Queen Mary and King George V Emergency Draw Down Schemes

BRYN PHILPOTT, Thames Water Utilities Ltd
YINKA OYEYEMI, Jacobs UK Ltd
JOHN SAWYER, Jacobs UK Ltd

SYNOPSIS.
Thames Water owns a large number of non-impounding reservoirs. These have unusually long embankments with narrow clay cores and gravel shoulders, which could be susceptible to piping failure and erosion. They are typically located in urban areas. Thames Water has therefore reviewed its policy regarding emergency drawdown capacity and started an improvement programme on the most critical reservoirs.

The Queen Mary and King George V reservoirs are two of these critical non-impounding reservoirs with continuous embankment lengths of 6.3km and 6.5km and storage volumes of 30 Mm^3 and 12 Mm^3 respectively. Following the statutory inspection of these reservoirs, a safety recommendation was made which required a significant increase to the existing emergency draw down capacity of each reservoir. This required Queen Mary reservoir to achieve 0.75 metre emergency draw down from top water level within 24hrs and King George V reservoir to achieve 1m draw down in 24hrs. Studies instigated as a result looked at various options of achieving the draw down with the final solution involving the design and construction of twin siphon pipes fitted with submerged discharge valves.

It is believed that a number of UK reservoirs may require additional emergency draw down capacity as measures in the interest of safety, as defined within the terms of the Reservoirs Act 1975, over the next few years. This paper looks at the options considered before arriving at the final solution. It also discusses challenges in the design and construction of the schemes.

Ensuring reservoir safety into the future. Thomas Telford, London, 2008

ENSURING RESERVOIR SAFETY

EMERGENCY DRAW DOWN REQUIREMENTS IN THAMES WATER

The requirement to provide facilities to enable large storage reservoirs to be drained quickly in the event of an emergency is well understood. However the determination of the minimum requirements in this respect is less clear.

This paper sets out Thames Water's rationale behind its target policy to provide 1 m per day emergency draw down capacity to all of its storage reservoirs and provides details of projects to increase the capacity at Queen Mary and King George V Reservoirs.

Thames Water's Storage Reservoirs

Thames Water has a stock of 23 storage reservoirs within the terms of The Reservoirs Act 1975. The majority are Non Impounding and largely of similar construction detail. Table 1 shows the key features of the total stock as follows: -

Table 1: Key features

Feature	*Range*
Age Range	35 to 175 years old
Total capacity (approx.)	220 Mm^3
Embankment shoulders	River Terrace Gravels
Watertight element	Thin Clay Core Wall
Embankment Heights	5 m to 25 m
Total Embankment Length	77,500 m

Risk Assessment

The principal risk associated with Thames reservoirs revolves around their construction. The thin clay cores (without designed filters) leave them potentially susceptible to hydraulic fracture and internal erosion in certain circumstances. The embankment shoulders, being of erodable gravel, are likely to have a shorter than average time to failure once a leak develops.

Hazard Assessment

The majority of the reservoirs are located in and around London and are mainly category A reservoirs. These are all located near to heavily populated areas with significant infrastructure.

Other Issues

Whilst Thames Water undertakes routine reservoir surveillance to all of its reservoirs, the nature of the geology, embankment construction and length, means that early stages of leakage can be difficult to detect visually. Instrumentation on a 6 km embankment is not likely to be representative of the total situation. Therefore the time available to react to an incident when detected is likely to be reduced when coupled with the time needed to mobilize resources to commence an emergency drain down.

The significant length of the reservoir embankments is also likely, on a purely statistical basis, to increase the probability of failure of Thames Water's reservoirs when compared with other undertakers in the UK.

Consideration and Constraints when determining EDD rate

- The large surface areas of the Thames Water reservoirs results in high volumes to be disposed of. There clearly needs to be a sizable receiving body of water to take the required discharge rate. Unlike the majority of UK reservoirs, Thames Waters reservoirs are non-impounding and are not always very close to the River Thames or Lee.

