

DRAFT FOR CONSULTATION

Climate Risk & Resilience Matrices
for Infrastructure PPPs

Developed based on the World Bank Group's Climate Toolkits for Infrastructure PPPs

Hydropower · Solar PV · Wind · Water Production & Treatment · Roads · ICT

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RESILIENCE TABLE
EVERY DISCIPLINE. ONE TABLE.

Climate Risk & Resilience Matrices for Infrastructure PPPs

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Draft for consultation, November 2026

Why this series

Infrastructure built today will operate for decades in a changing climate. Storms, floods, wildfires, heat, drought and other hazards can damage assets, interrupt essential services and erode the value of long-term investments. Planning for these risks early pays off: resilient assets tend to stay insurable, bankable and preserve value over time, while delivering critical services reliably to the communities.

Yet resilience is still not consistently reflected in the infrastructure build-out decisions made. Governments, project developers, engineers, architects, lenders and insurers often work with different information, in different formats and at different stages of the project cycle. Insurers, for example, are frequently engaged only when insurance needs to be placed for construction, after the main siting and design decisions have been made that would impact resilience outcomes.

The World Bank Group's Climate Toolkits for Infrastructure PPPs provide comprehensive guidance to address these issues across the following assets:

- Hydropower Generation;
- Solar and Wind Power Generation;
- Water Production and Treatment Infrastructure;
- Roads; and
- Information and Communication Technology.

This series offers a concise entry point to that guidance: for each sector covered in-depth by the Toolkit, a Climate Risk & Resilience Matrix summarizes on a few pages which climate hazards matter, how they can affect assets and operations, and which adaptation measures can reduce the impact. The aim is a shared reference, prepared at an executive-level format, so that every discipline at the table can use as a reference on resilient thinking at the start of a project.

The Matrices also go a step further. Drawing on documented events and engineering research, Resilience Table has added additional detail to complement Toolkit guidance. These additions are shown in **blue** on each Matrix, and address resilience to the following four dimensions associated with growing physical climate risk, previously less expanded in the Toolkit.

- **Dependence on grid power and backup supply:** generators, fuel, storage and protection settings that keep water plants, telecom networks, and solar and wind farms running when the grid fails.
- **Consequences for people:** boil-water notices, lost emergency calls and evacuation gridlock.
- **Cold climates:** freeze-thaw damage, icing, heavy snow loads and permafrost thaw.
- **Operational resilience:** inspections before reopening, mutual aid, debris clearance and realistic repair times.

The **blue** additions are the parts of each Matrix where feedback from operators and practitioners will be most valuable.

What a Climate Risk & Resilience Matrix is, and how to read it

Each Matrix covers one infrastructure sector and is organized as a simple grid:

- **Columns** are the climate hazards identified in the corresponding sector toolkit, such as severe storms, flooding, wildfire, extreme heat, drought, extreme cold, sea-level rise and landslides. The hazard categories follow the toolkits, so users can trace each column back to its source.
- **Impacts** describe how each hazard can affect the sector's assets, operations, workforce and dependent services.
- **Potential Solutions** list adaptation and resilience measures identified in the toolkits, from siting and design to operations, maintenance, emergency response and continuity planning.
- **Blue text** marks Resilience Table additions drawn from documented events and research on established engineering practices.

The Matrices describe categories of measures in plain language. They do not recommend specific products or providers. Each Matrix names the toolkit it draws upon.

How the Matrices can be used

The Matrices are designed to support conversations across disciplines at each stage of the project cycle:

- **Project identification and screening:** a quick checklist of which hazards and impacts to consider, alongside the toolkits' screening tools and hazard information.
- **Feasibility and design:** a starting list of measures to evaluate, with costs, benefits and value for money assessed as the toolkits describe.
- **Procurement and contracts:** input into RFP and procurement specifications, KPIs development, maintenance obligations and risk allocation.
- **Engagement with lenders and insurers:** a common reference for presenting, early in the process, which risks have been assessed, and which measures have been built into the project.
- **Operations:** a reminder of the emergency response, monitoring and continuity measures that keep services running.

Scope and limitations

- **The Matrices are summaries.** They do not replace the toolkits, site-specific climate risk assessments, engineering design or professional advice.
- **Measures are indicative.** Their relevance and cost-effectiveness depend on location, asset design, applicable codes and standards, and project-specific analysis.
- **Content is derived from the World Bank Toolkits, except as shown in blue.** The blue additions draw on documented events and should be validated for each project context.
- **This is a draft for consultation.** Feedback from practitioners is welcome and will inform future versions.

Acknowledgments, attribution and licence

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The sector toolkits were prepared by World Bank Group teams led by Mariana Carolina Silva Zuniga, Khafi Weekes and Jade Shu Yu Wong, working with GRID Engineers.

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Climate Risk & Resilience Matrix: Hydropower Assets

Blue = Resilience Table addition, not drawn from the World Bank Toolkit.

	Extreme rainfall / floods / severe storms	Wildfire	Avalanches/ glacier and snowpack change / extreme cold
Impacts	• **Debris and sedimentation:** Heavy runoff washes sediment and floating debris into reservoirs, clogging intake trash racks, accelerating turbine wear, and reducing storage capacity. • **Structural stress and overtopping:** Intense inflows, landslides, or glacial lake outbursts can cause spillway blockages, foundation scour, or dam overtopping (a major failure mode especially for embankment dams). • **Reduced generation efficiency:** Forced flood releases or inaccurate inflow forecasts lead to sub-optimal water use; high downstream tailwater levels also reduce hydraulic head. • **Grid and access disruptions:** High winds and lightning damage transmission lines and switchyards, while washed-out access roads delay maintenance and repairs.	• **Direct fire and smoke damage:** Flames can destroy powerhouses, substations, and transmission poles, while dense smoke and ash cause electrical flashovers on high-voltage lines. • **Post-fire erosion and debris flows:** Burned catchments erode rapidly, sending charred debris and sediment into reservoirs and reducing storage; mudslides can also clog intakes and wear down turbines. • **Flash flooding and water contamination:** Vegetation loss increases rapid flood runoff, while ash and nutrient inflows degrade water quality and foul plant cooling systems. • **Grid and access disruptions:** Preventative utility de-energizations force plants to curtail generation, while evacuations and blocked roads delay operations and maintenance.	• **Shifting seasonal water supply:** Warming temperatures degrade glaciers and reduce snowpack, increasing river flows in the short term but reducing them over the long term, with earlier spring runoff and lower late-summer water availability. • **Glacial floods and avalanches:** Melting glaciers form unstable glacial lakes prone to outburst floods, while changing snowpacks increase avalanches and moving ice that can strike dams, intakes and other infrastructure in mountain regions • **Ice blockages and equipment freezing:** Frazil ice and river ice jams clog intake trash racks, while extreme cold freezes spillway gates and exerts heavy structural ice pressure on dams. • **Grid and access disruptions:** Freezing rain and heavy snow damage transmission lines and switchyards, while winter storms block remote mountain access roads.
Potential Solutions	• **Structural & Overtopping Protection.** Use future flood-risk projections and stringent design for critical assets, designing spillways for larger flows and debris and dams to withstand overtopping impacts. For existing dams, consider increasing height and increasing spillway capacity. Flood-protect the powerhouse, use upstream flood defenses, install early warning sensors and monitor scour at foundations. • **Debris & Sediment Management.** Install upstream barriers and debris booms, equip intakes with automated trash-rack cleaners, and use sediment-flushing outlets or abrasion-resistant turbine coatings to protect equipment and preserve reservoir storage. • **Operational & Forecasting Systems.** Use weather stations, river/stream instrumentation, and decision-support systems for inflows, releases, turbine operation, and emergency flood protocols, while accommodating varying environmental flows and fish passage needs. Provide independent backup power for spillway gates, add storage and space for future turbines/generators where feasible. • **Grid & Access Resilience.** Harden transmission lines and switchyards against high winds and lightning, reinforce access road drainage and slopes to prevent washouts, and maintain redundant remote communication systems.	• **Fire & Smoke Protection.** Leverage wildfire models and fire-management plans to mitigate risk, including controlled burning and maintaining defensible space around facilities and transmission lines. Install fire-protection systems such as early warning and automatic suppression systems. • **Post-Fire Erosion & Debris Management.** Restore vegetation and use anti-erosion protection across burned catchments. Install debris booms and automated trash-rack cleaners to handle charred wood and mudflows. Monitor sediment and maintain/update reservoir flushing plans to preserve storage and protect turbines. • **Water Quality & Flood Preparedness.** Update flood-routing protocols for rapid post-fire runoff, and inspect cooling-water strainers and HVAC filters after fires to prevent ash and smoke from fouling plant systems. • **Grid & Operational Continuity.** Enable remote plant monitoring and control for safe operation during staff evacuations, establish alternate access routes, and install on-site backup power to maintain critical functions during preventative grid de-energizations.	• **Seasonal Water Supply Adaptation.** Use future streamflow projections in plant sizing, leave room for future turbines, and plan for additional reservoir storage or flexible operating rules to manage earlier spring runoff and lower late-summer flows. • **Glacial Flood & Avalanche Protection.** Monitor glacier conditions and install early warning systems for glacial lake outbursts; in high-risk cases, consider measures such as controlled breaching or pumping water from glacial lakes. Observe snowpack and use avalanche-risk management techniques, including controlled explosions where appropriate and installing avalanche barriers where needed. • **Ice Management & Cold-Weather Hardening.** Implement ice management protocols at intakes and trash racks, monitor ice formation in reservoirs at and above the intake, and keep a frazil-ice response plan with key personnel. Consider cold-weather hardening strategies such as heated trash racks, spillway gate heaters, upstream ice booms, and air-bubbler systems to keep gates and intakes ice-free. • **Grid & Mountain Access Resilience.** Harden transmission lines and switchyards against heavy snow and ice accretion, maintain winter road-clearing equipment and avalanche control for remote mountain access. Enable remote plant operations during severe winter storms.

