Appendix 2.1: Dam Type Selection

1.1 Introduction

1.1.1 In selecting the most appropriate type of dam for the upper reservoir site, the factors listed in Table 1 below have been considered. Various types of dams were considered for the upper reservoir, including clay core rock fill, asphalt cored rock fill, asphalt faced rock fill, roller compacted concrete (RCC), and concrete faced rock fill dam (CFRD).

1.1.2 At the outset all dam types were considered but as each factor was examined in turn, it became evident that only two types of dam would be suitable. Each factor was considered with observations being carried forward to a selection matrix which forms Table 1. The purpose of the selection matrix is to summarise the reasoning behind the final selection of dam type and design.

Table 1 - Factors Affecting Dam Type Selection

Technical Factors	Local Factors	Economic Factors
Topography	Climate	Buildability
Foundation	Construction schedule	Capital cost
Construction materials	Environmental and visual impact	Maintenance cost
Seismic hazard	Available expertise	
Flood hazard		
Rapid drawdown		

1.2 Technical Factors

<u>Topography</u>

1.2.1 At Coire Glas, the valley profile at the dam axis is ‘bowl’ shaped with relatively steep abutment slopes. The left (north) abutment rises from the river level at about 1 on 3 until approx.. elevation 600 mOD and then steepens to about 1 on 1.2 above this level up to Meall a’ Choire Ghlais. The lower slopes are characterised by hummocky peat and glacial deposits masking boulder fields and rockhead while the upper slopes are characterised by steep cliffs and scree.

1.2.2 The topography at the dam site is suitable for construction of most types of dam under consideration.

1.2.3 With respect to a concrete structure, the topography lends itself to gravity, rather than arch, structures and the most economic form of modern concrete gravity dam would be based on the use of RCC.

<u>Foundation Conditions</u>

1.2.4 The ground conditions at the upper dam site were assessed using the published geological maps and by general observations from site walkover surveys. The British Geological Survey (BGS) also carried out geological mapping (solid and drift) over the project area as part of these studies.

1.2.5 The upper reservoir is located within the northeast-southwest trending valley of the Allt a Choire Ghlais stream. The upper reservoir is bounded by Coire Glas at the south-western end of the valley, the valley sides above the stream and the proposed dam that will cross the valley at its north eastern end. The valley is a “U” shaped glaciated valley with a wide floor.

1.2.6 In conclusion, the foundation appears to be favourable for dam construction with no significant risks and would be suitable for either an embankment type dam or a concrete dam.

Construction Materials

1.2.7 Suitable materials can be obtained locally from the required excavations and from quarrying within the upper reservoir basin. The bedrock is expected to be strong, durable and groutable and could readily be quarried to produce good quality rock fill, concrete aggregates and graded granular materials. However, there is not expected to be any cohesive materials at the project site that would be suitable for constructing an impervious clay core embankment dam. Therefore, dam types that rely on impermeable cohesive materials have not been considered.

1.2.8 The excavation of the various tunnels, shafts and caverns is also expected to generate suitable material for use in the permanent works, subject to processing as required. The viability, snd challenges associated wi this are described in ch. 7: Spoil Management. A major consideration for selection of dam type is the requirement to minimise importation of materials to the site. Therefore, dam types that require less imported materials have been favoured in the screening assessment.

1.2.9 Other than excavated spoil from the underground works, the main source of material would be provided by a rock quarry located within the upper reservoir basin (below minimum operating level). The valley is relatively narrow and working space will be somewhat restricted. However, it is considered that sufficient quantities of quarried material could be produced from within the reservoir basin. Sands and fine to coarse gravels have also been observed within scalps of superficial deposits just downstream of the proposed dam axis and might be suitable for filter material or fine aggregates, subject to further investigation.

1.2.10 The total fill volume of a rock fill type embankment would obviously be much greater than for a concrete dam, although there appears to be an adequate supply of rock fill from establishment of a quarry within the reservoir basin alone if required. Therefore, rock fill dams will require less processing of the quarry materials, as the majority of specifically quarried fill would be placed with little or no selection or processing (spoil from underground works would be likely to require some degree of processing). The quarry operation is expected to produce good quality high modulus rock fill. The quarry will generate additional storage in the upper reservoir.

1.2.11 A major factor in selection of dam type is the requirement to minimise importation of materials to the upper reservoir sites, on environmental, safety and cost grounds. In the case of a concrete gravity (RCC) dam, the quantity of cement required for a scheme of this size would be over 150,000 tonnes (approximately) which would require approximately 15,000 truck movements to the site, which is un-desirable. In the case of a CFRD dam, the quantity of concrete required for the appurtenant works (diversion culvert/spillway/face slab) will be much less than for RCC construction.

