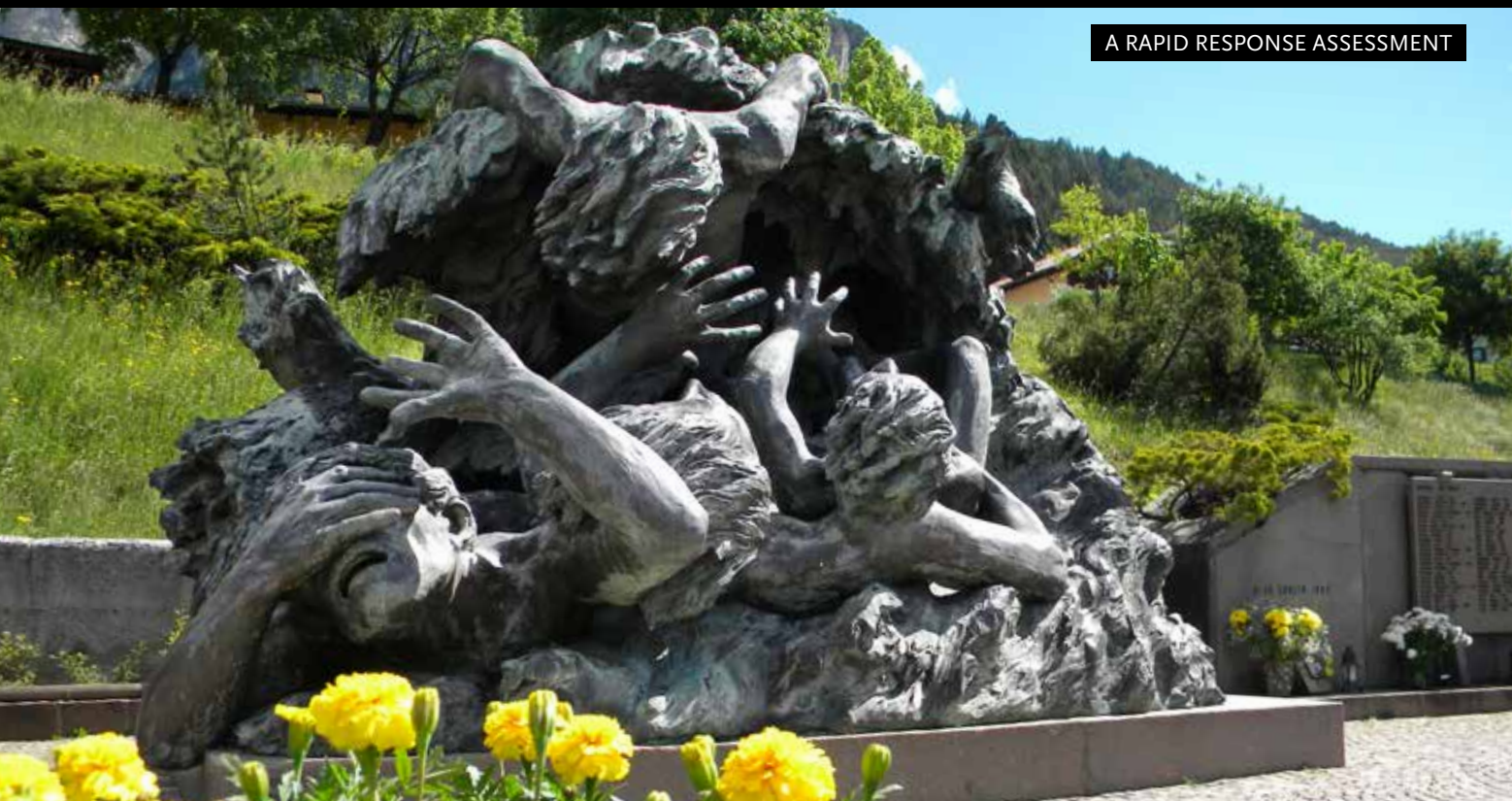




MINE TAILINGS STORAGE: SAFETY IS NO ACCIDENT

A RAPID RESPONSE ASSESSMENT



On the cover

Top photo: The township of Bento Rodriguez. On the 5 November 2015, the Samarco Mineração S.A Fundão tailings dam, containing approximately 55 million m³ of tailings collapsed. The failure released an estimated 33 million m³ of tailings, which travelled down a natural waterway first inundating the town of Bento Rodriguez, approximately 8 km from the dam site. The mud and debris continued to move downstream for 650 km along the Rio Doce River, reaching the Atlantic coast 17 days later. Sadly 19 people were killed, including 14 workers at the dam site, and 5 people in the Bento Rodrigues community. Hundreds more people were displaced in towns and cities downstream.

Bottom photo: The Stava memorial, Italy. The sculpture depicts the scene that faced rescue workers following the Stava dam failure. The bodies of the men, women and children were found in the mud, with their hands held in front of their faces to protect themselves; they had no chance to escape when a tsunami of mud came down their valley at lunch time on a beautiful sunny day on 19 July 1985. The memorial is a poignant reminder of why safety should be the main priority in mining and that mining should support sustainable development, not destroy lives and livelihoods.

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MINE TAILINGS STORAGE: SAFETY IS NO ACCIDENT

A RAPID RESPONSE ASSESSMENT

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Preface

Developing the green technologies needed to achieve the 2030 Sustainable Development Goals means the demand for large quantities of minerals and metals will continue to grow for the foreseeable future. Safer, cleaner and less wasteful extraction and production is paramount to ensuring resource availability, but also community well-being and ecosystem resilience.

Mining companies, communities and governments recognize that mine waste, contaminated water and land pollution damage lives and livelihoods but also threaten the development of the mining sector. For this reason, they are committed to work together to reduce the industry's footprint.

Despite many good intentions and investments in improved practices, large storage facilities, built to contain mine tailings can leak or collapse. These incidents are even more probable due to climate change effects. When they occur, they can destroy entire communities and livelihoods and remain the biggest environmental disaster threat related to mining.

The mining industry has acknowledged that preventing catastrophic tailings dam incidents with zero fatalities and environmental protection is fundamental and achievable. For decades, companies, industry bodies and regulators have been continually improving best practice guidelines for the construction and management of tailings dams. However, eliminating all catastrophic incidents remains a challenge.

The United Nations Environment Rapid Response Assessment on mine tailings looks at why existing engineering and technical knowhow to build and maintain safe tailings storage facilities is insufficient to meet the target of zero catastrophic incidents. It examines the ways in which the established best practice solutions in international collaborative governance, enhanced regulations, more resource efficient approaches and innovation could help to ensure the elimination of tailings dam failures. It uses case studies from different parts of the world to highlight the efforts of industry to reduce mine waste and stimulate new activities while suggesting how these could be accelerated through regulatory or financial incentives.

It is hoped that this report will encourage targeted action at the policy and technical level to make zero catastrophic incidents become a reality and ensure that economic prosperity is fully compatible with community health and safety.

Ligia Noronha

Director Economy Division

United Nations Environment Programme



**Preventing
catastrophic tailings
dam incidents is
fundamental and
achievable.**

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Tailings dams are complex systems that have evolved over the years. They are also unforgiving systems, in terms of the number of things that have to go right. Their reliability is contingent on consistently flawless execution in planning, in subsurface investigation, in analysis and design, in construction quality, in operational diligence, in monitoring, in regulatory actions, and in risk management at every level. All of these activities are subject to human error.

– Mount Polley expert panel, IEEIRP 2015, p. 119

Mine tailings and tailings storage facilities

Mine tailings are a major waste stream generated in mining operations. Tailings are the waste material left over after the valuable component has been removed through processing. They include ground-up rock or sand, and the chemical reagents and process water used to extract the commodity. Tailings dams, also referred to as tailings storage facilities,¹ are the most common method used to store this material.

Due to the physical and chemical nature of tailings, they pose potential risks to people and the environment, which means they require proper treatment and dedicated, safe storage locations. Unfortunately, tailings dams can fail. These failures can release vast quantities of water and sediment, often capable of devastating downstream communities and the environment.

Some key facts:

- Despite the many advances made in the mining sector and increased geotechnical engineering knowledge, tailings dam failures still occur. Since 2014 there have been seven failures significant enough to make international news. These occurred in Canada, Mexico, Brazil (x2), China, USA and Israel (WISE 2017). While not all have resulted in loss of life, they have all caused extensive damage to the environment. Six case studies of failures dating back to 1985 are described in this report. They illustrate the causes and consequences of failures, including catastrophic loss of life (a combined total of 287 direct casualties), damage to infrastructure and the environment, and the lasting impact these failures can have.
- For many years the overall number of annual tailings dam failures has been in decline, however, the number of serious failures has increased (Bowker and Chambers 2015).
- There is no publicly accessible inventory of tailings dams, however, one estimate has put the number of tailings dams at 3 500 (Davies and Martin 2000). This is likely an underestimate as there could be more than 30 000 industrial mines (SNL 2016).
- The global volume of stored tailings is also unknown, but recent disasters illustrate the potential scale of accidents. For example, the Mount Polley and Samarco failures in 2014 and 2015 respectively each released more than 25 million cubic metres of tailings into the environment – combined, this represents enough material to fill more than 20 000 Olympic swimming pools.
- The cost of tailings dam failures to industry can be extremely high. For example, BHP has provided US \$174 million to the Renova Foundation for remediation and compensation programmes following the Samarco dam failure and is also facing a potentially costly civil claim.

1. Tailings dams are commonly referred to as tailings storage facilities (TSF) or tailings management facilities (TMF).



Example of a tailings dam/storage facility – The Fort Knox gold mine in Alaska. The tailings are contained in a valley behind an earth and rock embankment that creates a dam. This tailings storage facility is eventually expected to cover 395 hectares and store approximately 270 million tonnes of tailings (calculated as equivalent dry weight, Kinross Gold Corporation 2015).

Mining and mine waste

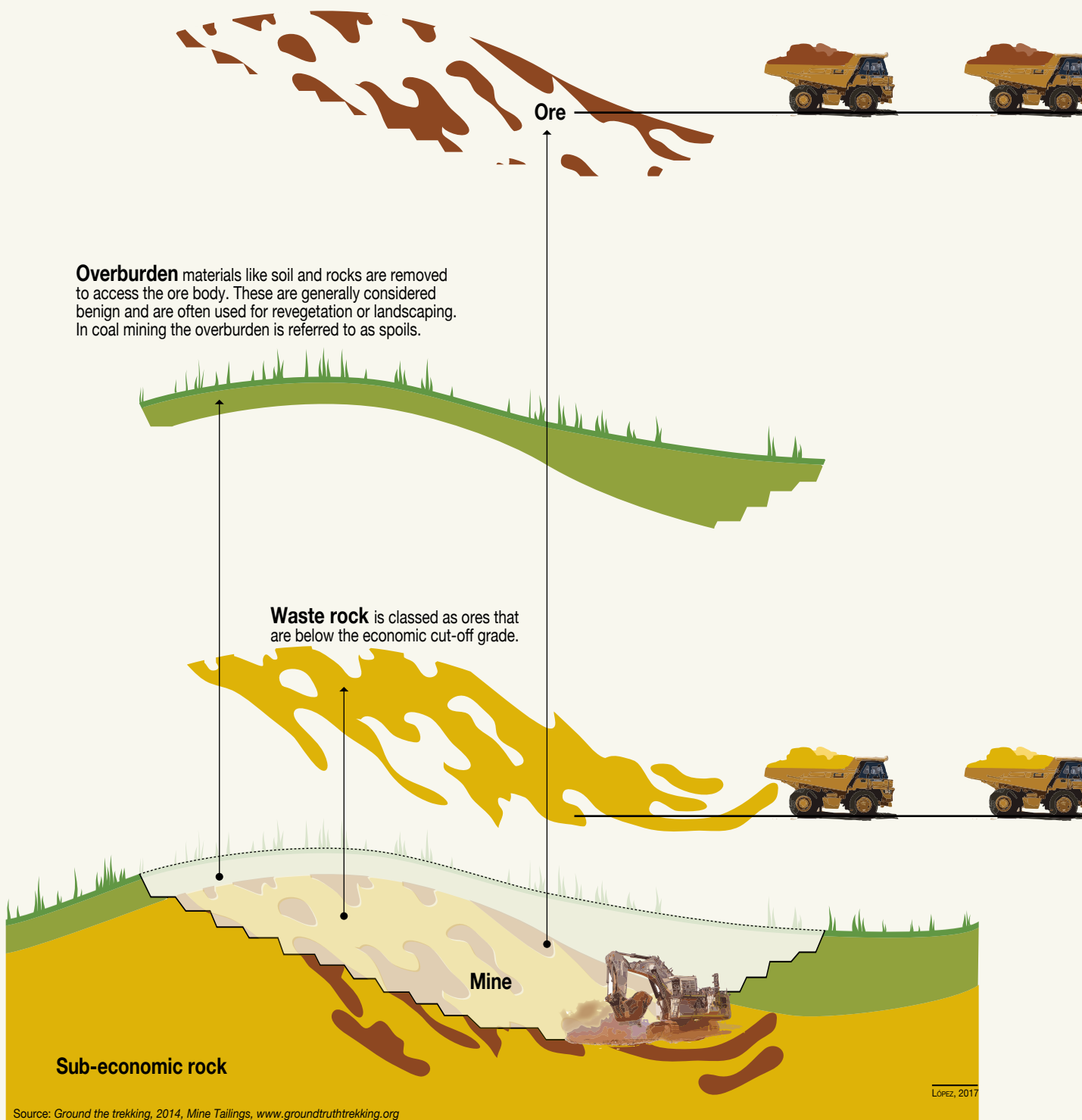
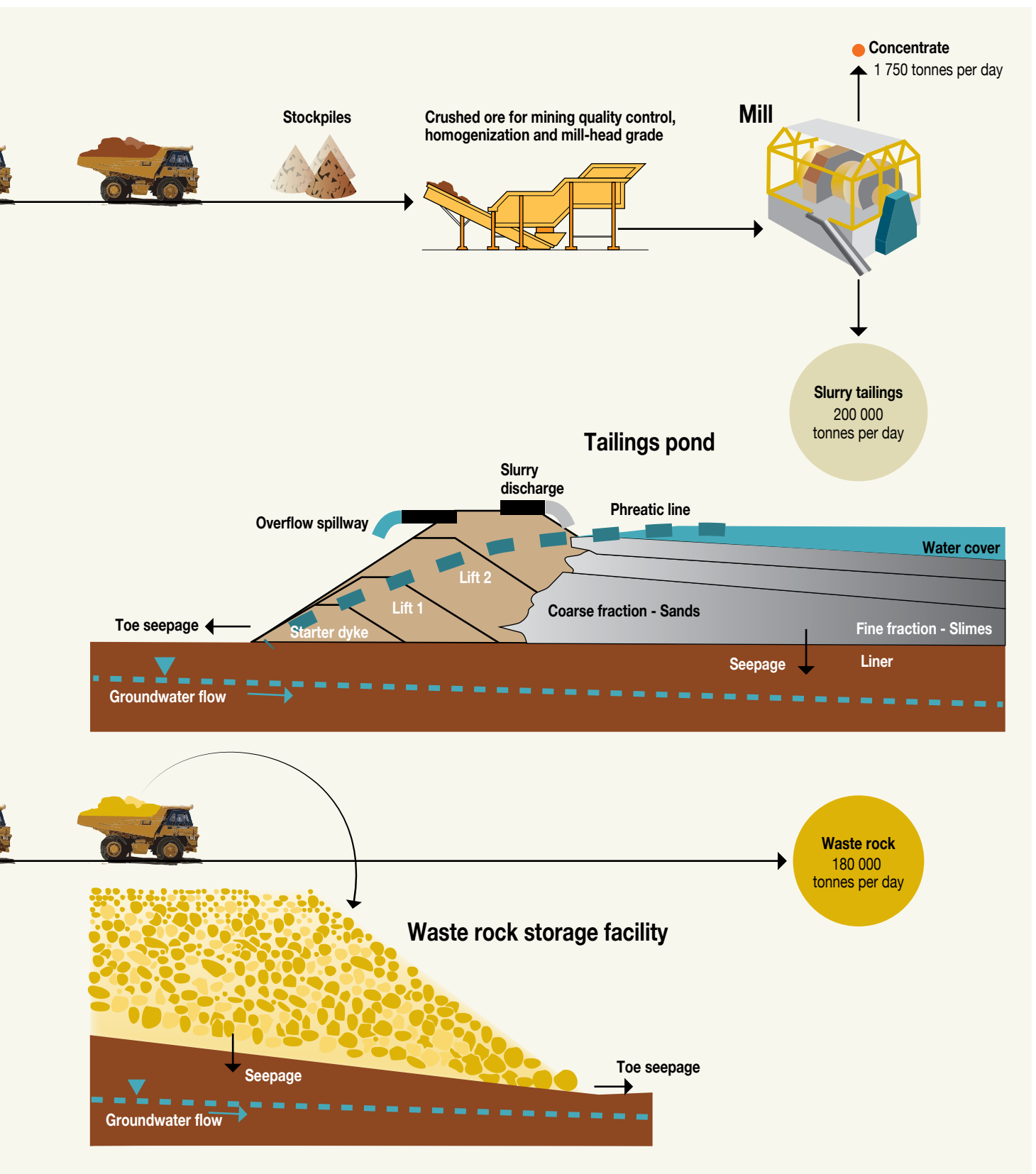


Figure 1. A mining operation, illustrating a typical process in an open pit mine, from excavation to waste disposal.



Executive summary

This report is part of the United Nations Rapid Response Assessment series and is motivated by the human and environmental costs of continued tailings dam disasters.

Acknowledging community concerns over the impact of tailings dam failures, such as at Mount Polley and Samarco, this report seeks to examine and explain why tailings dam failures continue to occur. It provides an accessible and balanced description of the complexities surrounding tailings dam failures, informing the global community of the issues. Sixteen years on from the 2001 International Commission on Large Dams (ICOLD) “Tailings Dams: Risk of Dangerous Occurrences” report, it gives an update on the status of reforms and provides momentum and direction for advancing the shared ambition of eliminating tailings dam failures. It also provides an overview of the key issues, using case studies to illustrate causes and consequences of tailings dam failures, the progress of reform and the need for a coordinated stakeholder response.

The comprehensive 2001 ICOLD report established an urgent need for the reform of tailings storage-facility planning, management and regulation. The authors found that all 221 failures examined were avoidable – that the technical knowledge to build and maintain tailings storage facilities existed, but that an inadequate commitment to safe storage combined with poor management was the cause of most failures. Unfortunately, despite this realization and the development of many new measures, guidelines and improved practices, tailings storage facilities have continued to fail. Furthermore, the issue of safely storing tailings may become even more challenging as the volume of waste

from mines increases due to lower ore grades (Mudd 2007) and as climate change brings about more intense and variable weather events. An inadequate response will see failures continue, impacting communities, human rights and environments, and the reputation and profitability of mining ventures.

Mining is a complex industry, ranging from small to medium single-site companies and junior explorers to global giants. While the risks and rewards for industry players are clear and subject to annual reviews, those for local communities are not always as apparent. Improving the safety of tailings storage facilities requires a change of focus. Currently, project-based feasibility assessments can underestimate risk and impact over time, leading to poor tailings management design and practices and increased risks to the community and the environment. Although there are existing guidelines and regulations, the costs of externalities and perpetual waste management need to be thoroughly defined to provide an accurate assessment of project viability. Industry and regulators need to adopt more holistic thinking, which is flexible enough to allow for site variation, but which also clearly identifies best practices. Most importantly, these best practices need to be competently implemented. But as noted by the Mount Polley expert panel (IEEIRP 2015), existing best practices and regulations may not be enough to eliminate failures – what is also required is a fundamental change in the way we produce, reuse and perpetually store tailings.

This Rapid Response Assessment makes two recommendations and suggests a range of policy actions that are aimed at catalysing the change needed to ensure tailings dam safety. These actions stem from the first recommendation – the mining industry’s acknowledged priority of “safety first”.

Recommendations

The Rapid Response Assessment highlights issues that are serious enough to warrant more detailed consideration and action by the regulators, financiers, owners and operators of mines (Figure 2).

The actions below are contained in the 2001 ICOLD report or have been drawn from subsequent academic research, industry reports and post-failure investigations that identify the scale, predictability and drivers of tailings dam failures. They are further developed in section 8.



Recommendation 1

The approach to tailings storage facilities must place safety first by making environmental and human safety a priority in management actions and on-the-ground operations. Regulators, industry and communities should adopt a shared zero-failure objective to tailings storage facilities where “safety attributes should be evaluated separately from economic considerations, and cost should not be the determining factor” (Mount Polley expert panel, 2015, p. 125)

Recommendation 2

Establish a UN Environment stakeholder forum to facilitate international strengthening of tailings dam regulation.



Figure 2. Recommendations and suggested actions for stopping tailings dam failures



Introduction

Industrial scale mining generates huge volumes of waste tailings. The way mining companies deal with these tailings can have major long-term implications for local communities and the environment. The largest tailings storage facilities are among the biggest man-made structures on Earth. They are expected to provide “secure” storage of tailings in perpetuity. But is this a realistic expectation?

Recent tailings dam failures have provided evidence that tailings storage facilities are not always safe. For example, the 2015 Samarco mine tragedy in Brazil resulted in 19 deaths and polluted hundreds of kilometres of river (see case study, pg 17). Even when fatalities do not occur, the failure of tailings storage facilities can have lasting social, environmental and economic consequences and often prove extremely difficult and costly to remediate.

We understand that the failure to implement adequate tailings dam standards, guidelines and risk controls can result in catastrophic events. So, is there a way to reduce the risk of dam failure? Are there some practices that are inherently riskier than others that should be reconsidered? And are there alternatives to the commonly accepted tailings storage and disposal methods?

Tailings storage facilities are built by industry and should be regulated by governments, however, all stakeholders, particularly local communities, bear the impact of failure. The recently commissioned International Council on Mining and Metals (ICMM) report (Golder and Associates 2016) concludes that we have the means to ensure the safe management of mine tailings, we just need to make sure this occurs.

