model set out in the Flood Estimation Handbook[5] (FEH). This is the approach taken by Atkins in their report *Assessment of Design Flood*, March 2013.

There is always a level of uncertainty associated to any hydrological estimates. Those based on a long record of gauged flow data will result in the lowest level of uncertainty, whilst those based on generic empirical methods will give a much higher level of uncertainty. There may be higher than average uncertainty attached to the use of standard methods of flood estimation for the ponds of Hampstead Heath due to the small size of the catchments feeding them. The Flood Studies Report (FSR)/FEH Rainfall-runoff used by Atkins in their flood assessment, was derived using data from gauging stations throughout the country, none of which have catchment sizes as small as those of the Hampstead Ponds. However, distributed hydrological modelling, the approach used by Haycock, can also produce considerable uncertainties unless calibrated or validated, which ideally involves inputting recorded rainfall data into the model, and comparing the resulting flow against recorded flow data. Catchment parameters within the model are then adjusted until the calculated flow gives a good match to the recorded data. This was not carried out – it is presumed due to lack of appropriate recorded data.

The two studies give very differing results in terms of peak flows (Table 2.1). The main reason for this appears to be the difference in percentage runoff that each approach used. Percentage runoff is the percentage of rainfall that is available to generate runoff over the catchment, once losses such as storage in surface depressions and infiltration into the soil are deducted. It is largely controlled by the soil type and degree of saturation of the ground prior to the storm event. Typically for extreme events, the percentage runoff is in the region of 50 – 80%, depending on the soil type and antecedent conditions. Haycock identified there was an unusually high degree of compaction of the soil within the Hampstead catchments due to high visitor use. The standard FSR/FEH rainfall runoff method gives low percentage runoff at around 27% in the catchments. However, Haycock undertook a small number of infiltration tests near the path network, and concluded a more realistic percentage runoff lay between 80 and 90% for extreme events. In view of the Haycock studies, Atkins increased the standard

[5] *Flood Estimation Handbook,* Institute of Hydrology, 1999

percentage runoff (SPR) to 53% to account for increased runoff from the path areas and for drying/cracking of the soil during the summer. This resulted in an overall percentage runoff of 76% for the PMF event, which we consider reasonable.

Table 2.1: Comparison of Haycock and Atkins peak flow estimates

Pond Catchment	Maximum Flow (m^3/s)					
	1 in 100 year		1 in 10,000 year		Probable Maximum Flood (PMF)	
	Haycock	Atkins	Haycock	Atkins	Haycock	Atkins
Highgate Chain						
Stock	2.34	2.74	14.49	6.86	28.98	15.54
Ladies Bathing	2.85	3.63	18.15	9.10	36.30	20.35
Bird Sanctuary	3.76	5.82	24.14	14.53	48.28	31.88
Model Boating	4.15	6.15	31.23	15.65	62.46	33.71
Men's Bathing	4.48	6.57	34.13	17.02	68.26	36.48
Highgate No 1	4.79	7.02	36.84	18.44	73.68	39.10
Hampstead Chain						
Vale of Health	1.64	0.57	4.67	1.45	9.34	3.32
Viaduct	0.85	0.31	6.04	0.78	12.08	1.78
Mixed Bathing	2.49	2.46	22.80	6.31	45.60	14.15
Hampstead No 2	2.58	2.81	25.62	7.27	51.24	16.14
Hampstead No 1	2.78	3.34	26.30	8.49	52.60	18.82

Theoretically, a distributed rainfall runoff model such as that developed by Haycock, should give a more representative and accurate flow estimate when compared to standard empirical methods. However, a number of major issues exist with the Haycock method:

- Local rainfall gauge was used to generate a rainfall frequency curve and extrapolate to give the 1 in 10,000 year rainfall. It is not statistically robust to extrapolate 100 years of rainfall data to give 10,000 year return period.
- The critical duration for the reservoir was assumed, rather than correctly identified by modelling a range of storm durations
- It did not estimate the PMF event: merely used the 1 in 10,000 year event and doubled the peak flow to estimate the PMF event. This relationship between peak flows for the 10,000 year and PMF events is used in the rapid assessment method (ICE guide, 3rd and 4th edition), which is only suitable for use as a screening tool, not for detailed design.
- It is understood the percentage runoff adjusted for the high compaction was applied to the whole catchment area, not just the path network, which is unnecessarily conservative.
- The model is uncalibrated

Issues with the standard FEH rainfall-runoff used by Atkins are:

- Uncertainty of validity of FSR/FEH methods for small catchments

The large difference between the Atkins and Haycock estimates of PMF illustrate the high levels of uncertainty attached to any hydrological estimate. We do not know exactly what the PMF peak flow is; we can only estimate it using hydrological methods. It is common practice by hydrologists to use more than one method to estimate flood flows. It is usual to take the precautionary approach and adopt figures that are considered conservative. In this case, the hydrological method adopted for design does not give the most conservative figures. The Atkins PMF estimates are more in line with Haycock's 1 in 10,000 year estimates. Atkins has followed the standard recommended method and has applied it correctly, with the only .major source of uncertainty being the validity of the method when applied to very small catchments. Whilst theoretically, Haycock's distributed rainfall-runoff model of the Heath should be more representative of the catchment response, it has not been possible to calibrate the model and appears to use extremely pessimistic runoff coefficients. Haycocks' PMF estimates can therefore be considered to be towards the upper bound of possible flood estimates.

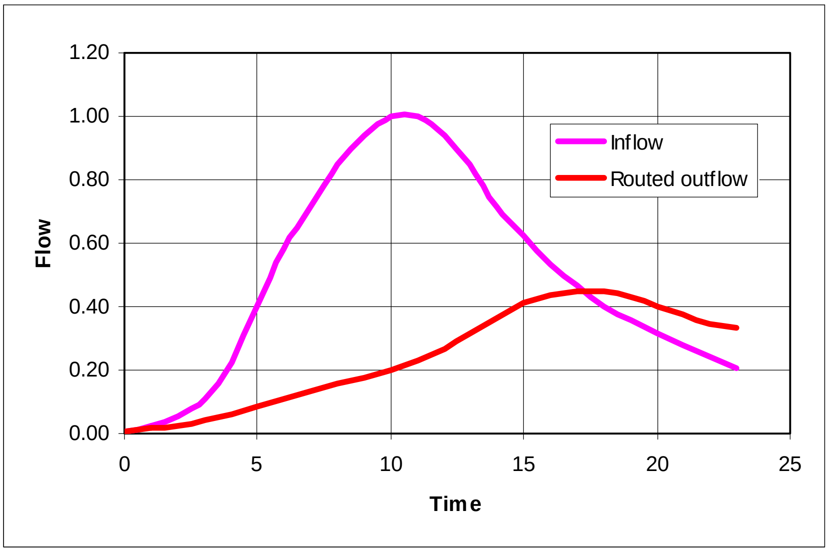
Comments from many third parties focus on the stated return period probability of a PMF of 1 in 400,000. In theory, a return period cannot be assigned to the PMF, defined as it is, as "the flood that may be expected from the most severe combination of critical meteorologic and hydrologic conditions that are reasonably possible in a region". Conceptually therefore, the PMF cannot be exceeded and forms an upper limit of flood estimates. However, for the purposes of allowing inclusion of PMF in the risk-based approach, the RARS guide suggests adoption of a probability of 1 in 400,000 years for the PMF, based on plotting Table 2 in the *Floods and Reservoir Safety*, 3rd edition on lognormal probability paper and extending it to the PMF. Table 2 gives design flood inflows as fractions of PMF (eg 10,000 year = 0.5 x PMF, 1000 year = 0.3 x PMF) for use with a rapid flood assessment method. The FEH also gives a couple of methods to allow the PMF to be located on the flood frequency curve. The geometry based estimation method uses the ratios of PMF to 1000 year and 100 year estimates to estimate the PMF return period. For the Heath ponds, this method would give a probability of PMF of 1 in 1,000,000.

In other words, not only is the PMF estimate subject to uncertainty, but its probability is also extremely uncertain, and in any case quantifying its probability is irrelevant to the standards-based approach which forms the rationale for the scheme. In reality, designing the mitigation works for the dams on the Heath using the Atkins estimate of PMF, could be equivalent to a return period of anything between around 1 in 10,000 and 1 in 1,000,000. Given the uncertainty associated with both the PMF peak flow estimates and associated return period, we accept the use of Atkins flow estimates as the basis for design, but would certainly caution against adoption of any lower design flows.

2.3 Flood routing

Flood routing involves modelling the route of a flood through the reservoir. Flow reaching a reservoir as the result of runoff during a storm event, will cause the water level in the reservoir to rise. The level of this rise depends on the volume of flow entering the reservoir, the reservoir's surface area, and its spillway capacity. The rise in water level results in temporary storage of the flood and the flood hydrograph is "attenuated" – the peak outflow from the reservoir is lower and is delayed and the time base of the hydrograph increases (Figure 2.1).

Figure 2.1: Reservoir flood attenuation



A large volume of runoff entering a reservoir with a small surface area and small spillway capacity will result in a large rise in water level. Options to reduce the water level rise in a reservoir to prevent it overtopping the dam crest therefore include reducing the volume entering the reservoir (for example by providing temporary flood storage upstream), increasing the spillway capacity, or either reducing the spillway level or increasing the crest level to provide more temporary storage below the dam crest. Often, the optimum solution is a combination of these measures. Providing upstream storage or increasing temporary storage in the reservoir will tend to reduce the peak outflow from the dam, whilst increasing the spillway capacity will tend to increase the peak outflow.

Flood routing was undertaken for the Hampstead Ponds by Atkins using InfoWorks RS 2D software, which is an industry standard hydrodynamic modelling software package, and suitable for this task.

The ponds were represented as 1-dimensional units linked to 2-dimensional domains representing the ground around the perimeter and downstream of the dams. It is relatively unusual to undertake 2-dimensional modelling for this type of project; however the increased level of sophistication is entirely appropriate in this case, given the importance of understanding the overland flow routes between the dams and in the urban areas downstream which are essentially 2-dimensional in nature. The elevations in the 2-dimensional domains are obtained from the Digital Elevation Model (Infoterra, 2006). The resolution of the DEM is not quoted, but is assumed to be 1m or 2m, and will have an accuracy of ±15cm, which is adequate for the purposes of this project.

The Kenwood reservoirs (Wood Pond and Thousand Pound Pond) at the upstream end of the Highgate chain are not explicitly included in the model. There will be minimal attenuation in these ponds, given their surface area, and this assumption, which in any case is conservative, is not considered to compromise the accuracy of the model output.

Flow hydrograph boundaries representing runoff from the catchment areas to each pond, and direct rainfall on the pond surface have been correctly provided as inputs to the model. The ponds have been represented as level-pool storage areas, with the underlying assumption that the water level is constant over the entire surface area. Again, this is standard practice and entirely appropriate. Initial water levels in the ponds are correctly represented as top water level (the level of the invert of the overflow pipes). Dam crests are represented as spill units using dimensions and elevations taken from topographic survey, with discharge coefficients that are appropriate. These are connected to the upstream pond, and downstream either directly to the downstream pond or to the 2-dimensional domain as appropriate to the arrangement. The pond overflow pipes are represented as flow-head controls, rather than conduits (pipes), presumably to improve the stability of the model. This is an appropriate representation.