1.2.12 It is clear that the absence of cohesive materials at the project site precludes the selection of clay-core fill type dams. The abundance of readily available strong rock favours rock fill or concrete type dams, although rock fill type dams would be more favourable on environmental and cost grounds as they will require less imported cement and less processing of granular materials / aggregates.

Seismic Hazard

1.2.13 The seismic hazard posed to the dam structure would be evaluated in detail as part of the design stage and site specific seismic hazard assessments should be carried out for a structure of this size.

1.2.14 However, theseismic hazard posed to the dam structure is not anticipated to be significant at this site and there are no particular seismic risks that would preclude construction of a large dam.

Flood Hazard

1.2.15 The upper dam would be sited at the head of the Allt a' Choire Ghlais valley. It is likely that the reservoir would be categorised as High Risk under current reservoir legislation and for such a large raised reservoir, the general flood protection standard would be the Probable Maximum Flood (PMF). In addition, the control of pumped inflows would also need to be carefully managed.

1.2.16 In terms of dam type, concrete dams would tend to incorporate the spillway over the main body of the dam, creating a relatively economic solution, as concrete dams can withstand overtopping. In the case of fill type dams, the preference would be to locate the spillway remote from the embankment and a separate spillway structure would be provided. Therefore, concrete dams are inherently more advantageous than fill type dams in terms of overtopping resistance. However, the magnitude of natural floods at this site are not large and would not prove to be a significant disadvantage in the case of a fill type dam.

1.2.17 Flood hazard during construction would be handled by construction of a diversion structure which would divert the natural stream around the construction works. In terms of dam selection, concrete dams are inherently better than fill dams at accommodating both construction stage floods and natural floods during operation. However, the magnitudes of construction floods, natural floods and over pumping are not large at this site and would not prove to be a significant disadvantage in the case of a fill type dam.

Rapid Drawdown

1.2.18 Rapid drawdown remains an onerous condition for pumped storage schemes particularly affecting the stability of any dam with impermeable shoulders or core zones. The rapid drawdown of the water level in the upper reservoir during generating mode could cause instability in the upstream shoulder of the dam if the material is not sufficiently 'free draining' to allow rapid dissipation of pore water pressures. Therefore, earth fill and soft rock fill dams are not suitable for this situation and asphaltic core dams would need to be carefully detailed to mitigate the risks.

1.2.19 Concrete dam types and fill type dams with upstream impervious membranes (such as CFRD) are not susceptible to rapid drawdown failure and both types would be suitable at this project site.

1.3 Local Factors

Climate

1.3.1 The climate conditions at the upper reservoir is expected to be harsh with cold wet climates and high winds. Work during the winter months (November through to April) is expected to be particularly challenging. In terms of dam construction dam types that are more susceptible to problems due to inclement weather are earth fill dams with cohesive materials. However, these have been excluded from consideration due to other factors.

1.3.2 Rock fill type dams would be least susceptible to inclement weather as fill placement could continue during in cold/wet weather. Concrete works would ideally be programmed to coincide with more favourable months of the year to avoid cold weather concrete placement, although special measures could be employed for cold weather concreting.

1.3.3 In the case of a concrete (RCC) dam the weather conditions would be more onerous. Placement of RCC during heavy rainfall should be avoided as it can affect compaction and create a layer of laitance on the lift surface. Likewise, special measures would need to be taken during cold weather placement to minimise the risk of frost attack (i.e. frost blanketing over large areas). Ideally, RCC placement would be programmed to coincide with the summer months to avoid these problems.

1.3.4 In terms of dam type, earth fill embankments are not suitable for this project area, as they are highly susceptible to adverse climatic conditions and special measures would need to be taken in the case of either an RCC dam or a rock fill embankment. However, on balance, it is considered that rock fill placement would be less susceptible to climatic conditions than a concrete (RCC) type dam.

Construction Schedule

1.3.5 The overall construction programme for the scheme is likely to be dominated by the scheduling of the underground works. Therefore, the upper dam construction is not likely to be on the critical path for the project. There will be certain elements of the works that will be common to all dam types (i.e. establishment of the site, river diversion works, foundation grouting, intake construction, reservoir basin works etc.).

1.3.6 The initial set-up time required for RCC placement needs to be carefully considered and winning and processing of the concrete aggregates and setting up concrete transport systems (especially if a conveyor system is deployed) will require significant enabling works and planning. Likewise, delivery of large quantities of cement to this remote location will also require significant logistical planning to minimise adverse impacts on the local environment. Therefore, it could be slightly misleading to think that RCC dam would be quicker to construct than a rock fill type dam.

1.3.7 The advantage of a rock fill embankment is that there is much less processing of materials required to form the embankment shell. Most of the material required would be ‘as blasted’ material, which could be placed in most weather conditions. Production rates for rock fill would be high, as haulage distances are very short and could be placed in most weather conditions.