Numerous well-conceived initiatives have, over the past decades, made recommendations to improve mine waste management (Figure 3). Examples include the Mining, Minerals and Sustainable Development Project (MMSD 2002 and Buxton 2012), the World Bank Extractive Industries Review (Salim 2003) and the 2001 ICOLD report. Franks et al. (2011) developed a set of sustainable development principles for the disposal of mining and mineral processing waste. Most recently, the ICMM produced a specific tailings-focused report (Golder and Associates 2016) and a position statement on preventing the catastrophic failure of tailings storage facilities (ICMM 2016). National industry bodies, such as the Mining Association of Canada, also produce guidance on tailings management, which their members are required to follow (MAC 2011). However, despite all these guiding

principles and recommendations, major failures are still occurring (Figure 3) and are predicted to continue (Bowker and Chambers 2015).

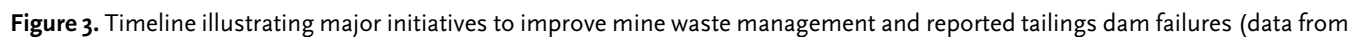
Sustainable development and mine tailings (adapted from LPSPD 2016)

The United Nations Sustainable Development Goals should support and underpin the mining industry's contribution to development objectives and their social licence to operate. The licence should acknowledge that the failure or poor performance of a tailings storage facility can be fatal for communities and can cause widespread damage to the environment on which they depend.

A commitment to sustainable development requires early and ongoing consultations, where information sharing and dialogue with stakeholders are required during the design, operation and closure phases of every mine. This needs to be supported by transparent compliance with industry-specific guidelines and by applicable government regulations, to establish a practical and ethical basis for mining to contribute to sustainable development and safely store tailings.

From the earliest planning stages, sustainable closure of tailings storage facilities requires the incorporation of closure landform design that will ensure sustainable post-mining land use and ecological function.

Breaking New Ground, Mining, Minerals, and Sustainable Development, Global Mining, Large Mines and Tailings Management, Case studies on Tailings Management, Tailings and Dangerous





Chambers 2015 and WISE 2017)

China makes advances in tailings dam safety

In the last decade, the Chinese mining industry has made significant changes in the treatment of mine waste, including improving engineering design, construction and monitoring of tailings storage facilities. The government has increased regulation and mines are now required to have a tailings disposal system in operation before mining can begin. Improving tailings dam safety in China is vital since there are more than 12 000 tailings dams, of which more than 6 000 were in use at the last report (Chen et al. 2016). While most of these tailings dams are small, 95 per cent of them are constructed using the upstream method, which, while economical, has proven to be less stable than other methods (Wei et al. 2013). Due to the large number of failures, mine owners are now required to provide stability analyses and flood-control analyses, which are generally undertaken by professional design companies (Wei et al. 2013). Li et al. (2017) recently suggested four initiatives to improve tailings dam safety in China:

- Improve supervision over the whole life cycle of tailings storage, including closure and reclamation.
- Consider safety, economy and societal and environmental risks in risk analysis during the design phase.
- Raise dam stability standards and maximum flood safety standards to be in line with international best practice.
- A reclamation and environmental protection fund should be established by the mining enterprise at the planning and design phase.

The challenge of safely storing mine waste is growing in scale and complexity. Over the last few decades, the tailings-to-ore ratio has been increasing, as mineral deposits with increasingly lower ore grades are mined (Mudd 2007). The fate of this increasing volume of waste is a major focus of the debate on the general sustainability of mining and the practicalities of storing ever-increasing quantities of tailings. This is a challenge that could be further complicated by the increased severity and occurrence of extreme weather events expected under climate change predictions (Franks et al. 2011).

With community confidence shaken by recent failures, the mining industry is being challenged to guarantee the health and safety of people and the environment. The alarm over tailings dam failures, along with concerns over land access, water use and contamination, indigenous rights and inequality raises questions about the way mining contributes to sustainable development.





Case study: Samarco, Brazil, 2015

The mineral-rich area known as the Iron Quadrangle is located in Minas Gerais state in south-east Brazil. There are more than 300 mines in operation (including gold, topaz, niobium, manganese, diamond and other ores and gems), producing more than 17 per cent of the state's revenue. Mining activity dates back to the eighteenth century and has shaped both the environment and urban development. Among these mines is the Germano mine, close to the city of Mariana, which is operated by Samarco – a joint venture between Vale SA and BHP Billiton, two of the largest mining companies in the world. It produced just over 23 million tonnes of iron ore pellets in 2014 and in the process, generated almost 20 million tonnes of tailings (Samarco 2015).

On 5 November 2015, the mine's Fundão dam breached, releasing an estimated 33 million cubic metres of mine waste (Samarco 2015a; Grupo da Força-Tarefa 2016). The tailings slurry flowed down the valley as a high-density mudflow and inundated parts of the village of Bento Rodrigues. Nineteen people were killed, including village residents and Samarco employees. The slurry reached the Doce River Valley, the fifth largest river basin in Brazil, and travelled for 650 kilometres until it reached the Atlantic coast 17 days later. The flow and its impacts are illustrated in Figure 4.

The investigation to determine the cause of the dam failure identified a number of issues that cumulatively led to the failure. These included inappropriate dam construction procedures, improper maintenance of drainage structures and inadequate monitoring (Morgenstern et al. 2016). Prior to the collapse there had been several incidents that necessitated alterations to the original dam design. These changes established the conditions for failure by creating drainage problems that resulted in large volumes of saturated sand adjacent to the dam wall. Immediately prior to the collapse, three small earthquakes exacerbated the structural weakness of the sand, initiating the flow slide (Morgenstern et al. 2016).

The final government report (GFT 2015) listed 36 factors that contributed to the dam failure and noted that the mining company did not have an emergency plan, or even warning lights and sirens that could be activated to alert employees or villages in the event of a disaster. Brazilian authorities charged 22 individuals over the incident, which killed 19 people (Wood 2017). The Brazilian government has suspended Samarco's environmental and operation licences. A compensation agreement was reached in March 2016 between the relevant Brazilian authorities and the mining companies, however, Samarco is also facing a civil claim, which it expects to settle in 2017.

Germano mine storage facility failure

The **Fundão** dam, one of the tailings dams at Germano mine, broke on the afternoon of 5 November 2015. The breach discharged 33 million m³ of iron ore tailings slurry.

Initially it was believed that the **Santarém** dam had also broken, but later it was verified that the mud from the Fundão dam had covered it, causing it to overflow as well.

The mud devastated the sub-district of **Bento Rodrigues**, pulling vehicles downstream and destroying hundreds of houses, following the **Gualaxo** and **Doce** rivers affecting the municipalities of Minas Gerais and Espírito Santo before reaching the Atlantic Ocean.

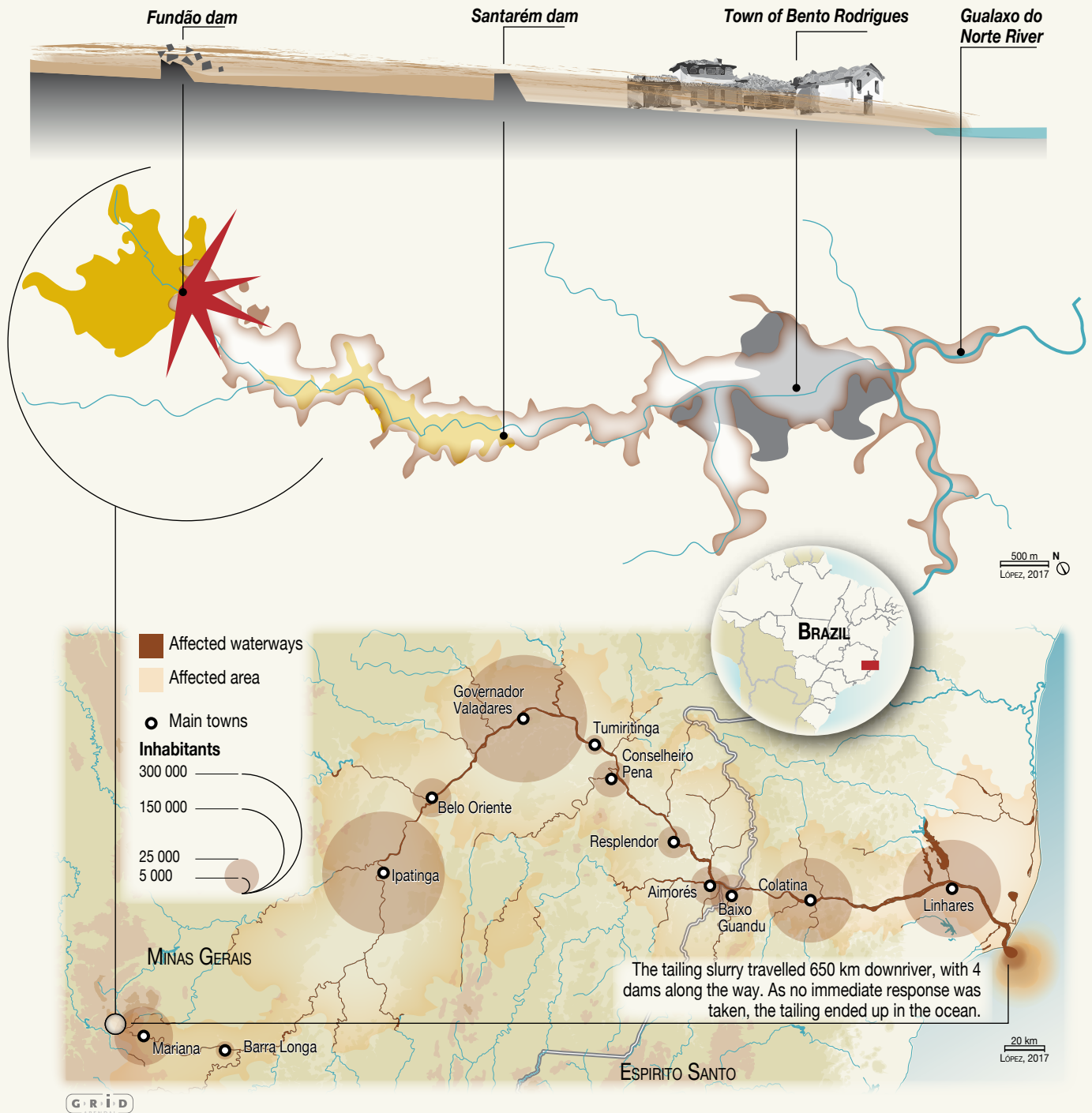


Figure 4. Location and impacts of the tailings storage-facility failure at the Samarco mine in Brazil, November 2015

Direct impacts

PEOPLE

19 people died, 600 families were displaced and at least 400 000 people had their water supply disrupted.

FAUNA

Entire fish populations- at least 11 tons- were killed immediately when the slurry buried them or clogged their gills.

HERITAGE

Numerous colonial monuments dating back to the 1700s were destroyed.

INFRASTRUCTURE

The slurry filled 650 km of hydrologic networks.

VEGETATION

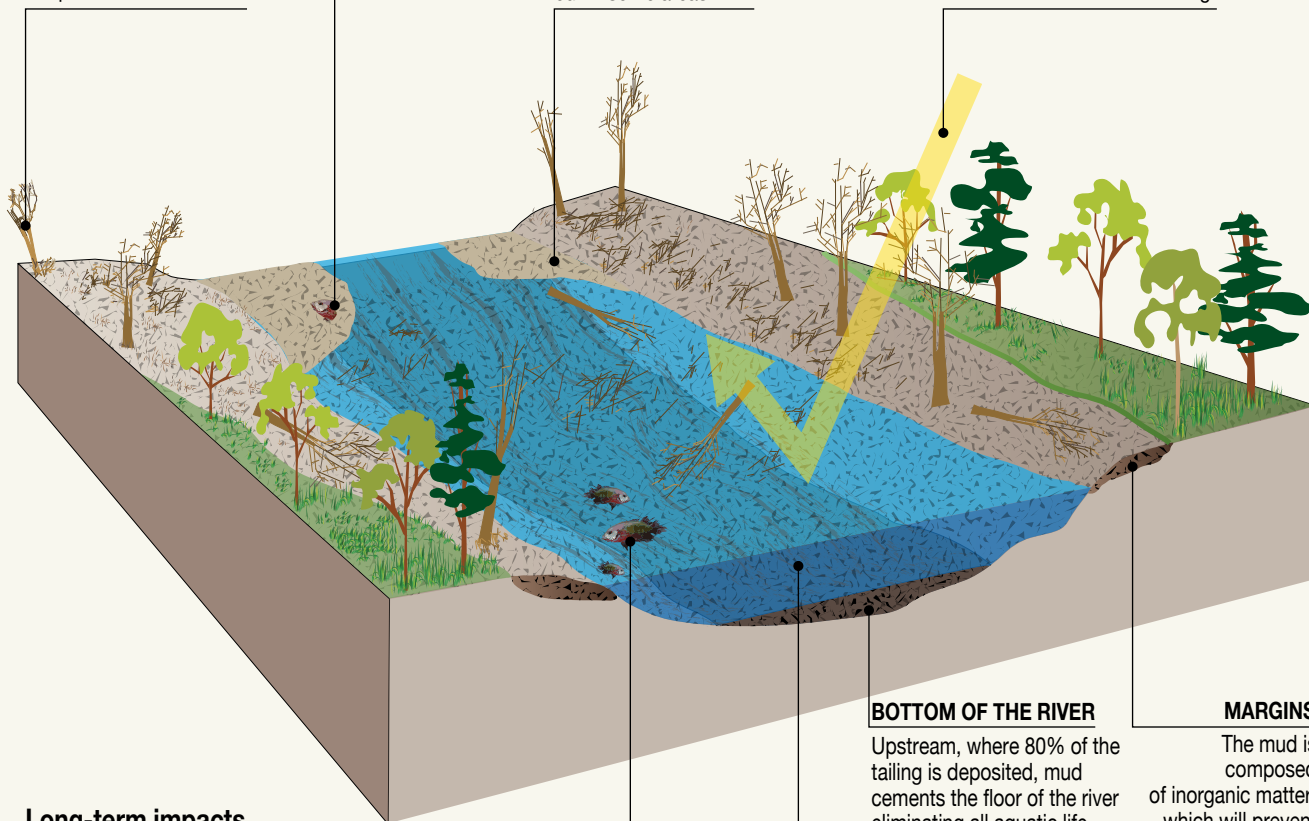
The force of the mudflow destroyed 1 469 hectares of riparian forest.

SILTING

The riverbed became shallow and even dried out in some areas.

LIGHT

The turbidity of the water prevents light from passing through it, preventing photosynthesis from occurring.



Long-term impacts

PEOPLE

The destruction of riparian, freshwater and marine ecosystems eliminated irreplaceable natural resources and ecological processes that support traditional livelihoods, disrupting fisheries, agriculture, tourism and freshwater resources. The interruption of the mining activity will severely affect the local economies of 37 villages and cities. Fishing and agriculture are banned across affected areas for an indefinite period and misguided future use and restoration designs may increase human exposure to heavy metals.

pH AND TEMPERATURE

The sediment altered the acidity and the temperature of the water, killing aquatic life.

TURBIDITY

Downstream and close to the river mouth, when the river level rises after the rainy season, turbidity increases and metal levels in the water column return to the same level as in November 2015.

BOTTOM OF THE RIVER

Upstream, where 80% of the tailing is deposited, mud cements the floor of the river eliminating all aquatic life.

MARGINS

The mud is composed of inorganic matter, which will prevent plants from growing where it has settled.

Sources: Geraque E. et al, 2015, *Rastro de lama, Folha de São Paulo*; Costa C., 2015, *O que já se sabe sobre impacto da lama de Mariana?*, BBC Brasil; Fernandes, G.W. et al, 2016, *Deep into the mud: ecological and socio-economic impacts of the dam breach in Mariana Brazil*, *Natureza & Conservação*, n. 14, pp. 35-45; IBGE, 2017, *Cidades. População*, ibge.gov.br; Alex Bastos Universidade Federal do Espírito Santo, Brazil.

What are mine tailings?

Mine tailings are one of the components of mine waste. Other wastes include overburden, waste rock and mine water. Figure 5 shows an example of the scale of each component. This report is primarily concerned with the impacts and safety of tailings storage facilities, which primarily store tailings and to a lesser extent, mine water and other mine waste.

The physical and chemical properties of mine tailings are highly variable and depend on a number of factors, including the mineralogy of the host rocks, method of processing, size of mined materials and moisture content. Tailings may contain hazardous materials, such as heavy metals, metalloids, radioactive metals, sulphide minerals and processing reagents (e.g. cyanide used in gold mining). Tailings are also generated during the extraction of the oil from oil sands. These tailings contain sand, silt, clay and water, plus unrecovered hydrocarbons and other contaminants. Table 1 describes some of the potentially harmful components that can be found in mine tailings, although each mine or processing facility produces tailings that are unique in their physical and chemical properties.



Waste type	Description
Sulphide waste	Not all sulphide minerals are extracted when processing massive sulphide ores (which may contain copper, lead, zinc, gold and other minerals). When this residue of sulphide minerals is exposed to the atmosphere and groundwater in the tailings dam, it oxidizes to form acidic sulphate-rich drainage, commonly referred to as acid mine drainage (AMD).
Heavy metal waste	Depending on the type of mine, the tailings can contain various heavy metals. For example, gold mine tailings may contain elevated concentrations of metals such as arsenic (As), cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu), lead (Pb), manganese (Mn), nickel (Ni), and zinc (Zn).
Cyanide waste	Cyanide waste is generated primarily in the extraction of gold and silver. This waste will occur in the form of heap-leach residues, tailings and spent process water.
Radioactive waste	Radioactive elements are found in tailings generated in the extraction of uranium, some copper deposits and the processing of placer and mineral sands deposits. Uranium extraction is selective and therefore, up to 87% of the radioactivity can remain in the tailings (Mudd 2000).
Phosphate waste	Phosphate waste is generated from mining potash and phosphate ores. The major waste products are brine solution and tailings consisting of salts, clay, sulphides, oxides and evaporative salts.
Bitumen waste	Bitumen waste is generated from oil-sand mining. It can contain elevated concentrations of salts, metals (arsenic, cadmium, chromium, copper, lead and zinc), polycyclic aromatic hydrocarbons, naphthenic acids and solvents that are added during the separation process. Naphthenic acids are toxic to aquatic organisms (Grant et al. 2013).

Table 1. Examples of potentially harmful substances that can be found in tailings

Mine waste from a large copper mine

The scale of a large copper mine can make it difficult to comprehend the challenge of safely storing tailings. The example below illustrates just how much ore, waste rock, tailings and water are involved in the production of copper.

Copper concentrate generally contains 20 to 30 per cent copper; for this example, 270 000 tonnes per day of mined material may produce 1 750 tonnes of copper.

An average day in a large-sized copper mine

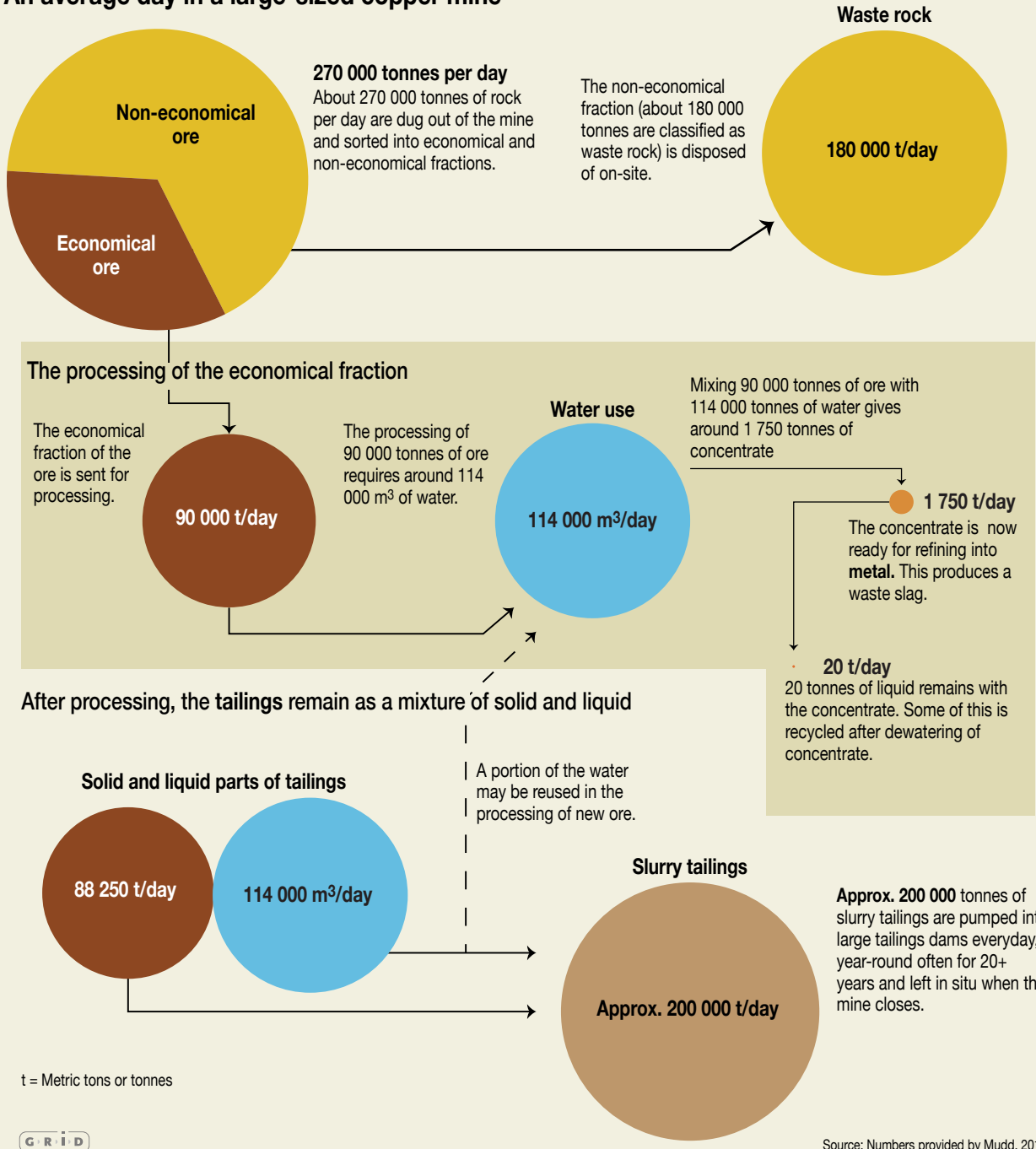


Figure 5. An example of the volumes of tailings and other waste that can be generated in a large copper mine

Case study: Mount Polley, Canada, 2014

The Mount Polley mine, a large, open-pit and underground copper-gold mine in British Columbia, began operation in 1997 and currently processes about 22 000 tonnes of ore per day. The mine's tailings dam failed in August 2014, releasing approximately 25 million cubic metres of tailings and wastewater into a nearby creek (OAGBC 2016; Figure 6). Mine operations were suspended for a year following the breach and did not fully recommence until June 2016.

