Tailings System Safety Review for the Quirke Tailings Management Area in Elliot Lake

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Abstract

Rio Algom Limited's Quirke Tailings Management Area in Elliot Lake contains 46 million tonnes of low-level radioactive, acid-generating tailings. Rehabilitation of the tailings area began soon after mining ceased in 1990. Since 1995, the 192 ha tailings area has been successfully flooded under a series of terraced cells. This provides a permanent water cover over the tailings to inhibit acid generation . The facility has been designed to safely contain the tailings for the long term with on-going maintenance provided to ensure that the containment structures continue to function as intended in accordance with the decommissioning plan.

This paper describes a comprehensive tailings safety review for the facility along with the care, maintenance and surveillance program and discusses potential consequences associated with extreme disruptive events such as floods and earthquakes. The tailings safety review was broad based and focused on the performance of the tailings system as well as the individual structures. The intent of the review was to confirm that the facility had been designed, constructed and managed in accordance with acceptable standards. Where applicable, the review was based on Dam Safety Guidelines proposed by the Canadian Dam Association.

The eight perimeter containment dams at the Quirke Tailings Management Area are zoned earthfill embankments on competent foundations. The internal dykes are rockfill or tailings structures with a low permeability cap of till founded on tailings. As such they are more susceptible to damage from earthquake and flood loadings than the perimeter dams. However, the result of a dam break analysis for the dyke system demonstrated that there is a low probability of failure and that the release of water over the 1,000 year assessment period would have a limited environmental impact. Modification of the internal drainage system was subsequently completed to further reduce the risk of dyke failure.

The flooded tailings facility is stable and performing well. The existing care, maintenance and monitoring program is described. A tailings safety review will be carried out periodically as part of the due diligence process for dam safety evaluation.Introduction

This paper discusses the results of a Tailing Safety Review for the Quirke Tailings Management Area (TMA) in Elliot Lake, Ontario. The review, which was conducted by Golder Associates Ltd. (Golder) in conjunction with Cumming Cockburn Limited (CCL) between 1998 and 1999, provided a number of recommendations to enhance the performance of the facility and to address specific concerns for safety and long-term management.

The Quirke TMA contains a total of 46 million tonnes of acid generating uranium tailings and waste rock. Mining operations ceased in 1990 and since 1996 the tailings have been flooded under a shallow water cover. The deposited tailings (Figure 1) are contained within five flooded internal cells with an average difference in operating level between adjoining cells of 3.5 m. Drainage is provided via spillways on the internal dykes. Figure 2 schematically illustrates the west to east tailings profile of the deposited tailings. The effluent is treated with lime and barium chloride and is discharged into a series of settling ponds and ultimately to the Serpent River.

There are eight (8) low permeability, zoned earthfill dams around the perimeter of the TMA (Figure 1) and two (2) fresh water diversion

dams. The internal cells are retained by four engineered dykes.

The Tailings Safety Review was part of Rio Algom's due diligence process for environmental protection for their mining facilities. The intent of the review was to undertake a full, re-assessment of the Quirke TMA from design principles and criteria, through design, construction, operations and decommissioning, focusing on the long-term risk and dam safety aspects. The protocol of the review was, where applicable, in accordance with the Dam Safety Guidelines (CDA, 1999).

The objectives of the review were threefold: 1) to confirm the facility had been designed, constructed and managed in accordance with the state-of-the-practice standards; 2) to evaluate the performance of the facility to date; and, 3) through an assessment of the potential failure modes for dykes and dams, to identify improvements to the tailings system which may minimize such risks and impacts.

Review Process

The review team of Golder and CCL (Review Team) was responsible for the design of the TMA dating back to the late 1970's. Rio Algom appointed an external technical review panel comprising Dr. N. R. Morgenstern (University of Alberta) and Mr. H. L. MacPhie (SNC-Lavalin), to assist in the review process and to provide an independent opinion on key issues relating to dam safety and long-term performance. Rio Algom also set up an internal review group consisting of Maxine Wiber and Roger Payne.

The Review Team, the external review panel members and representatives from Rio Algom visited the Quirke TMA and interviewed the site staff. The external review panel issued an independent report to Rio Algom in May 1999 (Morgenstern and MacPhie 1999).

