

Remedial works at Sunderton Pool

M. D. ACFORD, Environment Agency, Exeter, UK

C. A. GOFF, Halcrow Group Ltd, Swindon, UK

R. I. LEWIS, Environment Agency, Exeter, UK

A. L. WARREN, Halcrow Group Ltd, Swindon, UK

SYNOPSIS In 2005 the Environment Agency exercised its reserve powers as the enforcement authority for the Reservoirs Act 1975 to commission an inspection of the privately-owned Sunderton Pool near Shrewsbury. The inspection found the dam structures to be in very poor condition. In particular, the masonry spillway was in a state of considerable disrepair and concerns were raised for the safety of the dam. This paper details the work carried out in identifying those legally responsible for the safety of the reservoir, taking enforcement action, assessing the likely impact in the event of a dam breach, and in planning and procuring design and construction services to improve the safety of the dam. The remedial works included the construction of a labyrinth spillway. A number of difficulties were overcome during the construction of the works. This paper discusses how the reservoir safety risks were identified, assessed and managed.

INTRODUCTION

Sunderton Pool is situated in Shropshire, five kilometres north east of Shrewsbury. The reservoir, which is retained by a 6m high by 80m long embankment dam and has an estimated raised capacity of approximately 83,000m³ and falls within the ambit of the Reservoirs Act 1975 (the Act). For many years, the previous and current owners of the reservoir have failed to comply with the requirements of the Act. As the enforcement authority for the Act in England and Wales, the Environment Agency took legal action against the owners and exercised its reserve powers to appoint supervising and inspecting engineers and to carry out remedial works to the dam spillway. This paper describes the history of land ownership at the site and the action taken by the enforcement authority to secure compliance with the Act. It goes on to describe the remedial works that the enforcement authority undertook to promote the safety of the reservoir.

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HISTORY OF THE SITE

Land ownership at the reservoir site is legally complex and is disputed. The Environment Agency took legal advice from external counsel to help it perform its duty as enforcement authority and to secure that the reservoir undertakers comply with the requirements of the Act. The reservoir appears to have been built in the 18th century, to provide water for the Sundorne Castle estate, which was owned by the Corbet family. The estate was broken up and sold in stages during the 20th century and the castle was demolished. A fishing club bought the reservoir basin, together with the northern (upstream) face of the dam and the spillway, in 1992. Unfortunately the club obtained no rights of access to the reservoir and was subsequently unable to negotiate access with the surrounding landowners. The southern (downstream) section of the dam is owned by another party.

ENFORCEMENT ACTION

In October 2004, the Environment Agency took over from Shropshire County Council as the enforcement authority for the Act. The Environment Agency discovered that Sunderton Pool had no registered supervising engineer, had had its last ten-yearly statutory inspection in 1988, and had seven safety measures outstanding from this inspection report.

Through letters, telephone calls and face-to-face meetings, the Environment Agency contacted all of the landowners in the vicinity of the reservoir and attempted to persuade them to co-operate to secure compliance with the Act. However, the fishing club claimed that they had no funds and were not able to obtain any, as they were unable to access the reservoir. In the face of a continuing impasse, the Environment Agency served enforcement notices on both the fishing club and other landowners (deemed undertakers under section 1.4(b) of the Act) to appoint a supervising engineer and an inspecting engineer. After 28 days the undertakers had made no appointment so the Environment Agency exercised its reserve powers to appoint, on behalf of the undertakers, both a supervising engineer and an inspecting engineer to carry out an inspection and prepare a report.

In his subsequent inspection report of December 2005 (Hinks, 2005), the inspecting engineer stated that the dam and spillway were in poor condition and might collapse if exposed to an extreme flood. The reservoir was assigned as Category C (ICE, 1996) as there appeared to be no lives at risk from a failure of a dam. However the dambreak flood would cross a B-road and enter the River Severn a short distance downstream, causing considerable environmental damage and pollution. The following statutory measures were recommended:

'Within twelve months of the date of this report consultants should be appointed to strengthen the spillway and design remedial works which will allow the flood with a return period

of 1,000 years to be passed safely whilst maintaining at least 300 mm freeboard for waves. The works should be completed within three years of the date of this report.

Within twelve months of the date of this report the flow of water from the brick chamber at the left abutment should be re-routed so that it no longer feeds the morass at the toe of the dam.'