The tailings storage facility (surface area approx. 2.4 km²) was designed with three embankments – the Main Embankment, the Perimeter Embankment and the South Embankment. These were constructed with a core built from excavated, fine-grained glacial till deposits, supported downstream by filter and rock-fill zones and upstream by a tailings/rock-fill zone. While the mine was in operation, the height of the embankments was increased in nine stages, to an eventual height of 40 metres. Shortly before the collapse, approval was being sought for Stage 10, which would have further increased the dam wall height (IEEIRP 2015).

The Mount Polley dam failure created the largest environmental disaster in Canadian mining history (Schoenberger 2016). The mine is adjacent to Polley Lake and Hazeltine Creek, which flow into Quesnel Lake, one of the world's deepest glacial lakes and an important commercial, recreational and aboriginal fishery. It supports sockeye salmon, rainbow trout and a diverse range of other fish species. Prior to the dam collapse, the water in the lake had a very low level of particulate material. The collapse resulted in a massive sediment-laden plume scouring Hazeltine Creek and entering the west basin of the lake. Petticrew et al. (2015) monitored the lake for two months post-spill. They found increases in conductivity and temperature and a persistent, high-turbidity layer below the thermocline. While subsequent monitoring indicated that the turbidity reduced to near background level by the beginning of 2015 (SMA 2016), the full effects of the spill may not yet be apparent or easily identifiable.

The government of British Columbia commissioned a report from a panel of experts to determine what caused the failure (IEEIRP 2015). The review found that a breach occurred suddenly in the Perimeter Embankment on the northern flank of the tailings storage facility, as a result of foundation failure. They concluded that the tailings storage-facility design was not appropriate for the site, as it did not properly take into account the underlying geology. The original foundation investigation failed to understand the nature of a layer of weak glacial deposits, composed of silt and clay, which are found about 8 to 10 metres below the ground surface in the vicinity of the Perimeter Embankment. The report also found that the dam was susceptible to failure from overtopping and internal erosion. The panel found that additional inspections of the tailings storage facility would not have identified the foundation problems.



An audit of compliance and enforcement carried out by the Auditor General (OAGBC 2016) noted regulatory failures. It found that the Ministry of Energy and Mines did not ensure that the tailings dam was being built or operated according to the approved design, nor did it ensure that the mining company rectified design and operational deficiencies that were observed during site inspections. Rather, it continued to approve permit amendments to raise the tailings dam. As a result of the findings, the Auditor General recommended that the government of British Columbia create an integrated and independent compliance and enforcement unit for mining activities, with a mandate to ensure the protection of the environment.

In May 2017, Amnesty International (2017) published the results of its investigation into the spill. The report documents the impact on the rights of Indigenous peoples to hunt, fish, pick medicines and berries, and engage in cultural practices within their traditional territories in the area damaged by the spill. It makes recommendations to ensure robust monitoring of the medium and long-term impacts of the spill on the environment and peoples' health.

There has not been any government charge against the corporation to date, but multiple lawsuits have been launched. These include, three of the main Indigenous Peoples (First Nations) affected by the spill, MiningWatch Canada, which filed private charges against both the corporation and the government of British Columbia for alleged violations of the Federal Fisheries Act, and the former chief of Xat'sull First Nation, Bev Sellars who filed private charges for 15 counts under the provincial Environmental Management Act (Louie 2017; St'at'imc Chiefs Council 2017; Members of the Tl'esqox 2017; Lapointe 2017).

The corporation that owns and operates the Mount Polley mine also launched lawsuits against the mine's engineers of record, claiming that their flawed mine designs were the cause of the dam breach. The defendant engineering companies have also launched a counterclaim against the plaintiff mining corporation (Imperial Metals Corporation 2017). All of these litigations are still pending.

Mount Polley mine storage facility failure

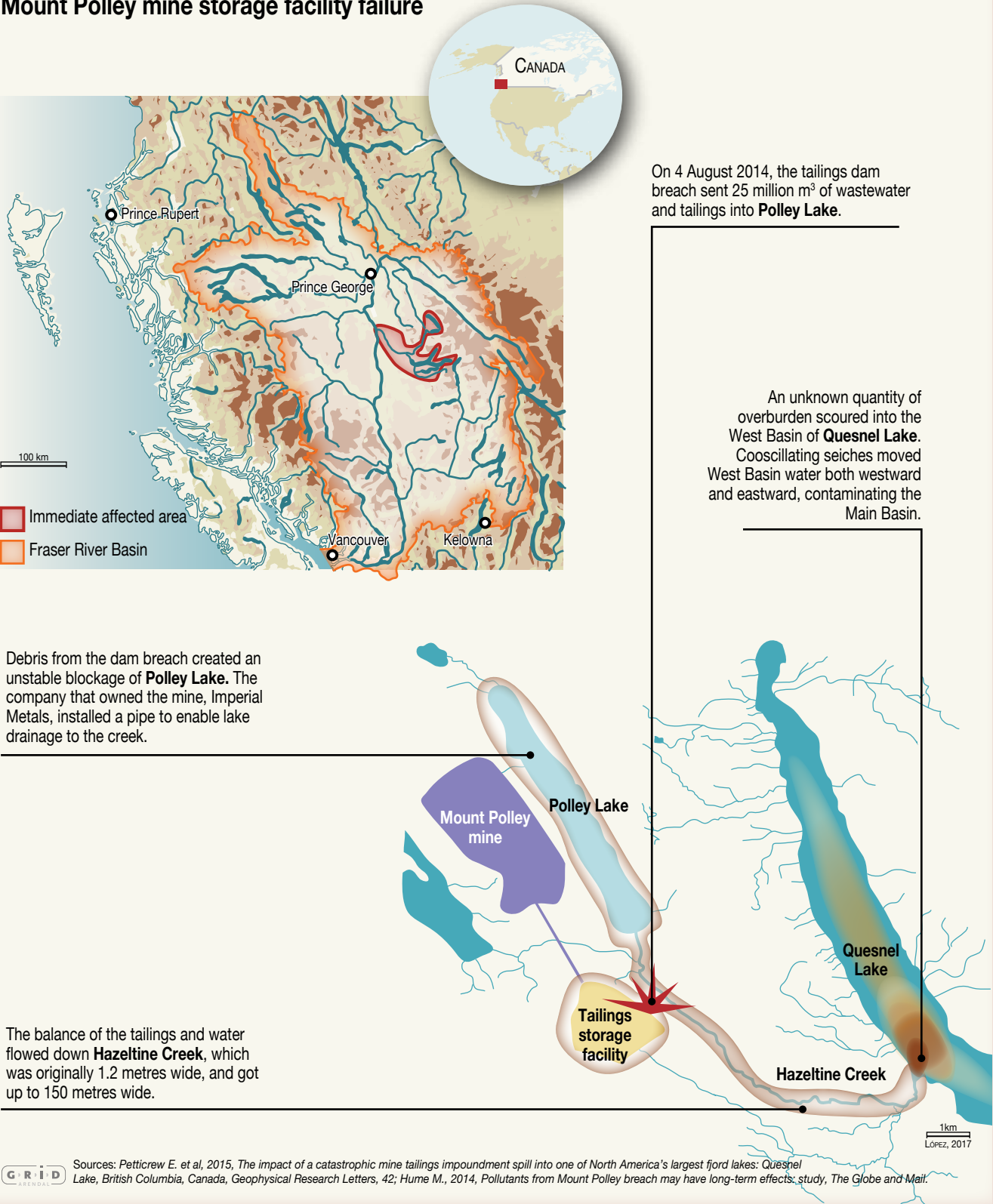


Figure 6. Tailings dam failure at the Mount Polley mine in Canada





Tailings dam failures

An analysis of tailings dam failures over the last three decades, indicates that while the overall number of failures has decreased, the number of serious failures has increased (Bowker and Chambers 2016; Figure 7).



It is widely accepted in the technical and scientific community that good management, with an integrated approach that extends from facility design to closure, plays a significant role in mitigating and reducing the risk of tailings storage-facility failures. However, some external factors may increase the risk of failure. Bowker and Chambers (2015) found a significant correlation between an increase in the severity of tailings storage-facility failures and economic conditions that squeeze cash flow for miners, such as a decrease in commodity prices and an increase in production costs (due to lower grades of ore).

The 2001 ICOLD report recommended that a conservative approach should be taken in designing tailings storage facilities. This would take into account the most conservative assumptions about capacity requirements and natural events, such as floods and earthquakes (Bowker and Chambers 2015).

Known mining accidents

Very serious tailings dam failures

Multiple loss of life (~20) and/or release of $\geq 1\,000\,000\text{ m}^3$ total discharge, and/or travel of 20 km or more.

Serious tailings dam failures

Loss of life and/or release of $\geq 100\,000\text{ m}^3$ semi-solid discharge.

Other tailings dam failures

Engineering/facility failures other than those classified as very serious or serious, no loss of life.

Other tailings-related accidents

Accidents other than those classified under the first three categories of dam failures.

Non-tailings (or unknown type) failure

Non-tailings incidents - groundwater, waste rock, etc.

1985-1996

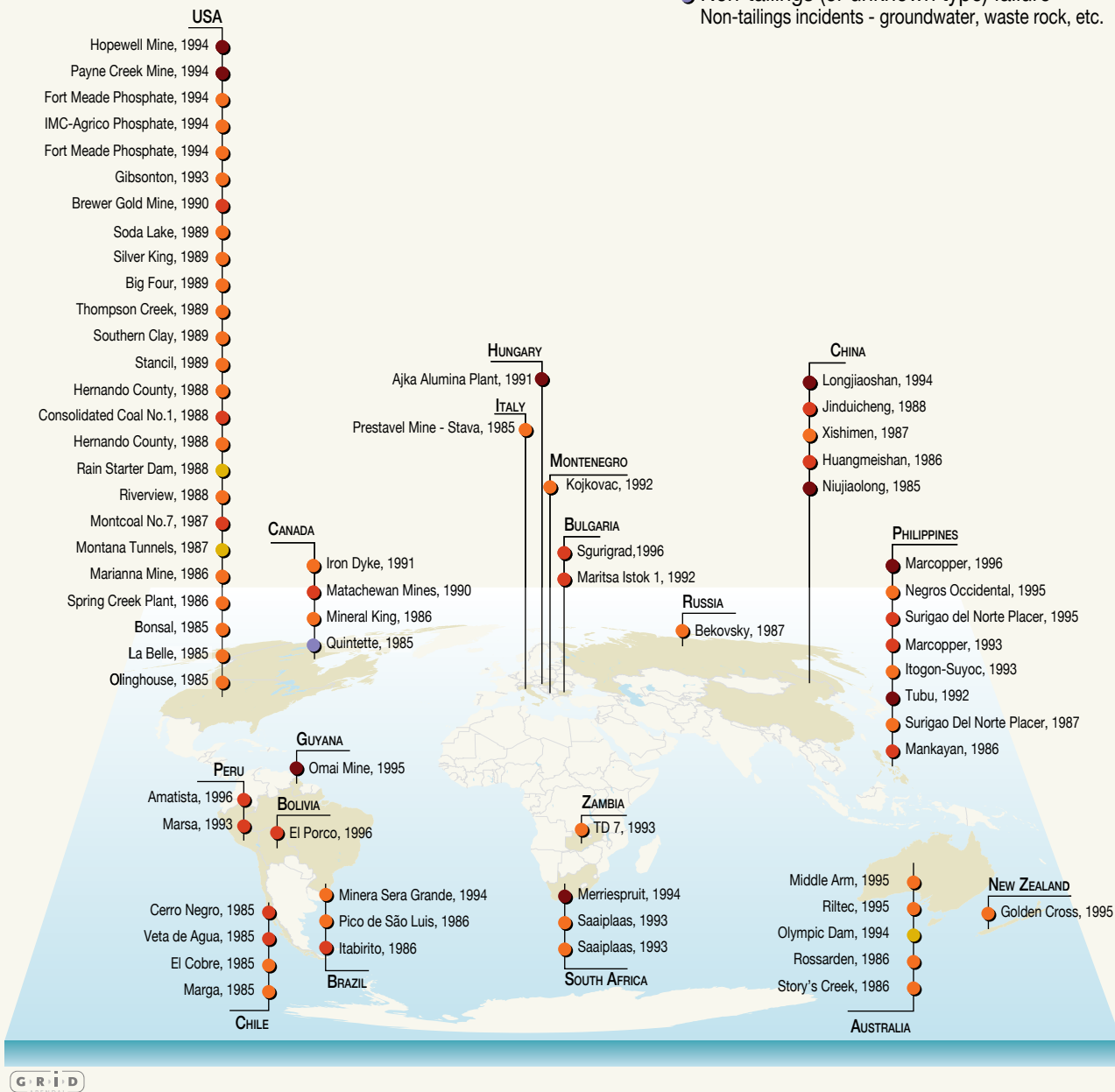


Figure 7. An indication of the number and location of tailings dam failures since 1985

2007 - 2017



1997-2006



LÓPEZ, 2017

Source: Center for Science in Public Participation; Wise Uranium Project.

Storage dams – why are tailings dam failures more common than water dam failures?

Water dams have been known to fail with catastrophic consequences but in the last 40 years, failures have become very rare, whereas tailings dams have continued to fail. Is there something that can be learned from water dams to improve the safety of tailings dams? Unlike water-retaining dams, where the dam wall is usually constructed from concrete or some combination of engineered rock-fill and soil, most tailings storage facilities are built using designs that partially depend on the tailings themselves for support, a design feature not available to water supply reservoir dams (Chambers 2012).

Other key differences between water-retaining dams and tailings storage facilities are:

- Water-retaining dams are built to full height, then filled and operated; tailings storage facilities are usually built incrementally and operated during this incremental building phase.
- Construction of a tailings storage facility may take many decades until it reaches final design height, with a single tailings storage facility often being used for the entire life of the mine. During the operational period of a tailings storage facility, there are likely to be many changes to the operating and management personnel, creating challenges that are often not addressed.
- A water-retaining dam is regarded as an asset, typically for common use, while tailings storage facilities are seen as a cost – a means of storing waste rather than providing a service (Figure 8).



Differences between water-retention dams and tailing dams

Component	Tailings dam	Water-retention dam
Stored material	Tailings solids and processed water with various contaminant levels, run-off water	Water
Regulatory regime	Ministry of Mines, Ministry of Environment	Ministry of Public Works, Regional Authorities, National Dam Associations
Operation life	Limited operation life - 5 to 40 years	Typically designated as 100 years but “as long as required by society”
Construction period	Raised over the mines operating time	Usually 1 to 3 years
Closure	Infinite closure period, aim for “walk away” design	Often not addressed, but facility may be decommissioned
Engineering	Medium to high level	High level
Continuity of engineering	Varies: Owner and engineer may change frequently during the construction period	Usually one engineering firm for design and construction
Quality assurance and quality control	Generally good for starter dam, variable levels during construction period. Can be at a low level for some companies	High level
Consequences of failure	Tailings debris flow resulting in physical damage and environmental contamination	Water-inundation damage
Dam section	Can vary during the design life, e.g. transition to centreline or downstream	Usually a consistent section

Figure 8. Comparison of water dams and tailings dams

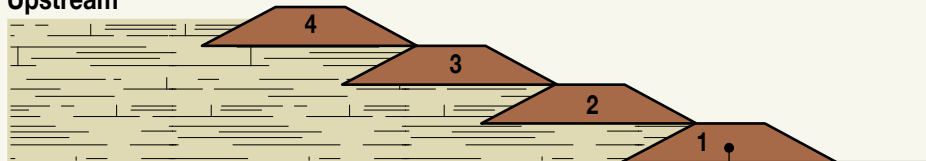
Water and Tailings dam construction methods

Using natural materials water supply reservoir dams have only one design option – known as downstream type construction. Tailings dams sometimes use this construction type, but more often use, what is termed

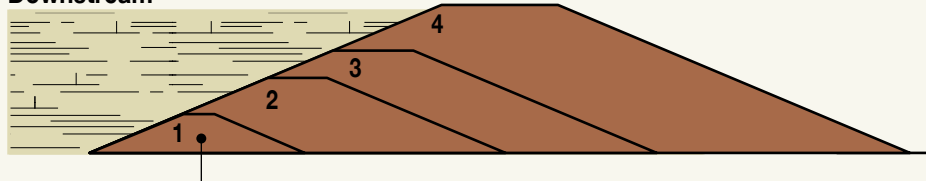
centerline or upstream- construction, designs that water supply reservoir dams cannot employ. Centerline and upstream dams are not as inherently safe as downstream construction.

Types of sequentially raised tailings dams

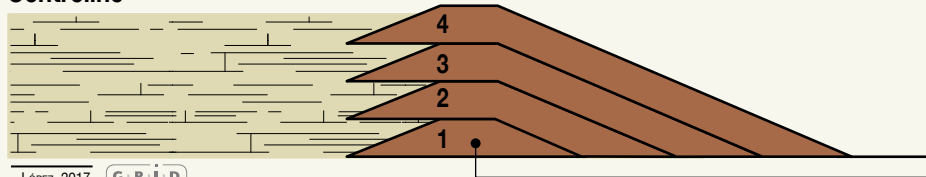
Upstream



Downstream



Centreline



Starter dyke: 1.

The dam design terms, upstream, downstream and centreline, indicate the direction in which the embankment crest moves in relation to the starter dyke at the base of the embankment wall.

Dyke: 2 to 4 or more

Dykes are added to raise the dam wall. This continues throughout the operation of the mine.

LÓPEZ, 2017 G R I D ARENDAL

Source: Vicks 1983, 1990

Figure 9. Dam building methods

Causes of failure

In the literature on the topic, the majority of the tailings storage-facility failures discussed can be attributed to a few factors – in particular, the lack of management continuity and inadequate resourcing (especially financial) for the facility (Figure 10). In cases of failure triggered by mechanisms such as overtopping or piping, inadequate management has occurred over a period of time. The failure may ultimately have been triggered by a particular mechanism, but the tailings storage facility should never have been permitted to reach a point where it was susceptible to such a triggering mechanism in the first place. In the case of failures due to earthquakes, where the loading is rapid and unexpected, the initial design of the tailings storage facility is the most important management consideration. The design needs to be fit for purpose – for example, tailings storage-facility studies indicate that the upstream method of dam construction is more susceptible to



Causes of tailing dams failures 1915-2016

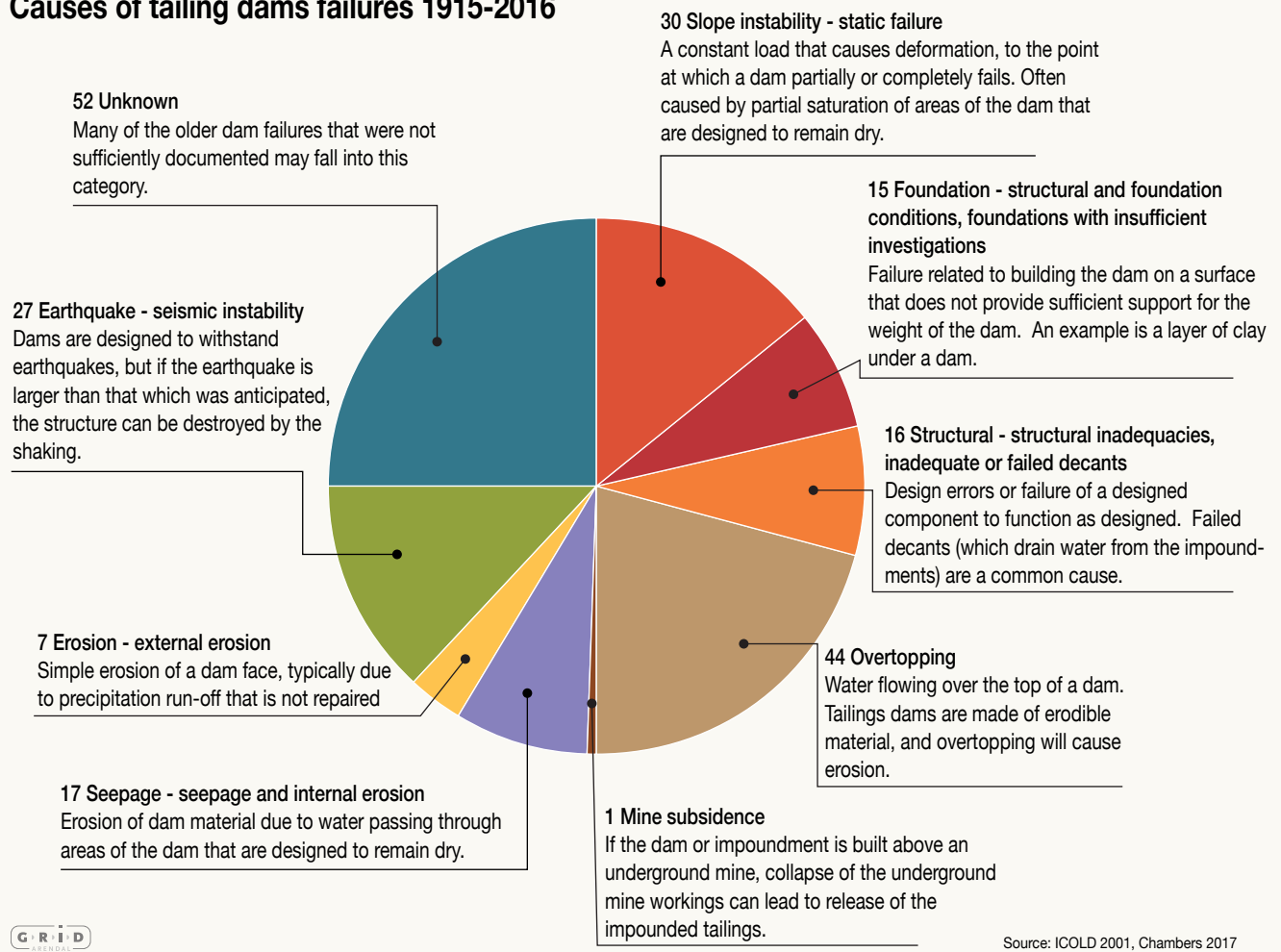


Figure 10. Reported causes of tailings dam failures

instability from seismic loading compared to the downstream method (Liang and Elias 2010).