The model has been used to identify the critical storm duration for the existing arrangements at the ponds – the storm duration that has a combination of peak flow and volume that results in the highest water level at the greatest number of ponds. The resulting critical durations are short, ranging from just under 2 hours for the 1 in 1000 year event, to just under 4 hours for the 1 in 5 year event. Given the small size of the catchment areas, and the minimal attenuation at the ponds, this is in the expected range. The critical duration for the PMF was found to be significantly longer at 9.5 hours. Atkins requested and received advice from the Centre of Ecology and Hydrology (previously the Institute of Hydrology) who published the FEH methodology, on the reason for the longer PMF critical duration. It is explained by the differences in the way the PMF and return period floods are generated and their underlying assumptions, particularly with regard to the wetness of the catchment prior to the flood event.

The proposed works will alter the storage and overflow characteristics of the ponds which could change the critical duration, with the result that the peak water levels could be underestimated. At our request, the critical duration for the proposed works has been checked by Atkins and found to be unchanged from that applicable to the existing arrangements. This confirms the correct peak water levels have been identified.

Overtopping Assessment

Outputs from the flood routing modelling have been used to assess overtopping of the dams in order to determine the performance and safety of the existing structures. The assessment revealed that 8 of the 11 ponds are likely to overtop during a 100 year event, and 5 ponds overtop at less severe events, with Stock Pond overtopping during a 5 year event. All the ponds overtop during the 10,000 year event. The estimated frequency of overtopping is wholly unacceptable given the population downstream. What is not made clear in the report is whether the overtopping is of sufficient duration and velocity to result in breach of Stock Pond during a 5 year event, for example, and if so, whether that would release sufficient volume that, together with the flood volume, would result in overtopping and failure of the dams downstream. This aspect is addressed in the QRA report when determining the probability of failure, discussed in Section 5.3.

Table 2.2: Atkins' overtopping assessment results

Pond	5 year	20 year	50 year	100 year	1000 year	10,000 year	PMF
Highgate Chain							
Stock							
Ladies Bathing							
Bird Sanctuary							
Model Boating							
Men's Bathing							
Highgate No 1							
Hampstead Chain							
Vale of Health							
Viaduct							
Mixed Bathing							
Hampstead No 2							
Hampstead No 1							

	Overtopped
	Not overtopped
	Auxiliary Spillway Overtopping

The velocity and duration of overtopping of the dams during the PMF event is reported. These are the relevant factors that determine whether the downstream face of the dam will be eroded by the overtopping, and lead to failure of the dam. The overtopping durations range from 2 hours to over 9 hours, and velocities from 2.3 to 5.4 m/s. Using standard guidance (CIRIA grass performance curves), only 5 of the 11 ponds could potentially withstand the predicted overtopping on the assumption that the grass cover on the downstream face is of good quality. However, this assumption is questionable for the ponds on the Heath, as the non-uniform crest levels and presence of trees and shrubs on many of the downstream faces will focus the overtopping flow, tending to result in local increases of flow depth, velocity, and turbulence, which in turn will lead to gullying of the downstream face and potentially lead to failure of the dam. However, whether some of the dams could withstand overtopping during a PMF event is likely moot, as failure of any of the upstream reservoirs is likely to result in breach of the most downstream reservoir in each chain, and the subsequent release of a dam break flood to the downstream area.

2.4 Summary

The flood standard applied from the ICE guide is Category A, i.e. a case "where a breach could endanger lives in a community", and on review we fully agree with this categorisation and the need to accommodate the corresponding design flood.

We also fully agree with the approach taken that considers all the ponds within the Highgate and Hampstead chains, rather than only those that fall under the Reservoirs Act 1975. This ensures that the non-statutory reservoirs are not still vulnerable to failure, allows mitigating measures to be targeted at most appropriate sites rather than only at the statutory reservoirs, enables "softer" engineering solutions to be incorporated in the design, and will ensure full compliance when the relevant parts of Floods and Water Management Act 2010 are implemented.

We confirm that the methodologies used to determine flood inflows to the ponds, and the modelling undertaken to route the floods through the ponds, assess spillway capacities and overtopping flows, are suitable, reasonable and follow industry best practice, and are appropriate for use to design the upgrading works.

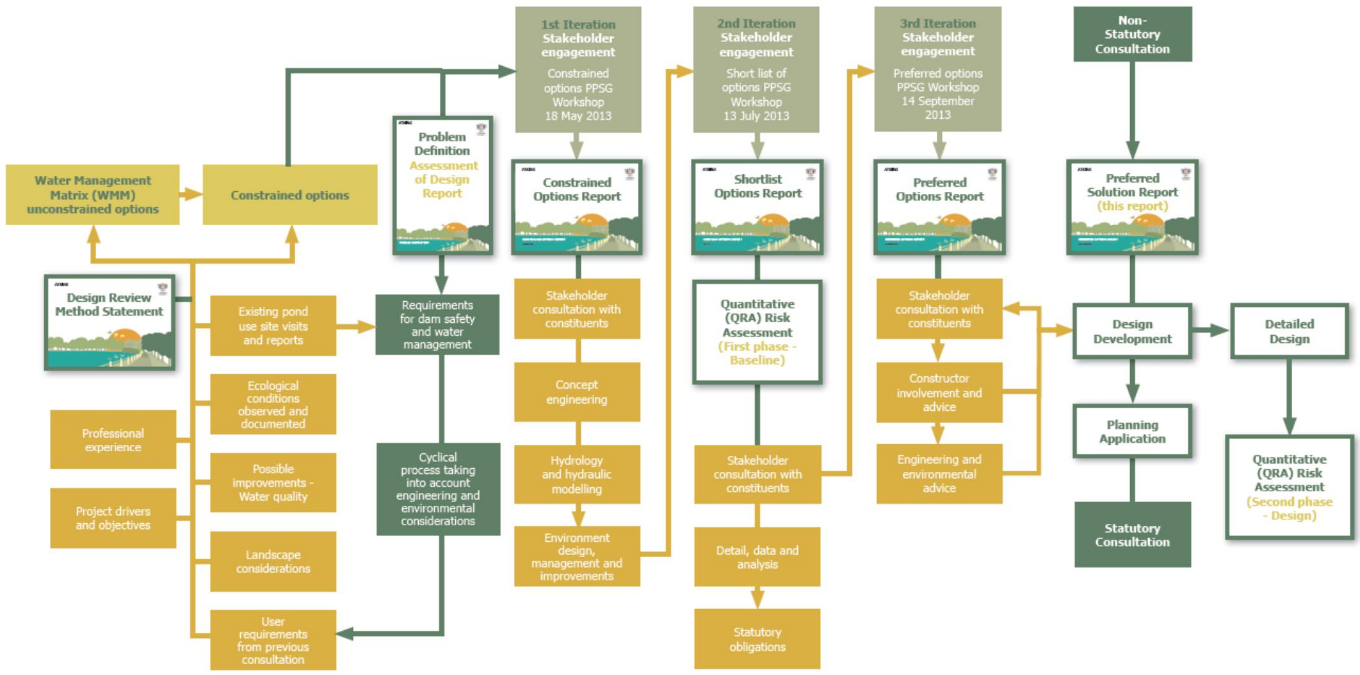
The modelling indicates the current spillway and storage arrangements at the ponds are wholly inadequate to safely accommodate even a relatively frequent flood event without putting the dams at risk of failure. The project is clearly necessary to bring the risk to life from breach of the dams by extreme flood events to within an acceptable level.

3 Design Development

3.1 Consultation process

An extensive consultation process has taken place at stages in development of the selected design option. Extensive lists of comments and responses are included in the documentation, notably Volume 2 of the Preferred Options Report (Atkins, October 2013) that includes a Log of Questions and Answers from all external consultation on the project from January 2011. A flowchart outlining the design development showing stages of consultation is given in the Preferred Solution Report of June 2014 and is reproduced below.

Figure 3.1: Design development and consultation process



The stakeholders consulted include

- Brookfield Mansions and EGOVRA
- Dartmouth Park CAAC
- Fitzroy Park Residents' Association
- Heath & Hampstead Society
- Highgate Men's Pond Association
- Highgate Society
- Kenwood Ladies Pond Association
- Mixed Pond Association
- Prem Holdaway
- Protect Our Ponds (David Lewis)
- West Hill Court RA

The responses by the Design Team to the questions and comments raised are thorough, and necessarily refer to details provided elsewhere or to be provided as part of the design development process. Most of the questions and comments are concerned with the effect on amenity and preservation of the Heath and the ponds by the project and the construction process. Responders also question the legal requirement and justification of the very extreme flood adopted for design, which we address in the preceding and following sections of this Report.

There is understandably much more engagement with stakeholders who use and enjoy the Heath than with those living or working downstream who are potentially at substantial risk from dam breach, but are generally unaware of the risk and are therefore less engaged. Brookfield Mansions is one of the minority of stakeholders living downstream of the ponds, and they stated “Ensuring safety of dams is top of the priority list”. This under-representation significantly distorts the consultation process.

Those living or working downstream, whether or not they are forthcoming in the consultation process, will rightly expect that those who manage assets with potential for risk do so responsibly, and that consideration of those potentially at risk downstream should be given due weight in the design objectives.

The standards set out in the ICE Guide Floods and Reservoir Safety serve the objective of giving an appropriate degree of protection to those potentially at risk from dam failure caused by floods. Where there is potential for dam failure causing loss of life in a community, the Probable Maximum Flood (PMF) is given as the appropriate standard of flood for safety consideration, which has been adopted by Atkins.

In summary, the process of consultation has been sufficiently thorough and wide-ranging, although it has to be borne in mind that there is a disproportionate amount of representation of the views of stakeholders who use and enjoy the Heath, compared with those living or working downstream who are potentially at substantial risk from dam failure, but generally unaware of the risk.

3.2 Remedial options considered

The Hampstead Heath ponds pose an unacceptable societal risk so work is necessary. The question as to whether the proposed solution is technically appropriate has been raised in the consultation process generally in terms of the nature and scale of the proposed options impacting the amenity of the Heath, and in terms of downstream flood risk both from discharge during the natural range of floods and from dam breach .

Regarding the nature of the proposed works, the required flood is accommodated by a combination of increased temporary storage and supplementary overflow capacity. The design has been substantially modified during development in two key respects:

1. Re-designing most of the supplementary overflows in the form of “soft” grassed spillways instead of “hard” concrete structures to reduce visual impact on the character of the area. (Grass spillways are set at a level above the main overflow so that they carry flow only occasionally and in all but flood conditions are available for access and allow grass growth.) The exceptions are at those dams where physical or amenity constraints favour “hard” structures that are buried as much as possible to reduce visual impact.
2. Re-allocating the location of raised dams for temporary storage during floods to those dams where this minimises loss of amenity, and in one case (Catch Pit) building a new flood storage reservoir

A wide range of alternative options to address the dam safety hazard has been considered and evaluated, and a process of staged evaluating and short-listing of options and consultation has been carried out and given in reports at various stages. The options considered have all been arrangements for storage and discharge of floods by various arrangements of raising of dam crests and provision of additional spillways, plus an additional flood storage dam at Catchpit on the Hampstead chain.

The Preferred Options Report details the outcome of the process of the 3rd stage of engagement with stakeholders. It focuses on the preferred options / combinations for each chain of ponds and provides an indication of specific pond restoration and water quality works, including possible proposed mitigation and compensation measures for the impact of the engineering works. It describes two preferred options in detail at each chain. Both remedial options consider each chain of ponds as a whole system, and incorporates a passive system of floodwater management. We fully endorse the decision to engineer a passive system.

