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Monitoreo de avanzada para una minería responsable

PHYSICAL STABILITY MONITORING AND ASSESSMENT STANDARD FOR TAILINGS STORAGE FACILITIES

A PROPOSAL FROM CHILE

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Recommended Document: Standard For Monitoring and Assessment of Natural Water Surrounding Tailings Storage Facilities . A Proposal From Chile

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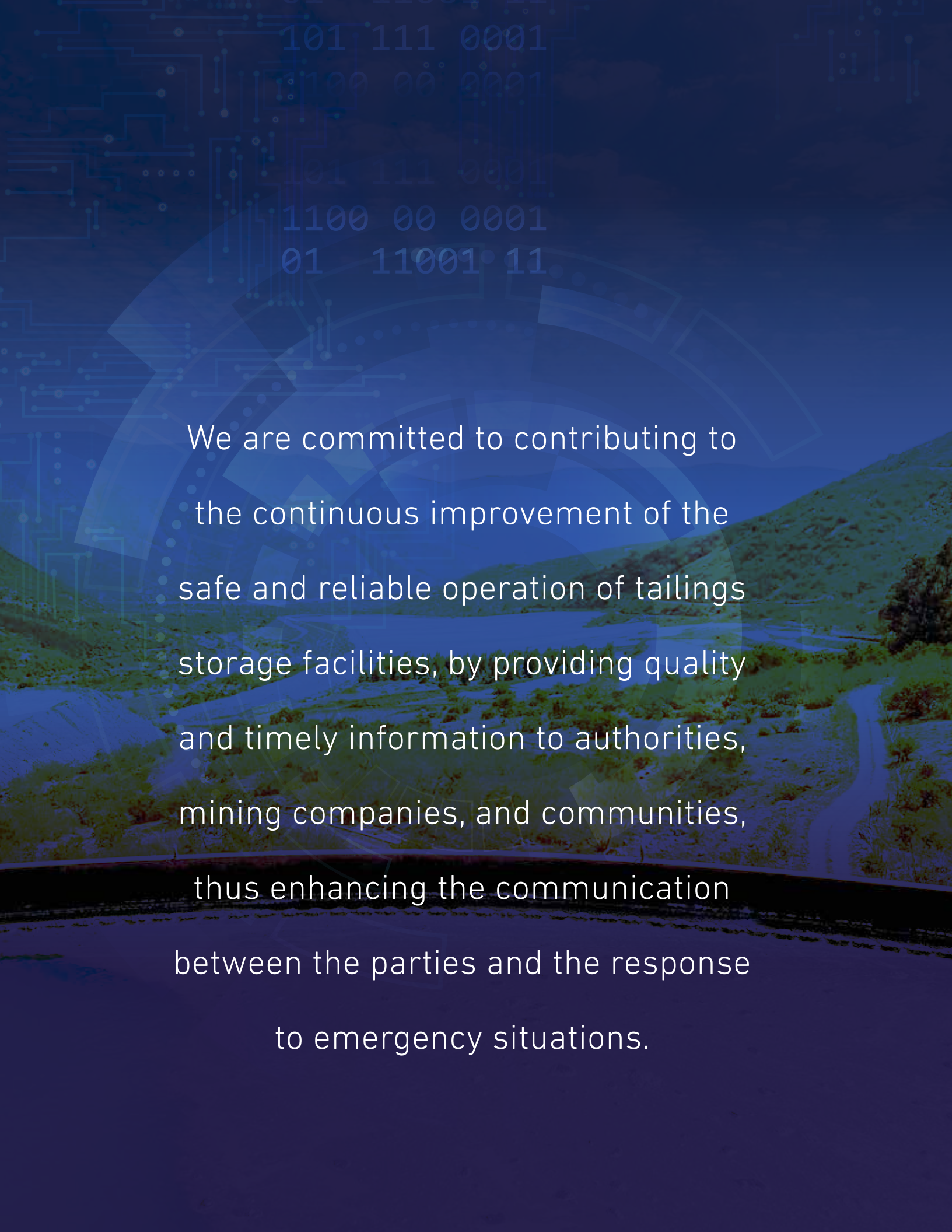


We are committed to contributing to the continuous improvement of the safe and reliable operation of tailings storage facilities, by providing quality and timely information to authorities, mining companies, and communities, thus enhancing the communication between the parties and the response to emergency situations.

FOREWORD

Despite the long-standing discussion between the worlds of science and philosophy on whether the metaphor Isaac Newton wrote to Robert Hooke in 1676 belonged to him or, instead, was taken from one of John of Salisbury's documents in 1159, the fact remains that the sentence **"If I have seen further it is by standing on the shoulders of giants"** describes an important characteristic featured by the Transparent Tailings Initiative. The world invoked by the above phrase highlights the collective nature of the initiative, where much has been built on the efforts of many technicians, scientists, mining companies, community leaders, and politicians whose work, for the three past years, has helped elaborate the initiative herein described.

Our organization, the National Service of Geology and Mining (SERNAGEOMIN) has set out the challenge of reviewing its strategic plan and putting forward a proposal for the 2020–2023 period. In that sense, we are focusing our efforts on adapting our processes to the increasing inflow of industry 4.0 and prioritizing initiatives intended to improve the strategic products devised for the community and authorities.

The Transparent Tailings Initiative objectives have proved to be absolutely aligned with our own goals and, on the grounds of that alignment, we have assumed the future creation and management of the National Tailings Observatory as our own challenge. This system will preventively warn us of the impacts derived from the different events that can take place in these facilities.

This represents a key tool in remote control and management, providing the Service with relevant information regarding each TSF commitments and how these are monitored during operations, in order to identify possible deviations from the originally approved design. This information and communication flow between the Service and mining companies will serve to better guide on-site enforcement and early warning management efforts, which is, no doubt, a major step in our daily activities.

Additionally, the system will also provide information to the communities who must understand and recognize they play active roles in the events taking place in their territories.

The Transparent Tailings Initiative monitoring standard presented in this document is deemed relevant not only because it technically defines tools to monitor all TSF existing in our country but, also, because it represents a major progress towards the standardization of best practices in the Chilean mining industry and has turned the latter into a world leader in TSF management.

Based on these reasons and vital advances, we will continue to uphold and work on this initiative, until its implementation is gradually completed nationwide.

Jorge Vargas

Head of Large-Scale Projects Department & Tailings Dams,
SERNAGEOMIN

PRESENTATION

One of the significant results derived from the Transparent Tailings Initiative framework is the monitoring standard for tailings storage facilities (TSF). This document is the result of a collaborative work that has been validated by all the private and public parties engaged in the Initiative. It includes the necessary tools to assess the physical stability performance of such facilities as well as to assess and monitor their surrounding waters. This standard proposes the critical variables and parameters required for the monitoring process, including sample/instrumental frequency and density and puts forth assessment tools. The results obtained will allow the early management of potential emergency situations through an information management platform.

The present document offers a technical version of the physical stability monitoring and assessment standard[1], whose acronym IEF corresponds to its name in spanish. The document is organized as follows. The first part presents a brief description of the Transparent Tailings Initiative and a concise summary of the tools required to monitor the TSF physical stability performance as well as to assess their surrounding waters, and the monitoring and early warning system.

The second part explains the IEF, the development process and methodology applied by the tool, its objectives, components, and scope and the general flow, starting from the data entry process until alerts are generated.

The third part details the implementation of each module of the IEF, the events, and the management and communication of the alert system.

This standard is represents the common view held by all the parties engaged in the Initiative, which is the development of a sustainable mining, capable of reconciling industrial development with territorial vocations, by expanding the knowledge about TSF operations and take their management to the highest standard.

1. The proposed standard by the Transparent Tailings Initiative is neither mandatory nor legally enforced.

PART I
INTRODUCTION

In recent history, mining has driven Chile's development and has thus become one of the main economic activities in our country. Nowadays, the challenges imposed by national and international circumstances have caused the industry to ponder on its operation standards and practices; thus, a number of initiatives have been put in place to elaborate guidelines and take actions designed to promote a sustainable mining development.

Bearing in mind that Chile is the third country with the largest number of tailings storage facilities (TSF) globally and that these deposits are of key importance for the industry, there is no question that solutions must be developed to enhance their management to better control their performance and relationship with the environment they sit in. Likewise, and based on the catastrophic events occurred lately in the world, not only environmental issues governed by different regulations or the social aspects that grant the social license to operate must be addressed, but also the fact that mining is facing the challenge of keeping the confidence of investors who provide the industry with the financial license to maintain its development.

