Cantab Consulting Ltd

Hemerdon Mine Waste Facility
Environmental Permit Application

EPR/FB3639RK/A001

Appendix 3G: The Design Basis

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Executive summary

The design process also involves the identification of all potential hazards, not only during operation but post closure as well. This enables the designer to mitigate risks during the design and construction process. The key risks, which must be addressed in addition to those normally associated with dam design, are the geotechnical and geochemical characteristics of the mine waste, the site water balance, the local hydrology and the robustness of the design under seismic loading. The risk to life and to the environment downstream must be identified in order to assess the risk category of the facility, and thus appropriate factors of safety be used in the design. Again, these risk assessments must include an evaluation of the potential for long-term geotechnical/geochemical deterioration of the materials stored in the depository or used to Wolf Minerals (UK) Ltd (Wolf) has retained Cantab Consulting Ltd (CCL) to prepare a Design Basis report in support of an Environmental Permit (EP) application for the mining waste facilities associated with the mineral extraction and processing operations to be undertaken at the Hemerdon Tungsten Project on Crownhill Down in south Devon. These operations will result in a significant volume of both coarse and fine mine waste arising on the site and being stored in a purpose-built mine waste facility (MWF). The fine waste (tailings) derived from mineral processing will be deposited into a purpose-built reservoir stage-constructed throughout the operating life of the mine using the mine waste rockfill from the open pit.

The engineering design of such waste management facilities is complex and must be undertaken by experienced consulting engineers in order to meet the requirements of cost-efficiency, safety and stability, as well as compliance with planning, environmental regulations and closure requirements. The processed tailings need to be deposited within a facility engineered and constructed in accordance with statutory requirements and with good practice in order to:

- provide a cost-effective and environmentally appropriate means of storing the waste and of recycling the process water;
- provide safe, stable storage of the waste such that at closure the facility will remain geotechnically and geochemically stable, effectively in perpetuity.

The Hemerdon MWF includes a 113m-high rockfill embankment constructed from run-of-mine waste, and all necessary infrastructure such as emergency spillways, decant structures, tailings and return water pipelines and seepage control systems. An additional embankment dam, the Tory Pond, will be constructed immediately downstream of the MWF to provide emergency process water supply as well ultimate control for all seepage flows and site runoff.

Wolf has appointed Mike Cambridge of Cantab Consulting Ltd, an independent All Reservoirs Panel Engineer (ARPE), as the Competent Person responsible for certifying the final design and confirming that construction and operation proceed accordingly. The design principles for the MWF, the Tory Pond and all infrastructure have been developed by the designer in close consultation with the Competent Person. The design and construction will be in accordance with all statutory requirements and comply with UK and international standards. In particular all material parameters, partial factors of safety and stability and flood assessments will be compliant with good practice and meet international and UK criteria for such facilities such that the mine wastes and process waters are stored in safety.

The design process also involves the identification of all potential hazards, not only during operation but post closure as well. This enables the designer to mitigate risks during the design

and construction process. The key risks, which must be addressed in addition to those normally associated with dam design, are the geotechnical and geochemical characteristics of the mine waste, the site water balance, the local hydrology and the robustness of the design under seismic loading. The risk to life and to the environment downstream must be identified in order to assess the risk category of the facility, and thus appropriate factors of safety be used in the design. Again, these risk assessments must include an evaluation of the potential for long-term geotechnical/geochemical deterioration of the materials stored in the depository or used to confine the waste product. The stability, hydrological and seismicity design assessments in particular must be robust for each phase of dam raise/construction.

The design and construction of the Hemerdon embankments will be reviewed annually by the Competent Person appointed by Wolf, with the independent inspection reports being made available to the Enforcing Authority as required. These inspection reports will confirm the stability of the embankments and the ongoing validity of the risk assessments, and that appropriate standards of construction and maintenance have been evident throughout the intervening period.

The proposed design approach is considered to satisfactorily address the principal ICOLD risk criteria for the avoidance of failure, and the mitigation measures to be incorporated will reduce the overall risk of a significant untoward event during construction or operation to an extremely low level. The design of the facility is being developed to meet all necessary statutory requirements for each stage of the operational life and after closure. The ongoing risk assessments, to be completed during both the final design stages and the construction of the MWF, will allow for any fluctuations in material characteristics and their availability as well as for any changes in the physical environment.

Contents

1. Introduction

Wolf Minerals (UK) Ltd (Wolf) has retained Cantab Consulting Ltd (CCL) to prepare a design basis report for inclusion in support of an Environmental Permit (EP) application. The application is for a Mining Waste Facility (MWF) at the Hemerdon Mine in Devon. The mine is comprised of an open pit, processing facility, MWF and associated infrastructure. This application relates solely to the MWF.

The Hemerdon site is located within an area characterised by historic and current quarrying and mining operations. The city centre of Plymouth lies approximately 10km to the south-west, with the town of Plympton approximately 3km to the south-west, as shown in Figure 1 below. There are a number of scattered farms and residential properties within 2km of the proposed site boundary, with the small villages of Yondertown, Sparkwell and Hemerdon to the south-east and south respectively.

The MWF lies on Crownhill Down and covers an area of approximately 175 hectares which extend on to the lower slopes of the Tory Brook valley. Waste from the open pit will be used to construct the stage-raised confining embankments, and the tailings generated from the processing plant will be deposited continuously within the MWF. The final stage of the MWF's development is shown in Figure 2 below.

The site was given conditional Planning Permission by Devon County Council (the Mineral Planning Authority) in 1985. A Modification Order was approved in January 2011, updating the planning conditions in line with legislative changes made since 1985.

The wastes generated at the site are defined as extractive waste, which falls under the scope of the Mining Waste Directive (MWD), and an Environmental Permit (EP) is therefore required.

2. Background

Mineral extraction and processing operations are to be undertaken by Wolf at the Hemerdon Tungsten Project on Crownhill Down in south Devon. These operations will result in a significant volume of coarse and fine mine waste arising on the site being stored in a purpose- built mine waste facility (MWF). The fine waste (tailings) derived from mineral processing on the site will be deposited into a purpose-built reservoir stage-constructed throughout the operating life of the mine. The facility will be designed to accommodate both mine waste rockfill from the open pit and the processed tailings, and will be constructed in accordance with statutory requirements and with good practice in order to store these wastes in safety.

2.1 Mine waste disposal

Most sectors of the minerals industry produce a residue which, on completion of the refining process, comprises a fine particulate waste, generally emanating from the process plant in slurry form. Such materials, regardless of their consistency, need to be placed in a secure containment facility and, in most cases, would not be stable without being suitably confined. Further, the efficiency of the refining process and the requirements of the site water balance require that the greater part of the water contained within the slurry be recycled and reused. Thus the containment normally includes a sedimentation and decanting system enabling clarified industrial water to be returned to the plant. The residue is usually pumped from the plant to the storage facility as a slurry, the consistency of which will vary depending on the economic material, the process adopted and the configuration of the storage basin. The slurry may take the form of a very thin pulp with low solids concentrations, as for many silt lagoons, or be thickened to 70% or 80% solids and be deposited as a paste. The purpose of a mine waste management facility is therefore twofold:

- to provide a cost-effective and environmentally appropriate means of storing the waste and of recycling the process water;
- to provide safe, stable storage of the waste such that at closure the facility will remain geotechnically and geochemically stable, effectively in perpetuity.

The engineering design of a waste management facility is complex and must be undertaken by experienced consulting engineers in order to meet the requirements of cost-efficiency, safety and stability, as well as compliance with planning, environmental regulations and closure requirements. The design of an MWF will therefore include the following provisions:

- safety – design and construction to meet both short- and long-term geotechnical and geochemical stability requirements;
- economy – use of mining waste, where appropriate, for confining embankment construction;
- water management – maximisation of water recycle and re-use whilst managing flood events in safety;
- closure – design of facility at mine closure to achieve a sustainable landform which minimises long-term liabilities;
- facility management – operation, inspection and monitoring in accordance with good practice and with statutory requirements;
- environmental management – control and monitoring of all potential emissions.

