Ericht and Dalwhinnie Dam refurbishment and protection works

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SYNOPSIS. Following the statutory inspection of Loch Ericht reservoir both Ericht and Dalwhinnie Dams have been recategorised A from category B and assessed in relation to their capacity to safely pass a PMF event combined with wave surcharge allowances.

The paper describes the investigation, identification of the requirement for protection and subsequent design of works to primarily prevent wave surcharge levels overtopping the existing crest levels of both dams. Further refurbishment and protection works were also identified in relation to concerns over the ability of the spillway\corewall interface to resist erosion, poor spillway basin configuration and the potential vulnerability of the scour penstock during spill conditions at Ericht dam.

INTRODUCTION

The investigation and subsequent works carried out at Loch Ericht reservoir were required following the 10 yearly statutory inspection under the Reservoirs Act 1975 (1) which was carried out in June 2000 by Dr A K Hughes. The reservoir was recategorised A (general/minimum) from its previous category of B under the Floods and Reservoir Safety Guide (2). The various structures associated have therefore been assessed in relation to their capacity to safely pass a Probable Maximum Flood (PMF). Concerns were also raised over the vulnerability of the scour penstock and general spillway basin configuration.

DESCRIPTION OF RESERVOIR AND DAMS

Loch Ericht reservoir is situated approximately 75km northwest of Perth and was completed in stages over the period 1928 to 1954. The reservoir is one of the main storage reservoirs within Scottish and Southern Energy plc's (SSE) Tummel valley cascade hydro scheme system and provides long term seasonal storage from a catchment extending to 135.22km^2.

The reservoir is formed by the construction of Ericht and Dalwhinnie dams. Ericht dam at the southwest of the Loch comprises of sections of concrete gravity; concrete corewall with downstream grass covered embankment as support and is approximately 340m long and 14.3m maximum height above ground level. There is also a homogenous earth embankment section with grass covered upstream and downstream faces, approximately 65m long and 2.1m maximum height above ground level. Dalwhinnie dam at the northeast end is an embankment dam with a central concrete corewall supported by both upstream and downstream embankments, the upstream face is protected by concrete slabs and the downstream face is grass covered, approximately 350m long and 4.5m maximum height above ground level. The volume stored within the reservoir is 230 million m^3 with a surface area of 23.27km^2 at spillway level of 359.359mOD and water length of 24.4km. General sections of both dams are shown in Figures 1 and 2 respectively.

Scour from the reservoir is provided via a penstock that was added in 1957 as an extension to the original culvert through the concrete dam section. The penstock is a 2.13m diameter steel plate section extending 15.7m from the toe of the dam within the spillway basin. An anchor block with a 1.83m diameter disperser valve is located at the end of the penstock.

