CASE STUDIES ON

TAILINGS MANAGEMENT

INTERNATIONAL COUNCIL
ON METALS AND THE ENVIRONMENT

UNEP
United Nations Environment Programme

The International Council on Metals and the Environment

Founded in 1991, the International Council on Metals and the Environment (ICME) is a non-governmental organization that promotes the development and implementation of sound environmental and health policies and practices in the production, use, recycling and disposal of non-ferrous and precious metals.

These case studies have been published by ICME as part of a series of publications providing information on environmental and health matters relating to the metals mining and producing industry. The contents of ICME publications range from general and technical information about these topics to discussions of issues relevant to environmental and/or health-related policies affecting the mining and metals sector. It is believed that the topics examined are of concern not only to the industry, but also to others, including policy makers, regulators, educators and the public at large. ICME hopes that these publications provide insight into what are sometimes difficult and complex issues.

In addition to its publications, ICME has an extensive information program which includes a Web site and a quarterly newsletter with a worldwide distribution.

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1) Encourage the incorporation of environmental criteria in industrial development plans;
2) Facilitate the implementation of procedures and principles for the protection of the environment;
3) Promote the use of safe and clean technologies;
4) Stimulate the exchange of information and experience throughout the world.

UNEP IE provides access to practical information and develops cooperative on-site action and information exchange backed by regular follow-up and assessment. To promote the transfer of information and the sharing of knowledge and experience, UNEP IE has developed three complementary tools: technical reviews and guidelines; *Industry and Environment*—a quarterly review; and a technical query-response service. In keeping with its emphasis on technical cooperation, UNEP IE facilitates technology transfer and the implemenation of practices to safeguard the environment through promoting awareness and interaction, training and diagnostic studies.

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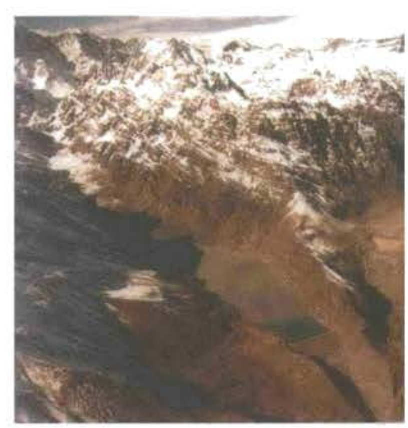


Foreword

Tailings disposal is an integral part of mining operations throughout the world. The processing of ore to produce a concentrate, from which metals such as copper, nickel, zinc and gold are recovered, results in residual mineral wastes that require containment. Such wastes are known as tailings and are generally contained in impoundments.

Tailings continue to concern the industry as well as regulators and the general public due to several highly newsworthy tailings dam failures. Several such failures have arisen from unexpected natural events, while others seem to be related to a deficiency in some aspect of the tailings life cycle. The mining industry strives to minimize human error in tailings disposal systems through improved technology and management practices.

The Environmental Protection Working Group on Mining and Metallurgy, a joint initiative of the International Council on Metals and the Environment (ICME) and the United Nations Environment Programme (UNEP), has identified tailings issues as one of the key challenges to achieving improvements in environmental performance. One of the main mechanisms identified by the Working Group is an expanded information exchange using workshops and publications to promote good environmental practices.

In 1996, ICME and UNEP published the booklet *Case Studies Illustrating Environmental Practices in Mining and Metallurgical Processes*. In 1997, ICME and UNEP, in collaboration with the Swedish International Development Cooperation Agency (SIDA), hosted the "International Workshop on Managing the Risks of Tailings Disposal" in Stockholm, of which proceedings have been published. A subsequent workshop on Risk Assessment and Contingency Planning was organized in November 1998 in Buenos Aires, Argentina.

This current publication is a collection of case studies prepared by technical experts throughout the industry to illustrate the sophistication of approaches used in managing the risks of tailings systems. The publication also provides an overview describing tailings, the main concerns and issues relating to them, and how they are managed by industry. Each case study provides a brief description of the approach used to address a specific aspect of tailings management.

The purpose of this booklet is to enhance understanding of tailings management and to demonstrate how the mining industry is managing the risks associated with tailings disposal. It is aimed at people who work within the mining community, at officials who regulate the industry and at other stakeholders, such as those who live in the vicinity of mining operations.

Gary Nash
Secretary General
ICME

Introduction

With the cooperation of a large number of experts, ICME has compiled this collection of case studies of tailings management practices in operations in many parts of the world. The first section provides the reader with an overview on tailings and the issues that need to be addressed in all stages of the life cycle of tailings. This section is followed by 21 case studies illustrating the specific components of management of tailings from planning through to closure. The cases are mainly presented in a two-page format in order to provide the reader with a quick appreciation of particular challenges and the means used to manage them. Each case study includes the name and address of a individual or individuals whom readers are encouraged to contact for additional information.

Readers may note that the terminology may vary somewhat. For example, the terms *tailings dams*, *tailings embankments*, *tailings impoundment systems*, *tailings storage systems* and *tailings management areas* are used throughout the text and may seem to be synonymous, but each has a distinct and specific meaning within the industry. For clarity, the editors have tried to minimize confusion over such terms. A glossary of common terms is provided, as well as a list of references that may prove useful to individual readers wishing to learn more about the management of tailings.

A Management Perspective

Henry Brehaut, *Sustainability Consultant, Placer Dome Inc., Canada*

The challenge to the mining industry is to assure itself, governments, local communities and other stakeholders that it is capable of meeting its responsibilities to manage tailings deposition in a manner which achieves the highest standards. It is not enough to rely on the fact that the technology is available to ensure all environmental objectives are met. The mining industry must go beyond technical excellence and demonstrate that it has the commitment, and the management systems and skills, to be able to manage tailings in keeping with the expectations of its stakeholders.

PUBLIC TRUST

The mining industry must recognize that public trust is an essential requirement if mines are to be permitted and operated for the benefit of all stakeholders. Governments are striving to balance their resources to govern with their ability to rely on corporate responsibility. Public stakeholders demand an understanding of the standards being employed at each stage of tailings management and seek the opportunity to satisfy themselves that their expectations are being met. To achieve the full trust of stakeholders, the mining industry has to have credibility in delivering its message.

Public trust can be achieved within a framework of effective laws and regulations, industry guidelines, corporate responsibility and corporate accountability. No one element in itself will achieve the desired result, but together these factors can be mutually reinforcing, leading to a better overall result.

Industry must also engage stakeholders in a process of consultation. Public concerns must be identified and considered in planning activities during all stages and system performance must be verified in a transparent manner. In this way, the mining industry will be able to satisfy stakeholders by responding to their concerns and by demonstrating a commitment to high standards.

The key to an effective system is industry leadership in establishing comprehensive management guidelines. By bringing together best practices around the world, a framework can be developed and used to establish higher standards of performance. All companies, large and small, will benefit from collective experience, and governments and the public will have credible measures to judge individual situations.

THE KEY TO AN EFFECTIVE SYSTEM IS INDUSTRY LEADERSHIP IN ESTABLISHING COMPREHENSIVE MANAGEMENT GUIDELINES.

The Mining Association of Canada has made an excellent start in this direction by publishing *A Guide to the Management of Tailings Facilities*, which is featured in this publication. This guide was prepared through the cooperative efforts of several of its member companies and is designed to assist all companies in the responsible management of their tailings facilities. It covers each stage of tailings management from design through construction, operation and then closure and reinforces the integrated nature of each element. Once the guide has been tested, it could be adapted to a set of international guidelines.

MANAGEMENT SYSTEMS

The key to high standards, however, still rests with diligent application by individual companies. Stated commitment and sincere intent are insufficient in themselves. Companies must implement comprehensive management systems to ensure that the requirements for a job well done are determined, documented and carried out every time.

Management systems work best within the total quality perspective provided by the ISO 9000 and ISO 14000 international standards. In particular, the ISO 14001 environmental management systems provide the necessary framework to establish objectives, responsibilities, plans and other activities for all stages of tailings management from design through closure and for the multitude of activities within each phase. While certification under the ISO standard is not a prerequisite to effective tailings management, it provides an excellent framework and the credibility of an internationally approved standard.

The key requirements of an effective management system are that responsibilities be assigned, environmental objectives be defined, detailed plans or programs be prepared and conformance with the plans be verified. At the design stage, environmental objectives must be established with regard to water management, the prevention of acid rock drainage, structural integrity, groundwater protection, seepage control, pipeline spill control, effluent standards, and wildlife and dust control.

At the operating stage, the list of issues expands to include solids and water management, and contingency and emergency planning. Objectives must be defined for each issue within an operating perspective and operating plans developed and documented. The plans should include operating procedures, monitoring and inspection programs, reporting requirements, individual responsibilities, and competency and training needs.

Responsibilities need to be defined for a wide range of individuals representing operating, maintenance, environmental and other disciplines. A tailings management plan is a prerequisite for establishing individual duties in job descriptions and training manuals. It also ensures that inspection and monitoring programs are adequate and that a clearly understood reporting system exists so that all activities are carried out on a consistent basis.

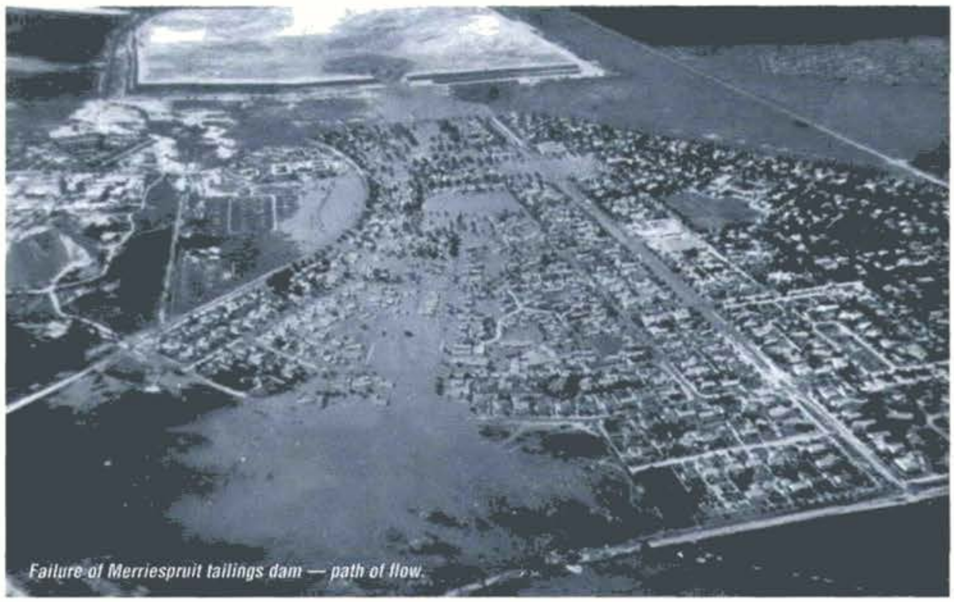
CONCLUSIONS

By committing to best practice guidelines, comprehensive management systems and public accountability, the mining industry will be able to illustrate its commitment through credible programs and demonstrated performance. Such programs will also provide the basis for a refinement of regulatory systems. If industry accepts its responsibilities, regulatory authorities can consider more effective approaches to the benefit of all concerned. The solution to public acceptance and higher performance standards lies in an integrated approach led by the industry itself.

The Need for Dam Safety

Dr. A. D. M. Penman, *Chairman, ICOLD Committee on Tailings Dams and Waste Lagoons, UNITED KINGDOM*

Mankind has been building dams for many thousands of years, and through experience has improved their design. The heights of dams have slowly increased, enabling large volumes of water to be stored. Some water dams have failed, however, and two examples follow.


Failure of Merriespruit tailings dam — path of flow.

- The 45.7 m high Estrocho de Rientes built in Spain between 1755 and 1789, which breached in April 1802, shortly after the reservoir became full for the first time. The town of Lorca was flooded, drowning 600 people.
- The 21.9 m high South Fork dam in Pennsylvania, which was overtopped on May 31, 1889 and breached three and a half hours later. The resulting flood caused the loss of 2209 lives.

During the course of the twentieth century, a number of factors have facilitated the construction of bigger and safer dams to retain water: an improving understanding of the behaviour of materials, new developments in the art and science of soil mechanics, and the introduction of earth-moving machinery of ever-increasing power. Since its formation in 1928, the International Commission on Large Dams (ICOLD) has provided an interchange of experience and the dissemination of research findings which have played an important role in the development of safe dams. Notably, ICOLD's technical committees have provided a great deal of valuable guidance in their numerous bulletins.

The need for tailings dams came long after the need for water-retaining dams and, because the former were built by mining companies themselves, they did not always benefit from existing civil engineering knowledge. Indeed, ICOLD had not considered tailings dams to be worthy of its consideration and when the World Register of Dams was first being compiled (1958–1964), tailings dam were specifically excluded. By the mid-1970s, however, there were many tailings dam more than 100 m high and, following the greater involvement of dam design engineers in the problems of tailings dams, they were included as a subject for discussion by the 12th Congress on Large Dams, held in Mexico City in 1976. So much interest was expressed that ICOLD decided to establish a committee to consider tailings dams, and the Committee on Tailings Dams and Waste Lagoons was born. It has now published nine bulletins, the latest of which is a joint ICOLD-UNEP publication entitled *A Guide to Tailings Dams and Impoundments—Design, construction, use and rehabilitation* (1996).

Tailings dams continue to fail, as the following two examples demonstrate.

- In 1985 a pair of tailings dams in Italy, one situated above the other, collapsed. The released tailings slurry flowed down into the narrow, steep-sided valley of the Rio Stava, initially at a speed of 30 km/h, demolishing much of the nearby small village of Stava. The flow continued on at an increasing speed, estimated to have been 60 km/h, to another small town, Tereso, located about 4 km downstream at the junction of the Rio Stava and Avisio rivers. The only surviving eyewitness, a tourist, had the horrifying experience of watching the disaster from a hillside and saw the hotel where his family were taking lunch being swept away by the torrent of tailings. Because of the density of tailings, the damage caused by a tailings spill is much more extensive than would be the case for a similar volume of water —whereas water can flood a building, tailings can push it over and sweep it along with the flow.

- In South Africa, the Virginia No. 4 tailings dam had been built as a long dam encircling and retaining a 154 h lagoon with 260 million m^3 of gold mine tailings containing cyanide and iron pyrite. The 250-house suburb of Merriespruit had been built near the mine in 1956. The tailings dam was begun in 1974 and a straight section was placed only 320 m away from the nearest houses. The construction of the dam and filling of the impoundment continued until March 1993, when the section of the dam closest to the houses was 31 m high. The summer of 1993–94 in the Orange Free State had been particularly wet and on the night of Tuesday, February 22, 1994 there were violent thunderstorms over Virginia and 50 mm of rain fell in a very short time. During the early evening between 19:00 and 21:00, eyewitnesses saw a solid flow of water going over the crest of the dam above the houses. At about 21:00, there was a sudden collapse and a 50-metre-wide breach formed through the dam, releasing 1.2 million tonnes of tailings that flowed for a distance of 1 960 m. The flow passed through the suburb, where the power of the heavy liquefied tailings demolished everything in its path—houses, walls, street furniture and cars—and carried people and furniture with it. Remarkably, only 17 people were killed.

Today our knowledge of design methods and experience with both embankment dams to retain water and tailings dams are such that safe and environmentally acceptable dams can be built. The failures that occur are due to a lack of adequate application of known methods, bad designs, poor supervision during the prolonged construction, or disregard of vital features that should have been incorporated at certain stages of construction.

An Introduction to Tailings

***A/Professor Richard J. Jewell**, Director, The Australian Centre for Geomechanics, Australia*

WHAT ARE TAILINGS?

Tailings are the waste products generated during the recovery of mineral commodities from ore. Typically, the original rock is crushed or ground to a particle size of less than 0.1 mm in order to release the valuable constituents. Water and small amounts of chemical reagents are usually added during this process to enhance the recovery of the product mineral from the waste.

A typical zinc-lead ore might contain 6% zinc and 3% lead. After the metal concentrates are extracted, about 850 kg of residual solid waste and an equal amount of water containing somewhat less than a kilogram of residual chemicals are generated for every tonne of ore. The term "tailings" is derived from the fact that the process generates a product called concentrate at the top (or "head") and a waste called tailings at the end (or "tail").

Most tailings are in the form of a fine-grained slurry with a solid fraction that behaves like a soil. The principles of soil mechanics are applicable in characterizing tailings and their behaviour, provided due recognition is given to the appropriate consolidation processes, the relevant drainage conditions and the way in which the slurry flows.

Nevertheless, tailings are different from most naturally occurring soils. The density and strength of a body of tailings are initially low and increase relatively slowly with time.

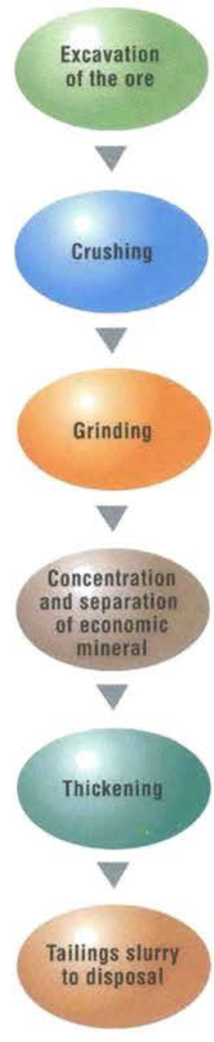


Figure 1.

HOW TAILINGS ARE PRODUCED

The procedures for extracting economic minerals from primary ores vary with the different types of mineral, but there are a number of common steps in the process (as seen in Figure 1). First, the ore is excavated either underground or in open pits and then reduced by crushing and grinding to fine sand, silt and clay-sized particles. Water is added to the grinding process and, in most cases, small amounts of chemicals are added to facilitate the separation and recovery of the economic mineral.

The tailings, along with the spent process water, form a low-density, free-flowing liquid. In order to conserve and reuse the process water and to concentrate the slurry, the tailings are often thickened by a dewatering process to a consistency at which they can be pumped to the tailings storage facility.

GEOTECHNICAL PROPERTIES OF TAILINGS

Hard silicate rocks generally produce angular particles in the sand, silt and even clay-size fractions. As a result, tailings have characteristics more common to granular materials than to clays, regardless of the size of the particles.

Tailings slurries can be pumped at a solids content ranging from 40% to 50%. This is equivalent to a water content of 150% and 100% respectively, which for most soils represents a slurry with fluid properties. The slurry is normally transported to the tailings impoundment area by pipeline, either with the aid of pumps or by force of gravity. The slurry is then distributed by spigots onto the exposed tailings surface ("subaerial" discharge method) or, in a few cases, injected below the water surface ("subaqueous" discharge method). In some circumstances, some of the water is removed from the slurry before the tailings are placed in the impoundment ("thickened discharge"). The slurry is then allowed to settle. The rate at which the solid particles settle is influenced by the discharge method and rate.

The term "consolidation" describes how the particles become more closely packed under the effect of gravity. Consolidation has three benefits: it increases the amount of solids that can be stored in a given volume; it increases the strength of the body of soil as excess water is driven out; and it decreases the extent of seepage that can occur.

When the slurry is discharged onto a tailings dam by sub-aerial disposal, it forms a sloping "beach" from the point of deposition. Under optimum conditions, the coarser fractions of the tailings settle closer to the point of deposition, while finer materials settle further down the beach. The contained water then forms a pool at the bottom of the sloped beach. Consolidation is rapid. Tailings that are thickened by the removal of much of the water before discharge will flow without segregation and produce steeper slopes.

When this process is complete, and some maximum density has been achieved, the upper surface of the tailings may have become partially unsaturated, but the majority will remain saturated. This remaining water is very difficult to remove and is essentially "bound" up with the tailings. Water contents of 20% or more are commonly bound up with the tailings even in very arid environments with high evaporation.

The permeability of tailings is used to estimate the consolidation of, and seepage from, stored tailings. Permeability can vary by two to four orders of magnitude and it is not always possible to predict the lowest permeability. The result of the gravitational segregation of particle size is that the permeability of the tailings is greatest near the point of deposition and progressively lower towards the pool.

OTHER IMPORTANT PROPERTIES

Tailings differ from naturally occurring soils in several respects:

- Many metals occur as sulphide-rich ores, and the tailings from such orebodies may therefore have the potential for acid generation in the presence of oxygen and water.
- In addition to economic metals, orebodies often contain other minerals, e.g. those containing potentially toxic elements such as arsenic. Such situations may require special consideration in tailings dam design and operation.
- Similarly, chemical reagents such as the cyanide used to recover gold are toxic in sufficient concentrations. Salt introduced in saline process water can be toxic to flora. It can also have a significant influence on evaporation processes, which slows down consolidation.

THE CHALLENGE

As a low-strength deposit in a loose, saturated state, tailings are vulnerable to liquefaction due to dynamic forces such as earthquakes. Low-strength tailings can also flow for considerable distances if a breach develops in a confining embankment. The impact on public safety and the environment from an embankment failure or from seepage of contaminants can be disastrous.

The challenge to miners and their geotechnical advisors is to design, construct and operate tailings dams in such a way that they will remain safe and stable into the future and result in minimal impact on the environment.

Construction of Tailings Dams

Professor Geoffrey E. Blight, *Department of Civil Engineering, South Africa*

A unique difference between tailings dams and conventional water-retaining dams, i.e. those built for hydroelectric generation, is that construction of the former is an ongoing process. The size and capacity of a tailings dam expand in conjunction with the mine's production. The embankments are increased in height and breadth to accommodate the increasing volume of wastes generated by the processing of ore. The operation of a tailings impoundment therefore requires continuous construction and attention to all of the factors that can affect its safety.

The outer wall of a tailings dam may be built of material consisting of natural soils, mine overburden, other current mine waste or tailings from a pre-existing tailings deposit. Alternatively, and more commonly, the outer wall is built of current tailings production.