The options provide the following:

- A spillway at most ponds
- Crest restoration where overtopping is not tolerable
- Grass reinforcement where it is tolerable
- Current water levels in ponds will be retained
- Tree loss to be minimized
- New spillways to be set above existing water levels so will be dry with grass surface (either pre-grown turf on Enkamat, or by itself where velocities low)

Regarding the scale of the proposed works, this is constrained by the need to withstand the highest standard of flood (PMF) in view of the potential risk to life downstream. A separate risk assessment process that has established that the number of downstream fatalities attributable to a breach during flood (Section 5) makes the PMF standard both proportionate and necessary. Nevertheless, the scale of the works has been reduced where possible by allowing some of the peak flood to discharge over the embankment, where the nature of the embankment allows a limited amount of overtopping without causing significant damage.

The range of alternatives considered is wide-ranging and sufficient. The reasons for discounting these alternatives are stated in the relevant documents with an appropriate level of detail being given for this purpose.

Regarding the nature and scale of the proposed works, the required flood is accommodated by a combination of increased temporary storage and supplementary overflow capacity, providing a passive system that does not rely on human intervention during a flood event.

We consider a sufficient range of alternatives have been considered, and that those alternatives have correctly been constrained to a passive solution.

3.3 Preferred scheme

The preferred option for each chain was outlined in the presentation given at the meeting of 2 October 2014: Option 6 for the Highgate Pond chain and Option M for the Hampstead Pond chain. These are illustrated below

Figure 3.2: Highgate pond chain – proposed Option 6

Capabilities on project:
Water

Figure 3.3: Hampstead Pond Chain – proposed Option M

4 Downstream impact of proposed scheme

4.1 Introduction

Both the London Borough of Camden and Thames Water have an interest in any change to the flow passed downstream of the dams, either through the outlet pipes at Hampstead No 1 and Highgate No 1 which discharge into the drainage network, or over the proposed spillways which may impact surface water flooding downstream. This section assesses the impact of the proposed scheme on the flows passing downstream.

The proposed works include an increase in temporary storage within the ponds on the Heath both by raising some of the dam crest and provision of an additional storage area at Catchpit. The overall effect of this is to attenuate the flood hydrograph, reducing the peak flow but lengthening the time base of the hydrograph (Figure 2.1). Overall, the total volume is unchanged, but at any given point in time during the flood event, the volume passed downstream will be less.

Flow passes downstream of the ponds on the Heath by two routes. Firstly, flow passes through the outlet pipes at Hampstead No 1 and Highgate No 1 into the Thames Water drainage system. The amount of flow entering the drainage system is controlled by the difference in water levels in the downstream reservoirs of each chain, and the water level in the drainage system. As the proposals do not include any change to either outlet pipe, any change in the water levels in Hampstead No 1 and Highgate No 1 between the existing and proposed arrangement will impact the flow entering the drainage system.

Secondly, flow passes overland from overtopping of the dam crests in the existing situation, and over the spillways in the proposed situation. Such flows are controlled by both the water levels in Hampstead No 1 and Highgate No 1 and the length over which the spill occurs, i.e. the dam crests for the existing situation, and the spillway widths for the proposed. It has been established that the proposed spillway flow will be less than the crest overtopping flow.

The total flow passing downstream (pipe + spillway) will reduce due to the attenuating effect of the additional storage provided.

4.2 Impact on a Thames Water drainage network

At a meeting with Thames Water on 30th July, it was requested that Atkins check that the proposed works also did not affect the lower return periods (5 year, 20 year and 50 year), since Thames Water are only obliged to deal with floods up to a return period of 30 years. They were not concerned with larger floods of the kind that would be evaluated in a dam safety context, since in very large floods all the surface water systems would be full.

Atkins has provided us with the model results for both the lower return periods modelled for Thames Water, and for the 100 year, 1,000 year, 10,000 year and PMF, shown in the figures below for Highgate No 1. Note the 100 year proposed pipe flow result appears anomalous. We would have expected that the lower return period events would have been for the critical storm duration quoted in the Assessment of Design Flood report (2.9 – 3.9 hours). However it is clear that the results are from a much longer storm duration, and will therefore not show the highest peak flows. Nevertheless, neither of these apparent anomolies has any significant consequence on the scheme design or effects downstream of the proposed scheme and we are still able to draw the following conclusions:

- There is no crest raising proposed at Hampstead No 1. With the additional storage provided in the upstream reservoirs, the water level in Hampstead No 1 during floods that do not currently overtop the dam (10,000 year), must be lower than than existing. We can therefore conclude that for the Hampstead Chain, the peak flow into the drainage system will be lower for floods less than the 1 in 10,000 year event.
- Crest raising is proposed at Highgate No 1. However, once again, because there is additional storage provided in the upstream reservoirs, the water level in Highgate No 1 during floods that do not currently overtop the dam (1,000 year), must be lower than existing. We can therefore conclude that for the Highgate Chain, the peak flow into the drainage system will be lower for floods less than the 1 in 1,000 year event.

These show that the discharge from Highgate No 1 reduces significantly in terms of both flow and volume for the lower return periods. The discharge from Hampstead No 1 outlet pipe reduces in terms of peak flow, and a very slight increase in volume (2-4%) which is not significant.

Figure 4.1: Flow through Highgate No 1 outflow pipe for 5 year, 20 year and 50 year flood events

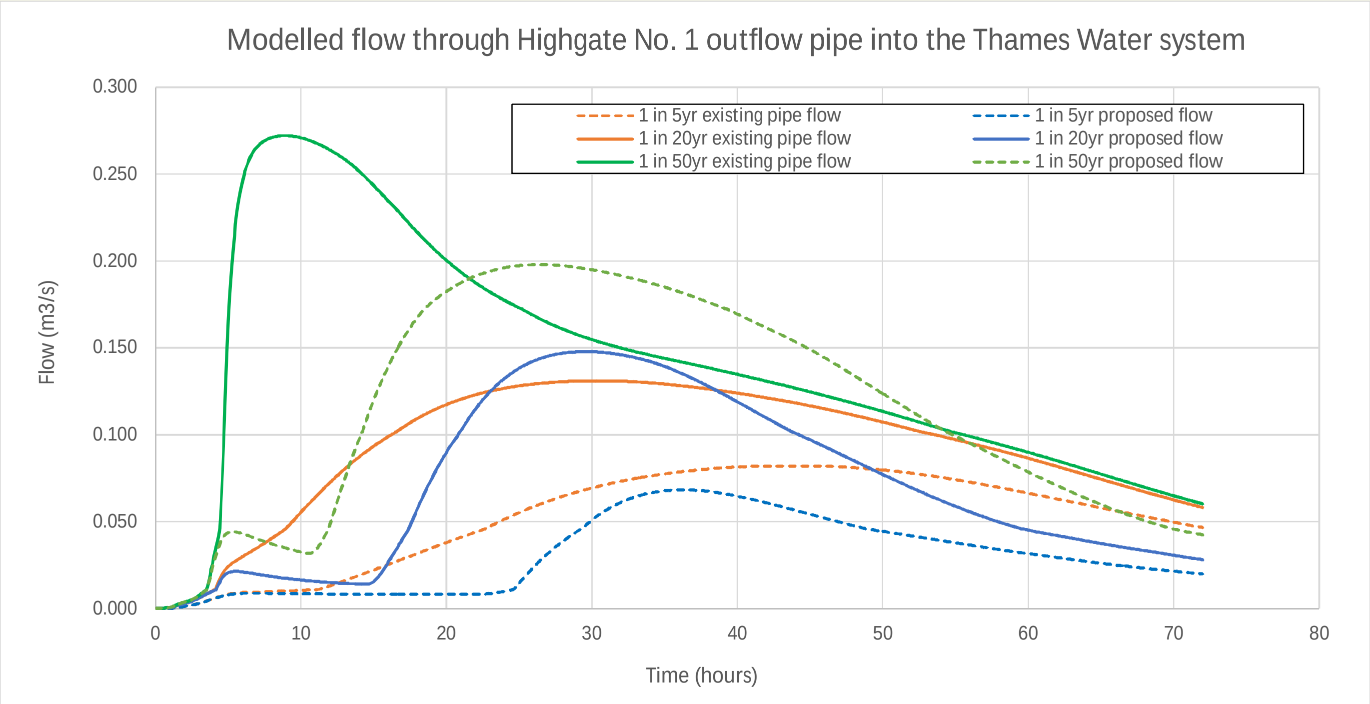
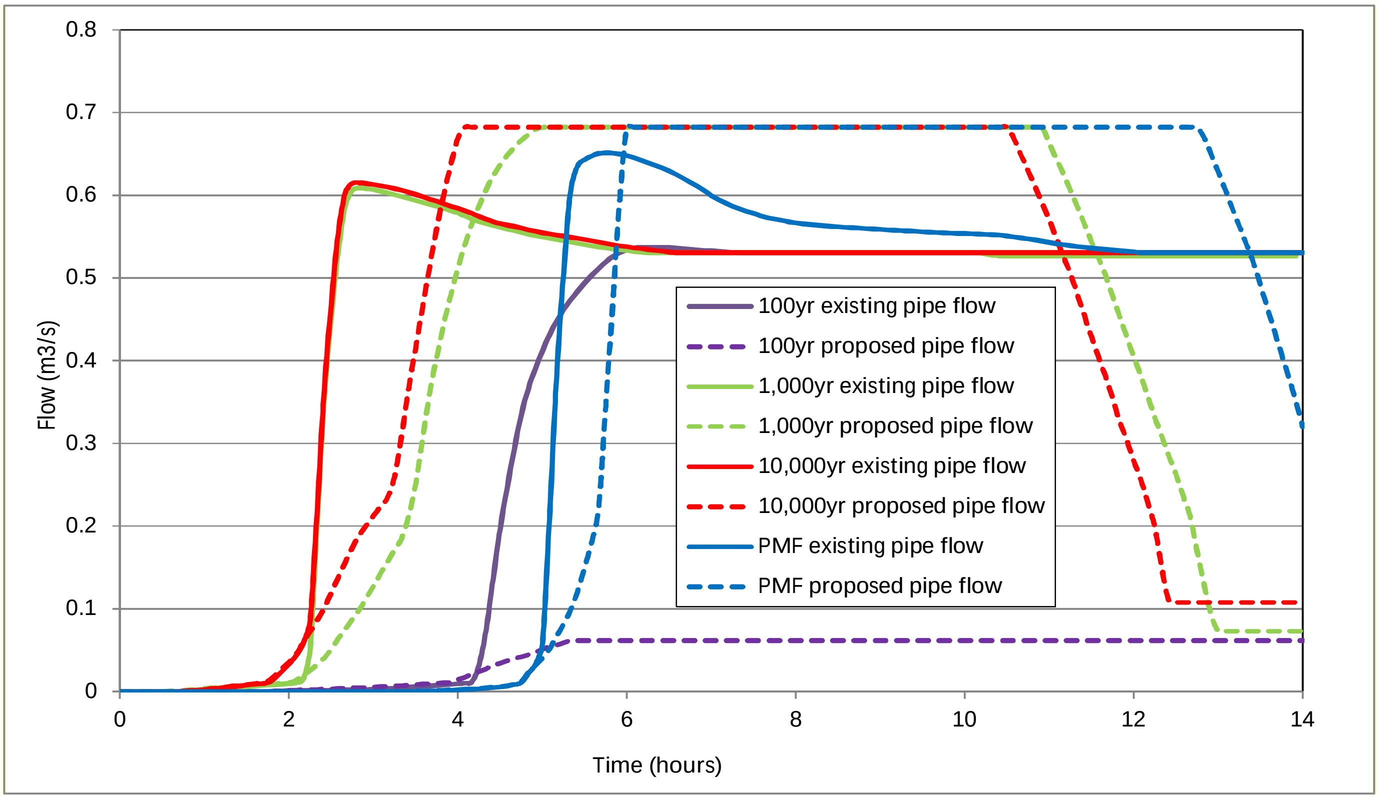


Figure 4.2: Flow through Highgate No 1 outflow pipe for 100 year, 1000 year, 10,000 year and PMF events



Because the results are for different storm durations, there is a discontinuity between the volumes discharged into the drainage network at lower return periods (5 year, 20 year and 50 year) and the higher return periods (Table 4.1 for Highgate). Nevertheless, there is a consistent reduction in volume over 72 hours for the lower return period events, and over 14 hours for the higher return period events between the existing and proposed pipe flow.