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Climate Risk & Resilience Matrix: Hydropower Assets (continued)

Blue = Resilience Table addition, not drawn from the World Bank Toolkit.

	Drought / heat / streamflow variability	Landslides / mudflows / slope failures	Erosion / sedimentation / debris
Impacts	• **Reduced water supply and evaporation.** Longer droughts, lower spring and summer flows, and higher reservoir evaporation shrink water availability. These changes hit run-of-river plants and small reservoirs hardest. • **Lower hydraulic head and shutdowns.** Dropping reservoir levels reduce hydraulic head and generation efficiency. Extreme low water can also cause turbine cavitation or force complete shutdowns at minimum operating levels. • **Competing water demands and environmental rules.** Rising competition with agriculture and cities limits water available for power. Mandatory environmental releases to protect warm, low-flow rivers further restrict generation. • **Equipment overheating and biofouling.** Extreme air and water temperatures push transformers and cooling systems past thermal limits. At the same time, algal blooms and aquatic weeds clog intakes and cooling lines. • **Unpredictable streamflow swings.** Greater variability in precipitation and runoff complicates reservoir management. Inaccurate forecasts can lead to inefficient water storage and dispatch decisions.	• **Dam, reservoir, and spillway hazards.** Landslides into reservoirs can cause overtopping, accelerate sedimentation or contribute to dam failure. Landslide debris can also choke spillway discharge channels. • **Conveyance and turbine damage.** Slope shifts and mudflows can rupture high-pressure penstocks, bury intakes, block tailraces, and send abrasive sediment through turbines. • **Powerhouse and grid impacts.** Rockfalls and mudslides can strike powerhouses and switchyards, while slope deformation tilts or topples transmission towers. • **Access and foundation failures.** Rainfall-driven slope failures wash out access roads, pipelines, and facility foundations, delaying operations and repairs. • **Permafrost thaw and ground settlement.** Thawing permafrost destabilizes soils, causing ground settlement along access roads, cracking facility foundations, and tilting transmission structures.	• **Storage and project lifetime loss.** Erosion and sedimentation steadily fill reservoirs, shrinking active water storage, reducing long-term generation potential, and shortening asset lifespan. • **Intake clogging and cleanup costs.** Eroding shorelines and watershed runoff send floating logs and vegetation into waterways, clogging trash racks, damaging equipment, and raising debris-removal costs. • **Turbine abrasion and system fouling.** Suspended sediment grinds down turbine blades and seals while clogging cooling water lines, cutting efficiency and increasing maintenance requirements. • **Gate blockages and downstream scour.** Sunken debris and silt can jam low-level outlets and spillway gates, while sediment-starved downstream releases scour riverbeds and dam foundations.
Potential Solutions	• **Water & Drought Planning:** Develop drought contingency plans, diversify energy-supply plans, and reduce water loss by sealing leaks in canals, gates, and penstocks. • **Shared Water & Operations:** Make water-use decisions inclusively with communities and regional users through regularly reviewed agreements. Adjust turbine operating schedules to avoid low-head cavitation and use seasonal forecasting to optimize water storage. • **Thermal & Biofouling Protection:** Specify generators, transformers, and electrical equipment for higher temperatures, with adequate cooling and ventilation in the powerhouse, and use intake strainers and routine clearing to prevent algae and weed clogging.	• **Slope & Reservoir Stability.** Conduct comprehensive geotechnical investigations; monitor movement of unstable slopes and stabilize them where needed. Use vegetation for shallow slope stabilization and erosion control where site conditions support it; assess the soil-root interaction and don't assume vegetation is beneficial in every setting. Manage reservoir drawdown rates to prevent shoreline slumping and maintain freeboard buffers against landslide-induced waves. • **Conveyance, Powerhouse & Grid Protection.** Equip high-pressure penstocks with automatic shutoff valves to prevent washouts during ground shifts, protect intakes and spillways with debris barriers, and site powerhouses and switchyards away from active slide paths. • **Access Roads & Permafrost Adaptation.** Reinforce access road drainage and retaining walls against washouts. In permafrost areas, set critical foundations on deep piles and use thick gravel insulation pads to reduce ground thaw under roads.	• **Reservoir Storage & Sediment Management.** Monitor sediment, manage sediment flows, and update flushing plans to preserve reservoir storage and project lifespan. Regularly exercise low-level outlets and spillway gates to prevent silt and sunken debris from jamming them. • **Watershed & Shoreline Protection.** Monitor catchment land cover and preserve/restore vegetated catchment cover, to manage stormwater runoff; apply anti-erosion measures to limit incoming sediment and falling vegetation. • **Debris Control & Intake Clearing.** Install upstream and river-margin barriers alongside automated trash-rack cleaners to limit debris entering the plant, and keep a debris-buildup response plan with key personnel. • **Turbine, Cooling & Downstream Protection.** Protect turbines against hydro-abrasive wear using abrasion-resistant runner coatings and operational shutoffs during extreme sediment spikes, install self-cleaning strainers on cooling-water lines, and armor downstream riverbeds and dam toes with riprap to prevent scour.

Note: Beyond direct climate hazards, land-use, demographic, and policy changes can alter water demand, upstream runoff, flood risk, and project costs. Compounding drivers—such as wildfires, intense rainfall, and land-cover changes—can also multiply watershed erosion and debris loads, while warmer water and lower river levels can degrade aquatic habitats and trigger stricter regulatory limits on generation. To manage these broader systemic risks, developers and operators should assess basin-wide external changes alongside physical hazards, maintain flexible agreements with local stakeholders, and embed climate and regulatory risk-sharing into project contracts.

Source: *World Bank Group. 2023. Climate Toolkits for Infrastructure PPPs: Hydropower Sector. Washington, DC: World Bank. Summarized and adapted by Resilience Table; text in blue is a Resilience Table addition, not drawn from the Toolkit. This summary is not a World Bank Group publication and has not been reviewed or endorsed by the World Bank Group. Draft for consultation (v0.9), November 2026 ·* *Summary and additions © Resilience Table · Free for non-commercial use with attribution (CC BY-NC-ND 4.0)*

Climate Risk & Resilience Matrix: Solar PV Assets

Blue = Resilience Table addition, not drawn from the World Bank Toolkit.

