

Ok Birim Tailings Storage Facility Project

Environmental and Social Impact Assessment

Appendix J

Climate change risk assessment report



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Climate Change Risk Assessment

Ok Tedi Mining Ltd (OTML)



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29 May 2026

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UNITS AND SYMBOLS

Units and symbols	Definition
%	percent
°C	degree Celsius (temperature)
km	kilometre
ha	hectare
m	metre
m ²	square metre
m ³	cubic metre
ML	megalitre
MW	megawatt
mm	millimetre

TERMS AND ABBREVIATIONS

Terms and abbreviations	Definition
ALARP	as low as reasonably practicable
AEP	annual exceedance probability
AMD	acid and metalliferous drainage
AMSL	above mean sea level
EPRP	emergency preparedness and response plan
GCM	global climate model
GEV	generalized extreme value
GHG	greenhouse gas
GISTM	Global Industry Standard on Tailings Management
ICMM	International Council on Mining and Metals
ITCZ	Intertropical Convergence Zone
KCB	Klohn Crippen Berger
NAF	non-acid forming
NDC	Nationally Determined Contribution
OTML	Ok Tedi Mining Limited
PAF	potentially acid forming
PFS	pre-feasibility study
PMF	probable maximum flood
PMP	probable maximum precipitation
PNG	Papua New Guinea
SPEI	Standardized Precipitation Evapotranspiration Index

Terms and abbreviations	Definition
SSP	Shared Socioeconomic Pathway
TARP	Trigger Action Response Plan
TCFD	Task Force on Climate-related Financial Disclosures
TSF	tailings storage facility
the project	Ok Birim Tailings Storage Facility Project

1. INTRODUCTION

1.1 BACKGROUND AND SCOPE

This Climate Change Risk Assessment (CCRA) report has been prepared for the Ok Birim Tailings Storage Facility Project (the project) proposed by Ok Tedi Mining Ltd (OTML) as part of the Environmental and Social Impact Assessment (ESIA) process. This CCRA is conducted to identify and evaluate potential climate-related physical risks that may influence the construction, operation, and closure of the project. This CCRA supports the integration of climate considerations into project planning to enable and enhance the climate resilience of the project over its life cycle.

This CCRA has been prepared to address and align with international standards and guidance, including the Equator Principles (EP) (2023). As required under Principle 2 of the fourth version of the EPs (EP4), the assessment of climate-related risks and the preparation of CCRA, as part of the environmental and social assessment process, supports the early identification and management of climate-related impacts and risks within project designs and decision-making. Additionally, this CCRA facilitates the alignment of the project with international industry practice, including the Task Force on Climate-related Financial Disclosures (TCFD 2026) and broader objectives associated with the Paris Agreement.

Other international standards used to inform and perform climate risk assessments include the International Finance Corporation (IFC) Performance Standards (IFC 2012a; b; c) and the Global Industry Standard on Tailings Management (GISTM; ICMM et al. 2020). The IFC Performance Standards require consideration of risks associated with a changing climate, as well as the identification of adaptation opportunities. GISTM requires operators to incorporate climate change and associated physical risks into the tailings facility lifecycle by developing a knowledge base that captures climate-related uncertainties, integrating climate change considerations into site characterization, impact assessment, and design (including water management systems), and applying adaptive management to regularly evaluate and update risk mitigation measures in response to evolving climate conditions and extreme weather hazards.

This CCRA has also been undertaken with consideration of Papua New Guinea (PNG)'s Nationally Determined Contribution (NDC) under the Paris Agreement (Government of Papua New Guinea 2020), in alignment with the expectations of EP4 to consider a project's compatibility with host country climate commitments. PNG's NDC identifies the country as highly vulnerable to climate change and places strong emphasis on assessing climate impacts and risks such as those from inland flooding, coastal flooding, and drought. Additionally, PNG's NDC highlights the importance of strengthening infrastructure resilience and integrating climate considerations into planning and decision-making. Consistent with such objectives of PNG's NDC, this CCRA considers climate adaptation and resilience by evaluating how the project design responds to various climate hazards and how the project can contribute to climate-resilient development, thus serving as a basis for assessing climate risks of the project and to consider, plan, and implement appropriate adaptation measures.

This CCRA is focused on the assessment of physical climate risks and the associated resilience and adaptive capacity of the project. The assessment considers how climate variability and change may affect key aspects of the project, including hydrology, water management, infrastructure, and operation. The subsequent identification of appropriate adaptation and risk management measures is intended to support the long-term integrity of the project and reduce potential risks to the project and affected communities. This study focuses exclusively on the assessment of physical climate risks, with climate transition risks considered outside the scope.

1.2 PROJECT DESCRIPTION

The project is in the northwestern corner of Western Province, south of the Central Cordillera Mountain range which runs east-west along the length of PNG (see Figure 1). The proposed tailings storage facility (TSF) is approximately 1 km west of the confluence of the Ok Birim and Ok Tedi, and about 55 km south of the existing Ok Tedi Mine (90 km by road via the Kiunga-Tabubil Highway). The mine lies approximately 5 km west of the Ok Tedi, a major tributary of the larger Fly River.

Based on the proposed project layout, the total disturbance footprint is estimated at approximately 1,900 ha. Project activities will primarily occur in the following two areas:

- TSF development area (approximately 1,500 ha) – This includes the TSF footprint, hydro-cyclone house and ancillary infrastructure, surface water management facilities and internal roads and tracks. The area is within a lowland setting with regional topography gently sloping to the south. The TSF site is in a sub-catchment of the Ok Yep, to the west and south of Ok Birim and Ok Tedi confluence. The northern part of the TSF site is approximately 1 km west of this confluence. The TSF site is generally flat with undulated shallow valleys ranging in elevation from approximately 40 m to 80 m above mean sea level (AMSL).
- Infrastructure corridor development area (approximately 400 ha) – This includes the proposed pipeline access road, bridges and water/ravine crossings, tailings pipeline and supporting facilities outside the TSF development area. The corridor area varies from the rugged, steep-sided valleys near the mine to the more gently undulating terrain and floodplains towards the TSF site.

Key components of the project are:

- A hydro-cyclone house for separating coarse and fine tailings, with coarse underflow sand used for embankment construction and fine overflow directed to the TSF impoundment.
- A ring-dyke TSF comprising internal storage cells developed progressively, with embankments primarily constructed using cyclone underflow sand.
- An 87-km-long tailings delivery pipeline from the existing TPP at Ok Tedi Mine to the proposed TSF site, including associated pumping and piping distribution systems (i.e., one pump station at the mine site and two intermediate choke stations).
- A pipeline access road corridor including three bridges and several minor water/ravine crossings.
- Ancillary infrastructure including site offices, laydown areas, workshops, maintenance stations, waste and sewage management facilities, fuel storage, borrow and gravel pits and accommodation camps (as required).
- Power supply primarily from on-site diesel generators, with an installed capacity of up to 11 MW during operations.
- Water supply sourced primarily from existing mine site supply, TSF decant water during operations, supplemented by rainfall and potential abstraction from nearby watercourses or groundwater for construction and potable water (if required).

Project activities will occur over three main phases:

- Construction phase - approximately 36 months, from 2027 to 2030.
- Operations phase - 20 years, from 2030 to end of 2049.
- Decommissioning, closure and rehabilitation - approximately 36 months, from 2050 to 2053.

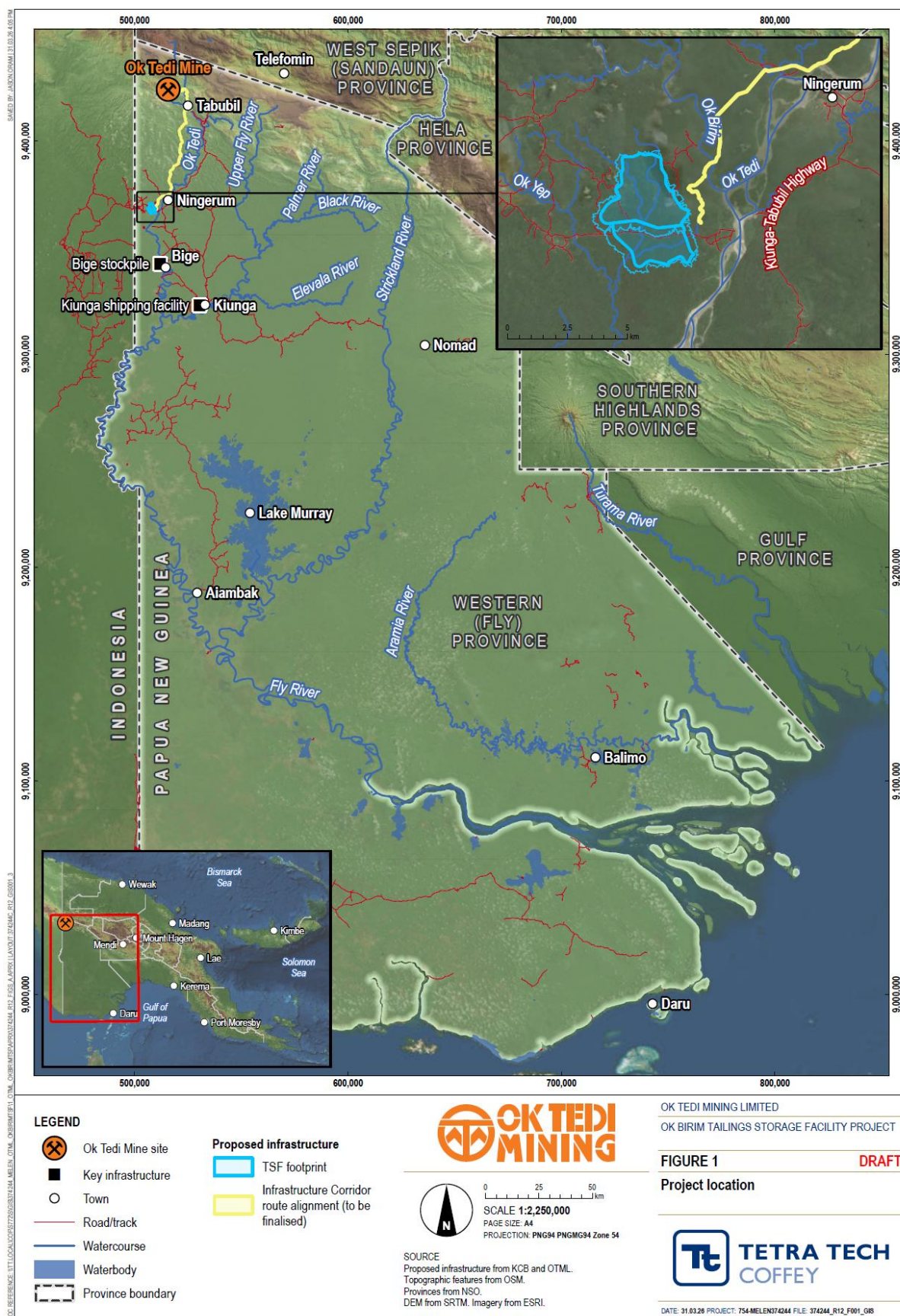


Figure 1. The project location and footprint, including the two main project components (TSF development area and infrastructure corridor).

1.3 ASSESSMENT APPROACH

This CCRA focuses on the identification and evaluation of physical climate risks relevant to the project, including both acute (event-driven) and chronic (long-term) risks. Consistent with the framework described under EP4, the assessment adopts a structured approach comprising: (i) physical risk screening and scoping, (ii) physical risk assessment, and (iii) risk management and resilience planning. This approach is intended to support a systematic and transparent evaluation of how climate variability and change may influence the performance and resilience of the TSF and associated infrastructure over the project life cycle.

Physical risk screening and scoping involve characterizing the baseline and projected climate conditions relevant to the project area. This includes review of historical climate and hydrology, evaluation of climate conditions and assumptions used in the project design basis, and the analysis of climate data and future climate projections for the project location. Climate trends and variability are assessed using available local monitoring data, supplemented by regional datasets and outputs from global climate models (GCMs). This step also includes identification of key climate hazards (for example, extreme rainfall, flooding, temperature variability, and other relevant factors) that may represent material risks to the project, taking into account the location and design of the project.

The physical risk assessment builds on the identified hazards to evaluate their potential implications for the project. This includes analysis of historical records and projected future climate conditions to derive relevant climate parameters used in engineering designs of the project and as an indication of long-term chronic risks. The assessment considers how these parameters may influence hydrological conditions, water management, geotechnical performance, and overall operational stability of the TSF and supporting infrastructure. The outcomes of this step inform an evaluation of the project's exposure and sensitivity to climate-related hazards, and the extent to which the current design and operational assumptions provide resilience to these conditions.

Risk management and resilience planning focus on identifying and describing measures to manage the physical climate risks estimated through this analysis. This includes consideration of existing design features, operational controls, and management practices incorporated into the project, as well as potential measures that can be implemented to enhance resilience. The intent is to support integration of climate risk considerations into all three phases of the project in a manner consistent with international industry practice, applicable standards and guidelines identified above (including EP4, IFC Performance Standards, and GISTM), and PNG's NDC.

The assessment presented in this document has been informed by a combination of published literature, existing project information, and climate data analyses. Key references include the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (IPCC 2023) and regional climate risk information for PNG, supplemented by other relevant peer-reviewed studies. Climate datasets used in the assessment include both historical observations and projected future climate modelling results from the sources consistent with EP4 expectations. Such future climate projections are based on outputs from GCMs developed under the Coupled Model Intercomparison Project (CMIP), including the most recent CMIP6 where available and CMIP5 where required (Eyring et al. 2016).

Future climate conditions are considered using a range of representative climate scenarios to reflect uncertainty in global emissions pathways and associated climate change outcomes. Current global policy trajectories indicate a likely warming outcome in the order of approximately 2.7°C to 2.8°C by the end of the century (UNEP 2025), broadly consistent with intermediate scenarios such as Shared Socioeconomic Pathway (SSP) 2-4.5 (Venmans and Carr 2024). Higher-end scenarios (e.g., SSP5-8.5) represent more extreme warming outcomes and are considered to provide an upper bound for sensitivity testing, although such scenarios are generally regarded as less likely (Venmans and Carr 2024). Rather than adopting a single scenario, this assessment considers a range of plausible climate futures to evaluate variability in climate-related risks. The approach is consistent with GISTM (ICMM et al. 2020), which requires consideration of

climate change uncertainties and incorporation of a robust climate knowledge base into the assessment and design of TSFs.

This scenario-based approach supports a risk-informed assessment by enabling consideration of both central (most likely) and more adverse climate conditions. This CCRA therefore focuses on understanding how the project may perform under a range of climate outcomes, including extreme weather conditions, and whether the design and management framework is sufficiently robust to accommodate these conditions. In alignment with GISTM, the outcomes of such analyses with various scenarios inform the integration of climate considerations into site characterization, impact and risk assessment, and support an adaptive management approach to periodically review and adopt necessary measures in response to evolving climate conditions over the project lifecycle.

2. OVERVIEW OF CLIMATE CHANGE

2.1 GLOBAL CLIMATE CHANGE

Historical observations indicate that the global climate system has undergone rapid and widespread change over the past century. According to the IPCC Climate Change 2023 Synthesis Report (IPCC 2023), global average surface temperature has increased by approximately 1.1°C in 2011–2020 relative to pre-industrial conditions (1850–1900), with the rate of warming since 1970 exceeding that of any comparable period over at least the last two millennia. This warming has been accompanied by significant physical changes across all major components of the climate system, including increases in ocean heat content, widespread glacier retreat, reductions in snow cover, and thawing permafrost. Mean global sea level has risen by approximately 0.20 m between 1901 and 2018, with the rate of rise accelerating in recent decades.

One notable aspect of historical climate is the frequency and intensity of climate and weather extremes. Studies suggest strong evidence of increasing occurrence and severity of heatwaves, heavy precipitation events, droughts, as well as an increased likelihood of compound events (IPCC 2023). The impacts of these changes are evident across natural and human systems, including shifts in ecosystems, species loss, reduced water availability in some regions, and impacts on food production and human health (IPCC 2023).