The presence of water on tailings exacerbates the consequences of a tailings dam failure. The Mount Polley expert panel noted: “Without exception, dam breaches produce tailings releases. This is why best practices can only go so far in improving the safety of tailings technology that has not fundamentally changed in the past hundred years. Improving technology to ensure against failures requires eliminating water both on and in the tailings: water on the surface, and water contained in the interparticle voids.” (IEEIRP 2015, pp. 119–120). An initial breach of the retaining embankment of a tailings storage facility – for example, due to overtopping – can result in erosion of the embankment to the extent that retained water begins flowing from the tailings storage facility. Once this begins, it invariably escalates, with the entire volume of retained water flowing through the breach, usually mobilizing a large volume of fluid tailings

in the process. If no water were retained on top of a tailings storage facility, overtopping would be a vastly reduced risk.

Unfortunately, getting rid of all free water on top of existing tailings storage facilities depends on the storage method employed. Many tailings storage facilities deposit wet tailings. When the solids settle, large volumes of free water separate out and must be stored and managed (in most cases, water is returned to the mill), although in wet climates, a “wet cover” is a common closure strategy to prevent acidic and metallic drainage. This requires the surface of the tailings storage facility to be kept submerged, potentially for decades or even centuries. In light of the Mount Polley failure, there will undoubtedly be a focus on assessing the risk of using wet covers as long-term closure options.

In order to avoid, or at least minimize the storage of water on top of a tailings storage facility, what are the realistic options

Failures at management level – a recurring theme

A recurring theme in the vast majority of tailings storage-facility failures is the failure to recognize and react to an emerging problem, often because of a reluctance to adequately finance tailings management. For example, the main question that arises from reading the extensive literature on the Stava failure in Italy in 1985 (see case study below) and the Merriespruit failure in South Africa in 1994 is: how did a failure not occur much sooner?

It is clear that in most documented failures (with the exception of earthquake-induced failures), there were ample warning signs beforehand. The tragedy is that the warning signs were either ignored or not recognized by under-resourced management. When developing strategies to prevent future catastrophic failures, it is therefore inadequate to simply think in terms of technology. Rather, the focus should be on assessing risk and choosing the best technology available for a given site, and then ensuring that the operation and management of the site is properly resourced, in terms of both personnel and finances.

The issue of adequate resourcing of an operational tailings storage facility is a topic that was highlighted in the recent report by the ICMM, which summarized findings from their “Global Tailings Management Review” (ICMM 2016). The report illustrates the critical importance of an integrated approach to managing tailings, from initial site selection and facility design, through to construction, operation, monitoring and closure, emphasizing the role and importance of monitoring and independent, third-party review throughout this process.

for such a scenario? In the aftermath of the Mount Polley failure, a great deal of discussion focused on the concepts of best available practice (BAP) and best available technology (BAT). One outcome of the debate has been the perception, at least in some quarters, that best available technology always means complete removal of water from a tailings storage facility. The options offered include utilizing filtered tailings (see box on dry stacking) and high-density thickened tailings as solutions that solve the key problems associated with water storage. However, as industry rightly points out, there is no single solution. Each site must be assessed individually and the lowest risk strategy for managing tailings adopted, but finding an alternative to water covers on new tailings dams would significantly reduce the risk of failure in the future. According to the Mount Polley expert panel, for established mines with wet tailings, the primary goal should be a dry closure (IEEIRP 2015, p.122). This can be achieved by draining and treating water, for example.

Is climate change increasing the risk of tailings dam failures?

Our changing climate presents significant challenges for mining companies and governments that are responsible for regulating the industry (Figure 11). Increased climate variability and extreme weather events have not necessarily been considered in the design and construction of existing tailings dams. Planning for an uncertain climate future is now an essential part of risk management. Heavy rain has been implicated in 25 per cent of global and 35 per cent of European tailings dam failures (Rico et al. 2008).

With the increasing uncertainty around climate change, the planning of tailings dams will have to factor in this uncertainty and the associated risks. Reliable data are essential in developing a life-cycle plan for current and future operations that incorporates climate change adaptation. By utilizing the existing climate projections, coupled with good planning and a zero-risk approach, it may be possible to mitigate against climate-related changes and construct safe and responsible tailings storage facilities.



Attempts are being made to repair the spillway at the Gold Ridge mine in the Solomon Islands. In 2015, following extremely heavy rainfall, the mine's tailings dam was breached, releasing contaminated water into the nearby river system. The mine has since been sold by the Australian company St Barbara to the local landowners for Aus\$100 (approximately US\$78). At the time of the sale, the dam was considered to be unstable with the possibility of a future collapse and the potential release of millions of tons of cyanide- and arsenic-contaminated sludge (Armbruster 2016). Consequently, the Solomon Islands' government cancelled the mining licence. However, in early 2017 the licence was reinstated and there are plans by the local company, Gold Ridge Community Investment Ltd., to reopen the mine.

Climate change and its effect on the stability and lifespan of a tailings dam

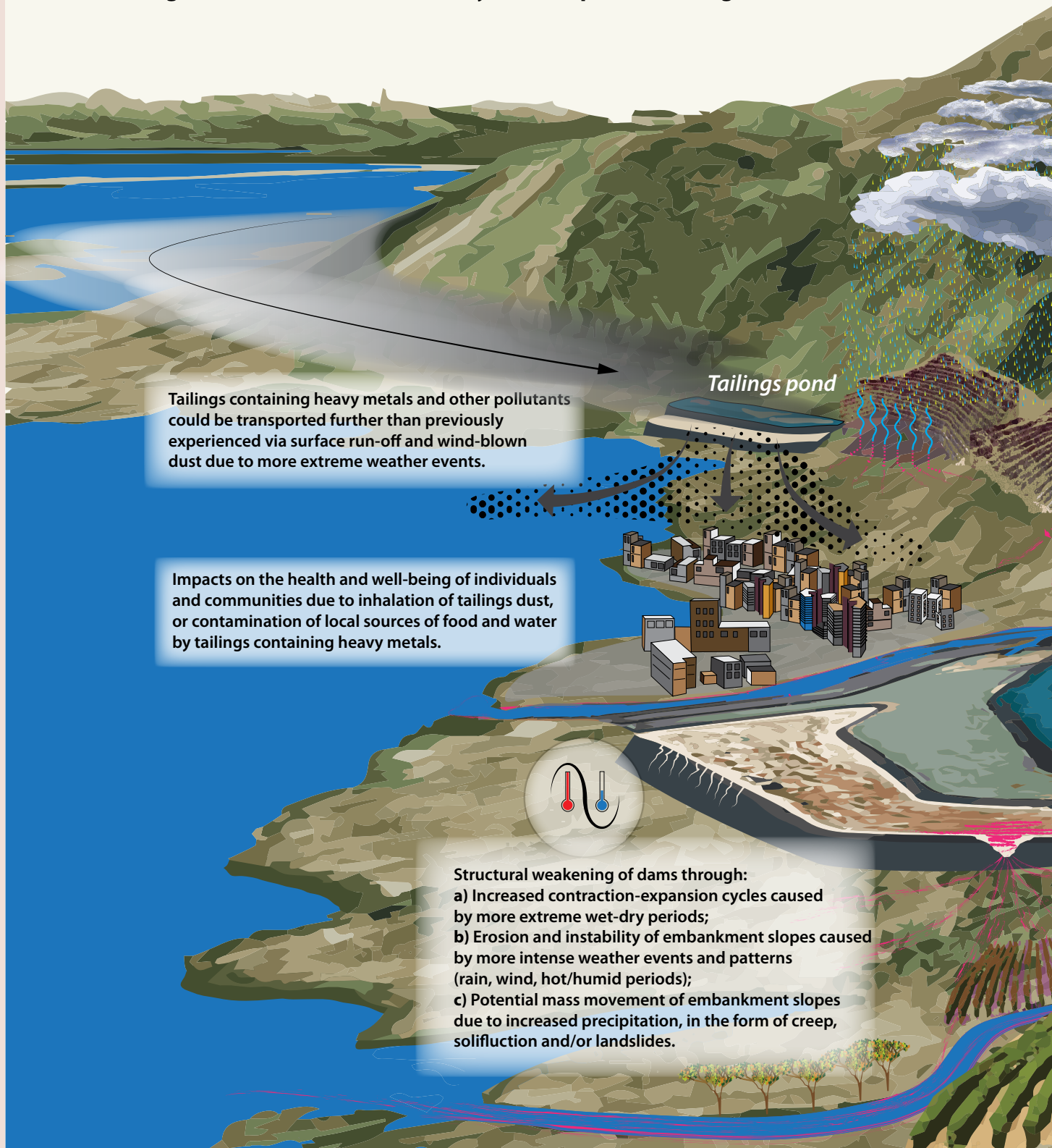
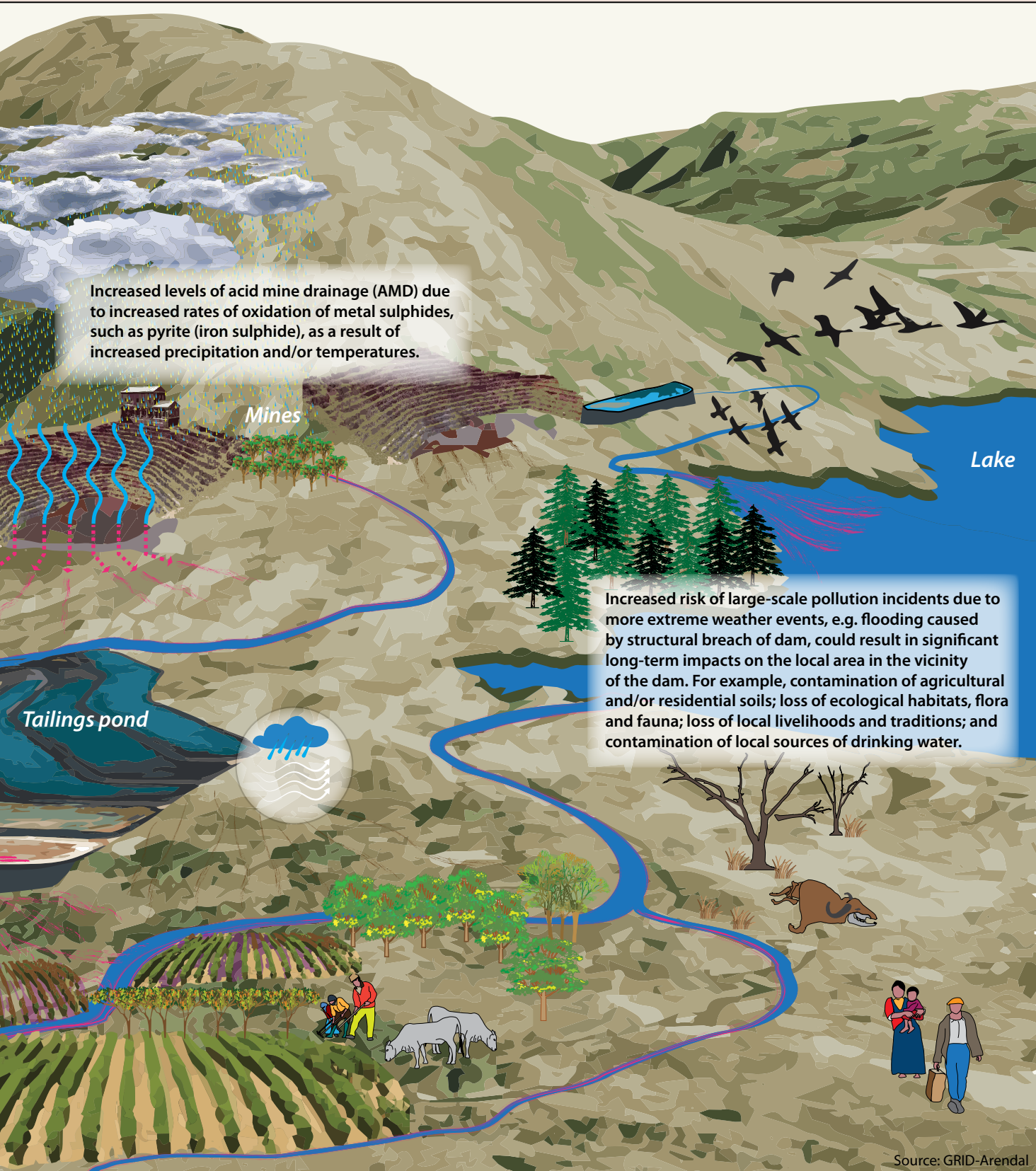


Figure 11. Potential impacts of climate change



Increased levels of acid mine drainage (AMD) due to increased rates of oxidation of metal sulphides, such as pyrite (iron sulphide), as a result of increased precipitation and/or temperatures.

Mines

Lake

Tailings pond

Increased risk of large-scale pollution incidents due to more extreme weather events, e.g. flooding caused by structural breach of dam, could result in significant long-term impacts on the local area in the vicinity of the dam. For example, contamination of agricultural and/or residential soils; loss of ecological habitats, flora and fauna; loss of local livelihoods and traditions; and contamination of local sources of drinking water.

Source: GRID-Arendal

Case study: Stava, Italy, 1985

In July 1985, the tailings dam of the Prestavel fluorite mine in northern Italy collapsed, causing the deaths of 268 people. Since the end of World War II the mine had a number of owners, but from 1980 to the time of the dam collapse, it was managed by Prealpi Mineraria. The mine tailings had been stored in two upstream cascading dams, built on a small tributary of the Stava Creek. Around lunch time on a summer's day, the upper dam collapsed without warning onto the lower dam, which subsequently also collapsed. Approximately 180 000 cubic metres of semi-fluid tailings were released, burying the downstream villages of Stava and Tesero (Figure 12).

The tailings dams had been constructed on a steep mountain slope with poor foundations and inadequate drainage systems (Sammarco 2004). The lower dam was built in 1961 and the upper dam in 1969. The method of construction for the upper dam, which involved part of the base of the dam resting on the weakly consolidated lower dam tailings, has been identified as one of the principle causes of the failure (Campanella et al. 1989). The mine operators assumed that the tailings in both dams would consolidate soon after deposition and that the tailings stored in the lower dam could support the load of the upper dam. However, due to poor management, this assumption was never verified and the construction and expansion of the tailings basins occurred in the absence of any monitoring or geotechnical testing. Essentially, the dams were an accident waiting to happen.

The exact nature of the failure sequence has never been established, but the heavy rainfall that occurred in the two days prior to the disaster has been considered as a contributing factor (Takahashi 2007). This was compounded by the fact that in the month before the disaster, widespread land clearing had been carried out on the slope directly above the upper dam. There were no water diversion structures upstream of the dams and drainage pipes below the dams were not functioning



effectively – evidence suggests they failed at least twice in 1985 (Luino and de Graff 2012). Combined, these factors lead to increased water seepage and retention in the dams.

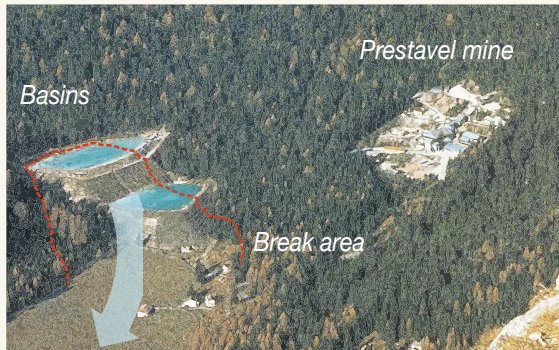
At the criminal trial which followed the disaster, 10 people were convicted of multiple manslaughter offences. Among those convicted were the mine managers, employees of companies contracted by the mine and the local government officials who failed to competently monitor the dams. Compensation was paid by companies who had contributed to the construction and management of the upper dam and by the local government. The mining company, Prealpi Mineraria, was declared bankrupt and paid no compensation (Stava 1985 Foundation).



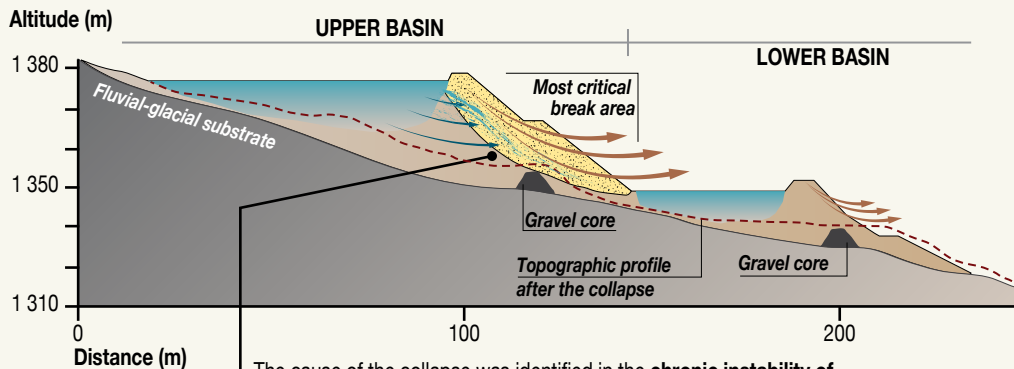
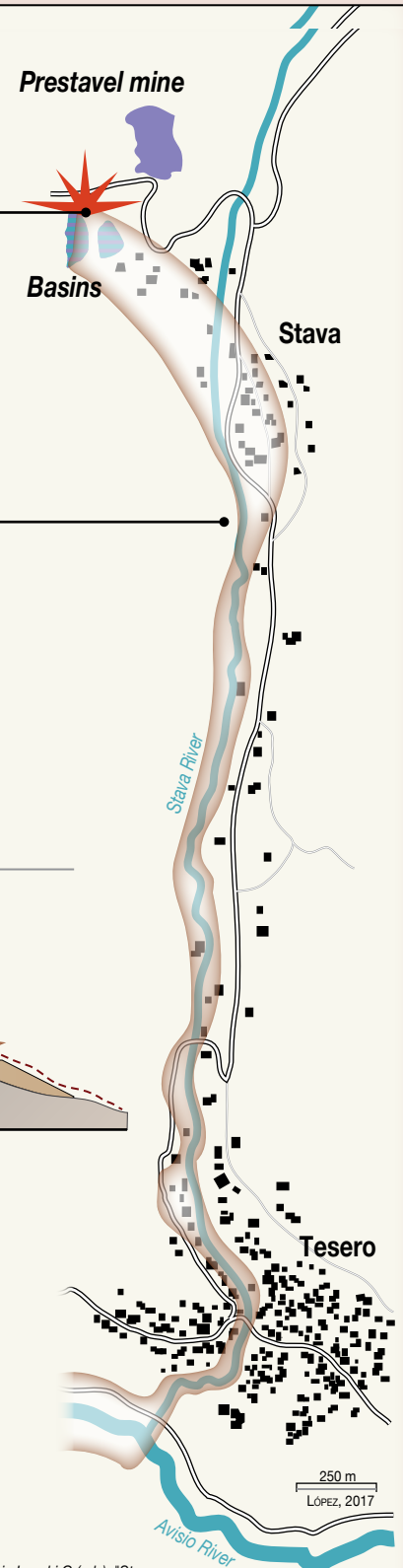
Val di Stava dam collapse



In July 1985, the embankment of the upper decanting basin dropped, causing the collapse of the lower one as well. This released a mass of about **180 000 m³ of water and mud pouring** at a speed of about 90 km/h in the valley below. Along the route, another 40 000-50 000 m³ of erosion caused the destruction of buildings and hundreds of trees.



Mudflow caused the **death of 268 people** (including 59 under-18s), the complete destruction of 3 hotels, 53 houses, 6 sheds and hundreds of trees. In addition, 8 bridges and 9 heavily damaged buildings were demolished. A **layer of mud between 20 and 40 cm thick covered an area of approximately 435 000 m²** for a length of 4.2 km.



The cause of the collapse was identified in the **chronic instability of landfills**, and in particular the upper basin, which did not have the minimum safety coefficients needed to avoid the collapse. In over 20 years, landfills were never subjected to a series of stability checks.

Among others, the causes of instability have been identified in:

- the humid nature of the soil, which did not enable sludge drainage;
- the incorrect construction of the upper reservoir embankment and in the proximity to the lower one;
- the excessive height (34 m) and slope (up to 40°) of the embankment;
- the incorrect location and maintenance of the overflow pipes of decanting waters.



Sources: Fondazione Stava1985 (<http://www.stava1985.it>); Chandler J, Pellegrini M and Tosatti G, 1995, Le cause del disastro, in Lucchi G (eds), "Stava: Perché la genesi, le cause, la responsabilità della catastrofe di Stava negli atti dell'inchiesta ministeriale e nelle sentenze del procedimento penale", pp. 221-230, Curcu & Genovese, Trento.