2.2 Legislation

The MWF will be operated in accordance with both UK legislation and the European Union "Extractive Waste Directive" (EWD) in order to meet good standards of inspection and monitoring, and will be closed to an acceptable end-point on cessation of mineral operations.

The principal regulations governing the design, operation and closure of the MWF, and the associated key guidance documents, are listed below:

- Mines & Quarries Tips Act 1969
- Health and Safety at Work Act 1974
- Reservoirs Act 1975
- Quarries Regulations 1999
- Extractive Waste Directive 2006 (EWD)
- Floods and Water Act 2010
- Environmental Permitting Regulations 2010
- EPR 6.14 Additional guidance for mining waste operations 2011
- Extractive Waste Directory Annex guidance (2010-12):
    - General waste characterisation;
    - Sampling;
    - Kinetic testing;
    - Inspections.

The physical stability of a mine waste containment structure and the competence of both the design and operation is determined by the HSE, who will approve the design and all subsequent modifications in accordance with the Mines and Quarries (Tips) Legislation. The UK Mines and Quarries (Tips) Legislation was deemed to be competent and fully compliant with the general requirements of the EWD with respect to design, operating and inspection standards. These regulations define a classified tip, prescribe the procedures necessary for a facility to be fully compliant and specify the statutory appointments to be made by the Owner. These appointments include that of a Competent Person to report on all aspects of such facilities, the responsibility for approval being vested in this independent civil engineer. The process mirrors that required under the UK Reservoirs Act 1975, where the Environment Agency (EA), as the enforcing authority, is reliant on suitably qualified civil engineers, namely All Reservoir Panel Engineers (ARPE), for the ongoing safety and stability of all large raised reservoirs.

The HSE is deemed to be responsible for determining that a facility meet all necessary design, operating and inspection standards by ensuring that a suitably qualified Competent Person is engaged to undertake all statutory inspection and reporting. The recommendation for the engagement of a civil engineer, who is independent of the designer, as inspector for this purpose is included in the EU Guidance on inspection of mine waste facilities (EC 2012).

The EWD applies to all mine waste facilities, i.e. waste rock dumps, tailings management facilities, silt lagoons and, by inference, ash and sewage sludge lagoons, and provides additive regulation. The EWD and the associated Decisions were transposed into UK legislation in 2009, and guidance documents (principally EPR6.14 in England and Wales) were prepared for waste and facility categorisation in particular. The permitting guidance recognised the importance of the categorisation process and the following specific technical considerations required for a Category A facility:

- Waste categorisation
- Facility categorisation
- Permitting
- Competence in design and operation
- Inspection
- Financial guarantees
- Emergency planning for Category A facilities
- Closure

Categorisation of the waste in accordance with the UK Regulations (the Extractive Waste Permitting Regulations) is enforced by the EA and requires assessment of the hazardous nature of the mine waste, of the risk posed by the storage of this waste, and for the facility to be defined as either Category A or Non Category A accordingly. The test work undertaken on this waste has satisfactorily demonstrated that the material is non-hazardous. However, regardless of the non-hazardous nature of the waste it has been recognised that the Hemerdon MWF should be classified as Category A under the EWD by virtue of the potential downstream impacts arising from a failure of the facility, as is described elsewhere.

3. The Hemerdon Mine Waste Facility

This MWF includes a 113m-high rockfill embankment constructed from run-of-mine waste in order to confine the finer residues (tailings) and the excess process water. The facility also includes all necessary infrastructure to enable safe and efficient management of tailings management operations, including emergency spillways, decant structures, tailings and return water pipelines and seepage control systems. An additional embankment dam, the Tory Pond, will be constructed immediately downstream of the MWF to provide emergency process water supply as well the ultimate control for all seepage flows and site runoff.

As is common for mine waste facilities the MWF will be raised in a number of discrete lifts in order to provide safe storage for the process residues, and thus the construction of the zoned confining embankment will be ongoing, subject only to the tonnage of mine waste rock generated by the extraction operations. The placement of mine waste rock and of the coarser process wastes (DMS residue) to form a robust confining embankment will be continuous throughout the mine operation. The stage-constructed confining embankment will include the main structural section, comprising zoned courses and fine waste rockfill, together with the necessary engineered filter zones, underdrains and seepage collection system. The earthworks placed throughout the confining embankment will comprise engineered fill placed to an appropriate specification to suit the properties of the waste rock materials. The seepage control zones will be extended progressively to ensure the capture of embankment and mine waste seepages. The system will collect and control seepages, recycling these through a pump and return system. The seepage system controls the lateral movement of interstitial water through the embankment via engineered filter zones into a basal collection drain. This enables all releases to be controlled and recycled back to the main reservoir. At closure, once the surface reservoir has been removed, the rate of seepage through the tailings will reduce until the water reporting to the seepage control system comprises local runoff only. Experience from other facilities has shown that seepage control during disposal leads to effective drainage of the mine wastes and to a decline in the volume reporting to the downstream outlet within a few years of cessation of mining operations. The rate of this decline will be enhanced by the early landscaping of the upper surface of the depository.

It is envisaged that deposition will be arranged to achieve maximum density and efficient disposal. This requires exploiting the tailings' properties and the elevated horizontal-to-vertical permeability ratios in the deposit to promote horizontal drainage, maximising lateral seepage, reducing saturation levels and thus increasing storage density. In addition, there will be a progressive improvement in overall stability as a result of the decrease in pore pressures and the corresponding rise in effective stress. The desaturation of the tailings also leads to a reduction in risk, both of liquefaction and the potential for mobilisation on disturbance. At Hemerdon the tailings disposal and the internal drainage systems will be integrated to maximise consolidation, increase stability and enable early restoration, rehabilitation and landscaping at closure.

A full description of the MWF and of the Tory Pond is presented elsewhere and is not included here in the interests of brevity. The principal dimensions of the facility are presented in Table 1.

	MWF	**Tory Pond**
Embankment crest level	200mOD	71mOD
Maximum embankment height	113m	Approx. 10m
Crest length	3100m	700m
Reservoir volume to TWL	100,000m^3	70,000m^3
Maximum operating reservoir volume	50,000m^3	70,000m^3
Embankment volume	11,700,000m^3	To be determined
Tailings storage volume	7,700,000m^3	N/a

Table 1: Principal dimensions of the proposed facility

4. Design principles

4.1 Overview

The MWF will include all necessary infrastructure to enable the facility to be operated and closed in accordance with the design parameters and with both planning and environmental constraints. The MWF, the Tory Pond and all infrastructure will be designed and constructed in accordance with statutory requirements, with both UK and international standards and with good practice in order to store the mine wastes and process waters in safety. The design principles for this project have been developed by the designer in close consultation with Wolf's "Competent Person" – a civil engineer independent from the designer, but required to certify the final design and confirm that construction and operation proceeds in accordance with the design. Wolf has appointed Mike Cambridge, an All Reservoir Panel Engineers (ARPE) of Cantab Consulting Ltd, as the Competent Person for this project. In particular, all material parameters, partial factors of safety and stability and flood assessments will be compliant with good practice and will meet standard international and UK criteria for such facilities. The design and construction of the Hemerdon embankments will be reviewed annually by the Competent Person appointed by Wolf, with the independent inspection reports being made available to the Enforcing Authority as required. These inspection reports will confirm the stability of the embankments and the ongoing validity of the risk assessments, and that appropriate standards of construction and maintenance have been evident throughout the intervening period.

4.2 Design basis

Compared to water-retention dams, which are often built to the final height in one stage, mine-waste confining embankments are raised in a number of lifts as mining activities proceed and the waste tonnage in the impoundment increases. It is not unusual for the methodology for raising the embankments, for tailings placement and even the waste characteristics to change during the operational period of a tailings pond. Thus, though the waste confining embankment, being staged-raised, differs in concept from a conventional water dam, it needs to meet all necessary design requirements at each lift. The design risk analysis, Table 2, should therefore include the possibility that materials, as well as the surrounding conditions (including extreme hydrological or seismic events), may change during the operating life (Cambridge 2004). It should therefore be reviewed and updated regularly by the Competent Person during the life of the project.