Further increase of global temperature is expected to drive changes across major components of climate system. Global average temperature is projected to increase in the near term (2021–2040) under all assessed scenarios, with warming levels of approximately 1.5°C likely to be reached or exceeded within this period (IPCC 2023; UNEP 2025). The magnitude of long-term warming by the end of the century depends on future emissions pathways, with projected increases ranging from about 1.4°C under very low emissions scenarios to approximately 4.4°C under high emissions scenarios (see Figure 2).

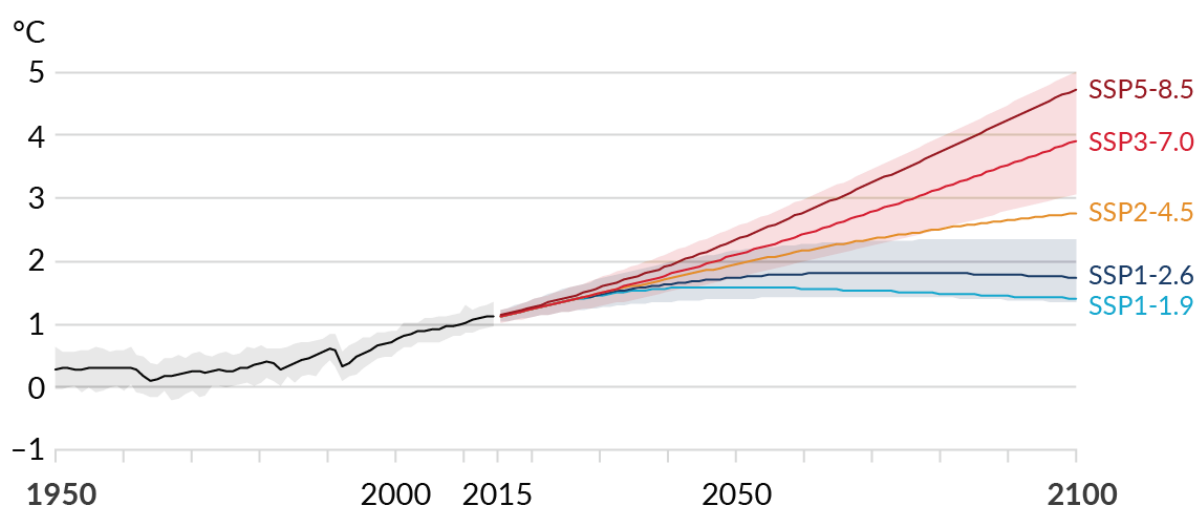


Figure 2. Historical and projected global mean surface temperature with different SSP scenarios provided by IPCC AR6. Lines and coloured areas show the mean and 90% confidence intervals, respectively. The numbers in the SSP labels refer to the additional radiative forcing in watts/m^2 due to greenhouse gas buildup in the atmosphere, compared to pre-industrial levels.

The projected increase in global average temperature is expected to lead to continued intensification of climate hazards in the future. Increases in extreme heat, heavy precipitation, and drought are projected in many regions, along with further sea level rise and ongoing reductions in glaciers and ice sheets (IPCC 2023). Changes in the hydrological cycle are expected to result in greater variability, including more intense rainfall events and severe dry periods. With each increment of global warming, these changes become more pronounced, leading to increased frequency and severity of compound and cascading climate risks. Over

longer timescales, some changes can also be irreversible: sea level rise will continue for centuries to millennia due to ongoing ocean warming and ice sheet response. The likelihood of large-scale, abrupt, or irreversible changes—such as ice sheet loss or ecosystem collapse—increases with higher levels of warming. Consequently, future climate conditions are expected to involve progressively greater physical changes and risks, while the magnitude of such changes depend on socioeconomic developments and mitigation policies.

2.2 CLIMATE CHANGE IN PNG AND WESTERN PROVINCE

The broader South Pacific and the Pacific Island region have experienced notable historical climate change although such changes vary spatially. According to the IPCC's Sixth Assessment Report (IPCC 2022), the following changes have been noted for the region: a temperature increase rate of 0.14°C per decade has been identified for the islands in the West Pacific; rainfall change exhibits no clear pattern in the Pacific Ocean; tropical cyclones show a decreasing frequency; and the regional sea level rise (in the Western Tropical Pacific region) is greater than the global average. Analyses of climate in the Western Pacific Islands in McGree et al. (2019) suggest that, average temperature increases have been observed in most of the stations analysed and extreme temperature increases are greater. However, this study also notes that changes in precipitation are less consistent (with both average and extreme precipitation decreasing in some stations, suggesting greater drought risks).

PNG has been studied and reported as one of the most at-risk countries from climate change. As described by the World Bank Group (2021a), although PNG is projected to have an average temperature increase slightly lower or similar to a global average, riverine and coastal flooding and landslide are likely to intensify and pose increasing risks because of a significant exposure to these hazards in PNG. The World Bank Group (2021a) also points out that the limited historical and future local climate and vulnerability data makes it difficult to conduct a more comprehensive climate risk assessment. According to INFORM 2025 Risk index (European Commission 2025)—which shows the risks of humanitarian crises and natural disasters including those associated with climate hazards—PNG is placed in the high-risk class and ranks in the 20th place out of 191 countries (See Table 1) (the lower the number the higher the risk). Of the physical climate hazards, PNG faces greater-than-average hazards and risks due to tropical cyclones, and coastal flooding, and slightly higher risks than the global average for riverine flooding, as shown in Table 1.

Table 1. Selected natural hazard indicators in the INFORM 2025 Index for PNG. Higher index values suggest greater risks, whereas the numbers in brackets show the global average among the 191 countries.

Drought (0-10)	Tropical Cyclone (0-10)	River Flood (0-10)	Coastal Flood (0-10)	Tsunami (0-10)	Earthquake (0-10)
2.5 [3.4]	2.8 [1.6]	4.6 [4.5]	6.3 [3.5]	7.1 [2.7]	9.2 [3.7]

Results provided by the European Commission (2025).

Similarly, extreme heat, drought, flood and landslide, and cyclone and storm surge have been identified as several notable climate hazards in PNG. The country regularly experiences hydrological hazards such as riverine and coastal flooding, which are driven by intense rainfall, seasonal variability (including ENSO cycles), and sea level rise, as well as frequent landslides in mountainous regions where heavy precipitation and seismic activity destabilize slopes (CFE-DM 2025a). For example, inland flooding affects over 22,000 people yearly and floods displace over 6,000 people and cause damage of over US\$8 million per year (CFE-DM 2025a). In early April 2020, flooding from the Zokozoi River in the Eastern Highlands Province caused widespread damage, destroying or affecting approximately 500 homes; in March 2020, a landslide in Western Highlands Province led to 10 fatalities and impacted at least 1,000 people (CFE-DM 2025b).

Tropical cyclones—though less frequent near the equator—bring damaging winds, heavy rainfall, and storm surges, whereas droughts associated with El Niño events can lead to severe water shortages, crop failures,

and food insecurity (CFE-DM 2025a). For example, in September 2022, drought conditions caused water levels at three of Papua New Guinea's six hydroelectric dams to fall to critical levels (CFE-DM 2025a), disrupting electricity supply to about one million people (hydropower provides roughly 40% of total generation in PNG). Additionally, Naumann et al. (2018) suggests that the frequency of droughts can substantially increase in the Oceania region, although the changes in droughts for PNG are subject to uncertainty and can deviate from such regional findings. While previous studies have suggested that the frequency of tropical cyclones will likely decrease in the southern hemisphere as well as in the South Pacific (Bell et al. 2019; Walsh et al. 2012), the strongest tropical cyclones may intensify (IPCC 2022). These responses are complex, and the reported study results are inconclusive.

3. LOCAL CLIMATE AND HYDROLOGY

3.1 CLIMATE

The project area is located in the North Fly region of PNG on the southern flanks of the Central Cordillera, within the tropical rainforest climate zone characterized by persistently high temperatures and abundant rainfall in all months (KCB 2024). See Figure 3 for the general site location. The regional climate is strongly influenced by the seasonal interaction of the Southeast Trade Winds and the Northwest Monsoon, with the Intertropical Convergence Zone (ITCZ) migrating across the region. The Southeast Trade Winds dominate from May to October and produce sustained orographic rainfall on the windward mountain slopes, while the Northwest Monsoon (December to March) brings convective storm activity and highly localized, intense rainfall events. Transitional conditions typically occur in April and November.

Historical rainfall records indicate a very high rainfall environment, with annual totals ranging from approximately 4,000 mm to over 10,000 mm, depending on elevation and location (KCB 2024). Average annual rainfall is in the order of ~5,500 mm at Bige and up to ~9,800 mm at higher elevation stations, for example. Monthly rainfall is consistently high throughout the year, typically ranging between about 490 mm and 680 mm in each month (with an annual total of ~6,700 mm) based on long-term data from the PMP59 station (1994–2024). The rainfall regime does not exhibit a pronounced dry season, although relatively higher rainfall generally occurs between May and October. Further analysis of extreme rainfall characteristics indicates the high short-duration rainfall intensities, reflecting the convective nature of storm events in the region.

3.2 HYDROLOGY

Assessing historical hydrology is largely constrained by the limited availability and quality of long-term streamflow records, particularly within the mine area and in the upper catchments (Pickup 2025). Available gauging data are sparse and discontinuous; the use of such data for analyses such as deriving rating curves is subject to uncertainty, especially in low-gradient downstream reaches. Regional hydrologic characterization therefore relies heavily on estimated relationships (e.g., flow duration curves based on catchment area) and the development of synthetic flow records to represent long-term discharge variability.

The Ok Tedi and Middle Fly River systems (See Figure 3) exhibit highly variable flow regimes with a wide range of discharge rates including extreme flood events, consistent with the extreme rainfall environment described in the previous section. According to the regression models developed to estimate river discharge rates at different stations (Pickup 2025), the regression parameters used for different stations vary, suggesting that the flow behaviour can be affected by many factors. In the downstream reaches, hydrodynamics is further complicated by backwater effects and tidal variations, which affect stage-discharge relationships and increase uncertainty in flow estimation.

A key defining factor of the historical hydrology of the systems is the dominant role of sediment transport processes and modification of such processes by mining activities (Pickup 2025). Since the commencement of mining, large volumes of tailings and waste rock have been discharged into the river system, fundamentally altering the natural sediment transport regime. These inputs have resulted in substantial increases in sediment load and changes in sediment composition, driving widespread channel aggradation, elevation of riverbeds, and associated increases in water levels and overbank flooding, particularly in the Lower Ok Tedi. Riverine tailings disposal, historically in the order of tens of millions of tonnes per year, has been a primary contributor to these changes, with a significant proportion of transported material consisting of mine-derived sediments.

Active management measures have been adopted to address the altered sediment regime, notably large-scale dredging operations at Bige, which have been implemented since 1998 (Pickup 2025). Dredging has

played a key role in controlling water levels and sediment accumulation in the Lower Ok Tedi. Prior to dredging, sustained tailings inputs caused significant aggradation and a rise in water levels of approximately 3.5 m at the Konkonda gauging station; following dredging, water levels stabilized and then gradually declined as sediment was removed from the channel. The excavation of the dredge slot created a deeper, lower-energy channel that traps sand and modifies sediment transport processes.

Overall, historical hydrology at the project site is characterized as a highly variable, sediment-dominated system driven by extreme rainfall, strong spatial heterogeneity, and significant modification from mining-related sediment inputs. These factors—combined with data limitations and evolving channel conditions—introduce substantial uncertainty into hydrologic analysis and make robust prediction of future hydrology challenging. Consequently, the CCRA adopts a scenario-based and risk-informed approach, focusing on projected changes in climate conditions—particularly precipitation—to assess potential future risks and inform the underlying climate drivers and relative influences on hydrologic response. Due to the inherent uncertainties and system complexities, quantitative evaluation of absolute future hydrology has not been undertaken as part of the CCRA and global-scale model outputs may be interpreted as indicative of relative change rather than precise forecasts.



Figure 3. Project location and delineated catchments in the region.

3.3 CLIMATE-RELATED PROJECT DESIGN BASIS

In addition to local climate and hydrology, an independent evaluation of weather and climatic conditions used as the design basis of the project (KCB, 2025) is conducted in this section. With a focus on design parameters related to precipitation, runoff, and flood processes, a compilation of climate-related design basis and criteria for key infrastructure components of the project is conducted and presented below. The results summarize and provide the adopted engineering design values—such as design storm events, flood return periods, and storage allowances—for the two main project components (TSF development area and infrastructure corridor) as well as individual facilities for each component. These design criteria represent the climatic and hydrologic conditions that the project is designed to withstand. Such compiled project design basis information also facilitates subsequent risk assessments for future climate change conditions.

Further, this compilation of project design basis and criteria focus on climatic and hydrologic extremes, reflecting acute climate risks, such as those from extreme rainfall events, flooding, and inundation. Compared to other chronic climate risks, such as gradual increase in average temperatures, extreme events and acute risks can significantly affect the performance and safety of the TSF and related infrastructure. As described in

World Bank Group (2021b), these high-intensity, relatively low frequency extreme events are typically the key drivers of critical failure modes in other TSF sites, including overtopping, erosion, and uncontrolled discharge (Ling et al. 2026).

Table 2 provides available project design information related to extreme rainfall and flooding events. The categorisation of infrastructure components aligns with the overall project description, distinguishing between the TSF development area and the infrastructure corridor, with further breakdown into separate elements (e.g., TSF footprint, surface water management facilities, roads, and crossings). This categorisation ensures consistency with the project description and facilitates a component- or element-specific evaluation of climate risks. A key metric presented in the table below is the Annual Exceedance Probability (AEP), the magnitude of extreme event that may be exceeded at a certain frequency. Thus, a 1:10 AEP refers to an event that may be exceeded once in 10 years.

Table 2. Compiled project design basis and criteria related to extreme rainfall and flooding

Project Component	Sub-component	Design Element	Design Criteria
TSF development area	TSF footprint	Normal Operational Condition	200–600 million litres (ML) (Cell 1) 200 ML (Cell 2)
		Maximum Pond Capacity	1,000 ML and 7,600 ML as contingency storage (Cell 1) 600 ML and additional 5,200 ML as contingency storage (Cell 2)
		Wet Season Storage	30-day inflow allowance
		Extreme Rainfall Event Storage	1:100 AEP, 72-hour duration
		Wind-wave Run-up Storage	1:10 AEP
		Pond Storage Critical Duration Storm	1:100 AEP, 72-hour duration
		Flood Protection of Southeast Corner	1:2,000 AEP if required
		Flood Design	PMF (~1:100,000 AEP; PMP-derived)
		Closure Condition	Water-shedding landform conveying PMF flows
	Surface water management facilities	Sedimentation Pond Flow Capacity	1:10 AEP
		Sedimentation Pond Design Storm	1:100 AEP, 24-hour duration
		Ditches and Channel Diversion Design Storm	1:100 AEP, 24-hour duration
		Erosion Protection Design Runoff	1:100 AEP

Project Component	Sub-component	Design Element	Design Criteria
		Spillways	PMF (~1:100,000 AEP) capacity
	Hydro-cyclone house and ancillary facilities	Process water supply	~32,000 ML/year (includes rainfall and TSF decant water)
	Perimeter road and site access roads/tracks	Roadside Drainage Design Storm	1:100 AEP
		Minor Access Roads, Temporary Construction Tracks Design Storm	1:20 AEP
Infrastructure Corridor	Pipeline access road, bridges and crossings	Main Access Roads Design Storm	1:100 AEP
		Construction and Minor Roads/Tracks	1:20 AEP
		Table Drains, Cross Drains Design Storm	1:10 AEP
		Bridge Design Storm	1:100 AEP

AEP: Annual Exceedance Probability; PMF: Probable Maximum Flood; PMP: Probable Maximum Precipitation

The compiled design criteria in Table 2 indicates a risk-informed application of design standards across the project, reflecting the different risk profiles of infrastructure components/elements.