The dam condition is described in more detail in the section below.

Despite further meetings and communications, the fishing club continued to refuse to take any action to comply with the Act. Therefore the Environment Agency served enforcement notices on the club in July 2007, requiring them to carry into effect the measures in the interests of safety in the 2005 report.

As the enforcement authority is entitled to do, the Environment Agency invoiced the fishing club for the cost of the supervising and inspecting engineer appointments it had made on behalf of the undertakers. When the club failed to pay the invoices, the Environment Agency attempted to recover its costs through the small claims court. Eventually part of the costs were recovered through court mediation.

On account of the fishing club's access difficulties, the Environment Agency decided that there was insufficient evidence to justify prosecuting the club for failure to comply with the Act. Therefore a written warning was issued instead.

BONA VACANTIA

The fishing club decided that its position was untenable and was voluntarily struck off the Register of Companies on 8 September 2009. An ownerless property is termed 'bona vacantia', literally 'vacant goods'. When a company is dissolved or a person dies intestate without known kin, their assets pass to the Crown. However, as a matter of policy (see <http://www.bonavacantia.gov.uk/output/companies.aspx>), on behalf of the Crown the Treasury Solicitor disclaims onerous property, including large raised reservoirs. Depending on the location of the reservoir, the Crown Estate, Duchy of Lancaster or Duchy of Cornwall will retain the right to become the owner, but does not in fact do so until and unless it takes possession or otherwise manages the reservoir (which usually it will not do in practice).

In the case of Sunderton Pool, the Treasury Solicitor disclaimed its interest in the reservoir on 27 October 2009, the freehold estate was destroyed and the reservoir escheated to the Crown Estate Commissioners. The Environment Agency's legal advice was that the Commissioners were not liable for the reservoir unless they took steps to manage it or take possession of it, and that in practice they would do neither.

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The effect of this was to render the reservoir basin, the spillway and the upstream section of the dam effectively ownerless. Counsel advised the Environment Agency that there was a risk that a court might hold that where the undertakers of a reservoir were owners, their responsibilities and liabilities would be limited to the parts of the reservoir which they owned. Counsel also advised that the Environment Agency would probably be criticised if it failed to exercise its reserve or emergency enforcement authority powers, but that it would be most unlikely that such failure could give rise to civil liability in negligence. The Environment Agency therefore decided that it was unacceptable for it to leave the dam in a potentially dangerous state of repair and that it should exercise its enforcement authority powers to improve the safety of the dam. Between 2010 and 2012, works were therefore planned, designed and constructed to improve the safety condition of the dam.

DAM CONDITION AND SAFETY MEASURES

The 2005 inspection found the dam embankment and spillway in a poor condition. The embankment crest is very narrow in places, the downstream face is irregular and heavily vegetated and there are two separate areas of morass at the downstream toe of the dam which appear to be linked with seepage either through the dam foundation or through the base of the embankment. It was not possible to ascertain the exact locations of the seepages and draining of the morass areas to try to locate the seepage points was not favoured without first reducing the hydrostatic loading on the dam. A small high level supply pipe, which once served a pumped water supply system, had been left without any hydraulic control and water was flowing into the morass area, making visual monitoring of any seepage increase through or under the dam more difficult.

The masonry/concrete free overflow spillway at the left abutment was found to be in a very poor condition and at risk of collapse even under moderate flow conditions. The structure is well founded within a sandstone cutting through the left abutment. At some point in time it seems likely that the dam was raised using poorly-cemented rubble and covered over with a mass concrete slab. It is speculated that the slab became damaged during a flood and erosion within the underlying rubble fill led to a loss of support to the slab and progressive deterioration. The capacity of the spillway was also considered inadequate and there were concerns that the dam embankment might not survive being overtopped given the very narrow dam crest (less than 2m in places). The safety measures therefore focused on repair of the spillway, improvement of flood safety and improvement to seepage surveillance by preventing the high level pipe flow from feeding water into the morass.