- Whilst all the reservoirs have existing inlet and outlet pipe work or tunnels connected to water treatment facilities, they do not always have scour pipe work, which runs directly to waste. Careful assessment needs to be made as to how much of the stated treatment capacity of the works can be relied on at all times. A large algal bloom, for example, can significantly reduce works capacity.

- Some existing outlet routes, if opened fully in an uncontrolled manner, may result in residual flooding downstream due to the inability of the receiving water to take the high flows. Limited residual flooding may be preferable to the consequences of a major dam breach but the undertaker must clearly understand the risks and potential consequences when looking at risk mitigation.

- The selected draw down rate needs to take into consideration the permeability of the embankment shoulder material to ensure that rapid draw down does not adversely impact on the stability of the internal embankment by generating high pore water pressures within the internal slopes. Thames Water has assessed this with respect to the embankment shoulder materials at its reservoirs and do not envisage an issue at the rates required.

Existing draw down capacities at Thames Water's storage reservoirs

There currently appears to be little by way of industry guidance and in the past figures of the order of 300 mm per day have been accepted. In recent years, larger figures, between 0.75 m and 1 m per day, have been required by Inspecting Engineers.

Thames Water has modelled the potential draw down capacity utilising all existing pipework connections. Table 2 shows a summary of the modelled draw down capacity ranges as of 2007 and differentiates between existing supply routes and dedicated scour facilities.

Table 2: Summary of draw down capacity

Emergency Draw Down Capacity Range	*No of Reservoirs Achieving Stated Capacity*	
	Treatment & Waste	Waste Only
> 1 m / day	16	7
0.8 – 1 m / day	4	0
0.5 – 0.79 m / day	1	6
0.3 – 0.49 m / day	1	7
< 0.3 m / day	1	3

It can be seen that the exclusion of treatment capacity significantly impacts on the ability to draw down the reservoirs quickly. Two of the larger reservoirs were assessed as having low emergency capacities after allowing for treatment capacity. It is Thames Waters policy to provide a target of 1 m per day at all its reservoirs and reduce its reliance on the availability of treatment capacity. This paper describes the design and construction of new fully dedicated facilities to improve the emergency draw down to waste at Queen Mary and King George V Reservoirs.

Queen Mary and King George V Reservoirs

Queen Mary Reservoir, located at Ashford in Middlesex, was completed in 1925, following a suspension of construction during W.W.1. It was believed to be the largest storage reservoir of its kind ever constructed at that time. King George V was completed in 1913 and is located at Chingford in the Lee Valley. Both are of similar construction. Table 3 gives the principal details of the reservoirs.

Table 3: Principal details

Feature	*Queen Mary*	*King George V*
Max. height of embankment	12 m	10 m
Length of embankment	6324 m	6532 m
Total capacity	30.4 Mm^3	12.4 Mm^3
Surface area at TWL	2.863 km^2	2.168 km^2
Inflow capacity (controlled)	770 Ml/d	375 Ml/d

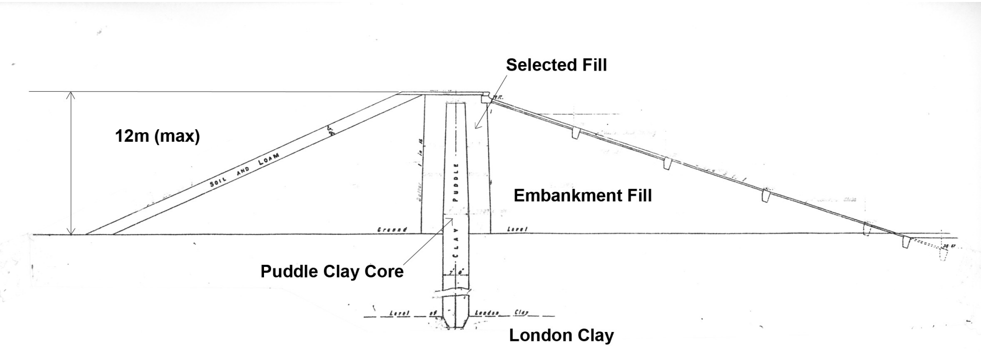

Figure 1: Section through Queen Mary (King George V is similar)

Following periodic inspections in 2005 at Queen Mary and 2006 at King George V reservoirs, the Inspecting Engineers assessed that the existing draw down capacity of 0.25 m and 0.35 m per day respectively was inadequate. The requirement to improve the emergency draw down capacity to 0.75 m and 1 m per day respectively was recommended in the interests of safety, as defined within the Reservoirs Act 1975.