1.3.8 In terms of construction programme, the upper dam is likely to be of shorter duration compared with the underground works and therefore, it would appear that the construction programme for the upper dam is not a significant factor in selection of dam type for this scheme.

Environmental and Visual Impact

1.3.9 The upper reservoir site is remote from the public road infrastructure and located in rugged mountainous terrain. In terms of dam type selection, it is clear that there are several environmental considerations that could be relevant during design, construction and operation of the scheme.

1.3.10 In broad terms, dam types that require less imported material during construction are more likely to minimise environmental impact on the surrounding land and local infrastructure and are considered more favourably. The importation of large quantities of cement for a concrete dam would require significant truck movements to the remote upper dam site, which could have a detrimental effect on the local environment. Rock fill dams would require much less imported materials. The ratio of imported cement for RCC/CFRD for example would be 20:1.

1.3.11 The dam and its appurtenant works would be laid out in a sympathetic way to minimise visual impact of a large dam. Concrete structures would be screened (as far as possible) and in the case of a rock fill embankment, the downstream face would be finished with a uniform rock appearance.

1.3.12 The bulk of the materials required to form the dam should be obtained locally to the site. In the case of a rock fill embankment, the bulk of the materials could be obtained from spoil from the underground works and quarrying within the reservoir basin to provide rock fill, with possibly small quantities of imported sand for critical filters (if no source can be identified close to the dam). In the case of a concrete dam, a smaller quarry would be required, but the materials would require processing to produce satisfactory concrete aggregates.

1.3.13 In summary, rock fill dams would tend to create less environmental impact than concrete dams at this site.

Available Expertise

1.3.14 There are numerous heavy civil engineering contractors that would be capable of undertaking major earthworks, quarrying and heavy RC civil structures. However, there are few (if any) UK contractors that would possess recent relevant experience in concrete dam (RCC) construction, since no major RCC dams have been built in the UK. It is likely that a specialist international contractor would need to be engaged for this type of construction. Local contractors could provide a supporting role to an international contractor. In the case of asphaltic concrete facings or membranes, there are several reputable international specialists based in Europe and the UK that would be capable of undertaking this type of work.

Economic Factors

1.3.15 Consideration was also given to the proposed capital cost for construction, as well as on-going maintenance costs of each dam type.

Selection of Dam Type

1.3.16 As noted, two types of dam have been examined in detail.

Roller Compacted Concrete

1.3.17 There are now many hundred major Roller Compacted Concrete (RCC) dams in the world and indeed for concrete gravity works this is usually the favoured option for constructing even the very highest concrete dams. Traditional mass concrete gravity dams and concrete buttress dams would be uneconomical due to the low production rates for conventional mass concrete and the high cost of formwork in the case of a concrete buttress dam.

1.3.18 For the Coire Glas Project, any RCC dams would feature a conventional profile with vertical upstream face and 0.75 on 1.0 or 0.80 on 1.0 sloping downstream faces depending on final stability assessments. The spillway would be formed over the central part of the dam with a pre-cast concrete bridge deck over to allow access to the gate shaft.

1.3.19 The dam would feature an upstream inspection, grouting and drainage gallery. This is deemed especially relevant in the case of Pumped Storage works where dam foundation issues were noted in a retrospective performance study on a number of existing pumped storage projects. The gallery affords the opportunity to re-visit, re-grout and generally redress foundation issues should problems emerge later.

1.3.20 To ensure a conservative cost estimate, the proposed design includes a spillway sized for over-pumping, i.e. a condition whereby the operation in pumping mode cannot be curtailed. Further operational analysis may eliminate this requirement so that the spillway need only be designed for the passage of the reservoir design flood. The spillway works for a RCC dam would comprise a long ogee crest, steps on the downstream face of the dam for energy dissipation and a foreshortened downstream concrete apron.

Concrete Faced Rock Fill Dam

1.3.21 Rock fill dams have a long pedigree and are ideally suited to environments such as the Scottish Highlands where there is such an abundance of good rock. Advances in design practice and construction methodology in the past 40 years have now rendered a CFRD as almost always the most economic dam type (if ancillary works such as a powerhouse or spillways are not to be incorporated directly into the works at a site).

1.3.22 The available rock at the upper reservoir site is generally excellent, though there is some foliation and mica content.

1.3.23 In the same manner as the RCC variant, the proposed design includes a spillway. A chute spillway, with a concrete ogee crest has been included in the costing, but the high quality of the bedrock indicates that a partially lined excavated chute might be acceptable.

Proposed Dam Design

1.3.24 Based on the quantities measured from the outline designs for each type of dam, the cost of the RCC alternative dam was found to be more than 160% of the cost of the CFRD. Also considering other relevant technical and local factors a CFRD was selected for the design of the main dam.