

A strategy for sustainable construction of lagoons for power station ash disposal at Longannet Power Station

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SYNOPSIS. Ash lagoons for power station use can have a very short operational life in reservoir terms but can also be re-used after excavation of ash for commercial use thus extending their life. Longannet Power Station on the banks of the Forth Estuary is operated by ScottishPower and they apply the Reservoirs Act to their lagoon operations. They currently operate two lagoons close to the station in a cyclical manner whilst developing a much larger remote site in a planned sequence of one-off use lagoons that is being progressively developed as an amenity and wildlife area. Lagoon 21 is currently under construction and, together with operational and recently filled lagoons, presents a number of interesting aspects of design, construction, operation and regulation.

BACKGROUND TO SCOTTISHPOWER'S ASH LAGOON OPERATIONS

ScottishPower's generating station at Longannet is being developed to minimise environmental impact whilst maximising efficiency. As part of the overall development, a strategy has been developed for the ongoing and sustainable disposal of the ash residue from the furnace coal-burn such that the life of the station can be extended, well beyond its original anticipated life, to maximise the benefits of the efficiencies planned.

Furthermore, ScottishPower is currently investing in other environmental enhancements to Longannet Power Station, including a potential new Biomass Power Station, a Flue Gas Desulphurisation (FGD) project and Carbon Capture and Storage (CCS).

The potential Biomass Power station, currently under design, is a separate generating station which would be constructed on the Longannet site. This station is proposed for energy generation from a diverse range of sources, primarily waste derived fuels. A project that is currently well under way is

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the retrofitting of FGD equipment to three of the four generating units at Longannet and this is due to be commissioned shortly. Finally a ScottishPower consortium is leading the way with the development of CCS and currently has a prototype unit at Longannet for research and development. Once fully developed this technology has the potential to be used worldwide to combat carbon emissions.

As an integral part of the development policy and to ensure sustainable operation of the station, the ash by-product of coal burning has an active disposal strategy that includes commercial sales and disposal (storage). The ash settling lagoons form the central part of this strategy both for commercial use and storage.

Longannet Power Station was first commissioned in 1970 with an original design life of 30 years. Initially, furnace ash was processed on site with a high proportion sold for construction industry use. Two lagoons were created at Longannet and these still operate as the ash sales source.

As the life of the power station was extended by upgrades and the market for ash diminished, the need for a long-term ash disposal site became necessary. Valleyfield was an area of intensive coal mining some 6 km from the station and offered the opportunity for land reclamation and rehabilitation in an extensive inter-tidal area between active shoreside mining and historic offshore island shaft sites. The gradual decline of mining allowed this area to be planned for improvement as amenity and wildlife sites, and ash was deposited to an agreed landscape plan. The site extends to some 220 hectares and a schematic of the site is indicated in Figure 1.

The ash is pumped to Valleyfield in a 30% slurry using three 350mm diameter HDPE pipelines at a maximum rate of 6000 gpm. The lagoons at Valleyfield differ from those at Longannet as they can be progressively filled and overbuilt to create the desired land profile.

Amenity and wildlife objectives have already been realised through landscaping, habitat creation and coastal path construction. The site is a haven for animals including deer, foxes and small mammals with extensive bird colonies including the presence of buzzards and hawks. A country park ranger part-funded by ScottishPower and Fife Council is based on site.

Environmental constraints are imposed on the site as a result of the waste management licence; these include discharge consent for the effluent from

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the slurry / settlement process, monitoring of groundwater quality for a range of chemical / heavy metal indicators and control of wind-blown dust.