Components of Review

The review focused on the physical stability of the facility, emphasizing long-term performance of the tailings system as well as the adequacy of the individual structures. It included a "Dam Safety Review", which was based, in principle, on the Dam Safety Guidelines (CDA 1999), and an assessment of dyke failure risks and impacts.

The process consisted of:

- a review of historical data on dam design and construction;
- an evaluation of dam and system performance to date; and,
- a review of management practices for the facility including emergency preparedness provisions.

Design Aspects

The design criteria evolved over the years and the prediction of extreme design events also changed. The site seismicity was re-assessed by Atkinson (1992). The design bases were reviewed in light of the new data and the as-built configuration.

The dam design storm event is the Probable Maximum Precipitation (PMP) which is the 12 hour event producing a total of 424 mm of rain. Rainfall plus snowmelt design conditions are predicted to be less critical. The use of the PMP event, as the inflow design flood, was reaffirmed.

Following construction, culverts had to be added to the invert of the internal spillways to maintain the design pond levels. The flood routing analysis was updated as part of the review to confirm that they continue to have the capacity to convey the inflow design flood.

All of the perimeter dams are zoned embankments with low-permeability (glacial till) central cores. Figure 3 shows a typical perimeter dam cross-section (Dam K1). The dam shells are constructed of granular materials. The internal dykes were constructed over old rockfill dykes founded on tailings. They are designed to retain tailings and to reduce seepage through the dyke.

The design seismic event is the 1000-year return earthquake, which was originally predicted in 1979 to have a peak ground acceleration of 0.03 g. The peak ground acceleration for this event was subsequently revised by the

Geological Survey of Canada to 0.05 g in 1990. In addition, the dynamic stability of the containment structures was confirmed for the 0.065 g "maximum credible earthquake" event (Western Geophysical Research 1977). More recently Atkinson, (1992, 2001) suggested that earthquakes with greater intensity could occur. This led to an in-depth reassessment of the stability of the Main Dam (Golder 1996, 2001). It was concluded that the Quirke dams would remain stable with no loss of containment for the 10,000 year return earthquake.

The geotechnical design criteria were found to meet the Dam Safety Guidelines (CDA 1999).

Piezometers have been installed on all of the dams and dykes to verify the design assumptions regarding porewater pressure and to monitor future fluctuations.

Permanent settlement points have been installed on the crests of the dykes for long-term monitoring purposes. Provisions have been made in the monitoring program to detect dyke settlement and to remediate as required to ensure the dyke freeboard is maintained. Reference station markers, at 60 m intervals, have been provided on the dykes.

Construction

All of the Quirke dams and dykes were constructed under the full time supervision of technical staff whose roles included:

- performing QA/QC on construction;
- providing technical directions with regards to field design modifications;
- evaluating and directing construction, e.g. bedrock grouting program;
- conducting investigations and collecting data for the preparation of as-built records; and,
- monitoring progress and assisting in contractual matters.

Routine quality control testing consisted of compaction and material quality control. The test results confirmed that the embankments were constructed in compliance with the design intent. The test protocol was found to be in accordance with good practice for similar work.

A total of 33,700 m of bedrock was drilled and grouted beneath the perimeter dams. The grouting effort was found to be strongly influenced by the geological conditions. In all cases, satisfactory closure of the grout curtain was achieved.

The dams and dykes were constructed substantially in accordance with the design. Minor design modifications were made during construction to suit actual site conditions and to accommodate the construction equipment being used. These changes are discussed in the as-built documents.

Management Practices

At the time of the review, Mine Waste Management Inc. (MWM), on behalf of Rio Algom, was responsible for the day-to-day management of Quirke TMA. MWM operated the treatment plant, conducted environmental sampling and compliance testing, carried out care and maintenance of the facility, managed data and prepared the monitoring reports. The program involved routine inspections and instrumentation monitoring complemented by an annual inspection by a qualified professional engineer.

Rio Algom and MWM had developed a protocol for routine inspection, reporting, internal review and follow-up action. A specialized data management system had been established to archive and validate data, set action limits and schedule routine monitoring, testing and maintenance activities.

During the tailings safety review, MWM suggested clear guidelines/action limits for monitoring data could be set by the design engineer which would enable the "management contractor" to alert the Engineer and the Owner at an early stage should data be obtained outside the anticipated range.

The Emergency Preparedness Plan (EPP) was reviewed. This plan contained the following components:

- an identification of credible failure scenarios,
- an outline of potential mitigation measures, and
- spill response and notification procedures.