Figure 12. The Val di Stava tailings dam failure

Case study: Marinduque, Philippines, 1996

In 1996, Marcopper Mining Corporation, 39.9 per cent owned by Canadian Placer Dome, began mining the Mount Tapan copper-gold deposit on the island of Marinduque in the Philippines. By 1990 the mine was exhausted and the company opened a second site at San Antonio, three kilometres away. Following a failed attempt to obtain permission to dispose of tailings directly into the sea, the company was granted a 10-year certificate to deposit tailings into the mined-out Tapan Pit. Tunnels that had previously been used to drain the pit were sealed with concrete to contain the tailings. On 24 March 1996, after four years of tailings disposal into the Tapan Pit, the plug in the drainage tunnel leading to the Boac River gave way, resulting in one of the most catastrophic mining disasters in history (Figure 13).

Three to four million tons of metal-enriched and acid-generating tailings were discharged into the 26-kilometre-long Boac River, flooding villages and agricultural land. An investigative team from the United Nations visited the island shortly after the tailings spill and noted: "... it is unclear why an environmental impact assessment of the Tapan Pit option was never carried out; why no apparent efforts had been made to find an alternative disposal method and site ... why no monitoring of the portal area was being carried out even though it was reported to the U.N. Mission that the mine tailings had been escaping in some quantity for a considerable period of time. The unconventional use of the Tapan Pit as a containment system for tailings, particularly because of the presence of a disused drainage tunnel near its bottom, should have been sufficient to ensure that risk assessment and contingency

planning were carried out. Furthermore, it is clear from cross-sectional diagrams of the drainage tunnel that were reviewed at the mine site that fracture zones and ground water seepage were likely to occur along its length." (UNEP 1996). The United Nations team noticed unrelated leaks in other mine structures and concluded, "it is evident that environmental management was not a high priority for Marcopper" (UNEP 1996). Placer Dome divested from Marcopper a year after the spill and consistently denied responsibility for the disaster, blaming it instead on a small earthquake that happened a week before the collapse (Coumans 1999). Initially, the company pledged to clean up the Boac River, but this has not been achieved and a large quantity of tailings remain in the river system (Macdonald and Southall 2005). The Philippine Department of Environment and Natural Resources has rejected the proposed clean-up methods, due to concerns about additional environmental and safety issues. The companies involved have paid no compensation, although two years after the disaster, communities impacted along the Boac River had received a total of 21.6 million pesos (approximately \$426 000) from the government's Environmental Guarantee Fund – this equates to around \$124 per household (Bennagen 1998).

The Boac River was essentially destroyed by the spill, which resulted in the complete loss of river-based sources of livelihood. The few environmental studies of the river that have been carried out suggest there will likely be ongoing acid leaching of heavy metal from the tailings, which will continue to contaminate the river (Taylor 1999; USGS 2000).

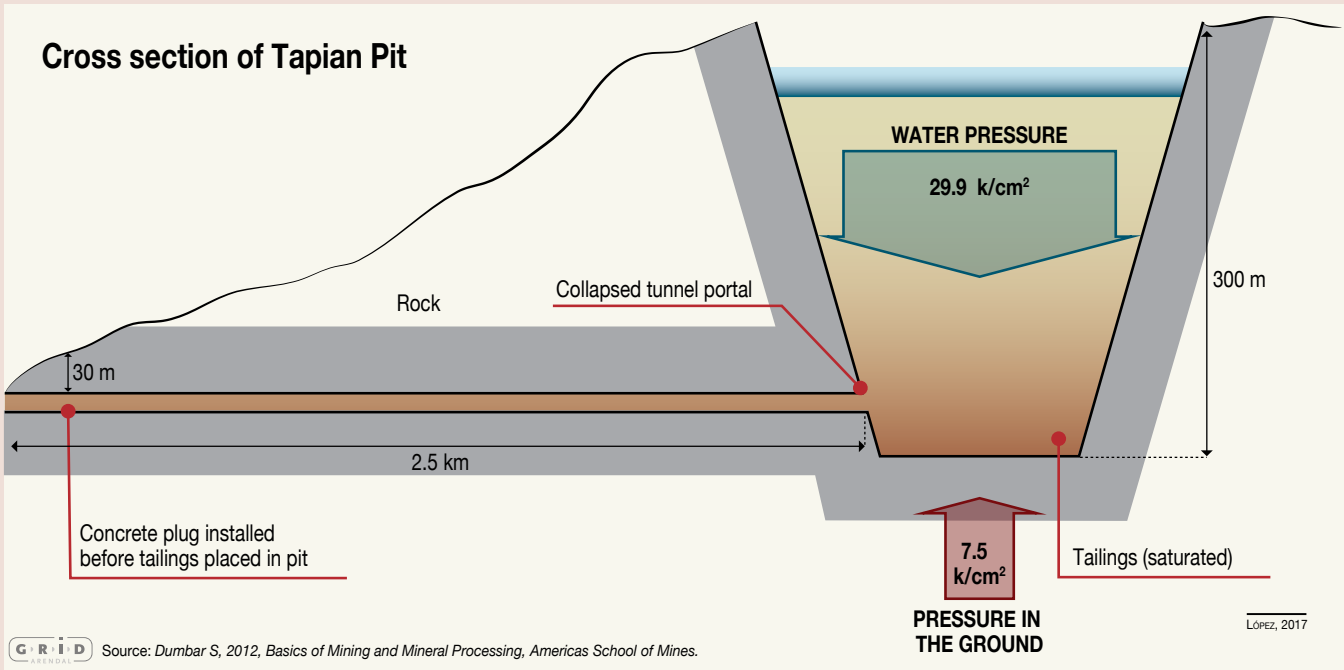
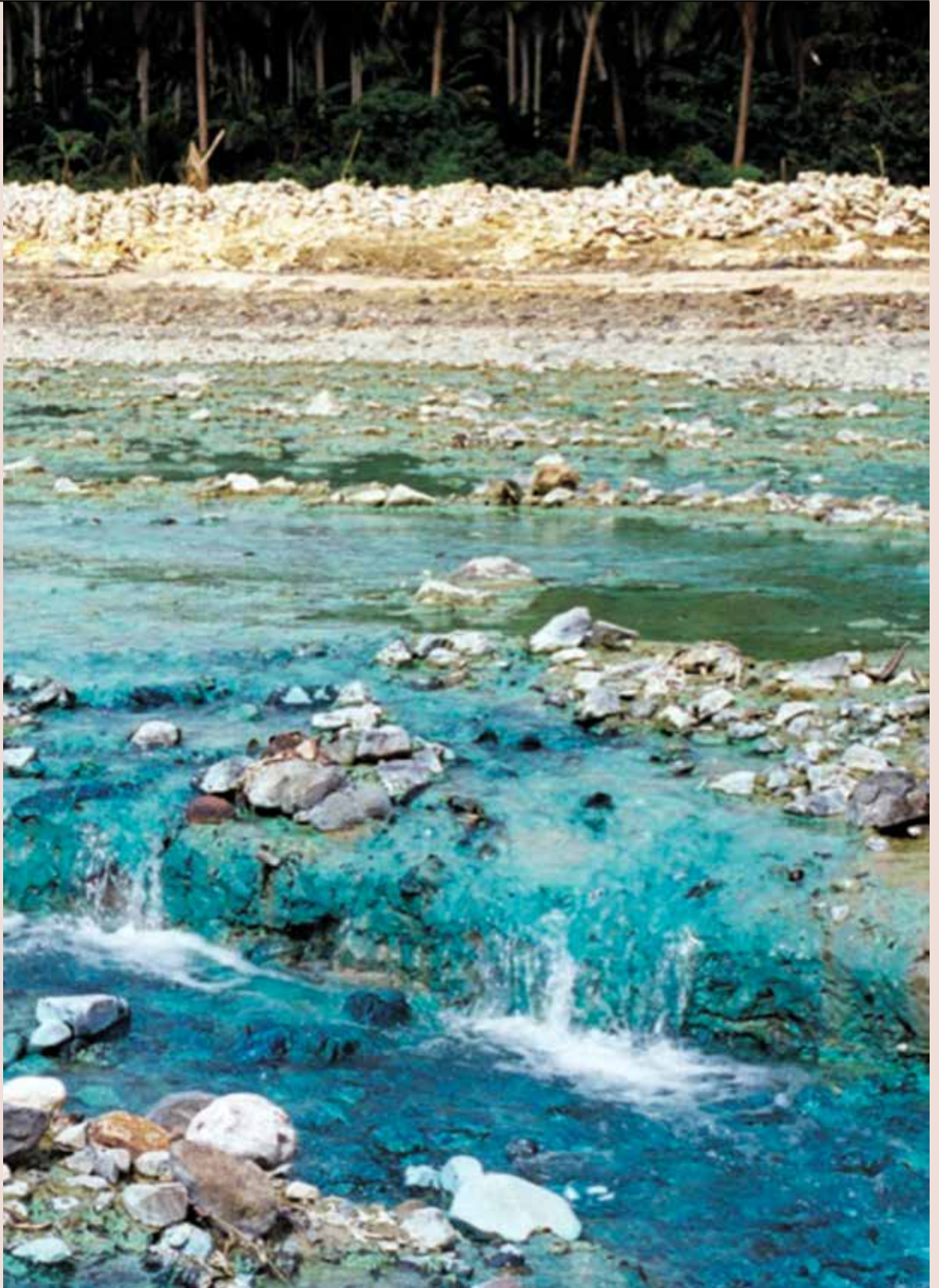


Figure 13. Illustration of the Tapan pit



Boac River with bursting bags of tailings piled up on the far bank. The blue colour is due to copper contamination.

Mine tailings management and disposal

Successfully managing mine tailings is a significant part of any large-scale mining operation. The methods employed for long-term storage should be based on a number of factors, illustrated below (Figure 14).

Major disposal techniques

The pre-disposal treatment of the tailings, especially the degree of de-watering, influences the design and

management of tailings storage facilities. Tailings can be stored as wet slurry, thickened, paste, dry cake or a mix of tailings and coarse waste.

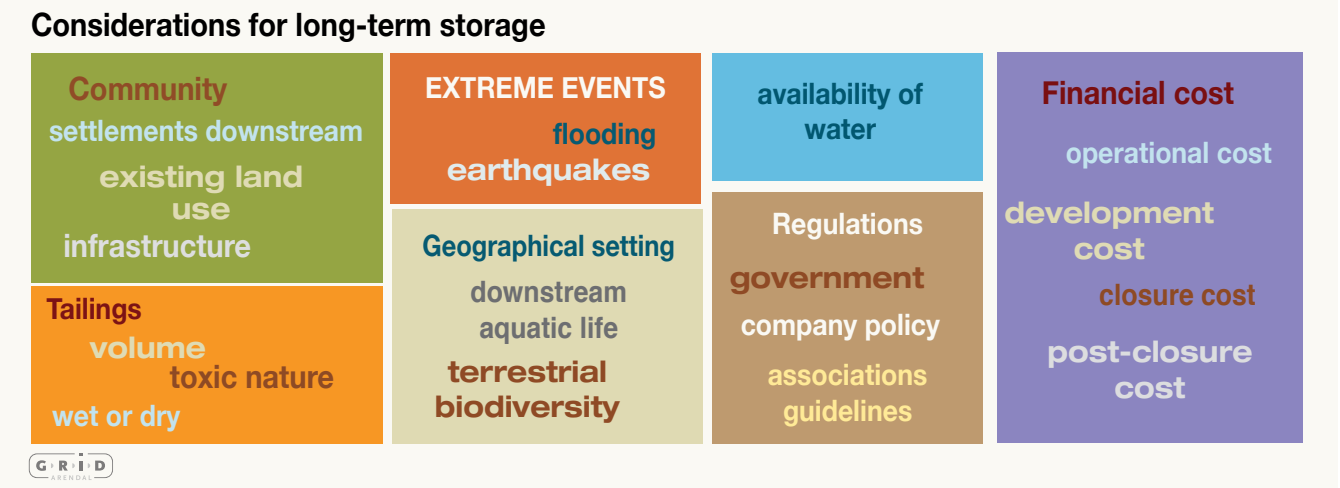


Figure 14. Considerations for implementing the long-term storage of mine tailings



Overview of environmental issues related to major tailings storage and disposal techniques

Options	Advantages	Disadvantages
Impoundments Without dewatering	More economical construction; Maintaining water in the tailings reduces the possibility of acid mine drainage by restricting oxidation of sulphides.	Water-intensive; High risk of seepage; High risk of damage in the event of dam failure due to large volume of water; Large footprint and habitat disturbance; Rehabilitation only possible after mine closure.
Impoundments With thickened or past tailings	Lower risk of damage caused by dam failure; Lower risk of seepage due to smaller volume of water; Reduced volume of tailings; Slightly smaller footprint.	Additional costs (thickening, paste, pumping); Relatively large footprint and loss of habitats; Moderately water-intensive; Paste tailings can be costly to pump; Rehabilitation only possible after mine closure.
Impoundments With co-disposal of tailings and coarse grained waste	Lower risk of damage caused by dam failure; Lower risk of seepage due to less water; Smaller footprint to store separate waste streams.	Additional costs (Thickening, Paste, Pumping, larger dam required); Relatively large footprint and habitat loss; Moderately water intensive; Paste tailings can be costly to pump; Rehabilitation only possible after mine closure.
Impoundments With dewatering after closure	Economical construction (a drain system must be installed before operation).	Only slightly more costly than impoundments without dewatering; Post-closure drain seepage probably needs passive treatment.
Backfilling Paste tailings and binder	Reduced surface storage area; Low risk of groundwater contamination; More water is recycled and more volume of tailings is reduced; Minimal rehabilitation required.	Additional costs (thickening, paste, pumping, barricade, binder); Seepage; Only for underground mines.
Filtered tailings Dry stacking	Reduced water use; Elimination of the risks of catastrophic tailings flow associated with dam failures; Reduction of risk of groundwater contamination through seepage; Reduced storage footprint enabling progressive rehabilitation during mine operation; Easier to gain a permit for; Potential for treatment of long-term seepage if potentially acid generating (PAG) material is dry stacked; Some progressive reclamation possible.	High capital costs and moderate operational costs with modern filtration and conveying technology; Requires surface management system to prevent wind and water erosion.
River (RTD)	Low capital and operating cost.	Environmental contamination and disturbance; Difficult to gain a permit for; Water-intensive due to low water recovery; Difficult or impossible to mitigate impacts.
Sub-marine and deep marine (STD, DSTD)	Low capital and operating cost.	Environmental contamination and disturbance; Mass wasting from the ground sites; Difficult to gain a permit for; Water-intensive due to low water recovery; Lack of data on environmental impacts; Difficult or impossible to mitigate impacts.

Table 2. Overview of environmental issues related to major disposal techniques

Dry stacking of tailings

The majority of the world's large-scale surface mines store tailings in impoundments. These complex, engineered structures are designed to contain wet mine waste, which, as reported in this report, can fail with catastrophic consequences.

An alternative to this method of storage is dry stacking, which involves filtering the tailings to produce a stackable material (Davies 2011). The filtered tailings are stacked in “cakes” – unlike slurries, which can be pumped to the disposal site, the filtered tailings must be transported, usually either by conveyor or truck. Dry stacking has been identified as an option in areas where water is scarce or conventional impoundments are not feasible. One advantage of dry stacking is that it can make land reclamation and rehabilitation easier. Dry-stacking systems have generally been restricted to smaller mining operations (less than 50 000 tons/day throughput), although recently the technology has been scaled up to work successfully at bigger mines (120 000 tons/day; FLSmidth pers. comms. 2017). However, the potential pitfalls must be acknowledged and thoroughly evaluated. These include (but are not limited to) high initial costs, the need for redundant machinery due to the inevitable downtime required to clean filters, impacts of climate (e.g. erosion of the stack) and potential geotechnical instability, particularly when placing filtered tailings on an existing footprint



Dry stacking at the currently closed La Coipa gold and silver mine in Chile (installed 1990) with a capacity of 28 800 tonnes per day

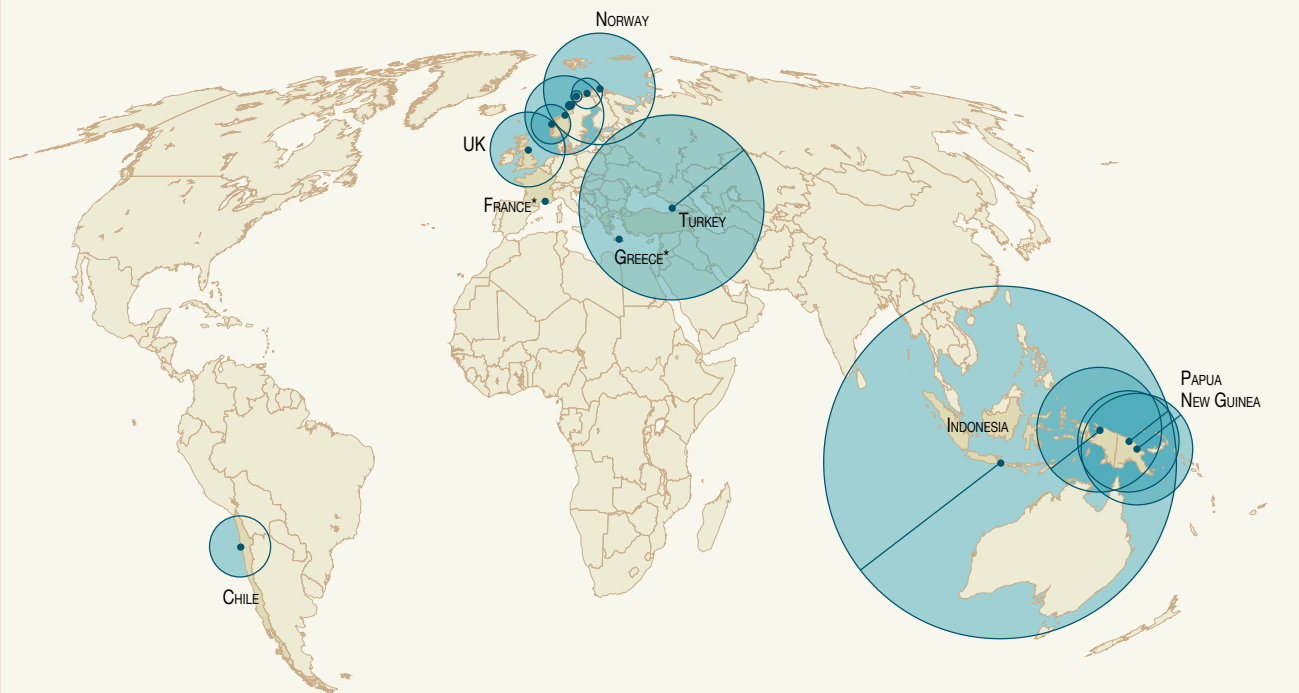
Riverine and offshore disposal

In some areas where tailings dam construction is difficult (e.g. mountainous areas), mining companies have been allowed to dispose of tailings in river systems. In some coastal areas, submarine disposal has also been permitted. These methods are generally considered to be an undesirable option for waste management and are not permitted in many countries, including Canada and Australia. Although initially cost-effective, the documented environmental impacts and the potential for long-term effects have prompted some companies to develop internal standards that prevent riverine or marine disposal. Figure 15 shows the locations of mines carrying out marine and riverine tailings discharge in 2012. All of these mines have government permits to discharge into the ocean or rivers.

One emerging issue relates to deep-sea mineral extraction, where marine waste disposal of fine material – but not strictly tailings unless processing takes place at sea, which is unlikely – is the only option. Deep-ocean ores are often much higher grade than their on-land counterparts, making them attractive in terms of the value of the ore, however, they remain unproven with concerns over financial viability. Scientists and communities have voiced concerns over the mining process and the on-site disposal of waste material, which may cause significant environmental impact due to increased turbidity and the blanketing of sea-floor organisms with fine material.



Marine discharges of mine tailings



Mine tailings

Tonnes per year

90 000 000

40 000 000

10 000 000

2 000 000

500 000

*No data available

Source: UNEP Global Programme of Action, 2013, *International Assessment of Marine and Riverine Disposal*; Group of Experts on the Scientific Aspects of Marine Environmental Protection, *Scoping Paper on the Impacts of wastes and other matter in the marine environment from mining operations*.

GRID
ARENAL

Riverine discharges of mine tailings



López, 2017

Figure 15. Locations of reported marine and riverine tailings disposal sites in 2012

Planning for safe closure

Mine closure considerations

Physical stability of the site - tailings storage facilities, roads, buildings, etc. must not pose any hazard to public health and safety; engineered structures must not deteriorate or fail; erosion from the site must not adversely impact surrounding terrestrial or aquatic environments.

Geochemical stability - harmful materials must not leach from or erode the site; surface waters and groundwater must be protected against contamination.

Land use - the closed mine site should be rehabilitated to pre-mining conditions or conditions that are compatible with the surrounding land or achieve an agreed, alternative, productive use of the land.

Sustainable development - elements of mine development that impact the sustainability of social and economic benefits, should be maintained and transferred to succeeding custodians.

Required outcome

Protect public health and safety.

Alleviate or eliminate environmental damage.

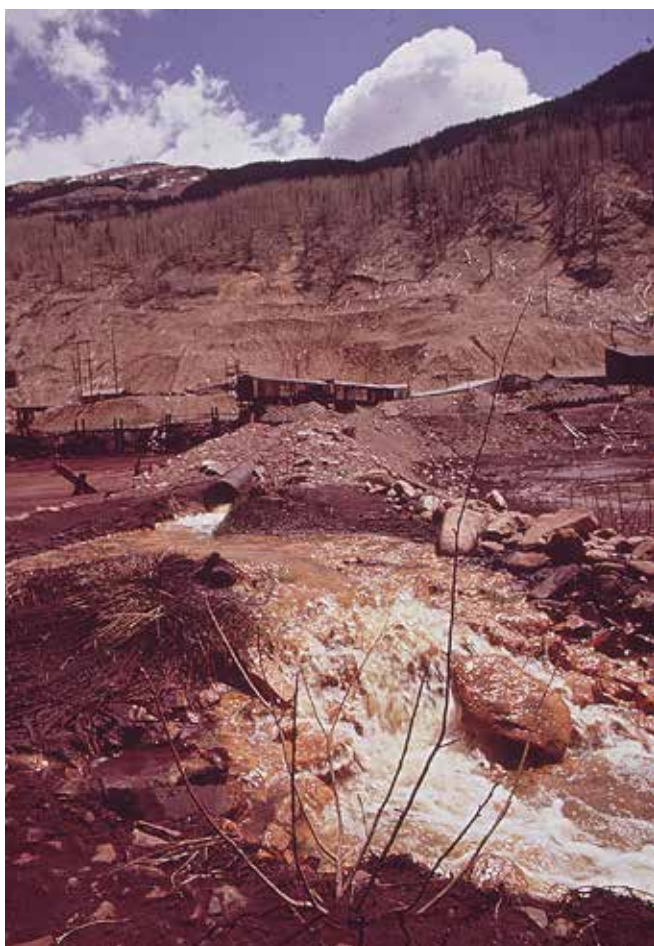
Make productive use of the land, return it to its original condition or find an acceptable alternative.

