Flood control measures at UK tailings management facilities

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SYNOPSIS. There is a long history of mineral exploration and exploitation in the United Kingdom, but few projects were successfully developed during the latter part of the 20th century. New mine projects permitted after the enactment of reservoirs and mine tips legislation are therefore limited in number. However, those that have been developed have included both the design and construction of large embankment dams for the containment of the tailings, together with the associated water management structures necessary to ensure safety as well as environmental compliance.

This paper presents the flood control measures adopted for tailings management facilities in the UK and demonstrates how these differ in design and concept from those for conventional water dams due to the general emphasis on staged construction and the more strict discharge permitting required. The hydrological approach taken to ensure that these facilities meet the highest flood standards whilst permitting discharges into controlled rivers is described. The paper illustrates the design basis for three current projects and demonstrates the ability of these facilities to meet the highest standards of flood control without compromising either operational efficiency or environmental compliance.

LEGISLATIVE BACKGROUND

Though mine and quarry lagoons are specifically excluded from the ambit of UK reservoirs legislation, it is accepted that good practice requires tailings storage facilities to be designed, constructed and operated to the same standards and in accordance with the same risk categories (Cambridge, 2008). In the UK, most tailings dams would be placed in the highest risk category, i.e. Dam Category A (ICE, 1996), due to the implications of an untoward release for both life and the environment in their downstream catchments. The Mines and Quarries (Tips) Act 1969 defines a tailings management facility (TMF) as being a “classified tip” where, inter alia, the volume of the tip exceeds 10,000m^3. Any TMF, therefore, which has the ability to store more than 25,000m^3, or indeed 10,000m^3, of water should, in accordance with the HSE principle of nearest equivalent standard, require that a suitably qualified civil engineer be engaged to undertake any necessary hydrological assessment and be responsible for defining the necessary flood standards to be applied.

Further, in May 2008, the EU Directive on the management of waste from the extractive industries came into force, with transposition into national legislation scheduled for completion in 2009. This legislation is intended to ensure that suitable regulations exist in all EU member states to prevent a repeat of untoward events such as the overtopping of the Baia Mare TMF in Romania in 2000 (EC, 2009a,b). The "Mining Waste Directive" requires characterisation of a TMF in terms of the risk posed in relation to type and volume of material stored, the highest risk facilities being identified as "Category A" sites. This legislation defines the minimum design flood standard for these facilities as the Probable Maximum Flood (PMF).

HYDROLOGY OF TAILINGS MANAGEMENT FACILITIES

The design of a TMF needs to consider the geotechnical and hydrological parameters conventional for any dam, but also to incorporate the flexibility to provide continuous water supply to the plant and to meet the stringent environmental conditions often associated with mining projects.

A TMF, unlike a conventional water reservoir, involves the retention of both settled solids and process water which may, if released, give rise to degradation of water courses and of the downstream catchment. Flood control measures for a TMF therefore require both environmental controls during operation, as well as safe designs against extreme events. Such measures are complicated by the construction method commonly adopted for these confining structures. This involves staged construction with successive, often annual, raises over a period of many years to meet the demands of process and mine life. The facility will therefore need:

- to be capable of flood management at every stage of construction, and thus may need to incorporate a series of control structures throughout its operational life;
- to provide a robust water supply as the majority of the water used during mineral processing is derived by recycling that discharged into the storage reservoir with the tailings;
- to comply with strict regulation of any discharge into local water courses, or indeed accommodate zero release where there are overriding environmental concerns.