	Extreme winds / storms / cyclones / lightning	Floods / sea-level rise	Wildfire	Extreme heat / rising temperatures / lower wind speeds
Impacts	• **Wind Uplift & Racking Failure.** Extreme wind gusts and cyclones can unbolt and damage solar panels and increase dust accumulation on panels. Systems fail most often where racking and bolts are undersized. • **Hail & Cell Damage.** Large hail can shatter glass and crack cells across thousands of panels in minutes, with the worst damage where panels lie flat. • **Lightning & Surge Damage.** Frequent lightning causes direct strikes and nearby surges that damage inverters, trackers, and monitoring systems. • **Grid Outages & Loss of Access.** Storms and cyclones can damage inverters, panels, transmission and distribution lines, and access roads, impairing the whole park. Grid loss can also stop trackers without backup power from stowing safely. Even when the solar plant survives, storm damage to the grid can leave it unable to export power for weeks or months.	• **Infrastructure & Electrical Damage.** Floods can physically damage the solar facility, transmission lines, substations, and the roads and other infrastructure it depends on. Inundation can submerge and short-circuit critical components. Ground-mounted equipment and panels in coastal areas may flood frequently. • **Soil Instability, Scour & Debris.** Rising seas can threaten coastal facilities through inundation, or through added loading as sea level and groundwater pore pressures rise, leading to soil instabilities. Fast-moving floodwaters can also erode soil around foundation piles and carry floating debris that damages racking. • **Saltwater Corrosion.** Coastal flooding and rising seas expose racking, fasteners, enclosures, and grounding grids to saltwater, accelerating corrosion and equipment failure. • **Loss of Access & Inspection Downtime.** Flooded access roads and mandatory post-flood safety inspections can keep a plant offline for days or weeks, even when equipment is undamaged.	• **Direct Fire, Heat & Firefighting Damage.** Fires can physically damage power facilities, transmission and distribution equipment, and hinder access to the facility. Intense radiant heat can also melt panel back-sheets, wiring, and junction boxes. Live daytime DC voltage often prevents firefighters from spraying burning arrays with water. • **On-Site Vegetation Ignition.** Dry grass under the arrays can carry flames across the site, ignited either by external wildfires or on-site electrical arc faults and inverter fires. • **Grid Faults & Proactive Shutoffs.** Faults on fire-damaged transmission lines, as well as proactive utility shutoffs during extreme fire weather, can cause inverters to disconnect, taking large amounts of solar offline at once. • **Smoke Shading & Ash Soiling.** Heavy smoke can cut sunlight and output across a whole region for days or weeks, while falling ash coats panels and reduces generation until they can be washed.	• **Panel Efficiency & Inverter Derating.** PV performance falls by about 0.3% to 0.5% for every 1°C rise in temperature. In extreme heat, inverters also reduce output to protect themselves, which is a primary cause of heatwave losses. • **Heat Trapping from Low Wind & Vegetation Loss.** Wind naturally cools panels, so lower average wind speeds combined with higher temperatures trap heat and worsen efficiency losses. Extreme heat also dries out or damages nearby vegetation, reducing the localized cooling it provides. • **Accelerated Aging & Thermal Fatigue.** Long-term exposure to higher temperatures—and wide daily temperature swings—ages materials faster, causing delamination and faster wear of transformers, cables, and batteries. • **Peak Demand Mismatches.** On very hot days, surging air-conditioning demand can exceed what a heat-derated solar park can supply, straining the wider grid.
Potential Solutions	• **Wind-Resistant Racking & Fasteners.** Use dual-post piers, through-bolted modules, lateral racking supports, mechanical dampers, and vibration-resistant connections, paired with construction QA/QC and pre-storm bolt torque checks. • **Hail-Rated Glass & Automated Stow.** Specify hail-rated glass in hail-prone regions and program single-axis trackers with automated stow modes to tilt panels steeply before hailstorms or into aerodynamic angles during high winds. • **Lightning, Surge & Fire Protection.** Install lightning rods, deep grounding grids, and surge protection on inverters and combiner boxes, while clearing dry vegetation and debris to prevent fires and flying projectiles. • **Distributed Inverters & Tracker Backup Power.** Use distributed string inverters to limit outage impacts. Equip trackers with dedicated local backup batteries so panels can still stow safely if the grid goes down.	• **Forward-Looking Site Selection.** Carry out in-depth flood risk analysis during site selection using forward-looking climate projections. Avoid flood-prone and low-lying areas where possible. • **Flood Elevation & Site Drainage.** Elevate inverters, transformers, and combiner boxes on raised pads above flood levels, and grade the site with drainage channels to prevent soil erosion around foundation piles. Consider future sea-level rise in design by elevating critical equipment above projected flood levels. Use deeper foundation piles or scour protection to resist soil instability and erosion. • **Site Drainage, Natural Buffers & Access Roads.** Increase site drainage capacity, protect natural flood barriers, and build elevated access roads with culverts. • **Waterproofing & Corrosion Protection.** Use flood-rated electrical enclosures, waterproof cabling, and marine-grade corrosion coatings in coastal or high-moisture areas. • **Post-Flood Re-Energization Plans.** Prepare post-flood inspection and safe re-energization procedures in advance to shorten downtime once waters recede.	• **Vegetation Management & Defensible Space.** Use fire-smart landscaping by keeping grass short under and around arrays, creating perimeter firebreaks, and clearing around inverters and transformers. • **Electrical Fire Prevention & Rapid Shutdown.** Maintain inverters and enclosures to prevent equipment fires. Use arc-fault detection and rapid shutdown so firefighters can safely de-energize arrays. • **Fire Planning, Monitoring & Access.** Prepare fire zoning, prevention, and firefighting plans with local responders. Maintain unobstructed access roads, and use continuous monitoring and early warning systems for immediate action when a fire starts. • **Grid Preparedness & Ash Cleaning.** Set inverter protection to ride through momentary grid faults and prepare water-efficient ash-cleaning protocols to restore output after smoke clears.	• **Heat-Tolerant Modules & Components.** Use modules with low temperature coefficients and temperature-resistant materials for other components. • **Passive Airflow & Agrivoltaic Ground Cover.** Elevate mounting structures and optimize row spacing to maximize passive airflow beneath panels, and plant low-growing native grasses and wildflowers under arrays (agrivoltaics) to cool the microclimate and reduce dust. • **Inverter Shading, Sizing & Pre-Summer Maintenance.** Size inverters and their cooling systems for future peak temperatures, house them in shaded or ventilated enclosures, and clean cooling fans and filters before heatwave season to prevent derating. • **Extreme-Heat Yield Modeling.** Base financial and grid output forecasts on extreme-heat climate projections rather than historical typical-year weather data.

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Climate Risk & Resilience Matrix: Solar PV Assets (continued)

Blue = Resilience Table addition, not drawn from the World Bank Toolkit.

	Drought / reduced rainfall / dust and soiling	Changes in sunlight / cloudiness / humidity	Icing / freezing / snow	Landslides / soil instability
Impacts	• **Soiling Yield Loss & Hotspot Damage.** Dust, dirt, and air pollution on panels reduce performance and raise operating costs through more frequent cleaning, especially where rainfall declines or dust storms intensify. Uneven dirt buildup along panel edges also creates localized hotspots that accelerate cell degradation. • **Water Scarcity & Washing Constraints.** Drought increases water demand and conflicts over water use, while less rain hinders cleaning that relies on natural rainfall, forcing operators to restrict or replace water-based panel washing. • **Glass Abrasion & Equipment Clogging.** Windblown sand and frequent dry cleaning erode anti-reflective glass coatings, while fine dust clogs inverter filters and tracker motors. • **Soil Shrinkage & Fire Risk.** Prolonged drought dries out clay soils, reducing foundation grip around driven piles, and leaves surrounding vegetation parched, elevating wildfire risk.	• **Reduced Irradiance & Cloud Shading.** Less solar irradiation or prolonged cloudiness directly reduces PV output, while frequent rain clouds cut generation even though rain can help clean panels. Rapidly passing clouds also create sudden output swings that strain grid stability and inverter electronics. • **Surface Condensation & Cemented Soiling.** Higher humidity reduces output as water droplets on panels reflect or refract sunlight, and morning dew mixes with dust to form stubborn, baked-on grime. • **Moisture Ingress & Material Degradation.** Sustained high humidity speeds deterioration of panels and other components by driving moisture past edge seals, causing corrosion and delamination and triggering insulation faults in inverters.	• **Snow Shading & Cleaning Costs.** Colder temperatures naturally raise PV voltage and output, but snow accumulation blocks sunlight, reduces performance, and increases cleaning and maintenance needs. • **Structural Overload & Snow-Shedding Damage.** Heavy snow and ice can exceed racking and module load limits, buckling supports and breaking panels, while sliding snow can tear off clamps and damage lower-mounted equipment. • **Freeze-Thaw Stress & Frost Heave.** Rapid swings from hot to cold let meltwater freeze in frames and seals, bending frames and cracking modules. Deep ground freezing causes frost heave that can push foundation piles out of alignment. • **Equipment Freeze-Ups & Grid Shortfalls.** Freezing rain and extreme cold can jam tracker motors, freeze batteries, and force inverters and other equipment offline right when winter heating demand peaks.	• **Landslides & Infrastructure Damage.** Facilities in landslide-prone areas, including transmission lines and access roads, face rising landslide risk as rainfall extremes intensify over the project life. Sudden landslides, mudflows, and rockfalls can damage critical components, bury inverters, and block site access. • **Soil Subsidence & Racking Misalignment.** Soil subsidence, slope creep, and erosion around piles shift foundations out of alignment—twisting racking, jamming single-axis trackers, and overloading motors. • **Buried Cable & Grounding Damage.** Shifting soil stretches and snaps underground power cables, communication lines, and grounding grids, causing widespread electrical faults.
Potential Solutions	• **Water Planning & Conservation.** Assess water use early to avoid harm to local communities and operations. Secure a reliable, low-impact water source for essential washing. • **Waterless Robotic Cleaning & Coatings.** Favor waterless cleaning, such as robotic brushes, over water-heavy washing. Specify anti-soiling coatings on new panels. • **Smart Tilt & Condition-Based Monitoring.** Set panel tilt angles to shed dust and prevent dew-cemented grime. Use soiling sensors and inspections to optimize cleaning schedules. • **Site Dust Control & Equipment Sealing.** Stabilize dirt access roads with gravel or dust suppressants, plant drought-tolerant ground cover, and use sealed enclosures with regular filter maintenance to keep dust out of inverters and trackers.	• **Climate-Adjusted Modeling.** Analyse solar irradiation in depth, including future cloudiness and climate projections, when sizing the plant and forecasting yield. • **Diffuse-Light & Shading Optimization.** Use monocrystalline panels with textured or antireflective glass, bypass diodes, and trackers with diffuse-light algorithms to maximize output in cloudy or shaded conditions. • **Moisture Sealing & Humidity Protection.** Specify dual-glass modules, hydrophobic glass coatings, and moisture- and corrosion-resistant cabling, while fitting inverters and combiner boxes with sealed, heated enclosures to prevent humidity faults. • **Proactive Cleaning & Grid Smoothing.** Maintain a frequent cleaning and maintenance programme to remove dew-cemented grime. Use smart inverter ramp controls to smooth out sudden cloud-induced power swings.	• **Snow-Load Racking & Frost-Proof Foundations.** Design racking and heavy-duty modules for local snow loads and drifts, with reinforced clamps and foundations below the frost line. • **Steep Tilt, Ground Clearance & Snow Shedding.** Set steeper panel tilt angles, program trackers with automated snow-shedding stow positions, and build higher ground clearance—paired with hydrophobic coatings or low-profile frames—so snow slides off without piling up. • **Snow Fences & Protected Equipment Placement.** Install snow fences to control drifting, and mount inverters and enclosures off the ground under hoods so sliding snow cannot bury them. • **Winterized Enclosures & Cold-Voltage Sizing.** Winterize inverters, batteries, and electrical enclosures with cold-rated components and heaters, and size string voltages for extreme cold to prevent inverter trips.	• **Forward-Looking Site Selection & Setbacks.** Carry out in-depth landslide risk analysis during site selection using future rainfall projections, avoiding landslide-prone areas and keeping setback buffers from steep slope edges. • **Drainage, Vegetation & Targeted Slope Protection.** Control runoff with graded drainage channels, maintain deep-rooted vegetation to stabilize soil, and use targeted retaining walls or slope reduction around critical infrastructure like substations and access roads. • **Terrain-Following Racking & Deep Foundations.** Use strong, deep foundations, paired with terrain-following trackers to accommodate slopes without heavy grading. • **Above-Ground Cabling & Post-Storm Monitoring.** Run cables in above-ground trays with flexible expansion loops so shifting soil cannot snap buried lines. Inspect slopes after heavy rains.