As far as possible, ensure sustainability of social and economic benefits resulting from mine development and operations.



Source: adapted from Robertson and Shaw (2002)

Table 3. Mine closure



Managing for mine closure – perpetual management

Planning for tailings storage-facility management after mine closure should be an essential component of mine planning. Best practice requires that it should commence before the start of mining and be continually updated throughout the life of the mine until final closure. Proper post-closure management of tailings not only safeguards communities and the environment, but also makes good business sense by avoiding costly future remediation and compensation.

Mine planning must take into consideration the long-term physical, chemical, biological, social and land-use characteristics of the area surrounding the mine. The extent of the mine footprint needs to be carefully determined prior to mining. The poor performance of post-closure management of tailings is one of the drivers for governments imposing significant final rehabilitation commitments on mining companies before mining projects are approved (LPSPD 2016). There are too many examples where problematic mining operations have been abandoned or offloaded by those responsible, leaving the regulators and community to clean up. In the worst cases, clean-up is not even attempted, and mines are abandoned and continue to release pollutants into the environment.

Impacts of mining waste on biodiversity

The impacts of tailings dam failures on biodiversity can be both immediate and long term (Figure 17). When large volumes of tailings enter waterways, the material can have

Estimated cost of mine clean-up – an example from oil-sand mining in Alberta, Canada

The Alberta Energy Regulator (AER) estimates that mine clean-up costs in the province have increased with the growth of oil-sand mining and in 2016, topped more than Can\$23 billion (approximately US\$18 billion; Cryderman 2017). The extraction of bitumen from surface oil sands in north-eastern Alberta produces an enormous amount of fluid tailings – for every barrel of bitumen extracted from the oil sands, 1.5 barrels of tailings waste is produced (Grant et al. 2013; Figure 16). It is estimated that Alberta currently has more than 1 billion cubic metres of oil-sand tailings (AER 2017).

The Alberta Mine Financial Security Program collects a security deposit from oil-sand miners to protect the public

from end-of-life project closure costs. The programme requires a base security, which increases when the mine has less than 15 years of life remaining. The fund currently holds about Can\$1.38 billion – it is designed to cover the cost of making the site safe and providing ongoing management if the approval holder fails to meet its obligations (AER 2017). The AER has recently introduced measures to improve tailings management and ensure compliance with legislative requirements (AER 2016). However, there is concern that the programme does not currently obtain sufficient financial security from mine operators to safeguard the public from clean-up liabilities (Cryderman 2017).

Growth in the volume of stored oil-sand tailings

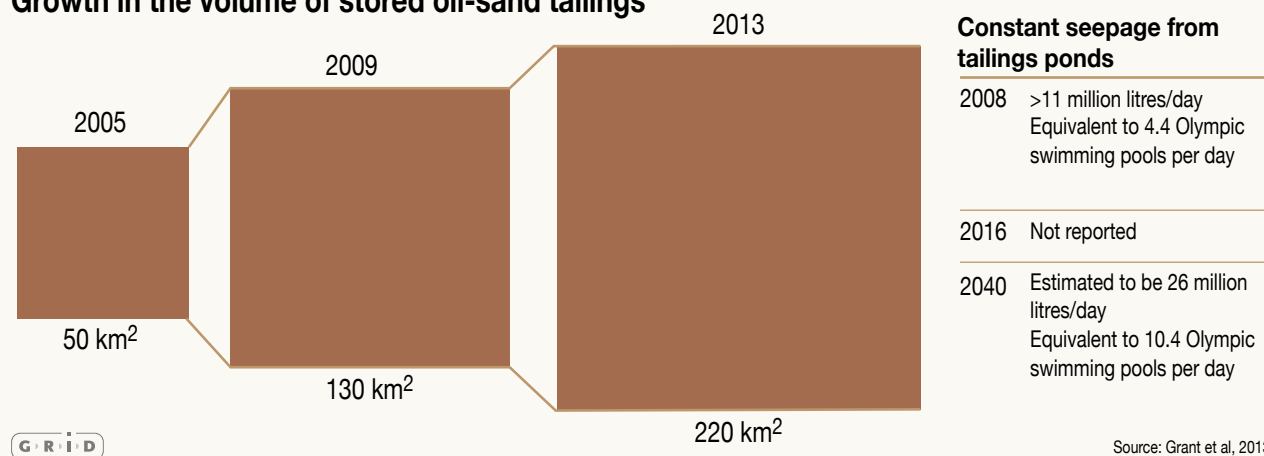


Figure 16. The increasing volume of oil-sand tailings stored in Alberta, Canada, evidenced from the increase in the surface area of storage ponds

Impacts of tailings dam failures on biodiversity and associated ecosystem services

Immediate environmental impacts	Long-lasting effects	Changes in ecosystem structure and function	Social implications
Directional effect →			
Decreased water quality and oxygen content	Loss of regenerative capacity	Altered species composition	More floods
High levels of toxicity	Bio-accumulation of heavy metals	Change in vegetative structure	Reduced fish catches
Decreased populations of aquatic species	Persistence of heavy metals in floodplain sediment	Loss of ecosystem connectivity	Reduced carbon capture
Loss of vegetation and nursery habitats		Increase in bank/bed erosion	Loss of tourism revenue
			Decreased clean-water supply

Source: UNEP-WCMC

Figure 17. A summary of potential impacts of tailings dam failures on biodiversity and associated ecosystem services



physical (e.g. increased turbidity, smothering) and chemical (e.g. toxicity from toxic contaminants, decreased oxygen) impacts on aquatic organisms. The type and location of failure is, however, an important factor in the severity and extent of these impacts. Analysis of 306 reported tailings dam failures (reported in WISE 2017) indicates that 24 have occurred within a legally protected area, and a further 158 occurred within 10 kilometres of a protected area.

The impacts of these tailings dam failures on biodiversity are immediate, in terms of smothering habitats and contaminating waterways. Aquatic life is heavily impacted due to the extreme change in water chemistry. The suspended solids that are introduced can get trapped in fish gills, with flow-on effects on semi-aquatic and terrestrial species.

The flow of tailings burying aquatic and riparian nursery habitats and the persistence of heavy-metal contamination have also been shown to negatively affect the regenerative capacity of aquatic and terrestrial ecosystems, leading to long-term changes in ecosystem structure and functions. This severely impacts the services these ecosystems provide to people, such as flood defence, erosion control and soil stability, water purification and regulation, nutrient cycling and carbon storage. (Fernandes et al. 2016; Kossof et al. 2014). While the direct human costs of tailings dam failures are quantified, the long-term social costs in terms of poor health, and loss of income and livelihoods that result from a degraded environment, remain largely unknown.

Case study: Maramures County, Romania, 2000

In February 2000, an upstream tailings dam at the Baia Mare gold mine in Maramures County, Romania failed. The failure is thought to have been caused by a combination of poor design, unforeseen operating conditions and heavy rain and snow, which resulted in overtopping (BMTF 2000).

Two months later, this failure was followed by another upstream dam failure at the nearby Borsa lead and zinc mine, which also occurred as a result of overtopping. These two incidents released more than 200 000 cubic metres of contaminated water and 40 000 tonnes of tailings into tributaries of the Tisza River, a major tributary of the Danube (WWF 2000).

The Baia Mare spill was the most damaging of the two failures, releasing 50 to 100 tonnes of cyanide, as well as copper and other heavy metals, making it the worst environmental disaster in Europe since Chernobyl. Over a four-week period the combined spills travelled through Romania into Hungary, Serbia and Bulgaria, and finally entered the Black Sea. The spill traversed a number of ecologically sensitive and highly populated areas, with significant transboundary implications (Figure 18). Acute effects of the cyanide were observed along the river system to the point where the Tisza River meets the Danube. The Baia Mare failure created a 30- to 40-kilometre-long wave of contaminants that wiped out the flora and the fauna of the central Tisza River. Plankton were killed instantly by the plume; fish were killed in the plume or died soon after. In the Hungarian section of the river, the impact was especially severe – it is estimated that 1 240 tonnes of fish were killed (UNEP/OCHA 2000).

An international task force, chaired by the European Commission, was created to assess the damage and propose remedial actions (EU 2000). The task force insisted on the necessity of providing adequate emergency-storage facilities and recommended that new tailings storage facilities should not be allowed to store water or slurry containing cyanide in tailings ponds open to the elements (Lucas 2001).

Case study: Romania



Progress of the spill plume

- 1 30 January**
Cyanide spill occurs at Baia Mare, Romania
- 2 1 February**
Spill plume reaches Romanian-Hungarian border
- 3 5 February**
Cyanide registers in tests at Tiszaľök
- 4 9 February**
Spill plume reaches Szolnok
- 5 11 February**
It crosses the Hungarian-Yugoslavian border
- 6 13 February**
It reaches Belgrade (Perlez), Yugoslavia
- 7 15 February**
It meets the Romanian border again, at Ram
- 8 17 February**
Cyanide registers in tests at Iron Gate, Romania
- 9 25-28 February**
The plume reaches the Danube Delta



G R I D Sources: UNEP/OCHA, 2000, *The Cyanide Spill at Baia Mare, Romania. Before, During and After.*

Figure 18. The location of the Baia Mare and Borsa tailings disasters in Romania and the affected rivers



Risk, rewards and responsibility

Mining makes many important contributions to society, but it also has a range of social and environmental impacts (ICMM 2016a). Among the most challenging is the treatment and storage of mine waste. The reality is that all methods of tailings and mine waste management and disposal present a host of challenges and entail varying degrees of risk. Keeping in mind that the risks from tailings vary depending on who is considering them, this section explores these risks from various stakeholder perspectives.

Understanding the risks of mine waste

Mine planning involves risk assessment. Typically, a project will go through a due diligence process that identifies a range of issues and risks, including market forces, force majeure and those of a technical, financial, regulatory, operational, environmental, social and political nature (Tinsley 2007). These are all assessed within the context of project feasibility, and the process is usually designed and undertaken by the proponent. This can mean that risks are assessed from a company standpoint, which considers social and environmental risk from a business-risk perspective. The same risk, for example, of impact of dam failure, could be expected to be assessed quite differently by a community immediately downstream (Table 4). Consequently, the potential impact to the community or environment is often analysed in terms of the flow-on risk to the mine owner, operator and financier, rather than to governments or host communities (Franks 2014).

However, risk can also be assessed from a community perspective, including the varying risks faced by men, women and children. Women and children are particularly vulnerable to polluted tailings, with the impact of heavy metals and toxins affecting maternal and foetal health and children's physical and mental development (Jenkins 2014). Their risks are very different from those faced by the owners and operators. This is evident when you compare the impact of tailings dam disasters on owners and operators and on community members. Companies generally suffer financial and reputational losses while communities can suffer death and destruction of homes, income and environment (see case studies). Community impacts can also be long-lasting as evidenced by the communities affected by the Marinduque disaster, which occurred more than 20 years ago.

These negative human and environmental impacts can be described as externalities – that is, the costs of mining not borne by the miner, but rather transferred to other stakeholders. Consequently, externalities, whether in monetary or non-monetary terms, fall outside feasibility assessments and company balance sheets, which often leads to the risk being

undervalued or ignored. This transfer of cost, common in relation to pollution or carbon dioxide emissions, is regarded by economists as a market failure (Cardoso 2015). Declining water quality is an example of a risk that is often undervalued, and yet it can have a considerable impact, especially for indigenous, agricultural and/or subsistence communities that rely on healthy aquatic ecosystems as a food source and to support agriculture.

The risks associated with tailings dams are not confined to catastrophic failures (which attract the most attention internationally). There are many mine sites scattered around the world that pose a slow-motion environmental problem associated with the leaching of harmful substances from tailings dams into the environment. These mines are areas of chronic impact that may need to be managed in perpetuity. Remediation and long-term monitoring of these sites is generally not included in the original cost-benefit analysis of the mining operation. They are externalized costs that often only become apparent after the mine has closed or a disaster occurs (Roche and Judd 2016). The duration of long-term or perpetual management can extend beyond current financial management structures. Under these circumstances, there is little certainty about society's ability to manage mine sites whose management costs could eventually exceed production benefits (Kempton et al. 2010).

The physical impacts and costs of addressing negative externalities on the environment are not, however, the only cost transferred to communities. In addition to direct impacts, tailings dam disasters and pollution can also force changes to local and/or traditional community practices, especially where complex social and ecological interdependencies exist. The difficulty in agreeing on the extent of impact should not be underestimated and the usual economic valuation tools do not easily apply to these impacts (Centemeri 2015).

Mental health impacts from tailings dam failures should also be recognized. People feel grief, loss and anger when destruction affects their environment and their sense of place.

Sector	Stakeholders	Impact	Risk from mine waste - extent of exposure	Reward from mining	Influence and control over risk
Company	Local Staff	Injury, temporary or permanent loss of work/income, impact on family/housing/subsistence	High (multiple indicators)	Low to medium (good salaries and opportunities, improved infrastructure and services)	Low
	International staff and management	Injury, loss of work/income, civil or criminal liability	Low or high for criminal responsibility	High - salaries	High
	Investors	Loss of share value	High for \$ invested, (limited exposure if balanced investments, no additional liability)	Low to high, depending on investment (can only lose investment)	Medium
	Financiers	Loss of investment, reputational damage	High for \$ invested, (limited exposure if balanced investments, limited additional liability)	Low to high, depending on security	High
Government	Local	Physical impact, lower community resilience and function, loss of income, cost of rehabilitation	High (multiple indicators - exposed to chronic and catastrophic impacts)	Medium to high (economic growth, local opportunities, local taxes, improved infrastructure)	Low
	National	Loss of income, cost of rehabilitation	Low to medium (depends on balance/size of economy and waste problem)	Medium (economic growth, taxes)	High
	Regulatory	Nominally responsible	Low (limited to no liability)	No direct reward	High
Community	Local	Injury, temporary or permanent loss of work/income, impact on family/housing/subsistence	High (multiple indicators)	Low (royalties, rents, business opportunities, improved infrastructure and services)	Low
	National	Economic	Low (chronic) Medium (catastrophic)	Low (economic growth - depends on balance/size of economy)	Low
	Individuals	Injury, temporary or permanent impact on family/housing/subsistence	High (multiple indicators)	Low (opportunities, improved infrastructure and services)	Low
	Consumers	N/A	N/A	High - in products	Low for commodities
	Specific groups	Women and children more vulnerable to social and environmental change	Low (limited to no liability)	No direct reward	Low
Environment	Biota	Altered environment, chemical or physical harm	High (exposed to chronic and catastrophic impacts)	N/A	N/A
	Land	Erosion, contamination	High (exposed to chronic and catastrophic impacts)	N/A	N/A
	Water	Change in water balance, groundwater pollution	High (exposed to chronic and catastrophic impacts)	N/A	N/A
	Ecosystem processes	Breakdown/altering of processes caused by direct physical or chemical impacts or indirect due to change in species composition/behaviour	High (exposed to chronic and catastrophic impacts)	N/A	N/A

Table 4. Impact, risk, reward and control

These impacts are rarely captured in impact assessments, existing as very real but unacknowledged externalities (McManus et al. 2014).

Table 4 illustrates the correlation between reward and risk. The highest financial rewards go to international staff, financiers and investors, with the level of rewards to government and local staff dependent on tax schemes and wage levels. In contrast, non-financial risk to local staff, communities and the environment, for example, receives little or no reward. In other words, risking your financial investment provides a reasonable return with some control, while the community (and the environment) are exposed and vulnerable to events outside their control. For example, while BHP, the part-owner of Samarco, suffered a short-term financial loss, the communities and environment will be affected for decades.

Responsibility for mine waste

Despite the efforts of the mining companies, regulators and other stakeholders to eliminate tailings dam failures, they still occur, although at a lower rate. After the tragic failure of the Samarco tailings dam, the ICMM consulted with its 23 member companies to determine how best to minimize the risk of a recurrence of such a catastrophic dam failure. The conclusion of the Review of Tailings Management Guidelines (Golder and Associates 2016) was that an increased emphasis on governance is needed to ensure that the extensive existing technical and management guidance is implemented more effectively. A position statement was issued (ICMM 2016a) that commits member mining companies to minimizing the risk of catastrophic failures of tailings dams. Six key elements of the tailings dam governance framework are detailed in the position statement:

1. Accountability, responsibility and competency
2. Planning and resourcing
3. Risk management
4. Change management
5. Emergency preparedness and response
6. Review and assurance

The emphasis of the six key elements is in defining clear responsibilities and improving the knowledge of those involved in the design, construction, operation, closure and overall management of the tailings dams. Examples of some of the initiatives or changes to the governance of tailing dams being undertaken or further developed by the ICMM member mining companies include the following:

- Appointing a Dam Owner, a Responsible Dam Engineer and an Engineer of Record (EOR) for all significant tailings dams: As stated in the ICMM position statement, accountability for the overall governance of tailings facilities

resides with the owners and operators. The appointed Dam Owner and Responsible Dam Engineer are employees of the mine owner's organization. The Dam Owner is the single point of accountability for maintaining the integrity of the tailings dam throughout its life cycle, so that the risks associated with dam design, construction, operation and closure are effectively identified, controlled and managed to minimize impacts on health, safety, communities and the environment. The Responsible Dam Engineer is a member of the Dam Owner's team, and is a suitably qualified individual accountable for maintaining overall engineering stewardship of the tailings dam. The engineer of record is a professional engineer responsible for ensuring that the tailings dam is safe, i.e. that it is designed, constructed, operated and/or closed in accordance with the current state of practice and applicable regulations, statutes, guidelines, codes and standards. The engineer of record is an integral part of the risk management system for the tailings dam, and provides design continuity and ongoing technical support to the owner with respect to tailings dam safety over the life of the facility. The engineer of record is an individual, supported by a team of experts in the field, as applicable, who has been appointed by the owner and has accepted the responsibility.

- Implementing a Stewardship Programme for all significant tailings dams: Provide a high level of attention and governance to ensure implementation of good practices and common standards; improve the efficiency of the dam operation; promote benchmarking and exchange of information between different mines; improve knowledge and discipline; and raise risk awareness. Performing site inspections, reviewing relevant documents and data pertaining to tailings dam management, and training of site personnel are some of the activities included in the programme.
- Improving tailings dam surveillance and emergency response systems: This includes improvements in monitoring instrumentation, adopting early-warning systems and emergency response systems, and training site personnel and communities in emergency response.

Other activities include performing Dam Safety Reviews, developing preventive and mitigating controls, appointing Independent Technical Review Boards and investing in technology development aimed at reducing dam safety risks (e.g. monitoring instrumentation, tailings dewatering and dry stacking).

The implementation of these guidelines by ICMM member companies would serve as a valuable example to all other mining companies and an opportunity to put into practise some of the reforms identified in and since ICOLD.

Case study: Los Frailes, Spain, 1998

The tailings dam at the Los Frailes gold-copper-lead-zinc mine, located at Aznalcóllar near Seville, failed in April 1998

(Figure 19). It released approximately 5.5 million cubic metres of acidic, metal-rich water and approximately 1.3 to 1.9 million

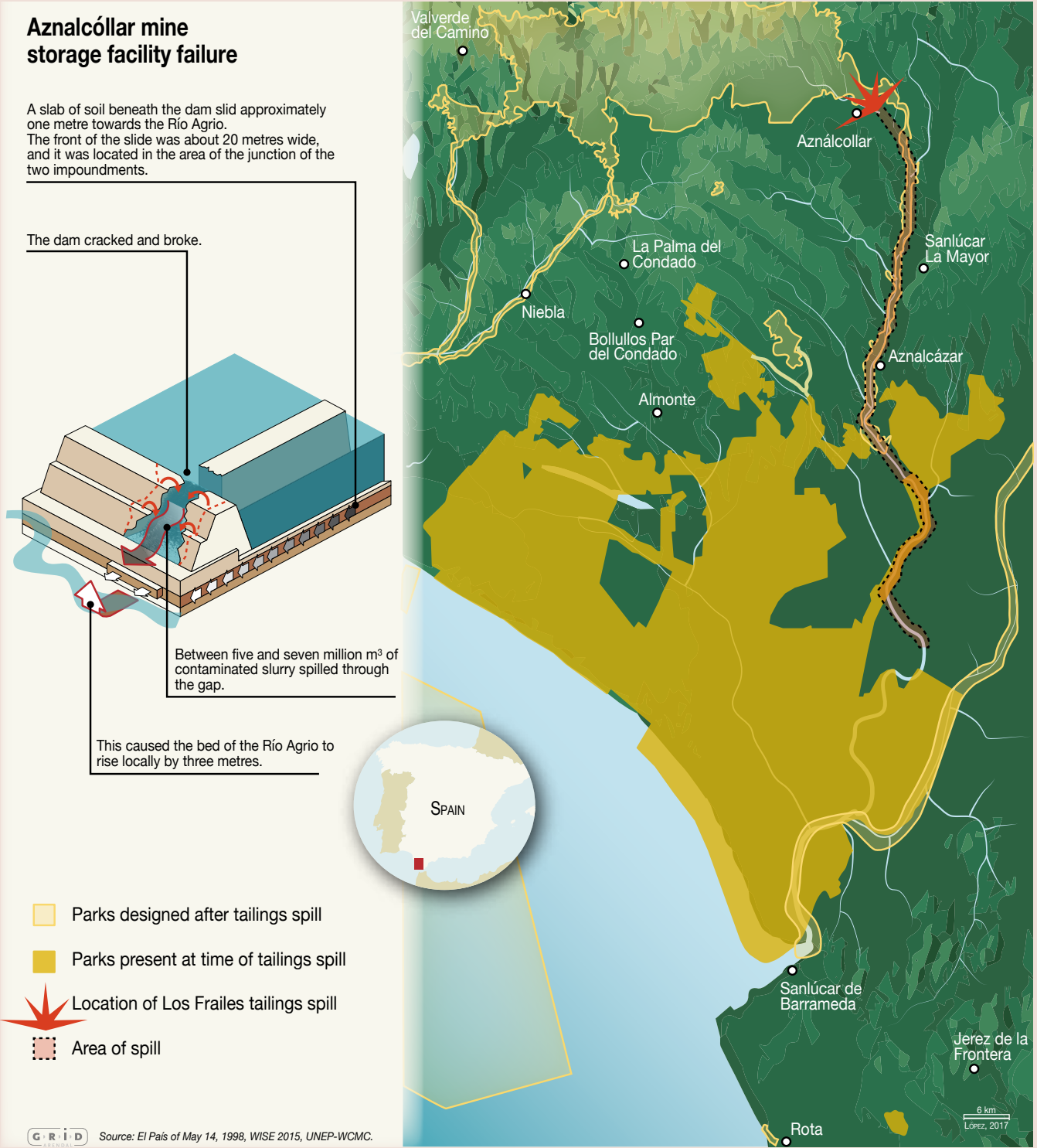


Figure 19. The tailings dam failure at the Los Frailes gold-copper-lead-zinc mine

cubic metres of toxic tailings into the Agrio, Guadiamar and Los Frailes Rivers (WWF 2002). The contamination affected 62 kilometres of waterways and 4 286 hectares of land, including farmland in the fertile Guadiamar basin and part of the ecologically significant Doñana National Park – a Natura 2000 and World Heritage Site. The emergency construction of barriers stopped more extensive waste intrusion into the park, which is the largest reserve in Spain and significantly, home to 361 bird species (Grimalt et al. 1999).

