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Tour Mirabeau, 39-43, quai André Citroën, 75739 Paris Cedex 15, France
Tél. : (33-1) 44 37 14 50 • Facsimilé : (33-1) 44 37 14 74 • Télex : 204 997 F • E-mail : unepie@unep.fr

Environmental and Safety Incidents concerning Tailings Dams at Mines

Results of a Survey for the years 1980-1996
by

Mining Journal Research Services
The Mining Journal Ltd
60 Worship Street
London EC2A 2HD, UK

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United Nations Environment Programme
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Tour Mirabeau, 39-43 Quai André Citroën
75739 Paris Cedex 15, France

Joint UNEP/DHA Environment Unit
Department of Humanitarian Affairs
Palais des Nations
CH 1211 Geneva 10, Switzerland

PREFACE

Several recent incidents concerning tailings dams were regarded as environmental emergencies by the countries in which they occurred. Both UNEP and DHA were called upon to provide an evaluation of the extent of the disasters, and to give technical assistance and advice in the follow-up phase. During this work UNEP and DHA became aware that environmental impacts from tailings dams occur more frequently than is sometimes thought, and that the consequences are not always well understood.

In order to put these incidents into a clearer perspective the two organizations carried out a survey of recent incidents with a view to:

- identifying the environmental and safety impacts most commonly encountered,
- the actual frequency of such incidents,
- the environmental and human consequences of such incidents.

The task of undertaking the survey was entrusted to the Mining Journal Research Service, which augmented information in its database by way of a questionnaire to national authorities around the world. Organizations concerned with tailings dam safety volunteered their assistance, notably the International Commission on Large Dams (ICOLD). The additional information thus provided proved invaluable.

We are now able to provide better researched answers to the three questions above.

However despite the useful results obtained in this study a complete quantification of tailings dam incidents remains elusive. Data from some countries has been difficult to obtain. Different interpretations persist as to what constitutes an "incident". UNEP and DHA, with the assistance of other organizations, will soon decide how to follow up this study and refine the information.

In the meantime the current report provides a useful overview of the situation in major mining countries, and allows companies and government authorities to better identify the potential impacts from their tailings operations. UNEP intends to incorporate the conclusions into its ongoing work in producing technical publications, and recommending training curricula, and in providing to government officials information to develop their policies to address mining and environment issues.

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The Environmental Health & Safety Division of OECD assisted in the project administration.

For further information contact UNEP IE, 39 Quai André Citroën, 75739 Paris Cedex 15, France, or Fax (33-1) 44 37 14 74, or e-mail unepie@unep.fr

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EXECUTIVE SUMMARY

This study has been prepared by *Mining Journal Research Services* at the request of the United Nations Environment Programme (UNEP). It reviews the occurrence of reported failures and other similar incidents involving mine tailings dams in a number of countries during the period from 1980 to early 1996. The study contains an overview of dam designs and construction techniques in current use.

Placed in a global context, the study is based on a survey of tailings dams in countries that account for 65% of global gold production, some 75% of established market economy country (EMEC) newly mined copper output, and around 60% of EMEC lead and zinc. The countries covered are also responsible for significant proportions of world production of industrial (non-metallic) minerals and coal. In total, 52 organisations were contacted in 18 countries. Of this group, 23 agreed to participate and were sent questionnaires; 20 replies were received.

The term "tailings" is defined as waste products that are generated during the recovery of mineral commodities from their ores or other sources. The term "tailings dam" is used in its widest sense, to include both the retaining structure and the impounded material. The recovery of most metals and non-metallic minerals invariably results in the production of large amounts of unwanted waste material, often ground to particle sizes of below 100 microns in order to release the valuable constituents. The production of non-metallic minerals can also result create tailings, as does the upgrading of coal.

The tonnage of tailings generated each year is huge but tends to be concentrated into specific areas of the world. World copper production in 1995, for example, required the treatment of upwards of 1,500 Mt of rock, virtually all of which was stored in tailings dams. Annual gold output requires the production of around 500 Mt of tailings, plus obsolescent leaching heaps. For potash, over 140 Mt of potash-bearing ore was mined, and around 120 Mt of tailings, mainly consisting of salt and insoluble clays, would have been produced during 1995.

Tailings dams and other impoundments are essentially a 20th Century invention. Earlier, residues from mineral recovery operations were generally discharged either on to the surface close to the mine concerned, or into the nearest watercourse for disposal downstream. In some cases, river or marine disposal still occurs, but is increasingly a target for environmental concern. In contrast to earlier practice, the modern tailings impoundment is usually of highly sophisticated construction based on firm geotechnical foundations. The design and construction of tailings dams has evolved considerably over the last 20 years. There is also a large population of tailings impoundments that date from earlier times, however, some of which are still in use while others are now abandoned.

In such circumstances, incidents occur from time to time that have some impact on the surrounding environment. Such cases may range from the release of small amounts of dirty water, or dust emissions from dry tailings surfaces, to full-scale collapses. Fortunately, large-scale incidents are infrequent. The research for this study has identified fewer than ten major failures or similar incidents that were reported between 1980 and 1996.

The level of public reporting and discussion following a major failure is very variable. There is currently no centralised source for information about tailings dam incidents, either internationally or, for the most part, nationally. The professional interest of organisations such as the International Commission on Large Dams (ICOLD), set up in the late 1920s to monitor water-retention structures, has been extended to encompass tailings impoundments as well.

There are a number of important factors that have a direct bearing on the stability of tailings dams, and hence on their long-term retention capability. Most are concerned with water handling in one form or another. Principal amongst these are the water control methods and the foundation materials used.

Virtually all failures occur as a result of the presence of water. This may be as a result of percolation through the dam wall, internal erosion, overtopping or flooding, and may be exacerbated by natural phenomena such as earthquakes or persistent heavy rain. The majority of the incidents reported in this study were attributed by respondents to such natural processes, which in some circumstances may have provided a trigger for the collapse of already weakened structures.

As few major mining countries have a single authority responsible for maintaining records on tailings dams, it is rarely possible to estimate the true population of impoundments on a national basis, and even less so world-wide. To illustrate the scale of the numbers, respondents reported total (active and abandoned) dam populations in some individual countries or regions as being 350 in the state of Western Australia, with a further 43 in Tasmania. The Canadian provinces of Quebec, British Columbia and New Brunswick reported 164, about 130 and seven dams respectively, while for the Republic of South Africa, the dam population is estimated to be in the order of 400.

Collating data on tailings dam performance remains largely a matter for individual agencies, with a wide variation in the amount and quality of information held. Reorganisation of government departments has in some cases also left a vacuum regarding information gathering and the maintenance of records, and breaks in the continuity of the collation process. Incidents that occur in more remote areas, or in countries that remain closed to outside inspection, are much less likely to be recorded than those involving industrialised counties or where companies with international operations are involved.

The information presented here has the potential to form the foundation of a comprehensive store of tailings dam performance data. It is not complete but does contain a range of information from numerous, usually reliable sources and may be used by the UNEP to foster an improved information-sharing effort in this field. Other specific areas in which UNEP's position could be used to advantage in addressing safety issues pertinent to tailings dams include continuing the statistical compilation of dam numbers on a world-wide basis, and assisting national authorities in advising communities perceived to be at risk from potential dam incidents.

1.0 INTRODUCTION

This study has been prepared by *Mining Journal Research Services* at the request of the United Nations Environment Programme (UNEP). It reviews the occurrence of reported failures and other similar incidents involving mine tailings dams in major mining regions during the years since 1980.

"Tailings" are defined as waste products that are generated during the recovery of mineral commodities from their ores or other sources. Typically, the original rock has been crushed or ground to small particle sizes in a wet recovery process. The term does not encompass waste rock produced during the mining process in order to uncover or access the ore; such material is usually handled at as large a particle size as possible and is normally stored separately from process tailings, close to the mining area. Waste rock may, however, be used to construct retention dam walls for tailings impoundments, for example, but is generally not mixed with the finer material. "Slimes" is sometimes used as a synonym for tailings, particularly in southern Africa.

The terms "tailings dam" and "tailings impoundment" have different connotations in various countries. In some areas, tailings are retained in an impoundment, pond or lagoon that is formed by a dam wall; in others, a tailings dam refers to the dam structure *and* the impoundment area as well. For the purposes of this study, "tailings dam" is used in its widest sense, to include both the retaining structure and the impounded material.

The UNEP view is that an "incident" consists of an unplanned event that has some effect on humans, the environment and property. This includes both dramatic structural failures, which are usually short-term in occurrence (although the effects may be long-lasting), and persistent low-level discharges and emissions, such as groundwater seepage and dust. This report focuses mainly on larger-scale incidents that occurred over a brief time period and had a greater impact on people and the environment. Smaller incidents, such as minor structural slips in a dam wall, or short-term discharges of process water, are often contained within the mine property and are addressed by the company involved, with little outside impact or publicity.

In a development that is tangential to this study, the use of acid or cyanide leaching on lower-grade ores ("heap leaching") has increased significantly since 1980. Here, run-of-mine ore is crushed and then stockpiled for leaching on an impervious liner; when the leaching process has reached its economic limit, the heap is no longer of economic value. Despite being process waste, such obsolescent heaps are not "tailings" *per se* on account of the larger particle size of rock they contain. Moreover, the free-draining characteristics of these heaps means that there is minimal water retention after leaching has finished, and they are thus much more stable than impoundments containing finely ground tailings; the latter may be saturated with water long after abandonment.

The recovery of most metals and non-metallic minerals from their ores or other sources usually involves some type of mechanical or chemical treatment. Given that the proportion of any mineral within its natural host rock is usually low (ranging from a few parts per million for rare metals such as gold to below 10% for most other metals), recovery through mineral processing invariably results in the generation of large amounts of unwanted material, often ground to particle sizes of below 100 microns in the course of releasing the valuable constituents from the ore.

It is evident that recovering gold from ores that contain a few grammes of metal in a ton of rock results in the need for the long-term storage of the total amount of rock mined, to all intents and purposes, albeit in ground form. A copper ore grading 0.5% metal will similarly require the storage of at least 99.5% of the mined rock. Bulk commodities such as iron ore, which naturally have a higher metal content of between 45 and 65%, are also upgraded before shipment, resulting in a lesser proportion of finely ground process waste, but a tonnage that is still very significant.

Processing industrial, or non-metallic minerals can also create tailings. Phosphate fertilizer, for example, is extracted from phosphate ore by a two-stage chemical process, both of which involve the production of tailings. Even a simple item such as construction aggregates often involves washing as-dug gravels to yield a graded product and to remove clays and soil from the raw material.

Similarly, the upgrading of coal through the removal of non-combustible mineral matter, or through sizing to produce a specification product, also produces process tailings. In this case, the tailings contain both finely divided waste and fine coal. Tailings disposal practice in the coal industry can differ from other branches of the minerals industry in that process waste is sometimes re-combined with other mining waste in order to minimise the risk of spontaneous combustion and to enhance dump stability.

In contrast to earlier practice, the modern tailings impoundment is usually the result of sophisticated civil engineering and construction techniques based on firm geotechnical foundations. The design and construction of tailings dams have evolved considerably over the last 20 years. There are, of course, many tailings impoundments that date from earlier times, some of which are still in use while others are now abandoned, either on active mine sites, or in areas where mining is no longer practised.

In such circumstances, incidents will occur from time to time that impact on the surrounding environment. These may range from the release of small amounts of dirty water, or dust emissions from dry tailings surfaces, to a full-scale catastrophic collapse that may have major environmental and economic impact, cause loss of human life, and be widely reported in the media, as well as having the potential for loss of human life.

Fortunately, large-scale incidents are infrequent. Research during this study has identified fewer than ten major failures or similar incidents reported during the period from 1980 to early 1996. Of these, only four for which detailed information is available - at Stava in Italy, Jinduicheng in China, Placer in the Philippines and Harmony in South Africa - each involved the loss of more than ten lives. One further incident, in Brazil, resulted in seven fatalities, apart from which there are no other records of deaths. In the 15 years between 1965 and 1980, however, there were at least five other reported large-scale incidents that involved mine tailings or other waste, four of which incurred significant casualties while the fifth caused extensive low-level radioactive contamination.

It became evident during this research that the level of public reporting and discussion following a major incident is also very variable. The most recent well-publicised discharge from of a major tailings impoundment, at Omai (Guyana) in August 1995, focused much attention on the safety of such structures, although it did not cause the loss of human life. By contrast, the collapse of a tailings dam wall at the Harmony gold mine in the Republic of South Africa in 1994, which resulted in 17 deaths, received far less publicity despite having a greater human impact.

As varying regulations apply from country to country regarding construction methods for tailings dams, so the requirements for reporting incidents involving tailings also vary widely. Even if a comprehensive control policy did exist, implementation is only as effective as the inspection organisation responsible for it. Some countries still have no effective control over tailings disposal, while others permit discharges into rivers or to the sea rather than tailings impoundment. Examples include fluvial tailings disposal at the Ok Tedi copper-gold mine in Papua New Guinea and from silver and base metal mining in Bolivia, and marine disposal from the (currently shut) Atlas copper mine in the Philippines.

1.1 Scope and methodology

This study aims to identify and to annotate major incidents involving mine tailings dams since 1980. Comprehensive, global information was not readily available, and it is conceivable that a major incident that occurred in the former Soviet Union or in China, for example, may have gone unreported in the international media. It is much less likely that incidents of lower significance in such countries reached world attention.

Although mining in some form takes place in almost every country, it was not feasible, within the time constraints of the study schedule, to investigate every country with a mining industry of a sufficient size to require major tailings dams. The emphasis has therefore been on researching as completely as possible the occurrence of incidents in a cross-section of countries, including major minerals producers and other states in which mining is also important but is of lower economic significance.

There is currently no centralised source for information about tailings dam incidents, either on an international basis, or for the most part, nationally. The closest attempts to this type of collation of information are to be found in the U.S.A. at the United States Committee on Large Dams (USCOLD) in Denver, Colorado and at Stanford University, Palo Alto, California. Both have comparatively comprehensive listings of reported (and in some cases, anecdotal) incidents, although the emphasis at both organisations is on tailings dams in the U.S.A.

General information about incidents has been obtained from the records of *The Mining Journal* and from other literature searches, as well as from the American sources noted above. More specific details of individual incidents has been sought from state authorities in Australia and the U.S.A., from provincial authorities in Canada, and from the appropriate government departments in 14 other, selected countries. In some cases, mining companies and engineering consultants have been asked to provide details of incidents, although responses obtained from interviews have in some cases been guarded in view of unresolved regulatory issues. Details on methodology and the organisations that were contacted for information are included in the Appendix volume of this report.

Much of the information that is contained in this study has been generated from questionnaires that were completed by identified respondents in the appropriate agency or government organisation. It should be noted that the level of detail provided varies considerably from reply to reply, and may reflect the detail that individual government departments are required to hold. In some cases, different organisations may hold information on different aspects of an incident, making the search for a complete record that much more complex.

The information obtained from completed questionnaires and other sources forms the basis for the data presented in tabular and text form in Chapter 6 of this report, and for the 37 individual incident reports contained in the Appendix. A discussion of the level of confidence that may be placed in this sample of incidents for which detailed information is available is presented in Chapter 2.

2.0 REVIEW OF WORLDWIDE MINING ACTIVITIES

Any mining operation that recovers only a component of the ore mined will produce some form of tailings. In recent times, the introduction of increasingly sophisticated mineral recovery techniques has meant that tailings have become finer in size, while the expansion of mineral output has given rise to the generation of greater annual volumes of tailings material.

Mining can also be categorised by its location, the size of the operation and the type of commodity. Selected large-scale mining areas, by country and commodity, are listed in Table 1, which shows that there is a clear geographical concentration of large-scale activity. It follows, therefore, that the principal concentrations of large tailings dams also occur in these areas. Estimates of tailings production on a selected commodity-by-commodity basis are given in the following sections.

2.1 Copper

Western World new mine copper production in 1994 was 7.6 Mt, most of which came from low-grade "porphyry"-type deposits that contain from 0.4% to perhaps 0.8% copper. A reasonable average is 0.5-0.6%. Thus the production of 7.6 Mt of copper metal, at an assumed recovery rate of, say, 80% of the copper contained in the run-of-mine ore, required the treatment of upwards of 1,500 Mt of rock, virtually all of which was stored in tailings dams.

Notable exceptions to this are the Ertsberg mine in Irian Jaya (Indonesia) and Ok Tedi in Papua New Guinea, neither of which has permanent tailings retention facilities. Other mines, currently closed, that worked on this basis included Bougainville (PNG), Atlas (Philippines) and Island Copper (B.C.). In each case tailings are or were discharged directly into rivers or the sea.

2.2 Gold

Mine production was 2,296 t in 1994, from ores that grade a few grammes per tonne. However, not all of this ore was processed by milling. For example, a considerable proportion of the U.S.A. output of 331 t was obtained from heap-leach operations.