The Technological Initiative of Online Monitoring of Tailings Storage Facilities (Transparent Tailings Initiative) comes as a way of contributing to the safe operation of the TSF existing in the country, improving the coordination and trust relationships between the different parties involved, and of positioning Chile as world benchmark in TSF management.

The Transparent Tailings Initiative is a public-private project launched by the end of 2016, aimed to develop a public good consisting of a standardized monitoring and early-warning system applicable to TSF. Through an information management platform, this system provides the parties involved (authorities, mining companies, and communities) with quality, reliable, and timely information regarding TSF performance, in aspects of physical stability and surrounding water monitoring. This initiative, under the auspices of the Alta Ley program, has been co-designed and implemented by Fundación Chile, CORFO, Ministry of Mining, National Service of Geology and Mining (SERNAGEOMIN), National Emergency Office (ONEMI), Superintendence of the Environment (SMA), General Water Department (DGA), Antofagasta Minerals (AMSA), BHP, CODELCO, National Mining Company (ENAMI), National Mining Society (SONAMI), INRIA Chile, Advanced Mining Technology Center of the University of Chile (AMTC), and Valor Compartido.

In 2018, the initiative gained new momentum following the decision by the Ministry of Mining to include it in the National Tailings Policy whose main pillars consider the implementation of active TSF management tools through the creation of the National TSF Observatory.

The aforementioned system exhibits two interrelated components: (1) the monitoring system including the data capturing methods and technologies, their

collection and storage, post processing and the differentiated visualization of the data collected for the TSF performance definition; and (2) an early-warning system notifies events and alerts to the main actors involved; public entities, mining companies, and communities, in case of eventual emergencies. For better understanding, its terminology has been adopted from the emergency nomenclature applied by ONEMI

The monitoring system, developed as part of the Transparent Tailings Initiative is based on a standard that defines a number of technical criteria especially designed to monitor and evaluate the physical stability of TSF and its inluence on surrounding waterbodies. This standard has been agreed upon by all the parties comprising this public-private alliance.

In order to evaluate the physical stability of TSF, the Transparent Tailings Initiative has developed a tool capable of assessing a TSF condition on the basis of three main failure mechanisms (overtopping, piping, and slope instability) that can compromise the physical stability of such facilities. These mechanisms contain three sequential assessment modules differentiated by the frequency, volume, and complexity of the information required. This physical stability assessment tool has been mainly conceived to learn and notify how deposits behave in front of factors such as location, selected design, and the operation, in order to have a comprehensive panorama that helps enhance the TSF preventive management.

The way TSF behave in relation with their surrounding waters is addressed by the Transparent Tailings Initiative through the development of four tools in charge of assessing the influence of the TSF on the waterbodies, both surface and underground, surrounding the TSF, by monitoring a number of critical chemical and physical water quality variables. The set of these tools is called EMAC standard.

The technical proposals for these tools were put forward by AMTC and Fundación Chile teams, while experts from all the Transparent Tailings Initiative institutions participated in their elaboration and approval.

This document provides a detailed description of the Transparent Tailings Initiative IEF standard and its operation from the data input, their analysis, management, to warning notifications.

PART II
OVERVIEW OF THE IEF

Within the framework of the Transparent Tailings Initiative, and complementing the definition of the Chilean law N° 20551, the physical stability concept of TSF is defined as the structural equilibrium state in which hydro-mechanical disturbances do not cause failure, collapse, removal or release of the stored tailings. To ensure the physical stability, several critical controls should be realized and critical parameters monitored. Such critical parameters are properties of a tailings deposit that individually, or in combination with other parameters, could affect the physical stability. The IEF is a multivariate tool to assess the physical stability of the TSF from qualitative and quantitative information obtained from sensors, field observations, and expert judgment.

The objectives of the IEF are:

(1) Identify and monitor the critical parameters that control the physical stability of a TSF in accordance with the current national regulatory framework, international best practices, and authority recommendations.

(2) Centralize all the monitoring information in a single platform, maintaining a historical record of all anomalous events that occurred during the operation, design backup documents, and as-built drawings.

(3) Integrate models (numerical, empirical, and analytical) that allow the integral evaluation of physical stability.

(4) Identify and record irregular events during the operation (qualitative and quantitative monitoring) to provide general recommendations for the proper management and control processes.

(5) Communicate the performance of the TSF according to the monitored variables, to effectively respond to situations that may compromise its physical stability.

The standard evaluates the occurrence of a failure mechanism, which is a process or sequence of processes caused by a trigger event, such as natural phenomenon or an operational situation, that result in increased failure potential of the TSF and subsequent loss of containment. Following this definition, the standard organizes a significant number of failure modes, collected from the technical literature, into three main groups: overtopping, internal erosion, and slope instability, which are described below:

Overtopping occurs when the input volume of either tailings or water into the reservoir exceeds its capacity, generating an overflow of the crown and the slope downstream of the dam. The overflow can erode the retaining dam, producing a progressive failure that can result in the formation of a breach and subsequent collapse.

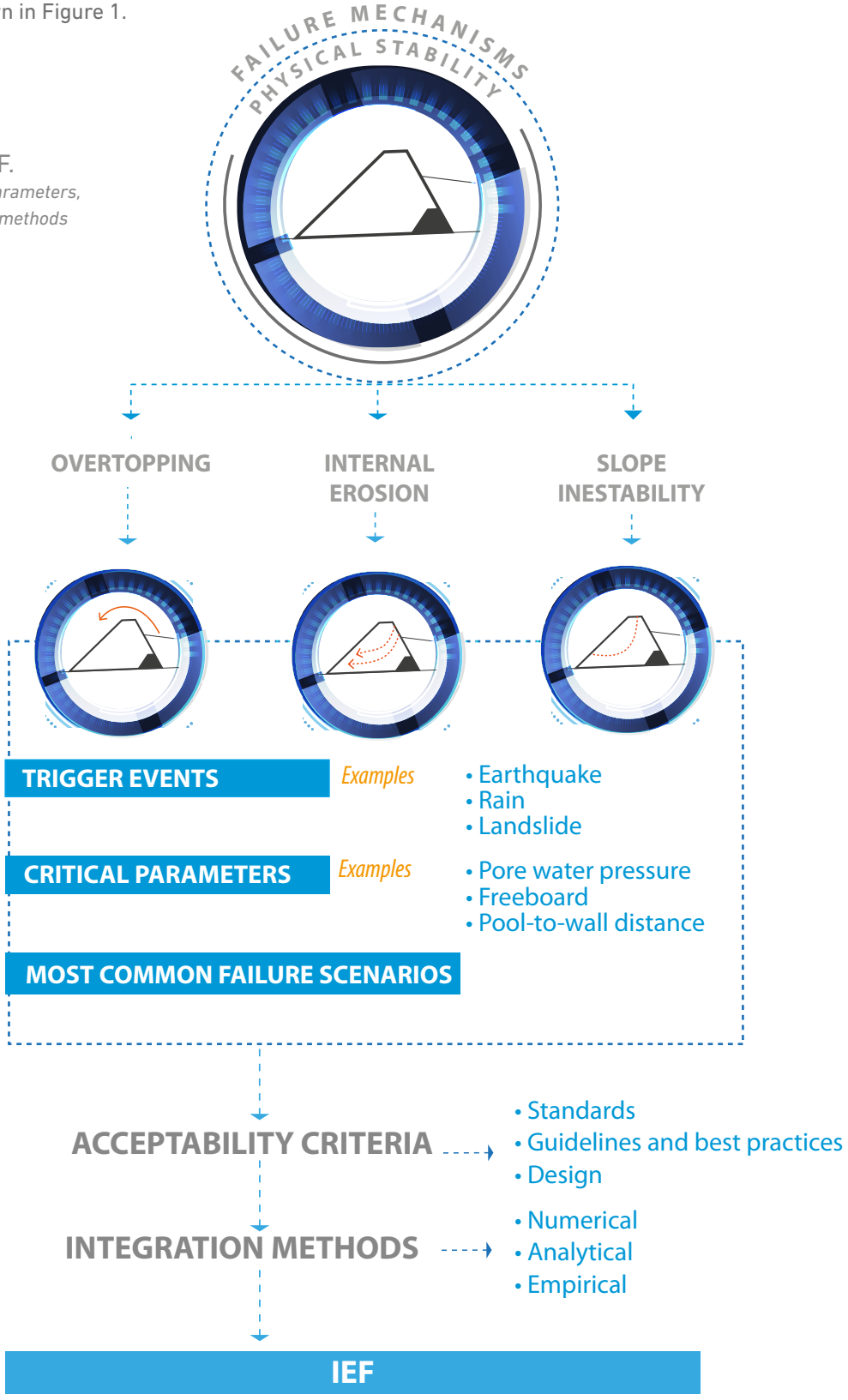
Internal erosion (also commonly known as piping) is the migration of material through the interior of the retaining dam or the foundation soil, leading to the formation of conduits that promote preferential flux paths for the circulation of water or tailings. The resulting cavities favor the progress of erosion, which can generate a local or global failure of the deposit or its foundation soil.