If the tailings comprise a wide range of particle sizes, it is common practice to separate the sand (coarse fraction) from the slimes (fine fraction). The sand is used to build the outer wall or shell of the impoundment, while the slimes are delivered into the body of the impoundment. When the tailings have a narrow range of particle sizes and the fine fraction is not clayey, the total product may be used to build the outer wall. Since the object of a tailings dam is to retain solids, not water, the embankments are usually designed to be as pervious as possible.

The geometry of a tailings dam depends on the topography of its site. In hilly or mountainous country, damming a valley to form a valley impoundment may be the best solution (Figure 1). On flat terrain, a circular wall called a ring-dike impoundment may contain the tailings (Figure 2).

Figure 1.

Figure 2.

ENVIRONMENTAL CONSIDERATIONS

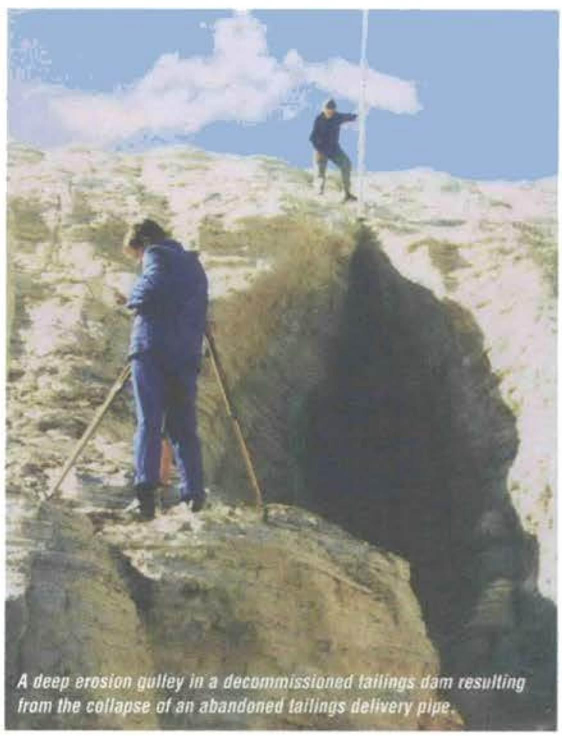
Good environmental practice requires that any water originating in water bodies outside of the tailings area not become contaminated by contact with the tailings. A surface-water diversion system must be designed and constructed to ensure this. Similarly, all water falling within the containment area must be retained therein. Because tailings material will inevitably be lost by erosion from the slopes of tailings dams, provision should be made to catch the lost material at the toe of the dam by means of silt-catchment paddocks or traps.

Depending on climatic and operating conditions, tailings storage systems may generate either a water surplus or deficit. In the case of a surplus, excess water must be discharged periodically into an adjacent water body (river, lake or sea). The discharge must meet acceptable quality standards and, in many cases, must be treated to remove deleterious or toxic substances. If there is a deficit, special construction methods can conserve water and maximize its return to the process. These methods include dewatering the tailings before disposal or co-disposing the fine tailings with coarser waste. Both of these old technologies have recently regained popularity as a result of advances in dewatering technology.

In addition, depending on geological conditions and process characteristics, it may be necessary to provide the tailings dam with an impervious liner. This liner may be constructed of clay or plastic and designed to contain seepage from the tailings completely.

Finally, the dam wall should be designed to be stable at all stages of operation, from first commissioning until closure. The wall must be stable against shear or landslide-type failures and those caused by overtopping of the wall, gully erosion and tunnelling (or piping) erosion. Conventionally, designers ensure shear stability under gravity and seismic forces by incorporating a factor of safety (usually 1.3). Overtopping is prevented by maintaining a minimum freeboard of 0.5 to 1 m on the dam wall under an adverse set of assumed conditions. More recently, the technique of risk analysis has been applied to estimate the risk of failure of any component of a tailings dam and the consequences of such a failure (ICME/UNEP, 1997).


A shear failure of the wall of a ring dike resulting from too rapid a rate of rise.


A deep erosion gulley in a decommissioned tailings dam resulting from the collapse of an abandoned tailings delivery pipe.

FLEXIBLE DESIGN

Because the construction of a tailings dam is an ongoing process, the design must be subject to continuous examination and confirmation during the early period of operation, and to periodic review thereafter. In most cases, tailings dams are designed before the first tailings have been produced, or when only samples from a pilot-scale metallurgical process are available. These samples are often not representative of the tailings that will eventually be produced from the full-scale plant. Furthermore, operational variability may change the characteristics of the tailings. Hence, the "final" design on which the preliminary works for the tailings dam is based is only provisional, and must be confirmed once tailings production is under way.

Requirements for quality assurance may vary from country to country but, at the very least, should include a daily recording of the:

- consistency (water content) and particle size distribution of the incoming tailings;
- rainfall and evaporation;
- freeboard on the dam wall, or water level over the spillway shaft or decant; and
- quantity of tailings deposited on the dam and the volumes of water decanted.

Operators must make monthly measurements of pore pressure and movement with instruments buried in the dam and, every few years, conduct a full safety audit, including drilling into a tailings deposit to sample and test it. These observations must be planned, supervised and analysed by an independent authority, then reported to the owner and regulators with recommendations for corrective action where necessary.

Until recently, requirements for closure were not considered in designing for operational conditions. It is now regarded as essential to consider the entire life cycle, from siting and design to commissioning, operation, closure, rehabilitation and subsequent use. Ultimately, the rehabilitated tailings deposit should be a stable landform that blends into its surroundings, should not require more than minimal maintenance and should have a subsequent use that is acceptable to the community.

Environmental Issues in Tailings Management

Fritz Balkau, *Principal Officer, United Nations Environment Programme, Industry and Environment (UNEP IE)*

Traditionally, companies have focused the greatest environmental scrutiny on the production cycle of the mine, that is, exploration and exploitation. Today, ancillary operations such as tailings dams are also acknowledged to have a high environmental impact, and sound tailings management is now becoming one of the criteria by which companies' environmental performance is judged.

Some past tailings dam failures have claimed lives and may have caused considerable environmental damage. Serious accidents that result in large volumes of tailings being discharged into the open environment are fortunately infrequent, but there is no room for complacency. Tailings impoundments are becoming bigger and frequently involve toxic effluents and other potentially hazardous materials. Several papers in this document describe the measures that ensure a high degree of safety in tailings structures.

In addition to the risk of catastrophic events, various ecological impacts of tailings impoundments during normal operation are also increasingly giving rise to concern among environmental agencies and local communities. Ongoing impacts from tailings disposal operations include transport of tailings solids into adjacent environments by wind and water erosion, and pollution of ground and surface water by toxic substances such as cyanide, sulphates or dissolved metals from the tailings. What follows is an outline of some of the main impacts that must be avoided or minimized.

WATER QUALITY

Releases of supernatant water from a tailings impoundment, whether in normal operations or as the result of storm surges, have the ability to change the quality of the receiving waters to which they flow. This is especially true if the pH and heavy metal content are considerably different from that of natural waters.

In some cases, changes in water quality are limited to small areas near the point of discharge. In others, effects can be observed tens of kilometres downstream. The extent of the effects on water quality depends on several factors, including chemical loading rates, the hydrological regime of the receiving waters, and mine management and operating procedures. A baseline study of receiving waters together with regular monitoring of effluent will reveal the extent of treatment required before release is acceptable.

Some seepage can be expected from most impoundments, and this will affect the underlying groundwater to a greater or lesser extent. In addition to the possible degradation of water quality affecting nearby users, changes in groundwater regime caused by seepage can result in damage to adjacent land and habitats through water-logging, or the opposite can occur and the watertable can be lowered if excessive pumping takes place.

While little can be done to alter the hydrological regime of an area, much will depend on the water management practices implemented at the site. As water issues also affect other operational considerations, such as physical stability, control and acid mine drainage, a balance may have to be struck between various environmental and safety criteria.

CYANIDE

The issue of cyanide at gold and other types of mines has captured public attention. Many countries have comprehensive control requirements over toxic substances including release of contaminated effluents, but public concern remains high and has been able to influence the mine permitting process in some countries. The cyanide problem not only concerns seepage or release during a possible rupture of the dam, but also the risk of intoxication of wildlife during normal operation. This aspect is especially serious in dry climates where animals are attracted to the water in a tailings impoundment. All potential problems are theoretically amenable to technical solutions, and cyanide destruction prior to release to tailings impoundments is becoming a more common practice, as is the lining of ponds. The long-term fate of cyanide complexes in closed sites is one aspect that may need additional study.

WILDLIFE

In many areas, the impacts on wildlife have to be considered. The toxicity of effluents on birds and animals that have free access to the site can be significant in some areas. Burrowing and grazing animals may interfere with attempts at re-vegetation, resulting in control programs that may also affect innocent species. Ancillary structures such as monitoring boreholes and flumes should be designed in such a way that small animals are not trapped or drowned in them.

It is also important to consider what type of ecosystem the new tailings impoundment represents—or could represent—and take appropriate measures to manage this aspect. The question of habitat is of course especially crucial for the rehabilitated site, but should be addressed on an ongoing basis even during the often prolonged operational period which characterizes many tailings impoundments.

CLOSURE AND RECLAMATION

The above impacts are as relevant during the post-closure phase as they are during operation.

After the closure of the mine, all areas including the tailings deposit must be left in a physically and chemically stable condition. This stability should be an intrinsic characteristic of the design of the final site, and there should be a minimal need for permanent surveillance and intervention.

Reduction in the potential for acid mine drainage is an important feature. A stable, long-term water regime that takes into account extreme natural events is another. Finally, the rehabilitation program should establish a permanent, robust vegetation pattern that is adapted to local climatic regimes. Of course, the final land use should be one that makes a positive contribution to both local and national values. It is important to analyse potential risks at all stages of planning, design, construction, operation and closure to avoid inadvertent weaknesses in the system.

EMERGENCY PREPAREDNESS

There is increasing public concern about the potential impact of tailings disposal systems on the surroundings. Communities seek assurance that such risks are properly assessed and managed. From the point of view of the authorities, the concept of design risk also has to be seen in the context of how many structures are involved. A commonly agreed low risk level for a single dam may still result in the unacceptably high aggregate probability of an accident in a country where several hundred units are in operation.

Emergency preparedness goes hand in hand with risk reduction. Most dams are designed to a particular risk standard such as a "one in so many years" flood or earthquake. However, more thought must be given to measures that should be in place in case a failure occurs due to unexpected natural events or some deficiency in the system.

Community involvement must be central to the development of contingency and emergency preparedness plans. The community, which usually remains long after the mine closes, requires assurance of long-term safety, environmental protection and the integrity of reclaimed mine land, and a knowledge of how to act if an incident or malfunction should indeed occur.

HOW SHOULD WE RESPOND TO THE ISSUES?

All of the above issues can be successfully resolved with the adoption of an integrated approach to environmental management. This requires a knowledge of environmental conditions, multi-objective planning, close supervision of construction, careful operational surveillance, and ongoing monitoring after closure.

Sound engineering remains the basis of safe structures. Long-term stability is ensured by a design that is intrinsically stable, self-repairing and low-risk, and able to stand up to weather and other local influences. The concept is more to design a permanent landscape feature than a short-term utility. In all cases, however, a monitoring and verification procedure is needed to confirm that this goal has truly been achieved.

There is also the need for emergency preparedness and planning. No matter how well we design and plan, some failures will occur at tailings dams. The concepts of secondary security measures and emergency preparation need to become incorporated into tailings dam management. Emergency preparedness approaches as already adopted in other industry sectors need to become more commonplace in the mining industry as well.

The Importance of Tailings Stability

***Iain G. Bruce**, President, Bruce Geotechnical Consultants, British Columbia, Canada*

The basic requirement of a tailings facility is to store tailings in a physically stable and environmentally sound manner for perpetuity. The major short- and long-term concerns include physical stability and safety, chemical stability and groundwater pollution, dust emissions and long-term reclamation.

In the past, the primary focus of tailings dam design was to provide well-engineered starter structures into which tailings could be deposited. Little attention was given to long-term management of the facility or to closure requirements, especially with respect to environmental issues. However, public concern, among other factors, has forced all industries to address long-term environmental control and adopt state-of-the-art management methodologies.

PHYSICAL STABILITY

The stability of a tailings dam embankment is a major issue because a catastrophic failure can impact water quality and waterways, wildlife and people. Recent releases of tailing effluents and solids from containment facilities around the world, including Merriespruit in South Africa (1994), Omai in Guyana (1995), Marcopper in the Philippines (1996) and Los Frailes in Spain (1998), have raised public awareness as well as expectations that the risk of failure be fully addressed during all phases of a facility life. The environmental and socio-economic impacts created by these incidents have prompted the mining community to question the state of practice of tailings impoundment design. Among the most pressing questions are:

- Does the technology exist to design and safely construct tailings dams?
- If so, are tailings dams being designed and built to state-of-the-art standards?

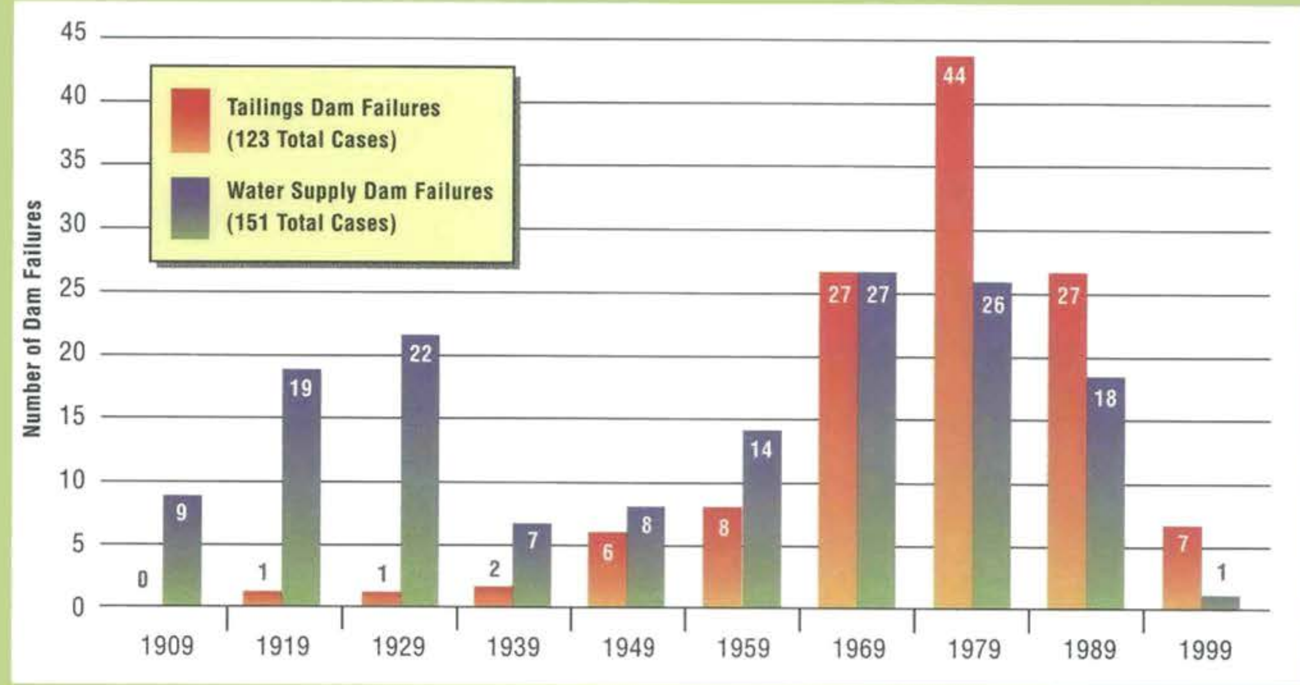
Although many of the early tailings dam structures (constructed between the 1920s and 1940s) were built slowly, with common-sense approaches, a number of them failed. Concepts of theoretical soil mechanics were introduced in the 1950s, but it was not until the 1960s that they were refined and accepted throughout most of the mining community. In the last 30 years, the science of soil mechanics has been applied to the design and construction of tailings dams, and methodologies have constantly improved through lessons learned from both mistakes and successes. It is now recognized that several key factors must be addressed in order to design a safe dam by today's standards (ICOLD, 1995a). These include an understanding of:

- tailings dam containment systems as a whole and tailings management practices;
- seismicity and earthquakes and the corresponding response of the structures;
- hydrology and the prediction of flooding and water erosion;
- seepage control with respect to minimizing excess pore pressures and preventing solid migration (piping); and
- the mechanisms of the plugging of filters and drains by fines and/or precipitates.

Design methodology is well documented by international organizations such as the International Commission on Large Dams (ICOLD), the Canadian Dam Safety Association (CDSA), the United States Committee on Large Dams (USCOLD), and the Canadian Electrical Association (CEA). A 1992 publication by ICOLD provides methods for predicting floods, choosing probable maximum floods and assessing downstream hazards, while a more recent bulletin (ICOLD, 1994) provides a complete list of state-of-the-art practices for filter design. A number of books have also been written to give the geotechnical engineer a guide and technical supplement for the design of tailings facilities (e.g. Vick, 1990; Fell, MacGregor and Stapledon, 1992).

In particular, the design of earth embankments for seismic conditions has improved dramatically in recent years. The following key factors to ensuring seismic stability are now understood:

- an appropriate method of seismic stability analysis that can predict the earthquake and ground-motion magnitudes for which the tailings dam should be designed;
- the geotechnical properties of the tailings dam foundation and dam fill material; and



HOW SAFE ARE TAILINGS DAMS?

While it appears that the mining industry has the knowledge to design dams safely, can it be said that all dams are built to the same standards, with state-of-the art technology and management? Some are better than others, and failures have occurred. Several recent studies have been conducted to compile data on tailings dam failures, isolate the causes of these failures and identify trends (USCOLD, 1994; UNEP, 1996). No single legislative body, however, records tailings dam statistics. Furthermore, the data do not allow comparisons between the number of tailings dam failures and the total number of tailings dams built in any given area or time period.

However, comparisons have been made between tailings dam failures and incidents at hydroelectric and water-retaining structures (ICOLD 1995b). Although the database is incomplete, some convincing trends have emerged. The above chart shows a plot of the total number of failures reported for all countries in 10-year increments for both tailing dams and water supply dams. Before the 1940s, there were very few reported failures of tailings dams, either because many of the existing dams were not documented, or because the total number of failures was small. From the 1940s to the 1970s, the number of failures for both tailings dams and water supply dams increased substantially. The rise in the number of failures in the 1950s to 1960s may have been due to the increasing size and weight of earthmoving equipment. This trend peaks in the late 1960s for water supply dams, and in the 1970s for tailings dams. The overall behaviour of the two structure types is, in general terms, very similar.

- the range of remedial measures available for enhancing seismic resistance and/or mitigating potentially detrimental downstream effects resulting from a facility's unsatisfactory performance.

Closure and Reclamation

Mining activities are temporary. At the end of the mine life, the area must be returned to some public authority or to the original owners so that it can be used for another constructive purpose such as farming, forest growth or recreation. Therefore, tailings dams must be left in physically and chemically stable condition. Chemical stability, dusting and long-term water management are closure concerns.

Chemical stability

Acid rock drainage (ARD) and leaching of metals are major chemical environmental concerns for closure. Recently, covering the tailings with water ("flooding") has became a popular option for mitigating ARD. However, flooding to ensure chemical stability can aggravate physical stability concerns and also lead to an increase in seepage rates. The easiest way to maintain embankment stability and minimize seepage during and after operations is to remove or at least minimize the liquid pool. New methods of soil cover design and evaluation that produce a dry, reclaimed impoundment at closure may be the best method of ensuring long-term stability and minimal impact on the environment. Separating the high sulphur fraction (pyrite) from the rest of the tailings and placing it either underground or in a special containment area may be a cost-effective solution for ARD control.

Dust Control

Short-term impacts from dusting are often felt in areas where freeze-drying or prolonged periods of drying occur. As well as being a persistent nuisance in nearby communities, some dust components may cause gradual health deterioration, for example, in base metal mines where lead constitutes a large component of the tailings. This is a particular concern in some tropical climates where, according to local habits, children and pregnant women may ingest iron-rich residual soils either directly or indirectly. In areas where sulphidic dust has migrated from the dry tailings, there is a potential for minor amounts of acid to be generated off-site. In other areas, dust containing asbestos fibres may cause concern.

Sprinkling water on beaches and keeping the tails wet can control dusting. Flooding is also an option, but this technique is rarely used because of its negative impact on dam stability. Long-term dusting is best mitigated by a good reclamation and revegetation plan. In many cases, the fine-grained tailings can be covered with coarser waste rock.

Long-term water management

The methods used to control long-term water problems depend on the climate. In dry climates, water management may be considered a minor issue, but a lack of understanding of rare storm events may lead to inadequate storage and spillway capacities both during operations and at closure. In wet or cold and snowy climates, choosing the correct design combination for snow melt, rain on snow and probable maximum precipitation may be critical to safe long-term closure.

If care is taken to place the tailings impoundment in an area where water-handling concerns are minimized, long-term management becomes a minor issue. For instance, placing tailings at the upper end of catchments or in side-valley impoundments may assist in closure and minimize the impact of hydrologic changes to the catchment area.