Table 1. Selected major mining districts by commodity

Country/region	Districts
Copper	
United States	Arizona/New Mexico/Utah
Mexico	Sonora
Canada	British Columbia
Zambia/Zaire	Copperbelt
Chile	Central/Northern
Peru	Central/Southern
Southeast Asia	Indonesia/Philippines/Papua New Guinea
Former Soviet Union	Kazakstan
Gold	
United States	Nevada
Canada	Northern Ontario/Quebec
Chile	Central
South Africa	Gauteng/Free State
Australia	Western Australia
Southeast Asia	Indonesia/Philippines/Papua New Guinea
Lead and zinc	
United States	Mississippi Valley
Canada	British Columbia/Ontario
Peru	Central
Australia	Queensland
Spain	Southern
Sweden	Central/Northern
Iron Ore	
Australia	Western Australia
Brazil	Minas Gerais/Amazonia
United States	Minnesota
Canada	Quebec/Labrador
Sweden	Northern
Former Soviet Union	Ukraine/Russia
Mauritania	Northern

Table 1. (continued)

Country/region	Districts
Phosphate	
United States	Florida/North Carolina/Idaho
Middle East	Jordan
North Africa	Morocco
Uranium	
Canada	Ontario/Saskatchewan
Australia	Northern Territory/South Australia
United States	New Mexico/Colorado/Wyoming
Southern Africa	Namibia/South Africa
West Africa	Niger/Gabon
Coal	
United States	Wyoming/Colorado/Utah/Illinois/ Appalachia
Europe	Eastern England/western Germany/Poland-Czech Republic/northern Spain
Former Soviet Union	Ukraine/Russia/Kazakstan
Southern Africa	South Africa/Zimbabwe/Zambia
Asia	Eastern India/Indonesia/China
Australia	New South Wales/Queensland
Latin America	Venezuela/Colombia/Mexico

Assuming an average run-of-mine ore grade of 4 g/t, which may be generous on account of the large proportion of heap-leach production in the U.S.A. and surface-mined output in Australia and elsewhere, in 1994 this total would have required the production of around 500 Mt of tailings, plus obsolescent leaching heaps. South Africa alone produces over 100 Mt/y of gold ore tailings, the largest single concentrated accumulation anywhere.

2.3 Lead and zinc

New mined output of lead was just over 2 Mt in 1994, while zinc production was 6.6 Mt. The pattern of output of lead and zinc is more complicated than for some other metals, in that both are often co-products with copper and/or nickel. As a rule of thumb, it would be unusual to mine a straight lead-zinc orebody unless the combined grade was at least 8%, although this can be less if economic credits can be obtained from other metals in the ore.

Assuming a global average grade of 8%, which is probably high, the production of 8.6 Mt of lead and zinc in 1994 would have required the treatment of around 140 Mt of run-of-mine ore (assuming an 80% metal recovery) and the consequent disposal of some 130 Mt of tailings in that year.

2.4 Bauxite

Producing aluminium metal involves a two-stage process in which alumina is first reduced from run-of-mine bauxite ore, and is then smelted to yield metal. Bauxite output in the established market economy countries was 97.7 Mt in 1994, which was treated to produce 35.4 Mt of alumina. Applying this ratio globally, it is estimated that the 110 Mt mined would have yielded 40 Mt of alumina. This in turn would have left 70 Mt of tailings, or "red mud" for disposal.

2.5 Fertilizer minerals

Fertilizer minerals include potash, phosphate and sulphur. Both potash and phosphate are mined conventionally, and are then upgraded, while most sulphur is solution-mined from the Frasch liquefaction process or is a by-product from oil and gas processing or metallurgical industries.

Potash deposits, usually found in association with halite (common salt), typically contain up to 35-30% K_2O, of which perhaps 80% is recovered through solution and differential crystallisation technology. World K_2O production in 1994 was 22.6 Mt. Thus over 140 Mt of potash-bearing ore would have been mined, and around 120 Mt of tailings, mainly consisting of salt and insoluble clays, would have been discarded.

World phosphate rock production was 124 Mt in 1994. Two types of ore are exploited: soft and hard. Soft, sedimentary ores mined are typically high-grade, containing around 60% bone phosphate of lime (BPL). There is some upgrading by washing and screening to produce a phosphate rock concentrate. Tailings from this process, typified by Florida in the U.S.A., contain very fine clays that can present storage problems on account of their high water-retention capabilities. Hard phosphate ores, as mined in Russia, are upgraded from an initial 20% to over 80% BPL.

Transforming the concentrate into phosphate fertilizer involves the intermediate stage of phosphoric acid, of which phosphor-gypsum tailings are a waste product. The annual level of tailings production (of both types) is not easy to estimate owing to the very individual characteristics of each phosphate deposit; however, a figure of perhaps 50-60 Mt would be representative.

2.6 Coal

Total world hard coal production was 3,181 Mt in 1994, plus an additional 1,270 Mt of brown coal and lignite. Tailings are produced from washing coal, mainly to reduce its ash content and enhance its heating value. Virtually all lignite and brown coal is used unwashed, while the proportion of hard coal that is upgraded before use varies markedly from around the world.

For example, coal mines in Queensland produced 111 Mt of raw coal in 1993-94, of which 85.7 Mt was classed as saleable, giving 24.3 Mt of discard or tailings. In New South Wales, the corresponding figures were 84 Mt saleable from 101 Mt of raw coal, generating 17 Mt of discard. However, in the Ruhr coalfield in Germany, the discard rate reaches around 50% at some mines, meaning that half the run-of-mine output is set aside for disposal.

Coal washery tailings fall into two categories, however. The standard washery discard is often of a comparatively large particle size (several millimetres and above) compared to metalliferous tailings, for which a better comparison is the fine coal produced by screening or spiral treatment to give a better sized product. The removal of coal fines often requires their storage in lagoons or other impoundments, where they can sometimes form an energy resource for later recovery with improved technology.

2.7 Uranium

Uranium is increasingly being produced from in-situ leaching operations, in which solution mining has replaced conventional excavation and milling. As world uranium demand is flat, the amount of tailings being created from uranium mining has been falling. Nonetheless, there remain large volumes of uranium tailings from mining since the 1950s, which in some countries, the U.S.A. for example, have become subject to extensive clean-up operations.

Given the potential for longer-term environmental impacts owing to radioactivity, uranium tailings dams have received increased attention from all quarters. More emphasis has been placed on adequate retention, curbing dust emissions and preventing fluid seepages, while in some cases worked-out open pits have been used for tailings impoundment.

In addition to primary deposits, uranium is also produced as a by-product of phosphate mining in the U.S.A., and as a co-product at some South African gold mines.

2.8 Global context

This study has drawn information from selected sources, and does not attempt to provide a comprehensive list of tailings dam incidents on a world-wide basis. Nonetheless, the countries and regions covered in the study represent a major proportion of world mineral production. For example, between them Australia, Canada, the U.S.A. and Zambia, from all of which information was received, represented over 40% of established market economy country (that is, non-C.I.S. and China) copper mine production in 1994; if Chile, Papua New Guinea and South Africa (from which information was requested but was not received) are included, the proportion rises to over 75%.

For lead and zinc, the countries covered in the study represent nearly 60% of established market economy country output. The comparative proportion is 65% of global newly mined gold, while for phosphate rock the figure is around 35% of global production. Massive production from China and the C.I.S. countries, for which direct information remains scarce, skews the proportions for world coal output away from the countries covered, although as noted above, coal tailings represent a different situation to those generated by metal mining.

3.0 REVIEW OF CONSTRUCTION METHODS

Tailings dams and other impoundments are essentially a 20th Century invention. Before that, residues from mineral recovery operations were generally discharged either on to the surface close to the mine concerned, or into the nearest watercourse for disposal downstream. In some cases, river or marine disposal still occurs. Recent examples of a lack of tailings retention include the Ok Tedi and Bougainville mines in Papua New Guinea. Mines such as the Kilo-Moto gold operations in northeast Zaire still use local rivers to wash away their residues. Tin producers in western England also traditionally discharged tailings to the sea, while the former copper mines on Vancouver Island, Canada, and the Black Angel lead-zinc mine in Greenland all used deep-water deposition for tailings disposal.

Tailings dam construction methods have advanced with time, incorporating better knowledge of the geotechnical and hydrological parameters that influence dam performance. The study of soil mechanics has been transferred to dam design, and the professional interest of organisations such as the International Commission on Large Dams (ICOLD), set up in the late 1920s to monitor water-retention structures, has been extended to encompass tailings impoundments as well.

The earliest record in the USCOLD review of tailings dam incidents dates to 1917, when reference is made to a failed tailings dam in South Africa. That this was noted in a paper entitled "The Construction and Maintenance of Slimes Dams" suggests that South Africa took an early lead in this area, probably on account of the very concentrated nature of the Witwatersrand gold mines and the lack of surface water for tailings disposal. On reflection, that has been of long-term economic benefit, given the success of the Ergo and other tailings retreatment schemes that have recovered significant amounts of gold from these old tailings dams.

3.1 Tailings dam types

Tailings dams are classified into four general types: cross-valley, valley bottom, valley side and ring, or enclosed. A brief summary of each type follows.

Location of a tailings impoundment depends to a large extent on the natural topography. Sites deemed suitable on this criterion must then be examined in detail to establish the nature of the underlying rocks, their permeability and other factors.

3.1.1 Cross-valley

The simplest form of tailings dam, this involves the construction of a dam wall from side to side of a valley. Provision must be made for the natural watercourse either to be diverted, or to be piped beneath the dam wall. Such dams are clearly at increased risk in the case of flash floods, or if the watercourse diversion system becomes clogged. As in all the valley-type situations, several impoundments can be constructed, one topographically above the other, to increase the total tailings retention capacity.

The Stava tailings impoundments in Italy that failed in 1985 were of this type, as is the original tailings dam servicing the Los Bronces mine in central Chile, where it is reported that a major failure was narrowly averted when the river diversion tunnel became blocked.

3.1.2 Valley side

This approach is used where the topography is gently sloping, the valley side or hillside impoundment requires the construction of both front and side dam walls. While less at risk from flash floods, an extensive surface water diversion system is needed on the higher side of the impoundment to prevent excess water collecting behind the dam.

3.1.3 Valley bottom

A combination of the cross-valley and valley side types, these are used where a valley is too wide or flat for a single dam wall to be constructed economically. Valley bottom impoundments feature two dam walls, the longer lying parallel to the fall of the watercourse. If constructed too close to this, there is the risk of erosion of the toe of the dam wall, as occurred in the early 1990s at the Kojkovac tailings dam in Montenegro, former Yugoslavia.

3.1.4 Ring

Used in flat-lying topography, this type requires the construction of a complete retaining dam wall, within which the tailings are stored. Internal dam walls may also be constructed to give multiple deposition possibilities. South African and Western Australian gold mine tailings dams are typically of this type, reflecting the flat-lying countryside overlying the goldfields.

3.2 Methods of tailings dam construction

A brief review of tailings dam construction techniques may be useful.

3.2.1 Upstream construction

The earliest system to be used, "upstream" construction, involved the formation of a low bund or retaining wall from coarse material, behind which the tailings were deposited. As the pond level approached the top of the wall, another layer was added on top of both the existing wall and the edge of the tailings beach, and the filling process re-started. The process of increasing the dam height could be repeated several times.

The disadvantage of this system is that there is a line of potential weakness at the base of each lift, as the new wall is founded on both coarse and fine materials. This could enable the wall to fail under the influence either of water springing through it, and eroding the dam, or from the effects of a natural phenomenon such as an earthquake, which could cause liquefaction of the impounded tailings. Nonetheless, upstream construction is still used, in particular in dryer areas of the world where water levels in the impoundment are kept to a minimum level through recycling, and where the risk of seismic activity is low.

3.2.2 Downstream construction

In view of these shortfalls, "downstream" construction of the dam wall has become more widely used. The system has the advantage that part of the coarsest fraction of the mill tailings can be used for dam wall construction, with the finer material being retained in the impoundment.

An impervious barrier is often constructed on the pond side of the dam wall, and internal drainage provided to ensure that the phreatic surface within the wall is kept well away from its downstream face. The thickness of the dam wall increases in relation to the height, providing additional stability, but requiring increasing amounts of material for its gradual enlargement.

3.2.3 Centreline construction

This technique combines the advantages of both upstream and downstream construction methods, while providing better seismic stability than the former and requiring less construction material than the latter. Its water-retention capabilities are not as good as those of a dam formed using the downstream system, however.

3.2.4 Water retention

Based on designs originally intended for water storage, this type of dam includes the use of an impervious core in the wall, as well as filter and drainage layers within its downstream face. Water seepage is thus minimised, but at the disadvantage of much higher construction costs. It is also more difficult to increase the height of this type of structure should a larger tailings retention volume be needed in the future.

3.3 Key factors in tailings dam construction

There are a number of important factors that have a direct bearing on the stability of tailings dams, and hence on their long-term retention capability. Most are concerned with water handling in one form or another.

3.3.1 Water control

Unlike water-retention dams, which are made of compacted natural fill material with an impervious core, such as concrete, mine tailings dams are typically formed from either coarse tailings or from locally excavated fill. Both materials permit water to permeate, and the prevention of water erosion, either on the dam face or within the dam wall is paramount. Thus modern tailings dam construction practice includes filter and drainage layers within the dam wall.

Water contained within the dam wall and the impoundment behind will find a natural level (the phreatic surface) that may vary with the seasons, the volume of tailings disposal, and other factors. If the phreatic surface intersects the downstream face of the dam, a spring line will develop, leading to rapid erosion of the dam wall material. Erosion in turn leads to slippage of the face as the angle of repose of the now-saturated material is exceeded. This moves the intersection point between the face and the phreatic surface further back into the dam wall, and the cycle is repeated with the possibility of a breach being formed unless prompt action is taken to secure the dam face.

Reasons for the initial springing can be many, but mostly concern inadequate drainage of the impoundment and hence a higher phreatic surface within the tailings. Examples of causes of this could include a blocked decant system, sudden heavy rain that overwhelms the decant capacity, blockage to a spillway or watercourse diversion, poorly managed or unbalanced tailings discharges, or the retention of too much water in the impoundment pond, perhaps on account of its chemical contents.

Controlled seepage is often necessary to manage the water level behind and within the dam wall, and to dewater the impoundment after tailings deposition is complete. The water-retention capacity of finely ground material is high, and dewatering to a stable water content takes years to achieve, even in arid climates. Seepage can be contained through the use of catchment structures downstream from the dam, or by pumping groundwater, with the effluent being returned to the dam or purified before release. An example is the capture of saline water that seeps from the tailings dams at potash operations in Saskatchewan, with borehole pumps used to capture seepage that has entered local aquifers from beneath the impoundment.

Decanting from the impoundment pond is used either to recycle water to the processing plant or to reduce the water level behind the dam. Decants take two principal forms; either a fixed structure that maintains the water at a level corresponding to its top opening, or a pontoon-mounted pumping system. Solid decant towers must be raised in height with each increase in the dam wall, but have no operating costs. Floating pump stations can be used to regulate the water level more effectively, but incur operating costs. A break in either the decant outflow, which generally lies beneath the dam wall, or in the tailings inflow pipe, can lead to rapid erosion of the wall. A number of dam wall failures have been attributed to internal erosion caused by damaged or blocked decant pipes, as water swirling from the break caused extensive internal potholing and eventual breakthrough of the impounded material.

3.3.2 Foundation material

The selection of an appropriate site for a tailings dam calls for favourable topography and the presence of suitable foundation materials. Unsuitable rock material beneath a dam can lead to failure of the overlying structure. Thus deep soil or sub-soil that are liable to become saturated, or clays that could develop slips when wet, are not suitable foundation materials for dam wall foundations, although clays could provide a naturally impervious barrier beneath the impoundment area. Similarly, the presence of excessive jointing, faulting or fractures in the underlying rock could lead to long-term weakness and the potential for dam failure.

4.0 CAUSES OF TAILINGS DAM FAILURE

This study gathered information not only on catastrophic failures, such as dam wall collapses, but also on lesser incidents. These include over-topping of the dam wall by water or fluid tailings, accidental or uncontrolled discharges of fluids, and other situations where effluent of one form or another from a tailings dam affected the environment either near the dam or further afield.

Virtually all failures occur as a result of the presence of water. Examples of such water action are percolation through the dam wall, internal erosion, overtopping or flooding. The water movement may be triggered by natural phenomena such as earthquakes or persistent heavy rain. The majority of the incidents recorded in this study are a direct result of such processes.

4.1 Breached retaining walls

Breaches in dam walls occur for a number of reasons, most of which are situations in which the phreatic surface within the wall rises until it intersects the downstream dam face (*see* Section 3.3.1). Other possibilities include piping or 'rat-holing' within the dam wall, as a result of leakages from decant pipes or spillways, for example, where water under pressure causes internal damage that eventually weakens the wall structure to the extent that it can no longer retain the tailings.

Rapid erosion of the dam wall material, which is usually graded sand, will result in breaches through which the semi-fluid tailings can flow, assisted in the process by the water ponded on the impoundment surface. This in turn causes further wall erosion, accelerating the rate of escape.

4.2 Earthquake effects

Shock waves generated by earthquakes or tremors can devastate relatively unconsolidated dam wall materials, as well as causing the impounded tailings to liquify. Some major tailings dam disasters have been caused in this way, notably the incidents in Chile in 1965 and at Mochikoshi in Japan in 1978.

The effect of such shock waves on semi-fluid materials has been well-documented. As well as causing the tailings to liquify, repeated shocks can cause waves to form through the impoundment, increasing the risk of overtopping the dam wall and giving rise to cyclical higher pressures on the wall structure. Particularly at risk in these circumstances are walls constructed using the upstream method, where the joint between individual lifts can form a weak point in the structure.

4.3 Flooding

Torrential rain, such as occurs with typhoons, or even persistent heavy rain, can flood the lower reaches of valleys as the increased flow from numerous watercourses combines. In the upper valley reaches, flowrates in watercourses can increase significantly, leading to rapid erosion of both natural material and man-made structures.