Slope instability corresponds to the sliding of a section of the dam slope along a failure surface, due to an imbalance between destabilizing forces and resistant ones. In general, the stability of slopes is mainly determined by the geometry of the dam (e.g., height and sloping angles), the physical and mechanical properties of the materials that conform the dam and the foundation soil.

1. The proposed standard by the Transparent Tailings Initiative is neither mandatory nor legally enforced.

The critical parameters, the methodology to estimate the threshold values of the critical parameters, and the trigger events that can lead to the development of each failure mechanism have been established. The conceptual model of the definition of the IEF is shown in Figure 1.

FIGURE 1.
Conceptual model of the IEF.
Examples of trigger events, critical parameters, acceptability criteria, and integration methods are also shown.



The standard consists of two interrelated modules that are assessed in sequence, as shown in Figure 2, and described below:

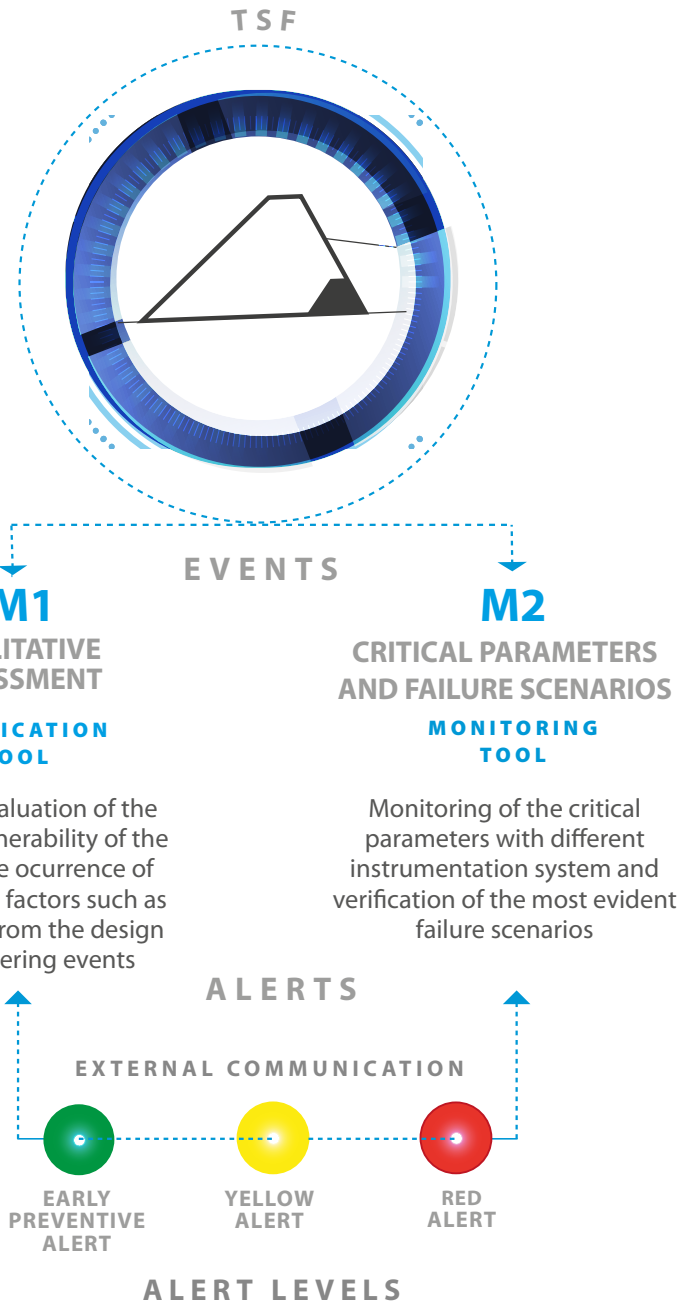
M1

Module 1 Qualitative assessment: Qualitative verification tool that periodically assesses the physical vulnerability of the TSF and verifies the occurrence of aggravating factors, such as deviations from the design and events that can facilitate the triggering of a failure mechanism.

M2

Module 2 Verification of critical parameters and failure scenarios: Monitoring tool that verifies the physical condition of the TSF by analyzing the monitoring values of the critical parameters and their trends compared to threshold values. Exceedance of the threshold values can activate alert signals or alarms depending on the severity of the situation. This tool also verifies the combined occurrence of anomalous critical parameters values and trigger events that can configure a failure scenario, whose definition depends on the analysis of the most common types of historical failures. The results of the assessments of these two modules M1 and M2 are used to issue an external communication to the stakeholders about the physical stability of the TSF.

FIGURE 2.
Structure of the IEF



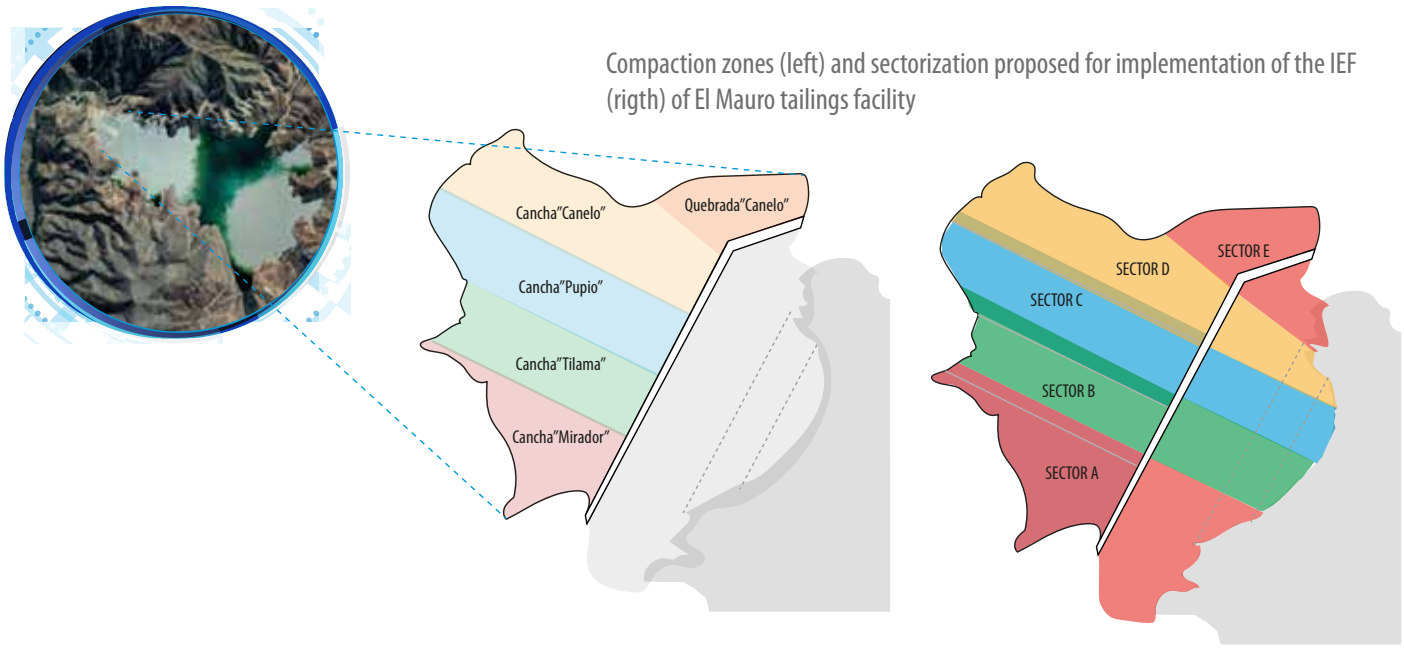
PART III
IMPLEMENTATION, OPERATION, AND ALERT MANAGEMENT OF THE IEF

1. IMPLEMENTATION

The first step of the implementation process is the sectorization of the embankment dam, which considers dividing the dam footprint into sectors based on different criteria, with the aim of discretizing the monitoring areas and facilitating the analysis of multiple events or abnormal situations, as shown in Figure 3. The sectorization process considers the following criteria:

- Conform sectors of approximately 200 meters length along the longitudinal direction of the dam.
- For cyclone-sand dams, accommodate the sectors to the discharge zones or compaction fields.
- Consider distributing the sectors according to the geometry of the drainage system, prioritizing main drain locations near the centerline of the sectors.
- Define independent sectors where changes in the geotechnical conditions of the foundation soil are detected
- Define independent sectors in zones where the embankment dam has changes in the direction of the longitudinal axis and changes in the cross-section (e.g., sloping angles).
- The embankment dam abutments are considered as independent sectors.
- Tailings facilities with more than one dam should be sectorized following the same criteria for each dam.