The high acidity (pH 3), low dissolved oxygen and turbidity caused by the spill resulted in the widespread death of aquatic organisms. Thirty-seven tons of dead fish were collected from the river mouth and all shellfish disappeared (Grimalt et al. 1999). The possibility of heavy-metal contamination (Figure 20) resulted in the closure of over 50 irrigation wells for a period following the spill. There was also a ban on the sale of agricultural produce from affected farmland. The land was not considered suitable for future agriculture and the government of Andalusia began a programme of compulsory acquisition. The disaster had major economic impacts on agriculture, fishing, tourism and the mining sector in the region.

The metals released were mostly in the form of insoluble sulphides, but when exposed to oxygen in the environment,

these quickly began to oxidize and form more mobile, water-soluble sulphates.

Immediately following the spill, clean-up work began to create a green corridor along the Guadiamar River, connecting two large natural areas – the Doñana National Park and the Sierra Morena (Rico et al. 2008). The cost of remedial and restoration works reported in 2013 was estimated at more than €170 million (BIO Intelligence Service et al. 2012). Most of the deposited tailings and 4.6 million cubic metres of contaminated soil were excavated and placed into the open-mine pit. This was successful in removing a significant amount of contamination from the Guadiamar River channel and floodplain, although elevated levels were still present in samples collected six months after the first remediation programme (Hudson-Edwards et al. 2003; Kemper and Sommer 2002). The clean-up activities, however, changed the structure of the river and floodplain and removed the riparian vegetation that provided a natural refuge for fauna (Macklin et al. 2003; Rico et al. 2008). Reptile populations, for example, were still found to be severely depleted eight years after the dam collapse. The green corridor failed to meet the requirements for their reintroduction due to the absence of shelters (Márquez-Ferrando et al. 2009).

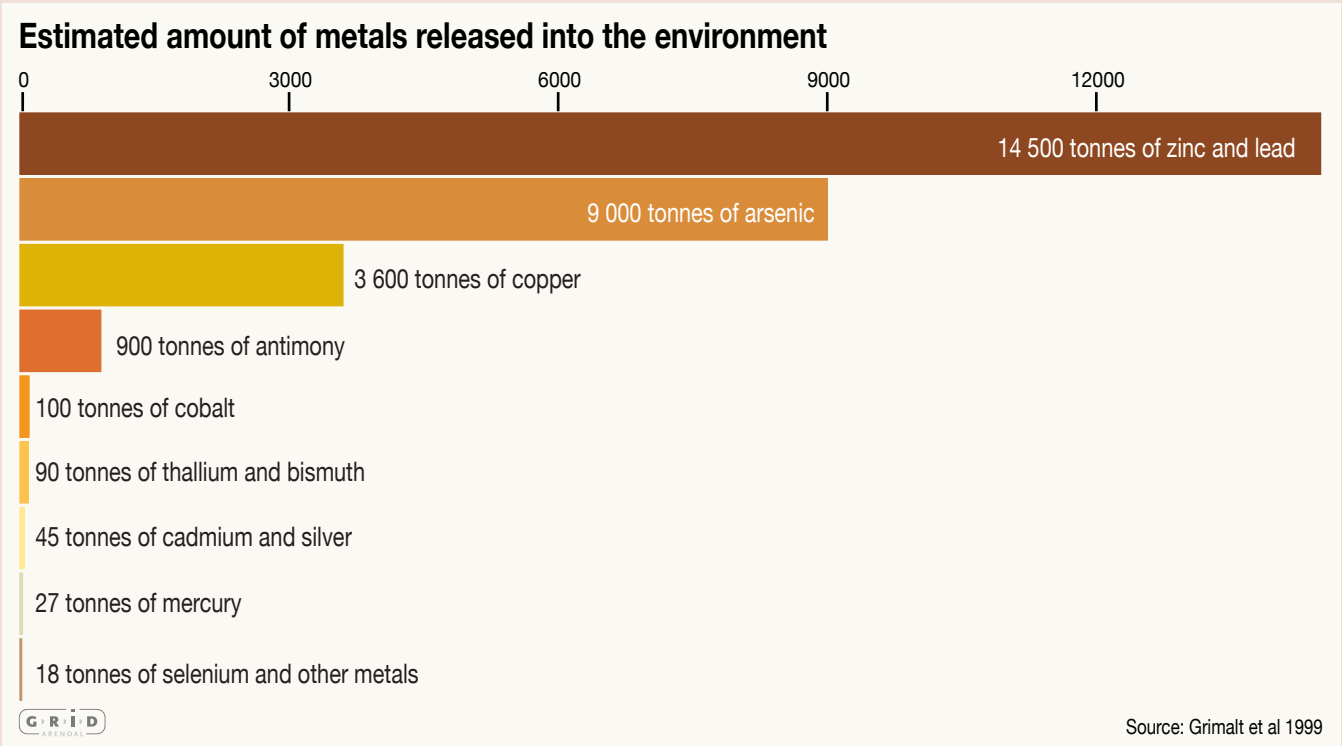


Figure 20. Estimated volume of heavy metals released into the environment by the Los Frailes tailings dam failure



Life cycle of mine waste and tailings dams – from refuse to resources?

If we think of tailings as a product of the mining process, rather than a waste, it becomes something for which we only have to discover a use (Rankin 2015).

Is it wise to continue storing increasingly larger volumes of mine tailings, believing that they are safely locked away, or can society demand more sustainable practices in the design and planning of tailings management, including zero (or minimal) mine waste and turning mine waste into secondary resources?

Within the mining and metals industry there is a growing interest in finding value in mine tailings and developing new and innovative ways to reduce and reuse them. The extraction of additional resources provides an opportunity to create value and reduce environmental liability, and is potentially one way the industry can improve sustainability (Golev 2016; Figure 21).

New mining and waste technologies

The technologies for processing minerals have not changed significantly over the last century, driven largely by throughput and economics. However, as the industry moves into processing more complex, lower-grade ores and environmental standards increase, new technologies are

emerging. These include the use of more benign leaching reagents to improve recovery and reduce the transfer of toxins with mine wastes (Alvarado-Macias et al. 2015; Anderson 2016). Technologies that improve the containment of tailings, and lessen leaching and acid mine drainage are also being developed. They include methods that reduce water infiltration by decreasing the porosity of the tailings, systems

Bioleaching

Bioleaching, using microorganisms, can be an effective technology for metal extraction. It has been used in the recovery of copper, uranium and gold from sulphide minerals and applications are expanding. The key organisms come from the genus *Acidithiobacillus*. They derive their energy by oxidizing naturally occurring sulphur and sulphide compounds to generate sulphuric acid. As the process takes place at atmospheric pressure and low temperatures, there is also the potential to reduce operational costs and energy requirements compared to conventional methods (Beolchini et al. 2013; Watling 2015). Alkaline bioleaching, using alkalophilic microorganisms such as *Burkholderia* sp. (Hu et al. 2016; Ramanathan and Ting 2016a; Ramanathan and Ting 2016b; Yang et al. 2016), have been shown to recover metal ores. While anaerobic bacterium, *Clostridium* sp., has been exploited to pretreat and stabilize radioactive contaminated wastes and mineral tailings (Francis et al. 1994, Black 2011). Bioleaching also has potential for use in re-mining and detoxification of tailings and soil contaminated with heavy metals.

Smart sensors for monitoring

Smart sensors can be used to monitor conditions in tailings storage facilities. They can provide early warning of structural failures, monitor environmental compliance (air and water), slope stability, water levels, discharge rates and weather conditions. Traditionally, tailings storage facilities have been monitored using manual measurements of various parameters, such as pore water pressure and embankment deformation. However, these occasional measurements may not give adequate warning of rapidly evolving problems. Automatic sensor networks, which make it possible to continually monitor dams in real time, provide a more robust indication of dam stability and are becoming more common. In situ monitoring systems include wires, optic cables or wireless networks that obtain data from permanent sensors installed in the dams. Automated monitoring can be used at active mine sites as well as reclaimed or closed sites. Goldcorp has recently installed a trial smart-monitoring system at their closed Equity Silver mine in British Columbia, Canada. At one of the three dams that contain the 120 hectares of water-covered tailings, the company has installed a solar power source, data loggers, radio monitoring stations, an automated survey station, a weather station, digital cameras and sensors to capture information on water levels, pore water pressure and structural integrity of the dam. Any incidents are automatically reported to the relevant personnel (Goldcorp 2016).

that neutralize the acidity of drainage water (e.g. successive alkalinity-producing systems (SAPS)) and barrier systems. Improving the quality of contaminated tailings and restoring soils affected by acid mine drainage using biological, chemical, electrokinetic and filtration methods are also being utilized to improve rehabilitation (Schindler et al. 2017).

Re-thinking mine tailings

Mine wastes, including tailings and waste rocks, can be defined as by-products of mining, mineral processing and metallurgical extraction. They are unwanted, have no current economic value and accumulate at mine sites (Lottermoser 2010). However, some tailings and waste rocks may have an immediate use (Table 5) and this has been recognized since mining and smelting operations first began. For example, European miners in the sixteenth century already reprocessed existing tailings to extract leftover ore minerals. Additionally, the reuse of slag can be traced back to historic times, when the Romans used iron slag in construction, road surfacing and as a flux in the production of iron. Thus, the concept of waste as a resource is not new to the modern



world. Humanity has always pursued mine waste recycling (i.e. the extraction of new value-material and/or conversion of waste to value-added products) and reuse (i.e. the new, beneficial use or application of waste). Yesterday’s waste can become today’s resource.

Scientists have important contributions to make by providing the knowledge necessary for the identification of cost-effective reuse and recycling options that can be adopted by industry, and for rational decision-making in critical areas such as waste recycling and reuse. The most pressing challenge facing scientists working on the recycling and reuse of tailings and waste rock is the quantification and distribution of resource ingredients and the environmentally significant elements in these waste products. We must accurately describe mine tailings and waste rock, and understand their properties and processes as well as their short- and long-term behaviour (Lottermoser 2017; Edraki 2014). Unfortunately, many modern concepts of reuse and recycling of tailings and waste rock have remained ideas, theoretical designs or laboratory trials without wider application. These concepts have not been

Reuse and recycling possibilities for tailings and waste rock	
Tailings	<ul style="list-style-type: none"> → Reprocessing to extract minerals and metals; → Waste reduction through targeted extraction of valuable minerals during processing; → Sand-rich tailings mixed with cement used as backfill in underground mines; → Clay-rich tailings used as an amendment to sandy soils and for the manufacturing of bricks, cement, floor tiles, sanitary ware and porcelains; → Manganese-rich tailings used in agro-forestry, building and construction materials, coatings, cast resin products, glass, ceramics and glazes; → Bauxite tailings used as sources of alum; → Copper-rich tailings used as extenders for paints; → Iron-rich tailings mixed with fly ash and sewage sludge for lightweight ceramics; → Energy recovery from compost - coal tailings mixtures; → Phlogopite-rich tailings for sewage treatment; → Phosphate-rich tailings for the extraction of phosphoric acid; → Ultramafic tailings for the production of glass and rock wool; → Carbon dioxide sequestration in ultramafic tailings and waste rocks.
Waste rock	<ul style="list-style-type: none"> → Source of minerals and metals; → Backfill for open voids; → Landscaping material; → Capping material for waste repositories; → Substrate for revegetation at mine sites; → Aggregate in embankment, road, pavement, foundation and building construction; → Asphalt component; → Feedstock for cement and concrete; → Sulphidic waste rock used as soil additive to neutralize infertile alkaline agricultural soils.

Table 5. Reuse and recycling possibilities for tailings and waste rocks (Lottermoser 2011)

Capturing and generating value from mine tailings

Waste treatment	Description	Examples	Value
Upcycling 	<ul style="list-style-type: none"> Extracting more from tailings Using tailings in new products 	<ul style="list-style-type: none"> Recovery of additional minerals 	<ul style="list-style-type: none"> Provides additional income-generation stream Reduces loss of valuable material Reduces mine footprint
Downcycling 	<ul style="list-style-type: none"> Finding on-site alternatives to long-term storage 	<ul style="list-style-type: none"> The use of mine waste for site remediation 	<ul style="list-style-type: none"> Limits potential for future recovery Generates savings on site remediation



Source: Golev 2016

Figure 21. Capturing and generating value from mine tailings (adapted from Golev 2016)

taken up by industry because poor economics, resistance to change and budget priorities have prevented their evaluation and application in the real world. To this day, the recycling and reuse of tailings and waste rock is largely driven by their practical applications and financial returns. However, there is a clear business case for the reuse and recycling of mine tailings and waste rock to achieve zero-waste mining.

New solutions to waste production and disposal are required if we are to reduce waste and achieve the zero-failure objective. Stakeholders need to work collaboratively to ensure that potential and innovative solutions are applied at the mine design phase. Finally, the regulator should use its tax and legal options to make it more profitable for companies to use mine tailings and waste rock for other purposes.



Potential utilization of bauxite residue

As storage, remediation, rehabilitation and monitoring costs rise, and land space is increasingly at a premium, there is a growing interest in finding ways to profitably utilize bauxite residue. There have been numerous patents and trials and some applications have been commercialized, but matching the tonnage arising annually with possible commercial application has been, and continues to be, a major challenge. In many cases the possible use involves replacing another low-cost raw material, so while the concept may be technically feasible, the costs cannot be justified. Significant barriers include distance to market (especially for high volume-low value applications), chemical and physical characteristics, resistance to change by market incumbents and, in some cases, impeding regulations.

The possible uses for bauxite residue fall into various categories: extracting some of the components (e.g. iron or rare-earth elements); using it as a source of a particular component (e.g. iron and alumina in cement); using the material for a specific characteristic (e.g. colour); using it as a construction material (e.g. bricks, tiles, aggregate, blocks, wood substitute); or using it as a bulk impermeable material for covering landfill. The majority of patents filed have involved bauxite residue being used in construction, building and agricultural industries.



The main application areas that have been evaluated include:

Cement production: Work on using bauxite residue in Portland cement has been under way for over 75 years. Substantial quantities of residue have been used in cement production in Greece, Russia and China.

Road construction: When dewatered, compacted and mixed with a suitable binder, bauxite residue makes a good road-building material. Trials have been carried out successfully in France, Australia and Jamaica.

Brick production: Mixtures of bauxite residue with clay, shale, sand and fly ash have been proposed and evaluated by groups in Jamaica, Sardinia, Hungary and Sardinia. Roof tiles have been manufactured from residue in Turkey.

Soil amelioration: Addition of bauxite residue to acidic and sandy soils can be beneficial in many ways and considerable work in this area has been undertaken in Western Australia. The additions imparted improved water retention and nutrient-utilization ability. Though the use of red-mud waste has been controversial with farmers concerned about pollution and toxicity.

Iron production: The high iron content of bauxite residue (up to 60 per cent) has prompted a lot of activity and experimental work. Many methods have been proposed but all are currently uncompetitive with high-quality iron ore sources.

Acid mine drainage and heavy-metal absorption: The ability of residues to react with heavy metals has been examined by several groups around the world, including in Italy, Australia and Korea.

Phosphate removal: Partially neutralized residue has been shown to be effective in removing phosphate from treated sewage water.

Pigments and catalyst manufacture: The high iron content and finely divided nature of residue has generated interest in it as a pigment. Considerable interest has also been shown in the ability of bauxite residue to act as a low-cost, high-surface area, “disposable”, iron oxide and titania catalyst.

Wood substitute: Good results have been achieved using bauxite residue with natural fibre and polyester resin to make a wood substitute product for building applications. Products with high strength, and good water resistance, weatherability and fire resistance have been obtained.

Geopolymers: The potential for bauxite residue to be used in the production of geopolymers as a substitute for ordinary Portland

cement has been studied for many years, and attempts have been made to render it a sustainable commercial proposition.

Extraction of rare-earth and other metals: Strongly growing markets and the very high prices in recent years for certain rare-earth elements has reawakened interest in their extraction from bauxite residue. Light and heavy rare-earth metals (e.g. lanthanum, cerium, neodymium, praseodymium, terbium, etc.) plus scandium and yttrium are among the elements of interest.

The global ambition for more efficient use of resources has led to increased efforts in looking into uses of bauxite residue over the past few years. Increased enthusiasm from industry, more university activities and the contribution of funds from organizations such as the European Union has

led to greater cooperation between industry and academia. Under the Horizon 2020 initiative, the European Union is funding substantial research programmes on the recovery of materials from and the utilization of bauxite residue. The Zero-Waste Valorisation of Bauxite Residue project is focusing on the extraction of iron, aluminium, titanium and rare-earth elements, and the production of new building materials. A European Innovation Partnership – Bauxite Residue and Aluminium Valorisation Operations (BRAVO) – has also been formed to bring together industry, researchers and stakeholders to explore the best available technologies for recovering critical raw materials (BRAVO 2017). The Alumina Technology Roadmap (2010) has a strategic goal of 20 per cent reuse by 2025 and the Chinese government a target of 25 per cent. Research and development investment continues in the search for application breakthroughs.



Construction using bricks made from residue

Driving forces for tailings management

The 2001 ICOLD report and subsequent research have illustrated that both chronic and catastrophic tailings storage-facility failures are preventable – caused not by a lack of technical knowledge but by management failures. As demonstrated by the Mount Polley and Samarco case studies, even failures relating to natural events, such as rainfall or earthquakes, or technical faults such as overtopping can reflect a flawed design or management failure. Acknowledging that technical solutions are site-specific, the driving forces identified below relate to management approaches that frequently contribute to technical failures.

Stakeholder risk and reward ratios

As identified in chapter 5, the various stakeholders in a mining project are exposed to different risks and experience different degrees of benefit from and control over the operation. The interests of shareholders are generally prioritized and do not account for the potential losses that could result from a failure. This has the potential to produce poorer outcomes for other stakeholders. The McArthur River mine in the Northern Territory of Australia provides a salient example (Mudd 2016). There, successive mine expansions have led to chronic

leaching of acid, metals and salts from the tailings storage facility and waste rock dump, causing tailings storage-facility fires and contamination of the local river system. With a series of government approved mine expansions overlooking or undervaluing the cultural and environmental values identified by local indigenous communities.

An international industry with local impact

Many of the essential decisions that govern tailings storage-facility performance may be made by remote decision makers



The mouth of the Doce River on the Atlantic coast – the tailings plume five days after the Samarco disaster.

A conceptual model for calculating the net present value of mine closure

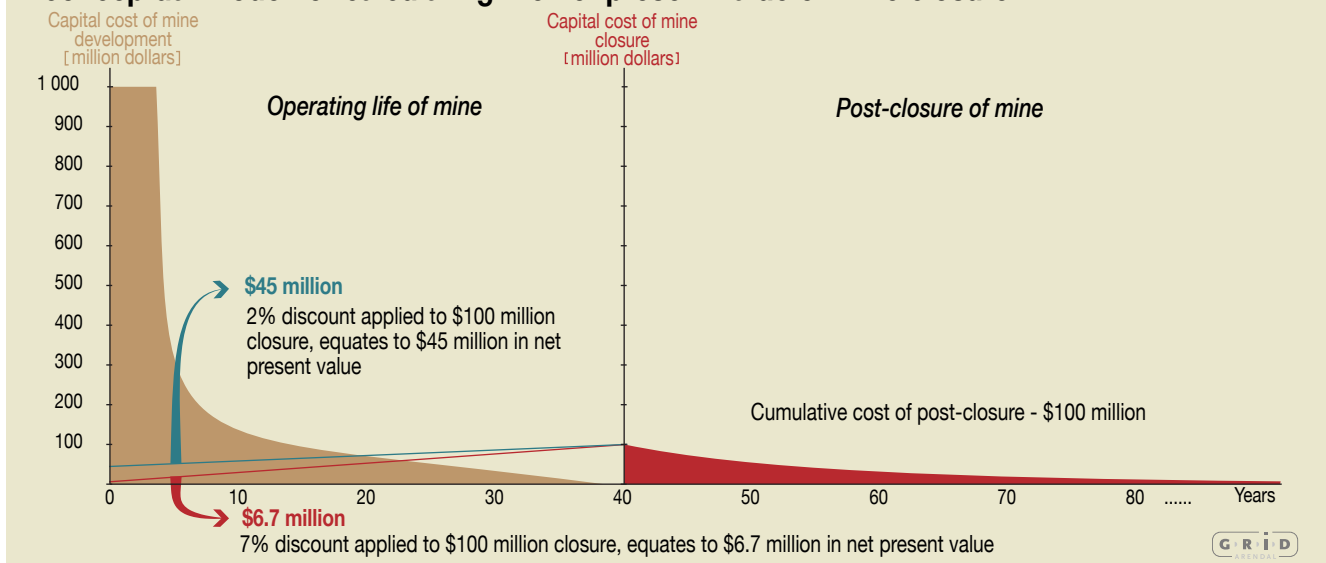


Figure 22. A conceptual model of net present value of closure costs and perpetual mine management

who have little or no exposure to any long-term risks. For example, key decision makers may live off-site in company home countries or only work on the project for a limited period. This can lead to a focus on a narrow range of factors, such as declining ore grades, commodity price fluctuations and pressure for higher shareholder returns. In contrast, those most at risk from waste management failures live near or downstream from the mines, often over successive generations, and have little influence over the design, regulation and management of tailings storage facilities. These communities stand to lose much more than their investment if a failure or major pollution incident occurs.

