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Safety of the Tailings Management Facilities in the Danube River Basin

Technical Report

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Abstract: Safety of the Tailings Management Facilities in the Danube River Basin

The surface water bodies of the Danube River Basin (DRB) were severely damaged by several major accident events at industrial and mining tailings management facilities (TMF) in the last two decades. These disasters dramatically demonstrated how catastrophic consequences the inappropriate operation of TMFs might have on the adjacent aquatic environment, population and socio-economic goods. There is a substantial number of TMF in the basin where adequate safety conditions should be ensured. The Danube countries, under the umbrella of the International Commission for the Protection of the Danube River, jointly implemented the Danube TMF project to address these challenges.

The overall objective of the project was to contribute strengthening the technical and management capacity at the concerned facilities and responsible authorities by providing them with practical tools for self-assessment and inspection, respectively. This will ensure that in the medium term a common set of minimum TMF standards and safety requirements are respected in the DRB so that the overall TMF safety is improved and the population and water bodies are protected.

This report presents the technical outcomes of the project. An important result is the developed Tailings Risk Index methodology. It combines hazard and risk factors and considers the exposure of the population and the environment to TMF accidents. Moreover, a previously developed Checklist methodology was updated and enhanced to evaluate TMF safety conditions and recommend measures for their improvement. Competent authorities, TMF operators, concerned stakeholders and the public in the DRB and beyond are encouraged to apply these tools. Furthermore, an assessment of historical TMF accidents is provided demonstrating the severity and spatial dimensions of recorded past accidents. Finally, a preliminary TMF inventory complied for the DRB is presented, which includes both TMF mapping and risk assessment.

Kurzbeschreibung: Sicherheit der Rückstandsmanagementanlagen im Donauraum

Die Oberflächengewässer des Donauraums (DRB) wurden in den letzten zwei Jahrzehnten durch mehrere schweren Unfälle von Bergbau- und Industrierückständeabsetzbecken (TMF) schwer beschädigt. Diese Fälle haben auf dramatische Weise gezeigt, welche katastrophalen Folgen der unangemessene Betrieb von TMFs für die angrenzende aquatische Umwelt, die Bevölkerung und sozioökonomischen Güter haben kann. Es gibt eine beträchtliche Anzahl von TMFs im DRB, bei denen angemessene Sicherheitsbedingungen gewährleistet sein sollten. Die Donauländer haben unter der Koordination der Internationalen Kommission zum Schutz der Donau das Donau TMF Projekt gemeinsam umgesetzt, um diesen Herausforderungen zu begegnen.

Die übergeordneten Ziele des Projekts bestanden darin, zur Stärkung der technischen und Managementkapazitäten in den betroffenen TMFs und zuständigen Behörden beizutragen, indem ihnen praktische Instrumente zur Selbstbewertung bzw. Inspektion zur Verfügung gestellt wurden. Dadurch wird es sichergestellt, auf mittelfristig ein gemeinsames Verständnis von Mindeststandards und Sicherheitsanforderungen im DRB eingehalten wird, so dass die allgemeine TMF-Sicherheit verbessert und die Bevölkerung und die Gewässer geschützt werden.

Dieser Bericht präsentiert die technischen Ergebnisse des Projekts. Ein wichtiges davon ist die entwickelte Tailings Risk Index-Methode, die Gefahren- und Risikofaktoren kombiniert und die Exposition von Bevölkerung und Umwelt gegenüber TMF-Unfällen berücksichtigt. Darüber hinaus wurde eine zuvor entwickelte Checklistenmethode aktualisiert und verbessert, um die TMF-Sicherheitsbedingungen zu bewerten und Maßnahmen zu deren Verbesserung zu empfehlen. Zuständige Behörden, TMF-Betreiber, betroffene Interessengruppen und die Öffentlichkeit im DRB und darüber hinaus werden aufgefordert, diese Instrumente anzuwenden. Darüber hinaus wird eine Bewertung historischer TMF-Unfälle bereitgestellt, aus der die

Schwere und räumliche Dimension aufgezeichneter vergangener Unfälle hervorgeht. Abschließend wird ein für den DRB entwickeltes, vorläufiges TMF-Inventar vorgestellt, das sowohl die TMF-Kartierung als auch die Risikobewertung umfasst.

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List of abbreviations

BAT	Best Available Techniques
CRF	Credibility Factor
DRB	Danube River Basin
DRPC	Danube River Protection Convention
EC	European Commission
EU	European Union
EWD	Extractive Waste Directive
FD	Floods Directive
FoS	Factor of Safety
GIS	Geographic Information System
ICMM	International Council on Mining and Metals
ICOLD	International Commission on Large Dams
ICPDR	International Commission for the Protection of the Danube River
IED	Industrial Emissions Directive
JEG	Joint Expert Group
MS	Member States
MSRF	Meeting Safety Requirements Factor
PAR	Population At Risk
PGA	Peak Ground Acceleration
PRI	Principles for Responsible Investment
TEI	Tailings Exposure Index
TEIA	Transboundary Effects of Industrial Accidents
THI	Tailing Hazard Index
TMF	Tailings Management Facility
TRI	Tailings Risk Index
UBA	German Environment Agency
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme
WFD	Water Framework Directive
WHC	Water Hazard Class

Summary

The dramatic accidents in the last two decades worldwide but also in the Danube River Basin (DRB) have shown that failures of Tailings Management Facilities (TMFs) can lead to major catastrophes for both human health and environment. Although safety conditions have been significantly improved over recent last decades in many countries thanks to strict requirements and respective measures, the safety of a number of TMFs is still lower than expected, especially due to economic constraints and lack of capacity.

Furthermore, a steep increase in mining activities over the next decades is expected, including an increase in the number of TMFs, as smart and advanced technologies will force a dramatic rise in demand for specific metals like cobalt, copper, lithium and nickel. Thus, society may also have to face an increasing risk of TMF failures with potential casualties and ecological damages if TMF safety is not managed appropriately, i.e. in compliance with standards and taking climate change impacts into account.

More than 300 TMFs are located in the DRB, for which adequate safety conditions and measures have to be put in place. Past accidents at Baia Mare (Romania) in 2000 and Ajka (Hungary) in 2010 dramatically demonstrated how serious the impacts of inappropriate TMF operation might be on people, environment and water resources. These events call for the development and implementation of consistent and harmonised management strategies, practical safety assessment tools and suitable safety measures complying with a minimum set of standards throughout the DRB. The International Commission for the Protection of the Danube River (ICPDR), being the organisation in charge of transboundary water management in the DRB, implemented the Danube TMF project to help Danube countries cope with these challenges and improve safety conditions of the TMFs.

Within the framework of former pilot projects of the German Environment Agency (UBA), a TMF-Methodology was worked out to support regional and local assessment of TMF safety. The methodology comprises an index-based evaluation of the hazard potential for a large number of TMFs, the so-called Tailings Hazard Index (THI), and a detailed checklist for the safety analysis of individual TMFs. Building on the strengths of the methodology but also improving and adapting it based on up-to-date technical knowledge and best available techniques (BAT), Danube countries are provided with a set of practical tools to improve safety conditions of TMFs and to strengthen the capacity of operators and authority inspectors.

The THI has already proved its usefulness in directing limited country resources (financial and personnel) to TMFs representing the highest hazard potential (e.g. in Ukraine). The underlying criteria used for the THI approach have been improved by taking up the results of a historical TMF failure analysis. As the THI takes only hazard potential into account, the potential impacts of individual TMF failures posing different threats to the environment and population are not considered. This problem has been solved by defining a potential risk zone in the vicinity of a TMF based on the dimensions of previous accidents for assessing the environment (aquatic ecosystem) and the population at risk. The result of this approach turns the THI into the Tailings Risk Index (TRI), which is even better reflecting the most dangerous TMFs in one country with regard to the potentially affected population and environment.

A preliminary TMF inventory was developed for the DRB based on open access data and official national information. The inventory includes basic data and a preliminary THI assessment for each identified TMF. Moreover, the TRI method was also tested and applied to all TMFs in the DRB. The results are demonstrated by an interim TMF mapping for the Danube region. The inventory will be completed and integrated into the ICPDR database once official TMF data from

all countries are available and appropriate population and water body data are collected for the TRI method.

The checklist for operating TMFs was revised and updated to ensure good harmony with EU legislation and better adaptation to the DRB conditions. Moreover, the safety evaluation tool was amended to make it more suitable for practical purposes. Competent authorities, TMF operators, concerned stakeholders and the public in the DRB and beyond are encouraged to apply the updated methodology, which is intended to contribute towards limiting the number of accidents at TMFs and minimising the severity of their consequences for human health and the environment.

The outcomes of the Danube TMF project provide practical tools for risk-based TMF prioritization and detailed safety assessments, which have been adapted to the conditions of the DRB and could therefore be applied in several countries. The project started paving the way towards a consistent TMF safety assessment methodology at both regional and facility level and its results offer a reliable concept and sound technical basis for follow-up national activities. The ICPDR highly recommends adopting these tools at national level in the DRB and encourages the Danube countries to establish national or regional capacity building programs and conduct regular training events for TMF safety management. Moreover, the outcomes will serve the elaboration of a position paper for the DRB that will provide recommendations for the Danube countries on how to improve the safety conditions of the TMFs located in the DRB. This will ensure that in the medium term a common set of minimum standards and safety requirements are respected in the DRB.

This report and all technical results of the project can be downloaded from the website: https://www.sendaiplatform.org.

Zusammenfassung

Die dramatischen Unfälle in den letzten zwei Jahrzehnten weltweit, aber auch im Donauraum (DRB) haben gezeigt, dass Ausfälle von Bergbau- und Industrierückständeabsetzbecken (TMF) zu schwerwiegenden Katastrophen für die menschliche Gesundheit und die Umwelt führen können. Obwohl sich die Sicherheitsbedingungen in den letzten Jahrzehnten in vielen Ländern aufgrund strenger Anforderungen und entsprechender Maßnahmen erheblich verbessert haben, ist die Sicherheit einer Reihe von TMFs immer noch geringer als erwartet, insbesondere aufgrund wirtschaftlicher Zwänge und Kapazitätsmängel.

Darüber hinaus wird ein starker Anstieg der Bergbauaktivitäten in den nächsten Jahrzehnten erwartet, einschließlich eines Anstiegs der Anzahl von TMFs, da intelligente und fortschrittliche Technologien einen dramatischen Anstieg des Bedarfs an bestimmten Metallen wie Kobalt, Kupfer, Lithium und Nickel erzwingen werden. Daher wird die Gesellschaft möglicherweise einem zunehmenden Risiko von TMF-Ausfällen mit potenziellen Opfern und ökologischen Schäden ausgesetzt sein, wenn die TMF-Sicherheit nicht angemessen, d. h. in Übereinstimmung mit Standards und unter Berücksichtigung der Auswirkungen des Klimawandels, verwaltet wird.

Im DRB befinden sich mehr als 300 TMFs, für die angemessene Sicherheitsbedingungen und Maßnahmen getroffen werden müssen. Die Unfälle in der Vergangenheit bei Baia Mare (Rumänien) im Jahr 2000 und Ajka (Ungarn) im Jahr 2010 haben auf dramatische Weise gezeigt, wie schwerwiegend die Auswirkungen eines unangemessenen TMF-Betriebs auf Menschen, Umwelt und Wasserressourcen sein können. Um solche Unfälle künftig vermeiden zu können, ist die Entwicklung und Umsetzung einheitlicher und harmonisierter Managementstrategien, praktischer Sicherheitsbewertungsinstrumente und geeigneter Sicherheitsmaßnahmen erforderlich, die einen Mindeststandard im gesamten DRB etablieren. Die Internationale Kommission zum Schutz der Donau (IKSD), die als Organisation für das grenzüberschreitende Wassermanagement im DRB zuständig ist, hat das Donau TMF Projekt umgesetzt, um die Donauländer bei der Bewältigung dieser Herausforderungen und der Verbesserung der Sicherheitsbedingungen der TMFs zu unterstützen.

Im Rahmen früherer Pilotprojekte des Umweltbundesamtes (UBA) wurde eine TMF-Methodik erarbeitet, um die regionale und lokale Bewertung der TMF-Sicherheit zu ermöglichen. Die Methodik umfasst eine indexbasierte Bewertung des Gefährdungspotenzials für eine große Anzahl von TMFs, den sogenannten Tailings Hazard Index (THI) und eine detaillierte Checkliste zur Sicherheitsanalyse einzelner TMFs. Aufbauend auf den Stärken der Methodik sowie auf Grundlage aktueller bester verfügbarer Techniken (BVT), werden den Donauländern eine Reihe von praktischen Instrumenten zur Bewertung und Verbesserung der Sicherheitsbedingungen von TMF und zur Stärkung der Kapazität von Betreibern und behördlichen Inspektoren zur Verfügung gestellt.

Der THI hat sich bereits nützlich darin gezeigt, die in den Ländern nur begrenzt vorhandenen finanziellen und personellen Ressourcen an solche TMFs zu leiten, die das höchste Gefahrenpotential zeigen (z. B. in der Ukraine). Die zugrunde liegenden Kriterien für den THI-Ansatz wurden nunmehr weiter verbessert, indem die Ergebnisse einer historischen TMF-Unfallanalyse integriert wurden. Da der THI vor allem das Gefahrenpotential einzelner TMFs berücksichtigt, konnte er bislang die potenziellen Auswirkungen einzelner TMF-Ausfälle und ihre Bedrohungen für Umwelt und Bevölkerung, nicht darstellen. Dieses Problem wurde gelöst, indem eine potenzielle Risikozone in der Nähe eines TMF anhand der Dimensionen früherer Unfälle definiert wurde, um die Umwelt (aquatisches Ökosystem) und die gefährdete Bevölkerung zu bewerten. Das Ergebnis dieses Ansatzes macht den THI zum Tailings Risk Index (TRI), der die gefährlichsten TMFs in einem Land in Bezug auf die potenziell betroffene Bevölkerung und Umwelt noch besser widerspiegelt.

Für den DRB wurde ein vorläufiges TMF-Inventar entwickelt, das auf frei verfügbaren Daten und offiziellen nationalen Informationen basiert. Das Inventar enthält Basisdaten und eine vorläufige THI-Bewertung für jeden identifizierten TMF. Es bildete die Grundlage auf der die TRI-Methode getestet und auf alle TMFs im DRB angewendet wurde. Die Ergebnisse werden durch eine vorläufige TMF-Kartierung für den DRB demonstriert. Das Inventar wird weiter vervollständigt und in eine bestehende IKSD-Datenbank integriert, sobald offizielle TMF-Daten aus allen Ländern verfügbar sind und geeignete Bevölkerungs- und Gewässerdaten für die TRI-Methode gesammelt wurden.

Die bereits bestehende Checkliste für den Betrieb von TMFs wurde in diesem Projekt überarbeitet und aktualisiert, um eine gute Übereinstimmung mit den geltenden EU-Rechtsvorschriften sowie eine Anpassung an die im DRB-Raum herrschenden Bedingungen zu gewährleisten. Darüber hinaus wurde das Instrument zur Bewertung der TMF-Sicherheit geändert, um es für praktische Zwecke besser geeignet zu machen. Die zuständigen Behörden, TMF-Betreiber, betroffenen Interessengruppen und die Öffentlichkeit im DRB und darüber hinaus werden aufgefordert, die hier aktualisierte Methodik künftig aktiv anzuwenden. Sie soll dazu beitragen, die Anzahl von TMF-Unfällen zu begrenzen und die Schwere ihrer Folgen für die menschliche Gesundheit und die Umwelt zu minimieren.

Die Ergebnisse des TMF-Projekts im Donauraum bieten praktische Instrumente für die risikobasierte TMF-Priorisierung und detaillierte Sicherheitsbewertungen. Diese wurden speziell an die Bedingungen des DRB angepasst und können daher nun einheitlich in mehreren Ländern angewendet werden. Das Projekt ebnet damit den Weg zu einer einheitlichen TMF-Sicherheitsbewertung auf regionaler und v.a. betrieblicher Ebene. Die Ergebnisse bieten ein zuverlässiges Konzept und eine solide technische Grundlage für die Etablierung weiterer nationaler Aktivitäten. Die IKSD empfiehlt diese Instrumente auf nationaler Ebene in die DRB aufzunehmen und ermutigt die Donauanrainer, nationale oder regionale Programme zum Aufbau von Kapazitäten einzurichten sowie regelmäßige Schulungsveranstaltungen für das TMF-Sicherheitsmanagement durchzuführen.

Die Ergebnisse dieses Projektes bilden die Grundlage für die Ausarbeitung eines Positionspapiers für den DRB, welche Empfehlungen für die Donauanrainerstaaten zur Verbesserung der Sicherheitsbedingungen der im DRB befindlichen TMFs enthält. Dadurch wird sichergestellt, dass mittelfristig ein gemeinsames Verständnis von Mindeststandards und Sicherheitsanforderungen im DRB eingehalten wird.

Dieser Bericht und alle technischen Ergebnisse des Projekts können von der folgenden Website heruntergeladen werden: https://www.sendaiplatform.org.

1 INTRODUCTION

Mining is one of the most traditional and historically relevant industrial sectors in the world, providing valuable ores and minerals for further processing. Nowadays it is becoming even more important, as with the spread of smart and advanced technologies, a steep rise of connected mining activities is expected to supply the necessary battery storages with the specific metals needed. However, mining also represents a significant waste stream generated by its operations. One of the many types of the mining waste is the tailings, the fine-grained waste material derived from a mining processing plant and frequently transported by hydraulic methods to and deposited and handled at Tailings Management Facilities (TMFs).

Different studies estimate the number of industrial mines worldwide as up to 18,000 (Azam and Li, 2010) or even 30,000 (SNL, 2016; Roche, 2017). While there is no publicly accessible global inventory of tailings dams, one reliable estimate has put the number of tailings dams worldwide at about 3,500 (Davies and Martin, 2000).

Ideally, TMFs should ensure the safe long-term storage of fine-grained mineral processing waste. However, TMFs can leak or collapse due to unfavourable natural conditions, design and construction deficiencies and inappropriate operation and management practices. Due to the physical characters and/or chemical nature of substances that can be found in the tailings, but also due to the significant amounts of stored mining waste, TMFs pose a risk to the environment and population. Such risks may be present at all kind of TMFs, including active, temporarily or permanently closed, abandoned or even rehabilitated sites (e.g. long-term chemical pollution).

Over the last two decades, there has been a growing concern about the environmental degradation caused by unintended large-scale movement of hazardous materials related to failures of TMFs. Failures may result in uncontrolled spills and releases of hazardous tailings materials to the environment. These accidental pollution events may have serious acute impacts and direct damages on human health, built infrastructure, economic activities and environmental and natural resources. Pollution of waterbodies very often has a negative large-scale or transboundary effect on environmental resources. Moreover, accidents at TMFs may lead to long-term water and soil pollution and have negative chronic and accumulative effects on human health and the environment. Unintended release of the tailings imposes substantial associated costs on society. The economic cost associated with cleaning up the contamination after a TMF failure can reach hundreds of millions of Euros (UNEP, 1998).

According to Davies (2002), the failure rate of TMFs over the last 100 years is estimated to be more than two orders of magnitude higher than the failure rate of conventional water retention dams (reported as 0.01 %). Important factors that make the probability of TMFs failure higher than that of other earth structures or dams include lack of understanding of behaviour of tailing materials, inappropriate site monitoring and geotechnical investigations (Berghe et al., 2011) and low availability of financial resources. Worldwide, almost 60 major tailings dam failures that caused significant human fatalities and pollution were reported in the period of 2010–2019. The management of TMF safety has not improved significantly and remains a serious problem throughout the world. Major TMF disasters followed by serious consequences still occur quite often and the problem of TMF failures will even further rise if no consistent strategies and measures to improve the TMF safety level are implemented.

One of the most recent examples that included human fatalities was an accident at the TMF in Minas Gerais State, Brazil on 26 January 2019. The incident has become one of Latin America's worst ever mining disasters. This disaster killed 259 people and other 11 remain reported missing. It is the second incident of its kind in less than four years as on 5 November 2015, another TMF accident occurred in the same area, killing 19 people. About 60 million cubic meters of iron-rich mud flowed down through several rivers towards the Atlantic Ocean (WISE, 2020).

In China, the Ministry of Environmental Protection responded directly to 56 reported tailings-related pollution accidents in the period of 2006–2014 (Liu et al., 2015). Other major accidents in China include the Zhen'an gold tailings spill in Shaanxi Province in 2006, the Wulong gold tailings leakage in Liaoning Province in 2008, the Minjiang manganese tailings spill in Sichuan Province in 2011 and the Wantai manganese tailings leakage in Guizhou Province in 2012 (Liu et al., 2015).

The severe environmental damage caused by TMF dam breaching at the Baia Mare gold processing facility in Romania in 2000 is a well-known example of mining disasters. On the night of 30 January 2000, a dam holding contaminated waters burst at the mining works in Baia Mare, and 100,000 m^3 of cyanide-contaminated water spilled into the Someş River (EC, 2000). The polluted water eventually reached the Tisza River and then the Danube River, killing large quantities of fish in Hungary and Serbia and seriously damaging the aquatic ecosystem of the Tisza and the Danube. The lessons learnt from this accident significantly contributed to the improvement of the EU mining waste regulation.

On 4 October 2010, the dam of a TMF of an alumina processing plant located near Ajka collapsed and a huge amount of caustic red mud (almost 1 million cubic metres of liquid waste) was released. The red mud reached via local creeks the municipalities of Devecser, Kolontár, Somlóvásárhely, Somlójenő, Tüskevár, Apácatorna and Kisberzseny and caused significant devastation. In the following days, the red mud contaminated the Torna creek and the valley of River Marcal and River Rába. Through the Torna, Marcal, Rába and the Mosoni branch of the Danube, the alkaline slurry entered the Danube, causing destruction to some extent in all the waters affected. The disaster killed 10 people and almost 150 others slightly or severely injured by the caustic exposure, including both local residents and participants in the rescue operations (Mecsi, 2013). These two TMF accidents were recorded as the most serious failures in the DRB.

Recognising the importance of the TMF accidents, in 2001 the International Commission on Large Dams (ICOLD) announced its conclusion that the frequency and severity of tailings failures were increasing globally (ICOLD, 2001). To keep that recognition in the spotlight, they created a global failures compilation (ICOLD, 2001, 2007).

Many efforts have been undertaken recently by the international expert community to improve TMF safety through the strengthening of the safety requirements, for instance, by putting into practice advanced remediation technologies and modern techniques in mining practices. Achievements in Earth sciences within the field of geological, seismic, hydrological and climate risks have also been taken into account for the design and operation of TMFs. For example, at the Baia Mare gold processing facility measures were implemented to improve the TMF safety, such us enhancing the planning activities for waste management, assessment and inspection of activities, including the permit/licence issuing process, investment to increase dam safety around the TMF and treatment of mine waters. Although the facility is currently inactive, it has licence for functioning under safe conditions. Nevertheless, TMFs in many countries of Central and Eastern Europe and the former Soviet Union urgently need measures to improve their safety.

Recent accidents clearly demonstrate the necessity of taking actions to improve the safety level of TMFs in order to avoid a high number of serious accidents. Putting in place additional and appropriate preventive and contingency measures at TMFs - at least according to international safety standards - will help and support minimizing of risks and the adverse impacts of accidents to avoid loss of human life and severe environmental impacts. This was also stressed by Santamarina et al. (2019), urging to gain better understanding of the mechanisms of tailings dam failures and to use this knowledge to improve management practices and to make regulations more effective.

Over the medium- to long-term, many more deaths may occur as a result of long-term toxicity in relation to soil or sediment pollution caused by TMF spills, but no direct links to tailings dam failures have been made yet. Also, the financial consequences of TMF failures are incredibly high. Post-accident costs range from a few hundred million of Euros for remediation and clean-up costs to several billion of US Dollars (e.g. the Brazilian Government claimed 40 billion of US Dollars from the Vale mining company after the TMF accident in Minas Gerais State).

In the last twenty years, serious concerns have been coming up and the request for higher safety standards has reached the policy level including the EU, national governments and international organisations.

1.1 Policy context

The International Commission for the Protection of the Danube River (ICPDR) has been dealing with accidental pollution since its establishment by implementing the Danube River Protection Convention (DRPC, ICPDR, 1994). The DRPC, the main legal instrument for transboundary co-operation on water management in the Danube River Basin (DRB), mandates the ICPDR Contracting Parties to make all efforts to control the hazards originating from accidents involving substances hazardous to water. Inter alia, the DRPC requires the minimisation of the risks and consequences of accidental pollution by taking appropriate preventive, control and response measures and to provide coordinated communication, warning and alarm systems and emergency plans in a basin-wide context, supplementing the systems operated at the bilateral or multinational levels.

Besides the commitments of the DRPC on controlling accidental pollution events, the implementation of water-management-related European Union (EU) legislation in the DRB also requires addressing of accident prevention issues. The ICPDR has been mandated to coordinate the implementation of the EU Water Framework Directive (WFD, EC, 2000) and the EU Floods Directive (FD, EC, 2007) in all transboundary aspects. When the WFD and FD were adopted in 2000 and in 2007 respectively, all cooperating countries under the DRPC decided to make every effort to implement the WFD throughout the whole basin. In line with the obligations of these Directives, the ICPDR develops and publishes the DRB District Management Plans and the Flood Risk Management Plans for the DRB District.

The purpose of the WFD is to protect and enhance the status of inland surface waters, transitional waters, coastal waters and groundwater, and to ensure both the sustainable use of water resources and that all waters meet 'good status' by 2027 at the latest. With respect to accidental pollution, the WFD obliges countries to prevent or reduce the impact of accident events through which water can be polluted. Measures with the aim of doing so have to be included in the programme of measures of the river basin management plans, to be elaborated upon every 6 years. The aim of the FD is to reduce and manage the risks that floods pose to human health, the environment, cultural heritage and economic activities. Concerning accidental pollution, flood risk maps shall indicate installations, which might cause accidental pollution in case of flooding. The flood management plan shall list flood-related measures to be taken regarding the control of major accidents involving dangerous substances.

On the European level, EU Member States (MS) are obliged to implement the Seveso Directive (EC, 2012) to prevent major accidents involving dangerous substances and to limit the consequences of such accidents. Operators of dangerous facilities storing or processing dangerous substances in quantities above certain thresholds (given for lower and upper tier) have to develop a major accident prevention policy, to implement this policy by a safety management system, to provide safety reports and information on accidents and to elaborate emergency intervention plans for the internal areas of the establishments. Moreover, competent authorities of EU MS are obliged to develop external emergency plans for the surrounding areas of the dangerous plants, to provide the public with necessary information regarding the risks posed by the respective plants, to ensure that appropriate remediation measures are taken in case of accidents and to conduct periodic inspections to check whether technical requirements are fulfilled.

Regarding mining activities, EU MS have to implement the Extractive Waste Directive (EWD, EC, 2006), which aims to prevent or reduce any adverse effects on the environment and any resultant risks to human health as a result of the management of waste from the extractive industries including mineral processing. Operators shall draw up a waste management plan for the minimisation, treatment, recovery and disposal of extractive waste and shall have a permit from the competent authority. Similar obligations to those of the Seveso Directive (safety reports, accident prevention policy, on-site emergency plans, information for the public) shall also be complied with for Category A mining waste facilities.

To ensure enhanced industrial technologies, EU MS have to comply with the Industrial Emissions Directive (IED, EC, 2010). The IED prescribes that authorities need to ensure that pollution prevention and control measures at the relevant industrial units are up-to-date with the latest Best Available Techniques (BAT) developments. The industrial plants covered by the IED must have an environmental permit with emission limit values for polluting substances to ensure that certain environmental conditions and technical standards are met.

In accordance with the EWD and IED, a revised EU BAT Reference Document for the Management of Waste from Extractive Industries was published, presenting updated data and information on the management of waste from extractive industries, including information on BAT, associated monitoring, and developments in them (JRC, 2018). Moreover, the European Commission (EC) recently adopted technical guidelines for inspections of waste facilities in accordance with the EWD (EC, 2020). The guidelines are to be carried out by competent authorities. The inspections are aimed at ensuring that any waste facility has obtained the required permit and complies with the relevant permit conditions. The inspections relate to the different life-phases of the waste facilities.

At large regional scale, Parties to the Convention on the Transboundary Effects of Industrial Accidents (TEIA Convention, UNECE, 2008) of United Nations Economic Commission for Europe (UNECE) have to fulfil obligations related to industrial hazards similar to those of the Seveso Directive. The TEIA Convention aims at preventing accidents that can have transboundary effects and at helping countries to prepare for and respond to accidents if they occur. It also promotes active international cooperation regarding accident risk mitigation. To further support the countries, the UNECE Convention on the Protection and Use of Transboundary Watercourses and International Lakes (Water Convention, UNECE, 2008) and the TEIA Convention established a specific Joint Expert Group (JEG) focusing in particular on transboundary water pollution issues, which are related to industrial accidents. The JEG supports the elaboration of guidelines and checklists and organises seminars and trainings to help countries to develop, improve and harmonise their national procedures and requirements related to safety measures and contingency planning.

To address the rising concerns about TMF safety, the UNECE published the Safety Guidelines and Good Practices for Tailings Management Facilities (Safety Guidelines, UNECE, 2014). These include both recommendations to operators for the safe design of TMFs and to authorities for the legal basis to cover issuing permits for the safe operation of TMFs. The UNECE called on governments of its countries and TMF operators to include and implement these safety guidelines into national regulations and technical standards. In subsequent years however, it became clear that the implementation of the safety guidelines is fraught with difficulties since safety standards are outlined only in general terms.

In response to the need to improve cooperation and coordination between land-use planning and industrial safety procedures, the UNECE decided to develop guidance on land-use planning and the related safety aspects under three UNECE instruments: the TEIA Convention, the Convention on Environmental Impact Assessment in a Transboundary Context (Espoo Convention, UNECE, 1991) and its Protocol on Strategic Environmental Assessment (Protocol on SEA, UNECE, 2003). The Guidance on Land-Use Planning, the Siting of Hazardous Activities and related Safety Aspects was published in 2017 (UNECE, 2017). This document also noticed that the UNECE TMF Safety Guidelines address the need for land-use planning considerations to be considered when evaluating optimum siting of new TMFs, and the need to carry out an environmental impact assessment prior to construction as well as a risk assessment.

Furthermore, following the Brumadinho TMF accident in Brazil, in January 2019, the International Council on Mining and Metals (ICMM), the Principles for Responsible Investment (PRI) and the United Nations Environmental Program (UNEP) initiated a Global Tailings Review to review existing good practices and develop on that basis an international standard for the industry (GTR, 2020).

1.2 The UNECE TMF-Methodology

Based on the recommendation of the UNECE Joint Expert Group of the Water and Industrial Accidents Convention, the Parties to the Convention supported the further implementation of the Safety Guidelines in all UNECE countries and called for an implementation tool to help increase the overall safety level of TMFs. The issue was taken up by the German Environment Agency (UBA), with the aim of developing a methodology for the evaluation of TMF safety along with a checklist serving as a toolkit for competent authorities and operators responsible for the safety of TMFs storing mining waste. Both the UNECE and the German Environment Agency encouraged the countries where the TMF issue is relevant to disseminate the Methodology for Comprehensive Evaluation of Tailings Management Facilities Safety (TMF Methodology, UBA, 2016) for use by the appropriate authorities.

The TMF Methodology was developed, tested and fine-tuned in several pilot projects in UNECE countries (UBA, 2016; 2018; 2020a). It is mainly based on the UNECE Safety Guidelines and consists of two major parts. Firstly, the hazard potential of a TMF is evaluated according to a simple but reliable method. The so-called Tailings Hazard Index (THI) takes the most relevant safety aspects of a TMF into account. The THI allows countries to receive a fast overview on the number of TMFs with the highest hazard potential so that additional safety measures needed at the respective TMFs can be implemented subsequently. Considering the limited financial and personnel resources of a lot of countries, this approach seems to be most realistic and pragmatic to fight actual TMF safety problems.

Secondly, the individual TMF safety levels are analysed by a questionnaire (checklist) pertaining to the realized and missing safety measures on the site. The deficiencies can be compared with a potential measure catalogue and based on recommended short-, medium- and long-term additional safety measures competent authorities might obligate TMF operators to implement. In addition, operators might also use the results for their own safety checks and future investment planning at the site.

Summing up, the two main elements of the TMF-Methodology are:

- the THI method providing a sound and simple approach to ranking the relative hazard of a large number of TMFs;
- a Checklist for examinations of a minimum set of TMF technical safety requirements, combined with potential technical measures to implement international standards for the safe operation of TMFs (Measure Catalogue).

1.3 Scope of the report

Since its first publication, the TMF-Methodology has been amended by follow-up projects in Ukraine, Georgia and Armenia, resulting in an updated methodology. In 2019-2020, the ICPDR implemented a project in the north-eastern Danube River Basin to strengthen the capacity of TMF operators and authority inspectors and provide them with practical tools ensuring safe operation and management of the TMFs based on minimum technical and safety standards.

The main tasks of the Danube TMF project were:

- to amend the already existing "Tailings Hazard Index" method and to develop a "Tailings Risk Index" method;
- to update and evaluate the draft TMF inventory of the DRB;
- to revise the TMF Checklist for more adequate examinations on the technical safety requirements of operating TMFs;
- to revise and update the recommended technical measures to implement international standards for the safe operation of TMFs (Measure Catalogue).

This report presents the technical outcomes of the Danube TMF project. It starts with an assessment of historical TMF accidents demonstrating the severity and spatial dimensions of recorded past accidents. The assessment examines in particular the runout distances of the TMF accidents in order to determine the dimension of the potential risk zone downstream of the TMFs where population and environmental resources are at risk.

The report also highlights two index-based tools to assess accident hazard and risk of TMFs. Using the methods, a large number of TMFs can be evaluated with limited efforts and data demand. The tools are highly recommended for national authorities and international river basin organisations and environmental bodies to undertake preliminary hazard and risk assessment at regional level, to prioritize TMFs according their hazard and risk and to ensure the effective use of financial and technical resources targeted to the TMFs with the highest risk.