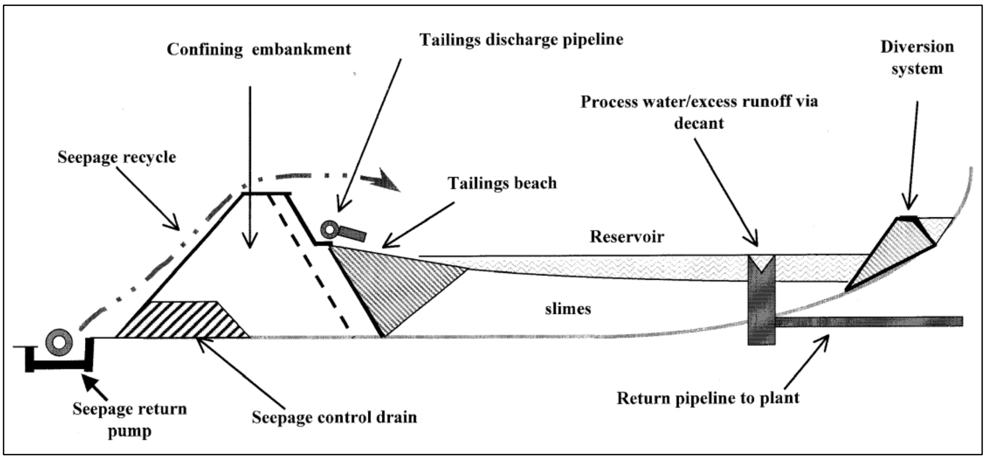

Figure 1. Schematic cross-section through a TMF

The water balance will determine annual/monthly storage volumes whilst also defining flood storage/discharge requirements. The ability of an operator to manage the water balance effectively over the life of the project will be heavily influenced by the permitting conditions, i.e. the agreement as to the quality and volume of any waters permitted to be discharged into the downstream environment. On many mine sites the water quality of the reservoir and the sensitivity of the downstream receptors may preclude the release of waters at any time, and a “zero controlled release” facility may be a condition of project development. Under such conditions the designer will need to ensure that the TMF, as the only significant water storage body on the mine site, has sufficient capacity to enable it to be operated in a compliant manner. For such facilities some mitigation can be achieved by the expedient of reducing runoff entering the TMF by diverting as much of the upstream catchment as is practicable, i.e. the effective separation of catchment and process waters. A careful balance must be struck, however, between upstream diversion and continuance of water supply during dry periods, requiring detailed calculation of the monthly water balance for all climatic conditions. Where regular discharge from the TMF is permitted, both volumes and quality will be fully regulated via a discharge consent. In both circumstances the operator must have the ability to control and manage water levels in the reservoir in accordance with the permit and with safe operation.

The TMF must be robust under the design flood, and thus for a “zero controlled discharge” facility sufficient freeboard will need to be available at all times to store the design flood event (generally the PMF). It is evident that this imposes a significant constraint on the design of the facility and moreover may impose overly conservative operating criteria and negatively impact on disposal efficiency. Maintaining such retention capacity at all times is likely to result in inefficient construction and operation, and threaten the viability of the facility and thus of the project. In the past ten-to-twenty years or so, as the magnitude of design floods has tended to increase and discharge controls have become tighter, a more flexible approach to the design and operation of emergency spillways for UK TMFs has been developed with regulators. It has been recognised that a limited discharge from a TMF during an extreme flood event will be likely to have a negligible contributory effect on any flooding impacts downstream. Further, the environmental risks are also likely to be negligible due to the significant dilution which will occur during such events.

In recent years, therefore, flood control structures for TMFs have been designed to minimise reservoir rise for a combination of process water discharges and an extreme flood event. For safety reasons these structures continue to be required to be robust under the design flood. However, the design no longer considers only retention of the PMF volume but addresses the discharge of a portion of this volume via the emergency spillway. This pragmatic approach assumes a two-tier flood control system, with the safety design based on robustness under the PMF and the operating design on environmental criteria.

EXAMPLES OF UK TMF HYDROLOGICAL DESIGN

In the UK the operating criteria at three facilities have been modified during the last twenty years in accordance with this more rational approach. In all three cases emergency spillways are provided to pass the PMF in safety, but the approach to the normal operating conditions has been modified and a more realistic, less onerous but environmentally acceptable set of criteria derived. Accordingly the hydrology of the catchment contributing to flood design for the TMF has been assessed to derive not only the PMF, but also the 1000 year event, from which peak flood discharges and volumes have been calculated. Flood routing of the extreme event through the emergency spillway has been undertaken to confirm the capacity of the waterways. In addition, the flood volume for the lower-bound extreme event (1000 years) has been assessed. These reservoirs are now operated on the basis that all floods up to the 1000 year event will be retained and that sufficient freeboard is maintained to accommodate this flood volume at all times.

A brief description of the flood and discharge control measures at each of these three projects is described below by way of example.