Note: Solar parks also depend on infrastructure outside their boundary. Failure of interconnecting transmission lines (overhead lines are far more exposed than underground ones) from storms or wildfires, damage to access roads from storms or permafrost thaw, and damage to control buildings can halt operations and endanger staff, while extreme weather can also disrupt construction. Co-located battery storage is particularly vulnerable to extreme heat, which increases cooling loads and raises the risk of thermal runaway, fire, and explosion. Shifts in demand, land use, water policy, or local acceptance can also affect project viability. High adaptation costs, spare-part supply bottlenecks, or unavailable insurance can make these risks harder for a private partner to manage. To address these broader risks, budget for spare parts, water reserves for cleaning, more frequent maintenance, and post-storm repairs, and use integrated monitoring, weather stations, and early warning systems to optimize maintenance and prevent damage.

Source: *World Bank Group. 2023. Climate Toolkits for Infrastructure PPPs: Renewables Sector. Washington, DC: World Bank. Summarized and adapted by Resilience Table; text in blue is a Resilience Table addition, not drawn from the Toolkit. This summary is not a World Bank Group publication and has not been reviewed or endorsed by the World Bank Group. Draft for consultation (v0.9), November 2026 · Summary and additions © Resilience Table · Free for non-commercial use with attribution (CC BY-NC-ND 4.0)*

Climate Risk & Resilience Matrix: Wind Power Assets

Blue = Resilience Table addition, not drawn from the World Bank Toolkit.

	Extreme winds / turbulence / storms / cyclones / lightning	Floods	Landslides	Wildfire
Impacts	• **Structural Stress, Fatigue & Component Damage.** Extreme winds, high turbulence, and wind thrust stress blades, tower, and foundation and cause vibration of the structure and machinery - accelerating wear on gearboxes and bearings, while beyond design capacity, components are damaged. • **Storm Damage to Grid, Access & Ports.** Storms, cyclones, and hurricanes can damage transmission and distribution lines, access roads, and port facilities, while tornadoes can topple turbines in their path. • **Safety Shutdowns, Grid Loss & Offshore Wave Impacts.** Turbines are halted for safety during extreme winds, so output drops. If the grid goes down, turbines without backup power cannot turn their nacelles or blades out of the wind to protect themselves. For offshore sites, rough seas also batter foundations and block marine repair access. • **Lightning & Hail Damage.** Lightning is the leading cause of blade damage, and power surges can damage electrical and control systems, while hail and flying debris erode blade surfaces.	• **Facility, Foundation & Grid Damage.** Floods can physically damage the wind facility, transmission lines, substations, and the roads and other infrastructure it depends on. Fast-flowing water can scour turbine foundations and expose buried collector cables, while floodwater entering tower bases ruins transformers, switchgear, and control electronics. • **Saturated Crane Pads & Prolonged Outages.** Prolonged soil saturation softens ground conditions needed for heavy repair cranes, while flooded substations and access roads force turbine shutdowns and delay maintenance.	• **Foundation Tilting, Cable Shearing & Grid Loss.** Facilities in landslide-prone areas, including transmission lines and access roads, may face increased landslide risk as rainfall extremes change over the project life. Slope movement can tilt tall turbine foundations beyond safe tolerances, shear buried collector cables, and topple transmission poles. • **Blocked Mountain Access & Crane Pads.** Landslides and debris flows can bury steep access roads and erode crane pads, cutting off maintenance crews and heavy repair equipment for prolonged periods.	• **Direct Fire Damage & Grid Outages.** Wildfires can physically damage power facilities, composite blades, pad-mounted transformers, and transmission and distribution equipment, while utility preventative shutoffs during fire weather also force turbines offline and cut external grid power. • **Smoke, Ash & Access Blockages.** Approaching wildfires can force turbines offline, and smoke and ash can clog nacelle and substation air filters—causing overheating. Even without reaching the facility, uncontrolled wildfires can temporarily block access for maintenance crews. • **Secondary Grass Fires & Post-Fire Erosion.** Dry brush increases fire spread around pads, while burned slopes face heightened erosion and debris-flow risks during later rains.
Potential Solutions	• **Structural & Blade Hardening.** Design turbines to withstand extreme wind loads safely, consider specifications beyond code thresholds, and use materials with longer fatigue life. Apply leading-edge blade protection against hail erosion and add scour protection around offshore foundations. • **Lightning & Electrical Protection.** Enhance lightning protection and grounding, install surge arresters, bury on-site collector cables underground, and inspect and repair blades regularly. • **Storm Controls & Backup Power.** Use weather early warnings (and LIDAR where feasible) to detect severe gusts, pause turbines in a controlled way before cut-out speed, and provide backup power so turbines can pitch blades and yaw during grid outages.	• **Siting & Flood-Proofing.** Carry out in-depth flood risk analysis during site selection using future projections; avoid flood-prone areas. For existing sites, use flood barriers, sump pumps, and waterproof seals to protect substations and tower bases. • **Equipment Elevation, Scour & Cables.** Increase site drainage capacity, elevate critical equipment (e.g., transformers, inverters), and position turbines with flood risk in mind. Armor foundations against water scour and use waterproof underground collector cables. • **Access Roads & Crane Pads.** Build and maintain raised, well-drained access roads and crane pads with adequate culverts so heavy maintenance equipment can reach turbines safely after floods.	• **Site Selection & Slope Drainage.** Carry out in-depth landslide risk analysis during site selection using future projections; re-evaluate the site and avoid landslide-prone areas. Use cost-effective slope protection such as surface drainage ditches, vegetation, and moderate slope grading. • **Cable Routing & Access-Road Maintenance.** Route collector cables along stable ridgelines or inside flexible conduits to tolerate minor soil movement, and keep access-road culverts clear to prevent runoff washouts. • **Early Warning & Rapid Clearing.** Use weather alerts and built-in turbine tilt sensors to detect ground movement early. Maintain local earthmoving agreements to clear blocked access roads quickly.	• **Wildfire Planning, Monitoring & On-Site Readiness.** Prepare wildfire zoning, fire prevention, and firefighting plans, with continuous monitoring and early warning for immediate action when a fire starts. Maintain emergency vehicle access and on-site firefighting water reserves for local responders. • **Defensible Space & Fire-Hardened Assets.** Use fire-smart landscaping and keep vegetation clear around turbine bases, substations, and access roads. Install fire detection and suppression in nacelles; and bury collector cables underground (or use steel/concrete poles) to prevent fire damage. • **Shutdown Protocols & Post-Fire Recovery.** Shut turbines down in a controlled way ahead of a fire, replace smoke-clogged air filters afterward, and install basic erosion controls on burned slopes before heavy rains arrive.