In the case of Queen Mary it was decided to provide facilities to discharge the full 0.75 m per day to waste whilst the existing 0.25 m per day would be available to assist the rate in line with Thames Waters policy objective of 1 m per day draw down.

OPTIONEERING

Queen Mary Reservoir

Thames Water had initially considered internally various options for achieving the required drawdown rate for the Queen Mary reservoir. The preferred option was to install two 1600mm diameter siphons to pass over the reservoir embankment and discharge via a new concrete culvert into a new concrete spillway and into the existing Laleham Aqueduct. The study considered using butterfly valves or cone valves for flow control at the downstream end of the siphon.

Jacobs was employed to review Thames Water’s design proposals and to finalise the design. Jacobs confirmed the suitability of using the 1600mm diameter siphons and looked at various options for achieving the proposals within the constraints of the site. The site constraints governed the location and discharge point of the siphons.

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Location of Options

The main location options considered for the Queen Mary reservoir emergency drawdown related to the pipeline route and the discharge point of the siphon outlets into the Laleham aqueduct. The choice of location was also governed by a number of site constraints, which include the following:

- Existing service pipes and mains.
- High Voltage overhead cables
- The ability of the Laleham Aqueduct to take the required flow and velocity without scouring
- Working in water within the reservoir, while maintaining the normal operating water level
- Limited cutting into the embankment to protect the integrity of the puddle clay core
- The 'River Ash' (a stream) adjacent to the embankment
- Maintaining access to the treatment works

The substantial number of constraints led to the decision to extend the siphon as an above ground pipeline to the point clear of all services. The concrete channel was reduced to a relatively short structure connecting the stilling well to the Laleham Aqueduct.

King George V Reservoir

The existing outlet works consist of an inner and outer tower, either side of the embankment core, linked by a 1.44m I.D tunnel below the core. The current discharge capacity is around 0.35m per day. Jacobs looked at options for achieving the required 1m/day drawdown rate. The options considered two fundamental approaches to achieving the emergency discharge of the reservoir: providing a new facility or modification of the existing outlet. The options considered using these approaches include the following:

New Facilities:

Option 1 – New siphons over the embankment discharging into the river Lee diversion via a stilling basin.

Option 2 – New tunnel beneath the embankment connecting two new shafts located within the reservoir and beside the river Lee diversion.

Modifications to existing outlet:

Option 3 – New siphon to connect existing outlet towers. The siphon would work in the same way as in option 1.

Option 4 – New siphon over the embankment connecting either the existing inside outlet tower or the bottom of the reservoir to an existing 1500mm diameter outlet pipe.

Option 5 – A new 2000mm diameter tunnel connection through the embankment connecting two new launch and reception shafts, which in turn are connected to the existing outlet towers.

Option 6 – Enlargement of existing tunnel between the outlet towers to a diameter of 2500mm.

As with the Queen Mary reservoir, the preferred option for achieving the drawdown was option 1 which is shown in the schematic below.