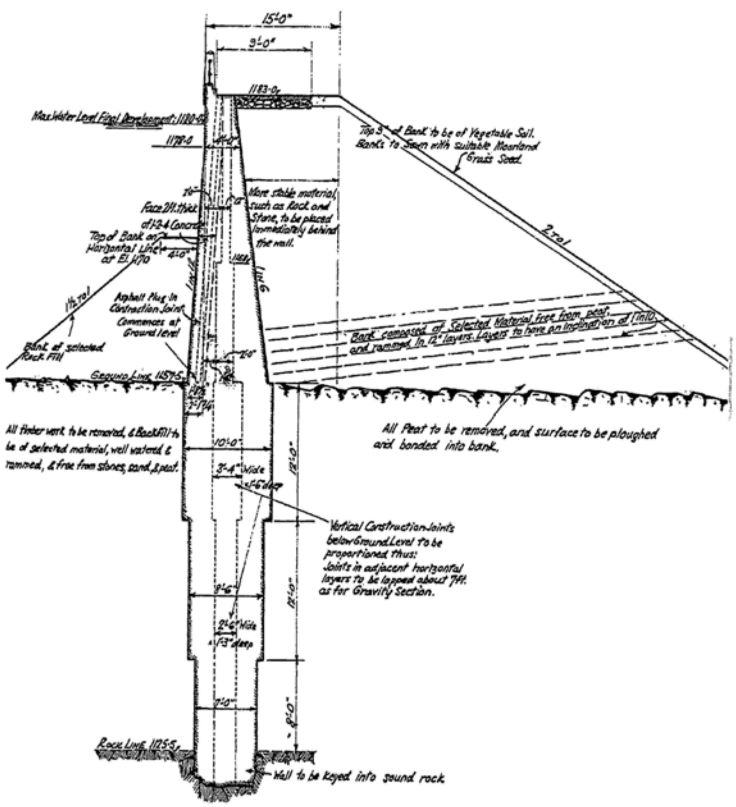

Figure 1 Typical cross section through Ericht corewall Dam

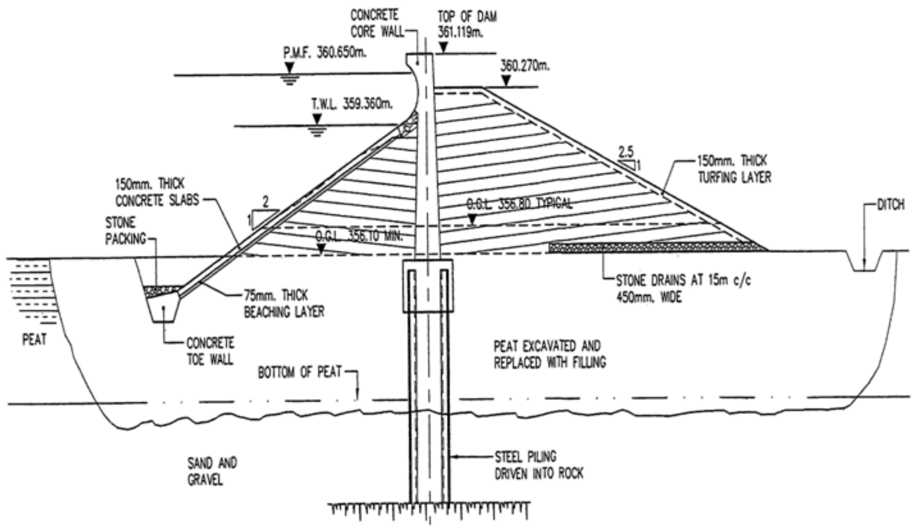

Figure 2 Typical cross section of Dalwhinnie Dam

RESERVOIR RECATEGORISATION

As a key element of the initial review the potential consequences, in particular the incremental consequences between PMF and dam breach were considered.

Ericht Dam failure

The inundation maps prepared and subsequent consequence study fully supported the recategorisation of the dam on the basis that should Ericht Dam breach other cascade failures would be likely in the Tummel valley reservoir system and hence a significant impact on communities beyond the next reservoir in cascade. The mapping also showed the cumulative effect on a number of isolated properties along the shoreline of Loch Rannoch.

Dalwhinnie Dam failure

Under normal conditions and flood events Dalwhinnie Dam prevents flow from the Loch Ericht catchment from passing into the River Truim. Should the dam breach the reservoir inundation mapping and subsequent consequence study clearly demonstrated that there would be an unacceptable level of inundation and significant impact on Dalwhinnie and the downstream communities. Application of Category A is therefore also appropriate for Dalwhinnie Dam.

INVESTIGATION PHASE

As part of the statutory inspection SSE led and implemented a detailed investigation to allow assessment of the impact of recategorisation and to prepare options for subsequent detailed design and implementation.

PMF and wave surcharge assessment

SSE completed flood studies for both PMF and 1 in 10,000 year return period events under worst case conditions of the syphons unprimed, due to some longstanding doubt over their operation and a snowmelt rate of 70mm/day. The following key flood results were obtained.

10,000 year (FSR) (3)	360.065mOD
10,000 year (FEH) (4)	360.348mOD
PMF (FSR)	360.575mOD

The wave surcharge levels using normal approaches were estimated for each of the component dams with a straight line fetch of 3.7km adopted for Dalwhinnie Dam rather than the bent fetch of 24.4km. The identified deficiencies are summarised in table 1.

Table 1 Wave surcharge assessment

Element	**Wave surcharge**	**PMF + wave**	**Crest**	**Deficiency**
Ericht gravity	0.64m	361.215m	360.58m	N/A
Ericht corewall	1.02m	361.595m	360.58m	1.015m
Ericht saddle	1.73m	362.305m	361.19m	1.115m
Dalwhinnie	2.93m	363.505m	361.19m	2.315m

As a result of the above analysis various parts of the dams were considered to be vulnerable and would be effected under extreme flows. Such sections required to be protected or modified in order that wave overtopping would not erode embankment sections, which if allowed too could ultimately lead to a breach of one or more of the dam sections.