Table 4.1: Volumes discharged into the Thames Water drainage network from Highgate No 1 outlet pipe (m^3)

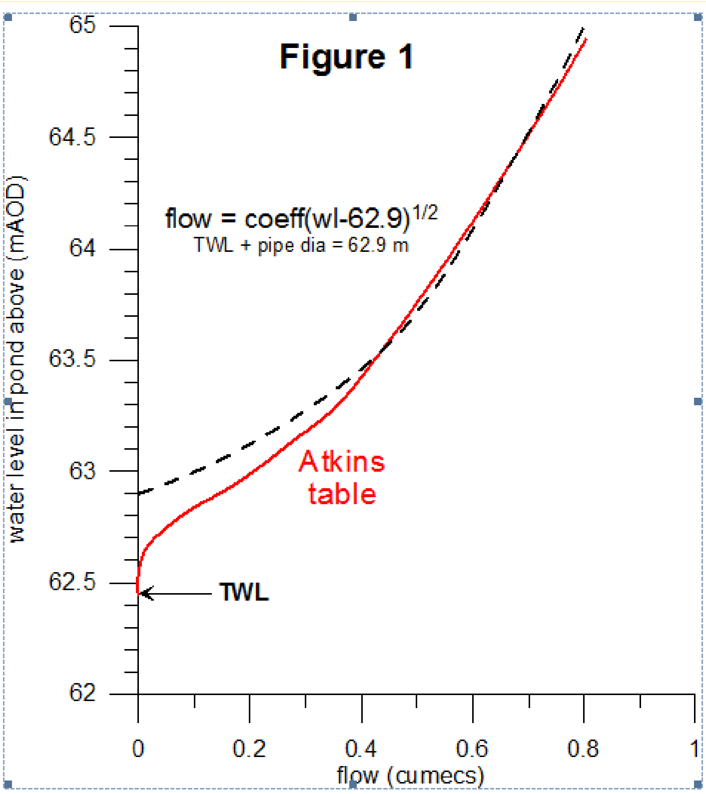
Return period	Existing	Proposed	Difference
5 year	13,793	8,020	-42%
20 year	24,080	18,519	-23%
50 year	36,490	29,998	-18%
100 year	17,772*	2,149*	-88%
1,000 year	22,649	21,347	-6%
10,000 year	22,856	21,539	-6%
PMF	199,594	157,508	-21%

*anomalous result

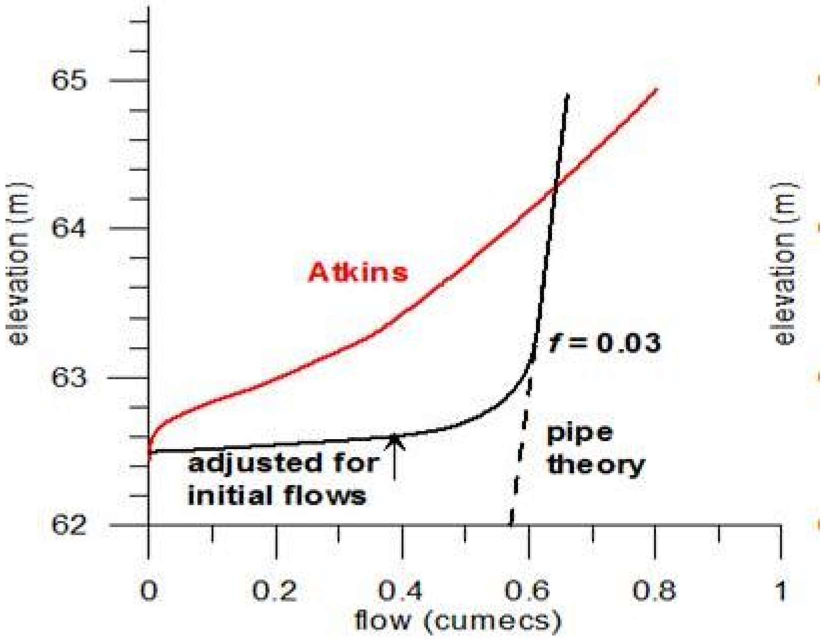
Thames Water confirmed by email on 14th October 2014 that following review of the modelled flow figures supplied by Atkins, they have no objection to the proposed scheme, commenting “the sewer network in the vicinity of the ponds is typically more susceptible to intense convective type rainfall and as the inflows from the ponds are attenuated, overall the changes proposed by the City of London will result in an increase in the available peak capacity within the sewer network”.

4.3 Modelling of Highgate No 1 outlet pipe

We have been asked to include in our review, comments received from Brookfield Mansions Ltd, which include a paper from Professor K R Rushton regarding the overflow from Highgate No 1. In it, he presents a graph showing the Atkins rating curve for the Highgate outlet pipe (in red below), and from it, draws the conclusion that Atkins have used some form of orifice equation to calculate the flow through the Highgate No 1 outlet pipe.



Professor Rushton goes on to explain that the flow through the pipe should not be estimated by orifice theory, but by hydraulic pipe theory. He has plotted the difference in the graph below.



In fact, the hydraulics of the overflow pipe will be a combination of types of hydraulic flow. To start with, when the inlet of the pipe is not submerged, the flow will be controlled by a weir type flow at the inlet. As the water level rises and begins to submerge the inlet, orifice flow will occur. As the downstream pipe is supercritical, this flow type will continue until the pipe approaches full, at which point air will be expelled and full pipe flow will govern the discharge. The discharge curve will therefore follow Atkin's red line until it is intersected by the black line, whereupon it will follow the pipe theory curve. For Highgate No 1, this transition point between orifice theory and pipe theory occurs when the reservoir level is above the crest of the dam and therefore the stage is not reached where this would come into effect. Atkins discharge curve is consistent with this and we consider their rating curve to be appropriately derived within the normal limit of accuracy of standard hydraulic calculations.

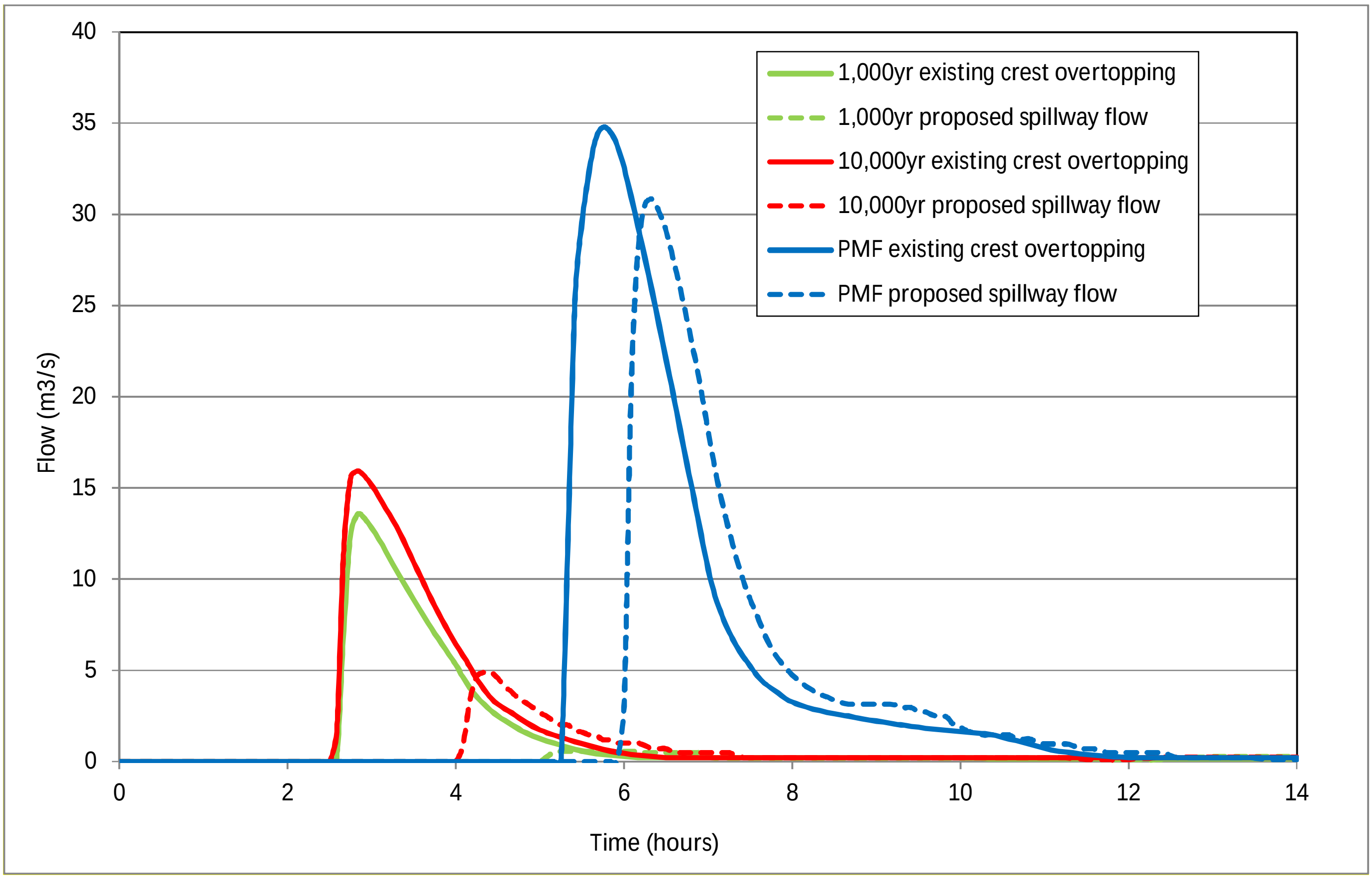
4.4 Impact on flooding downstream

One of the requirements of the project was to ensure that the frequency and volume of floodwater passing downstream of the ponds was not increased by the proposed works. Atkins checked this for the design flood (PMF) once a design arrangement had been established that ensured no overtopping of any of the dams where overtopping would not be tolerable. Then, for the purposes of the Flood Risk Assessment, the 1:100, 1:1,000 and 1:10,000 events were checked to compare the volumes of floodwater overtopping the existing dam (in the existing case) against the volumes discharging over the proposed spillways. This is shown in the figure and table below for Highgate No 1. It can be seen that there is a reduction both in peak flow and volume being discharged overland from the new spillway. This is to be expected, as the proposed works provide greater temporary storage capacity by the provision of a new dam at Catchpit, and by raising some of the dam crests. The proposed works will therefore reduce the contribution from the Heath to downstream surface water flooding. Although this is not the primary aim of the project, the proposed works will provide some benefit in terms of flood alleviation.