Most active tailings impoundments have a settling pond area in which there is standing water, the level of which is maintained by some form of decant system. Water inflows to the pond that exceed the capacity of the decant, or which result in blockage to the system, carry the risk of overtopping the dam wall and its subsequent erosion. A case in point is a Chilean copper operation in which a by-pass tunnel became blocked during heavy rain. Anecdotal reference suggests that the security of a major tailings impoundment, situated above residential and agricultural land, was only assured through the rapid construction of a new concrete spillway that permitted the storm water to be carried safely over the dam wall.

Other incidents in which flooding played a major role include the Stava dam failure in Italy in 1985, the Harmony failure in South Africa in 1994, and several failures or potential failures in the Philippines since 1980, in all of which rains associated with typhoons were a contributory factor.

4.4 Decant failure

As noted in Section 3.3.1, decants can be either fixed or floating. Fixed structures present a higher risk because inspection of the pipes beneath the tailings and the dam wall is not usually possible. Thus any fracture in the pipes, perhaps as a result of movement of the whole structure or through earthquake damage, increases the possibility of internal erosion and 'rat-holing'.

Blockages to decant systems can also mean an increased risk of overtopping. In general, this appears to be less of a problem with active dams, from which water is often recycled for mineral processing, than with dams that have been abandoned and for which regular inspection is less assured. Thus some incidents of water contamination have been reported from Canada, although in each case the dam involved was in a remote location where mining had ceased. Subsequent investigation of the downstream effluent drew attention to decant systems blocked by natural debris or by pipe collapse.

5.0 ENVIRONMENTAL EFFECTS

In addition to the direct results of wall failures, overflows and other incidents essentially of a structural nature, gradual emissions from tailings impoundments may affect the surrounding environment. Such impacts include long-term seepage that results in groundwater contamination, dust emissions, and disturbance of wildlife habitat. It should be noted that structural failures generally result in a rapid release of material over a short timespan. Emissions, on the other hand, can continue for years, both during active use of the dam and after mine closure.

5.1 Groundwater contamination

The movement of possibly contaminated water from an impoundment into underlying strata depends on the relative permeability of the materials. In cases where there is a highly permeable zone beneath the tailings, it has been known for fluids from dams to enter underlying aquifers, forming a 'contamination plume' that spreads in the direction of aquifer flow. The solution has been to install a ring of wells at an appropriate distance from the dams, and to pump the groundwater back to the settling ponds.

It should be noted that seepage assists in drying the tailings in an impoundment, especially after abandonment. In the dry climate of Western Australia, for example, seepage is regarded as being inevitable and is perceived as having little effect on groundwaters that are already highly saline. In some circumstances, however, seepage has been recorded as having caused the groundwater table to rise, bringing saline water closer to the surface and damaging vegetation.

5.2 Dust emissions

Normally only a problem when a dam has been abandoned, and also climate-dependent, dust emissions can be a significant nuisance to the surrounding countryside as well as having the potential for spreading hazardous materials such as asbestos fibre or heavy metals. Uranium tailings pose a special concern in this context.

Solutions generally revolve around revegetation to stabilise the dam surface, but the success of this step often depends on the nature of the tailings material, the water-retention capability of the surface layer, and long-term husbandry of the project. Incidents in which dust has played a role include the cobalt-rich pyrite dumps and tailings from the former copper mine at Kilembe, Uganda, the surfaces of which have not revegetated successfully, and the dams associated with the Xihuashan, Dangping, Piaotang and Xialong tungsten mines in China, where dust emissions are believed to have caused cadmium contamination of the food chain in neighbouring communities.

5.3 Other environmental impacts

Although not directly related to dam failure, ancillary impacts include the effect of strongly mineralised or cyanide-bearing water on wildlife. Reference has been made to wildfowl deaths at the Northparkes copper-gold mine in New South Wales as a result of a temporary increase in cyanide levels in the tailings pond water.

The provision of safety closures over openings such as boreholes used for monitoring groundwater levels and quality has also been highlighted as becoming of increasing importance to prevent wildlife ingress.

It is also relevant to note that tailings dams can provide additional habitat for wildlife, with abandoned impoundments forming a valuable wetland resource provided that the water present is of suitable quality.

5.4 Community location

The location of housing near to tailings dam structures can present increased risk should a failure or other incident occur. Examples include the Le Cobre failures in Chile in 1965, in which tailings released following earthquake-induced dam wall collapses inundated a mining camp below, while casualties that resulted from the Stava disaster in 1985 were also sustained by the population living downstream from the dams.

The proximity of the South African township of Merriespruit to the Harmony tailings dam undoubtedly increased the potential for casualties when the dam wall failed, and those reported following the Jinduicheng breach in China were due to material flowing into residential areas downstream. In fact, in each case within the review period where casualties have been reported in the general population, rather than within the mining workforce, the dead and injured were people living or working close to the failed structure.

Mining companies and government authorities vary in their ability to regulate where communities are located. The existence of squatter camps set up by people seeking work presents a particular problem, especially in countries with limited housing and social infrastructure. Where the community at risk is directly employed by the mine, its relocation is simpler, a recent example being the resiting of a residential camp serving the Argyle diamond mine in Australia. Once it was realised that the mine's tailings dams posed a potential hazard to the camp in the event of an earthquake, its complete relocation to higher ground was achieved within three months.

6.0 SIGNIFICANT FAILURES AND OTHER INCIDENTS SINCE 1980

This section notes the tailings dam failures and other incidents that have been reported as having occurred since 1980. Summaries of responses received are also included. Specific details of incidents are listed in the Appendix volume.

Table 2 lists selected major incidents recorded in the period 1965-1979. Table 3 lists incidents since 1980 that were identified during this study. Full information is not, however, available on all of the incidents included in Table 3.

As might be expected, Table 3 shows that the number of recorded incidents for which details are available increases in the 1990s. Specific information on dam incidents in the early 1980s is limited to those that had the greatest impact, while in recent years not only is there more information but the number of records is also significantly higher. This reporting reflects increased environmental awareness as well as the adoption of expanded recording systems.

6.1 Summaries of responses

Initial approaches to collect data for this study were made mainly to government organisations in 17 selected countries with an established mining industry. In some cases, the system for maintaining records on tailings dams is fragmented, with several agencies or other organisation holding partial information. In others, reorganisation of government departments, or changing personnel, has meant that responsibilities have changed or records of incidents, usually those in the 1980s, have been lost. Respondents who agreed to participate were provided with a questionnaire relating to each incident that occurred during the review period for which records exist.

The following sections contain information on the various national agencies with responsibility for tailings dams, and review the responses received.

6.1.1 U.S.A.

Responsibility for monitoring tailings dams is split between various agencies. The Mine Safety and Health Administration (MSHA) has regulatory responsibility for active dams. The Office of Surface Mining has responsibility for abandoned dams from the coal industry. Abandoned dams from other sectors of mining are the responsibility of various state

Table 2. Selected tailings dam incidents, 1960-1980

Date	Record	Location	Outline Details	Fatal-ities	Environmental impact	Property damage
1965		Chile	Earthquake related failure of some 15 tailing dams	210	Tailings flows downstream from dams	Extensive damage to miners' camp
1972		Buffalo Creek, WV, USA	Successive failures of coal mine waste dumps	126	Pollution downstream from debris and dirty water	Extensive damage to communities downstream
1970		Mufulira, Zambia	Tailings flow into underground workings	89	Slight	Extensive damage to underground workings
1974		Impala Platinum, South Africa	Dam wall breach	14	-	Damage to shaft and underground workings
1978		Mochikoshi, Japan	Liquefaction and dam failure following earthquake	1	-	-
1978	•	Arcturus, Zimbabwe	Dam wall breach following heavy rain	1	Extensive siltation of water course and grazing land	Minor damage to neighbouring village
1979	•	Church Rock, NM, USA	Breach in tailings dam caused by foundation settlement	0	Extensive low-level contamination by released process effluent	-

Notes: • Record included in the Appendix;
- Information not available

Table 3. Selected tailings dam incidents, 1980-1996

Date	Record	Location	Outline Details	Fatal-ities	Environmental impact	Property damage
1980	•	Heath Steele, NB, Canada	Continuing leakage of effluent since 1970s	0	Localised to immediate downstream from dam	Nil
1980		Sweeney Mill, CO, USA	Dam failure, uranium tailings	-	-	-
1980	•	Tyrone, NM, USA	Dam wall breach, possibly caused by poor construction methods or external erosion	0	Localised	Inundation of farm land
1981		Dixie, Idaho Springs, CO, USA	Dam failure, inactive impoundment	-	-	-
1982	•	Sipalay, Philippines	Dam foundation failure	-	Localised	Inundation of farm land
1983	•	Gray Eagle, CA, USA	Effluent seepage into groundwater	0	-	Nil
1983	•	Golden Sunlight, MT, USA	Effluent seepage through underlying strata	0	Localised	Nil
1984		Battle Mountain, NV, USA	Dam wall instability	-	-	-
1984	•	Aurora, NC, USA	Dam wall failure following seepage drain blockage	0	-	Nil
1985	•	Marga, Chile	Overtopping after decant failure on abandoned impoundment	-	-	-
1985	•	Olinghouse, NV, USA	Dam wall failure following unsupervised construction	0	-	-
1985	•	Cerro Negro, Chile	Earthquake-induced dam failure	-	-	-

Table 3. (continued)

Date	Record	Location	Outline Details	Fatal-ities	Environmental impact	Property damage
1985	•	Veta de Agua, Chile	Earthquake-induced dam failure	-	-	-
1985	•	LaBelle, PA, USA	Dam wall slippage following foundation failure	0	Nil	Nil
1985	•	Stava, Italy	Successive dam failures following heavy rain	268	Extensive spread of tailings in valley below dams	Extensive within communities below dam
1986	•	Mineral King, BC, Canada	Dam wall breach following diversion blockage	0	Minimal	Minimal
1986	•	Brazil (iron ore)	Collapse of brick dam	7	-	Loss of equipment and infrastructure
1986	•	Rossarden, TAS, Australia	Washout of part of dam wall	0	River polluted by tailings	Minimal
1986	•	Story's Creek, TAS, Australia	Dam wall collapse following flood	0	River polluted by tailings	Minimal
1986	•	Pico de Sao Luis, Brazil	Dam wall failure following spillway erosion	-	-	-
1986	•	Mankayan, Philippines	Dam failure	-	-	-
1987	•	Montana Tunnels, MT, USA	Effluent seepage into groundwater	0	Localised downstream from dam	Nil
1987	•	Xishimen, China	Dam wall breach following decant blockage	-	-	-
1987	•	Montcoal, WV, USA	Pipe failure	-	-	-
1988	•	Grays Creek, TN, USA	Internal pipe failure, leading to emptying of impoundment and erosion of dam wall	0	-	-

Table 3. (continued)

Date	Record	Location	Outline Details	Fatal-ities	Environmental impact	Property damage
1988	•	Jinduicheng, China	Dam wall failure following decant blockage	20	-	-
1989		Dwight, PA, USA	Pipe failure	-	-	-
1989		Jewett, TX, USA	Dam failure	-	-	-
1989	•	Silver King, ID, USA	Overtopping, following slump of material into impoundment	0	-	Slight
1990		Annapolis, MO, USA	Dam failure	-	-	-
1990		Brazil (fluorite)	Dam failure	-	-	-
1990		Coal Mountain, WV, USA	Pipe failure	-	-	-
1990		Toa Baja, Puerto Rico	Dam failure	-	-	-
1991	•	Iron Dyke, BC, Canada	Slump of part of dam wall	0	Nil	Damage to dyke only
1992	•	Padcal, Philippines	Dam failure following earthquake	-	-	-
1992	•	Kojkovac, Montenegro	River erosion of dam wall footing	0	Nil	Nil
1992		Pembine, WI, USA	Dam failure	-	-	-
1993	•	Itagon Suyoc, Philippines	Dam failure following typhoon-related decant blockage	-	-	-
1993		Mankayan, Philippines	Spillway collapse following typhoon	-	-	-
1993	•	TD7, Chingola, Zambia	Slurry overflow after heavy rain	0	Minimal	Interruption to domestic water supplies

Table 3. (continued)

Date	Record	Location	Outline Details	Fatal-ities	Environmental impact	Property damage
1994		Simi Valley, CA, USA	Dam failure	-	-	-
1994		Taft, CA, USA	Dam movement	-	-	-
1994		Ray, AZ, USA	Partial dam breach	-	-	-
1994		Turkeypen, KY, USA	Water outflow	-	-	-
1994		Mulberry, FL, USA	Pipe failure	-	-	-
1994	•	Harmony, South Africa	Dam wall breach following heavy rain	17	Limited to surrounding area	Extensive damage to residential township
1995	•	Riltec, TAS, Australia	Leakage of contaminated water	0	Pollution to watercourses	Minimal
1995	•	Middle Arm, TAS, Australia	Dam wall erosion	0	Minimal	Minimal
1995	•	Omai, Guyana	Discharge of tailings effluent	0	Temporary pollution to rivers and sediments	Limited to dam structure
1995	•	Placer, Philippines	Dam foundation failure	12	Coastal pollution	Loss of mining equipment
1995	•	Golden Cross, New Zealand	Dam movement (continuing)	0	Nil	Nil
1996	•	Marcopper, Philippines	Loss of tailings from storage pit	0	Siltation of watercourses	Nil

agencies, with no federal organisation providing overall consistency of inspection procedures. The Environmental Protection Agency could become involved in the case of a significant incident, or if effluent from a tailings dam reaches watercourses. In addition, the Federal Emergency Management Agency might also have a role in the case of a tailings dam-related disaster, as might the U.S. Army Corps of Engineers.

Non-government groups that also hold information include the United States Committee on Large Dams (USCOLD) and the Center on the Performance of Dams at the Department of Civil Engineering, Stanford University, Palo Alto, California. Outline information was received from MSHA, the National Mine Health and Safety Academy, USCOLD and Stanford University. Detailed information has not been provided in most cases. The USCOLD publication *Tailings Dam Incidents* is referenced to primary information sources where possible.

The Buffalo Creek, West Virginia, incident in 1972 remains one of the most widely reported, although it was not actually a tailings dam that was washed away, but rather coal mine waste. Other failure types have included foundation collapse, overtopping, uncontrolled seepage and structural weakness in dam walls; earthquake effects have been noted in water-retention dams in California, but do not appear to have resulted in recorded damage to tailings dams.

6.1.2 Canada

Regulatory responsibility for tailings dams is held at Provincial government level, the Federal government only having responsibility for those derived from uranium production. Responses were sought from the appropriate authorities in the six major mining provinces of British Columbia, New Brunswick, Newfoundland, Ontario, Quebec and Saskatchewan, and were received from four: British Columbia, New Brunswick, Quebec and Saskatchewan.

None of the respondents noted any major failures since 1980, although there have been a few structural failures in dam walls, and some cases of seepage, as at the Rocanville potash operations in Saskatchewan and at Heath Steele in New Brunswick. Newfoundland reported three minor incidents, all involving water damage to abandoned dams where the decant or spillway systems became blocked.

Responsibility for dams in New Brunswick is held by the provincial Department of the Environment and the Department of Natural Resources and Energy. Tailings dam incidents must be reported, as in British Columbia, where responsibility is held by the provincial Department of Employment and Investment, Energy and Minerals Division, both for active dams and for abandoned dams where care and maintenance has been neglected by the owners, if known. The responsible agency in Quebec is the Ministry of Environment, to which incidents must be reported.

6.1.3 Latin America

Requests for information were made to the authorities in Chile, but no response was received. Situated in an active tectonic area, Chile has had a number of reported incidents in the past, the most severe being in 1965 when the La Ligua earthquake caused damage to around 15 dams, resulting in over 200 fatalities from the collapse of the El Cobre Old Dam.

Chile's mountainous terrain has also favoured the past construction of cross-valley dams, which are particularly vulnerable to flood damage both when active and when abandoned.

6.1.4 Europe

Requests for information were made to the authorities in four countries with a well-established mining sector: France, Germany, Poland and Sweden. Information on Italy was sought at the Department of Civil Engineering at Imperial College, London. No information was received from France, Germany and Poland. No incidents were reported by the respondents in Sweden, or by Imperial College.

With the exception of the Stava incident in Italy in 1985, no records have been identified of tailings dam incidents in Europe. The Aberfan incident in Wales in 1966 involved mine waste, not tailings, while a sand slide into a Spanish open pit iron ore mine in the mid-1980s resulted from the failure of an overburden dump. In general, mining in Europe is dominated by coal and construction raw materials, neither of which typically call for large tailings dams.

In terms of metallic minerals, tailings from French uranium mining probably hold the greatest potential for environmental concern, but the lack of records of any incident involving this sector suggests that controls are both adequate and well enforced. In terms of tonnage, Sweden has the largest metallic mineral output in Europe on account of its iron ore production, but no incidents were identified.

6.1.5 Africa

Requests for information were made to Ghana, South Africa, Zambia and Zimbabwe. Responses were received from Zambia and Zimbabwe.

South Africa has the most extensive mining industry on the continent, and consequently has a large population of tailings impoundments. Only two major incidents have been recorded since 1970, at Impala Platinum in 1974 in which a breach in a dam wall caused tailings to flood an operating mine shaft, and at Merriespruit (Harmony) in 1994. However, a press report (*Mining Journal*, March 4, 1994, p.163) notes that on average there are at least two slimes dam failures each year, most of which are small and do not involve loss of life.

Gold mining produces extensive slimes dams, many of which have been reclaimed and retreated to recover residual gold. Coal washing also produces large amounts of coarser waste, for which retreatment techniques are being developed. Past asbestos mining has left both waste and tailings dumps that are perceived to present a health hazard from dust emissions.