TAILINGS DAM MANAGEMENT

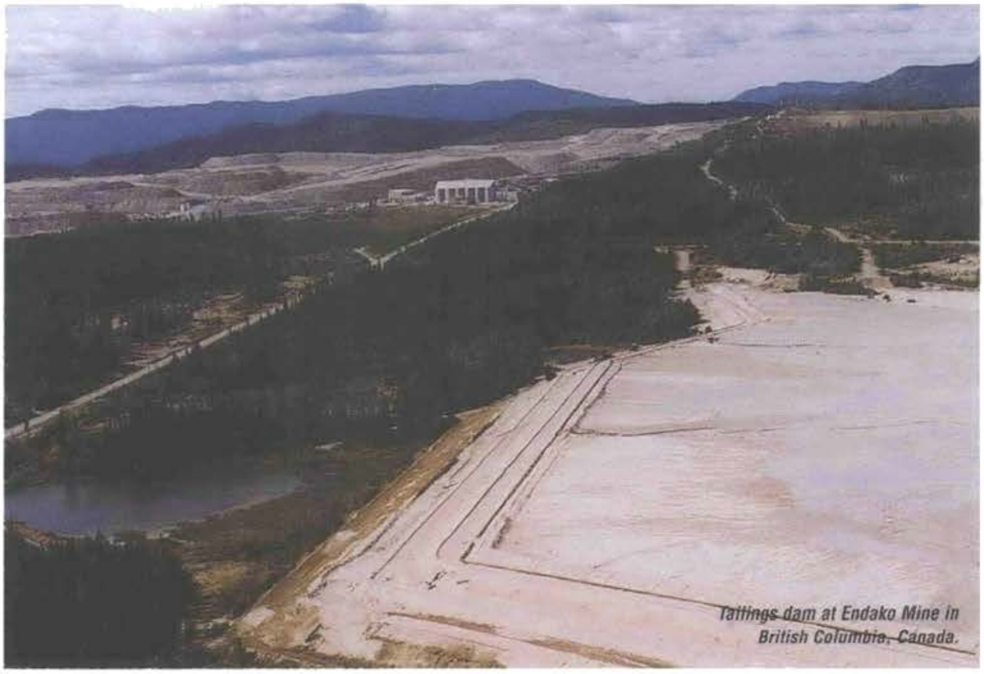
Tools for safe design are available, but operators must also address issues of construction and of operating quality control and management. A tailings dam is a constantly evolving entity. Diligent inspections, the use of operating manuals and a dedicated team of tailings operators are the requirements for successful tailings management with minimal and acceptable impacts on the environment.

Overview of an Environmental Management System: Endako Mine

SUMMARY: *The evolving environmental management system (EMS) at the Endako molybdenum mine includes parameters for the design, operation and inspection of the tailings dams; a tailings management committee to oversee day-to-day operations and conduct monthly reviews; and an annual external review. The system addresses the key components of tailings disposal, outlines responsibilities and reporting frequencies, and features several manuals that detail standard procedures.*

BACKGROUND

The Endako Mine, owned and operated by Thompson Creek Mining Ltd., produces some 5 000 tonnes of molybdenum in concentrates at Fraser Lake in British Columbia, Canada.



Tailings dam at Endako Mine in British Columbia, Canada.

ENVIRONMENTAL MANAGEMENT SYSTEM

Endako's EMS includes a tailings management plan that covers four basic elements and related activities:

1. Design, Operation and Inspection

Design: factors affecting the design include seismicity, geotechnical criteria, environmental sensitivity, pond water quality, discharge water quality, hydrological criteria, regulatory considerations, seepage control, surface and ground water protection and water handling systems.

Operation: the annual tailings deposition plan incorporates design, deposition, water handling, maintenance and environmental protection requirements. The tailings management committee conducts a monthly review of deposition.

Inspection: regular internal and external inspections and audits are conducted to check dam integrity and ensure that tailings operation is in accordance with planned activities.

2. Identification of key components

The structure of the plan addresses the following key components of the tailings system: tailings lines; dam design, construction and stability; tailings deposition; hydrology; water control and environmental impact management.

3. Tailings management committee

The tailings management committee consists of representatives from the engineering, operations, mill and environmental departments. The committee has a mandate to ensure the structural integrity of the tailings dams and related structures and to check that day-to-day operations are in accordance with design requirements. This mandate includes a monthly review and inspection, an assignment of corrective actions and a follow-up to ensure timely completion of the assigned actions.

4. External review

The EMS calls for a geotechnical consultant to inspect and assess Endako's tailings systems on an annual basis. The

Responsibilities

Responsibilities for the tailings management system are as follows:

Mine Manager	- Oversees the operational affairs of the mine and therefore has final responsibility for the tailings systems
Mine Superintendent	- Ensures adherence to and reviews the tailings management plan; - Ensures that resources required to implement the plan are available
Chief Engineer	- Ensures that technical and survey data required for constructing and maintaining stability are collected; - Coordinates an annual inspection and evaluation of stability by an external expert; - Monitors water parameters within the dams
Mill Superintendent	- Coordinates mill activities with the construction and daily operations of tailings dams; - Ensures that interruptions in flow of mill process water to the tailings dams are communicated to the tailings operators
Surface Crew Foreman	- Develops and documents the annual tailings deposition plan in conjunction with engineering, mill and environmental personnel; - Supervises tailings deposition; - Plans maintenance, replacement, relocation and regular inspections of tailings lines; - Maintains access roads, diversion ditches, emergency spill catchment areas and the reclaim water system
Pit Shift Foreman	- Provides safety inspections of tailings operations during off shifts and provides support when required
Tailings Operator	- Deposits mill tailings as per the deposition plan; - Inspects operating tailings lines; - Repairs minor line leaks; and - Conducts routine maintenance according to the *Tailings Operator's Manual*
Environmental Co-ordinator	- Develops and maintains spill response and tailings reclamation plans; - Ensures that safety features prevent severe damage to the environment; - Coordinates reclamation with annual tailings deposition plan; - Provides monthly weather and annual snow pack data to mine engineering; - Coordinates tailings management committee

results of the review are integrated into the inspection and monitoring programs and form the basis for system improvements. The consultant's report includes:

- plan and representative cross-sections;
- site photographs;
- climatic review;
- summary of past year's construction and descriptions of any stabilization issue;
- water balance review;
- freeboard and storage availability;
- seepage occurrence;
- surface water control and surface erosion;
- construction and instrumentation review of phreatic, surface and piezometer data, settlement, and lateral movement;
- stability review; and
- recommendations for monitoring and improvements

STANDARD PROCEDURES

Standard procedures for tailings are outlined in different manuals, according to the area of activity. For example, there is a manual for tailings operations, one for tailings dam inspection and a general one for emergency response procedures. The emergency response procedures manual outlines what to do in case of tailings dam incidents. It includes procedures for notifying appropriate staff members, government agencies and local communities, for containing and cleaning up spills, and for organizing response personnel. It also lists the information required for spill reporting, including follow-up action and contingency plans.

Technicians conducting a monthly piezometer reading.

Reporting

The following reports are made on a regular basis:

Every five years	Mine closure plan
Annually	Tailings deposition plan Tailings reclamation report Water balance reconciliation External consultant's report
Quarterly	Review of major issues
Monthly	Water balance report

CONCLUSIONS

When the tailings management plan was first developed in 1996, everything related to tailings was included. Since then, the content of the plan has been reviewed and revised, as some of the items were found to be irrelevant to tailings stability or in need of simplification. A plan such as this should be treated as a living document and reviewed periodically.

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Anglogold's Environmental Management System

SUMMARY: *The environmental management system (EMS) at Anglogold's West Rand Region (WRR) is based on the ISO 14000 series of standards. The system incorporates a number of management, activity and monitoring codes designed to minimize the environmental impact of the large complex. Managers of each activity, including tailings disposal, took part in developing the EMS, and key personnel received relevant training. The main benefits of the EMS are expected to be lower costs and higher revenues.*

BACKGROUND

WRR comprises the Western Deep Levels, Elandsrand and Deelkraal gold mines situated approximately 75 km west of Johannesburg, in Mpumalanga and North West Provinces, South Africa. There are five ultra-deep mining operations with associated shafts, four metallurgical plants and thirteen tailings dams. The dams are at various stages of their life cycles, from commissioning to preparation for closure.


Aerial view of site.

Under South African law, mines must submit an environmental management program (EMP) to the government for approval. Once approved, the EMP becomes legally binding. In this manner, the mining company officially commits to implementing a program designed to minimize impacts during operation and after closure. Anglogold's EMS ensured that the necessary tools existed to achieve these pre-determined requirements.

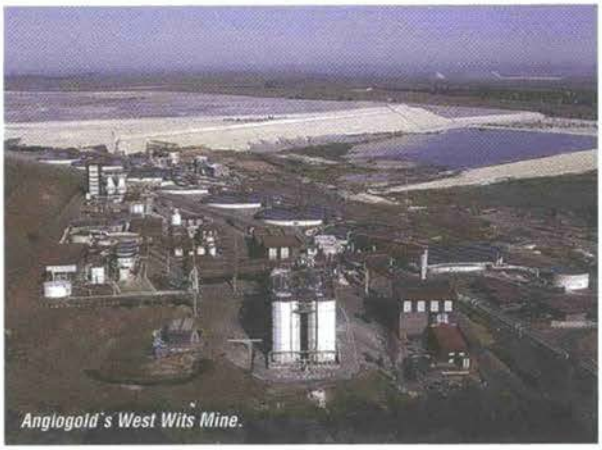
APPROACH

In accordance with its environmental policy, WRR has implemented an EMS that incorporates audits, management reviews and responses to deficiencies through planned and timely remediation. The framework, which was structured in accordance with the ISO 14000 series of standards, established the overall direction of the EMS and set the goals and principles to which WRR aspired and against which all subsequent actions could be judged. To facilitate the process, the EMS included a clear audit trail.

WRR noted the potential environmental impacts of its mining operations in a register during the early stages of the EMS. The development process of the impact register and the overall framework for the EMS included a series of workshops for managers responsible for activities with potential environment effects. This approach ensured that the experience of people in the field was incorporated into the EMS. As a result, managers were encouraged to become involved and to take responsibility for the EMS.

A comprehensive dam management and monitoring system was established and incorporated into the EMS. As a result, the dams now operate at known risk levels, and preventative measures can be taken before crises develop. Anglogold's EMS, which was used as a model for the South African Bureau of Standards' *Code of Practice for Mine Residue Deposits* (see p. 26), incorporates activity and monitoring codes of practice. These codes define the way to manage activities that may affect the environment, and specify what monitoring is required to evaluate whether environmental objectives are being achieved. Each code is structured to be a separate, self-contained document covering significant activities such as tailings disposal and handling.

The activity codes ensure that the activities associated with each operation are managed in a manner that generates minimal environmental damage. The codes provide a "road map" that outlines the responsibilities of each manager. These responsibilities include execution of management actions, performance monitoring and reporting. Where appropriate, the codes provide reference to more detailed procedures or operating manuals. In the case of the tailings dams, for example, the technical consultants responsible for the structural integrity of the dams compiled a detailed operating manual. In addition, key personnel received the training necessary to allow them to fulfil their responsibilities effectively.


Anglogold's West Wits Mine.

The objectives of the activity codes are to:

- ensure that strategies designed to minimize adverse environmental impacts are implemented;
- respond to changing requirements, improved technology and the results of environmental monitoring; and
- meet rehabilitation and closure objectives.

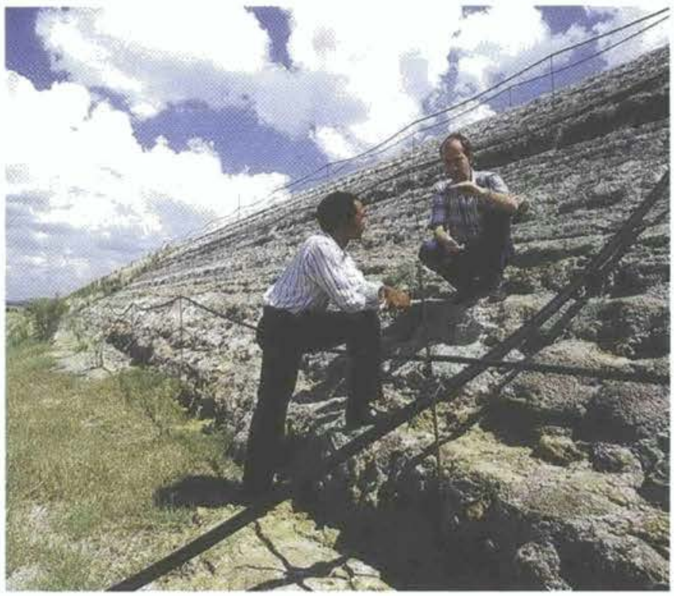
The objectives of the monitoring codes are to:

- obtain a history of environmental quality;
- determine any impact the project may have on the environment;
- inform the managers of the activities causing adverse impacts so that action can be taken; and
- obtain data for design purposes.

BENEFITS

The main benefits of implementing an EMS are expected to be reduced costs and/or increased revenues, both in the short and long terms. A number of additional factors also encouraged WRR to implement an EMS, including:

- legislative and regulatory compliance and enforcement, both nationally and internationally;
- the introduction of levies on emissions (i.e. the "polluter pays" principle);
- cost savings from cleaner production and environmental efficiency;
- impacts on business from accidents and failures (i.e. the cost of remediation and business interruption); and
- increasing pressure from interested and affected parties.


Monitoring successful tailings dam vegetation program.

CONCLUSIONS

There are sound commercial and environmental reasons to implement a comprehensive EMS. At WRR, valuable spin-offs are already evident in the tailings disposal system, including:

- comprehensive integrity and environmental monitoring systems, which permit ready comparison with predetermined standards;
- proactive maintenance of the facility; and
- rehabilitation works, which will commence as soon as possible.

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The External Audit: An Efficient EMS Tool for Rio Tinto Brazil Ltd.

SUMMARY: *The external audit is an integral part of Rio Tinto Brazil Ltd.'s environmental management system for the Rio Paracatu Mineração (RPM) tailings dam. The audit allows routine checks and reviews to be performed on all aspects of construction and operation, including dam design, safety factors, construction drawings, and materials and performance. The audit has allowed Rio Tinto to maintain a safe and increasingly efficient tailings operation.*

BACKGROUND

The RPM deposit is one of the lowest-grade orebodies (0.5 g per tonne of gold) currently being exploited in the world and, as a result, it produces a relatively high proportion of waste. This challenge has required continuous improvement in the engineering and management of RPM's tailings dam.

The dam is a conventional cross-valley structure constructed of compacted earth fill with vertical and horizontal gravel and sand filters. It is situated in the upper section of the Santo Antonio creek, a small, low-flow stream with a catchment area of about 19 km^2. The maximum storage capacity is 126 million tonnes of tailings and four million m^3 of free water. The dam wall is 59 m high and 1 960 m long, surrounding an area of about 480 ha.

Site selection, initial design and construction began in 1986 in preparation for production start-up a year later. By the end of 1997, eight stages had been completed using the downstream method of construction. Throughout the stages, design, construction and operation have been rigidly controlled and audited in accordance with Brazilian and international standards for large dams, specifically those set by the International Commission on Large Dams (ICOLD).

The dam serves two major functions: first, it settles and stores the process plant tailings, and second, it conserves and recycles process water. Despite a prolonged dry season in this part of Brazil, over 80% of the water for gold processing is recycled from the dam.

ENVIRONMENTAL MANAGEMENT SYSTEM

The most important feature assuring an efficient and safe operation is the well-structured management system applied to all design, construction, operation and audit stages. There is a close, tiered link between the professionals and organizations that participate in each stage. An RPM team, supported and monitored by external engineers and consultants, closely supervises construction contractors and is responsible for continuous operational monitoring and inspection. The dam designers, Promon and Geohydrotech, also follow up the construction and operation stages by maintaining a continuous presence in the field and verifying monitoring data.

EXTERNAL AUDIT

The external audit is an integral part of the management system from the design stage through to construction and monitoring. Representatives of UK-based Knight Piésold, which has extensive experience in tailings design and construction, serve as consulting engineers and external auditors. They carry out the audit at least once per year, but often at more frequent intervals to advise on improvements and changes.

The annual audit was first set to coincide with the design and construction of each stage. Typically, Knight Piésold checks the dam design in one visit, and in the next visit audits the construction that is already under way. During each audit, the external auditor verifies aspects related to design criteria, construction methods and dam performance and follows up on previous recommendations for improvement. The audit process enables the routine checking and reviewing of the following:

- Dam design, including hydrological data analysis, water management, materials specification, seismological characteristics, slope angles stability and dam wall safety factors. The design engineer presents and discusses the conceptual and engineering bases for the proposed design.
- Adopted safety factors: the auditor may suggest modifications or may require additional data to be collected.
- Construction drawings and the quality of construction materials.
- Construction reports, including visual inspections, degree of compaction, materials moisture and other construction-related features.
- Dam performance based on a comprehensive monitoring network that includes: standpipe piezometers, survey beacons, piezocone tests, underground water quality analysis, seepage flow rate measurements, seepage water quality analysis, water inventory, tailings/water profile measurements and tailings microscope scanning.

During the audit, all data are checked for consistency and evaluated according to international standards. The auditor also conducts a detailed visual inspection to collect any evidence of problems (e.g. cracks, erosion, seepage, subsidence). The audit is followed by a detailed report that includes recommendations and main issues that will eventually be included in an action plan (e.g. additional tests of materials, additional instrumentation, management improvements).

CONCLUSIONS

Through this comprehensive external audit system, RPM has been able to maintain safety with an increasingly efficient tailings dam operation.

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Risk Assessment of Tailings Disposal at Osborne Mines

SUMMARY: *Osborne Mines conducted a risk assessment of its tailings management system in order to determine the stability of the tailings, the long-term integrity of the impoundment and the risk of polluting the environment. The assessment took the form of a brainstorming session in which a multidisciplinary team assigned severity and probability rankings to each operational risk.*

Fresh flotation cell, containing more than one million tonnes of tailings. Tailings are peripherally discharged in a cyclic manner which allows them to settle and dry. Water can be recovered through the central decant tower.

Tailings delivery and return lines are located in an earth bund containment system which will hold a full line rupture from any line for a minimum of four hours. The lines are inspected physically every four hours for leaks.

BACKGROUND

The Osborne copper–gold mine, a member of the Placer Dome Group, is situated about 195 km southeast of Mount Isa in Northern Queensland, Australia. It was commissioned in July 1995 with an operating capacity of 1.2 million tonnes of ore per year. The tailings impoundment was designed to contain 11 million tonnes of tailings over the life of the mine.

Tailings are pumped to a paddock-style impoundment, a common structure used in this arid and relatively flat region of Australia. Thickened tailings, at 55% solids, are discharged at a single deposition point, which is rotated around the periphery of the impoundment. About 70% of the water is recovered and recycled, 10% is lost to evaporation and the other 20% remains in the tailings.

APPROACH

In 1996, Placer Dome initiated a risk assessment program on tailings disposal for all the 19 operating mines with which it is associated. Osborne Mines conducted a risk assessment of its tailings management system in November 1996.

Risk assessment involves a series of steps:

1. Select the best risk assessment method. Osborne selected the potential problem analysis (PPA) approach because it allows people of any background to participate in brainstorming scenarios and contribute to ranking of risks.
2. Identify the skill sets required and call on professionals, practitioners and people with no technical knowledge but with good lateral thinking skills. Someone unfamiliar with the issues can challenge the others with scenarios they might not consider or imagine. It is also important to have people from outside the company.
3. Collect data for review, including design and construction drawings; process flow charts; tailings tonnages over time; water circuits and water management plans; previous tailings impoundment audits; planned maintenance schedules; maintenance history; incident reports, including injury, near-miss and production loss; equipment damage;

and environmental incidents such as spills and impact on fauna.

4. Do the risk assessment.
5. Have the report reviewed by the risk assessment team to ensure that everything is correct.
6. Follow up on high-risk issues with knowledgeable people (e.g. the original designers were contacted to ensure that any unknown factors, such as seismic activity, wall stability, seepage modelling and site selection criteria, were addressed in the design).
7. Re-address any issues arising and re-rank risk if necessary.
8. Use the risk assessment documentation as a reference tool when process changes or additions are proposed.

Table 1. Identified Risks and Actions

ITEM	IDENTIFIED OPERATIONAL RISKS	ACTION
Tailings delivery lines	Disruption to production from line rupture or leakage	Efforts to minimize are well in hand
Dam stability	No formal stability analysis results were available	Analysis in progress
Dam seepage	No formal predictive seepage model	Installation of shallow monitoring bores at the toe of the external embankment being considered
Underground interaction	Future underground mine development: subsidence	Geotechnical advice will be required
	Placement of tailings underground: personnel safety	A key consideration in design
ITEM	**IDENTIFIED CLOSURE RISKS**	**ACTION**
Dam seepage and groundwater impact	No formal predictive seepage model	Formal assessment of tailings acid potential required
Land use	Land use	Re-assess Land Contamination Act at end of mine life
Underground interaction	Subsidence and loss of dam integrity	A key consideration in design

At Osborne, the objective was to assess the stability of the tailings, the long-term integrity of the impoundment, and the risk of polluting the environment. An assessment team was formed with competencies in geotechnical engineering, civil engineering, tailings operation, risk assessment processes, environmental management, public liaison and hydrology.

The team brainstormed each component of the tailings system in failure mode and identified likely effects. All ideas and postulations were accepted, regardless of the level of credibility. The risk assessment team assigned a severity ranking and probability to each failure mode. The severity of an event was assessed in terms of the effects on regulatory agencies, environmental harm, damage to corporate image and non-budgeted production costs. The probability of an event was rated in one of five categories, from "extreme" to "negligible."

The assessors then reviewed the systems and mechanisms that could reduce the likelihood of occurrence, and the possible response. Risk management mechanisms include engineering control, procedural functions such as a contingency response plan, and a monitoring program. Where there is an extremely high-risk potential, the project should have well-engineered protection systems with a solid and tested contingency or emergency response plan. For low-level risks, an inspection procedure or monitoring program may be all that is necessary.

An acceptable level of risk is very difficult to define, because guidelines and interest groups assess the severity of consequences differently. It is important to incorporate all risk factors into the assessment process to get a balanced result. While no major risks were identified in the Osborne tailings management system, some issues in the operational and closure phases will require further investigations (see Table 1).

