The Discontinuance of Devils Dingle Ash Lagoon

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SYNOPSIS. Devils Dingle Ash Lagoon is the principal means of ash disposal for Ironbridge Power Station. The lagoon is impounded by an embankment constructed largely of PFA with an upstream clay core. Filling of the lagoon is entering the final stages and plans for the restoration of the site are currently being formalised.

This paper describes the proposed decommissioning of Devils Dingle Ash Lagoon and the measures taken to ensure that the reservoir will have its storage capacity reduced to less than 25,000m^3 and therefore fall outside the ambit of the Reservoirs Act 1975. The methods used to complete the filling and landscaping of the lagoon whilst maintaining and enhancing the important wildlife habitat that have established around the site are also described.

INTRODUCTION

The Devils Dingle Ash Lagoon has been the main means of ash disposal for the 1000 MW Ironbridge 'B' Power Station since it commenced operation in 1968. It comprises an embankment, constructed mainly of pulverised fuel ash (PFA) impounding a lagoon in a small tributary valley of the River Severn above the village of Buildwas, Shropshire. The embankment straddles the confluence of two small streams flowing down the valley.

The embankment was raised in stages ahead of the ash disposal requirement to a maximum height of 66m. The crest of the embankment has an approximate length of 570m. Approximately 3 million tonnes of ash were used to construct the embankment and another 2 million tonnes were used to fill the lagoon. A compacted clay embankment with stone drainage layers and an upstream rockfill berm was constructed for the initial impounding prior to the availability of the conditioned ash. The main body of the dam was then constructed from compacted PFA with a rockfill berm at the downstream toe. The upstream face of the dam was then sealed with a 3.5m thick clay blanket which is protected from wave erosion by a layer of coarse

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gravel and rockfill. A vertical wall drain was constructed downstream of the final crest line which connects with a horizontal drainage blanket located beneath the downstream shoulder of the embankment. A cross section of the embankment is shown in Figure 1.

PFA has been delivered to the lagoon in two ways. Conditioned ash with a moisture content of about 23% was delivered to the site by truck between 1967 and 1983. The remainder of the ash was slurried and pumped to the lagoon by pipeline. However, in December 2000 the pipeline delivering slurried ash was ruptured by slope movements along the valley between the power station and the ash lagoon. As a result the ash required to complete the filling of the lagoon and provide landscaping features is being delivered by road.