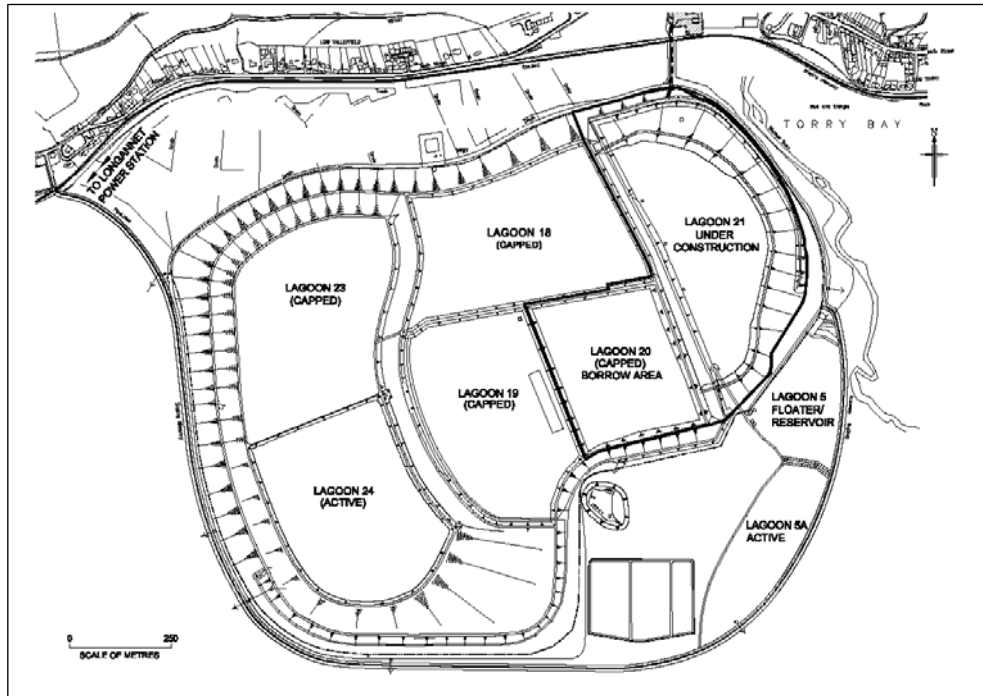


Figure 1. Schematic of Valleyfield Site

There is a major issue with potential dust blow from the drying surface ash on an exposed estuarial site and the site management programme includes extensive water spraying through the use of tractor-towed bowsers and fixed rain curtains (elevated rows of irrigation spray heads upwind of drying lagoon surfaces). Much of the fixed system is computer controlled and can be operated remotely.

The settling process also produces a by-product called cenospheres; microscopic spheres that come to the surface in the final effluent settling pond and are skimmed off for use in the chemical industry.

As part of the overall site management, ScottishPower applies the Reservoirs Act to their lagoon construction and ash deposition operations as a means of demonstrating engineering control of the process.

INFLUENCE OF THE RESERVOIRS ACT ON ASH LAGOON ENGINEERING

Relevance of the Act

Although it is generally accepted that the Reservoirs Act does not apply to ash lagoons, ScottishPower, in common with other coal fired electricity

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generators, treats its ash lagoons as though it does. Accordingly, the lagoons at Longannet are registered with Fife Council; being the local council with Enforcement Authority status as applied in Scotland. This approach is as recommended in the Guide to the Reservoirs Act. However, due to the special nature of the ash deposition operations at Longannet, some aspects of the Act are inappropriate.

The ash disposal lagoons at Valleyfield are transient reservoirs as they are designed to settle out the ash from the transporting slurry and release the surplus water whilst minimising the retained depth of water. The lagoons are low structures, typically 4m to 5m high, and are built to full height but unusually operate with variable height overflows greatly limiting the stored volume of water at any time. The depth of free water is generally limited to around 1m in relation to the impounding embankment although initially depths can be greater where borrow for the embankment construction has been taken from the lagoon solum.

The ash grading is largely silt sized with generally a maximum size of 2mm well graded down to a fine fraction below silt size of around 10%. There are variations in ash characteristics according to the coal quality used and the burn characteristics of the furnace. For the volume of slurry pumped the settlement characteristics are relatively benign with most material coming out of suspension within 50m of the point of discharge and lagoons having a maximum life of two years. Consolidation of the deposited ash is rapid and can usually support tracked plant after some six months of final deposition although it is noted that wild animals, including deer, can cross the surface almost as soon as deposition rises above water level.