CONCLUSIONS

The risk assessment of the tailings system provided senior management with a clear level of risk. The most significant risks were found to be a possible rupture of the pipeline or failure of the pumping system. These would reduce productivity and could cause losses of up to A$1 million per year. This finding emphasized the need to continue to improve preventative maintenance programs and periodic inspections of both the pumps and the pipelines. No major risk to the environment was identified.

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A Guide to the Management of Tailings Facilities

Prepared by the Mining Association of Canada

SUMMARY: *The Mining Association of Canada (MAC) has developed a guide to help companies manage tailings facilities in a safe and environmentally responsible manner. The guide outlines a management system that begins with a framework of principles and objectives and expands into a series of checklists that can be used throughout the life cycle of the facility.*

BACKGROUND

In June 1996, the MAC established a task force to promote safe and environmentally responsible management of tailings and mine rock. The task force determined that engineering capability exists and generally is applied by Canadian companies in the safe design, construction, operation and closure of tailings facilities. It was noted, however, that the consistent application of that engineering capability within an effective management framework is the key to managing tailings throughout the life cycle of a facility.

To promote the exchange of information and best practices, the task force arranged two workshops: one on management of tailings and mine rock and another on tailings risk assessment. These workshops and related consultations identified the need for a guide to tailings management. Consequently, MAC developed *A Guide to the Management of Tailings Facilities* through the collaborative efforts of 19 experts from the Canadian mining industry. The guide has three objectives:

- To provide information on the safe and environmentally responsible management of tailings facilities.
- To help companies develop tailings management systems that include environmental and safety criteria.
- To make the application of sound engineering and management principles to tailings facilities more consistent.

The guide incorporates good management practices. It adopts principles and approaches from many sources, including mining company manuals; proceedings of the two MAC workshops; the MAC Environmental Policy and Environmental Management Framework; the ISO 14000 Essentials; the Canadian Dam Association's draft Dam Safety Guidelines; and international guidelines and standards.

THE GUIDE

The guide outlines a system to manage tailings facilities in a safe and environmentally responsible manner throughout

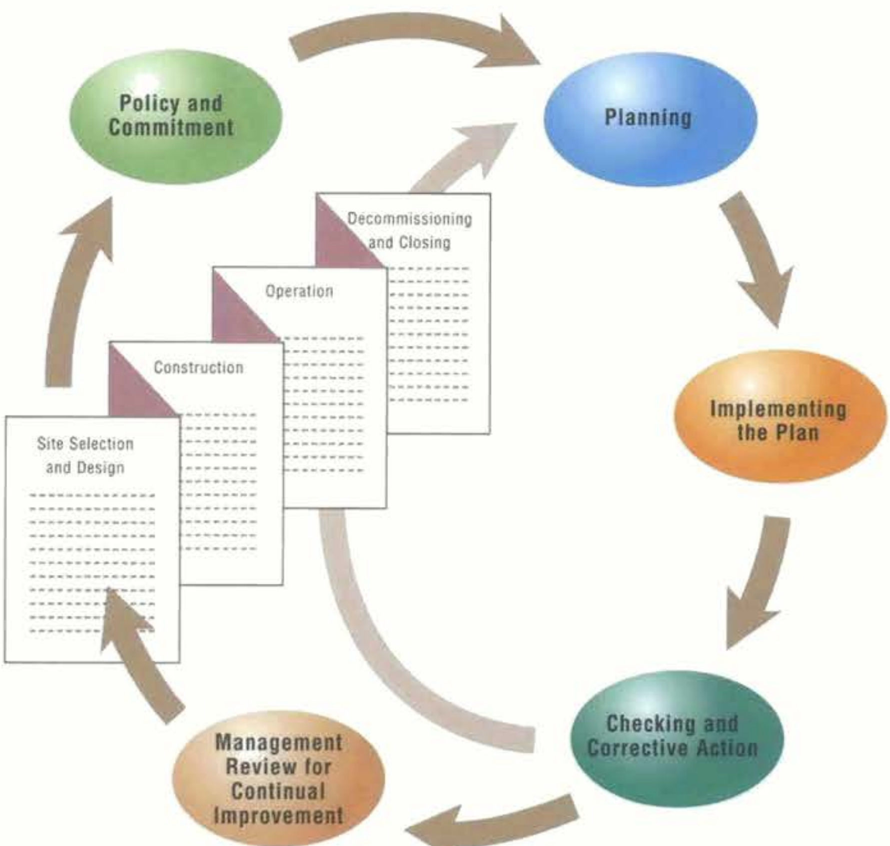

Figure 1. Application of the Tailings Management Framework through the Life Cycle

the life cycle: from site selection and design, through construction and operation and finally to decommissioning and closure. It is a reference tool designed to help mining companies ensure that they are managing their tailings facilities responsibly. It is meant to be customized and adapted to specific sites, individual company policies and local regulatory and community requirements.

The system begins with a framework of management principles and objectives that address policy and commitment, planning, implementation, checking, and corrective action and management review. The incorporation of continual improvement in safety and environmental performance into all aspects of tailings facility management is a key underlying principle of the framework.

The framework then expands into a series of management action checklists applicable through the various stages of the life cycle. The checklists identify the following key elements necessary to implement the framework: management actions, corporate responsibility, performance measures and schedules. At any stage, the checklists can be used to develop operating procedures and manuals; expose gaps within existing procedures; identify training requirements; communicate with stakeholders; obtain permits; conduct audits; and aid compliance and due diligence. The integration of what is to be managed and effective management techniques is of prime importance. Figure 1 illustrates the application of the tailings management framework through the life cycle of a tailings facility.

The guide also contains appended lists of technical considerations that address environmental setting, facility design and operation, and risk assessment and management aspects. The checklists make reference to these technical considerations and revisit them at different stages in the life cycle.

CONCLUSIONS

The guide will help companies comply with government regulations, protect the environment and the public, and demonstrate due diligence. Furthermore, it will help companies integrate environmental and safety considerations in a consistent manner, with continuous improvement in the operation of their tailings facilities.

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National Regulations and Codes: South Africa, Malaysia and Mexico

SUMMARY: *Governments and national mining associations around the world are developing environmental policies and practices for all aspects of the mining operation, including tailings disposal. The South African Bureau of Standards Code of Practice for tailings addresses the entire life cycle of tailings dams, especially in terms of safety and environmental impact. Malaysia and Mexico are also revising their mining legislation, including new requirements for tailings dams.*

THE SOUTH AFRICAN BUREAU OF STANDARDS CODE OF PRACTICE FOR MINE RESIDUE DEPOSITS

The South African Department of Minerals and Energy (DME) recently commissioned an independent group, the South African Bureau of Standards (SABS), to develop a Code of Practice. This Code is now complete for inclusion in either the Water Act or the Minerals Act.

The Code of Practice (COP) is intended to address the life cycle of residue deposits, including tailings, in terms of their safety, environmental considerations, construction and management. The COP contains fundamental objectives, principles and minimum requirements for good practice, all aimed at ensuring that no unavoidable risks, problems and/or legacies are left to future generations.

Objectives

- Safety to life, limb and property
- Environmental responsibility
- Effectiveness
- Efficiency

Principles

- Continual management throughout the life cycle
- Minimization of impact and risk
- Precautionary approach to promote prevention
- Internalized costs
- Cradle-to-grave control

SAFETY AND ENVIRONMENTAL CLASSIFICATIONS

Safety and environmental classifications determine the minimum requirements for investigations, design, construction, operation and decommissioning of the residue deposit, and also specify tasks and minimum qualifications. The higher the safety risk, and/or the more significant the potential environmental impacts associated with the residue deposit, the more stringent the requirements specified in the COP. Hazard is the key concept on which the safety classification is based and is defined as "the potential to cause harm as a consequence of failure." Each deposit is thus classified as being a high, medium or low safety hazard. The deposits are also classified according to the spatial extent, duration and intensity of potential impacts and are labelled as a "significant" or "not significant" impact.

PHASE-SPECIFIC REQUIREMENTS

Each phase of the life cycle of a residue deposit has certain objectives, principles and minimum requirements.

Phase 1: Conceptualization, Planning and Site Selection

- Understand the broad issues involved
- Consider all alternatives
- Ensure a sustainable end land use
- Avoid unnecessary waste and minimize impacts
- Consider modification of the residue
- Ensure the defensibility and justification of decisions
- Reassess options and decisions throughout the phase

Alternatives are compared on the basis of substantive analytical techniques. All residue deposits with a medium- to high-hazard classification, or with a significant impact on any environmental component, require a planning report.

Phase 2: Investigation and residue characterization

- Site characteristics
- Residue characterization
- The pre-development environment
- Background environmental data
- The alternative impact management measures
- Any unique circumstances which may influence the residue deposit

Suitably qualified people must be involved in the preparation of geotechnical and geohydrological reports for medium- and high-hazard deposits. Baseline environmental data must be included in the Environmental Management Program Report (EMPR) for the mine.

Phase 3: Design

The design-phase objectives are to ensure the reliability and sustainability of the structural design and the environmental mitigation measures. Again, the use of suitably qualified people is essential. A design report, operating manual, risk management plan and approved working drawings are mandatory. The application of "best practice" is also a minimum requirement. Specific environmental objectives must be set and included in the EMPR.

Phase 4: Construction and Operation

Objectives are listed for each of the four sub-phases: construction, commissioning, operation, and monitoring and maintenance. Requirements pertain to suitably qualified supervision personnel, specifically a professional engineer in the case of medium- and high-hazard deposits. Equipment must be operated and maintained according to legislated standards, and a system to maintain and audit the relevant standards must be in place.

Phase 5: Decommissioning and Aftercare

The objectives of this phase include:

- safeguarding the health and safety of humans, the ecological environment and the integrity of property and infrastructure on and around the residue deposit;
- achieving the final land use and capability;
- addressing the procedural and substantive needs of all interested and affected parties; and
- minimizing adverse existing and residual impacts.

A decommissioning and aftercare plan with specific measures must be documented in the EMPR. Aftercare management takes into account effective design, compatibility with aftercare objectives, and mitigation measures for extreme circumstances. Monitoring systems must be designed and implemented until the closure objectives are reached.

CONCLUSIONS

As a result of the Mine Health and Safety Act, mines are required to compile a code of practice based on guidelines issued by the Chief Inspector. The SABS Code of Practice and the Chamber of Mines guidelines will be referred to as source documents within these guidelines. The SABS Code of Practice for the health, safety and environmental management of tailings dump is in the process of being enacted into South African legislation.

ENVIRONMENTAL POLICY IN MEXICO

The Mexican Official Standard, approved in 1997, stipulates the compulsory requirements for site selection, construction, operation and monitoring of tailings dams. These requirements include:

- An environmental impact study
- Compliance with laws governing the preservation of historical or cultural heritage
- Assurance that there will be no percolation of toxic leachates to the nearest aquifer or surface water body within 300 years
- Approved plans for surface and groundwater monitoring
- Detailed characterization of the underlying geological structure and the mechanical properties of rock formations and soil deposits
- Land surveys of the site to delineate elevations and features such as roadways and pipelines
- Compliance with civil works design standards for dams of the Federal Electricity Commission
- Monitoring instruments for dams over 50 m in height

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ENVIRONMENTAL POLICY IN MALAYSIA

Malaysia's current mining legislation is limited in scope because it deals almost exclusively with the small-scale alluvial tin mines that have dominated the country's mineral sector. In order to attract foreign investment, Malaysia has proposed new legislation for large-scale hard rock mining. The proposed legislation includes specific requirements for tailings management such as:

- A detailed plan
- A design that complies with good engineering practice
- Construction under the supervision of a professional engineer
- Stability against any static and dynamic loading
- Freeboard of not less than one metre
- Phase-specific requirements similar to those outlined by the South African Code of Practice

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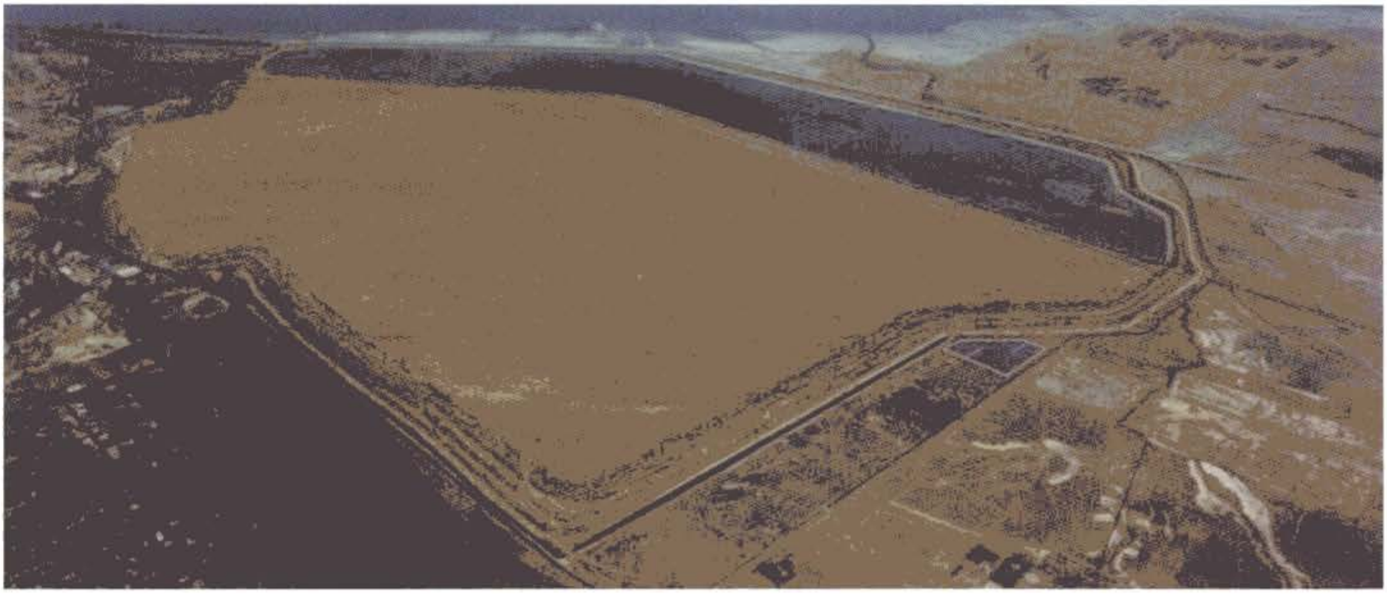
Site Selection Criteria at Kennecott Utah Copper

SUMMARY: *In compliance with US environmental law, Kennecott Utah Copper used several different criteria to evaluate sites for a new or expanded tailings storage facility at its Bingham Canyon copper mine. The criteria, which were based on current engineering practices and best available technology, were divided into three categories: technical, logistical and economic.*



BACKGROUND

The Bingham Canyon open pit copper mine is located in the southwestern United States, 50 km southwest of Salt Lake City, Utah. Copper mining and processing operations have been carried out in this area since the early 1900s. In 1993, Kennecott determined that the existing tailings dam should be upgraded to comply with current engineering standards and provide storage capacity for the next 25 to 30 years.

Siting and construction of an expanded tailings dam meant placing fill material in wetlands or other waters, which required a federal government permit. As well, compliance with the US National Environmental Policy Act required an environmental impact statement for the project, including an assessment of alternative sites.

APPROACH

Kennecott evaluated alternative sites by investigating and establishing operating standards and maximum thresholds. Environmental and regulatory factors were also considered during the screening process. The criteria used to review each site fell into three categories: technical, logistical and economic.

Technical criteria

Technical criteria, which were based on current engineering practices and best available technology for constructing and operating tailings facilities, included:

- **Storage capacity for 1.9 billion** tonnes of tailings. Since the existing dam could hold only 300 to 400 million tonnes, the proposed expansion or new tailings facility needed to accommodate 1.5 billion tonnes.
- **Upgrade of existing dam embankment** to account for dynamic stability considerations. Factors included existing embankment conditions, suitability of dewatering, location and design requirements for reinforcing berms or embankments, and the availability of suitable construction materials.
- **A rate of rise** no greater than an average of 4.3 m per year. Factors included the time for tailings to settle and form a suitable foundation, the time for pore water pressures within the embankment and foundation to dissipate, the amount of water required and available to manage tailings processing and slurry transport, and the method of tailings deposition.

Table 1. Factors Used in Comparison of Alternatives
(amounts in US dollars)

FACTOR	ONE POSSIBLE ALTERNATIVE
Storage Capacity	300–400 million tonnes in existing impoundment; 1.5 billion tonnes in expansion
Rate of Rise	Average of 2 to 2.5 metres per year
Footprint of Tailings Impoundment/ Embankment	1 500 hectares
Dam Height	75 metres
Seismic Upgrade	Yes
Liners	Natural clay liner
Capital Cost (millions 1992)	$510
Reclamation Costs: Existing and New Impoundment (millions)	$42.3
Operating Costs (millions)	$451.2
Operating Costs ($/tonne)	$0.24 — approximately 50% higher than current operating costs
Surface Water	Reroute C-7 ditch
Groundwater Recharge and Discharge	Groundwater discharge area underlain with Bonneville clay
Threatened and Endangered Species and Wildlife	No resident threatened or endangered species; snowy plover has been sighted in the area; possible casual overflight and forage by peregrine falcon and bald eagle
Hazardous Materials	Phosphogypsum stack remains as is and will not be sealed under tailings

- **Embankment design** based on location and site conditions, foundation characteristics, the potential for seismic activity, and permit and environmental conditions. Criteria included:
  - maximum dam height
  - embankment section requirements
  - materials requirements
  - operational parameters
  - site and foundation conditions

Logistical criteria

Logistical criteria were based on current practices and best available technology, thresholds for storing tailings, and standards for constructing and operating a tailings dam. Criteria included:

- **Availability of materials** for embankment and ancillary construction activities. Construction required sufficient on-site borrow material and/or cycloned tailings for the life of the project.
- **Reliability**, or the level of difficulty of maintaining facility operations. The operation required a design that minimized maintenance, downtime and disruptions in tailings delivery or embankment construction. The following components relate to reliability:
  - *Pumping:* gravity flow for tailings transport and distribution is preferable to pumping because it requires minimal maintenance, has lower failure potential, and is significantly more reliable. Pumping requires additional systems such as booster stations and overflow retention basins. These add to the potential risks, increase construction costs and reduce reliability. Furthermore, higher pressures and velocities—in combination with the increased erosion potential of pumped slurries—lead to higher maintenance and operation costs.
  - *Length of delivery:* longer delivery increases the possibility of a system breakdown. A redundant delivery system, which can involve substantial logistical planning and additional cost, was considered.
  - *Liners:* synthetic liners are relatively expensive and somewhat unreliable when installed over unstable foundation material, and diminish in effectiveness as the size of the area increases. Consequently, under certain soil and aquifer conditions, clay liners may be required to prevent tailings water from infiltrating groundwater. For instance, the naturally occurring clay existing beneath a site can serve as a liner.

Economic criteria

Economic criteria included the costs of upgrading, constructing and operating the tailings facility. Factors considered were type and length of tailings delivery system; maintenance; number of dams operating concurrently; the length and type of water recovery system; length and rate of rise of embankment; and labour requirements.

Kennecott did not use investment capital and operating capital costs to distinguish one alternative from another. Long-term operating costs that were more than double the existing operating costs were considered infeasible.

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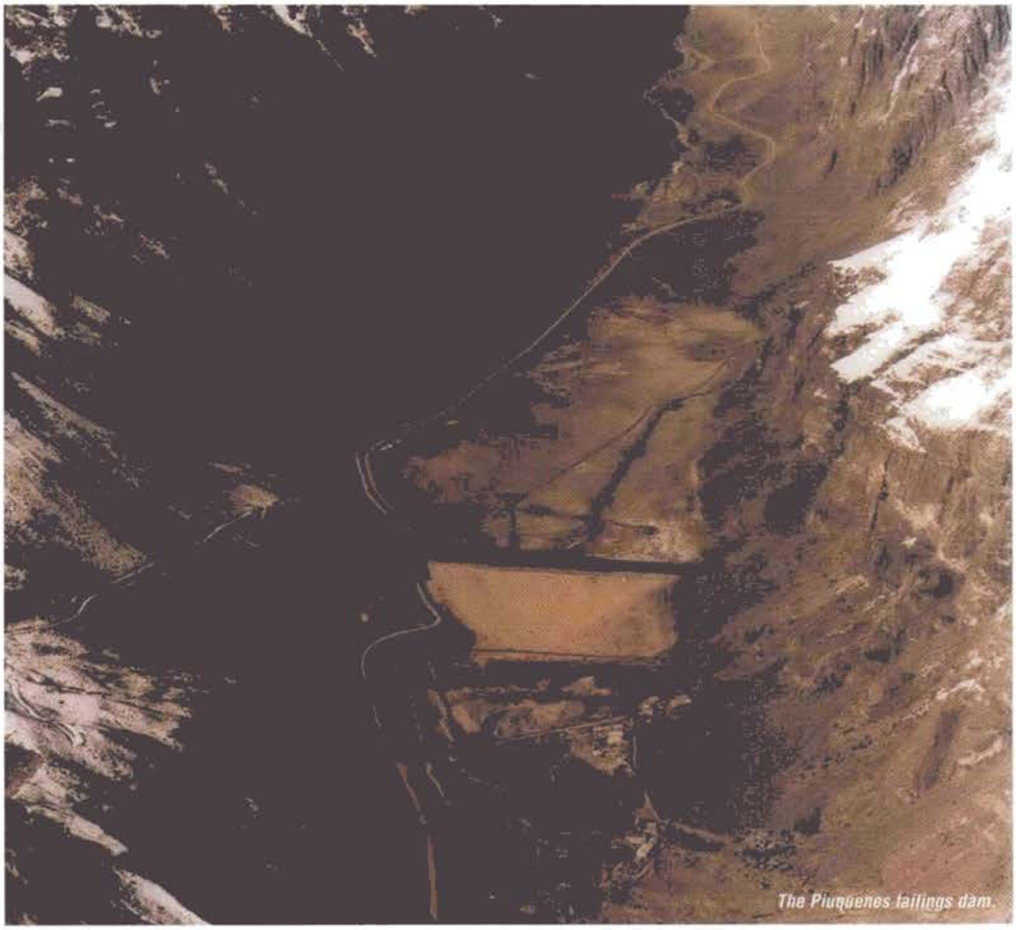
Site Selection at Codelco-Chile

SUMMARY: *Since Codelco opened the Rio Blanco mine in 1970, average production has more than tripled to 34 000 tonnes of copper per day and will double again around the turn of the century. As a result, the company has exhausted capacity at the original tailings dam, is about to reach capacity at the second and is currently constructing a third. Site selection for each tailings dam was based on the attributes and/or risks of each location.*


The Piuquenes tailings dam.