FIGURE 3.
Sectorization of the embankment dam from the deposition sectors, as part of the IEF implementation process



Compaction zones (left) and sectorization proposed for implementation of the IEF (rigth) of El Mauro tailings facility

2. MODULE 1: QUALITATIVE ASSESSMENT

This module of qualitative verification periodically assesses the physical vulnerability of the tailings facility and verifies the occurrence of aggravating factors, such as deviations from the design and events that can facilitate the triggering of failure mechanisms.

The evaluation is performed from information gathered from routine inspections, performed periodically by the TSF operator. Figure 4 summarizes the stages of the qualitative assessment and Table 1 describes the elements included in the evaluation process.

FIGURE 4.
Stages of the qualitative assessment (M1)

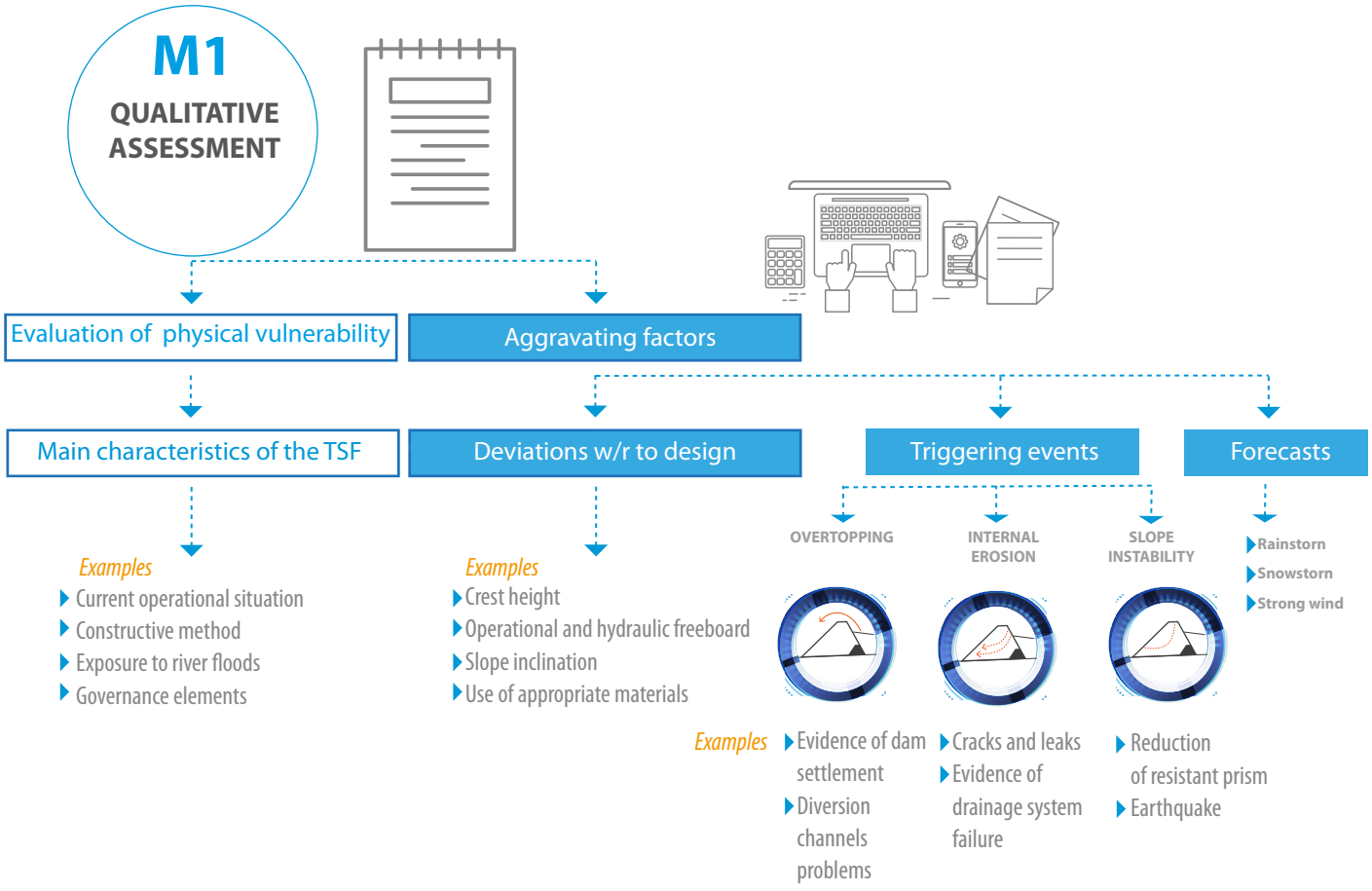


Table 1. Elements of the qualitative assessment (M1) of the IEF

Stage	Description	Evaluated items
Evaluation of the Physical Vulnerability	This assessment assigns scores to the deposit according to different characteristics and conditions. The physical vulnerability is directly proportional to the score (a deposit with a high score is more physically vulnerable compared to one with a lower score). A monthly evaluation is advised.	• Current operational status • Constructive method • Type of tailings (i.e., conventional, thickened, and paste) • Elements of governance (e.g., existence of an EoR, competent person, and/or panel review board) • Operative geotechnical instrumentation • Exposure to river floods • Exposure to runoff accumulation • Exposure to avalanches and / or floods • Updated design
Aggravating factors: Deviations from design	Daily visual inspection based on the criteria of the operator and oriented to an early identification of problems in the facility. This visual inspection does not require instrumentation or field measurements.	• Crown height • Operational and hydraulic freeboard • Crown width • Surface area of the embankment dam and tailings pond • Decant water pool location and size • Downstream and upstream slopes of the dam • Proper dam construction materials • Installation and state of the upstream dam geomembrane
Aggravating factors: Verification of trigger events	Daily verification of the occurrence of trigger events that may affect the embankment dam physical stability. The objective is the early detection of different events.	• Noticeable earthquake ground motion • Large earthquake ground motion (unable to stay stand) • Reduction of the resistant prism at the foot of the dam • Improper discharge distribution of slimes and tailings inside the pond • Slip surface in a sector of the embankment dam • Severe sliding of the surface material of the dam that affects the slope geometry • Stability problems of the dam abutments • Emergency spillway failure or blockage • Modification of the operational level of the emergency spillway • Decant water recovery system failure • Failure or blocking of the diversion channels • Evidence of differential settlements of the dam • Evidence of drainage system failure • Leaks or unusual moisture in the dam • Subsidence or sinkholes in the dam • Subsidence or sinkholes in the tailings pond • Cracks in the dam • Imminent landslide into the tailings pond • Natural landslide towards the dam or critical sectors • Detection of particulate material at the exit of the drainage system • Rain start • Overtopping of slimes or clear water
Aggravating factors: Forecast	Daily verification of the different climatic forecasts that may affect the tailings deposit.	• Rain • Snowfall • Strong winds

In Appendix 1, detailed descriptions of each stage and the evaluated items are included, see www.fch.cl/proyecto/sustentabilidad/tranque/

3. MODULE 2: CRITICAL PARAMETERS AND FAILURE SCENARIOS

The two principal assessment tools of Module 2, the **critical parameters analysis** and the **verification of failure scenario**, as well as the **data verification and validation process** are described next.

1. Critical parameters

Module 2 of the IEF compares the values of the recorded critical parameters with threshold values established from the Chilean law, the TSF design, and the best available operational practices. This module also monitors the temporal evolution of parameters potentially related to physical stability issues. The IEF requires critical parameters to be recorded, either manually or automatically, with a certain frequency and precision level to properly include the data in the physical stability assessment process.

This module is developed in such a way that the data can be collected from different means: from online instrumentation and from offline instrumentation. Table 2 summarizes the 30 critical parameters included in the IEF and their associated requirements such as frequency, precision and instrumental density.