Moreover, a TMF inventory complied for the DRB is discussed which includes TMF mapping and risk assessment. TMF hazard and risk in the DRB are assessed and the situations of Danube countries are compared.

Finally, the report presents an updated version of the TMF Checklist methodology and Measure catalogue, with focus on the operating TMFs. The Checklist has been significantly updated and aligned to the DRB conditions. The evaluation method has also been revised, restructured and simplified.

2 ANALYSIS OF HISTORICAL TAILINGS DAM FAILURES

A substantial number of TMF accidents occurred in the past decades, which could have been avoided or partly controlled if adequate safety measures had been put in place and land-use planning aspects taken into account. A comprehensive analysis on the past TMF accidents was carried out to better understand the severity and dimensions of these TMF disasters, including the potential number of casualties and spreading distance of the tailings downstream of the TMF in case of an accident. Moreover, satellite images taken before and after some selected TMF accidents were analysed to investigate the potential runout distances before reaching water bodies.

2.1 Data collection

A database of historical TMF failures was compiled using bibliographic sources as well as open source information. In the first step, the existing inventories on past TMF failures were explored. Currently, various investigations and comprehensive reviews have attempted to summarize the causes of TMF failures throughout the world using historical TMF failure data (e.g. USCOLD, 1994; Davies, 2002; ICOLD, 2007; Rico et al., 2008a; Rico, et. al, 2008b; Bowker and Chambers, 2015; Bowker and Chambers, 2016; Bowker and Chambers, 2017; Lohunova, 2019; CSP2, 2020; WISE, 2020). For this report, the data of Bowker and Chambers (CSP2, 2020) were used as core database.

Although the published data are undoubtedly very valuable, they are certainly incomplete, as smaller incidents are very common (e.g. Villarroel et al., 2006) and remain underreported in both scientific literature and public media. It is also considered that many incidents are unreported because of fears of bad publicity and legal ramifications (Davies, 2000), particularly in China, Russia and other emerging and developing countries. Therefore, the selected database may be subject to further fine tuning and update.

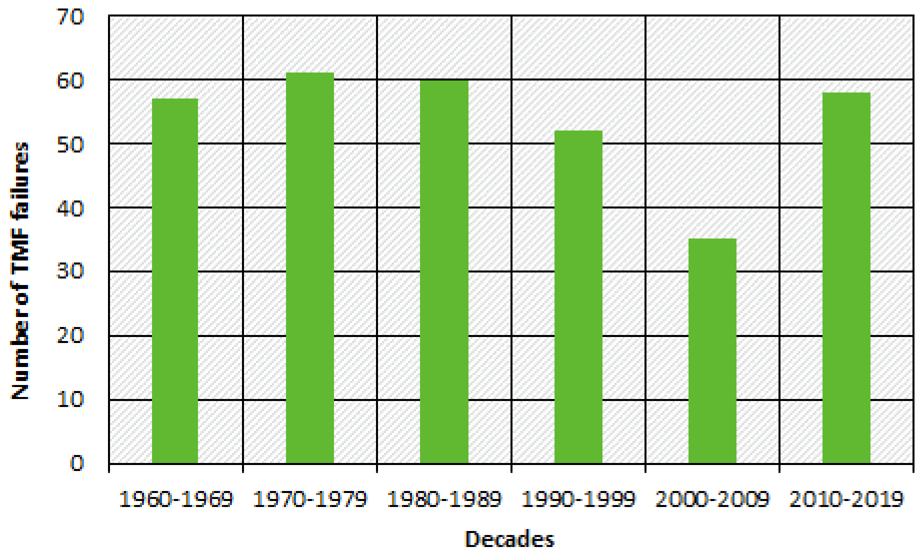
2.2 Assessment results

2.2.1 Number and severity of TMF failures

Data records over 350 failures of TMFs in the world are available since 1915. However, data sets on failures occurred before the 1960s are rather incomplete. Moreover, there are only a few reports about these failures, because the total number of TMFs was small and the operation of the TMFs was not properly documented. Therefore, only the accidents in the last 60 years were considered for the assessments (Figure 1 and Annex A).

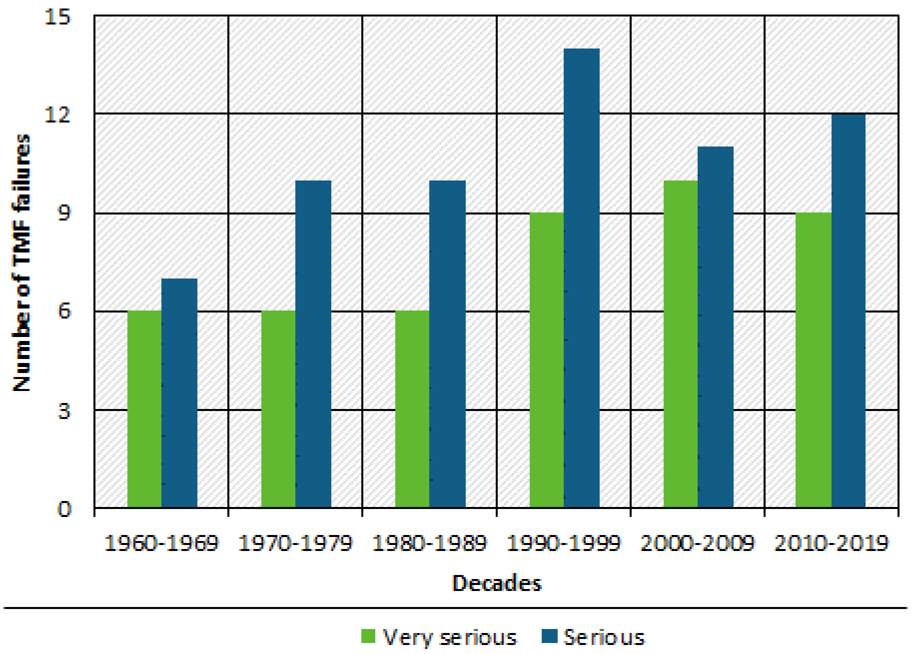
During the last 60 years, 323 accidents were reported in total. The number of failures was stagnant in the first three decades then decreased after 1990 over two decades (1990-1999 and 2000-2009), presumably reflecting to reduced mining activities between 1990 and 2009, in particular in the former Soviet Union countries. However, over the last decade the number of failures returned back to the level of the 1970ies. In 2019 alone, there were 7 TMF failures, two of which were very serious with multiple deaths. The failure trend is rising, therefore actions need to be taken to avoid a high number of serious accidents. Nevertheless, modern surveillance techniques and visual recording have become widespread in the last decade which provide sound evidence and reliable data on accidents but these tools were not available in the past therefore historic records may be uncertain. Besides this, the effects of climate change (increasing frequency and intensity of heavy rainfall, thunderstorm and flash flood events, rapid snow melt) may also contribute to this increasing tendency.

Figure 1. Number of TMF dam failures by decades from 1960 to 2019.



Categorizing the impacts of TMF failures is a difficult - and to some extent subjective - task. Also the line between a serious failure and a very serious failure is not clearly defined. Bowker and Chambers (2015) defined serious failures as 'having a release of greater than 100,000 m³ and/or loss of life' and very serious failures as 'having a release of at least 1 million m³ and/or a release that travelled 20 km or more and/or multiple deaths'. Both types show increasing tendency since the 1990ies (see Figure 2).

Figure 2. Number of very serious and serious TMF dam failures by decades from 1960 to 2019.

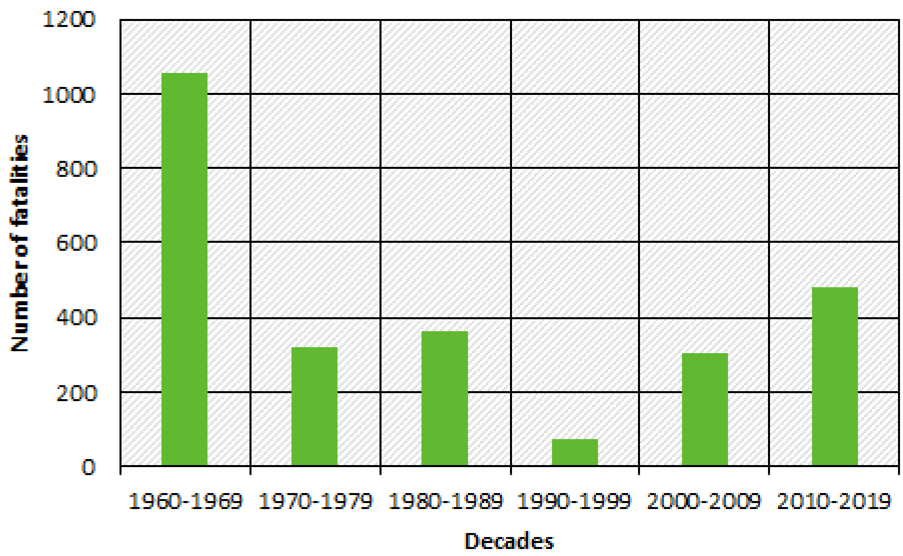


In the last 60 years, 2,599 deaths due to 323 accidents at TMFs have been registered (Figure 3 and Annex A). Across decades, the figures show that the loss of human life has significantly increased in the last 20 years. During the last 10 years, there were 480 deaths stemming from 13 TMF failures. In 2019 alone, 327 people died or are missing because of two accidents (dam failure in Brumadinho, Brazil: 259 people were killed and 11 are reported missing; disaster in

Hpakant, Kachin state, Myanmar: 3 workers died and 54 workers are reported missing, see Annex A). The figure of cumulated deaths is comparable to the finding of Santamarina et al. (2019), showing almost 3,000 deaths in the last 100 years.

Loss of human life because of TMF dam failures stayed within the range of 300-400 in most decades (from 1990 to 1999 there was a significant decrease). From 1960 to 1969, a very high death number was recorded due to some very dramatic accidents such as the accident on Mir mine, Sgorigrad, Bulgaria in 1966, when half of Zgorigrad village was destroyed, killing 488 people (WISE, 2020).

Figure 3. Reported human life loss because of TMF dam failures by decades from 1960 to 2019.



On the top of the number of accidents and casualties, the rate of serious accidents and the failure-specific loss of life related to fatal accidents (number of deaths per failures with casualty) and to the overall accidents (number of deaths per total failures) were also analysed. The results of this evaluation are presented in Table 1.

Table 1. Analysis of historical TMF failures.

Decade	Failures	Failures with casualty	Deaths	Rate of fatal failures (%)	Specific loss of life (all accidents)[1]	Specific loss of life (fatal accidents)[2]
1960-1969	57	9	1054	15.8	18	117
1970-1979	61	9	322	14.8	5	36
1980-1989	60	6	365	10.0	6	61
1990-1999	52	6	72	11.5	1	12
2000-2009	35	6	306	17.1	9	51
2010-2019	58	13	480	22.4	8	37
Total (1960-2019)	**323**	**49**	**2599**	**15.2**	**8**	**53**

[1] related to the total number of accidents

[2] related to accidents with loss of life

Over the examination period, 49 accidents out of the total number of 323 TMF failures (15%) were fatal and led to nearly 2,600 deaths (the environmental damages and costs are not counted). Importantly, the number of accidents with fatalities has significantly increased in the last 10 years in comparison to the previous decades. Moreover, while the rate of failures with loss of life over a period of 40 years (from 1960 until 1999) remained almost unchanged with an average of 13%, over the past 20 years the number of fatal accidents began to grow and their rate reached 22% during the last two decades. The reasons behind may include ageing of TMFs, inadequate planning of land-use and urban areas or impacts of climate change. The long-term specific loss of life related to overall accidents and fatal events has a dramatic value of 8 and 53, respectively and they remained significant in the last two decades (on the global average, region or country level data may be different).

In Table 2 statistical data on the "conventional" hazardous industries ("Seveso-sites") for Germany during 2010-2019 are presented (UBA, 2020b) and compared to TMF accident data for the same period. Despite the total number of failures being 4 times higher at conventional hazardous installations in comparison to TMFs, the number of deaths was more than 30 times lower. Moreover, more than 20% of the TMF accidents was fatal, this figure is only 4% for the SEVESO sites. Accordingly, the specific loss of life value related to all and fatal accidents is much higher for TMF failures (two orders of magnitude and 20 times, respectively). It should be noted that no detailed data were available for the EU countries except Germany, therefore these findings should be carefully interpreted and the comparison is not representative. Bearing in mind that Germany is a developed industrial country where safety measures are of a high standard, the differences might be less significant in comparison to EU level data, regional figures or global numbers.

Table 2. "Seveso-site" accidents in Germany and TMF failures in the last decade (2010-2019).

Decade	Failures	Failures with casualty	Deaths	Rate of fatal failures (%)	Specific loss of life (all accidents)[1]	Specific loss of life (fatal accidents)[2]
SEVESO	232	9	16	3.9	0.07	1.8
TMF	58	13	480	22.4	8	37

[1] related to the total number of accidents

[2] related to accidents with loss of life

These figures clearly demonstrate the necessity of improving the safety level of TMFs. Putting in place additional and appropriate preventive and contingency measures at the TMFs, at least according to international safety standards, will help and support the minimizing of risks and adverse impacts of accidents to avoid human losses and severe environmental impacts.

Nowadays, land-use planning aspects, such us population, natural resources and heritage and socio-economic goods within the vicinity of a TMF that may be potentially affected in case of an accident should also be prominent issues to be considered.

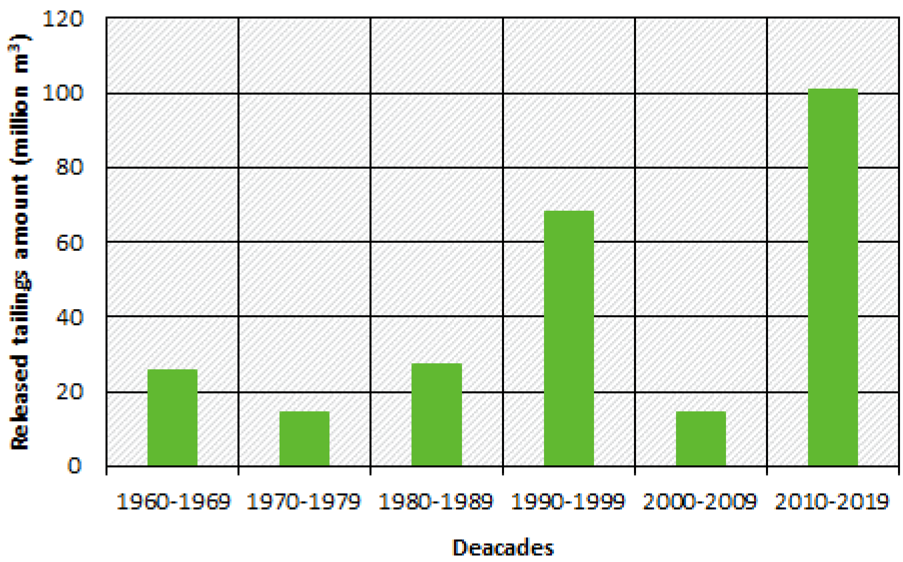
By analysing historic mining metric indicators such as production costs and prices of various metals, Bowker and Chambers (2015) developed a correlation between these indicators and failure severity, enabling an estimation of projected future failures. The results forecast that if the present mining metric "driven by continuously lower grades in identified resources and continuously falling real prices of most metals" continues, serious and very serious failures of tailings dams will also continue to rise as a consequence of limited financial and human resources allocated to safety measures in the past. Despite the ambitious and strict regulations in many countries, a number of "legacy" TMFs exists with low level of safety measures.

2.2.2 Released volumes

Findings of research studies associated with TMF failures made by Rico et al. (2008b) and Concha Larrauri et al. (2018) show that reasonable statistical analysis can also be made for both the volume of tailing materials that could be released from a TMF and the distance downstream, over which the released tailings could move.

Looking at the last 60 years, a total of almost 250 million m³ tailings materials in 323 TMF accidents were released (Figure 4 and Annex A, note that only about half of the accidents have recorded tailings release, the others either had minimal released amount or data are not available). In the last 10 years, the amount of released tailings has significantly increased, 58 TMF dam failures released more than 100 million m³ of tailings into the environment.

Figure 4. Recorded total amount of released tailings by decades from 1960 to 2019.

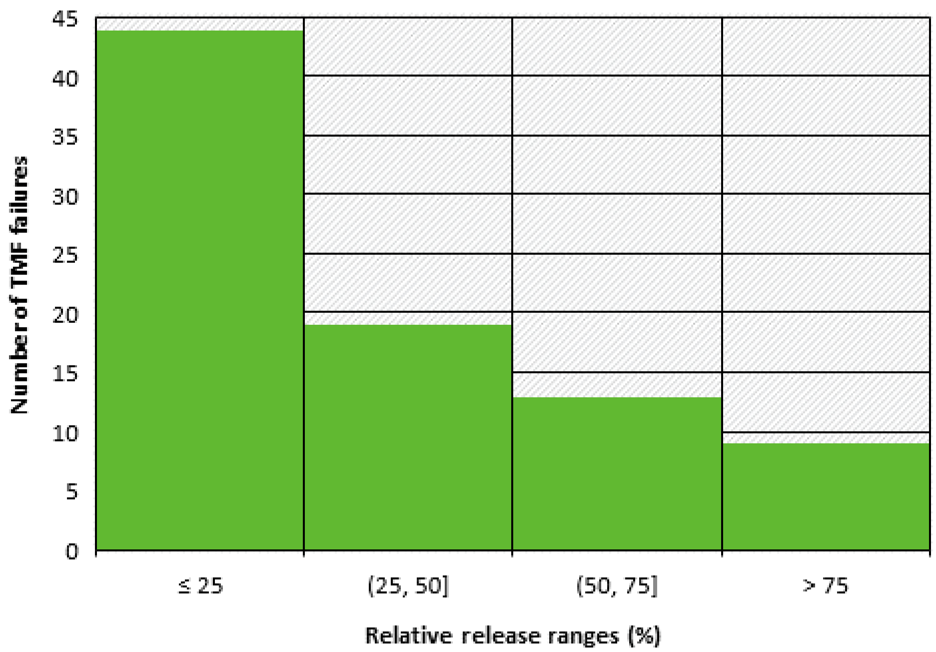


The number of human fatalities may directly depend on the distance between the settlements located downstream and the TMF. The smaller the runout distance to reach a settlement and the higher the volume of the substances released, the higher the number of causalities that may occur in case of TMF failures. Therefore, the amount of released materials related to TMF capacity and the runout distance downstream of a TMF were further analysed for the recorded TMF accidents.

Out of the 323 TMF accidents, for which data were collected (see Annex A), only 85 cases contained data on the total capacity of the collapsed TMF together with information on the released volume of materials (see Annex B). The results of this evaluation are presented on Figure 5.

In most of the cases (44 of 85) the released volume was less than 25% of the total TMF capacity. The number of accidents where the relative volume of released materials ranged from 25 to 50% was more than two times less (19). The number of cases when spilled tailings volume reached a range of 50-75% and 75-100% of the total capacity was around 10 (13 and 9, respectively).

Figure 5. Distribution of TMF failures according to the relative amount of released materials.



2.2.3 Runout distances downstream

Regarding the runout distance, official data were available for 91 cases (see Annex C). The reported distance values have a large range varying between 0 and 2,000 km. According to the distribution of the runout distances, for majority of the cases (60%) the runout distance did not exceed 10 km (see Annex C). For almost 30% of the cases, the reported transport distance exceeded 20 km indicating different definitions of the runout distance used in various official sources. Some sources indicate only the near-field distance from the TMF to the receiving water (field transport). Some others indicate the far-field distance of the tailings spreading including both, field and in-stream transport. This is well reflected in the large range of reported distance data (4 orders of magnitude). Almost one third of the transport route distances include both field and in-stream transport distances and almost all of these distances are bigger than 20 km (see Annex C).

2.2.3.1 Investigations on direct runout distances

To more accurately determine the direct runout distance, an additional analysis was performed for those cases, where the official runout distance exceeds 10 km (37 accidents). Additional information on runout distances was collected from open sources. Moreover, it was also checked if any information is available whether the reported runout length includes river transport distance. In case no information was accessible, the possible direct runout distances were estimated based on the location of the TMFs and the closest water bodies by using online satellite maps. Unfortunately, for some historical accidents additional information on the runout distance or the exact TMF location was not available due to limited data records from the past.

The map analysis was carried out by using high-resolution satellite images showing the surrounding area of the selected TMFs before and after the accidents. Three examples are presented in detail.

2.2.3.1.1 Case study 1: Córrego de Feijão mine, Brumadinho, Minas Gerais, Brazil

According to WISE (2020), during the disaster on Córrego de Feijão mine (Brazil, 2019), the slurry wave moved downhill and then was transported further downstream by the River Rio

Paraopeba. The mud first hit the mine administrative area and a small community about 1 km downstream of the mine. The National Water Agency stated that the tailings had polluted over 500 km of rivers. The image analysis shows that the downhill runout distance was approximately 7 km after that the plume reached the river (Figure 6).

Figure 6. Territory near the Córrego de Feijão dam on 14.01.2019 (left) and 30.01.2019 (right).

2.2.3.1.2 Case study 2: Samarco Mineração S.A Fundão Minas Gerais, Brazil

The failure on the Samarco Mineração S.A Fundão tailings dam on the 5th of November 2015 released tailings, which travelled downstream via a natural waterway. The mud continued to move further about 650 km along the Rio Doce River, reaching the Atlantic coast 17 days later. However, the image analysis of the accident (Figure 7) shows that the distance to the affected main waterbody is less than 1 km.

Figure 7. Territory near the Fundão dam on 21.07.2015 (left) and 11.10.2015 (right).

2.2.3.1.3 Case study 3: Ajka Alumina Plant, Kolontár, Hungary

During a disaster near Ajka, the red mud reached the municipalities of Devecser, Kolontár, Somlóvásárhely, Somlójenő, Tüskevár, Apácatorna and Kisberzseny. An area of about 8 km^2 was flooded. In the following days, the red mud contaminated the Torna creek and the valley of river Marcal, almost reaching the river Rába. Through the Torna, Marcal, Rába and the Moson branch of the Danube, the alkaline red slurry travelled about 80 kilometres downstream and finally entered the Danube River. The image analysis (Figure 8) shows that the distance to the nearest settlement and surface water that were contaminated with the released tailings is about 4 km.

Figure 8. Territory near the Ajka TMF on 07.10.2010 (left) and 22.10.2010 (right).

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2.2.3.1.4 Outcomes of the runout analysis

The results of the runout estimation are shown in Annex C. For 17 out of the 37 cases it was possible to find additional information or to identify the location of the TMFs and estimate the potential transport distance. In all these cases, the estimated direct runout distance is much less than the reported value. Moreover, for 15 of them, the runout distance of the tailings did not exceed 10 km.

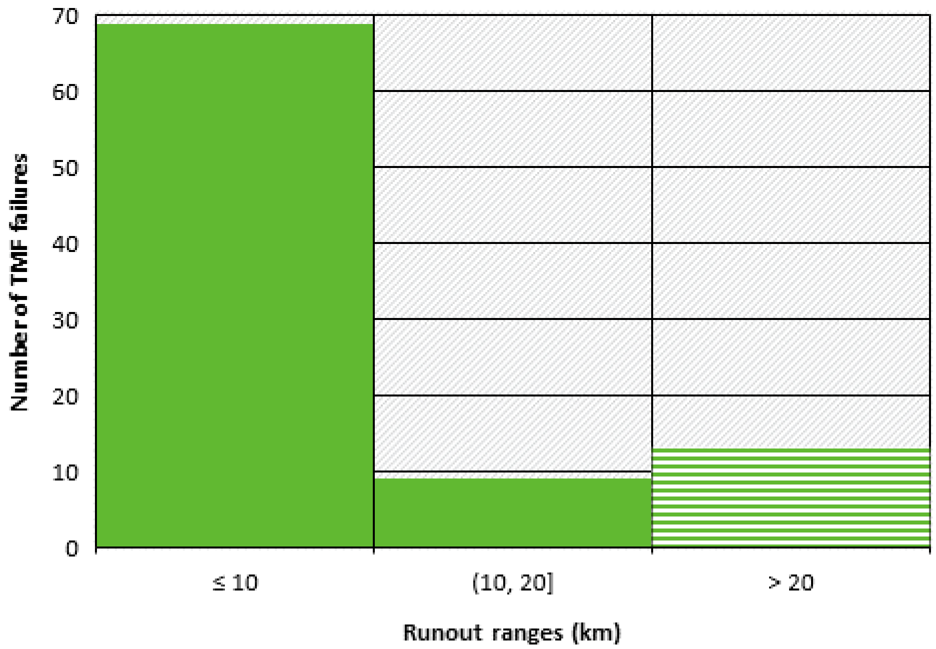
2.2.3.2 Potential risk zone delineation

As it can be seen from the additional investigations, the difference between the actual runout distance and the distance reported in open sources may be significant. Although large distances are reported, the majority of the investigated accidents show that the direct runout distance to the river/settlement nearby is less than 10 km if only field transport is taken into account.

The reason for this discrepancy is that in many cases official documents report on the maximum travelling distance but do not distinguish between field and river transport routes. However, to understand the dimensions of the potential risk zone in the direct downstream vicinity of a TMF where people and environmental resources may be at risk, the field transport distances need to be known.

Updating the original runout distance data with the investigation results presented in Annex C, the amended overall runout length analysis shows that 69 cases out of the 91 reported accidents have less than 10 km direct runout distance (see Figure 9). Out of the remaining 22 cases, 9 have a runout length between 10 and 20 km, whereas 13 cases show a runout above 20 km. However, for all of these 13 accidents in-stream transport is indicated, thus, the direct runout distance needs to be further investigated. However, it is very likely that in 10 km distance the spill would reach a surface water body or the overland spread would slow down and the released materials would be retained in surface depressions and ponds, over flat areas, in vegetated surfaces or behind landscape objects or terrain barriers. Neglecting the 13 cases with incomplete information, the proportion of runout distances less than 10 km is almost 90% (69 out of 78). This indicates that a distance of 10 km could be a suitable threshold for delineation of a direct risk zone downstream of TMFs.

Figure 9. Distribution of TMF failures according to the runout distance of the tailings.



The striped column indicates data with uncertainty

The obtained statistical data do not allow for a discrete runout distance threshold to be lined out due to lack of information and merging overland and in-stream runout lengths. However, a solid reference is the Ajka alumina plant accident, being the best recorded and analysed TMF accident within the DRB. Based on the impacts experienced with that accident, no deaths or serious acute toxicity occurred in an area beyond 10 km distance (the maximum field runout length was 4.2 km before reaching a surface water body or a terrain barrier). Also, no data on serious health damages out of 10 km zone were found at other TMF accidents within the DRB or the UNECE region. Therefore, and based on the findings of the investigations on past events, a standard runout distance of 10 km was defined to assess the population at risk within the DRB (also recommended for the UNECE region). This may be different in other regions of the world and the exact values are case-specific depending on the site conditions and the accident dimensions. Data on some TMF accidents suggest a larger distance, especially if riverside wetlands and the terrestrial watershed area cannot be clearly distinguished.

3 TMF HAZARD ASSESSMENT

The TMF-Methodology offers an index-based assessment of the hazard potential of a number of TMFs, the so-called THI method (UBA, 2016). With this simple index method, a large number of TMFs can be sorted and prioritised according the calculated hazard potential. The approach already proved its usefulness in directing limited country resources (financial and personnel) to TMFs representing the highest hazard potential. The underlying criteria of the *THI* were worked out and agreed by international experts and have been improved taking up the results of a historical TMF failure analysis. Also, it is very useful in the graphical mapping of TMFs in countries or international regions (i.e. UNECE, river basins).

The original THI method was slightly modified by revising and adjusting several parameters. The overall calculation procedure was not changed, therefore only a short description of the updated THI method is presented in this report.

3.1 The Tailings Hazard Index method

The THI method takes the following parameters into account that have been identified as being most crucial:

- total capacity of TMFs,
- toxicity of substances of the stored tailings,
- TMF management status,
- natural conditions specific to the TMF site,
- and dam safety parameters.

3.1.1 Calculation of the THI

According to the above-mentioned parameters, the calculation procedure of the *THI* includes five steps. In case values of some parameters are unavailable or impossible to identify, the maximum values have to be used (worst-case scenario). Thus, the hazard related to an unavailable TMF parameter (for example toxicity) is expected to be the highest.

3.1.1.1 Tailings capacity

The parameter "Tailings capacity" (THI_{Cap}) is related to the volume of stored tailings materials in the facility (m^3). The parameter is assumed to increase with growing volume by logarithmic relation with the base of 10. Thus, increasing the volume of tailings materials by 10 times (one order) will increase the index by 1. The parameter is calculated by the formula:

$$THI_{Cap} = \mathrm{Log}_{10}\,[V_t] \tag{1}$$

where V_t is the total volume of tailings materials in the TMF (m^3).

3.1.1.2 Tailings toxicity

The parameter "Tailings toxicity" (THI_{Tox}) is evaluated based on the Water Hazard Class (WHC) of the materials in the tailings according to the German national classification (UBA, 2017). For integrated toxicity characterization, it is crucial to have a parameter representing all potential threats to the aquatic ecosystem in the short and longer term. The WHC is considered as a validated methodology integrating all potential threats to aquatic ecosystems, including acute and chronic toxicity as well as bioaccumulation and accumulates dangers for different organism (fish, crustacean, bacteria). The data are online available for around 7,000 substances.

Alternatively, a self-classification is possible according to the United Nations Globally Harmonized System of Classification and Labelling of Chemicals. Table 3 shows the WHC classification and the respective toxicity index to be used.

Table 3. Evaluation of the tailings toxicity.

Water Hazard Class, WHC[1]	THI_{Tox}
no hazard	0
low hazard	1
medium hazard	2
high hazard	3

[1] According to the German classification

A specific problem is related to radioactive waste, as radioactivity is not integrated into the WHC classification. However, there is a need for considering it since many TMFs contain materials resulted from mining of radioactive substances (e.g. in Central Asia). Therefore, it is suggested to apply $THI_{Tox} = 4$ in case radioactive substances are stored in TMFs and their radioactivity exceeds the doubled value of the local background radioactivity.

3.1.1.3 Management conditions

The parameter "Management conditions" (THI_{Man}) is the TMF status that should be identified from four options shown in Table 4 (revised in comparison to the original method). The TMF accident statistics (Rico et al., 2008a, 2008b) show that closed and rehabilitated TMFs are safer in terms of accident frequency. No accidents were recorded at these TMFs. For this reason, the parameter related to TMF management is assumed to be lower for the closed or rehabilitated facilities compared to the active TMFs. As closed TMFs might still miss necessary safety measures, their hazard potential might be higher than that of the fully rehabilitated ones. On the other hand, abandoned or orphaned TMFs may have at least the same hazard potential as active TMFs due to the missing operation, management and controlled surveillance on the spot. Therefore, and because of precautionary aspects the hazard potential for abandoned facilities is rated by the same value as that of the active sites.

The value of THI_{Man} is determined according to Table 4.

Table 4. Evaluation of the management conditions.

Management status	THI_{Man}
Rehabilitated	0
Closed	1
Abandoned, orphaned	3
Active	3

3.1.1.4 Natural conditions

The parameter "Natural conditions" (THI_{Nat}) is related to environmental risks, which are very often involved in TMF failures. Especially earthquakes, heavy rainfalls and floods have been many times classified as causes for TMF accidents.

Accordingly, the respective hazard potential is calculated by the following equation:

$$THI_{Nat} = THI_{Seism} + THI_{Flood} \quad (2)$$

where THI_{Seism} is the hazard index for seismic activity and THI_{Flood} is the hazard index for flooding based on the geological and hydrological conditions of the TMF site.

The value of THI_{Seism} is calculated based on the data on reference peak ground acceleration (PGA) corresponding to a specified reference probability of exceedance or a reference return period (JRC, 2008). The parameter Reference PGA can be taken from freely available data sources (e.g. GFZ, 2011). It allows harmonizing different scales of national classifications. The seismic hazard is defined as "Low" if the Reference PGA is below or equal to 0.1, and "Moderate or High" if the Reference PGA is above 0.1.

Accordingly, the earthquake hazard (THI_{Seism}) is described based on the following assumption in Table 5.

Table 5. Evaluation of the seismic hazard.

Reference PGA[1]	THI_{Seism}
≤ 0.1	0
> 0.1	1

[1] as recommended in EUROCODE 8 (JRC, 2008).

The influence of floods (THI_{Flood}) is related to the flood prone areas with a statistical parameter of HQ-500 that quantifies flood event frequency with a five-hundred-year return period (floods with a probability of 1 in 500 years). The flood-induced hazard at the TMF location area is determined according to Table 6. The flood prone areas according to the values of HQ-500 can be obtained from open sources (e.g. JRC, 2016).

Table 6. Evaluation of the flood hazard.

TMF location	THI_{Flood}
In the flood prone area of HQ-500	1
Beyond the flood prone area of HQ-500	0

3.1.1.5 Dam safety

Dam stability is probably the most critical parameter within the hazard evaluation. The parameter "Dam conditions" (THI_{Dam}) is considered to be related to the dam design parameter "Factor of Safety" (FoS) that has to be calculated already at the TMF design stage and it refers to dam slope stability (Coduto, 1998; Cruz et al., 2008; Fredlund et al., 2012). The term FoS is commonly used to express the safety margin of slopes on embankment dams. The influence on the TMF hazard potential of this parameter is assessed according to Table 7, based on Cambridge (2018).

Table 7. Evaluation of the dam safety.

Factor of safety (FoS)	THI_{Dam}
> 1.5	0
≤ 1.5 (or not available)	1

In a former THI methodology (UBA, 2016), the age of TMFs was also taken into account. Older TMFs were classified as more dangerous than newer ones. However, no satisfactory proof was found for this assumption in the historical analysis and therefore the age was left out. In fact, there are even some hints that it might be vice versa. Especially new TMFs seem to be very much involved in TMF failures. One explanation could lie with poor management and lack of experience at new sites or even on the other hand a consolidated geological stability at old TMFs. For future studies, this aspect should be considered more closely.