Project feasibility

The mining industry uses a combination of metrics such as the internal rate of return (IRR), return on investment (ROI), or net present value (NPV) to assess the viability of a mine in the context of feasibility assessments. All of these tools assess the financial profitability of the mine from a shareholder's perspective. The concern is that they may not fully recognize the overall value of a project, as they concentrate on the cost of development for mine owners and do not necessarily take into account the cost to the community or the true end-of-mine costs. Unfortunately, this approach can leave governments, communities and the environment exposed to the impacts of mines designed to be funded and approved, rather than closed and maintained successfully.

Of the three metrics, net present value and the application of discounting to future costs is the most relevant to mine closure and the ongoing, safe storage of mine waste and tailings. Applying net present value enables proponents

to discount the value of future costs by a percentage every year, reducing future costs to an insignificant amount at the development stage. For example, see the reduction of costs from \$100 million to \$6.7 million illustrated in Figure 22 above. This means that the cost of managing a tailings storage facility in 40 years time is of minimal relevance to project design and feasibility.

Currently when determining net present value, the environmental and social costs are generally discounted at the same rate as other costs. A better approach might be to apply dual discounting, where environmental and social costs are treated separately from other costs, with the lower discount rate more accurately capturing the non-financial impacts of closure on communities. This reduces the discount applied to future costs, increasing the relevance of future costs to project planning and viability. As illustrated in Figure 21, applying a dual discount rate of 2 per cent increases the present cost to \$45 million. This method results in a more accurate sustainable cost-benefit analysis (Kula and Evans 2011). The 2008 ICM report, in discussing the closure costs for mines, recognized the flaws in feasibility assessments, noting orders of magnitude errors and the lack of incentive for proponents to clearly identify closure costs, of which safely storing mine waste is a major component.

Financial assurance

While in most countries, there are some financial assurance requirements for reclamation and closure, there are no financial assurance requirements for catastrophic failure. If a catastrophic failure occurs, either the operator must be able to provide financial compensation, and/or that responsibility

falls to government. If neither is able to provide compensation, then the environmental and social costs fall on those who live near the mine. A revised scheme could help address the risks to and vulnerability of affected communities, such as those downstream of the Marindique dam disaster, for whom no satisfactory or equitable compensation system exists.

Similarly, the financial liability of long-term or perpetual management of legacy sites has concerned the industry for many years, with two significant reports from the ICMM on financial assurance and integrated closure planning (Miller 2005; ICMM 2006). Further work by Kempton (2010) outlines the diverse management issues and potential for hundreds of years of management for problems like acid mine drainage, or thousands of years for radioactive mine tailings. These are potential liabilities with a longevity greater than many of our financial institutions. If long-term management was adequately costed, the required financial assurance could help incentivize innovation in mine design and tailings management.

Changes to financial assurance are required for both dam failures and long-term management. While management could be improved with more accurate project assessment and costings (see above) a compensatory mechanism is required to address failures. The oil industry compensation fund for accidents provides a model which could be applied to the mining industry.

Regulators

Regulations governing mining operations are specific to national and jurisdictional regulations and local circumstances. While their variation precludes an extensive review in this report, given that regulatory failures and inadequacies contribute to tailings dam failures (Golder and Associates 2016), an international regulatory systems review would be beneficial in improving tailings management.

Tailings Dam failures are a shared responsibility, caused as much by regulatory as management failure. In cases of catastrophic failures, the regulatory system has failed to ensure good design, and to implement, monitor and enforce adequate standards. As ICOLD determined, these failures are frequently human-caused. Regulatory systems with multiple, independent checks are required to ensure standards and detect impending failures.

A regulatory system, for example, should cover the civil works, environmental performance and risk calculations associated with tailings storage facilities. They should also stipulate financial requirements for perpetual management of waste or a requirement for rehabilitation to a level that enables the site to be safely relinquished for reuse for non-mining purposes. While the practical requirements for mine waste planning, treatment, storage, monitoring and management are highly specific to the mine location, some higher-level issues are widely applicable. Figure 23 illustrates an evolution of tailings management, from proponent-driven to a gradual increase in regulations for a more inclusive approach that would reduce risk for all stakeholders.

The issue of regulation remains a sensitive one for the industry. The recommendations in the 2001 ICOLD report concentrated on industry responses, such as increased professionalism, more studies and planning, skilled audits and better monitoring – the basic premise being that as poor management was the cause of most failures, better management would be the solution. The UN Environment view, expressed in the same report, more clearly addresses the need for effective regulation to improve waste management, stating “the major driving force in reducing the number of tailings dam incidents is ... the adoption of regulations that require regular independent auditing...” (ICOLD 2001, p. 56).

After the Samarco failure, the ICMM conducted a review of tailings management (Golder and Associates 2016) and issued a position statement and tailings management framework (ICMM 2016). While identifying owners and operators as those responsible for tailings safety, the review found that most companies have guidance documents that meet or go beyond good practice. Although the position statement represented a significant step-up in leadership and commitment, it again suggested that improvements in management, and more specifically design, construction, supervision and auditing would prevent failures. While the importance of assurance was recognized, the absence of a role for regulation in the position statement was stark and perhaps indicated the industry's preference for self- or voluntary regulation. Whether this reflects the ICMM's general preference for self-regulation (Dashwood 2012), or a specific belief that more robust regulations are not required to resolve tailings dam failures, is unclear.



Others see a much clearer role for regulation. For example, the 2016 United Nation Development Programme recommends the incorporation of all relevant sustainable development goals (of the 17 defined SDGs) into mining regulations, while Dashwood (2014) suggests that the mining industry would accept a higher global standard to ensure certainty and consistency across operations. Certainly, implementing global standards that do incorporate wider aspects of human development could help overcome past regulatory failures. Such an approach is reflected in the recommendations of de Oliveira Neves et al. (2016), derived from the Samarco disaster, which emphasize rigorous licensing procedures, protection of ecosystems, regional planning, internalization of negative externalities, increased tax rates and royalties and diversification – all dependent on a strong, holistic regulatory approach.

While tailings dam failures are more common at active sites (IEEIRP 2015; Strachan and Goodwin 2015; Rico et al. 2008), chronic problems arising from legacy sites have been

well known for many years (Lyon 1993). Less publicized is the high rate of unplanned closures of mine sites. For example, in Australia this occurs at 75 per cent of mine sites (Laurence 2006, 2011). These unclosed or poorly closed sites may require long-term or perpetual management, with the risk of failure and maintenance costs potentially borne by local communities and authorities. In contrast, properly planned and implemented closure and remediation can have significant environmental and social benefits – one example is the Phoenix #5 surface coal mine in West Virginia, US. The site received a US Office of Surface Mining award for reforestation and reclamation (WV Coal 2017).

More female involvement to accelerate improvements in tailings dam safety
A lack of diversity on company boards may encourage groupthink and result in underestimation of the costs and risks of externalities. The latest “Mining for Talent” study, commissioned by Women in Mining UK (PwC 2015) found

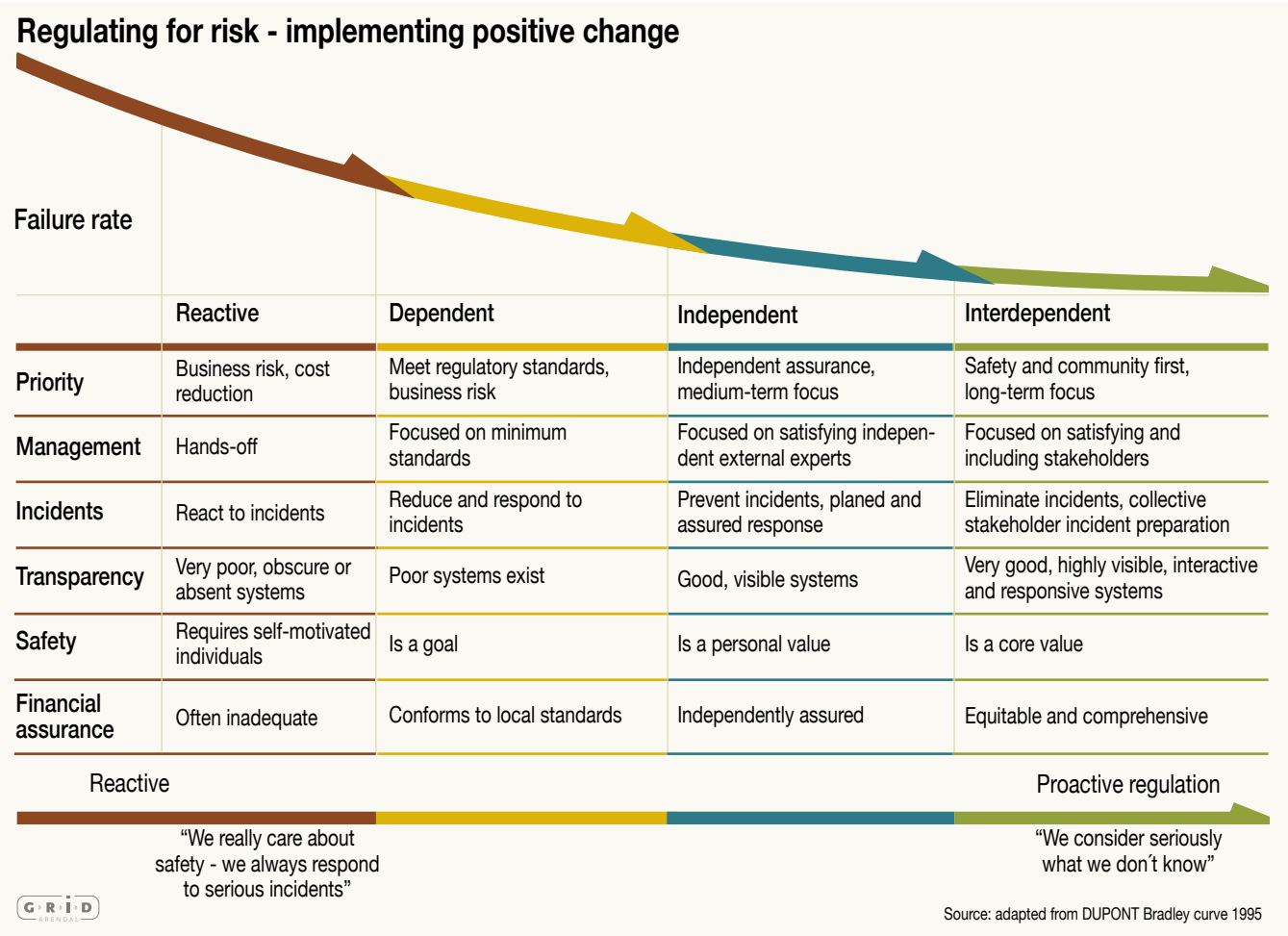


Figure 23. The DuPont Bradley curve adapted to illustrate proactive regulation to improve safety in mine waste management

that companies gain significantly from increased female representation on boards. The benefits include better overall financial performance, increased disclosure and transparency for environmental, social and governance performance and a greater adherence to global standards. Having more women in leadership positions may go some way to ensuring there is greater consideration of risks to the community and environment from tailings dam failures. The Mining for Talent study also found that while the mining industry had almost the lowest number of women on company boards of any industry group worldwide (only marginally ahead of the oil industry), a positive trend in female board representation was occurring.

Policies and practices

In addition to national regulatory regimes there are some guidelines, reporting instruments, global agreements and soft law initiatives that should influence mine tailings management. Many were referenced when the ICMM benchmarked their 10 principles for sustainable development (which member companies are required to implement) against the 1992 Rio Declaration (ICMM 2015). They include:

- Global Reporting Initiative
- Mining Association of Canada Tailings Guidelines
- The OECD Guidelines for Multinational Enterprises
- The OECD Convention on Combating Bribery of Foreign Public Officials in International Business Transactions
- The International Finance Corporation's Environmental and Social Performance Standards
- International Labour Organization Conventions
- The Voluntary Principles on Human Rights and Security
- Equator Principles

While there is evidently a role for industry policies to become a driver of better tailings management, it is difficult to determine what effect these guidelines and company policies are having on waste management practices without a comprehensive assessment. Undoubtedly, there are good examples of best practice and harm reduction, but these are overshadowed by industry failures. Greater transparency of what these initiatives have achieved would help encourage adoption and build community confidence.

The Samarco tragedy, which helped prompt this assessment, demonstrates that despite these positive initiatives, more progress is needed to prevent tailings dam failures. The Samarco mine is owned by two of the world's largest and most profitable mining companies, BHP Billiton and Vale SA. BHP Billiton is a long-term member of the ICMM, while Vale SA, who were not a member at the time of the accident, have recently re-joined. The inability of these industry giants, with their vast experience and expertise, to safely manage tailings demonstrates both how difficult tailings management is and the inadequacy of these initiatives in changing our approach to mine tailings.

European Union mining waste regulation

The European Union has multiple legal instruments to regulate waste including mining waste, promoting safety and sustainability (Figure 24). In addition to general industrial regulation, specific legislation includes the Mining Waste Directive, which details the requirements for the safe management of extractive waste, including proper characterization of the waste, provision of financial guarantees, emergency plans, a policy for prevention of major accidents and the development of safety management systems for operations where there is a risk to public health or the environment (Twardowska et al. 2010).

The European Commission, Member States, the mining industry and stakeholders have progressively built up this regulatory framework, starting with publication of a Best Available Techniques reference document for the management of tailings and waste rock in 2004 (currently under revision), adoption of the Mining Waste Directive in 2006 and a series of supporting Commission Decisions and guidance documents from 2009 to 2012. Recognizing that innovation is the indispensable and fundamental basis of growth in the European Union, a European Innovation Partnership on Raw Materials was launched at the end of 2012, to bring together raw-material suppliers and raw-material users and to ensure that innovations with a societal benefit get to market more quickly (Allard et al. 2013).

The European Union also has applicable rules regarding water protection, nature protection, environmental impact assessment, major industrial accidents, environmental liability and health and safety. It has been suggested that this robust legislation could provide a model for other countries to emulate (Allard et al. 2013; Scannell 2012).

Waste generation by economic activities and households

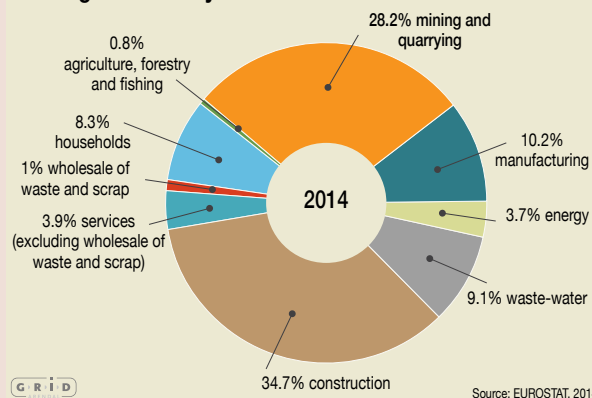


Figure 24. Percentage of waste generated by various sectors in the European Union

Opportunities for better tailings management

The prevention of a tailings dam disasters is an ambitious, but challenging goal. A goal made more difficult by the cyclical, competitive and international nature of the mining industry. Although ICOLD (2001) provided recommendations for change, which have, in many jurisdictions, improved tailings management, the industry has not yet achieved a zero-failure rate.

The approach to tailings storage-facility design, construction and management must place safety as the number one priority. Failure to implement change, coupled with the reality of declining ore grades and consequent increasing waste volumes, will inevitably lead to more catastrophic failures with more deaths, human suffering and environmental destruction.

This report makes two recommendations and identifies actions to improve regulation and practice, and inform the UN Environment stakeholder forum.

Recommendation 1. The approach to tailings storage facilities must place safety first, by making environmental and human safety a priority in management actions and on-the-ground operations. Regulators, industry and communities should adopt a shared zero-failure objective to tailings storage facilities where “safety attributes should be evaluated separately from economic considerations, and cost should not be the determining factor”. (Mount Polley expert panel, 2015, p. 125)

Recommendation 2. Establish a UN Environment stakeholder forum to facilitate international strengthening of tailings dam regulation.

The actions below are contained in the 2001 ICOLD report or have been drawn from subsequent academic research, industry reports and post-failure investigations that identify the scale, predictability and drivers of tailings dam failures.

Action 1. Facilitate international cooperation on mining regulation and the safe storage of mine tailings through a knowledge hub

- a) Create and fund an accessible public-interest, global database of mine sites, tailings storage facilities and research.
- b) Fund research into mine tailings storage failures and management of active, inactive and abandoned mine sites.
- c) Compile and review existing regulations and best practice guidance.

Industrial mining is a complex, globalized enterprise with the many disaggregated stakeholders exhibiting high levels of

inter- and intra-variability. States have different approaches to regulation and enforcement, while companies make different commitments to public safety and shared benefits. These factors can be further complicated by global inequalities and asymmetries of power, knowledge, resources and influence that, combined with high financial flows, can create the conditions for corruption and poor regulation. These local and global realities make international cooperation essential in overcoming the voluntary, incremental and site-specific factors that restrict tailings reform.

The international cooperation and coordination that comes with a global agreement could ensure a firm, universal commitment to eliminating tailings storage-facility failures and could provide the impetus for countries to learn from each other, and agree on rather than bargain away essential protections. Such an agreement could assist in overcoming obstacles posed by a lack of research and data sharing, by supporting a freely accessible international database and comprehensive research programme. With the acknowledgement that some tailings storage failures are never adequately addressed, a global agreement could provide the necessary structure for an international system of financial assurance to protect states from disaster and default.

Action 2. Failure prevention

- d) Expand mining regulations, including tailings storage, independent monitoring and the enforcement of financial and criminal sanctions for non-compliance.
- e) Regularly publish disaster management plans that relate to local and regional circumstances and planning.
- f) Increase gender diversity on company boards, and include local representatives and skill sets focusing on community engagement, ethics, social and environmental impact.
- g) Establish independent waste-review boards to conduct and publish independent technical reviews prior to, during construction or modification and throughout tailings storage-facility lifespan.
- h) Avoid dam construction methods known to be high risk.
- i) Ensure any project assessment or expansion publishes all externalized costs, with an independent life-of-mine sustainability cost-benefit analysis.

- j) Require detailed and ongoing evaluations of potential failure modes, residual risks and perpetual management costs of tailings storage facilities.
- k) Enforce mandatory financial securities for life of the mine (includes post-closure).
- l) Ban or commit to not use riverine tailings disposal. Adopt a presumption against the use of submarine tailings disposal, water covers on tailings dams and the use of upstream and cascading tailings dams unless justified by independent review.

Under an international agreement, authorities would be encouraged to adopt regulations to ensure failure prevention. Such a system would provide certainty and inspire industry confidence in the regulatory system, supporting companies who want to innovate and adopt best practice and new technologies. It could also reward transparency and best practices in assessing projects against proponents' established reputation and against practices around the world. While approaches will vary between jurisdictions, and in acknowledging and leaving the specificity of technical matters to regulatory authorities, action two identifies a number of core elements that should apply across the board.

Of these actions, the role that financial tools and instruments play is perhaps the least well known in the wider community. The problems created by the failure to recognize future costs and the future discounting of externalized impacts and risks can be partially overcome by dual discounting for future social and environmental liabilities and by a separate assessment of project value. Rather than being limited to investor returns, this would consider social financial returns, non-financial values, other potential land uses and perpetual management costs. Such an assessment would be independent of the proponent and would enable a decision to be made on whether the project would produce an adequate return for the risks and impacts to the environment, local communities, governments and future generations.

Agreement on which practices are inherently unsafe would provide greater certainty to all stakeholders. Increased transparency and responsibility are also vital, with independently reviewed and frequently updated risk assessments and disaster management plans made in conjunction with and available to local stakeholders. In addition to greater financial securities, director liability of operator and parent companies would encourage more active management of and responsibility for risk. Balancing this, regulators should encourage best practice and incentivize better tailings management, reuse and recycling, and the re-mining of older mine sites or waste streams.

Lastly, effective regulation relies on well-resourced regulatory authorities, which are able to attract and retain expert personnel in policy formation, monitoring and enforcement. This challenge, which could be examined by the knowledge hub, must be overcome if industry, regulators and other stakeholders are to have access to the expert advice and services they require.

Action 3. Crisis response

- m) Establish a global financial assurance system for mine sites to ensure rehabilitation, tailings management and monitoring.
- n) Fund a global insurance pool to address any unmet liabilities from major tailings dam failures on local communities.

Tailings dam failures create crises for a number of stakeholders, who are often unprotected and lack the resources or capacity to move on from or overcome the impact of a disaster. A financial assurance system would provide resources to address the impacts of failure with adequate funds for site clean-up and remediation. While an insurance pool would provide compensation for affected stakeholders, particularly local and downstream communities and incentivize the industry to reduce the number of failures.

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