As the lagoons fill the area of free water reduces quickly to about 70% and thereafter progressively until full. This follows a pattern similar to sediment deltas at the head of large reservoirs with erodible catchments but at a much faster rate, with an advancing face of deposition and a build up of material above water level. The difference here is that the point of discharge can be varied by design and operation to more evenly distribute the deposition across the full width of the lagoon (typically there are three fixed discharge points during first filling of a new lagoon covering two quadrants of the generally rectangular lagoons; later stages of filling involve moving the discharge points to different parts of the perimeter to ensure even filling to full height). It is possible to fill each lagoon to within 300mm of the embankment crest over 95% of the area before decommissioning, although the mechanics of delta formation result in large areas of deposition approaching embankment crest level in the final stages of filling. All of this

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makes conventional interpretation of the Act less relevant than might be assumed initially.

Whilst the foregoing describes a typical filling operation, and this normally leads to decommissioning of the lagoon, there are exceptions to this which potentially change the way in which the Act can be interpreted. The general principle at the Valleyfield site is based on completing each lagoon as a building block in each horizon of the overall landscape envelope, whereby new levels are built on the consolidated surface of the previous horizon. A typical cross section through the site, showing the various horizons of ash deposition is indicated in Figure 2. However, there are times when a previously infilled lagoon has to be brought back into commission in order to maintain lagoon availability within the overall strategy of having service and reserve capacity available whilst building future lagoons. Usually this is combined with use of the deposited ash as fill material for a new lagoon embankment. At the Longannet lagoons the operating regime is different. Although there is an overall landscaping envelope for the site which will ultimately result in a sequence similar to the Valleyfield regime, the two lagoons are operated on an alternate fill, consolidate, excavate and refill cycle.

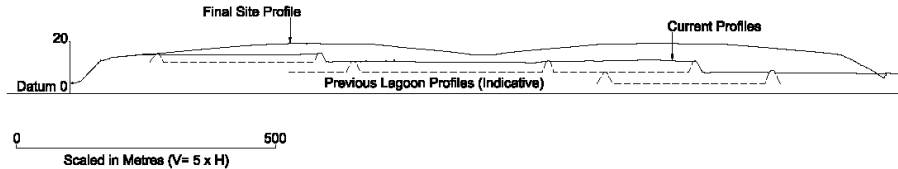


Figure 2. Typical section through ash deposition at Valleyfield.

Certification

Established precedent on the Valleyfield site has treated each service lagoon as a commissioning work in progress with certification under the Act being given under a series of Preliminary Certificates setting the level of operation for progressive stages. This approach is permitted by the variable overflow level rising towards ultimate design level and only reaching that point when the lagoon is virtually full of ash.

Current practice is then to discontinue the lagoon under the Act. The lagoons are rarely in service for longer than two years and so a Final Certificate never becomes due. However, a Certificate of Efficient Execution is prepared on completion of each new lagoon embankment.

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There have been no cases of lagoon re-use at Valleyfield under the present Construction Engineer for the site, but the current construction works include for the excavation of Lagoon 20 which was capped in 2007. When this happens the original draw-off works will be re-set to the lowest operating level of the lagoon. Although not yet determined, it is likely that the lagoon will be dealt with under Section 6 of the Act (alteration of an existing reservoir).

Commissioning, Monitoring and Inspection

After completion of construction of a new lagoon the first preliminary certificate is issued to allow commissioning. As these are bunded reservoirs built on a foundation of previous lagoons including drainage infrastructure, the first objective is to monitor the behaviour of the reservoir solum. This is achieved by observing flows in all the accessible drainage manholes on the site. The uncertainties of solum performance are increased when the underlying lagoon has been used as a source of fill for the new lagoon embankment and there is potential for previous drainage features and permeable zones to be intercepted. Prior to the introduction of water, base readings are taken of drainage flows on the site as well as from the piezometers and level stations on the new embankment.

The level set by the first preliminary certificate is very low in relation to the embankment and is intended to test the solum without placing the new embankment drainage under any significant load. This level can be below the minimum level of the outlet structure and thus the lagoon may not be in service during the initial commissioning process. There is a period of intensive monitoring on a daily basis during commissioning, principally to identify any unexpected flows that might be related to unidentified features within the foundation.

There is a hierarchy of monitoring based on the performance characteristics of ash lagoons. This assumes that drainage will provide the first indication of performance, followed by piezometer response then physical displacement.

After the commissioning phase the second Preliminary Certificate is set at a minimum level above initial overflow control. At this point the lagoon becomes fully operational receiving ash slurry from the power station and discharging supernatant flow through the outlet. Subsequent Preliminary Certificates allow free water levels to rise by a maximum of 1m. The overflow units are added in 150mm increments.

