Knowledge Gaps in Relation to the Environmental Aspects of Tailings Management

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Abbreviations

ASGM	Artisanal and small-scale gold mining
ASM	Artisanal and small-scale mining
EHS	Environmental, health and safety issues
EIA	Environmental impact assessment
EU	European Union
FPIC	Free, Prior and Informed Consent
GISTM	Global Industry Standard on Tailings Management
GTMI	Global Tailings Management Institute
ICMM	International Council on Mining and Metals
IFC	International Finance Corporation
IGF	Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development
IRMA	Initiative for Responsible Mining Assurance
Natech	Natural hazards triggering technological accidents
PRI	Principles for Responsible Investment
Safety First	Safety First: Guidelines for Responsible Mine Tailings Management
SEA	Strategic environmental assessment
TSF	Tailings storage facility
TSM	Towards Sustainable Mining
UN	United Nations
UNEA	United Nations Environment Assembly
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme

Executive Summary

Tailings are the mineral waste material left over from mineral processing, commonly deposited as a liquid slurry into purpose-built ponds or dams. In the artisanal and small-scale mining (ASM) sector, which is prevalent in some regions, tailings may be dumped or piled with little planned management. Billions of tons of mine tailings globally are produced each year, and the volume is rising. Tailings may contain toxic chemicals and other contaminants, which can remain hazardous for decades. Their inadequate management may cause pollution of rivers, water quality or soil as well as negative impacts on biodiversity and ecosystem connectivity.

Resolution 5/12 of the United Nations Environment Assembly, on the environmental aspects of metals and minerals management, mandated the United Nations Environment Programme to prepare a report on knowledge gaps in relation to the environmental aspects of tailings management, in consultation with Member States and other experts. The report, structured in thematic topics, identifies these knowledge gaps both in relation to LSM and ASM, and proposes some focus areas for the future. Below is a summary, organized broadly according to the life cycle of mine tailings.

Planning: Current guidance on environmental impact assessments (EIAs) has little focus on tailings management issues, and the use of life-cycle assessments – for example, for tailings circularity – could be improved. Accordingly, long-term environmental monitoring of tailings facilities, or use of alternative tailings storage, as well as re-processing or reuse of tailings, and closure requirements, are aspects that are not well considered during the design and permitting of mining projects. Planning for tailings management (including EIAs, design and closure plans) could also better incorporate climate change considerations as well as natural hazards triggering technological accidents, also known as ‘’Natech’’.

Operation: Variation in the implementation of best practices relating to tailings management in different mines and regions was noted as a challenge, including in relation to identifying and managing chronic environmental impacts, minimizing environmental contamination from processing chemicals, and responsible water management

Member States noted that the existence of multiple voluntary standards causes confusion and may hinder the implementation of best practices. It was suggested that even with the multitude of standards, there are still issues of low adherence and limitations in their coverage or effectiveness.

Member States have suggested a need for enhanced cooperation, capacity-building and technical support in relation to monitoring and enforcement of tailings management best practices, including incentivizing and verifying company reporting. Issues associated with lack of transparency, community participation and public access to data were considered important gaps in the oversight of tailings management, with social and human rights issues described as indivisible from environmental aspects.

In ASM, tailings management presents specific challenges (such as mercury pollution) for reasons such as lack of formalization, lack of operators’ environmental education, and lack of operators’ access to capital and data. These issues are often overlooked because regulations are designed for LSM models.

Closure: Closure of mines has not been well managed historically, a scenario that has led to a proliferation of abandoned sites. Management of such sites is hindered by low-quality records on the composition and location of legacy tailings, as well as inadequate funding for and implementation of methods to measure and prevent longer-term and chronic environmental impacts.

Circularity: Circularity was widely cited by experts and Member States as one of the most effective ways to reduce the negative impacts associated with tailings management. However, research is still needed in this area. Re-processing or recycling tailings has the potential to recover valuable elements from tailings or to repurpose these tailings as by-products for other industries, but it could also have negative environmental and social impacts. It was noted that the overall reduction of tailings is a priority, which would be supported through the promotion of consumer awareness, public education programmes and traceability schemes focused on mine waste.

Several mechanisms that could assist address identified gaps are proposed in the report. These include:

1) Undertaking a global assessment of the existing tailings management instruments, to identify good practices, gaps, and areas for improvement, as well as the effect (and cost) of implementation, which can support efforts to streamline or consolidate existing standards.

2) Continuing work towards establishing the Global Tailings Management Institute and its role as independent body in leading tailings management practices, with an emphasis on capacity-building, technical and legislative support, and oversight of the Global Industry Standard on Tailings Management, addressing identified gaps over time.

3) Supporting the elaboration policy, legislative gap analysis and other national measures, including to formalize tailings management in the ASM sector; improve EIAs, life-cycle assessments and mine closure requirements relating to tailings; manage liabilities created by legacy sites; and incentivize innovations in minimization of tailings, alternative tailings storage methods, and tailings re-processing and reuse.[1]

4) Continuing efforts to develop inventories of tailings, including via the GRID-Arendal Global Tailings Portal.

[1] This is a summary and amalgamation of several possible future focus areas, proposed separately in different sections of the report.

1 Introduction

This report constitutes an information document for the sixth session of the United Nations Environment Assembly (UNEA), which will take place in February-March 2024 in Nairobi, Kenya. The objective of this report is to respond to the request – in operative paragraph 5 of UNEA Resolution 5/12 on the environmental aspects of metals and minerals management – for the United Nations Environment Programme (UNEP) to prepare a report on knowledge gaps in relation to the environmental aspects of tailings management, and to inform discussions at UNEA-6. The UNEA resolution requested UNEP, in preparing the report, to build upon the Global Industry Standard on Tailings Management (GISTM) (Global Tailings Review [GTR], 2020) and to engage as appropriate with the secretariats of relevant multilateral environmental agreements, organizations and stakeholders. The GISTM emanated from the Global Tailings Review (Oberle, Brereton and Mihaylova 2020).

This report has been prepared by UNEP, with support from the Geological Survey of Finland in conducting background research and in organizing an expert panel roundtable and consultation process to provide feedback on an earlier version of the report.

In addition to the GISTM, and a desktop literature review, this report builds on several sources of information, including:

- a previous UNEP assessment, *Mine Tailings Storage – Safety Is No Accident* (Roche, Thygesen and Baker 2017),
- the "Towards Zero Harm" compendium of the Global Tailings Review in 2020,
- the intergovernmental consultation contributions from Member States and observers gathered during the regional intergovernmental consultations on the implementation of UNEA Resolution 5/12 (UNEP 2023a; UNEP 2023b; UNEP 2023c; UNEP 2023d; UNEP 2023e; UNEP 2023f) (more than 150 relevant comments reported) and
- points raised by international experts from civil society, academia, the public sector and industry during a consultation process carried out for this report (more than 350 relevant comments received) (UNEP, 2023j).

The Global Tailings Review (and the resulting GISTM) were co-convened by UNEP, the Principles for Responsible Investment (PRI) and the International Council on Mining and Metals (ICMM). This work targeted catastrophic failures of large-scale tailings dams. The current report builds on that work but also highlights other aspects of tailings management, such as chronic environmental impacts, tailings from artisanal and small-scale mining (ASM) and circularity in tailings management.

The following sections summarize the current state of knowledge on key topics related to tailings management, broadly following the Global Tailings Review compendium structure: it sets the scene and then analyses the "regulatory," "social" and "operational" dimensions in separate sections. A summary of the knowledge gaps identified for the different aspects of tailings management, and some ideas for future focus, are provided at the end of each section.

The identified issues include: 1) knowledge gaps, i.e. issues where further knowledge is required to move forward, as well as 2) gaps in the application of knowledge (or implementation gaps), i.e. where knowledge exists but has not been effectively implemented.

2 Tailings: Setting the Scene

Tailings are the waste material left over from mineral processing. They include ground-up rock (ore) containing the unrecovered metals, as well as substances added during processing (e.g. chemicals and water).

Although the GISTM was designed for industrial-scale mining[2], Member States have reported many issues also related to artisanal mining. Therefore, this report explores the issues that arise for 1) large-scale industrial mining and 2) artisanal and small-scale mining, which may involve different considerations (Fig. 1).

Figure 1. Definitions of large-scale mining and artisanal and small-scale mining

Large-scale mining (LSM) refers to large site excavations conducted by mining companies, with significant investment and a high level of mechanization.	**Artisanal and small-scale mining (ASM)** refers to mining by individuals, groups, families or cooperatives with minimal or no mechanization, often in the informal (and sometimes unregulated or illegal) sector of the market.

Source: World Bank 2009.

For LSM, ore is usually transported (e.g. by truck, railway, conveyor belt or pipeline) to a nearby site for processing. Processing methods can vary but generally include crushing the ore into smaller parts, separating the minerals from one another through grinding, and then further processing into a concentrate. Annual volumes of mine tailings from LSM are estimated at 13 billion tons and rising (Franks *et al.* 2021), with the most significant contributors being copper and gold mines, followed by iron and coal.

As lower-grade ore is mined, the ratio of tailings to recovered metal increases. For some metals, for every unit produced, there may be as little as less than 1 per cent metal and greater than 99 per cent tailings (Edraki *et al.* 2014). Tailings are commonly deposited as a slurry into tailings storage facilities (TSFs), which typically comprise one or a series of dams or embankment ponds. Unlike water dams, which are usually built fully before being operational, tailings dams are often raised over time to increase storage capacity while also in use, and they may use waste materials from the mine in their construction (Piciullo *et al.* 2022).

The total number of TSFs globally is unknown, with estimates for inactive and active facilities varying widely, for example from 11,000 to 35,000 sites (Franks *et al.* 2020; Rana *et al.* 2022; International Commission on Large Dams [ICOLD] 2023; World Mine Tailings Failures [WMTF] 2023). The number and

[2] For example, tailings facilities higher than 2.5 metres measured from the elevation of the crest to the elevation of the toe of the structure, or with a combined volume of water and solids of more than 30,000 cubic metres (GTR 2020).

size of TSFs is expected to increase with the rise in global mineral demand (Franks *et al*. 2020; UNEP 2020a).

Failures of TSFs are regularly reported across the globe (Baker *et al*. 2020). Tailings may contain toxic contaminants, which can remain hazardous for decades. In addition, chemical reactions in the tailings material itself may result in long-term releases of contaminated drainage. Faults in TSFs can cause chronic long-term environmental damage – such as contamination of surface and groundwater bodies or soil with acid, toxins, radioactivity or metals – which leads to changes and negative impacts on biodiversity and ecosystem functioning (Roche, Thygesen and Baker 2017; International Network for Acid Prevention [INAP] 2018; Morrill *et al.* 2022). Sudden failure of the facilities is also a risk, which can lead to catastrophic results including environmental devastation and loss of human life. Abandoned TSFs are an issue globally and can act as potential sources of toxic or hazardous substances or acid drainage, in turn impairing ecosystem services and leading to the ill health of nearby communities (Nash 2020).