Survey and Site Investigation

A full topographic survey was completed at both dams and the surrounding area in order that key dimensions and physical layouts could be confirmed. Site investigation works followed to confirm ground conditions and to provide information for the subsequent design of remedial works. Investigations comprised ten cable percussive boreholes, seven trial pits and 18 Macintosh probe penetration tests at Dalwhinnie Dam with two boreholes and seven trail pits at Ericht Dam. Disturbed samples were taken for subsequent grading analysis, seven falling head permeability tests were carried out and insitu standard penetration tests were made in granular material to assess the relative density. The sulphate contents and pH values of ground water and soil samples were determined. Piezometer standpipes were installed in four boreholes at Dalwhinnie Dam with pressure transducers attached to dataloggers and the water levels monitored and related to reservoir level.

Hydraulic model

In order to examine concerns raised over the vulnerability of the scour penstock and poor spillway basin configuration a 1 in 50 scale physical model of the spillway, scour penstock anchor block and adjacent river channel was constructed and tested by ABPMer. The model was built to provide an understanding of the flow mechanisms existing on the downstream side of the dam and in particular examine hydrodynamic loading and scour on the valve structure and the corewall embankment where it intersects with the spillway section of the dam.

The model confirmed that whilst the existing velocities and differential head across the penstock were not significant at $2ms^{-1}$ and 0.4m respectively the penstock would be submerged and the protruding body of the disperser valve may be vulnerable, in particular during flow build-up. Winter operation is to empty the penstock to avoid freezing, but the penstock was not designed to be submerged under this condition. With the high replacement cost of the valve if damaged by debris, it was considered prudent to encapsulate the penstock and provide a protection wall.

The water levels within the spillway basin were found to be at a level were erosion of the corewall embankment was possible, especially with an eddy between the penstock and the embankment toe. The optimum configuration and top wall level for a spillway basin training wall was developed using the model.

Localised infilling of the unlined spillway floor were also modeled to improve conditions during routine operation and avoid problems with water ponding around the penstock.

When comparing each of the configurations tested, the addition of a slab, penstock protection and a baffle wall did not significantly affect the hydrodynamic environment. The exception was an increase in eddy speed adjacent to the scour valve, however the scheme does provide substantial protection to the valve and penstock against impact of debris in flow from the dominant direction. The addition of the corewall embankment toe protection progressively reduced the strength of the eddy but with a corresponding detrimental effect on water levels and flow speeds in other areas.

Option Study

Following review of the various elements of the investigation measures were considered to prevent the wave overtopping. Comprising of reducing the reservoir operating level to create further freeboard; additional spillway capacity to reduce the flood lift; providing wavewalls to prevent overtopping; providing downstream protection and to create a rougher upstream face to absorb wave energy thus limit run-up.

Reducing the reservoir operating level would place restrictions on the generation output from Rannoch Power Station and would require large elements of the diverted catchment to be turned out during extended periods to maintain freeboard levels.

Limited potential exists for economically adding further spillway provision at Ericht and Dalwhinnie dams due to the nature of the embankment and corewall sections and the excessive overtopping levels that required to be mitigated. The main Inverness to Perth railway line traversing 100m downstream of the dam compounds this at Dalwhinnie.

Wave overtopping prevention by the addition of wavewalls is well proven and could be combined with additional upstream face rip-rap and or slope reprofiling to absorb energy and reduce wave heights. An optimum balance between upstream face rip-rap protection, wave wall and downstream erosion protection was considered the best solution at this stage.

The penstock protection and spillway basin improvement works required a compromise between the construction costs of implementing them and minimisation of the hydraulic forces and scour velocities.

At this stage SSE prepared an option study report to summarise the findings and to provide the basis for detailed design. A subsequent contract was awarded to Faber Maunsell Limited to carry out the detailed design.

