AURUS MINING

Built for the New Climate

Resilience for mines, corridors, ports, power and water systems

WP10 | DESIGN

MINING | INFRASTRUCTURE | ENGINEERING | ENVIRONMENT

OUR POSITION

Physical climate evidence can be converted into an explicit design basis, then tested through stress scenarios and adaptation pathways, so that mines and enabling infrastructure make controlled investment decisions under uncertainty and disclosure expectations.

EVIDENCE FIRST | DECISIONS MADE EXPLICIT | DELIVERY CONDITIONS STATED

Contents

Executive summary

Climate now enters engineering and investment discussions through both hazard evidence and disclosure frameworks. TCFD formalised physical risk categories as acute event driven hazards and chronic shifts, and IFRS S2 carries the same structure into a global baseline standard that requires climate scenario analysis of resilience, while noting that adoption is jurisdiction by jurisdiction. For mining and enabling infrastructure, this changes what “reasonable” looks like for a design basis because the design needs an auditable link from climate evidence to loads, levels and operating envelopes, more than narrative risk registers.

Sources: WP10-10, WP10-08, WP10-09

The physical signal relevant to design is not abstract. IPCC AR6 reports that heavy precipitation has likely increased over a majority of land regions and that annual maximum one day precipitation tends to intensify at roughly 7 percent per 1 °C of warming, with model projections giving a 4 to 8 percent per °C range for precipitation extremes. Sea level rise adds a different profile of risk, with AR6 likely ranges by 2100 of 0.28 to 0.55 m under SSP1 1.9 and 0.63 to 1.01 m under SSP5 8.5, while near term rise through 2050 is relatively similar across scenarios.

Sources: WP10-02, WP10-01, WP10-05

Engineering practice has clear failure modes when it assumes stationarity. Peer reviewed work cited in this dossier shows that stationary assumptions in intensity duration frequency design can underestimate extreme precipitation by as much as 60 percent, which is material for flood capacity and failure risk in infrastructure. On the operations side, the exposure is already visible in attributed reporting, such as the 2010 to 2011 Queensland floods where inquiry and trade sources report around 15 percent of annual coal output was cut and at least US$1 billion in lost production, with force majeure declarations. These are not forecasts, but they show the cost of untested assumptions.

Sources: WP10-12, WP10-19

A practical route exists because industry bodies and lenders already publish stepwise methods and assurance expectations. ICMM sets out a stepwise process to integrate climate considerations into existing risk management, and the Mining Association of Canada publishes a sector guide on climate change adaptation. Where projects are lender exposed, IFC Performance Standard 1 requires a management system responsive to changing conditions, and EP4 requires a climate change risk assessment for Category A projects and for projects above a Scope 1 plus 2 threshold, aligned to TCFD physical and transition categories. The design task is to connect these instruments to a traceable design basis, stress tests and staged investments.

Sources: WP10-06, WP10-07, WP10-21, WP10-22

At a glance

Six evidence markers establish the scale, threshold or decision condition carried into the chapters that follow.

~7% per 1 °C

SCALING OF ANNUAL MAXIMUM 1 DAY PRECIPITATION INTENSIFICATION (CLAUSIUS CLAPEYR

Source: WP10-01

0.18 to 0.23 m

LIKELY GLOBAL MEAN SEA LEVEL RISE BY 2050 ACROSS SCENARIOS (RELATIVE TO 1995 TO

Source: WP10-05

16%

CRITICAL MINERAL MINES, DEPOSITS AND DISTRICTS ON LAND IN HIGH OR EXTREMELY HIGH

Source: WP10-11

Up to 60%

POSSIBLE UNDERESTIMATION OF EXTREME PRECIPITATION WHEN IDF DESIGN ASSUMES STATIO

Source: WP10-12

~1:10,000 AEP

TYPICAL AEP ASSOCIATED WITH PMF DESIGN FOR HIGH HAZARD OR EXTREME CONSEQUENCE DA

Source: WP10-18

1 Jan 2024

IFRS S2 EFFECTIVE DATE FOR ANNUAL REPORTING PERIODS BEGINNING ON OR AFTER THIS D

Source: WP10-08

Method and boundaries

This paper is a bounded synthesis of registered public evidence. Source identifiers remain visible so that each quantitative or framework statement can be traced to its dossier row.

INTENDED READERS

- Mine owners and operators
- Project directors and engineering managers
- Rail, road and port corridor authorities and operators (public or private)

READING METHOD

- Read each chapter opener as a decision frame.
- Use the three section exhibits as working review instruments.
- Return to the evidence ledger before reusing any number or requirement.

BOUNDARIES

- This paper uses only evidence rows registered in the WP-10 dossier and does not claim any delivered climate-resilience engagement. [WP10-06]
- IPCC AR6 scenario, warming and sea level figures are 2021 values and should be checked against the latest IPCC cycle at point of use. [WP10-04][WP10-05]
- IFRS S2 effective date is the standard's own; jurisdictional adoption is not universal and must be confirmed for the reporting entity. [WP10-08]
- Queensland flood impacts are attributed to inquiry and trade reporting and are presented as contextual evidence, not as predictive forecasts. [WP10-19]
- CDP mining disclosure figures are disclosure based and dated; they should not be treated as project level benefit guarantees. [WP10-20]
- The Central African worked example is explicitly illustrative and built only from public sources cited in this dossier. [WP10-15][WP10-11]

PUBLICATION DISCIPLINE

- No client identity or company-age claim is published.
- No Aurus delivery result is inferred from public guidance.
- Dated forecasts retain their institution and vintage.

01

DESIGN BASIS

Climate enters the design basis

Turn climate evidence and disclosure expectations into explicit design criteria and acceptance tests.

Acute and chronic

PHYSICAL RISK CATEGORIES USED TO STRUCTURE DESIGN QUESTIONS AND RESILIENCE TESTS | WP10-10

Scenario analysis

REQUIRED BY IFRS S2 AS PART OF RESILIENCE DISCLOSURE, WITH JURISDICTIONAL ADOPT | WP10-08

0.18 to 0.23 m

SEA LEVEL RISE THROUGH 2050 SITS IN A NARROW BAND ACROSS SCENARIOS, SHAPING NEAR | WP10-05

1.1 From risk statements to engineered requirements

A design basis is the contract between evidence and asset behaviour. Climate enters that contract when the project needs to show which hazards were considered, how they were quantified, and which performance states were selected for design, operations and emergency response. TCFD’s physical risk taxonomy is useful because it separates acute event driven hazards such as floods, storms and heatwaves from chronic shifts such as sea level rise and mean temperature change. That separation prevents a common error where long term trends are logged as generic “medium risks” instead of being converted into specific load cases, freeboard allowances, derating curves and operational thresholds.

WP10-10

Disclosure frameworks now reinforce this engineering discipline. IFRS S2 was issued in June 2023 and is effective for annual reporting periods beginning on or after 1 January 2024, while adoption is jurisdiction by jurisdiction rather than a universal legal mandate. The standard integrates and builds on TCFD and requires climate scenario analysis to describe resilience. In practice, this pushes engineering teams to preserve traceability, including what scenarios were used, why they were selected, and how they affected design decisions. It also creates a governance question: who signs off the translation from climate evidence to design loads.

WP10-08, WP10-09

DECISION INSTRUMENT

Design basis translation gate

Decision instrument to turn climate risk categories into explicit design requirements and acceptance criteria.

TEST	EVIDENCE READING	DECISION RESPONSE
Trigger	Acute hazards and chronic shifts identified using the TCFD physical risk categories.	List the specific engineering variables affected, such as flood level, rainfall intensity, wind load, temperature envelope, sea level datum.
Design variables	Each variable is mapped to a design criterion or operational limit that can be tested.	Assign a responsible discipline, calculation method, and a verification test or commissioning check.
Sign off	Scenario analysis is needed for resilience disclosure under IFRS S2, subject to jurisdictional adoption.	Approve a documented link from scenarios to design criteria, with review and update triggers.
Update cadence	Near term sea level rise to 2050 is in a narrow likely range across scenarios.	Set near term allowances and a review point for later century divergence.

Sources: WP10-10, WP10-08, WP10-05

1.2 Selecting performance levels and consequence classes

Engineering already contains climate sensitive performance conventions that can anchor decisions. For high hazard or extreme consequence dams, including tailings dams, dam safety literature and ANCOLD guidance describe design to safely pass the Probable Maximum Flood, typically associated with an annual exceedance probability of about 1:10,000 or rarer. The inflow design flood is selected through consequence classification, and at closure ANCOLD requires PMF and maximum credible earthquake design for consequence classified tailings dams. The point for broader mine infrastructure is not to apply PMF everywhere, but to make the chosen performance level explicit, consequence based and documented.

WP10-18

The engineering decision should also recognise where climate drivers change the hazard distribution itself. IPCC AR6 states that heavy precipitation has likely increased at the global scale over a majority of land regions and attributes this mainly to human greenhouse gas emissions. For drainage networks, water management ponds and downstream interfaces, that attribution supports a design posture that treats past extremes as a lower bound rather than a fixed reference. Where consequence is high, the design discussion should explicitly compare stationary and nonstationary methods and state which method is used for capacity and overtopping checks.

WP10-02, WP10-12

DECISION INSTRUMENT

Consequence led performance selection

Decision instrument to align consequence classification with performance targets and climate sensitivity.

TEST	EVIDENCE READING	DECISION RESPONSE
Asset element	Identify elements where failure has high hazard or extreme consequence profiles.	Assign a consequence class and record the rationale and downstream receptors.
Performance target	High hazard dams commonly adopt PMF passability, about 1:10,000 AEP or rarer, via consequence classification.	Select and document the design flood and acceptance criteria for the chosen class.
Climate sensitivity check	Heavy precipitation has likely increased over a majority of land regions, with documented nonstationarity concerns in IDF design.	State whether stationary assumptions are acceptable; if not, specify an update method and review trigger.
Closure and life of asset	ANCOLD notes closure design expectations for consequence classified tailings dams.	Record life stage requirements and how the design basis changes at closure.