For ASM, tailings are likely to be dealt with in the most convenient manner possible, with little or no planned tailings management. This may involve simply piling tailings next to the mine site, dumping them in nearby water bodies or re-filling the original mine pit with untreated waste material. Mercury-contaminated tailings from artisanal and small-scale gold mining (ASGM) are particularly difficult to clean up and are pernicious in the way they spread and accumulate in the ecosystem and food chain (United Nations Industrial Development Organization 2008; Velasquez *et al.* 2022).

Human and animal health can be directly affected, where air, soil or water sources become contaminated with mercury or toxic mining tailings. This can also lead to bioaccumulation in major food sources, such as fish (Mantey *et al*. 2020). Due to inefficient ore processing, ASGM tailings often contain unrecovered gold and may subsequently be reprocessed, using cyanide leaching. Combining mercury and cyanide generates mercury-cyanide complexes that are highly mobile and bioavailable and that can exacerbate the spread and adverse impact of mercury in the ecosystem (UNEP 2021).

Poor disposal of ASM tailings also negatively affects biodiversity, causing declines in rare and threatened species and the destruction of ecosystems (Harlow *et al.* 2019). ASM tailings storage also leads to topsoil loss and erosion and deforestation, as forest is cleared to make way for tailings ponds (Swenson 2011; United States Agency for International Development [USAID] 2017; Ofosu *et al.* 2020).

3 Regulatory Dimension

3.1 Existing Performance Standards for Tailings Management

Significant efforts have been invested globally into promoting safe tailings management, good practices, and sustainability, involving various actors from the industry, governments, civil society and the finance sector (Fig. 2). This engagement has resulted in the creation of several tailings management good practice guidelines and tools at the global, regional, and national levels, covering tailings management practices and physical stability aspects of TSFs for LSM. Some of the existing standards are considered briefly below, highlighting different sources and ending with a gap analysis.

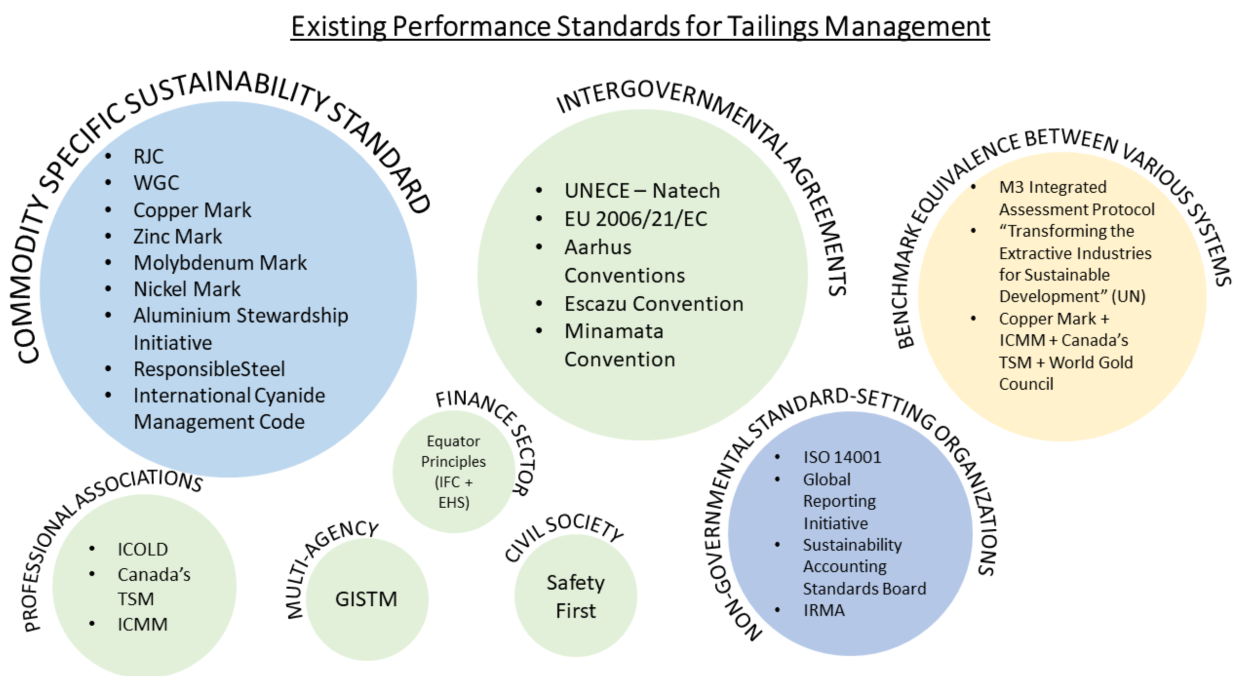

Figure 2. Existing performance standards for tailings management

Some of the initiatives are led by professional associations, for example:

- The International Commission on Large Dams, an international professional body, has released numerous bulletins on the safety, design, construction, operation, closure, monitoring and management of TSFs since the 1980s (Legge 1982; Bjelkevik 2023).

- The Mining Association of Canada’s Towards Sustainable Mining (TSM) programme, established in 2014, includes a Tailings Management protocol, supported by a table against which conformance is reported annually, and two guidance documents aim at implementing best practices around management of TSFs (Mining Association of Canada 2023). TSM works through national mining associations in nine countries, which require their members to adopt it.

- The International Council on Mining and Metals (ICMM), representing a third of the global metals and mining industry, published the *Tailings Management Good Practice Guide* (ICMM 2021a), providing information on how to manage TSFs, with management and engineering practices in line with the GISTM. ICMM also launched a Tailings Reduction Roadmap to reduce the production of tailings by its members through innovations across the mining life cycle (ICMM 2022).

A multi-agency approach was taken with the Global Industry Standard on Tailings Management (GISTM), developed by a multi-disciplinary expert panel with input from a multi-stakeholder advisory group and extensive public consultation (GTR 2023). It was launched in 2020 by UNEP, ICMM and PRI (which comprises more than 5,000 institutional investors representing more than US $120 trillion of assets).

- The GISTM was a result of an extensive review of current best practices on tailings management and was informed by existing standards cited above, as well as by findings of studies on past tailings dam failures and by extensive consultations (Oberle, Brereton and Mihaylova 2020).

- The GISTM focuses on good governance practices and good engineering practices across the life cycle of TSFs for LSM, also recognizing the critical role of stakeholder engagement. It is a voluntary governance standard directed to operators and is not intended to replace, but rather to complement, technical standards and jurisdictional legal requirements.

- From 2020, ICMM in its “Performance Expectations” has required validation, assurance and annual disclosure in relation to the GISTM at both the corporate and asset levels from all its members. ICMM has produced GISTM conformance protocols (ICMM 2021b) to support the assessment of conformance with the GISTM requirements.

- The GISTM may be used as a roadmap for countries wishing to establish an effective regulatory programme for tailings management (Squillace 2020) and as a catalyst for improving regulation of TSFs (Campbell *et al.* 2020).

- UNEP, ICMM and PRI are now working to establish a multi-stakeholder independent Global Tailings Management Institute (GTMI) (Oberle, Bateman and Kemp 2020; UNEP 2023g). The aim is to oversee the effective implementation of the GISTM and to manage an assurance framework where a TSF will be audited and certified against the GISTM by independent, third-party auditors. The GTMI could work to revise and improve the GISTM, taking into account feedback and critiques over time.

Civil society initiatives relevant to tailings management also play a significant role in the standards landscape. For example, in 2020 the non-governmental organizations Earthworks, London Mining Network and Mining Watch Canada released *Safety First: Guidelines for Responsible Mine Tailings Management* (“Safety First”), which was updated in 2022 (Morrill *et al.* 2022). Several independent experts contributed to the guidelines, and they are endorsed by multiple civil society organizations and tailings experts.

- Safety First calls for safety (not economics) to be the guiding principle in the design, construction, operation and closure of TSFs. Safety First specifically calls for bans of upstream-raised facilities, tailings disposal into water bodies, and construction of new facilities near communities. Moreover, Safety First requires independently guaranteed, reliable and readily available financial assurance and environmental liability insurance to cover the closure of storage facilities, as well as damage caused by a potential failure or chronic contamination. The guidelines also require mining companies to obtain consent for TSFs from potentially affected communities (which should be supported by independent technical experts) and call for extremely comprehensive release of information about the facilities.

Non-governmental standard-setting organizations also have instruments that are applicable to tailings management. These include, for example:

- the International Organization for Standardization's ISO 14001 standard on environmental management systems (ISO 2015);

- the Global Reporting Initiative’s (GRI) mining sector supplement, which contains entries for reporting on the volume of tailings produced and their risk (GRI 2023);

- the Sustainability Accounting Standards Board's Metals and Mining standard – designed for investors, lenders and insurers – which encompasses tailings management; and

- the Initiative for Responsible Mining Assurance (IRMA) Standard for Responsible Mining, which dates from 2018 and includes several requirements for tailings management in its chapter 4.1 (IRMA 2018). IRMA is a comprehensive voluntary assurance programme that offers independent third-party auditing at the site of the mine. IRMA in late 2023 launched consultations on revisions of its existing Mining Standard and Chain of Custody Standard (IRMA 2023a; IRMA 2023b).

Another category of instruments are commodity-specific sustainability standards.

- Some such standards are driven by concern about sourcing from conflict zones. For example, the Responsible Jewellery Council (RJC) Code of Practices (RJC 2019) contains requirements and prohibitions in relation to tailings management, and the World Gold Council's (WGC) Responsible Gold Mining Principles (WGC 2019) requires conformance to "widely supported good practice guidelines" for tailings management and includes an assurance framework and equivalency benchmarking documents for ICMM and TSM.

- Single-commodity sustainability standards include: the Copper Mark, Zinc Mark, Molybdenum Mark and Nickel Mark, which have adopted the GISTM as the standard for their tailings management (The Copper Mark 2023); the Aluminium Stewardship Initiative (ASI), which contains criteria for mine waste management as well as for air, water and soil pollution, including from spills and leakages (underpinned by third-party audit) (ASI 2023); and ResponsibleSteel™, which contains criteria on the management of wastes, by-products and production residues (ResponsibleSteel™ 2023).

- An International Cyanide Management Code has been developed to improve the management of cyanide at gold and silver mines, with certification of compliance with the voluntary code to be obtained from the International Cyanide Management Institute (ICMI) (ICMI 2021).

The finance sector also may require environmental and social performance standards in projects it finances. Perhaps the most widespread framework adopted by financial corporations is the Equator Principles (Equator Principles 2023). The principles have their origin in the environmental and social responsibility work by the International Finance Corporation (IFC) of the World Bank Group and the related Environmental, Health and Safety (EHS) guidelines (IFC 2007a). Tailings are also included in the IFC's EHS guidelines for waste management facilities (IFC 2007b).

