Cobbins Brook Flood Storage Reservoir

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SYNOPSIS. Cobbins Brook flood storage reservoir was the preferred option for a flood alleviation scheme to reduce the risk of flooding to the town of Waltham Abbey, Essex. The reservoir is formed from an earth embankment with a sheet pile cut-off and can hold 754,000m³ when full following a 1:100 year (1%) probability flood event. It is the largest flood storage reservoir in the Thames North East Area of the Environment Agency.

The paper will give the background as to how the scheme was developed, aspects of the engineering and environmental design, operational requirements, environmental impact assessment, and the construction phase of the dam, through to its commissioning. Features specific to the design of flood storage reservoirs will be highlighted, including best practice incorporated from other flood storage reservoirs in Thames NE Area.

INTRODUCTION AND BACKGROUND

The town of Waltham Abbey in Essex has a history of flooding going back over the past 60 years, with the most recent event occurring in October 2000 when 97 properties including a secondary school, a nursery and local roads were flooded up to 1.5m deep, causing an estimated £2.3M in financial damages. This flood event was assessed as having a return period of between 1:20-1:30 years (5% to 3.3 % average annual probability - AAP). The current level of service of 1:5 years (20%) is significantly below the indicative standard of 1:50-1:200 years (2%-0.5% AAP) recommended by Defra for the area (Land Use Band A - dense urban). Without a flood alleviation scheme a 1:200 year flood event would put 466 properties and the M25 motorway at risk giving rise to present value damages in the order of £38M. The predicted effects of climate change could make this situation even worse.

Options

In 2001 the Environment Agency commissioned Halcrow Group Ltd to undertake initial feasibility studies into the viability of a flood alleviation scheme to reduce the risk of flooding to the town. Initial studies concluded that there was enough viability to consider a scheme in detail. A detailed feasibility study was undertaken in 2003 - 2004. Six options were assessed in detail providing different levels of service, including the Do Nothing and Do Minimum Options. Of the options assessed, the construction of an on-line Flood Storage Reservoir (FSR) 2km upstream of Waltham Abbey, near Brookmeadow Wood in the village of Upshire, was selected as the recommended option.

This FSR would have a maximum embankment height of 7.5m and a maximum storage volume of 754,000m^3, providing a 1:50 year level of service within Waltham Abbey to 314 properties. A FSR at Brookmeadow Wood also provided the opportunity to enhance the natural environment through the creation of a new woodland area, a seasonal wet meadow and wetland habitats. Non-structural options such as flood warning on their own were not appropriate to reduce flood risk to the town, due to the fast response of the catchment to rainfall, typically 1-4 hours with a peak flow of 15m^3/s before flooding would occur. The estimated 1:200 year flow within the town is approximately 59m^3/s.

Policy

The development of the scheme proceeded as a priority scheme in advance of the relevant Strategy and Catchment Flood Management Plans being developed. The scheme was developed in line with the Defra policy of Making Space for Water. Flood storage was a favoured solution as it helped ensure the flood risk problem was not passed downstream. As the North East Area of the Thames Region has a number of flood storage areas which are Statutory Reservoirs under the 1975 Reservoirs Act the team was able to use the experience of the area staff throughout the design process.

DESIGN AND DEVELOPMENT

The detailed design of the scheme took place between 2005 and 2007 and included a number of distinguishing features. Key to the development of the design was the involvement of the Environment Agency's Operations team to ensure the design met their requirements. This included learning lessons from the designs of other previously constructed flood storage reservoirs. The Reservoir itself has the following details:

Table 1 – Cobbins Brook FSR Key Details

Max Volume	754,000m³ (1:100 years)
Max flooded Surface Area	29ha
Height of Embankment	7.5m
Length of Embankment	750m
Slopes	1:3 with Spillway at 1:6
Spillway	155m Cast in-situ concrete blockwork Whole embankment overtops for greater than 1:100 year event
Control Structure	2 No. Penstocks (0.7m x 1m) acting as fixed orifices
Category	A
Construction	Clay
Design Life	100 years

Material

The feasibility study had determined that a volume of approximately 48,000m³ of clay was needed to construct the embankment. Through site investigations it was determined that the site of the scheme had large quantities of suitable London Clay which could be excavated to form an earth embankment. This gave the advantages of saving cost and removing the uncertainty of sources with importing material, and it mitigated planning concerns regarding large volumes of construction traffic on local rural roads. There were, however, some concerns over the moisture content of the clay which was wetter than optimum. Optimum moisture content (OMC) for the material varied from 18.5% to 27.9% with an average value of 21.5%. In addition to a specified OMC the final shear strength was specified at 50kPa. The natural moisture content of the material on site was approximately 24% which was higher than the OMC specified. The concerns over the OMC were addressed in the construction phase.