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Climate Risk & Resilience Matrix: Wind Power Assets (continued)

Blue = Resilience Table addition, not drawn from the World Bank Toolkit.

	Extreme heat / rising temperatures	Changes in wind resource	Ice / freezing	Sea-level rise / salinity / wave action
Impacts	• **Lower Wind Output During Peak Demand.** Higher temperatures reduce air density, lowering power production. Heatwaves often arrive with high pressure and calm winds, cutting output just as demand peaks, so on very hot days, demand may exceed what the park can supply. • **Equipment Overheating, Derating & Battery Decay.** Turbines reduce output or shut down at very high temperatures to protect gearboxes, generators, and electronics, and heat speeds up the decay of backup batteries. Substation transformers can also overheat, while sagging power lines and grid congestion restrict power export. • **Technician Heat-Stress Limits.** Extreme heat inside towers and nacelles restricts safe working hours for field crews, slowing maintenance and repairs.	• **Lower Output, Wind Droughts & Wake Losses.** Lower average wind speeds or shifting wind directions reduce park performance over the long term. Output can also fall during prolonged periods of wind below the operating threshold ("wind droughts"). • **Missed Generation & Seasonal Mismatches.** If winds strengthen, a park sized too small misses part of the available energy, while shifts in seasonal or daily wind patterns can misalign generation with peak grid demand and trigger curtailment. • **Revenue & Grid-Balancing Strain.** Greater wind variability reduces forecasting accuracy, raising grid-balancing costs and undermining expected long-term project revenues.	• **Aerodynamic Loss, Rotor Imbalance & Shutdowns.** Ice on blades reduces aerodynamic performance and creates uneven rotor weight that increases vibration and wear on bearings and gearboxes. Deep cold can force turbines to shut down to avoid equipment failure, moderate cold slows them, and heavy icing can keep turbines offline for days. • **Mechanical, Sensor & Battery Failures.** Cold speeds deterioration of structural components and can cause electrical or mechanical failures. Icing on anemometers and wind vanes also causes measurement and control errors. • **Ice-Throw Hazards & Access Delays.** Ice thrown or shed from blades endangers workers and the public near turbines, while heavy snow, icy access roads, and frozen harbors complicate installation and delay maintenance.	• **Coastal Inundation, Erosion & Landfall Cables.** Rising sea and groundwater levels can inundate coastal facilities or cause settlement and foundation instability. Coastal erosion can also expose and damage buried subsea export cables where they come ashore. • **Saltwater Corrosion & Salt-Spray Fouling.** Salinity increases corrosion of steel components (such as towers, foundations, and substation gear), while heavy sea spray fouls cooling systems and accelerates blade erosion. • **Offshore Waves & Seabed Scour.** Offshore, harsher waves, currents, and storm surges increase loading and can cause tower damage, foundation tilt or failure, and turbine collapse; seabed scour around foundations can lead to tilting or collapse. • **Drifting Sea Ice.** In polar areas, melting, drifting sea ice adds static and dynamic loads that can exceed structural or geotechnical capacity.
Potential Solutions	• **Turbine & Cooling Upgrades.** Optimize rotor/blade selection and tip-speed ratio for the expected air density. Specify high-temperature packages with upgraded component cooling in hot regions. Keep backup batteries and substation electronics in climate-controlled enclosures, and clean cooling radiators ahead of summer. • **System Pairing & Yield Planning.** Pair wind with battery storage or other resources (such as solar) for calm, hot periods, and use site temperature projections in derating assumptions. • **Substation & Crew Heat Management.** Upgrade substation transformer cooling to avoid export curtailment. Shift tower maintenance to cooler hours to protect worker safety during heatwaves.	• **Forward-Looking Sizing, Layout & Turbine Selection.** Analyse wind potential in depth, including future projections, when sizing the park and selecting taller hub heights or larger rotors suited to lower wind speeds. Optimize turbine spacing for multi-directional winds to limit future wake losses. • **Smart Controls & Forecasting.** Use computer control and tracking systems that monitor wind speed and direction and adjust turbine orientation for optimum performance, paired with advanced wind-forecasting tools to reduce grid-balancing errors. • **Storage, Hybridization & Portfolio Diversification.** Co-locate battery storage or complementary renewables to bridge prolonged low-wind periods and store excess energy when winds strengthen. Diversify wind sites geographically to stabilize revenues.	• **Blade Anti-Icing & Heated Sensors.** Use anti-icing techniques such as active blade heating or passive hydrophobic coatings. Install ice sensors and heated anemometers to prevent control errors. • **Cold-Weather Packages & Lubricants.** Specify cold-weather packages that heat gearboxes, yaw, pitch systems, and backup batteries. Heat turbines through cold spells, use cold-rated lubricants and seals, and shut turbines down below their rated temperature. • **Ice-Throw Safety & Winter Access.** Set safe buffer distances from roads and trails, post warning signs, and shut down turbines near roads and paths during icing. Maintain snow-clearing plans for site access roads.	• **Coastal Siting, Elevation & Subsea Landfalls.** Consider projected sea-level rise in design, set back or elevate onshore coastal turbines and substations above projected inundation and groundwater zones, and bury or duct subsea export cables deeply at coastal landfalls to prevent erosion exposure. • **Corrosion & Salt-Spray Protection.** Use anti-corrosive materials and coatings alongside cathodic protection on steel foundations, seal coastal substations against salt spray, and apply leading-edge blade protection. • **Offshore Foundations, Scour & Sea Ice.** Offshore, incorporate drifting sea-ice loads in design; increase foundation size or change foundation type (e.g., monopile to multi-pod), and install foundation and scour protection, preferably nature-based designs that support marine life.

Note: This section covers both onshore and offshore wind; points marked "Offshore" apply only to offshore turbines. Wind parks also depend heavily on external infrastructure. Failure of interconnecting transmission lines (overhead lines are far more exposed than underground ones), storm or permafrost damage to access roads and ports, and damage to control buildings can halt operations and endanger staff. Co-located battery storage is also vulnerable to extreme heat, which raises the risk of thermal runaway and fire, while high adaptation costs or limited insurance coverage can complicate private-sector risk management.

To manage these broader risks, operators should budget for additional storage, more frequent maintenance, and post-storm repairs, and link weather monitoring directly to turbine controls. Following preventive maintenance schedules, planning timely replacement of ageing turbines, and keeping technicians and critical spare parts within a day's reach of the site also ensure rapid recovery.

Source: *World Bank Group. 2023. Climate Toolkits for Infrastructure PPPs: Renewables Sector. Washington, DC: World Bank. Summarized and adapted by Resilience Table; text in blue is a Resilience Table addition, not drawn from the Toolkit. This summary is not a World Bank Group publication and has not been reviewed or endorsed by the World Bank Group. Draft for consultation (v0.9), November 2026 ·* *Summary and additions © Resilience Table · Free for non-commercial use with attribution (CC BY-NC-ND 4.0)*

Climate Risk & Resilience Matrix: Water Production & Treatment Assets

Blue = Resilience Table addition, not drawn from the World Bank Toolkit.