There is daily observation of the lagoons and routine monitoring is carried out at six monthly intervals

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Given that the typical new ash lagoon operates under Preliminary Certificates and is Discontinued before the need for a Final Certificate there is no requirement to carry out inspections under section 10 of the Act. However it is normal practice for the Construction Engineer for the operational lagoons to carry out a biannual inspection and to prepare an informal report on these inspections. These reports also cover the Construction Engineers assessment of the routine monitoring. Although not part of the legislative process the reports contain a signed statement on reservoir safety.

Comparison with conventional reservoir design

The dominant influence on conventional reservoir structures is the likely period of operation which can greatly exceed normal structural design life allowances of around 50 years. The hazard associated with the extended life of reservoirs introduces onerous design criteria in relation to seismic events and flooding that recognises the extended exposure. However, the operational life of the lagoons at Valleyfield is very short, in some cases less than two years, and this has an influence on design standards.

The combination of short operational life and a carefully controlled service regime plus a high level of observation and monitoring allows certain design decisions to be taken. The impounded slurry / residual water is not allowed to exceed tight limits on depth and, for most of their short service life, the lagoons operate under very low head with generous freeboard. Unlike some process related lagoons, the deposited ash gains strength relatively quickly and places limited load on the impounding structures; there is also the benefit of considerable past performance of similar lagoons on the same site as well as a high level of performance monitoring on a daily basis. All of this greatly reduces the risk of undetected failure.

LAGOON DESIGN ISSUES

The elements which need to be considered in the design of an ash lagoon are no different to the design of most reservoirs; however, at Valleyfield the design can take account of the very short operational life which is shorter than the temporary works phase of many larger dam projects.

The foundation

The foundation of the lagoons at Valleyfield is one area where the designer has little influence as the lagoons are usually constructed over made ground, both existing lagoons and colliery shale deposition. This scenario also applies to the solum of the lagoon. Accordingly, the performance of the lagoon foundation represents the greatest risk to the designer.

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Generally the immediate foundation materials are hydraulically placed PFA. These deposits may be of variable consistency across the foundation as the filling process results in the coarser materials being deposited near the discharge and the finer particles closer to the outlet. To the east of the Valleyfield site lower foundation levels are of colliery shale where this has been stockpiled as a mining residue. This material is additionally present as a thin layer, typically ~300mm thick, across completed (discontinued) lagoons. The designer also needs to take cognisance of the underlying natural deposits. As the Valleyfield site is essentially reclaimed from the Forth Estuary, the natural superficial deposits comprise a variable thickness of normally consolidated alluvial deposits which overlie Boulder Clay and ultimately bedrock. The alluvial deposits typically comprise interbedded very soft clay, silt, sand and gravel and have been identified to an elevation of around -30mOD. These deposits typically increases in thickness in a southerly direction across the Valleyfield site as the site encroaches further into the Forth Estuary, but are often absent at the north of the site near the original foreshore.

The final factor which can influence the lagoon foundation is the presence of services, typically drainage related features from earlier lagoon construction. Such features are variable in their depth, size and nature of construction and, unless well understood in the design, can present challenges during construction.

Design information for the foundation is obtained through a search of ScottishPower's previous lagoon construction records, including historic ground investigation data. This is supplemented by new ground investigation data as necessary. A simplified ground model is compiled, along with a record of the existing service features which may influence the design. Normally the designer limits work on the foundation to the removal of any capping material (coarse colliery shale) and other shallow features which might influence the seepage paths across the foundation. Such features include bands of coarse PFA, inclusions of colliery shale and occasionally residual vegetation and rootlets. There is a trade-off between removal and exposure of wetter material.