There is no global treaty focused on mine tailings, but there are relevant regional intergovernmental agreements and resources. For example:

- The United Nations Economic Commission for Europe (UNECE) Convention on the Transboundary Effects of Industrial Accidents provides a legal framework for countries to develop and strengthen tailings safety, and it offers tools, guidelines and methodologies to strengthen tailings safety and management practices (UNECE 2023). The Convention, in force since 2000, requires Parties to identify hazardous activities and take measures to prevent accidents, and covers tailings and natural hazard-triggered technological events ("Natech") as well as abandoned mine sites (UNECE 2022a). The guidelines focus on safety principles throughout the life cycle of a TSF and include recommendations for governments, with a specific focus on transboundary cooperation. The German Environment

Agency in cooperation with UNECE has developed a methodology to support countries in practical implementation (Kovacs *et al.* 2020; UNECE 2022b). TSF mapping and the safety guidelines and methodology have been applied in the assistance and cooperation programme of UNECE, for example in the Danube River Basin and in Central Asia (UNECE 2022b).

- The Management of Waste from Extractive Industries Directive of the European Union (EU) (2006/21/EC), which must be implemented in national legislation by the EU Member States, contains requirements for the management of extractive waste. The EU further compiled "best available techniques" conclusions to support the implementation of the Directive (Garbarino *et al.* 2018). This is aimed at preventing and minimizing any adverse effects of tailings on the environment and human health. There is also a European standard (EN 16907-7:2018) on hydraulic placement of extractive waste, i.e. tailings (EU 2018).

- Other multilateral or regional agreements that are not specific to mining or tailings but that have relevant application include the Aarhus and Escazu conventions (on open access to information, public participation and access to justice in environmental matters) and the Minamata Convention on mercury (see section 3.2).

There are a multitude of standards and instruments that have similar objectives but that originate from diverse sources and have different applications and target users. This may lead to confusion and to duplicative reporting burden (UNEP 2023f). As a result, activities to benchmark equivalence between various systems are under way. These include:

- The M3 Integrated Assessment Protocol by the Mining, Minerals, and Metals Standards Partnership (comprising TSM, IRMA, the Responsible Jewellery Council and ResponsibleSteel™).

- Recent reports by the International Resource Panel and by the International Institute for Sustainable Development (IISD) in partnership with the Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development (IGF), which analyse the properties of many schemes of various types, noting the voluntary nature of many (IISD 2018a; UNEP 2020a).[3]

- The project of Copper Mark, ICMM, the Mining Association of Canada's TSM and the World Gold Council, which commenced in 2023, to streamline their individual voluntary standards into one consolidated standard to raise performance and simplify the standards landscape (ICMM 2023a).

- The 2020 initiative of the United Nations Secretary-General called "Transforming the Extractive Industries for Sustainable Development," which established a working group to align relevant efforts carried out across the United Nations system, coordinated by UNEP, the United Nations Development Programme (UNDP) and United Nations Regional Economic Commissions (UN 2021). The Secretary-General's Policy Brief on Transforming Extractive Industries for Sustainable Development calls for harmonization of national standards and further enforcement of clear regulatory frameworks (UN 2021).

[3] A weblink to a report in French on a similar theme is available at: https://www.systext.org/sites/all/documents/RP_SystExt_Controverses-Mine_VOLET-2_Tome-2.pdf.

- The proposal during the UNEA Resolution 5/12 consultation meetings to undertake a global assessment of existing instruments related to minerals and metals value chains.

Finally, the role of the State is key in setting legally binding requirements for miners as well as providing guidance (Department of Mines and Petroleum, Western Australia [DMP] 2013; DMP 2015; Australian Government 2016). It is not within the scope of this report to analyse individual State approaches and legislation for tailings management. However, good practices from individual States and regions can be found in the different reports prepared during the UNEA resolution 5/12 intergovernmental consultation process – in which stringent reforms may be seen particularly in regions that had suffered failures of TSFs causing significant harm (UNEP 2023a; UNEP 2023b; UNEP 2023c; UNEP 2023d; UNEP 2023e; UNEP 2023f).

Other resources that have examined national-level practices of tailings management show significant diversity from country to country in relation to legal frameworks and implementation (Mine Environment Neutral Drainage Program [MEND] 2017; Garbarino *et al*. 2018; IGF 2021a; Cacciuttolo and Atencio 2022; Emerman 2022; Baker, Thygesen and Haworth 2023).

Experts consulted during the development of this report emphasized that environmental management of mine tailings should be seen as a shared responsibility across government, the mining industry, local communities, civil society organizations and the scientific community.

Knowledge Gaps

This report does not intend to pre-empt the global assessment of existing instruments that was recommended during the UNEA 5/12 consultations, which would itself identify specific gaps. However, there have been several critiques of existing standards or their use, which are useful to note.

Member States have noted the need for wider adoption and implementation of the GISTM (UNEP 2023a; UNEP 2023b). The GISTM has seen significant uptake within the industry's safe tailings management frameworks, particularly through the efforts of ICMM. However, the GISTM has not had the same uptake within legally binding frameworks and may be less implemented by smaller-scale mining companies (UNEP 2023e). Implementation of the GISTM could be better supported, for example by the UNEA 5/12 Member State representative national focal points (UNEP 2023c) and by the planned Global Tailings Management Institute.

Limitations of existing standards have been recognized (UNEP 2023f). The GISTM has a limited focus, for example only covering TSFs for LSM (Joyce and Kemp 2020). Civil society organizations have criticized many current standards for not easily applying to existing storage facilities, not banning outright certain tailings storage practices, inadequate requirements for dam break studies, and lacking an enforcement regime, rendering such standards ineffective (McLaughlin 2022; comments raised by experts during consultations for this report).

Many have emphasized the importance of developing an independent verification mechanism for standards, as a mean to drive meaningful change, hold operators to account and avoid reinforcing existing asymmetrical power relations. An important challenge is moving away from self-reporting by industry, and imposing penalties for failures or inaccuracies in reporting (UNEP 2023e).

Experts during the development of this report raised a concern that over-reliance on specific standards may give a false impression of safety (for example, risks may arise in areas and from factors not addressed by the existing standards). Existing standards may lack future proofing, and their piecemeal nature, in the absence of a truly international instrument, presents challenges for harmonized practice (UNEP 2023b; UNEP 2023e). Current and future costs and effects of implementation of the various standards are under-studied.

A focus on greater application of tailings requirements through legislation or other binding means would strengthen the impact of standards (UNEP 2023a UNEP 2023c; UNEP 2023d; UNEP 2023e). Additionally, some States have noted that international agreements or international binding and standardized rules may be of benefit (UNEP 2023c; UNEP 2023e). National legislation may contain gaps (UNEP 2023a; UNEP 2023c; UNEP 2023d). In some locations, regulations may be outdated, inconsistent or otherwise inadequate to address the current risks and challenges associated with tailings management (UNEP 2023b).

Reference to existing standards such as the GISTM or IRMA (or equivalent content) as requirements in national legislation may strengthen the national regulatory framework and enhance uptake of otherwise voluntary standards (UNEP 2023d). National laws may also be amended, in line with recent precedents, to include specific criteria for the design and location of TSFs (UNEP 2023c).

States have also identified a specific gap in national regulatory regimes relating to financial guarantees covering safe tailings management and associated environmental liabilities. Full cost accounting addressing total life cycle costs, including direct and indirect costs and externalities, has been identified as another missing element in global tailings management (Roche, Thygesen and Baker 2017; Burritt and Christ 2021).

States have noted that increased multilateral leadership and multi-stakeholder engagement may assist in addressing power imbalances and industry resistance to State-led reforms (UNEP 2023b).

Strengthening government enforcement and institutional capabilities was seen as necessary in some regions for governments to enact and implement legislation effectively (UNEP 2023b; UNEP 2023d; UNEP 2023e). Governments and experts have suggested (in consultations for this report) that there is a large demand in the global South for investment in regulatory capacity and in studies about legislative and policy frameworks for tailings management to create effective policy guidance. On a national level, gaps are also observed in clarity and allocation of governmental responsibilities as well as coordination among agencies, noting that tailings management straddles several public sectors within national contexts (UNEP 2023a; UNEP 2023e).

Some countries have expressed a need for technical support to monitor and audit TSFs, as well as training courses and expert assistance regarding the technological aspects of tailings management, with low-cost technology described as a gap (UNEP 2023d; UNEP 2023e; expert consultations). Guidelines to assist technical review are available for parts of the tailings management life cycle (for example, environmental impact assessment), but there are gaps in implementation of best practices for other topics, such as establishing adequate mining waste and reclamation plans at the project design phase and identifying and managing abandoned/orphaned sites (UNEP 2023a).

Inter-State cooperation in exchanging best practices and lessons learned can be beneficial regarding the design, construction, operation, monitoring, safety of workers and communities, emergency response, closure of tailings deposits and circular economy (UNEP 2023a; UNEP 2023c; UNEP 2023e). Representatives from developing countries have noted that barriers may also include lack of access to the funding needed to work on tailings management (UNEP 2023b; UNEP 2023d).

Building on the GISTM, the opportunity for enhanced collaboration among international agencies has also been identified. These include, for example, the Associatión de Servicios de Geología y Minería Iberoamericanos, UNECE, UNEP, PRI, ICMM, IGF, multilateral environmental agreements and cooperation among regional country groupings (UNEP 2023c).

Gaps persist in transparency of data. Opportunities exist in enhancing disclosure, including through the Global Tailings Portal hosted by GRID-Arendal, to which contributions from States are currently a gap (UNEP 2023b). Public disclosure requirements alone may not lead to improved outcomes without more complex consideration and measures in place to support the capability of the receiving environment (considering, for example, low levels of literacy, low regulatory capacity, and/or high levels of corruption and inequity) (Kemp, Owen and Lébre 2020).

The independence of auditors, and inclusivity in industry decision-making processes (for example, including collectively governments, Indigenous Peoples, workers, impacted communities and civil society) have also been identified as gaps (UNEP 2023c).

Addressing transboundary effects of dam failures and the chronic impacts caused by storage of tailings (for example, to rivers and to air, soil and water quality) requires cross-border coordination that could be strengthened (UNEP 2023a; UNEP 2023c; UNEP 2023e). There is potential, for example, to promote application of UNECE´s guidance globally.

The confusing multitude of voluntary sustainability standards is itself causing a problem, undermining implementation at the national level (UNEP 2022; UNEP 2023a; UNEP 2023b).

The volume and composition of tailings generated, and improvements in tailings management practices, could be better included in existing traceability and certification schemes (Kinnunen *et al.* 2022; UNEP 2023b; expert consultations).

Ideas for possible future focus:

1) Undertake a **global assessment** of the existing tailings management instruments, cooperating with partners and diverse stakeholders, to identify good practices, gaps, and areas for improvement, as well as the effect (and cost) of implementation; this can support efforts to streamline or consolidate existing standards.

2) Continue work towards establishing the **Global Tailings Management Institute** and its role as an independent body in leading tailings management practices, with an emphasis on capacity-building, technical and legislative support, and sight of the GISTM with a focus on addressing identified gaps over time.