Having the borrow pit in close proximity to the embankment caused some concerns over borrow pit slope stability. This was mitigated by having shallower slopes which reduced the quantity of material available but ensured a more natural and landscaped look would result from the finished borrow pit. To obtain the additional material a second smaller borrow pit of 8,000m³ to the north of the brook was proposed. The material tested from the northern borrow pit area had a considerable proportion of granular material within the cohesive material i.e. a seam of gravel 1.5m below the clay which had the potential to act as a seepage path. To undertake a cut-off trench would have been difficult as it would have needed to have been 5m deep and would need to have been excavated under bentonite. As a result the decision was taken to install a sheet piled cut-off 300m long using AU14 pile sections. The advantages of the sheet piles were the improved construction safety and ease of installation, which was proven during the construction phase by the piling being completed ahead of programme.

Upstream shoulder protection

It had been noted from a number of other clay embankments within the Thames Region that the upstream shoulder was prone to cracking due to the high clay content. To help reduce this cracking and make use of the granular material, the gravelly clay from the northern borrow pit was proposed to be used on the upstream shoulder of the embankment, as shown in Figure 1.

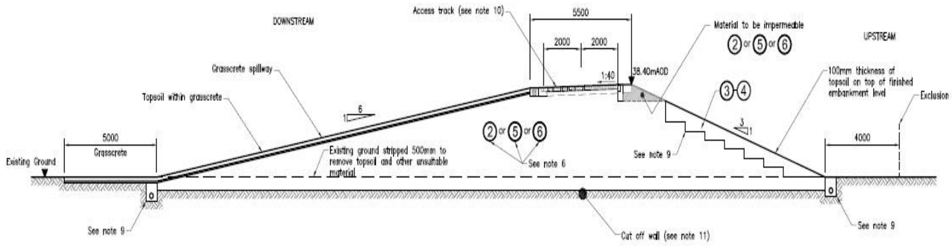


Figure 1. Typical section of the spillway showing upstream shoulder protection as benched profile

Twin Roads

With the predicted impacts of climate change it is likely that operational resources will become increasingly under pressure in the future with the requirement to cover more areas with fewer people. It was therefore important that the reservoir design had a degree of resilience built in. This was achieved with the construction of two roads, one on the crest and a lower road to access the inlet structure (See Figure 2). The lower road level was set at a level of 36.35m AOD, just greater than a 1:20 year flood level.

This gives 12 hours from the start of a storm and allows Operations staff the flexibility to either deploy resources to the Cobbins Brook site before or during a flood event, or to rely on the design of the screen to safely pass the design flow, as the screen area is significantly greater than the culvert area, and can pass the design flow even if partially blocked.

The choice of access into the site was also considered based on where Operations staff would be travelling from in a flood event and the potential closures on the surrounding road network. Telemetry installed can also advise if there is a change in water levels and reduce the need to have operational staff monitoring the site through specific alarm settings which are linked to alert staff at predefined trigger points.

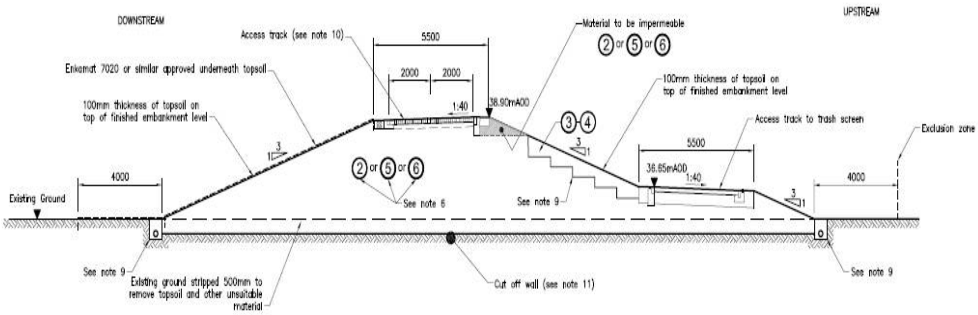
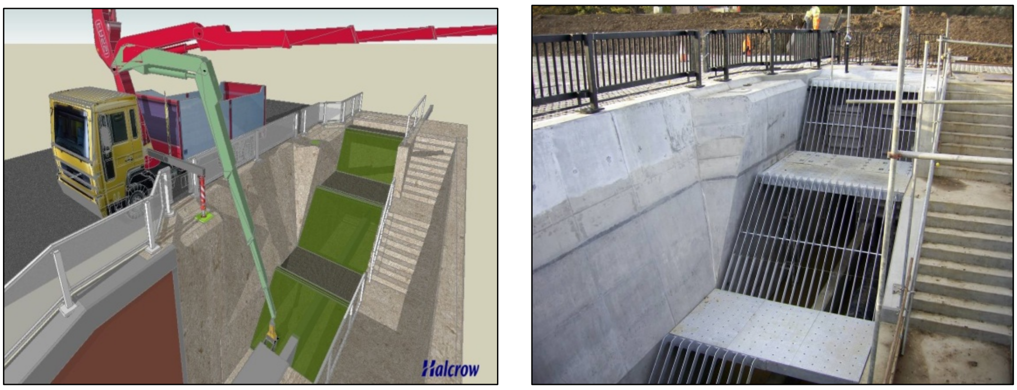