The Embankment

The embankment profile adopted at Valleyfield has had similar geometry (and construction) since the start of work with only height being varied. The structural envelope typically comprises a 1(v):2.5(h) upstream slope and a 1(v):3(h) downstream slope with a 5m wide crest incorporating an access track. Engineered PFA, sourced from earlier lagoons on the site, is the primary construction material for these embankments. The engineered

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PFA is placed to achieve a minimum of 95% of the maximum dry density for the material. A typical embankment cross section is shown in Figure 3

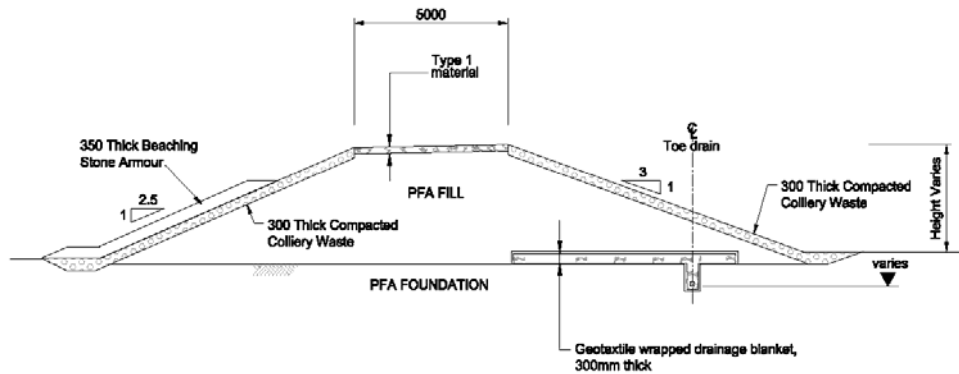


Figure 3. Typical section through impounding embankment.

At the site perimeter the downstream slope of the lagoon is much less steep than quoted above as a result of placing landscape materials. This fulfils the requirements of the Planning Conditions which dictate the shape of the finished landform on the site. These landscape materials are not placed to a strict engineering specification and hence their beneficial influence is not considered within the design.

There are a number of unique factors that need to be considered by the designer in every new embankment. These include:

- The source of PFA. The quality of the ash varies due to a number of factors such as sediment grading and ultimately the origin of the coal burned at Longannet. This can influence the compacted density of the ash, and also the ease by which materials that exceed the optimum moisture content for engineered fill can be dried;
- The age of the underlying PFA, in particular its moisture content, consolidation properties and whether it can be safely trafficked;
- The thickness of the various ash and natural alluvial deposits along the line of the new lagoon embankment which affects the long term settlement of the embankment;
- The position of the phreatic surface.

Such factors are considered in the stability analysis, the bearing capacity analysis and the settlement performance of the embankment. Parameters are determined from the ground investigation data and the sensitivity of these is checked.

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Seepage Control and drainage

As with all embankment dams control of seepage is fundamental to performance. However, the case with ash lagoon embankments is somewhat different to most dams due to the homogeneous construction, short design life and the nature of operation (staged filling).

Although the operational life of a lagoon is short, typically around two years, it is found that the permeability of the PFA (k_H being of the order of 10^{-6} m/s) will ultimately lead to the development of steady state seepage during operation. Some form of drainage is therefore required to ensure that the phreatic surface in the downstream face is controlled as this is fundamental to the stability analysis. Accordingly, blanket drainage has always been provided at formation level beneath the downstream shoulder of the embankment. The blanket is combined with a filter drain and perforated pipe to collect the seepage flows as indicated in Figure 3.

The construction of the blanket drainage has evolved. The drainage medium was initially self filtering using furnace bottom ash (FBA) and subsequently the FBA was wrapped in geotextile. As the availability of FBA declined (since it became a valuable commodity for other uses) the drainage medium changed to an imported granular material. Inspections from recent lagoons show that this was typically well graded sand and fine gravel (largely self filtering) but still wrapped in geotextile. More recently, for Lagoons 24 and 21, an open drainage medium has been used with filtration solely by geotextile.

It is necessary to evaluate the magnitude of seepage to determine drainage capacity. Analyses are undertaken to determine the peak seepage flow and to allow the optimum position and geometry of the blanket drain to be established under a variety of operating conditions. The critical case is typically at top water level, towards the end of operation. The outflows from the filter trench are directed to existing drainage infrastructure and sea outfalls which are located around the site. Silt traps are provided in selected inspection chambers to highlight if any fine particles are migrating into the drainage system during operation. Additionally, the designer needs to take account of the influence of long term settlement on the pipe gradient and the constructability of the drainage trench as depth increases due to the relatively weak hydraulically placed ash deposits.