The Review Team and the external technical panel considered that additional information was required in several areas:

- *Identification of situations which constitute an emergency*

The use of a trigger mechanism should be considered to alert the engineer of potential problems. Trigger mechanisms could include changes in piezometric levels, movements and seepage rates. The facility should be inspected following adverse weather or seismic events. Guidelines for identifying and reporting dam incidents, e.g. NPDP (1997), could be adopted.

- *Downstream Impacts*

Knowledge of the likely failure mechanisms and specific procedures which could be undertaken to mitigate such events is crucial to better manage the consequences. The external review panel suggested that the EPP should consider in more detail the implications of a failure of a perimeter dam.

- *Specific Action Plan*

The review highlighted specific procedures to deal with spills from the TMA. This information should be included in the EPP.

Performance of facility

Facility performance was evaluated based on a review of the historical instrumentation and operational data and the results of a visual inspection.

The Quirke TMA has required very little maintenance. Routine maintenance consists of removal of debris and beaver blockages from channels, road grading, snow removal and occasional clearing of vegetation on dams. The containment dams have remained stable with no reports of incidents that required intervention.

The observed piezometric water levels are stable and consistent with the assumptions made during the design . Typical pore water condition in a dam founded on bedrock is shown on Figure 4.

Soon after the initial filling in 1996, several small sinkholes developed upstream of Dykes 14 and 15. The sink holes were immediately plugged with glacial till. The relatively high seepage gradient and migration of fines from the till blanket were considered to be the likely causes of these sinkholes. Glacial till berms, extending some 10 m upstream from the dyke crest were subsequently placed to lengthen the seepage pathway. No further problems were reported since berm construction in 1997.

During the site visit a longitudinal crack was noted along the centreline of Dyke 16. A subsequent investigation suggested that the crack was caused by frost with no detrimental effects to dam performance. A similar frost crack was also observed on Dyke 14 in 1993.

Minor crest settlement was noted on Dyke 15 in 1997. The dyke crest was restored in 1999.

The internal spillway system has been functioning well with no incidents of beaver activity, blockage or high water that might threaten dyke stability.

- *Long Term Performance*

  - Internal Drainage

A concern is the potential change in the drainage characteristics of the dams and foundations as a result of chemical precipitation or solution. No deterioration has been observed to date. Changes in dam drainage will be detected by changes in piezometric levels and seepage rates.

  - Grout and Concrete

All of the dam foundations were treated with grout or concrete prepared with sulphate resistant cement (CSA type 50) for maximum durability.

- Slurry Cut-off Trench

The Main Dam has a slurry trench for seepage control in its foundation. The slurry trench is performing satisfactorily. Testing showed that the soil-bentonite mix would not be substantially affected by the acidic groundwater. As the insitu hydraulic conductivity of the slurry trench backfill is between 1 and 2 orders of magnitude lower than the design value, it is expected that the slurry trench will remain effective even if some deterioration of the bentonite material occurs.

Failure Risks and Consequences

In 1991 a probability based risk assessment was carried out for the Quirke TMA (Welch et al 1997). The analysis was based on integrating the impacts of maintenance, earthquake, flood and drought. A fully maintained facility and a no maintenance scenario were evaluated. The analysis clearly showed that for a fully maintained facility the risk of failure is relatively small. This has been the guiding principal for the management of the facility.

Although the containment structures have been designed and constructed to meet current stability requirements, extreme disruptive events could occur and damage the tailings system.

The Quirke TMA dams, by design, are more robust than the internal dykes that are founded on tailings. The primary causes for dam failure are earthquakes and undetected defects. The stability of an internal dyke could be adversely affected by earthquakes, floods and undetected defects. In addition, a sudden release of pond storage due to the failure of one or more dykes during an extreme event could cause the downstream dykes to fail. However, unless dyke failure is accompanied by a breach of a perimeter dam, there will, be no massive flow of tailings. Any such failure and resultant spill however would likely impact the east end of the TMA and the Serpent River.

The National Weather Service Model (NWS) DAMBRK was used to simulate the dyke breach process and to predict the consequences associated with various failure scenarios. The analysis involved:

- Selection and application of an appropriate hydraulic model
- Identification of failure modes
- Simulation of various system failure modes
- Identifications of measures which could be undertaken to minimize the failure consequences.