	Tropical storms / cyclones / coastal storm surge	Extreme rainfall / inland flooding	Sea-level rise / coastal erosion / saltwater intrusion / rising ground water	Landslides / mudflows
Impacts	• **Physical & Buffer Damage.** Tropical storms can damage treatment plants, intakes and tall water tanks, raising repair and maintenance costs. Fallen trees can break surface pipelines, and loss of coastal or riparian buffers exposes inland assets. • **Flooding & Source-Water Contamination.** Storm surge can flood coastal treatment plants and intakes and push saltwater into freshwater sources, while storm-driven sediment raises turbidity, and sewage and debris clog intakes. • **Power Loss, Boil-Water Notices & Access Delays.** Power outages stop treatment and pumping, and pressure loss can trigger boil-water notices. Blocked roads delay repairs, refueling and chemical deliveries.	• **Inundation, Scour & Reservoir Strain.** Floods can inundate treatment plants, intakes, and conveyance systems, damaging pumps, pipelines, and electrical equipment. Fast-moving floodwaters also scour and break pipes at river crossings, while peak flows into raw-water reservoirs strain storage capacity. • **Sediment, Debris & Sewage Contamination.** Storm runoff and landslides carry sediment and debris into source water, lowering quality and raising treatment costs, while flooded wastewater systems wash pathogens and pollutants into water sources. • **Access & Service Disruptions.** Flooded roads cut off access to plants and pump stations, delaying repairs, chemical deliveries, and generator refueling during grid outages.	• **Coastal Erosion & Structural Damage.** Sea-level rise increases coastal erosion, structurally damaging water-system components near shore, breaking water mains, and draining storage reservoirs. • **Rising Groundwater.** Rising groundwater can cause soil subsidence, seep into underground vaults, or damage buried tanks through increased buoyancy. • **Saltwater Intrusion & Well Loss.** Sea-level rise or increased pumping intensifies saltwater intrusion in coastal aquifers, forcing utilities to abandon salinized wells. • **Water Quality, Treatment Costs & Corrosion.** Facilities drawing from nearby aquifers or surface intakes face poorer water quality and higher treatment costs, including for desalination. Salty groundwater also corrodes buried pipes, well casings and pumps.	• **Intake Burial & Water Contamination.** Debris flows can bury intakes and springs and contaminate water, disrupting service until drinking-water quality is restored. • **Pipeline, Reservoir & Facility Damage.** Landslides can physically damage conveyance pipelines, treatment plants, and pump stations, while slides into reservoirs reduce storage capacity or temporarily block upstream river flows. • **Access & Power Cutoffs.** Slope failures block access roads and sever power lines to remote facilities, delaying repairs, deliveries and generator refueling.
Potential Solutions	• **Design, Flood Defenses & Buffers.** Use forward-looking tropical storm data and stricter design standards for critical assets; build flood defenses such as seawalls and dikes. Protect or restore coastal and riparian buffers, and trim trees near surface pipelines. • **Equipment Elevation & Backup Power.** Elevate pumps, motors and electrical controls above flood and storm-surge levels, and keep backup generators with enough fuel and treatment chemicals on site to run through extended outages. • **Source-Water, Intake & Network Protection.** Equip intakes with debris screens, maintain off-stream raw-water storage or backup wells to bypass saline surges, and use isolation valves to contain pipe breaks. • **Early Warning & Monitoring.** Use early warning systems and monitor critical components and water quality to issue timely boil-water notices.	• **Siting, Flood-Proofing & Scour Protection.** Site and design facilities using forward-looking flood projections. Protect existing plants with flood barriers, elevate critical electrical and pumping equipment, and armor pipelines at river crossings to prevent flood scour. • **Source Diversity & Raw-Water Storage.** Diversify water sources (e.g., combining surface water and groundwater) so service can continue if one source is contaminated. Build raw-water storage and redundant intakes so plants can pause intake during high-turbidity events. • **Watershed & Treatment Adaptation.** Restore watershed vegetation to reduce runoff and erosion, install upstream water-quality sensors for early warning, and equip treatment plants to handle muddy or contaminated inflows. • **Access & Supply Readiness.** Maintain extra on-site reserves of treatment chemicals and generator fuel, alongside emergency access plans for flooded roads.	• **Aquifer & Estuary Salinity Control.** Manage aquifers and groundwater levels (including monitoring with piezometers) to control saltwater intrusion, inject fresh water into aquifers to form hydraulic barriers, and install salinity barriers or low-head dams across tidal estuaries where feasible. • **Coastal Buffers, Relocation & Buoyancy Protection.** Use ecosystem management and coastal buffers to limit coastal erosion, relocate vulnerable wells, intakes, and pipelines further inland where needed, and anchor underground tanks or equip basements with sump pumps and waterproofing to counter rising groundwater. • **Corrosion & Treatment Upgrades.** Use corrosion-resistant materials and protective coatings in saline soils and groundwater, and upgrade treatment or desalination plants to handle higher salinity levels.	• **Site Screening & Slope Drainage.** Screen sites for landslide hazards, keep slope drainage ditches clear, and use vegetation or basic retaining barriers to protect intakes, plants, and access roads. • **Pipe Protection & Isolation.** Design pipes for ground deformation and install automatic shutoff valves to prevent broken mains from washing out slopes. • **Monitoring, Backup Power & Rerouting.** Use modern water-contamination monitoring with automatic alerts. Diversify water supplies or duplicate critical components where feasible, and prepare reroute, backup power and alternate access plans for rapid recovery.

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Climate Risk & Resilience Matrix: Water Production & Treatment Assets (continued)

Blue = Resilience Table addition, not drawn from the World Bank Toolkit.

	Degraded water conditions / algal blooms	Wildfire	Extreme heat / drought / low flow	Extreme cold / freezing / ice
Impacts	• **Water Quality, Taste & Toxin Risks.** Algal growth in low-flow areas can compromise water quality, causing taste-and-odor problems and disinfection byproduct spikes. Toxic algal blooms that reach intakes can force intake shutdowns and do-not-drink advisories. • **Filter Clogging & Reduced Output.** Dense algae and organic matter clog intake screens and treatment filters, increasing backwash water losses and reducing daily plant production capacity. • **Higher Treatment & Energy Costs.** Advanced treatment (such as activated carbon or ozone) and increased chemical dosing raise energy demand and capital and operating costs.	• **Physical, Pipe & Pressure Damage.** Wildfire can physically damage water facilities, melt plastic pipes and drain tanks during firefighting; lost pressure can draw smoke and toxic chemicals into pipes. • **Post-Fire Sedimentation & Ash.** Runoff and flash floods from burned land increase reservoir sedimentation, reducing capacity and service life. Ash and debris from burned watersheds can foul source water for months to years after a fire. • **Water Contamination & Treatment Strain.** Higher pollutant loads accelerate algal growth, clog filters and raise treatment costs. • **Power Loss & Access Cutoffs.** Fires can knock out power at intakes and treatment plants, forcing utilities to switch sources, while evacuations and blocked roads delay repairs and chemical deliveries.	• **Supply Shortages & Peak Demand.** Demand on very hot days can exceed daily output capacity. Lower aquifer, reservoir and river levels reduce production and can force use restrictions; declining snowpack brings earlier peak runoff that reservoirs cannot hold, causing summer shortages. • **Water Quality & Algal Blooms.** Lower streamflow and warm water degrade source-water quality, trigger filter-clogging algal blooms, and let saltwater advance upstream toward intakes, requiring advanced treatment and raising operating costs. • **Equipment Overheating, Power Outages & Pipe Breaks.** Extreme heat causes pumps and electrical equipment to overheat and triggers power outages that disrupt pumping and treatment. Dry, shrinking soils crack buried water mains.	• **Burst Pipes & Equipment Damage.** Freezing can burst exposed and shallow pipes, crack underground water mains through frost heave and cold water inflows, and damage intakes, pumps, valves, and chemical feed lines. • **Intake Blockages & Frozen Storage.** Ice on rivers and reservoirs (including frazil ice) can block intakes, while ice buildup inside water tanks and vents can disrupt storage and system pressure. • **Power Outages & Access Delays.** Winter power outages can stop pumping and treatment, while heavy snow and ice block roads - delaying main-break repairs, chemical deliveries, and backup generator refueling.
Potential Solutions	• **Source & Reservoir Management.** Combine watershed management (to curb nutrient runoff), groundwater recharge, and reservoir management, including lake aeration, and draw water from deeper multi-level intakes to avoid surface blooms. • **Early Warning & Emergency Switching.** Install source-water sensors and early-warning systems to detect algal blooms before they reach intakes, and maintain backup water sources or advisory protocols if toxins exceed treatment limits. • **Treatment & Filter Optimization.** Optimize coagulation and filter-backwash routines to prevent filter clogging, and add targeted treatment, granular activated carbon, or ozonation to remove algal toxins and taste-and-odor compounds.	• **Watershed & Fuel Management.** Develop wildfire models and fire-management plans, manage fuels, and protect or restore forested watershed ecosystems to reduce sediment and nutrient runoff. • **Facility Hardening & Backup Power.** Maintain defensible space around plants and pump stations, protect exposed pipes, and keep backup generators and fuel for grid outages. • **Network Isolation & Interconnections.** Secure interconnections with neighboring systems. Use isolation valves so damaged pipes cannot drain tanks or draw in contaminants. • **Monitoring & Treatment Readiness.** Monitor reservoirs, water quality and critical components for early signs of sedimentation and ash. Keep extra treatment chemicals for post-fire runoff.	• **Supply Diversification & Storage.** Diversify supply (e.g., desalination, water reuse and water trading) and build aquifer storage and recovery. Increase storage by building dams, removing reservoir sediment, and lowering intakes or adding intakes at multiple depths. • **Drought & Conservation Planning.** Prepare drought contingency plans with alternate supplies and use restrictions, and conservation plans covering metering, timing of water-intensive use, efficient appliances and rain harvesting; cut network losses through leak detection and pressure management. • **Water Quality & Disinfection Control.** Manage water quality through watershed, groundwater, and reservoir management and increase treatment standards to handle lower-quality or brackish water. • **Heat-Resilient Power & Equipment.** Use on-site or alternative power, including renewables, and upgrade ventilation or thermal ratings for pumps and electrical equipment.	• **Pipe, Tank & Equipment Protection.** Bury pipes below frost depth, insulate or heat exposed equipment and valves, and keep water circulating to prevent storage tanks from freezing. • **Ice-Adapted Intakes.** Design intakes to manage ice and follow routine ice-clearing protocols to prevent frazil and surface ice blockages. • **Winterized Power, Supplies & Access.** Secure winterized backup power, store treatment chemicals and fuel on site for multi-day events. Maintain snow-clearing plans and spare repair clamps for winter pipe bursts.