Table 4.2: Downstream overland flow volume discharged from Highgate No 1 over 14 hours (m^3)

Flood event	100yr	1,000yr	10,000yr	PMF
Existing crest overtopping	17,772	65,362	81,981	199,285
Proposed spillway flow	0	0	26,847	157,508

Figure 4.3: Existing and proposed flow discharged overland downstream

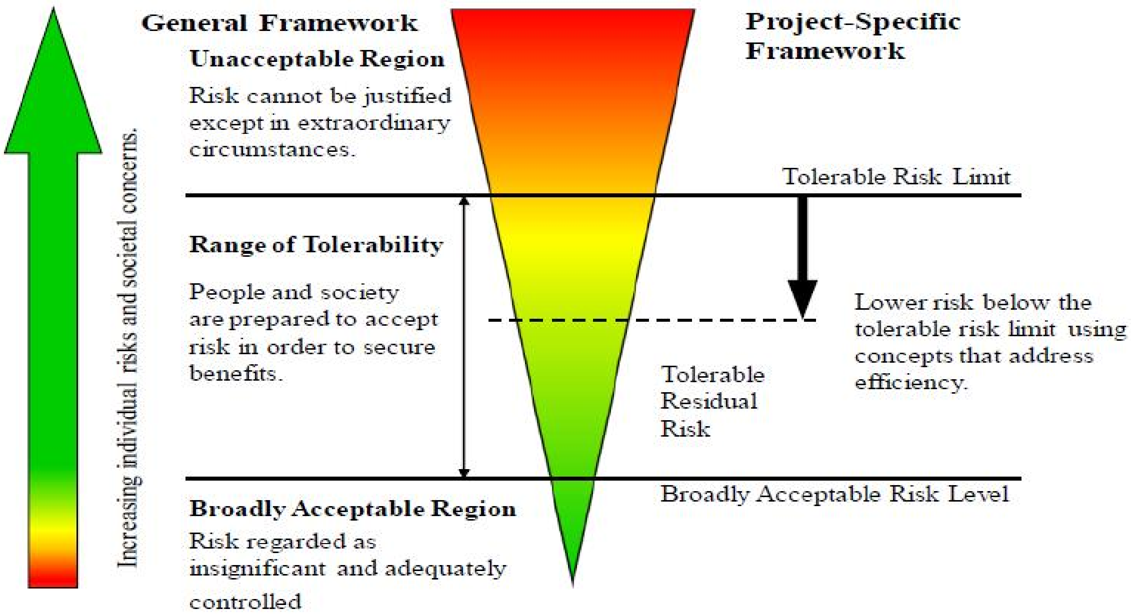


5 Evaluation of Risk

5.1 Risk Assessment

In the Health and Safety Executive's (HSE) 2001 publication *Reducing risks, protecting people*, tolerability of risks is examined, both in terms of addressing hazards at work, and also to the general public. It sets out a framework to aid the decision on whether risks are unacceptable, tolerable or broadly acceptable. Tolerable in this context refers to a willingness by society as a whole to live with a risk to secure certain benefits – in other words the risk is worth taking, provided they are confident that the risks are being properly managed and reduced still further if practicable. Except in exceptional circumstances, risks that fall in the unacceptable region must be reduced by structural or non-structural measures, irrespective of the cost, to bring them down into the range of tolerability. Even if a risk is in the 'range of tolerability', it should be reduced to be 'as low as reasonably practicable' (ALARP). The ALARP principle is met when it is deemed grossly disproportionate in terms of expending resources to gain any further reduction in risk.

Figure 5.1: Risk framework



Although there is currently no statutory requirement to apply a "risk-based" approach to reservoir projects, it has been adopted in revised guidance currently in preparation (*Floods and Reservoir Safety, 4th edition, ICE)* as an alternative to the current "standards-based" approach, to assist in determining the degree of extreme flood that needs to be accommodated to achieve a degree of safety proportionate to the circumstances at the reservoir. This approach assesses the likelihood of failure of a dam, the consequences in terms of likely number of fatalities, damage to infrastructure, cultural heritage and environment, and provides tools to assess the proportionality of the proposed works to reduce the risk. The method uses procedures for risk assessment that have been developed for reservoirs based on practice in other high-hazard industries, and is set out in the recent Defra/EA publication: *Guide to risk assessment for reservoir safety management*, 2013 (known as the RARS guide). The aim of this approach is to ensure that proposed works reduce the risk to society to a tolerable level, and that the scale of the works is proportionate to the risk.

5.2 RARS Procedure

The purpose of the RARS guide is to provide a tool for the management of reservoir safety using risk assessment methods. The guide sets out 3 “tiers” for the analysis, the steps for each being identical, but with an increasing level of detail. Tier 1 is essentially a qualitative assessment, whilst Tier 2 and Tier 3 provide increasingly detailed quantitative assessments. The procedure is as follows:

- Risk identification: failure mode identification
- Risk analysis: estimate likelihood of failure, assess consequences of dam failure
- Risk evaluation – tolerability of risk assessed, options to reduce risk, proportionality of options

The final step of risk evaluation determines whether society can accept the level of risk, i.e. does it lie in the unacceptable, ALARP or broadly acceptable region. Should the risk be unacceptable or in the ALARP region, the reduction in risk afforded by mitigation options is then assessed. Cost estimates of the mitigation options can then be compared with the value of preventing a fatality to determine whether the cost of the works is proportionate to the risk.

A risk assessment has been carried out on this basis for the Hampstead Heath chains by Atkins, and is reported in *Hampstead Heath Ponds Quantitative Risk Assessment – Interim Report*, August 2013. The assessment was subsequently updated for amended modelling (which included the removal of the A400 bridge), and including detailed survey of the number of basement flats in the inundation area downstream, reported in *Consequence Analysis Technical Note*, September 2014, These reports are reviewed and commented upon in the following sections.

5.3 Assessment of Probability of Failure of Hampstead Heath Ponds

Atkins identified 3 main credible failure modes: overtopping, internal erosion and slope failure. Using procedures in the RARS guide, informed by the overtopping assessment, they have derived annual probabilities of failure (POF) for the Highgate and Hampstead chains for the existing structures.

In general, we agree with Atkins’ assessment of POF. They have made some generalised assumptions, such as a standard response curve to overtopping used for all dams; but these are appropriate to the level of detail of the study (Tier 2). Further refinement, while possible, would be unusual for such a project, and would not alter the overall outcome, which clearly indicates the probability of failure from overtopping grossly exceeds acceptable levels for dams in such situations.

The POF of the Highgate chain is dominated by the POF of Stock Pond, assessed by Atkins to be 1 in 23, based on the likely frequency of overtopping, and is more than one order of magnitude greater than the POF of any other ponds in the chain

The studies do not extend to consider the POF of the Kenwood ponds upstream of Stock Pond. However for the current situation, the higher order of magnitude of the POF of Stock Pond means the additional effect on the POF of the chain from the Kenwood Ponds is insignificant.

We have used their figures to assess the POF for each chain following implementation of the proposed works, assuming the POF due to overtopping is reduced to 2.5×10^{-6} (PMF equivalent return period of 1 in 400,000 years). For this calculation, it has been assumed that no other measures to address other defects or shortcomings (leakage/settlement, integrity and adequacy of outlet arrangements etc) are carried out. The figures are given in the table below. They show that currently, the dominant mode of failure that influences the POF for both chains is failure from overtopping.

Following implementation of the proposed scheme, the dominant mode of failure for Highgate remains as overtopping. However, for the Hampstead chain, the dominant mode of failure post-scheme is internal erosion.

Table 5.1: Existing and post-scheme Probabilities of Failure

Failure mode	Highgate		Hampstead	
	Existing	**Post-scheme**	**Existing**	**Post-scheme**
Overtopping	1 in 23	1 in > 400,000	1 in 1,900	1 in > 400,000
Internal erosion	1 in 1,650,000	1 in 1,650,000	1 in 30,000	1 in 30,000
Stability	1 in 671,000,000	1 in 671,000,000	1 in 671,000,000	1 in 671,000,000
Total	1 in 23	1 in 320,000	1 in 1,800	1 in 28,000

5.4 Consequence of Failure of Hampstead Heath Ponds

In the second part of their analysis, Atkins have undertaken a consequence analysis using dam breach modelling results to estimate the population at risk, and the resulting loss of life (ASLL) from a PMF event leading to failure of both chains. Dam breach initiation and formation processes are extremely uncertain, particularly for historic dams where there is little information about the material forming the embankment, which is one of the major controlling factors of breach formation. It is therefore common for this level of analysis to use empirical methods to estimate the breach parameters. Atkins have assumed that the dams start to breach after they have experienced overtopping flow for 1 hour, and that it takes a further 1.5 hours for the full breach to form. These assumptions are within the valid range but are by no means the worst case scenario. In our view, they may be an overestimate: other empirical breach prediction equations suggest the time to full breach could be as short as 0.25-0.5 hours. A shorter breach formation time would result in a higher peak outflow, and likely increase the ASLL figures.

Analysis carried out by Atkins in their interim QRA report for different assumptions on the number of basement flats in the inundation area revealed the resulting figures of ASLL were extremely sensitive to these assumptions. Subsequently, Atkins undertook a detailed survey of the types of properties in the inundation area using virtual walkover survey supplemented by site visits. This is reported in *Consequence Analysis Technical Note*, September 2014, and has provided a much more robust estimate of ASLL.

The relevant number of fatalities is the incremental loss of life attributable to dam breach i.e. discounting the loss of life that would arise from the flood event without breach The studies (including supplementary information provided for this review) indicate that the incremental number of fatalities (ASLL) that would arise from dam breach compared with that arising from the extreme flood alone is in the range 31 to104, depending on whether a 20% or 100% fatality rate is assumed for the basement flats. We agree that the fatality rate in such properties is likely to be higher than elsewhere, and would lie within this range, although possibly towards the lower figure. Such assessments will always contain uncertainties, but nevertheless, we regard the range currently derived for the number of fatalities as valid. Loss of life from lesser floods causing dam failure will also be significant and likely to be in a similar range.

Atkins ASLL figures assume both chains fail. Failure of each chain has not been modelled explicitly. However, we have drawn some information from Haycock's September 2010 report6, for which loss of life figures for each chain are quoted for a PMF flood event, with and without breach, shown in Table 5.1 below. This suggests the incremental ASLL for each chain are the same. The figures are also much higher than the Atkins' estimates, indicating the uncertainty involved in such analysis, but we can infer that Atkins' figures are not overly conservative. In the following analysis, we have assumed that the ASLL is apportioned equally between the reservoir chains (i.e. between 15 and 52 for each).

It should be noted that the of loss of life (ASLL) estimated by Atkins may be underestimated as it does not include potential loss of life related to transport infrastructure, i.e. users of roads, underground and train lines within the area at risk. These losses could be considerable, as there are numerous Network rail routes, tube lines and main roads within the potential worst case inundation area.