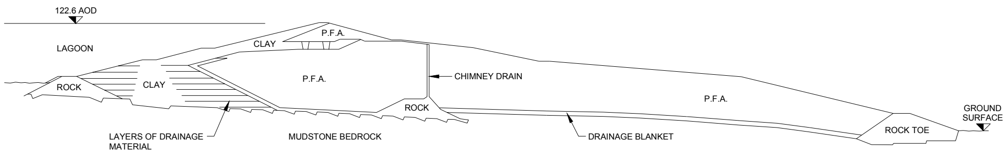

Figure 1: Cross section of the embankment

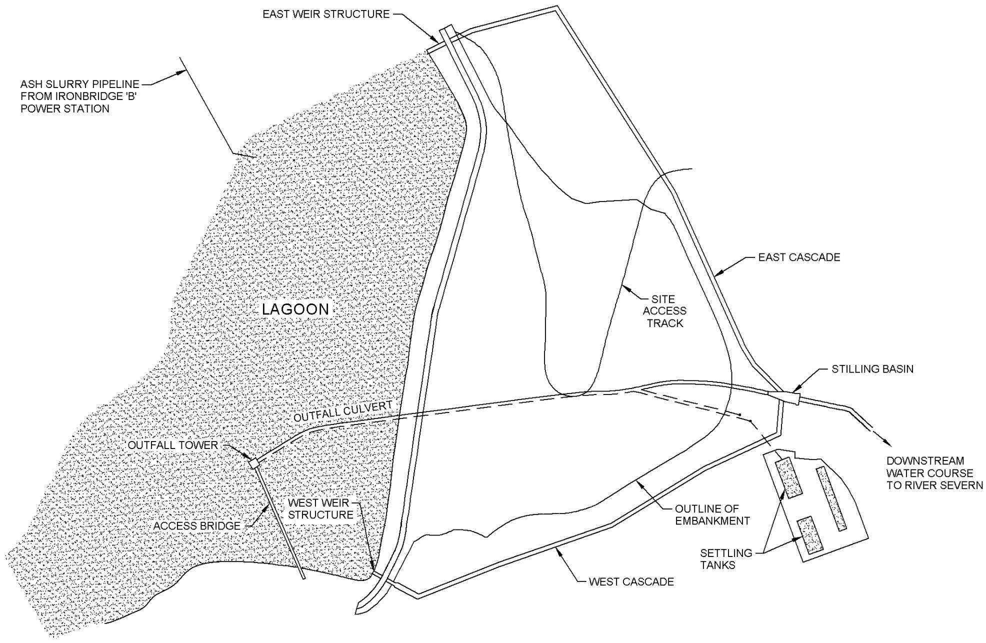

Figure 2: Plan of the embankment at Devils Dingle

OVERFLOW ARRANGEMENTS AND FLOOD CONTROL

During operation of the lagoon supernatant water is discharged over dam boards set in a slot in the side of the 4.6m diameter outfall tower. The water level in the lagoon can be varied by adding or removing these dam boards. Recently water within the reservoir has been held at 122.34mOD although the level can be raised to a maximum of 123.0mOD which coincides with the weir of the outfall tower. Access to the top of the tower is gained via a raised steel platform and walkway from the western (right hand) bank of the reservoir.

Decanted water drops down the tower to the base where a retained pool of water is used to dissipate the energy of the falling water. At the base of the tower a 600mm, reducing to 450mm, diameter pipe is set below in the main weir of the pool to discharge ‘normal’ flows to stilling ponds downstream of the dam. This pipe runs along the outfall culvert connecting the base of the tower to the downstream toe of the dam. Towards the end of the outfall culvert the pipe is diverted from the main culvert into a smaller secondary culvert that leads into the settling ponds situated just off the toe of the embankment.

During flood events water is initially discharged over the dam boards until the water level in the lagoon reaches 122.6mOD when flows also pass over two cascades located at either end of the embankment. The cascades are constructed of reinforced concrete and form trapezoidal channels with baffle blocks at regular intervals along their length. Each has been designed to discharge a flow of approximately $2m^3/s$ and both discharge to the stilling basin at the toe of the embankment. A weir and venturi flume at the head of each cascade ensures that the design flow is not exceeded even under extreme PMF conditions. As part of the original design the cascade structures were model tested to confirm the arrangements.

As the water level in the reservoir continues to rise overtopping of the outfall tower weir set at 123.0mOD occurs. When the capacity of the 600mm pipe at the base of the tower is exceeded water discharges over the weir directly into the outfall culvert. The flood waters pass down the outfall culvert into the stilling basin before flowing back into the stream leading to the River Severn. The outfall culvert and stilling basin are designed for a maximum flow of $22m^3/s$. The levels of the principal structural elements are summarised in Table 1 below:-

Table 1: Levels of the principal structural elements within the ash lagoon

Structure	**Level (mOD)**
Embankment Crest	124.30
PMF Flood Level	123.53
Outfall Tower Weir Level	123.00
Cascade Weir Level	122.60
Damboards (Typical weir level)	122.34

A recent hydrological assessment of the site undertaken by KBR reported the catchment area of the ash lagoon to be approximately 1.38 square kilometres with an average annual rainfall (SAAR) of 736mm. The peak inflows for the different flood events within the Devils Dingle catchment area are detailed in Table 2 below:-

Table 2: Peak inflows for the Devils Dingle catchment area during various flood events

Flood Return Period	**Peak inflow**
Mean annual flood	0.7 m^3/s
1,000 year flood	4.7 m^3/s
10,000 year flood	9.7 m^3/s
Probable Maximum Flood	19.1 m^3/s

Prior to the recent period of infilling with the ash lagoon, the attenuation within the lagoon results in the PMF peak outflows being approximately 16m^3/s, with 3.5m^3/s flowing down the two side cascades and 12.5 m^3/s flowing into the outfall tower and along outfall culvert.