At the upper end, the TSF footprint and associated storage adopt the most conservative design criteria. Extreme flood conditions are governed by PMP/PMF (~1:100,000 AEP), which represents a near-physical upper bound on precipitation/rainfall and associated flood. This is consistent with the high consequences and risk profile of TSF, the failure of which could result in major downstream impacts. In addition to PMF-based design for flood and spillways, intermediate design levels are also incorporated, including 1:100 AEP events for operational storm storage and 1:2,000 AEP for flood protection of vulnerable areas, providing multiple layers of resilience. The inclusion of 30-day wet season storage allowances reflects the design conditions of sustained rainfall in the tropical region, in addition to the design for the shorter-duration extremes.

Surface water management facilities (e.g., sedimentation ponds, ditches, and diversions) are generally designed based on 1:100 AEP events, with hydraulic capacity for more frequent flows (e.g., 1:10 AEP for sedimentation ponds). This reflects their operational role in managing routine and moderately extreme runoff conditions, while still maintaining robustness against significant storm events. Such designs reflect the importance of such facilities for controlling sediment transport and maintaining water quality.

For linear infrastructure and access components (including roads, drains, and crossings within both the TSF development area and infrastructure corridor), less stringent design criteria are used depending on criticality of the infrastructure components/elements. Major access roads and bridges are typically designed for 1:100 AEP events, reflecting the importance of such critical transport infrastructure. Minor roads and temporary construction tracks adopt lower design thresholds (e.g., 1:20 AEP), and local drainage elements such as table drains are designed for more frequent events (e.g., 1:10 AEP). This gradation reflects their lower consequence of failure, shorter design life (in the case of temporary works), and the relative ease of repair or replacement following extreme events.

Overall, the project design basis and criteria involve a balance between risk tolerance, functional importance, and economic practicality and reflect a consistent hierarchy of designs:

- TSF and associated systems are designed for extreme, low-probability events (such as PMF)

- Supporting water management systems are designed for moderate to high return period events (typically 1:100 AEP)
- Depending on the criticality, ancillary and linear infrastructure adopts lower return period criteria (1:10 to 1:20 AEP) where appropriate.

By consolidating these design parameters in Table 2, the assessment establishes a framework to support subsequent climate change analysis, particular those related to acute risks. The identified design values—ranging from more frequent, lower-magnitude events (e.g., 1:10 to 1:20 AEP) to rarer, high-consequence events (e.g., 1:100 AEP and PMF conditions)—provide the basis for systematically evaluating how projected changes in future climate may influence both the frequency and magnitude of these events. In the subsequent sections, these design thresholds will be examined against future climate projections to assess the extent to which different components and elements of the project may be exposed to increased probabilities of exceedance, and to characterize the resulting climate-related risks across the infrastructure system.

In addition to these design criteria generally corresponding to extreme events with acute climate risks, construction and operation of the TSF is also subject to chronic climate risks (such as from temperature increases), which can cause the equipment to be operated outside normal conditions for an extended period of time, accelerate the degradation of facility components and infrastructure, and negatively affect the working conditions of the labour force. Additional evaluation of chronic climate risks—including longer-term changes in baseline climate conditions (e.g., precipitation patterns, water balance, and temperature-related processes)—is also addressed in this CCRA.

4. HISTORICAL CLIMATE CHANGE

Evaluating historical climate data is a key step because it evaluated the baseline conditions against which future changes may be defined. Historical records provide insight into natural variability, long-term trends, and the frequency and magnitude of extreme events, all of which are necessary for understanding how the local climate has behaved in the recent past. Twenty-four active hydrometeorology monitoring stations have been established by OTML, many of which provide long-term historical weather and climate data and facilitate the analysis of historical climate change. The historical data from these monitoring stations were then used to investigate climate change in this section: a subset of 6 of the 24 monitoring stations was selected based on their long-term hydrometeorological data to analyse historical climate change. The locations of the hydrometeorology monitoring station relative to the project area are shown in Figure 4.

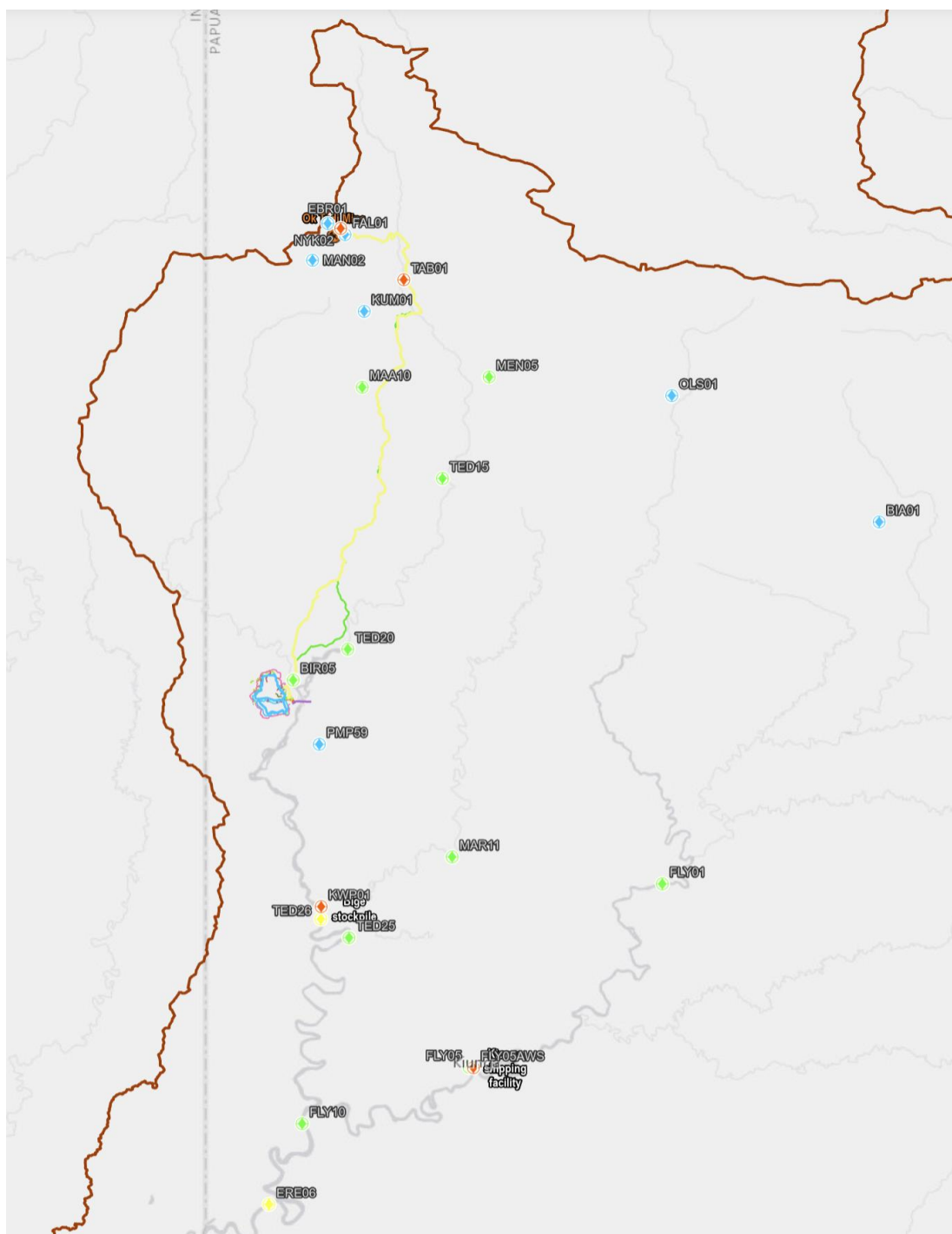


Figure 4. Map of the project location and hydrometeorology monitoring stations. The brown outline shows the boundary of Fly River catchment.

Additionally, the project is located within the Fly River regional catchment or watershed EAP004187 according to HydroBasin global watershed level 4 delineation (Lehner and Grill 2013). The location of the greater Fly River catchment relative to the project site is shown in Figure 5. Both historical climate conditions and future projections of the Fly River catchment are provided by the World Bank’s Climate Change Knowledge Portal (CCKP; World Bank Group, 2025). The downloaded data from the CCKP were subsequently used to assess historical and future climate change.



Figure 5. The location of the Fly River catchment relative to the project area.

Long-term precipitation (or rainfall) records from the OTML monitoring stations were compiled and used to assess historical changes of two annual precipitation indices in Figure 6: annual total precipitation and maximum 1-day precipitation.

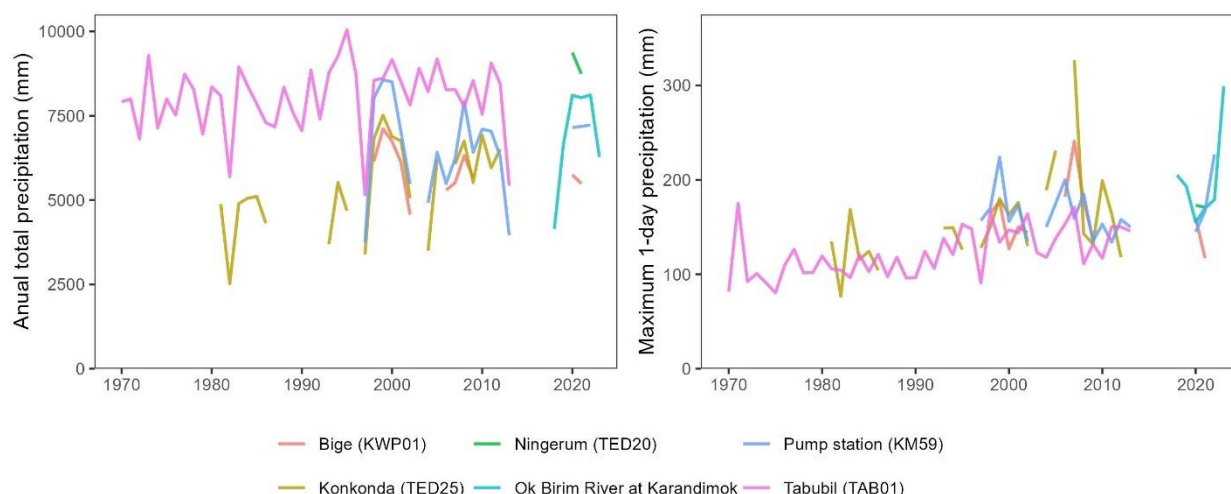


Figure 6. Historical precipitation records from selected monitoring stations.

The regional climate is characterized by persistently high precipitation, both in terms of annual totals and short-duration extremes, driven by a combination of large-scale atmospheric controls and local topographic effects (as also described in the previous section). Rainfall is influenced by the seasonal interaction of the Southeast Trade Winds and the Northwest Monsoon, together with the migration of ITCZ. As shown in Figure 6, the region experiences very high annual precipitation, typically ranging from approximately 4,000 mm to over 10,000 mm. Extreme rainfall intensities (as suggested by the 1-day precipitation) are also high in the region.

Substantial spatial variability in both annual precipitation and rainfall extremes is evident in Figure 6, reflecting differences in elevation and exposure to prevailing weather systems. Higher-elevation inland stations such as Tabubil (TAB01) record greater annual precipitation totals, consistent with orographic effects under trade wind conditions. In contrast, lower-elevation stations, including Konkonda (TED25) and PMP59 (KM59), generally exhibit lower annual totals, although the annual maximum 1-day precipitation of these two stations can be higher than that of Tabubil (TAB01) station. This indicates that while total rainfall accumulation is strongly influenced by elevation and terrain, extreme rainfall intensity can be closely associated with localized convective processes, particularly during the monsoon season.

Within this high-rainfall and spatially variable baseline, temporal trends indicate that changes in precipitation extremes are more pronounced than changes in annual average precipitation. As shown in Figure 6, the TAB01 station—providing the longest continuous record—shows no clear trend in annual totals but a notable increase in maximum 1-day precipitation. Although other stations have shorter or less complete records, their data are generally consistent with this pattern. This suggests that, regional climate variability and change may be more strongly expressed through increases in rainfall intensity and extremes rather than shifts in mean annual precipitation.

Using the full record of annual maximum 1-day precipitation at the Tabubil (TAB01) station (Figure 6), precipitation intensities corresponding to various AEPs, as well as the PMP, were estimated. Tabubil (TAB01) station was used, because it provides the longest period of record among all monitoring stations that were provided to us. The results of precipitation intensities estimated for the TAB01 stations are thus provided in Table 3.

Table 3. Estimated historical intensities (mm/hr) of precipitation extremes.

Duration and AEP	Historical, TAB01	Historical, near TSF, based on ratio of TAB01 and KM59 stations
24-hour, 1:2	5.7	7.6
24-hour, 1:5	6.7	9.0
24-hour, 1:10	7.3	9.8
24-hour, 1:20	7.8	10.5
24-hour, 1:50	8.4	11.3
24-hour, 1:100	8.8	11.8
72-hour, PMP	10.8	11.9

These results of extreme rainfall analyses with a 24-hour duration and different AEPs in Table 3 were obtained following a typical estimation method. The historical maximum 1-day precipitation records of TAB01 station shown in Figure 6 were used to estimate rainfall intensities with different AEPs by fitting with a generalized extreme value (GEV) distribution. This method has been used by the U.S. National Oceanic and Atmospheric Administration for extreme precipitation analysis (Perica et al. 2024). Estimated 1-day precipitation intensities are further scaled by 1.13 to calculate the 24-hour intensities to account for daily precipitation that is reported with fixed 24-hour intervals (DeGaetano and Zarrow 2011).

The 72-hour PMP in Table 4 is based on the Hershfield method for the PMP analysis (Sarkar and Maity 2020; WMO 2009). The Hershfield method represents an efficient statistical method of estimating PMP, as opposed to physics-based methods, which require a significant amount of historical storm data and data processing (NASEM 2024). The precipitation records from the TAB01 station were used to calculate annual maximum 3-day precipitation, which was then used to estimate PMP by using a default, conservative value of 15 (Hershfield 1961; Sarkar and Maity 2020) as the frequency scale factor (i.e., $PMP = \text{mean} + 15 * \text{standard deviation}$). No additional scaling factor was applied to convert 3-day precipitation to 72-hour amount, assuming the recorded annual maximum of 3-day precipitation is similar to that of 72-hour amount.

Additionally, the precipitation intensities near the project area were derived. These estimates are informed by data from the KM59 station (also shown in Figure 6), which is located in close proximity to the TSF development area. However, KM59 data were not used directly for extreme value analysis due to the limited length of its record. To account for spatial differences between stations, results from TAB01 were scaled to KM59 using the average ratios of annual maximum precipitation between the two stations. On average, annual maximum 1-day and 3-day precipitation at KM59 are approximately 35% and 10% higher, respectively, than those at TAB01. The results of precipitation intensities estimated for the KM59 stations are also provided in Table 3.

It should be noted that, although the measured precipitation data from the local monitoring stations begin in 1970 for the TAB01 station, these data records are still limited with respect to analysing long-term climate change trends and extreme value analyses. Many project designs involve the calculations of AEPs from 1:100 to 1:10,000 as well as PMP, which have significantly smaller frequency and generally benefit from a longer period of data.

In addition to precipitation data, the local monitoring stations also provide other historical climate data such as temperature, humidity, and wind speed. However, because such climate variables are more limited with respect to the reporting data periods, the long-term time series and trend analysis were not performed. Instead, the historical reanalysis data as well as historical results from the CCKP (World Bank Group 2025) are used to examine long-term trends in the other climate variables.

Long-term historical average temperature and precipitation changes based on the climate reanalysis data (Hersbach et al. 2020) provided by World Bank Group (2025) were further studied for the region. The results from the CCKP for the Fly River regional catchment are presented in Figure 7.