The construction of the embankment, though following normal geotechnical design procedures, will involve use of materials derived from the mineral extraction operation (mine waste rock) or from the process (DMS residues). The intrinsic geotechnical and geochemical properties of the materials to be used need to be characterised and the design prepared accordingly, using recognised good practice. The storage facility, and particularly the confining embankment, must be configured in the knowledge that materials available for construction and the properties of the waste product may change during the life of the facility, and thus a degree of flexibility must be incorporated into the design.

The storage facility requires adequate capacity to store not only the particulate waste but also process waters and any runoff from precipitation, both on the mine site and potentially on the upstream catchment. The confining embankment must therefore be sited to ensure adequate capacity and be robustly designed to prevent failure or long-term deterioration which might lead to an untoward release of the waste product or of the contained process water.

The engineering design of a mine waste facility is complex and is being undertaken by experienced consulting engineers supported by other specialists in order to meet the requirements of cost-efficiency, safety and stability, as well as compliance with planning, environmental regulations and closure requirements. The design will include the following provisions:

- safety – design and construction to meet both short- and long-term geotechnical and geochemical stability requirements;
- economy – use of mining waste, where appropriate, for confining embankment construction;
- water management – maximisation of water recycle and re-use whilst managing flood events in safety;
- closure – design of the facility at mine closure to achieve a sustainable landform which minimizes long-term liabilities;
- facility management – operation, inspection and monitoring in accordance with good practice and with statutory requirements;
- environmental management – control and monitoring of potential emissions.

The MWF requires adequate capacity to store not only the waste rock and process waste (tailings) but also process waters and direct rainfall falling within the impoundment area. The confining embankment has therefore been sited to ensure adequate capacity, and is being robustly designed to prevent failure or long-term deterioration which might lead to an untoward release of the waste product or of the contained process water. The design of the MWF has taken into consideration:

- site suitability, noting the existing planning permit and previous detailed site option studies, but also reviewing topography, geological, geotechnical and seismic characteristics, hydrology and hydrogeology and environmental risk;
- construction specification QA/QC;
- the Operating and Maintenance Manual;
- the inspection and auditing protocols;
- engineered closure.

The design of the facility is therefore being developed to meet all necessary design requirements at each stage of its operational life and after closure. The design risk analysis, to be completed during the final design stages, allows for changes in material characteristics and availability, and includes an allowance for changes in the surrounding conditions (including extreme hydrological or seismic events), as shown in Table 2 (Cambridge 2004).

Event	**Typical risk assessment for a MWF**		**Applicable standards**
Natural event	**Hazard**	**Consequence**	
Seismic event	Catastrophic failure Untoward discharge	Extreme loss of life Environmental damage	BRE Report "An engineering guide to seismic risk to dams in the UK"
Extreme flood	Catastrophic failure Untoward discharge	Extreme loss of life Environmental damage	ICE Report "floods and reservoir safety" Recent Defra guidance EU Directive
Unknown geology	Progressive failure Uncontrolled release	Possible environmental damage & loss of life	BRE "An engineering guide to the safety of embankment dams in the UK" BS5930/EN ICOLD Bulletins
Upstream instability	Overtopping Untoward release	Extreme loss of life Environmental damage	ICE Report "floods and reservoir safety" Recent Defra guidance ICOLD Bulletins Eurocode 7
External event	**Hazard**	**Consequence**	
War or sabotage	Progressive failure Uncontrolled release	Possible environmental damage & loss of life	ICOLD Bulletins
Internal event	**Hazard**	**Consequence**	
Internal instability	Progressive failure Uncontrolled release	Possible environmental damage	BRE "An engineering guide to the safety of embankment dams in the UK" ICOLD Bulletins Eurocode 7
Operational fault	Catastrophic failure Untoward discharge	Extreme loss of life Environmental damage	HSE Guidance ACOP ICOLD Bulletins
			Ref. CIRIA Report, Risk management for UK reservoirs

Table 2: Risk summary for all design stages

The basis of the design risk assessment will be reviewed and updated regularly by the Competent Person (see "Regulatory Compliance") during the life of the project.

4.3 Design risk assessment

The design process therefore involves the identification of all potential hazards, not only during operation but post closure as well. This enables the designer to mitigate the risk during the design and construction process. The key risks, which must be addressed in addition to those normally associated with dam design, are the geotechnical and geochemical characteristics of the mine waste, the site water balance, the local hydrology and the robustness of the design under seismic loading. The risk to life and to the environment downstream must be identified in order to assess the risk category of the facility and thus appropriate factors of safety be used in the design. Again, these risk assessments must include an evaluation of the potential for long-term geotechnical/geochemical deterioration of the materials stored in the depository or used to confine the waste product. The stability, hydrological and seismicity design assessments in particular (Table 3) must be robust for each phase of dam raise/construction.

	Embankment stability assessment
	Embankment at all stages designed in accordance with UK and ICOLD guidance. • Minimum long-term factor of safety f >1.5 • Minimum short-term factor of safety f >1.1
	Hydrological considerations during design and construction
	Designed in accordance with current Defra/EA guidance for flood standards for dams in the UK and for identified risk category.
	The "safety check flood", often made equal to the Probable Maximum Flood. It is considered acceptable practice for the crest structure, waterway, and energy dissipater to be on the verge of failure, but to exhibit marginally safe performance characteristics for the flood condition.
	The "design flood" strictly representing the inflow which must be discharged under normal conditions with a safety margin provided by the freeboard. It is usually taken as a percentage of PMF or a flood with a given probability of excedence (1:100, 1:1000, etc).
	Embankment seismic assessment
	Stability assessment includes seismic considerations - MWF being designed in accordance with BRE publication "An engineering guide to seismic risk for dams in the United Kingdom", as below: • Design Base Earthquake - when subjected to the DBE, no significant damage will occur. • Maximum Credible Earthquake - when subjected to the MCE, damage is limited and no catastrophic failure will occur.
	Embankment stability assessment at closure
	At closure, final embankment profile complies with EU and ICOLD sustainability guidelines (ICOLD, 2011).

Table 3: Principal design assessments

Material properties
The site investigation and other laboratory test work have indicated the waste rock and the DMS rejects (coarse tailings) to have suitable properties for inclusion in this 113m-high embankment. However, it is recognised that the characteristics of the waste materials used to construct the MWF, and also of the fine tailings themselves, may change during the operational period, particularly as mining operations progress from the oxide to unaltered ore. However, the design of the confining embankment and the construction practices defined are considered to be suitably robust to enable such changes to be accommodated without recourse to redesign or for there to be any compromise on safety. It is also recognised that there is a similar likelihood of the characteristics of the fine tailings changing, and it is again considered that the staged design is robust enough to meet any changes in tailings production.

Stability
Material parameters, factors of safety and stability will be compliant with good practice and meet standard international and UK criteria for such facilities. The confining embankment will include a main structural section, comprising zoned waste rockfill, together with the necessary engineered filter zones, underdrains and seepage collection systems. The earthworks used for the construction of the confining embankment will comprise engineered fill placed to an appropriate specification to suit the properties of the waste rock and DMS reject materials.

The stability of the embankment will be assessed for a range of conditions, and the design of each stage of construction reviewed to ensure the safety of the confining structures at all times during development. The overall stability will be calculated using industry-standard software and will include consideration of both normal and extreme (seismic) conditions.