BACKGROUND

The Rio Blanco mine is situated at the upper end of the Aconcagua basin, north of Santiago, at about 3 000 m above sea level. The Aconcagua valley is one of Chile's most fertile and developed areas. Codelco, one of the world's largest copper producers, is currently producing ore at a rate of some 34 000 tonnes per day. The mine has three tailings dams at various stages of their lives: Piuquenes, Los Leones and Ovejería.

Piuquenes and Los Leones are subject to the risks associated with being located on a major river system in a mountainous, seismically active area. These risks include:

- static or dynamic instability;
- massive seismic disturbance that could obstruct the diversion canals or create high waves in the reservoir;
- extraordinary floods due to rainfall or snow melt;
- variation in hydrogeological behaviour of the system; and
- dam erosion.

Codelco used several measures to control these risks, including site selection, finite element analysis to ensure the dam walls could withstand dynamic instability, additional freeboard to accommodate extraordinary floods, security spillways and vegetative cover to prevent erosion.

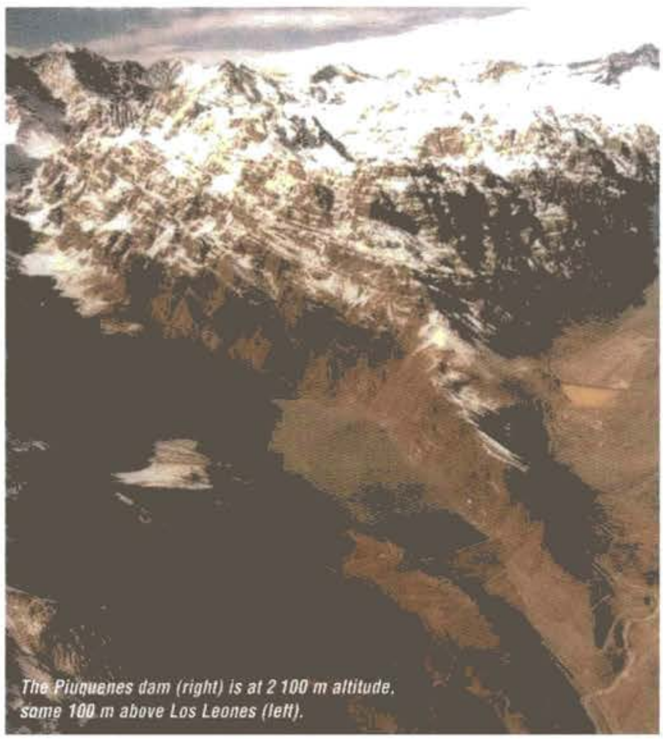
SITE SELECTION

Piuquenes: 1970–1980

Codelco built the Piuquenes dam to handle tailings generated during the first decade of the mine's life, when production averaged 10 000 tonnes per day. The dam, situated 2 100 m above sea level, was built with cycloned sand to a height of 57 m. To prevent sand saturation, the dam was located on the pervious material of the Rio Blanco streambed. An aqueduct used to decant clear water when the dam was operating now drains groundwater from the valley to prevent a rise in the saturation level. The aqueduct also has a series of pumps that can lower the groundwater level in a matter of days. Although Piuquenes currently lacks the facilities required for abandonment, future adjustments to guarantee stability and environmental protection are expected to prepare the dam for closure with minimum supervision.

Los Leones: 1980–1999

The Los Leones tailings dam was built on a tributary of the Rio Blanco at an altitude of 2 000 m. The dam, which will ultimately reach 160 m in height, lies in a valley filled with a sequence of glacial moraines and alluvial and colluvial material that has alternate pervious and impervious layers. The dam core is situated on a trench cutting through the upper pervious layers. The impervious zone on the upstream slope is equipped with a filter and drain system. Los Leones is in the final operational phase and will be used until mid-1999. Thereafter, it will serve as an emergency reservoir to complement the new dam, Ovejería.



The Piuquenes dam (right) is at 2 100 m altitude, some 100 m above Los Leones (left).

Ovejería: 1999–

Mine production will increase to 64 000 tonnes per day from December 1998. After mid-1999, tailings will be transported to the Ovejería dam through an 85-kilometre-long concrete channel, which includes 23 km of tunnels. Ovejería, located about 45 km north of Santiago at 700 m above sea level, is designed to accommodate 2 000 million tonnes of tailings, the expected future production from Rio Blanco.

Ovejería will be built with cycloned sand to an estimated height of 110 m. A 16-metre-high starter dam wall will consist of 1.1 million m³ of borrow material. To prevent dam saturation, the dam will be equipped with a foundation drainage system and an impervious membrane on the upstream slope.

The Ovejería dam site was selected based on the following attributes:

- no permanent flows discharge into the reservoir;
- most of the basin is covered with low permeability soils;
- groundwater lies deep under the site and is isolated by impervious soils;
- the flooded site has very low agricultural value; and
- the reservoir is not exposed to avalanches or massive landslides.

The reservoir design includes a contour channel to divert tributary flows downstream. Extraordinary floods that exceed dam capacity and are not diverted by the channel will be collected in a system of towers with concrete gates that act as variable crest elevation spillways. The floodwater will then flow along a 2-kilometre-long tunnel with 25 m³ per second capacity and be discharged into a downstream channel that leads to the Chacabuco streambed. The reservoir operation is conceived with a permanent water dam capacity estimated at 15 million m³.

CONCLUSIONS

The following observations can be made about the siting process at Rio Blanco:

- There are no longer any suitable sites for tailings dams in the mountainous area near the mine. Tailings must now be transported long distances to a new dam site at increased cost.
- Siting in the central valleys improves the ability to manage risks, especially with respect to human safety and environmental impacts.
- The permitted capacity at the Ovejería dam will accommodate all future production at Rio Blanco.

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Subaqueous Tailings Disposal: Results of the MEND Program

SUMMARY: *The Canadian Mine Environment Neutral Drainage (MEND) program examined the applicability of underwater disposal for acid-generating tailings derived from sulphide-rich ores. The research focused on a design for permanently flooded tailings impoundments that would compensate for the constant presence of water and the risk of failure. The program culminated in the development of a guide containing information on the chemical and physical factors affecting the design, operation and closure of a subaqueous disposal facility.*

Subaqueous tailings disposal facility at Louvicourt Mines, Aur Resources Inc., Quebec, Canada.

BACKGROUND

Orebodies in which metals such as nickel, copper, zinc or lead occur as sulphide minerals are among the most common sources of non-ferrous metal. The tailings created by mining and processing these ores contain unwanted sulphide minerals such as pyrite (iron sulphide). These reactive tailings oxidize slowly when exposed to air and moisture to produce sulphuric acid, yielding what is called acid mine drainage.

The disposal of fresh sulphide-rich tailings under water inhibits acid generation and the associated release of metals into the environment. However, the potential deterioration of the quality of the receiving water and the environmental impact of excessive concentrations of dissolved metals are causes for concern. Research conducted since 1988 as part of the MEND program has addressed these concerns.

THE MEND PROGRAM

Research consisted of three major phases:

- Preliminary studies to determine the effectiveness of subaqueous disposal at several sites.
- More detailed geochemical studies at two specific sites.
- Development of design guidelines for an application guide.

A major component of the research focused on geochemical mechanisms that limit the leaching of metals from subaqueous tailings impoundments.

A communication program kept the various stakeholders informed as the project evolved. This was a critical step in obtaining public and regulatory endorsement. Furthermore, peer reviews were conducted to examine progress, maintain focus and enhance the research methodology.

Although an assessment of the use of natural lakes for tailings disposal was considered, time and resource constraints led to a focus on the design of constructed, permanently flooded tailings impoundments. Such facilities require special design considerations to accommodate the permanent presence of water and to protect against the risk of failure. Consequently, a generic design guide was developed to incorporate the chemical and physical factors affecting design, operation and closure.

Entitled *Design Guide for the Subaqueous Disposal of Reactive Tailings in Constructed Impoundments* (MEND Report 2.11.9), the guide provides general information on:

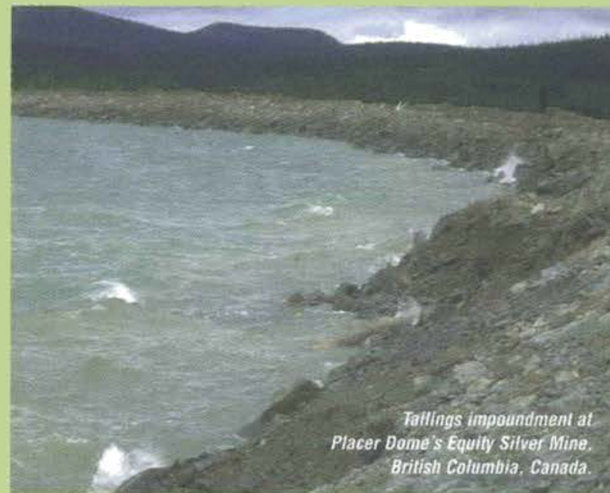
- geochemistry of acid mine drainage and trace metals;
- data collection and database development;
- chemical considerations for tailings impoundment design;
- physical considerations for tailings impoundment design;
- overall monitoring of tailings impoundments; and
- closure management and options.

Some 30 reports and scientific papers arising from the MEND program support the guide's database. Potential sites can be pre-screened for the applicability of subaqueous disposal using the guide's logic flowcharts. Thereafter, independent consultants should be retained to develop a proper and complete tailings system design.

ENVIRONMENTAL BENEFITS

The placement of reactive tailings under a water cover can provide a very stable geochemical environment. With proper and thorough engineering and sound management, subaqueous tailings disposal systems are one of the best technologies available to prevent acid mine drainage.

Note: *MEND was a cooperative research program financed and managed by three partners: the Canadian mining industry, the Government of Canada and Canadian provincial governments. The C$17.5 million program focused on finding solutions to the long-term management of reactive tailings, waste rock and mine adits. Currently, technology transfer aspects of this work are continuing under a program called MEND 2000.*


Tailings impoundment at Placer Dome's Equity Silver Mine, British Columbia, Canada.

Field Verification at Equity Silver

As part of the MEND design guide, a flowchart and algorithm integrating the variables, both fixed and controllable, were developed. These provide an iterative process for deriving an optimum design for impoundment configuration on a site-specific basis.

Field verification of the MEND research was completed at Placer Dome's Equity Silver Mine tailings impoundment located in British Columbia, Canada, where subaqueous disposal was used until the site closed in 1994. The study examined the physical and chemical characteristics of the sediments at various locations in the impoundment. Field work included an analysis of historical data, measurements of water depth throughout the impoundment and visual observations of the effects of wind on the water-sediment interface. The most important control factor was water depth since most of the other parameters were fixed by nature of the design. The study verified predictions of the algorithm.

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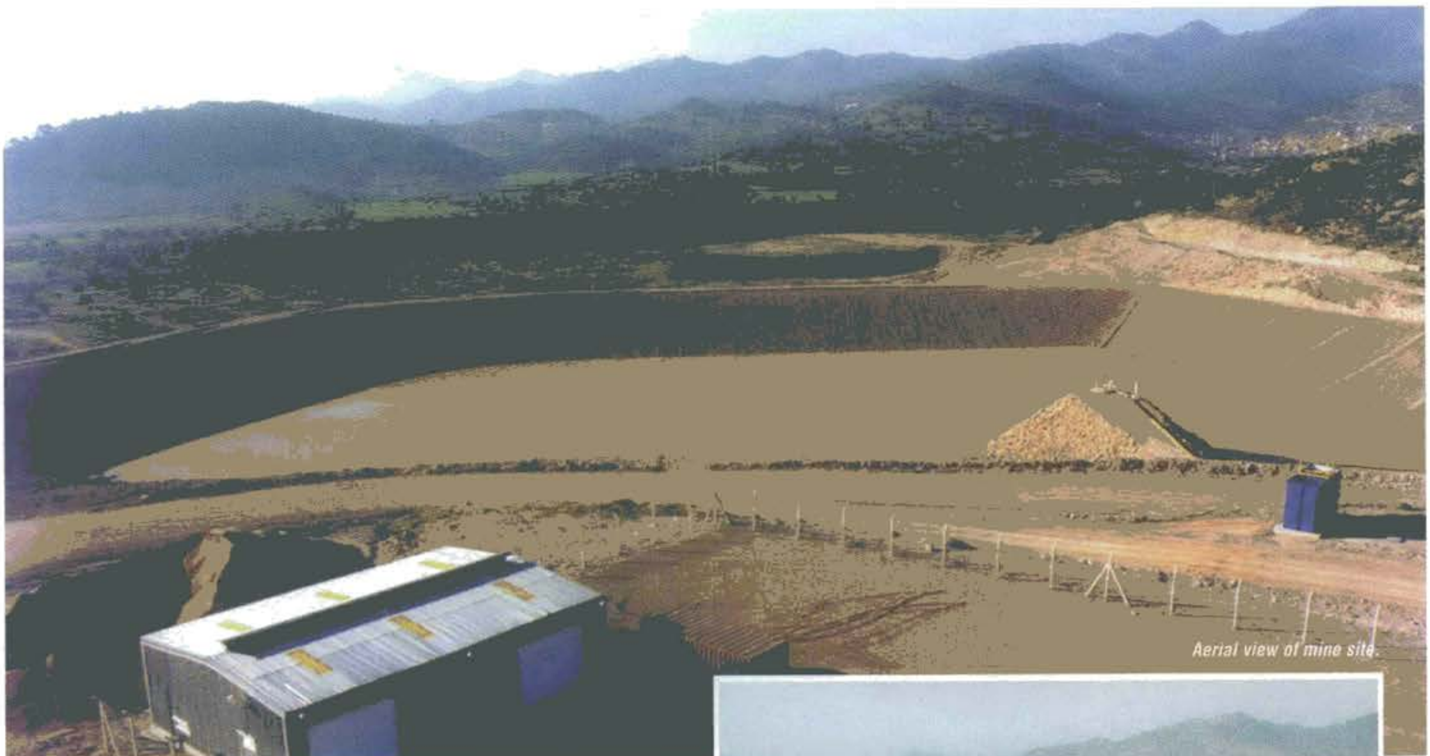
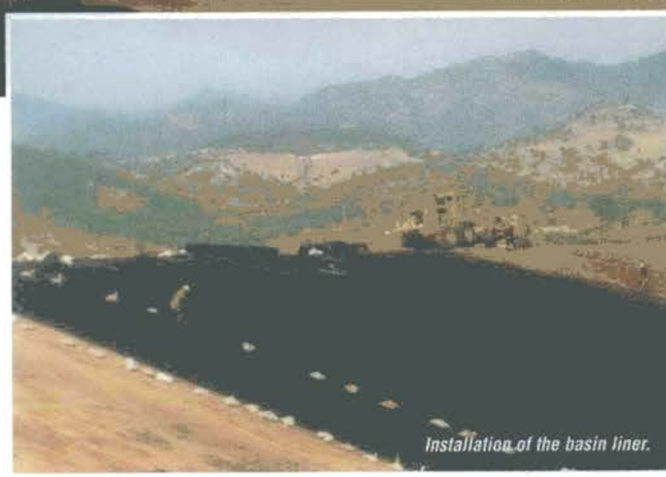
Double Safety System at the Ovacik Gold Mine

SUMMARY: *The combination of cyanide destruction and composite-lined containment used to manage wastes at the Ovacik gold mine is the first of its kind. The mine's tailings management facilities include an Inco detoxification plant that treats the cyanide solutions and a tailings dam with a composite liner of high-density polypropylene sandwiched between two layers of clay. An independent audit on the project showed that the project design met both national and international environmental standards.*



Aerial view of mine site.



Installation of the basin liner.

BACKGROUND

The Ovacik gold mine is owned by Eurogold Madencilik A.S., a joint venture of Normandy La Source of France and Inmet of Canada. The mine is situated 100 km north of Izmir on the west coast of Turkey, some 15 km inland from the Aegean Sea. Annual ore production of 300 000 tonnes from both open-pit and underground mines is processed to recover about 100 000 ounces of gold. The principal environmental challenge is to manage the production of solid and liquid waste containing cyanide and heavy metals.

The mine is located in an area of known seismicity where peak ground accelerations of 0.4 G[1] have been recorded by the Turkish Earthquake Research Institute. This corresponds to a 1-in-500-year event. Information derived from published Turkish data and the British Geological Survey catalogue of instrumented earthquakes indicates the expectancy of earthquakes to be a 0.6 G event about every 3 000 years, 0.4 G every 500 years and 0.2 G every 100 years.

APPROACH

Gold Recovery

The process used to extract gold from ore uses cyanide as a principal reagent. This process is the most common method used for gold extraction worldwide. After recovery of the gold, the residual solid tailings and leach solutions are discharged into the tailings management facilities.

The solutions are treated in an INCO cyanide destruction plant. The INCO process has three stages:

- Sulphur dioxide and air are added to oxidize the weak acid dissociable (WAD) cyanide, and copper sulphate is added to catalyze the oxidation and precipitate the more stable iron cyanides in soluble cupric salts.
- Ferric sulphate is then added to precipitate arsenic and antimony and to suppress any residual iron cyanides.
- More ferric sulphate is added to a recycle stream of decant liquid to further reduce antimony. The concentration of cyanide discharged with the tailings is reduced to less than 1 ppm (1 mg/L) by this INCO process.

Tailings Dam Design

The tailings dam was designed in accordance with the Turkish Earthquake Code and was approved by Turkish State Hydraulic Works (DSI). It is designed to accommodate an earthquake of 0.6 G acceleration. The principal features of the tailings management facility are the two compacted rockfill embankments that provide storage for 2 million m^3 of tailings. The basin is lined with a composite lining system consisting of 500 mm of compacted clay overlain by 1.5 mm of high-density polypropylene, 200 mm of compacted clay and 200 mm of gravel. This composite lining system prevents seepage. Other construction features include:

- a decant water system in the dam to recirculate excess water to the plant
- under-drains to prevent water build-up and liner damage
- surface water diversion to prevent wall erosion

The INCO SO_2/air detoxification plant that treats the waste prior to deposition in the tailings dam provides additional protection. The plant reduces the cyanide concentration to internationally acceptable levels and precipitates heavy metals as insoluble hydroxides (in some jurisdictions, such waste may be discharged directly into surface water bodies). Furthermore, the double liner system (clay-geomembrane-clay) makes the dam as leakproof as possible.

Tailings Construction Management

The tailings embankments were constructed in accordance with Turkish dam construction standards as set out by the DSI. An engineer from DSI supervised all construction. Rock was placed in one-metre layers that were compacted by eight passes of a 15-tonne compactor. The entire dam was lined with a clay layer in accordance with British Standard 1377. The supplier installed the geomembrane and all joints were pressure-tested according to international standards. All intrusion joints were vacuum-tested. Sections of each roll of membrane and representative sections of the joints were sent for physical testing at an independent laboratory. After installation, Golder Associates, an international consulting firm, carefully inspected the membrane to ensure its integrity. A number of holes and tears (5 mm to 3.5 m) were repaired and retested.

CONCLUSIONS

The meticulous design of the environmental protection measures was the result of an exhaustive two-year review by the Turkish Ministry of the Environment. An independent international consultant carried out an environmental audit on the project and the results showed that the project design met all national requirements as well as the internationally relevant standards for comparable projects. This combination of cyanide destruction and composite-lined containment is the first of its kind in the world. As a result of this combined safety system, the risk of contamination of local groundwater is very low.

1. G: Newton's gravitational acceleration constant

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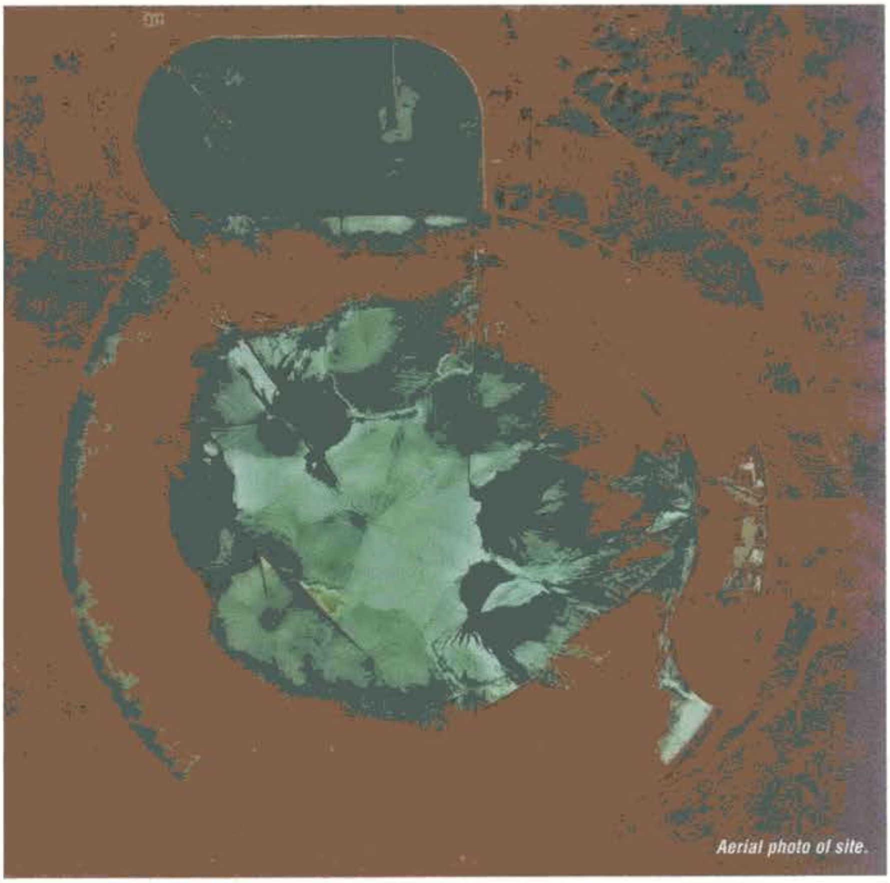
WMC's Central Discharge Tailings Storage Facility

SUMMARY: *To cope with tailings production of up to 15 million tonnes per year at the Mt. Keith nickel operation, WMC Resources Ltd. (WMC) designed a circular tailings storage facility that includes features such as a fully automated tailings pump station, open drains to collect decanted water and a stormwater storage area. The new facility has several advantages over the former paddock-style system, including lower costs, gentle side slopes that more closely resemble the natural landscape and a reduction in saline seepage of up to 90%. Specially designed software is expected to help monitor the system, while several mechanical backups and controls will minimize environmental damage from spills or ruptures.*



Aerial photo of site.