Table 2. Critical Parameters

Categories	Description	Critical Parameters	Unit	Frequency	Precision	Instrumental density
Geometrical Aspects	Parameters that describe the geometry of the deposit	Dam height	[m.a.s.l.]	Weekly (cyclone-sand dam) Monthly (embankment dam)	0.1	1 measurement by profile 2 profiles by sector
		Crown width	[m]	Monthly	0.1	1 measurement by profile 2 profiles by sector
		Dam slope	[H:V]	Monthly	0.1	1 measurement by profile 2 profiles by sector
		Beach slope (applicable to thickened and paste tailings)	[H:V]	Monthly	0.1	1 measurement by profile 2 profiles by sector
		Minimum distance between the dam and the pool	[m]	Weekly	1	1 measurement by sector
Deformations	Parameters that monitor deformations of the embankment dam and foundation soil	Deformation of the foundation soil	[m]	Weekly	0.01	Inclinometers located in critical sectors (Defined by design, EoR or similar)
		Deformation of the dam crown	[m]	Weekly	0.01	Inclinometers located in critical sectors (Defined by design, EoR or similar); Monoliths along the profiles / 2 profiles per sector
External integrity	Parameters associated to the external integrity of the deposit that can be visually detected	Cracks	[m]	Weekly	0.01	1 Monolith in the crown for each profile / 2 profiles per sector
		Humidity or leaks	-.	Daily	-	-
		Subsidence or sinkholes	-	Daily	-	-
		Abutment integrity	-	Daily	-	-

Table 2. Critical Parameters

Categories	Description	Critical Parameters	Unit	Frequency	Precision	Instrumental density
Operational aspects	Parameters related to the lifting process, deposition, and internal monitoring of the embankment dam in general	Hydraulic freeboard	[m]	Every 1 hour	0.1	2 sensors installed in the clear water pool
		Operational freeboard	[m]	Weekly	0.1	1 measurement per profile 2 profiles per sector
		Disposed amount of tailings	[ton]	Monthly	1	In charge of the monitoring plant
		Emergency spillway state	-	Daily	-	Plant monitoring
		Phreatic surface in the pond (applicable for thickened tailings)	[m.a.s.l.]	Weekly	0,1	Piezometers located in critical sectors (Determined by design, EoR or similar)
		Pore water pressures (dam and foundation soil)	[m.a.s.l.]	Every 1 hour	0,1	4 instruments per sector (2 at the crowning level and 2 at the downstream slope)
		Rain intensity	[mm/h]	Every 1 hour during rain	1	2 measurements associated with the station
		Overtopping potential (ratio between the pond capacity and the incoming water volume)	-	Every 1 hour when exist a forecast of rain or during rain	-	Global platform measurement
		Grain size distribution of the dam material	[%]	Weekly	1	According to the design and operation
		Density of the dam material	[%]	Weekly (for tailings-sand dam)	1	According to the design and operation
Design aspects	Parameters related to documentation that supports the design and construction of the deposit	Seismic acceleration	[m/s²]	Sampling frequency of strong ground motion 100-200 Hz	1	A pair of accelerographs by crowning the dam, base of the natural terrain and rocky outcrop
		Study of threshold freeboard	-	Every 5 years	-	-
		Shear stiffness and strength of the dam	-	SPT or similar tests: Annual campaign. Lab tests : Annual campaign	-	Test in the dam suggested by design, EoR or similar
		Appropriate geotechnical characterization of the foundation	-	Documentation associated with the design period	-	-
		Shear strength of the tailings in the pond (applicable for thickened tailings)	-	Test in the pond suggested by design, EoR or similar	-	Test in the pond suggested by design, EoR or similar

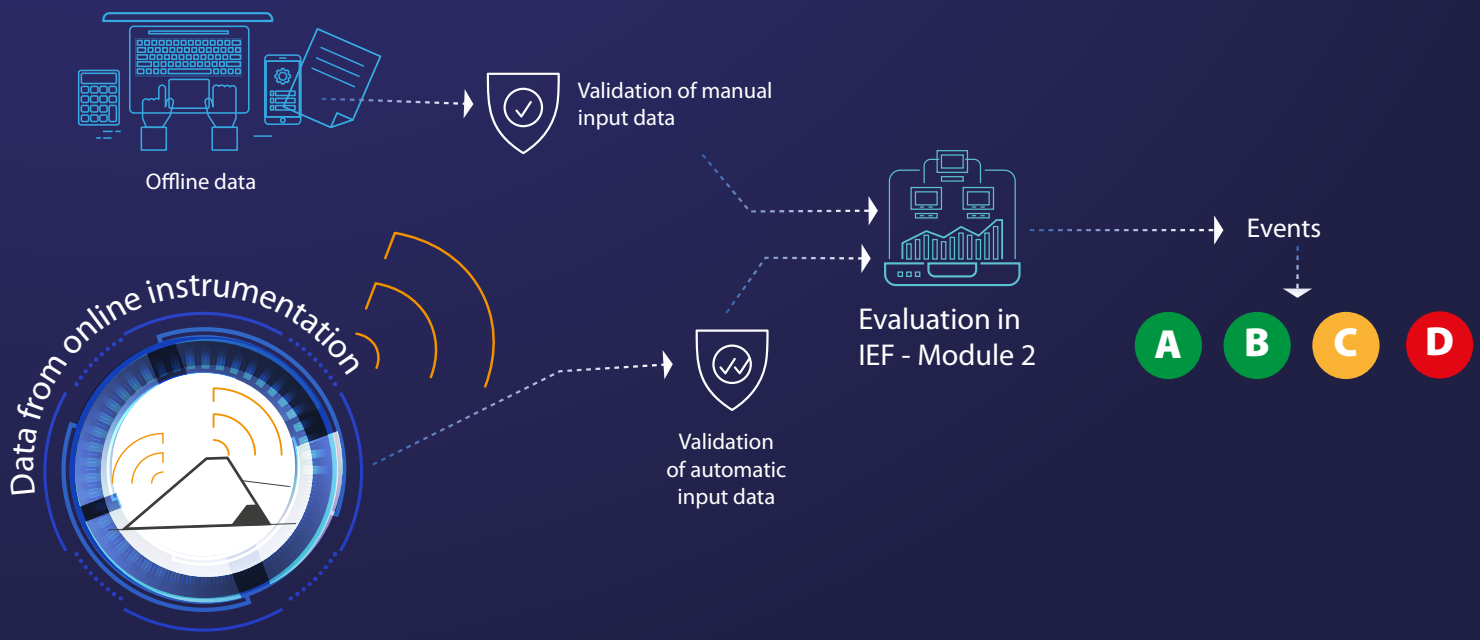
Table 2.Critical Parameters

Categories	Description	Critical Parameters	Unit	Frequency	Precision	Instrumental density
Operability of the drainage system	Parameters related to monitoring the integrity of the drainage system	Compliance with the design characteristics of the drainage system	-	Documentation associated with the design and construction period	- -	-
		Integrity of the drainage system	[m.a.s.l.] [L/h]	Piezometers: 1 hour Flowmeter: 1 hour	0,1 10	Piezometers: As required by design / Flowmeter: 2 instruments at the exit of each drain
		Turbidity of the drainage system	[NTU]	Turbidimeter: 1 hr Visual inspection: Daily	10	Turbidimeter: At the exit of each drain

2. Data verification

The monitored critical parameters, using either automatic instrumentation or manual tools, are verified before entering the assessment process in M2. The first validation is the physical meaning of the parameters. For instance, the piezometric head cannot be lower than the piezometer installation elevation. The spreadsheets used for manually-input data are also validated. Finally, the M2 constantly verifies instrumental failures and problems with the data. Figure 5 shows the data collection and verification process in M2.

FIGURE 5.
M2: Data collection and verification process



3. Verification of Failure Scenarios

Module 2 also verifies the activation of conditions that can configure failure scenarios, which are the most common combinations of critical parameter values and the occurrence of trigger events that can lead to a TSF failure. The standard defines a total of 12 failure scenarios based on the analysis of the most common features of historical failures reported in the literature, as shown Table 3.