Flood risk
The overall design approach for the containment is to provide sufficient storage and to adequately manage water during operations such that no process water is released directly from the fine tailings containment into the environment other than through internal seepage within the MWF during the life of the mine. The HSE requires that storage facilities be designed, constructed and operated in accordance with good UK/International practice and that the same risk categories as used for large raised reservoirs be applied to flood criteria (Cambridge 2008). Therefore a mine waste facility which includes the potential to store a significant volume of water (more than 10,000m^3) would be placed in the highest reservoir risk category for flood storage, i.e. Category A (ICE 1996), due to the implications of an untoward release for both life and the environment in the downstream catchment. An ARPE has been engaged to advise on the necessary flood standards to be applied to ensure that the necessary hydrological assessment for the MWF and for the Tory Pond – both of which will have storage capacity which exceeds 10,000m^3 - is compliant with this standard.

The flood standard to be applied to the MWF will be in accordance with current Defra/EA guidance for flood standards for dams in the UK for the identified risk category. In accordance with accepted UK practice for mine waste facilities it is proposed that the Hemerdon MWF be designed to retain all floods arising from storm events up to and including the 1-in-1,000 without spilling, but to pass in safety those arising from greater storms up to and including the PMF (Cambridge 2010). In addition, an emergency spillway will be provided and must be designed to pass in safety the PMF at all construction stages as overtopping of the embankment is not permissible. The Tory Pond would be categorised as a Category A reservoir in accordance with ICE 1996 and the spillway will accordingly be designed to a similar standard.

Seismicity
The basic seismic stability assessment will be based on current UK guidance (BRE 1991) as shown below in Table 4. Using this guide the reservoir would be placed in Hazard Category III on the basis of the following preliminary assessment:

Parameter	**Value**	**Classification factor**
Capacity	<120,000,000m^3	4
Height	>45m	6
Evacuation requirements	1-100	4
Potential damage	High	8
Total		**22**

Table 4: Seismic classification

This category requires the dam to be assessed against a Maximum Credible Earthquake with a peak ground acceleration of 0.65, representing a return period of 10,000 years. The overall height of the embankment and the implied construction method indicate that a more detailed seismic safety evaluation will be required for this dam and the British Geological Survey (BGS) has been appointed to provide a detailed seismic risk assessment from which the following will be derived:

- Design Base Earthquake (DBE) - the operating basis earthquake (OBE) has been selected as a 1:500-year AEP event having a horizontal peak ground acceleration (PGA) of 0.025g;
- Maximum Credible Earthquake (MCE) - has been selected as a 1:10,000-year AEP event. having a horizontal peak ground acceleration 0.065g for a MCE (1:10,000 year AEP).

5. Compliance monitoring

5.1 Statutory requirements

Technical compliance with the EWD is recognised to be fully addressed by existing competent UK legislation, particularly under Health and Safety Regulations, leaving the additive regulatory requirements of waste and facility categorisation to be addressed through environmental permitting. The Health and Safety Executive (HSE) is unequivocal concerning the definition of tips which fall under the Mines and Quarries (Tips) Act 1969, and thus has the responsibility for enforcement and application of the associated 1971 Regulations and for the safety and stability of these facilities. The key issues of competence in design, operation, waste management, inspection and monitoring are therefore already enforced by the HSE under existing regulations.

Mines and Quarries (Tips) Act 1969

These regulations impose a duty on the Owner/Manager of every mine to ensure that the provisions of the Act are strictly applied and that a Competent Person be appointed to report on the design and construction of the tip, and to ensure that tipping rules are prepared prior to the commencement of any deposition. The Regulations also require that a Competent Person be engaged to undertake regular inspections of the facility and to report on the safety, stability and competence of the waste management operations on the site, on the statutory appointments and the competence of the regular inspections and monitoring.

The Quarries Regulations 1999

The Quarries Regulations 1999 endorsed the 1969 legislation, and further strengthened it by ensuring that the, generally smaller, quarry silt lagoons were also included. These Regulations detail the approach to be taken in the design and execution of tips and excavations, and define the nature of geotechnical hazards which require a specified level of competence in assessment, design, operation and monitoring.

Competent Person

The HSE requires Owners to ensure that the Competent Person engaged to report on any tip has the relevant professional qualifications and experience. The HSE indicated that a tailings management facility (TMF), in particular, requires more extensive expertise and knowledge of additional engineering skills beyond the purely geotechnical.

Further, guidance (reinforced by recent EU Inspection Guidelines, EC2012) also specifies that these inspections be undertaken by an engineer who is independent of both the Owner and the designer. The HSE relies on the expertise of the independent civil engineer (the Competent Person) to review critically the design, operation and all other technical aspects of a mine waste facility.

5.2 Inspection monitoring and reporting

Any facility used for the storage of mining waste and/or industrial water, and the associated structures, should be monitored for both safety and stability purposes as well as to ensure their efficient operation and environmental compliance. The inspection of any waste or water facility, and the monitoring of the instrumentation, should be undertaken on a regular basis by appropriately trained operators, supervising engineers and departmental managers, with annual safety, stability and compliance audits by the independent Inspecting Engineer (Competent Person). All inspectors, engineers and appointed operators should be familiar with the operation and the general inspection and monitoring procedures for each structure. Typical inspection data recording and instrumentation and sampling protocols would be described in a manual produced as part of the design process. The guidelines including suitable record sheets for the regular inspection and monitoring of the facilities are to be provided in the proposed Operating and Maintenance Manual.

Statutory reporting
The legislative framework under which a mine waste facility is designed, constructed and operated in the UK puts a strict requirement on the Owner to engage an independent Competent Person with the relevant expertise and experience. The Regulations require inspections to be undertaken and reports prepared at key stages of the project, and that these reports shall be available on the site for inspection by the Inspectorate. The construction and ongoing development and operation of the facility is entirely dependent on these reports as "it shall not be lawful for tipping operations to be carried out at the tip unless a report has been obtained … from a person competent to make the report on the tip". The frequency with which the inspection and reporting has to be carried out is summarised in Table 5, which includes the regime required under the Reservoirs Act for comparison.

	MINES & QUARRIES (TIPS) ACT (i)	RESERVOIRS ACT
Pre-deposition	**Mine waste facility**	**Large raised reservoir**
Appointments	**Competent Person**	**Inspecting Engineer**
	Certification of Regulation 9 Report (ii)	**Section 6 Certificate**
Operation		
Appointments	**Regulation 5 Appointee**	**Supervising Engineer**
Regular supervision	**Weekly inspections**	**Minimum of annual inspection**
Statutory records	**Weekly record of waste tipped** **Record of all defects and remedial actions**	**Prescribed Form of Record**
Independent inspections		
Appointments	**Competent Person**	**Inspecting Engineer**
Frequency	**2-yearly reporting (iii)**	**10-yearly reporting**
Closure	**5-yearly reporting for closed classified tips**	

Table 5: Summary of statutory reporting under UK legislation

6. MWF risk assessment

A review of the frequency of the dominant failure modes for tailings dams was undertaken by the tailings dam sub-committee of ICOLD and published in Bulletin 121, Tailings Dams - Risk of Dangerous Occurrences, in 2001. The summary of this review is shown in Table 6, and the data has been used in order to undertake an overall risk assessment of the Hemerdon MWF.