Outlet Works

A single piped conduit passes through the structural embankment, typically allowing outflow to commence at the formation level for the embankment. The pipe is encased in concrete where it passes through the structural embankment to ensure efficient compaction of the surrounding structural

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PFA. A metal gantry structure is provided to allow the discharge point to be accessed and level control is achieved by square weir sections added above the discharge point. The weir sections are formed from GRP, each section approximately 150mm in height. The typical arrangement for the outlet is shown in Figure 4.

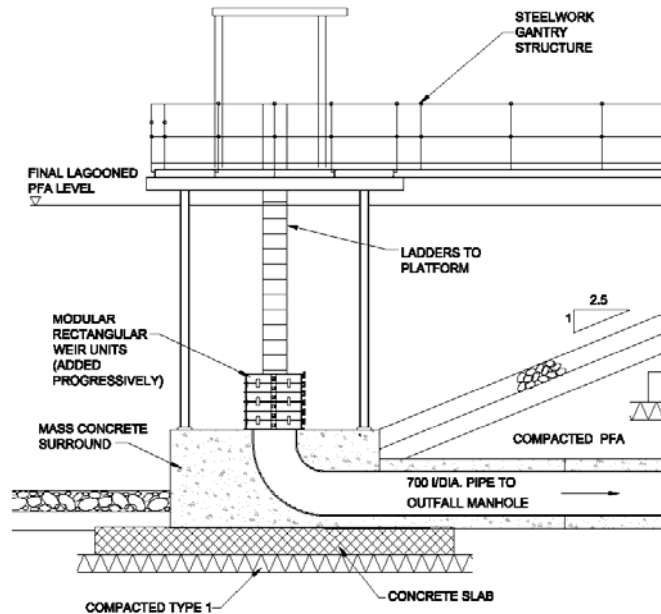


Figure 4. Typical outlet arrangement.

Wave Protection

Protection of the upstream slope of the lagoon embankment is of great importance in the design due to the vulnerability of the PFA, which is essentially a non-cohesive silt. Historically at Valleyfield two lines of defence have been provided to prevent erosion, the first being a 300mm layer of colliery shale (sandy gravel grading) and the second a 350mm layer of beaching stone (mainly 100mm to 225mm in size). The colliery shale also serves to prevent dust blow from the upstream slopes of the embankment before water inundation. The beaching stone is sized using the maximum fetch and wind velocity to determine the acceptable size and thickness. Savings can be made by limiting the extent of placement of the beaching stone according to exposure.

The north eastern corners of the lagoons have been identified to be most susceptible to wave erosion, a function of the predominantly westerly wind. As such, these areas are protected from toe level to an elevation of around 1m below the crest level. The level of protection in other areas is lower, typically 2m below crest level. The design reflects limited exposure to wave action experienced near the crest of the embankment (the water level

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is typically at top water level for less than six months). A supply of beaching stone is in place on the site and could be placed at very short notice should a daily inspection identify any signs of erosion.

LAGOON CONSTRUCTION ISSUES

Overall the design and construction objective is to simplify design features and reduce construction complexity. However, there are issues which need to be carefully controlled, principally in relation to the selection and placement of the fill within the structural envelope, the sequencing of the works and interface detailing.

PFA Selection and placement

The material used in the construction of a lagoon embankment is PFA borrowed from previous ash lagoons, the source typically being within the solum of the finished lagoon. Normally the material is not considered for use in embankment construction for around two years post final deposition due to its high moisture content. Selection and appropriate processing (conditioning) of the PFA for construction is fundamental to the successful construction of the structural embankment.

The moisture content of the lagooned ash varies typically between 40% and 70%, increasing with depth and towards the outlet where the finer particles are deposited. Often it is possible to recover the upper deposits (to a depth of around 2m) for direct use in embankment construction, but usually below this depth the material requires conditioning to render it suitable. The conditioning is usually achieved by excavating the material into windrows and turning as required. Alternatively, marginal materials can be used for landscape fill where it can be used without conditioning.

Given the silty nature of the PFA and its moisture content, which is typically on the wet side of optimum, it is usually compacted with a dead weight smooth wheeled roller. Vibratory rollers and tamping rollers have generally not proved successful with this material and usually cause further issues, either drawing water through the previously placed layers, thus softening the material, or leaving a surface which does not freely drain. However, when the PFA and the formation are dry, vibratory rollers can be used successfully. Experience has shown that layers of around 200mm to 250mm thickness can be compacted with large (circa 20t) smooth wheeled rollers. Material selection appears to have the greatest influence on satisfying compaction requirements.