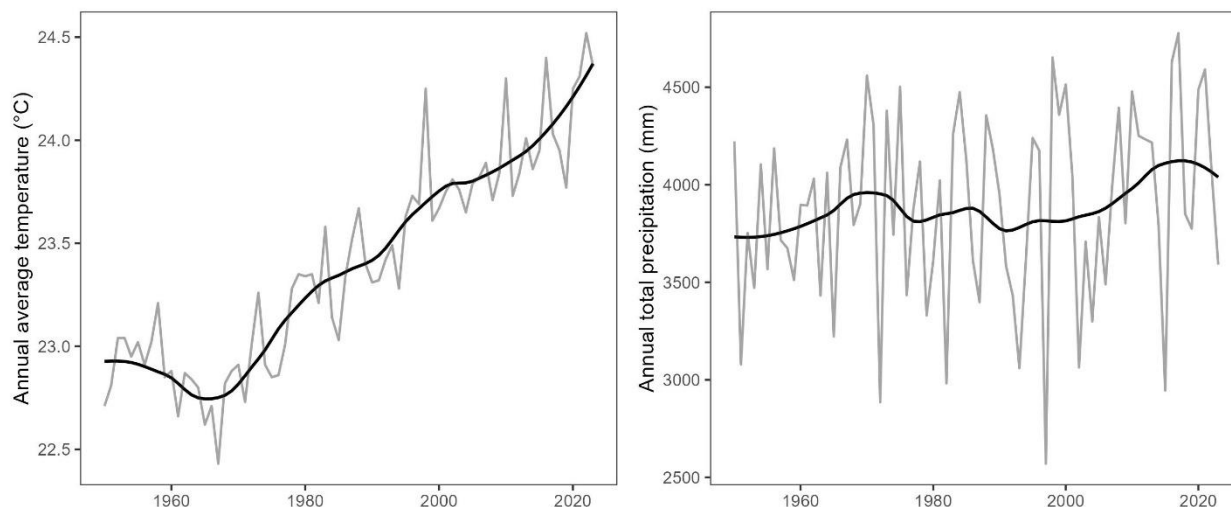


Figure 7. Historical annual average temperature and total precipitation of the Fly River catchment during 1950 to 2023 based on the ERA5 reanalysis data (Hersbach et al. 2020). Results provided by World Bank Group (2025).

As shown in Figure 7, annual average temperature increased around 1.5°C from 1950 to 2023 in the Fly River catchment, whereas the annual precipitation change is not evident. Such results are consistent with the previous findings in the IPCC's Sixth Assessment Report (IPCC 2022) and McGree et al. (2019).

Consequently, based on the existing climate data, the following conclusions can be derived regarding historical climate change in the region: historical temperature near the project location exhibits a notable increasing trend, annual average precipitation shows no observable change, whereas an increase of precipitation extremes is more evident.

5. FUTURE CLIMATE PROJECTIONS

Future projections of climate change were assessed based on the CCKP results (World Bank Group 2025) in Figure 8 and Figure 9. The results are based on the GCM simulations from the CMIP6 analysis using four different SSP scenarios, identified as SSP1-2.6, SSP2-4.5, SSP3-7.0, SSP5-8.5, corresponding to greater radiative forcing due to increasing greenhouse gas concentrations, and thus increasing impacts of climate change over the 21st century. In this case, the four SSP scenarios were analysed to capture the greater range of plausible future conditions; this CCRA, as mentioned previously, focuses on SSP2-4.5 and SSP5-8.5 as representative “central” and “upper-bound” cases, respectively. SSP2-4.5 and SSP5-8.5 scenarios are considered most relevant for risk evaluation and decision-making in this work, reflecting both the most likely trajectory based on current policy trends and a conservative sensitivity case (UNEP 2025; Venmans and Carr 2024). Results from the additional scenarios are included in this section to provide context and to illustrate the broader range of potential variability.

Additionally, six climate indices are presented in these figures: annual average temperature and precipitation changes (which indicate the changes in average temperature and precipitation conditions), changes in annual daily maximum temperature (i.e., suggesting the changes in temperature extremes), changes in annual maximum 1-day precipitation (indicating changes in precipitation extremes), annual Standardized Precipitation Evapotranspiration Index (SPEI) and relative humidity anomaly (indicating projected drought conditions).

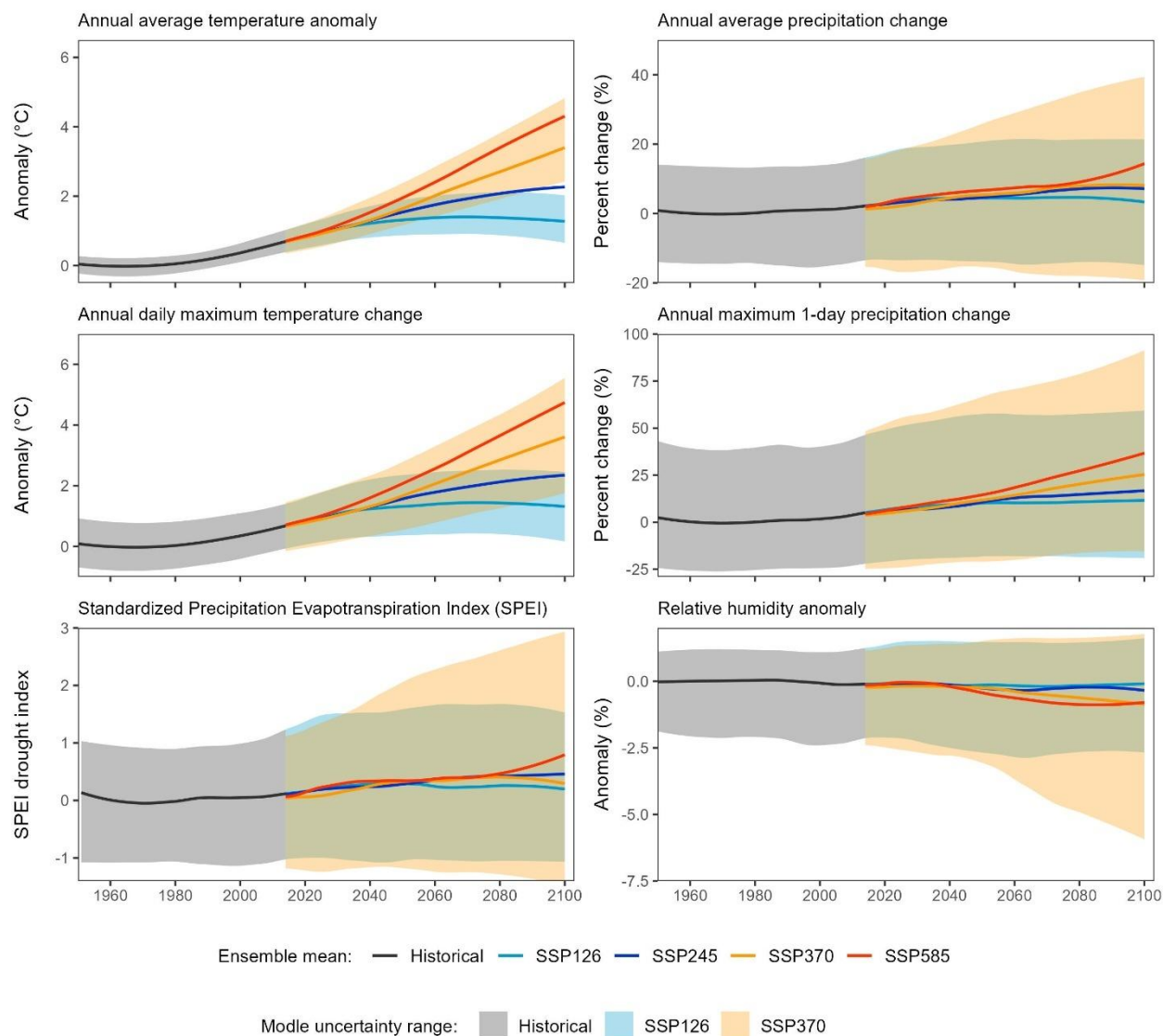


Figure 8. Climate projections for the Fly River catchment. Modelled 80% confidence intervals are presented for historical, SSP1-2.6, and SSP3-7.0 simulations. Results provided by World Bank Group (2025).

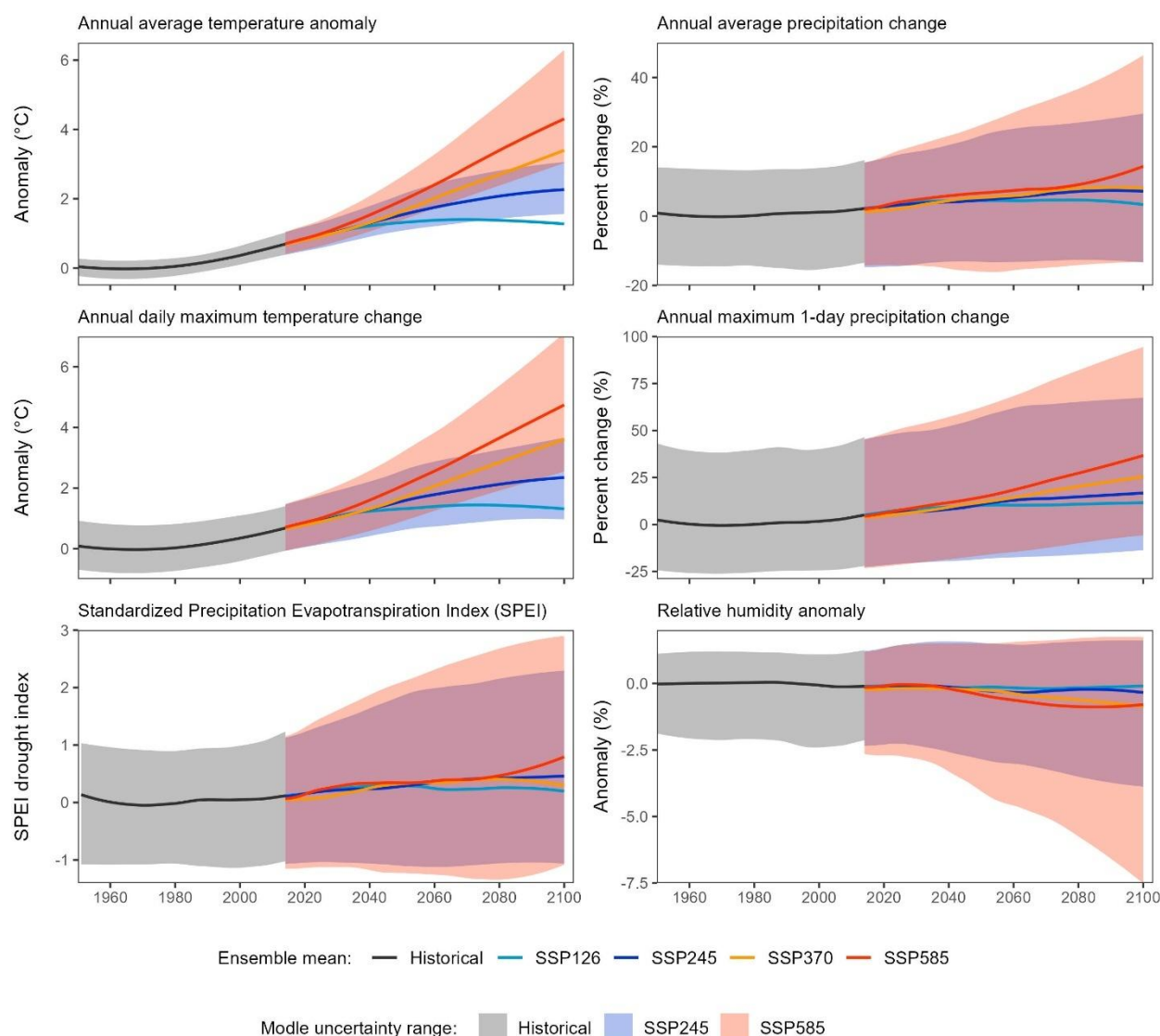


Figure 9. Climate projections for the Fly River catchment. Modelled 80% confidence intervals are presented for historical, SSP2-4.5, and SSP5-8.5 simulations. Results provided by World Bank Group (2025).

The projections in Figure 8 and Figure 9 show a notable increase in temperature in both average conditions and extremes, a modest increase in average precipitation, and a larger increase in precipitation extremes. Upper confidence intervals of projected SPEI drought index show increases in some SSP scenarios, suggesting wetter conditions. At the same time, the lower confidence intervals of relative humidity anomalies exhibit a decrease in some SSP scenarios, indicating increased probabilities of drought conditions. Such results suggest that the projections of droughts are inconclusive, while it is likely the average conditions will become wetter while droughts can be more severe.

6. ASSESSMENT OF SELECTED CLIMATE HAZARDS

The results presented in the previous sections provide a characterization of both historical climate change and projected future climate conditions for the project area, which together form the basis for identifying and screening relevant climate hazards. In accordance with a risk-informed approach, hazards are selected for further assessment based on: 1) the magnitude and direction of projected climate changes, 2) the exposure of the project given its geographic and environmental setting, and 3) the potential for these hazards to affect the performance, integrity, or operation of the TSF and associated infrastructure.

Climate projections in the previous section suggest that the most pronounced changes are associated with increasing temperature (including more frequent extreme heat conditions) and greater intensity of precipitation extremes. Such changes are directly related to the project, as they serve as key risk drivers including water balance, runoff generation, erosion processes, geochemical behaviour of tailings, and operational conditions. Therefore, (i) extreme heat and prolonged hot days and (ii) rainfall extremes and associated flooding are identified as two key climate hazards for detailed assessment.

In addition to these climate-driven hazards, site-specific factors are considered in the screening process. The project is located in a densely vegetated tropical environment (see Figure 10), which introduces exposure to wildfire risk, particularly under conditions of elevated temperature and potential drying. Although projections of wildfire trends remain uncertain, the presence of extensive surrounding vegetation and historical occurrence of fires in the broader region warrant inclusion of wildfire as a relevant operational hazard.

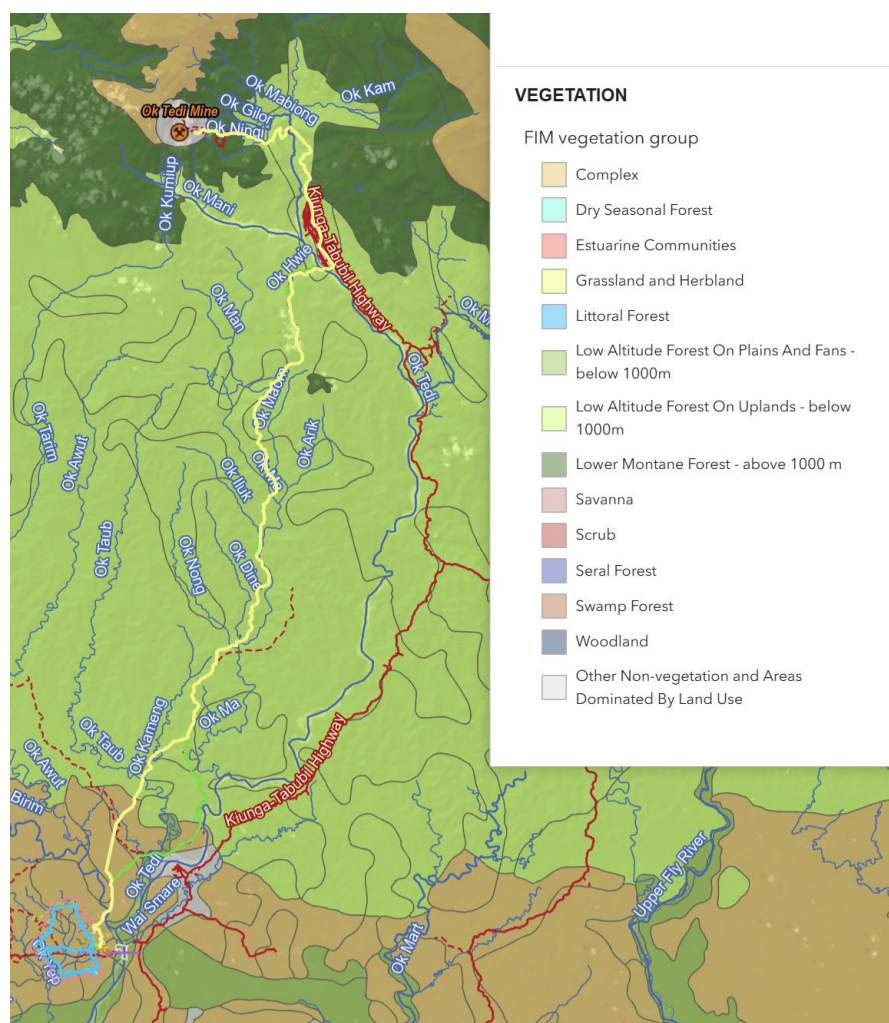


Figure 10. Land cover and vegetation types in the project area.