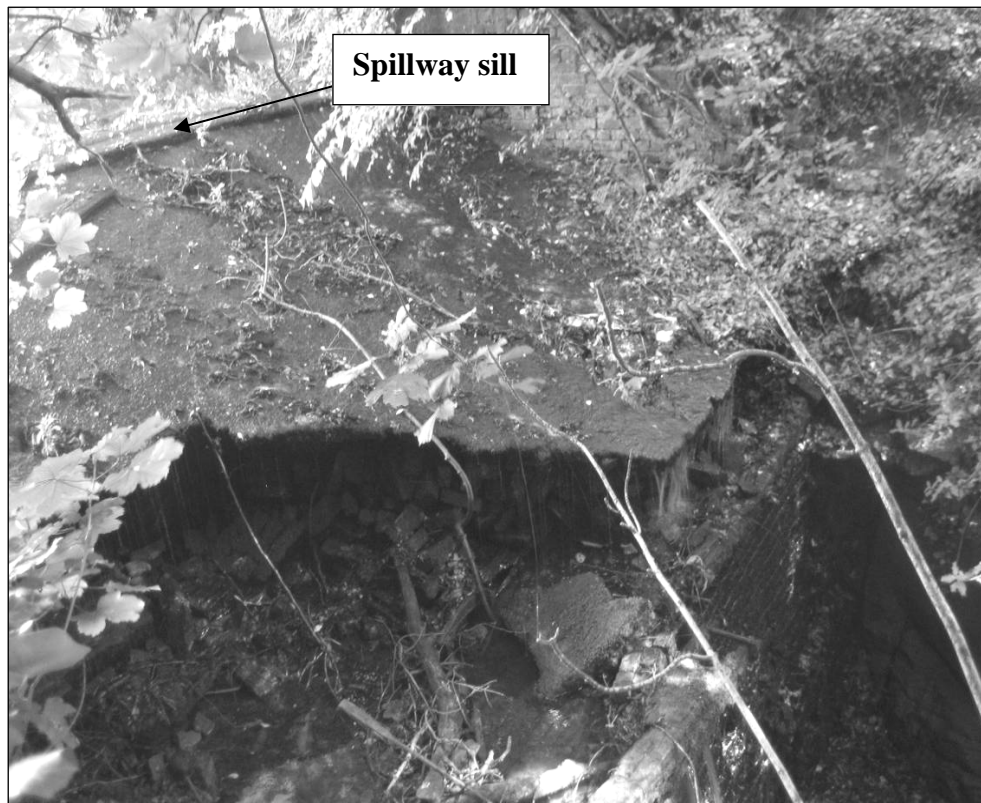


Figure 1. The original spillway structure was found in poor condition

The work to divert the 125mm diameter high level pipe flow from feeding the morass was relatively straightforward and this work was carried out by the Environment Agency in 2010. A small gate valve was installed within a brick chamber at the pipe outfall which effectively isolated the flow.

To scope the flood safety concerns and spillway repair work, studies were undertaken by Halcrow Group Ltd. The options studied in 2009 are summarised below:

Table 1. Strategy Options

Option	Description
1	Repair the spillway and improve the flood freeboard (this option has the least volumetric impact on the reservoir).
2	Reduce the reservoir capacity to below 10,000m ³ by significantly lowering the top water level.
3	Complete removal of the reservoir.

Option 2 was scoped in recognition of proposed changes to the Act under the Flood and Water Management Act 2010. This study found that the cost

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of all of the options would be broadly similar and it was necessary to evaluate the benefits of preventing a dam breach to provide clear direction. Hence more detailed economic appraisal work was carried out to include for the economic damages arising from a dam breach. This appraisal followed the guidance in FCERM-AG (Environment Agency, 2010) and estimated the costs and damages over a 100-year period using information from the options report and information derived using the Environment Agency's dambreak map. Option 1 provided the highest benefit: cost ratio at 7.2 and this work was important in proving the case for intervention using public money and in securing funding for the project.

Following advice from panel engineers and legal Counsel it was clear that intervention by the Environment Agency was necessary to reduce the relatively high probability of failure which the dam was exposed to. Allowing the dam to fail was not considered acceptable on reputational, safety, environmental and financial grounds. Options giving positive benefit to cost ratios had been identified which were significantly cheaper to the public purse than the projected cost of a dam failure.

In considering the environmental, social and economic factors involved in a scheme to repair the structure to safe operating condition, regard was given to the Environment Agency's main aim under the Environment Act 1995 to protect and enhance the environment and its duty to promote the conservation of inland waters and the fauna and flora dependant on the aquatic environment. Having been left without maintenance for many years the area had become an important habitat for a number of protected species. The reservoir was also identified as an important archaeological and historical feature in the landscape. These factors combined with the highest benefit to cost ratio gave rise to the selection of option 1 as the preferred option.