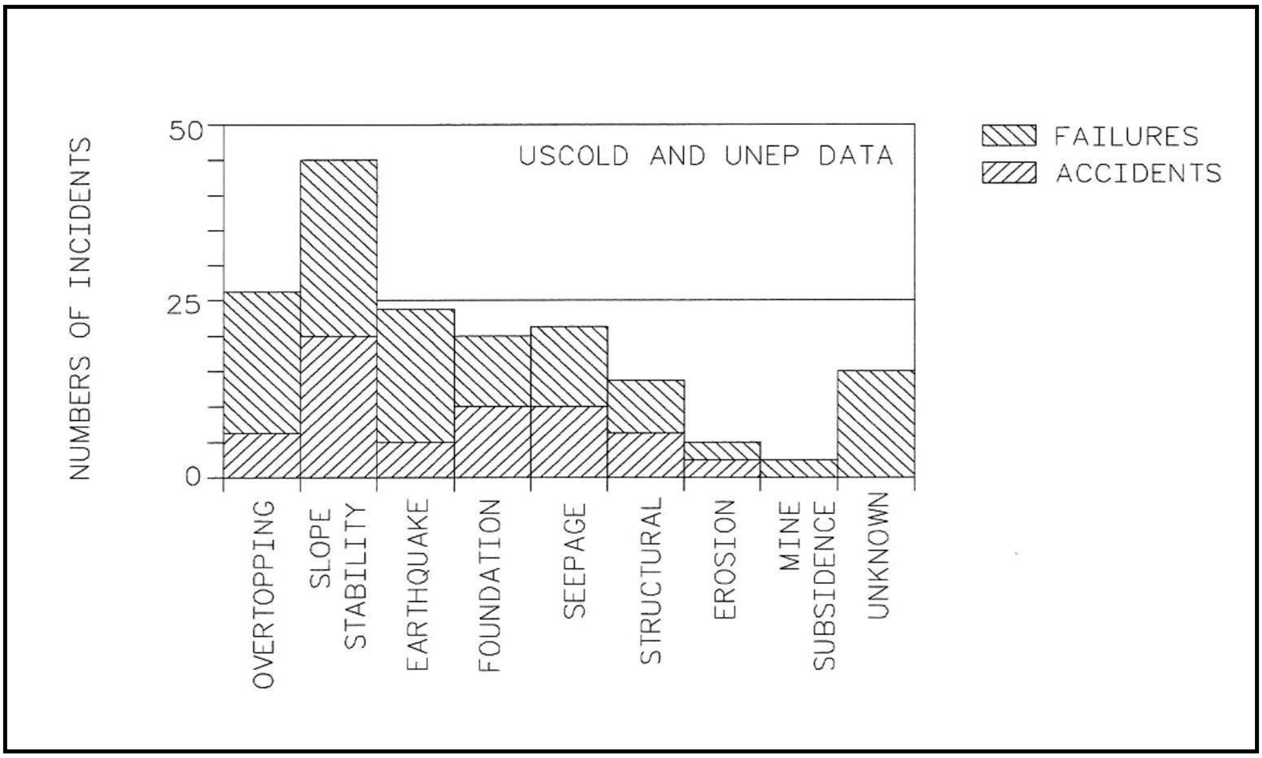

Table 6: Summary of historic tailings dam incidents

Bulletin 121 concluded that "attention at the design stage to the critical issues that can affect the long term safety of a tailings dam, will pay dividends throughout the life of the dam". The bulletin provided a list of the primary features affecting the design of a tailings disposal facility and, in particular, those concerning the stability of the confining embankment:

- Detailed foundation conditions.
- Ultimate height and angle of the outer slope.
- The rate of deposition and the detailed properties of the tailings.
- Provision of adequate drainage.
- Seismic influences.
- Control of hydrology to avoid overtopping
- Control of dangerous rises of the phreatic surface within the dam body.

The above elements are a direct reflection of the principal historic failure modes for mine waste facilities and have been used in order to assess the overall risks associated with the Hemerdon structure and to confirm that the proposed mitigation measures are in line with good practice. This assessment is shown in Table 7.

Failure mode	Consequence	Mitigation measures	Pr
Overtopping	Failure of embankment leading to loss of production and discharges downstream, with potentially severe consequences for danger to life, environmental impact and corporate reputation.	Spillway designed to pass routed PMF in safety at all stages of construction.	$<10^{-6}$
Slope Stability	Failure of embankment leading to loss of production and discharges downstream, with potentially severe consequences for danger to life, environmental impact and corporate reputation.	Detailed site investigation and laboratory study of construction materials, leading to stability assessment with factors of safety exceeding minimum ICOLD and UK criteria.	10^{-6}
Earthquake	Failure of embankment leading to loss of production and discharges downstream, with potentially severe consequences for danger to life, environmental impact and corporate reputation.	Adoption of UK seismic and stability guidelines, which exceed minimum ICOLD and UK criteria.	$<10^{-5}$
Seepage	Development of sinkholes and promotion of internal stability leading to localised failure of embankment, with potential loss of production and discharges downstream and severe consequences for environmental impact and corporate reputation.	Design of internal drainage control system to cater for seepage volumes at all stages of deposition with suitable factors of safety and quality control of embankment construction materials to ensure internal filter relationships.	10^{-7}
Structural	Potential for piping failure and promotion of internal stability leading to localised failure of embankment, potentially leading to loss of production and discharges downstream and to severe consequences for environmental impact and corporate reputation.	Decant and other internal structures designed to accommodate total embankment stresses with built-in redundancy and full instrumentation.	
Erosion	Potential for erosion of embankment walls as well as untoward discharge of tailings and process waters, potentially leading to loss of production and discharges downstream with severe consequences for environmental impact and corporate reputation.	All embankment surfaces to be placed to encourage runoff and all vulnerable pipelines to be instrumented to enable untoward leakage/discharges to be identified.	
Mine subsidence	Potential for settlement beneath embankment walls and instability leading to localised failure and untoward discharge of tailings and process waters, potentially leading to loss of production and discharges downstream with severe consequences for environmental impact and corporate reputation.	Detailed site investigation and literature study of old workings, leading to design of suitable stabilising measures in accordance with UK guidance for treatment of underground voids, adits and shafts.	

Table 7: MWF design risk assessment

7. Conclusions

A review of the proposed design basis for the Hemerdon MWF has been carried out on behalf of Wolf. The review has been undertaken by an independent civil engineer as a precursor to the statutory approval process. This assessment of the proposed design, construction and operation parameters has been undertaken against a combination of good practice, UK and ICOLD guidelines. Particular note has been taken of the criteria summarised in Table 8 (ICOLD 2001, 1995) below in order to confirm the appropriateness of the design proposals and of the associated mitigation measures.

1. Dam and Foundations	**1.1 Has the dam been designed by competent engineers, with due regard for foundation conditions internal drainage, slope stability, seismic loading and contaminant containment?** **1.2 Are tailings or cyclone sand to be used for construction and has the structure been assessed with the same rigour as an earth/rockfill dam?** **1.3 Is the dam instrumented and/or monitored so as to reveal any abnormal behaviour?**
2. Waterways	**2.1 Are the decant systems secure and have all pipes through the dam or foundation been adequately sealed?** **2.2 Is there sufficient flood storage capacity and are spillways and/or diversions adequate for the design floods?** **2.3 Are there any hazards associated with the tailings delivery lines and water reclaim lines?**
3. Closure	**3 Has the structure been designed to accommodate potential changes in operating conditions over the closure period, e.g. erosion, floods, sediment, inflows or natural landslides, etc?**

Table 8: Design risk criteria to prevent untoward failure

The review has concluded that the current design approach is wholly appropriate and satisfactorily addresses all the ICOLD criteria. Further, the mitigation measures to be incorporated into the design reduce the overall risk of a significant failure event during construction or operation to an extremely low level.