Table 5.2: Loss of life figures from previous Haycock work

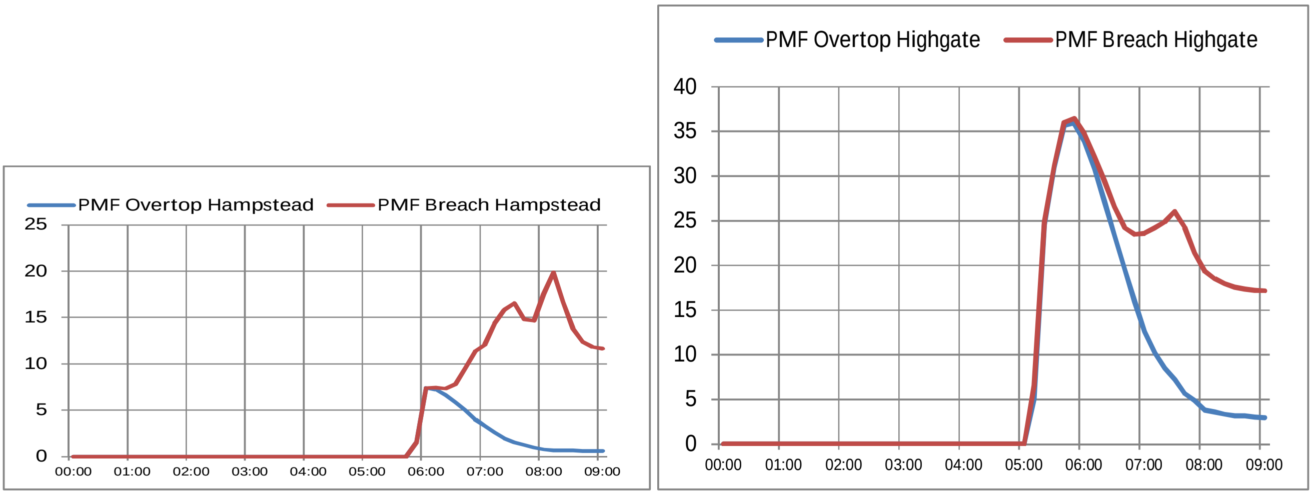
	Hampstead	**Highgate**	**Total**
Population at risk (PAR)	467	2602	3069

[6] *HiDEP Work Package 6 – Flood Envelope Model,* Haycock Associates Ltd, 23 September 2010

ASLL, PMF no breach	209	831	1040
ASLL, PMF breach	415	1037	1452
incremental ASLL	206	206	412

Usually, the flow intensity of a dam breach flood in terms of depth and velocity is considerably higher than the peak of a natural flood, and incremental fatalities are caused by the additional intensity of flow, as well as the additional volume of the flood that causes a greater area to be inundated. This is the case for Hampstead, but not for the Highgate chain, where the PMF peak flow (approximately 36 m^3/s) is higher than the peak of the subsequent dam breach flood (approximately 26 m^3/s) (Figure 5.2). This means that for the Highgate chain, fatalities cannot be attributed to the additional intensity of flood resulting from breach of the dam during PMF, although fatalities can be attributed to the additional volume of the flood, that would cause a greater area to be inundated to a degree that would cause fatalities. Furthermore, fatalities can also be attributed to additional intensity and volume from dam breach over the whole range of flood events of less severity than the design flood. For such lesser floods, incremental loss of life would also be significant, and a major consideration in the assessment of risk.

Figure 5.2: Comparison of Overtopping and Breach Hydrographs



5.5 Risk Evaluation for Hampstead Heath Ponds

Using the estimated POF and ASLL figures, the acceptability of risk can be evaluated by plotting the probability of failure and the number of fatalities on a chart that also has accepted zones of “Unacceptable” and “Broadly Acceptable” with an intermediate zone defined as requiring risk to be brought to As Low As Reasonably Practicable (ALARP). The chart is provided in the RARS guide and has been adopted from HSE (2001)[7] and Le Guen (2010)[8]. This is shown in Figure 5.3 below. It can be seen that the risk from the existing structures in both the Highgate chain and the Hampstead chain of reservoirs lie within the unacceptable region and the risks must be reduced, irrespective of the costs.

Plotting the position following implementation of the proposed scheme then uses the post-scheme POF and the appropriate loss of life for the dominant mode of failure. For Highgate this remains the same at between 15 and 52 as the incremental loss of life from a breach during a flood event. For Hampstead, this is the ASLL assessed for a sunny day failure from internal erosion. This has not been reassessed for the updated dam breach modelling and basement flat levels, but we have attempted to make an appropriate adjustment for this to the figures quoted in the Interim QRA report. This indicates that following implementation of

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[7] *Reducing Risks, Protecting People, HSE’s decision-making process*< HMSO, 2001

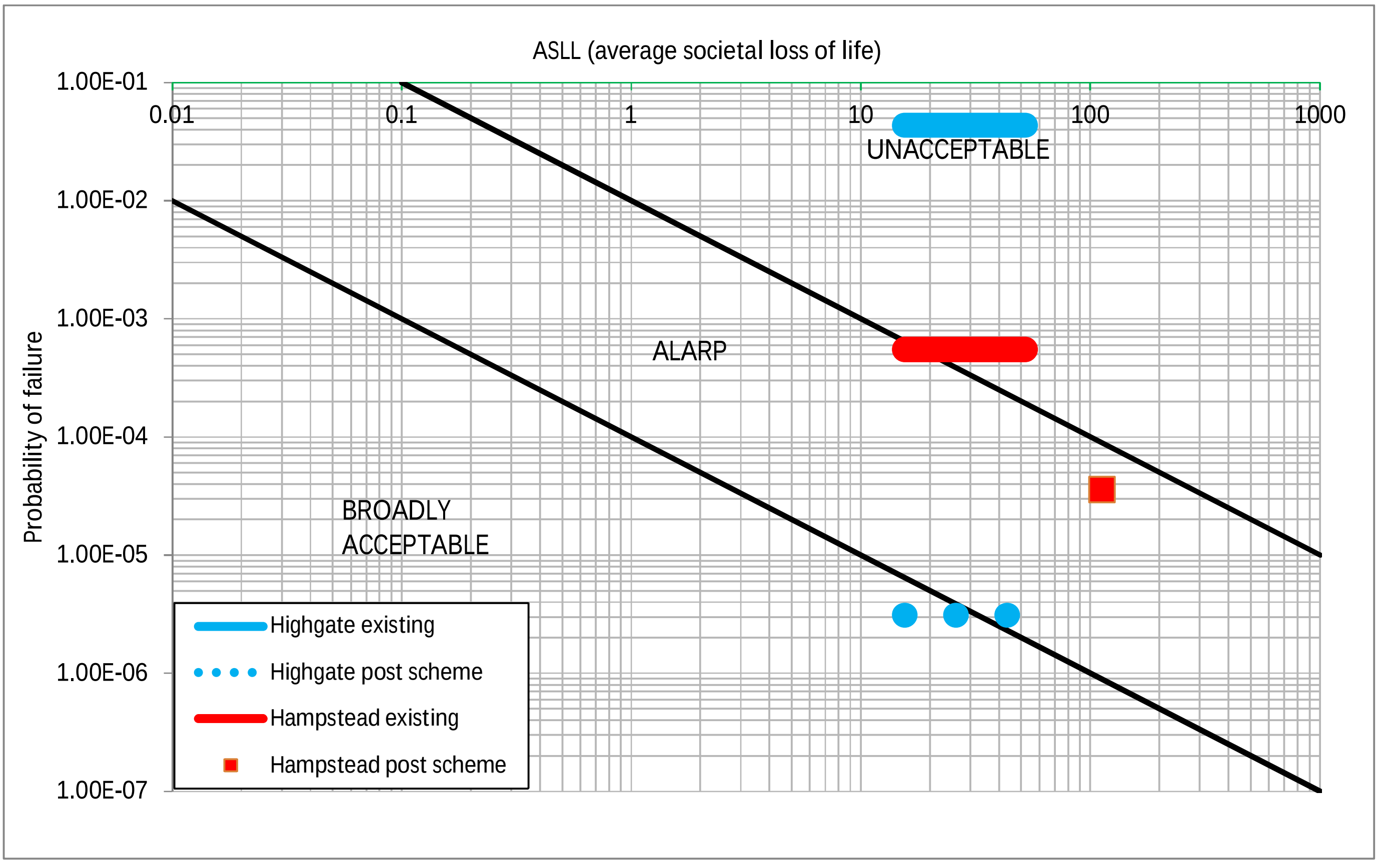
[8] *Exploration of the Tolerable Risk Guidelines for Levee Systems*, Le Guen, Proceedings of the Workshop, Exploration of Tolerable Risk Guidelines for the USACE Levee Safety Program, 2010, USACE

the scheme, both chains of reservoirs move out of the unacceptable region into the ALARP region. The risk posed by the Highgate chain moves towards the lower boundary of the ALARP region, whilst the risk from the Hampstead chain lies just in the ALARP region, towards the upper boundary.

This indicates that the proposed scheme successfully reduces the risk to society for both the Highgate chain and Hampstead chain to a tolerable level, although it indicates the importance of including additional work where practicable to reduce the risk of internal erosion on the Hampstead chain. It certainly does not indicate that the reduction in risk is excessive nor gives justification that the works could be designed for a lower return flood period event.

The proposed scheme reduces the risk to the dams from flood to a level where the greatest residual risk lies with other causes of failure. It is understood that where other potential defects and deficiencies at the dams are identified as significant, such as blocked outlet pipes and an area of settlement and leakage at Mens Bathing Pond Dam, measures will be included in conjunction with the works to reduce these risks where reasonably practicable.

Figure 5.3: Risk evaluation



*ASLL for Hampstead post scheme is greater because the applicable ASLL figure is the total, not the incremental value

The final step in the risk assessment procedure is to consider proportionality: whether the costs of the measures to reduce the risk are proportional to the reduction in risk achieved by those measures. This is done by calculating the cost to prevent a fatality (and damages if to be included) (CPF) and comparing it with the value of preventing a fatality (VPF). The ratio of CPF to VPF is then the proportional factor (PF). Gross disproportion is required before ALARP is satisfied. HSE guidance on this (www.hse.gov.uk/risl/theory/alarp.htm) states:

"*Nuclear Safety Directorate takes as its starting point the HSE submission to the 1987 Sizewell B Inquiry that a factor of up to 3 (that is costs three times larger than benefits) would apply for risks to workers; for low risks to members of the public a factor of 2, for high risks a factor of 10*

The value of preventing a fatality (VPF) as assessed by the Department of Transport is £1.7 million in 2012 (www.dft.gov.uk/webtag/documents/expert/unit3.4.1.php).

Budget costs have been provided from City of London at £15.2million +or- 15% at Q4 2010. This has been updated to £17 million to represent 2015 prices. The calculation is complicated by the fact that there are two chains with different probabilities of failure before the works are carried out, so the proportionality must therefore be analysed for each separately, requiring the costs to be separately between the two chains. As a broad indicator of costs, the volume of dam raising (including the new dam at Catchpit) has been used. The raising volume for Hampstead is approximately 10% smaller than Highgate; however there will be additional costs involved in forming the new dam at Catchpit. We have therefore assumed that the project costs can be apportioned equally between the Highgate and Hampstead chains.

Excluding damages and based on the value of saving lives only, the proportion factor for the Highgate chain lies between 0.07 and 0.25, depending on the ASLL. For Hampstead, the factor lies between 6 and 21. This should be compared with a factor of 10, deemed to be the threshold of disproportionality by the nuclear Safety Directorate.

There are many uncertainties involved in dam breach modelling and consequence assessment. Atkins have carried this out using assumptions that are broadly acceptable and valid, but may underestimate the consequences in two aspects: namely the time to failure may be overestimated leading to a lower breach flow intensity, and by ignoring the fatalities associated with the transport network, the ASLL may be underestimated. Conversely the probability of failure of the Highgate chain may be overstated. Whilst Atkins have provided an estimate of the probability of failure in accordance with the RARS procedure of 1 in 23 (giving a probability of failure of 4.35×10^{-2}), precedent suggests that the dams could withstand a higher flood event than this, given the chain withstood the August 1975 event, which in all likelihood, was more severe than a 1 in 23 event. The 1975 event is discussed in greater detail in section 6. We have very approximately estimated return period of the event on the Highgate chain as 1 in 200 years. As a sensitivity check on the proportion factor, we decreased the probability of failure of Highgate chain to 1 in 200. The proportion factor increases to between 0.6 and 2.2, but still remains well below the threshold of disproportionality, implying that the cost of the scheme is entirely proportionate to the reduction in risk achieved.

For the Hampstead chain, the ASLL would have to be below 30 before the scheme would be deemed to be grossly disproportionate. Given the potential underestimation in this figure discussed above, it is our view that the cost of upgrading the Hampstead chain also lies below the threshold of disproportionality.