DESIGN PHASE

PMF Reassessment

Following the interim guidance for owners and panel engineers issued by DEFRA (5) the PMF was reassessed by bench marking against the FEH 10,000 year rainfall depth for the critical storm duration. The all year PMP was 241 mm against an FEH 10,000 year depth of 285.65mm for an 18.5 hour storm. The PMF hydrograph was generated assuming the modified PMP storm depth (equal to the FEH 10,000 year rainfall) and routed through the reservoir. The view was also taken that the syphons would prime under such conditions and full account taken of this. This resulted in an inflow of $1684m^3s^{-1}$, outflow $459m^3s^{-1}$ and maximum water level 360.65mOD. An increase of $322m^3s^{-1}$ for inflow, $43m^3s^{-1}$ outflow and 150mm above an equivalent FSR estimate. Also 75mm over SSE's previous assessments which were considered to be conservative by assuming unprimed syphons.

Wave surcharge Reassessment

Wind-wave generation in most reservoirs is governed by fetch limited conditions for wave generation and deepwater conditions for wave propagation. However, these conditions were considered not to prevail for waves approaching Dalwhinnie. A detailed reassessment of wave conditions during the mean annual and the 1 in 200 year wind-wave event was carried out and is reported upon separately (6). The mean annual significant wave height is estimated at 2.12m for the PMF level of 360.65mOD. The 1 in 200 year significant wave height is estimated at 1.47m for the top water level of 359.37m. A significant reduction over previous estimates.

Fetch limited and deep water conditions apply at Ericht Dam, and the wave conditions approaching both the corewall and embankment dam sections was reassessed using the standard Donelon/JONSWAP method, as recommended in Floods and Reservoir Safety (2) and a bent fetch slightly longer than previously adopted. The mean annual significant wave height is estimated at 1.14m for the PMF level. The 1 in 200 year significant wave height is estimated at 1.55m.

The above estimated wave conditions for both Dalwhinnie and Ericht Dams were used together with the maximum flood levels to calculate wave overtopping discharge for freeboard assessment and wave loading for the structural design of wave walls. A methodology for deriving impact loading, occurring when waves break directly on the structure, was developed to provide an improved prediction of impact forces due to concerns over damage and instances of failures of wave walls, reported separately (6).

Value Engineering

A value engineering meeting was held to discuss preliminary design options for the works required. Formal value engineering techniques were used to evaluate options for overtopping protection at Dalwhinnie Dam, while the remaining items were discussed more informally.

The basic options considered for Dalwhinnie Dam were A) placement of open stone asphalt layer on upstream face with additional wave wall; B) placement of rip-rap on upstream face at existing 1:2 slope with additional wave wall and C) placement of rip-rap on upstream face at 1:4 slope with additional wave wall. All options assumed crest protection would be installed. Permutations included infilling the maximum depth section in the foreshore to limit the incident depth limited waves to the average depth condition, installation of downstream protection, use of grouted rip-rap to reduce the stone size, and inclusion of a tandem rock breakwater upstream to reduce incident wave height.

A value tree with importance weightings assigned to each criteria and the options were evaluated in more detail with the aim of identifying the best value alternative to be carried forward to detailed design. A decision matrix was developed from the weighted value criteria identified during the structuring of project objectives. The results of the decision matrix are shown in Table 2.

Table 2 Dalwhinnie Dam decision matrix results

Option	**Description**	**Total rating**
A iii)	Open stone asphalt layer	8.6
B iii)	Rip-rap at 1:2	6.9
BG iii)	Bituminous grouted rip-rap at 1:2	6.9
C iv)	Rip-rap 1:4	7.4
C v)+	Rip-rap at 1:4, tandem breakwater	6.5

The matrix analysis showed clearly in favour of option Aiii), placement of open stone asphalt on the upstream face, with wave wall, crest and downstream protection. This was partially due to the significant cost savings of this option; estimated to be approximately £200k cheaper than the next cheapest option considered.

Design Solutions

At Dalwhinnie Dam the upstream face will be overlaid with a 250mm thick layer of open stone asphalt and the low area in front of the dam infilled to the general level of 356.8mOD at the mitres of the dam. The wave wall will be raised by precast concrete unit’s approximately 2m height, supported by an insitu concrete beam formed at the base of the existing wave wall on the upstream side, and anchored to the upper part. The crest and downstream face will both be armoured with concrete reinforced grass, to increase the tolerance to wave overtopping discharge. The works are generally shown in Figure 3. Mass concrete corewall extensions are also required at either abutment to prevent floodwater bypassing the dam and eroding the downstream embankment toe.