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May 2013

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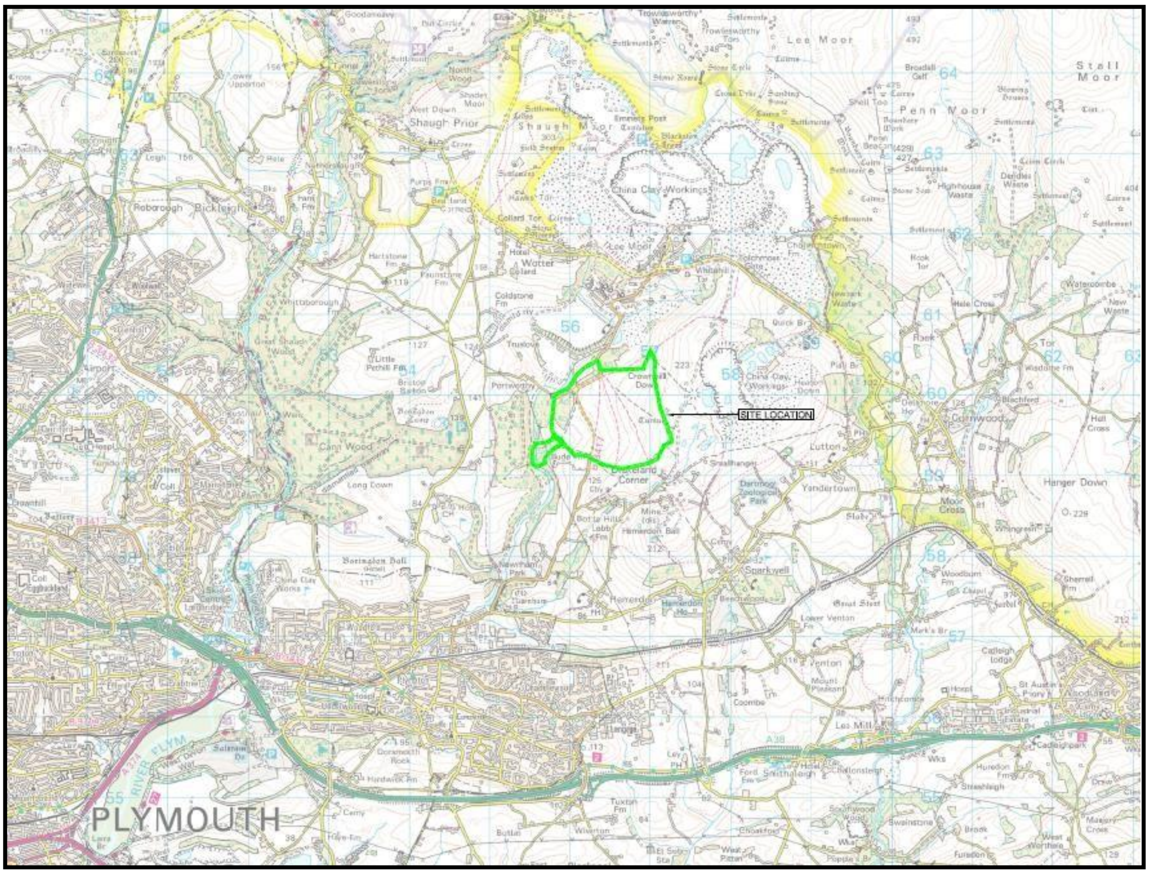