ScottishPower has traditionally placed the compliance testing with their Engineer to independently ensure that the 'end product' specification of achieving a minimum of 95% of the maximum dry density is met. This also

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allows the Engineer to closely control the works as the Contractor requires the Engineer's approval to proceed with further layers. Until recently, testing by the Nuclear Density Gauge (NDG) was adopted, but this has now changed to measurement by core cutter tests with calibration by sand replacement tests. The variable composition of the ash, in particular the elevated carbon content, was found to lead to inconsistencies in the calibration of the NDG, resulting in uncertain placement control and inefficient over-compaction.

Sequencing

Careful sequencing of the works is important to limit the number of construction interfaces, to avoid differential fill height and to reduce differential settlement. Lagoon construction projects are generally undertaken during the summer and early autumn months, but can extend well into the autumn if the weather remains dry. The PFA is particularly susceptible to heavy rain, but recovers more quickly than cohesive fills provided construction activity stops in good time.

The main objective of detailed programming and sequencing of the works is to ensure maximum continuity of earthworks layers which is crucial to the integrity of the completed lagoon. For this reason the works are generally sequenced to allow layers to be placed over long lengths thus reducing the number of transverse interfaces which represent potential seepage paths. This requires the Contractor to commence as early as possible with the formation preparation and blanket drain construction to free-up areas for material deposition. Maximising the length of the layers is also beneficial in increasing the turn-around time before following layers are placed; this allows some in situ conditioning of the material. Often the material is placed and left for a few hours prior to compaction to allow a degree of air/wind drying. However, whilst the wind can be beneficial from a material conditioning perspective, it is also detrimental from a dust blow perspective and the Contractor needs to consider this in his planning of the works.

Construction detailing

Although appropriate detailing is undertaken at the design stage, various issues, usually related to intercepted drainage, tend to arise during construction. Typically these are the result of encountering existing services in an unexpected manner, i.e. at a different depth, with unexpected backfill arrangements, or live services previously thought to be redundant.

The perception of the design and the overall development of the site has changed over the years. Recent innovations include the detailing of an interceptor filter drain where new embankments interface with existing and the provision of a common outfall pipe serving multiple future lagoons.

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CURRENT ACTIVITY AT VALLEYFIELD

Lagoon 21, which commenced construction in July 2009 and is due for completion in September 2010, is the main area of activity at present and represents a number of challenges to the design and construction teams. This lagoon is untypical of the more routine construction of previous and anticipated future lagoons:

- The footprint of Lagoon 21 comprises three material types, lagooned PFA, mechanically placed PFA and colliery shale. This is the last area of original land use on the site and includes the lowest point on the site;
- Lagoon 21's impounding embankment has a considerable height variation ranging from 4m to around 9.5m. Normally lagoon embankments have a consistent height, generally no higher than 4m;
- Although the entire Valleyfield site sits above former coal mining, this is generally at significant depth and does not represent a problem. However, at Lagoon 21 a shallow mine adit is at the ground surface beneath the impounding embankment and traverses part of the lagoon. This necessitated treatment works by partial grouting of the adit;
- Typically only a few drainage services are present in the formation, but the solum of Lagoon 21 includes numerous services of various ages and construction details.

The design of Lagoon 21 was based on a detailed review of the future strategy for lagoon provision at Valleyfield. This identified that the topography of the site, which was at five different elevations, would quickly represent a constraint to future lagoon construction. This is due to the reducing operational area of the site as the various levels, or tiers, of lagoons are constructed (the site can simply be considered as a squat pyramid) compounded by the requirement to allow the lagooned PFA to partially drain before proceeding with the next level of construction. The resulting fallow time would ultimately create periods when ash deposition could not take place, thus restricting generation activities at Longannet.

The design and construction of ashing lagoons at Valleyfield is scheduled to continue for at least ten years and the current ash strategy will ensure that deposition can proceed continuously whilst ensuring a balance of active, reserve and under-construction lagoons.

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