Figure 2. Typical Cross Section through embankment showing twin roads

3D Modelling

The Environment Agency's Operations team requested confirmation that their grab lorry would be able to reach the base of the trash screen of the inlet to the control structure. In order to test the design and demonstrate that this would be possible a 3D computer model was developed, initially using the package Sketch-Up. Detailed dimensions of the lorry and the grab arm were taken and used to create a 3D model of the lorry and inlet structure. Clash detection software was used to test the operation and revealed that the original proposed design with vertical walls would restrict access to the screen. As a result the design was changed to accommodate a sloping wall. Without the use of the 3D modelling it would have proven difficult to determine and potentially delay handover with expensive re-work required on site. See Figures 3 and 4.



Figures 3 and 4. 3D Model and As-constructed inlet structure

Maintenance

One of the concerns identified during the design process was to ensure that long term maintenance of the scheme was at the heart of the design. Access requirements were an important consideration. The structure through the embankment was proposed as a 40m long box culvert. As these culverts often require maintenance of joint sealant and inspection it was decided to design the culverts for safe person access. The culverts were sized to 2.1m high by 2.4m wide to allow an operative with hard hat to walk comfortably through the culvert. They were also designed with a 1:100 gradient to be self cleansing as much as possible.

Low level wall
To further aid in maintenance and inspection requirements a low level wall of 0.7m was designed to run centrally through the culvert. The advantage this gave was that flow could be diverted down one side of the culvert whilst inspections and any work could be undertaken in the dry on the other side. A raised section of concrete benching at the inlet was also introduced to create a low flow channel along one side of the wall to improve the flow characteristics.

Textured Bed
A textured bed was also proposed to allow a roughened surface for additional grip. This also had the benefit of aiding fish movement by creating a non-uniform surface. See Figure 5.

Figure 5. Textured bed at inlet achieved with a rake finish

Choice of Penstocks
One of the most important questions faced during the design of the Cobbins Brook FSR was how the structure could be operated safely to meet operational requirements. A particular area of consideration was the design of the control structure. The default position was to consider options which help to reduce or eliminate maintenance or any human activity if at all possible, to 'design it out'. As the site has a large wooded catchment upstream and due to the volume of water to be retained within the flood storage area and size of embankment, a number of considerations were

made before agreeing a final design. These included health and safety, hydraulics, cost (capital and whole life), environmental impact and flexibility for future operation and maintenance. Options considered for the type of control structure are outlined below:

Hydrobrake
A hydrobrake was considered as a ‘passive’ structure requiring little maintenance. However, due to the relatively low head of water for the design flow the hydrobrake would not have been able to fully initiate, meaning a number of hydrobrakes would have been required which would have significantly increased costs.

Fixed Orifice
The fixed orifice offered simple effective flow control but would be prone to blockages from debris. This would mean that a screen would be required to ensure debris did not block the orifice and prevent the orifice from functioning.

Gates/Sluices
Different types of active gates/sluices were considered as options to the flume and hydrobrake and orifice. Amongst these were radial gates, however these were not suitable for the scheme as they would have required power and increased maintenance over other options.

Chosen Option
The team eventually selected the option of manually operated twin penstocks which would act as a fixed orifice but retain the flexibility to be used to optimise performance or closed for maintenance if necessary. Only after all other practical alternatives were rejected and the need for a screen could not be designed out was the decision made for a trash screen. The screen would be necessary to restrict blockages from debris but also to prevent unauthorised access.