Our analysis above indicates that the proposed scheme reduces the risk to society from a clearly intolerable level to a tolerable one. Further, it indicates that the scale and costs of the proposed scheme are not grossly disproportionate to the reduction in risk achieved.

6 Consideration of objections to the scheme

A large number of objections have been levelled at the proposed scheme, including a petition signed by over 11,700 people. However English Heritage, Natural England and Thames Water have no objection to the application. The majority of objections from the public reveal a lack of understanding of the risk posed to downstream residents by the dams, and as such, to them the works appear unnecessary and disproportionate. Although the ponds may look natural, they are not, and they pose a risk that natural water bodies do not: namely the presence of a man-made dam which retains the water behind it, which could fail and result in a sudden and catastrophic release of water downstream.

More specific objections on technical grounds have been received and we have been asked by LBC to specifically consider objections received by Mr Jeremy Wright on 23/7/14, Brookfield Mansions Ltd on 13/10/14, and the Heath and Hampstead Society on 04/11/14, to determine whether their responses to the planning application identify any reasonable concerns about the technical content of the submission. The following section discusses these responses, and we have also addressed some other key objections that have been expressed either on the planning portal or within documentation relating to the judicial review.

We have drawn the relevant parts of our review together in the following section to specifically comment on these objections of a technical nature. These objections are essentially:

1. There are special circumstances regarding the dams on Hampstead Heath which make application of the ICE Guidance questionable
2. The scheme is disproportionate, and is based on an irrational approach to risk, being designed to an event with a probability of 1 in 400,000 (PMF) which this exceeds the design basis of any ordinary civil engineering project
3. The Planning Application is solely designed to prevent dam breach, so that the City of London complies with its perceived legal obligations. It is not designed to reduce the amount of flood water that overtops the dams, or to reduce surface water flooding in the downstream communities.
4. The area downstream would already be flooded prior to dam failure so the storm itself would provide warning. The loss of life due to dam failure would therefore be zero
5. Alternatives that include active systems such as early warning should have been considered
6. The dams did not fail during the 1975 storm and have not failed in their 300 year history

1. Special Circumstances

The ICE guidance is relevant to reservoirs in all situations prevailing in the UK, not just to those referred to of communities located some miles downstream of a reservoir, or collapse of dams on upstream remote hills. The circumstances at Hampstead Heath regarding risk, safety and law are no different from typical relatively small lowland reservoirs except for three aspects:

- the untypically high extent of urban development downstream,
- the complete covering of the downstream watercourse in the Fleet that forms part of the local drainage network.
- the requirement for preservation of the Heath under the Hampstead Heath Act

The untypically high extent of urban development downstream results in an unusually high population and associated infrastructure being potentially at risk in the event of a breach of the dams. This has been taken into account qualitatively in assigning the dams as Category A in terms of the ICE floods guide, i.e. a case “where a breach could endanger lives in a community”, and has been confirmed quantitatively as appropriate using a risk-based approach. The high population in the downstream areas potentially at risk is severely under-represented in the responses to the consultation on the proposals.

The complete covering of the Fleet watercourse to form part of the local drainage network has been fully taken into account by assessing the flow hydrograph entering the drainage network and the residual flow, and the acceptance of the results by Thames Water.

The requirement for preservation of the Heath under the Hampstead Heath Act raises a question of which of the conflicting legal requirements (preservation under the HH Act, or reservoir safety under the Reservoirs Act) takes precedence. This matter of interpretation of the law remains unresolved and it is understood that enquiries made by Atkins to government have received a response that this would be a matter for the courts. The measures taken to resolve the apparent conflict between the interests are to implement the requirements of the Reservoirs Act to achieve the standard of reservoir safety appropriate to the potential risk to downstream interests including risk to life, in a manner that accommodates the interests expressed for preservation of the Heath as much as is practicable. This includes providing "soft" engineering solutions such as grass spillways and scaling down the proposed works to make use of the ability of some of the dams to withstand occasional limited overtopping

2. Interpretation of risk

The assertion that the project is based on an illogical interpretation of risk does raise a potentially valid point. As explained in Section 1.3, as an alternative to the "standards-based" approach, new ICE guidelines (*Floods and Reservoir Safety, 4th edition)*, when published, provides for an alternative "risk-based" approach. This approach can be used to check whether the risk to society posed by the existing structures is tolerable, and if not assess whether proposed mitigation measures are proportionate to the reduction in risk. This procedure has been followed by Atkins to produce their QRA report. We have used the data to infer a further outcome in terms of the proportionality of the proposed scheme, which is reported above. The result confirms that the works are proportionate with reduction in societal risk, are therefore entirely logical, and there is no supporting reason to reduce the design standard for the proposed scheme.

3. Purpose of the scheme

Mr Wright states in his letter that the Planning Application is solely designed to prevent dam breach, so that the City of London complies with its perceived legal obligations, and that it is not designed to reduce the amount of flood water that overtops the dams, or to reduce surface water flooding in the downstream communities. The scheme *is indeed* designed to reduce the amount of flood water overtopping the dams, by directing flow safely over spillways rather than the dam crests. The project is a dam safety project, not a flood alleviation scheme and we are agreement that it is not primarily designed to reduce surface water flooding in the downstream communities. The purpose of the scheme is to safeguard against the large loss of life in those communities by preventing failure of the dams. By virtue of the increased storage provided, the scheme will provide a measure of flood alleviation over that which currently exists, or would exist if the dams were not present as discussed in Section 4.

4. Downstream loss of life

There is an assertion in Mr Wright's objection to the planning application that the incremental loss of life following failure of the dams would be zero. This assertion is made on the basis that breach of the ponds will occur around 6 hours after the start of the storm, at which point, the concurrent flooding downstream would mean that all the people in the area would either already be drowned, or have escaped. We do not agree or accept this assertion for the following reasons:

- The conditions downstream area could be anything from dry to extreme flooding, depending on the size and path of the storm cell generating the rainfall. As such, it cannot be assumed with certainty that widespread severe flooding downstream will occur concurrently.
- The Risk Assessment has established there is a substantial incremental loss of life, over and above those fatalities caused by the natural flood alone. It is our view that the incremental number of fatalities presented in the updated Risk Assessment of 31 to 104 represents a reasonable and valid estimate.

5. Active v passive systems

At the outset, the Supervising Engineer and the City of London determined that the mitigating measures to reduce the risk of dam breach should be limited to engineering works and should not include active systems such as early warning or intervention.

The storm itself does not provide warning of dam break that would result in a sudden and significant increase in flood above that arising from the storm itself as shown by the hydrographs produced for the QRA study. The Guide to Floods & Reservoir Safety (3rd and 4th Editions) and the Risk Assessment for Reservoir Safety Guide both state that for the "base case highest individual risk and average societal life loss it should be assumed that there is generally no warning". Guidance is that warning and evacuation will not be effective unless there is a minimum of 2 hours travel time of the dam breach hydrograph before it reaches the downstream community, i.e. the community is at risk 2 hours after the dam fails. This is not the case for the Hampstead Ponds, where the community at risk is immediately downstream.

Appendix C of the Preferred Options Report notes discussion at the meeting on QRA of 27 September 2013 on the matter of "early warning – both warning people and having weather warnings. Heath officers, or Police and Fire (officers) cannot be expected to go in as it will be too dangerous".

The Designer's view elaborated informally at the presentation made on 2 Oct 14 is that it is likely that a significant time would be required to receive and respond to an alert of possible dam failure, assess the situation, and then issue a warning downstream, before activating an emergency plan and moving people. The matter of response to warnings has been further addressed by Atkins' "Additional Comments" given in response to a further submission from the Heath and Hampstead Society dated 4 November 2014 and addressed below. We fully agree with Atkins' views on this matter.

Best practice has therefore been followed in this case by assuming no warning when estimating the loss of life and we fully endorse this approach. In the context of the Hampstead Heath Ponds, and having due regard to the likely time to breach and location of the population at risk, it is our view that any such active systems are not appropriate, would not provide the level of protection that the public at risk downstream is entitled to reasonably expect and would not constitute best practice.

A passive system is the only way to reliably achieve the required reduction in risk. Whilst early warning systems may be desirable or even necessary in terms of Civil Contingencies procedures, they do not detract from the need to prevent dam failure in the first place as required by the ambit of the Reservoirs Act. We consider that the alternatives considered have rightly been constrained to a passive solution.

6. Previous overtopping

Many of the objections raised the topic of previous behaviour of the dams to date. They either question the need for the upgrading works to be carried out at all, or question the scale of the works, and why they are designed to such a stringent flood standard.

We have dealt with the matter of the appropriate flood standard in Section 5. Not only does the PMF standard comply with the ICE guide for Category A dams, i.e. a case "where a breach could endanger lives in a community", but it also brings the risk to the downstream population to within tolerable limits of risk to society based on accepted guidance (Health and Safety Executive, 2001[9], Environment Agency, 2013[10]) (see section 5.5). Relaxing the design flood to a lesser standard would not reduce the societal risk to an acceptable level.

The need for any works at all to be carried out is questioned by a number of objectors, given the dams have not failed in their 300 year history, even during the most serious event recorded in the area which occurred in 1975. The 1975 event has been analysed by Haycock[11]. They estimate the rainfall on the Highgate chain to have been 99.5mm, and 127.4mm on the Hampstead chain. This equates to approximately a 1 in 350 year rainfall depth over Highgate, and approximately 1 in 750 over Hampstead over 3 hours. A storm of a certain return period will not necessarily generate a flood of the same severity, due to variations in catchment conditions prior to the storm – if the catchment is very dry prior to a rainfall event, the resulting flood runoff will have a lower return period. Haycock report there was little rainfall prior to the 1975 event, so one would expect the catchment to be dry and for a considerable proportion of rainfall to be lost before any runoff was generated. As a very rough estimate, the flood return period of the 1975 event could therefore perhaps be somewhere in the range of 200 – 500 years.

Haycock report that observations by City of London staff during the storm event suggest that all the dams on the Heath except for Hampstead No 1 and Highgate No 1 overtopped. The overflow pipe of Viaduct Pond was washed away, and there was a substantial slip on the downstream face of Hampstead No 2. Intervention was required at Highgate No 1, where the outlet pipe was opened to prevent it overtopping. It is clear from the observation reports, that at Viaduct and Hampstead No 2, the process of failure had commenced but was not completed. It was only the short duration of the storm which limited the duration of overtopping of the dams, and intervention to open the Highgate No 1 outlet pipe (although this may have had limited effect), that prevented a full scale cascade dam failure. Thus, the fact that the dams survived the 1975 event cannot be taken as evidence

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[9] *Reducing Risk, Protecting People*, HSE, 2001

[10] *Guide to risk assessment for reservoir safety management*, Defra/Environment Agency, 2012

[11] *HiDEP WP20* - *Review of the August 1975 Storm relative to the 1:10,000 year rainfall event*, July 2011, Haycock Associates

that the dams would not fail during a more severe event. In fact, given the observations, it should be taken as evidence that the dams may not withstand an event only slightly more severe than the 1975 one.

The design flood event (in this case PMF) is rightly of a severity that has not been experienced in living memory, which in this context, is a relatively short time, but this is a difficult concept for the general public to appreciate. However, such an event could occur next month or next year and any lesser level of protection would mean the societal risk would remain unacceptable. If the dams were upgraded to a standard of protection less than that provided to other populations living downstream of a dam, and they did fail, there would be an adverse public reaction and it would be legally indefensible that a foreseeable risk had not been appropriately addressed.