Sources: WP10-18, WP10-02, WP10-12

1.3 Materiality and governance for engineered resilience

Materiality enters through both hazard costs and governance obligations. WMO reports 11,778 recorded disasters from weather, climate and water extremes over 1970 to 2021, with over 2 million deaths and US$4.3 trillion in economic losses, and a sevenfold rise in losses from the 1970s to the 2010s in per day terms. A mine corridor can translate a single event into a multi week logistics shock, and the cost may fall across parties. For governance, the shift is to treat resilience not as an optional add on, but as part of the design and operating model that can be audited.

WP10-14

Disclosure can supply additional discipline on how investment claims are tested. CDP's disclosure analysis reports that about half of mining sector companies disclosed climate risks and opportunities, that the median return on physical climate risk spending was about US$10 per US$1, and that disclosing companies reported US$30.6 billion in materialised risks in the reporting year. This is dated and disclosure based rather than a causal engineering study, but it signals what boards and finance teams may expect: scenario framed quantification, and a value at risk lens on physical impacts. Engineering inputs need to be structured so they can feed these statements without overreach.

WP10-20

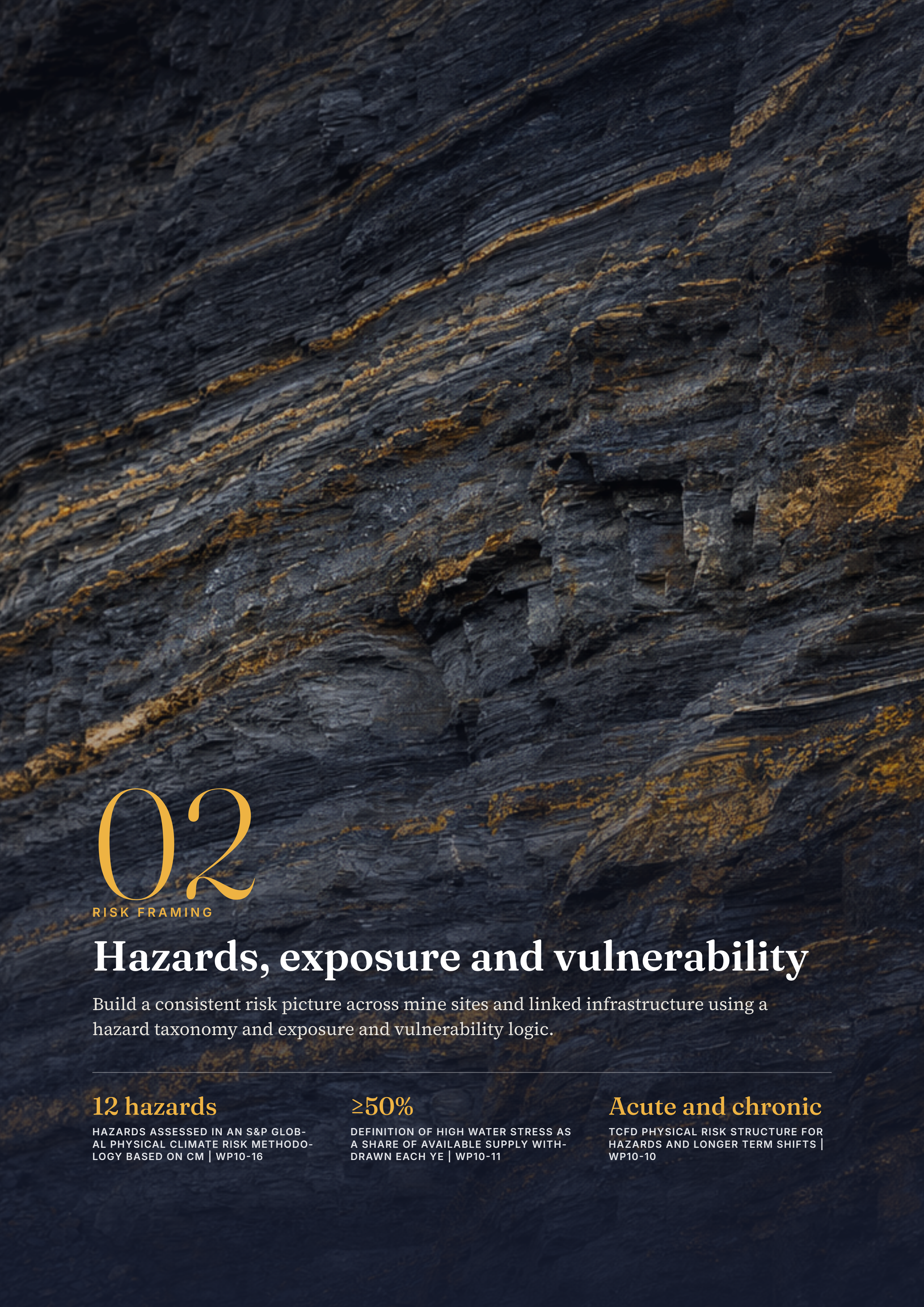
DECISION INSTRUMENT

Resilience governance and materiality gate

Decision instrument to connect engineered resilience decisions to governance and disclosure expectations without overstating certainty.

TEST	EVIDENCE READING	DECISION RESPONSE
Materiality screen	WMO documents large historical losses from weather, climate and water extremes.	Identify which failure modes could create material outages, safety risks, or third party impacts.
Disclosure posture	IFRS S2 requires scenario analysis of resilience, with adoption jurisdiction by jurisdiction; CDP disclosures show VaR style framing is increasing in mining.	Define what the project will disclose and what will remain engineering working material.
Evidence control	Disclosure figures are secondary and dated; engineering calculations need clear provenance.	Create a traceable evidence register linking each key claim to a source, method and reviewer.
Board level sign off	TCFD structure underpins IFRS S2 governance and strategy pillars.	Assign accountable signatories for design basis, scenario selection and update triggers.

Sources: WP10-14, WP10-08, WP10-20, WP10-09



02

RISK FRAMING

Hazards, exposure and vulnerability

Build a consistent risk picture across mine sites and linked infrastructure using a hazard taxonomy and exposure and vulnerability logic.

12 hazards

HAZARDS ASSESSED IN AN S&P GLOBAL PHYSICAL CLIMATE RISK METHODOLOGY BASED ON CM | WP10-16

≥50%

DEFINITION OF HIGH WATER STRESS AS A SHARE OF AVAILABLE SUPPLY WITHDRAWN EACH YE | WP10-11

Acute and chronic

TCFD PHYSICAL RISK STRUCTURE FOR HAZARDS AND LONGER TERM SHIFTS | WP10-10

2.1 A hazard library that engineers can use

Hazard lists often fail because they are either too short to drive design or too long to drive action. One way to keep the list engineering ready is to adopt a hazard library that is already aligned to climate model outputs and that covers both flooding and heat and water constraints. S&P Global describes a physical climate risk methodology that uses CMIP6 and assesses twelve hazards including coastal, fluvial and pluvial flood, drought, water stress, extreme heat and heat stress, tropical cyclone, wildfire, subsidence and landslide. The exact tool is not the point here. The value is a bounded set of hazard types that can be mapped to asset elements and design checks.

WP10-16

Within that library, category language matters because it changes the proof burden. TCFD distinguishes acute risks, which are event driven, from chronic risks, which are longer term shifts such as sea level rise and mean temperature rise. When engineers adopt this split, they can define different evidence and modelling approaches. Acute hazards typically drive capacity and stability checks and emergency response triggers. Chronic hazards tend to drive design allowances, equipment derating, corrosion and fatigue regimes, and land use constraints. Using a single register but two evidence tracks avoids mixing event statistics with trend projections in a way that hides decision critical assumptions.

WP10-10

DECISION INSTRUMENT

Hazard library to asset mapping

Decision instrument for creating an engineering ready hazard register across a mine and its corridors.

TEST	EVIDENCE READING	DECISION RESPONSE
Hazard set	Adopt a bounded set of hazards that includes flood, heat and water constraints.	Select hazard types relevant to the asset portfolio and document inclusions and exclusions.
Acute versus chronic	TCFD separates event driven hazards from longer term shifts.	Assign each hazard to acute or chronic, or both, and state the evidence track used.
Asset mapping	S&P Global list covers flood, water stress, heat and slope related hazards.	Map hazards to asset elements and to the design checks that will test them.
Control owners	Each mapped hazard implies monitoring and response needs.	Assign an owner for design updates and for operational controls.

Sources: WP10-16, WP10-10

2.2 Exposure and the corridor problem

A mine is rarely a single site risk. The exposure extends across corridors, ports, power and water systems, and the interfaces between owners. Attributed reporting on the 2010 to 2011 Queensland floods illustrates the corridor effect in a production system. Inquiry and trade sources report that the floods cut about 15 percent of the state's annual coal output and cost at least US$1 billion in lost production, with multiple force majeure declarations. The engineering lesson is not the number itself. It is that exposure should be traced as a network and that single point failures, such as a bridge, culvert, embankment, conveyor or substation, can dominate losses.

WP10-19

Exposure also includes water competition and shared basins. WRI Aqueduct reports that at least 16 percent of the world's critical mineral mines, deposits and districts on land sit in areas of high or extremely high baseline water stress, defined as at least 50 percent of available supply withdrawn each year, and that the high stress share could rise to 20 percent by 2050. This is a global screen, not a site prediction, but it supports an early design question: does the project depend on water sources in a stressed basin, and are there credible alternative supply and recycling options if allocations tighten or drought sequences extend.

WP10-11

DECISION INSTRUMENT

Network exposure trace

Decision instrument to describe exposure as a mine plus corridor system rather than isolated assets.