While the main aim of the project was to reduce the probability of dam failure significant additional Water Framework Directive and Biodiversity Action Plan benefits were incorporated at low cost with the agreement of local landowners. The removal of large benthic fish, establishment of reed beds and partial exclusion of livestock from adjacent fields were designed to reduce sediment and contaminants entering the reservoir and passed downstream to the River Severn. It is intended that the reservoir will become a filter and sink for agricultural contaminants with water passing the spillway being of significantly improved quality over that in the brook upstream.

It was also recognised that retaining the reservoir would bring environmental benefits. Notably, the reservoir acts as a pollutant sink by removing potentially harmful particulates from reaching the Severn. The

detailed design work for the spillway works was awarded to Halcrow in 2011.

HYDROLOGICAL STUDIES

The 2005 Section 10 report (Hinks 2005) assigned the dam as Category C in accordance with Floods and Reservoir Safety (ICE, 1996). The flood safety standard assigned for the reservoir was that it should pass the 1,000-year flood event with not less than 300mm freeboard for waves (slightly less than the 400mm recommended in the guidance given the short fetch and sheltered nature of the reservoir).

For the detailed design a hydrological analysis was undertaken using the Flood Estimation Handbook (IH, 1999) methodology in order to confirm the routed design outflow at the reservoir. Due to a lack of gauged data from this catchment, data from a suitable donor catchment was applied. This analysis resulted in a design flood peak reservoir inflow of 25.5m³/s in the 10,000-year event. The design flood hydrograph was then routed over the existing spillway in order to determine the current flood rise condition. The results showed that the current spillway capacity was only 14.8m³/s and that the design flood would cause the dam to overtop by nearly half a metre, even before any allowance for waves was considered. As the project progressed and a design solution evolved, the hydraulic model was revisited on several occasions in order to test the routing of the design flood over the proposed new weir design.

Further hydrological studies were undertaken during the detailed design phase to determine the median annual maximum flood event at the site in order to allow design of suitable temporary works and procedures to keep the site safe during construction.

FLOOD SAFETY IMPROVEMENT OPTIONS

To inform the detailed design a bathymetric survey of the reservoir and a topographic survey of the dam was commissioned.

Options to improve the flood safety of the reservoir were studied, taking into account the following considerations:

- There is limited vehicular access to the site. Vehicular access to either abutment is possible, but difficult, and no vehicular access along the dam crest or toe is practicable.
- As far as possible, the reservoir top water level and volume should be preserved to maintain the environmental benefits provided by the reservoir.
- Minimise construction costs
- Minimise the environmental impact of construction activities

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Raising the dam crest was considered impracticable and costly. A topographic survey of the dam crest identified some localised low spots which could be raised through manual construction to provide an even crest level and achieve an improvement in freeboard at modest cost. However, the condition of the existing spillway structure meant that works would be needed to the spillway and an arrangement with a reduced sill level was appropriate. Consideration was given to widening the spillway structure. Although the structure itself was in a very poor condition, there was no evidence of seepage around the sides of the structure. Widening the structure might have led to seepage issues around the sides or under the enlarged structure which would then require costly grouting works. In maintaining the existing spillway footprint, a simple replacement overflow at a much reduced top water level was considered. An alternative labyrinth spillway was favoured, resulting in a much lesser reduction in top water level for the same degree of flood safety. These options are summarised in Table 2.

Table 2. Flood safety improvement options

Option	Description	Conclusion
A	Raise entire dam crest	Not feasible due to access constraints, costs, environmental damage
B	Lower spillway drastically	Undesirable on environmental grounds
C	Lengthen spillway crest	Feasible but difficult and expensive. Risk of not achieving abutment/foundation watertightness without costly grouting works
D	Replace spillway weir within existing footprint with improved weir design (e.g. Labyrinth weir) and raise dam crest low spots	Selected option

The topographic survey showed a minimum dam freeboard of 0.85m at the localised low spots on the crest, and generally a dam freeboard of 0.94m overall. This meant that after allowance for waves, only 0.64m freeboard was available for flood rise.