Clemows Valley Tailings Dam, Cornwall

The Clemows Valley Tailings Dam (CVTD) is associated with the Wheal Jane mining project and is located at Baldhu near Truro in Cornwall. This dam comprises a complex earthfill/tailings embankment (Cambridge, 2004) which was raised on an annual basis throughout the operational period, undergoing a number of design changes to ensure that the disposal area fulfilled the storage requirements and complied fully with statutory obligations. The confining walls to the facility have a combined crest length of 1300m and a maximum height of 50m. The staged raises included not only a decanting system to enable excess water of suitable quality to be discharged into the River Carnon but also a series of emergency spillway structures designed to pass the extreme flood event.

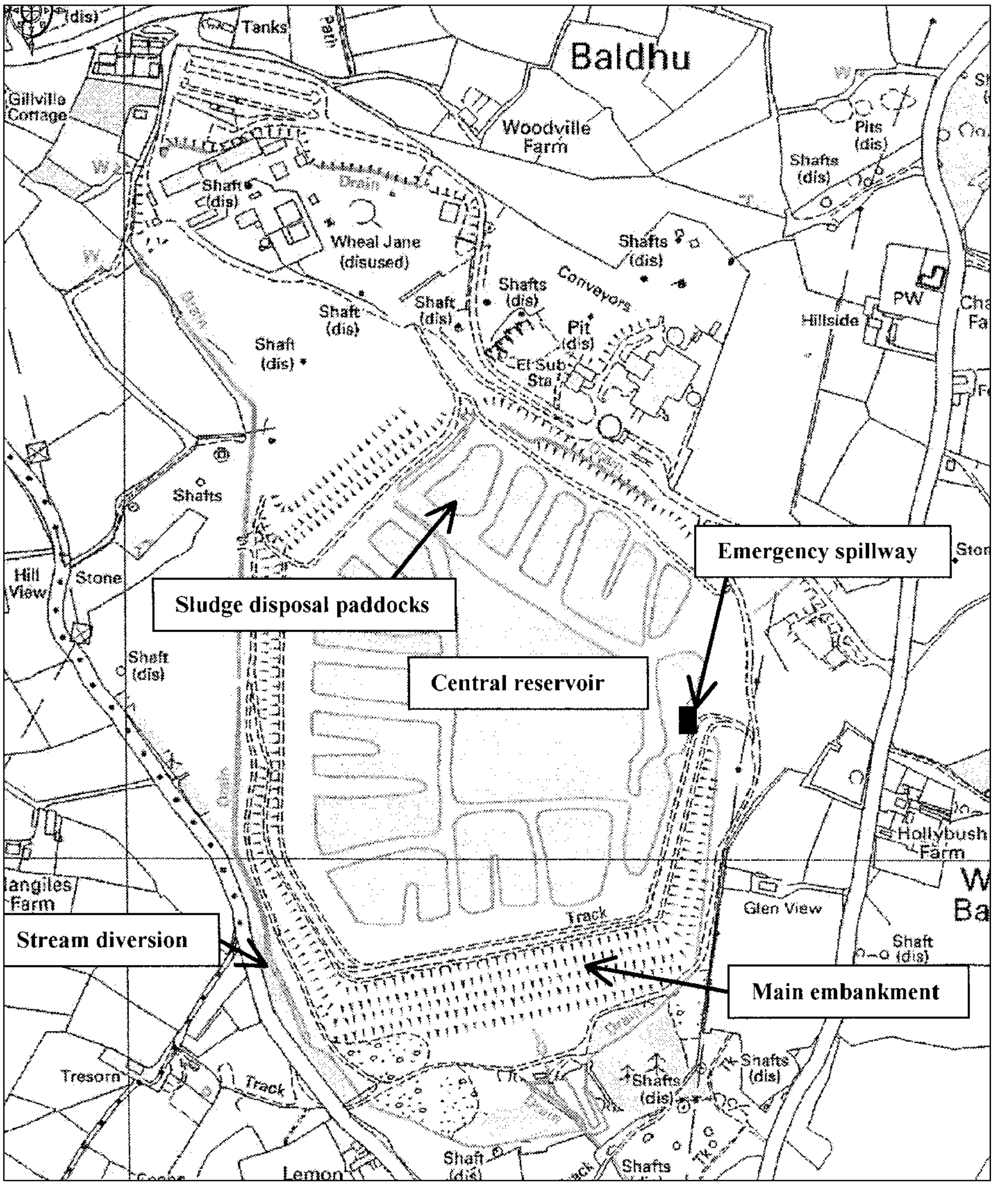

Figure 2. Clemows Valley Tailings Dam
(Drawing courtesy of Wheal Jane Ltd)