The analysis showed that Dams G1 and G2, located at the east end of the TMA, would likely be overtopped should one or more of the internal dykes fail. It was recommended that these dams be raised and reinforced, and an auxiliary spillway be added on each of the internal dykes.

Recommendations and Follow-up Actions

No structural deficiencies were identified for any of the containment structures in the review. Key recommendations offered by the Review Team and the external review panel, and follow-up actions undertaken, are summarized below:

➢ *Dams and Dykes*

- As recommended by the external review panel the subsurface conditions downstream of the Main Dam have been confirmed and the seismic stability has been reassessed based on this data
- The longitudinal cracklines on dykes have been investigated and repaired.
- Dams G1 and G2 have been upgraded and an auxiliary spillway provided on each of the internal dykes.

➢ *Emergency Preparedness Plan*

- The review identified specific procedures to deal with a spill at the east end of the Quirke TMA.
- Guidelines have been developed to identify situations for actions, e.g. intensity of storm, which warrants additional inspections.

- A dam break analysis is currently underway to determine the extent of the downstream flood inundation.

➢ *Operations*

- Trigger levels for actions have been established for the interpretation of geotechnical instrumentation data and follow-up action.

➢ *On-going Review*

- It was recommended that as part of the annual inspection an engineer should also review the maintenance, monitoring and other operational data, which may have safety implications.

➢ *Data Archiving*

- Key information should be preserved for future generations. A data archiving protocol is being established to maintain records for the long term.

Discussions

The Quirke TMA has reasonable and acceptably low failure risks. All of the component structures have been designed to standards that continue to meet current industry requirements for such a facility. The tailings system has performed adequately since closure. Its well being, is dependent on a comprehensive care, maintenance and surveillance program.

There is a high confidence level that the perimeter dams will continue to function well, given the long period of service for these structures.

There is a greater degree of uncertainty in the performance of the dykes because of the variability of the foundation conditions. Some minor problems were noted on some of the internal dykes during initial filling. Remediation work completed at that time has been successful. The dykes however, are susceptible to damage by extreme disruptive events

The internal drainage system has been upgraded to reduce the risk of flood damage and to minimize the potential for adverse downstream impacts. The enhanced flood handling capacity has provided an additional safeguard against the potential operational deficiencies and potentially reduced the need for future upgrading due to changing design criteria.

The Tailings Safety Review contained all required components of a dam safety review. The review was carried out by the design engineer with an independent review provided by a technical review panel. This model was considered to be a sensible and reasonable approach given the vast amount of background information that had to be collected and assimilated. The principal authors of the review report had not involved with the original planning and design of most of the dams.

A comprehensive review of the tailings system is crucial to identify and manage the risks of failure. Design standards have evolved, typically becoming more stringent. For critical installations, some over design may be appropriate.

The Review Team and the external review panel emphasized the need to preserve vital information such as:

- design and construction records,
- results of on-going inspections,
- instrumentation and monitoring data,
- maintenance and repair records, and
- performance assessment.

It is recommended that an independent data archiving centre be created to maintain permanent records and to ensure that these records are available for future use.

Conclusions

The Quirke TMA is performing as intended. The review did not identify any deficiencies that had immediate safety implications. The Quirke TMA satisfies the current CDA Guidelines for safe design, construction and operations for similar facility. There is a comprehensive care, maintenance and monitoring program in place to ensure that the facility will remain in good operating condition in the long term.

The probability and the consequence of failure are low. The likely failure mode is expected to be the internal dyke system due to extreme disruptive events. The spillways and dams upgrading program reduces the probability of dyke failure risks and their consequences.

The need to maintain key information for future generations is critical for a facility that must remain serviceable in perpetuity.

The reviewers recommended that a comprehensive review of the tailings system should be carried out at a maximum interval not exceeding 10 years.

Emergency response procedures are available to deal with unforeseen situations including poor environmental performance. Additional recommendations have been provided to mitigate the impact of spills and to identify situations for emergency response.