Note: Utilities can also establish mutual-aid agreements, water trading and emergency resource sharing.

Source: *World Bank Group. 2023. Climate Toolkits for Infrastructure PPPs: Water Sector – Production & Treatment. Washington, DC: World Bank. Summarized and adapted by Resilience Table; text in blue is a Resilience Table addition, not drawn from the Toolkit. This summary is not a World Bank Group publication and has not been reviewed or endorsed by the World Bank Group. Draft for consultation (v0.9), November 2026 ·* *Summary and additions © Resilience Table · Free for non-commercial use with attribution (CC BY-NC-ND 4.0)*

Climate Risk & Resilience Matrix: Road Assets

Blue = Resilience Table addition, not drawn from the World Bank Toolkit.

	Severe storm / hurricane	Extreme rainfall / inland flooding	Sea-level rise / storm surge / coastal erosion	Landslides / slope failures
Impacts	• **Wind Debris, Bridge Stress & Power Outages.** Extreme winds can bring down trees, signs, and lightweight equipment—disrupting traffic, causing accidents, and blocking evacuation and emergency routes. Strong winds also stress bridges (especially suspension bridges) and make driving unsafe, while downed power lines knock out traffic signals, street lighting, and tunnel pumps. • **Storm Surge, Wave Uplift & Scour.** Storm surge can cover low-lying coastal roads and damage bridges and roadside equipment, while storm surge and waves can lift bridge decks off their supports, wash out causeways, scour road embankments and culverts - cutting communities off for weeks.	• **Road Inundation, Base Weakening & Safety Hazards.** Floodwater can cover pavements and close roads. Prolonged saturation also weakens underlying road bases, accelerating potholes and pavement collapse after waters recede. • **Bridge Scour, Culvert Washouts & River Undercutting.** Fast-flowing water can scour bridge foundations, leading to failure. Debris-blocked culverts can overtop and wash out the road above. River undercutting can close key corridors for months, with high repair costs. • **Drainage Overload, Tunnels & Slope Runoff.** Intense rain can overwhelm drainage, while grid outages knock out underpass and tunnel pumps. Water can enter tunnels and underground structures through stairways, vents, and other openings, and saturated slopes can send landslides and debris flows onto roads.	• **Chronic Tidal Flooding & Access Disruptions.** Low-lying coastal road assets may be inundated by chronic sea-level rise and regular king tides—blocking coastal drainage outfalls, flooding underpasses, and disrupting daily traffic and emergency access. • **Coastal Erosion, Scour & Slope Instability.** Sea-level rise, strong wave action, and coastal flooding can progressively erode coastal roads, bridge foundations, and earthworks, potentially causing malfunction or collapse. Coastal erosion can also contribute to coastal cliff and slope instability or landslides. • **Road-Base Saturation & Saltwater Corrosion.** Rising coastal water tables soften road sub-bases and accelerate pothole failure, while saltwater spray and flooding corrode steel bridge reinforcement, guardrails, and roadside electrical equipment.	• **Structural Damage, Rockfalls & Road Closures.** Slope failures can displace, destabilize, or collapse roads, bridges, and retaining structures, while rockfalls damage guardrails and pavements. Debris flows can obstruct road operations and isolate communities along key mountain corridors for weeks. • **Drainage Blockages & Secondary Washouts.** Mud and slide debris clog roadside ditches and culverts, diverting stormwater onto pavements and washing out adjacent embankments.
Potential Solutions	• **Wind Hardening & Vegetation Management.** Wind-proof signs, lights, and lightweight equipment; trim hazardous roadside trees to prevent wind-blown debris from blocking roads. • **Bridge & Causeway Protection.** Raise coastal bridge decks above projected surge and wave levels, restrain decks against uplift and lateral movement, and armor coastal causeways and embankments against wave scour. Budget for suspension-bridge rehabilitation. • **Traffic Power & Evacuation Operations.** Equip critical traffic signals and tunnel pumps with backup power, deploy early warnings and wind-speed closure rules for extreme winds and storm surge, and pre-stage debris-clearance crews along evacuation routes.	• **Drainage, Nature-Based Solutions & Slope Runoff.** Monitor and maintain drainage capacity, and increase it where required through larger culverts and channels. Use river or lake restoration and nature-based solutions to minimize runoff, and manage roadside slope drainage to prevent rain-triggered debris flows. • **Tunnel & Underpass Protection.** Install floodgates at tunnel entrances, and upgrade tunnel and underpass sump pumps with backup power to prevent flooding during grid outages. • **Road Elevation, Scour & Flood Barriers.** Raise roads and bridges in floodplains, install fixed flood barriers (e.g., levees/dikes) where needed, and protect embankments and bridge piers against scour. Use well-drained, water-resistant road bases to prevent pavement collapse after flooding. • **Driver Safety & Flood Operations.** Apply anti-skid pavement treatments as needed, install flood-warning sensors and closure gates at flood-prone underpasses and crossings, and maintain pre-planned emergency detour routes and debris-clearance crews.	• **Retreat, Elevation & Hard Defenses.** Consider retreating or elevating roads and flood protection measures (e.g., seawalls, dikes, and bulkheads), armor bridge foundations against wave scour, and upgrade road sub-bases to tolerate higher coastal groundwater tables. • **Nature-Based Coastal Protection.** Investigate where breakwaters, artificial reefs/groynes, berms and dunes, beach nourishment, and planting trees, marshes, or mangroves make the most sense to install to absorb wave energy and slow erosion. • **Drainage Backflow & Corrosion Control.** Install one-way tidal check valves on coastal storm drains to prevent high-tide street flooding, and use corrosion-resistant rebar, marine coatings, and sealed electrical cabinets to withstand salt spray. • **Early Warning & Slope Monitoring.** Provide storm-surge early warnings, monitor precarious coastal slopes, and maintain pre-planned detour routes for tidal closures.	• **Slope Stabilization & Rockfall Protection.** Screen routes for geohazard risks and use slope stabilization and protection (retaining structures, surface protection, and slope drainage), rockfall containment (such as netting or catch fences), and field monitoring of precarious slopes. • **Early Warning & Traffic Closures.** Use early warning systems for extreme weather and slope hazards where appropriate, paired with automated road-closure gates or signage to keep motorists out of active slide zones. • **Drainage Maintenance & Rapid Recovery.** Keep roadside ditches and culverts clear of debris to prevent secondary washouts, and maintain pre-staged clearing equipment and emergency detour plans to reopen isolated corridors quickly.

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Climate Risk & Resilience Matrix: Road Assets (continued)

Blue = Resilience Table addition, not drawn from the World Bank Toolkit.