3.1.1.6 Overall THI

The overall THI is calculated by the following formula taking all individual critical parameters into account that influence TMF hazard, i.e. the volume of tailings stored in TMF, the toxicity of substances contained in tailings, the hazard related to the actual management of the facility, the specific natural (geological and hydrological) conditions at the TMF site and the dam functionality:

$$THI = THI_{Cap} + THI_{Tox} + THI_{Man} + THI_{Nat} + THI_{Dam} \quad (3)$$

The THI is to be understood on logarithmic scale, meaning that an increase of the THI value with one indicates 10 times higher hazard. An example calculation for the THI can be found in Annex D.

The THI provides a simple tool to roughly assess the accident hazard of a number of TMFs in a region. More detailed assessment tools may be used at national or sub-regional level. Moreover, parameters shown in this report may be subject to fine-tuning according to national conditions (e.g. taking the type and conditions of the deposited materials into account, adjusting several parameter values).

The developed THI methodology is primarily designed to assess the danger level of TMFs and prioritize hazard hotspots. No quantified risks for specific areas downstream of a TMF can be outlined by applying the THI and it does not take any potential direct impacts on people or environment into account.

However, in case of detailed land-use planning activities, which should be performed in the frame of TMF design and licensing, potential risks to people and the environment have to be taken into account.

4 TMF RISK ASSESSMENT

Bearing in mind that the TMFs pose significant risks to peoples' lives, the environment and economic goods that are located downstream, potential failures have to be already taken into consideration during licensing of a TMF. In this regard taking susceptible people and the environment within the vicinity of TMFs into account is one of the priority tasks of land-use planning in order to minimize losses in case of an accident.

Disaster risk originates from the complex interaction between development processes that determine conditions of exposure, vulnerability and hazard (UNISDR, 2015). Disaster risk is therefore considered as the combination of the severity and frequency of a hazard, the number of people and assets exposed to the hazard and their vulnerability to damages.

The THI approach does not consider important land-use planning criteria such as the distance to waterbodies and settlements downstream, as well as the landscape of the downstream territory. Consequently, there might be significant differences in terms of accident risk between TMFs with the same THI but located in different vulnerable areas.

There are different formal definitions of land-use planning but all of them have the common understanding, that it is defined as a process where land is allocated and regulated for different social and economic activities such as agriculture, industry, recreation, housing and commerce issues. In order to manage the appropriate siting of activities and prevent land-use conflicts, land-use planning decisions must account for all sources of land-use related risk, both natural and manmade, which include potential threats to human health, property and the environment arising from hazardous facilities, some of which are TMFs.

As already mentioned, the TMF-Methodology was designed to implement the Safety Guidelines into a living document, but this Methodology does not include any land-use planning aspects or risk assessment measures yet. Therefore, and as a first step, it is important to design an amended methodology by taking into consideration the risks to human health and environment in relation to any TMF accident.

For doing so, risk assessment and risk mapping are an important part of land-use planning for TMFs. Moreover, the risk assessments also have obvious benefits for individual countries to target their limited financial and personnel resources to TMFs according to their risk level.

In order to support land-use planning activities, the Tailings Risk Index (TRI) methodology has been developed to assess the risks of potential accidents on different receptors.

4.1 The Tailings Risk Index method

The THI (already described in Chapter 3) describes and quantifies the potential accidental hazard of TMFs based on the volume and hazardousness of the stored substances and their management, natural site and dam stability conditions. However, it does not consider the socio-economic and environmental values located nearby the TMF, which may be at risk. Therefore, an advanced methodology assessing these additional risks is needed. The TRI has been developed to address these aspects, particularly considering risks to people and environment.

The TRI method can be used:

- To provide a preliminary generalized semi-quantitative overview of the different risks in a large area (e.g. transboundary river basins or several countries) or to indicate the most dangerous TMFs on national level (territory of the whole country or some regions);

- To enable the prioritization of the different types of risk (to environment and population) for further detailed analysis.

The TRI assessment takes into account the total hazard potential plus the population and water bodies downstream as potential receptors at risk of exposure in case of an accident. As the socio-economic values at risk and vulnerability of the potential receptors can be estimated only by a detailed assessment, the TRI approach does not include these aspects. Any further detailed risk assessment for individual TMFs to support contingency planning or specific safety assessments needs to integrate more specific aspects and information directly at and around the site (e.g. further receptors to be potentially exposed, vulnerability of the receptors).

4.1.1 Data collection and processing

To assess the risk of a TMF, first of all the population and water bodies in the vicinity downstream of the TMF dam are considered. The subsequent TRI can then be determined taking into account different potentially affected downstream zones for population and environment.

Past accidents show that the usual runout length of the released tailings in the field (before reaching surface waters) is up to 10 km from the concerned TMFs (see Chapter 2). Therefore, a zone with 10 km radius is considered as a potential risk zone for the TRI methodology.

The respective data collection and processing consists of the following steps:

1. Definition of a circular area (risk zone) around the TMF with a specified radius that represents the potential spreading distance of the probable effect of a failure downstream of the TMF (10 km).
2. Identification of the settlements and waterbodies located downstream of the TMF and inside the potential risk zone and therefore may be affected in case of a TMF failure. The downstream settlements and water bodies can be identified using Geographic Information System (GIS) techniques (e.g. determining flow routes based on a topographic map and intersecting them with a land use map). In case the user of this methodology does not have a license to use or proper knowledge in GIS, the estimation of the risk zone and downstream settlements/waterbodies can be made by visual inspection of any available digital or hard copy maps (e.g. satellite, terrain).
3. Obtaining population data and summing up the population of the downstream settlements for the potential risk zone (Population At Risk, PAR).
4. Obtaining the mean discharge rate/water surface area of the closest stream/lake water body downstream in the potential risk zone.

4.1.2 Risk assessment

The TRI method first assesses the potential direct exposure on population and environment by calculating Tailings Exposure Index (TEI) values for both receptors. The overall TEI is then combined with the THI resulting in the TRI.

4.1.2.1 Calculation of the TEI

The calculation of the TEI is a simplified (basic) approach based on the total population and the size of nearest water body within 10 km distance.

4.1.2.1.1 Impact on population

The parameter TEI_{Pop} is a factor taking into account the downstream population located up to 10 km from the TMF (PAR). The TEI_{Pop} factor is determined by a simple classification shown in Table 8.

Table 8. Population exposure index.

PAR in 10 km zone	TEI_{Pop}
< 100	2
100 - 1000	3
1000 - 10000	4
10000 - 100000	5
≥ 100000	6

4.1.2.1.2 Impact on the environment

The TEI_{Env} is a factor that considers the size of the nearest waterbody to the TMF located downstream within 10 km distance of the TMF and may be polluted by a TMF accident. The TEI_{Env} factor is determined based on the mean river discharge value or the lake surface area presented in Table 9. The size classification for rivers refers to the ICPDR scheme used for the Danube Accident Emergency Warning System (ICPDR, 2018). For pragmatic reasons, instead of a mathematical equation (e.g. a logarithmic function of the mean river flow rate) a simple classification is set, as accurate flow/water surface area data are very often not available.

Table 9. Environment exposure index.

Stream flow rate, m^3/s or lake surface area, km^2	TEI_{Env}
< 100	2
100 - 1000	3
> 1000	4

4.1.2.1.3 The overall TEI

The total TEI is calculated by the following formula:

$$TEI = TEI_{Pop} + TEI_{Env} \tag{4}$$

4.1.2.1.4 Detailed TEI

In case more detailed investigation is needed, the TEI can be determined for different risk zones. For example, sub-zone borders can be assigned at 1 and 5 km downstream of the TMF and the PAR can be summed up according to these zones (0-1, 1-5, 5-10 km). Moreover, the TEI values can be calculated more precisely from the population and the stream flow rate/lake surface area. The detailed TEI is calculated according to the following equation:

$$TEI_d = TEI_{Pop,d} + TEI_{Env,d} = \log_{10} PAR_w + \log_{10} Q_{n,a} = \log_{10}\left(\sum_{i=1}^{3}\left(PAR_i \cdot f_{d,i}\right)\right) + \log_{10}(Q_n \cdot f_{d.n}) \tag{5}$$

where TEI_d is the detailed TEI, $TEI_{Pop,d}$ is the detailed TEI_{Pop}, $TEI_{Env,d}$ is the detailed TEI_{Env}, PAR_w is the weighted PAR, $Q_{n,a}$ is the adjusted discharge of the nearest river water body (m^3/s) or the adjusted water surface area of the nearest lake surface water body (km^2) PAR_i is the PAR in zone i, $f_{d,i}$ is the distance adjustment factor for zone i, Q_n is the discharge of the nearest river water body (m^3/s) or the water surface area of the nearest lake surface water body (km^2) and $f_{d,n}$ is the distance adjustment factor for the zone where the nearest water body is located.

The distance adjustment factor takes into account the different downstream distances of the sub-zones from the TMFs and indicates that the consequences are likely the worst for the closest sub-zone. Using the example sub-zone borders at 1 and 5 km and assuming that the transported tailings amount decreases along the downstream runout pathway according to a reciprocal function of the runout distance (i.e. only 10% can reach 10 km distance), the respective correction factors are shown in Table 10.

Table 10. Distance correction factor.

Sub-zones	$f_{d,i}$
0-1 km	1
1-5 km	0.33
5-10 km	0.13

4.1.2.2 Calculation of the TRI

The TRI is calculated based on the THI and TEI values by the following formula:

$$TRI = THI + TEI \tag{6}$$

Similarly to the THI, the TEI and the TRI are also to be evaluated on the logarithmic scale. An example calculation for TRI (with basic and detailed TEI) can be found in Annex E.

4.2 Risk mapping considerations

Mapping is a necessary part of land-use planning to clearly illustrate existing environmental conditions, the location of urban areas, land use types, potential sources of risks and potential consequences. For land-use planning and risk assessment of hazardous TMFs, a set of maps is recommended to be collated that demonstrates the concerned area and its conditions:

1. Land uses in areas surrounding the TMF;
2. Urban developments and industrial facilities downstream;
3. Topographical and landscape conditions (e.g. slope, landscape elements)
4. Hydrological and environmental features (e.g. surface water and groundwater bodies, floodplains, nature protection areas).

By using modern risk assessment tools (based on geographical information systems), all georeferenced maps and spatial hazard and risk data can be overlapped to clearly present the situation. The result is a spatial risk map, in which the potential exposure of hazardous activities to other land uses and developments can be evaluated.

For the evaluation of consequences on people, society, economy and the aquatic resources, the following parameters are recommended to be integrated and assessed by responsible authorities:

1. location of the TMFs
2. volume of the tailings and capacity of the TMF,
3. list of hazardous materials and their toxicity,
4. operational conditions of the TMF,
5. natural hazards at the TMF location (seismicity, floods, rainfall, snowmelt, landslides, wind),
6. dam stability parameters,
7. risk zone downstream with a defined radius,
8. population downstream in defined risk zones,
9. water bodies downstream in defined risk zones,

10. landscape and topographic properties around (potentially),
11. socio-economic and ecological values downstream in defined risk zones (potentially),
12. distance to other TMFs or hazardous installations (potentially),
13. distance to country or state borders (potentially).

This selection allows to consider also land-use planning aspects. Besides, visualization is very important for proper risk assessment and resulting strategies for contingency planning. Moreover, in case of a dam failure, the affected areas including soil, settlements and polluted water can be easily seen thanks to visual inspection and analysis of images collected from different satellites that show the territory nearby the failed TMF before and after the disaster.

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5 TMF INVENTORY FOR THE DANUBE RIVER BASIN

Recently, the ICPDR has been developing a basin-wide inventory on TMFs in order to undertake a hazard and risk assessment using the THI and TRI methods. This assessment aims at identifying and prioritizing the TMF hotspots in the DRB.

5.1 Inventory development

Data have been collected in two steps. In the first step, the basic data for the initial THI assessments were collected from open access data sources (ICPDR, 2019). Therefore, the compiled data sets and the related assessments are to be considered as preliminary database and information. In the second step, the basic data need to be revised and approved by all concerned Danube countries and they should be improved where necessary based on official national information. The second step of the data collection (revision and approval), the updated THI calculation and the TRI assessment are still on-going and will be finalised in 2021.

Table 11 shows the current status of the inventory demonstrating the number of TMFs in the DRB countries and how these data were collected. In total, 343 TMFs were identified in the DRB. These sites do not include mine waste heaps that store mining waste without dam retention and drainage facilities. The reported TMFs are located within the boundaries of the DRB and in the territory of 10 countries. Revised official data are available from Bosnia and Herzegovina (entity of Republika Srpska), Czech Republic, Hungary, Romania and Slovakia. For the rest of the countries the data revision still needs to be done therefore for these countries the database is still preliminary.

The index-based approaches presented in Chapter 3 and 4 were applied for comparative purposes and to undertake a first prioritization for the TMFs identified in the DRB. The THI have been calculated for all TMFs and in line with the data availability conditions indicated in Table 11. The TRI method was initially tested for Romania based on national population data (digital population map) and river discharge (hydrological database). Settlements and rivers located downstream of the TMFs and within 10 km distance were identified by GIS techniques. For the other DRB countries, preliminary data were collected from open sources that need to be further revised and approved by the Danube countries. The inventory will be completed once official TMF data from all countries have been made available and appropriate population and water body data in the 10 km risk zones have been collected for each identified TMF. The preliminary inventory with a limited set of parameters is presented in Annex F.

Some of the critical TMF parameters were missing or very uncertain in the open sources. In cases where plausible assumptions have been made to preliminarily evaluate these parameters as follows.

- TMF capacity. In case the amount of tailings materials was indicated in tonnes, TMF capacity was calculated based on the average density of tailings materials. In cases where the TMF capacity was unknown, it was estimated as the product of the TMF area measured using Google Maps and the average thickness of tailings materials in all TMFs with recorded data.
- Tailings material toxicity. In cases where tailings materials were unknown, they have been identified according to production activities of the company responsible for TMF operation. Specific contaminants in mining wastes were identified using geological data about by the kind of metal ore and other minerals.

Table 11. Results of the TMF data collection for the DRB.

Country	Number of TMFs[1]	Comments
Austria	6	No available database, open sources were used
Bosnia and Herzegovina	8	Data were revised and approved by national experts for the entity Republika Srpska, otherwise open sources were used
Bulgaria	3	No available database, open sources were used
Croatia	0	Statement of national experts on TMF absence in country's part of the DRB, no results in open sources for the DRB
Czech Republic	10	Data were revised and approved by national experts
Germany	0	Statement of national experts on TMF absence in country's part of the DRB, no results in open sources for the DRB
Hungary	39	Data were revised and approved by national experts
Moldova	0	Statement of national experts on TMF absence in country's part of the DRB, no results in open sources for the DRB
Montenegro	4	No available database, open sources were used
Romania	152	Data were revised and approved by national experts
Serbia	31	No official available database, open sources were used
Slovak Republic	60	Data were revised and approved by national experts
Slovenia	30	No available database, open sources were used
Ukraine	0[2]	There are no TMFs in the DRB in the national database
Total identified TMFs[3]	**343**	

[1] in the DRB only

[2] 344 TMFs are out of the DRB; there is one waste heap in the DRB without dam retention facilities

[3] The total number of TMFs in some countries significantly exceeds the number of TMFs located in the DRB (e.g. in the Czech Republic, Bulgaria and Montenegro)

5.2 TMF mapping

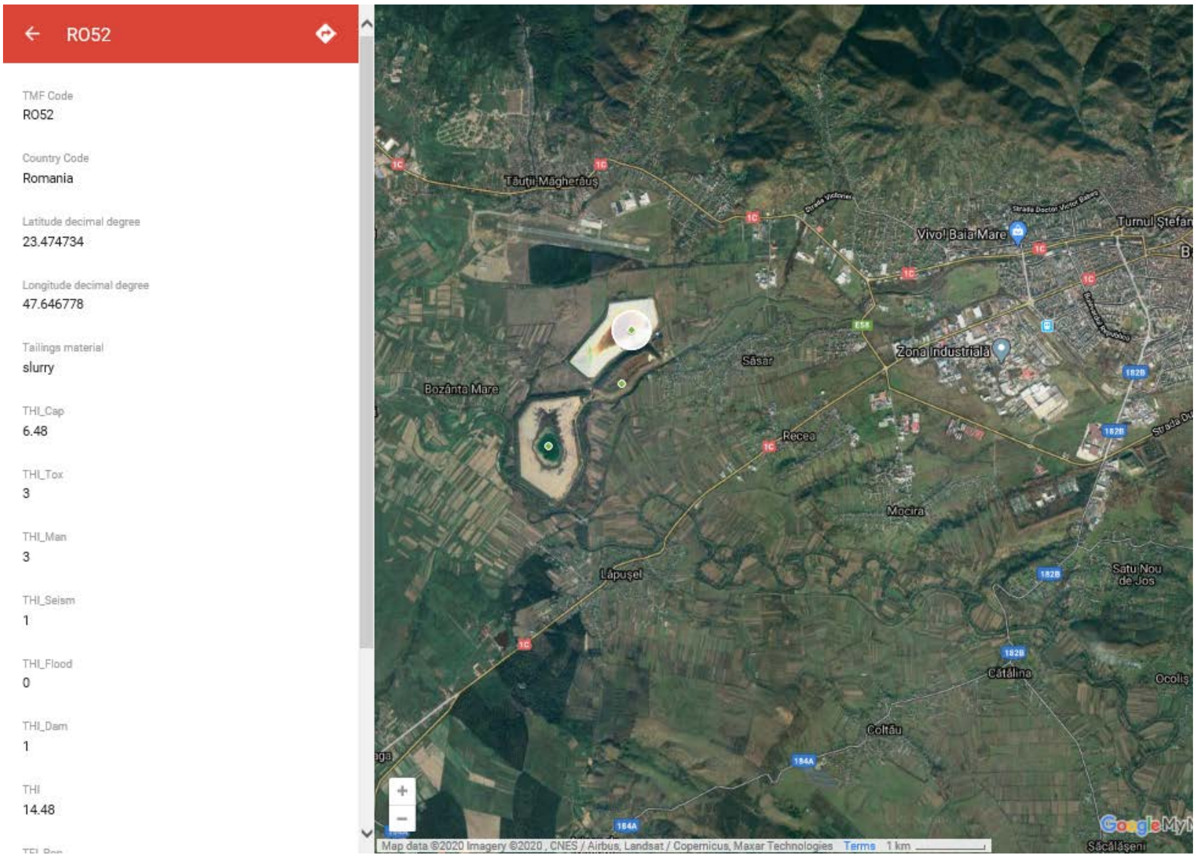
For supporting the implementation of land-use planning measures, an initial TMF hazard map was created for several countries of the Caucasus region where the TMF issue is relevant (UBA, 2020). This has been adapted to TMFs located in the DRB. By developing an online map, the intention was to create a pragmatic and easy-to-use tool, also for those people without specific knowledge on mapping and specific GIS software. To make the mapping simple, the Google Maps service has been selected as the interim mapping program. Once official data from all countries are available, the datasets will be integrated into the official ICPDR database called DanubeGIS including a standardized TMF map. This will allow further assessments, comparisons and updates to be accomplished based on more recent data. On the top of this, the integrated data and the related analyses will serve the elaboration of the 3rd Danube River Basin District Management Plan to be developed by the ICPDR by December 2021.

The following set of parameters were included to the preliminary Danube TMF map for each TMF (see Figure 10):

- TMF code;

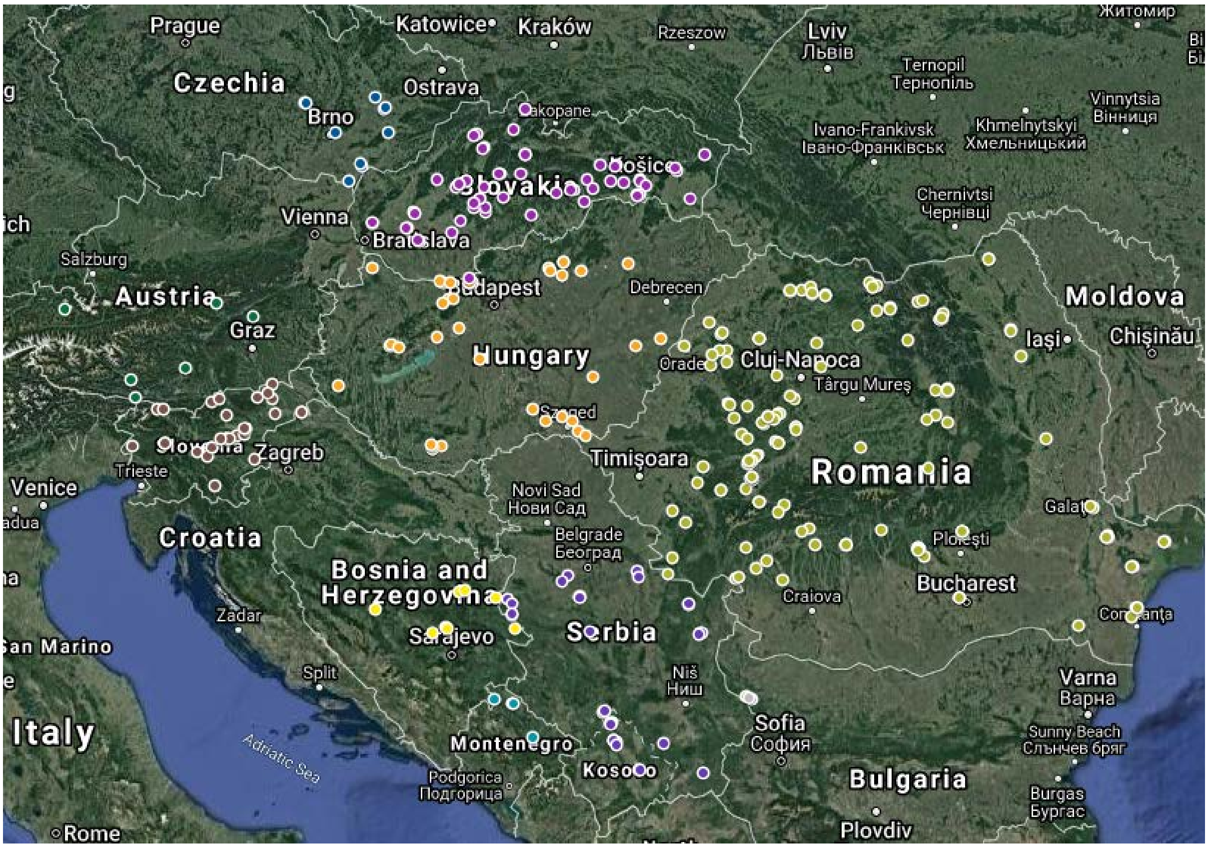
- Tailings material;
- Tailings capacity (THI_{Cap});
- Tailings toxicity (THI_{Tox});
- Management conditions (THI_{Man});
- Seismic hazard (THI_{Seism});
- Flood hazard (THI_{Flood});
- Total natural conditions (THI_{Nat});
- Dam conditions (THI_{Dam});
- Total THI value;
- Population Exposure (TEI_{Pop});
- Environment Exposure (TEI_{Env});
- Total TEI value;
- TRI value.

Figure 10. Display of the parameters for an example TMF.



A snapshot of the map is presented in Figure 11, the entire map is available on the link: https://www.google.com/maps/d/viewer?mid=11vS2CgbPEPPpW0j1_uAB_aemw9z03pf3&ll=46.16802179496559%2C20.8467&z=6.

Figure 11. Map of TMFs in the DRB countries.



5.3 TMF characterization in the DRB

Figures 12-16 demonstrate the distribution of all and active TMFs, the total volume of tailings materials and the average tailings toxicity over the DRB countries. The total volume of tailings materials in 343 identified TMFs (including 95 active TMFs) is more than 1500 million m^3. Most of the identified TMFs (248 or 72%) are inactive, many of them were already rehabilitated or are currently under rehabilitation. The highest shares of TMFs in the DRB (Figure 12) belong to Romania (44%), Slovakia (18%) and Hungary (11%). Romania (29%), Slovakia (27%), Serbia (21%) and have the highest shares of active TMFs (Figure 13). The highest amount of tailings materials was evaluated for Serbia, Romania and Slovakia (Figure 14). Bulgaria and Serbia show substantial weighted average toxicity of the tailings at the national level (Figure 15). The average toxicity of tailings materials in Czech Republic also exceeds the DRB average because of two facilities that store radioactive waste. The average tailings amount is by far the highest in Serbia (Figure 16).

Populated areas and water bodies within the 10 km risk zone of almost all TMFs could be identified. In total, 207 populated areas are located in the vicinity of 295 TMFs, whereas surface water bodies of 143 rivers or lakes can be found near 313 of the TMFs. Almost 5 million people in the DRB live in a potential risk zone that may be affected by a TMF accident. These settlements include the Romanian capital city Bucharest and 9 additional cities with population of more than 100,000 inhabitants. Majority (75%) of the settlements are small towns or villages with fewer than 10,000 citizens. Regarding the water bodies, the Danube and Sava Rivers, as large rivers could be directly polluted by a TMF accident. Moreover, 9 middle-sized rivers (100-1,000 m^3/s) are within the risk zones. The vast majority (92%) of the rivers is either small rivers, streams or creeks with a mean discharge less than 100 m^3/s.

Figure 12. Distribution of the TMFs over the DRB countries.

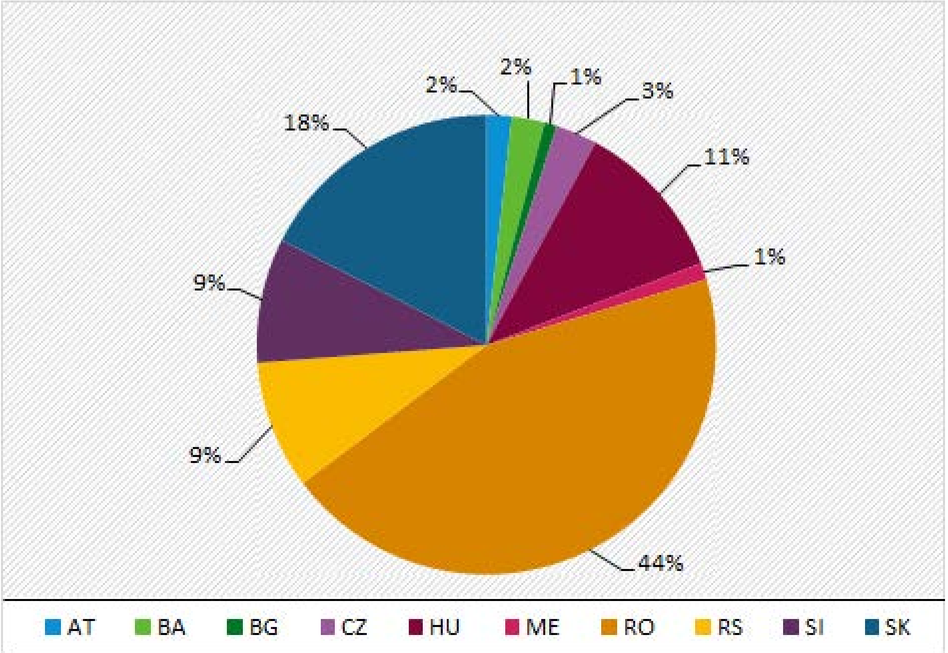


Figure 13. Distribution of active TMF over the DRB countries.

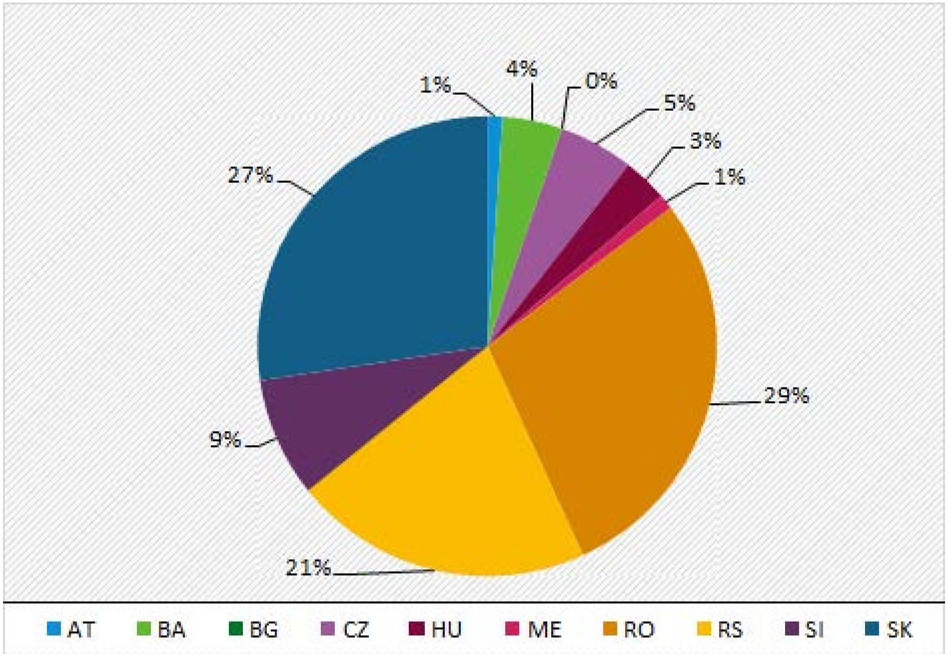


Figure 14. Distribution of the total volume of tailings materials over the DRB countries.

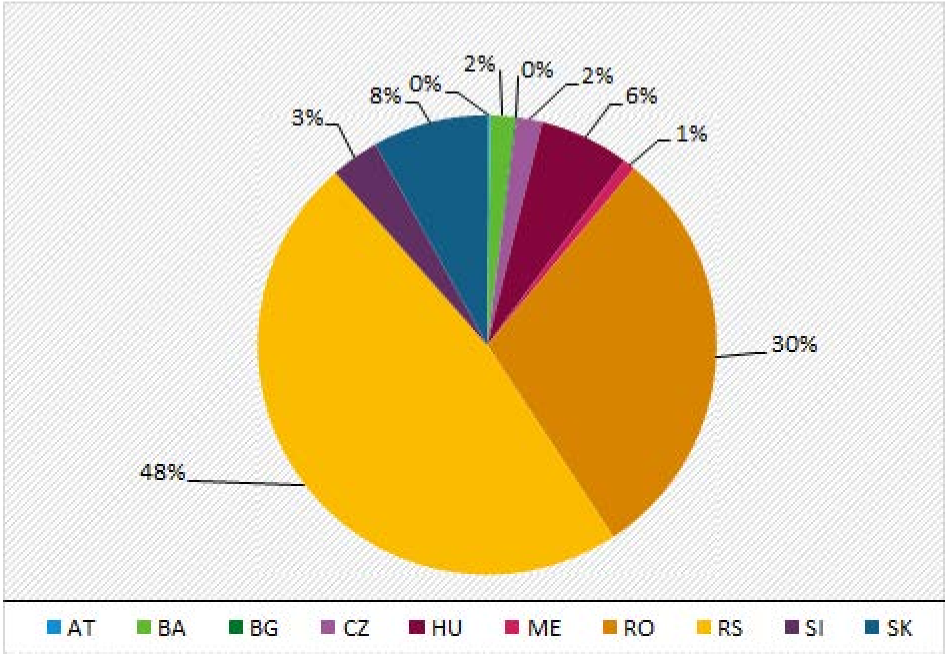


Figure 15. Weighted average toxicity of stored tailings materials in the DRB countries.

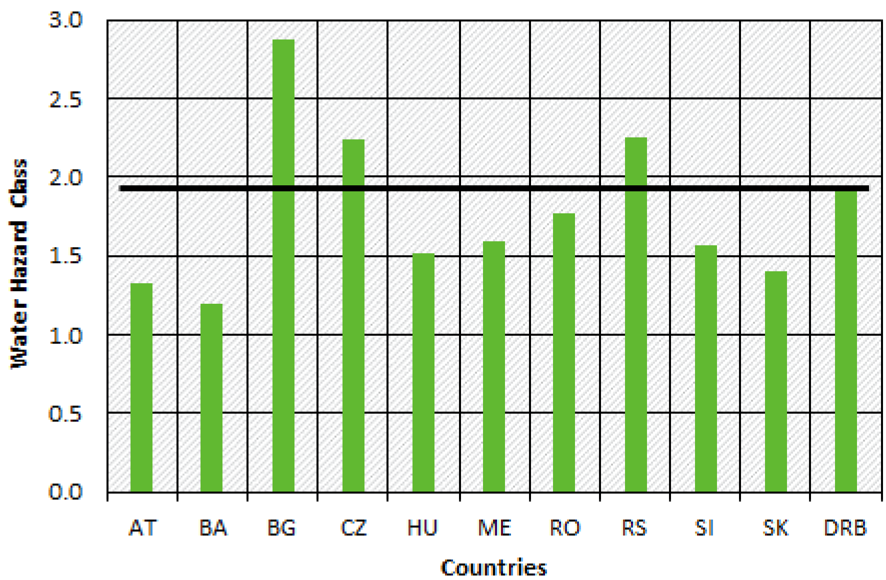


Figure 16. Average tailings amount in the DRB countries.