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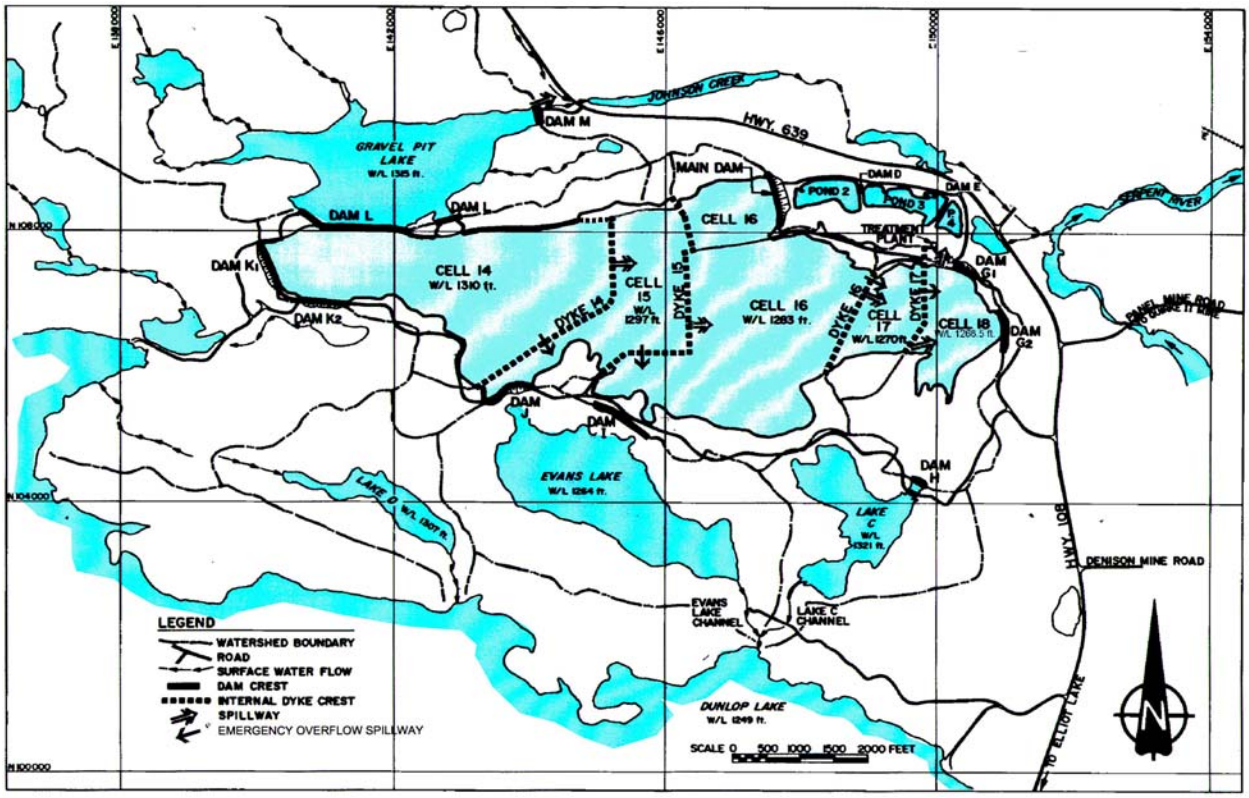
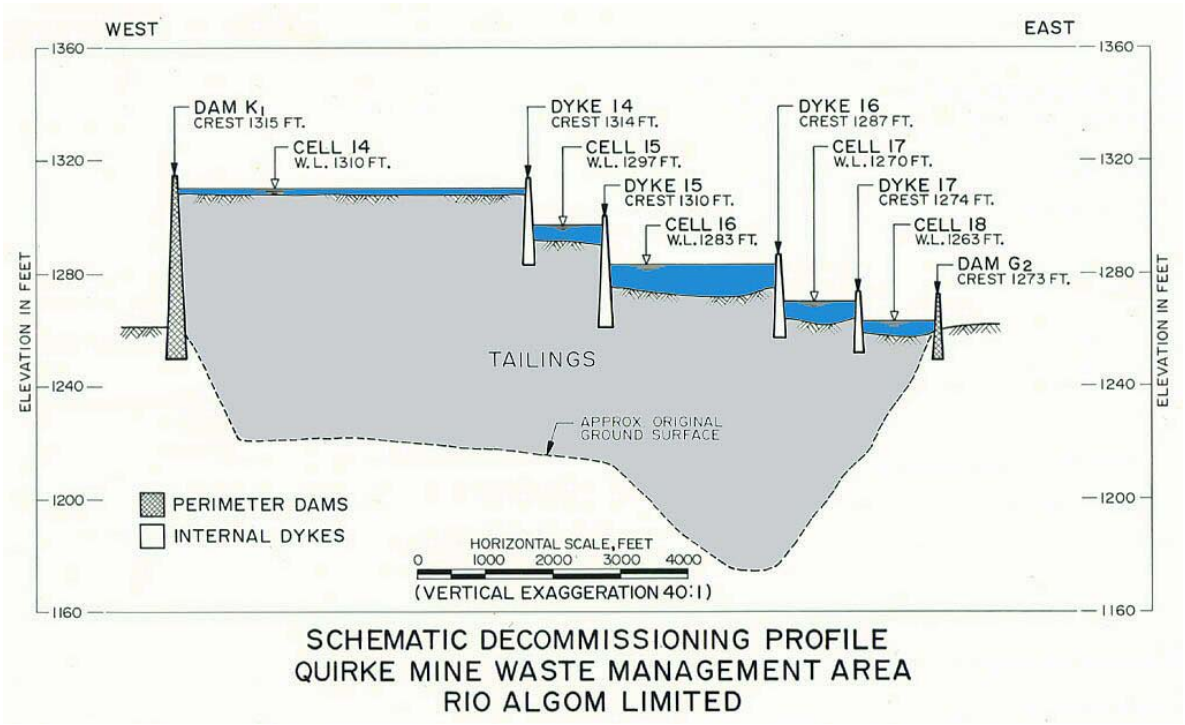