ENVIRONMENTAL CONSIDERATIONS

Environmental Impact Assessment
The Environment Agency’s vision is to ‘Create a Better Place’ for people and wildlife. Through delivery of the Agency’s flood risk management works, it has a duty to conserve and enhance biodiversity and natural beauty and to give due consideration to recreation and cultural heritage. Therefore environmental appraisal is a key process in the development of the Agency’s flood risk management schemes.

The Cobbins Brook Flood Alleviation Scheme was subject to a statutory Environmental Impact Assessment (EIA) under Schedule 2 of the Town and Country Planning (Environmental Impact Assessment) Regulations (1999), as amended. The Environmental Statement for the scheme was completed in January 2005. There were a number of environmental sensitivities that were taken into account in the design and construction of the Cobbins Brook FAS and the project has resulted in a net environmental gain.

Landscape Design

The location of the scheme has a high landscape value that was a key consideration in the design. The project is located within the Metropolitan Green Belt and its location is designated as an Area of Ancient Landscape and Public Open Space. Therefore the visual impact and impacts on recreation needed to be taken into account. Through the early appointment of landscape architects as part of the project team the design was developed to ensure structures were screened where possible and the choice of materials and finishes (including appropriate seed mixes and scrub planting for the embankment) were sympathetic to the local landscape. The shape and gradient of the embankment has been designed to take account of local landforms where possible. Photomontages of the scheme were produced during the design phase to demonstrate the landscape design and were a very effective tool for the planning phase of the scheme.

The use of borrow pits provided an opportunity to reduce the environmental impact of the scheme and its carbon footprint. It also provided an opportunity to create Biodiversity Action Plan (BAP) habitat. A total of 3ha of Priority BAP habitat has been created in the borrow pits, which comprise a mosaic of seasonal wetlands, wet grassland and wet woodland. Piezometers were installed in the main borrow pit and were measured for three years prior to construction to give an indication of ground water levels, which informed the design levels of the seasonal ponds.

The most visible engineered structure within the project is the main flow control structure. Through integrated engineering and environmental design, the visual impacts of this structure have been minimised. The inlet and outlet walls have been clad using a combination of brick and exposed aggregate concrete finish, to soften the stark appearance of steel sheet piles. Brick was used to match an existing weir structure that has been retained on site for its heritage value. Planting in gabion baskets and trailing plants have also been incorporated to soften the appearance of the hard engineered structure in the local landscape.

River Corridor

A significant amount of time was spent in developing ways to maintain continuity of the river corridor. Scrub planting over the embankment to maintain the river corridor and assist the navigation of bats and other species was developed. This required 600mm of sacrificial topsoil to be placed over the embankment adjacent to the control structure to stop roots penetrating into the clay of the embankment. The impacts of the control structure were minimised through integration of ecological features. The culvert has been designed with a textured bed, to provide a roughened surface for invertebrate habitat. A mammal ledge has also been integrated into the low level wall of the structure to allow passage for otters and other mammals. Bat roosts have also been designed into the outlet walls.

Figure 6. Aerial view of the reservoir under construction.

Ecological Mitigation

Protected species have been a major consideration for the project team during the construction phase. Great crested newts and water voles are both species known to inhabit the site. The Environmental Clerk of Works worked closely with the contractor to ensure that safeguards were in place to avoid any impacts on these species and their habitats. Great Crested Newt exclusion fencing was erected around the boundaries of the site and trapping exercises were carried out during summer 2008. A water vole receptor site was established on an adjacent brook to provide compensatory habitat for loss of water vole habitat on the main site. Mink monitoring rafts were used throughout the construction phase to limit disturbance from vole predators.

Through the EIA process and an integrated engineering and environmental design approach a multifunctional flood alleviation scheme has been provided, by creating a better place for people and wildlife whilst giving due consideration to local sensitivities.

CONSTRUCTING THE STORAGE RESERVOIR

Construction of the scheme began in March 2009 with site clearance works. As described above there had been some concern over the moisture content of the clay. The in-situ material did not meet the specified OMC value and it was felt at the time that some conditioning, i.e. drying of the material, would be required before it could be placed. The Reservoirs Act Construction Engineer, Jim Millmore, visited site and a number of hand shear vane tests from several trial holes were undertaken, recording readings of between 30kPa and 80kPa, which indicated that the compacted shear strength would be acceptable. The Construction Engineer visited site as the first layers of clay were being placed, and hand shear vane tests indicated values between 80kPA and 100kPa were being achieved, although the moisture content was outside the optimum. Dry density and moisture content plots showed that the placed material achieved between 0% and 5% air voids, proving that the contractor's methodology allowed the material to be worked and compacted to achieve the required end specification. It assisted the scheme that the Construction Engineer had been involved throughout the design process.