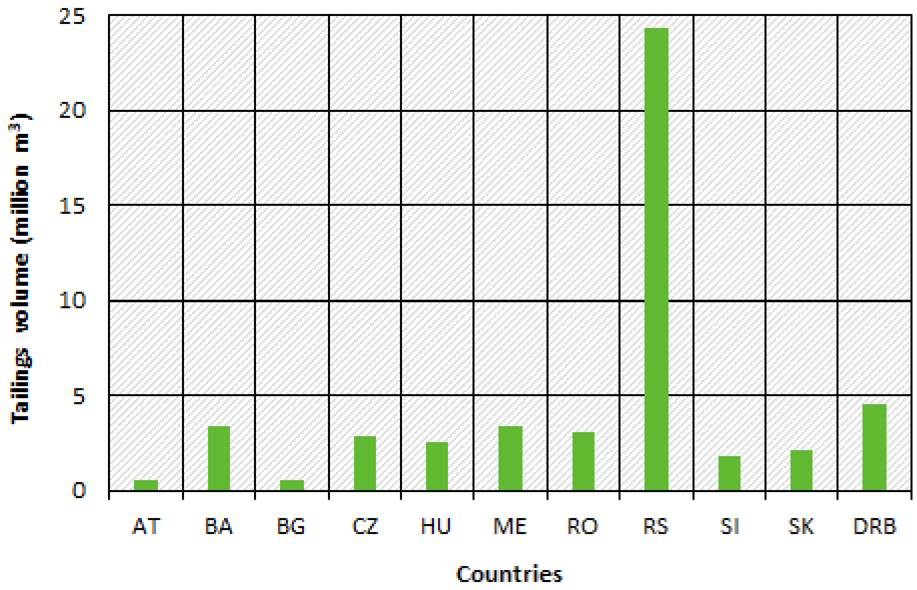
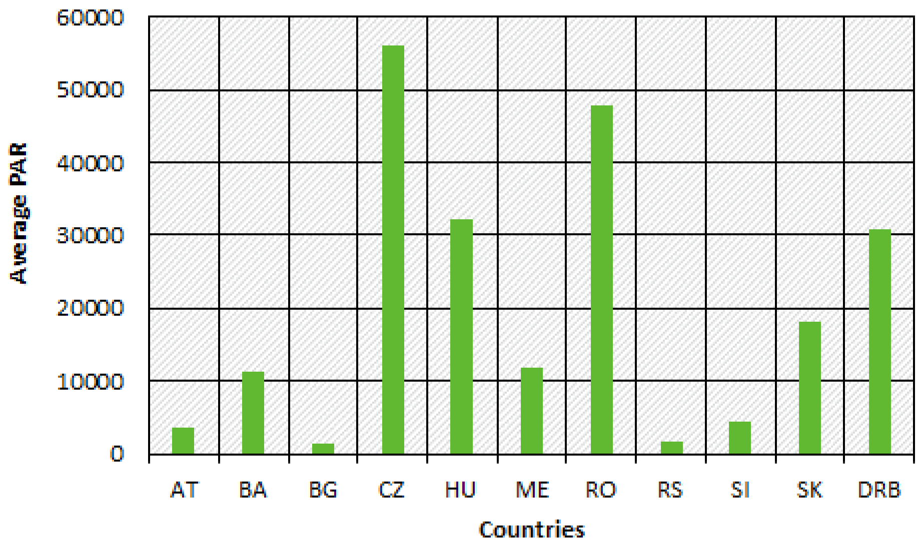


Figure 17 shows the average PAR associated to TMF risk zones in the Danube countries and in the DRB. Throughout the DRB, the average PAR per TMF is 31,000 inhabitants (note that multiplying this value with the total number of TMFs would overestimate the total PAR in the DRB since certain settlements are located in the vicinity of more than one TMF). The Czech Republic, Romania and Hungary have higher average PAR values than that of the overall DRB since in these countries several larger settlements can be found in the risk zones.

Figure 17. Average PAR in the DRB countries.



5.4 Preliminary hazard assessment of TMFs in the DRB (THI approach)

Figure 18 demonstrates the distribution of the TMFs in the DRB according to THI ranges. In total, 146 TMFs have very low (THI≤8) or low (8<THI≤10) hazard. Additional 115 TMFs have medium hazard (10<THI≤12), whereas high (12<THI≤14) and very high (THI>14) hazard was determined for 82 TMFs. Figure 19 shows the location of the TMFs categorized by hazard level.

The detailed map can be seen on the link:
https://www.google.com/maps/d/viewer?mid=11vS2CgbPEPPpW0j1_uAB_aemw9z03pf3&ll=46.16802179496559%2C20.8467&z=6.

Figure 18. Distribution of the TMFs in the DRB according to THI.

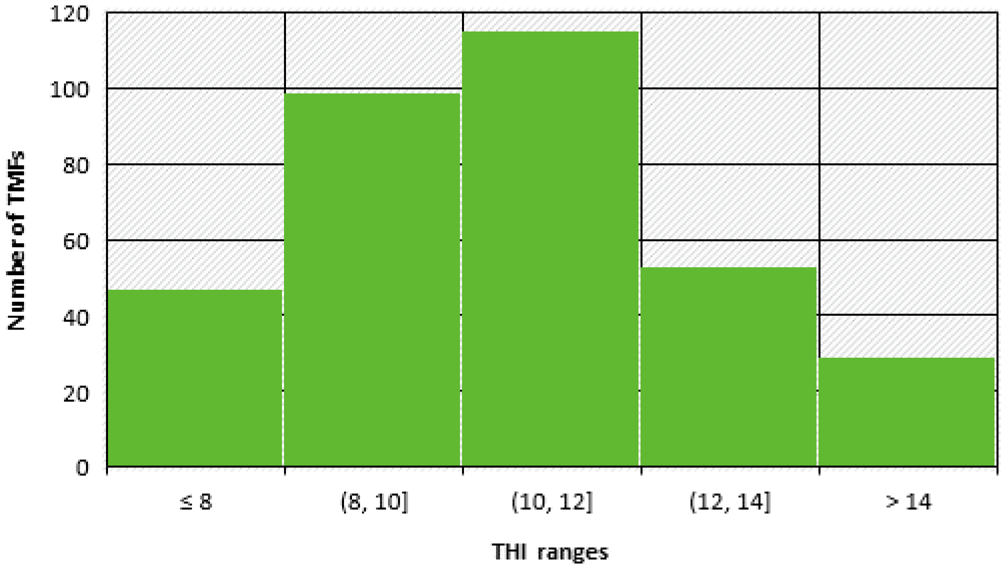
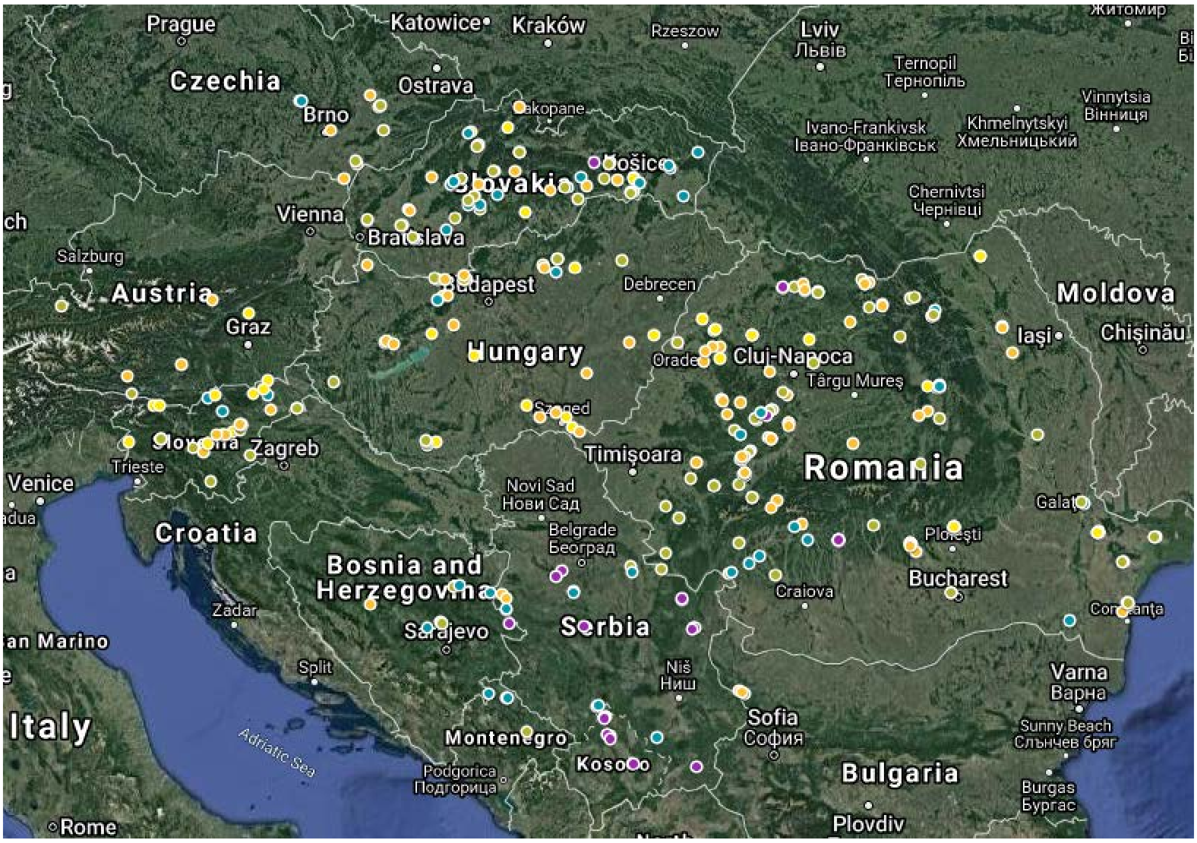


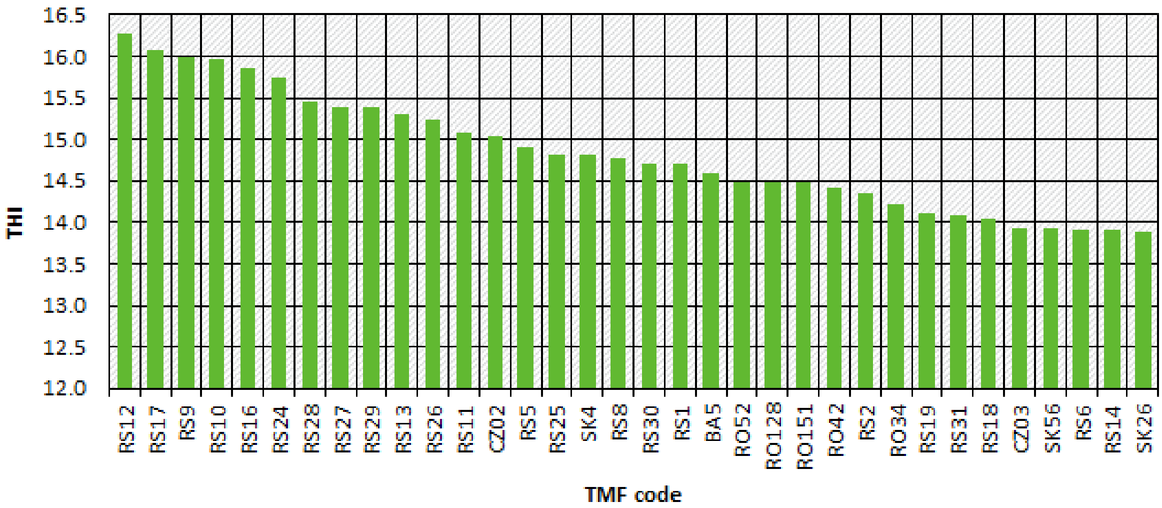
Figure 19. TMF hazard map for the DRB countries.



Color scheme: lilac – very high hazard (THI>14), blue – high hazard (12<THI≤14), green – medium hazard (10<THI≤12), orange – low hazard (8<THI≤10), yellow – very low hazard (THI≤8), © Google

Most of top 10% TMFs with the highest THI values are located in Serbia (Figure 20). Out of the 34 TMFs, 23 can be found in Serbia, 5 in Romania, 3 in Slovakia, 2 in the Czech Republic and 1 in Bosnia and Herzegovina. The vast majority of these TMFs store slurry or sludge of non-ferrous and precious metal ore extraction with heavy metals as major contaminants. The TMFs in Czech Republic are ranked as quite highly hazardous because they contain radionuclides.

Figure 20. Top 10% TMFs with the highest THI in the DRB.



Preliminary assessment results for the DRB countries are presented in Figure 21. The median THI value for the DRB (10.4) is exceeded in Bosnia and Herzegovina (11.3), Czech Republic (11.1), Montenegro (12.1), Serbia (14.7) and Slovakia (11.2). Majority of the TMFs can be found in a relatively small upper range in Serbia and Montenegro. On the contrary, TMFs are spread around a low value in Bulgaria and Hungary. The country average values are the highest in Serbia, Montenegro, Bosnia and Herzegovina and Slovakia. The difference of 5 between the highest (Serbia) and lowest (Hungary) average THI indicates 100,000 times higher hazard.

Figure 21. Median, 10%-90% percentiles, minimum and maximum THI in the DRB countries.

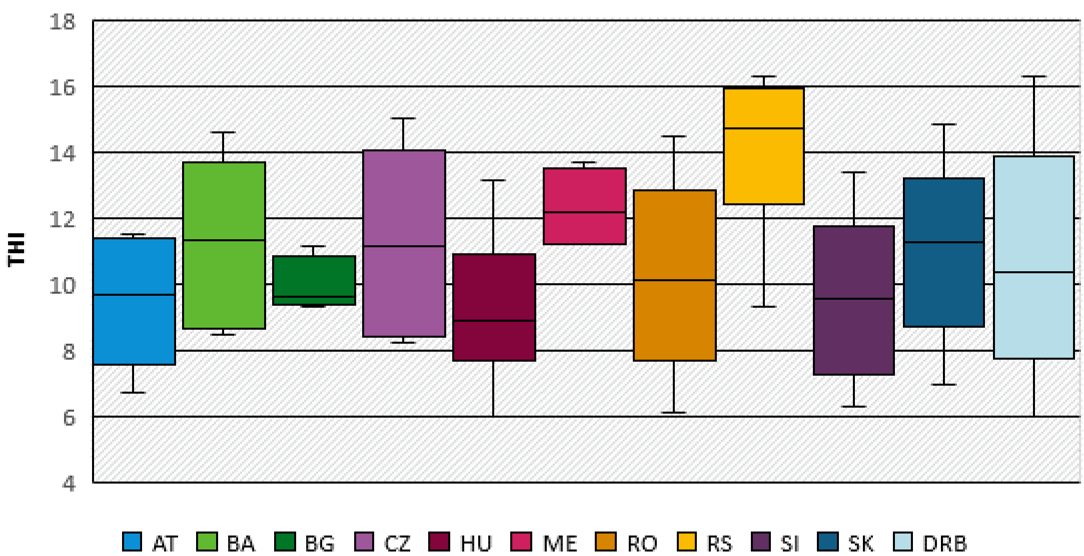
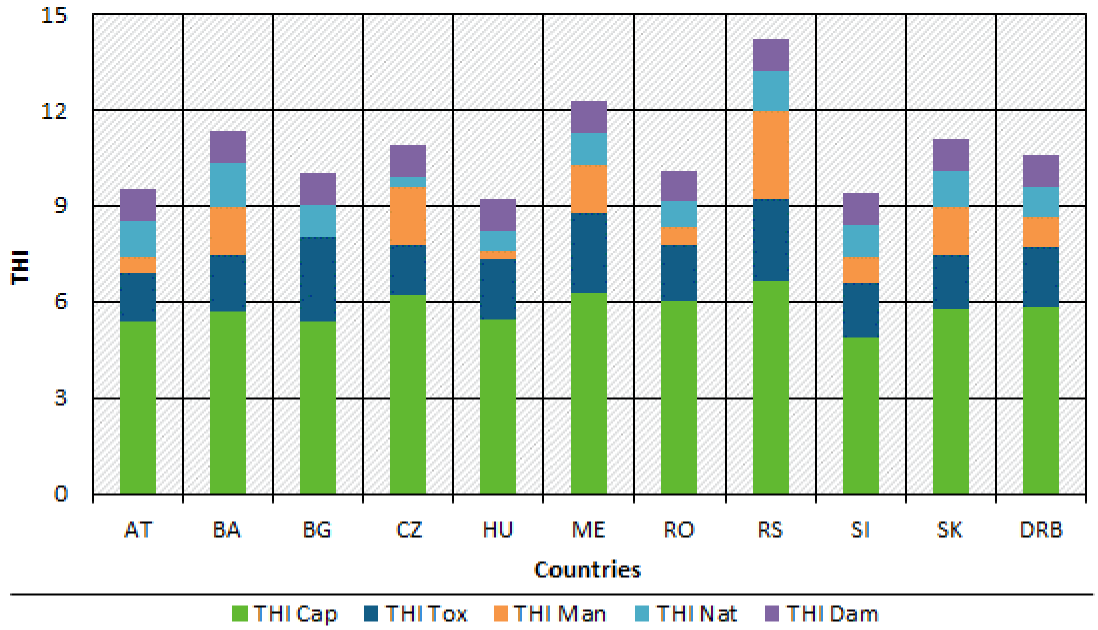


Figure 22 demonstrates the breakdown of the average THI constituents for the DRB countries. The TMF capacity strongly dominates the hazard assessment, toxicity and management status related hazards have significant impact on the overall THI, whereas natural hazards and dam stability have minor influence. The hazard of dam failure was evaluated equally for all countries because no data were found or received on the Factor of Safety of the dams. The hazard of tailings toxicity is high for the TMFs in Bulgaria, Serbia and Montenegro. The hazard caused by TMF capacity is substantial in Serbia, Montenegro, and the Czech Republic.

Figure 22. Breakdown of the average country's THI in the DRB.



The number of TMFs and the amount of tailings materials in Austria, Bosnia and Herzegovina, Bulgaria, Czech Republic and Montenegro are relatively small. Nevertheless, there are also a few hazardous TMFs in these countries. Hungary and Slovenia have a significant number of TMFs, but of a lower hazard level due to lower toxicity of the waste, lower amount of tailings and closure and rehabilitation efforts. In contrast, the number and/or the amount of TMFs and the calculated hazard index in Romania, Serbia and Slovakia are much higher, these countries are of high concern regarding TMF safety and they should be in focus of future activities on safety improvement and capacity building.

5.5 Preliminary risk assessment of TMFs in the DRB (TRI approach)

TMF distribution according to TRI classes (Figure 23) is similar to that of based on the THI. Very low and low risk was calculated for 128 TMFs, 133 TMFs have medium risk and 82 facilities show high and very high risk. A snapshot on the TMFs grouped according to the main TRI ranges is presented in Figure 24. The detailed online map can be found on the link: https://www.google.com/maps/d/viewer?mid=11vS2CgbPEPPpW0j1_uAB_aemw9z03pf3&ll=46.16802179496559%2C20.8467&z=6.

Hotspots associated with the highest risk (TRI) are shown in Figure 25. The top 10% sites are dominated by Romania (12) and Serbia (11) but other countries are also present, making the TRI list more balanced in comparison to the THI top 10% list.

Figure 23. Distribution of the TMFs in the DRB according to TRI.

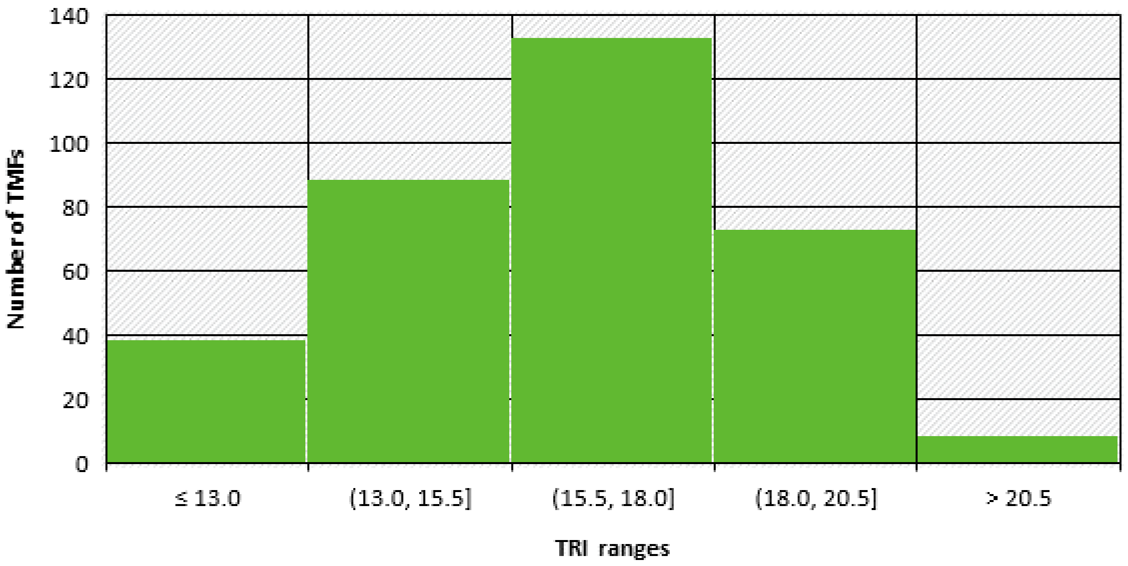
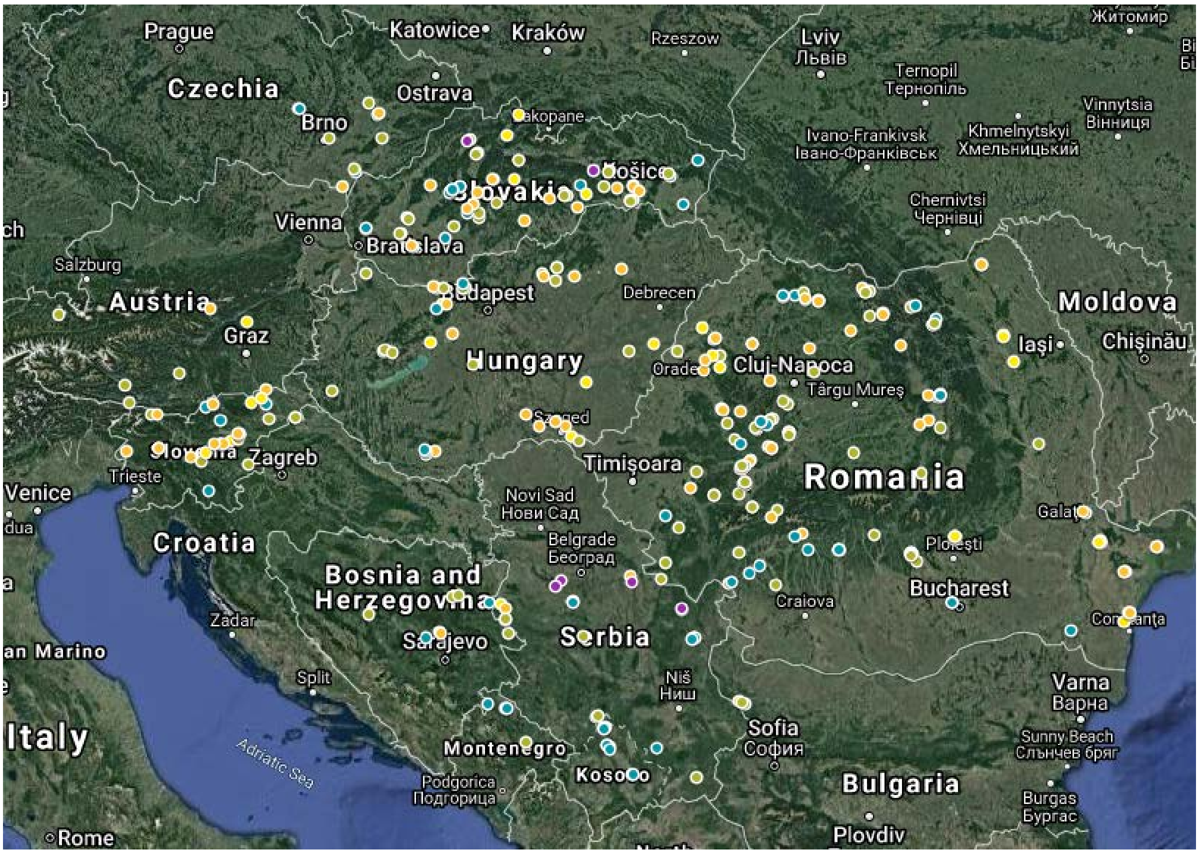
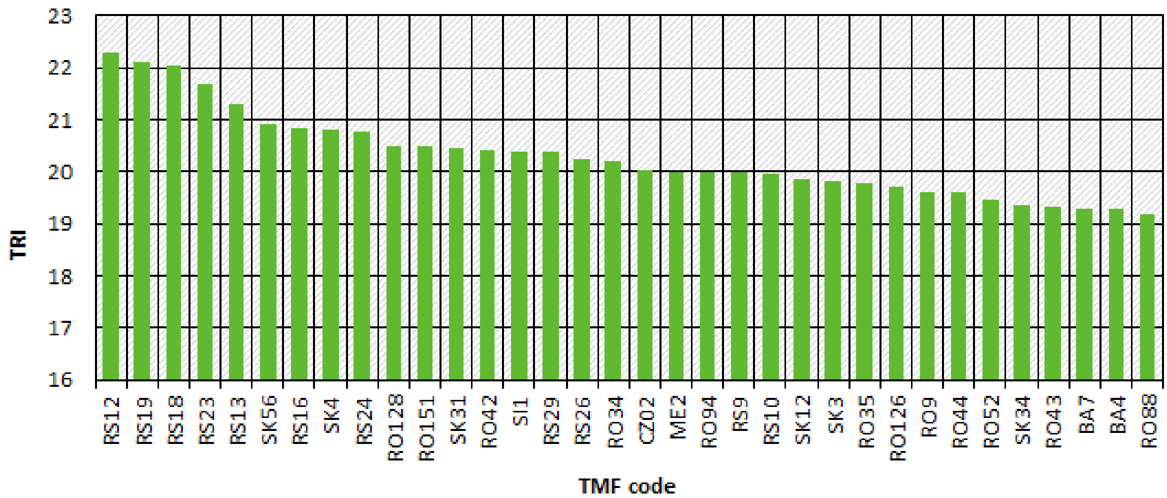


Figure 24. TMF risk map for the DRB countries.



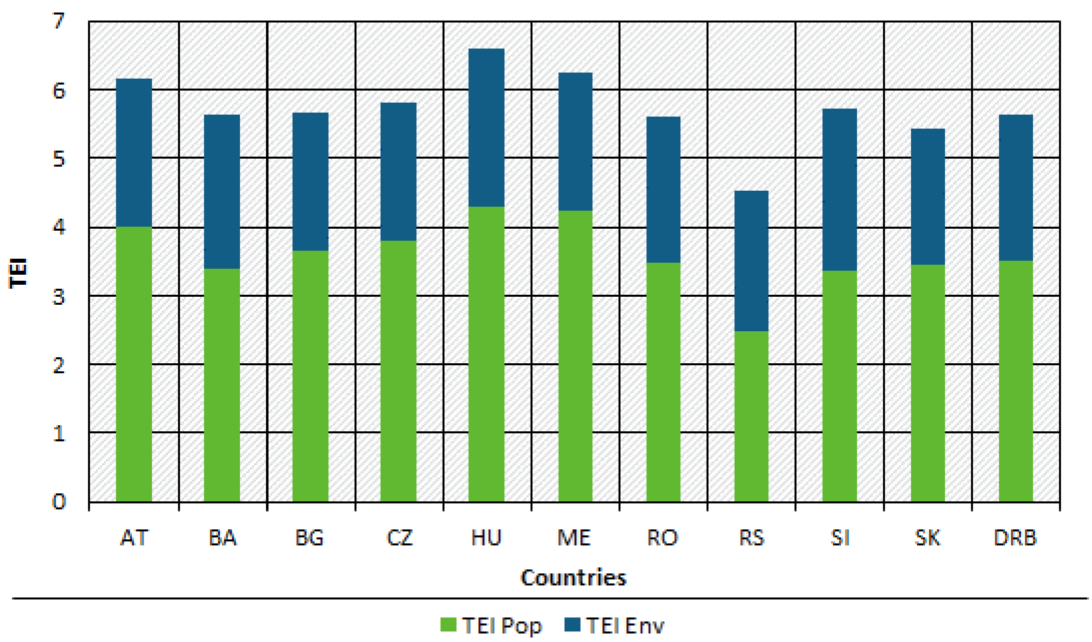
Color scheme: lilac – very high risk (TRI>20.5), blue – high risk (18<TRI≤20.5), green – medium risk (15.5<TRI≤18), orange – low risk (13<TRI≤15.5), yellow – very low risk (TRI≤13), © Google

Figure 25. Top 10% TMFs with the highest TRI in the DRB countries.



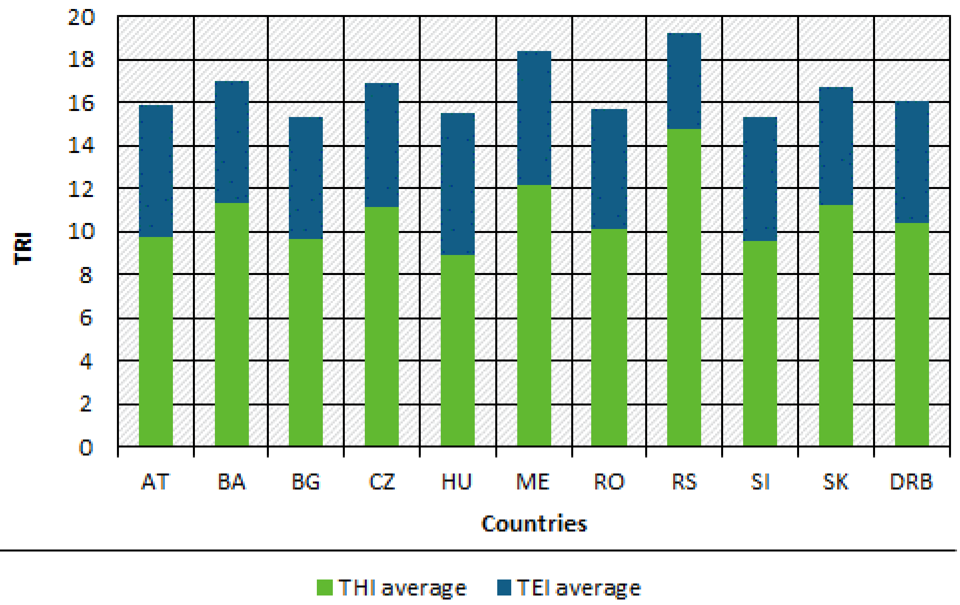
Assessment of the average TEI of the Danube countries is presented in Figure 26. Potential population exposure is the highest in Hungary and Montenegro. Nevertheless, the differences between countries are rather small, except in Serbia, where mainly small villages or scattered houses are located in the risk zones. The environmental exposure is the largest in Slovenia and Hungary, but their exposure index values are in a very similar range compared to the rest of countries.

Figure 26. Breakdown of the average country's TEI in the DRB.



The country average TRI values, the summed THI and TEI, are shown in Figure 27. Similarly to the THI, the TRI is the highest in Serbia and Montenegro, followed by Bosnia and Herzegovina, Czech Republic and Slovakia. The rest of the countries are below the DRB mean. The difference between the maximum (Serbia) and the minimum (Slovenia) is about 3.5, representing a risk 4,000 times higher.

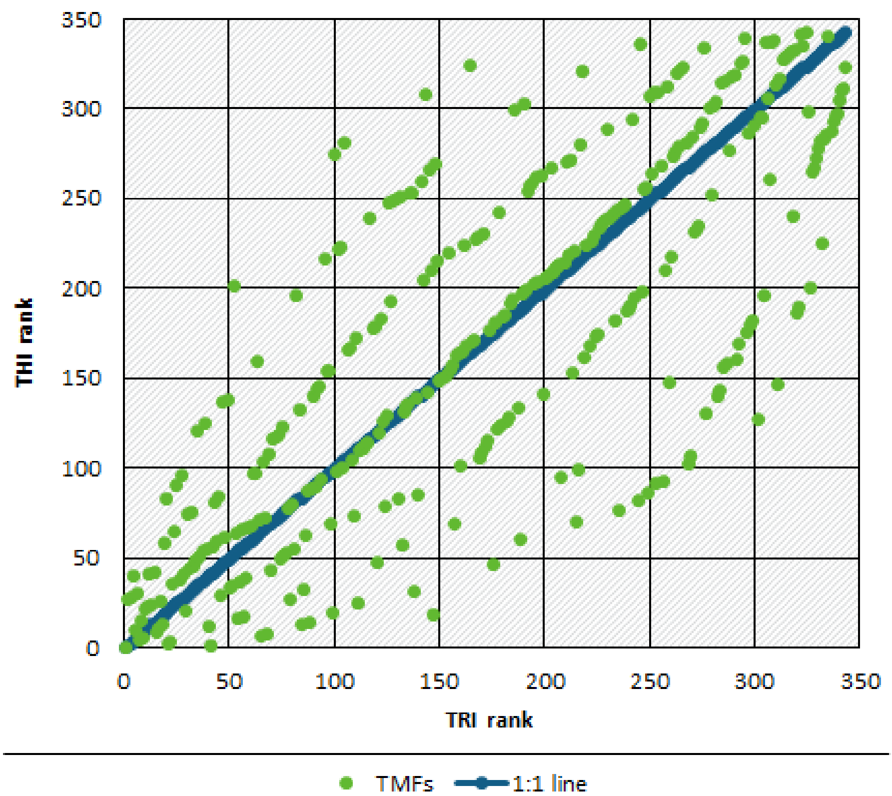
Figure 27. Average TRI values of the Danube countries.



5.6 Comparing THI and TRI

For each TMF, both the THI and TRI were calculated and ranked in the DRB. The preliminary ranks of all sites are presented in Figure 28. Blue dots indicate the TMFs according to their TRI and THI ranks, whereas black line represents completely identical rankings (no difference between TRI and THI).

Figure 28. Comparison of the preliminary THI and TRI values for the TMFs in the DRB.