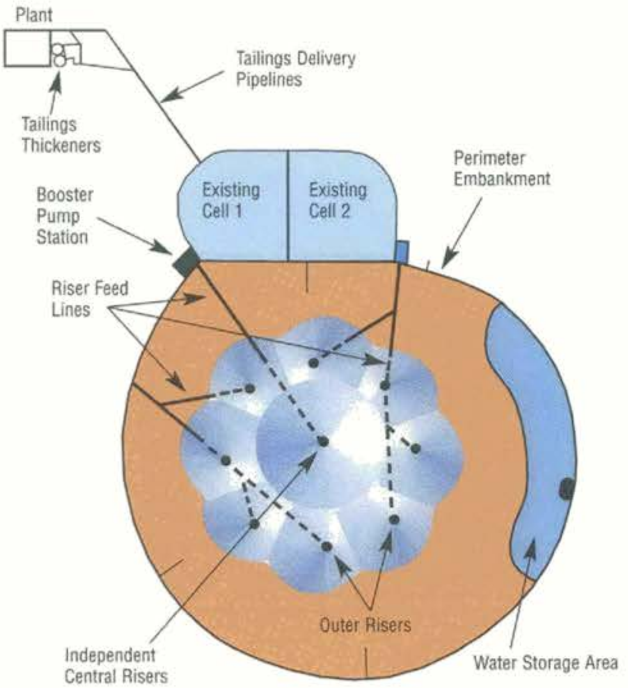


Figure 1: Diagram of the Centralized Discharge Tailings Storage Facility

BACKGROUND

WMC, a major producer of gold and base metals, mines a disseminated nickel sulphide ore from an open pit at the Mt. Keith operation in Western Australia. The mine currently produces 11.5 million tonnes of tailings per annum. It is situated in a semi-arid region with an average annual rainfall of 220 mm and an average annual pan evaporation of 3 800 mm.

Faced with the operational limitations and potential environmental risks of a paddock-style system, WMC set out to develop a new storage facility with the flexibility to accommodate planned tailings production of up to 15 million tonnes per annum.

CENTRAL DISCHARGE TAILINGS STORAGE FACILITY

The 250-million-tonne tailings storage facility (TSF) was conceived after an intensive nine-month field and laboratory investigation program. The circular TSF has an average diameter of 4.6 km and covers approximately 1 700 ha. Natural surface elevation drops 12 to 14 m from west to east across the TSF. Figure 1 illustrates the main features of the design, including:

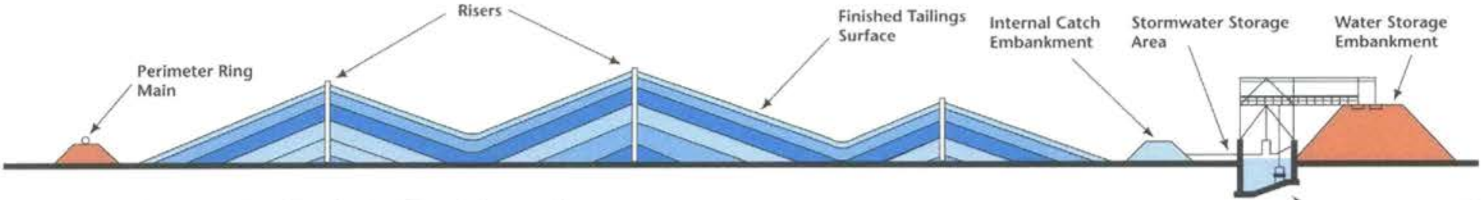


Figure 2: Schematic East/West Section Through Storage Area
Exaggerated Vertical Scale

- a 14-km perimeter embankment wall, which carries the tailings distribution lines;
- a fully automated three-train, two-stage tailings pump station capable of delivering tailings to any riser at up to 3 000 m^3 per hour;
- nine internal risers (between 35 and 45 m high) from which the tailings are discharged to form low conical mounds;
- buried underdrainage immediately surrounding each discharge riser;
- open drains throughout the facility to collect and convey decanted water;
- a stormwater storage area to separate stormwater from tailings mounds; and
- a concrete decant sump.

OPERATION

A number of mechanical backups and controls are provided to minimize environmental damage from spills or ruptures. These include a contingency tailings delivery line around the perimeter of the facility, a buffer zone, bypass lines, dump valves, redundant risers and 24-hour monitoring using telemetry. The TSF is unmanned and the one-off construction means that the only future earthworks required will be ongoing maintenance of open-drainage channels.

MONITORING

The Mt. Keith operation has a regular auditing program to ensure compliance with commitments and operating conditions. To help monitor the storage, WMC developed a software package called TMOD/32. The package allows direct comparison between predicted and actual mound development using aerial photography. It will assist greatly in the correct management and development of the mounds and the collection of tailings, supernatant water and stormwater run-off.

BENEFITS

The new facility was commissioned in December 1996 and has been operating continuously since then. In all aspects, the performance of the storage to date has either met or bettered initial goals and predictions. The design won an engineering excellence award from the Institution of Engineers Australia in 1997. The new facility's benefits are as follows:

- The centralized discharge storage results in a mounded structure with gentle side slopes (about 3%), which are more in keeping with natural features than steep-sided paddock structures. The new storage can be rehabilitated to blend less obtrusively into the existing landscape.
- Saline seepage to the groundwater can be reduced by as much as 90% relative to a comparable conventional storage system because there is no permanent ponding of saline water. Only rainwater may be stored in the water-storage area for a limited period of between three and six months.
- Tailings storage costs are reduced by about 60% relative to a conventional paddock system over the life of the mine.
- Since no water is stored on or within the tailing storage area, the tailings have improved long-term structural stability and erosion resistance.
- The risk management of the TSF is superior to that of paddock-type structures. Because water is contained in the tailings and collected in the decant pool in more conventional structures, the risks of wall instability and tailings and water releases are greater.

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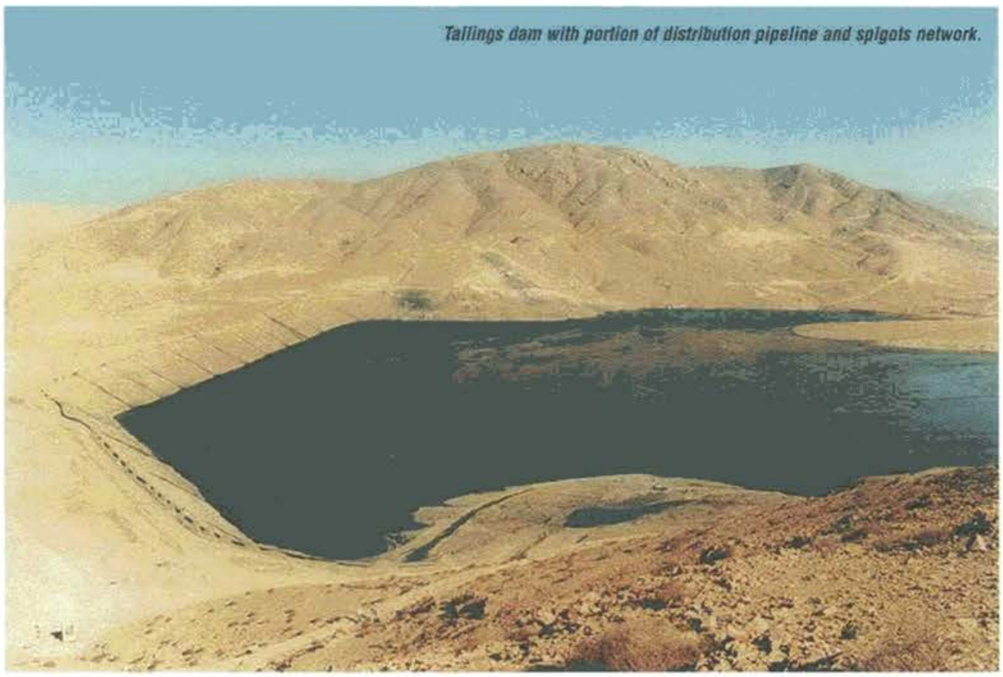
ICME
Member

Conserving and Protecting Scarce Water Resources: Candelaria Copper

SUMMARY: *An outstanding feature of the Candelaria copper mining project in Chile is its tailing impoundment/cut-off wall system. The system is specifically designed for the conservation and protection of the scarce water resources of the Copiapó River valley. The system prevents water used in the mine and concentrator facility from being released to the environment. Instead, all water used in the project is recycled within the project itself.*

BACKGROUND

The Candelaria project is one of the largest private undertakings to date in Chile, with an investment totalling US$900 million. The Compañia Contractual Minera Candelaria (CCM Candelaria) is a joint venture of Phelps Dodge Corporation of the USA and Sumitomo Metal Corporation of Japan. Facilities include the copper mine, a 60 800-tonne-per-day concentrator and a port facility. The mine, which has an estimated life of 20 years, is located in the Sierra El Bronce mountain range at an elevation of 600 m. Operations were inaugurated in March 1995.



Tailings dam with portion of distribution pipeline and spigots network.

With an average annual rainfall of only 21 mm, the project area is considered a "normal desert climate." As a result, diversity and abundance of plant and animal species are low. No plant or animal species suffering from any conservation status problems are found in the area, nor are there any archaeological remains or signs of past or present agricultural activity within the boundaries of the facility.

The primary potential environmental impact of the project is on the region's scarce water resources. With such an arid climate, it is important to conserve water and to prevent potential pollution of the Copiapó River valley. The water that is found within the valley is used primarily for agricultural irrigation, as potable water for cities and towns, and for industrial activities.

ENVIRONMENTAL MANAGEMENT

The Candelaria project is designed to include all technically feasible measures required to prevent any liquids used in the mine and concentrator facility from being released to the environment. This goal is achieved by catching all seepage, spills and runoff in trenches, launders and drains, and by recirculating all potential effluent back to the processing facility. Excellent water conservation is achieved through the inclusion of:

- two tailing thickeners;
- ceramic drying filters for the concentrate;
- spill collection systems at the grinding and flotation areas of the concentrator;
- use of pipelines for conveying all liquids;
- a wastewater treatment plant;
- a temporary containment pond; and

- a system of flood protection consisting of dikes and canals.

TAILING DISPOSAL SYSTEM

The following general design criteria were established for the tailing impoundment/cut-off wall system:

- Optimize the use of water by recirculating all possible process water back to the processing facility.
- Provide protection of the aquifer of the Copiapó River valley through collection and recirculation of process water and by minimizing the use of fresh water taken from the aquifer.

Concentrator plant and ancillary facilities.

Tailings produced in the concentrate facility are thickened to 50% solids content and transported to the disposal area by pipeline. The slurried tailings are then deposited from several positions into the impoundment basin, forming moist sand beaches.

A number of studies were performed to provide environmental design parameters for the tailing disposal system relating to the following features:

- seismic strength;
- capacity to withstand flood events without damage and to collect runoff water and use it for processing;
- capacity to collect and reuse all tailings water that seeps through the dam;
- operating procedures that ensure the tailings beaches will remain moist to prevent wind erosion;
- a pumping system that will continually reclaim and recycle water back to the processing facility;
- control of the decant pond to ensure optimum recirculation of water; and
- site-abandonment management systems designed to minimize environmental risk after closure of operations.

The major component of the 450-hectare tailings disposal facility is the dam constructed of mine waste material. It is a prism-shaped structure with an internal permeable zone to act as a tailings filter. Construction is being performed in several stages as the demand requires using a downstream construction method. The starter dam is 800 m long and had the capacity to contain the tailings from the first year of operation, or 15 million tonnes. The final dam height will be 172 m with a length of 1.8 km and a capacity of more than 350 million tonnes. A freeboard of at least 4 m will be maintained to accommodate any possible influx of flood water from rainfall runoff. In the post-operational period, the freeboard will be increased to 5 m and flood control and monitoring systems will be installed.

Cut-off Wall, Tunnel and Shaft Arrangement

A cut-off wall, tunnel and shaft arrangement collects any seepage through the dam and channels it to a sump from which it is pumped back to the processing facility. The cut-off wall features an impermeable membrane in a trench keyed into the bedrock. Since this will eventually be covered by mine waste, a tunnel (1.8 m wide by 2.3 m high) was constructed to drain water collected by the cut-off wall. The tunnel leads to a concrete shaft at the bottom of which is a sump fitted with a pumping system. A diesel-powered back-up unit ensures reliability. Water collected in the cut-off wall system is checked regularly for quantity and quality.

RESULTS

The extensive water-resource monitoring program located throughout the Copiapó River valley has confirmed the expectations of the baseline study and the effectiveness of the tailing impoundment/cut-off wall system in preventing pollution and in maintaining both surface and ground water quality in the region.

In summary, the Candelaria project avoids releasing industrial effluent to the environment by using a seepage collection system to intercept and recycle water back to the processing facility. Moreover, recycling minimizes the need for additional fresh water. The overall environmental impact of Candelaria will be minimal due to the conservation and mitigation measures included in the project.

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ICME Member

Quality Control and Quality Assurance at the Musselwhite Mine

SUMMARY: *A key feature of tailings dam construction at the Musselwhite mine was the integration of experienced design and construction teams. The design consultant's engineers worked in the field alongside the owner and contractor and were therefore able to respond immediately to challenges such as difficult or varying soil foundations. This collaboration ensured quality control and design compliance, fostered an overall commitment to quality and integrity, and allowed the project to be completed on schedule despite a short construction season.*

BACKGROUND

The Musselwhite gold mine is located about 500 km north of Thunder Bay in a remote section of northwestern Ontario, Canada. In 1996, Placer Dome Canada and TVX Gold Inc. completed a feasibility study and started construction.

Final (operational) tailings system.

The region is generally flat-lying with numerous streams, lakes and ponds, and limited natural areas for tailing disposal. The location chosen for the tailings dam encompassed a shallow pond with a clay and peat bottom, bordered on one side by a glacially deposited linear mound.

ENVIRONMENTAL OBJECTIVES

As the mine is located in an environmentally sensitive area with a valuable trout-spawning lake located only 500 metres from the main tailings dam, the key environmental objectives were to ensure that sediment, seepage and overflow did not reach the lake during the construction and operation of the tailings system. To help meet these objectives, storm events and groundwater flow were modelled to determine pond capacity and foundation soil requirements. Baseline, construction and operation monitoring programs for surface and groundwater were also established.

DESIGN AND CONSTRUCTION

The tailings dam has a relatively complex design. Three till core dams fill gaps in the esker and a till blanket in the clay pond bottom prevents seepage. The design was subjected to independent technical reviews and a full risk assessment prior to construction. These investigations did not identify any major concerns, but prompted some additional evaluations and increased the confidence in the overall design of the facility.

The owner and the contractor developed a partnership based on quality control and design compliance. The owner assumed all risk for productivity, including difficult unforeseen conditions or sensitive construction techniques.

Table 1. Quality Assurance and Quality Control: Musselwhite Project

	Sampling/Inspection	Routine Testing on Site	Other Testing	Specification	Testing Frequencies
Engineered Fill					
Borrow Sources	Test pitting, inspection of stockpile	Grain size, water content and compaction test			Grain size and Proctor compaction tests at a rate of 1/5 000 m³ average
Fill Placement	Grade and dimensions, segregation of fill, material handling, subgrade preparation, sampling and construction equipment and procedures	Density test, water content and grain size	Corrosive potential test	95% of Proctor Dry Density, gradation for various material zones, lift thickness and compaction	Field density test at a rate of 1/200 m³ to 1/1 000 m³
Foundation Inspection	Subgrade preparation, dewatering and compaction	Field density test, water content and grain size		95% of Proctor Dry Density	Field density test for all sites inspected
Geotechnical Investigation	Test-pitting and boreholes	Grain size, water content and classification tests	Shear strength and consolidation		
Concrete	Trial mix, sampling of sand and aggregate	Test cylinders, air content, slump and compressive strength		As specified for various grades	As requested

The contractor was paid on a cost-reimbursable basis.

The quality control and quality assurance programs summarized in Table 1 were based on experience gained from similar projects completed in Papua New Guinea, Australia, Chile and the United States. The use of experienced staff was critical to completing the work during a construction season cut short by extreme winter weather conditions.

The design consultant's field engineers were ever present at the construction site, working with the owner and the contractor. Whenever difficult or varying foundation soils were encountered, the engineers made decisions in the field in accordance with the design criteria. This immediate response ensured construction excellence and design compliance without compromising the overall project schedule.

CONCLUSIONS

The elimination of adversarial roles, the integration of the design and construction personnel, and the sharing of knowledge fostered a commitment to quality and integrity and ensured that the objectives of all stakeholders were achieved in a synergy of quality, safety and environmental protection.

Construction of Dam B.

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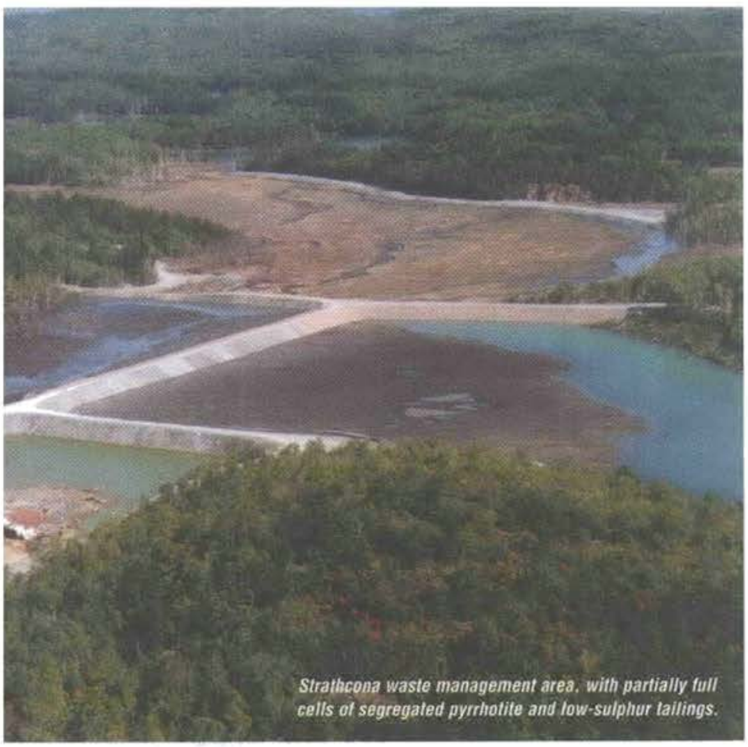
ICME Member

Operating and Monitoring a Tailings Area: A Falconbridge Example

SUMMARY: *Falconbridge's tailings management system consists of several procedures designed to prevent failure and provide an appropriate response if incidents do occur. The mill management department, supported by the company's environmental and technical services departments, is responsible for the tailings area. Personnel with specific skills conduct routine inspections of the area on a regular basis, noting any potential problems. The company also performs risk assessments and environmental audits on both new and existing tailings facilities.*



Strathcona waste management area, with partially full cells of segregated pyrrhotite and low-sulphur tailings.

BACKGROUND

Falconbridge Limited operates four underground mines, a mill and a smelter from its operations located in Sudbury, Ontario, Canada. The mill, situated at the Strathcona Mine some 50 km northeast of Sudbury, processes 10 000 tonnes of nickel-copper ore per day. Since 1968, the mill has produced a total of about 30 million tonnes of tailings.

Tailings are deposited hydraulically into a 100 ha basin located several kilometres from the mill. Water effluent from the tailings area is treated with lime to adjust the pH prior to discharge. Two tailings streams are produced: a final one with low sulphur content, and a pyrrhotite stream consisting mainly of iron and sulphur. The final tailings are further split into a slimes fraction, which typically contains less than 1% sulphur, and a coarse fraction, which is used as backfill in the underground mines.