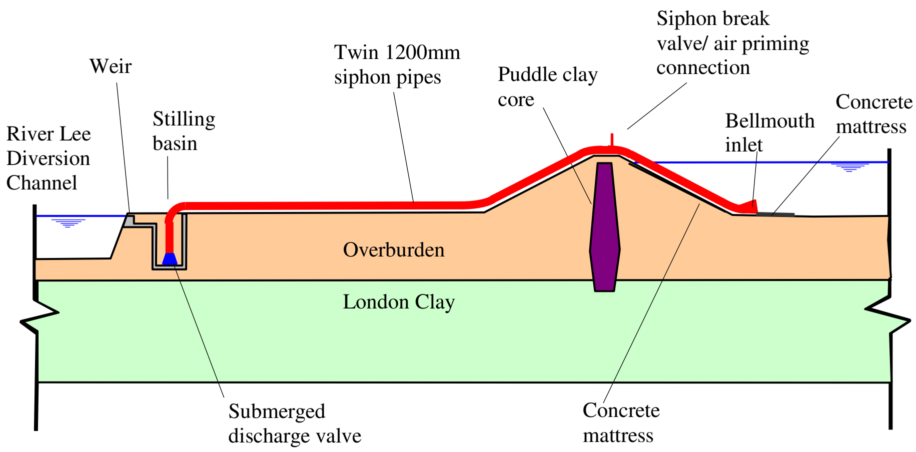

Figure 2: Schematic of the King George V Siphons

The preferred discharge water body was the River Lee Diversion on the east side of the reservoir as the alternative River Lee Navigation had limited hydraulic capacity.

DESIGN

One of the main criteria of the project was that the design had to be robust. This was because of the assessed potential for damage to the surroundings as a result of potential embankment failure and the infrequent use of the siphons. The main design elements, which had to be able to stand the test of time, include delivery of the hydraulic requirements, the siphon pipe material, the water priming system, the vacuum priming system and the flow control device.

Hydraulic Modelling

A mathematical model of the siphons system was developed to deliver the drawdown requirements set by the respective QCE's. This meant delivering a flow of 24.8 $m^3/_s$ and 20.8 $m^3/_s$ for Queen Mary and King George V reservoirs respectively. The velocities in the siphon pipes were similar for both projects, in the order of 6.1m/s. The choice of valve to dissipate the energy generated by the velocity was therefore critical and is discussed later.

A discharge curve was generated showing total outflow through the siphons vs reservoir water level. An empirical relationship between flow velocity and inlet submergence for the onset of vortex formation was used to derive a second discharge curve. This shows the allowable discharge vs reservoir water level at the onset of vortex formation. The combined curve is shown below.