3.2 Artisanal and Small-Scale Mining Regulation

Artisanal and small-scale mining is a widespread economic sector providing livelihoods for more than 44 million people in developing countries, particularly in remote and rural areas (World Bank 2020). ASM produces up to 25 per cent of the total global diamond supply, 20 per cent of the world's gold supply, 80 per cent of the world's sapphire supply and 18-30 per cent of the world's cobalt supply (Organisation for Economic Co-operation and Development 2019).

Despite the economic importance of ASM, around 80-90 per cent of the mining activities and miners of this type are informal (i.e. unpermitted by law) (IISD 2018b; World Bank 2020); this is seen as one of the root causes for ASM's negative environmental and social impacts (IISD 2018b). The informality can be attributed both to a lack of comprehensive legislation specific to ASM, and to inadequate supervision of this sector (IISD 2018b), since in many countries ASM is either illegal or is legal but unregulated.

Several international-level agreements and initiatives are focused on best practices in ASM. In 2013, the Minamata Convention on Mercury was adopted as a legally binding international treaty to control the use of mercury, particularly in ASGM, which is recognized as the largest anthropogenic source of mercury emissions globally (UNEP 2018). The Minamata Convention requires parties with ASGM activity to develop National Action Plans, tailored to be context-specific, with the aim of reducing and, where feasible, eliminating mercury use (UNEP 2017).

The Minamata Convention also calls on State Parties to take further steps to formalize ASM and to build technical capacity to achieve the aims of the Convention. A guidance document focused on the management of ASGM tailings has been produced under the Convention (UNEP/MC/COP.4/INF/6; UNEP 2021), and examples of formalization at the national level can also be seen (for example, in Burkina Faso, Ghana, Guyana, Tanzania and Zambia) (World Bank 2016; UNEP 2021).

In 2005, UNEP established the Global Mercury Partnership, a collaborative global initiative aimed at protecting human health and the environment from releases of mercury, and now more specifically to support the implementation of the Minamata Convention (UNEP 2023h). The Partnership operates at the national level, with support for the implementation of National Action Plan projects, but also at the international level, through facilitation of information exchange, training and regional collaboration among countries (UNEP 2023i).

In 2018, mining ministers in Africa adopted the Mosi-oa-Tunya Declaration on Artisanal and Small-scale Mining, Quarrying and Development (International Conference on Artisanal and Small-scale Mining and Quarrying 2018). The declaration recognizes the key role of ASM in Africa's socio-economic development, calling for formalization and legalization of the industry as well as for improved, context-specific legal and regulatory frameworks for ASM. Miners are called upon to do all possible to avoid and minimize environmental harm caused by process chemicals, and governments are urged to strengthen effective oversight.

Other relevant reform initiatives relevant to ASM tailings management include:

- the Alliance for Responsible Mining's (ARM) Fairmined Standard, a certification system that sets social, environmental and economic criteria for responsible ASM practices (ARM 2014);

- the planetGOLD programme, funded by the Global Environment Facility (GEF) and led by UNEP, that works in more that 20 countries to make ASGM safer, cleaner (mercury-free) and more efficient (planetGOLD 2023); and
- Delve, a global online ASM data platform launched by the World Bank and Pact in 2017 to address the global data gap (Delve 2023).

As noted earlier, a key factor in improving the environmental impacts of ASM tailings management is the formalization of ASM activities – for example, through legal frameworks and licensing processes for ASM (IISD 2018b). Formalization of the ASM sector may not be a panacea (for example, if operators evade regulatory mechanisms, or where regulation lacks context-specificity) (International Conference on Artisanal and Small-scale Mining and Quarrying 2018). Formalization is more likely to enhance practices where the process engages ASM communities in bottom-up approaches; is accompanied by ASM miners having access to financial, technological and institutional support from the State; and provides clear benefits to the ASM actors (Salo *et al.* 2016; Siwale and Siwale 2017; UNEP 2021; Laing *et al.* 2023).

Knowledge Gaps

ASM is associated with many challenges (UNEP 2023a; UNEP 2023c; UNEP 2023d; UNEP 2023e), for which ASM-specific approaches are needed. However, it can be seen that the list of existing performance standards and governance initiatives set out in section 3.1 relate mainly to LSM and are not tailored to address ASM issues (UNEP 2023c).

Formalization and more effective regulation of ASM is a current gap, and specifically formalization in relation to mine closure, tailings management and land rehabilitation. Addressing this requires identification and inclusion of the needs of ASM communities and all relevant stakeholders. A lack of mapping of ASM locations can also present challenges to government regulation of ASM (UNEP 2023c; UNEP 2023e).

Some national laws do not delineate clearly between LSM, ASM and illegal mining. This can hinder efforts for reform, by criminalizing ASM operators or holding them to inapplicable standards (United Nations Office on Drugs and Crime [UNODC] 2022).

Environmental education may be lacking for ASM operators, related to tailings management and associated environmental impacts (UNEP 2023c; UNEP 2023e).

The Minamata Convention on Mercury provides a good example of promoting increased environmental awareness and good practices, but broader international approaches may be required, as ASM is not limited only to gold mining with mercury.

The relationship of ASM with environmental corruption and crime, and its relevance to tailings (for example, waste trafficking), is a topic that may benefit from further (open-access) research (UNEP 2023b; UNEP 2023e).

Ideas for possible future focus:

3) Support the elaboration of **tailored national measures to formalize** the ASM sector, building on successful approaches demonstrated by the Minamata Convention that are applicable to other types of ASM issues (in addition to mercury pollution from gold mining).

3.3 Environmental Impact Assessment for Tailings Management

Within a regulatory framework, perhaps the most important process that can affect the outcomes of tailings management is the environmental impact assessment (EIA) and subsequent (environmental) permitting phases. It is during these processes that most of the risks regarding tailings management are scrutinized, and agreed parameters and impact mitigation measures are determined. These administrative processes, usually required by law before a mining project is permitted, are also designed for stakeholders to have their say on the planned projects and to ensure transparency in the decision-making regarding mining projects, their impacts and project alternatives.

General EIA practice is typically well developed, and considerable research and precedent is available on how EIAs should be implemented. However, mining is a unique industry with processes, impacts and risks that requires special expertise and insight for the EIA to be successful, and tailings management is a sub-set within that sector.

Most mining EIA guidance documents cover a need to describe project alternatives (including options for tailings management) and to gather adequate environmental baseline data, which are important components. However, most guidance arranges the actual impact assessment section according to environmental receptors (air, water, soil, health, biodiversity, etc.), rather than by the mining processes that generate the hazards. This may hamper a focus specifically on tailings management.

There is no guidance document focused specifically on EIA for tailings. Where tailings considerations are included within a broader EIA for a mining project, the evaluation of relevant risks (and mitigation measures) specific to tailings management may lack detail or scrutiny. The long-term nature of impacts from tailings, including post-mine closure, may require particularly complex EIA predictive modelling, and methodologies. Uncertainties (for example, due to climate change or urban sprawl) should also be captured in tailings EIA and decision-making processes (GTR 2020).

Process concerns that arise over EIAs generally (not only in the field of mining) are also relevant to EIAs pertaining to tailings management. These include concerns about, for example, the quality and independent verification of the data presented, as well as meaningful public participation in EIAs and permitting decisions, including access to understandable information for relevant stakeholders, sufficient time and technical support to review, publication of comments, and rationale for which comments are implemented or not. Specialist insights are likely to be needed for technical review of submitted EIAs covering tailings management.

Guidance for technical review of EIA documents of mining projects includes the following:

- A guidebook prepared by Environmental Law Alliance Worldwide (ELAW) in 2010 is extensive in scope and is written mainly to help non-professional stakeholders to understand the EIA process and the nature of mining projects and to critically review EIA documents. It includes useful commentary relating to tailings (ELAW 2010).

- EIA Technical Review Guidelines for mining by the United States Environmental Protection Agency (US EPA), developed in 2011 in regional collaboration with five Latin American and Caribbean countries, provides support for those preparing and reviewing EIA documents. It includes tailings in its scope and contains an extensive section on requirements, standards, predictive tools and international codes for appropriate benchmarking (US EPA 2011). The Guidelines are also now under review to capture advancements in tailings technology and EIA methods.
- A guide on *Environmental Impact Assessment Procedure for Mining Projects in Finland*, published in 2015 to orient mining project developers, includes a specific section on tailings (Jantunen *et al.* 2015).
- The IGF provides guidance and supporting studies for governments for improving management of EIAs and related processes (IGF 2023).

Regional geology can result in several mining projects of similar nature – as well as supporting infrastructure and TSFs – locating in the same region at the same time. Project-specific EIAs may not appropriately address the cumulative and synergistic impacts of multiple projects, and multiple facilities being built close to each other. In some regions, strategic environmental assessment (SEA) has been increasingly used as a tool to support governments to take a higher-level approach to regional-scale or sectoral-scale planning of industries or multiple projects, or impacts on specific areas of concern, such as watersheds (UNEP 2004). Several SEAs of this type have been carried out (for example, in Australia, Canada, Ghana, Malawi, Mongolia, Namibia, Sierra Leone, South Africa, Suriname and West Africa) (Netherlands Commission for Environmental Assessment 2017).

Knowledge Gaps

While EIA literature is well-developed, a focus specific to tailings management within EIA guidance is lacking. This includes how impacts are assessed; how to choose the location for a TSF; the impact that the length of the licence might have on tailings management; and how to set monitoring and reporting requirements based on the EIA's findings (UNEP 2020b; UNEP 2023e). Other aspects that experts suggested may be overlooked in EIAs for tailings included: comprehensive environmental baseline data in and around the site proposed for the TSF; the chemicals planned for use in ore processing; different options for tailings storage taking into account the specific characteristic of the tailings likely to be produced as well as local conditions; dam breach studies; alternatives to minimize tailings volume; demonstration of "best available techniques"; energy use and emissions from processing and tailings management; and obtaining a "social licence to operate" the TSF. Use of life cycle assessments, such as for tailings circularity, could be improved (Beylot *et al.* 2022).

Guidance and templates for re-processing and re-mining tailings in old facilities and for relevant environmental baseline data requirements may also be lacking.

General gaps that arise with EIAs apply equally to EIA processes for tailings management – for example, public participation and transparency (UNEP 2023c; UNEP 2023d). Some regions report issues with the reliability and accuracy of data reported by auditors in impact assessments (UNEP 2023e), as well as challenges due to the low public trust in the mining sector (UNEP 2023a; UNEP 2023c). Experts consulted for this report considered that public trust in EIA processes may be low where too little time is provided for public review. Another gap is access to independent technical experts to assist civil society in evaluating

EIA studies. The implementation of an EIA peer review process was cited as a means of improving trust in EIAs.

Some countries have cited a gap in technical assistance to conduct strategic environmental assessments for mining projects and planning for tailings management at the strategic level (UNEP 2023e).