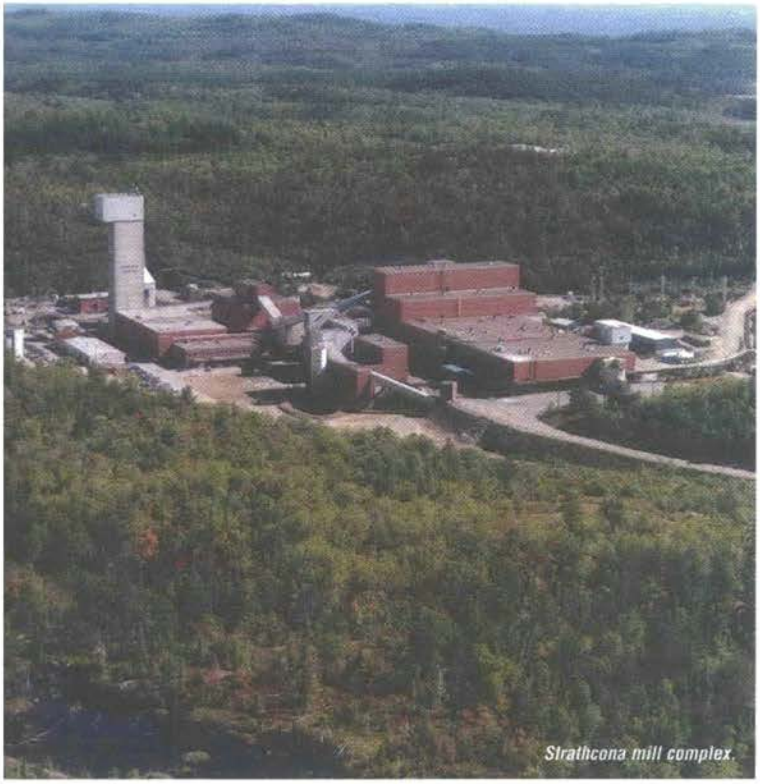
TAILINGS DEPOSITION

Since 1994, efforts have been under way to reduce acid mine drainage (AMD) by changing the operation of the tailings area. For example, pyrrhotite tailings are now deposited with a cover of low-sulphur slimes by using waste rock to construct segregated cells (or compartments) within the dam. This reduces the area of high-sulphur tailings exposed to the atmosphere, and therefore oxidation, by at least 50%. The tailings also remain saturated, preventing oxidation and acid generation. In the near future, as part of the closure plan, the pyrrhotite tailings will be deposited into the open-water section of the tailings area by subaqueous disposal. The exposed tailings and waste-rock dikes will be covered with a two-metre layer of low-sulphur slimes.

ENVIRONMENTAL MANAGEMENT

Responsibility for the active tailings area and pipelines rests with mill management. A technical services department supports the mill management in day-to-day and long-term requirements by providing engineering, planning and implementation services and maintaining water treatment and containment systems. The company's environmental departments, at both the corporate and divisional levels, provide support for legal requirements and closure planning. A mill environmental supervisor maintains the link between the mill department and the environmental and technical services departments.

The company does not have a dedicated tailings management department because its tailings area is mid-sized (compared



Strathcona mill complex.

with those operated by other Canadian companies) and the containment dams are built at defined intervals. Instead, the responsibility for operating the tailings facility is included in designated job functions.

MANAGEMENT PROCEDURES

The mill environmental supervisor is responsible for ensuring that the following procedures and plans are put in place and reviewed and upgraded on an annual basis:

- a preventative maintenance plan;
- a spill response plan;
- an emergency preparedness plan;
- construction of engineered containment structures and tailings transportation systems;
- a tailings deposition plan;
- an operating manual for all plants and systems;
- documented water management plan;
- identified skill requirements (supporting departments identify individual training needs);
- an environmental monitoring and reporting plan;
- log books or record keeping on operational conditions, maintenance, unusual occurrences and all construction;
- a reporting and information transfer structure;
- documented roles and responsibility matrix;
- the inclusion of tailings closure considerations in all aspects of the operation and maintenance plans; and
- long-term financial requirements

MONITORING

Falconbridge recognizes that, once the plans and procedures are in place, the personnel who undertake the day-to-day operations, inspections and maintenance hold the key to maintaining the integrity of the tailings. They conduct scheduled routine inspections (i.e. daily tailings line inspections, continuous or daily water level and quality monitoring) and look for deficiencies when performing other work in the area. They follow guidelines detailing job requirements, and any deficiencies in skills are reinforced with training. Items of concern are reported to the general mill foreman or the chief stationary engineer in technical services, who then takes appropriate action. The mill environmental supervisor reviews the concern and the action and determines if longer-term changes should be implemented.

As part of the inspection program, the technical services department conducts an annual visual inspection of the perimeter containment structures. The resulting report and recommendations, including identification of areas that need additional monitoring, are issued to the appropriate supervisors. The technical services department also identifies and reviews older containment structures. If necessary, a geotechnical engineering firm is contracted to provide assessments and recommendations for remedial actions or methods of operation required to ensure the dams are stable. Falconbridge performs risk assessments on both new and existing critical facilities to help determine the level of design requirements, maintenance, inspection and documentation. Scheduled environmental audits help ensure that the systems in place are adequate and functioning properly.

RESULTS

All levels of management have endorsed Falconbridge's environmental policy. The guidelines for operating tailings areas, where implementation systems are critical for a safe and environmentally acceptable facility, are an integral part of this policy. A sound and well-documented protocol ensures that the quality of tailings system operation is sustained in spite of changes in operational and management personnel.

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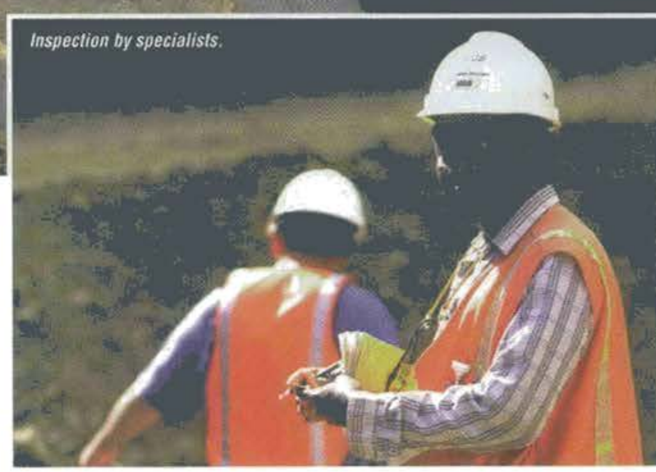
ICME Member

Risk Assessment of Tailings Areas at Noranda

SUMMARY: *In addition to regular inspections of its tailings dams, Noranda Inc. has recently introduced two new levels of risk assessment. In the first stage, independent consultants inspect and rate the condition of each dam, then recommend corrective action and a surveillance schedule. In the second stage, they conduct a detailed technical review, model dam stability under major seismic and rainfall events and, based on this information, determine a rating for each dam.*

Approximately 305 000 m³ of tailings and rock fill were moved and placed at a cost of US$1.5 million to achieve the required stability factor.



Inspection by specialists.

BACKGROUND

Noranda manages four active and eleven inactive tailings areas in Canada and the United States. The company has made financial provisions for reclamation on all sites and developed or implemented closure plans for each location. Operating tailings ponds are inspected on a daily basis by Noranda personnel and on an assigned frequency by an independent consulting firm. Two more levels of tailings review have been added, whereby independent specialists provide an assessment of the physical stability of the tailings and water retention ponds.

APPROACH

In 1995, Noranda retained consultants to provide a visual inspection of all active and inactive tailings and water retention ponds. The consultants developed a 30-point checklist to examine evidence of erosion, surface cracking, movement of material, seepage, vegetation quality, acidic drainage and inadequate water storage and flow conditions. Each dam was then classified as having a low, high or very high failure consequence and rated on a poor-to-satisfactory scale. During this phase, the consultants also recommended corrective measures or further studies where appropriate. All items were placed on a two-year action schedule according to significance and priority. These actions will all be completed in 1998. The consultants also designed an itemized surveillance report and schedule for operating and closed mines. As a result, additional inspections

1996 Tailings Dam Inspection Summary Table*

MINE SITE	DAM NAME	PRELIMINARY DAM CLASSIFICATION**	TYPE OF DAM	GENERAL CONDITIONS OF THE DAM	CORRECTIVE ACTION PLAN COMPLETED
Geco Mine	Tailings Area E3	Low	Low permeability	Satisfactory	N/A
Manitowadge Ontario, Canada	Dam E1-E2 Dam	High or very high	Low permeability	Satisfactory	N/A
	CN2 Dam	Very High	Low permeability with grout curtain	Satisfactory	N/A
	Red Pond Dam	Very high	Low permeability with grout curtain	Satisfactory	N/A
	CN1/CP Bank	Very high	Upstream tailings construction	Poor	September 1998
	Dams CP3 Dam	High	Upstream tailings construction	Some upgrading required	September 1998
	Seepage Collection Facilities	Low	Low permeability with grout curtain	Satisfactory	N/A
Brunswick Mine #12	Tailings Area	Probably very high	Upstream spigotted tailings	Probably not satisfactory	June 1998
	Buffer Pond	High	Low core with grout curtain	Satisfactory	N/A

**Part of the complete 1996 Tailings Dam Inspection Summary Table*
***Consequence Associated with a Failure*

are called for during severe spring runoff, heavy rainfall and seismic events.


Geco Division tailings dam after sloping (August 1998).

A second level of risk assessment has also been initiated. In this stage, independent consulting experts are carrying out a detailed technical review which includes an examination of site geology, dam design and construction records. In addition, dam stability is being modelled under major seismic and rainfall events. This exercise provides a comprehensive rating for each dam structure, taking into account its physical characteristics, the potential consequences associated with a failure, and local community and environmental sensitivities. Special studies and an action plan based on the consultant's recommendations are scheduled and completed on a priority basis.

CONCLUSIONS

This multi-level management program for tailings ponds and water retention dams provides assurance to Noranda's senior management and Board of Directors, as well as to governmental agencies and local communities, that risks are being assessed and managed on an ongoing basis in fulfilment of Noranda's Environment Policy.

The process has also established a schedule for future surveillance and inspection by specialists and will result in the implementation of corrective action plans to minimize risks to the environment and communities.

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ICME
Member

Monitoring Tailings by Telemetry at Rio Algom

SUMMARY: *Rio Algom Limited uses a combination of environmental technology and management systems to monitor operations and manage environmental risks at its six uranium tailings sites. Among the unique features of the plan is a telemetry system that monitors operations, controls additions of reagents, and collects and records data at five separate effluent treatment plants. Relevant environmental information is collected, stored and managed using a sophisticated information management system.*

Quirke tailings facility at Elliot Lake.

BACKGROUND

Between 1956 and 1996, mining in the Elliot Lake region of Ontario, Canada produced more than 135 million kg of uranium and 100 million tonnes of tailings. Now that the mines are closed, Rio Algom is utilizing progressive environmental technologies and management systems to reduce and manage the environmental risks associated with potentially acid-generating tailings in six regional waste management areas.

The Elliot Lake uranium tailings deposits have low residual concentrations of uranium, radium and thorium and also contain about 5% pyrite. Therefore, the decommissioning and associated environmental management objectives are to protect long-term public health and safety as well as the environment by applying cost-effective technologies that inhibit long-term acid generation and minimize radiological releases from the facilities. Additional objectives are to minimize the reliance on long-term care and maintenance requirements and to optimize management systems to reduce long-term operating costs while ensuring compliance with government regulations and company environmental policies.

MONITORING BY TELEMETRY

Rio Algom's Remote Plant Monitoring and Control Network (RPMCN) uses today's leading technology to monitor tailings and store operating information from each of the five remote tailings effluent treatment plants and from the lime-slaking operation. The automated plants are located within a 35-km radius of the City of Elliot Lake in areas that are not serviced by telephone lines and are networked via telemetry to a central personal computer–based Supervisory Control and Data Acquisition (SCADA) system. Operating personnel use the network to monitor plant operations, control reagent additions, and collect and record plant operating data. The network also incorporates an alarm and dial-out component, thus providing 24-hour-a-day monitoring and response for all plant operations. The on-call operator can respond to many plant alarms without leaving home by dialling into the network with a laptop computer.

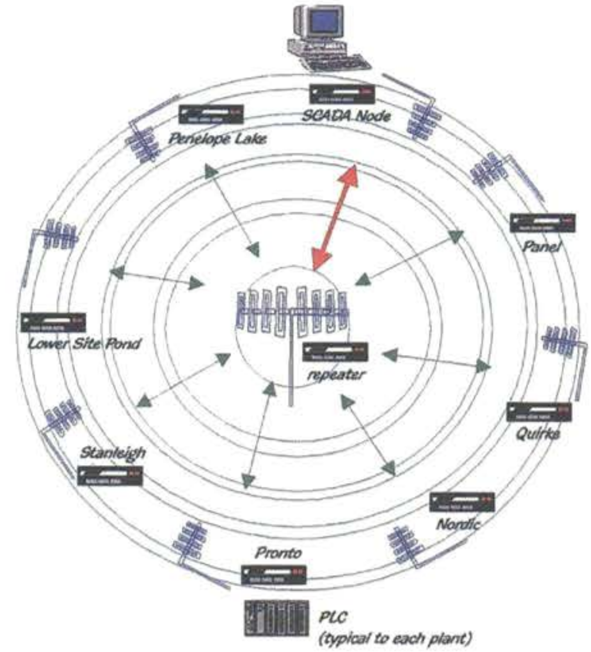
REGIONAL ENVIRONMENTAL INFORMATION MANAGEMENT SYSTEM (REIMS)

The REIMS provides an integrated, process-oriented and requirements-driven approach to the collection, long-term storage and management of required environmental information. The system supports quality management initiatives by:

- enforcing appropriate and consistent environmental protocols;
- providing an audit trail of all monitoring and inspection activities from scheduling to reporting;
- preventing data integrity problems through data validation;
- prompting reporting and response requirements when action limits are exceeded;
- maintaining an archive of all environmental data;
- streamlining production of regular reports for regulators and management; and
- providing capabilities to perform queries for analysis of specific situations.

RESULTS

Implementation of the Remote Plant Monitoring and Control Network and the environmental management system (EMS) has enabled Rio Algom Limited to reduce costs and improve the efficiency and reliability of its Elliot Lake operations. Through plant instrumentation, automation and networking, the number of plant operators has been reduced from five to two. Laptop-based technologies enable off-hour operating control, thus reducing call-out (the need to bring staff in) and overtime costs. The accessibility of both real-time data and historic trends assists the operators in evaluating ongoing operations, in planning contingencies and improvements and in responding to upset conditions. Plant automation, combined with cross-training and the scheduling and compliance verification components of REIMS, has enabled a workload redistribution among operating and compliance staff, resulting in reduced travel time and increased operating and compliance reliability. The audit trail (from scheduling to reporting), data validation and control limit components of REIMS reinforce EMS accountability and accuracy, thus ensuring the integrity of the database as well as compliance with government regulations and company environmental policies.



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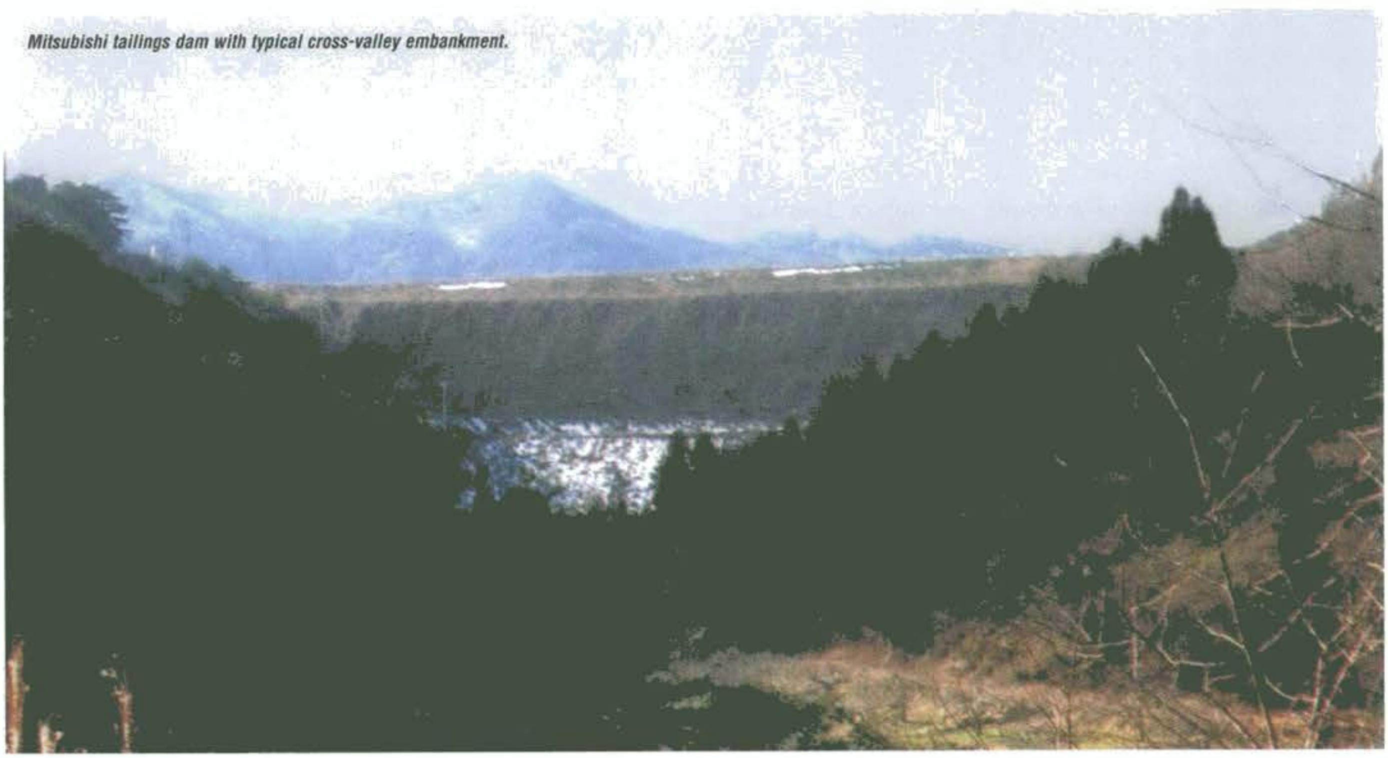
ICME Member

Mitsubishi's Emergency Management Manual for Tailings Disposal at Adandoned Mines

SUMMARY: *Mitsubishi Materials Co. (MMC) manages about 50 tailings dams across Japan, where earthquakes and seasonal rains pose special challenges for mine waste management. In order to provide both head office and on-site managers with standard responses to emergencies at these sites, the company compiled an emergency management manual. The manual, which includes definitions of emergency, checklists, and instructions for updating data, has improved communication between the corporation's head office and sites and also ensures continuity for new staff having little or no experience with tailings disposal.*

Mitsubishi tailings dam with typical cross-valley embankment.

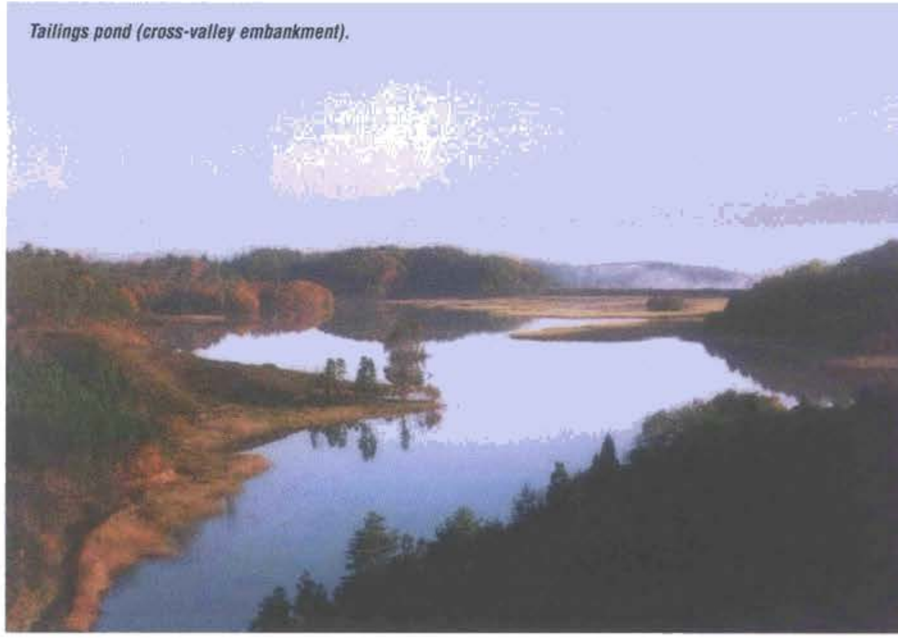


BACKGROUND

Japan is subject to frequent earthquakes and heavy seasonal rains. Moreover, the majority of the country's tailings dams are located in mountainous areas that are sources of both drinking water and water used in industry and agriculture. The most common tailings disposal system in the country is the "cross-valley" type, which uses the upstream method of embankment and has a large catchment area for precipitation. A few of these tailings dams are located near urban areas. As a result, proper management of tailings disposal and an appropriate emergency response plan are essential to prevent dam failure and minimize environmental risk.

Most of the numerous tailings dams located throughout Japan belong to abandoned mines. Regulations stipulate that mine owners have the responsibility for managing tailings disposal and water treatment long after the orebody has been exhausted. Today, Mitsubishi manages about 50 such sites either directly or through its subsidiaries.

The company employs about five workers at each of the abandoned mines, all of which have been closed for at least 10 years. The recruitment of managers with experience in tailings disposal management and other mining activities is becoming more difficult each year.



Tailings pond (cross-valley embankment).

APPROACH

In order to standardize and facilitate the management of tailings emergencies throughout its network of abandoned mines, Mitsubishi's environmental administration department compiled a manual for both head office managers and on-site employees. Entitled *The Emergency Management Manual for Tailings Disposal*, the manual outlines procedures to be performed by on-site personnel in case of an emergency. It contains the following features:

Definitions of emergency

An emergency is defined as a rate of precipitation of 30 mm/hour (or more) or a seismic intensity of 3 on the Japanese scale (a scale of 0 to 10) or over. An extraordinary emergency situation is defined as a situation in which a disaster has been confirmed.

Outline of organization and duties for tailings disposal management

A temporary workforce that can be called upon to help out during the initial stage of the emergency is established. A roster of temporary workers, including names, addresses and telephone numbers, is posted at all times in the site's administration office.