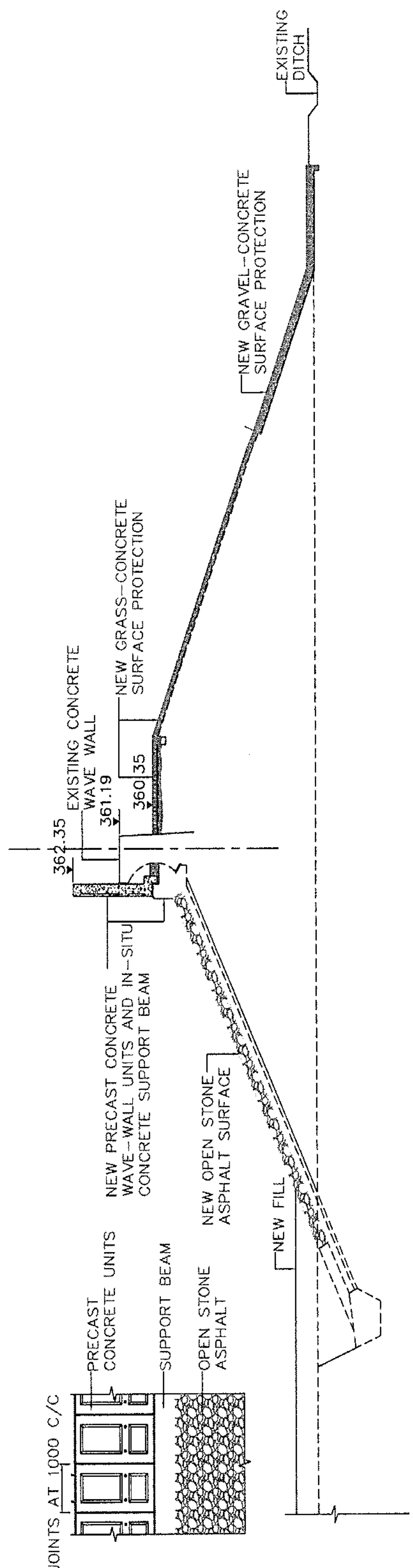

Figure 3 Dalwhinnie Dam

The corewall section of Ericht Dam requires a wave wall 1m in height to be added to limit overtopping to an amount acceptable for an unprotected downstream face. A reinforced concrete wall anchored onto the corewall section will provide this. Rip-rap is to be placed on the upstream face of the embankment dam at a slope of 1V: 2H to reduce wave run-up and overtopping discharge. A low berm will be formed above the crest level, negating the need for a wave wall. The crest of the embankment will be reinforced with grass-concrete blocks, to increase the tolerance to wave overtopping. Both sections are indicated in Figure 4.

In order to provide protection to the exposed penstock concrete encapsulation beyond the toe of the dam will be carried out and a baffle wall added to protect the protruding disperser valve. Permanent access to the interior of the penstock will be provided by 1m diameter flanged branch pipe. Improvement of the spillway training and invert protection will consist of placement of a reinforced concrete slab on the invert of the spillway channel to a maximum level of 347mOD, draining towards the river channel downstream. A reinforced concrete training wall along the interface with the corewall embankment be constructed to a nominal height appropriate for frequent spill events, with the remaining slope to be protected with grass-concrete blocks to prevent erosion during extreme events. The penstock and spillway works are shown in Figure 5.