Gaps in incorporating climate change considerations in relation to tailings management EIAs were raised in both the expert panel workshops and during the UNEA 5/12 global consultations (UNEP 2023c). There is growing concern that climate considerations, including emissions from tailings management, are not adequately understood, nor addressed in current models of environmental risk assessments (Mebratu-Tsegaye *et al.* 2021). As temperatures rise and extreme weather events such as flooding and heavy rainfall, or arid conditions, become more frequent, further (open access) research is needed to understand how to make TSFs "climate proof" and Natech resilient (UNEP 2023b; UNEP 2023c; UNEP 2023d; UNEP 2023e).

ASM operations tend not to be subject to EIA rules, and so the opportunity to improve practices and set performance standards via an EIA and permitting process is not usually available for ASM. Existing EIA practices tend not to be tailored to ASM, and so can impose unachievable requirements for ASM operators, hindering formalization.

Ideas for possible future focus:

4) Develop **guidance on an EIA focus on tailings management**, incorporating issues such as ASM operations, re-processing of tailings, alternative tailings storage options, interaction between climate change and tailings management, and life cycle assessment.

4 Social Dimension

Although this report is mandated to focus on "environmental aspects of tailings management," Member States have emphasized the close and important intersection between environmental sustainability of the minerals and metal life cycle with human rights and social issues (UNEP 2023f). This section considers social aspects, with a focus on the inter-relation with environmental aspects of tailings management.

Historically, the management of tailings may have been treated as a strictly technical and environmental issue; however, catastrophic dam failures that have left hundreds of people dead and displaced have brought to the fore considerations of social and human rights. The management of mine tailings may be relevant to a broad spectrum of human rights. These include procedural rights (right of access to information, participation in decision-making and access to justice) as well as substantive rights to life, food, health, water and sanitation, and a clean, healthy and sustainable environment, as well as social and cultural rights (UNGA res. 76/300; International Institute for Environment and Development [IIED] 2002ac; Kemp *et al.* 2010; ICMM 2023b). Conflicts driven by mineral-related issues may pose substantial threats to security, peace and human rights. Environmental activism may also be suppressed in violation of the rights to expression and freedom of assembly (Hines 2022).

Mining processes and regulatory regimes should safeguard the rights and interests of groups that are historically marginalized and/or in vulnerable situations that may be disproportionately and negatively affected by adverse impacts of tailings; this includes women, Indigenous Peoples, children, workers, and environmental and land human rights defenders (IIED 2002a; UNEP 2022; ICMM 2023b).

The mining sector suffers from a legitimacy crisis, with low trust between communities and mining companies (UNEP 2023e). Experts consulted for this report noted that people most impacted were frequently excluded from decisions to build, operate, expand, or close TSFs, which can lead to conflict. For Indigenous Peoples, international law recognizes their inherent right to self-determination and to Free, Prior and Informed Consent (FPIC), which may also be transferable as best practice in engagement with non-Indigenous communities.

The Global Tailings Review considered the engagement of TSF operators with affected communities (Joyce and Kemp 2020). The resulting GISTM includes, alongside the environmental standards, social performance requirements such as due diligence throughout the facility life cycle, FPIC, meaningful community engagement and effective grievance mechanisms (GTR 2020; Joyce and Kemp 2020). Other social considerations are integrated throughout the GISTM, such as factoring into management decisions the knowledge of populations downstream of the TSF, incorporating social factors into EIAs, and addressing involuntary resettlement and the engagement of communities in emergency preparedness and response plans (GTR 2020).

Steps that can assist with disaster prevention from the failure of TSFs, where conducting in consultation with the relevant community, include (UNEP 2001a):

- mapping of risks and emergency response participants,
- identifying and regularly updating existing emergency warning and response plans, based on worst-case scenario modelling (such as "maximum credible earthquake" or "probable maximum flood," which consultees described as being used in Brazilian and Indonesian regulations),
- effectively communicating the plans to communities and emergency responders,
- periodically testing and reviewing those plans, and
- adopting throughout an inclusive multi-stakeholder approach involving the companies, the relevant communities (and their technical experts), as well as government agencies and local authorities.

Experts consulted for this report commented on the important role to be played by an independent grievance mechanism for stakeholders affected by TSFs. Best practice for such mechanisms has been outlined in Principle 31 of the United Nations Guiding Principles on Business and Human Rights, which stipulates that they be: (a) legitimate, (b) accessible, (c) predictable, (d) equitable, (e) transparent, (f) rights compatible, (g) a source of continuous learning, and (h) based on engagement and dialogue (UN 2011).

During consultations for this report, experts emphasized that transparency and community engagement is essential, among others, to ensure that mining activities foster sustainable development and that mining revenues are reverted to projects that benefit the surrounding areas, while lack of engagement and right to participation leads to certain communities being disproportionately affected by the impacts of TSFs.

There may be economic impact, for example where local livelihoods (such as in agriculture or tourism) or public infrastructure are adversely affected, or where revenues are not efficiently collected and managed, or are inequitably distributed. Cultural heritage sites may be at risk of harm. Social challenges from tailings deposits also arise due to land degradation, deforestation and other opposing interests around land use, such as protected sites, housing, arable land or livestock herding (UNEP 2023e). Experts consulted for this report raised how such impacts can lead to conflict within or between communities.

The risks may be especially acute for ASM operations, where a lack of regulation can lead to hazardous working conditions, risks entailed with the use of explosives, child labour, gender-based violence, and direct effects on communities from pollution and other poor environmental outcomes (Alliance for Responsible Mining 2013; World Bank 2014). ASM is associated with health crises, including cardiovascular disease and respiratory illnesses, leading to a reduction in life expectancy in communities engaged with ASM. Experts consulted for this report noted that women constitute a significant share of ASM workers and rural community dwellers who suffer health impacts due to proximity to mine tailings.

Knowledge Gaps

Effective public participation mechanisms in relation to decisions related to tailings management continue to be described as a gap (Joyce and Kemp 2020).

One important gap when it comes to the social dimension of tailings management is the lack of open-access research regarding the impacts on the health and well-being, as well as the human rights, of the surrounding communities.

While extensive work has been done to establish and operationalize FPIC protocols (see, for example, Cultural Survival and First Peoples Worldwide 2023), experts find that Indigenous rights and the role of FPIC and traditional knowledge remain overlooked in decisions about tailings management.

Emergency preparedness relating to tailings is an area highlighted as needing more work (UNEP 2023c). Gaps include comprehensive pro-active communication, including sharing of maps of sites and data on TSFs, with surrounding communities (UNEP 2023a; UNEP 2023e). Mandatory requirements for operators to develop comprehensive dam break and "worst-case scenario" studies are lacking, as well as a focus on early signs of failure, such as slippage or overtopping (UNEP 2023d). Remediation, compensation and insurance provisions in the event of a disaster are often overlooked in TSF planning decisions and regulatory frameworks.

Ideas for possible future focus:

5) **Raise community awareness** about nearby tailings sites (risks, environmental impacts, operator commitments, emergency preparedness) through public education campaigns, school programmes, and media coverage, in accessible formats and language.

6) Create mechanisms to guarantee, at the local level, the promotion of **inclusive multi-stakeholder dialogues**, consultations and independently managed grievance procedures that have meaningful influence on policy and decisions taken about tailings management, from design to post-closure land use, in a manner consistent with best international practices.

5 Operational Dimension

5.1 Tailings Storage Methodology and Design

The characteristics and volume of tailings from any mine are governed by the type and mineralogy of the ore deposit, as well as the mining and processing methods. The operations in which tailings are produced typically extend over several years or decades, while the TSF may remain in perpetuity. Good engineering practices covering long-term safety across the full life cycle of the facility – from project conception, design, construction, and operation to closure and post-closure – are essential (ICMM 2021a).

Even so, good management practice for TSFs requires continued emphasis that catastrophic events can still occur, and a focus on additional measures to minimize impact, with the aim of zero tolerance to human fatality (GTR 2020; Kemp, 2020). Impacts of climate change, such as extreme weather events, should be accounted for throughout the facility life cycle (see, for example, GTR 2020; Mckenna and van Zyl 2020).

The forms of LSM TSFs and the method of construction vary from region to region, considering the variability of local (climatic, topographic, seismic, regulatory) conditions (Franks *et al.* 2020; Williams 2020). However, a typical TSF for LSM comprises an earth dam impoundment, which may use mine waste as a construction material. Different methods may be used to raise the dams, including the most common upstream and downstream constructions and the less common centreline, hybrid and single-raise facilities (Franks *et al.* 2021). Experts consulted noted historical issues where construction in practice differs from agreed designs. The geotechnical stability of storage facilities is a vital component of tailings that has received significant attention and progress (GTR 2020; Oberle, Brereton and Mihaylova 2020).

The upstream method has been associated with increased geotechnical stability risks compared to other types of TSFs (Franks *et al.* 2021; UNEP 2021; Darling 2023). Thus, this method has been subjected to wide criticism, advice against its construction in seismically active areas, and outright prohibition of its construction in some countries, including Brazil, Chile, Ecuador and Peru (Emerman 2022).

Alternative tailings management methods (other than purpose-built dams) may focus on reducing the volume of tailings generated in the first place or changing tailings composition to a more benign content. These methods include: backfilling to underground spaces and open pits, stockpiling dewatered tailings, commingling of tailings and waste rock, or a combination of techniques (Ramsey and Martin 2009; Franks *et al.* 2021).[4] Experts consulted for this report emphasized the importance that the public, and relevant government authorities, should participate in decisions about alternative tailings disposal methods.

Dewatered methods (also known as "tailings filtering") have the advantages of increased water recovery (which can be reused in the processing operation, thereby reducing overall water use), smaller environmental footprint, reduced geotechnical and environmental risks, and potential for faster closure (and greater likelihood to have a solid landform more easily rehabilitated following closure). However, the use of dewatered methods is still much less common than that of conventional tailings due to capital and operating costs, energy requirements, challenges with high production rates, and unpredictability with changing ore properties (Watson *et al.* 2010; Franks *et al.* 2020). In arid and colder regions, dewatered methods may be attractive, and in areas with scarce water resources the collected water from filtering can

[4] For more examples, see Interstate Technology and Regulatory Council 2023.

be reused; however, more experience is needed to understand if dewatered stacking will work safely in humid climates (Araya *et al*. 2021a).

Dewatering methods also may require more dust suppression efforts. Handling, transport and storage of tailings – especially dewatered types – releases dust into the air. Dust emissions can be an occupational health issue, an environmental health issue, and can spread contamination, causing wider negative impacts on ecosystems, water bodies and human health. Tailings dust hazards include those related to inhalable particles, or radiation or chemical residues attached to the material. Besides the respiratory route, humans and biota may be exposed to dust-related contamination through edible plants, soil or water.

The backfilling of mine pits is another disposal method for tailings. Although some jurisdictions require or encourage backfilling of open pits, underground in-pit backfilling is less common. It is typically used in the final phases of an operation, often as co-disposal of tailings with waste rocks. There are different backfilling techniques, including rock, hydraulic and paste (Stone 2014). Backfilling is promoted as a preferred tailings management approach in some jurisdictions (for example, China, New Caledonia and the United States) (Guo 2022).