When mining and ore processing at Wheal Jane finally ceased in 1998 the CVTD was modified to receive mineral sludges from the treatment of up to 420l/sec of minewater (Hallett, 2003). Further design modifications were required to ensure that all minewater sludges could be accommodated without compromising flood control or safety. In order to provide safe and efficient disposal of the sludge, the reservoir area was subdivided into paddocks constructed on the surface of the depository around the reservoir periphery whilst maintaining a central reservoir for water control (Fig.1).

Modification of the combined decant and emergency spillway was required to prevent any sludges from being discharged off-site whilst ensuring that the extreme flood could be passed in safety. The spillway invert level was raised to its maximum consistent with the freeboard required to pass the design flood, and the reservoir operating rules were redefined to prevent any discharge below the lower-bound event (1000 years). The modifications included the installation of alarm systems, both advisory and emergency, to operate should the reservoir level exceed the critical lower-bound storage freeboard values. The decant continues to be operational as a flood control device, controlling the maximum level of the reservoir and preventing overtopping in an extreme flood event. This decant will continue to operate until the CVTD is fully restored and no longer has flood storage potential.

<u>Cononish Gold Mine, Perthshire</u>
The Cononish Gold Mine is located in Perthshire towards the west coast of Scotland in the headwaters of the River Tay, an important salmon river. The mine was permitted in 1997 following an eight-year gestation period, but failed to be developed at the time (Cambridge, 2003). The planning documentation for the project included a 50m-high embankment dam for the containment of the tailings, together with the necessary water management structures to ensure environmental compliance. In 2009 the project was regenerated by a new owner, and a modified application submitted. The development of this project is scheduled to be implemented in 2010, subject to receipt of the updated permission.

The facility is located in an area of high rainfall and it was thus recognised at the onset of the permitting process that both an extreme flood control system and a permitted discharge would be required on the site. During the original feasibility study of the TMF it was recognised that the importance of the design of the water-control structures in this sensitive Highland setting should ensure that the highest flood standards be met, whilst permitting controlled discharges into the headwaters of arguably the best salmon river in Europe.

The Cononish TMF, like the CVTD, is to be phase-constructed, and flood capability will be required at each staged raise. The flood control system will thus include a series of emergency spillways located on the right flank of the TMF which will have the capacity to discharge the PMF in safety into the Cononish River. To avoid inefficient disposal and to ensure ongoing stability, the reservoir will be operated such that it is maintained at an elevation below spillway crest level and that all floods with a return period of less than 1000 years can be retained within the reservoir basin.