TEST	EVIDENCE READING	DECISION RESPONSE
System boundary	Production depends on mine, processing, logistics, port, power and water links.	Draw the boundary and list critical interfaces, including third party dependencies.
Single point failure check	Attributed Queensland flood reporting shows how floods can cascade into production loss and contractual disruption.	Identify components whose failure stops the system and flag them for higher performance targets.
Water exposure screen	WRI Aqueduct gives a global baseline water stress screen and a definition of high stress.	Run a basin level screen and decide if the project needs a higher confidence water balance and alternative supply options.
Ownership and control	Some elements may be outside the project's direct control.	Assign interface agreements and minimum design and maintenance standards for shared assets.

Sources: WP10-19, WP10-11

2.3 Vulnerability as performance degradation

Vulnerability is often described as an abstract score. Engineers can make it actionable by defining how hazards degrade performance and which failure modes follow. For extreme precipitation, IPCC AR6 provides a mechanism level expectation: annual maximum one day precipitation tends to intensify at roughly 7 percent per 1 °C of warming, with model projections giving a 4 to 8 percent per °C range for precipitation extremes. This can be turned into stress tests on drainage capacity, pond freeboard, slope stability and access reliability. The goal is not to compute a single “future rainfall”. It is to test how the system behaves under plausible increases relative to the observed baseline and to identify where performance margins are thin.

WP10-01

Vulnerability also arises from how design methods treat stationarity. Peer reviewed work in this dossier indicates that assuming a stationary climate in IDF design can underestimate extreme precipitation by as much as 60 percent, and points to nonstationary generalised extreme value methods used to update IDF curves. This is a method warning rather than a mandate. Projects should treat it as a prompt to ask whether the rainfall frequency analysis used in hydrology reports is fit for purpose under current design life and consequence levels. Where the answer is uncertain, the project can adopt staged measures that are compatible with later upgrades.

WP10-12

DECISION INSTRUMENT

Vulnerability to failure mode link

Decision instrument to convert hazard intensity changes and method choices into explicit failure modes and controls.

TEST	EVIDENCE READING	DECISION RESPONSE
Performance margin	Extreme precipitation tends to intensify with warming and has a model range.	Define which margins are critical and how much headroom exists in current design.
Method sensitivity	Stationary IDF methods can materially understate extremes; nonstationary methods exist.	Decide which method is required for each consequence level and document the rationale.
Failure modes	Drainage, freeboard, slope stability and access can fail under different pathways.	List credible failure modes and assign design or operational controls to each.
Upgrade compatibility	Some measures are hard to retrofit once built.	Prioritise early decisions that keep upgrade options open.

Sources: WP10-01, WP10-12

03

EVIDENCE CONTROL

Data and uncertainty

Choose climate and hydrology data that can be defended, then document uncertainty so it does not become hidden risk.

Five SSPs

AR6 CORE SCENARIO SET USED FOR SCENARIO ANALYSIS AND STRESS TESTS | WP10-04

~3.0 °C

AR6 EQUILIBRIUM CLIMATE SENSITIVITY BEST ESTIMATE, WITH A LIKELY RANGE OF 2.5 TO | WP10-03

0.28 to 0.55 m

LIKELY SEA LEVEL RISE BY 2100 UNDER SSP1 1.9 | WP10-05

3.1 Scenario choice that is auditable

Scenario analysis becomes useful when it is explicit about what is being varied and why. IPCC AR6 defines a core set of five SSPs spanning 1.9 to 8.5 W/m^2 of 2100 radiative forcing. These labels do not directly tell a designer what to build. They provide a disciplined way to test sensitivity and avoid anchoring on a single path. A project can select a small set of scenarios to cover low and high forcing and align them to decision horizons such as commissioning, midlife refurbishment and closure. The selection should be recorded as a decision, not a technical default, because it sets the stress envelope the design is expected to tolerate.

WP10-04

Climate uncertainty also sits under the scenarios. AR6 reports an equilibrium climate sensitivity best estimate of about 3.0 °C and a likely range of 2.5 to 4.0 °C, noting that raw CMIP6 models span a wider range and include a hot model issue. Engineers do not need to restate these debates. They need to recognise what the uncertainty implies for hazard translation, especially where non linear thresholds matter, such as heat stress limits or rainfall intensity scaling. For governance, IFRS S2 requires scenario analysis as part of resilience disclosure, so the project should document how scenario and model choices affect the design and which uncertainties are treated as design allowances versus monitored variables.

WP10-03, WP10-08

DECISION INSTRUMENT

Scenario selection record

Decision instrument to document which scenarios and models were used and how they map to design horizons and disclosure needs.

TEST	EVIDENCE READING	DECISION RESPONSE
Scenario set	AR6 core scenarios include five SSPs spanning low to high forcing.	Select scenarios that cover decision relevant tails and record the rationale.
Time horizons	Design and refurbishment decisions occur at different timescales.	Map each scenario to asset life stages and specify which stage each stress test targets.
Model and parameter uncertainty	AR6 narrows climate sensitivity but notes remaining uncertainty and model spread.	State how uncertainty is handled: allowances, conservative assumptions, or monitoring triggers.
Disclosure link	IFRS S2 requires scenario analysis of resilience.	Define what outputs are suitable for disclosure and how they will be reviewed.

Sources: WP10-04, WP10-03, WP10-08

3.2 Sea level and coastal boundary conditions

Ports, coastal roads and low lying rail alignments face a boundary condition that shifts over decades. IPCC AR6 provides likely global mean sea level rise ranges by 2100 of 0.28 to 0.55 m under SSP1 1.9 and 0.63 to 1.01 m under SSP5 8.5, relative to 1995 to 2014. Through 2050, the likely range is narrower across scenarios at 0.18 to 0.23 m. These statements do not replace local extreme sea level and storm surge studies, but they do give a defensible basis for near term allowances, datum selection and staged upgrades. They also justify separating near term design decisions from long term pathway decisions where scenarios diverge more strongly.

WP10-05

Coastal flooding is rarely only a sea level number. The design basis needs to specify which components are tied to mean sea level, which to extreme water levels, and which to compound events such as storm surge plus river flood plus rainfall runoff. Even where project teams use third party coastal studies, they can still preserve evidence control by documenting the scenario assumptions, the reference period and the confidence bounds. The objective is an auditable line from IPCC class evidence to the chosen allowances and protection levels. This supports consistency with a broader physical risk taxonomy and with disclosure requirements that ask for resilience under climate scenarios, not simply a statement that sea level rise was “considered”.

WP10-05, WP10-08, WP10-10

DECISION INSTRUMENT

Coastal boundary condition specification

Decision instrument to define which sea level values and related extremes control each coastal asset decision.

TEST	EVIDENCE READING	DECISION RESPONSE
Reference frame	AR6 sea level rise ranges are relative to 1995 to 2014 and diverge more after mid century.	Select reference periods, vertical datums, and review points aligned to asset life.
Allowances	Near term rise to 2050 sits within a narrow likely band across scenarios.	Set near term allowances and identify triggers for upgrading based on later divergence.
Compound events	Coastal flooding can combine sea level rise with storm surge and catchment flooding.	Specify which compound cases must be tested and where additional studies are required.
Disclosure trace	Scenario analysis of resilience is required by IFRS S2.	Prepare a traceable summary suitable for disclosure, with methods and limitations stated.

Sources: WP10-05, WP10-08

3.3 Hydrology data and nonstationarity controls

Hydrology studies often inherit assumptions that were reasonable when stationarity was a working premise. The evidence in this dossier highlights that assuming a stationary climate in IDF design can underestimate extreme precipitation by as much as 60 percent, and that nonstationary generalised extreme value approaches are used to update IDF curves. A project does not need to mandate a single method everywhere. It needs to define when nonstationary treatment is required, such as for assets with high consequence or long design life, and how the method will be reviewed. The engineering output should be a set of design storms and runoff cases with confidence bounds and a statement of method validity over the design horizon.

WP10-12

The uncertainty management task is to stop method choices from being invisible. Engineers should record which observational datasets were used, how gaps were treated, and what the statistical fitting choices were. Where external advisers provide the analysis, the project should still require a reproducible trail, because evidence control supports both safety and disclosure. This is consistent with a stepwise adaptation approach in mining industry guidance, which starts by understanding exposure and then assessing vulnerability and risk before prioritising options. It is also consistent with lender frameworks that require management systems responsive to changing conditions. A clear evidence trail makes later updates cheaper because the project can re run steps without rebuilding context.

WP10-12, WP10-06, WP10-21

DECISION INSTRUMENT

Nonstationary hydrology decision log

Decision instrument to determine where nonstationary IDF and related hydrology updates are required and how they are controlled.

TEST	EVIDENCE READING	DECISION RESPONSE
Applicability screen	Stationary IDF can understate extremes; nonstationary methods exist.	Classify assets by consequence and design life to decide where nonstationary treatment is required.
Dataset control	Hydrology outputs depend on observational records and gap handling.	Record datasets, periods, and quality controls in a reproducible log.
Method statement	Nonstationary GEV methods are used to update IDF curves.	Document the chosen method, parameters, and how uncertainty bounds are represented in design inputs.
Review trigger	Adaptation guidance is stepwise and iterative; lender frameworks expect responsiveness to changing conditions.	Set a schedule and trigger conditions for updating hydrology assumptions and design storms.

Sources: WP10-12, WP10-06, WP10-21

04

CORE ASSETS

Mine and plant systems

Apply climate driven load cases to mine water, geotechnical, processing and site access systems, with consequence led performance targets.