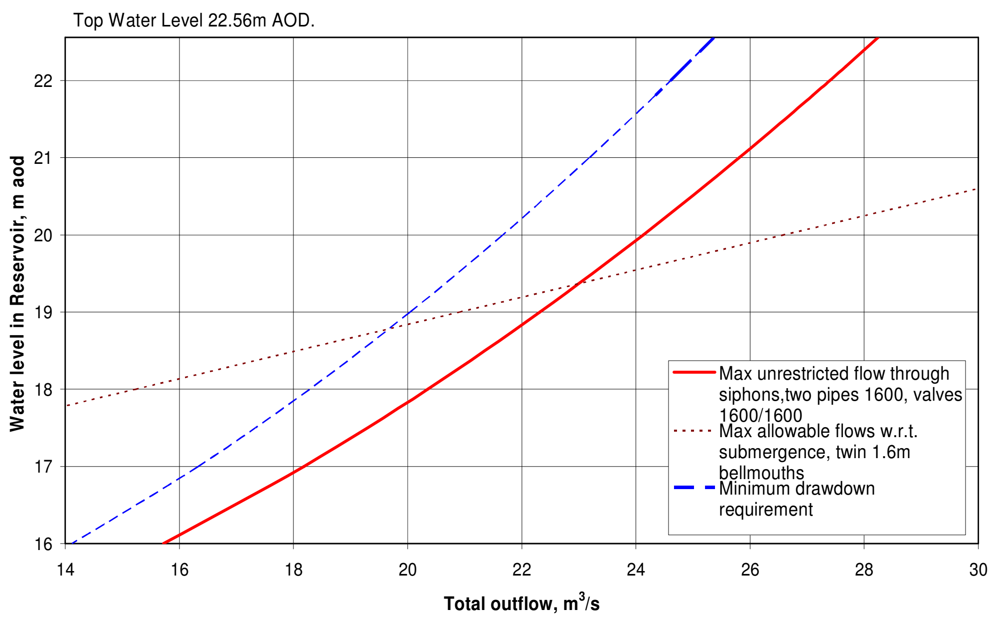

Figure 3: Queen Mary Reservoir siphons hydraulics as designed

The depth of water of the Queen Mary reservoir at the location of the siphons was 9.6 m. From the chart above, the effect of vortices is noticed at a depth of 3.06 m below top water level for a standard 1600mm diameter bellmouth. In order to improve on the depth at which vortices start to form, a non-standard bellmouth was designed which improved the vortex formation depth to 5.8 m. This however proved difficult and expensive to build. As a result, the QCE accepted a standard bellmouth with its limitations. During construction it proved possible to locate the inlet at a greater depth, thus reducing the constraint in operation.

Pipe Material

The preferred choice of pipe material over the embankment was one with minimal risk of joint failure so as not to break the siphon. Therefore a welded steel pipe with epoxy coating was chosen. During contractor pricing for the Queen Mary reservoir, the contractor suggested changing the pipe material to Ductile Iron as he could offer some savings from the change while maintaining the integrity of the design. This was accepted by the client for the non-vacuum section and the pipe material was changed to Ductile Iron downstream of the embankment.

Water and Vacuum Priming

The options considered for priming of the system included water priming and vacuum priming. Water priming while being a robust and reliable system would require an upstream valve on the siphon pipes, located within the reservoir. The valve was considered to be difficult to install, maintain and operate. Vacuum priming on the other hand has the advantage of not requiring an upstream valve but may be slow for the large volume of pipe to be filled and susceptible to non-sealing of the siphon system. Vacuum priming would also require pipes with thick walls to resist the vacuum pressure. The designed system was a combination of water and vacuum priming systems as this combines the advantages of both systems. This process was to involve two stages of priming.

The first stage would involve water priming of the system with the pipes downstream of the crest being filled to the reservoir crest level. Various options for water priming of the siphons were considered. These included using existing reservoir pipework or pumps, portable pump on the embankment crest and a new pumping station independent of the existing works. The latter option was chosen as the water priming can be undertaken as a first stage of a suspected emergency. The new pumping station would use water from the Laleham Aqueduct for water priming the Queen Mary reservoir. For King George V reservoir a secure supply was identified, which avoided the need for a new pumped supply.

The second stage of priming would involve vacuum priming to fill the remainder of the system. This would be carried out by using vacuum pumps on the pipes at the crest of the reservoir. The vacuum priming system would also serve to remove air which collects in the siphon during the operation of the system.

Control Valves

The flow and velocity generated to achieve the required emergency drawdown for the two reservoirs were relatively high. At the point of discharge the local velocity is over 12 m/s. It was therefore essential to be able to provide a robust flow control device at the discharge point to the Laleham Aqueduct and the River Lee diversion for Queen Mary and King George V reservoirs respectively. The flow control also had to dissipate energy in order to minimise risk of damage to the discharge water bodies.

Figure 4: Submerged discharge valves awaiting installation.

The flow control chosen was a vertical sleeve type Submerged Discharge Valve. These have been used successfully on dam outlets and would be able to provide the required control and energy dissipation. Two options for the material of the submerged discharge valve were considered; fabricated steel and cast iron construction. The client chose the more robust cast iron construction.