DEVELOPMENT OF THE SPILLWAY WEIR DESIGN

The idea of using a gated spillway structure was quickly discounted as this would have an ongoing operation and maintenance burden that was unlikely

to be fulfilled by any of the landowners and was not the responsibility of the Environment Agency.

Although the existing weir length was only 8.5m, the width available was significant and this allowed consideration of both labyrinth and piano-key weir arrangements within the footprint of the existing structure. The design of labyrinth and piano key weir design is covered in, for example, Erpicum (2011).

A labyrinth weir can be a simple rectangular weir in cross section but has a zigzag or saw-tooth shape in plan meaning a much longer effective weir length, and thus lower flood rise, can be accommodated.

Piano key weirs are relatively recent evolution of the labyrinth weir and were first constructed on concrete dams in 2006. Instead of vertical sides these slope down towards the centre of the structure meaning the weir can be founded on, and overhangs, a much smaller base width.

A labyrinth weir solution was chosen to replace the spillway at Sunderton Pool for the following reasons:

- A traditional broad/sharp crested weir will not meet the required discharge capacity
- A free overflow spillway is more reliable than gates, less expensive and requires minimal operation/maintenance
- A piano-key weir would need to be pre-cast which would be more expensive and more difficult to install at this site due to access constraints
- The flow characteristics of piano-key weirs are a relatively new concept and have not yet been tested exhaustively
- The existing spillway has a large footprint and is thus more suitable for a labyrinth weir
- The discharge capacity of a labyrinth spillway at this site is sufficient to pass the design flood with the need to lower the reservoir top water level by only 0.26m.

The design of the reinforced concrete labyrinth spillway features two cycles and an angle of 18° giving an effective crest length of 18.1m within an overall length of 8.5m in the dam crest. A 3D representation of the new weir is shown in Figure 2.

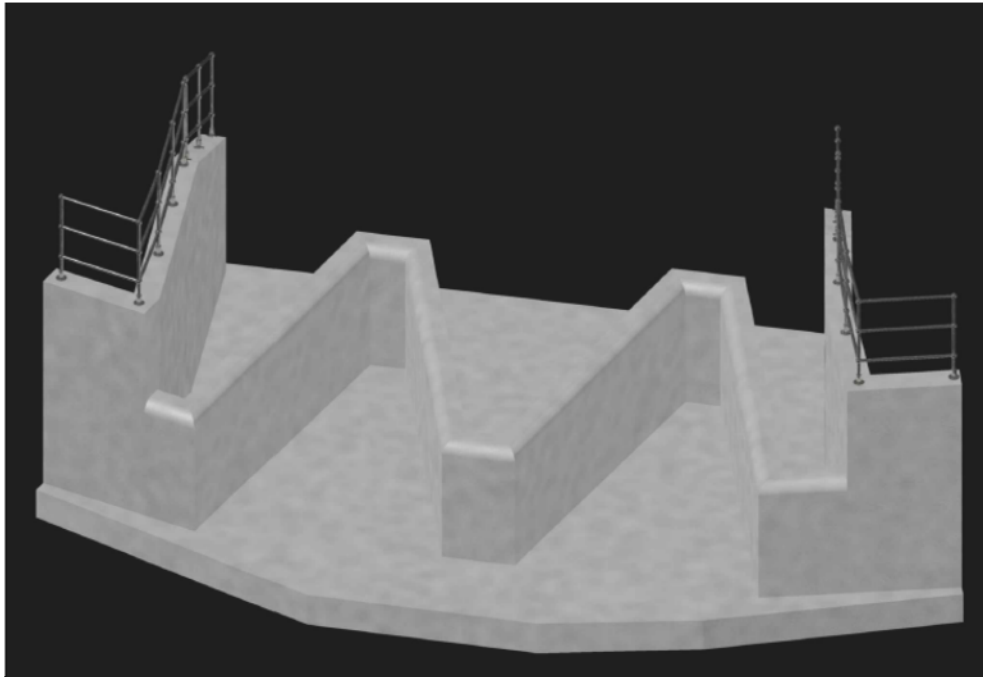


Figure 2. 3D CAD representation of the new labyrinth spillway weir

By reducing the reservoir top water level by 0.26m, the new labyrinth weir allows safe passage of the design flood rise (0.84m) plus wave freeboard allowance (0.3m) totalling 1.14m, within the improved available 1.2m dam freeboard.