Benefits of backfilling include reducing geotechnical stability, and physical isolation of wastes; in some cases, in-pit disposal has also shown successful control of acid mine drainage (MEND 2015; Cacciuttolo and Atencio 2023). In-pit backfilling of tailings, however, can be associated with groundwater contamination, geochemical risks, as well as instability of underground spaces and pit walls, safety restrictions, surface deformation and sterilization of future reserves; thus, there is a need for thorough assessment on a case-by-case basis, and thorough characterization of the backfill materials (MEND 2015; Garbarino *et al.* 2018).

At a limited number of sites, tailings are disposed to freshwater bodies (lakes or rivers), fjords or the deep sea. This method has usually been employed where seismic activity, mountainous terrain or intensive rainfalls pose challenges to the safe management of TSFs (Kwong *et al.* 2019). However, very few countries globally permit this method of tailings disposal (IIED 2002b; Vogt 2013; Group of Experts on the Scientific Aspects of Marine Environmental Protection 2016; MEND 2017). This is due to serious concerns about the adverse environmental impacts, including smothering of habitat and biodiversity at the waterbed, and potential contamination with heavy metals, with bioaccumulation in fish stocks posing potential risks to human health (International Maritime Organization and UNEP 2013). Other environmental concerns with aquatic tailings disposal continue to be identified (Vare *et al.* 2018; Ramirez-Llodra *et al.* 2022).

Knowledge Gaps

Despite ongoing tailings inventory efforts – such as the Global Tailings Portal, a global registry under development by ICOLD (Bjelkevik 2023; Global Tailing Portal 2024), and UNECE's work on mapping and risk assessing tailings management facilities across the UNECE region (UNECE 2020) – significant knowledge gaps persist regarding the number and location of TSFs, as well as associated management practices and risks. Privately owned, state-owned and small-scale mining companies may be less likely to make voluntary disclosures to such inventories (Franks *et al.* 2021).

Concerns were raised during the intergovernmental consultations and in the expert panels regarding the extent to which current practices, guidance and legislation consider the impacts of climate change, such as extreme weather events (UNEP 2023b; UNEP 2023c; UNEP 2023f).

The need for continued investment in innovative practices and technologies for tailings management has been acknowledged (UNEP 2023a; UNEP 2023b; UNEP 2023c; UNEP 2023e), as well as best practices for dam design (UNEP 2023d; UNEP 2023e), and the use of machine learning and artificial intelligence methods in tailings management. Member States in some regions have expressed interest in international cooperation regarding technology and innovation exchange in this area (UNEP 2023c).

Gaps in guidance, regulations and the current understanding related to non-conventional tailings management methods (such as dewatered tailings management) were raised in the expert panel meetings convened to develop this report. Due to negative perceptions, including about costs, incentives may be needed for operators to adopt more innovative methods of tailings disposal (UNEP 2023e). More analysis that factors in the true costs of a TSF's maintenance, closure, and rehabilitation, and moving towards a whole-of-life long-term costing approach, may change the common perceptions regarding which methods present the most economic approaches to tailings management (Williams 2020; Cox *et al.* 2022).

Experts and Member States also mentioned a need for further open-access research to determine the long-term behaviour of alternative tailings storage options. This includes research on the stability of dewatered "dry stacked" tailings, notably in tropical and wet climates and highly seismically active areas (UNEP 2023a); on geochemical properties; and on the interactions with groundwater of backfill and in-pit disposed tailings over time. Experts stressed the importance of selecting the most suitable tailings management method based on case-by-case assessment, with consideration (including through EIA processes) of local conditions, climate change, tailings characteristics and local capacitation.

There are knowledge gaps in how to enhance independent oversight of tailings management (UNEP 2023e). Many governments emphasized a difficulty in verifying the data reported by mining companies regarding TSFs, due to a lack of capacity to verify audit reports, further aggravated by the scarcity of tailings experts in certain countries (UNEP 2023b; UNEP 2023c; UNEP 2023e). At the same time, there need to be incentives for reporting minor issues and risks before they can cause major failures (UNEP 2023e).

Ideas for possible future focus:

7) Develop **policies and legal requirements** regarding alternative tailings management technologies, incorporating local conditions, with the aim of minimizing tailings, separating reactive and non-reactive material, and incentivizing safe and environmentally sound alternative storage methods.

5.2 Chemical Stability of Tailings

Chemical stability and toxicity of tailings play a critical role in the "slow burn" chronic environmental impacts of TSFs. Disposal of tailings may result in seepage of contaminated waters. In addition, tailings may be radioactive or have direct toxic impacts on fauna and human health – for example, through dust, direct contact by humans or animals with tailings or affected water, or long-term chronic release of tailings into surface water or river systems (Griffiths *et al.* 2009; Plumlee and Morman 2011; Macklin *et al.* 2023).

Oxidation of sulphide minerals in sulphide-containing tailings can lead to metal and sulphate-contaminated drainage (acid mine drainage or neutral mine drainage) (Nordstrom and Alpers 1999). The contaminated drainage can spread into the environment as seepage through the base or the dams of a TSF, or as run-off from dam faces themselves constructed from sulphide mine tailings or waste rock. In the worst cases, it can continue for decades or even centuries unless prevention techniques are applied. Sulphide oxidation may dissolve and mobilize toxic metals, such as lead, arsenic, copper, and nickel, into surface and groundwater, causing significant impacts to human health and the environment.

Research programmes have been carried out globally to address the formation of contaminated drainage from mine tailings, and its effects and management.[5] A focused industry organization, the International Network for Acid Prevention (INAP), was established in 1998, releasing a *Global Acid Rock Drainage Guide* summarizing best practices and technologies (INAP 2018; INAP 2023). As a result, notable progress has been made in addressing the issue, including tailings management techniques (for example, basal, dam and cover structures; water management and treatment systems) (Garbarino *et al.* 2018; INAP 2018). Tailings characteristics, disposal type, and site-specific environmental and climatic conditions should be considered in selecting appropriate management techniques (Garbarino *et al.* 2018; INAP 2018; Williams 2020).

Significant research effort has focused on methods to characterize extractive waste to predict the drainage quality from tailings, and to inform their successful management (Öhlander, Chatwin and Alakangas 2012). A site-specific approach is important since every mine site has unique geological and environmental conditions. A versatile set of characterization and prediction methods has been developed (MEND 2000; Price 2009; EU 2012; INAP 2018), but consultations suggest that those characterizations could be better applied in practice to assess the long-term impacts of tailings. It is also notable that most of the studies and methods discussed earlier were designed for LSM, and although the same principles apply to ASM, it would be important to conduct studies that focus specifically on methods and solutions that are economically and technologically viable for ASM operators, since chemical seepage from ASM is clearly also a major problem (see ASM sections, above and below).

Knowledge Gaps

Several knowledge gaps concerning the chemical stability and chemical impacts of tailings were raised during recent intergovernmental processes (UNEP 2023c; UNEP 2023d; UNEP 2023e). These include implementation or knowledge gaps in: the characterization of tailings content and toxicity; prevention and management of release of contaminated drainage; understanding impacts and risks of tailings to surface and ground water and to the food chain; and robust, low-cost soil sampling or other methods to be used in monitoring impacts and toxicity (see, for example, UNEP 2023c; UNEP 2023d). Case-specific solutions that are tailored to local conditions and that account for climate change are required.

Many of the currently operated TSFs were built before the knowledge of today, and therefore their documentation has insufficient waste characterization data, and they lack the structure now considered necessary to achieve best environmental performance, or to address evolving challenges, such as Natech and the impacts of climate change.

One key gap in the management of tailings chemical stability is the lack of implementation of the current knowledge and best practices. Best practices could be added as requirements in national legislation to ensure that the current state of knowledge is applied in the operations.

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[5] Such as the MEND (Mine Environment Neutral Drainage) programme by Natural Resources Canada, and the MiMi (Mitigation of the Environmental Impacts from Mining Waste) programme by the Swedish Foundation for Strategic Environmental Research (MISTRA).

Ideas for possible future focus:

8) Require in standards and regulations **sufficient characterization of tailings** and audited reporting on indicators relating to chronic longer-term environmental impacts.

5.3 Chemicals Used in Processing Minerals

Various inorganic and organic chemicals are used in mineral processing, particularly in flotation, in leaching and in solid-liquid separation processing techniques. Residues of chemicals, such as sulphate from the use of sulphuric acid, remain in the water, which is typically pumped into the tailings storage site along with the tailings solids. Chemical residues may pose risks to the environment, for example by being toxic to aquatic fauna, changing the water quality (nutrients, salinity, acidity) or causing human health risks. Direct exposure of biota and humans to process chemicals can occur through direct use of tailings pond water or tailings-affected water bodies (Griffiths *et al.* 2009; Plumlee and Morman 2011).

Many mine sites use cyanide as a reagent in the recovery of gold and silver. The release of cyanide to the environment, or its improper handling, can pose a risk to human health, water resources and ecology (Johnson 2015; ICMI 2021). Significant health impacts have been detected due to the use of mercury in ASM (Plumlee and Morman 2011). Cyanide use to re-mine tailings previously contaminated with mercury can cause particularly adverse effects (UNEP 2021).

Another widely used reagent in flotation processing is xanthate. Xanthates degrade quickly in aqueous solutions, but one of the degradation products is carbon disulphide, which is hazardous to the environment, and xanthates are known to bioaccumulate in organisms (Bach *et al.* 2016). Xanthates are expected to degrade in the water circulation system at the mine site, so only minor reagent residues remain in the tailings slurry. However, little is known about actual xanthate emissions levels, since no measurement technique is currently available to detect low concentrations, which may nevertheless pose hazards to the biota. In addition, the degradation time of xanthates in cold climates is unknown (Bach *et al.* 2016).

In principle, the aim of mineral processing should be to use only the amount of process chemicals needed to make the process effective. The amount of reagent residues in the discharge can be decreased through water treatment (Kinnunen *et al.* 2018). More sustainable alternatives to the traditional process chemicals are under development, such as cellulose-based compounds that are renewable, biodegradable, and non-toxic, and can partially replace the use of traditional froth stabilization agents (Nuorivaara and Serna-Guerrero 2020).

Knowledge Gaps

Despite the available information on the risks of processing chemicals to the environment and the existing good practices in their risk assessment and water treatment, little attention is paid in some regions to <u>evaluating and analysing all chemical residues in tailings and process waters</u>, and to assessing their environmental impacts.

<u>Additional data</u> are needed in some areas, including data on xanthate emissions and long-term behaviour in the environment. Application of chemicals in Arctic conditions requires further specific consideration

and adaptation because of the sensitivity of the environment, the slower degradation times of chemicals and the higher bioaccumulation potential (Bach *et al.* 2016).

Future innovations – such as increased water circulation, re-mining and re-processing technologies – may take advantage of new chemicals or result in the release of emerging contaminants (including nutrients) that are not currently regulated and have properties and impacts that are poorly known or understood.