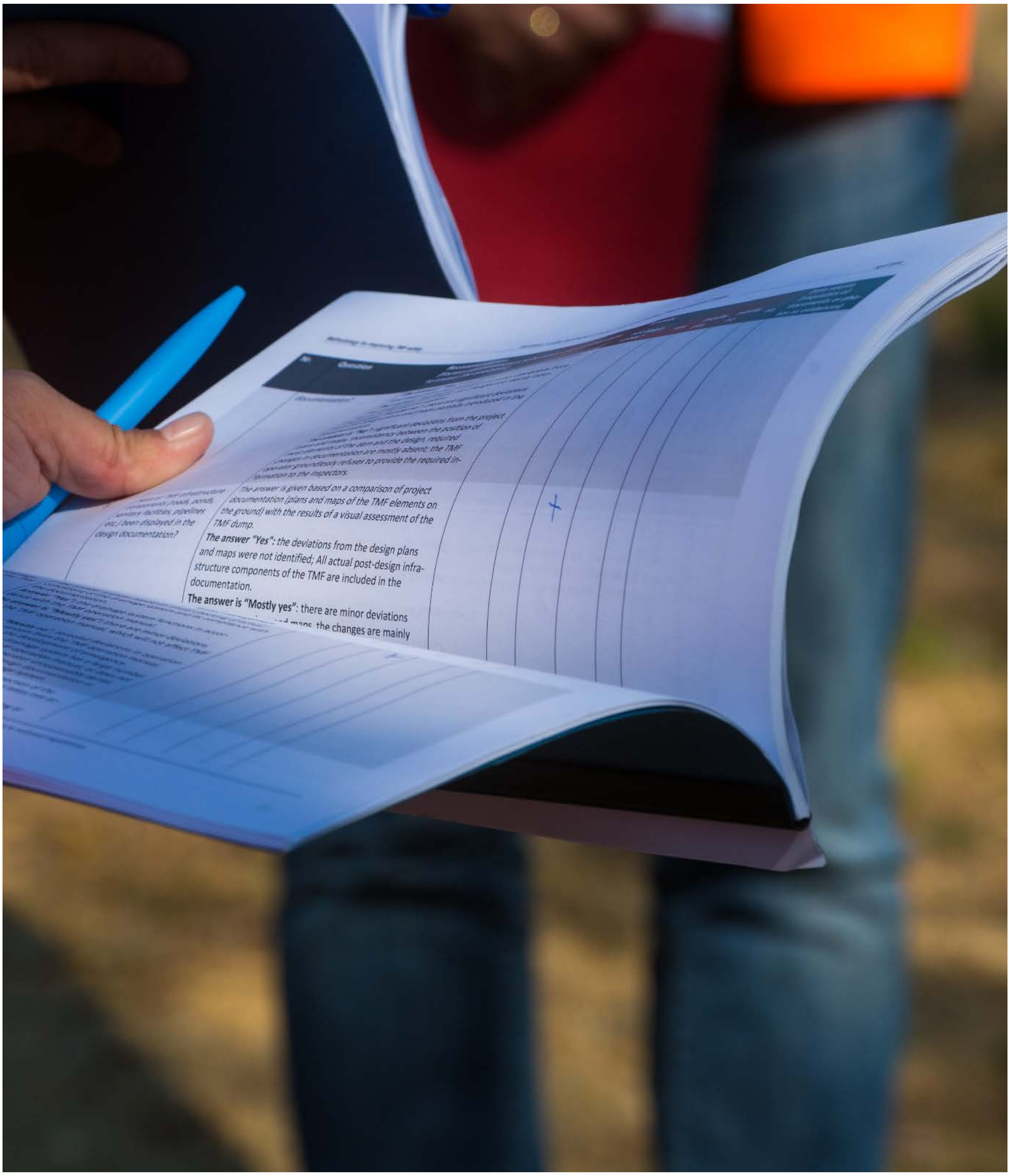


For many TMFs, the blue dots are scattered close to the black line, representing similar ranking results for the two indexes. This is because the TRI includes the THI and for these cases the TEI value has less impact on the overall TRI. However, for a high number of TMFs the ranks based on the two indexes are significantly different, indicating the necessity of considering land-use planning aspects at the point when TMFs are prioritized. For these TMFs, the TEI has a major impact on the final TRI value. This is very apparent for the top 10% TRI list (34 TMFs), where 16 TMFs posing high risk to population and environment would have much lower priority if only hazard was taken into account, i.e. only the remaining 18 TMFs are on both top 10% lists. Moreover, for only 10 TMFs are the ranks similar (rank difference less than 10). The index values and ranks of the top 10% TMFs (sorted by TRI rank ascending order) are highlighted in Table 12.

Table 12. Top 10% TMFs ranked by the TRI and THI.

TMF Code	TRI	TRI rank	THI	THI rank
RS12	22.28	1	16.28	1
RS19	22.11	2	14.11	27
RS18	22.05	3	14.05	29
RS23	21.70	4	13.70	40
RS13	21.30	5	15.30	10
SK56	20.92	6	13.92	31
RS16	20.85	7	15.85	5
SK4	20.82	8	14.82	16
RS24	20.75	9	15.75	6
RO128	20.48	10	14.48	22
RO151	20.48	11	14.48	23
SK31	20.44	12	13.44	42
RO42	20.41	13	14.41	24
SI1	20.39	14	13.39	43
RS29	20.38	15	15.38	9
RS26	20.24	16	15.24	11
RO34	20.22	17	14.22	26
CZ02	20.04	18	15.04	13
ME2	19.99	19	12.99	59
RO94	19.98	20	11.98	84
RS9	19.98	21	15.98	3
RS10	19.95	22	15.95	4
SK12	19.84	23	13.84	36
SK3	19.81	24	12.81	65

TMF Code	TRI	TRI rank	THI	THI rank
RO35	19.78	25	11.78	91
RO126	19.71	26	13.71	38
RO9	19.60	27	11.60	96
RO44	19.59	28	13.59	41
RO52	19.48	29	14.48	21
SK34	19.37	30	12.37	75
RO43	19.32	31	13.32	45
BA7	19.30	32	12.30	76
BA4	19.28	33	13.28	46
RO88	19.18	34	13.18	49


The answer is given based on a comparison of project documentation (plans and maps of the TMF elements on the ground) with the results of a visual assessment of the TMF dump.
The answer "Yes": the deviations from the design plans and maps were not identified; All actual post-design infra-structure components of the TMF are included in the documentation.
The answer is "Mostly yes": there are minor deviations

6 TMF CHECKLIST METHODOLOGY

Proper control of TMF safety requires regular inspections of these objects to be performed according to national regulations, taking into account international safety requirements and the BAT and offering engineering solutions for sustainable mining and environmental restoration.

As indicated above, one of the main elements of the TMF-Methodology is a Checklist for examinations of a minimum set of TMF technical safety requirements, combined with potential technical measures to implement international standards for the safe operation of TMFs (Measure Catalogue). The Checklist allows a detailed evaluation of the TMF safety level to be performed and recommends protective and preventive measures based on BAT.

The Checklist method as the core of the TMF-Methodology is based on the requirements and principles declared in the UNECE Safety Guidelines as well as other comparable international TMF standards. Thus, the method is a powerful tool for the process of harmonizing technical standards for the entire life cycle of TMFs throughout the UNECE region. However, it has to be noted that application of the methodology itself can be seen only as one of the first steps that has to be taken to improve the safety of TMFs. Additional steps have to be implemented, as recommended by the Measure Catalogue for short-, medium- and long-term time period.

The Measure Catalogue provides recommendations and measures for all stages of the TMF life cycle largely based on the revised EU BAT Reference Document for the Management of Waste from Extractive Industries (JRC, 2018). It helps to safely manage TMFs with optimized efforts of competent authorities and operators. It is also a benchmark for the UNECE countries fighting TMF failures and strengthening their mining standards.

The advantages of the Checklist are:

- all users (competent authorities, inspectors and operators) work with the same inspection procedure allowing a consistent safety evaluation;
- TMF operators can detect non-compliances with minimum set of the safety requirements as a self-assessment at the TMF;
- all users work with the same Measure Catalogue that is accumulating best available technologies in sustainable mining.

The Checklist is a practical tool that includes three sub-elements:

- a Questionnaire with three groups of questions;
- a Safety Evaluation Tool for assessing the TMF safety level;
- a Measure Catalogue recommending actions to improve TMF safety.

The questions of the Questionnaire are formulated in such way to encompass the minimum set of the requirements critical for TMF safety, which allows evaluating the TMF conditions. Questions in all groups of the Checklist are sorted by the TMF life cycle and each subsection contains relevant questions applied to the specific stage. Globally accepted stages of the TMF life cycle include site selection and design; construction; operation and management; decommissioning, closure and maintenance.

The Safety Evaluation Tool gives the assessment of TMFs in compliance with applicable safety requirements. The Evaluation Matrix evaluates the answers to the questions based on a simple scoring system; it includes both overall and categorical evaluation using specific categories, which allows thorough checking all TMF elements. Besides, the Matrix enables evaluation of uncertainties caused by the lack of data on the inspected TMF.

The application of the TMF Checklist is supported by a Measure Catalogue with short-, medium- and long-term safety measures. The short- and medium-term measures should be based mostly on economic aspects whereas the long-term measures should meet high international safety standards.

The Checklist is available in Excel format to facilitate its practical use via automatic calculation of the safety level and simple identification of appropriate safety measures.

Separated evaluation tools were developed for three question groups as follows:

- "Basic Check" (Group A);
- "Detailed Check" (Group B); and
- "Check of Inactive Sites" (Group C).

Each group includes two additional subgroups; the first subgroup is intended for visual inspection, while the second subgroup is elaborated to work with documentation. Visual inspection is mandatory for all groups.

The "Basic Check" group (Group A) is intended to be used by competent state authorities. The evaluation can be performed based on the analysis of available operator's documentation and site visit results within a short period. It provides a general assessment of the TMF safety level and helps to determine the need for more detailed evaluation by using the "Detailed Check" group (Group B).

The "Detailed Check" group (Group B) is recommended to be applied by state inspectors and TMF operators in order to evaluate the safety level of an individual TMF. Evaluation can be performed based on the analysis of available design and construction information as well as operator records, reinforced with additional studies and tests clarifying all TMF parameters performed by external experts if required and using information received during site visit to the TMF company and via interviews with TMF staff.

The objectives of the "Detailed Check" group are:

- assessment of all TMF systems and technical components;
- assessment of all risks/hazards, impacts and potential impacts, linked with TMF construction, operation, closure, and rehabilitation;
- and determination of the needs and priorities for taking short-, medium, and long-term measures aiming to improve the TMF safety level.

The safety evaluation with the "Detailed Check" group requires appropriate professional expertise to assess the technical implementation of the executed measures. A Measure Catalogue is attached to "Detailed Check" group to identify necessary measures to be implemented.

The group "Check of Inactive Sites" (Group C) is intended to be used for evaluation of non-active TMFs also including abandoned and orphaned ones. Its aims are to assess inactive sites, set inspection priorities and improve the management at inactive sites.

Implementation of the Danube TMF project and detailed testing and evaluation within the framework of a training event at the Baia Mare TMF revealed that the Checklist, in particular the Group B questions, needed to be revised and a better harmonisation with the relevant EU legislation was necessary. Moreover, several measures had to be updated and a stronger link to the BAT Reference Document had to be provided. In addition, structural changes were recommended by the training participants and it was suggested to amend the evaluation tool and to make it more practical. In response to these requested changes, the “Detailed Check” group (Group B) has been fully revised and updated along with an amended evaluation tool.

Detailed documentation on the “Basic Check” (Group A) and “Check of Inactive Sites” (Group C) can be found in former project reports (UBA 2018, UBA 2020a). The revised and updated “Detailed Check” group (Group B), as a standalone tool for TMF safety assessment, is described in the following chapters.

6.1 Detailed Checklist for operating TMFs

Thorough and comprehensive analysis of TMF safety is to be made through answering the questions of the “Detailed Check” Group and assessing the answers according to specific categories and criteria. The “Detailed Check” Group should be used along with a thorough documentation check and site visit and implies further deskwork on computer by filling out the TMF Checklist. Based on the assessment submitted, the authorities can make a counter check if required.

The “Detailed Check” Group should be used by experienced inspectors and personnel. It can also be used for advanced training programs. It is recommended to use this checklist primarily for unsafely operating TMFs to improve safety conditions, but also in response to changes of regulatory requirements, implementation of new technical processes, construction upgrading. Moreover, it can be useful for assessing safety level in the light of after-effects and lessons of accidents occurred at similar facilities.

As indicated above, the Checklist tool has three technical components: a Questionnaire, a Safety Evaluation Tool and a Measure Catalogue. The Checklist has been composed in MS Excel (see the file "Checklist Tool.xlsx" attached to this report). A tabular approach towards formatting the TMF Checklist has been applied in spread sheets (Excel format). This is intended to facilitate simple data processing and an automatized evaluation procedure.

6.1.1 Questionnaire

The "Detailed Check" group includes the subgroups "Detailed Visual Inspection" (Subgroup 1) and "Detailed Document Check" (Subgroup 2). The application of both subgroups is required for complete and reliable evaluation of the TMF safety level.

Subgroup 1 contains 38 questions while Subgroup 2 comprises of 223 questions. Both subgroups cover the three main phases of the TMF’s entire life cycle from design & construction phase through operation & management to closure & maintenance. Each of the main phases is further subdivided into several categories allowing the assessment of TMF safety according to different planning, technical and operational aspects besides the overall safety evaluation. The categories and the number of questions falling into them for both subgroups are presented in Table 13.

All Checklist questions are to be answered by choosing one of five alternative options:

1. “Yes” is applied if there are enough data or sufficient information to give the positive answer.
2. “No” is applied if there are enough data or sufficient information to give the negative answer or if there is no information at all to answer the question.
3. “Mostly yes” is applied if there are no enough data or sufficient information to give the definitive answer (“yes” or “no”) but there are more arguments to accept the positive answer “yes” rather than “no”.

4. "Mostly no" is applied if there are no enough data or sufficient information to give the definitive answer ("yes" or "no") but there are more arguments to accept the negative answer "no" rather than "yes".
5. "Not applicable" is chosen if the question is not relevant for the particular TMF or situation.

Table 13. Structure of the "Detailed Check" questionnaire.

TMF life cycle phase/category	Subgroup 1	Subgroup 2
Design and Construction phase		
Hazard Identification and Risk Assessment		26
Environmental Impact Assessment and Land-use Planning	3	21
Emergency Planning		6
Design Documentation and Permitting	3	30
Organisational and Corporate Management		6
Operation and Management phase		
Dam Raising Operations and Tailings Control	9	5
Water Management	8	13
Transportation and Infrastructure	5	6
Training and Personnel		18
Organizational and Corporate Management		17
Emergency Planning	3	26
Monitoring of Infrastructure Elements and Processes	5	12
Monitoring of Environmental Elements	2	13
Closure and Maintenance phase		
Closure and Rehabilitation Plan		12
Organizational and Corporate Management		8
Monitoring of Infrastructure Elements and Processes		2
Monitoring of Environmental Elements		2
Total	**38**	**223**

Each question is formulated in a way that the positive answer "yes" is interpreted as the maximum level of TMF safety, whereas the negative answer "no" is considered as the minimum level of TMF safety for the given question. The ambiguous answers "mostly yes" and "mostly no" allow the Checklist user to be flexible in evaluation, taking into account availability and credibility of data sources.

Subgroup 1 questions have to be answered based on a site visit covering all critical components of the TMF. Consultation with the TMF operators during the visit is highly recommended. Areas, which cannot be visited personally should be investigated by drone recording.

Answering Subgroup 2 questions needs to have access to the TMF design documentation, operational manual, emergency plans and regular monitoring and safety inspection reports.

6.1.2 Safety Evaluation Tool

Evaluation of the TMF safety level within the Checklist is performed with the Safety Evaluation Tool. For both subgroups and also for the entire questionnaire an overall and a categorical safety level evaluation is performed.

The overall evaluation of the TMF safety level summarizes the numerical contributions of all answers to the Checklist questions. It identifies the TMF state and quantifies the priority of recommended interventions and remedial actions.

The categorical evaluation is additional to the overall evaluation, it demonstrates the TMF safety from different aspects and provides details of TMF performance and conditions.

In the first step, each answer is numerically evaluated using the same scoring system. The numerical evaluation is based on the values presented in Table 14.

Table 14. Numerical evaluation of the answers.

Answer	Numerical value
“Yes”	4
“Mostly yes”	3
“Mostly no”	2
“No”	1
“Not applicable”	0

The final score is determined with the following weighting function:

$$S = A \cdot f_w \qquad (7)$$

where S is the score of the answer, A is the numerical value of the answer and f_w is the question weight.

Questions considered critical are related to technical safety requirements of the TMF operation that, in case they are not met, may lead to an emergency. These questions are considered more important to TMF safety than the other (general) questions. Critical questions are assumed to have double the significance of a general question, so the question weight is 1 for general questions and 2 for critical questions.

6.1.2.1 Overall evaluation

In the second step, the TMF safety performance is evaluated by using two factors that are quantified from the answer scores of the individual questions. The factor “Meeting Safety Requirements (MSRF)” is the index quantifying how many components and parameters of the inspected TMF meet the minimum set of requirements of environmental and industrial safety. The factor “Credibility (CRF)” is the index quantifying the sufficiency and consistency of data used for the performance evaluation.

The MSRF is calculated by summing up the scores of the quantitative answers and relating it to the sum of the maximum scores for both subgroups:

$$MSR_{tot} = \frac{MSR_1 + MSR_2}{2} = \left(\frac{\sum_{i=1}^{N_1} S_i}{\sum_{i=1}^{N_1} S_{i,max}} + \frac{\sum_{j=1}^{N_2} S_j}{\sum_{j=1}^{N_2} S_{j,max}}\right) \cdot 0.5 \quad (8)$$

where $MSRF_{tot}$ is the overall MSRF factor, $MSRF_1$ and $MSRF_2$ are the MSRF factors for Subgroup 1 and 2, N_1 and N_2 are the number of questions of Subgroup 1 and 2, S_i and S_j are the answer scores for question i and j, $S_{i,max}$ and $S_{j,max}$ are the maximum answer score for question i and j (value 4 is to be applied for general questions, value 8 for critical questions), i and j are the indexes of the questions in Subgroup 1 (i) and 2 (j).

Answering all questions negatively ("no") or positively ("yes") makes the MSRF value equal to 0% or 100%, respectively. If an ambiguous answer ("mostly yes" or "mostly no") is given to some (but not all) questions, then the value of the MSRF will be less than 100% indicating deficiency in comparison to the expected technical standards.

The CRF is calculated by summing up the number of the definitive answers ("yes" or "no"), which is then divided by the number of relevant questions (total number of questions minus not applicable questions) for both subgroups:

$$CR_{tot} = \frac{CR_{tot,1} + CR_{tot,2}}{2} = \left(\frac{N_{def,1}}{N_{rel,1}} + \frac{N_{def,2}}{N_{rel,2}}\right) \cdot 0.5 \quad (9)$$

where CRF_{tot} is the overall CRF factor, CRF_1 and CRF_2 are the CRF factors for Subgroup 1 and 2, $N_{def,1}$ and $N_{def,2}$ are the number of definitive answers ("yes" or "no") in Subgroup 1 and 2, $N_{rel,1}$ and $N_{rel,2}$ are the number of relevant questions ("yes", "mostly yes", "mostly no", or "no") in Subgroup 1 and 2.

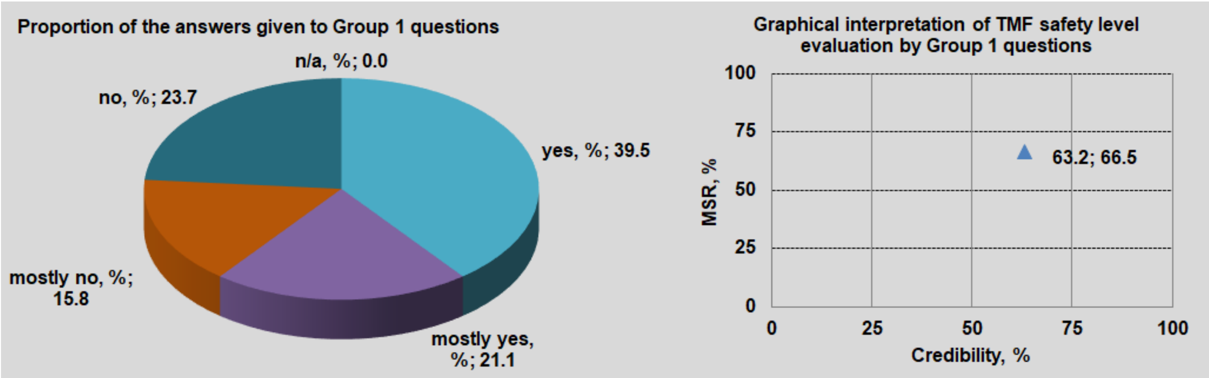
The more definitive answers are received, the higher the CRF becomes and thus, ambiguous answers decrease this factor. A CRF value of less than 100% means that there are ambiguous answers for some Checklist questions. Answering either only positively or only negatively to all questions makes the CRF value equal to 100% for both cases, although the MSRF values would be different (100% and 0%, respectively). If all answers are ambiguous ("mostly yes" or "mostly no") the value of the CRF will be 0%.

The overall evaluation primarily takes into account the TMFs' safety status based on the factor "MSRF". The evaluation follows the "one out all out" principle: the MSRF has to be 100% (full compliance with standards) for "Acceptable" safety level. In case the MSRF is less than 100% but only "yes" or "mostly yes" answers were given, the assessment will be "Acceptable with conditions", indicating that some of the questions with ambiguous answers need to be further investigated. In all other cases, the assessment will result in "Unacceptable" safety level indicating that some of the standards are not met and the reliability of the information sources needs to be improved.

In cases where the TMF safety level is evaluated as "Unacceptable" it is recommended to develop an action plan along with a financial plan to improve TMF safety based on the appropriate measures listed in Measure Catalogue. The evaluation report along with the action plan may be valuable information for the TMF operators and the competent authorities in terms of measure implementation in line with the respective national legislation and the required financial resources.

Assessment results (distribution of the answers, MSRF and CRF values for the subgroups and the overall questionnaire) are automatically presented in summary tables and diagrams in the checklist tool (see Figure 29). They are automatically generated once all questions are answered.

Figure 29. Overall evaluation of the Checklist answers.



Source: UBA, 2016 (redesigned)

6.1.2.2 Categorical evaluation

Evaluation of the TMF safety level using the questions of the Group "Detailed Check" is based on independent assessment of question subsets falling into several categories. These categories listed in Table 15 cover all major aspects of TMF performance, management, technical properties and site conditions. In total, 8 categories are defined for Subgroup 1 and 12 for Subgroup 2.

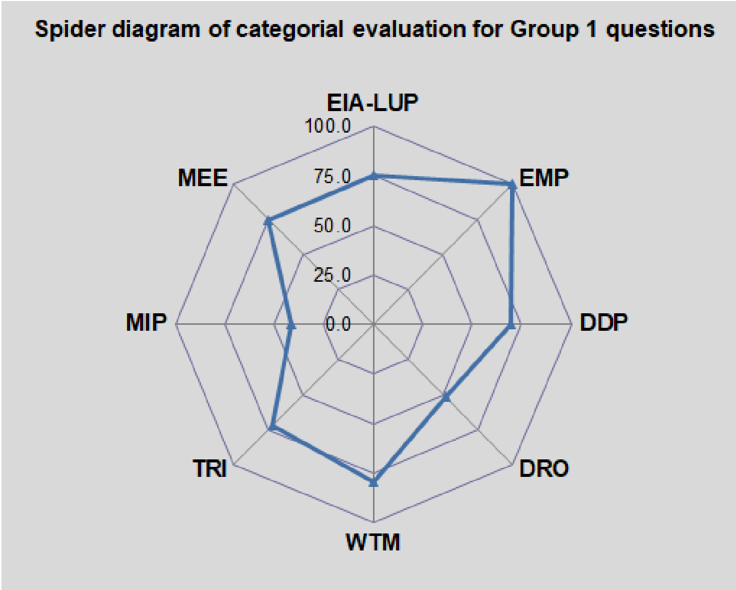
Table 15. Question categories according to various TMF management aspects.

Categories	Abbreviation	Subgroup 1	Subgroup 2
Hazard Identification and Risk Assessment	HRA		26
Environmental Impact Assessment and Land-use Planning	EIA-LUP	3	21
Emergency Planning	EMP	3	32
Design Documentation and Permitting	DDP	3	30
Organisational and Corporate Management	OCM		31
Dam Raising Operations and Tailings Control	DRO	9	5
Water Management	WTM	8	13
Transportation and Infrastructure	TRI	5	6
Training and Personnel	TP		18
Monitoring of Infrastructure Elements and Processes	MIP	5	14
Monitoring of Environmental Elements	MEE	2	15
Closure and Rehabilitation Plan	CRP		12
Total		**38**	**223**

Categorical evaluation of the TMF safety level is performed by calculating the MSRF with Equation (8) for all categories (where N_1 and N_2 are question numbers of Subgroup 1 and 2 falling into the defined categories shown in Table 15). For those categories, which have questions only for Subgroup 2, the MSRF value calculated for Subgroup 2 is used.

Assessment results (MSRF values by categories for the subgroups and the overall questionnaire) are presented in summary tables and spider diagrams in the checklist tool (see Figure 30). They are automatically generated once all questions are answered.

Figure 30. Categorical evaluation of the Checklist answers.



Source: UBA, 2016 (redesigned)

6.1.3 Measure Catalogue

The Measure Catalogue includes a list of actions recommended to be taken in cases where non-compliance of TMF conditions with current safety requirements or regulations has been identified. Experts should determine the appropriate actions for each problem detected at the TMF.

The Measure Catalogue is based on experiences in sustainable extractive waste management and modern and advanced safety standards, in particular the respective BAT Reference Document (JRC, 2018), the guidelines and recommendations provided by Cambridge (2018) and the EU technical guidelines for inspections (EC, 2020). The list of measures is recommended to be updated permanently in line with the advanced technologies, reviewed standards and application experiences.

The measures cover all phases of a TMF's life cycle and they are grouped to solve specific problems (non-compliances) detected during TMF evaluation. The measures are further specified according to their priority and time horizon (short-, mid- and long-term).

The detected problems are certain non-compliances between applicable safety requirements and the actual state of TMF components or parameters. Each question of the questionnaire refers to a certain problem in the Measure Catalogue to which some solutions are proposed.

Actions are recommended for all questions that are not answered 100% positively (answers "no", "mostly no", or "mostly yes"). The proposed measures are one or more actions aiming to improve the TMF safety level. There can be several measures proposed to solve or mitigate the same problem. The user can select the most appropriate measures for the specific case taking into account TMF and site-specific features.

Each measure is specified in the Measure Catalogue by the number of the problem detected and by a capital letter indicating the recommended action, such as 3A, 21D, etc. The questionnaire makes clear references to these measures so that the questions are explicitly linked to measures to be implemented in cases where non-compliance is identified. The measure priority depends on the urgency and costs of the proposed actions and can be defined as short-, mid-, and long-term interventions. These measures are classified in Table 16.

Table 16. Measure priorities.

Duration	Aim and standards applicable	Resources	Recommended terms[1]
Short-term measures	Urgently reconcile inconsistencies with safety requirements at the TMF according to national[2] technical standards	Available resources of the TMF operator; sufficient to provide low-cost measures or actions	To be completed not later than 3 months after prescription
Mid-term measures	Reconcile the inconsistencies with safety requirements that need some months for geotechnical or technological implementation according to national[2] technical standards	Available resources of the TMF operator and external sources; the measures have to be justified by "cost-effectiveness" criteria	To be completed not later than 1 year after prescription
Long-term measures	Technical upgrade of the inspected TMF to meet the safety requirements or recommendations regarding the implementation of modern international standards for industrial and environmental safety	Available resources of the TMF operator and external sources including governmental sources; the measures have to be justified by "cost-effectiveness" criteria	To be completed no later than 5 years after prescription

[1] This limitation can be changed in case of emergencies, accidents and for other important reasons

[2] International standards are applied if no national standards to a specific issue are available

6.2 Evaluation procedure

The Checklist should primarily – but not exclusively – be used for those TMFs considered unsafe based on preliminary hazard or risk assessments (e.g. the THI or TRI methods). These high priority sites should be first investigated by applying the detailed Checklist to assess the TMF safety level.

In order to accomplish the evaluation procedure, the Checklist user should first develop a TMF Evaluation Program. Checklist user can be a legal or natural person who must meet the criteria laid down by national law for being competent to perform the TMF Evaluation Program. The Program should cover all working phases resulting in the evaluation of the TMF safety level and should include a well-defined and realistic timeline.

The Program should involve the following work phases:

1. Preliminary check of the availability and accessibility of all relevant information on the TMF,
2. Visiting the TMF site for visual check (Subgroup 1),
3. Checking the TMF documentation (Subgroup 2),
4. Evaluation of the Checklist and reporting on the results.

6.2.1 Preliminary information check

Prior to start applying the Checklist, the user has to be familiar with the company and the TMF being evaluated. For this reason, a request should be sent to the TMF operator with a template to be filled in to indicate what information is available about the TMF and its operation. The operators should provide a brief summary for each item of the template along with a list of available documentation. The template should include the categories indicated in the Table 17.

Table 17. Categories for preliminary information check.

No	Requested information (categories)
1	Technical information and design documentation: flowcharts, description of the production process used at the enterprise, specification of input raw materials, chemical and physical composition of tails, etc.
2	Geographical site information: climate conditions, including weather extremes, precipitation and flood statistics
3	TMF Deposition Plan: maps, schemes, cadastral boundaries, adjacent infrastructures
4	Geological and hydrogeological conditions: seismic activity, landslides, faults, karst areas, soil properties, groundwater regime, etc.
5	Ecology and environment: flora, fauna, water and land ecosystems
6	Social environment: location, condition and size of communities and settlements; land use, access to the TMF territory
7	Risks to: surface water bodies, groundwater, air, soils, and biota
8	Stored material: hazardous substances and materials stored in the TMF
9	TMF history: construction and operation periods, contractor(s), accidents occurred.
10	TMF management system and bodies/persons responsible for TMF operation/maintenance

If any part of this information is not provided without written justification of the TMF operators, the Checklist user should assume the worst-case scenario and evaluate the TMF safety level as "Unacceptable conditions" due to lack of necessary data. The Checklist user has to submit an appropriate report to the competent authorities drawing attention to the following conditions:

1. the TMF site was preliminarily evaluated to have a high level of accident hazard, therefore a detailed investigation is urgently needed;
2. the recommended detailed investigations cannot be performed because of limited information accessible from the operator;
3. real danger of an accident event with possible dramatic consequences may exist due to potentially missing safety measures;
4. an authority inspection has to be urgently executed followed by taking immediate actions where necessary.

6.2.2 Site visit

Visual inspection and the related safety evaluation should be carried out according to a site visit plan that includes the necessary steps for using the Checklist methodology. The site visit plan should be based on studying the preliminary information provided by the TMF operator, should include a work plan on the site and should indicate a preliminary list of documents requested for evaluation. During the site visit, the Checklist user can immediately fill in the Subgroup 1 questionnaire as much as possible.

During the site visit, building a close and open dialogue with the operators is highly recommended to ensure transparency and to avoid any misunderstanding or hiding unfavourable operation conditions. The better they understand the aim of the inspection and are involved into the evaluation, the higher the acceptance of the evaluation results is. Bilateral discussions, meetings, staff interviews can support the smooth information exchange.

Using drones with high-resolution cameras, photo shooting, and appropriate remote-control equipment are strongly recommended for visual inspection of hard-to-reach parts of the TMF but being critical to its safety. The video and pictures recorded should be used as evidences in the evaluation of visual inspection results.

If the inspection is actively prohibited by the operator through hindering discussions with TMF personnel, groundless denial of inspecting any of TMF parts (especially those are critical for safety) or by prohibiting the use of remote checking equipment, the Checklist user has to suspect a serious problem, which could result in a dramatic TMF failure. In this case the Checklist user should assume the worst-case scenario and evaluate the TMF safety level as "Unacceptable conditions" due to insufficient site visit conditions. Similarly to the preliminary check, an authority inspection has to be urgently executed.

6.2.3 Document check

Answering the Subgroup 2 questionnaire requires comprehensive deskwork based on the available TMF documentation and additional information received from the company (e.g. interviewing, photos). The document check can be either combined with the site visit if the operators can accept a longer stay for the inspectors at the TMF or can be accomplished after the site visit using copies of the documents made available by the TMF personnel.

The following documents are required at least:

- Licensed design documentation;
- Environmental impact assessment;
- Operational manual, waste management plan;
- Monitoring reports or logs on technological, ecological and environmental parameters;
- Certificates of qualification and staff training;
- Management documents;
- Internal and external emergency plans where relevant.

6.2.4 Evaluation and reporting

The filled in Checklist is automatically evaluated resulting in overall and categorical evaluation parameters and a selection of necessary measures for improving the TMF safety level. Based on evaluation results, the Checklist user should compile a report on the work performed and the safety conditions of the investigated TMF. The report should summarize the results of the TMF safety level evaluation, the problematic aspects/TMF areas detected by the evaluation, all the decisions on further actions required to implement the recommended measures (timing, resources, efforts) and the procedures for controlling the actions/measures to be implemented (resources, timing). Supporting documentation (maps, photos, video records, meeting summaries) should also be attached to the report.

6.3 Practical test at the Baia Mare TMF in Romania

In the framework of the Danube TMF project, a regional demonstration training event was organised on the 1st - 3rd of October 2019 in Cluj-Napoca and Baia Mare, Romania for invited national TMF operators and environmental inspectors. The training event included theoretical lectures on the Checklist at the Babes-Bolyai University in Cluj-Napoca, site visit and field exercises at the Baia Mare TMF and desk exercises to test, discuss and amend a detailed checklist methodology (again in Cluj-Napoca). In total, 24 trainees from Romania, Hungary, Ukraine, the Czech Republic and Serbia (observer country) and 16 trainers, international experts and project partners participated in the training event.

On the first day, a comprehensive programme of lectures was provided to familiarise the participants with the checklist methodology. In addition, a site visit was organised to Baia Mare on the second day to test a specific checklist designed for visual inspection. During the site visit, participants were divided into three groups and each group performed a separate inspection on the facility. The trainees had their own checklist and answered the questions independently. Each group was accompanied by two trainers and a local TMF operator who provided explanations of the questions. Finally, a practical evaluation exercise on the third day completed the training programme. The participants evaluated the overall and categorical safety conditions of the TMF, compared the results of the visual inspections, exchanged their impressions on the site visit and provided recommendations on how to improve the checklist methodology. The outcomes of the training event significantly contributed to the revision and update of the Checklist, in particular the questionnaire and the measure catalogue.