Tropical cyclones are also considered despite the inland location of the project. While direct exposure to cyclone landfall is low and the site is not influenced by coastal processes such as storm surge or sea level rise, cyclonic systems in the region can generate intense rainfall and, in some cases, strong wind fields that extend inland. Assessment of tropical cyclones is therefore included to evaluate potential indirect impacts and to confirm the level of risk to the project under current and future climate conditions.

Other potential hazards—such as sea level rise and coastal flooding—are screened out due to the project’s inland location and lack of exposure.

Based on this screening process, four climate hazards are selected for further analysis: 1) extreme heat and prolonged hot days, 2) rainfall extremes and flooding, 3) wildfires, and 4) tropical cyclones. These hazards represent the main pathways through which climate change may influence the project’s physical performance and operational resilience over its lifecycle.

6.1 EXTREME HEAT AND PROLONGED HOT DAYS

Historical and future projected temperature (both averages and extremes) show 2-4°C increases from 1950 to the end of century in the project region as shown in Figure 8 and Figure 9. Such increases of temperature as well as temperature extremes are considered as a key climate hazard: extreme temperature events and prolonged hot days pose chronic climate risks related to underground water infrastructures such as pipelines

(e.g., Wols & Van Thienen, 2014), operation conditions of water quality (Price 2009), equipment, and labour force (e.g., as suggested by Somanathan et al., 2021).

Historical and projected numbers of hot days are shown in Figure 11 using two indices: the number of days in a year with daily maximum temperature ($T_{\max}$) above 30 and 35 °C.

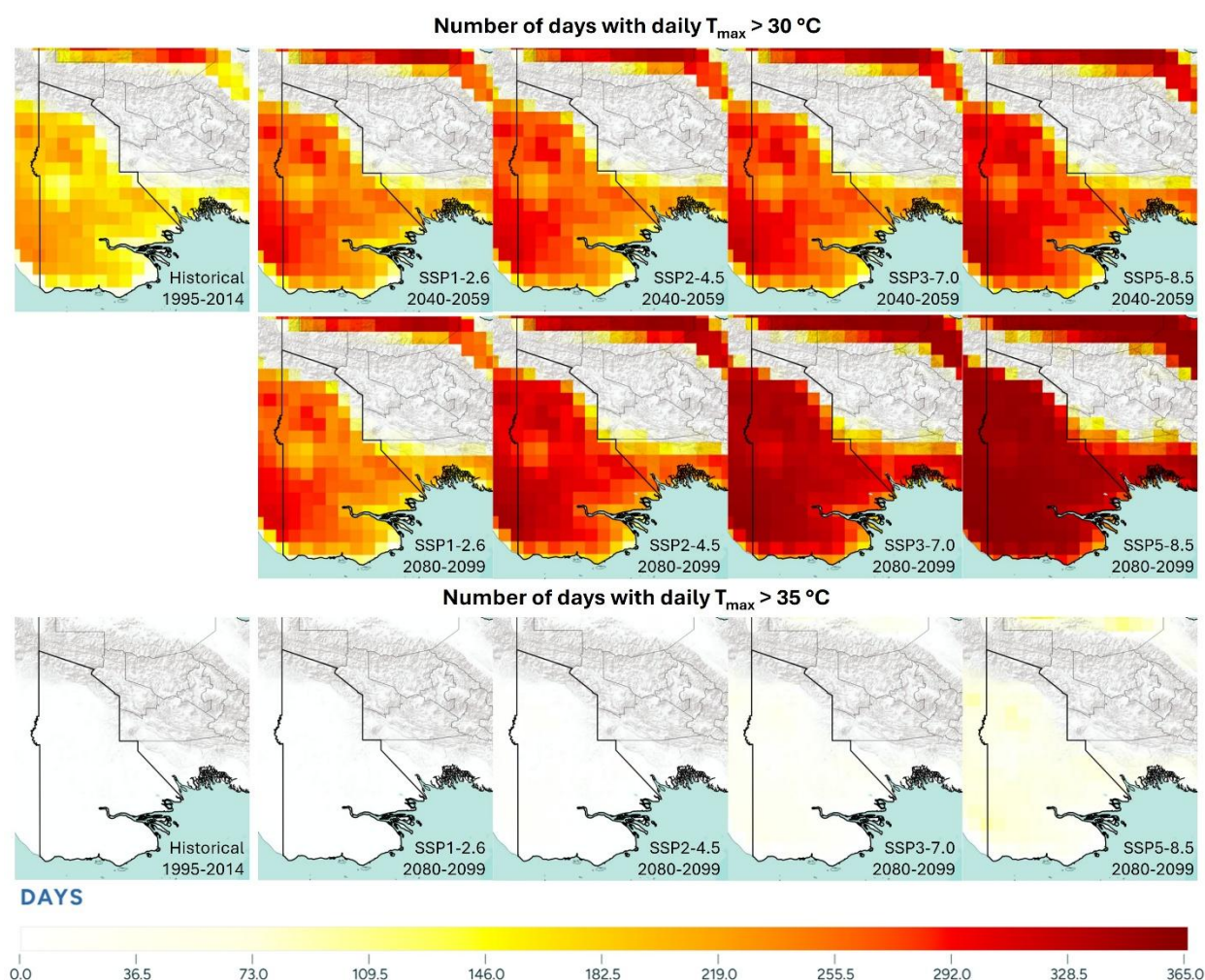


Figure 11. Historical and projected temperature extremes. Results provided by World Bank Group (2025). The perimeter in darker lines show the Western Province.

As shown in Figure 11, the numbers of days with $T_{\max}$ greater than 30 °C largely increase and the days with $T_{\max}$ greater than 35 °C (which do not typically happen historically) are projected to occur more often in some scenarios. The historical period of 1995-2014 is calculated with an average of 153 days with $T_{\max}$ greater than 30 °C, which increases to around 230 days by the mid-century (differences among SSPs are minor) and to around 300 days under SSP2-4.5 and 350 days under SSP5-8.5 by the end of the century. Days with $T_{\max}$ greater than 35 °C also occur more often by the end of the century; SSP 5-8.5 shows greater increases in number of these hot days (~ 80 days by the end of the century).

Increasing ambient temperature could, hypothetically, lead to acceleration of the processes associated with acid and metalliferous drainage (AMD) in TSF as a result of increased rates of sulphide oxidation reactions and associated geochemical pathways (Fan et al. 2022; Park et al. 2019; Price 2009). Tailings for copper porphyry deposits and flotation circuits typically contain residual sulphide minerals such as pyrite and when these sulphide-bearing tailings are potentially acid forming (PAF) and are exposed to oxygen and water during deposition and long-term storage, they can become a major source of AMD, leading to acidification and elevated metal concentrations (Price 2009). Temperature is a major factor in reaction kinetics, i.e., higher

temperatures cause increases in oxidation rates and thus acid generation (Fan et al. 2022; Price 2009). In addition, sulphide oxidation can elevate internal temperatures within tailings (Price 2009); this self-heating enhances oxidation kinetics and can increase oxygen flux through advective processes, reinforcing AMD generation.

Geochemical characterisation kinetic testwork for the project showed that tailings oxidation rates are reduced by one to two orders of magnitude when saturated, suggesting on average TSF tailings oxidation rates are likely to be relatively low. The leachate pH for all samples under both free draining and saturated conditions remained neutral through the first 4 months of testing, consistent with the non-acid forming (NAF) AMD classification of these materials; the leachate chemistry for all samples under both free draining and saturated conditions are dominated by calcium and SO_4 , consistent with ongoing sulphide oxidation and concomitant calcite dissolution and acid neutralisation, albeit at a much reduced rate in saturated columns. Leachate copper concentrations are similar for saturated and free draining columns, suggesting that copper is not readily mobilised from these tailings, even under the oxidising conditions of the free draining columns.

While increased temperatures may increase oxidation kinetics this is not expected to fundamentally change the NAF characterisation of the tailings given their average oxidation rates are already likely to be relatively low. The ongoing removal of pyrite by the Tailings Processing Plant and limestone addition to the mill to increase acid neutralizing capacity (OTML 2025) will help manage this risk. The project proposes a comprehensive water monitoring program to detect changes to the geochemical behaviour of tailings and this is anticipated to detect any climate-related change in leachate. Further, the closure plan design for the TSF involves capping the facility with NAF material, further limiting the potential for ongoing oxidation of the NAF tailings.

While extreme heat is not expected to trigger acute failure modes for the TSF, projected increases in ambient temperature and the frequency of hot days represent a material chronic stressor on both workforce and mechanical and infrastructure systems. Elevated temperatures reduce labour productivity, particularly in hot and humid environments, through heat stress, fatigue, and increased risk of heat-related illness; with studies indicating measurable declines in work productivity above wet-bulb temperatures of $\sim 30^\circ\text{C}$ (Burke et al. 2015; Dunne et al. 2013). The projected increase in temperature and prolonged hot days will therefore result in reduced effective working hours, increased need for work-rest cycles, and potential impacts on construction and operational scheduling of the project. Sustained high temperatures can also degrade the performance and reliability of equipment and infrastructure. Thermal stress can reduce pump and generator efficiency and accelerate wear of mechanical components (Guddanti et al. 2025). For pipelines, elevated temperatures can influence material properties (e.g., thermal expansion, reduced stiffness of polymer components), as well as soil–structure interaction through drying, shrinkage, or softening of foundation materials; potentially affecting alignment, support conditions, and long-term integrity of pipelines (Wols and Van Thienen 2014). Although these effects are gradual and unlikely to result in systematic failure, they can cumulatively increase maintenance requirements, reduce asset lifespan, and introduce operational inefficiencies over time.

6.2 RAINFALL EXTREMES AND FLOODING

Rainfall extremes and associated pluvial and riverine flooding events represent a critical climate hazard for the project, given the dominant role of intense precipitation in controlling hydrological response, water management performance, and TSF stability. As described in the previous section, the design of many project components is based on rainfall- and flood-related design criteria expressed in terms of AEP, ranging from more frequent operational events (e.g., 1:10 to 1:100 AEP) to extreme conditions defined by PMP/PMF.

Building on the compiled design basis and criteria information in the previous section, the assessment here adopts a structured approach to evaluate climate-related risks associated with precipitation and flooding. First, precipitation magnitudes corresponding to a range of AEPs, as well as Probable Maximum Precipitation (PMP), were independently derived using available historical rainfall records (as described in Section 4). This

is undertaken using standard extreme value analysis techniques to establish a consistent, site-relevant set of baseline design rainfall estimates. Such estimates are then compared with the design values of same AEPs and PMP used in the project design. Subsequently, projected changes in precipitation extremes derived from GCM results were applied and used to inform future precipitation design values via a change-factor approach. These adjusted rainfall intensities thus reflect potential future climate conditions.

The resulting historical and climate-change-adjusted precipitation estimates provide a quantitative basis for comparison with the design values used in the project designs, enabling an evaluation of the resilience of different infrastructure components to future changes in rainfall intensity and associated flooding.

Building upon the historical extreme precipitation intensities shown in Table 3 and to consider the projected future conditions, annual maximum 1-day precipitation shown in Figure 8 and Figure 9 are then used to estimate the increase of precipitation intensities in 2050 and 2100 in Figure 12.

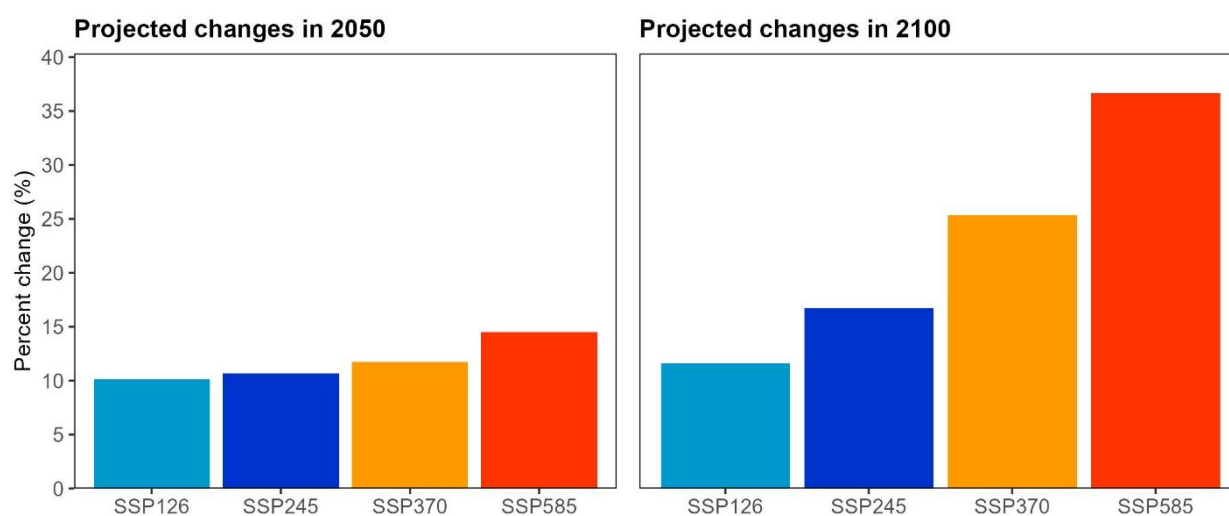


Figure 12. Projected average changes in annual maximum 1-day precipitation from present 2024 to 2050 and 2100 based on the CCKP projections for the EAP004187 watershed (projections of maximum consecutive 3-day precipitation are not available).

Figure 12 shows a range of 10-35% increases in annual maximum 1-day precipitation, depending on climate scenario; consequently, such 10-35% increases of precipitation extremes were used to project the future range of precipitation extremes. The results of projected future precipitation intensities are thus presented in Table 4.

Table 4. Estimated historical and future precipitation intensities (mm/hr) near the project area and a comparison with the values reported by KCB (2024).

Duration and AEP	Historical, derived near TSF (refer to Table 3)	Future, lower bound (10% increase)	Future, upper bound (35% increase)	KCB 2024 estimates used for Basis of Design ¹
24-hour, 1:2	7.6	8.4	10.3	7.6
24-hour, 1:5	9.0	9.9	12.2	9.0
24-hour, 1:10	9.8	10.8	13.3	9.8
24-hour, 1:20	10.5	11.6	14.2	10.7
24-hour, 1:50	11.3	12.4	15.3	11.8

¹ Klobn Crippen Berger Ltd. (KCB) 2024. Ok Birim Tailings Storage Facility Pre-Feasibility Study: Basis of Design. Appendix V - Surface Water Management. Table V-3.

24-hour, 1:100	11.8	13.0	16.0	12.7
72-hour, PMP	11.9	13.1	16.1	19.6

The estimated increases of 10 to 35% represent the approximated lower and upper bounds of future precipitation increase. The 10% and 35% increases as scale factors follow a simplified change factor method, i.e., projected increases from GCMs are calculated with adjustment factors of changes and then applied to historical estimates (Perica et al. 2024). A 10 to 35% increase thus aligns with the projected average increases in Figure 12 and indicate the future precipitation intensities at the TSF area (10% and 35% increases approximately present the lower and upper bounds of the increases). The 10-35% increases also align with basic physics through the Clausius-Clapeyron relation (~7% increase of precipitation per °C temperature increase), given the temperature increases are around 1 to 3°C from 2025 to the end of century.