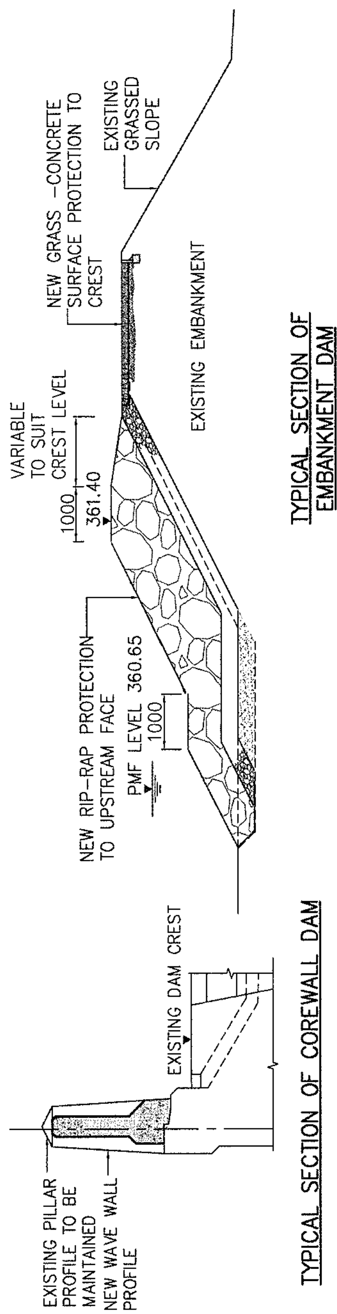

Figure 4 Ericht corewall and embankment dam works

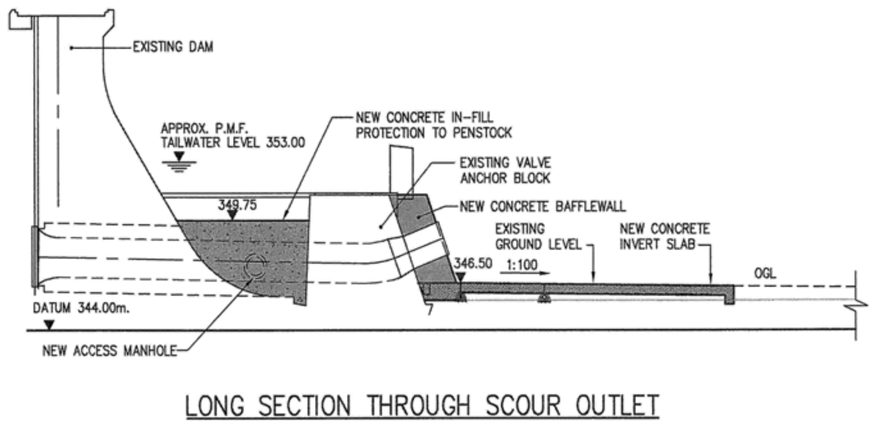

Figure 5 Ericht penstock and spillway works

IMPLEMENTATION

Consents

An application to implement the works was made under the Electricity Act 1989 (7) in December 2002. This Section 36 consent remains outstanding one year on for what should have been a minor consent application. No EIA was required and consultation processes were carried out with each local authority, Scottish Natural Heritage and local estates.

Contract Strategy

Tender documents were based on the NEC Engineering and Construction Contract (8) with an activity schedule, all for implementation of the works during 2003 with a reservoir draw down over 18 weeks. However due to consent delays the works have been deferred to 2004 with the subsequent increase in costs. Estimated costs are £700k and £300k at Dalwhinnie and at Ericht respectively.

Water management issues lead to the adoption of sectional completion on the spillway and scour penstock protection works in advance of the main works to allow compensation water to be released downstream of Ericht in the event of plant failure at Rannoch Power Station. This will also provide a further control on the reservoir level should it be required.

Valve and penstock Refurbishment

The original plan was to remove in advance and refurbish the disperser valve to coincide with the sectional completion of the penstock civil works. Shot blasting and repainting of the internal surfaces of the penstock and the addition of an access manhole was included within the civils scope to avoid interface issues during concrete works. Due to the consent delay SSE decided to mitigate this and carry out all of the penstock mechanical works in advance and awarded the works to Isleburn MacKay & MacLeod. The works were completed in December 2003 at a cost of £80,000.

CONCLUSIONS

Both Ericht and Dalwhinnie Dams have been recategorised A, which was fully supported on the basis of inundation mapping and consequence studies. Subsequent investigation demonstrated that certain elements of the structures would be vulnerable under PMF conditions and required to be modified.

PMF re-estimation increased inflow by 24%, outflow by 10% and the resultant flood lift indicated by 14% following the application of the FEH 10,000 year rainfall depth as an estimate of PMP. In this situation the difference in level adopted was relatively small in relation to the overall surcharges being considered, and the economic implications were generally acceptable. It may even provide some degree of insurance against subsequent changes to future methodologies.

Wave surcharge reassessment concluded that depth limited prediction methods reduced the significant wave heights compared to those estimated using the standard wave run-up method. A methodology for estimation of wave impact forces on the wavewall extensions at Ericht Dam has been established.

A value engineering exercise established an open stone asphalt system combined with a wave wall extension at Dalwhinnie Dam as the optimum solution, previously unconsidered in the investigation stage.

Delays to the consent process were partially mitigated by carrying out the penstock mechanical works in advance. Future reservoir projects will be considered closely and where appropriate not be subject to the section 36 consent processes.

REFERENCES

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