PMF passability

HIGH HAZARD OR EXTREME CONSEQUENCE DAMS TYPICALLY DESIGN FOR PMF, ABOUT 1:10,000 | WP10-18

4% to 8% per °C

MODEL RANGE FOR PRECIPITATION EXTREME INTENSIFICATION PER DEGREE OF WARMING | WP10-01

Water stress and ㅋ

S&P GLOBAL FINDING THAT WATER STRESS AND EXTREME HEAT CARRY THE HIGHEST FINANCIA | WP10-16

4.1 Mine water and containment systems

Mine water systems are the first line where precipitation change becomes an engineered load case. IPCC AR6 reports that precipitation extremes intensify with warming, and the scaling provides a defensible stress increment to test diversions, channels, ponds, pump capacity and freeboard. Where the consequence is high, dam safety practice provides a clearer anchor. ANCOLD and related dam safety literature describe that high hazard or extreme consequence dams, including tailings dams, are designed to safely pass the Probable Maximum Flood, typically about a 1:10,000 annual exceedance probability or rarer. Even for non dam elements, the same discipline applies: define consequence, choose performance level, then test the system under climate stress increments.

WP10-01, WP10-18

A common failure mode is allowing the hydrology method to set the design without checking fit under nonstationarity. The cited literature notes that stationary IDF assumptions can underestimate extreme precipitation by as much as 60 percent, which directly affects spillway sizing, diversion capacity and operational pond management. If nonstationary methods are adopted, they need to be tied to a scenario set and an update plan, not treated as a one off technical flourish. Industry guidance supports this iterative control. ICMM's stepwise approach emphasises understanding exposure, assessing vulnerability and risk, then prioritising and implementing options with monitoring and review. That loop maps well to mine water systems where operational data can validate assumptions and trigger upgrades.

WP10-12, WP10-06

DECISION INSTRUMENT

Mine water design case selection

Decision instrument to select design floods, operating rules and upgrade triggers for mine water systems under changing extremes.

TEST	EVIDENCE READING	DECISION RESPONSE
Consequence screen	High consequence dams use PMF passability as a design anchor in dam safety practice.	Assign consequence classes to dams and to critical diversions and sumps, then select performance targets.
Extreme precipitation stress	Precipitation extremes intensify with warming; stationary methods can understate extremes.	Define stress increments and decide where nonstationary IDF updates are required.
Operating rules	Design includes both structural capacity and operational management of storage.	Set trigger levels for pumping, controlled releases where permitted, and shutdown criteria.
Monitoring and review	ICMM frames adaptation as iterative with monitoring and review.	Define instrumentation and data checks that validate the design case and trigger reassessment.

Sources: WP10-18, WP10-01, WP10-12, WP10-06

4.2 Geotechnical and earthworks sensitivity

Earthworks and slope systems couple precipitation intensity to stability and access. In design terms, the key is to identify where extreme rainfall controls pore pressures, erosion, and trafficability, and then to test those mechanisms under plausible precipitation intensification. The IPCC AR6 scaling for annual maximum one day precipitation offers a defensible way to define stress cases without claiming a single forecast event. When paired with a hazard library that includes landslide and subsidence among its categories, teams can ensure that slope stability is not treated as separate from climate. The output should be design and operational controls, such as drainage redundancy, erosion protection, and access closure triggers tied to rainfall thresholds and forecasts.

WP10-01, WP10-16

Heat and water constraints also degrade geotechnical controls. S&P Global's methodology notes that water stress and extreme heat carry the highest financial impacts to 2050 for exposed sectors including mining, within that specific methodology's framing. Even if the project does not use that tool, the hazard prioritisation logic is sound: water stress can limit dust suppression and compaction water, and heat can narrow working windows for critical lifts and liners. Water stress extends beyond a local engineering issue; WRI Aqueduct defines high water stress as at least 50 percent of available supply withdrawn each year and reports a meaningful share of critical mineral sites in such areas. That supports early design choices that reduce water intensity and preserve contingency supply paths.

WP10-16, WP10-11

DECISION INSTRUMENT

Earthworks climate sensitivity check

Decision instrument to test whether earthworks designs are sensitive to rainfall extremes, water limits and heat constraints.

TEST	EVIDENCE READING	DECISION RESPONSE
Rainfall controlled mechanisms	Extreme precipitation intensifies with warming in AR6 evidence.	Identify slope and earthwork elements where short duration rainfall controls stability or erosion and define stress cases.
Water constrained construction	Water stress is a prioritised hazard and has a defined high stress threshold in WRI Aqueduct.	Decide whether construction water and dust suppression need alternative sources or reduced water design.
Heat constrained work windows	Extreme heat is prioritised in S&P Global hazard impact screening for mining.	Define temperature based work limits and specify how schedules and curing regimes will be managed.
Operational triggers	Acute events and chronic shifts need different controls under TCFD framing.	Set rainfall and temperature triggers for access closure, inspection, and restart acceptance checks.

Sources: WP10-01, WP10-11, WP10-16, WP10-10

4.3 Processing plant operability under heat and water constraints

Processing plants concentrate vulnerability because small degradations can stop throughput. The hazard screen should include extreme heat and water stress as first class operability constraints, consistent with the hazard prioritisation in S&P Global's physical climate risk methodology. Engineers can translate this into explicit design and operating envelopes, such as cooling system capacity, HVAC limits for control rooms, and derating curves for motors and transformers inside the plant boundary. The design basis should also define what is protected for continued safe shutdown rather than continued production. This distinction helps keep resilience investment proportional to consequence and supports a staged approach where the plant can operate within a defined envelope while upgrade options remain open.

WP10-16, WP10-10

Water stress adds both volume and quality risks. WRI Aqueduct provides a global baseline screen and a definition of high stress, which helps projects justify early focus on recycling, process water balance assurance and contingency sources. The mine sector also faces external expectations. CDP disclosure analysis notes that mining companies are advancing value at risk analysis of physical impacts and reports materialised risks reported by disclosing companies. These disclosure statistics are secondary and dated, but they reinforce an engineering point: plants need a quantified view of outage modes and recovery times. A plant resilience plan should include spares, bypass routes, and operating rules that reduce exposure to single point failures under heat and water constraints.

WP10-11, WP10-20

DECISION INSTRUMENT

Plant operability and safe shutdown envelope

Decision instrument to define which functions must operate through heat and water constraints and which must support safe shutdown and recovery.

TEST	EVIDENCE READING	DECISION RESPONSE
Priority functions	Extreme heat and water stress are prioritised hazards in physical risk screening approaches.	List plant functions needed for safe shutdown, environmental protection, and critical continuity.
Envelope definition	Chronic shifts and acute events require different operating limits.	Set temperature and water availability limits for operation, and define shutdown and restart acceptance checks.
Water stress response	High water stress has a defined threshold and a documented prevalence in critical mineral locations.	Specify recycling targets as design choices, and define contingency water sources and quality management.
Quantification readiness	Disclosure analysis shows increasing use of VaR style framing of physical impacts.	Define the minimum outage and recovery metrics needed to support internal decisions and potential disclosure.

Sources: WP10-16, WP10-10, WP10-11, WP10-20

05

LOGISTICS

Rail, road and port corridors

Treat corridors as engineered networks where floods, heat and sea level rise set performance and availability outcomes.

15% and US$1 bn

ATTRIBUTED QUEENSLAND FLOODS IMPACTS ON COAL OUTPUT AND LOST PRODUCTION | WP10-19

0.63 to 1.01 m

LIKELY SEA LEVEL RISE BY 2100 UNDER SSP5 8.5 RELATIVE TO 1995 TO 2014 | WP10-05

Acute and chronic

TCFD PHYSICAL RISK STRUCTURE APPLIED TO CORRIDOR AVAILABILITY AND DEGRADATION | WP10-10

5.1 Corridor availability as a design requirement

Corridor design often treats “availability” as an operational statistic rather than a design requirement. Attributed reporting on the 2010 to 2011 Queensland floods shows why that is risky in commodity systems. Inquiry and trade sources report about 15 percent of annual coal output was cut, at least US$1 billion in lost production, and force majeure declarations. This is not a template for every corridor, but it provides a clear prompt: define the design availability requirement and the tolerated outage duration for each corridor link. Then set performance levels for bridges, culverts, embankments, drainage, and slope protections to meet that requirement under specified hazard cases.

WP10-19

The hazard cases should be structured using a recognised taxonomy. Under TCFD, acute hazards such as floods and storms drive immediate outage and damage, while chronic shifts such as mean temperature rise and sea level rise drive gradual degradation and tighter operating envelopes. When engineers separate these, they can write acceptance criteria that are testable. Acute acceptance might be “pass the design flood without loss of track geometry beyond a defined tolerance”. Chronic acceptance might be “maintain geometry and bearing capacity within limits at a higher design temperature” or “maintain minimum deck clearance under a defined sea level allowance”. This structure also supports scenario analysis for disclosure where required by IFRS S2, without forcing disclosure to dictate engineering detail.

WP10-10, WP10-08

DECISION INSTRUMENT

Corridor availability requirement definition

Decision instrument to convert attributed outage lessons and risk taxonomy into explicit corridor performance requirements.

TEST	EVIDENCE READING	DECISION RESPONSE
Availability target	Attributed Queensland flood reporting shows production losses and force majeure from corridor disruption.	Define tolerated outage duration and recovery time for each corridor link and for the system.
Acute hazard cases	TCFD defines acute physical risks as event driven, including floods and storms.	Select design events and acceptance criteria for bridges, culverts, embankments and drainage.
Chronic degradation cases	TCFD defines chronic risks as longer term shifts, including temperature and sea level rise.	Define design allowances and maintenance triggers for heat, corrosion and clearance changes.
Disclosure alignment	IFRS S2 requires scenario analysis of resilience subject to jurisdictional adoption.	Prepare a scenario to requirement trace that is auditable and does not over claim certainty.