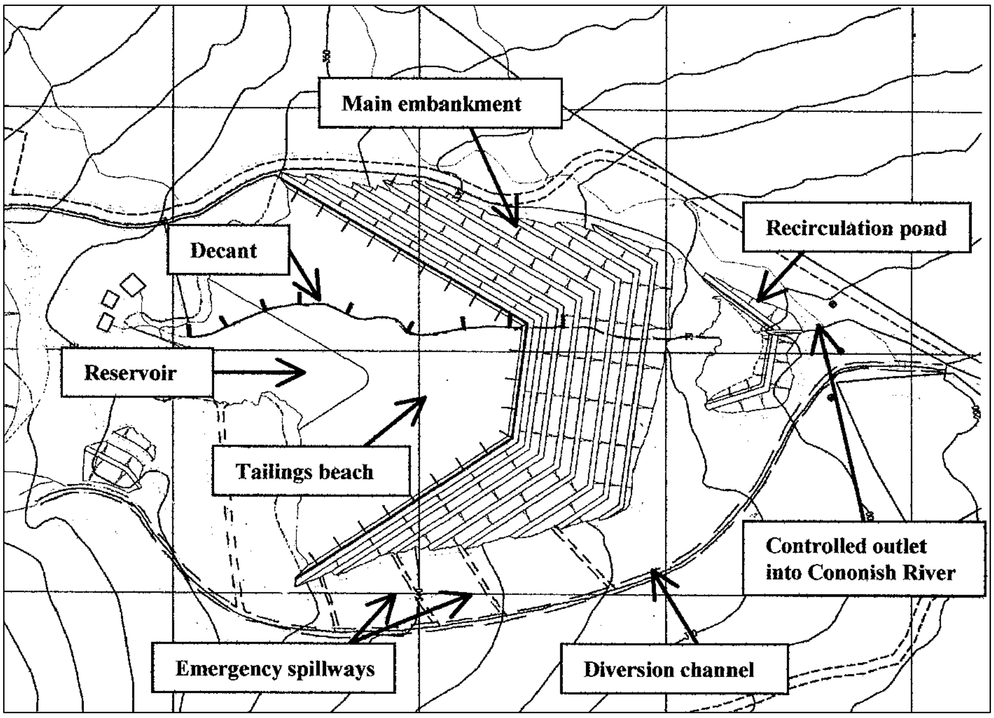

Figure 3. The Cononish Tailings Dam
(Drawing courtesy of AMEC Earth and Environmental Ltd)

Excess water in the TMF is to be discharged via a decant structure into a recirculation pond from where it is to be pumped back to the plant for recycle. However, the water balance for this facility dictates that regular release of process water will be required. Due to the sensitive nature of the receiving waters, the quality and quantity of any discharge must be controlled to ensure that it does not negatively impact on the Cononish River. To address this issue, laboratory testing has been undertaken in order to generate quality data for the resulting process water. These data have been used to assess the volume and rate at which discharge from the TMF into the stream can be achieved without detriment. The analyses of the water balance and of the water chemistry have led to the development of an electronic control system for all operational discharges from the facility.

SEPA has set limitations on normal discharges from the recirculation pond, with no discharge at extreme low flows and a minimum dilution ratio above this level. The project has therefore already been permitted on the basis of automatic control of outflows using electronically controlled valves located in a gauging station on the Cononish River immediately above the receiving point. This station will include a series of stream-flow measurement devices which will be linked via a telemetry system to the recirculation pond control valves. When flow drops to the lower limit the valve will shut automatically to prevent any discharge. At other times the operation of the valve will be controlled electronically to achieve the necessary dilution in the river. It is noted that for safety reasons the valve will be fitted with a default closure device, preventing any untoward discharges.

Blakedon Hollow Tailings Dam, Derbyshire

Glebe Mines Ltd (GML) operates the fluorspar mining and processing facilities at Cavendish Mill in northern Derbyshire, with which are associated a number of tailings management facilities. The current disposal facility, Blakedon Hollow Tailings Dam (TD4), stores both solid residues from the process operations on the site as well as all excess process waters and runoff. The main valley dam was constructed in 1978 and was subsequently modified between 2006 and 2009 to meet updated hydrology and safety requirements.