Comment on the application on behalf of Brookfield Mansions Freehold Ltd

Brookfield Mansions are located downstream of Highgate No 1 pond. We have been asked to consider further comments on the application on behalf of Brookfield Mansions Freehold Ltd, made on 13 October 2014 by Harriet King. There appears to be a misunderstanding that some changes to the outlet pipe at Highgate No 1 are included in the proposals, for example, provision of an orifice. This is not the case – the outlet pipe is unchanged in the proposed design.

The response from Brookfield Mansions also includes a paper from Professor K R Rushton regarding the estimation of discharge from the outlet pipe at Highgate No 1. This has been addressed in Section 4.3 above. Responses from Atkins have also been received and are reproduced in the table below. We concur with the responses and have nothing further to add.

Thames Water clarified their statutory duties; we understand that they have been asked to comment on the proposals. Thames Water told us that it is a material consideration under the Town and Country Planning Act that they do not agree to any works which may be to the detriment of residential areas downstream from the Ponds. Although the buildings that make up Brookfield lie downstream of the ponds, they are upstream of the junction of TWA's sewers with the overflow and scour pipes from the Highgate chain. Brookfield includes the most vulnerable properties directly below the Highgate chain. Atkins: Several properties are more low lying, as shown on our flood extent maps issued last week. *We are concerned about the proposed reduction in the size of the overflow pipe; this would increase the flows over the spillway of Highgate No1 and potentially into Brookfield.* Atkins: This is not being proposed. *In addition, the overflow will be positioned in the spillway (at present it is in the dam) where it could easily become blocked.* Atkins: This implies that we are moving the overflow, but we are not proposing any works to the overflow inlet. None of our proposed works would increase the likelihood of the inlet being blocked. The inlet will be maintained and kept clear by the Heath staff as is done currently. *In the existing situation in an extreme event, some water would flood areas adjacent to the higher ponds. As proposed, all excess water, that is water not held in the ponds or discharged down the overflow, will be discharged down the spillway of Highgate No 1. Atkins clarified that the overflow reaches peak capacity in a 1:20 storm.* Atkins: We have not said this. We have explained on a number of occasions that the discharge through the overflow pipe increases as water level in Highgate No.1 Pond rises in a flood, but the peak capacity is not reached even in a PMF event. Thames Water had visited the Heath and looked at the toe of Highgate No 1 and were sympathetic to the consideration of a bund (say 1m high) to the south of Brookfield. They also stated that in an extreme storm, any increase in flow down the pipe would be insignificant, particularly in view of the fact as there would be a delay (approximately 6 hours) from the start of the storm to the maximum discharge of water through the overflow. Atkins: The increase in flow down the pipe is not significant compared to the flow over the spillway (in the proposed case) or over the top of the dam (in the existing case). Any works beyond the dam at Highgate No.1 Pond are beyond the scope of the City of London in their role as responsible undertakers of the dams. *We have also proposed that an additional overflow at top water level would in fact increase our protection significantly in extreme events and we believe this would not have a significant effect on flooding downstream.* Atkins: We are already increasing the protection significantly by raising most of the dam by 1.25m and filling in low spots elsewhere (since the spillway level is around 500 – 600mm above the low spots). This, combined with the storage capacity works at upstream ponds, would increase the standard of protection (the return period of overtopping / spilling) from around 1:100 in the existing situation to over 1:1,000 in the proposed scenario. This should be compared to typical

Environment Agency flood alleviation schemes, which generally aim for a design standard of protection of around 1:75 to 1:100. It should also be noted that this is not a flood alleviation scheme and the increase in storage capacity is intended to reduce the impact of dam safety works downstream. However, residents downstream will benefit from reduced flooding during large (greater than 1:1000) events, as shown in our flood extent maps for the 1:10,000 event.

I've attached a comment that has been prepared by Professor Rushton. We haven't been told what the proposed orifice reduction would be.
Atkins: There doesn't need to be one.

Further submission from the Heath and Hampstead Society

We have also been asked by LBC to comment on a further submission from the Heath and Hampstead Society dated 4 November 2014 in which the Society specifically requests that AECOM consider the points they raise, which relate to the following documents:

- *Quantitative Risk Assessment Interim Report* (Atkins, dated 29 August 2013),
- *Quantitative Risk Assessment Interim Report – additional comments for Stakeholders* (Atkins, dated 7 November 2013)
- *Reply by the Heath & Hampstead Society to Atkins "Additional Comments for Stakeholders* (Heath & Hampstead Society, dated 15 November 2014)

The Society has not received any response to their reply of 15 November 2013 in which they comment on a number of aspects of the QRA, and detail the comments previously submitted that remain unanswered.

Overtopping

The Society submitted a number of very detailed queries on Atkins' overtopping analysis and identification of probability of failure for each dam. There are some limitations in the overtopping analysis carried out by Atkins that could impact the probability of failure, but not to an extent that substantially alters the validity of the conclusions. The current probability of failure from overtopping of each chain would have to be as low as the order of 1 in 10,000 in order to lie out with the region of unacceptable risk to society. Both chains, and in particular the Highgate Chain, are very far short of this standard, and no amount of refinement of the overtopping analysis will alter this conclusion.

Average Societal Loss of Life

The City has no responsibility for and little control over the 1095 predicted deaths due to run-off, dam overtopping and surcharge of the inadequate sewers downstream. It has a statutory responsibility to try to prevent the 319 "residual" deaths only, which might arise from the dams breaching, and this alone is the main purpose of this project.

We agree with this statement. The incremental or "residual" loss of life has since been updated to between 31 and 104.

We agree that the Environment Agency will categorise the Heath dams as "High Risk". This means only that they will be covered by the full requirements of the Reservoir Act 1975 in respect of supervision and inspection etc. This Act has nothing to do with design, which is left to the Supervising and Inspection Engineers, who may make recommendations in the interests of safety. *This term is not defined in the Act.*

The requirements of the Reservoirs Act 1975 includes for appointment of a Qualified Civil Engineer to supervise the carrying into effect of measures to be taken in the interests of safety. Where such measures involve design this is included in the scope of supervision.

The preamble to the Act states that the Act is "*to make further provision against escapes of water from large reservoirs ...*". No specific definition of safety is given in the Act, but there are references to safety in Sections 16(1) and 16(2) of the Act which refer to the Enforcement Authority having powers to take immediate action "*to protect persons or property against an escape of water from the reservoir*." From this, it appears that safety is defined in relation to its effect on persons and property.

Warning Time

The Society again argue that there will be adequate warning as the lowest dams on each chain may not start to breach until more than 6 hours from the onset of the storm, and that the downstream loss of life should therefore be recalculated on this basis. Our opinion on this is presented in *Downstream loss of life* and *Active v Passive Systems* sections above. The onset of the storm itself is not warning of imminent dam breach, and evacuation of downstream residents would not be initiated at this stage, so it is extremely misleading to imply there is over 6 hours warning time of dam failure. Atkins has very clearly set out the procedures that would be followed before evacuation would be triggered, and the extent of difficulties involved in relying on such procedures that rule these out particularly in the circumstances at these reservoirs with very extensive downstream population and infrastructure. We are aware that Dr Hughes has personal experience with emergency response at reservoirs and is very well placed to give authoritative opinion on this matter including the associated difficulties. We have some similar experience of emergency response at reservoirs in addition to professional awareness of these issues and we entirely agree with Atkins' response.

Assessment of the severity of the situation in advance of imminent failure of the downstream dams on each chain would likely require assessment of the situation at the ponds further upstream. Access to these locations on the Heath may be extremely hazardous or potentially impossible during the storm event.

The Society further argue that the Emergency Services will already have been working for some hours in the flooded area before possible dam failure, and state that the additional water released by a dam breach will probably not make the situation materially more serious than that already being dealt with. This fundamentally underestimates the potential severity of dam failure. Particularly for the less severe events that have been assessed to put the dams at risk of failure, the additional flow intensity and volume discharged downstream following dam failure would be considerable, and would indisputably make the situation materially more serious and likely result in significant loss of life and casualties.

We consider that the alternatives considered have rightly been constrained to a passive solution, and the downstream loss of life estimated appropriately assuming no warning.

Preliminary Comments that remain unanswered

The Society has asked a number of detailed questions on the Atkins QRA assessment. It is not possible for us to answer these queries – they would have to be addressed by Atkins. Nevertheless, we can make some comments on general issues that the queries raise. None of these queries alter our conclusions that, having received clarification from Atkins on some matters of the technical content, we consider that no further submission by the applicant is necessary prior to planning permission being able to be recommended.

6. and 7. ...you have assumed a single extremely conservative probability of one overtopping failure relationship applied to every one of the dams, rather than develop a specific model for each individual dam. ….Duration of overtopping is a key aspect in failure…

The risk of failure from overtopping is assessed for each dam on the basis of general industry accepted figures of maximum depth and peak velocity of overtopping for floods over a range of return periods, and this is valid. This takes into account the overtopping flow behaviour at each dam in a consistent manner, stated as being generally conservative, but possibly not so at some dams as regards the untypically long time to failure of 1.5 hours from start of overtopping. It does not take account of some of the various other properties of each embankment, and we agree that a possible refinement would be to develop a system response curve for each individual dam, accounting for the resistance of the differing crest and downstream face cover, the properties of the fill material, and for the effect of duration. However, such an analysis would involve a much higher level of detail than would be normally expected for such a project, and would not change the overall outcome that the dams cannot safely pass the design flood.

13. and 22. A total cascade failure of all Hampstead dams is assumed. Please substantiate that this would occur….Please substantiate that a "sunny day slope stability failure" of Stock pond would lead to a cascade collapse of the entire Highgate chain.

This is a valid consideration and is confirmed by considering the storage capacity at each dam with respect to the storage capacity between the spillway and crest of the next dam downstream.: the volume of water released from failure of an upper dam is compared with the temporary storage available at the downstream dam (ignoring any storage already used by the flood inflow from the catchment). If the temporary storage is exceeded, the downstream dam will overtop and likely fail. In all cases, the volume of the upstream dam substantially exceeds the temporary storage volume available at the downstream dam. It is therefore highly likely that failure of any of the dams will result in failure of the dams downstream.

16 and 17. Please calculate ASLL based on the recommended minimum of 2 hours warning….Figure 5.1: this shows a line showing the reduction in LLOL with 60 mins warning. Please show the line for 2 hours warning

It is not appropriate to assume any warning time as explained above. Figure 5.1 is from standard guidance and does not include a line for 2 hours warning.

18. and 19. Please produce your inundation maps for the current project for PMF overtopping and PMF breach…. Please substantiate that Kings Cross and St Pancras stations are within the risk area.

We have been provided with the inundation maps and confirm that Kings Cross and St Pancras stations are within the risk area. Note: It is normal for inundation areas to be made available to the public, but dissemination of details of flow parameters are subject to protocols for security reasons.

20. Tables 5.2 and 5.3 – do they assume cascade failure of all dams on both Highgate and Hampstead chains simultaneously, and do they present the totals for both chains combined? If so, please present the totals for each chain separately.

See section 5.4: Atkins ASLL figures assume both reservoir chains fail. Failure of each chain has not been modelled explicitly. However, we have drawn some information from Haycock's September 2010 report[12], for which loss of life figures for each chain are quoted for a PMF flood event, with and without breach. This suggests the incremental ASLL for each chain are the same.

Summary

In our opinion, none of the objections raise reasonable concerns about the technical content or considerations of the submission. We consider that no further submission by the applicant is necessary to enable a recommendation on the application to be made.

[12] *HiDEP Work Package 6 – Flood Envelope Model,* Haycock Associates Ltd, 23 September 2010