In Zimbabwe, which has smaller-scale and more scattered mines, reported tailings dam incidents have been rare. With the exception of its asbestos industry, Zimbabwean tailings dams are small. This may change once the Hartley platinum project comes on stream. The country's most serious tailings incident, which occurred at the Arcturus gold mine in 1978, was overshadowed in terms of publicity by the death of the mine manager during a payroll robbery the same day. Responsibility for monitoring active dams is held by the Chief Government Mining Engineer, and for abandoned dams by the Natural Resources Board.

The 1972 Mufulira disaster in Zambia, while involving tailings entering the mine through an unstable surface area, was not the result of a dam or impoundment failure, but rather the unforeseen consequences of tailings disposal in an inappropriate position above the mine. Incidents that have occurred subsequently have predominantly been associated with heavy seasonal rainfall. The Mines Safety Department and the state mining company, ZCCM, have responsibility for monitoring both active and abandoned dams.

6.1.6 Asia

Requests for information were made to the authorities in India, China, Papua New Guinea and the Philippines. No response was received from China or the Philippines, while the response from India was that there have been no tailings dam incidents recorded during the review period. The authorities in Papua New Guinea claim that information on tailings dams is confidential and declined to respond.

Papua New Guinea hosts a number of major copper and gold mines of which two, Ok Tedi and Bougainville, do not have tailings impoundments. The same is true at the Ertsberg copper-gold mine in Irian Jaya, Indonesia. At Bougainville, currently closed, tailings disposal was via a flume to the sea, while at Ok Tedi and Ertsberg, it is into local rivers. The original tailings dam site at Ok Tedi was destroyed by a landslide in 1984, and subsequent studies concluded that the construction of a permanent facility would be uneconomic.

Being in an area of significant tectonic activity, Papua New Guinea's terrain may be largely unsuitable for tailings dam construction, as earthquakes and landslides could lessen long-term dam stability. The same applies to the Philippines, where records would indicate that a disproportionate number of incidents have occurred during the review period. Earthquake activity is reported as being significant in a number of these incidents, while torrential rain associated with typhoons has also been cited.

Information on failures in China is limited, and is often only reported well after the event, when an incident has had an effect on international markets for a particular material for which the country is a significant supplier.

Mining in Japan, meanwhile, has been decreasing. The most recent dam incident of significance was the earthquake-induced collapse of two dams at the Mochikoshi gold mine in 1978.

6.1.7 Australia and New Zealand

As in Canada, regulatory responsibility for tailings dams in Australia is at State government level, with the Commonwealth government responsible only for tailings impoundments derived from uranium mining. Information was requested from the appropriate agencies in seven Australian states: New South Wales, Northern Territory, Queensland, South Australia, Tasmania, Victoria and Western Australia. Responses were received from all but Queensland.

Neither Northern Territory, South Australia nor Victoria recorded any incidents during the review period. In New South Wales, there have been two cases of seepage and one 'unplanned discharge', although in each case the effects were contained within the mine site. A respondent from Western Australia, the state with the most active mines, noted that there have been several small-scale incidents since 1980, consisting of localised embankment failures, shallow groundwater contamination and wind erosion, all of which were successfully managed by the mining companies.

Other positive points identified as being significant in minimising tailings dam incidents in Western Australia include the low rainfall and high evaporation rates experienced in the main mining areas; that the majority of dams are free-standing structures built on virtually flat ground with minimal catchment areas; that most dams are located in the upper parts of watercourse catchments; and that virtually all starter walls are constructed from selected mine waste, on which subsequent minor failures have little impact.

The agencies responsible for monitoring both active and abandoned tailings dams in Western Australia are the state Department of Minerals and Energy and the Department of Environmental Protection. Any incidents must be reported, and in 1993 the Department of Minerals and Energy established a database to record details of tailings dams in general.

In Tasmania, regulatory responsibility for active dams is held by the Department of Industry Safety and Mines. Together with the Department of Environment and Land Management, this body is responsible for abandoned dams until they are rehabilitated to the satisfaction of the Chief Inspector of Mines. They then become the responsibility of the leaseholder or landowner. There is no legal responsibility to report dam incidents unless they are life-threatening.

Mining activity in New Zealand is limited, and the responsible agency reports no incidents involving dam failures. The continuing slippage being exhibited by the dam at Golden Cross is unusual, and while the potential for failure is reported by the mining company involved to be minimal, the long-term stability of the impoundment has yet to be proven.

6.2 Tailings dam populations

With very few major mining countries having a single authority responsible for maintaining records on tailings dams, it is difficult to estimate accurately the true population of impoundments on a national basis, and even less so world-wide. A representative sample from responses received and other references is shown in Table 4.

Table 4 has been compiled mostly from information supplied by questionnaire respondents. Differences in recording requirements used, and in the scale of the mining industry in each country, province or state, are reflected in the level of detail available. To illustrate, the Canadian province of New Brunswick provided data that are more precise than British Columbia, with its larger, more diversified and longer established mining sector.

With no direct response received from South Africa, the total number of tailings dams shown in Table 4 is based on literature source estimates, and reflects the scale of that country's mining industry. Many of the dams are also of large capacity. By contrast, a respondent in Zimbabwe reported a total of some 500 dams, of which around 450 are in the gold industry. Given the small-scale nature of this sector in Zimbabwe, the capacity of most of these dams will be low.

Table 4. Selected tailings dam populations

Country/region	Active	Abandoned	Total
Canada			
British Columbia	c.30	c.100	c.130
New Brunswick	4	3	7
Quebec	27	137	164
Africa			
South Africa			c.400
Zambia	21	17	38
Zimbabwe			c.500
Australia			
Tasmania	26	15	43
Western Australia	210	140	350

The data presented in Table 4 represent a small sample obtained from questionnaire responses. Major mining countries such the U.S.A. and Chile are not included, but clearly each has a substantial number of tailings impoundments, as do the countries of the C.I.S. and, in all probability, China. However, it is unlikely that a comprehensive census has ever been taken of all tailings storage facilities in the U.S.A., for example.

It would be unwise to attempt an estimate of total world, or regional tailings dam populations on the basis of such a small sample. Even within individual countries, the number of dams found in one area is no guide to the complete population; thus the number of dams in Western Australia (where the mining industry is centred on gold, iron ore and nickel), cannot be used as the basis for extrapolation, given that the mining sector in other Australian states is of a different capacity and produces different minerals.

6.3 Types of incidents

Respondents were asked to indicate the types of incidents that were recorded within their jurisdiction. Information given is shown in Table 5, together with details of incident types from other sources. Dust emissions are most prevalent in drier climates, while earthquake damage is typically restricted to circum-Pacific countries.

In the case of damage caused by rainfall or river action, it is usually unclear from the information available whether failure resulted from the water flow as a primary cause or if the wet conditions exacerbated previously existing flaws in a dam's design, construction or operation. It is unlikely that such a technical judgement can be made without extensive investigation and interpretation of these findings. The task becomes particularly problematic when dealing with old or abandoned impoundments, which may have been designed to past criteria that were considered satisfactory at the time of construction, but which may not meet current standards.

Even in cases where internal erosion appears to have been the principal cause of failure, it may be impossible to specify the mechanism by which it occurred. A case in point is the Omai (Guyana) incident in 1995. The official report on the failure of the dam wall concludes that while it is clear that piping occurred in the dam core as a result of improper construction methods used for the rockfill, the water and slurry remaining in the pond make it impossible to determine when in the construction process the faulty work took place. Given that the Omai dam was constructed within the last five years to current design criteria, this puts into perspective the difficulty of determining exact causes of failures that have occurred in dams built many years ago.

A further important consideration is that while mining companies now accept the internalisation of costs associated with the treatment and storage of wastes, this was not the case in the past. Societal requirements have changed. Whereas tailings dams built earlier this century may have been constructed simply as a limited-life retention facility for the duration of the operation it served, this is not now the case. More and more, authorities expect full life-cycle costings and mine plans to include exit strategies that incorporate post-mining costs such as are represented by tailings dam inspection programmes.

Table 5. Incident type by location

Country/region	Types of incident recorded
United States	Dam wall failure Decant failure Flood damage Groundwater pollution Overflow Potential dam instability Surface water pollution Uncontrolled seepage
Canada	
British Columbia	Dam wall failure Flood damage Overflow Potential dam instability
New Brunswick	Dam wall failure Dust or gas emissions Groundwater pollution Potential dam instability Surface water pollution Uncontrolled seepage
Newfoundland	Decant failure Surface water pollution
Saskatchewan	Groundwater pollution
Latin America	
Brazil	Dam wall failure
Chile	Dam wall failure Earthquake damage Flood damage
Africa	
South Africa	Dam wall failure Decant failure Dust or gas emissions Overflow Potential dam instability Surface water pollution
Uganda	Dust or gas emissions Surface water pollution
Zambia	Dam wall failure Decant failure Dust or gas emissions Overflow
Zimbabwe	Decant failure Overflow Surface water pollution

Table 5. (continued)

Country/region	Types of incident recorded
Europe	
Italy	Dam wall failure Surface water pollution
Montenegro	Potential dam instability
Asia	
China	Dam wall failure Dust or gas emissions
Indonesia	Surface water pollution
Japan	Dam wall failure Earthquake damage
Papua New Guinea	Dam wall failure Flood damage Surface water pollution
Philippines	Dam wall failure Earthquake damage Flood damage Surface water pollution
Australasia	
New South Wales	Groundwater pollution Uncontrolled seepage
Northern Territory	Seepage Surface water pollution
Tasmania	Dam wall failure Decant failure Flood damage Overflow Potential dam instability Surface water pollution Uncontrolled seepage
Western Australia	Groundwater contamination Potential dam instability
New Zealand	Potential dam instability

6.4 Attitudes towards tailings dams

Public and official attitudes towards tailings dams differ from place to place, often reflecting the importance and age of the mining industry. Overall, the environmental movement has increased public awareness of mining. The following quotations are from specific responses provided by various countries on attitudes towards the safety and potential environmental impact of tailings dams.

Canada, British Columbia

"The public is very concerned about impacts from and the presence of mining. Government is committed to promoting and regulating environmentally acceptable mining."

Canada, New Brunswick

"The potential to negatively impact the environment is high. From a general perspective, most residents of New Brunswick are not aware of the specific safety and potential impacts of tailings dams. However, they generally do not trust the position taken by government and industry and require significant education to alleviate fears."

Canada, Quebec

"Safety of active tailings dams is very good and potential environmental impact is low. Some abandoned tailings dams, more than 25 years old, present some safety risks and have a moderate environmental impact. Many of them are currently being reclaimed and restored. About C$8 million were invested in 1995 by the government and industry to reclaim and secure abandoned mining sites."

Zambia

"Special dumps regulations exist under the Mines and Minerals Act. In recent years, there has been increased pressure for harmonisation and implementation of environmental laws."

Zimbabwe

"Generally accepted as part of a mining-related economy. Mining activities only affect 1% of the country's total area."

Australia, Tasmania

"The construction of tailings dams has always been controlled by the Mines Inspection Act, where specifications must be approved by the Chief Inspector of Mines. The construction, commissioning and decommissioning of tailings dams is also covered in any Environmental

Management Plan that is required prior to commencement of operations. The public is very concerned about the environment, and standards are forever being revised as public perception and expectation changes."

Australia, Western Australia

"The general public and government officials are well aware of the potential for both public safety and adverse environmental impact of poorly constructed and operated tailings storage. The response has been to make resources available to prevent such poor performance and ensure suitable legislation is enforced."

7.0 CONCLUSIONS

Tailings dams are an innovation of the 20th Century; before the advent of flotation technology and the treatment of low-grade ores, metallurgical processes were carried out at much coarser particle sizes and waste material was not impounded. By current standards, annual production rates of both metals and industrial minerals were low.

Tailings dam design has evolved from rudimentary construction to current, highly engineered standards. Improved knowledge in geotechnology, soil mechanics and associated fields has assisted in reducing the risk of dam failure markedly, although incidents still occur as unexpected or inadequately investigated conditions become apparent after construction. An area for concern continues to be the potential for inadequate supervision of construction, as noted by the New South Wales Mines Inspectorate:

"In regard to the construction of tailings dams we are concerned that while their design may be adequate their construction may not be to specifications; construction is often performed other than by the designer. We are considering imposing a mining lease condition requiring certification that the construction meets design requirements."

Major failures of tailings dams are rare and are often attributed by respondents, at least in part, to natural forces: earthquakes, flooding or exceptional rainfall. Of the most serious incidents that have occurred since the mid-1970s (those involving loss of human life), natural phenomena were associated with virtually all. In some cases, the effects may have been contributory to other factors. The possibility of determining the degree to which natural forces were the primary cause or exacerbated some previously existing weakness depends on the evaluation of geotechnical information that may not be available.

Dam embankments are typically constructed from non-cohesive materials such as cycloned tailings, earthfill or waste rock, all of which can be easily eroded by water. Failure of decant systems, spillways and diversion conduits is a major factor in smaller incidents that have a less extensive environmental impact, and can be a prime cause for localised dam wall erosion through overtopping or springing. Provision of inadequately sized spillway or decant systems to handle exceptional runoff from upstream catchment areas can also lead to wall failure. This applies to both active and abandoned dams, damage to the latter often only becoming apparent at some time after the event unless routine monitoring is carried out.

Recorded incidents involving uncontrolled seepage have become more common with the increased use of cyanide in the recovery of gold, both in parts of the world where it had not been used before, and in established markets. Being readily detectable in groundwater, the presence of cyanide beyond the confines of an impoundment is a clear indication of seepage beneath or through the dam. This may be caused by poor embankment construction or by permeation through the foundation strata. In general, however, the installation of cut-off wells and recycle pumps can prevent the contamination plume from moving far from the impoundment.

Dust emissions can also present localised nuisance. It is uncommon for this to persist over large areas, although examples such as dust blowing from the Kilembe tailings dams and pyrite stockpiles in Uganda, and the widespread cadmium contamination that is understood to have been emitted from Chinese tungsten mine waste indicate that this can occur. For the most part, revegetation of the dam walls and former pond surface provides an adequate remedy, although the tailings material must be made sufficiently fertile to permit plant growth. There is also a cost involved in long-term maintenance.

This investigation noted a considerable amount of confusion about the true nature of tailings dams and incidents involving them. For example, statements made in 1995 by advocates opposing gold mining in western Turkey cited cyanide pollution as having resulted from the dam failures associated with the La Ligua earthquake in Chile in 1965, and the Buffalo Creek disaster in West Virginia in 1972. In fact, the Chilean dams were all formed during copper ore processing, while Buffalo Creek involved coal mine waste; neither had any connection with cyanide.

A further example is provided by one respondent to this study who cited the pollution caused in the early 1990s by the Summitville, Colorado, gold mine as being from a tailings dam. This is also incorrect, as the emissions from the mine derived from its heap-leach operations, not from tailings. If these errors arise among professionals who are directly involved with tailings dams, it is easy to appreciate even greater misunderstanding by the general public.

The collation of data concerning tailings dam performance remains largely a matter for individual agencies, with a resultant wide variation in the amount and quality of information held. Reorganisation of government departments has in some cases also left gaps in information gathering and the maintenance of records. Similarly, personnel changes within the relevant authorities can break the continuity of collation.

Incidents that occur in remote areas, or in countries that are selective in their outside contacts, such as China, are much less likely to be reported than those in industrialised areas or where companies with international operations are involved. The failure of Manila Mining's Placer tailings dam in 1995 received little attention outside the Philippines; conversely, the escape of tailings from Marcopper's open pit impoundment in 1996 was widely reported, principally because a major Canadian mining company was involved.

The formation of databases by organisations such as the United States Committee on Large Dams and the Center on the Performance of Dams at Stanford University is still at a relatively early stage, tailings dams having taken a secondary role to their main task of monitoring dams used for water storage and hydroelectric generation. Nonetheless, records of tailings dam incidents have improved markedly since the mid-1980s, and such organisations make a valuable contribution to the availability of information.

Tailings dams are a necessary constituent of modern mining practice. Incidents of varying degrees of severity have occurred in the past, and will in the future. The task ahead is to ensure that the risk of major incidents is minimised in relation to the benefits to be obtained from mineral extraction. Improvements in design, construction and operating practice will assist in achieving this, requirements increasingly being stipulated in the relevant regulations. Australia's Northern Territory provides a suitable example:

"Present requirements for tailings dams in the Northern Territory require the application of best practice principles, the use of qualified engineers for the design and construction phase and an approved quality control program."

8.0 RECOMMENDATIONS

The information contained in this report has been provided principally by government agencies and international organisations that collect data on tailings dam performance. As mining is a truly global practice, in geographical terms the information presented in this study is somewhat restricted. Furthermore, the ability of reporting agencies to provide reliable information for parts of the world outside their areas of prime interest is hampered, in some cases by a lack of historical data and in others by a reluctance on the part of authorities to release what may be available.

The UNEP is in a special position to gather information that might otherwise be denied to other researchers, particularly in conducting a census of tailings dams, identifying the agencies responsible for their inspection, and gathering details pertaining to recent incidents that might otherwise go unreported. This report is a step in that process.

The information presented in this report has the potential to be the foundation of a permanent record of tailings dam performance data. However, these data must not used in isolation from other sources, several of which have contributed to its formation.

It is also important to encourage international agreement on the action to be taken based on the information acquired. For example, it may be that once sufficient data are accumulated, analysis will indicate that it is better to direct resources to addressing perceived shortcomings in the design and operation of tailings facilities in specific areas of the world, such as those prone to earthquakes or tropical storms. There is also the potential for technology transfer on this topic.