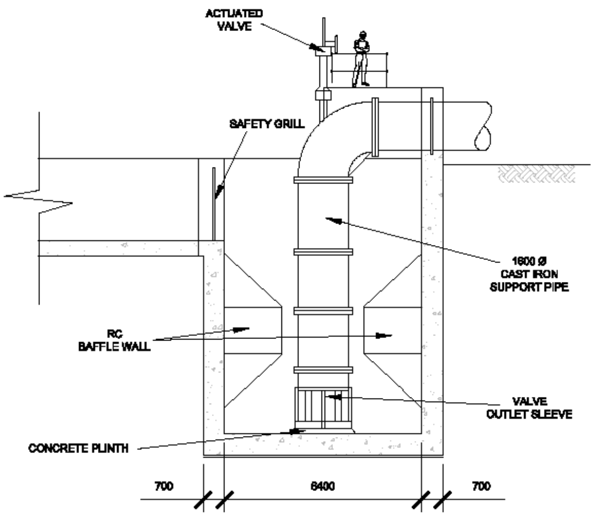

Figure 5: Drawing of the Submerged Discharge Valve

Pipelaying in the reservoir

One of the constraints at both reservoirs was the operational requirement of Thames Water to keep the reservoirs full while the pipelaying was carried out. Hence it was not possible to construct accurately aligned pipe saddles on the inner face of the embankment. The challenges for both Queen Mary and King George V reservoirs were however slightly different.

The inside face of the Queen Mary embankment at the siphons' location is finished with a wave wall and concrete facing all the way down to the bottom of the reservoir. The concrete facing provided a firm surface on which the pipe supports could be laid. The pipe support design involved the use of inflatable grout bags, which could be positioned under the pipes and injected with grout to even the loadings on the embankment. The bags were also used to provide load on the pipes at the vertical and horizontal bend to the bellmouth at the bottom of the reservoir. The load was required to anchor the pipes at the bends.

King George V reservoir, unlike Queen Mary reservoir, is constructed with a brick wave wall at the crest and a concrete lining, which only extends to a distance of about 2m down the slope of the embankment face. Below the concrete and down to the bottom of the embankment, the slope is unprotected and comprises the gravel embankment fill and silt settling down on top of the gravel. This face of the embankment may potentially be vulnerable to erosion as a result of wave action on the water surface when the reservoir water level drops below the concrete facing.

The design solution to protecting the upstream face of the King George V reservoir was to provide interlocking concrete mattresses on top of the exposed face which were tied back using stainless steel cables to the new reinforced concrete support to the pipes at the crest.

A similar grout bag arrangement to the QM reservoir was then used to support and anchor the siphon pipes.

COMMISSIONING AND OPERATION

Commissioning is planned to demonstrate successful operation to the Q.C.E. for final sign off and issue of a section 10(6) certificate. The need to fill and prime the siphons expediently is a requirement along with the need to demonstrate that the required flow rate is passed.

The flow rate will be determined by the use of temporary strap-on flow meters. These will be used to validate the design curves.

It is envisaged that routine testing will be undertaken at the six monthly Supervising Engineers examination visits, demonstrating the operation of one siphon every six months. This will help to ensure that the plant is checked as being operable and that all personnel involved remain familiar with the installation.

CONTRACT AWARD AND CONSTRUCTION

Contracts for the construction of both projects were awarded under the NEC conditions of contract.

The contract for Queen Mary was awarded in April 2007 to Barhale Construction Ltd. The submerged discharge valves were pre-ordered by Thames Water to ensure that the construction programme could be met. Work started on site in May 2007 and there were a number of construction challenges to overcome.

The requirement to keep the reservoir in operation meant that the upstream pipework had to be installed in the wet. This was assembled on a wide section of the embankment crest at the opposite side of the reservoir. A 1000 Tonne crane was needed to lift the assembly into the reservoir from where it was floated across some 2.5 km of water and lowered onto the internal embankment shoulder.

Figure 6: Pipework assembly being floated across Queen Mary Reservoir

The pipework on the downstream face was to be founded on a reinforced concrete slab, partly to spread the loads and partly to act as a channel to pass any leakage without impacting on the embankment should one develop during operation. In order to construct the slab, a 1 metre layer of loam had to be removed and replaced with compacted granular backfill. This was undertaken in sections to minimise the impact on the embankment. Particular care was needed when crossing the surface of the clay core wall.

A significant element of the work is associated with the stilling chamber and weir connecting into the existing intake channel. The chambers were constructed within a deep steel sheet pile cofferdam. The management of ground conditions and high water table along with periods of elevated river levels all contributed to programme delays.

At the time of writing the Queen Mary project is due to be completed during March 2008.

The contract for King George V was awarded to Morrison Construction Ltd in December 2007. This project is due to be complete before the end of December 2008.