Table 3. Failure scenarios[2] included in M2

Failure Scenario	Name	Description
SI-01	Instability due to an earthquake and adverse effects	Occurrence of a perceptible seismic event combined with an increase in pore water pressures and evidence of leaks or cracks in the dam after the seismic event.
SI-02	Instability due to increased pore water pressure with evidence of deformation	Detection of an increase in pore water pressure combined with evidence of dam deformation.
SI-03	Instability due to static liquefaction	Condition of the dam given by the detection of an internal layer with low in-situ density and a high pore water pressure, such that the minimum factors of safety are not met in a stability analysis in undrained condition.
SI-04	Instability due to cyclic mobility	Condition of the dam given by the detection of an internal layer with low in-situ density and a high pore water pressure combined with the occurrence of an earthquake.
SI-05	Instability due to loss of abutment integrity	Detection of problems in the abutments integrity due to cracks, leaks or displacements, combined with a reduced distance from the pool to the dam, high pore pressure or generalized leaks in the same sector.
SI-06	Instability due to sliding in the dam	Occurrence of a shallow landslide in the sector of the dam combined with the formation of cracks in the same sector and at least the detection of high pore water pressure, the presence of leaks, or a reduced distance from the pool to the dam.
IE-01	Internal erosion due to uncontrolled leaks	Evidence of leaks in the dam combined with high pore water pressure, turbidity in the drainage system, presence of cracks, or a reduced distance from the pool to the dam.
IE-02	Internal erosion due to subsidence in the dam tray	Evidence of a sinkhole or subsidence in the pond near the dam, combined with a reduced distance from the pool to the dam (activation of this scenario requires manual confirmation).
IE-03	Internal erosion due to subsidence in the dam	Evidence of subsidence or a sinkhole in the dam, combined with high pore water pressure, turbidity in the drainage system, presence of cracks, or a reduced distance from the pool to the dam.
OV-01	Overtopping due to loss of hydraulic freeboard during heavy rain	Occurrence of an intense rainfall that the Overtopping Potential evaluates as a trigger of overtopping if the rain develops according to the forecast. This scenario is activated if the time that remains until the overtopping occurs is shorter than or equal to the evacuation time of the closest town to the tailings facility.
OV-02	Overtopping due to a landslide-induced wave	Detection of a sector of the natural terrain with a high probability of generating a landslide over the pond, combined with a hydraulic freeboard close to the threshold.
OV-03	Overtopping of the tailings due liquefaction of the pond (Applicable for thickened tailings deposits)	Detection of a beach slope larger than that indicated by design, combined with a high phreatic surface in the pond and a volume of stored tailings larger than the maximum capacity of the pond if the tailings were stored horizontally.

2. SI= Slope instability IE=Internal erosion OV= Overtopping
In Appendix 2, a detailed description of the conditions associated with the critical parameters and the failure scenarios is included, see www.fch.cl/proyecto/sustentabilidad/tranque/

The definition of the IEF is general and applies to conventional, thickened, and paste tailings facilities. For the correct implementation of the standard, each TSF must go through an implementation process, the result of which defines the number of critical parameters to be monitored, the acceptability thresholds, the initial configuration data, and the failure mechanisms that must be considered. For instance, the critical parameter "minimum distance between the dam and the pool" is not measured in a dam built with borrow material that was designed to operate with the pool in direct contact with it.

The Transparent Tailings Initiative recommends that the IEF implementation process is led by a competent person, such as an engineer of record (EoR).

4. EVENTS AND ALERTS

The IEF can activate events and alerts associated with specific situations related to the results of the critical parameters monitoring and the evaluation of failure scenarios.

An event is defined as the fulfillment of a specific condition within the TSF, that may but does not necessarily affect its physical stability. Meanwhile, alert is defined as a situation of the TSF that does significantly affect the physical stability of the TSF.

The possible events that may occur are classified into seven types (Figure 6):

1. Medium or high physical vulnerability score (M1)
2. Occurrence of trigger events, deviations from design or climatic events (forecasts) (M1)
3. Situations of exceedances associated with critical parameters (M2)
4. Failure scenarios activation (M2)
5. Online instrumentation problems (M2)
6. Delays in uploading information associated with manual monitoring (M1 and M2)

FIGURE 6.
Events types associated to M1 and M2

The physical stability alert types considered in the standard are:

Early preventive alert : This alert represents a normal functioning of the tailings facility, which is permanently monitoring the critical parameters.

Yellow alert : This alert corresponds to an abnormal condition of the tailings facility that requires an intensification of monitoring, inspection and control from both mining company and authority.

Red alert : This alert is associated with a critical physical condition of the tailings facility that requires the implementation of the emergency plan to evacuate the facility and the downstream communities.

Events are categorized into four groups, which can be either A, B, C or D, depending on the importance of the event on the TSF physical stability. Group C and D are related to the most critical situations. The way how an event is managed and its visibility to the stakeholders is mainly associated with the group to which the event belongs. The groups of events are defined as follows (Figure 7):

Group A: Events that the mining company can manage internally. Upon activation, the visibility of the event will only be available for the mining company.

Group B: events that the mining company manages in coordination with the authority (the Chilean National Geology and Mining Service, SERNAGEOMIN). Upon activation, the visibility of the event will only be available for the mining company and the authority. This group may activate a yellow alert on the public website if the authority so requires.

Group C: Group of events that the mining company and the authority manage together (i.e. the mining company action plan is validated by the authority). Upon activation, the visibility of the event will be available for mining company, the authority and directly activates a yellow alert on the public website.

Group D: Group of events that the mining company and the authority manage together. Upon activation, the visibility of the event will be available for the mining company, and the authority. This group directly activates a Red Alert on the public website.

A detailed description of all yellow and red alerts associated to critical parameters and failure scenarios are presented in Table 4.

FIGURE 7.
Visibility and external communication of events and alerts

Table 4. Events associated to critical parameters that lead to yellow and red alerts

Critical Parameters	Yellow alert	Red alert
Distance between the dam and the pool	Pool in contact with the dam	Does not activate red alerts
Deformation of the foundation soil	Measured value is larger than the threshold set for deformation on the X or Y axis (Inclinometer)	Does not activate red alerts
Deformation of the dam	Measured strain value is larger than the threshold set for deformation on the X and Y axes, and also for settlements on the Z axis (monolith) Measured value is larger than the threshold set for deformation on the X or Y axis (Inclinometer)	Does not activate red alerts
Crown deformation	Measured strain value is larger than the threshold set for deformation on the X and Y axes, and also for settlements on the Z axis (monolith)	Does not activate red alerts
Cracks	It is determined that the cracks detected threaten the integrity of the dam. Cracks are detected after a seismic event and it is determined that they threaten the integrity of the dam Longitudinal cracks are detected after a section of the dam slides and threatens the integrity of the dam.	Does not activate red alerts
Humidity or leaks	It is determined that leaks or humidity threaten the integrity of the dam Leaks or humidity are detected after a seismic event and threaten the integrity of the dam.	Does not activate red alerts
Subsidence or sinkholes	It is determined that the event of subsidence or sinkhole threaten the integrity of the dam Sinkhole or subsidence are detected after a seismic event and risk the integrity of the dam	Does not activate red alerts
Abutment integrity	High deformations are detected in the abutment and uncontrolled seepage	Only if a relative displacement is detected between the dam and the foundation soil (Manual activation event)
Operational Freeboard	Operational freeboard exceeding the threshold value, so the stability criteria for the upstream slope are not fulfilled	Does not activate red alerts

Table 4. Events associated to critical parameters that lead to yellow and red alerts

Critical Parameters	Yellow alert	Red alert
Pore water pressures (dam and foundation soil)	If a piezometer exceeds the second threshold and a piezometer with which it is validated exceeds the first threshold. If two piezometers, validatable with each other, exceed the first threshold and: • A piezometer in the same sector, but in a different location exceeds the first threshold. • A piezometer in the same sector, but in a different location exceeds the second threshold. • Two piezometers in the same sector, but in different locations exceed the first threshold. • A piezometer in the same sector, but in a different location exceeds the second threshold and its validator exceeds the first threshold. • If two piezometers, validatable with each other, one exceeds the first threshold and the other exceeds the second threshold and at the same time a piezometer in the same sector, but in a different location exceeds the second threshold and its validator exceeds the first threshold. • If a piezometer, manually validatable, exceeds the first threshold and at least one piezometer in the same sector, but in a different location exceeds the first (independent if it is manually validated later) or second threshold. • If two piezometers, validatable with each other, one exceeding the first threshold is manually validated and the other exceeds the second threshold.	• If two piezometers, validatable with each other, exceed the second threshold. • If a piezometer, manually validatable, exceeds the second threshold
Seismic acceleration	Does not activate yellow alerts	• Maximum acceleration measured in rock exceeds the pre-defined threshold value • Maximum acceleration measured in the foundation soil exceeds the pre-defined threshold value • Maximum acceleration measured in the crown of the wall exceeds the pre-defined threshold value
Integrity of the drainage system	If the pore pressure in the drain exceeds a threshold in two piezometers that are validatable with each other or with one that is manually verified.	Does not activate red alerts
Turbidity of the drainage system	If granular material is detected in the drainage system and the turbidity value exceeds the threshold for a pre-defined time span.	Does not activate red alerts
Shear stiffness and strength of the dam	If a specialist engineer (e.g., EoR) detects that the strength and stiffness of the materials are incompatible with design specifications and if no actions are taken to correct the problem in a pre-defined time span. If SPT test results indicate the existence of a zone that does not meet the density criteria specified by the design and this threatens the stability of the deposit	If low density areas are detected in the dam in combination with high water levels or high saturation level in the affected area

The following figures show examples of failure scenarios, each of them consisting of events associated with Modules 1 and 2 of the IEF (the details of each event are explained in the Appendix of this report).