Sources: WP10-19, WP10-10, WP10-08

5.2 Rainfall extremes and drainage capacity on linear assets

Linear assets are vulnerable because drainage decisions repeat thousands of times. A small under design at culverts, cross drains or side drains can create recurring washouts and speed restrictions. IPCC AR6 reports that heavy precipitation has likely increased over a majority of land regions and that precipitation extremes intensify with warming, providing a basis to treat historical IDF curves as insufficient on their own for long lived corridors. The design response is to define a corridor wide drainage philosophy, then allocate performance levels by consequence, such as higher performance at low points, near communities, or where detours are not feasible. This reduces the chance that the corridor becomes as strong as its weakest culvert set.

WP10-02, WP10-01

Method choice is again decisive. The cited literature notes that stationary assumptions in IDF design can underestimate extremes by as much as 60 percent. In a corridor context, the project may choose a tiered approach: use nonstationary IDF updates for high consequence segments and keep simpler methods where consequences are low, while still applying stress tests derived from precipitation scaling. The key is to document the tiering and to maintain upgrade compatibility. For example, standardising culvert types and headwalls can allow later upsizing without redesigning every detail. ICMM's stepwise adaptation approach supports this, because it emphasises prioritisation, implementation and monitoring rather than a single one time redesign of the entire corridor.

WP10-12, WP10-06, WP10-01

DECISION INSTRUMENT

Drainage tiering and upgrade compatibility

Decision instrument for corridor drainage design that balances consequence, method selection and future upgrade practicality.

TEST	EVIDENCE READING	DECISION RESPONSE
Segment consequence	Corridor points differ in consequence and detour feasibility.	Classify corridor segments and crossings by consequence and assign performance targets accordingly.
IDF method selection	Stationary IDF can understate extremes; nonstationary methods exist; precipitation scaling provides stress increments.	Choose stationary, nonstationary, or stress test overlays by segment and record the rationale.
Standard details	Repeated assets drive maintenance and upgrade cost.	Standardise components to keep later upsizing and erosion protection upgrades feasible.
Monitoring plan	ICMM frames adaptation as iterative with monitoring and review.	Define inspection triggers after events and periodic reassessment of design storms and drainage capacity.

Sources: WP10-12, WP10-01, WP10-06

5.3 Ports, sea level rise and compound flooding

Ports and near shore corridors sit at the intersection of sea level rise, storm surge and catchment flooding. IPCC AR6 gives likely global mean sea level rise ranges by 2100 that differ significantly between low and high forcing scenarios, while near term rise through 2050 is in a narrower band. This pattern supports a design approach that distinguishes between near term commitments and longer term pathways. Near term decisions include setting the vertical datum, defining minimum deck and rail clearances, and protecting critical electrical and control systems above a chosen allowance. Longer term decisions can be staged through planned raising of wharves, protection structures, and relocation of vulnerable functions if warranted by observed change and updated projections.

WP10-05

For ports, compound flooding matters because failure is often systemic. An access road can flood, a substation can trip, and a berth can become unusable due to overtopping and debris. Using TCFD's acute and chronic framing helps structure the compound case selection. Acute cases include storm events that coincide with high tide and heavy rainfall. Chronic cases include higher mean sea level that raises the baseline for the acute case. IFRS S2 scenario analysis requirements can then be satisfied by showing that the selected compound cases were tested across scenarios and that design decisions, such as elevation allowances or staged upgrades, follow from those tests. The record should state limitations, including that global mean sea level ranges do not substitute for local extremes analysis.

WP10-10, WP10-08, WP10-05

DECISION INSTRUMENT

Port compound flood case selection

Decision instrument to specify which sea level and compound flood cases control port and near shore corridor design decisions.

TEST	EVIDENCE READING	DECISION RESPONSE
Near term allowance	Sea level rise to 2050 lies in a narrow likely band across scenarios.	Set near term elevation allowances for critical systems and define review timing.
Long term pathway	By 2100, likely sea level rise ranges diverge by scenario.	Define staged raising or relocation options and the triggers for committing to them.
Compound case definition	Acute events and chronic shifts interact under TCFD framing.	Specify storm surge plus rainfall plus river flood combinations that must be tested.
Disclosure trace	IFRS S2 requires scenario analysis subject to jurisdictional adoption.	Document case selection and design responses in an auditable form suitable for governance review.

Sources: WP10-05, WP10-10, WP10-08

06

UTILITIES

Power and water resilience

Design power and water systems for climate stressed operation, with explicit exposure screens and contingency planning.

16% to 20%

WRI AQUEDUCT SHARE OF CRITICAL MINERAL SITES IN HIGH OR EXTREMELY HIGH BASELINE | WP10-11

US$187 to 359 bn

UNEP ESTIMATED ADAPTATION FINANCE GAP FOR DEVELOPING COUNTRIES PER YEAR | WP10-13

Water stress and极

S&P GLOBAL SCREENING FINDS WATER STRESS AND EXTREME HEAT HIGHEST IMPACTS TO 2050 | WP10-16

6.1 Water supply, allocation and operational continuity

Water resilience starts with a basin screen and then narrows to site specific balances and operating rules. WRI Aqueduct reports that at least 16 percent of the world's critical mineral mines, deposits and districts on land are in areas of high or extremely high baseline water stress and defines high water stress as at least 50 percent of available supply withdrawn each year. It also reports that the high stress share could rise to 20 percent by 2050. This is not a project specific forecast, but it justifies treating water as a first order design constraint early, including selecting processing routes, setting recycle and storage strategies, and designing intake and transfer systems with contingency options under drought and allocation tightening.

WP10-11

The hazard priority is consistent with sector screening approaches. S&P Global's methodology assesses multiple hazards and finds that water stress and extreme heat carry the highest financial impacts to 2050 for exposed sectors including mining, within that methodology's own framing. For engineering, the response is to define minimum operating water envelopes, specify what loads will shed under shortage, and create restart and recovery sequences. These choices should be documented in the same stepwise manner as industry adaptation guidance recommends, including monitoring and review. Lender frameworks also read climate exposed projects against management systems responsive to changing conditions, so water continuity planning should be part of the management system, more than the design drawings.

WP10-16, WP10-06, WP10-21

DECISION INSTRUMENT

Water continuity decision tree

Decision instrument to define water continuity requirements and contingency actions under baseline stress and climate variability.

TEST	EVIDENCE READING	DECISION RESPONSE
Baseline screen	WRI Aqueduct provides a high water stress definition and prevalence for critical mineral locations.	Decide whether water stress triggers a higher confidence water balance and alternative supply assessment.
Operating envelope	Water stress is a prioritised hazard in physical risk screening for mining.	Define minimum water availability for safe operation and the load shedding order under shortage.
Contingency options	Adaptation guidance is stepwise and iterative.	Rank options such as additional storage, recycling changes, alternative sources and demand reduction, and set implementation triggers.
Management system integration	IFC PS1 expects responsiveness to changing conditions.	Embed water continuity measures, monitoring and review into the project management system.

Sources: WP10-11, WP10-16, WP10-06, WP10-21

6.2 Power system derating and outage management

Power systems face both acute outage risks and chronic derating. Using TCFD's physical risk categories helps teams separate storm and flood driven outages from longer term temperature increases that change equipment ratings, cooling performance and line sag constraints. The engineering deliverable should be a power resilience basis that identifies critical loads, black start capability where relevant, protection settings that anticipate heat driven load patterns, and physical protection of substations against flooding. Although this dossier does not quantify specific derating values, it does provide a hazard prioritisation signal through S&P Global's finding that extreme heat is among the hazards with high financial impacts for exposed sectors. That supports making heat stress a design input rather than an afterthought.

WP10-10, WP10-16

Governance and disclosure can impose additional structure. IFRS S2 requires scenario analysis of resilience, so the power design basis should state which scenarios were used to test outage and derating cases and how those cases affect operating cost and availability. Where projects are financed under lender principles, EP4 requires a climate change risk assessment for Category A projects and for projects above a Scope 1 plus 2 emissions threshold, aligned to TCFD physical and transition categories. This is a framework trigger rather than an engineering standard, but it means power resilience assumptions may be reviewed outside the engineering team. A traceable record reduces rework and prevents overstating certainty in public statements.

WP10-08, WP10-22, WP10-10

DECISION INSTRUMENT

Power resilience basis and disclosure trace

Decision instrument to define power resilience cases and document them so they can withstand lender and disclosure scrutiny.

TEST	EVIDENCE READING	DECISION RESPONSE
Critical loads	Power interruptions and derating affect safety and production differently.	Define critical safety and environmental protection loads and specify continuity requirements.
Acute outage cases	TCFD acute physical risks include storms and floods.	Select outage scenarios and protection measures for substations, lines and access.
Chronic derating cases	Extreme heat is a prioritised hazard in physical risk screening approaches.	Define temperature stress cases for equipment ratings and cooling performance and specify operating limits.
External review readiness	IFRS S2 requires scenario analysis; EP4 requires CCRA for certain projects aligned to TCFD categories.	Prepare a traceable scenario to design case record suitable for governance and lender review.

Sources: WP10-10, WP10-16, WP10-08, WP10-22

6.3 Financing reality and staged resilience investment

Resilience decisions sit inside capital constraints, especially in developing contexts. UNEP estimates an adaptation finance gap for developing countries of US$187 to 359 billion per year and reports that international public adaptation finance rose from US$22 billion in 2021 to US$28 billion in 2022. These figures do not set project budgets, but they help explain why staged investment approaches matter. Engineers should assume that not every desirable upgrade will be funded immediately and should design measures that can be expanded later. This includes reserving space for additional pumps, planning for future raising of embankments, and specifying modular protection works. A staged plan can also prevent stranded spending on measures that are not needed under observed conditions.

WP10-13

Benefit cost framing can help prioritise within constraints. The Global Commission on Adaptation reports benefit cost ratios of 2:1 to 10:1 for resilience investments and that investing US$1.8 trillion globally over 2020 to 2030 across five areas could yield US$7.1 trillion in net benefits. These are global and cross sector figures and should be treated as indicative rather than project specific. They still justify an engineering workflow that quantifies avoided downtime, reduced repair cost and improved safety margins for candidate measures. Where disclosure data is used, CDP reports a median return on physical climate risk spending of about US$10 per US$1 in its analysis, which is also secondary and disclosure based. The engineering task is to provide defensible inputs, not to claim those ratios will hold for a given asset.