The principal international organisations that currently gather dam data are interested primarily in water-retention facilities rather than tailings dams. It is strongly recommended that the further collation of information in this area should include input from organisations or individuals who have first-hand knowledge of the minerals industry, who can determine the types of information that have most relevance to the overall strategy being adopted, and who have the professional experience to be able to analyse the information collected in order to ensure that it can be put to good use.

Great importance should be attached to ensuring the relocation of communities that have a high risk of inundation should a tailings dam nearby fail. The fact that the largest number of casualties arising from failures recorded within the study period were sustained by the general population, and not mining company workers directly, underscores the potential vulnerability of these people. Liaison between the UNEP and appropriate authorities in those countries perceived to be most at risk from earthquakes or other natural triggers to dam failures would help to save lives.

As part of this effort, the UNEP could advise authorities on appropriate measures to ensure that communities considered to be at risk are adequately informed about the possible consequences from potential spillages.

9.0 BIBLIOGRAPHY

Detailed information on specific tailings dam incidents is normally held in the archives of the individual government agencies that hold regulatory responsibility for such structures. The detail varies, reflecting current policy, the level of environmental awareness at the time of the incident, and other factors. Official inquiries are usually convened only in the case of major incidents, in which case a detailed report will be placed in the public domain. A recent example is the Guyanese report on Omai:

Report of Commission of Inquiry into Discharge of Cyanide and Other Noxious Substances into the Omai and Essequibo Rivers. Guyana Geology and Mines Commission, Georgetown, Guyana.

Collated information on tailings dam incidents is contained in:

Tailings Dam Incidents. United States Committee on Large Dams, 1616 Seventeenth Street, Suite 483, Denver, CO 80202, USA.

Background information to tailings dam construction and performance can be obtained from publications such as:

Design and Evaluation of Tailings Dams. Report No. EPA 530-R-94-038 (NTIS PB94-201845). U.S. Environmental Protection Agency, Office of Solid Waste, Special Waste Branch, 401 M Street SW, Washington, DC 20460, USA.

Guidelines on the Safe Design and Operating Standards for Tailings Storages. Department of Minerals and Energy, 100 Plain Street, East Perth, WA 6004, Australia.

Ritcey, G M (1989). **Tailings Management, Problems and Solutions in the Mining Industry**. Process Metallurgy Vol.6, Elsevier Science Publishers, ISBN 0-444-87374-0.

Tailings and Mine Waste '94. Proceedings of the first international conference on tailings and mine waste '94, Fort Collins, CO, USA, 19-21 January 1994. A A Balkema, ISBN 90-5410-364-7.

Vick, S G (1990). **Planning, Design, and Analysis of Tailings Dams.** BiTech Publishers Ltd, ISBN 0-921095-12-0.

APPENDIX

List of 37 records included

Record No.	Location
100	Arcturus, Zimbabwe
110	Church Rock, NM, USA
120	Heath Steele, NB, Canada
130	Tyrone, NM, USA
140	Sipalay, Philippines
150	Gray Eagle, CA, USA
160	Golden Sunlight, MT, USA
170	Aurora, NC, USA
180	Marga, Chile
190	Olinghouse, NV, USA
200	Cerro Negro, Chile
210	Veta de Agua, Chile
220	LaBelle, PA, USA
230	Stava, Italy
240	Mineral King, BC, Canada
250	Brazil (iron ore)
260	Rossarden, TAS, Australia
270	Story's Creek, TAS, Australia
280	Pico de Sao Luis, Brazil
290	Mankayan, Philippines
300	Montana Tunnels, MT, USA
310	Xishimen, China
320	Grays Creek, TN, USA
330	Jinduicheng, China
340	Silver King, ID, USA
350	Iron Dyke, BC, Canada
360	Padcal, Philippines
370	Kojkovac, Montenegro
380	Itagon Suyoc, Philippines
390	TD7, Chingola, Zambia
400	Harmony, South Africa
410	Riltec, TAS, Australia
420	Middle Arm, TAS, Australia
430	Omai, Guyana
440	Placer, Philippines
450	Golden Cross, New Zealand
460	Marcopper, Philippines

Note: This system of numbering records has been adopted to simplify the insertion of additional information as it becomes available.

Methodology

Collecting information for this study involved a three-stage process. Appropriate countries were firstly selected on the basis of the contribution made to their national economy by mining, and potential respondents were identified from the *Mining Journal's* own lists, and from lists of names supplied by UNEP. Efforts were then made to contact these potential respondents, with the aim of seeking either their agreement to complete the third stage of the process, the questionnaire, or to assist in addressing enquiries to better qualified sources.

Initial contacts were made by either telephone or fax to 46 potential respondents in: Australia (seven states), Brazil, Canada (six provinces), Chile, China, France, Germany, Ghana, Guyana, India, Italy, New Zealand, Papua New Guinea, Philippines, Poland, South Africa, Sweden, U.S.A. (state and federal agencies), Zambia and Zimbabwe. Other organisations contacted included the International Labour Organisation in Geneva, Switzerland, and the Mineral Policy Center, Washington, D.C., and the geotechnical engineering consultants, Klohn Crippen, Golders Associates, and Steffen, Robertson and Kirsten. Contacts were initially requested to indicate whether any tailings dam incidents had occurred in their country or region since 1980, and if so, whether information existed that could form the basis for a questionnaire response.

Questionnaires were sent by fax to those respondents who indicated that such data is available. Nine respondents who replied initially that no incidents had occurred in their area of responsibility did not receive a further questionnaire. Those parties who did not respond to the initial invitation to participate were recontacted, usually by telephone. Questionnaires were not sent in cases where no further interest to take part was shown.

The following organisations were contacted in the initial stage:

Australia

- Commonwealth Department of Primary Industries and Energy
- New South Wales Department of Mineral Resources
- Northern Territory Department of Mines and Energy
- Queensland Department of Minerals and Energy
- South Australia Department of Mines and Energy
- Tasmania Development and Resources
- Victoria Department of Agriculture, Energy and Minerals
- Western Australia Department of Minerals and Energy

Brazil

- Departamento Nacional de Producao Mineral

Canada

- Mining Association of Canada
- Centre for Resource Studies, Kingston, Ontario
- Mine Environment Neutral Drainage Program
- British Columbia Ministry of Energy, Mines and Petroleum Resources
- New Brunswick Department of Environment
- Newfoundland Department of Mines and Energy
- Ontario Department of Northern Development and Mines
- Ministère du l'Energie et des Ressources (Quebec)
- Saskatchewan Industrial Branch, Environment and Resource Management

Chile

Steffen, Robertson and Kirsten, Santiago

China

Research Centre for Geo-Environmental Sciences

France

Department of Environment and Energy

Germany

Federal Institute of Geosciences and Natural Resources

Ministry of Environment

Ghana

Minerals Commission

Guyana

Golden Star Resources Inc

India

Central Mine Research Institute

Italy

Department of Civil Engineering, Imperial College, London

New Zealand

Ministry of Commerce, Energy and Resources Division

Coeur d'Alene Mines Inc

Papua New Guinea

Department of Mining and Petroleum

Philippines

Mines and Geosciences Bureau

Poland

Central Mining Institute

Polish Geological Institute

South Africa

Chamber of Mines of South Africa

Department of Mineral and Energy Affairs

Department of Civil Engineering, University of Witwatersrand

Sweden

Environmental Protection Board

Geological Survey

U.S.A.

Environmental Protection Agency

Mine Safety and Health Administration

National Mine Safety and Health Academy

Office of Surface Mining

Center on the Performance of Dams, Stanford University

US Committee on Large Dams

Zambia

SADC, Mining Sector Coordinating Unit

Zimbabwe

Chamber of Mines of Zimbabwe

Further to responses received from this initial list, questionnaires were subsequently sent to the following 23 organisations:

Australia
- New South Wales Department of Mineral Resources
- Northern Territory Department of Mines and Energy
- Queensland Department of Minerals and Energy
- South Australia Department of Mines and Energy
- Tasmania Development and Resources
- Victoria Department of Agriculture, Energy and Minerals
- Western Australia Department of Minerals and Energy

Canada
- British Columbia Ministry of Energy, Mines and Petroleum Resources
- New Brunswick Department of Environment
- Newfoundland Department of Mines and Energy
- Ontario Department of Northern Development and Mines
- Ministère du l'Energie et des Ressources (Quebec)
- Saskatchewan Industrial Branch, Environment and Resource Management

Chile
- Steffen, Robertson and Kirsten, Santiago

Ghana
- Minerals Commission

Guyana
- Golden Star Resources Inc

Philippines
- Mines and Geosciences Bureau

South Africa
- Department of Mineral and Energy Affairs

U.S.A.
- Mine Safety and Health Administration (MSHA)
- National Mine Safety and Health Academy
- Center on the Performance of Dams, Stanford University

Zambia
- SADC, Mining Sector Coordinating Unit

Zimbabwe
- Chamber of Mines of Zimbabwe

Completed questionnaires were received from all the Australian states apart from Queensland, all the Canadian provinces apart from Ontario, Golden Star Resources Inc, MSHA and the National Mine Safety and Health Academy in the United States, Zambia and Zimbabwe. Of 23 questionnaires sent out, responses were received from 17 organisations, with a further three (Chile, Ghana and Ontario, Canada) indicating that information might be forthcoming in the future.

UNEP STUDY OF INCIDENTS INVOLVING MINE TAILINGS DAMS

SPECIFIC INCIDENT DETAILS

Background information:

Record No.	100
Country	Zimbabwe
Name of tailings dam	Arcturus
Location of tailings dam	N/a
Date of incident	January 1978
Time of incident	Early morning
Mine served by the tailings dam	Arcturus gold mine
Mine operating company	Corsyn Consolidated Mines
Dam construction company	N/a
Dam active or inactive at the time of the incident	Active

Dam details:

Type of dam	Valley side
Age of dam when incident occurred	12-15 years
Retention capacity of dam	1.7-2.0 Mt
Height of dam wall	15 m
Other dam dimensions	150 x 110 m (approx)
Dam wall construction materials	Tailings
Method of dam construction	Downstream with evaporation paddocks
Criteria or standards applied during dam construction	N/a

Incident details:

Type of incident	Slurry overflow
Estimated volume/tonnage of tailings/water/slurry released	N/a
Primary cause of incident	Continuous rain over several days. Seasonal total rainfall above average
Other contributing factors	One faulty decant line
Result of incident	Public waterway partially blocked and contaminated
Number of fatalities	One
Extent of property damage	Minor damage to local village
Extent of environmental damage	Extensive siltation to the waterway and to adjoining rough pasture
Length of time damage persisted	Still evident
Estimated cost of remediation	N/a
Legal or other action resulting from the incident	Remedial work required to clear public waterway
Remedial action taken by the dam owner	Excavation of permanent diversion waterway and construction of silt-containing gabions downstream
Media coverage	No
Literature references	N/a
Contact details for further information	Mr J Eagling Chamber of Mines PO Box 712 Stewart House 4 Central Avenue Harare Zimbabwe Tel: +263 4 702841 Fax: +263 4 707983

UNEP STUDY OF INCIDENTS INVOLVING MINE TAILINGS DAMS

SPECIFIC INCIDENT DETAILS

Background information:

Record No.	110
Country	USA, New Mexico
Name of tailings dam	Church Rock
Location of tailings dam	Church Rock
Date of incident	16th July 1979
Time of incident	N/a
Mine served by the tailings dam	Church Rock uranium mine
Mine operating company	United Nuclear
Dam construction company	Raymond Kaiser Engineers
Dam active or inactive at the time of the incident	Active

Dam details:

Type of dam	Water retention
Age of dam when incident occurred	N/a
Retention capacity of dam	370,000 m^3
Height of dam wall	11
Other dam dimensions	N/a
Dam wall construction materials	Earthfill
Method of dam construction	N/a
Criteria or standards applied during dam construction	N/a

Incident details:

Type of incident	Breached dam wall led to discharge of contaminated water and slurry into local watercourse
Estimated volume/tonnage of tailings/water/slurry released	370,000 m^3 of radioactive water 1,000 t of contaminated sediment
Primary cause of incident	Differential foundation settlement
Other contributing factors	Inadequate foundation material strength; absence of beach between pond and dam wall
Result of incident	Contamination of watercourse sediments by radioactive material over a distance of up to 110 km from the dam site
Number of fatalities	Nil
Extent of property damage	N/a
Extent of environmental damage	N/a
Estimated cost of remediation	N/a
Legal or other action resulting from the incident	Litigation for damages by local inhabitants
Remedial action taken by the dam owner	Repair. Operation closed two years later in response to depressed uranium market
Media coverage	Yes
Literature references	USCOLD
Contact details for further information	N/a

UNEP STUDY OF INCIDENTS INVOLVING MINE TAILINGS DAMS

SPECIFIC INCIDENT DETAILS

Background information:

Record No.	120
Country	Canada, New Brunswick
Name of tailings dam	Heath Steele main dam
Location of tailings dam	Bathurst, New Brunswick
Date of incident	Continuing since 1970s
Time of incident	N/a
Mine served by the tailings dam	Heath Steele
Mine operating company	Noranda
Dam construction company	N/a
Dam active or inactive at the time of the incident	Active

Dam details:

Type of dam	N/a
Age of dam when incident occurred	2 years at commencement of leakage
Retention capacity of dam	N/a
Height of dam wall	30 m
Other dam dimensions	N/a
Dam wall construction materials	Rock and glacial till, clay core
Method of dam construction	N/a
Criteria or standards applied during dam construction	N/a

Incident details:

Type of incident	Persistent uncontrolled seepage
Estimated volume/tonnage of tailings/water/slurry released	Low volume, constant flow
Primary cause of incident	Construction of dam on fractured bedrock, with no liner or grouting
Other contributing factors	Acid generating rock on embankment above water table
Result of incident	Seepage of water containing copper and zinc through dam wall
Number of fatalities	Nil
Extent of property damage	Nil
Extent of environmental damage	Localised impact immediately downstream from the dam
Estimated cost of remediation	N/a
Legal or other action resulting from the incident	N/a
Remedial action taken by the dam owner	Collection of seepage, which is pumped back to tailings pond
Media coverage	No
Literature references	N/a
Contact details for further information	Department of the Environment PO Box 6000 364 Argyle Street Fredericton NB E3B 5H1 Canada Tel: +1 506 457 4848 Fax: +1 506 453 2265

UNEP STUDY OF INCIDENTS INVOLVING MINE TAILINGS DAMS

SPECIFIC INCIDENT DETAILS

Background information:

Record No.	130
Country	United States, New Mexico
Name of tailings dam	No. 3 tailings dam
Location of tailings dam	Tyrone, NM
Date of incident	13th October 1980
Time of incident	Night
Mine served by the tailings dam	Tyrone copper mine
Mine operating company	Phelps Dodge
Dam construction company	N/a
Dam active or inactive at the time of the incident	Active

Dam details:

Type of dam	Valley side
Age of dam when incident occurred	N/a
Retention capacity of dam	2.5 Mm^3
Height of dam wall	66 m
Other dam dimensions	N/a
Dam wall construction materials	Cycloned sand tailings
Method of dam construction	Upstream
Criteria or standards applied during dam construction	N/a

Incident details:

Type of incident	Breach in dam wall
Estimated volume/tonnage of tailings/water/slurry released	2.0 Mm^3
Primary cause of incident	Rapid increase in dam wall height causing high internal pore pressures
Other contributing factors	Possible leakage from pipeline
Result of incident	Tailings flowed through the breach, measuring 215 m wide by 35 m deep, down the slope below, up the opposite valley side, then down the valley for a distance of 8 km
Number of fatalities	Nil
Extent of property damage	Inundation damage to farm land
Extent of environmental damage	Localised
Estimated cost of remediation	N/a
Legal or other action resulting from the incident	N/a
Remedial action taken by the dam owner	Redesign and repair
Media coverage	N/a
Literature references	USCOLD
Contact details for further information	Phelps Dodge 2600 N Central Avenue Phoenix AZ 85004 USA Tel: +1 602 234 8100

UNEP STUDY OF INCIDENTS INVOLVING MINE TAILINGS DAMS

SPECIFIC INCIDENT DETAILS

Background information:

Record No.	140
Country	Philippines
Name of tailings dam	No.3 tailings pond
Location of tailings dam	Sipalay, Negros Occidental
Date of incident	8th November 1982
Time of incident	16.00
Mine served by the tailings dam	Sipalay copper mine
Mine operating company	Marinduque Mining & Industrial Corp.
Dam construction company	N/a
Dam active or inactive at the time of the incident	Active

Dam details:

Type of dam	N/a
Age of dam when incident occurred	4 years
Retention capacity of dam	37 Mt
Height of dam wall	N/a
Other dam dimensions	N/a
Dam wall construction materials	Mixed mine waste
Method of dam construction	N/a
Criteria or standards applied during dam construction	N/a

Incident details:

Type of incident	Failure of a section of embankment
Estimated volume/tonnage of tailings/water/slurry released	27 Mt
Primary cause of incident	Slippage of foundations on clayey soils and surface materials that were not removed before construction of the embankment began
Other contributing factors	Inadequate anchoring of starter embankment; use of mixed mine waste of very variable particle size
Result of incident	Widespread inundation of surrounding agricultural land with up to 1.5 m thickness of tailings
Number of fatalities	N/a
Extent of property damage	Extensive to crops, buildings and livestock
Extent of environmental damage	Localised
Estimated cost of remediation	N/a
Legal or other action resulting from the incident	Official inquiry
Remedial action taken by the dam owner	N/a; Assets of MMI now held by Marinduque Mining Corp.
Media coverage	N/a
Literature references	N/a
Contact details for further information	N/a