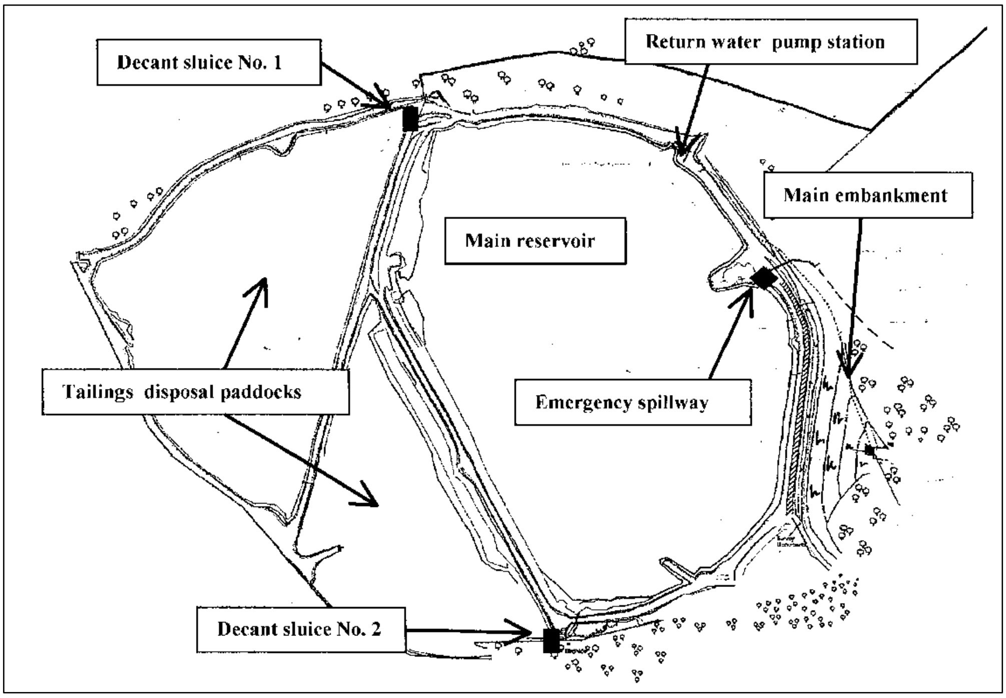

Figure 4. Blakedon Hollow Tailings Dam
(Drawing courtesy of Glebe Mines Ltd)

Unlike both the CVTD and the Cononish Dam, this main embankment was constructed in a single phase from mine waste rock and is some 30m in height, with a total crest length of approximately 500m. The permit for this facility requires it to be operated as a "zero controlled release" reservoir with no permitted discharge. However, the TMF includes an emergency spillway constructed on the left abutment of the main embankment to provide discharge capacity in an extreme event and to prevent the dam from being overtopped. Under all operating conditions, all process water and excess runoff is returned to the plant via a floating pump located in a fixed bay on the northern side of the reservoir.

The facility, though essentially non-impounding, has a small but significant direct catchment and receives runoff from the adjacent slopes as well as process water feed. The hydrology of the facility has recently been reviewed in order to confirm the adequacy of the existing spillway and freeboard. The updated hydrology, together with the need for safe access along the crest, led to the construction of a new wave wall and upgrading of the emergency spillway. As the TMF is a "zero controlled release" facility the original spillway was designed to cater for the extreme event but not to operate, i.e. the design flood was intended to be retained within the reservoir basin with no discharge over the overflow facility. The operating parameters adopted at other UK TMFs were cited as a precedent for the modification of the flood management structure on this site. The emergency spillway was upgraded to pass the PMF in safety and the operating rules modified such that all flood inflows with a return period of 1000 years or less were retained. The operating levels in the reservoir are now controlled with advisory-, emergency- and maximum-level indicators installed, the latter being set to retain the 1000 year flood event without spilling. The company manages reservoir operation on the basis of plant standby at the advisory level, and shut down at the emergency level, thus preventing further input of water, other than from direct runoff, and any untoward discharge over the spillway.

CONCLUSIONS

In the UK, most tailings dams would be placed in the highest risk category, i.e. Dam Category A, due to the implications of an untoward release for both life and the environment in the downstream catchment. A TMF therefore requires hydrological assessment and the definition of the necessary flood standards by a suitably qualified civil engineer. This design aspect has recently been reinforced by EU Legislation, which defines the relevant flood standard for all "Category A" mine waste facilities to be the PMF.

The hydrology of a TMF is complicated by the design and operational parameters which often require staged dam construction and provision of flood control measures at each storage level. In addition, as TMFs contain both solid tailings and process waters, discharge of effluents into river courses is controlled and often not permitted. Thus flood control measures require special attention if the facility is to be safe, stable and fully compliant with its permitting conditions.

The discharge consents for a TMF have resulted in the past in extremely onerous flood provisions, i.e. the retention of the PMF within the reservoir basin at each stage throughout its operating life. This has led to the maintenance of uneconomical freeboard at a number of sites in order to ensure that no discharge occurs. Alternatively, the lack of emergency spillway capacity has, at several well-publicised facilities outside the UK, resulted in disastrous outcomes in the past twenty years. The particular circumstances associated with the operation and construction of a TMF require that a more pragmatic approach to flood management be adopted without any compromise on safety. This has led to the development with UK regulators of the principle of permitting any flood with a return period in excess of 1000 years to be discharged via the emergency spillway and addresses the previously over-conservative nature of flood provision on these facilities. This design approach ensures the safety of the TMF, prevents overtopping and ensures environmental compliance by limiting discharges to periods when the dilution would be significant and any overflow via the spillway would add negligible contributory volume to any flooding downstream.

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