REQUIREMENTS OF THE RESERVOIRS ACT

Discontinuance of a reservoir can only be certified if a Panel AR Engineer is satisfied that the impounded volume of a reservoir, excluding any flood storage, has been permanently reduced to less than 25,000m^3. However, in situations such as ash lagoons this volume should include any silt or ash deposits that would flow in the event of an embankment breach or failure. Therefore, the volume of 'escapable contents' should be considered in this case.

Ash lagoons such as Devils Dingle are usually operated under a number of interim certificates as the lagoon is being filled to its final level. When filling of the lagoon is completed the final certificate is issued and is immediately followed by a certificate of discontinuance as the lagoon would no longer have any storage available. However, in this particular case the owners of the site were keen that the restoration plan included at least one body of water in order that the wildlife habitat that had established around the lagoon could be retained.

Plate 1: The reservoir at the Devils Dingle Ash Lagoon with draw-off tower access walkway in the background

Given that the current surface area of the lagoon is of the order of 125,000m^2, a single pond with a volume restricted to less than 25,000m^3 would have an average depth of less than 200mm for discontinuance to be possible. In addition any underlying layer of fluid ash would also need to be considered in the calculation of 'escapable contents' and would further reduce the volume of stored water allowed in the final scheme. In order that the final restoration of the site could incorporate some form of stored water feature it was hoped that the ash at the lower levels had consolidated with time, encouraged by under drainage and through drainage into surrounding lower water table. Significant depths of 'fluid ash' would make it not possible to have any form of large ponds within the restoration plan.

Given the large surface area of the current reservoir and the likelihood that a layer of 'fluid' ash exists below the retained water level it was envisaged that 3 or 4 smaller separate water bodies each with escapable contents of less than 25,000m^3 of water and ash would have to be formed rather than a single pond. However, the construction of multiple ponds would have undertaken in such a way as not create a situation where the capacity of each lagoon was considered to be part of the sum of all the lagoons and therefore have a capacity in excess of 25,000m^3. The final design must therefore include lagoons, each one considered to be fully independent of its neighbours and with little likelihood, under any situation including instability, overtopping or piping, of failure of the dividing bunds.

It was considered that the dividing bunds must therefore be designed as engineered structures on a suitable foundation. However there would be no requirement to construct the bunds as linear features, or with uniform cross sections and so it is envisaged that the dividing embankments will be constructed to give the lagoon area as natural an appearance as possible. It is considered that the separating bunds would have to be constructed with typical crest width in the region of 30m and maximum slope gradients of 1V:6H in order to ensure that the dividing embankments remain stable and the lagoons remain independent features.

INVESTIGATIONS AND SURVEYS

In addition to a detailed topographic survey of the site, a bathometric survey of the lagoon was undertaken to determine the levels of the ash within the reservoir. A three dimensional computer model was then developed to determine the remaining void space and to establish a number of discontinuance options using varying quantities of PFA. This design flexibility was required as the actual volume of PFA available for disposal and landscaping is uncertain and largely depends on the operational life of Ironbridge Power Station and the requirement of PFA for other uses. The number of ponds created in the reservoir, the height of the controlling weirs and the height and topography of the ash bunds within the lagoon were all varied to establish the minimum volume of ash required to achieve the discontinuance of this reservoir.

A geotechnical site investigation was carried out to establish the condition of the previously deposited ash and to determine the depth of ash that could be considered to be fluid. Experience from other sites suggested that the low water table around the site and under-drainage may have caused the lower levels of the ash to have partially drained and consolidated. However, the upper two or three metres were likely to be unconsolidated with a high moisture content.