UNEP STUDY OF INCIDENTS INVOLVING MINE TAILINGS DAMS

SPECIFIC INCIDENT DETAILS

Background information:

Record No.	150
Country	USA, California
Name of tailings dam	Gray Eagle
Location of tailings dam	Happy Camp, CA
Date of incident	1983
Time of incident	N/a
Mine served by the tailings dam	Gray Eagle
Mine operating company	Centurion Gold Ltd
Dam construction company	N/a
Dam active or inactive at the time of the incident	Active

Dam details:

Type of dam	N/a
Age of dam when incident occurred	1 year
Retention capacity of dam	N/a
Height of dam wall	N/a
Other dam dimensions	N/a
Dam wall construction materials	Earthfill
Method of dam construction	Downstream with clay core
Criteria or standards applied during dam construction	N/a

Incident details:

Type of incident	Uncontrolled seepage
Estimated volume/tonnage of tailings/water/slurry released	N/a
Primary cause of incident	Seepage of effluent through jointed rock beneath dam
Other contributing factors	Higher than expected rainfall; increased pumping of seepage back to the pond also put the fluid balance of the dam out of balance
Result of incident	Contamination of groundwater with cyanide-bearing tailings water
Number of fatalities	Nil
Extent of property damage	Nil
Extent of environmental damage	N/a
Estimated cost of remediation	N/a
Legal or other action resulting from the incident	N/a
Remedial action taken by the dam owner	Improved surface diversion and seepage pumping capability
Media coverage	N/a
Literature references	USCOLD
Contact details for further information	Centurion Gold Ltd 410, 750 West Pender Street Vancouver B.C. V6C 2T7 Canada Tel: +1 604 681 8466 Fax: +1 604 683 9219

UNEP STUDY OF INCIDENTS INVOLVING MINE TAILINGS DAMS

SPECIFIC INCIDENT DETAILS

Background information:

Record No.	160
Country	USA, Montana
Name of tailings dam	Golden Sunlight
Location of tailings dam	Whitehall, MT
Date of incident	From January 1983
Time of incident	Continuing
Mine served by the tailings dam	Golden Sunlight
Mine operating company	Golden Sunlight Mines
Dam construction company	N/a
Dam active or inactive at the time of the incident	Active

Dam details:

Type of dam	N/a
Age of dam when incident occurred	New
Retention capacity of dam	30 Mt
Height of dam wall	N/a
Other dam dimensions	N/a
Dam wall construction materials	Cycloned sand tailings
Method of dam construction	Centreline
Criteria or standards applied during dam construction	Installation of 20 m-deep bentonite slurry cut-off wall to contain seepage

Incident details:

Type of incident	Persistent seepage of contaminated water
Estimated volume/tonnage of tailings/water/slurry released	N/a
Primary cause of incident	Permeable plane in material below dam foundations, and beneath foot of cut-off wall
Other contributing factors	N/a
Result of incident	Persistent seepage of cyanide-containing water into groundwater below dam
Number of fatalities	Nil
Extent of property damage	Nil
Extent of environmental damage	Localised to immediately downstream from dam
Estimated cost of remediation	N/a
Legal or other action resulting from the incident	N/a
Remedial action taken by the dam owner	Repair to seepage cut-off wall, and pumping seepage back to tailings pond
Media coverage	N/a
Literature references	USCOLD
Contact details for further information	Placer Dome Inc 1600 Bentall IV 1055 Dunsmuir Street Vancouver B.C. V6C 1A8 Canada Tel: +1 604 682 7082 Fax: +1 604 682 7092

UNEP STUDY OF INCIDENTS INVOLVING MINE TAILINGS DAMS

SPECIFIC INCIDENT DETAILS

Background information:

Record No.	170
Country	USA, North Carolina
Name of tailings dam	Texasgulf 4B pond
Location of tailings dam	Aurora, NC
Date of incident	1st April 1984
Time of incident	N/a
Mine served by the tailings dam	Lee Creek phosphate mine
Mine operating company	Texasgulf Inc
Dam construction company	N/a
Dam active or inactive at the time of the incident	Active

Dam details:

Type of dam	N/a
Age of dam when incident occurred	N/a
Retention capacity of dam	12.3 Mm^3
Height of dam wall	8 m
Other dam dimensions	N/a
Dam wall construction materials	Tailings
Method of dam construction	Water retention
Criteria or standards applied during dam construction	N/a

Incident details:

Type of incident	Slippage of part of dam wall
Estimated volume/tonnage of tailings/water/slurry released	Nil
Primary cause of incident	Raised phreatic surface led to instability of the dam wall
Other contributing factors	Clay spoil piled at dam toe prevented seepage to keep phreatic surface at a safe level
Result of incident	A 60 m-long section of the dam wall suffered slippage
Number of fatalities	Nil
Extent of property damage	Nil
Extent of environmental damage	N/a
Estimated cost of remediation	N/a
Legal or other action resulting from the incident	N/a
Remedial action taken by the dam owner	Improved drainage installed to dam wall
Media coverage	N/a
Literature references	USCOLD
Contact details for further information	Texasgulf Inc PO Box 30321 3101 Glenwood Avenue Raleigh NC 27622-0321 USA Tel: +1 919 881 2700 Fax: +1 919 881 2847

UNEP STUDY OF INCIDENTS INVOLVING MINE TAILINGS DAMS

SPECIFIC INCIDENT DETAILS

Background information:

Record No.	180
Country	Chile
Name of tailings dam	Marga
Location of tailings dam	N/a
Date of incident	1985
Time of incident	N/a
Mine served by the tailings dam	N/a
Mine operating company	N/a
Dam construction company	N/a
Dam active or inactive at the time of the incident	Inactive

Dam details:

Type of dam	Cross-valley
Age of dam when incident occurred	N/a
Retention capacity of dam	N/a
Height of dam wall	N/a
Other dam dimensions	N/a
Dam wall construction materials	N/a
Method of dam construction	N/a
Criteria or standards applied during dam construction	N/a

Incident details:

Type of incident	Overtopping failure
Estimated volume/tonnage of tailings/water/slurry released	N/a
Primary cause of incident	Lack of spillway to handle water flows from catchment area upstream from the dam
Other contributing factors	Inadequate decant capacity
Result of incident	Damage to dam wall
Number of fatalities	N/a
Extent of property damage	N/a
Extent of environmental damage	N/a
Estimated cost of remediation	N/a
Legal or other action resulting from the incident	N/a
Remedial action taken by the dam owner	N/a
Media coverage	N/a
Literature references	USCOLD
Contact details for further information	N/a

UNEP STUDY OF INCIDENTS INVOLVING MINE TAILINGS DAMS

SPECIFIC INCIDENT DETAILS

Background information:

Record No.	190
Country	USA, Nevada
Name of tailings dam	Olinghouse
Location of tailings dam	Wadsworth, NV
Date of incident	1985
Time of incident	N/a
Mine served by the tailings dam	Olinghouse gold mine
Mine operating company	Olinghouse Mining Co.
Dam construction company	N/a
Dam active or inactive at the time of the incident	Active

Dam details:

Type of dam	Water retention
Age of dam when incident occurred	N/a
Retention capacity of dam	120,000 m^3
Height of dam wall	5 m
Other dam dimensions	N/a
Dam wall construction materials	Unconsolidated earthfill
Method of dam construction	N/a
Criteria or standards applied during dam construction	No engineering supervision

Incident details:

Type of incident	Embankment collapse
Estimated volume/tonnage of tailings/water/slurry released	25,000 m^3
Primary cause of incident	Saturation of embankment
Other contributing factors	Lack of compaction in dam wall
Result of incident	Outflow of tailings over a distance of 1.5 km from the dam site
Number of fatalities	Nil
Extent of property damage	N/a
Extent of environmental damage	N/a
Estimated cost of remediation	N/a
Legal or other action resulting from the incident	N/a
Remedial action taken by the dam owner	N/a. Property subsequently acquired by Green Hill Mining Venture
Media coverage	N/a
Literature references	USCOLD
Contact details for further information	Cliff Resources Corp. PO Box 14 1902, 95 Wellington Street West Toronto Ontario M5J 2N7 Canada Tel: +1 416 941 9440 Fax: +1 416 941 9450

UNEP STUDY OF INCIDENTS INVOLVING MINE TAILINGS DAMS

SPECIFIC INCIDENT DETAILS

Background information:

Record No.	200
Country	Chile
Name of tailings dam	Cerro Negro No.4
Location of tailings dam	Cerro Negro
Date of incident	3rd March 1985
Time of incident	N/a
Mine served by the tailings dam	Cerro Negro copper mine
Mine operating company	Cia Minera Cerro Negro
Dam construction company	N/a
Dam active or inactive at the time of the incident	Active

Dam details:

Type of dam	Valley side
Age of dam when incident occurred	N/a
Retention capacity of dam	2 Mm^3
Height of dam wall	40 m
Other dam dimensions	N/a
Dam wall construction materials	Cycloned sand tailings
Method of dam construction	Upstream and centreline
Criteria or standards applied during dam construction	N/a

Incident details:

Type of incident	Breach of dam wall
Estimated volume/tonnage of tailings/water/slurry released	500,000 m^3
Primary cause of incident	Liquefaction of material during earthquake
Other contributing factors	N/a
Result of incident	Outflow of tailings, which travelled for 8 km downstream from the dam site
Number of fatalities	N/a
Extent of property damage	N/a
Extent of environmental damage	N/a
Estimated cost of remediation	N/a
Legal or other action resulting from the incident	N/a
Remedial action taken by the dam owner	Repair
Media coverage	N/a
Literature references	USCOLD
Contact details for further information	Cia Minera Cerro Negro

UNEP STUDY OF INCIDENTS INVOLVING MINE TAILINGS DAMS

SPECIFIC INCIDENT DETAILS

Background information:

Record No.	210
Country	Chile
Name of tailings dam	Veta de Agua No.1
Location of tailings dam	N/a
Date of incident	3rd March 1985
Time of incident	N/a
Mine served by the tailings dam	N/a
Mine operating company	N/a
Dam construction company	N/a
Dam active or inactive at the time of the incident	Active

Dam details:

Type of dam	N/a
Age of dam when incident occurred	N/a
Retention capacity of dam	700,000 m^3
Height of dam wall	24 m
Other dam dimensions	N/a
Dam wall construction materials	Tailings
Method of dam construction	Upstream and centreline
Criteria or standards applied during dam construction	N/a

Incident details:

Type of incident	Failure of dam wall
Estimated volume/tonnage of tailings/water/slurry released	280,000 m^3
Primary cause of incident	Liquefaction of material during earthquake
Other contributing factors	N/a
Result of incident	Outflow of tailings, which travelled for 5 km below the dam site
Number of fatalities	N/a
Extent of property damage	N/a
Extent of environmental damage	N/a
Estimated cost of remediation	N/a
Legal or other action resulting from the incident	N/a
Remedial action taken by the dam owner	N/a
Media coverage	N/a
Literature references	USCOLD
Contact details for further information	N/a

UNEP STUDY OF INCIDENTS INVOLVING MINE TAILINGS DAMS

SPECIFIC INCIDENT DETAILS

Background information:

Record No.	220
Country	USA, Pennsylvania
Name of tailings dam	LaBelle
Location of tailings dam	Fayette County, PA
Date of incident	17th July 1985
Time of incident	N/a
Mine served by the tailings dam	LaBelle coal mine
Mine operating company	LaBelle Processing Company
Dam construction company	N/a
Dam active or inactive at the time of the incident	Active

Dam details:

Type of dam	N/a
Age of dam when incident occurred	N/a
Retention capacity of dam	1.2 Mm^3
Height of dam wall	79 m
Other dam dimensions	N/a
Dam wall construction materials	Mine waste
Method of dam construction	Downstream
Criteria or standards applied during dam construction	N/a

Incident details:

Type of incident	Slippage along dam face
Estimated volume/tonnage of tailings/water/slurry released	Nil
Primary cause of incident	Movement of foundations along clay layer beneath
Other contributing factors	Rainfall
Result of incident	A 240 m-long section of the dam wall slumped
Number of fatalities	Nil
Extent of property damage	Nil
Extent of environmental damage	Nil
Estimated cost of remediation	N/a
Legal or other action resulting from the incident	N/a
Remedial action taken by the dam owner	Construction of rock drains to dam face, and buttress of large waste rock to dam toe
Media coverage	N/a
Literature references	USCOLD
Contact details for further information	LaBelle Processing Company PO Drawer 1187 Uniontown PA 15401 USA Tel: +1 412 438 0536 Fax: +1 412 438 1322

UNEP STUDY OF INCIDENTS INVOLVING MINE TAILINGS DAMS

SPECIFIC INCIDENT DETAILS

Background information:

Record No.	230
Country	Italy
Name of tailings dam	Stava
Location of tailings dam	Stava, Trento region
Date of incident	19th July 1985
Time of incident	12.20
Mine served by the tailings dam	Prestavel fluorite mine
Mine operating company	Prealpi Mineraria
Dam construction company	Montedison/Prealpi Mineraria
Dam active or inactive at the time of the incident	Active

Dam details:

Type of dam	Twin cross-valley
Age of dam when incident occurred	23 years
Retention capacity of dam	300,000 m^3
Height of dam wall	29.5 m (Upper dam) 26.0 m (Lower dam)
Other dam dimensions	Crest length - 200 m (Upper), 180 m (Lower); design downstream slopes 40°
Dam wall construction materials	Cycloned tailings and fluvio-glacial material
Method of dam construction	Upstream (Lower); centreline (Upper)
Criteria or standards applied during dam construction	N/a

Incident details:

Type of incident	Sequential collapse of Upper then Lower dams
Estimated volume/tonnage of tailings/water/slurry released	N/a
Primary cause of incident	Inadequate decant pipe construction
Other contributing factors	Inadequate dam stability; poorly drained site; inadequate drainage to dam wall constructed by the upstream method; high pond levels caused by run-off collection; toe of Upper dam rested on tailings in Lower dam; high natural groundwater level
Result of incident	Catastrophic failure and mud rush down valley below the dams
Number of fatalities	268
Extent of property damage	Extensive
Extent of environmental damage	Extensive
Estimated cost of remediation	N/a
Legal or other action resulting from the incident	Official inquiry; arrest of mine owners
Remedial action taken by the dam owner	N/a
Media coverage	Extensive
Literature references	Chandler R J and Tosatti G. The Stava tailings dam failure, Italy, July 1985. *Geotechnical Engineering*; 113(2); 67-79 (April 1995)
Contact details for further information	Professor R J Chandler Department of Civil Engineering Imperial College London SW7 2BU Tel: +44 171 594 6080 Fax: +44 171 594 6053

UNEP STUDY OF INCIDENTS INVOLVING MINE TAILINGS DAMS

SPECIFIC INCIDENT DETAILS

Background information:

Record No.	240
Country	Canada, British Columbia
Name of tailings dam	Mineral King
Location of tailings dam	Invermere, B.C.
Date of incident	20th March 1986
Time of incident	N/a
Mine served by the tailings dam	Mineral King
Mine operating company	Mountain Minerals
Dam construction company	N/a
Dam active or inactive at the time of the incident	Inactive

Dam details:

Type of dam	Valley side
Age of dam when incident occurred	10 years approx.
Retention capacity of dam	Small
Height of dam wall	6 m
Other dam dimensions	N/a
Dam wall construction materials	Coarse tailings sand
Method of dam construction	Centreline
Criteria or standards applied during dam construction	N/a

Incident details:

Type of incident	Dam breach
Estimated volume/tonnage of tailings/water/slurry released	N/a
Primary cause of incident	High pond overtopped crest
Other contributing factors	Diversion ditch blocked by ice during onset of spring snow melt
Result of incident	Permanent closure of dam
Number of fatalities	Nil
Extent of property damage	Minimal
Extent of environmental damage	Minimal
Length of time damage lasted	2-3 months
Estimated cost of remediation	N/a
Legal or other action resulting from the incident	N/a
Remedial action taken by the dam owner	Repair
Media coverage	N/a
Literature references	Ministry internal memos
Contact details for further information	Mr T Eaton Manager, Geotechnical Engineering Ministry of Employment and Investment Energy and Minerals Division 4th Floor, 1810 Blanshard Street Victoria V8V 1X4 B.C. Canada Tel: +1 604 952 0462 Fax: +1 604 952 0481

UNEP STUDY OF INCIDENTS INVOLVING MINE TAILINGS DAMS

SPECIFIC INCIDENT DETAILS

Background information:

Record No.	250
Country	Brazil
Name of tailings dam	N/a
Location of tailings dam	Itabirito, Minas Gerais
Date of incident	Late May 1986
Time of incident	N/a
Mine served by the tailings dam	N/a
Mine operating company	Itaminos Comercio de Minerios
Dam construction company	N/a
Dam active or inactive at the time of the incident	N/a

Dam details:

Type of dam	N/a
Age of dam when incident occurred	20 years
Retention capacity of dam	N/a
Height of dam wall	30 m
Other dam dimensions	Dam length - 150 m
Dam wall construction materials	Bricks made from clay and iron ore tailings
Method of dam construction	Masonry construction
Criteria or standards applied during dam construction	N/a

Incident details:

Type of incident	Dam wall burst
Estimated volume/tonnage of tailings/water/slurry released	100,000 t
Primary cause of incident	Saturation of brickwork
Other contributing factors	N/a
Result of incident	Release of tailings, which flowed for 12 km down the valley below the dam
Number of fatalities	7
Extent of property damage	Loss of mining equipment and infrastructure
Extent of environmental damage	N/a
Estimated cost of remediation	N/a
Legal or other action resulting from the incident	N/a
Remedial action taken by the dam owner	N/a
Media coverage	N/a
Literature references	Engineering News-Record June 5, 1986
Contact details for further information	N/a

UNEP STUDY OF INCIDENTS INVOLVING MINE TAILINGS DAMS

SPECIFIC INCIDENT DETAILS

Background information:

Record No.	260
Country	Australia, Tasmania
Name of tailings dam	Rossarden
Location of tailings dam	Rossarden
Date of incident	16th May 1986
Time of incident	N/a
Mine served by the tailings dam	Aberfoyle
Mine operating company	Aberfoyle Ltd
Dam construction company	N/a
Dam active or inactive at the time of the incident	Inactive

Dam details:

Type of dam	Valley side
Age of dam when incident occurred	55 years
Retention capacity of dam	200,000 m^3
Height of dam wall	7.5 m, perched on valley edge 190 m above river
Other dam dimensions	N/a
Dam wall construction materials	Layered earth and tea-tree matting
Method of dam construction	Uncontrolled
Criteria or standards applied during dam construction	N/a

Incident details:

Type of incident	Dam wall partially washed out
Estimated volume/tonnage of tailings/water/slurry released	N/a
Primary cause of incident	Water breached the main side of the impoundment area, swept though the dam and eroded a section of the front wall
Other contributing factors	Poor drainage
Result of incident	Dam wall failure
Number of fatalities	Nil
Extent of property damage	Minimal
Extent of environmental damage	River polluted by tailings
Length of time damage persisted	12 months
Estimated cost of remediation	A$5,000
Legal or other action resulting from the incident	Mines department investigation; Government inquiry
Remedial action taken by the dam owner	Government repair funded by contractor
Media coverage	Local complaints only
Literature references	N/a
Contact details for further information	Mr J G Las Inspector of Mines Tasmania Development and Resources Industry Safety and Mines Division PO Box 56 Rosny Park Tasmania 7018 Australia Tel: +61 02 338318 Fax: +61 02 338338

UNEP STUDY OF INCIDENTS INVOLVING MINE TAILINGS DAMS

SPECIFIC INCIDENT DETAILS

Background information:

Record No.	270
Country	Australia, Tasmania
Name of tailings dam	Story's Creek
Location of tailings dam	Story's Creek
Date of incident	16th May 1986
Time of incident	N/a
Mine served by the tailings dam	Story' Creek
Mine operating company	Aberfoyle Ltd
Dam construction company	Aberfoyle Ltd
Dam active or inactive at the time of the incident	Inactive

Dam details:

Type of dam	Valley side
Age of dam when incident occurred	55 years
Retention capacity of dam	30,000 m^3
Height of dam wall	17 m
Other dam dimensions	Crest length - 130 m; crest width - 1 m; downstream slope - 1:1
Dam wall construction materials	Mainly tailings
Method of dam construction	Uncontrolled
Criteria or standards applied during dam construction	N/a

Incident details:

Type of incident	Wall collapse; discharge of water and slimes
Estimated volume/tonnage of tailings/water/slurry released	N/a (assumed minimal)
Primary cause of incident	Large influx of water
Other contributing factors	Unstable wall, and 1 in 100 year flood
Result of incident	Wall failure; spillway shifted; slimes escaped; pipeline washed out, causing further pollution of waterway
Number of fatalities	Nil
Extent of property damage	Minimal
Extent of environmental damage	River polluted by tailings/slimes for approximately 10 km downstream
Length of time damage persisted	12 months
Estimated cost of remediation	A$15,000
Legal or other action resulting from the incident	Mines department investigation; Government inquiry
Remedial action taken by the dam owner	Government repair funded by contractor
Media coverage	Local complaints only
Literature references	N/a
Contact details for further information	Mr J G Las Inspector of Mines Tasmania Development and Resources Industry Safety and Mines Division PO Box 56 Rosny Park Tasmania 7018 Australia Tel: +61 02 338318 Fax: +61 02 338338

UNEP STUDY OF INCIDENTS INVOLVING MINE TAILINGS DAMS

SPECIFIC INCIDENT DETAILS

Background information:

Record No.	280
Country	Brazil
Name of tailings dam	Pico de São Luis
Location of tailings dam	Minas Gerais
Date of incident	2nd October 1986
Time of incident	N/a
Mine served by the tailings dam	Pico de São Luis
Mine operating company	N/a
Dam construction company	N/a
Dam active or inactive at the time of the incident	N/a

Dam details:

Type of dam	N/a
Age of dam when incident occurred	16 years
Retention capacity of dam	N/a
Height of dam wall	20 m
Other dam dimensions	N/a
Dam wall construction materials	Tailings
Method of dam construction	N/a
Criteria or standards applied during dam construction	N/a

Incident details:

Type of incident	Failure of dam wall
Estimated volume/tonnage of tailings/water/slurry released	N/a
Primary cause of incident	Erosion at dam toe by water flowing over spillway
Other contributing factors	Soft clay foundation
Result of incident	Release of tailings
Number of fatalities	N/a
Extent of property damage	N/a
Extent of environmental damage	N/a
Estimated cost of remediation	N/a
Legal or other action resulting from the incident	N/a
Remedial action taken by the dam owner	N/a
Media coverage	N/a
Literature references	N/a
Contact details for further information	ICOLD

UNEP STUDY OF INCIDENTS INVOLVING MINE TAILINGS DAMS

SPECIFIC INCIDENT DETAILS

Background information:

Record No.	290
Country	Philippines
Name of tailings dam	No.3 tailings pond
Location of tailings dam	Mankayan, Luzon
Date of incident	17th October 1986
Time of incident	N/a
Mine served by the tailings dam	Mankayan copper mine
Mine operating company	Lepanto Consolidated Mining Co.
Dam construction company	N/a
Dam active or inactive at the time of the incident	Active

Dam details:

Type of dam	N/a
Age of dam when incident occurred	N/a
Retention capacity of dam	N/a
Height of dam wall	N/a
Other dam dimensions	N/a
Dam wall construction materials	Earthfill
Method of dam construction	N/a
Criteria or standards applied during dam construction	N/a

Incident details:

Type of incident	Embankment failure
Estimated volume/tonnage of tailings/water/slurry released	N/a
Primary cause of incident	Additional loading on original embankment from 8 m increase in height
Other contributing factors	Location of embankment in ancient slide area; slope of embankment too steep; decant tower too close to embankment
Result of incident	N/a
Number of fatalities	N/a
Extent of property damage	N/a
Extent of environmental damage	N/a
Estimated cost of remediation	N/a
Legal or other action resulting from the incident	N/a
Remedial action taken by the dam owner	N/a
Media coverage	N/a
Literature references	N/a
Contact details for further information	Lepanto Consolidated Mining Co. Bank of America - Lepanto Building 8747 Paseo de Roxas Makati Metro Manila 3117 Philippines

UNEP STUDY OF INCIDENTS INVOLVING MINE TAILINGS DAMS

SPECIFIC INCIDENT DETAILS

Background information:

Record No.	300
Country	USA, Montana
Name of tailings dam	Montana Tunnels
Location of tailings dam	Helena, MT
Date of incident	1987
Time of incident	N/a
Mine served by the tailings dam	Montana Tunnels gold mine
Mine operating company	Pegasus Gold Inc
Dam construction company	N/a
Dam active or inactive at the time of the incident	Active

Dam details:

Type of dam	N/a
Age of dam when incident occurred	1 year
Retention capacity of dam	250,000 m^3
Height of dam wall	33 m
Other dam dimensions	N/a
Dam wall construction materials	Mine waste
Method of dam construction	Downstream
Criteria or standards applied during dam construction	Impoundment floor fitted with soil/ bentonite liner

Incident details:

Type of incident	Uncontrolled seepage
Estimated volume/tonnage of tailings/water/slurry released	N/a
Primary cause of incident	Breaches in impoundment liner
Other contributing factors	Inadequate repairs to liner
Result of incident	Contamination of groundwater by cyanide-bearing tailings water
Number of fatalities	Nil
Extent of property damage	Nil
Extent of environmental damage	Localised to immediately downstream from the dam
Estimated cost of remediation	N/a
Legal or other action resulting from the incident	N/a
Remedial action taken by the dam owner	Increased seepage pumping capacity installed
Media coverage	N/a
Literature references	USCOLD
Contact details for further information	Pegasus Gold Inc 400 North 9 Post Street Spokane WA 99201 USA Tel: +1 509 624 4653 Fax: +1 509 838 8317

UNEP STUDY OF INCIDENTS INVOLVING MINE TAILINGS DAMS

SPECIFIC INCIDENT DETAILS

Background information:

Record No.	310
Country	China
Name of tailings dam	Xishimen
Location of tailings dam	Xishimen
Date of incident	21st March 1987
Time of incident	02.40
Mine served by the tailings dam	Xishimen iron ore mine
Mine operating company	N/a
Dam construction company	N/a
Dam active or inactive at the time of the incident	Active

Dam details:

Type of dam	N/a
Age of dam when incident occurred	9 years
Retention capacity of dam	N/a
Height of dam wall	31 m
Other dam dimensions	N/a
Dam wall construction materials	N/a
Method of dam construction	Upstream
Criteria or standards applied during dam construction	N/a

Incident details:

Type of incident	Breach in dam wall
Estimated volume/tonnage of tailings/water/slurry released	2,230 m^3
Primary cause of incident	Pond water level allowed to rise too high
Other contributing factors	Blocked decant
Result of incident	Outflow of tailings through breach
Number of fatalities	N/a
Extent of property damage	N/a
Extent of environmental damage	N/a
Estimated cost of remediation	N/a
Legal or other action resulting from the incident	N/a
Remedial action taken by the dam owner	Repair
Media coverage	N/a
Literature references	N/a
Contact details for further information	ICOLD

UNEP STUDY OF INCIDENTS INVOLVING MINE TAILINGS DAMS

SPECIFIC INCIDENT DETAILS

Background information:

Record No.	320
Country	USA, Tennessee
Name of tailings dam	Tennessee Consolidated No.1
Location of tailings dam	Grays Creek, TN
Date of incident	19th January 1988
Time of incident	N/a
Mine served by the tailings dam	Tennessee Consolidated No.1
Mine operating company	Tennessee Consolidated Coal Co.
Dam construction company	N/a
Dam active or inactive at the time of the incident	Active

Dam details:

Type of dam	N/a
Age of dam when incident occurred	N/a
Retention capacity of dam	250,000 m^3
Height of dam wall	85 m
Other dam dimensions	N/a
Dam wall construction materials	Mine waste
Method of dam construction	Downstream
Criteria or standards applied during dam construction	N/a

Incident details:

Type of incident	Internal erosion followed by failure of a section of the dam wall
Estimated volume/tonnage of tailings/water/slurry released	250,000 m^3
Primary cause of incident	Failure of an abandoned outlet pipe
Other contributing factors	N/a
Result of incident	Water flowing from abandoned pipe saturated dam wall, leading to erosion and breaching; the entire contents of the impoundment escaped
Number of fatalities	Nil
Extent of property damage	N/a
Extent of environmental damage	N/a
Estimated cost of remediation	N/a
Legal or other action resulting from the incident	N/a
Remedial action taken by the dam owner	Repair
Media coverage	N/a
Literature references	USCOLD, MSHA
Contact details for further information	Tennessee Consolidated Coal Co. Rt. 3 PO Box 343A Whitwell TN 37397 USA Tel: +1 615 658 5115 Fax: +1 615 658 6890

UNEP STUDY OF INCIDENTS INVOLVING MINE TAILINGS DAMS

SPECIFIC INCIDENT DETAILS

Background information:

Record No.	330
Country	China, Shaanxi province
Name of tailings dam	Jinduicheng
Location of tailings dam	Jinduicheng
Date of incident	30th April 1988
Time of incident	03.00
Mine served by the tailings dam	Jinduicheng molybdenum mine
Mine operating company	N/a
Dam construction company	N/a
Dam active or inactive at the time of the incident	Active

Dam details:

Type of dam	N/a
Age of dam when incident occurred	8 years
Retention capacity of dam	N/a
Height of dam wall	40 m
Other dam dimensions	N/a
Dam wall construction materials	N/a
Method of dam construction	Upstream
Criteria or standards applied during dam construction	N/a

Incident details:

Type of incident	Breach of dam wall, causing release of tailings
Estimated volume/tonnage of tailings/water/slurry released	700,000 m^3
Primary cause of incident	Spillway blockage caused pond level to rise too high
Other contributing factors	High phreatic surface within dam wall
Result of incident	Catastrophic failure of centre section of dam wall
Number of fatalities	20 approx.
Extent of property damage	N/a
Extent of environmental damage	N/a
Estimated cost of remediation	N/a
Legal or other action resulting from the incident	N/a
Remedial action taken by the dam owner	N/a
Media coverage	Noted in specialist metals industry press
Literature references	N/a
Contact details for further information	ICOLD

UNEP STUDY OF INCIDENTS INVOLVING MINE TAILINGS DAMS

SPECIFIC INCIDENT DETAILS

Background information:

Record No.	340
Country	USA, Idaho
Name of tailings dam	Silver King
Location of tailings dam	Adams county, ID
Date of incident	5th August 1989
Time of incident	N/a
Mine served by the tailings dam	Copper Cliff copper-silver mine
Mine operating company	Alta Gold Co.
Dam construction company	N/a
Dam active or inactive at the time of the incident	Active

Dam details:

Type of dam	N/a
Age of dam when incident occurred	N/a
Retention capacity of dam	37,000 m^3
Height of dam wall	9 m
Other dam dimensions	N/a
Dam wall construction materials	Earthfill
Method of dam construction	Downstream
Criteria or standards applied during dam construction	N/a

Incident details:

Type of incident	Overtopping of dam wall
Estimated volume/tonnage of tailings/water/slurry released	N/a
Primary cause of incident	Slump of waste material into tailings pond
Other contributing factors	N/a
Result of incident	Waste material displaced an estimated 1,200-2,400 m^3 of water, which overtopped the dam causing minor damage to the wall
Number of fatalities	Nil
Extent of property damage	Slight
Extent of environmental damage	N/a
Estimated cost of remediation	N/a
Legal or other action resulting from the incident	N/a
Remedial action taken by the dam owner	Repair
Media coverage	N/a
Literature references	USCOLD
Contact details for further information	Alta Gold Co. 140, 2319 Foothill Drive Salt Lake City UT 84109 USA Tel: +1 801 483 1116 Fax: +1 801 467 2137

UNEP STUDY OF INCIDENTS INVOLVING MINE TAILINGS DAMS

SPECIFIC INCIDENT DETAILS

Background information:

Record No.	350
Country	Canada, British Columbia
Name of tailings dam	Iron Dyke
Location of tailings dam	Kimberley
Date of incident	23rd August 1991
Time of incident	N/a
Mine served by the tailings dam	Sullivan
Mine operating company	Cominco
Dam construction company	N/a
Dam active or inactive at the time of the incident	Active

Dam details:

Type of dam	Ring
Age of dam when incident occurred	Foundation - 40 years Dykes - 16 years
Retention capacity of dam	N/a
Height of dam wall	21 m maximum
Other dam dimensions	1,500 m of ring dykes
Dam wall construction materials	N/a
Method of dam construction	Upstream
Criteria or standards applied during dam construction	N/a

Incident details:

Type of incident	Rotational slump of 300 m of ring dyke
Estimated volume/tonnage of tailings/water/slurry released	Nil
Primary cause of incident	Generation of excess pore pressure in old tailings foundation
Other contributing factors	Construction equipment travelling over the site during the 1991 annual dam wall height increase
Result of incident	Temporary closure of Iron Pond until interim dyke and operating plan in place
Number of fatalities	Nil
Extent of property damage	Damage to dyke only
Extent of environmental damage	Nil
Length of time damage lasted	1 year
Estimated cost of remediation	Over C$1 million
Legal or other action resulting from the incident	N/a
Remedial action taken by the dam owner	Geotechnical evaluation and rehabilitation for closure
Media coverage	Yes
Literature references	Geotechnical reports from Klohn Crippen Inc
Contact details for further information	Cominco Ltd 200 Granville Street Vancouver V6C 2R2 B.C. Canada Tel: +1 604 682 0611 Fax: +1 604 844 2516

UNEP STUDY OF INCIDENTS INVOLVING MINE TAILINGS DAMS

SPECIFIC INCIDENT DETAILS

Background information:

Record No.	360
Country	Philippines
Name of tailings dam	No.2 tailings pond
Location of tailings dam	Padcal, Luzon
Date of incident	January 1992
Time of incident	N/a
Mine served by the tailings dam	Padcal copper mine
Mine operating company	Philex Mining Corp.
Dam construction company	N/a
Dam active or inactive at the time of the incident	Active

Dam details:

Type of dam	N/a
Age of dam when incident occurred	estimated 10 years
Retention capacity of dam	80 Mt
Height of dam wall	N/a
Other dam dimensions	N/a
Dam wall construction materials	N/a
Method of dam construction	N/a
Criteria or standards applied during dam construction	N/a

Incident details:

Type of incident	Collapse of dam wall
Estimated volume/tonnage of tailings/water/slurry released	80 Mt
Primary cause of incident	Foundation failure
Other contributing factors	Suspected weakening of structure following major earthquake in July 1990
Result of incident	Outflow of tailings
Number of fatalities	N/a
Extent of property damage	N/a
Extent of environmental damage	N/a
Estimated cost of remediation	N/a
Legal or other action resulting from the incident	N/a
Remedial action taken by the dam owner	N/a
Media coverage	N/a
Literature references	N/a
Contact details for further information	Philex Mining Corp.