WP10-17, WP10-20

DECISION INSTRUMENT

Staged resilience investment screen

Decision instrument to prioritise resilience measures under funding constraints using indicative benefit cost evidence and project specific engineering estimates.

TEST	EVIDENCE READING	DECISION RESPONSE
Constraint statement	UNEP reports a large adaptation finance gap and limited public finance flows.	State funding constraints and define what must be built now versus what can be staged.
Candidate measures	Measures can be structural, operational or monitoring based.	List measures with cost class, lead time and dependency on other works.
Benefit framing	Global evidence reports resilience benefit cost ratios; CDP reports disclosure based returns on spending.	Use these as indicative screens, then compute project specific avoided loss and performance improvements with stated uncertainty.
Commitment triggers	Scenario uncertainty supports staged commitments.	Define triggers for committing to later stages based on monitoring, events, or updated projections.

Sources: WP10-13, WP10-17, WP10-20, WP10-04

07

PLANNING UNDER UNCERTAINTY

Adaptation pathways

Use pathways to stage decisions, keep options open, and make upgrade triggers explicit, including an illustrative Central African construct on public data.

+0.3 °C per decade

RECENT CONGO BASIN WARMING RATE CITED IN PEER REVIEWED LITERATURE | WP10-15

20% by 2050

WRI AQUEDUCT PROJECTION FOR SHARE OF CRITICAL MINERAL SITES IN HIGH STRESS AREAS | WP10-11

Five SSPs

AR6 SCENARIO SET USED TO STRUCTURE PATHWAY STRESS TESTS | WP10-04

7.1 Pathway logic and decision points

Adaptation pathways treat resilience as a sequence of choices rather than a one time upgrade. Industry guidance supports this structure. ICMM describes a stepwise process to integrate climate considerations into existing risk management, moving from understanding exposure to assessing vulnerability and risk, then identifying and prioritising options and implementing with monitoring and review. The pathway framing makes the monitoring and review step concrete by defining decision points, option sets and triggers. It also aligns with disclosure expectations. IFRS S2 requires scenario analysis of resilience, so a pathway can show how the asset remains resilient across scenarios through staged actions rather than claiming that a single design choice covers all futures.

WP10-06, WP10-08

Pathways work best when they make uncertainty explicit. IPCC AR6 provides a core set of five SSP scenarios spanning low to high forcing, which gives a transparent way to select stress envelopes for decision points. The pathway does not need to model every scenario. It needs to show that the selected envelope covers decision relevant tails and that triggers are tied to measurable indicators. For example, a trigger could be an observed frequency of threshold exceedances or a revised hydrology analysis that shifts design storm estimates, recognising that stationary IDF assumptions can materially underestimate extremes. The focus is on controlled commitment under uncertainty, not on pretending the uncertainty disappears once a plan is written.

WP10-04, WP10-12

DECISION INSTRUMENT

Adaptation pathway architecture

Decision instrument to define pathway stages, options and triggers in a form that supports both engineering control and scenario analysis disclosure.

TEST	EVIDENCE READING	DECISION RESPONSE
Stage definition	ICMM frames adaptation as a stepwise process with monitoring and review.	Define stages such as baseline build, midlife upgrade, and closure, with objectives for each.
Scenario envelope	AR6 provides five SSP scenarios spanning low to high forcing.	Select a scenario envelope for testing each stage and record why it covers decision relevant uncertainty.
Trigger metrics	Nonstationary effects can make historical IDF curves insufficient for long life assets.	Define measurable triggers tied to hydrology updates, threshold exceedances, or observed change.
Option sets	Options should be feasible to implement within lead times.	Predefine options and required prework so decisions can be executed when triggers occur.

Sources: WP10-06, WP10-04, WP10-12

7.2 Illustrative Central African worked example on public data

This worked example is illustrative only and is built from public sources cited in this dossier. Peer reviewed literature reports Congo Basin recent warming of about +0.3 °C per decade and projects end century temperatures of +1.5 to 2 °C with more frequent hot extremes, and notes that the Congo River Basin's approximately 75 million people face recurrent floods and droughts that climate change is likely to worsen. For a hypothetical mine plus road corridor in the basin, the pathway would treat flooding as an acute hazard and heat as both acute and chronic, then define staged measures. The purpose is to show the method, not to claim any client engagement or site specific forecast.

WP10-15, WP10-10

The illustrative pathway would start with a water and heat screen. WRI Aqueduct reports that a significant share of critical mineral locations sit in high baseline water stress areas, with a defined threshold, and projects an increase by 2050. Even if a specific basin is not classified as high stress, the screen helps justify early investment in metering, recycling and contingency planning. The pathway stages could include: stage 1 build with conservative drainage and access protection where consequences are high, stage 2 upgrades if rainfall threshold exceedances rise or if nonstationary IDF updates materially increase design storms, and stage 3 long term measures if temperature or water availability trends tighten operating envelopes. The key is that each stage is triggered and costed, not left as an aspiration.

WP10-11, WP10-12

DECISION INSTRUMENT

Illustrative Congo Basin pathway sketch

Decision instrument showing how public evidence can be structured into a staged pathway without claiming site specific forecasts or delivered engagements.

TEST	EVIDENCE READING	DECISION RESPONSE
Evidence inputs	Congo Basin warming rate, projected end century temperature change, and recurrent floods and droughts are documented in peer reviewed literature.	Define which hazards are in scope and which indicators will be monitored.
Stage 1 measures	Early measures should be compatible with later upgrades.	Implement conservative protections where consequence is high and establish monitoring systems.
Stage 2 triggers	Nonstationary IDF updates can materially change design storms.	Commit to upgrades if hydrology revisions or threshold exceedances show reduced performance margins.
Stage 3 triggers	Chronic heat and water constraints can tighten operating envelopes over decades.	Plan long term relocation, raising, or alternative supply options if monitored trends cross defined limits.

Sources: WP10-15, WP10-12, WP10-11

7.3 Cost discipline and benefit claims without overreach

Pathways also manage the tension between cost discipline and resilience ambition. Global evidence can guide prioritisation but must not be applied as if it were project specific. The Global Commission on Adaptation reports benefit cost ratios of 2:1 to 10:1 for resilience investments and large net benefits from global investment across five areas. These figures are useful as a screen to test whether a portfolio of measures is likely to be economically sensible, but the engineering case still needs local cost and performance estimates and clear uncertainty bounds. A pathway structure helps because it assigns cost to stages and only commits larger capital when triggers justify it.

WP10-17

Disclosure oriented datasets can also inform but should be treated carefully. CDP's analysis reports a median return on physical climate risk spending of about US$10 per US$1 and reported materialised risks from disclosing companies, and notes that mining companies are advancing value at risk analysis of physical impacts. This is disclosure based and can include reporting biases. It should not be used to promise a return. Instead, engineers can use the same framing to quantify project specific avoided downtime, repair cost and safety risk reduction for each pathway stage. IFRS S2 scenario analysis requirements then become easier to meet because the staged decisions, costs and triggers are explicit and can be explained with stated limitations.

WP10-20, WP10-08

DECISION INSTRUMENT

Pathway cost and evidence discipline

Decision instrument to use global benefit evidence and disclosure signals as screens while keeping project claims bounded and traceable.

TEST	EVIDENCE READING	DECISION RESPONSE
Global screen	GCA reports 2:1 to 10:1 resilience benefit cost ratios and large net benefits at global scale.	Use as an indicative screen to prioritise measures, then require project specific quantification.
Disclosure signal	CDP reports disclosure based returns and increasing VaR analysis in mining.	Adopt VaR style metrics internally, but state that disclosure figures are not predictive for the project.
Stage cost control	Pathways commit capital progressively.	Assign cost ranges to each stage and define funding gates tied to triggers and performance margins.
Disclosure readiness	IFRS S2 requires scenario analysis subject to jurisdictional adoption.	Prepare a bounded narrative and quantitative summary with explicit limitations and update cadence.

Sources: WP10-17, WP10-20, WP10-08

08

ASSURANCE

The resilience assurance case

Assemble evidence, design decisions and monitoring into an auditable case that can satisfy internal governance, lenders and disclosure expectations.

Governance,gr

FOUR PILLAR STRUCTURE USED BY IFRS S2 AND ORIGINATING IN TCFD | WP10-09

CCRA trigger

EP4 CLIMATE CHANGE RISK ASSESSMENT REQUIREMENT FOR CATEGORY A PROJECTS AND THOSE | WP10-22

Stepwise process

ICMM ADAPTATION PROCESS USED TO STRUCTURE THE ASSURANCE CASE LIFECYCLE | WP10-06

8.1 Assurance case structure and claim boundaries

A resilience assurance case is a structured argument that the asset will meet its performance objectives under defined climate stresses, with clear claim boundaries. The structure can align to IFRS S2, which is built on the four pillars of governance, strategy, risk management, and metrics and targets, and which integrates and builds on TCFD recommendations. The objective is not to turn engineering into disclosure. It is to ensure that the engineering basis can be explained consistently to boards, lenders and stakeholders. Since the TCFD was disbanded in October 2023 with monitoring transferred to the IFRS Foundation, teams should reference the correct instruments and avoid citing TCFD as an ongoing institution when preparing documentation.

WP10-09, WP10-08

Claim boundaries are especially important where evidence is secondary or dated. The Queensland floods impacts are attributed to inquiry and trade reporting, and CDP statistics are disclosure based. These can inform risk imagination and governance expectations, but they should not be used as deterministic predictors. The assurance case should label such evidence as contextual and separate it from design inputs derived from IPCC class evidence, hydrology analyses, and consequence classification decisions. This separation reduces the chance that a board paper converts a contextual figure into an implied forecast. It also supports updates. When new climate science or local studies emerge, the team can revise the design case inputs while leaving the contextual narrative in place with the same caveats.