The method of investigation was determined by the soft nature of the ash deposits both in terms of the sampling methods proposed and the ability to move around within the lagoon. Some elevated areas in the lagoon close to the outlets had been ‘dry’ for many years and as a result the upper layer of ash had become relatively firm and vegetated. However, the level of ash in other areas closer to the embankment was considerably deeper and had been under water for significant periods of time. Due to the positioning of the slurried ash pipeline outlets around the lagoon the surface levels of the ash deposits varied by up to 5 metres. As a result it was decided to use a CPT

(Cone Penetration Test) rig fitted with a Piezocone and mounted on a floating pontoon within the lagoon. The water level in the lagoon would be raised to the level of the two cascades (122.6mOD) by inserting dam boards in the outfall tower and this would enable the pontoon to access as large an area as possible including some of previously 'dry ' areas. Immediately after the completion of the investigation the water level would be reduced to the lowest level possible in order to dry out as much of the ash surface as possible.

In April 2002 the first phase of ground investigation was carried out consisting of forty nine cone penetration tests positioned on a grid at 50m spacings. Each hole was continued to a maximum depth of between 10m and 16m or until 'solid' ash was encountered. In addition six continuous piston sampling holes were carried out to assist in the interpretation of the CPT holes and to enable the geotechnical characteristics of the deposited ash to be determined.

RESULTS OF THE INVESTIGATION

The results of the investigation enabled a depth profile of the ash to be plotted. The results indicated that the majority of the ash deposit had consolidated and drained and that there had been some cementing of the deposits. The results indicated that the ash composition and properties were relatively uniform across the lagoon. A relatively thin layer (<1m) of very soft ash was encountered at the surface of the deposits during the investigation. However, in the event of a breach in the embankment, the PFA deposits would be relatively stable and no significant flow of ash would be expected.

TRIAL FILLING AREA

As part of the preliminary design and prior to the construction of any permanent separating embankments, a trial filling area was established. The trial would not only allow an area of previously submerged ash deposits to be exposed and the proposed foundation to be examined but would also allow a 'constructability' trial to be completed. This would assist the contractor in choosing appropriate plant and methods for completing the remaining filling and the construction of the separating embankments. A site was chosen near to the eastern end of the embankment where the topography of the existing ash surface was suitable and where the trial could be undertaken safely in a position away from the outfall tower.

The trial showed that pushing conditioned ash into the upper layer of ash displaced the majority of the very soft ash deposits present and that the dry ash became founded on a suitable foundation layer. The trial also demonstrated that the method of placing the fill over the previously deposited ash fill was suitable and that a suitable founding layer could be established for the remaining fill and proposed separating embankments.

Following completion of the trial filling area two survey positions were constructed above the areas that had received the greatest depth of fill. The levels of these two survey stations have been recorded on a monthly basis to determine the amount of settlement taking place in the foundation and newly placed fill. The results to date indicate that no noticeable settlement in either the foundation or recent fill is taking place. Therefore, it is likely, given the granular nature of these ash deposits, that the majority of the settlement has occurred during the construction of the trial filling area.

PHASE TWO SITE INVESTIGATION

A second investigation was commissioned in November 2003 after approximately 18 months of filling the lagoon with PFA. To enable comparison with the first phase CPTs, eleven new CPTs were carried out in locations coincident with CPTs from the phase one investigation. These CPTs were carried out using a truck mounted rig and were taken to a maximum depth of 10m. Not all areas of the lagoon were accessible to this truck mounted rig as some areas remain under water.

The Phase 2 investigation was undertaken to determine the condition of the newly placed fill, the changes within the previously deposited ash fill and to establish the presence, or otherwise, of the soft layer previously identified at the surface of these deposits.

The results show that the soft layer was no longer present probably resulting from the method of filling, consolidation as more ash was placed above and the re-distribution of pore water pressures. Also the ash placed above that tested in Phase 1 had improved density and stiffness properties. Therefore, it is considered unlikely that the ash would flow if the embankment were breached.

POND LAYOUT

Based on the results and interpretation of the various investigation phases a preliminary restoration plan was developed. Three ponds are proposed, two of which are to be located close to the embankment adjacent to each of the cascade structures. A third pond is proposed towards the western edge of the lagoon adjacent to and north of the location of the existing elevated walkway to the outfall tower opening. The two ponds located close to the embankment are to have water levels of 122.6mOD controlled by the existing cascade weirs. The third pond will have a slightly higher water level controlled by inlet and outlet structures on the stream entering this pond.