Countries have expressed interest in the development of low-cost methods of impact and toxicity monitoring, such as soil sampling, and in methods for managing the proliferation of heavy metals in the environment (UNEP 2023a; UNEP 2023e).

Ideas for possible future focus:

9) Promote research and adoption of standards on better assessing and **reducing environmental risks from mineral processing chemicals**.

5.4 Tailings Water Management

Mining is a water-intensive industry, and ore processing and tailings storage are no exception. Technical components of water management in TSFs include: water balance, release management and modelling, climate change and extreme events anticipation and mitigation, dam and pond management, seepage control, groundwater management, collection systems management, and monitoring and reporting (GTR 2020). Poor water management can lead to adverse environmental and social impacts, impacts to water quality, and even catastrophic failure of large-scale TSFs (Kemp *et al.* 2010).

Water treatment is usually performed when releasing wastewater from the mine site or recirculating the water back to the ore processing from the tailings or dewatering of the product. Increasingly, operations seek to keep water streams of differing qualities separated for recirculation and treatment. Water treatment is also used to recover elements of value from wastewater to gain better profit from mining operations (US EPA 2014; INAP 2018).

Various principles, standards and predictive tools can be applied to tailings water management (Welch 1997; ICMM 2014; Punkkinen *et al.* 2016; GTR 2020; ICMM 2021a). Planning should take into account how local conditions can change over time (for example, due to climate). Tailings water management needs to be integrated in design and management for the whole life cycle of mining. A wastewater management hierarchy can be applied: Avoidance > Reduction > Reuse > Recycling > Recovery >Treatment > Containment > Disposal (Victoria State Government 2023).

An essential part of water management transparency is reporting. ICMM (2023c) provides the outline of minimum reporting commitments for ICMM members, defines appropriate water reporting metrics and provides practical guidance for reporting. Additionally, IGF (2022) provides a surface water monitoring framework for governments, promoting participatory monitoring programmes.

Knowledge Gaps

In many jurisdictions, regulations may be inadequate on the control and monitoring of water management in relation to tailings management (UNEP 2023e).

Many mining operators have agreed to follow best practice guidelines on water management, but there is still noticeable variation of implementation between mines and regions.

An implementation gap also occurs where hydrogeological studies are not adequate to understand the tailings seepage below a TSF, and the subsequent flow and transport in groundwater. This may arise because subsurface conditions can be complex, and relevant studies require expensive drilling and assessment methods.

> Ideas for possible future focus:
>
> 10) Promote adoption of **water stewardship practices** in tailings management, tailored to the environmental and climatic conditions of the specific site, and incentivizing water recirculation and efficiency of mineral extraction from the water.

5.5 Artisanal and Small-Scale Mining Operational Aspects

Tailings management is often neglected in ASM (Amedjoe and Gawu 2013; UNEP 2021). Although ASM activities are diverse, some common factors contributing to adverse environmental impacts of ASM include: lack of legislation and regulation; lack of mechanization; use of rudimentary techniques; lack of a skilled workforce; lack of access to geological data, capital and equipment; and lack of awareness about environmental issues (IISD 2018b).

Different technical solutions and good practice guides to decrease the environmental impacts of ASM exist (UNEP 2021). As noted in section 3.2, efforts are under way to avoid the generation of mercury-contaminated tailings in the first place. For old tailings sites being re-mined, remaining mercury should first be removed, and cyanide for re-processing should be used only by trained miners.

Capital is needed for miners to invest in safer and more efficient mining methods, while access to modern equipment can increase productivity and reduce environmental impacts. Accessing capital can be challenging due to the informal nature of the ASM sector (UNODC 2022; USAID 2022).

In some cases, ASM tailings have been used as construction material (for example, in bricks and cement), a practice that in theory would decrease the use of primary resources and enhance the circularity and sustainability of ASM; however, if the material retains toxic content, this may also have potentially significant adverse environmental and health impacts (Velásquez *et al.* 2022).

Knowledge Gaps

There appears to be an implementation gap, where good ASM tailings management practices exist but have not been commonly applied. There is a need for policy approaches to be informed by local political, socio-economic, cultural, environmental and other site-specific contexts of ASM (IISD 2018b; UNEP 2021). This can be challenging where ASM operations are clandestine or widely scattered.

Access to geological data supports informed decision-making about where to mine, reducing the environmental impact and increasing efficiency. But geological data pertaining to ASM resources are often non-existent or hard to understand due to their technical nature. Capacitation is needed for the acquisition and use of geological data and for the use of more efficient mining and processing technology (UNEP 2023e). Lack of scalable and affordable technology is another gap.

Experts consulted for this report considered that more research is needed into the benefits and risks of re-utilization or re-processing of ASM tailings.

Ideas for possible future focus:
11) Develop strategies to facilitate the ASM sector's access to geological data and to capital to support techniques and equipment that **reduce toxins and wastes**.

5.6 Circularity in Tailings Management: Re-mining and Re-processing of Tailings

With increased demand for metals, higher metal prices, and declining ore grades in primary deposits (UNEP 2022), more interest has been shown in evaluating whether legacy tailings sites could be assets (Kinnunen and Kaksonen 2019; Araya *et al*. 2021b). It may be cost effective to re-mine and re-process existing tailings to recover valuable elements (such as gold) initially left in the tailings due to limitations of the processing methods of the time, or to extract minerals not previously targeted, such as rare earth elements or uranium (Ogola, Shavhani and Mundalamo 2017; Araya *et al*. 2021b; International Atomic Energy Agency 2021). Studies have explored the potential of tailings as a source of critical minerals in the European context, and the EU Extractive Waste Directive (2006/21/EC) encourages recovery by recycling and reuse (where environmentally sound).

Re-mining of old tailings enables remediation of the sites, decreasing the long-term environmental and social impacts. Since the tailings are previously processed, re-processing uses less energy, has lower greenhouse gas emissions, and creates the likelihood of little or no further land degradation (Maest 2023).

On the other hand, re-processing is a costly operation that involves risks. Companies may not remediate the previous environmental and social impacts. Furthermore, re-processing has the potential to cause new impacts, due to the release of contaminants into the environment, high demand for energy and water, and production of new types of extractive wastes (Adrianto and Pfister 2022). It also compounds previous impacts suffered in the same area and by the same communities (UNEP 2023e). Even when tailings are re-processed with the intent of extracting new metals, there will remain plenty of waste, needing tailings management, in line with the points raised throughout this report. There may also be safety risks if ASM miners seek to re-mine illegally in unsupervised TSFs (Baker, Thygesen and Haworth 2023).

Re-processing that involves the manipulation of slurried tailings can lead to instability or overflow of TSFs, or even a dam failure (Maest 2023). Such risk alone can cause social distrust of these types of projects, which means that they need to be preceded by extensive communication and public participation strategies (in a process separate from that for the original mine). Where the location is on or near Indigenous lands, FPIC from those communities is required. Prior EIA should also be conducted to analyse the environmental and social burdens of the project.

One factor that has caused reservations around re-processing of tailings is the lack of detailed guidelines and best practices surrounding EIA for the re-mining of tailings (Maest 2023). This may mean that these types of operations could be undertaken with limited regulation, which risks causing greater environmental and social impact – as was noted by experts during consultations for this report. In some countries, re-mining does, however, require a similar permitting process as in establishing a new mine, which may restrict interest in tailings valorization (Kinnunen and Kaksonen 2019).

There is also opportunity to repurpose certain tailings for use in the construction industry as sand (called "ore-sand") (Golev *et al.* 2022; Okane 2023). However, the practice has not yet been widely adopted, mostly because the cost of the repurposing process makes it difficult to have a product that is competitive in price and quality when compared to conventional materials; this is especially the case if there is no local market, which implies high transport costs (and associated environmental impacts) to convey the product to the buyer (Rogers *et al.* 2023). There may also be environmental and health implications if the tailings are not properly treated to remove toxicity (Velasquez *et al.* 2022), as well as adverse economic impacts from the large generation of construction materials on the market of ASM sand miners (UNEP 2023b; UNEP 2023c).

Any processing activity requires large investments, and the viability of re-processing may be finely balanced, depending on the scale of the operation and on the recoverability and value of residual metals (Kinnunen and Kaksonen 2019).

Knowledge Gaps

The activities of re-processing tailings are relatively new. Although the outlook is promising, more research is needed to predict, understand and prevent the potential adverse effects of re-mining on the environment, communities, and workers, to inform policy development in this area (UNEP 2023a; UNEP 2023b; UNEP 2023e; UNEP 2023f).

Establishment of "best practices" regarding circularity in tailings would be beneficial. Several countries have designed pilot projects or regulations to incentivize the reduction of waste or reuse of tailings in another industry (examples given during consultations included Algeria, Brazil, Chile, Finland, Indonesia and Sri Lanka) Learnings from these experiences could be shared with other countries (UNEP 2023b; UNEP 2023c; UNEP 2023d).

Existing regulatory frameworks may form barriers, such as conflicts between tailings re-processing and international treaties on hazardous waste, gaps in how domestic permitting systems for production of construction materials and metals produced from the same mine should be managed, and other policies that hinder reuse of tailings as construction materials (for example, transport emission restrictions, prohibition on the use of heavy metals required for secondary processing) (UNEP 2023b; UNEP 2023c).

Life cycle assessment is not commonly required in re-processing project planning but would assist in weighing the benefits of re-processing against the impacts generated throughout the entire life cycle (Adrianto and Pfister 2022). Studies comparing the energy and water use and the environmental, social, and economic effects for re-processing operations, compared to new mines, would also be helpful.

There is a need to understand if recycling or production of by-products useful for other industries (such as ore-sand) may obviate the need or interest in re-processing (UNEP 2023c). To make these determinations, experts consulted during the development of this report highlighted that it would be necessary to improve current practices on sampling and characterization of tailings for re-mining (UNEP 2023a). The lack of knowledge of the exact materials contained in tailings is considered one of the greatest challenges for the uptake of the re-mining process, since many mining sites lack detailed records dating back to the construction of their dams (Kinnunen and Kaksonen 2019). Mapping of potential sites, and upskilling around re-processing feasibility studies, are also gaps (UNEP 2023e).

Ideas for possible future focus:

12) Develop **policy incentives for re-processing of tailings** (where environmentally appropriate) and research and address the feasibility, potential adverse environmental effects, and regulatory barriers or conflicts with other legal obligations.

5.7 Circularity: Tailings Reduction and Designing Out Waste

An obvious pathway to reduce the environmental impacts, risks and costs of TSFs is to produce less tailings in the first place. A primary means of doing this would be to reduce the overall demand for metals and minerals, including by shifting away from disposables or over-consumption and improving recycling (UNEP 2023e).

Another approach is to minimize tailings from mining. This is the topic of ICMM's Tailings Reduction Roadmap, which builds on a landscape review of available, emerging and prospective methods and technologies to maximize ore and mineral recovery, minimize waste and produce more benign tailings (ICMM 2022). The roadmap lays out nine prioritized technical solutions that could have a tailings reduction impact, such as ore sorting, coarse flotation, non-chemical extraction, no-waste mine architecture, mining methods, smart comminution and in-situ leaching. Waste valorization and a tailings data platform are also covered (see section 5.6).