WP10-19, WP10-20, WP10-01

DECISION INSTRUMENT

Assurance case claim boundary register

Decision instrument to separate contextual evidence from design inputs and to prevent secondary figures being treated as forecasts.

TEST	EVIDENCE READING	DECISION RESPONSE
Design inputs	IPCC class evidence provides quantified ranges for precipitation extremes and sea level rise.	List each design input, the source row, and how it is converted into a design criterion.
Contextual evidence	Queensland flood losses are attributed; CDP figures are disclosure based.	Label contextual evidence and prohibit its direct conversion into design loads or guaranteed outcomes.
Governance mapping	IFRS S2 uses four pillars and inherits TCFD structure; TCFD monitoring moved to IFRS Foundation.	Map assurance case sections to governance needs and ensure correct institutional references.
Update control	Scenario analysis requires periodic refresh as evidence updates.	Define update triggers and responsibilities for revising the assurance case.

Sources: WP10-01, WP10-05, WP10-19, WP10-20, WP10-09

8.2 Lender and project assurance interfaces

Many projects need the assurance case to connect to lender and ESIA frameworks. IFC Performance Standard 1 requires a risk and impacts assessment and a management system that is responsive to changing conditions, and the World Bank ESF includes resource efficiency expectations through ESS3. These are not climate engineering standards, but they are the reference points that reviewers use to judge whether a climate exposed project has treated changing conditions credibly. EP4 adds a clearer climate requirement by calling for a climate change risk assessment for Category A projects and any project above a Scope 1 plus 2 emissions threshold, aligned to TCFD physical and transition categories. The assurance case should show how the engineering design basis and monitoring plan satisfy these interface expectations without stretching beyond the evidence.

WP10-21, WP10-22, WP10-10

The interface work is often about traceability rather than additional calculations. If the project can show how acute and chronic hazards were screened, how scenarios were selected, and how design criteria and operational controls were set, reviewers can follow the logic. Industry guidance can provide the scaffolding. ICMM’s stepwise adaptation process and the Mining Association of Canada guide both describe structured approaches suitable for integrating into existing risk management. Using those structures does not guarantee adequacy, but it creates a common language across engineering, environment, finance and governance functions. The assurance case then becomes a controlled document with an evidence register, decision logs, and monitoring and review commitments tied to triggers.

WP10-06, WP10-07, WP10-22

DECISION INSTRUMENT

Lender interface readiness checklist

Decision instrument to ensure the resilience assurance case is legible against lender and ESIA framework expectations.

TEST	EVIDENCE READING	DECISION RESPONSE
Framework map	IFC PS1 and World Bank ESF are commonly used reference frameworks; EP4 adds a climate risk assessment requirement for certain projects.	Map assurance case sections to each framework expectation and identify evidence artifacts.
Hazard taxonomy	EP4 alignment uses TCFD physical and transition categories.	Show hazard screening and categorisation and how it informed design and operations.
Scenario evidence	IFRS S2 requires scenario analysis of resilience, with jurisdictional adoption caveats.	Document scenario selection, outputs used, and limitations for lender and disclosure review.
Management system link	PS1 expects responsiveness to changing conditions.	Embed monitoring, triggers and update responsibilities into the project management system.

Sources: WP10-21, WP10-22, WP10-10, WP10-08

8.3 Monitoring, review and controlled change

A resilience design basis expires unless it is maintained. The assurance case should include monitoring and review that is specific to hazards and performance margins. For rainfall driven systems, this includes event based inspections, instrumentation checks, and periodic re analysis of IDF inputs where stationarity is not defensible. For coastal systems, it includes tracking sea level assumptions, asset elevations and observed nuisance flooding, and scheduling review points that reflect AR6's near term scenario convergence through 2050 and later divergence by 2100. Monitoring extends beyond technical. It also supports governance and disclosure because IFRS S2 requires scenario analysis and strategy narratives that remain accurate over time. A disciplined update process reduces the risk that disclosures lag behind engineering knowledge.

WP10-12, WP10-05, WP10-08

Controlled change also includes documenting decisions under uncertainty. When teams change a design criterion, they should record what evidence changed, whether the scenario envelope changed, and whether the consequence classification changed. This matters most for high consequence structures where dam safety practice sets strong expectations, such as PMF passability for high hazard dams, and for corridor systems where single point failures dominate. A documented change process helps avoid the silent drift where operational modifications, such as higher stockpile heights or new drainage diversions, erode resilience margins without review. It also aligns with the iterative adaptation framing in ICMM guidance, which expects implementation followed by monitoring and review rather than a final once and done sign off.

WP10-18, WP10-06, WP10-19

DECISION INSTRUMENT

Monitoring and change control plan

Decision instrument to manage the resilience design basis as a living set of assumptions, criteria and triggers.

TEST	EVIDENCE READING	DECISION RESPONSE
Hazard specific monitoring	Nonstationary effects can affect IDF curves; sea level rise evolves with time and scenario divergence.	Define monitoring variables, data sources, and inspection triggers for rainfall and coastal boundary conditions.
Review points	AR6 shows near term sea level rise convergence to 2050 and larger divergence by 2100.	Set scheduled reviews and event triggered reviews aligned to asset life stages and decision points.
Change control	High consequence structures follow consequence based performance selection such as PMF passability; corridor disruptions can have system wide impacts.	Require formal approval when design criteria or operating envelopes change and preserve traceability.
Governance link	ICMM frames adaptation as iterative monitoring and review; IFRS S2 requires scenario analysis of resilience.	Assign responsible owners for updates and specify what changes require governance escalation.

Sources: WP10-12, WP10-05, WP10-18, WP10-19, WP10-06

Decision checklist

Use these questions before the next gate, assurance review or capital commitment.

01 Write a climate design basis that lists hazards, scenarios, performance levels, and acceptance criteria. [WP10-10][WP10-08]

02 Classify assets by consequence and select performance targets explicitly, including design flood conventions where relevant. [WP10-18]

03 Screen the system as a network that includes mine, corridors, port, power and water dependencies and single point failures. [WP10-19][WP10-11]

04 Select an AR6 scenario envelope and document why it covers decision relevant uncertainty across asset life stages. [WP10-04]

05 For rainfall driven designs, document whether stationary IDF is acceptable and where non-stationary updates are required, with a review trigger. [WP10-12]

06 For coastal and port assets, set near term sea level allowances and define staged upgrade options for later century divergence. [WP10-05]

07 Build a water continuity plan using a basin screen, defined operating envelopes, and contingency actions under stress. [WP10-11][WP10-16]

08 Prepare a traceable evidence register that separates contextual secondary figures from design inputs and prevents over claim. [WP10-19][WP10-20][WP10-01]

09 Align assurance documentation to IFRS S2 pillars and record jurisdictional adoption caveats where relevant. [WP10-09][WP10-08]

10 Integrate monitoring, triggers, and change control into the management system so the design basis stays current. [WP10-06][WP10-21]

11 If lender principles apply, map the resilience assurance case to EP4 CCRA expectations and TCFD categories. [WP10-22][WP10-10]

12 Document staged investment gates and triggers so funding constraints do not force silent risk acceptance. [WP10-13][WP10-17]

Evidence ledger 1 of 2

Only dossier rows used in this edition are listed. Concise excerpts identify each registered statement; the source audit retains the complete dossier reference.

ROW	REGISTERED EVIDENCE EXCERPT	REGISTERED SOURCE
WP10-01	Extreme (annual-maximum one-day) precipitation intensifies at roughly 7% per 1 °C of warming, following the Clausius-Clapeyron relation; model projections give a 4% to 8% per °C...	IPCC, AR6 WGI, Climate Change 2021: The Physical Science Basis, Chapter 11 (Weather and...
WP10-02	The frequency and intensity of heavy precipitation events have likely increased at the global scale over a majority of land regions, with human GHG emissions the likely main...	IPCC, AR6 WGI, Chapter 11 / SPM, 2021
WP10-03	Equilibrium climate sensitivity best estimate ~3.0 °C, likely range 2.5-4.0 °C (AR6 narrowed from prior assessments; raw CMIP6 models span ~1.8-5.7 °C, the hot-model issue).	IPCC, AR6 WGI, 2021 (TS / Ch.7)
WP10-04	The AR6 core scenario set is five SSPs (SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0, SSP5-8.5), spanning 1.9 to 8.5 W/m² of 2100 radiative forcing; SSP1-2.6 gives ~1.8 °C best-estimate...	IPCC, AR6 WGI, 2021; DKRZ SSP overview
WP10-05	Likely global mean sea-level rise by 2100: 0.28-0.55 m under SSP1-1.9 and 0.63-1.01 m under SSP5-8.5 (relative to 1995-2014); through 2050 all scenarios lie within a narrow...	IPCC, AR6 WGI, 2021 (SPM / Ch.9)
WP10-06	ICMM published Adapting to a Changing Climate: Building Resilience in the Mining and Metals Industry (2019), setting out a stepwise process to integrate climate considerations...	International Council on Mining and Metals (ICMM), 2019
WP10-07	The Mining Association of Canada issued a Guide on Climate Change Adaptation for the Mining Sector (June 2021), a public sector adaptation guide.	Mining Association of Canada (MAC), 2021
WP10-08	IFRS S2 Climate-related Disclosures was issued by the ISSB in June 2023, effective for annual reporting periods beginning on or after 1 January 2024; it integrates and builds on...	IFRS Foundation / ISSB, IFRS S2, 2023
WP10-09	IFRS S2 is structured on the four TCFD pillars : Governance, Strategy, Risk Management, Metrics & Targets; the TCFD was disbanded in October 2023, its monitoring responsibilities...	IFRS Foundation; TCFD, 2023
WP10-10	TCFD classifies physical risk into acute (event-driven: floods, heatwaves, storms) and chronic (longer-term shifts: sea-level rise, mean-temperature rise); transition risk into...	TCFD, Recommendations of the Task Force on Climate-related Financial Disclosures, 2017
WP10-11	At least 16% of the world's critical-mineral mines, deposits and districts on land sit in areas of high or extremely high baseline water stress; a further 8% are in...	World Resources Institute (WRI), Aqueduct analysis with USGS data, 2024

Evidence ledger 2 of 2

Only dossier rows used in this edition are listed. Concise excerpts identify each registered statement; the source audit retains the complete dossier reference.