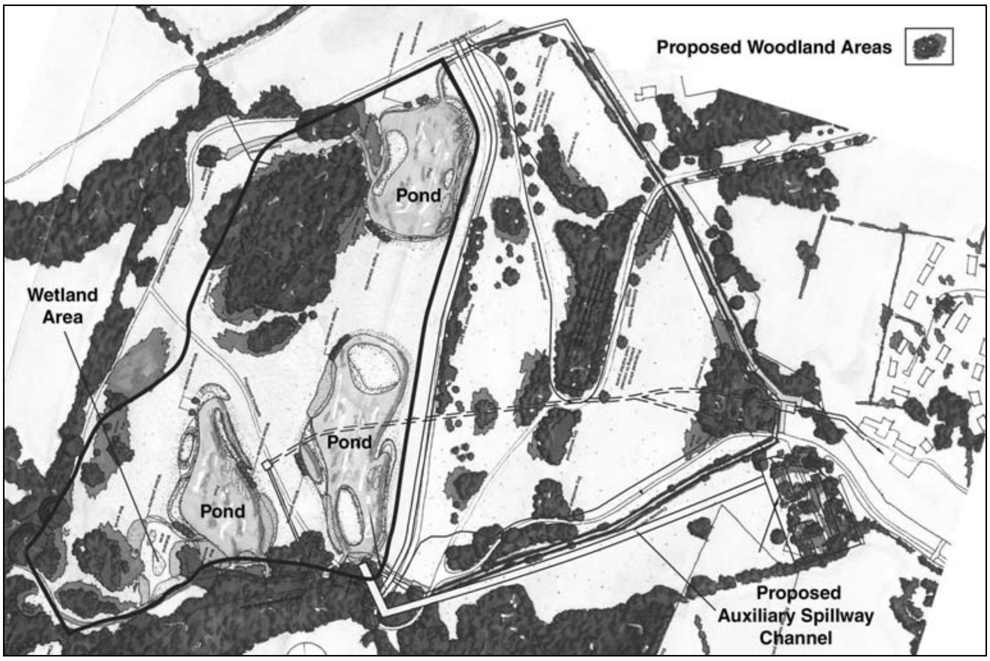

Figure 3: Plan of proposed restoration scheme

Each of the proposed ponds will have a specifically designed profile in order to try and establish a number of different aquatic habitats within the lagoons. Low lying areas close to the incoming streams will also be used to create new habitats such as wetland marginally areas.

Ecologists and landscape architects formed part of the project team that formulated the preliminary restoration plan for the site. Areas of young woodland and other vegetation that has become established within the lagoon area will be preserved where possible and new areas of both 'dry' and 'wet' woodland will be created around the proposed ponds.

PFA will also be used to construct additional landscaping areas on the downstream face of the embankment create a more natural landform and to mask the concrete features on the embankment that for hydraulic reasons tend to follow straight lines. Planting of selected shrubs and trees on the downstream face will also help to disguise the embankment.

MODIFICATIONS TO EXISTING STRUCTURES

In order to return the site to as natural an appearance as possible it will be necessary to carry out modifications to the existing structures associated with the lagoon. Sequencing of the necessary modifications to the overflow tower, cascades and stilling basins must be programmed such that no works are undertaken on these structures prior to the satisfactory discontinuance of the reservoir. As further ash is deposited in the existing lagoon both the volume of retained water and surface area of the reservoir are reduced. Although the further filling reduces the volume of the reservoir, the benefit of the flood attenuation provided by the lagoon is also reduced. A detailed programme of ash deposition, construction and modifications was therefore developed to ensure that a 'less safe' condition is not created during this process.

During the early planning and preliminary design stages of this scheme the issue of how the site will respond to flood events during and on completion of the restoration plan have had to be addressed. The original proposal for discontinuance includes the decommissioning of the outfall tower and culvert by sealing both ends and filling the void with a PFA/cement grout as this will reduce the future maintenance requirements of the site. The decommissioning of the outfall tower will reduce the discharge capacity of the site to the combined capacity of the two remaining cascade structure approximately $4m^3/s$ which equates to a 1000 year flood event.