The previously estimated precipitation intensity values in KCB (2024) are further shown in the rightmost column of Table 4. As suggested by Table 4, the estimated precipitation intensities in KCB (2024) at different AEPs align closely with our independent estimates for the project area. Because of the projected increase of future precipitation extremes, the estimates in KCB (2024) are slightly lower than the projected future values for more frequent precipitation events. The PMP estimate in KCB (2024), however, is conservative and is substantially larger than the results in Table 4, including the estimate with a 35% increase from historical levels.

Our independent analysis thus suggests that the PMP-based designs for the TSF are robust and subject to a limited future climate risk; other design components based on more frequent precipitation events (such as those associated with sediment ponds) are sufficient under current and near-future climate conditions, reasonable for the 20-year duration of the project, but are subject to a larger climate risk in a longer-term timeframe. However, the longer term climate risk is less of a concern because several operational components are not expected to be active beyond 2052 such as sedimentation ponds and temporary access tracks. However, some elements may continue to be in use, such as certain roads and bridges, and for these elements, continued consideration of climate change effects and adaptive management may be appropriate, as outlined in the following section.

In addition to pluvial processes, projections of riverine flooding from World Resources Institute's Aqueduct Floods (WRI 2020) are used to provide a preliminary assessment of potential changes in fluvial conditions. WRI (2020) provides modelled flood inundation estimates based on an ensemble of five CMIP5 GCMs under selected Representative Concentration Pathway (RCP) scenarios. Such modelling analysis relies on global-scale models with coarse spatial resolution and generalized hydrological assumptions, which do not explicitly account for the complex, site-specific conditions of the Ok Tedi system.

Such results are therefore interpreted as informing relative changes in flood extent and frequency rather than absolute flood magnitudes, given the substantial uncertainty associated with limited hydrological data and the significant influence of historical mining-related sediment transport on river morphology and hydraulics (as mentioned in Section 3). Accordingly, the riverine flooding analysis based on WRI (2020) is used in a complementary and exploratory manner to support understanding of potential trends, rather than as a definitive prediction of future flood behaviour. If riverbed conditions stabilize to levels pre-dating the operations and sediment discharges of the OTML, then the regional scale projections suggest that climate change may cause greater flooding. However, as noted in Section 3, this projection is complicated by the changing sediment dynamics in the basin, including due to the reduction from sediment loads as a consequence of the construction of the TSF. Indeed, the reduction of bed levels due to reduced sediment supply would be likely to decrease the incidence of the overflow of rivers across their banks. It is noted that this process counters the projection of greater riverine flooding in the global-scale analysis represented by WRI (2020), the results of which are presented in Figure 13 for two AEPs (1:10 and 1:100).

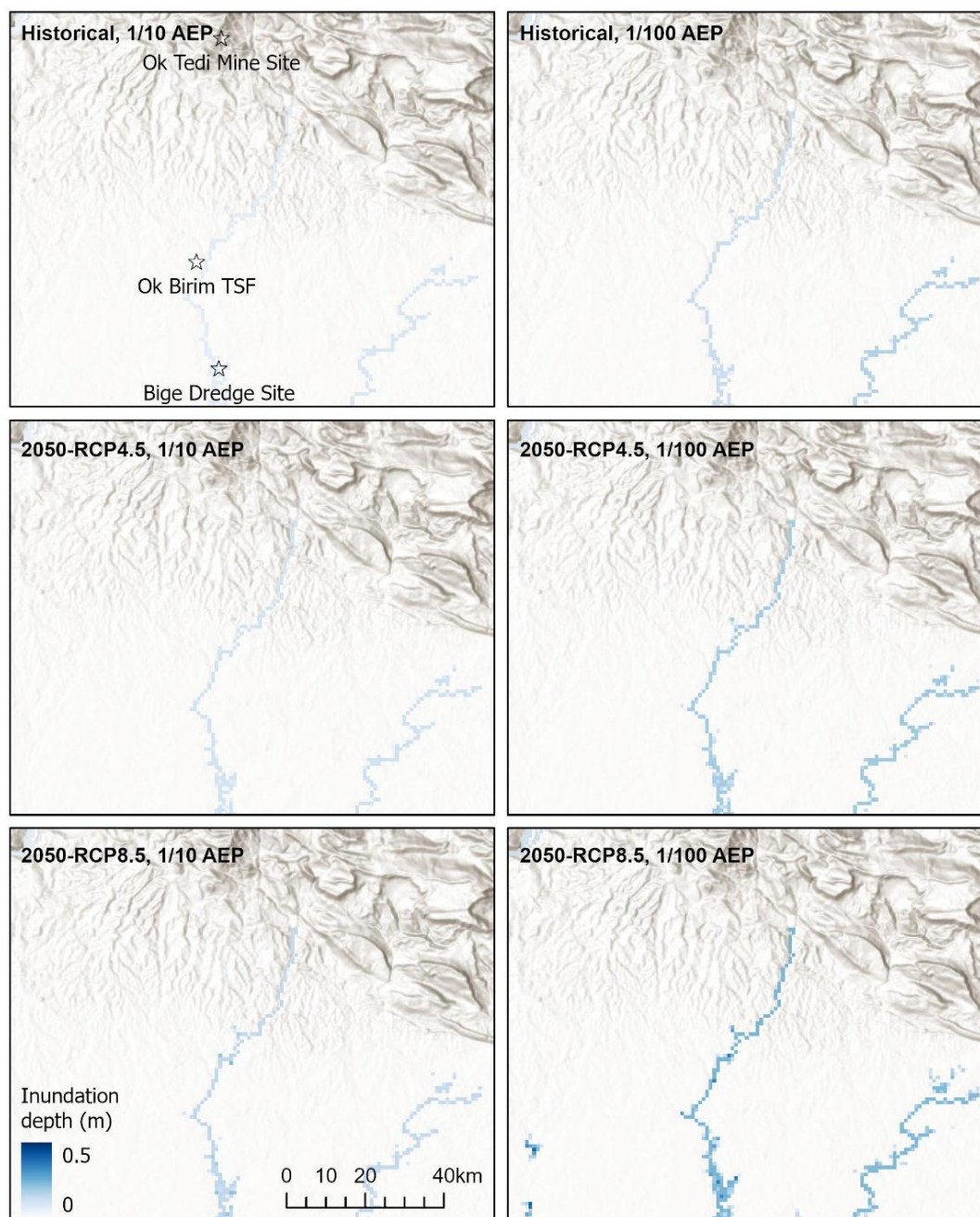


Figure 13. Inundation maps of historical and projected mid-century conditions (in RCP 4.5 and 8.5; average among five GCMs; only CMIP5 results are available) with (left) 1/10 and (right) 1/100 AEPs. Results provided by the World Resources Institute's Aqueduct Floods (WRI 2020).

The results in Figure 13 indicate a general increase in riverine flooding under future climate conditions, although these projections should be interpreted with caution given the limitations discussed previously. For example, model outputs suggest that inundation depths in the vicinity of the TSF may increase from approximately 0.05–0.1 m under historical conditions to around 0.1–0.2 m by mid-century (2050) and 0.15–0.3 m by late century (2080). While these changes provide an indication of a potential upward trend in flood magnitude, they are not considered precise predictions of site-specific flood behaviour due to uncertainties associated with model resolution and the complex hydrodynamics of the Ok Tedi system.

Nonetheless, the projected increases in riverine flooding potentially suggest the heightened exposure of certain project design components/elements, particularly those designed to more frequent events. Supporting

water management systems, which are designed for 1:100 AEP, and ancillary or linear infrastructure (e.g., roads, drainage systems, bridges and crossings) designed for more frequent events (e.g., 1:10 to 1:20 AEP), may be more susceptible to increased frequency of exceedance or reduced performance under future conditions. A water balance assessment conducted in KCB (2026) shows that, comparing the base case scenario with an upper SSP5-8.5 scenario, 5% higher total inflows, outflows, and discharges to Ok Tedi are projected under the upper case scenario. The TSF storage and spillway system, which is based on conservative PMP/PMF-based design criteria, is expected to retain a high degree of robustness.

6.3 WILDFIRES

The project area is located within a heavily forested landscape (see Figure 10 and Figure 14 part (a)), which provides fuel load and thus exposure to wildfire hazards. Climate projections of relative humidity (Figure 8 and Figure 9) indicate a potential for a decrease in the lower bound of humidity under higher emission scenarios, which could contribute to more favourable conditions for fire ignition and spread during dry periods. Therefore, wildfire risk is included for further assessment in this section.

Historical fire impacts are analysed in Figure 14 parts (b) and (c), which present spatial patterns of forest losses from 2001 to 2024 based on Tyukavina et al. (2022) and are also used by the World Resources Institute's Global Forest Watch (WRI 2025). It should be noted that the mapped forest loss includes all causes of forest cover change and is not limited to fire-related losses exclusively. At the regional scale, the Western Province has experienced some notable fire-related impacts historically, particularly in areas toward the southeast of the province near the coastline. In contrast to these broader regional patterns, the historical fire losses in close proximity to the TSF development area appear limited according to Figure 14, with much of forest losses attributable to non-fire-related losses. Such results suggest that, while wildfire is a recognized hazard at the regional scale and the extensive forest landscape in the project area creates a fire hazard environment, the observed occurrences of wildfires in the project area are limited.

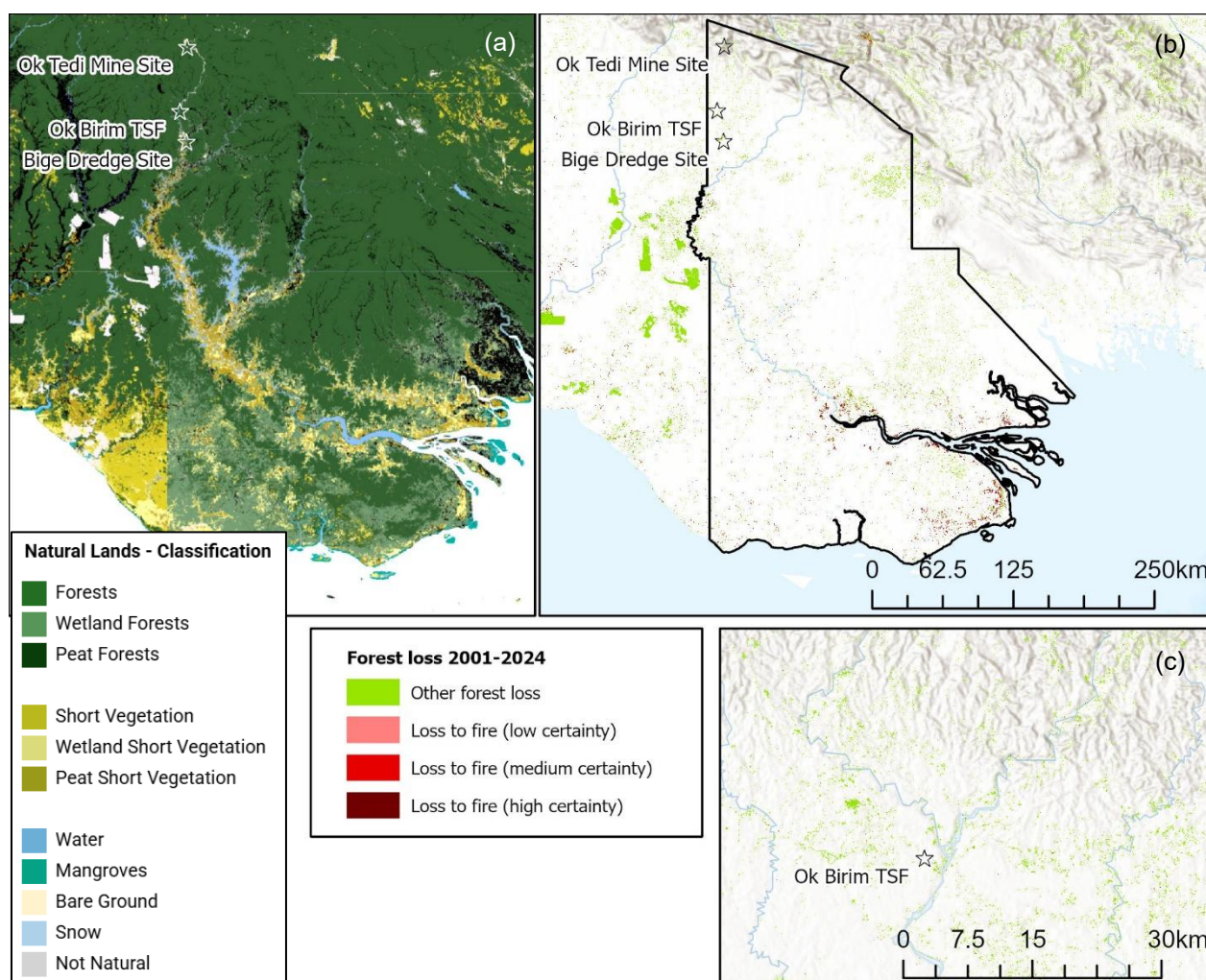


Figure 14. (a) SBTN (science-based target networks) natural land cover map (Mazur et al. 2024) and (b and c) historical forest loss from 2001 to 2024 from Tyukavina et al. (2022). The perimeter in darker lines show the Western Province of PNG.

Quantified historical burned areas from 2002 to 2023 in the Western Province were obtained from Copernicus Programme (2025) which provides the historical burned area by land cover types. These data are presented in Figure 15. Figure 15 suggests no notable increase of burned area from 2002 to 2023 and much of the burned area in the Western Province belongs to shrublands/grasslands with bushfires. Such landcover types of shrublands/grasslands generally align with the short vegetation types in Figure 14: historical events of fires therefore are generally located within the southeast part of the Western Province near the coastline with a greater cover of short vegetation while fire events in forestland near the project area are comparatively limited. However, the annual burned area and fire hazard in the Western Province are significant and based on Copernicus Programme (2025), the Western Province has the highest burned area and number of fires (~1171 km² and 651 fires per year) among all provinces of PNG.

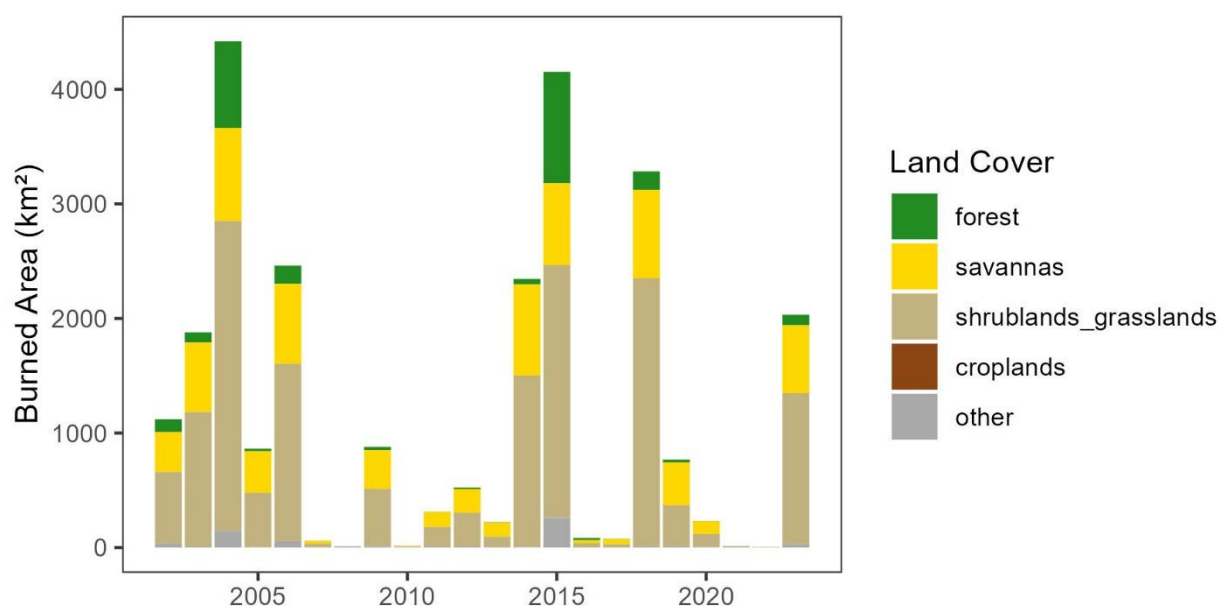


Figure 15. Annual total area burned by land cover types in the Western Province. Data provided by Copernicus Programme (2025).