ROW	REGISTERED EVIDENCE EXCERPT	REGISTERED SOURCE
WP10-12	Assuming a stationary climate in intensity-duration-frequency (IDF) design can underestimate extreme precipitation by as much as 60%, raising flood and failure risk in...	Cheng & AghaKouchak, Nonstationary Precipitation IDF Curves for Infrastructure Design in...
WP10-13	The adaptation finance gap for developing countries is estimated at US$187-359 billion per year; international public adaptation finance to developing countries rose from US$22 bn...	UNEP, Adaptation Gap Report 2024
WP10-14	Weather, climate and water extremes caused 11,778 recorded disasters (1970-2021), over 2 million deaths and US$4.3 trillion in economic losses; losses rose sevenfold from the...	World Meteorological Organization (WMO), Atlas of Mortality and Economic Losses...
WP10-15	Congo Basin recent warming is about +0.3 °C per decade (faster than the +0.2 °C/decade of 1961-1990); end-century temperatures are projected +1.5 to 2 °C with more frequent hot...	Peer-reviewed: Congo Basin climate reviews; Assessing the impacts of climate change on...
WP10-16	S&P Global's physical-climate-risk methodology uses CMIP6 models and assesses twelve hazards (coastal/fluvial/pluvial flood, drought, water stress, extreme heat, heat stress,...	S&P Global Sustainable1, Physical Climate Risk, 2024
WP10-17	The Global Commission on Adaptation found resilience-investment benefit-cost ratios of 2:1 to 10:1; investing US$1.8 trillion globally over 2020-2030 across five areas could yield...	Global Commission on Adaptation, Adapt Now, 2019
WP10-18	High-hazard / extreme-consequence dams, including tailings dams, are designed to safely pass the Probable Maximum Flood (PMF) : typically an annual exceedance probability of about...	ANCOLD guidelines; dam-safety literature (USBR; BC dam guidelines), 2019
WP10-19	The 2010-2011 Queensland floods cut about 15% of the state's annual coal output and cost the industry at least US$1 billion in lost production; numerous major miners declared...	Queensland Floods Commission of Inquiry (2012); trade reporting (E&MJ; RBA Statement on...
WP10-20	In CDP's disclosure analysis, about half of mining-sector companies disclosed climate risks and opportunities; the median return on physical-climate-risk spending was about US$10...	CDP, Disclosure Dividend, 2026; EY analysis of mining-sector CDP disclosures
WP10-21	IFC Performance Standard 1 (2012) requires a risk-and-impacts assessment and management system that is responsive to changing conditions; the World Bank ESF ESS3 addresses...	IFC, Performance Standards, 2012; World Bank, ESF, 2018
WP10-22	EP4 requires a Climate Change Risk Assessment for all Category A projects and any project whose combined Scope 1+2 emissions exceed 100,000 t CO_2e/yr, aligned to the TCFD...	Equator Principles Association, EP4, 2020

Glossary

Acute physical risk

Event driven physical climate risk such as floods, heatwaves and storms, as classified by TCFD. [WP10-10]

Chronic physical risk

Longer term physical climate shifts such as sea level rise and mean temperature rise, as classified by TCFD. [WP10-10]

Scenario analysis (climate)

Assessment of resilience under a set of climate scenarios; required under IFRS S2 as part of climate related disclosures, noting adoption is jurisdiction by jurisdiction. [WP10-08]

SSP scenarios

IPCC AR6 core set of five scenarios SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0, SSP5-8.5 spanning 1.9 to 8.5 W/m^2 radiative forcing by 2100. [WP10-04]

IDF curve

Intensity duration frequency relationship used to derive design rainfall intensities for given durations and return periods; stationary assumptions can be inappropriate under climate change. [WP10-12]

Nonstationary GEV method

A statistical approach using a nonstationary generalised extreme value model to update IDF curves when climate is not stationary. [WP10-12]

High water stress

Baseline condition where at least 50% of available water supply is withdrawn each year, as defined by WRI Aqueduct. [WP10-11]

Probable Maximum Flood (PMF)

Design flood used for high hazard or extreme consequence dams, including tailings dams, commonly associated with about a 1:10,000 annual exceedance probability or rarer, selected via consequence classification in dam safety guidance. [WP10-18]

Adaptation pathway

A staged plan of measures and decision points with triggers, consistent with stepwise adaptation guidance such as ICMM's process. [WP10-06]

Resilience assurance case

A structured, traceable argument supported by evidence and decision logs that an asset will meet performance objectives under defined climate stresses, aligned to governance and disclosure structures such as IFRS S2. [WP10-09][WP10-08]

Four pillars (TCFD, IFRS S2)

Governance, Strategy, Risk Management, Metrics and Targets structure used by IFRS S2 and originating in TCFD recommendations. [WP10-09]

Climate Change Risk Assessment (EP4)

Assessment required by EP4 for all Category A projects and projects exceeding the stated Scope 1 plus 2 emissions threshold, aligned to TCFD physical and transition risk categories. [WP10-22]

Equilibrium climate sensitivity (ECS)

Long term temperature response to CO_2 doubling; AR6 best estimate about 3.0 °C with a likely range of 2.5 to 4.0 °C. [WP10-03]

Sea level rise likely range

IPCC AR6 likely global mean sea level rise ranges by 2100 and a narrower band through 2050, relative to 1995 to 2014. [WP10-05]

Stepwise adaptation process (mining guidance)

Guidance approach to integrate climate considerations into risk management from exposure understanding through risk assessment and option implementation with monitoring and review, as described by ICMM and MAC guidance. [WP10-06][WP10-07]

Physical climate risk hazards (S&P Global methodology)

A set of twelve hazards assessed using CMIP6 models in S&P Global's described methodology, including multiple flood types, drought, water stress, extreme heat and others. [WP10-16]

Adaptation finance gap

UNEP estimated gap for developing countries, alongside reported international public adaptation finance flows. [WP10-13]

Disaster loss record (WMO Atlas)

WMO reported counts of disasters, deaths and economic losses from weather, climate and water extremes over 1970 to 2021. [WP10-14]

References and limitations

IPCC (2021)

AR6 Working Group I, Climate Change 2021: The Physical Science Basis (selected chapters and SPM cited for extremes, scenarios, ECS, sea level). Rows WP10-01 to WP10-05.

International Council on Mining and Metals (ICMM) (2019)

Adapting to a Changing Climate: Building Resilience in the Mining and Metals Industry. Row WP10-06.

Mining Association of Canada (MAC) (2021)

Guide on Climate Change Adaptation for the Mining Sector. Row WP10-07.

IFRS Foundation, International Sustainability Standards Board (ISSB) (2023)

IFRS S2 Climate-related Disclosures. Rows WP10-08 to WP10-09.

Task Force on Climate-related Financial Disclosures (TCFD) (2017)

Recommendations of the Task Force on Climate-related Financial Disclosures. Row WP10-10.

World Resources Institute (WRI) (2024)

Aqueduct analysis of critical-mineral mines, deposits and districts and baseline water stress (with USGS data). Row WP10-11.

Cheng and AghaKouchak (2014)

Nonstationary Precipitation IDF Curves for Infrastructure Design in a Changing Climate. Row WP10-12.

Silva et al. (2023)

Nonstationary precipitation and IDF update methods (Journal of Hydrology study cited in dossier capture). Row WP10-12.

United Nations Environment Programme (UNEP) (2024)

Adaptation Gap Report 2024. Row WP10-13.

World Meteorological Organization (WMO) (2023)

Atlas of Mortality and Economic Losses from Weather, Climate and Water Extremes 1970-2021. Row WP10-14.

Climatic Change (peer-reviewed) (2022)

Assessing the impacts of climate change on climatic extremes in the Congo River Basin. Row WP10-15.

S&P Global Sustainable1 (2024)

Physical Climate Risk methodology and sector findings. Row WP10-16.

USE LIMITATIONS

- This paper uses only evidence rows registered in the WP-10 dossier and does not claim any delivered climate-resilience engagement. [WP10-06]
- IPCC AR6 scenario, warming and sea level figures are 2021 values and should be checked against the latest IPCC cycle at point of use. [WP10-04] [WP10-05]
- IFRS S2 effective date is the standard's own; jurisdictional adoption is not universal and must be confirmed for the reporting entity. [WP10-08]
- Queensland flood impacts are attributed to inquiry and trade reporting and are presented as contextual evidence, not as predictive forecasts. [WP10-19]
- CDP mining disclosure figures are disclosure based and dated; they should not be treated as project level benefit guarantees. [WP10-20]
- The Central African worked example is explicitly illustrative and built only from public sources cited in this dossier. [WP10-15][WP10-11]

EDITION STATUS

This technical paper is an editorial synthesis for decision support. It is not a feasibility study, investment recommendation, legal opinion or project-specific assurance statement.

AURUS MINING

Built for the New Climate

Published as part of the Aurus Mining technical paper series. Mining, infrastructure, engineering and environment decisions are treated as one connected system, with evidence boundaries stated and source rows preserved.

Prepared for digital distribution in A4 format. Edition 1, 2026.

WP10 | EVIDENCE-BOUNDED TECHNICAL PAPER