Failure scenarios are met when the events are activated. Some scenarios require that the events are activated in the same sector. Otherwise, the failure scenario does not activate.

The use of the "and" symbol indicates that the events must be fulfilled at the same time, whereas the use of the "or" symbol indicates that it is sufficient that at least one of the events is fulfilled to activate the failure scenario.

FIGURE 8. Example Failure Scenario T-02: **"Instability due to increased pore pressure with evidence of deformation"**

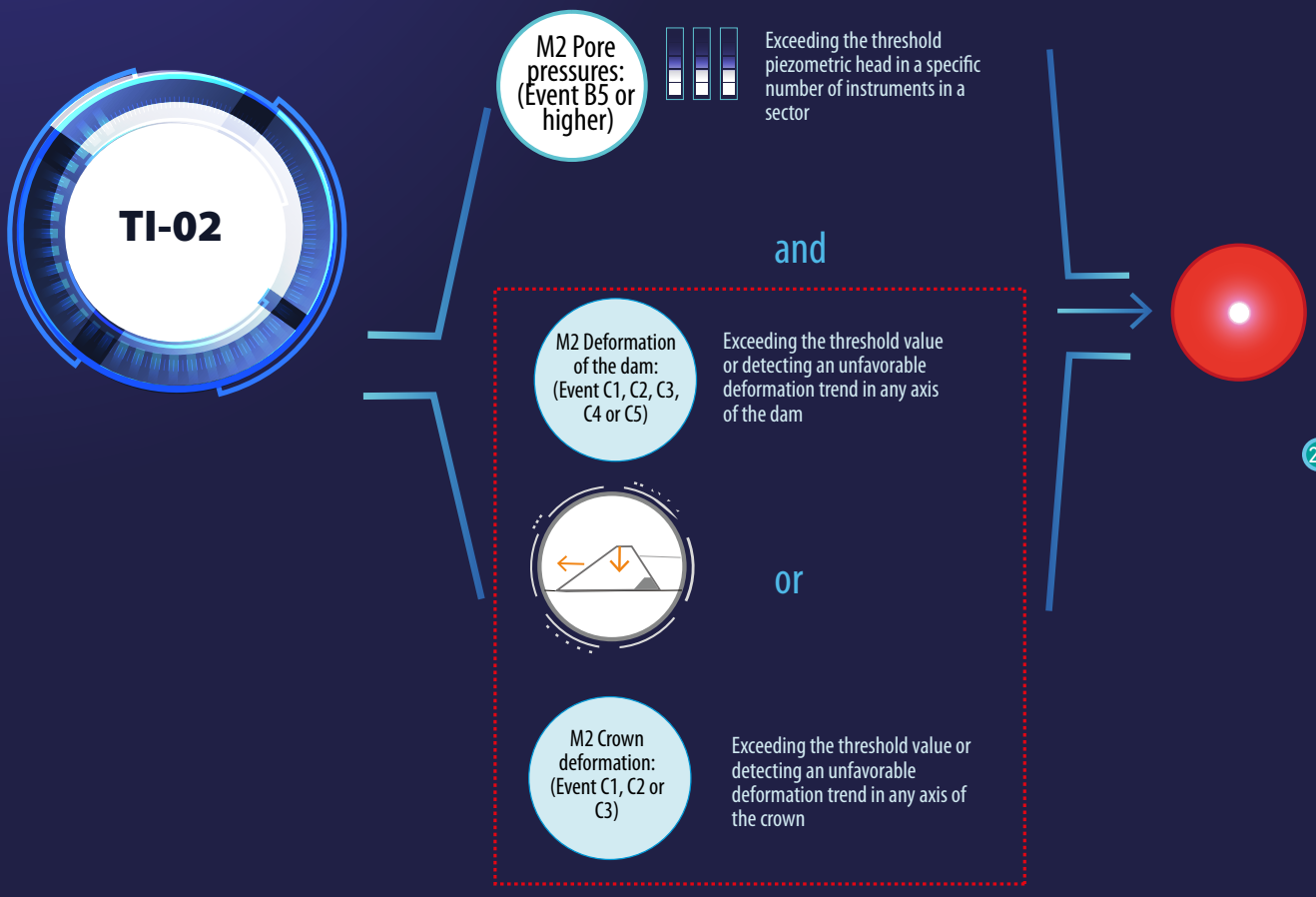


FIGURE 9. Example Failure Scenario Re-02: **"Overtopping by wave due to sliding"**

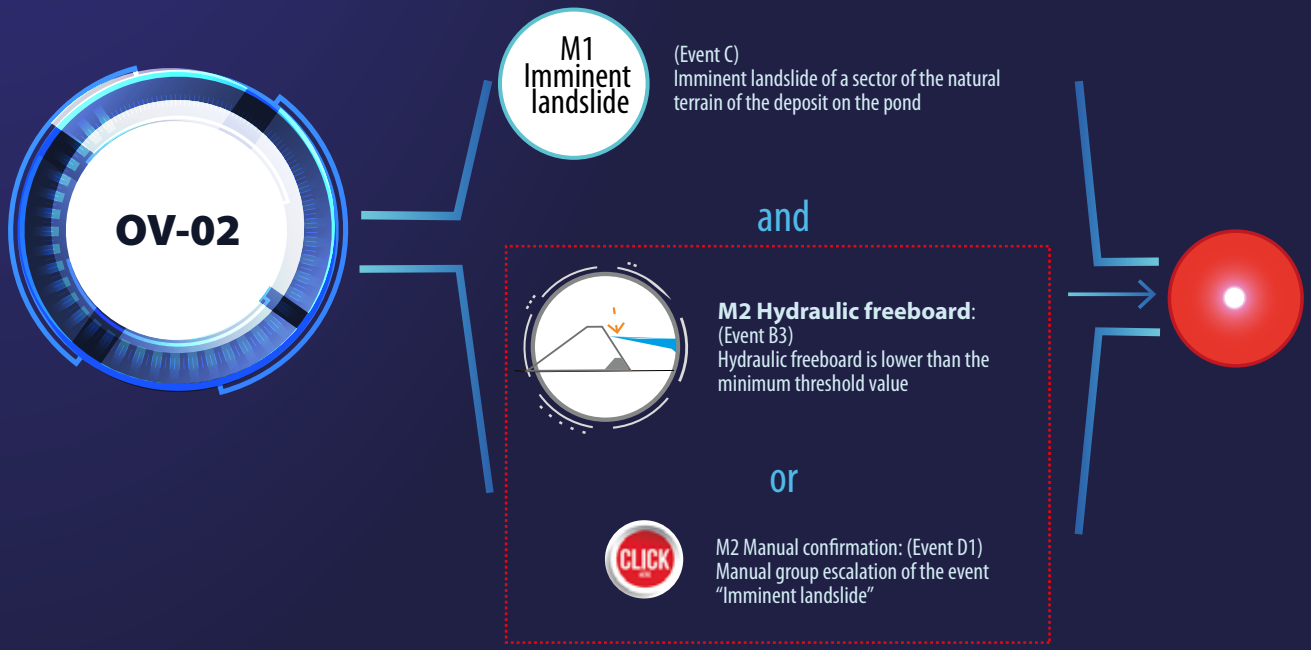
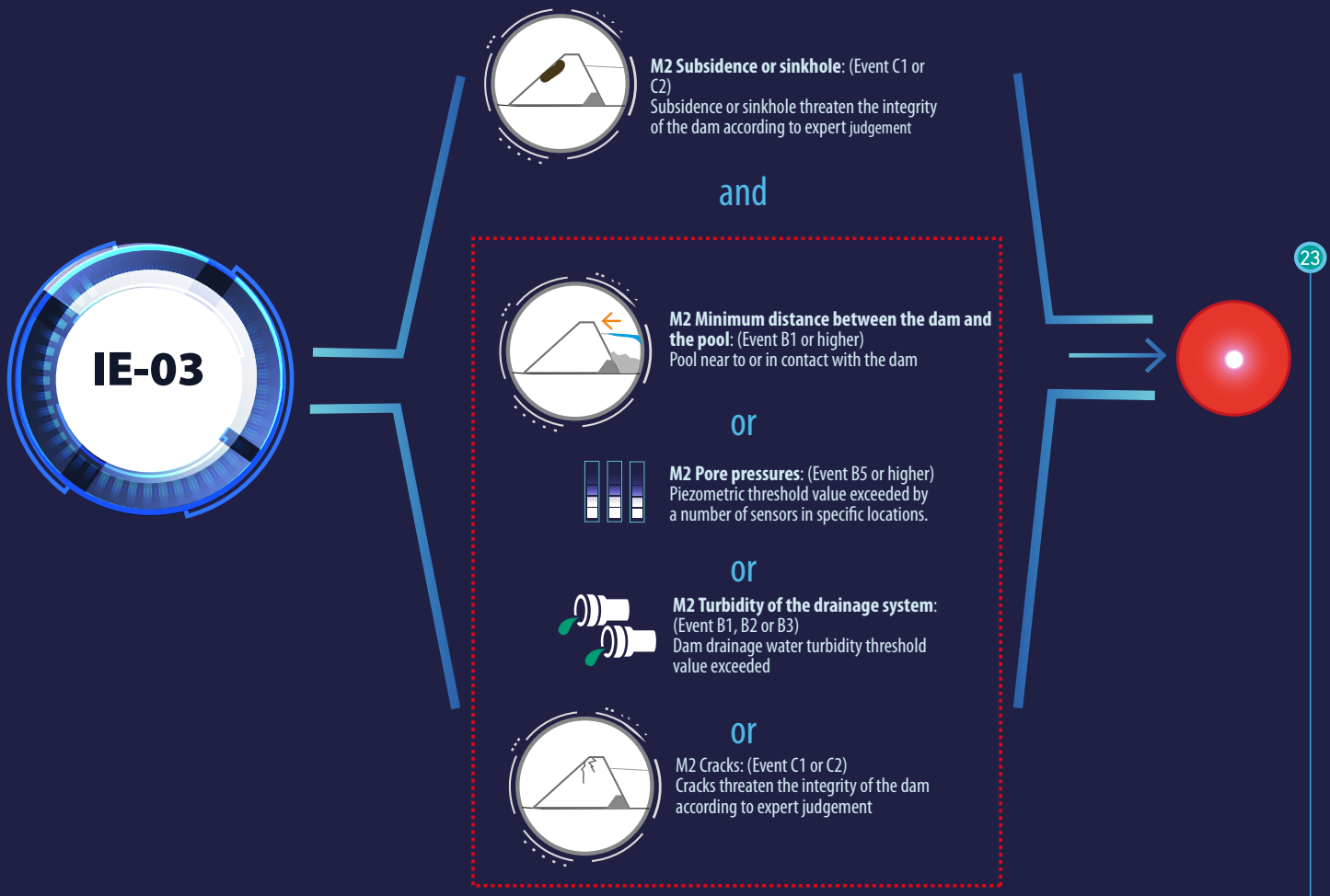