A merger of business models from several industries (such as construction, industrial minerals, agriculture and energy) in relation to a common ore deposit may also be an effective approach to reduce mining waste. In addition to "ore-sand" (discussed above), other uses of tailings (sometimes known as "development minerals") have included bricks, tiles, cement substitutes, concrete aggregates, jewellery, plasterboard, soil enrichment and ceramics (Lohmeier *et al.* 2021). These are often for local markets and use (given their high volume and moderate value) and can provide positive local economic diversification. If such reuse is designed in the process from the start, the likelihood of economic viability increases due to reduced costs.

The ACP-EU Development Minerals Programme, co-sponsored by UNDP, is a capacity-building initiative that aims to build the profile and improve the management of development minerals in Africa, the Caribbean and the Pacific (UNDP 2023). Other innovations also may be emerging. One expert consulted for this report discussed microbial activity in tailings as a potential opportunity and understudied nature-based solution.

ASM can also involve innovative reuse of tailings. Experts consulted for this report cited examples of artisanal soap, bricks, ceramics and handicrafts being produced from ASM tailings.

Knowledge Gaps

There is a need to innovate in thinking and practices around mine design, both to incentivize more efficient mining and to enhance recycling options for tailings (UNEP 2023b; UNEP 2023e).

Potential barriers to the re-purposing of tailings, and associated risks, need to be better identified (such as economic viability, level of hazard and toxicity, transport distances, quality control issues, business model diversification, institutional framework) (Kinnunen *et al.* 2022; UNEP 2023a; UNEP 2023e).

Consumer awareness regarding mine waste may also be a gap. Improvements in mine practice could be encouraged through educating the public on metals demand and the consequences of mining, with the aim of reducing demand, particularly for metals sourced with unsustainable tailings practices (UNEP 2023b; UNEP 2023c).

There is a need to conduct life cycle assessments to compare solutions, including case scenarios where waste is designed out using different methods and others where it is not.

Ideas for possible future focus:

13) **Promote guidance and policies to maximize the utilization and valorization of the mined materials**, "designing out" waste from the outset, and supporting the creation of traceable and economically viable circular economy systems spanning multiple industrial sectors around mining projects, while ensuring the viability of the primary mining operation.

14) Improve **consumer awareness** about mine waste and the circular economy, through public education on metals demand and the consequences of mining; also, support or develop metals **traceability/sustainability programmes that include tailings management**.

5.8 Closure and Reclamation

Mining projects have an inherently limited lifetime. However, as noted by experts during the consultation process for this report, a particular challenge with mine closure is that tailings persist – potentially in perpetuity. When a mine site is decommissioned, storage facilities containing the tailings are generally not dismantled. Even if such a TSF were properly maintained in perpetuity, following all best practices for risk reduction, it would be impossible to reduce the risks of failure to zero; this highlights the paramount importance of reducing the severity of the *consequences* of facility failure (Vick 2014a; Vick 2014b; GTR 2020; Oberle, Brereton and Mihaylova 2020).

The Safety First report calls for monitoring, maintenance and review in perpetuity or until all credible failure modes have been eliminated (Morrill *et al.* 2022). In practice, regulatory frameworks lack obligations for the continuous monitoring, risk management and maintenance of TSFs after a certain period.

Significant emphasis has been placed on mine closure management in recent years (including financial guarantees, baseline data collection, land reclamation and long-term environmental monitoring), by both the industry and governments worldwide. The World Bank has released a mine closure toolbox for governments, which includes consideration of tailings (World Bank 2021). Best practice guidance is also available for preparing mining closure plans for an individual project (Asia-Pacific Economic Cooperation 2018; Anglo American 2019; ICMM 2019; EU 2021). Mine closure management software is available, and a wealth of research on mine closure is available through proceedings of Mine Closure conferences organized since 2006[6].

Evolving best practice emphasizes the importance of integrated mine closure planning and tailings management, throughout the project's life cycle, including at the outset of the mine project (the "Design and Operate for Closure" principle); in this way, operators know early on if they need to treat tailings differently (for example, in order to be able to use some by-products in closure) (ICMM 2019; GTR 2020).

The GISTM requires operators of TSFs to report the estimated costs of planned closure, early closure, reclamation and post-closure of a facility. It also requires that these costs be reviewed periodically, to confirm the availability of adequate financial guarantees before mining operations begin, and throughout the life cycle. Miners have historically underestimated the costs required (IGF 2021b; Lilford and Haque 2023).

In many examples, long-term closure and reclamation of TSFs are overlooked during the initial design, and closure considerations are divorced from the facility construction and operation. This leads to higher life cycle costs, reduced performance and increased risk (McKenna and van Zyl 2020). Few TSFs have been successfully rehabilitated, with challenges including the technical difficulty and high costs of capping wet and soft tailings deposits, particularly at the end of operations when revenue is no longer produced (Williams 2020).

Lengthy time periods between project planning and project closure in the mining industry can cause evolving issues to be missed, such as climate change risks that are unlikely to occur immediately but may affect closure plans in the long term. This is why best international practices incentivize progressive or early closure (GTR 2020). As global temperatures warm and as water resources become more scarce, rehabilitation of vegetation to its previous form gets significantly harder (Mebratu-Tsegaye *et al.* 2021).

Knowledge Gaps

During consultations, many regions highlighted gaps associated with mine closure and the closure of TSFs, including the inadequacy of closure plans and financial guarantees and the inaccurate costing of closure (IGF 2021c; UNEP 2023a; UNEP 2023b; UNEP 2023c; UNEP 2023d; UNEP 2023e). Experts consulted for this report also described company liquidation, transfer of mine ownership, and complex corporate structures, as barriers to closure obligations being implemented.

Governments consulted have described gaps including: guidance for governments regarding mine closure as it relates to TSFs, particularly in the design phase (IGF 2021c; UNEP 2023a) and understanding of adverse social and economic impacts of mine closure as it relates to tailings (UNEP 2023c). Governments also describe lacking capacity and experience in relation to mine closure, robust practices around community involvement, and closure registries (IGF 2021c).

Regulatory gaps to manage mine closure and reclamation in an effective way for TSFs include assessment of closure commitments during the licensing process, setting clear and long-term post-mining legal

[6] Organized by the Australian Centre for Geomechanics: https://papers.acg.uwa.edu.au/f/mineclosure.

obligations for operators, including rehabilitation and post-closure monitoring of facilities and underpinned by financial guarantee (IGF 2021c; UNEP 2023b; UNEP 2023c; UNEP 2023d; UNEP 2023e).

There may be transparency gaps, where mine closure plans and details about financial guarantees are not subject to public input or publicly accessible. Lack of engineering, construction and tailings disposal records for existing TSFs can also be an issue for closure management.

The effect that climate change, Natech or other evolving issues will have on the closure planning for TSFs can be overlooked, especially due to the lengthy time periods between project planning and project closure in the mining industry.

Ideas for possible future focus:

15) **Promote adoption of current best practices in mine closure management**, including continuous progressive closure, factoring in social, economic, and environmental impacts including by public participation, considering longer-term risks such as climate change and Natech, setting clear post-mining legal obligations for operators in relation to TSFs, including long-term monitoring programmes or post-closure uses of the site, and properly costed financial guarantees.

5.9 Addressing Legacy Sites

Legacy sites are a major international environmental problem related to mining (UNEP 2001b; UNEP 2023a; UNEP 2023b; UNEP 2023c; UNEP 2023d; UNEP 2023e). “Legacy sites” in relation to tailings refer to “orphaned” storage facilities (i.e. where the owner cannot be found) or “abandoned” storage facilities (i.e. where the owner is known but is financially unable or unwilling to carry out rehabilitation and is beyond the government’s enforcement jurisdiction) (Nash 2020).

Unmanaged legacy sites present risks to local communities and biota. Their environmental impacts can include contamination of soil and water (through drainage contamination, toxicity, radioactivity, etc.), dust problems or loss of land use. There are also safety and health risks, with populations living close to structures that may be unsafe, unsupervised and at risk of failure, especially as urban populations spread (WMTF 2023).

Many legacy sites arise from mines that have been closed with no clear legislative requirements for closure, or that have been abandoned (in the absence of a financial guarantee). In such situations, site rehabilitation falls on State or municipal funding mechanisms, which may be challenging as rehabilitation is costly and requires state-of-the-art knowledge and techniques, tailored to the specific site (Nash 2020).

Governments have carried out inventories of legacy TSFs as well as assessments of the potential risks posed by these sites to human health or the environment, to enable prioritization of site rehabilitation (EU 2006; National Orphaned/Abandoned Mines Initiative [NOAMI] 2015; NOAMI 2016; Nash 2020; NOAMI 2023). Useful guidelines exist for this purpose (US EPA 2000; Stanley *et al.* 2011; DHI 2012; US EPA 2020). Cataloguing legacy tailings can be difficult as data may be limited and of unverified quality, and site investigations will be required (Nash 2020). Identification of legal mine owners and historic liabilities also presents challenges (UNEP 2023a). The global scale of the legacy TSFs is largely unknown, although initial impressions are daunting (UNEP 2023a).

The most efficient way to diminish future impacts from legacy sites would be to decrease the volume of tailings produced and deposited, through resource efficiency, promotion of re-mining and circular economy (Nash 2020; see also sections 5.6 and 5.7 on "Circularity"). Likelihood of future legacy sites can also be reduced by modern legislative and regulatory approaches, including requiring industry contributions for clean-up funds, extended liability provisions, properly costed financial guarantees, and following good practice guidelines focusing on safe closure and rehabilitation of sites (Nash 2020).

In addition, databases, such as the Global Tailings Portal, will help keep track of existing tailings dams (GRID-Arendal 2019). However, such databases include only limited data and relate to TSFs for LSM. Similar approaches are needed for ASM tailings deposits.

Knowledge Gaps

A major gap in many countries is in documentation of the location, size, composition and risks (including climate and Natech) associated with legacy TSFs (UNEP 2023a; UNEP 2023b; UNEP 2023e). Innovative technologies, such as artificial intelligence remote technology, may be helpful to identify and monitor legacy sites (UNEP 2023c; UNEP 2023d).

After closure, legal responsibility for TSFs often remains uncertain due to the lack of legislation imposing long-term liability on operators, or financial assurance to meet liabilities at the operator's cost, if the operator abandons the site (UNEP 2023c). It is difficult for a State otherwise to meet the liabilities, as requisite funds, expertise and site-specific knowledge may be lacking (UNEP 2023c; UNEP 2023d; UNEP 2023e).

Ideas for possible future focus:

16) Continue to investigate where useful minerals may occur in existing tailings, build tailings **inventories** (such as the GRID-Arendal Global Tailings Portal), and develop guidance on **best practices for reclamation of legacy tailings** sites, including strategies to deal with the liabilities created by legacy sites.

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