LICENSING

The works required a temporary drawdown and then re-impoundment to a level 260mm lower than original spillway crest level. Due to the permanent change in impoundment level the Environment Agency was required to obtain an impoundment licence under the Water Resources Act 1991. Flood Defence Consent under the Land Drainage Act 1991 was also required for both the temporary and permanent works.

During very dry spells it had been noticed that the reservoir does not spill over the existing weir. At such times the reservoir outflow comprises evaporation and seepage through the dam and spillway. A 150mm diameter pipe was incorporated through one of the weir walls below spillway crest level to replicate the long standing leakage through the structure and to ensure that a flow would be constantly maintained to the downstream watercourse during periods of low flow for ecological advantage. This provision was requested in order to gain Flood Defence Consent.

CONSTRUCTION PLANNING

The construction site was located 1.6km off the B5062 up a private access road serving local farms and cottages. The Environment Agency has the

legal right of access to land upon which a reservoir is situated for the purposes of carrying statutory recommendations into effect under the Act. A site compound was established at Dell Farm approximately 100m from the spillway weir.

The construction contract was awarded on a fixed price basis following a mini competition under the Environment Agency's Minor Works Framework governed by the NEC Short Contract Terms and Conditions. Halcrow provided contract supervision and QCE services under the Act.

The land between the compound and spillway weir is heavily wooded and crossed by the Sundorne Brook. An access route through the trees was created while minimising the loss of important trees. The site presented access, health and safety and environment considerations. Early consultation with the Environment Agency, Natural England, Shropshire Council, the CDM-C and the contractor allowed the works to be designed and planned so as to minimise cost, risk and environmental disruption.

Water level control during construction was critical to the cost and safe completion of the construction phase. Temporary works were designed to pass the median annual maximum flood of 3.0m³/s. This flood had an estimated 1% probability of being exceeded during the critical period of construction.

Other than the small-diameter high level supply pipe the reservoir has no functioning drawoff facilities. A drawdown rate of 100mm per day was achieved using the existing 125mm diameter pipe in combination with 1no. 150mm pump. The reservoir level was drawn down by approximately 1m to the invert level of the high level pipe.

Following completion of the temporary works the top 1.8m rubble and concrete masonry section of the spillway was demolished. The larger rubble arising from the demolition activity was re-used as erosion protection in the channel downstream. Removal of the upper section of the structure revealed that the structure had been formed of clay fill with a masonry retaining wall on the downstream side with internal counterforts.

The design of the structure was slightly modified to account for the clay. A cutoff trench and geotextile was incorporated into the design to ensure that no erosion of the clay would occur with the weir in service. A 300mm reinforced concrete vertical wall was cast against the downstream face of the masonry structure with drainage provisions. The main base slab was then cast followed by the reinforced concrete wing walls and the labyrinth structure. A key challenge for the design was fitting the new reinforced concrete structure to an existing irregular structure. Despite having had detailed topographical information at the time of the detailed design, and the

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benefits of 3-D CAD, some minor design adjustments were needed to optimise the geometry of the structure to the site conditions and constraints.

During construction the contractor was faced with a limited working area adjacent to a steep sided gorge requiring careful management of health and safety risks. Access for plant was restricted with an 8t excavator being the largest plant in operation. Ramps and platforms were constructed in the working area to prevent the machine from sliding. The crest raising works were carried out by manual labour to prevent machinery from loading the narrow dam crest. The access track through the woodland was retained giving improved vehicular access to the spillway for the future.

The works were completed within a 10-week programme.



Figure 3. The completed labyrinth weir structure

CONCLUSIONS

Sunderton Pool lies in a very small group of reservoirs where the Environment Agency has committed resources in addressing reservoir safety concerns for a reservoir for which it is not the Undertaker. The 'Category C' status of the reservoir makes the case very unusual. Studies undertaken demonstrated that the cost to the public purse of dealing with a dam failure outweighed the cost of remedial action by a significant margin. The very poor physical condition of the dam spillway structure led to the decision that this was not a case that the Environment Agency could ignore.

In developing and implementing the design of the new spillway works, care was taken to improve the flood safety of the reservoir in a manner which was in keeping with the Agency's commitment to the environment and the Water Framework Directive.

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