<u>GPS in earthworks</u>

A GPS system was used for both the excavation from the borrow pit and for placing the material in the embankment. The use of GPS enabled the embankment to be built faster and with less exposure to people working around heavy plant. This had several advantages over traditional methods:

- No setting out needed for the borrow pit. This meant less chance of a mistake, less chance of a person being run over and, as the borrow pit had been designed to be at a specific level, it could be finished to that level straight away. When the shape of the borrow pit on one side was modified it was just a matter of updating the model and inputting the details into the GPS in the excavator.
- No banksmen needed in the borrow pit. As all excavation was controlled using GPS there was no need to for any of the drivers to get out of their cabs or the need for a dedicated banksman to control levels. This saved time on setting out, timber use and meant more efficient working.
- The ponds in the bottom of the borrow pits were of a flowing shape. This would have been very hard to have created using profile boards and batter rails. The shape would have been roughed out and then trimmed

after the bulk of the material had been removed. With the GPS equipment all the contours and flowing shapes could be readily formed.

- All the material was placed in the embankment using the GPS system. This made it possible to overfill to obtain the correct compaction, and then trim the slopes to the designed shape. The GPS was also used for placing the topsoil and forming the access tracks.

Mitigating the effects of bad weather

As the site clearance works had been delayed by the discovery of water voles it became apparent that in order to complete the earthworks in the summer (drier months) the diversion of the existing river to its new alignment needed to take place as soon as possible in the programme. The control structure had been designed to be built off the line of the river in the dry to minimise the risks of working in the channel. It was recognised that the finishing works such as brick and exposed aggregate cladding, installation of trash screens, penstocks, and electrical monitoring equipment would not be complete in time to divert the river to enable the embankment to be completed before the onset of wet weather. Although some of these works could be undertaken in the river there would be both environmental and safety issues with this approach.

Options of over pumping were considered but dismissed due to the fish in the river, back-up capacity, refuelling close to the watercourse, cost and potential vandalism to the pumps. A solution was found by putting the brook in to a 600mm diameter and 120m long pipe. A temporary clay bund was built at the upstream end to channel the water into the pipe and a sheet pile and clay bund was built at the outlet in case of high flows. Before the water was diverted into the pipe the inlet/outlet weir to the main borrow pit was completed, as this would provide 3500m^3 of storage within the borrow pit before the works would flood. The pipe was in place from September to December 2009, with only three occasions during that period where there was over 10mm of rain in a day. At this point the main borrow pit filled and the flow exceeded the pipe's capacity but by this time the main earthworks had been finished with only minor channel finishing works remaining. This allowed early issue of the Preliminary Certificate allowing impounding of water and early reduction of flood risk to Waltham Abbey. See Figures 7 and 8 below.

Site set-up

The site was set up with a large open plan office. This led to a great atmosphere on site as everyone shared the same office including contractor, subcontractors, project manager, client and designer. This has led to team solutions and a genuine open working relationship on site. As part of a commitment to welfare mobile health screening has taken place on site. Daily hazard briefings and a monthly fish 'n' chip Friday for every month clear of accidents on site were also ideas successfully introduced.

Figures 7 and 8. Inlet structure in construction and pipe through structure.

CONCLUSIONS

The Cobbins Brook Flood Storage Reservoir has provided many benefits not least in terms of its main function of reducing flood risk to the residents of Waltham Abbey. The project has been undertaken in an exemplar manner and this has been recognised through the awarding of a national Environment Agency Health Safety and Environment award for the design and construction of the project.

A number of lessons learnt from previous schemes were considered throughout the design of the scheme. Notable examples include the use of 3D Modelling, integrated engineering and environmental design such as the textured bed of the structure and the use of the twin penstocks and low level wall approach to allow for safer maintenance access.

As with all schemes there are further lessons that can be learnt from the Cobbins Brook scheme and it is hoped that this paper will help inform others who are responsible for the construction and on-going management of such schemes in the future.

REFERENCES

Halcrow Group Ltd, 2007, *Cobbins Brook FAS Design Report*

Halcrow Group Ltd, 2006, *Cobbins Brook FAS (Geotechnical) Interpretative Report*

Environment Agency, 2005, *Cobbins Brook FAS Project Appraisal Report*

Halcrow Group Ltd, 2004, *Cobbins Brook FAS Environmental Statement*

Halcrow Group Ltd, 2004, *Cobbins Brook FAS Final Feasibility Report*

Halcrow Group Ltd, 2002, *Cobbins Brook FAS Feasibility Study – Stage 1 Final Report*