Studies related to the effect of future climate change on wild fires in the region are inconclusive. Climate projections in Figure 8 and Figure 9 show an increase of temperature, a moderate increase of precipitation, and a no notable change in the average level of humidity in the region (although lower bound decreases in some scenarios). Studies such as Richardson et al. (2022) also found that the pre-conditioned droughts and fire weather are not projected to change in the region. Similarly, as shown in Figure 15, no notable trend can be identified in the historically burned area, suggesting that the effect of climate change on increasing fire risks may be limited. However, given the extensive forest landscape, the project area has an exposure to fire risks and planning and management of such fire risks are needed (although climate change may not necessarily increase such risks in the future).

6.4 TROPICAL CYCLONES

In addition to extreme rainfall, tropical cyclones (TCs) are associated with intense precipitation and strong wind fields that can affect infrastructure and operations. Although the TSF site is located inland—hundreds of kilometres from the coastline—and is not exposed to coastal hazards such as storm surge or sea level rise, tropical cyclone systems occurring in the broader region may still influence inland areas through extreme rainfall and wind conditions. Tropical cyclones are therefore considered in this section to evaluate the potential for such indirect influences on the project area, including the extent to which cyclone-related rainfall and wind effects may contribute to site-relevant hazards. This assessment also considers whether projected changes in tropical cyclone characteristics—such as intensity, frequency, or regional patterns—could affect the level of exposure of the TSF site under future climate change conditions.

Historical TC tracks in the broader region, based on data from the Australian Bureau of Meteorology (IMAS, 2023), are presented in Figure 15. As shown, the project area is located approximately 300 km from the nearest recorded TC track centreline, indicating no direct historical cyclone passage over the project area. TCs typically have spatial extents in the order of hundreds of kilometres (NOAA 2026), the peripheral effects such as rainfall and wind may still affect the project area to a degree.

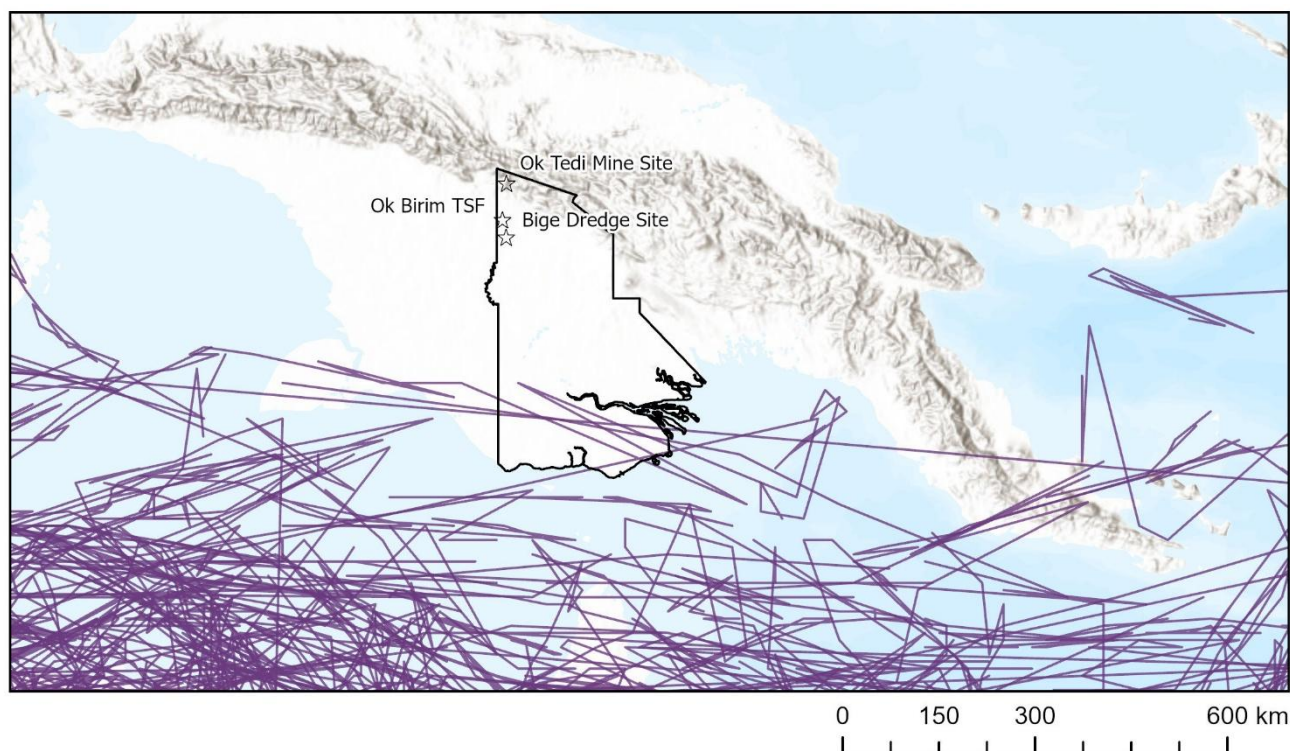


Figure 16. Tropical cyclone tracks (1907 to 2023) near the Western Province of the PNG. Data provided by the Australian Bureau of Meteorology.

Additionally, the estimated historical frequencies of tropical cyclones for each tropical cyclone category are shown in Figure 17. These results were obtained from the World Bank's CCKP (World Bank Group 2025). As suggested by Figure 17, the broader region has a relatively limited exposure to tropical cyclones, with the Category 1 tropical cyclones having an AEP of lower than 1:50. Tropical cyclones greater than Category 1 are not expected (i.e., to have a minimal probability) to occur near the region, as shown in Figure 17.

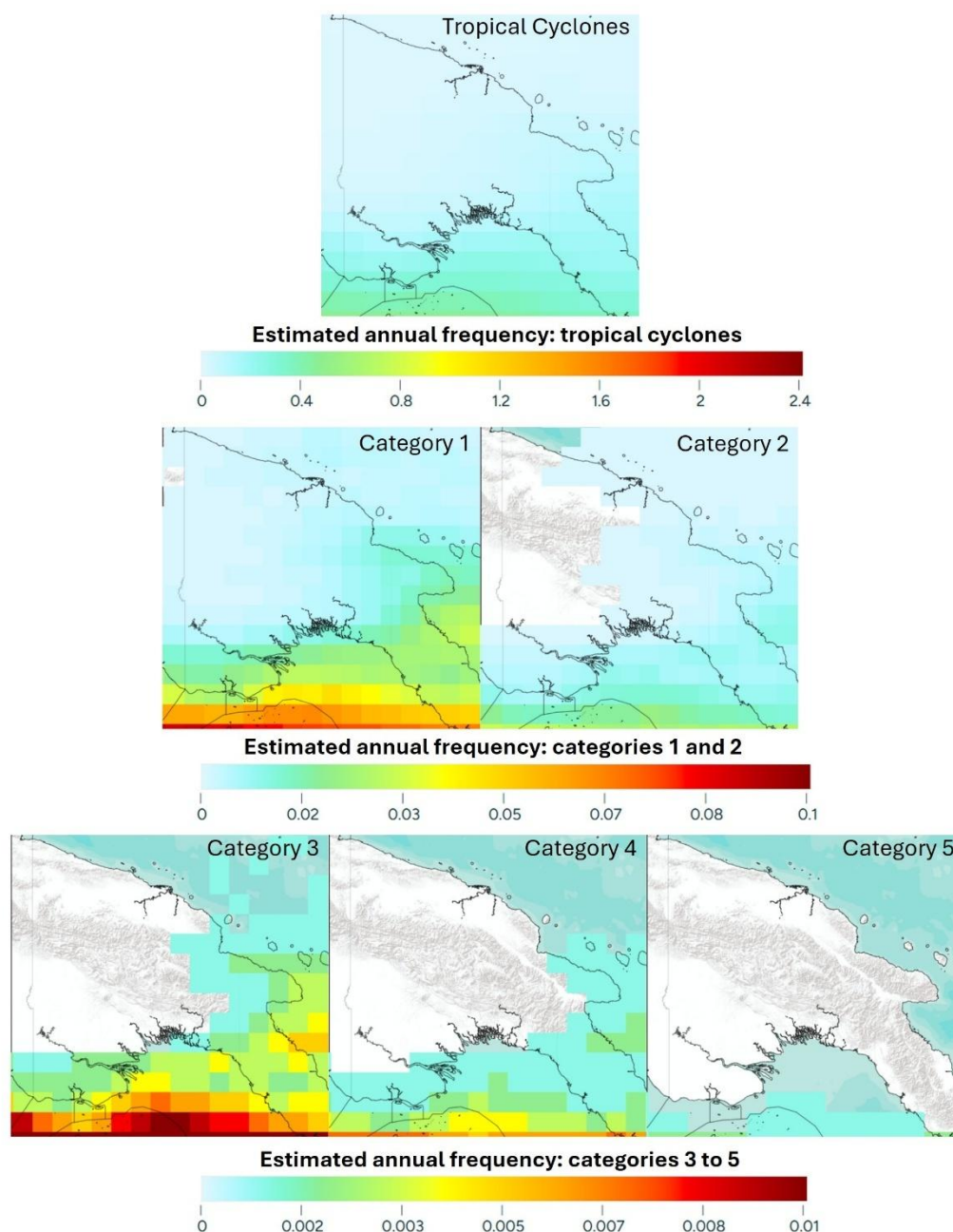


Figure 17. Estimated historical frequencies of tropical cyclones. Results provided by World Bank Group (2025).

Consequently, influence of TCs on the project area is expected to be indirect and limited according to historical data and analysis. No direct tropical cyclone passage occurs over the project area, which lies approximately 300 km from the nearest observed track; however, given the large spatial extent of cyclones, peripheral impacts such as rainfall and wind may still affect the project area. Regional cyclone frequency is also low, with only infrequent Category 1 events (AEP <1:50) and negligible likelihood of higher-intensity cyclones affecting the area.

To further analyse the effects of future climate change on the TC, the projected changes in tropical cyclones provided by the World Bank's CCKP (World Bank Group 2025) are further assessed (Table 5). The results show the estimated historical frequencies (same as presented in Figure 17) and future changes in such frequencies associated with different tropical cyclones that made landfall in PNG.

Table 5. Historical AEP and projected changes in frequency of different categories of tropical cyclones made landfall in PNG (mid-century projections under SSP2-4.5 are only available future projections as September 2025 in World Bank Group (2025)).

Category	Historical AEP	Mid-century (SSP2.4-5)
Category 5	0.015	+25% (-7% to 47%)
Category 4	0.045	+9% (-4% to 23%)
Category 3	0.062	+8% (-14% to 25%)
Category 2	0.076	+3% (-11% to 31%)
Category 1	0.191	+8% (-9% to 22%)
Tropical Storm	0.855	+13% (0 to 20%)
Total	1.244	+11% (-2% to +18%)

Table 5 indicates modest projected increases in the frequency of lower-intensity tropical cyclones (e.g., ~13% for tropical storms and ~8% for Category 1 events by mid-century); however, these projections are associated with substantial uncertainty. At the same time, PNG's NDC (Government of Papua New Guinea 2020) suggests that tropical cyclone frequency may decrease with medium confidence, highlighting the lack of consensus particularly in relation to frequency of TCs. On the other hand, the intensity of tropical cyclones may increase (Walsh et al. 2012) in the region although existing studies are not conclusive either, as described previously.

Overall, these uncertainties reinforce that TC projections for the region are highly variable, particularly with respect to frequency. Given the relatively low historical exposure of the project area and its inland location, the potential impacts of tropical cyclones are expected to remain limited, with any changes in risk primarily associated with marginal increases in peripheral effects such as rainfall and wind rather than direct cyclone impacts (as described in the previous section, the overall future increase of rainfall extremes is expected for the project area).

7. RISK MANAGEMENT AND RESILIENCE PLANNING

Table 6 provides a summary of key physical climate hazards, associated exposure levels, and key mitigation and management measures for the two main project components: the TSF development area and the infrastructure corridor. The exposure levels (low, moderate, high) reflect a qualitative assessment based on the sensitivity of each component or element to projected climate hazards, considering both design criteria (e.g., AEP levels) and functional importance. The mitigation measures summarized in the table align with the adaptive management framework adopted for the project and are consistent with international standards and guidelines such as GISTM (ICMM et al. 2020), including monitoring, iterative design review, and risk-informed operational controls. Detailed discussions of these adaptation and resilience measures are provided in the two subsections.

Table 6. Summary of project physical climate risk profiles and adaptation and management measures

Project Component	Infrastructure Element	Climate Hazard	Risk Level	Key Adaptation and Management Measures
TSF Development Area	TSF embankment, storage system, spillways	Extreme rainfall, flooding, and prolonged wet conditions	Low	Freeboard management; spillway capacity checks; maintaining contingency storage; continuous monitoring; adaptive management and periodic design review
	Water management system (sedimentation ponds, diversion channels, erosion protection)	Extreme rainfall and flooding	Low to Moderate	Implementation of Trigger Action Response Plan (TARP); continuous water balance monitoring; periodic reassessment of design storms; staged upgrades and capacity improvements; erosion control
	TSF geochemistry (tailings, water quality)	Increasing temperature and prolonged heat	Low to Moderate	Water quality monitoring; AMD management; integration into environmental management plans
	TSF operations and workforce	Extreme and prolonged heat	Moderate	Workforce heat management (work-rest cycles, hydration); equipment maintenance; operational adjustments
	TSF (general)	Wildfire	Low	Vegetation management; integration into operational risk management
Infrastructure Corridor	Roads (major and minor), access tracks	Extreme rainfall and flooding	Moderate to High	Routine inspection and maintenance; drainage upgrades; erosion control; rapid repair planning
	Drainage systems (table drains, culverts, cross-drains)	Extreme rainfall and flooding	Moderate to High	Checks, clearing, and maintenance; capacity reassessment; upsizing or retrofitting; additional drainage installation
	Bridges and crossings	Flooding, debris loading, scour	Low to Moderate	Scour protection; structural inspection; targeted upgrades based on monitoring; design review

Project Component	Infrastructure Element	Climate Hazard	Risk Level	Key Adaptation and Management Measures
	Slopes and embankments along corridor	Landslides and slope instability	Moderate	Slope stabilization; drainage control; erosion protection; identification of high-risk areas
	Pipeline and associated infrastructure	Flooding, ground instability, temperature effects	Low	Continuous automated monitoring of pipeline integrity; maintenance and checks; localized stabilization measures as required
	Corridor construction and workforce	Extreme and prolonged heat	Moderate	Workforce heat management (work-rest cycles, hydration); equipment maintenance; operational adjustments
	Corridor (general)	Wildfire	Low to Moderate	Vegetation management; inspection and maintenance

7.1 TSF DEVELOPMENT AREA

The TSF development area represents the highest-consequence component of the project and, as described for the design basis presented in previous sections, is engineered using a risk-informed hierarchy of design criteria ranging from relatively more frequent operational events (e.g., 1:100 AEP) to extreme events defined by PMP/PMF conditions. The climate risk assessment indicates that, the TSF storage and spillway systems—designed to accommodate PMP/PMF-scale events—are expected to remain robust under future climate change; a number of sub-components and elements is more sensitive to projected changes in climate, particularly increases in precipitation extremes and temperature.

Projected increases in precipitation intensity (in the order of 10–35%) may affect the performance of some elements of surface water management systems. Elements such as sedimentation ponds, diversion channels, and erosion protection measures are designed for 1:10 to 1:100 AEP events, which are more likely to experience exceedance under future conditions. This introduces risks of reduced hydraulic capacity, localized overtopping, erosion of channels and embankment faces, and increased sediment transport. Over time, these processes may degrade operational performance and increase maintenance requirements, and in combination events (e.g., prolonged wet periods followed by extreme storms) may challenge such facilities/components. Water balance assessment of the TSF has been conducted², including the use of a baseline case and upper case (with SSP 5-8.5) climate change scenarios (KCB 2026). According to this assessment (KCB 2026), TSF system is projected to exhibit approximately 5% higher total inflows, outflows, and discharges to Ok Tedi under the upper case scenario than the base case. Three recommendations have thus been proposed for TSF water management under future climate change: (i) climate and flow monitoring, (ii) tailings laboratory testing, and (iii) progressive model refinement.