UNEP STUDY OF INCIDENTS INVOLVING MINE TAILINGS DAMS

SPECIFIC INCIDENT DETAILS

Background information:

Record No.	370
Country	Montenegro
Name of tailings dam	Kojkovac
Location of tailings dam	Majkovac
Date of incident	November 1992
Time of incident	N/a
Mine served by the tailings dam	Inactive lead-zinc mines
Mine operating company	N/a
Dam construction company	N/a
Dam active or inactive at the time of the incident	Inactive

Dam details:

Type of dam	Valley bottom
Age of dam when incident occurred	20 years
Retention capacity of dam	3.5 Mm^3
Height of dam wall	N/a
Other dam dimensions	N/a
Dam wall construction materials	Earthfill
Method of dam construction	N/a
Criteria or standards applied during dam construction	N/a

Incident details:

Type of incident	Erosion of dam wall toe by adjacent river
Estimated volume/tonnage of tailings/water/slurry released	Nil
Primary cause of incident	Flood water in river
Other contributing factors	Original placing of dam
Result of incident	Dam wall toe was eroded by fast-flowing river over a distance of 150 m.
Number of fatalities	Nil
Extent of property damage	Nil
Extent of environmental damage	Nil; potential for widespread pollution into Tara river, thence via Danube to Black Sea
Estimated cost of remediation	N/a
Legal or other action resulting from the incident	N/a
Remedial action taken by the dam owner	Toe of dam supported by gabions to prevent further erosion under UN emergency project
Media coverage	Yes
Literature references	ICOLD
Contact details for further information	UNDRO, Geneva

UNEP STUDY OF INCIDENTS INVOLVING MINE TAILINGS DAMS

SPECIFIC INCIDENT DETAILS

Background information:

Record No.	380
Country	Philippines
Name of tailings dam	Itogon-Suyoc
Location of tailings dam	Baguio gold district, Luzon
Date of incident	26th June 1993
Time of incident	N/a
Mine served by the tailings dam	Itogon-Suyoc gold mine
Mine operating company	Itogon-Suyoc Mines
Dam construction company	N/a
Dam active or inactive at the time of the incident	Active

Dam details:

Type of dam	N/a
Age of dam when incident occurred	N/a
Retention capacity of dam	N/a
Height of dam wall	N/a
Other dam dimensions	N/a
Dam wall construction materials	N/a
Method of dam construction	N/a
Criteria or standards applied during dam construction	N/a

Incident details:

Type of incident	Flood water overtopped dam wall, leading to partial failure
Estimated volume/tonnage of tailings/water/slurry released	N/a
Primary cause of incident	Blockage to diversion tunnel carrying original river around dam
Other contributing factors	Typhoon
Result of incident	Collapse of part of dam wall
Number of fatalities	N/a
Extent of property damage	N/a
Extent of environmental damage	N/a
Estimated cost of remediation	N/a
Legal or other action resulting from the incident	N/a
Remedial action taken by the dam owner	N/a
Media coverage	N/a
Literature references	N/a
Contact details for further information	Itogon-Suyoc Mines

UNEP STUDY OF INCIDENTS INVOLVING MINE TAILINGS DAMS

SPECIFIC INCIDENT DETAILS

Background information:

Record No.	390
Country	Zambia
Name of tailings dam	TD 7
Location of tailings dam	Chingola
Date of incident	August 1993
Time of incident	05.30
Mine served by the tailings dam	Nchanga copper mine
Mine operating company	ZCCM
Dam construction company	Knight Piesold (Zambia)
Dam active or inactive at the time of the incident	Active

Dam details:

Type of dam	Ring
Age of dam when incident occurred	3 years
Retention capacity of dam	N/a
Height of dam wall	5 m
Other dam dimensions	Area: 2,500 m^2
Dam wall construction materials	Concentrator tailings and borrow material
Method of dam construction	Upstream
Criteria or standards applied during dam construction	N/a

Incident details:

Type of incident	Slurry overflow following rain storm; dam wall collapsed
Estimated volume/tonnage of tailings/water/slurry released	100 t
Primary cause of incident	Design inadequate for worst-case weather conditions
Other contributing factors	Increased rate of tailings deposition following plant shut-down
Result of incident	Slurry overflow into spillway
Number of fatalities	Nil
Extent of property damage	Blockages to water supply pipes for domestic usage
Extent of environmental damage	Minimal
Estimated cost of remediation	Minimal
Legal or other action resulting from the incident	Official enquiry
Remedial action taken by the dam owner	Diversion of tailings to disused open pit
Media coverage	No
Literature references	N/a
Contact details for further information	Mr J Masinga Head, Group Environmental Services ZCCM Ltd Kalulushi Zambia Tel: +260 2 749108 Fax: +260 2 733123

UNEP STUDY OF INCIDENTS INVOLVING MINE TAILINGS DAMS

SPECIFIC INCIDENT DETAILS

Background information:

Record No.	400
Country	South Africa
Name of tailings dam	Merriespruit
Location of tailings dam	Merriespruit, OFS
Date of incident	22nd February 1994
Time of incident	N/a
Mine served by the tailings dam	Harmony
Mine operating company	Harmony Gold Mines
Dam construction company	Fraser Alexander
Dam active or inactive at the time of the incident	Inactive

Dam details:

Type of dam	Ring
Age of dam when incident occurred	20 years
Retention capacity of dam	10 Mt
Height of dam wall	N/a
Other dam dimensions	Area: 154 ha
Dam wall construction materials	Cycloned tailings
Method of dam construction	N/a
Criteria or standards applied during dam construction	N/a

Incident details:

Type of incident	Breach through wall of ring dam released tailings slurry into nearby housing area
Estimated volume/tonnage of tailings/water/slurry released	2.5 Mt
Primary cause of incident	Surface water overtopped dam wall following persistent heavy rain
Other contributing factors	Possible increase in phreatic surface in dam wall as a result of the rainfall; weakened dam wall from springing; poor natural drainage beneath dam
Result of incident	Escaped tailings covered an area of 2 km by 400 m
Number of fatalities	17
Extent of property damage	Extensive
Extent of environmental damage	Limited
Estimated cost of remediation	N/a
Legal or other action resulting from the incident	Judicial inquiry; prosecution of mine operator and dam engineer
Remedial action taken by the dam owner	Repair
Media coverage	Extensive
Literature references	Official inquiry report
Contact details for further information	SA Government Mining Engineer Department of Mineral and Energy Affairs Private Bag X59 Pretoria 0001 South Africa Tel: +27 12 317 9125 Fax: +27 12 322 0810

UNEP STUDY OF INCIDENTS INVOLVING MINE TAILINGS DAMS

SPECIFIC INCIDENT DETAILS

Background information:

Record No.	410
Country	Australia, Tasmania
Name of tailings dam	Riltec
Location of tailings dam	Mathinna
Date of incident	6th January 1995
Time of incident	N/a
Mine served by the tailings dam	Riltec Mathinna
Mine operating company	Riltec (Tasmania) Pty Ltd
Dam construction company	R Gerke
Dam active or inactive at the time of the incident	Active (pre-commissioning)

Dam details:

Type of dam	Valley side
Age of dam when incident occurred	3 months
Retention capacity of dam	120,000 m^3
Height of dam wall	7 m
Other dam dimensions	Crest - 370 m; crest width - 4 m; downstream slope - 1:2
Dam wall construction materials	Random fill, clay lined
Method of dam construction	Centreline
Criteria or standards applied during dam construction	Consultants' specifications; layered compaction at optimum moisture content

Incident details:

Type of incident	Leakage of cyanide-contaminated water
Estimated volume/tonnage of tailings/water/slurry released	40,000 m^3 of cyanide-contaminated water
Primary cause of incident	Water table exposed in bottom of dam
Other contributing factors	Lack of supervision during construction
Result of incident	Pollution of local waterways; cessation of operations
Number of fatalities	Nil
Extent of property damage	Minimal
Extent of environmental damage	Polluted streams and local fish kill
Length of time damage persisted	2 months
Estimated cost of remediation	A$40,000
Legal or other action resulting from the incident	Mines department investigation; Government inquiry
Remedial action taken by the dam owner	Owner bankrupt; environmental bond used for remedial work
Media coverage	Extensive
Literature references	Department archives
Contact details for further information	Mr J G Las Inspector of Mines Tasmania Development and Resources Industry Safety and Mines Division PO Box 56 Rosny Park Tasmania 7018 Australia Tel: +61 02 338318 Fax: +61 02 338338

SPECIFIC INCIDENT DETAILS

Background information:

Record No.	420
Country	Australia, Tasmania
Name of tailings dam	No. 1 tailings dam
Location of tailings dam	Middle Arm, Launceston
Date of incident	25th June 1995
Time of incident	N/a
Mine served by the tailings dam	Beaconsfield
Mine operating company	Golconda Ltd
Dam construction company	WLPU Consultants (Australia) Pty Ltd
Dam active or inactive at the time of the incident	Active

Dam details:

Type of dam	Valley side
Age of dam when incident occurred	12 months
Retention capacity of dam	25,000 m^3
Height of dam wall	4 m
Other dam dimensions	Crest - 315 m
Dam wall construction materials	Borrow pit; mixed grey loam and stiff yellow clay
Method of dam construction	Centreline
Criteria or standards applied during dam construction	90% compaction at optimum moisture content

Incident details:

Type of incident	Erosion of top of wall, consisting of tailings
Estimated volume/tonnage of tailings/water/slurry released	5,000 m^3 of water released into the Tamar river
Primary cause of incident	Wave action on wall
Other contributing factors	Buildup of tailings above height of dam wall
Result of incident	Water containing 95mg/litre free cyanide released into the Tamar river
Number of fatalities	Nil
Extent of property damage	Minimal
Extent of environmental damage	Minimal on the property, and localised fish kill off the property
Length of time damage persisted	3 weeks
Estimated cost of remediation	A$20,000-30,000 estimated
Legal or other action resulting from the incident	Mines department investigation;
Remedial action taken by the dam owner	Reduce the water level
Media coverage	Yes
Literature references	Press reports
Contact details for further information	Mr J G Las Inspector of Mines Tasmania Development and Resources Industry Safety and Mines Division PO Box 56 Rosny Park Tasmania 7018 Australia Tel: +61 02 338318 Fax: +61 02 338338

UNEP STUDY OF INCIDENTS INVOLVING MINE TAILINGS DAMS

SPECIFIC INCIDENT DETAILS

Background information:

Record No.	430
Country	Guyana
Name of tailings dam	Tailings dam No.1
Location of tailings dam	Omai
Date of incident	19th August 1995
Time of incident	23.55
Mine served by the tailings dam	Omai gold mine
Mine operating company	Omai Gold Mines Ltd
Dam construction company	Knight Piesold/Golder Associates
Dam active or inactive at the time of the incident	Active

Dam details:

Type of dam	Valley bottom
Age of dam when incident occurred	3.5 years
Retention capacity of dam	5.25 Mm^3
Height of dam wall	44 m
Other dam dimensions	700 m face length, 300 m toe
Dam wall construction materials	Waste rockfill wall with a sand filter between the wall and a compacted saprolite core
Method of dam construction	Rear deposition with water at the face of the dam
Criteria or standards applied during dam construction	Standard Knight Piesold design and specifications

Incident details:

Type of incident	Piping failure leading to failure of the core
Estimated volume/tonnage of tailings/water/slurry released	4.2 Mm^3
Primary cause of incident	N/a
Other contributing factors	N/a
Result of incident	Discharge of cyanide-tainted water and sediments resulting from the washing of the core through the dam. No tailings slimes exited the impoundment.
Number of fatalities	Nil
Extent of property damage	Nil
Extent of environmental damage	Minor fish kill on the Omai river adjacent to the mine. No damage to the main Essequibo river where Canadian safe drinking water standards were not exceeded
Estimated cost of remediation	Nil
Legal or other action resulting from the incident	Formal praliamentary commission of inquiry, including dam review committee, process review committee and socio-economic/environmental committee
Remedial action taken by the dam owner	Clean-up of sedimentation in the Omai river that resulted from washing out the core of the dam.
Media coverage	Extensive
Literature references	Official report
Contact details for further information	Guyana Geology and Mines Commission Georgetown Guyana

UNEP STUDY OF INCIDENTS INVOLVING MINE TAILINGS DAMS

SPECIFIC INCIDENT DETAILS

Background information:

Record No.	440
Country	Philippines
Name of tailings dam	Placer
Location of tailings dam	Surigao Del Norte
Date of incident	2nd September 1995
Time of incident	N/a
Mine served by the tailings dam	Placer
Mine operating company	Manila Mining Corp.
Dam construction company	N/a
Dam active or inactive at the time of the incident	Inactive as a tailings dam, but used for waste rock storage on top of old tailings

Dam details:

Type of dam	N/a
Age of dam when incident occurred	Probably at least 12 years
Retention capacity of dam	N/a
Height of dam wall	17 m
Other dam dimensions	Length - 300 m
Dam wall construction materials	Earthfill
Method of dam construction	N/a
Criteria or standards applied during dam construction	N/a

Incident details:

Type of incident	Breach in dam wall
Estimated volume/tonnage of tailings/water/slurry released	50,000 m^3
Primary cause of incident	Failure of dam wall led to formation of 100 m-long breach, probably resulting from slippage in underlying foundation materials (marine sediments?)
Other contributing factors	Possible connection with magnitude 3.4 earthquake that occurred on 28th August 1995; top of dam wall was used as a haul road for off-highway trucks
Result of incident	Mud flow towards shoreline, with subsequent sea water ingress into the dam impoundment
Number of fatalities	12
Extent of property damage	Loss of mining equipment
Extent of environmental damage	Coastal pollution
Estimated cost of remediation	N/a
Legal or other action resulting from the incident	N/a
Remedial action taken by the dam owner	N/a
Media coverage	N/a
Literature references	N/a
Contact details for further information	Manila Mining Corp.

UNEP STUDY OF INCIDENTS INVOLVING MINE TAILINGS DAMS

SPECIFIC INCIDENT DETAILS

Background information:

Record No.	450
Country	New Zealand
Name of tailings dam	Golden Cross
Location of tailings dam	Waitekauri Valley
Date of incident	Continuing since December 1995
Time of incident	N/a
Mine served by the tailings dam	Golden Cross gold mine
Mine operating company	Coeur Golden Cross
Dam construction company	Previous owner
Dam active or inactive at the time of the incident	Active

Dam details:

Type of dam	Valley side
Age of dam when incident occurred	4 years
Retention capacity of dam	3 Mt (current)
Height of dam wall	25-30 m
Other dam dimensions	N/a
Dam wall construction materials	Waste rock fill
Method of dam construction	N/a
Criteria or standards applied during dam construction	Fully engineered

Incident details:

Type of incident	Slide involving complete dam structure
Estimated volume/tonnage of tailings/water/slurry released	None
Primary cause of incident	Movement on plane of weakness at some 50 m depth between ancient lava flows and later material, on which the dam was constructed
Other contributing factors	N/a
Result of incident	Ground movement monitoring equipment installed; construction of dewatering tunnels from existing underground mine workings; future of mining operations under review
Number of fatalities	Nil
Extent of property damage	Nil
Extent of environmental damage	Nil
Estimated cost of remediation	NZ$5 million
Legal or other action resulting from the incident	N/a
Remedial action taken by the dam owner	Dewater through tunnels beneath dam; construct rock buttress at dam toe
Media coverage	Extensive in local press
Literature references	N/a
Contact details for further information	Mr Richard Weston Mine Manager Coeur Golden Cross Tel: +64 7 863 6507 Fax: +64 7 863 6112

UNEP STUDY OF INCIDENTS INVOLVING MINE TAILINGS DAMS

SPECIFIC INCIDENT DETAILS

Background information:

Record No.	460
Country	Philippines
Name of tailings dam	Marcopper
Location of tailings dam	Marinduque island
Date of incident	March 1996
Time of incident	N/a
Mine served by the tailings dam	Marcopper
Mine operating company	Marcopper Mining Corp
Dam construction company	N/a
Dam active or inactive at the time of the incident	Active

Dam details:

Type of dam	Tailings storage in worked-out pit
Age of dam when incident occurred	4 years
Retention capacity of dam	N/a
Height of dam wall	N/a
Other dam dimensions	N/a
Dam wall construction materials	N/a
Method of dam construction	Tailings dredged from previous dam
Criteria or standards applied during dam construction	N/a

Incident details:

Type of incident	Tailings escaped through old drainage tunnel beneath worked-out open pit
Estimated volume/tonnage of tailings/water/slurry released	N/a
Primary cause of incident	Failure of existing concrete plug
Other contributing factors	N/a
Result of incident	Outflow of water and tailings through drainage tunnel, with deposition of tailings in waterways downstream
Number of fatalities	Nil
Extent of property damage	N/a
Extent of environmental damage	N/a
Estimated cost of remediation	N/a
Legal or other action resulting from the incident	N/a
Remedial action taken by the dam owner	Install plug in tunnel through which tailings escaped
Media coverage	Yes
Literature references	N/a
Contact details for further information	Placer Dome Inc PO Box 49330 1600 - 1055 Dunsmuir Street Vancouver V7X 1P1 B.C. Canada Tel: +1 604 682 7082 Fax: +1 604 682 7092