FIGURE 10. Example Failure EI-03: **"Internal erosion resulting from the appearance of subsidence in the dam"**



5. MANAGEMENT SYSTEM FOR EVENTS AND ALERTS

The activation of events allows managing any deviation in the normal functioning of the TSF. The management process considers three states:

- **To be managed**: Initial status of an event that occurred within the calculation of the IEF during data update, either in M1 or M2. This status alerts the operator that an event occurred and that it is required to verify the event and generate an action plan.
- **Being managed**: Status of the event once the operator accesses the activated event, confirming that the is aware of the recommendations and indicating the action plan and the measures that must be taken to resolve the event. An event under management will remain in this status as long as the detected problem is unsolved. The operator must verify the event periodically, and in some cases, he may scale-up the event, depending on the conditions. When scaling-up an event, the event group changes and thus can change the visibility of the event and the communication of the associated alert.
- **Closed**: Status of the event once the operator indicates that the event was solved or controlled within the operation. To close an event, a number of conditions associated with the parameters that triggered the event must be met (e.g., the instrumentation should return to record values between the thresholds, and the operator should ensure that the trigger events and deviations were solved).

A similar approach is followed to manage the alerts.

- **To be managed**: Initial state of an alert, activated when the conditions for activating an alert either yellow or red are met. In this status, the Authority must identify the events that triggered the alert and define an action plan for communication to the communities and management of the situation.
- **Being managed**: Alert status where the authority is managing the current situation, supervising the closure of the events associated with the alert and maintaining active communication with the responsible mining company. The authority can scale the alert if it is deemed necessary to a red alert. During the management of the alert, the authority may maintain an active communication to the general public, both through the monitoring platform and alternative communication media.
- **Closed**: The closure of an alert is the exclusive right to the Authority and can only be applied when all events associated with the alert were closed within the interface. Once an alert is closed, a record of the associated events and the adopted action plan by the authority is generated.

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Monitoreo de avanzada para una minería responsable

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The Transparent Tailings Initiative is aimed to contribute to the safe management of the tailings storage facilities (TSF) existing in the country, improving the coordination and trust relationships among the different parties involved, by putting in place a state-of-the-art monitoring system that lasts over time.

The standard contained in this document is a contribution towards taking the TSF management to its highest standard and turning Chile into a world leader in these matters. This work was made possible only by the collaboration and efforts deployed by many professionals we would like to acknowledge:

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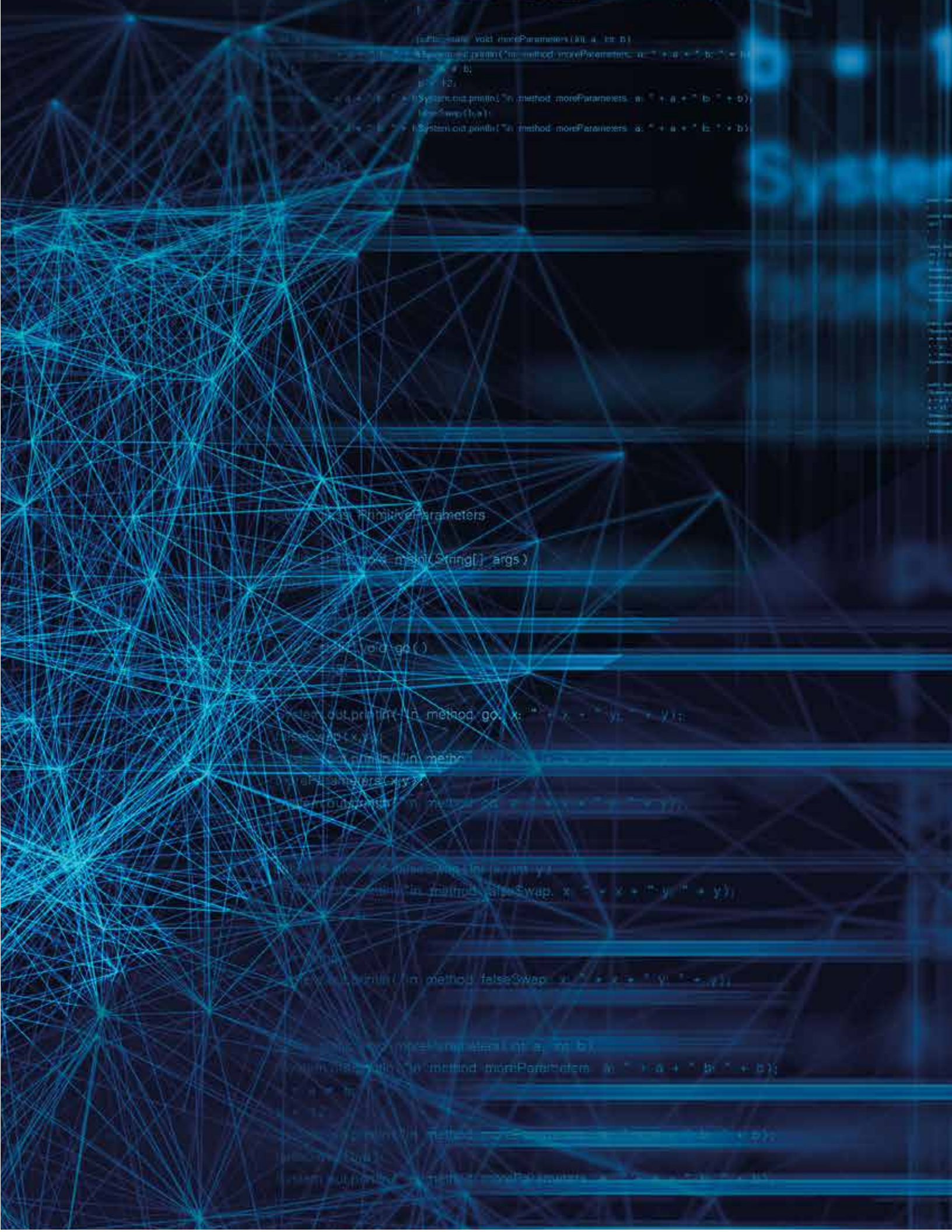
(*) As of the date of this publication, these professionals no longer worked for these institutions.