Figure 1 Quirke TMA General Arrangement



SCHEMATIC DECOMMISSIONING PROFILE
QUIRKE MINE WASTE MANAGEMENT AREA
RIO ALGOM LIMITED

Figure 2 Schematic Profile, Quirke TMA

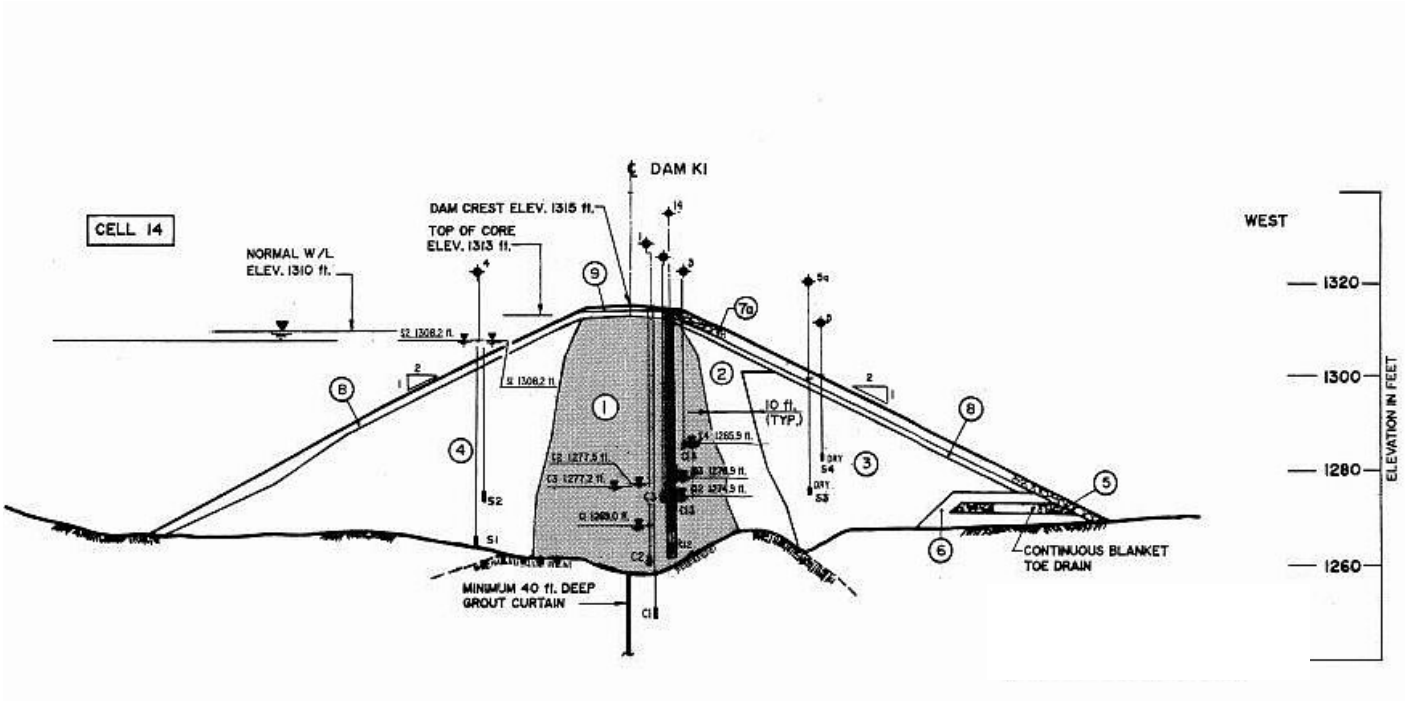


Figure 3. Typical Dam Cross Section, Dam K1.

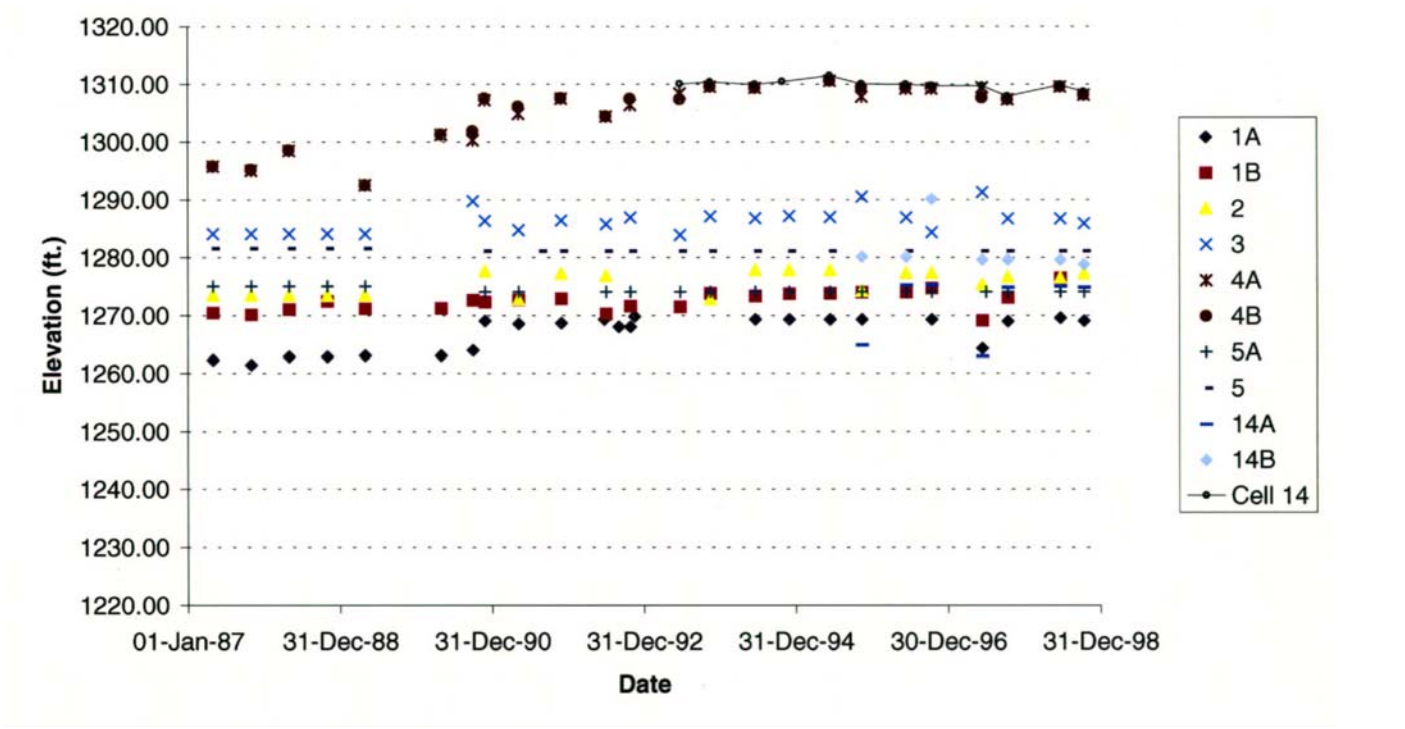


Figure 4. Piezometric Water Levels, Dam K1