Although the reservoir will no longer be subject to the Reservoirs Act 1975 and have a requirement to safely pass the PMF event, the owners were keen that the restoration plan should include measures to protect the embankment against overtopping and possible erosion from storms greater than the 1,000 year event. This would particularly important when maintenance and inspection regimes would be stepped down and in the long term when the site may possibly be sold. The potential for blockage of the existing cascades will also be more likely given the large number of trees and other vegetation to be planted around the proposed ponds

Therefore, it was decided to construct a reinforced grass auxiliary spillway down the right mitre of the embankment, adjacent to the western cascade channel, to give additional spillway capacity. The weir of this structure will be designed in such a way that the discharge capacity of the combined spillways will again be able to pass a PMF event safely and therefore the embankment will be protected from overtopping. Flood flows will pass via a reinforced grass channel into a newly constructed stilling basin at the toe of the embankment where the existing settling tanks are located. The construction of the auxiliary spillway is planned early in the programme prior to discontinuance of the reservoir in order that the adequate discharge capacity is always available during the works. This also will provide greater flexibility in the timing of the remaining ash placement, pond formation and modification of existing structures.

Outfall Tower and Access Walkway

The outfall tower and access walkway will become redundant in the proposed scheme. Removal of the raised walkway will be achieved by the construction of a large ash bund adjacent to the walkway from the western bank of the lagoon out towards the outfall tower. This bund will provide a working platform from which the access walkway will be dismantled and the supporting piers broken down. The bund will also allow access to the top of the outfall tower. It is proposed that the downstream end of the outfall culvert is sealed with a concrete bulkhead and the entire outfall tower and culvert be filled from the above using a PFA cement grout. This will ensure that there will be no long term maintenance issues associated with the outfall tower or outfall culvert.

Plate 2: Eastern cascade channel on the left mitre of the embankment

LONG-TERM BENEFITS AND PERFORMANCE OF DAMS

Spillway Cascades

Following the completion of the restoration plan the two cascades located at either end of the embankment will be in almost continuous use as these structures will control the level of the ponds. The structures are likely to be largely unchanged, however, some screening of the cascades using various types of vegetation will be undertaken in order to reduce the visual impact of these linear features.

Stilling Basin

The main stilling basin will still be required following discontinuance of the reservoir as flows from the east and west cascade channels will enter either side of the stilling basin. As the stilling basin will no longer receive flood flows from the outfall culvert some minor works are proposed to mask the sealed entrance of the outfall culvert and reduce the visual impact this feature.

Main Embankment

The placing of additional ash and topsoil on the downstream face and selected planting is proposed to create a more natural appearance and to create more rounded features and break up the straight lines of site that exist.

Settling Lagoons

The area currently occupied by the settling lagoons will be modified and will be used as a stilling facility for the reinforced grass auxiliary spillway. Measures will be taken to obscure the view of both the auxiliary spillway channel and stilling basin from the village of Buildwas located close to the toe of the embankment.

Pipeline

A 2.5km long pipeline exists between the power station and the lagoon through which slurried ash was pumped up to the lagoon. The pipe varies in depth considerably over its length being some 10 to 12m deep in places. Small land movements adjacent to the pipeline are thought to have caused cracking in the pipe leading to release of water and ash into and onto the surrounding ground on a number of occasions. This release of fluid may have lubricated the surrounding ground to encourage larger slips. As a result of these problems the pipe has not been used for a number of years and all PFA is now transported to the site by road.

It is anticipated that the pipe will be decommissioned as part of the reservoir discontinuance by grouting the pipe with a cement PFA grout. The pressure the pumped grout will need to be adjusted where there are fractures to ensure leakage from the pipe will be minimised.

PROPOSED PROGRAMME

The restoration scheme has already started with the deposition of ash in selected places within the lagoon in line with the final proposals. The construction of the auxiliary spillway is due to commence in the spring of 2004. Further filling of the lagoon, construction of the ponds and decommissioning of various structures is planned for 2005 and 2006 together with the final landscaping of the site.

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