On the other hand, the TSF storage and spillway systems are governed by PMP/PMF-level designs and therefore maintain a high margin of safety.

It should also be noted that, the local river systems are characterized by high hydrological variability, sediment-driven channel dynamics, and limited long-term data (as identified in earlier sections). This introduces uncertainty in both baseline estimates and future projections of riverine flooding events.

Projected increases in average temperature and the number of hot days primarily introduce gradual, long-term risks rather than acute failure modes. These include potential acceleration of geochemical processes (e.g.,

² KCB 2026. Ok Birim Tailings Storage Facility Feasibility Study: TSF Water Balance Assessment.

sulphide oxidation and AMD-related reactions), changes in water quality, and impacts on operational systems such as pumps, pipelines, and power supply. In addition, sustained high temperatures affect workforce productivity, health, and safety, particularly during construction and operational phases.

Wind and cyclone-related risks are considered low to negligible given the inland location (and thus not included in Table 6), but extreme wind events may still influence freeboard requirements and wave run-up.

Wildfire risk is considered low to moderate and the effects of climate change on the increased fire risk are inconclusive, although fire risk is still a relevant operational hazard due to the surrounding vegetation.

Consistent with GISTM (ICMM et al. 2020), resilience of the TSF development area can be further achieved through a combination of adaptive management, monitoring, and risk-based operational controls. For example, GISTM explicitly requires integration of climate change into the knowledge base, ongoing evaluation of climate risks, and implementation of adaptive management across the facility life cycle.

To improve the overall climate resilience and reduce physical climate risks, the project should adopt the observational method (i.e., adaptive management practices). The main steps of such risk management approach involve:

- Use of initial conservative design assumptions with predefined contingency measures
- Continuous verification of design performance through monitoring
- Iterative estimation and updates of related climate parameters (e.g., rainfall intensity, inflow assumptions) as new data and climate model results become available
- Implementation of mitigation measures when performance thresholds are approached or exceeded.

This adaptive management approach aligns with GISTM requirements to “evaluate, regularly update and use climate change knowledge throughout the tailings facility lifecycle” and to refine design and management strategies over time. Specific measures and actions are described subsequently.

Measure 1: Monitoring systems and trigger-based management

To provide the most-updated and detailed facility conditions, a comprehensive monitoring system should be implemented to track: (i) rainfall intensity and duration, (ii) pond levels, freeboard, and water balance, (iii) performance of diversion channels, sediment ponds, and spillways; and (iv) other performance indicators (e.g., water quality).

Trigger Action Response Plans (TARPs) should be established with defined thresholds (e.g., rainfall exceedance, pond level limits, erosion indicators) that initiate predefined responses such as controlled releases, pumping, reinforcement of drainage infrastructure, or temporary operational adjustments. This aligns with GISTM requirements for performance monitoring systems and predefined response actions to manage risks.

Measure 2: Water management and flexibility

Given the extreme rainfall impacts, water management is identified with low to moderate risks. Key measures to address the risks associated with water management facilities include but are not limited to: (i) based on the monitored conditions, maintaining conservative freeboard and contingency storage during project operation, (ii) periodic reassessment of design storm criteria (e.g., 1:100 AEP events) against updated historical data and climate projections, (iii) ensuring spillway and diversion systems maintain sufficient capacity under evolving conditions, (iv) allowing for staged upgrades or retrofits of water management infrastructure if monitoring indicates increasing risk.

Measure 3: Risk-informed design review and ALARP principle

Regular risk assessments and design reviews should explicitly consider updated climate data and reassess whether risks remain As Low as Reasonably Practicable (ALARP). This measure can also be integrated with Measures 1 and 2, which are related to monitoring systems and water management specifically, as well as

other measures and for other components/facilities. Where increased risks are identified (e.g., exceedance of design assumptions for sediment ponds), feasible upgrades or operational controls should be implemented as required. This is consistent with GISTM requirements for periodic risk assessment and continuous risk reduction.

Measure 4: Emergency preparedness and contingency planning

Emergency Preparedness and Response Plans (EPRPs) should incorporate extreme rainfall and flood scenarios, including those exceeding current design assumptions. These plans should define: (i) response actions for extreme inflow events, (ii) communication protocols, (iii) roles and responsibilities, and (iv) coordination with downstream stakeholders where relevant. Development of such plans based on credible failure scenarios is also required by GISTM.

Measure 5: Management of chronic temperature-related risks

Management measures for temperature-related risks focus on and construction and operational resilience, including: (i) regular inspection and maintenance of mechanical and electrical systems sensitive to heat, (ii) water quality monitoring and management to detect changes related to temperature-driven geochemical processes, (iii) workforce heat management plans (e.g., work-rest cycles, hydration protocols, scheduling adjustments), and (iv) integration of temperature considerations into long-term environmental management plans (e.g., AMD monitoring and mitigation).

Overall, the TSF area demonstrates a high level of inherent resilience to climate change due to the use of conservative PMP/PMF-based design for critical structures. The primary climate risks are associated not with catastrophic failure modes, but with the performance and reliability of supporting systems designed for more frequent events, and with long-term operational pressures from increasing temperatures.

Resilience is therefore best achieved through:

- Actively managing uncertainty through monitoring and adaptive management
- Periodically updating management and operational assumptions in response to evolving climate data
- Implementing risk-based operational controls and contingency measures

7.2 INFRASTRUCTURE CORRIDOR

The infrastructure corridor comprises the tailings pipeline, access roads, bridges and crossings, associated drainage systems, and ancillary facilities. Compared to the TSF development area, these components are generally designed to lower return-period events (1:10 to 1:100 AEP depending on criticality), reflecting their lower consequence of failure and the feasibility of repair or replacement. However, their distributed nature and direct interaction with riverine and hillslope processes result in higher exposure to climate hazards, particularly extreme rainfall, flooding, and landslides. Unlike the TSF area, infrastructure corridor elements are thus more sensitive to increases in the frequency and intensity of precipitation events and associated hydrological responses. These components represent a key area where climate change may lead to increased operational disruptions, maintenance requirements, and localized failures over the project life cycle.

Projected increases in precipitation intensity (in the order of 10–35%) are expected to directly affect surface runoff, drainage capacity, and flow conditions along the corridor. Road drainage systems (e.g., table drains and cross-drains), typically designed for more frequent events (e.g., 1:10 AEP), are particularly susceptible to exceedance under future conditions. This may result in overtopping of drainage structures, erosion of road surfaces, slope instability, and localized washouts. Similarly, access roads designed for 1:20 to 1:100 AEP events may experience more frequent inundation or damage, particularly in low-lying or floodplain areas. Bridges and watercourse crossings, which are designed for higher return periods (1:100 AEP), are also exposed to increasing risks from higher peak flows, increased debris loading, and enhanced scour potential. Increased sediment transport associated with extreme rainfall may exacerbate channel instability and

foundation exposure, increasing the likelihood of structural damage or reduced serviceability over time. In addition to fluvial processes, the corridor traverses steep and highly weathered terrain, where intense rainfall can trigger landslides and slope failures. Projected increases in rainfall intensity and antecedent moisture conditions may elevate the frequency of such events, posing risks to road stability, pipeline integrity, and access continuity. These risks are particularly relevant during prolonged wet periods or compound events.

Similar to the TSF area, the hydrologic uncertainty associated with limited long-term observational data and sediment dynamics makes it difficult to assess the baseline conditions and future projected risks. Such uncertainty is greater for the infrastructure corridor due to the spatial variability of catchments and localized conditions; prediction of site-specific responses to extreme events is complex and difficult.

Projected increases in temperature and prolonged hot days introduce chronic risks to infrastructure corridor components. These include thermal stress on pipeline materials, potential changes in soil strength and moisture conditions affecting slope stability, and impacts on mechanical and electrical systems supporting corridor operations.

Wind and cyclone-related risks are considered negligible given the inland location and absence of historical cyclone tracks in the region. Wildfire risk is also considered low to moderate and largely independent of climate change projections, although vegetation management along the corridor remains relevant for operational safety and access.

Consistent with GISTM principles, resilience of the infrastructure corridor is achieved through adaptive management, targeted monitoring, and risk-based maintenance strategies. Given the higher likelihood of frequent disruptions in infrastructure corridor compared to the TSF area, resilience planning focuses on maintaining functionality and enabling rapid recovery rather than preventing all exceedances.

Measure 1: Monitoring and inspection program

A monitoring and inspection program should be implemented along the corridor to identify emerging risks and performance issues, including: (i) rainfall intensity and runoff conditions at key catchments or corridor locations, (ii) condition of roads, drainage structures, and crossings, (iii) evidence of erosion, scour, or slope instability, and (iv) pipeline integrity and support conditions. Routine and event-based inspections (e.g., post-storm) are critical to identify damage early and initiate timely repairs.

Measure 2: Risk-informed design review

Similar to the TSF area, periodic review of infrastructure performance should be undertaken to assess whether risks remain acceptable under evolving climate conditions. These reviews should be informed by monitoring data and inspection findings (e.g., drainage performance, erosion, structural condition), enabling identification of recurring deficiencies or exceedances of design assumptions. Where such evidence indicates declining performance or increasing risk, measures 3 and 4 should be employed.

Measure 3: Drainage management and capacity upgrades

Drainage systems represent the primary control for managing precipitation-related risks. Key actions include: (i) regular maintenance and clearing of drains and culverts to ensure design capacity is maintained, (ii) periodic reassessment of drainage design criteria (e.g., 1:10 to 1:100 AEP) against updated historical data and future climate projections, (iii) upsizing or retrofitting of critical drainage structures where recurrent exceedance or failure is observed, and (iv) when necessary, installation of additional cross-drainage or erosion protection measures in high-risk areas.

Measure 4: Erosion, scour, and slope stability management

Depending on the routine monitoring and inspection results and review, targeted adaptation actions can be implemented to address geotechnical and geomorphic risks, the options of which include additional: (i) erosion protection (e.g., armouring, vegetation, geotextiles) in vulnerable sections of the corridor, (ii) scour protection at bridge abutments and culvert outlets, (iii) stabilization of slopes through drainage control, regrading, or reinforcement where required, and (iv) identification of landslide-prone areas and implementation of mitigation measures or alternative alignments if required and feasible.

Measure 5: Contingency planning and operational resilience

Given that disruptions to the corridor are likely under extreme conditions (as designs are based on more frequent events), contingency planning is important to ensure the recoverability and long-term functionality and reliability. Such contingency planning can include: (i) establishing alternative access or redundancy where feasible, (ii) stockpiling materials and equipment required for rapid repair, (iii) developing response procedures for unplanned road closures, bridge damage, or pipeline interruptions, and (iv) coordinating logistics to minimize operational downtime during extreme events.

Measure 6: Management of temperature-related effects

Management of temperature-related risks includes routine inspection and maintenance of pipeline systems, monitoring of ground conditions where relevant, and ensuring operational procedures account for heat-related impacts on equipment and workforce.

The infrastructure corridor exhibits a different risk profile from the TSF development area: while the consequences of failure are lower in the infrastructure corridor, the exposure to climate hazards—particularly extreme rainfall, flooding, and landslides—is higher, and the design criteria are more likely to be exceeded under future climate conditions.

Resilience is therefore best achieved through:

- Proactive monitoring and inspection of infrastructure conditions
- Adaptive, risk-informed design improvements based on observed performance
- Maintenance and upgrading of drainage and erosion control systems when necessary
- Effective contingency planning to ensure rapid recovery following extreme events

8. CONCLUSIONS

This CCRA evaluated the potential impacts of climate change on the Ok Birim Tailings Storage Facility Project, with a focus on physical climate risks affecting all three phases of the project (construction, operation, and closure). The assessment is aligned with international frameworks and standards, including EP4, IFC Performance Standards, and GISTM, and adopts a risk-informed, scenario-based approach to address uncertainties in future climate conditions.

The project is located in the tropical rainforest climate zone characterized by high rainfall with strong spatial variability. Historical observations and climate projections indicate that future climate change will be expressed primarily through increases in temperature and extreme rainfall intensity, rather than significant changes in mean annual precipitation. Precipitation extremes are projected to increase in the order of 10–35%, whereas temperature increases will lead to more frequent and prolonged hot conditions.

These projected changes have differing implications across project components. The TSF design such as storages and spillways were assessed to have high resilience due to the adoption of conservative design criteria for the PMP and PMF events. The estimates of PMP and PMF used for such designs are conservative and not expected to be materially exceeded under projected climate change conditions. Therefore, the likelihood of catastrophic failure associated with extreme hydrological events remains low under both current and future climate conditions.

Supporting infrastructure and operational systems—such as those designed based on more frequent events (e.g., with 1:10 to 1:100 AEP)—are more sensitive to projected increases in precipitation intensity. Such vulnerabilities are associated with surface water management systems (e.g., sedimentation ponds and diversion channels) and linear infrastructure (e.g., roads, culverts, and crossings). These components are expected to experience relatively more frequent exceedance of design conditions over time, resulting in increased risks of localized washouts and flooding, erosion, sediment transport, overtopping of drainage structures (such as along the access roads), slope instability, bridge scour, and operational disruption. While such risks are generally manageable and of lower consequence than TSF failure, they have implications for maintenance requirements, operational reliability, and life cycle costs.

Chronic climate risks associated with increasing temperature are also identified. While not expected to directly compromise structural integrity, elevated temperature may influence geochemical processes within the TSF (e.g., AMD risk), affect water quality, and impose operational constraints on equipment and workforce. These chronic risks can be managed through monitoring, operational controls, and integration into environmental management systems.

Other hazards, including wildfires and tropical cyclones, are assessed as having negligible to low project risks. Wildfire exposure is primarily driven by existing environmental conditions rather than climate change (i.e., climate change is not expected to increase wildfire risks based on current projections). Tropical cyclone risk is minimal due to the inland location of the project and absence of historical cyclone tracks in the project area.

One important note of this CCRA is related to the high level of uncertainty associated with hydrological characterization of the project area. Limited long-term data, strong spatial variability, and significant anthropogenic modification of river systems introduce constraints on quantitative prediction of future hydrological conditions. Consequently, the assessment focuses on relative changes in climate drivers—particularly through precipitation—rather than absolute projections of hydrological response. This reinforces the importance of adopting flexible and adaptive management strategies, as well as a robust monitoring program during the operations of the project, and potentially beyond, to more effectively quantify less frequent extreme events.

Our independent analysis of the rainfall data from the local monitoring stations found that the precipitation extremes for the most extreme events, i.e., PMF/PMP (with 1:100,000 AEP), are smaller than the

conservative design basis used for the most high-consequence components of the project design, even under future climate change conditions. This is a key finding related to the long-term future stability of the TSF after all project operations have concluded. However, we found that with future climate change, the intensity of more frequent events (with the AEPs of 1:10 to 1:100) can exceed the corresponding design bases used for some less consequential/critical components of the overall project design. In our assessment, the climate resilience for the project can be improved with adaptive management practices for these more frequent exceedances. Maintaining resilience over the project life cycle will require ongoing monitoring, periodic reassessment of design assumptions, and implementation of adaptive measures where necessary.

Key elements of this approach include: (i) continued development of site-specific climate and hydrological datasets, (ii) implementation of monitoring systems linked to TARPs, (iii) integration of future climate change considerations into operational and emergency preparedness planning, and (iv) periodic review and, where required, upgrading of drainage and water management infrastructure. This adaptive management approach is consistent with applicable international frameworks and standards (e.g., GISTM) for continuous evaluation and updating of climate-related risks throughout the project life cycle.

This CCRA concludes that with the implementation of the recommended monitoring, management, and adaptive measures, the Ok Birim TSF Project can be developed and operated to address climate risk under both current and future climate conditions. Through proactive and adaptive management, the long-term resilience and performance of the project can be achieved.

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