6.4 Benefits of TMF Checklist application

The Checklist was conceived as a toolkit to improve TMF safety level and to ensure public safety in the areas potentially affected by tailings spills. On the top of enhancing technical quality and safety, it may also bring many organizational and managerial benefits listed below:

- The TMF Checklist imposes standardised, unified qualification requirements both to TMF operators and state inspectors. Thus, systematic application of TMF the Checklist can permanently enhance the skills and qualification of both, TMF operators and state inspectors.
- The TMF Checklist unifies the procedure to evaluate the safety of various TMFs, which ensures a consistent assessment and complies with the relevant EU legislation.
- The Checklist covers the entire life cycle of the TMFs so that it can reveal design deficiencies and inappropriate operation conditions, can improve emergency preparedness and can support implementing an adequate closure and rehabilitation plan.
- Regular training for the TMF personnel can enhance staff knowledge on preventive measures and their preparedness to emergencies.
- Systematic application of the Checklist to various TMFs in different countries will contribute to better understanding the risks posed by TMFs across geographic regions or river basins.
- Communicating the TMF Checklist results to the public and discussing safety issues with local communities in the form of public hearings can help raise awareness in society of TMF safety, accident prevention and emergency management.

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ANNEXES

A Historical tailings dam failures with reported data

Based on Bowker and Chambers (WMTF, 2020).

No	Mine	Year	Storage volume (m^3)	Release (m^3)	Runout (km)	Deaths
1	Nossa Senhora do Livramento, Mato Grosso, Brazil (VM Mineração e Construção, Cuiabá)	2019	580,000		2.0	
2	Cobriza mine, San Pedro de Coris district, Churcampa province, Huancavelica region, Peru (Doe Run Perú S.R.L)	2019		67,488	375.0	
3	Hpakant, Kachin state, Myanmar,Shwe Nagar Koe Kaung Gems Co. Ltd., Myanmar Thura Gems Co. Ltd.	2019				3
4	Muri, Jharkhand, India (Hindalco Industries Limited)	2019			0.2	1
5	Machadinho d'Oeste, Oriente Novo, Rondônia, Brazil (Metalmig Mineração Indústria e Comércio S/A)	2019				
6	Brumadinho, Mina Córrego do Feijão, Minas Gerais, Brazil (Vale)	2019	12,000,000	9,570,000	600.0	270
7	Huancapatí, Recuay province, Áncash region, Peru (Compañía Minera Lincuna SA, Grupo Picasso)	2018		80,000		
8	Duke Energy, L.V. Sutton Power Station, Wilmington, North Carolina.	2018	2,100,000			
9	Duke Energy, HF Lee Power Plant, Goldsboro, North Carolina	2018	875,000	2,000		
10	Cieneguita mine, Urique municipality, Chihuahua, Mexico (Minera Rio Tinto and Pan American Goldfields)	2018		439,000	26.0	5
11	Hpakant Jade Mines, Myanmar	2018				20
12	Hector Mine Pit Pond, MN, USA	2018	185,000	123,000		
13	Cadia, New South Wales (Newcrest Mining)	2018		1,330,000		
14	Barcarena, Pará, Brazil , Alunorte (Hydro Alu Norte/Norsk Hydro ASA)	2018				
15	Hpakant Jade Mines, Myanmar	2018				6
16	Hernic PGM Project, South Africa (Jubilee Metals Group)	2017	4,875,000	-		
17	Kokoya mine, Liberia (MNG Gold-Liberia)	2017	300,000	11,356		
18	Vedanta Aluminium Limited Smelter Ash Pond, Jharsuguda, India	2017		2,625,000		
19	Mishor Rotem, Israel (ICL Rotem)	2017		100,000	20.0	
20	Husab, Namibia (Swakop Uranium (Taurus Minerals))	2017				
21	Highland Valley Copper, British Columbia, Canada (Teck Resources)	2017		850	0.0	0
22	Tonglvshan Mine, Hubei Province, China (China Daye Ltd.)	2017		200,000		2
23	Antamok, Baguio, Philippines (Philex)	2016		50,000		
24	Duke Energy Coal Ash, Goldsboro, North Carolina	2016	415,000			
25	New Wales plant, Polk County, Mulberry, Florida (Mosaic Co)	2016		800,000		

No	Mine	Year	Storage volume (m^3)	Release (m^3)	Runout (km)	Deaths
26	Louyang Xiangjiang Wanji Aluminum, China	2016	2,000,000	2,000,000	2.0	
27	Hpakant Jade Mines, Myanmar	2015				115
28	Fundao-Santarem (Germano), Minas Gerais, Brazil (Samarco = Vale & BHP)	2015	56,400,000	43,700,000	668.0	19
29	Gold King Mine, near Silverton, Colorado	2015		11,356		
30	Yellow Giant Mine, Banks Island, British Columbia, Canada	2015		240	1.0	
31	Herculano Iron Mine, Itabirite, Minas Gerais, Brazil	2014	4,500,000			3
32	Buenavista del Cobre mine, Cananea, Sonora, Mexico (Grupo Mexico)	2014		40,000		
33	Imperial Metals, Mt Polley, British Columbia, Canada	2014	74,000,000	23,600,000	7.0	
34	Queensland Nickel, Yabulu Refnery, Townsville, Australia	2014		80,000		
35	Dan River Steam Station, North Carolina (Duke Energy)	2014	155,000,000	334,000		
36	Zangezur Copper Molybdenum Combine, Armenia	2013				
37	Obed Mountain Coal Mine Alberta, Canada	2013		670,000	180.0	
38	Coalmont Energy Corporation, Basin Coal Mine	2013		30	30.0	
39	Casa Berardi Mine, La Sarre, Abitibi region, Quebec (Hecla Mining Company)	2013		57,000		
40	Gullbridge Mine Newfoundland	2012		100,000	0.5	
41	Sotkamo, Kainuu Province, Finland (Talvivaara)	2012	5,400,000	240,000		
42	Padcal No 3, Benquet Philippines (Philex)	2012	102,000,000	13,000,000		
43	Hudson Bay (HB) Mine, Salmo, British Columbia (Regional District of Central Kootenay & Teck)	2012	1,800,000			
44	Johson Gold Mining Corporation at Baranggay Bangong-Bayan	2012				
45	Mineracao Serra Grande Tailings Dam, State of Goias, Brazil (Anglo Ashanti)	2012		900		
46	Mianyang City, Songpan County, Sichuan Province, China	2011		10,000		
47	Ray Mine, Hayden, AZ, USA (Asarco)	2011		3,600		
48	Bloom Lake, Newfoundland, Canada (Cleveland Cliffs)	2011		200,000		
49	Ajka Alumina Plant, Kolontár, Hungary (MAL Magyar Aluminum)	2010	30,000,000	1,000,000	80.0	10
50	Zijin Mining, Xinyi Yinyan Tin Mine, Guangdong Province, China	2010				22
51	Zijin Mining, Zijinshan Gold & Copper Mine, (Ting River)	2010		500		
52	Zijin Mining, Zijinshan Gold & Copper Mine, (Ting River)	2010		9,100		
53	Huancavelica, Peru, Unidad Minera Caudalosa Chica	2010		100,000	110.0	
54	Las Palmas, Pencahue, VII Region, Maule, Chile (COMINOR)	2010	220,000	170,000	0.5	4

No	Mine	Year	Storage volume (m^3)	Release (m^3)	Runout (km)	Deaths
55	Veta del Agua Tranque No. 5, Nogales, V Region, Valparaíso, Chile	2010	80,000	30,000	0.1	
56	Tranque Adosado Planta Alhué, Alhué, Region Metropolitana, Chile	2010				
57	Tranque Planta Chacón, Cachapoal, VI Region, Rancagua, Chile	2010				
58	Tranque Adosado Planta Alhué, Alhué, Region Metropolitana, Chile (Florida Mining)	2010				
59	Karamken, Magadan Region, Russia (cyanide-leach processing facility of gold mines in the region)	2009	4,600,000	1,200,000		2
60	Huayuan County, Xiangxi Autonomous Prefecture, Hunan Province, China	2009		50,000		3
61	Kingston fossil plant, Harriman, Tennessee, USA (TVA)	2008		4,100,000	4.1	
62	Taoshi, Linfen City, Xiangfen county, Shanxi province, China (Tahsan Mining Co.)	2008	290,000	190,000	2.5	254
63	Ekati Mine, Northwest Territories, CA (BHP Billiton)	2008		4,500		
64	Bernburg, Germany (Solvay)	2007		150,000		
65	Glebe Mines, UK	2007		20,000		
66	Mineracao Rio Pomba Cataguases, Mirai, Minas Gerais, Brazil, Mineração (Industrias Quimicas Cataguases)	2007	3,800,000	2,000,000		
67	Fonte Santa ,Freixia De Espado a Cinta, Potugal	2006		231,600	2.5	
68	Nchanga, Chingola, Zambia (Konkola Copper Mines - Vedanta)	2006				
69	Miliang, Zhen'an County, Shangluo, Shaanxi Province, China	2006			5.0	17
70	Mineracao Rio Pomba Cataguases, Mirai, Minas Gerais, Brazil, Mineração (Industrias Quimicas Cataguases)	2006		400,000		
71	Tailings Dam, USA	2005	500,000	170,000	25.0	
72	Captains Flat Dump No 3, Australia	2005		40,000	12.0	
73	Bangs Lake, Jackson County, Mississippi, USA (Mississippi Phosphates Corp)	2005		64,350		
74	Pinchi Lake, BC, Canada (Teck Cominco Ltd.)	2004		7,000		
75	Riverview, Florida (Cargill)	2004		227,000		
76	Partizansk, Primorski Krai, Russia (Dalenergo)	2004	20,000,000	160,000		
77	Malvési, Aude, France (Comurhex, Cogéma/Areva)	2004		30,000		
78	Cerro Negro, near Santiago, Chile, (5 of 5)	2003		80,000	20.0	
79	Sasa Mine, Macedonia	2003	2,000,000	100,000	12.0	
80	Mineracao Rio Pomba Cataguases, Mirai, Minas Gerais, Brazil, Mineração (Industrias Quimicas Cataguases)	2003		1,200,000		
81	El Cobre, Chile - El Soldado (Exxon)	2002		4,500		

No	Mine	Year	Storage volume (m^3)	Release (m^3)	Runout (km)	Deaths
82	El Cobre, Chile, 2, 3, 4, 5 (Exxon)	2002		8,000		
83	San Marcelino Zambales, Philippines, Bayarong dam (Benguet Corp-Dizon Copper-Silver Mines Inc)	2002	47,000,000	1,000,000		
84	San Marcelino Zambales, Philippines, Camalca dam (Benguet Corp-Dizon Copper-Silver Mines)	2002				
85	Thalanga Mine, Queensland Australia	2002	290,000			0
86	Tarkwa, Ghana (Goldfields)	2001				
87	Cuajone mine, Torata water supply dam, Peru	2001	16,000,000	-		
88	Sebastião das Águas Claras, Nova Lima district, Minas Gerais, Brazil	2001			8.0	2
89	Nandan Tin mine, Dachang, Guangxi	2000				28
90	Inez, Martin County, Kentucky, USA (Massey Energy subsidiary Martin Co. Coal Corp)	2000		1,068,500	120.0	
91	Aitik mine, near Gällivare, Sweden (Boliden Ltd)	2000	15,000,000	1,800,000	5.2	
92	Borsa, Romania (Remin S.A - govt)	2000		9,140		
93	Baia Mare, Romania	2000	800,000	100,000	2,000.0	
94	Toledo City, Philippines (Atlas Con Mining Corp)	1999		5,700,000		
95	Red Mountain, BC	1999		10,000		
96	Surigao Del Norte Placer, Philippines (3 of 3) Manila Mining Corp	1999		400,000	12.0	4
97	Huelva, Spain (Fertiberia, Foret)	1998		50,000		
98	Zamboanga Del Norte, Sibutad Gold Project (Philex Mining Corp)	1998				
99	Los Frailes, near Seville, Spain (Boliden Ltd.)	1998	15,000,000	6,800,000	41.0	
100	Mulberry Phosphate, Polk County, Florida, USA (Mulberry Phosphate)	1997		200,000		
101	Zamboanga Del Norte, Sibutad Gold Project (Philex Mining Corp)	1997				
102	Pinto Valley, Arizona, USA (BHP Copper)	1997		230,000		
103	Tranque Antiguo Planta La Cocinera, IV Region, Vallenar, Chile	1997		60,000	0.2	
104	Algarrobo, IV Region, Vallenar, Chile	1997				
105	Algarrobo, IV Region, Vallenar, Chile	1997				
106	Maitén, IV Region, Vallenar, Chile	1997				
107	Amatista, Peru	1996		600,000		
108	Caravelí, Peru	1996				
109	El Porco, Bolivia (Comsur-62%, Rio Tinto-33%)	1996		166,000	300.0	
110	Sgurigrad, Bulgaria	1996	1,520,000	220,000	6.0	

No	Mine	Year	Storage volume (m³)	Release (m³)	Runout (km)	Deaths
111	Marcopper, Marinduque Island, Philippines (2 of 2) (Placer Dome and President Marcos)	1996		1,600,000	26.0	
112	Laisvall (Boliden), Sweden	1996	20,000,000	-		
113	Negros Occidental, Bulawan Mine Sipalay River, Philippines (Philex Mining Corp)	1995				
114	Golden Cross, Waitekauri Valley, New Zealand (Coeur d'Alène Mines)	1995	3,000,000			
115	Surigao del Norte Placer, Philippines (2 of 3) (Manila Mining Corp)	1995		50,000		12
116	Omai Mine, Tailings dam No 1, 2, Guyana (Cambior)	1995	5,250,000	4,200,000	80.0	
117	Middle Arm, Launceston, Tasmania	1995	25,000	5,000		
118	Riltec, Mathinna, Tasmania	1995	120,000	40,000		
119	Hopewell Mine, Hillsborough County, Florida, USA (IMC-Agrico)	1994		1,900,000		
120	Payne Creek Mine, Polk County, Florida, USA (IMC-Agrico)	1994		6,800,000		
121	Fort Meade Phosphate, Florida, USA (Cargill)	1994		76,000		
122	IMC-Agrico Phosphate, Florida, USA	1994				
123	Merriespruit, near Virginia, South Africa (Harmony) - No 4A Tailings Complex	1994	7,040,000	600,000	4.0	17
124	Olympic Dam, Roxby Downs, South Australia	1994		5,000,000		
125	Minera Sera Grande: Crixas, Goias, Brazil	1994	2,250,000	-		
126	Tapo Canyon, Northbridge, California	1994		135,000	0.2	
127	Fort Meade, Florida, Cargill phosphate (3 of 3)	1994		76,000		
128	Longjiaoshan, Daye Iron Ore mine, Hubei	1994				31
129	Marcopper, Marinduque Island, Mogpog Philippines(12/6) (1 of 2) (Placer Dome-President Marcos)	1993				2
130	Gibsonton, Florida, USA (Cargill)	1993				
131	TD 7, Chingola, Zambia	1993		42		
132	Itogon-Suyoc, Baguio gold district, Luzon, Philippines (Benguet Corp)	1993				
133	Saaiplaas, South Africa, failure on south ring dyke (22Mar93)	1993		100		
134	Saaiplaas, South Africa, 2 failures on west ring dyke (18-19Mar93)	1993		100		
135	Magma Copper Company Pinto Valley Division Pinto Valley Operations, Arizona	1993		90,000		
136	Ray Complex, Pinal County, Arizona, AB-BA Impoundment	1993		216,000	18.0	
137	Marsa, Peru (Marsa Mining Corp)	1993				6
138	Kojkovac, Montenegro	1992	3,500,000	-		

No	Mine	Year	Storage volume (m^3)	Release (m^3)	Runout (km)	Deaths
139	Maritsa Istok 1, Bulgaria	1992	52,000,000	500,000		
140	Tubu, Benguet, No.2 Tailings Pond, Luzon, Philippines - Padcal (Philex)	1992	102,000,000	32,243,000		
141	Ajka Alumina Plant, Kolontár, Hungary	1991	4,500,000	43,200		
142	Iron Dyke, Sullivan Mine, Kimberley, BC, Canada (Cominco, Inc)	1991		75,000		
143	Magma Mine Tailings Dam #3	1991		8,000		
144	Brewer Gold Mine Jefferson South Carolina	1990		41,640	80.0	
145	Matachewan Mines, Kirtland Lake, Ontario	1990		190,000	168.0	
146	Soda Lake, California, USA	1989				
147	Stancil, Maryland, USA	1989	74,000	38,000	0.1	
148	Silver King, Idaho, USA	1989	37,000	100		
149	Southern Clay, Tennessee, USA	1989		300		
150	Little Bay Mine (Atlantic Coast Copper Co), Little Bay, Newfoundland and Labrador, Canada	1989	1,250,000	500,000		
151	Big Four, Florida, USA	1989				
152	Thompson Creek, Idaho, USA (Cyprus)	1989	27,000,000			
153	Unidentified, Hernando, County, Florida, USA #2	1988	3,300,000	4,600		
154	Jinduicheng, Shaanxi Province., China	1988		700,000		20
155	Consolidated Coal No.1, Tennessee, USA,	1988	1,000,000	250,000		
156	Riverview, Hillsborough County, Florida (Gardiner/Cargill)	1988		246		
157	Unidentified, Hernando, County, Florida, USA #1	1988				
158	Rain Starter Dam, Elko, Nevada, USA	1988	1,500,000			
159	Surigao Del Norte Placer, Philippines (1 of 3) (Manila Mining Corp)	1987				
160	Montcoal No.7, Raleigh County, West Virginia, USA	1987		87,000	80.0	
161	Bekovsky, Western Siberia	1987	52,000,000	-		
162	Xishimen, China	1987		2,230		
163	Montana Tunnels, MT, USA (Pegasus Gold)	1987	250,000			
164	Marianna Mine #58, PA	1986	300,000			
165	Mankayan District, Luzon, Phillippines, No.3 Tailings Pond (Benguet Corp subsidiary Lepanto Con Mining Co)	1986		100,000		
166	Pico de Sao Luis, Gerais, Brazil	1986				
167	Story's Creek, Tasmania	1986	30,000	100		
168	Rossarden, Tasmania	1986	200,000			

No	Mine	Year	Storage volume (m^3)	Release (m^3)	Runout (km)	Deaths
169	Itabirito, Minas Gerais, Brazil (Itaminos Comercio de Minerios)	1986		100,000	12.0	7
170	Mineral King, BC, Canada	1986	Small			
171	Huangmeishan, China	1986				19
172	Spring Creek Plant, Borger, Texas, USA	1986	30,000			
173	Niujiaolong tailings pond, China	1985	1,100,000	730,000	4.2	
174	Bonsal, North Carolina, USA	1985	38,000	11,000	0.8	
175	Prestavel Mine - Stava, North Italy, 2, 3 (Prealpi Mineraria)	1985	400,000	180,000	4.2	269
176	La Belle, Pennsylvania, USA	1985	1,230,000			
177	Cerro Negro No. (4 of 5)	1985	2,000,000	500,000	8.0	
178	Veta de Agua No. 1, Chile	1985	700,000	280,000	5.0	
179	Niujiaolong, Hunan (Shizhuyuan Non-ferrous Metals Co.)	1985	1,100,000	731,000	4.2	49
180	Olinghouse, Nevada, USA	1985	120,000	25,000	1.5	
181	El Cobre No. 4 - El Soldado (Exxon)	1985				
182	Marga, Chile - El Teniente (Codelco)	1985				
183	Quintette, MaËmot, BC, Canada	1985		2,500,000	2.5	
184	Texasgulf 4B Pond, Beaufort, Co., North Carolina, USA	1984	12,300,000			
185	Mirolubovka, Southern Ukraine	1984	80,000,000	-		
186	Battle Mt. Gold, Nevada,	1984	1,540,000			
187	Virginia Vermiculite, Louisa County, Virginia, USA	1984				
188	Clayton Mine, Idaho, USA	1983	215,000			
189	Golden Sunlight, MT, USA	1983				
190	Vallenar 1 and 2	1983				
191	Grey Eagle, California, USA	1983				
192	Sipalay, Phillippines, No.3 Tailings Pond (Maricalum Mining Corp)	1982	22,000,000	15,000,000		
193	Royster, Florida, USA	1982				
194	Ages, Harlan County, Kentucky, USA	1981		96,000	163.0	1
195	Dixie Mine, Colorado, USA	1981				
196	Balka Chuficheva, Russia	1981	27,000,000	3,500,000	1.3	
197	Texasgulf No. 1 Pond, Beaufort Co., North Carolina, USA	1981	24,700,000			
198	Veta de Aqua A	1981				
199	Veta de Agua B	1981				
200	Tyrone, New Mexico (Phelps Dodge)	1980	2,500,000	2,000,000	8.0	

No	Mine	Year	Storage volume (m^3)	Release (m^3)	Runout (km)	Deaths
201	Sweeney Tailings Dam, Longmont, Colorado, USA	1980				
202	Marga, Sewell, VI Region, Rancagua, Chile - El Teniente (Codelco)	1980				
203	Arena, Sewell, VI Region, Rancagua, Chile - El Teniente (Codelco)	1980				
204	San Nicolas, Peru	1980				
205	Kyanite Mining, Virginia, USA	1980	430,000			
206	Churchill Copper, BC	1979		37,854		
207	Churchrock, New Mexico, United Nuclear	1979	370,000	370,000	110.0	
208	Union Carbide, Uravan, Colorado, USA	1979				
209	Unidentified, British Columbia, Canada	1979		40,000		
210	Suncor E-W Dike, Alberta, Canada	1979				
211	Incident No. 1, Elliot, Ontario, Canada	1979				
212	Arcturus, Zimbabwe	1978	680,000	39,000	0.3	1
213	Mochikoshi No. 2, Japan (2 of 2)	1978	480,000	3,000	0.2	
214	Mochikoshi No. 1, Japan (1 of 2)	1978	480,000	80,000	8.0	1
215	Norosawa, Japan	1978	225,000			
216	Hirayama, Japan	1978	87,000			
217	Syncrude, Alberta, Canada	1978				
218	Madison, Missouri, USA	1977				
219	Grants, Milan, New Mexico, USA mill site (Homestake Mining)	1977		30,000		
220	Western Nuclear, Jeffrey City, Wyoming, USA #2	1977		8,700		
221	Pit No. 2, Western	1977				
222	Unidentified, Hernando, County, Florida, USA	1977				
223	Kerr-McGee, Churchrock, New Mexico, USA	1976				
224	Zlevoto No. 4, Yugoslavia	1976	1,000,000	300,000		
225	Dashihe, China	1976				
226	Unidentified, Idaho, USA	1976				
227	Cadet No. 2, Montana,	1975				
228	Silverton, Colorado, USA	1975		72,500		
229	Madjarevo, Bulgaria	1975	3,000,000	250,000	20.0	
230	Carr Fork, Utah, USA (Anaconda)	1975				
231	Mike Horse, Montana, USA (Asarco)	1975	750,000	150,000	24.0	
232	Dresser No. 4, Montana,	1975				

No	Mine	Year	Storage volume (m^3)	Release (m^3)	Runout (km)	Deaths
233	Keystone Mine, Crested Butte, Colorado, USA	1975				
234	Heath Steele main dam, Brunswick, Canada (American Metals)	1975				
235	PCS Rocanville, Saskatchewan, Canada	1975				
236	Unidentified, Green River, Wyoming, USA	1975				
237	Bafokeng, South Africa	1974	13,000,000	3,000,000	45.0	12
238	Golden Gilpin Mine, Colorado, USA	1974				
239	Deneen Mica Yancey County, North Carolina, USA	1974	300,000	38,000	0.0	
240	Silver King, Idaho, USA	1974	37,000	13,600		
241	Galena Mine, Idaho, USA (ASARCO) (2 of 2)	1974		3,800	0.6	
242	Berrien, France	1974				
243	GCOS, Alberta, Canada	1974				
244	Unidentified, Mississippi, USA #2	1974				
245	Unidentified, Canaca, Mexico	1974				
246	Ray Mine, Arizona, USA #2 (Kennecott)	1973				
247	(unidentified), Southwestern USA	1973	500,000	170,000	25.0	
248	Earth Resources, N M,	1973				
249	Ray Mine, Arizona, USA	1972				
250	Brunita Mine, Caragena, Spain (SMM Penaroya)	1972	1,080,000	70,000		1
251	Buffalo Creek, West Virginia, USA (Pittson Coal Co.)	1972	500,000	500,000	64.4	125
252	Galena Mine, Idaho, USA (ASARCO) (1 of 2)	1972				
253	Cities Service, Fort Meade, Florida, phosphate	1971	12,340,000	9,000,000	120.0	
254	Certej gold mine, Romania	1971		300,000		89
255	Chungar, Peru	1971				1
256	Ticapampa, Peru	1971				3
257	Pinchi Lake, BC, Canada	1971				
258	Atacocha, Peru (Compañía Minera Atacocha)	1971				
259	Quiruvilca mine, Almivirca tailings dam, Peru (2 of 2)	1971				
260	Western Nuclear, Jeffrey City, Wyoming, USA	1971				
261	Mufulira, Zambia (Roan Consolidated Mines)	1970	1,000,000	68,000		89
262	Maggie Pye, United Kingdom, clay	1970		15,000	0.0	
263	Park, United Kingdom	1970				

No	Mine	Year	Storage volume (m³)	Release (m³)	Runout (km)	Deaths
264	Portworthy, United Kingdom	1970				
265	Unidentified, Mississippi, USA	1970				
266	Williamsport Washer, Maury County, Tennesee, USA	1970				
267	Phoenix Copper, BC	1969		11,356		
268	Bilbao, Spain	1969		115,000	0.0	1
269	Buenaventura, Peru	1969				
270	Monsanto Dike 15, TN,	1969	1,230,000			
271	Stoney Middleton, UK	1968				
272	Yauli-Yacu, Peru	1968				
273	Hokkaido, Japan	1968	300,000	90,000	0.2	
274	Agrico Chemical, Florida, USA	1968				
275	IMC K-2, Saskatchewan, Canada	1968				
276	Iwiny Tailings Dam, Poland	1967	16,000,000	4,600,000	15.0	18
277	Climax, Grand Junction, CO, USA - Mill (Climax Molybdenum Co)	1967		12,000		
278	Mobil Chemical, Fort Meade, Florida, phosphate	1967		2,000,000		
279	Unidentified, United Kingdom	1967				
280	Unidentified, United Kingdom #2	1967				
281	Unidentified, United Kingdom #3	1967				
282	Aberfan, Tip No 7, South Wales Colliery	1966	230,000	162,000	0.6	144
283	Geising/Erzgebirge, German Democratic Republic VEB Zinnerz	1966		70,000		
284	Mir mine, Sgurigrad, Bulgaria	1966	1,520,000	450,000	8.0	488
285	Williamthorpe, UK #2	1966				
286	Gypsum Tailings Dam (Texas, USA)	1966	6,360,000	130,000	0.3	
287	Williamthorpe, UK #1	1966				
288	Derbyshire, United Kingdom	1966		30,000	0.1	
289	Tymawr, United Kindom #2	1965			0.7	
290	El Cobre Old Dam	1965	4,250,000	1,900,000	12.0	200
291	El Cobre New Dam	1965	350,000	350,000	12.0	
292	El Cobre Small Dam - El Soldado (Penarroya)	1965	985,000			
293	La Patagua New Dam, Chile (La Patagua - private)	1965		35,000	5.0	
294	Los Maquis No. 3	1965	43,000	21,000	5.0	
295	Bellavista, Chile	1965	450,000	70,000	0.8	

No	Mine	Year	Storage volume (m^3)	Release (m^3)	Runout (km)	Deaths
296	Hierro Viejo, Chile	1965		800	1.0	
297	Ramayana No. 1, Chile	1965		150		
298	Cerro Blanco de Polpaico, Chile	1965				
299	El Cerrado, Chile	1965				
300	Los Maquis No. 1	1965	30,000	20,000		
301	Sauce No. 1, Chile	1965				
302	Sauce No. 2, Chile	1965				
303	Sauce No. 3, Chile	1965				
304	Sauce No. 4, Chile	1965				
305	Cerro Negro No. (3 of 5)	1965	500,000	85,000	5.0	
306	Cerro Negro No. (2 of 5)	1965				
307	Cerro Negro No. (1 of 5)	1965				
308	American Cyanamid, Florida #2	1965				
309	N'yukka Creek, USSR	1965				
310	Unidentified, Idaho, USA	1965				
311	Alcoa, Texas, USA	1964	4,500,000			
312	Castano Viejo Mine, San Juan, Argentina	1964	26,500	17,000	2.2	3
313	Utah Construction, Riverton, Wyoming, USA	1963				
314	Louisville, USA	1963	910,000	667,000	0.1	
315	Huogudu, Yunnan Tin Group Co., Yunnan	1962	5,420,000	3,300,000	4.5	171
316	Mines Development, Edgemont, South Dakota, USA	1962		100	40.0	
317	American Cyanamid, Florida	1962		11,356,230		
318	Quiruvilca mine, Almivirca tailings dam, Peru (1 of 2)	1962				
319	Union Carbide, Maybell, Colorado, USA	1961		280		
320	Tymawr, United Kingdon #1	1961			0.7	
321	Jupille, Belgium	1961	550,000	136,000	0.6	11
322	La Luciana, Reocín (Santander), Cantabria, Spain	1960	1,250,000	100,000	0.5	18
323	Lower Indian Creek, MO, USA	1960				

B Tailings dam failures with reported data on released volume and storage capacity

No	Mine	Year	Storage volume (m^3)	Release (m^3)	Relative amount of released material (%)
1	Brumadinho, Mina Córrego do Feijão, Minas Gerais, Brazil (Vale)	2019	12,000,000	9,570,000	79.8
2	Duke Energy, HF Lee Power Plant, Goldsboro, North Carolina	2018	875,000	2,000	0.2
3	Hector Mine Pit Pond, MN, USA	2018	185,000	123,000	66.5
4	Hernic PGM Project, South Africa (Jubilee Metals Group)	2017	4,875,000	-	-
5	Kokoya mine, Liberia (MNG Gold-Liberia)	2017	300,000	11,356	3.8
6	Louyang Xiangjiang Wanji Aluminum, China	2016	2,000,000	2,000,000	100.0
7	Fundao-Santarem (Germano), Minas Gerais, Brazil (Samarco = Vale & BHP)	2015	56,400,000	43,700,000	77.5
8	Imperial Metals, Mt Polley, British Columbia, Canada	2014	74,000,000	23,600,000	31.9
9	Dan River Steam Station, North Carolina (Duke Energy)	2014	155,000,000	334,000	0.2
10	Sotkamo, Kainuu Province, Finland (Talvivaara)	2012	5,400,000	240,000	4.4
11	Padcal No 3, Benquet Philippines (Philex)	2012	102,000,000	13,000,000	12.7
12	Ajka Alumina Plant, Kolontár, Hungary (MAL Magyar Aluminum)	2010	30,000,000	1,000,000	3.3
13	Las Palmas, Pencahue, VII Region, Maule, Chile (COMINOR)	2010	220,000	170,000	77.3
14	Veta del Agua Tranque No. 5, Nogales, V Region, Valparaíso, Chile	2010	80,000	30,000	37.5
15	Karamken, Magadan Region, Russia (cyanide-leach processing facility of gold mines in the region)	2009	4,600,000	1,200,000	26.1
16	Taoshi, Linfen City, Xiangfen county, Shanxi province, China (Tahsan Mining Co.)	2008	290,000	190,000	65.5
17	Mineracao Rio Pomba Cataguases, Mirai, Minas Gerais, Brazil, Mineração (Industrias Quimicas Cataguases)	2007	3,800,000	2,000,000	52.6
18	Tailings Dam, USA	2005	500,000	170,000	34.0
19	Partizansk, Primorski Krai, Russia (Dalenergo)	2004	20,000,000	160,000	0.8
20	Sasa Mine, Macedonia	2003	2,000,000	100,000	5.0
21	San Marcelino Zambales, Philippines, Bayarong dam (Benguet Corp-Dizon Copper-Silver Mines Inc)	2002	47,000,000	1,000,000	2.1
22	Cuajone mine, Torata water supply dam, Peru	2001	16,000,000	-	-
23	Aitik mine, near Gällivare, Sweden (Boliden Ltd)	2000	15,000,000	1,800,000	12.0
24	Baia Mare, Romania	2000	800,000	100,000	12.5
25	Los Frailes, near Seville, Spain (Boliden Ltd.)	1998	15,000,000	6,800,000	45.3
26	Sgurigrad, Bulgaria	1996	1,520,000	220,000	14.5