Figure 1: MWF and site location

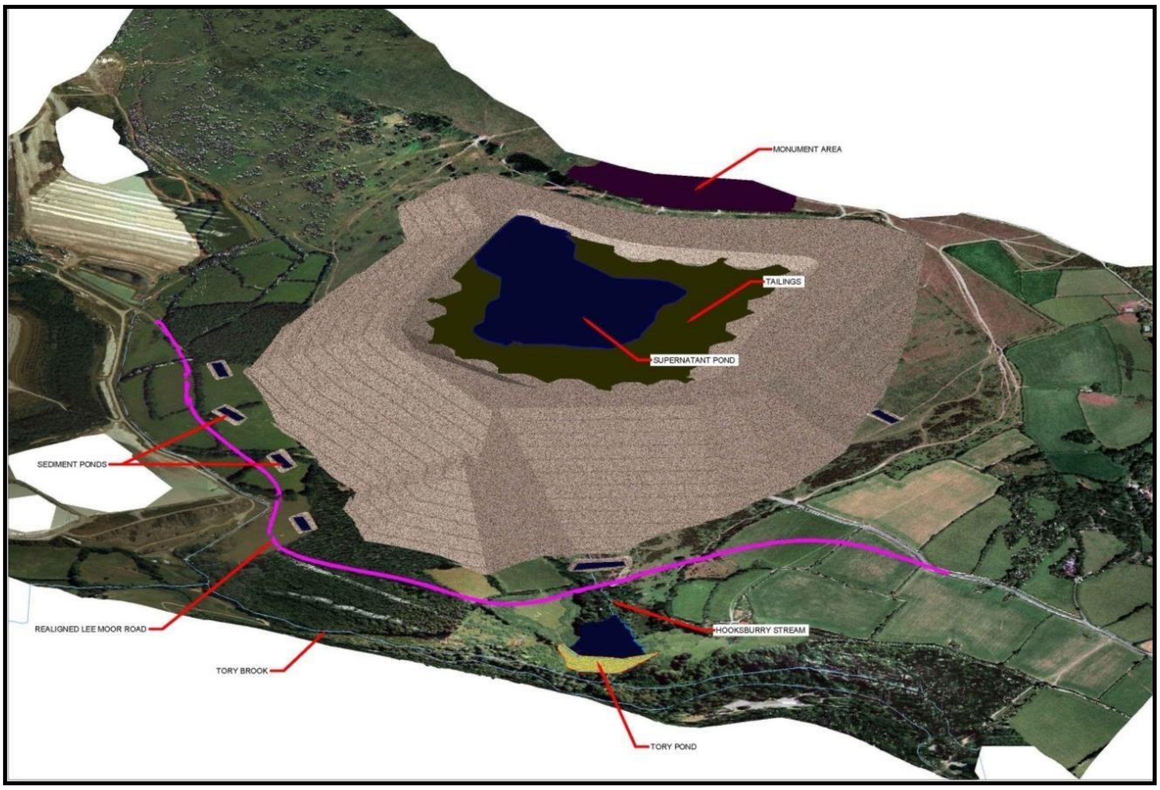

Figure 2: Three-dimensional representation of the MWF

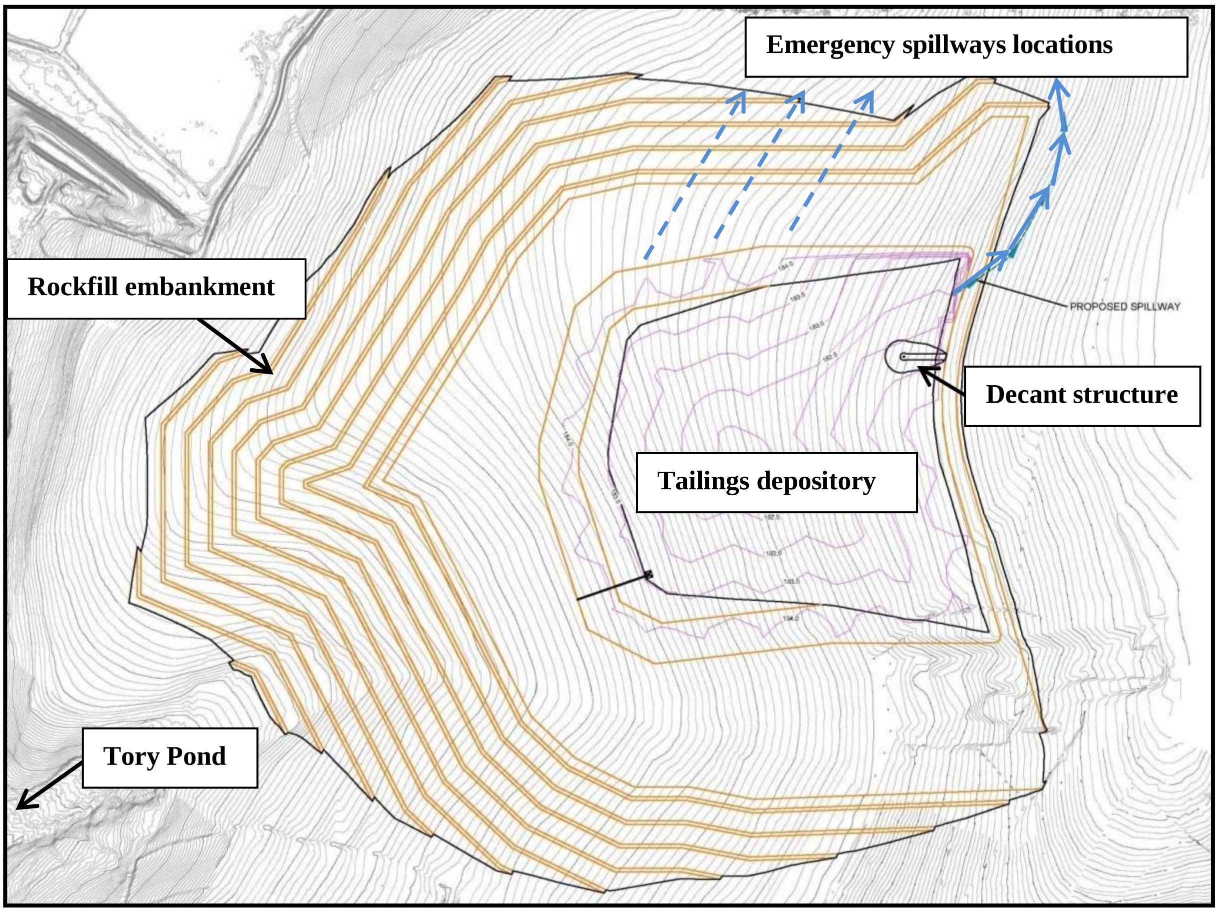

Figure 3: MWF conceptual layout

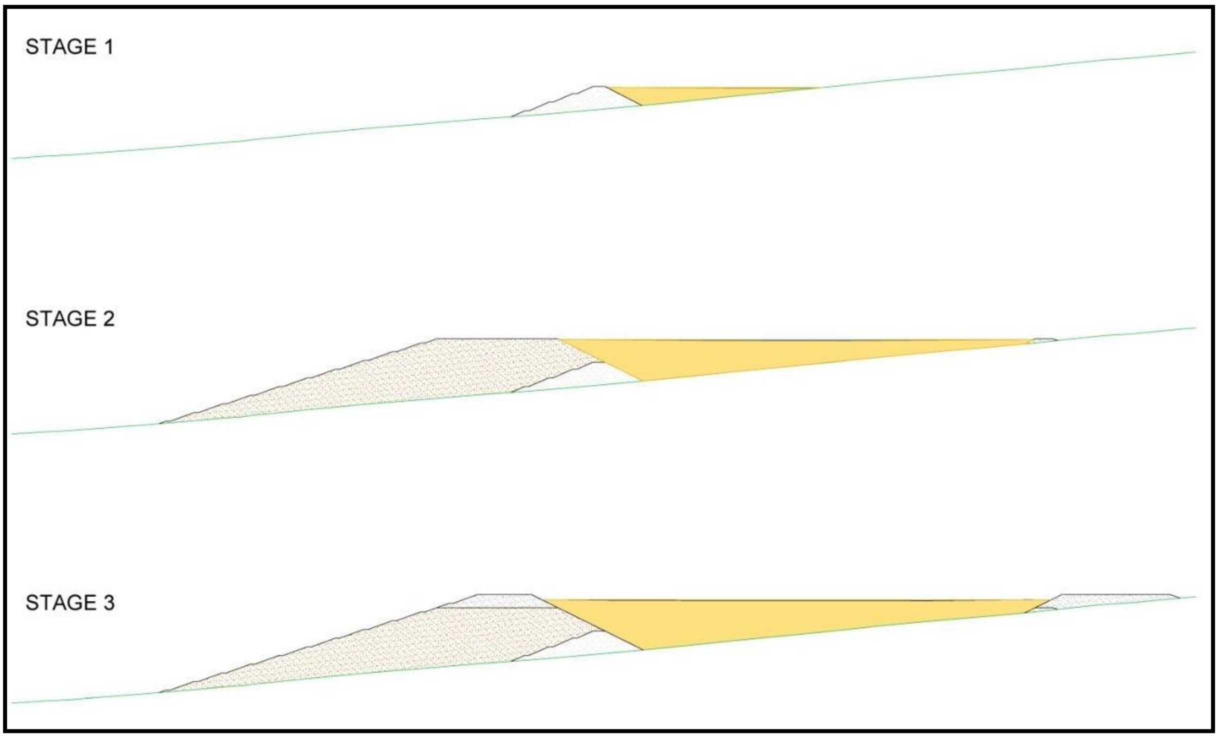

Figure 4: MWF conceptual construction stages

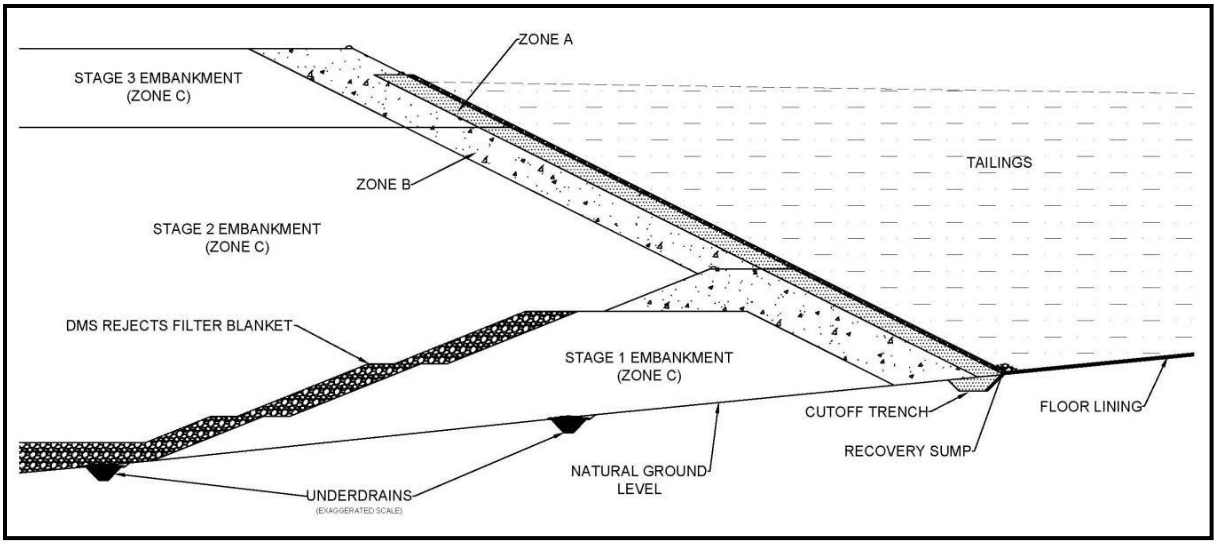