Liaison network system for extraordinary emergency situations

All of the affected personnel, companies and authorities are included in this communication network. Key members of the network are the communities located near the dam, the district mining bureaus of the Ministry of International Trade and Industry, the local fire department and the municipal authority.

Checklists and reports

Checklists for monthly routine inspections, emergency situations, and extraordinary emergency situations are included. Each list should be filled in correctly and reported, in a timely manner, to the manager in charge of tailings disposal in the MMC head office.

List of equipment

A list of equipment to be used for emergency situations is posted and periodically checked.

Instructions for updating data

Updates of the data from each tailings site are recorded and filed. The manual itself is reviewed and updated on a regular basis.

CONCLUSIONS

The manual allows head office managers to better advise and instruct on-site managers of tailings disposal and to share the results from one mine with another. As a result, communication between administration offices in the abandoned mines and head office has been improving, and a greater degree of continuity is ensured.

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ICME
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Emergency Response during the Omai Tailings Dam Failure

SUMMARY: *The response to the Omai dam failure illustrates strategies that can be used to manage tailings accidents. Among other requirements, successful emergency response and crisis management demand a competent team, an existing emergency response plan and the ability to communicate the facts, confront the crisis and restore calm.*

Left: In the aftermath of the accident, extensive forensic work was carried out on a cross-section of the dam to determine reasons for the failure.

Below: Representatives from the Government of Guyana Environmental Protection Agency, the US EPA and OGML take water samples from the Omai River shortly after the spill.

BACKGROUND

The Omai Mine in Guyana, currently producing at a rate of 345,000 ounces of gold per year, is one of the largest gold mines in South America. The mine is situated on the Omai River, a small tributary of the giant Essequibo River, about 160 km southwest of Georgetown, the country's capital. Omai Gold Mines Limited (OGML) is a joint venture held by Cambior Inc. (65%), Golden Star Resources (30%) and the State of Guyana (5%).

Since commencing production in January 1993, the Omai operation has been processing gold-bearing ore using cyanide extraction in a conventional carbon-in-pulp process. The tailings dam, whose embankment consisted of earth fill, was constructed north of the plant site in a small valley. The construction used locally available material and, based on the design and construction criteria, the dam should have been capable of providing the containment necessary for separation of fluids and solids. Both the tailings dam and the mine lie on the bank of the Omai, which is only several metres wide and carries a flow of 4.5 m^3/s before it joins the Essequibo, which in turn has a mean annual flow of 2 100 m^3/s.

Before midnight on August 19, 1995, an alarm was raised by a haul-truck driver who noticed a stream of water coming from the tailings dam. It was later revealed that there was another discharge at the opposite end of the dam and extensive cracking on the dam crest. One of the discharges was into the Omai River.

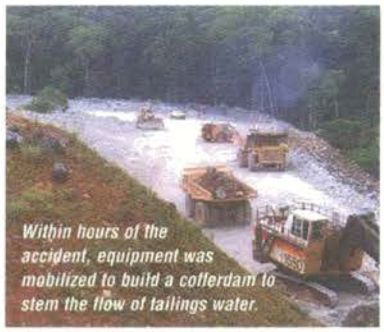
APPROACH

The mine crew immediately excavated a diversion ditch to carry a major portion of the flow, some 1.2 million m^3, to the main mine pit. Despite the implications of flooding a pit that served as the main source of ore, management made the decision within 15 minutes of learning of the discharge.

Over the $4^1/_2$ days that followed, approximately 2.9 million m^3 of tailings water containing diluted cyanide reached the Omai River, and from there, the Essequibo River. A cofferdam was built to contain the remainder of the flow.

Shortly after the spill was detected, a speedboat was sent downstream to notify those living along the Essequibo who could have been affected by the incident. All of the appropriate authorities were then notified and invited to the site.

Within hours, reports of the failure were broadcast worldwide. On the night of August 22, the government declared the area an environmental disaster zone and called for international assistance. Visions surfaced of the Jonestown, Guyana "mass cyanide poisoning" incident of 1978 that claimed over 900 lives. A crisis management situation had arisen.



Within hours of the accident, equipment was mobilized to build a cofferdam to stem the flow of tailings water.

Assessments by OGML and the government continuously showed there was never any danger downstream for human health or the environment. This was due to the high dilution capacity of the Essequibo and the natural degradation characteristics of cyanide, which does not bioaccumulate. The only documented environmental damage was fish kill in the Omai River. In addition, there was a plume of suspended clay particles in the river for several days following the spill.

The government appointed a commission of inquiry, including a number of experts, to carry out a full investigation and evaluation of the dam failure. The commission concluded that the concentration of cyanide from the spill was not injurious to health and that cyanide was still the most economical and environmentally acceptable means of extracting gold. It recommended that the government and OGML implement a program to educate the population about cyanide and its effects. By signing an agreement that embodied the recommendations of the commission's findings, Omai was able to resume operation within six months of the incident.

CONCLUSIONS

Through prompt and appropriate emergency response, on-site management and mine employees were able to significantly reduce the initial impacts and aftermath of the incident. This experience can help to prepare others for future incidents. It also illustrates the requirements for successful emergency response and crisis management, including:

Competent team: there is no time to clear everything with headquarters. Local managers must take the initiative and be prepared to take criticism without losing confidence in their good judgement and common sense.

Emergency response plan: an emergency is not the time to be designing a response plan. Plans for all credible accident scenarios must already exist. Sound planning can be the key to crisis survival.

Effective communication system: the communication system must be used to convey relevant facts on-site and to headquarters, and to maintain contact with the local community, government, media, NGOs, etc. There must be transparency in all outside communication and control over speculation.

Ability to confront the crisis: whether criticism comes from those affected by the crisis, the poorly informed, or critics with a vested interest, the company must be aggressive in meeting it and in trying to resolve any differences.

Ability to restore calm: this process begins after the company has developed strategies to solve the physical problems. Personnel must convey their sense of comfort to all those they contact.

Remediation: everyone involved must exert every possible effort to understand the problems and find solutions to repair any damage caused by the accident.

Effective public relations program: this is an important tool for surviving the aftermath of a tailings accident. Such a program should go beyond promoting the company, its products or its shares, and should have the full involvement of management.

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Awareness and Preparedness for Emergencies at the Local Level (APELL)

The APELL program of the United Nations Environment Programme (UNEP) is designed to help companies, local governments and emergency service providers develop a coordinated plan to improve public preparedness in case of industrial accidents, including those at tailings dams. A significant feature of the APELL program is that it involves all of the potentially affected parties, not only the company.

Tailings Emergencies

As tailings accidents may involve either physical or chemical consequences for persons and the environment, both these aspects need to be considered in emergency response. An informed public will initially question the acceptability of any externally imposed risk. Therefore, the company often undertakes a thorough risk management study as part of its APELL involvement and discusses the study with its partners. This allows the community as well as the response organizations to participate in planning the best emergency preparedness arrangements. If the community understands the real consequences of a spill *before* one occurs, it will be better prepared to deal with the emergency; among other things, the general anxiety level will be reduced. If, on the other hand, the community is uninformed, its anxiety and mistrust may prevent the mining company from being able to communicate with it effectively during an emergency.

It is too late to develop a plan once the emergency is under way. For example, the response to recent tailings accidents in Spain, Guyana and the Philippines may have been appropriate under the circumstances, but because the public was not informed about the consequences of a spill beforehand, the credibility of the action taken by the companies suffered. Trying to build confidence in the middle of a crisis is futile.

The basis of the APELL program is the establishment of a broadly based coordinating group that ensures information is made available to all stakeholders according to their needs. The coordinating group acts as the central point for dialogue, information exchange and questions. The group includes community leaders as well as emergency response specialists.

The APELL program has been applied at many industrial sites around the world. The handbook and supporting material are available in more than 20 languages. There is also a pool of UN and national experts to assist individual companies and communities in developing sound emergency plans that include public preparedness. The procedure is directly applicable to tailings structures as well as to other potentially hazardous mining operations.

The APELL Partners

At the local level there are three very important partners who must be involved if APELL is to succeed:

1. Local authorities. Provincial, district, city or town officials who are responsible for safety, public health and environmental protection in their area.

2. Industry. Industrial plant managers are responsible for safety and accident prevention in their operations. They prepare specific emergency measures within the plant and review their application. As leaders of industrial growth and development, they are in the best position to interact with leaders of local authorities and community groups in order to create awareness of how the industrial facility operates and how it could affect its environment, and to help prepare appropriate community response plans in the event of an emergency. The involvement and active participation of the workforce are also very important.

3. Local community and interest groups. Environmental, health, social care, media and religious organizations and leaders in the educational and business sectors, who represent the concerns and views of their members or consituents in the community.

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Tailings Management and Decommissioning: A Short Course

SUMMARY: *The management- and operator-level courses offered by the Australian Centre for Geomechanics provide a forum for transferring knowledge and an opportunity for participants to learn from one another's experience. The courses are structured to include case studies, workshops and a chance for participants to raise site-specific issues.*

BACKGROUND

The Australian Centre for Geomechanics (ACG) is a joint venture research centre between the University of Western Australia, Curtin University of Technology – WA School of Mines, the Commonwealth Scientific and Industrial Research Organisation, and the Department of Minerals and Energy of WA. The Centre's role is to coordinate research technology transfer and improved education and training in the geomechanics disciplines. Approximately eight short courses are provided each year on a variety of topics, mainly for the mining industry.

A total of 10 courses on tailings issues have already been provided. The courses have been given at both the management and operator levels. The management-level courses highlight the real costs of tailings disposal, the need for effective and efficient management practices, the concept of risk management and the value of incorporating operating and closure strategies during the early design and planning phases. The operator-level courses are intended to be more practical and are aimed at those responsible for managing and operating tailings dams on a daily basis.

The primary objectives of courses, seminars and workshops in this area are to provide:

- a forum for technology transfer of current knowledge; and
- the opportunity for those working in the field to interact and learn from each other's experiences.

APPROACH

The outline of the most recent operator level course, entitled *Tailings Management and Decommissioning* and conducted by the ACG in December 1997, is presented below. The course addressed the issues facing personnel involved with the day-to-day management of tailings dams. The objective was to enable them to comply with relevant operating standards as well as decommissioning and rehabilitation requirements, factors of increasing importance to both regulatory authorities and minesite personnel.

Operator-level course outline

The course involved presentations and group discussions over two consecutive days and covered the following elements:

Day One

- Overview of decommissioning issues
- Case Study 1: Commissioning to Closure
- Storage design and construction concepts
- Consolidation/Evaporation
- Groundwater hydrology/Seepage
- Surface water management and erosion
- Development of soils for rehabilitation

Day Two

- Setting closure objectives and emergency response concepts
- Case Study 2: Rehabilitation and monitoring of tailings dams in the mineral processing industry
- Case Study 3: a site-specific study
- Geochemical issues; effects of acid rock drainage, salinity, cyanide and arsenic
- Decommissioning/Rehabilitation
- Workshop
- General discussion

An important element of the course was the inclusion of a number of case studies in order to facilitate the concept of learning by example. The presenters were encouraged to discuss failures and shortcomings as well as successes so that there was the possibility of learning from the experiences of others.

Each of the presentations was given by someone with specific expertise in that area and ample time was allowed at the conclusion of each presentation for questions. In fact, participants were encouraged to ask questions at any time to clarify what was being said or to determine how issues related to their own operations.

The workshop allowed participants to use and reinforce the principles covered during the course. Participants were invited to solve various scenarios of environmental hazard and implement management strategies to avoid similar future risks. This method of feedback proved to be very effective for both course participants and presenters.

The final general discussion session was intended to provide an opportunity for participants, who were advised of the opportunity well before the date of the course, to raise specific issues relating to their own operations. This ensured that no one went away feeling that a specific issue of concern had not been raised.

Senior Management Level Tailings Seminar

The Australian Centre for Geomechanics also offers a seminar on tailings management entitled "Tailings – Corporate Risk and Responsibility." It is directed at senior company personnel involved in the decision-making process, from tailings storage design to closure.

The objectives of the seminars conducted at this level are to provide a comprehensive overview of the hazards, risks and consequences of a failure, as well as of the methods used to assess the potential impact of a failure and the probability of it occurring. The presenters also address the important issue of closure strategies to be adopted to ensure that tailings storage facilities remain safe and provide minimum potential for environmental degradation into the future.

There is a growing recognition that the management and decommissioning of tailings storages can have a significant effect on the economics of mining operations, that planning must be undertaken as early as possible, and that the responsibility for these facilities has to be taken at the appropriate (senior) level. This is an area in which an incident can have significant implication in terms of inviting more stringent regulations and even in terms of affecting the long-term viability of the industry.

Seminars at this level are limited to one day and are scheduled to ensure that the senior personnel at whom they are directed can fit it into their day-to-day operations.

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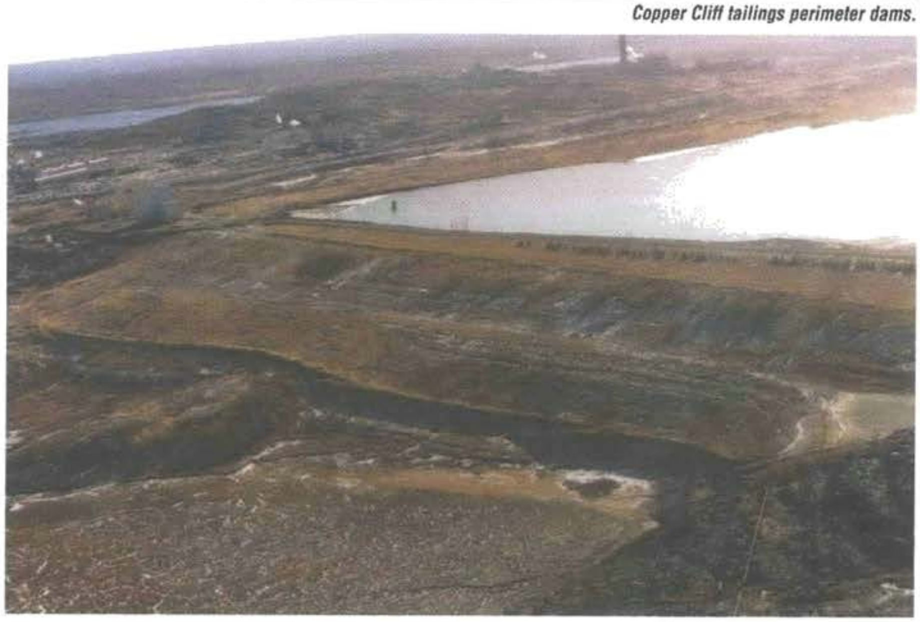
Sustaining the Corporate Memory at Inco's Copper Cliff Operations

SUMMARY: *New tailings management challenges have been created as a result of the trend toward mining larger, lower-grade deposits that generate greater quantities of waste, and as a consequence of the constant evolution of technology and the changing nature of the workforce. Inco tackled these challenges at its Copper Cliff Tailings Area by developing matrices for each component of its tailings dams, based on a range of data that had been recorded over several decades. By making the data readily available in a manageable format, the company improved its ability to manage ongoing demands for qualified personnel, technological assessment and identification of remedial action.*

BACKGROUND

The tailings management facility at Inco's Copper Cliff operations in Ontario, Canada commenced use in the 1930s and will not reach capacity until the 2030s. It currently encompasses 2 500 ha and stores 500 million tonnes of acid-generating wastes. Historically, a dedicated workforce with an orderly and logical generational change of personnel readily adapted to workplace rationalization as it dealt with ever greater waste quantities and evolving technologies. But today's competitive world marketplace no longer permits the luxury of historical transfers of skills, and employees must adapt through the development of broad skills and career change. Training new employees to properly manage wastes requires a format that responds to market forces while providing the necessary degree of assurance that risks are being managed in a safe and prudent manner.

Copper Cliff tailings perimeter dams.



APPROACH

The need to properly manage mine wastes is driven by multiple forces: environmental liabilities; regulatory change; closure planning and rehabilitation;

evolution of technology; workforce dynamics; and utilization of capital.

The common element within these forces is the need for information. Proper decisions on waste management, and the associated degree of risk, can be arrived at only by having full access to historical, current and future planning data.

The large tailings site in operation for many decades at Copper Cliff has evolved over multiple stages of growth. There are numerous sources of historical data dispersed throughout several locations. The volume of data, which ranges from personal experience and hand-written notes to formal technical analyses, is enormous and often difficult to access.

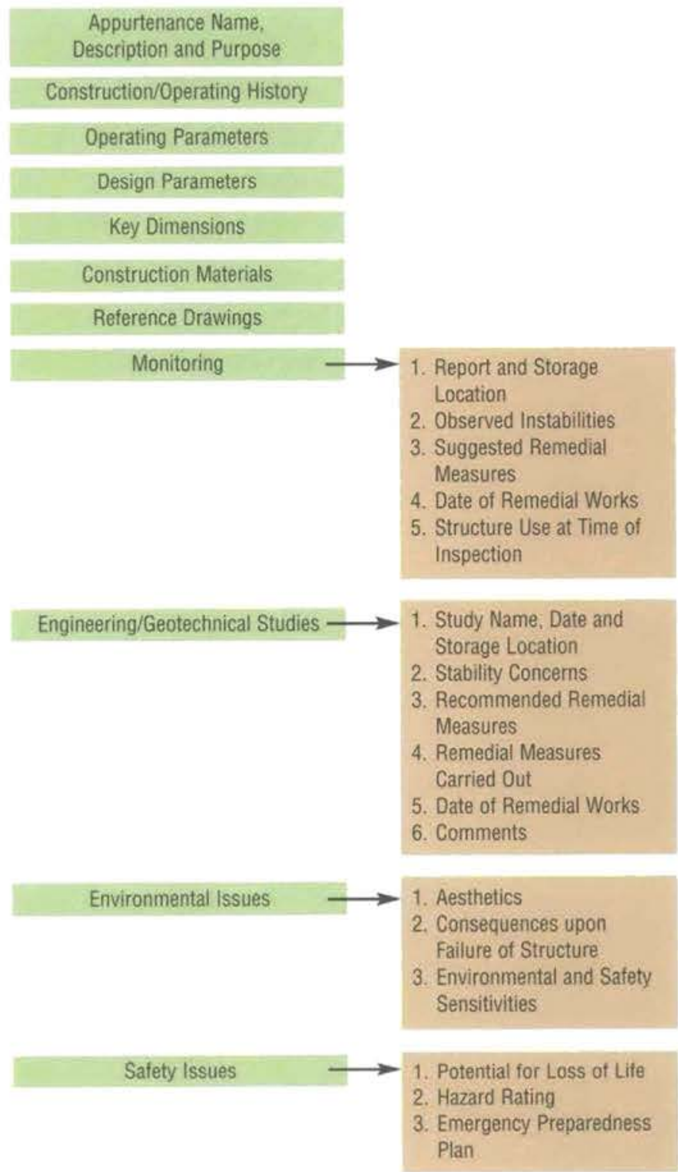
To assure the continuity of technical assessment and resource personnel, data must be condensed and made easily accessible for purposes of training, decision making, assigning resources and updating. The information format must allow for new technology to be applied to the data without a loss of continuity and without inadvertently increasing the degree of risk.

SOLUTION

The solution was to construct an information matrix for each individual dam structure and each appurtenance associated with the tailings site, ranging from decant towers to seepage cut-off walls. Historical data were included in an effort to provide all of the pertinent facts relating to each item. The final objective was to condense the data into single-page entries in a data bank and assign information to a common set of headings (see Figure 1).

The ready availability of data in a manageable format permits on-site management to handle the ongoing demands for the training and qualifying of personnel as well as for undertaking technological assessment and identifying remedial actions to minimize and manage risks.

Figure 1. Key Elements of the Data Matrix



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Glossary

acid mine drainage (AMD): the seepage of sulphuric acid solutions (pH 2.0–4.5) from mines and tailings; these solutions are produced by the interaction of oxygen in ground and surface water with sulphide minerals exposed by mining.

acid rock drainage (ARD): similar to AMD (above).

alluvium: unconsolidated material which is transported and then deposited by a river.

bioaccumulation: the collection of chemicals in animal tissue in progressively higher concentrations towards the top of the food chain; bioaccumulation occurs when the intake of a substance is greater than the rate at which it is excreted or metabolized.

borrow material: material taken from a nearby site when there is insufficient on-site material with which to build the dam.

carbon-in-pulp: a method of recovering gold and silver from pregnant cyanide solutions by adsorbing the precious metals onto granules of activated carbon.

cofferdam: a watertight enclosure pumped dry to permit work below the waterline.

cycloned tailings: tailings that have been sorted by centrifugal force to produce a sand product for the embankment.

decant pond: pond used to store the liquid that has been drained off after the tailings have settled.

decant tower: a vertical concrete or steel pipe that skims the water from the tailings dam through a series of regularly spaced ports.

dewatering: the process of removing or draining the water from tailings before deposition in the tailings dam.

finite element analysis: a method of modelling the behaviour of a physical object by breaking the object into several components or finite elements.

freeboard: the height between the waterline and the top of the dam wall.

geomembrane: a synthetic sheet used as a liner under tailings dams.

liquefaction: the state of becoming a liquid; becoming capable of flowing.

paddock dam: a type of dam in which tailings are deposited into a series of paddocks along the line of the dam; this method is commonly used is arid climates and is best suited for fine-grained tailings in the silt and fine sand fractions.

penstock: a channel for conveying water.

piezometer: an instrument for measuring the magnitude or direction of pressure.

piping: washing out or erosion of dam construction materials by water escaping from the impoundment.

pyrite: iron disulphide, the most widespread sulphide mineral.

pyrrhotite: iron sulphide with small amounts of nickel and cobalt.

rate of rise (m/yr): the rate at which the tailings dam is raised; usually coincides with the rate of deposition.

seismicity: the frequency of earthquakes.

supernatant: the clear water that sits above the tailings after settlement.

telemetry: a method of recording instrument readings and transmitting them by radio.

underdrain: drain placed beneath the tailings for the purpose of liquid removal.

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