No	Mine	Year	Storage volume (m^3)	Release (m^3)	Relative amount of released material (%)
27	Laisvall (Boliden), Sweden	1996	20,000,000	-	-
28	Omai Mine, Tailings dam No 1, 2, Guyana (Cambior)	1995	5,250,000	4,200,000	80.0
29	Middle Arm, Launceston, Tasmania	1995	25,000	5,000	20.0
30	Riltec, Mathinna, Tasmania	1995	120,000	40,000	33.3
31	Merriespruit, near Virginia, South Africa (Harmony) - No 4A Tailings Complex	1994	7,040,000	600,000	8.5
32	Minera Sera Grande: Crixas, Goias, Brazil	1994	2,250,000	-	-
33	Kojkovac, Montenegro	1992	3,500,000	-	-
34	Maritsa Istok 1, Bulgaria	1992	52,000,000	500,000	1.0
35	Tubu, Benguet, No.2 Tailings Pond, Luzon, Philippines - Padcal (Philex)	1992	102,000,000	32,243,000	31.6
36	Ajka Alumina Plant, Kolontár, Hungary	1991	4,500,000	43,200	1.0
37	Stancil, Maryland, USA	1989	74,000	38,000	51.4
38	Silver King, Idaho, USA	1989	37,000	100	0.3
39	Little Bay Mine (Atlantic Coast Copper Co), Little Bay, Newfoundland and Labrador, Canada	1989	1,250,000	500,000	40.0
40	Unidentified, Hernando, County, Florida, USA #2	1988	3,300,000	4,600	0.1
41	Consolidated Coal No.1, Tennessee, USA,	1988	1,000,000	250,000	25.0
42	Bekovsky, Western Siberia	1987	52,000,000	-	-
43	Story’s Creek, Tasmania	1986	30,000	100	0.3
44	Niujiaolong tailings pond, China	1985	1,100,000	730,000	66.4
45	Bonsal, North Carolina, USA	1985	38,000	11,000	28.9
46	Prestavel Mine - Stava, North Italy, 2, 3 (Prealpi Mineraria)	1985	400,000	180,000	45.0
47	Cerro Negro No. (4 of 5)	1985	2,000,000	500,000	25.0
48	Veta de Agua No. 1, Chile	1985	700,000	280,000	40.0
49	Niujiaolong, Hunan (Shizhuyuan Non-ferrous Metals Co.)	1985	1,100,000	731,000	66.5
50	Olinghouse, Nevada, USA	1985	120,000	25,000	20.8
51	Mirolubovka, Southern Ukraine	1984	80,000,000	-	-
52	Sipalay, Phillippines, No.3 Tailings Pond (Maricalum Mining Corp)	1982	22,000,000	15,000,000	68.2
53	Balka Chuficheva, Russia	1981	27,000,000	3,500,000	13.0
54	Tyrone, New Mexico (Phelps Dodge)	1980	2,500,000	2,000,000	80.0
55	Churchrock, New Mexico, United Nuclear	1979	370,000	370,000	100.0
56	Arcturus, Zimbabwe	1978	680,000	39,000	5.7
57	Mochikoshi No. 2, Japan (2 of 2)	1978	480,000	3,000	0.6

No	Mine	Year	Storage volume (m^3)	Release (m^3)	Relative amount of released material (%)
58	Mochikoshi No. 1, Japan (1 of 2)	1978	480,000	80,000	16.7
59	Zlevoto No. 4, Yugoslavia	1976	1,000,000	300,000	30.0
60	Madjarevo, Bulgaria	1975	3,000,000	250,000	8.3
61	Mike Horse, Montana, USA (Asarco)	1975	750,000	150,000	20.0
62	Bafokeng, South Africa	1974	13,000,000	3,000,000	23.1
63	Deneen Mica Yancey County, North Carolina, USA	1974	300,000	38,000	12.7
64	Silver King, Idaho, USA	1974	37,000	13,600	36.8
65	(unidentified), Southwestern USA	1973	500,000	170,000	34.0
66	Brunita Mine, Caragena, Spain (SMM Penaroya)	1972	1,080,000	70,000	6.5
67	Buffalo Creek, West Virginia, USA (Pittson Coal Co.)	1972	500,000	500,000	100.0
68	Cities Service, Fort Meade, Florida, phosphate	1971	12,340,000	9,000,000	72.9
69	Mufulira, Zambia (Roan Consolidated Mines)	1970	1,000,000	68,000	6.8
70	Hokkaido, Japan	1968	300,000	90,000	30.0
71	Iwiny Tailings Dam, Poland	1967	16,000,000	4,600,000	28.8
72	Aberfan, Tip No 7, South Wales Colliery	1966	230,000	162,000	70.4
73	Mir mine, Sgurigrad, Bulgaria	1966	1,520,000	450,000	29.6
74	Gypsum Tailings Dam (Texas, USA)	1966	6,360,000	130,000	2.0
75	El Cobre Old Dam	1965	4,250,000	1,900,000	44.7
76	El Cobre New Dam	1965	350,000	350,000	100.0
77	Los Maquis No. 3	1965	43,000	21,000	48.8
78	Bellavista, Chile	1965	450,000	70,000	15.6
79	Los Maquis No. 1	1965	30,000	20,000	66.7
80	Cerro Negro No. (3 of 5)	1965	500,000	85,000	17.0
81	Castano Viejo Mine, San Juan, Argentina	1964	26,500	17,000	64.2
82	Louisville, USA	1963	910,000	667,000	73.3
83	Huogudu, Yunnan Tin Group Co., Yunnan	1962	5,420,000	3,300,000	60.9
84	Jupille, Belgium	1961	550,000	136,000	24.7
85	La Luciana, Reocín (Santander), Cantabria, Spain	1960	1,250,000	100,000	8.0

C Tailings dam failures with reported data on runout distance

No	Mine	Year	Reported runout in official sources (km)	Surface water transport distance included?	Runout estimated by additional investigations (km)
1	Nossa Senhora do Livramento, Mato Grosso, Brazil (VM Mineração e Construção, Cuiabá)	2019	2.0		
2	Cobriza mine, San Pedro de Coris district, Churcampa province, Huancavelica region, Peru (Doe Run Perú S.R.L)	2019	375.0	Y	
3	Muri, Jharkhand, India (Hindalco Industries Limited)	2019	0.2		
4	Brumadinho, Mina Córrego do Feijão, Minas Gerais, Brazil (Vale)	2019	600.0	Y	7.0
5	Cieneguita mine, Urique municipality, Chihuahua, Mexico (Minera Rio Tinto and Pan American Goldfields)	2018	26.0	Y	12.0
6	Mishor Rotem, Israel (ICL Rotem)	2017	20.0	Y	0.5
7	Highland Valley Copper, British Columbia, Canada (Teck Resources)	2017	0.0		
8	Louyang Xiangjiang Wanji Aluminum, China	2016	2.0		
9	Fundao-Santarem (Germano), Minas Gerais, Brazil (Samarco = Vale & BHP)	2015	668.0	Y	1.0
10	Yellow Giant Mine, Banks Island, British Columbia, Canada	2015	1.0		
11	Imperial Metals, Mt Polley, British Columbia, Canada	2014	7.0		
12	Obed Mountain Coal Mine Alberta, Canada	2013	180.0	Y	20.0
13	Coalmont Energy Corporation, Basin Coal Mine	2013	30.0	Y	
14	Gullbridge Mine Newfoundland	2012	0.5		
15	Ajka Alumina Plant, Kolontár, Hungary (MAL Magyar Aluminum)	2010	80.0	Y	4.2
16	Huancavelica, Peru, Unidad Minera Caudalosa Chica	2010	110.0	Y	
17	Las Palmas, Pencahue, VII Region, Maule, Chile (COMINOR)	2010	0.5		
18	Veta del Agua Tranque No. 5, Nogales, V Region, Valparaíso, Chile	2010	0.1		
19	Kingston fossil plant, Harriman, Tennessee, USA (TVA)	2008	4.1		
20	Taoshi, Linfen City, Xiangfen county, Shanxi province, China (Tahsan Mining Co.)	2008	2.5		
21	Fonte Santa ,Freixia De Espado a Cinta, Potugal	2006	2.5		
22	Miliang, Zhen'an County, Shangluo, Shaanxi Province, China	2006	5.0	Y	
23	Tailings Dam, USA	2005	25.0	Y	
24	Captains Flat Dump No 3, Australia	2005	12.0		
25	Cerro Negro, near Santiago, Chile, (5 of 5)	2003	20.0	Y	4.6
26	Sasa Mine, Macedonia	2003	12.0		1.5
27	Sebastião das Águas Claras, Nova Lima district, Minas Gerais, Brazil	2001	8.0		
28	Inez, Martin County, Kentucky, USA (Massey Energy subsidiary Martin Co. Coal Corp)	2000	120.0	Y	

No	Mine	Year	Reported runout in official sources (km)	Surface water transport distance included?	Runout estimated by additional investigations (km)
29	Aitik mine, near Gällivare, Sweden (Boliden Ltd)	2000	5.2		
30	Baia Mare, Romania	2000	2,000.0	Y	0.7
31	Surigao Del Norte Placer, Philippines (3 of 3) Manila Mining Corp	1999	12.0		0.7
32	Los Frailes, near Seville, Spain (Boliden Ltd.)	1998	41.0		1.2
33	Tranque Antiguo Planta La Cocinera, IV Region, Vallenar, Chile	1997	0.2		
34	El Porco, Bolivia (Comsur-62%, Rio Tinto-33%)	1996	300.0	Y	1.5
35	Sgurigrad, Bulgaria	1996	6.0		
36	Marcopper, Marinduque Island, Philippines (2 of 2) (Placer Dome and President Marcos)	1996	26.0	Y	8.5
37	Omai Mine, Tailings dam No 1, 2, Guyana (Cambior)	1995	80.0	Y	3.5
38	Merriespruit, near Virginia, South Africa (Harmony) - No 4A Tailings Complex	1994	4.0		
39	Tapo Canyon, Northbridge, California	1994	0.2		
40	Ray Complex, Pinal County, Arizona, AB-BA Impoundment	1993	18.0	Y	
41	Brewer Gold Mine Jefferson South Carolina	1990	80.0	Y	1.0
42	Matachewan Mines, Kirtland Lake, Ontario	1990	168.0	Y	3.5
43	Stancil, Maryland, USA	1989	0.1		
44	Montcoal No.7, Raleigh County, West Virginia, USA	1987	80.0	Y	2.0
45	Itabirito, Minas Gerais, Brazil (Itaminos Comercio de Minerios)	1986	12.0		
46	Niujiaolong tailings pond, China	1985	4.2		
47	Bonsal, North Carolina, USA	1985	0.8		
48	Prestavel Mine - Stava, North Italy, 2, 3 (Prealpi Mineraria)	1985	4.2		
49	Cerro Negro No. (4 of 5)	1985	8.0		
50	Veta de Agua No. 1, Chile	1985	5.0		
51	Niujiaolong, Hunan (Shizhuyuan Non-ferrous Metals Co.)	1985	4.2		
52	Olinghouse, Nevada, USA	1985	1.5		
53	Quintette, MaËmot, BC, Canada	1985	2.5		
54	Ages, Harlan County, Kentucky, USA	1981	163.0	Y	
55	Balka Chuficheva, Russia	1981	1.3		
56	Tyrone, New Mexico (Phelps Dodge)	1980	8.0		
57	Churchrock, New Mexico, United Nuclear	1979	110.0	Y	
58	Arcturus, Zimbabwe	1978	0.3		
59	Mochikoshi No. 2, Japan (2 of 2)	1978	0.2		

No	Mine	Year	Reported runout in official sources (km)	Surface water transport distance included?	Runout estimated by additional investigations (km)
60	Mochikoshi No. 1, Japan (1 of 2)	1978	8.0		
61	Madjarevo, Bulgaria	1975	20.0	Y	
62	Mike Horse, Montana, USA (Asarco)	1975	24.0	Y	
63	Bafokeng, South Africa	1974	45.0	Y	
64	Deneen Mica Yancey County, North Carolina, USA	1974	0.0		
65	Galena Mine, Idaho, USA (ASARCO) (2 of 2)	1974	0.6		
66	(unidentified), Southwestern USA	1973	25.0	Y	
67	Buffalo Creek, West Virginia, USA (Pittson Coal Co.)	1972	64.4	Y	
68	Cities Service, Fort Meade, Florida, phosphate	1971	120.0	Y	
69	Maggie Pye, United Kingdom, clay	1970	0.0		
70	Bilbao, Spain	1969	0.0		
71	Hokkaido, Japan	1968	0.2		
72	Iwiny Tailings Dam, Poland	1967	15.0		
73	Aberfan, Tip No 7, South Wales Colliery	1966	0.6		
74	Mir mine, Sgurigrad, Bulgaria	1966	8.0		
75	Gypsum Tailings Dam (Texas, USA)	1966	0.3		
76	Derbyshire, United Kingdom	1966	0.1		
77	Tymawr, United Kindom #2	1965	0.7		
78	El Cobre Old Dam	1965	12.0		
79	El Cobre New Dam	1965	12.0		
80	La Patagua New Dam, Chile (La Patagua - private)	1965	5.0		
81	Los Maquis No. 3	1965	5.0		
82	Bellavista, Chile	1965	0.8		
83	Hierro Viejo, Chile	1965	1.0		
84	Cerro Negro No. (3 of 5)	1965	5.0		
85	Castano Viejo Mine, San Juan, Argentina	1964	2.2		
86	Louisville, USA	1963	0.1		
87	Huogudu, Yunnan Tin Group Co., Yunnan	1962	4.5		
88	Mines Development, Edgemont, South Dakota, USA	1962	40.0	Y	
89	Tymawr, United Kingdon #1	1961	0.7		
90	Jupille, Belgium	1961	0.6		
91	La Luciana, Reocín (Santander), Cantabria, Spain	1960	0.5		

D THI calculation example

For demonstrating the calculation of the THI (see Chapter 2), the Mortu TMF was chosen. This TMF is located in Romania, in Gorj county. All information that is needed for the calculation is presented in Table 18.

Table 18. General information about Motru TMF.

Information	Value
Latitude and longitude of the site (decimal degree)	22.968167 44.780417
Volume of the tailings in the TMF (million m³)	1.5
Stored materials	Trace elements in fly ash
Management status	Active
Reference peak ground acceleration (m/s²)	1.12
Location within the flood prone area with flood frequency of HQ-500	yes

1st step: Tailings capacity

$$THI_{Cap} = \mathrm{Log}_{10}\,[1500000] = 6.2$$

2nd step: Tailings toxicity

As the TMF contains trace elements in fly ash, the stored materials have a low water hazard class (according to the WHC classification), therefore $THI_{Tox} = 1$.

3rd step: Management conditions

As the TMF is active, therefore $THI_{Man} = 3$.

4th step: Natural conditions

The TMF is located in the flood prone area of HQ-500 and the Reference PGA is higher than 0.1 m/s^2, therefore:

$$THI_{Nat} = THI_{Seism} + THI_{Flood} = 1 + 1 = 2$$

5th step: Dam conditions

For this TMF the Factor of Safety is not available, therefore $THI_{Dam} = 1$

6th step: Total THI

$$THI = THI_{Cap} + THI_{Tox} + THI_{Man} + THI_{Nat} + THI_{Dam} = 6.18 + 1 + 3 + 2 + 1 = 13.2$$

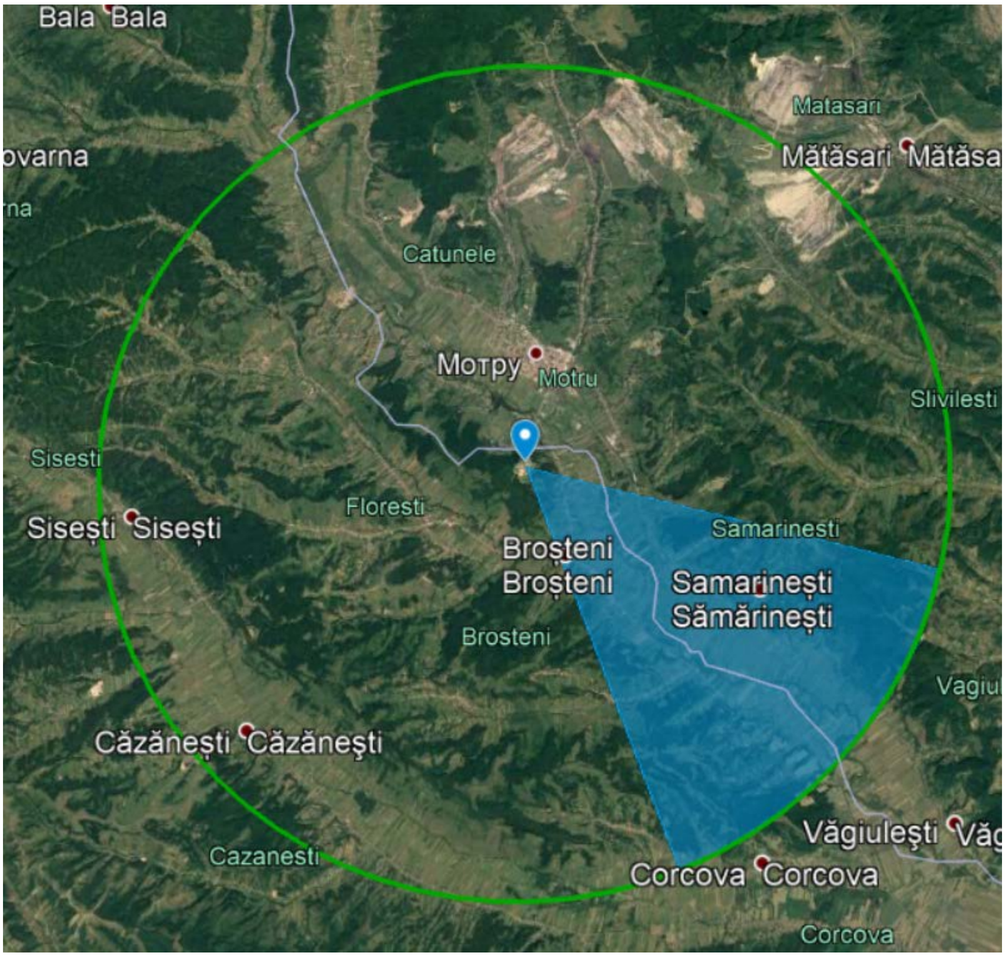
E TRI calculation example

The TRI calculation procedure (see Chapter 3) is demonstrated with the example of the same TMF in Motru. Both, the simplified (basic) and the detailed TRI calculation are demonstrated.

E.1 Basic TRI

Using Google Earth map the 10 km risk zone and the area downstream of Motru TMF were identified (see Figure 31). The settlements and water bodies at risk were determined by intersecting the downstream area with the risk zone.

Figure 31. Definition of risk zone downstream of the Motru TMF.



The green circle outlines the potential risk zone (with 10 km radius) and the blue zone shows the downstream territory that can be potentially affected within the risk zone in case of an accident, © Google

<u>1st step: Impact on population</u>

Settlements in the potential risk zone (10 km downstream): Meris city with a population of 2145, villages Brosteni, Capatanesti, Lupsa de Jos and Luncsoara, their total population is 1491.

The total population in 10 km distance is 3636, therefore $TEI_{Pop} = 4$.

<u>2nd step: Impact on environment</u>

The nearest water body in the potential risk zone: Motru river, its mean flow rate is 15.2 m^3/s.

The river discharge of the nearest water body in 10 km distance is 15.2 m³/s, therefore TEI_{Env} = 2.

3rd step: Total TEI

$$TEI = TEI_{Pop} + TEI_{Env} = 4 + 2 = 6$$

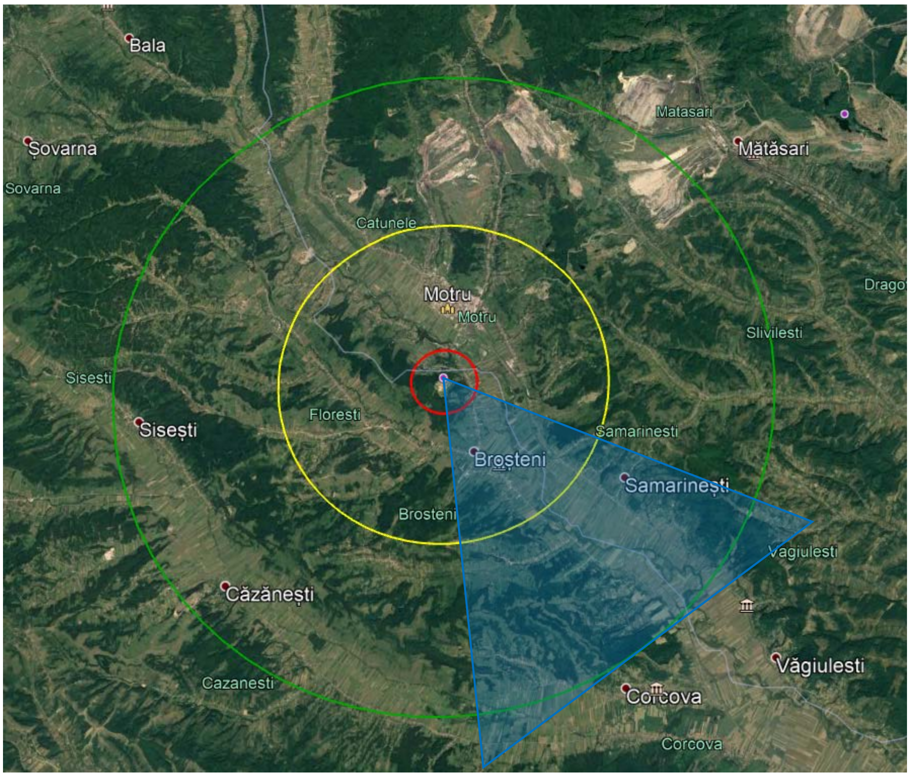
4th step: The TRI

$$TRI = THI + TEI = 13.2 + 6 = 19.2$$

E.2 Detailed TRI

For the detailed risk assessment, the 10 km risk zone was subdivided into three sub-zones and the settlements and water bodies at risk were determined by intersecting the downstream area with the risk zones (see Figure 32).

Figure 32. Definition of different risk sub-zones downstream of the Motru TMF.



The red circle outlines the risk zone I (0-1 km), the yellow circle outlines the risk zone II (1-5 km), the green circle outlines the risk zone III (5-10 km) and the blue zone shows the downstream territory that can be potentially affected within the risk zones in case of an accident, © Google

1st step: Impact on population

Settlements in zone I: Meris city with a population of 2145, in zone II: Brosteni and Capatanesti, their total population is 911, in zone III: Lupsa de Jos and Luncsoara, their total population is 580.

$$PAR_w = \sum_{i=1}^{3} \left(PAR_i \cdot f_{d,i}\right) = 2145 \cdot 1 + 911 \cdot 0.33 + 580 \cdot 0.13 = 2521$$

$$TEI_{Pop,d} = Log_{10}[PAR_w] = Log_{10}[2521] = 3.4$$

2nd step: Impact on environment

The nearest water body in the potential risk zone: Motru river in zone I, its mean flow rate is 15.2 m^3/s.

$$Q_a = Q_n \cdot f_{d,n} = 15.2 \cdot 1 = 15.2\ m^3/s$$

$$TEI_{Env,d} = Log_{10}[Q_a] = Log_{10}[15.2] = 1.2$$

3rd step: Total TEI

$$TEI_d = TEI_{Pop,d} + TEI_{Env,d} = 3.4 + 1.2 = 4.6$$

4th step: The TRI

$$TRI = THI + TEI_d = 13.2 + 4.6 = 17.8$$

F TMF Inventory for the Danube River Basin

TMF		THI							TRI			
TMF Code	Tailings material	THI Cap	THI Tox	THI Man	THI Nat		THI Dam	THI	TEI Pop	TEI Env	TEI	TRI
					THI Seism	THI Flood						
AT1	sludge	6.26	1.00	3.00	0.00	0.00	1.00	11.26	4.00	2.00	6.00	17.26
AT2	slurry	5.70	1.00	0.00	1.00	1.00	1.00	9.70	4.00	3.00	7.00	16.70
AT3	slurry	5.48	3.00	0.00	1.00	1.00	1.00	11.48	4.00	2.00	6.00	17.48
AT4	slurry	5.70	2.00	0.00	1.00	0.00	1.00	9.70	4.00	2.00	6.00	15.70
AT5	slurry	5.45	1.00	0.00	1.00	0.00	1.00	8.45	4.00	2.00	6.00	14.45
AT6	slurry	3.70	1.00	0.00	1.00	0.00	1.00	6.70	4.00	2.00	6.00	12.70
BA1	mine water	6.48	0.00	0.00	1.00	0.00	1.00	8.48	4.00	2.00	6.00	14.48
BA2	other	4.60	3.00	0.00	1.00	1.00	1.00	10.60	5.00	2.00	7.00	17.60
BA3	slurry	5.51	3.00	0.00	1.00	0.00	1.00	10.51	1.00	2.00	3.00	13.51
BA4	red mud	7.28	1.00	3.00	1.00	0.00	1.00	13.28	4.00	2.00	6.00	19.28
BA5	slurry	6.58	3.00	3.00	1.00	0.00	1.00	14.58	1.00	2.00	3.00	17.58
BA6	fly ash	6.08	1.00	3.00	1.00	0.00	1.00	12.08	3.00	2.00	5.00	17.08
BA7	calx	5.30	1.00	3.00	1.00	1.00	1.00	12.30	4.00	3.00	7.00	19.30
BA8	sludge	3.72	2.00	0.00	1.00	1.00	1.00	8.72	5.00	3.00	8.00	16.72
BG1	slurry	6.15	3.00	0.00	1.00	0.00	1.00	11.15	3.00	2.00	5.00	16.15
BG2	slurry	5.30	2.00	0.00	1.00	0.00	1.00	9.30	4.00	2.00	6.00	15.30
BG3	slurry	4.63	3.00	0.00	1.00	0.00	1.00	9.63	4.00	2.00	6.00	15.63
CZ01	calx	6.23	1.00	0.00	0.00	0.00	1.00	8.23	5.00	2.00	7.00	15.23
CZ02	sludge	7.04	4.00	3.00	0.00	0.00	1.00	15.04	3.00	2.00	5.00	20.04
CZ03	sludge	5.93	4.00	3.00	0.00	0.00	1.00	13.93	3.00	2.00	5.00	18.93
CZ04	fly ash	6.41	1.00	3.00	0.00	0.00	1.00	11.41	5.00	2.00	7.00	18.41
CZ05	fly ash	6.25	1.00	3.00	0.00	0.00	1.00	11.25	3.00	2.00	5.00	16.25
CZ06	fly ash	6.81	1.00	0.00	0.00	0.00	1.00	8.81	6.00	2.00	8.00	16.81
CZ07	fly ash	6.00	1.00	0.00	0.00	1.00	1.00	9.00	6.00	2.00	8.00	17.00
CZ08	slurry	4.98	1.00	3.00	0.00	1.00	1.00	10.98	5.00	2.00	7.00	17.98
CZ09	calx	6.41	1.00	0.00	0.00	0.00	1.00	8.41	1.00	2.00	3.00	11.41
CZ10	fly ash	5.70	1.00	3.00	0.00	1.00	1.00	11.70	1.00	2.00	3.00	14.70
HU01	mine water	5.93	3.00	0.00	1.00	0.00	1.00	10.93	4.00	2.00	6.00	16.93
HU02	mine water	5.38	3.00	0.00	1.00	0.00	1.00	10.38	4.00	2.00	6.00	16.38
HU03	red mud	7.30	1.00	0.00	0.00	0.00	1.00	9.30	5.00	2.00	7.00	16.30

TMF		THI							TRI			
TMF Code	Tailings material	THI Cap	THI Tox	THI Man	THI Nat		THI Dam	THI	TEI Pop	TEI Env	TEI	TRI
					THI Seism	THI Flood						
HU04	red mud	6.38	3.00	0.00	0.00	0.00	1.00	10.38	5.00	2.00	7.00	17.38
HU05	fly ash	6.63	1.00	0.00	0.00	0.00	1.00	8.63	5.00	2.00	7.00	15.63
HU06	residual oil	4.77	2.00	0.00	0.00	0.00	1.00	7.77	4.00	3.00	7.00	14.77
HU07	red mud	5.93	1.00	0.00	1.00	1.00	1.00	9.93	1.00	4.00	5.00	14.93
HU08	red mud	6.43	1.00	0.00	1.00	1.00	1.00	10.43	1.00	4.00	5.00	15.43
HU09	mine water	5.59	3.00	0.00	1.00	0.00	1.00	10.59	4.00	2.00	6.00	16.59
HU10	residual oil	4.83	2.00	0.00	0.00	0.00	1.00	7.83	3.00	2.00	5.00	12.83
HU11	residual oil	4.80	2.00	0.00	0.00	1.00	1.00	8.80	2.00	2.00	4.00	12.80
HU12	residual oil	4.74	2.00	0.00	0.00	0.00	1.00	7.74	5.00	2.00	7.00	14.74
HU13	residual oil	3.30	2.00	0.00	0.00	1.00	1.00	7.30	4.00	1.00	5.00	12.30
HU14	sludge	3.00	1.00	0.00	1.00	0.00	1.00	6.00	5.00	1.00	6.00	12.00
HU15	sludge	5.00	1.00	0.00	1.00	0.00	1.00	8.00	2.00	2.00	4.00	12.00
HU16	fly ash	4.78	1.00	0.00	1.00	0.00	1.00	7.78	5.00	4.00	9.00	16.78
HU17	sludge	5.56	1.00	0.00	1.00	0.00	1.00	8.56	5.00	1.00	6.00	14.56
HU18	fly ash	5.00	1.00	0.00	0.00	0.00	1.00	7.00	6.00	2.00	8.00	15.00
HU19	residual oil	4.80	2.00	0.00	0.00	1.00	1.00	8.80	5.00	2.00	7.00	15.80
HU20	other	5.00	2.00	0.00	0.00	0.00	1.00	8.00	4.00	4.00	8.00	16.00
HU21	residual oil	4.41	2.00	0.00	1.00	1.00	1.00	9.41	4.00	3.00	7.00	16.41
HU22	red mud	6.23	1.00	0.00	1.00	0.00	1.00	9.23	4.00	4.00	8.00	17.23
HU23	mine water	6.92	3.00	0.00	0.00	0.00	1.00	10.92	6.00	2.00	8.00	18.92
HU24	mine water	6.91	3.00	0.00	0.00	0.00	1.00	10.91	6.00	2.00	8.00	18.91
HU25	mine water	6.01	3.00	0.00	0.00	0.00	1.00	10.01	6.00	2.00	8.00	18.01
HU26	mine water	6.48	3.00	0.00	0.00	0.00	1.00	10.48	6.00	2.00	8.00	18.48
HU27	red mud	5.48	1.00	0.00	0.00	1.00	1.00	8.48	5.00	4.00	9.00	17.48
HU28	residual oil	4.08	3.00	0.00	0.00	0.00	1.00	8.08	4.00	1.00	5.00	13.08
HU29	mine water	4.26	3.00	0.00	1.00	0.00	1.00	9.26	4.00	2.00	6.00	15.26
HU30	residual oil	4.48	2.00	0.00	0.00	1.00	1.00	8.48	4.00	3.00	7.00	15.48
HU31	sludge	5.55	1.00	0.00	1.00	0.00	1.00	8.55	5.00	4.00	9.00	17.55
HU32	sludge	4.40	1.00	0.00	1.00	0.00	1.00	7.40	5.00	4.00	9.00	16.40
HU33	mine water	5.39	3.00	0.00	0.00	0.00	1.00	9.39	4.00	2.00	6.00	15.39
HU34	other	5.91	2.00	0.00	0.00	0.00	1.00	8.91	5.00	2.00	7.00	15.91

TMF		THI							TRI			
TMF Code	Tailings material	THI Cap	THI Tox	THI Man	THI Nat		THI Dam	THI	TEI Pop	TEI Env	TEI	TRI
					THI Seism	THI Flood						
HU35	residual oil	5.12	2.00	3.00	0.00	0.00	1.00	11.12	4.00	2.00	6.00	17.12
HU36	residual oil	4.85	2.00	0.00	0.00	0.00	1.00	7.85	4.00	2.00	6.00	13.85
HU37	fly ash	7.15	1.00	3.00	1.00	0.00	1.00	13.15	5.00	1.00	6.00	19.15
HU38	fly ash	7.32	1.00	0.00	0.00	1.00	1.00	10.32	4.00	1.00	5.00	15.32
HU39	fly ash	6.88	1.00	3.00	1.00	0.00	1.00	12.88	4.00	1.00	5.00	17.88
ME1	slurry	6.19	3.00	0.00	1.00	0.00	1.00	11.19	5.00	2.00	7.00	18.19
ME2	fly ash	6.99	1.00	3.00	1.00	0.00	1.00	12.99	5.00	2.00	7.00	19.99
ME3	slurry	5.70	3.00	3.00	1.00	0.00	1.00	13.70	3.00	2.00	5.00	18.70
ME4	slurry	6.30	3.00	0.00	1.00	0.00	1.00	11.30	4.00	2.00	6.00	17.30
RO1	slurry	6.99	3.00	0.00	0.00	0.00	1.00	10.99	3.00	3.00	6.00	16.99
RO2	slurry	6.60	3.00	0.00	0.00	0.00	1.00	10.60	4.00	2.00	6.00	16.60
RO3	slurry	7.05	1.00	0.00	1.00	0.00	1.00	10.05	5.00	2.00	7.00	17.05
RO4	slurry	6.95	3.00	0.00	0.00	0.00	1.00	10.95	4.00	2.00	6.00	16.95
RO5	slurry	6.76	3.00	3.00	0.00	0.00	1.00	13.76	3.00	2.00	5.00	18.76
RO6	slurry	5.66	3.00	0.00	0.00	0.00	1.00	9.66	4.00	2.00	6.00	15.66
RO7	slurry	6.08	3.00	0.00	0.00	0.00	1.00	10.08	3.00	2.00	5.00	15.08
RO8	slurry	7.00	3.00	0.00	0.00	1.00	1.00	12.00	3.00	2.00	5.00	17.00
RO9	slurry	6.60	3.00	0.00	0.00	1.00	1.00	11.60	6.00	2.00	8.00	19.60
RO10	slurry	7.04	3.00	0.00	0.00	1.00	1.00	12.04	5.00	2.00	7.00	19.04
RO11	slurry	6.71	1.00	0.00	0.00	0.00	1.00	8.71	5.00	2.00	7.00	15.71
RO12	slurry	6.62	1.00	0.00	0.00	0.00	1.00	8.62	5.00	2.00	7.00	15.62
RO13	slurry	5.45	3.00	0.00	1.00	0.00	1.00	10.45	4.00	2.00	6.00	16.45
RO14	slurry	6.76	3.00	0.00	0.00	0.00	1.00	10.76	4.00	2.00	6.00	16.76
RO15	slurry	6.22	3.00	0.00	0.00	0.00	1.00	10.22	5.00	2.00	7.00	17.22
RO16	slurry	6.12	3.00	0.00	0.00	0.00	1.00	10.12	4.00	2.00	6.00	16.12
RO17	slurry	5.18	3.00	0.00	0.00	0.00	1.00	9.18	4.00	2.00	6.00	15.18
RO18	other	6.34	3.00	0.00	1.00	0.00	1.00	11.34	3.00	2.00	5.00	16.34
RO19	slurry	5.11	3.00	0.00	1.00	0.00	1.00	10.11	4.00	2.00	6.00	16.11
RO20	slurry	6.04	3.00	0.00	0.00	0.00	1.00	10.04	4.00	2.00	6.00	16.04
RO21	slurry	6.54	3.00	0.00	0.00	1.00	1.00	11.54	4.00	2.00	6.00	17.54
RO22	slurry	6.20	3.00	0.00	0.00	0.00	1.00	10.20	4.00	2.00	6.00	16.20