Figure 5: MWF containment embankment zones

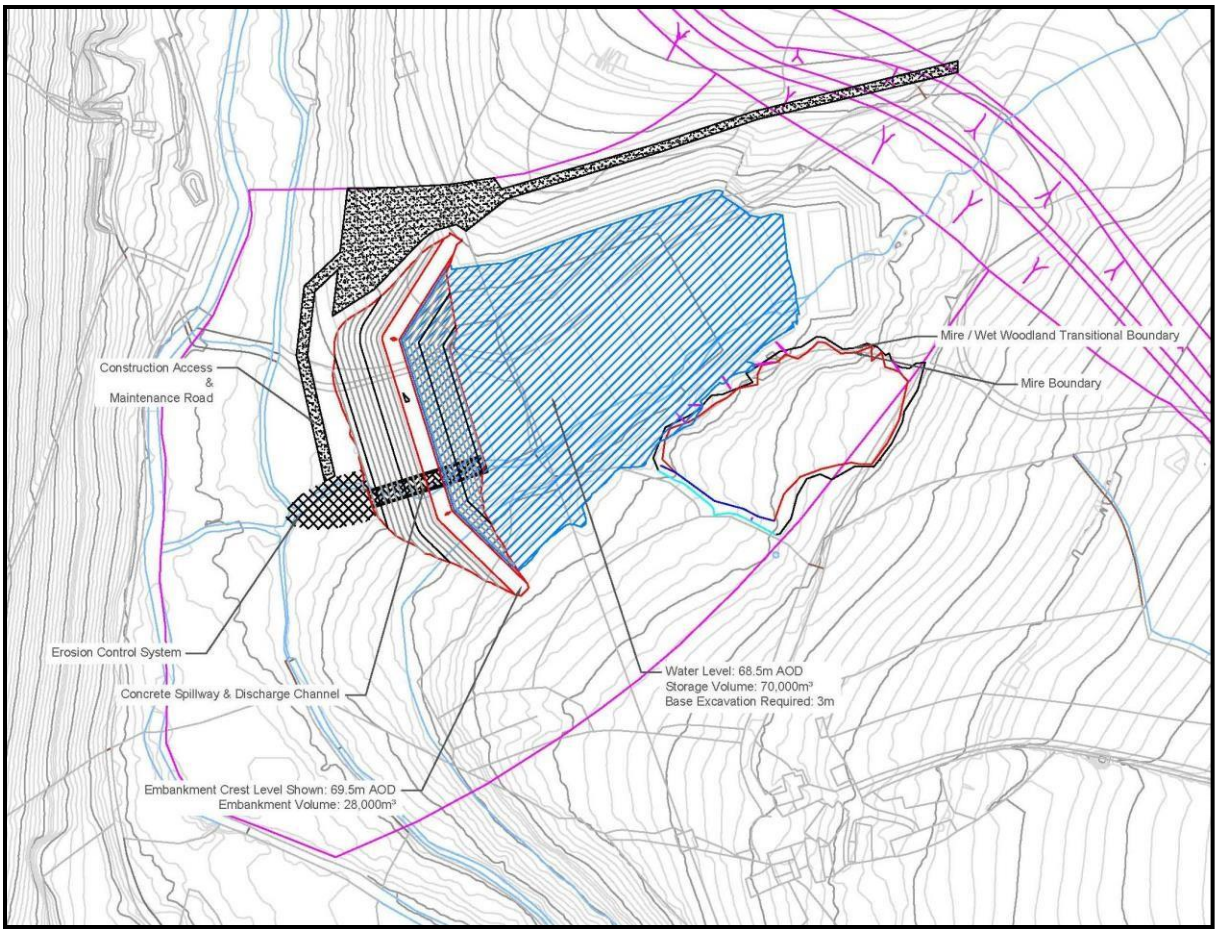

Figure 6: Tory Pond conceptual layout

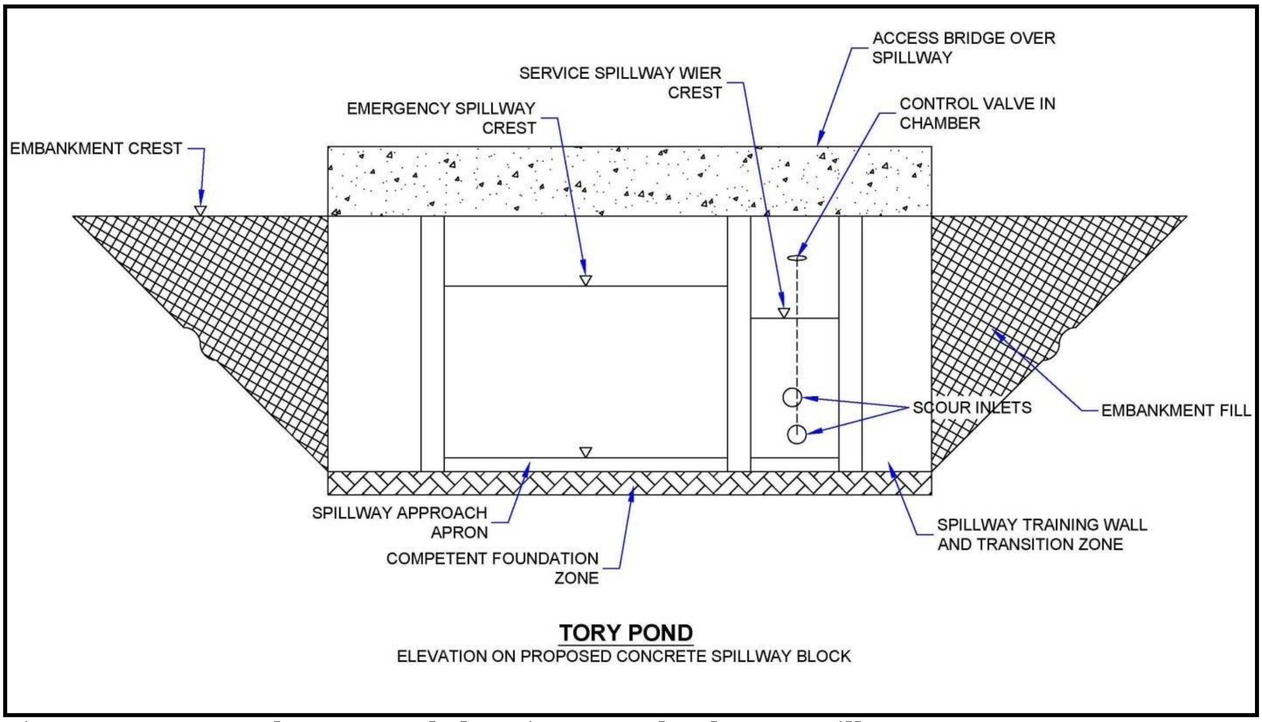

Figure 7: Tory Pond conceptual elevation on embankment/spillway

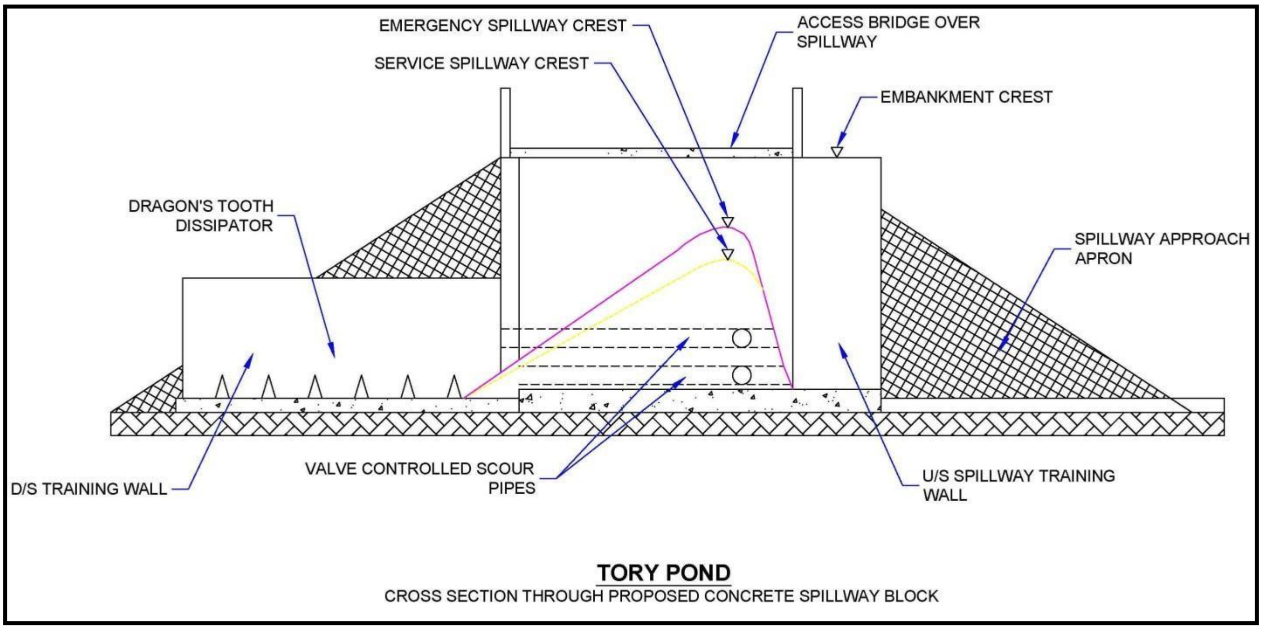

Figure 8: Tory Pond conceptual cross-section through spillway