TMF		THI							TRI			
TMF Code	Tailings material	THI Cap	THI Tox	THI Man	THI Nat: THI Seism	THI Nat: THI Flood	THI Dam	THI	TEI Pop	TEI Env	TEI	TRI
RO23	slurry	5.20	3.00	0.00	0.00	0.00	1.00	9.20	4.00	2.00	6.00	15.20
RO24	slurry	5.65	3.00	0.00	0.00	0.00	1.00	9.65	4.00	2.00	6.00	15.65
RO25	other	6.24	3.00	0.00	1.00	0.00	1.00	11.24	5.00	2.00	7.00	18.24
RO26	slurry	5.47	3.00	0.00	0.00	1.00	1.00	10.47	4.00	2.00	6.00	16.47
RO27	other	6.24	3.00	0.00	0.00	0.00	1.00	10.24	4.00	2.00	6.00	16.24
RO28	other	6.65	3.00	0.00	0.00	0.00	1.00	10.65	4.00	2.00	6.00	16.65
RO29	slurry	6.82	3.00	0.00	1.00	0.00	1.00	11.82	4.00	2.00	6.00	17.82
RO30	slurry	6.40	3.00	0.00	1.00	0.00	1.00	11.40	4.00	2.00	6.00	17.40
RO31	slurry	6.86	3.00	0.00	1.00	0.00	1.00	11.86	1.00	2.00	3.00	14.86
RO32	slurry	5.79	3.00	0.00	1.00	0.00	1.00	10.79	1.00	2.00	3.00	13.79
RO33	slurry	6.38	3.00	0.00	0.00	0.00	1.00	10.38	4.00	2.00	6.00	16.38
RO34	slurry	6.22	3.00	3.00	1.00	0.00	1.00	14.22	4.00	2.00	6.00	20.22
RO35	slurry	6.78	3.00	0.00	1.00	0.00	1.00	11.78	6.00	2.00	8.00	19.78
RO36	slurry	6.13	3.00	0.00	1.00	1.00	1.00	12.13	1.00	2.00	3.00	15.13
RO37	slurry	4.70	3.00	0.00	0.00	0.00	1.00	8.70	1.00	2.00	3.00	11.70
RO38	slurry	5.78	3.00	0.00	0.00	0.00	1.00	9.78	5.00	2.00	7.00	16.78
RO39	slurry	6.29	3.00	0.00	1.00	0.00	1.00	11.29	3.00	2.00	5.00	16.29
RO40	slurry	5.20	3.00	0.00	1.00	0.00	1.00	10.20	5.00	2.00	7.00	17.20
RO41	other	5.64	3.00	0.00	1.00	0.00	1.00	10.64	4.00	2.00	6.00	16.64
RO42	slurry	7.41	3.00	3.00	0.00	0.00	1.00	14.41	4.00	2.00	6.00	20.41
RO43	slurry	6.32	3.00	3.00	0.00	0.00	1.00	13.32	4.00	2.00	6.00	19.32
RO44	slurry	6.59	3.00	3.00	0.00	0.00	1.00	13.59	4.00	2.00	6.00	19.59
RO45	slurry	5.90	1.00	0.00	1.00	0.00	1.00	8.90	4.00	2.00	6.00	14.90
RO46	slurry	4.73	3.00	0.00	1.00	0.00	1.00	9.73	4.00	2.00	6.00	15.73
RO47	slurry	6.43	3.00	0.00	0.00	0.00	1.00	10.43	5.00	2.00	7.00	17.43
RO48	slurry	5.15	3.00	0.00	0.00	0.00	1.00	9.15	4.00	2.00	6.00	15.15
RO49	fly ash	6.08	1.00	3.00	0.00	0.00	1.00	11.08	3.00	2.00	5.00	16.08
RO50	fly ash	6.08	1.00	3.00	0.00	0.00	1.00	11.08	4.00	2.00	6.00	17.08
RO51	fly ash	5.91	1.00	0.00	1.00	0.00	1.00	8.91	6.00	2.00	8.00	16.91
RO52	slurry	6.48	3.00	3.00	1.00	0.00	1.00	14.48	3.00	2.00	5.00	19.48
RO53	sludge	6.11	3.00	0.00	1.00	0.00	1.00	11.11	3.00	2.00	5.00	16.11

TMF		THI							TRI			
TMF Code	Tailings material	THI Cap	THI Tox	THI Man	THI Nat		THI Dam	THI	TEI Pop	TEI Env	TEI	TRI
					THI Seism	THI Flood						
RO54	red mud	7.06	1.00	3.00	1.00	0.00	1.00	13.06	1.00	4.00	5.00	18.06
RO55	slurry	6.48	3.00	0.00	1.00	1.00	1.00	12.48	4.00	2.00	6.00	18.48
RO56	slurry	5.70	3.00	0.00	0.00	0.00	1.00	9.70	4.00	2.00	6.00	15.70
RO57	slurry	5.79	3.00	0.00	0.00	0.00	1.00	9.79	3.00	3.00	6.00	15.79
RO58	slurry	5.89	3.00	0.00	1.00	0.00	1.00	10.89	4.00	2.00	6.00	16.89
RO59	slurry	6.88	1.00	0.00	0.00	0.00	1.00	8.88	5.00	2.00	7.00	15.88
RO60	slurry	6.91	1.00	0.00	0.00	0.00	1.00	8.91	6.00	2.00	8.00	16.91
RO61	slurry	6.07	1.00	0.00	0.00	0.00	1.00	8.07	3.00	2.00	5.00	13.07
RO62	slurry	6.88	1.00	0.00	0.00	0.00	1.00	8.88	5.00	2.00	7.00	15.88
RO63	residual oil	4.00	2.00	0.00	1.00	0.00	1.00	8.00	1.00	2.00	3.00	11.00
RO64	residual oil	4.30	2.00	0.00	0.00	0.00	1.00	7.30	4.00	2.00	6.00	13.30
RO65	residual oil	4.48	2.00	0.00	0.00	0.00	1.00	7.48	4.00	2.00	6.00	13.48
RO66	other	5.48	1.00	0.00	0.00	0.00	1.00	7.48	5.00	2.00	7.00	14.48
RO67	sludge	6.69	2.00	0.00	1.00	0.00	1.00	10.69	1.00	1.00	2.00	12.69
RO68	slurry	5.51	1.00	3.00	1.00	1.00	1.00	12.51	1.00	3.00	4.00	16.51
RO69	residual oil	5.11	2.00	0.00	1.00	1.00	1.00	10.11	1.00	1.00	2.00	12.11
RO70	residual oil	5.90	2.00	0.00	1.00	0.00	1.00	9.90	1.00	1.00	2.00	11.90
RO71	residual oil	5.09	2.00	0.00	1.00	1.00	1.00	10.09	1.00	1.00	2.00	12.09
RO72	red mud	6.08	1.00	0.00	0.00	0.00	1.00	8.08	1.00	2.00	3.00	11.08
RO73	red mud	6.26	1.00	0.00	0.00	0.00	1.00	8.26	3.00	2.00	5.00	13.26
RO74	red mud	6.22	1.00	0.00	0.00	0.00	1.00	8.22	4.00	2.00	6.00	14.22
RO75	red mud	6.54	1.00	0.00	0.00	0.00	1.00	8.54	4.00	2.00	6.00	14.54
RO76	red mud	6.60	2.00	0.00	0.00	1.00	1.00	10.60	4.00	2.00	6.00	16.60
RO77	red mud	4.08	1.00	0.00	0.00	0.00	1.00	6.08	4.00	2.00	6.00	12.08
RO78	slurry	6.29	3.00	0.00	1.00	0.00	1.00	11.29	4.00	2.00	6.00	17.29
RO79	other	5.50	0.00	0.00	1.00	0.00	1.00	7.50	4.00	2.00	6.00	13.50
RO80	other	5.32	0.00	0.00	1.00	0.00	1.00	7.32	4.00	2.00	6.00	13.32
RO81	other	6.09	0.00	0.00	0.00	0.00	1.00	7.09	5.00	2.00	7.00	14.09
RO82	other	6.83	0.00	0.00	0.00	0.00	1.00	7.83	5.00	2.00	7.00	14.83
RO83	other	6.47	0.00	0.00	0.00	0.00	1.00	7.47	5.00	2.00	7.00	14.47
RO84	slurry	6.13	1.00	0.00	0.00	0.00	1.00	8.13	3.00	2.00	5.00	13.13

TMF		THI							TRI			
TMF Code	Tailings material	THI Cap	THI Tox	THI Man	THI Nat THI Seism	THI Nat THI Flood	THI Dam	THI	TEI Pop	TEI Env	TEI	TRI
RO85	sludge	6.08	2.00	0.00	1.00	1.00	1.00	11.08	1.00	1.00	2.00	13.08
RO86	slurry	4.51	3.00	0.00	1.00	0.00	1.00	9.51	6.00	2.00	8.00	17.51
RO87	fly ash	6.11	1.00	0.00	1.00	0.00	1.00	9.11	4.00	2.00	6.00	15.11
RO88	fly ash	6.18	1.00	3.00	1.00	1.00	1.00	13.18	4.00	2.00	6.00	19.18
RO89	fly ash	7.40	1.00	0.00	1.00	0.00	1.00	10.40	4.00	2.00	6.00	16.40
RO90	fly ash	6.08	1.00	0.00	0.00	0.00	1.00	8.08	5.00	2.00	7.00	15.08
RO91	other	5.94	0.00	0.00	1.00	0.00	1.00	7.94	4.00	2.00	6.00	13.94
RO92	sludge	5.13	1.00	3.00	1.00	0.00	1.00	11.13	6.00	2.00	8.00	19.13
RO93	sludge	5.18	1.00	3.00	1.00	0.00	1.00	11.18	6.00	2.00	8.00	19.18
RO94	sludge	5.98	1.00	3.00	1.00	0.00	1.00	11.98	6.00	2.00	8.00	19.98
RO95	fly ash	4.70	1.00	0.00	1.00	0.00	1.00	7.70	1.00	2.00	3.00	10.70
RO96	fly ash	4.48	1.00	0.00	1.00	1.00	1.00	8.48	1.00	2.00	3.00	11.48
RO97	other	4.60	1.00	0.00	1.00	1.00	1.00	8.60	1.00	2.00	3.00	11.60
RO98	other	6.34	0.00	0.00	1.00	0.00	1.00	8.34	1.00	2.00	3.00	11.34
RO99	other	5.73	0.00	0.00	1.00	0.00	1.00	7.73	1.00	2.00	3.00	10.73
RO100	other	6.26	0.00	0.00	1.00	0.00	1.00	8.26	1.00	2.00	3.00	11.26
RO101	other	5.85	0.00	0.00	1.00	0.00	1.00	7.85	1.00	2.00	3.00	10.85
RO102	other	5.71	0.00	3.00	0.00	0.00	1.00	9.71	4.00	2.00	6.00	15.71
RO103	other	6.00	0.00	0.00	1.00	0.00	1.00	8.00	1.00	2.00	3.00	11.00
RO104	other	6.94	1.00	0.00	1.00	0.00	1.00	9.94	4.00	2.00	6.00	15.94
RO105	other	6.26	1.00	0.00	1.00	0.00	1.00	9.26	4.00	2.00	6.00	15.26
RO106	fly ash	5.90	1.00	0.00	1.00	0.00	1.00	8.90	4.00	2.00	6.00	14.90
RO107	fly ash	6.85	1.00	0.00	1.00	0.00	1.00	9.85	4.00	2.00	6.00	15.85
RO108	fly ash	6.36	1.00	0.00	1.00	0.00	1.00	9.36	4.00	2.00	6.00	15.36
RO109	fly ash	6.07	1.00	0.00	1.00	0.00	1.00	9.07	6.00	2.00	8.00	17.07
RO110	fly ash	6.54	1.00	0.00	1.00	0.00	1.00	9.54	6.00	2.00	8.00	17.54
RO111	fly ash	6.60	1.00	0.00	1.00	0.00	1.00	9.60	5.00	2.00	7.00	16.60
RO112	fly ash	6.65	1.00	0.00	1.00	0.00	1.00	9.65	5.00	2.00	7.00	16.65
RO113	fly ash	6.83	1.00	3.00	1.00	0.00	1.00	12.83	4.00	2.00	6.00	18.83
RO114	other	5.47	3.00	0.00	1.00	0.00	1.00	10.47	4.00	2.00	6.00	16.47
RO115	other	6.18	0.00	3.00	1.00	0.00	1.00	11.18	4.00	2.00	6.00	17.18

TMF		THI							TRI			
TMF Code	Tailings material	THI Cap	THI Tox	THI Man	THI Nat THI Seism	THI Nat THI Flood	THI Dam	THI	TEI Pop	TEI Env	TEI	TRI
RO116	other	5.17	0.00	3.00	1.00	0.00	1.00	10.17	3.00	2.00	5.00	15.17
RO117	other	5.24	0.00	0.00	1.00	0.00	1.00	7.24	1.00	4.00	5.00	12.24
RO118	other	5.55	0.00	0.00	1.00	0.00	1.00	7.55	1.00	4.00	5.00	12.55
RO119	other	5.02	0.00	0.00	1.00	0.00	1.00	7.02	1.00	4.00	5.00	12.02
RO120	other	5.28	0.00	0.00	1.00	0.00	1.00	7.28	1.00	4.00	5.00	12.28
RO121	other	5.12	0.00	0.00	1.00	0.00	1.00	7.12	1.00	4.00	5.00	12.12
RO122	other	5.25	0.00	0.00	1.00	0.00	1.00	7.25	1.00	4.00	5.00	12.25
RO123	other	5.60	0.00	3.00	1.00	0.00	1.00	10.60	1.00	4.00	5.00	15.60
RO124	other	5.36	0.00	3.00	1.00	0.00	1.00	10.36	1.00	4.00	5.00	15.36
RO125	other	7.05	1.00	3.00	1.00	0.00	1.00	13.05	4.00	2.00	6.00	19.05
RO126	other	6.71	1.00	3.00	1.00	1.00	1.00	13.71	4.00	2.00	6.00	19.71
RO127	fly ash	6.23	1.00	3.00	1.00	1.00	1.00	13.23	1.00	2.00	3.00	16.23
RO128	slurry	7.48	1.00	3.00	1.00	1.00	1.00	14.48	4.00	2.00	6.00	20.48
RO129	slurry	6.27	1.00	0.00	1.00	0.00	1.00	9.27	4.00	2.00	6.00	15.27
RO130	slurry	5.11	1.00	0.00	1.00	1.00	1.00	9.11	4.00	2.00	6.00	15.11
RO131	other	6.89	3.00	0.00	1.00	0.00	1.00	11.89	1.00	4.00	5.00	16.89
RO132	other	6.67	3.00	0.00	1.00	1.00	1.00	12.67	4.00	2.00	6.00	18.67
RO133	other	6.30	0.00	0.00	1.00	1.00	1.00	9.30	3.00	2.00	5.00	14.30
RO134	other	6.11	1.00	0.00	1.00	0.00	1.00	9.11	4.00	2.00	6.00	15.11
RO135	other	6.37	1.00	0.00	1.00	0.00	1.00	9.37	5.00	2.00	7.00	16.37
RO136	other	5.79	1.00	0.00	1.00	0.00	1.00	8.79	5.00	2.00	7.00	15.79
RO137	other	6.37	1.00	0.00	1.00	0.00	1.00	9.37	5.00	2.00	7.00	16.37
RO138	other	5.63	1.00	0.00	0.00	0.00	1.00	7.63	4.00	2.00	6.00	13.63
RO139	other	6.39	3.00	0.00	0.00	0.00	1.00	10.39	1.00	2.00	3.00	13.39
RO140	other	4.70	3.00	0.00	0.00	0.00	1.00	8.70	4.00	2.00	6.00	14.70
RO141	fly ash	6.59	1.00	0.00	1.00	0.00	1.00	9.59	4.00	2.00	6.00	15.59
RO142	sludge	7.08	1.00	3.00	1.00	0.00	1.00	13.08	4.00	2.00	6.00	19.08
RO143	slurry	6.92	3.00	0.00	1.00	1.00	1.00	12.92	4.00	2.00	6.00	18.92
RO144	slurry	6.28	3.00	0.00	1.00	0.00	1.00	11.28	4.00	2.00	6.00	17.28
RO145	slurry	5.70	3.00	0.00	1.00	0.00	1.00	10.70	5.00	2.00	7.00	17.70
RO146	slurry	5.84	3.00	0.00	1.00	1.00	1.00	11.84	4.00	2.00	6.00	17.84

TMF		THI							TRI			
TMF Code	Tailings material	THI Cap	THI Tox	THI Man	THI Nat: THI Seism	THI Nat: THI Flood	THI Dam	THI	TEI Pop	TEI Env	TEI	TRI
RO147	slurry	5.96	3.00	0.00	1.00	1.00	1.00	11.96	5.00	2.00	7.00	18.96
RO148	other	6.02	1.00	0.00	1.00	1.00	1.00	10.02	3.00	2.00	5.00	15.02
RO149	slurry	5.70	3.00	0.00	1.00	0.00	1.00	10.70	1.00	2.00	3.00	13.70
RO150	slurry	5.18	3.00	0.00	1.00	0.00	1.00	10.18	1.00	2.00	3.00	13.18
RO151	slurry	7.48	1.00	3.00	1.00	1.00	1.00	14.48	4.00	2.00	6.00	20.48
RO152	slurry	5.48	1.00	3.00	1.00	0.00	1.00	11.48	1.00	3.00	4.00	15.48
RS1	slurry	6.70	3.00	3.00	1.00	0.00	1.00	14.70	1.00	1.00	2.00	16.70
RS2	slurry	6.34	3.00	3.00	1.00	0.00	1.00	14.34	1.00	2.00	3.00	17.34
RS3	slurry	5.40	2.00	0.00	1.00	0.00	1.00	9.40	1.00	1.00	2.00	11.40
RS4	slurry	5.30	2.00	0.00	1.00	0.00	1.00	9.30	4.00	1.00	5.00	14.30
RS5	slurry	5.90	3.00	3.00	1.00	1.00	1.00	14.90	1.00	2.00	3.00	17.90
RS6	slurry	5.90	3.00	3.00	1.00	0.00	1.00	13.90	1.00	2.00	3.00	16.90
RS7	slurry	5.88	3.00	3.00	1.00	0.00	1.00	13.88	3.00	2.00	5.00	18.88
RS8	slurry	6.78	3.00	3.00	1.00	0.00	1.00	14.78	3.00	1.00	4.00	18.78
RS9	slurry	7.98	3.00	3.00	1.00	0.00	1.00	15.98	3.00	1.00	4.00	19.98
RS10	slurry	7.95	3.00	3.00	1.00	0.00	1.00	15.95	3.00	1.00	4.00	19.95
RS11	slurry	7.08	3.00	3.00	1.00	0.00	1.00	15.08	3.00	1.00	4.00	19.08
RS12	slurry	8.28	3.00	3.00	1.00	0.00	1.00	16.28	5.00	1.00	6.00	22.28
RS13	slurry	7.30	3.00	3.00	1.00	0.00	1.00	15.30	5.00	1.00	6.00	21.30
RS14	slurry	5.90	3.00	3.00	1.00	0.00	1.00	13.90	1.00	3.00	4.00	17.90
RS15	slurry	5.00	3.00	3.00	1.00	0.00	1.00	13.00	1.00	3.00	4.00	17.00
RS16	slurry	6.85	3.00	3.00	1.00	1.00	1.00	15.85	3.00	2.00	5.00	20.85
RS17	slurry	7.08	3.00	3.00	1.00	1.00	1.00	16.08	1.00	2.00	3.00	19.08
RS18	fly ash	8.05	1.00	3.00	1.00	0.00	1.00	14.05	4.00	4.00	8.00	22.05
RS19	fly ash	8.11	1.00	3.00	1.00	0.00	1.00	14.11	4.00	4.00	8.00	22.11
RS20	fly ash	6.60	1.00	3.00	1.00	0.00	1.00	12.60	4.00	2.00	6.00	18.60
RS21	fly ash	6.40	1.00	3.00	1.00	0.00	1.00	12.40	4.00	2.00	6.00	18.40
RS22	fly ash	7.48	1.00	0.00	1.00	0.00	1.00	10.48	1.00	4.00	5.00	15.48
RS23	fly ash	6.70	1.00	3.00	1.00	1.00	1.00	13.70	4.00	4.00	8.00	21.70
RS24	slurry	6.75	3.00	3.00	1.00	1.00	1.00	15.75	3.00	2.00	5.00	20.75
RS25	slurry	6.82	3.00	3.00	1.00	0.00	1.00	14.82	1.00	2.00	3.00	17.82

TMF		THI							TRI			
TMF Code	Tailings material	THI Cap	THI Tox	THI Man	THI Nat THI Seism	THI Nat THI Flood	THI Dam	THI	TEI Pop	TEI Env	TEI	TRI
RS26	slurry	6.24	3.00	3.00	1.00	1.00	1.00	15.24	3.00	2.00	5.00	20.24
RS27	slurry	6.38	3.00	3.00	1.00	1.00	1.00	15.38	1.00	2.00	3.00	18.38
RS28	sludge	6.45	3.00	3.00	1.00	1.00	1.00	15.45	1.00	2.00	3.00	18.45
RS29	sludge	6.38	3.00	3.00	1.00	1.00	1.00	15.38	3.00	2.00	5.00	20.38
RS30	sludge	6.71	3.00	3.00	1.00	0.00	1.00	14.71	2.00	2.00	4.00	18.71
RS31	sludge	6.08	3.00	3.00	1.00	0.00	1.00	14.08	2.00	2.00	4.00	18.08
SI1	fly ash	7.39	1.00	3.00	1.00	0.00	1.00	13.39	5.00	2.00	7.00	20.39
SI2	red mud	6.65	1.00	0.00	1.00	0.00	1.00	9.65	5.00	3.00	8.00	17.65
SI3	sludge	5.36	1.00	3.00	1.00	0.00	1.00	11.36	5.00	2.00	7.00	18.36
SI4	slurry	5.60	3.00	0.00	1.00	0.00	1.00	10.60	1.00	2.00	3.00	13.60
SI5	slurry	6.00	3.00	0.00	1.00	0.00	1.00	11.00	1.00	2.00	3.00	14.00
SI6	slurry	4.93	1.00	0.00	1.00	0.00	1.00	7.93	5.00	3.00	8.00	15.93
SI7	slurry	7.12	3.00	0.00	1.00	0.00	1.00	12.12	4.00	2.00	6.00	18.12
SI8	slurry	5.11	3.00	0.00	1.00	0.00	1.00	10.11	3.00	2.00	5.00	15.11
SI9	slurry	4.48	3.00	0.00	1.00	0.00	1.00	9.48	4.00	2.00	6.00	15.48
SI10	slurry	4.70	1.00	0.00	1.00	0.00	1.00	7.70	3.00	2.00	5.00	12.70
SI11	slurry	5.11	1.00	0.00	1.00	0.00	1.00	8.11	3.00	3.00	6.00	14.11
SI12	fly ash	6.92	1.00	0.00	1.00	0.00	1.00	9.92	3.00	3.00	6.00	15.92
SI13	slurry	4.28	1.00	3.00	1.00	0.00	1.00	10.28	1.00	2.00	3.00	13.28
SI14	slurry	4.48	1.00	0.00	1.00	0.00	1.00	7.48	4.00	3.00	7.00	14.48
SI15	slurry	4.30	1.00	0.00	0.00	0.00	1.00	6.30	5.00	2.00	7.00	13.30
SI16	slurry	3.28	1.00	0.00	1.00	0.00	1.00	6.28	3.00	2.00	5.00	11.28
SI17	other	3.48	2.00	0.00	0.00	1.00	1.00	7.48	1.00	2.00	3.00	10.48
SI18	slurry	3.70	1.00	3.00	1.00	0.00	1.00	9.70	4.00	2.00	6.00	15.70
SI19	other	4.98	3.00	3.00	1.00	0.00	1.00	12.98	3.00	3.00	6.00	18.98
SI20	other	3.78	1.00	0.00	1.00	0.00	1.00	6.78	4.00	2.00	6.00	12.78
SI21	other	4.60	1.00	0.00	1.00	0.00	1.00	7.60	4.00	2.00	6.00	13.60
SI22	other	4.68	2.00	3.00	1.00	0.00	1.00	11.68	3.00	3.00	6.00	17.68
SI23	other	4.00	2.00	0.00	0.00	1.00	1.00	8.00	3.00	3.00	6.00	14.00
SI24	residual oil	4.30	2.00	0.00	0.00	0.00	1.00	7.30	3.00	2.00	5.00	12.30
SI25	other	4.36	2.00	0.00	1.00	0.00	1.00	8.36	3.00	3.00	6.00	14.36

TMF		THI							TRI			
TMF Code	Tailings material	THI Cap	THI Tox	THI Man	THI Nat THI Seism	 THI Flood	THI Dam	THI	TEI Pop	TEI Env	TEI	TRI
SI26	slurry	5.11	3.00	0.00	1.00	0.00	1.00	10.11	3.00	2.00	5.00	15.11
SI27	slurry	4.00	3.00	0.00	1.00	0.00	1.00	9.00	3.00	2.00	5.00	14.00
SI28	sludge	4.18	1.00	3.00	1.00	1.00	1.00	11.18	4.00	3.00	7.00	18.18
SI29	other	3.70	1.00	3.00	1.00	1.00	1.00	10.70	4.00	3.00	7.00	17.70
SI30	slurry	5.78	1.00	0.00	1.00	0.00	1.00	8.78	4.00	2.00	6.00	14.78
SK1	sludge	6.07	2.00	0.00	0.00	1.00	1.00	10.07	4.00	2.00	6.00	16.07
SK2	sludge	4.51	3.00	0.00	0.00	0.00	1.00	8.51	4.00	1.00	5.00	13.51
SK3	sludge	6.81	1.00	3.00	0.00	1.00	1.00	12.81	5.00	2.00	7.00	19.81
SK4	sludge	6.82	3.00	3.00	0.00	1.00	1.00	14.82	4.00	2.00	6.00	20.82
SK5	sludge	5.20	1.00	3.00	1.00	0.00	1.00	11.20	5.00	2.00	7.00	18.20
SK6	sludge	5.43	3.00	0.00	1.00	0.00	1.00	10.43	5.00	2.00	7.00	17.43
SK7	slurry	4.93	1.00	0.00	0.00	0.00	1.00	6.93	4.00	2.00	6.00	12.93
SK8	sludge	6.47	3.00	0.00	0.00	1.00	1.00	11.47	4.00	1.00	5.00	16.47
SK9	sludge	6.18	3.00	0.00	1.00	0.00	1.00	11.18	4.00	1.00	5.00	16.18
SK10	sludge	5.56	1.00	3.00	1.00	0.00	1.00	11.56	5.00	2.00	7.00	18.56
SK11	sludge	6.39	3.00	0.00	1.00	1.00	1.00	12.39	4.00	1.00	5.00	17.39
SK12	sludge	6.84	2.00	3.00	0.00	1.00	1.00	13.84	4.00	2.00	6.00	19.84
SK13	sludge	5.65	2.00	0.00	0.00	1.00	1.00	9.65	3.00	2.00	5.00	14.65
SK14	sludge	4.70	3.00	0.00	0.00	1.00	1.00	9.70	4.00	1.00	5.00	14.70
SK15	sludge	5.15	3.00	3.00	0.00	1.00	1.00	13.15	3.00	2.00	5.00	18.15
SK16	red mud	7.02	1.00	0.00	1.00	0.00	1.00	10.02	1.00	2.00	3.00	13.02
SK17	sludge	5.75	2.00	0.00	0.00	0.00	1.00	8.75	1.00	2.00	3.00	11.75
SK18	sludge	6.59	1.00	3.00	0.00	1.00	1.00	12.59	4.00	1.00	5.00	17.59
SK19	sludge	5.44	3.00	0.00	1.00	1.00	1.00	11.44	1.00	2.00	3.00	14.44
SK20	sludge	4.95	1.00	3.00	0.00	1.00	1.00	10.95	4.00	1.00	5.00	15.95
SK21	mine water	6.03	1.00	0.00	0.00	1.00	1.00	9.03	6.00	2.00	8.00	17.03
SK22	mine water	4.48	1.00	0.00	0.00	1.00	1.00	7.48	6.00	2.00	8.00	15.48
SK23	sludge	5.37	3.00	0.00	1.00	1.00	1.00	11.37	1.00	2.00	3.00	14.37
SK24	slurry	4.70	1.00	0.00	0.00	1.00	1.00	7.70	5.00	2.00	7.00	14.70
SK25	sludge	3.30	3.00	3.00	0.00	1.00	1.00	11.30	4.00	2.00	6.00	17.30
SK26	fly ash	6.88	1.00	3.00	1.00	1.00	1.00	13.88	3.00	2.00	5.00	18.88

TMF		THI							TRI			
TMF Code	Tailings material	THI Cap	THI Tox	THI Man	THI Nat		THI Dam	THI	TEI Pop	TEI Env	TEI	TRI
					THI Seism	THI Flood						
SK27	fly ash	7.16	1.00	3.00	0.00	1.00	1.00	13.16	3.00	2.00	5.00	18.16
SK28	fly ash	6.72	1.00	0.00	0.00	1.00	1.00	9.72	4.00	2.00	6.00	15.72
SK29	fly ash	7.18	1.00	3.00	0.00	1.00	1.00	13.18	3.00	2.00	5.00	18.18
SK30	fly ash	5.85	1.00	0.00	1.00	1.00	1.00	9.85	5.00	4.00	9.00	18.85
SK31	fly ash	6.44	1.00	3.00	1.00	1.00	1.00	13.44	5.00	2.00	7.00	20.44
SK32	fly ash	6.60	1.00	0.00	1.00	1.00	1.00	10.60	5.00	2.00	7.00	17.60
SK33	fly ash	6.34	1.00	3.00	1.00	1.00	1.00	13.34	3.00	2.00	5.00	18.34
SK34	fly ash	6.37	1.00	3.00	0.00	1.00	1.00	12.37	5.00	2.00	7.00	19.37
SK35	fly ash	6.20	1.00	3.00	1.00	1.00	1.00	13.20	1.00	3.00	4.00	17.20
SK36	fly ash	6.18	1.00	0.00	1.00	0.00	1.00	9.18	5.00	2.00	7.00	16.18
SK37	fly ash	6.00	1.00	3.00	0.00	1.00	1.00	12.00	1.00	2.00	3.00	15.00
SK38	fly ash	5.66	1.00	3.00	0.00	1.00	1.00	11.66	1.00	3.00	4.00	15.66
SK39	fly ash	5.51	1.00	3.00	1.00	1.00	1.00	12.51	1.00	2.00	3.00	15.51
SK40	fly ash	5.74	1.00	3.00	1.00	0.00	1.00	11.74	1.00	2.00	3.00	14.74
SK41	sludge	5.74	1.00	3.00	1.00	1.00	1.00	12.74	4.00	2.00	6.00	18.74
SK42	other	4.95	2.00	3.00	1.00	1.00	1.00	12.95	1.00	2.00	3.00	15.95
SK43	residual oil	5.20	2.00	0.00	1.00	0.00	1.00	9.20	1.00	2.00	3.00	12.20
SK44	other	5.05	1.00	0.00	1.00	1.00	1.00	9.05	5.00	3.00	8.00	17.05
SK45	sludge	6.80	2.00	0.00	0.00	1.00	1.00	10.80	4.00	3.00	7.00	17.80
SK46	other	5.79	1.00	3.00	0.00	1.00	1.00	11.79	4.00	2.00	6.00	17.79
SK47	other	5.68	1.00	0.00	1.00	0.00	1.00	8.68	5.00	3.00	8.00	16.68
SK48	other	4.48	1.00	3.00	0.00	1.00	1.00	10.48	1.00	2.00	3.00	13.48
SK49	calx	5.37	1.00	3.00	0.00	1.00	1.00	11.37	4.00	1.00	5.00	16.37
SK50	fly ash	5.77	1.00	3.00	0.00	0.00	1.00	10.77	4.00	1.00	5.00	15.77
SK51	other	5.06	2.00	3.00	0.00	1.00	1.00	12.06	4.00	2.00	6.00	18.06
SK52	other	6.17	2.00	3.00	0.00	1.00	1.00	13.17	4.00	2.00	6.00	19.17
SK53	other	5.65	2.00	0.00	1.00	1.00	1.00	10.65	1.00	3.00	4.00	14.65
SK54	sludge	5.60	3.00	0.00	0.00	1.00	1.00	10.60	4.00	2.00	6.00	16.60
SK55	sludge	5.59	3.00	0.00	1.00	1.00	1.00	11.59	5.00	2.00	7.00	18.59
SK56	fly ash	6.92	1.00	3.00	1.00	1.00	1.00	13.92	5.00	2.00	7.00	20.92
SK57	other	5.30	3.00	0.00	0.00	0.00	1.00	9.30	3.00	2.00	5.00	14.30

TMF		THI							TRI			
TMF Code	Tailings material	THI Cap	THI Tox	THI Man	THI Nat		THI Dam	THI	TEI Pop	TEI Env	TEI	TRI
					THI Seism	THI Flood						
SK58	other	4.36	3.00	0.00	0.00	0.00	1.00	8.36	1.00	2.00	3.00	11.36
SK59	sludge	6.14	3.00	0.00	0.00	0.00	1.00	10.14	5.00	2.00	7.00	17.14
SK60	other	4.20	1.00	3.00	1.00	0.00	1.00	10.20	1.00	2.00	3.00	13.20

//////////////// Deutschland //// Österreich //// Česká republika //// Slovensko //// Magyarország //// Slovenija //// Hrvatska //// Bosna i Hercegovina //// Србија //// Crna Gora //// România //// България //// Moldova //// Україна ////////////