	Dust storms	Wildfire	Extreme heat / drought	Extreme cold / snowfall	Permafrost thaw
Impacts	• **Visibility Loss & Road Closures.** Dust storms can cover roads and reduce visibility, causing closures and accidents.	• **Road Closures, Smoke & Evacuation Bottlenecks.** Wildfires and dense smoke can blind drivers, trap evacuees, and close roads, while utility power outages knock out traffic signals, lighting, and tunnel ventilation along key corridors. • **Direct Fire & Heat Damage.** Fire can burn wooden guardrails, signs, and markers, melt plastic culverts and asphalt surfaces, damage bridge joints and roadside electronics, and destroy roadside vegetation - leaving unstable hazard trees along rights-of-way. • **Post-Fire Erosion, Flooding & Debris Flows.** Loss of vegetation on slopes and embankments raises the risk of flooding, erosion, and landslides; heavy rain on burned slopes can send debris flows onto highways, closing them for weeks.	• **Asphalt Deterioration & Concrete Buckling.** High temperatures can soften asphalt, causing rutting, bleeding, and cracking (especially on roads with heavy truck traffic) and combined with heat, drought can speed up asphalt deterioration. Concrete slabs expand and can buckle suddenly. • **Soil Shrinkage & Roadbed Cracking.** Prolonged drought dries out underlying soils, causing ground shrinkage and uneven settlement that crack roadbeds, embankments, and bridge approaches. • **Bridge Expansion, Electronics & Worker Safety.** Steel bridges expand and movable bridges can jam, while extreme heat overheats traffic-signal controllers and roadside electronics. Heat also reduces worker safety and productivity during road construction and maintenance. • **Slope Vegetation Loss & Erosion Risk. D**rought can kill vegetation on slopes and embankments, raising the risk of later floods and landslides.	• **Slippery Roads, Whiteouts & Blocked Corridors.** Snow and ice can make pavements slippery, causing accidents and operational disruption, while snowdrifts, whiteouts, and heavy snow bringing down roadside trees close highways and strand motorists. • **Thermal Cracking, Freeze-Thaw Potholes & Plow/Salt Wear.** Cold can crack asphalt, and repeated freeze-thaw cycles crack pavements and create potholes, driving up repair costs and vehicle damage claims. Snowplows and heavy de-icing salt also wear road markings and accelerate corrosion of bridges and guardrails. • **Frozen Joints, Culverts & Roadside Systems.** Ice buildup can jam bridge expansion joints, block drainage culverts, causing meltwater flooding, and disrupt traffic signals and roadside electronics.	• **Ground Thaw & Road Collapse.** In permafrost regions, thawing ground can destabilize roads or cause them to collapse.
Potential Solutions	• **Windbreaks & Early Warning.** Install windbreaks and provide early warning for extreme winds and low-visibility conditions.	• **Defensible Space & Fire-Resistant Assets.** Create wildfire buffers along roads near forests by clearing brush, and use fire-resistant materials (such as steel or concrete) for guardrails, signs, and culverts in high-risk zones. • **Monitoring, Evacuation & Traffic Power.** Monitor fire hazard and smoke visibility in high-risk areas, equip evacuation-route traffic signals and tunnels with backup power, and prepare emergency-response plans with designated evacuation and contraflow routes. • **Post-Fire Recovery & Erosion Control.** Assess burned slopes quickly, and clear hazard trees, debris, and drainage channels (installing erosion barriers where needed) before the rainy season.	• **Heat-Resistant Pavements & Subgrades.** Adjust asphalt mixes and use binders that resist high temperatures, use reflective or high-albedo surfacing and urban greenery to keep pavements cooler, and replace moisture-sensitive subgrade soils to prevent shrinkage cracking. • **Thermal Joints, Bridge Cooling & Electronics.** Design bridge and pavement joints for larger thermal movement, spray steel movable bridges with water to prevent jamming, and shade or ventilate traffic-signal cabinets to prevent overheating. • **Heatwave Operations & Worker Safety.** Spread sand on softening asphalt, patrol for pavement buckles during heatwaves (restricting heavy trucks if needed), and shift road construction and maintenance to cooler hours to protect worker safety. • **Drought-Hardy Slope Vegetation.** Maintain drought-tolerant vegetation and erosion controls on slopes and embankments to hold soil through dry spells.	• **Winter Maintenance & Snow Control.** Apply anti-skid pavement treatments, pre-treat roads against icing, and use snowplows, ice fencing, and roadside tree-trimming to keep corridors clear. • **Cold-Weather Pavements, Bridges & Permafrost.** Improve drainage and use more durable asphalt to keep water out of pavements. Use corrosion-resistant coatings on bridges to withstand road salts. Insulate embankments and install sun sheds on permafrost slopes. • **Culvert Clearing & Safety Restrictions.** Keep culverts clear of snow and ice to prevent thaw flooding, and use weather warnings, winter-tire rules, and temporary closures during severe storms.	• **Embankment Insulation & Slope Protection.** Insulate embankment structures or use heat-extraction methods (e.g., heat drains); install sun sheds to protect permafrost slopes.

Source: *World Bank Group. 2023. Climate Toolkits for Infrastructure PPPs: Road Sector. Washington, DC: World Bank. Summarized and adapted by Resilience Table; text in blue is a Resilience Table addition, not drawn from the Toolkit. This summary is not a World Bank Group publication and has not been reviewed or endorsed by the World Bank Group. Draft for consultation (v0.9), November 2026 ·* *Summary and additions © Resilience Table · Free for non-commercial use with attribution (CC BY-NC-ND 4.0)*

Climate Risk & Resilience Matrix: Information and Communications Technology (ICT) Assets

Blue = Resilience Table addition, not drawn from the World Bank Toolkit.

	Severe storms / extreme winds / lightning	Flooding / snowmelt / humidity	Sea-level rise / coastal flooding / erosion	Landslides / subsidence
Impacts	• **Physical & Antenna Damage.** High winds, hail, and falling branches damage towers, aerial lines, and above-ground assets, while gusts knock microwave dishes and antennas out of alignment. • **Water Ingress & Signal Loss.** Wind-driven rain infiltrates outdoor equipment cabinets and cable splices, causing short circuits, while heavy storms degrade wireless and satellite signal quality. • **Lightning & Power Outages.** Lightning damages transmitters, cables, and power-supply equipment. Grid outages are the main cause of storm-related service failures once backup batteries or fuel run out. • **Network Congestion.** Spikes in emergency calls and data traffic overload surviving network nodes.	• **Facility, Power & Cooling Damage.** Floodwater and debris damage data centers, equipment rooms and electronics including ground-level switchgear, generators and cooling systems. • **Underground Ducts & Fiber Washouts.** Floods and snowmelt surges scour cables and fill ducts, manholes and cabinets with water and silt; washouts along roads, rivers and bridges can cut fiber routes and isolate communities. • **Humidity & Corrosion.** High humidity raises cooling and dehumidification demands, corrodes outdoor hardware and weakens wireless reliability. • **Access Disruption.** Floods disrupt crews and emergency access, delaying repairs and spreading outages beyond the damaged site.	• **Facility Inundation & Geotechnical Stress.** Rising seas and coastal storm surges can inundate low-lying facilities, knock out local power substations, and restrict repair access, while higher groundwater pore pressures threaten the structural integrity of buildings, including cable landing stations. • **Coastal Erosion & Subsea Cable Exposure.** Shoreline erosion destabilizes cable landing stations and scours protective sand over beach manholes and buried subsea cables, exposing critical fiber routes to wave damage and severe connectivity blackouts. • **Saltwater Intrusion & Corrosion.** Saltwater intrusion and rising water tables flood underground ducts and manholes, while increased salt spray accelerates corrosion on coastal towers, antennas, and backup generators.	• **Infrastructure & Cable Damage.** Landslides and subsidence threaten above- and below- ground ICT assets, crushing or shearing buried fiber conduits, tilting mast and antenna foundations out of alignment, and damaging transmission lines. • **Access & Outage Duration**. Slope failures wash out or block access roads, delaying cable repairs and preventing generator refueling after grid power lines are severed.
Potential Solutions	• **Structural & Line Hardening.** Strengthen mast foundations, design towers to current wind standards, and brace microwave antennas against twisting. Move vulnerable aerial cables underground where feasible, and trim trees near overhead telecom lines. • **Lightning & Weatherproofing.** Improve lightning protection and grounding across towers and power supplies, and weatherproof outdoor cabinets and cable entries against heavy, blowing rain. • **Backup Power & Pre-Storm Staging.** Extend battery runtime and install backup generators at critical cell and fiber sites. Keep spare poles, wires, and portable generators on hand, and have restoration crews ready before storms. • **Network Redundancy & Coordination.** Use redundant routing, emergency traffic prioritization and early warnings, and coordinate recovery with local authorities.	• **Siting & Elevation.** Locate key facilities outside future floodplains; raise critical equipment, switchgear, cooling units and generators above flood levels; install flood barriers, sump pumps and backflow valves. • **Underground & Route Protection.** Build redundant routes that avoid flood-prone roads and river crossings, and use underground designs resilient to groundwater flooding and subsidence; seal ducts, manholes and splice enclosures. • **Humidity & Corrosion Control.** Use dehumidification and corrosion-resistant enclosures, and factor precipitation and humidity exposure into site planning. • **Flood Preparedness.** Use flood and snowmelt early warnings, keep drainage clear, pre-stage pumps and fiber repair kits, and develop emergency access plans to speed recovery when roads flood.	• **Siting & Structural Foundations.** In spatial planning, site key facilities and cable landing stations inland, outside future storm paths, floodplains, and coastal erosion zones. Where coastal construction is unavoidable, build on deep piling foundations to prevent structural collapse from soil erosion and high groundwater pressure. • **Equipment Elevation & Remote Control.** Raise power generators, network switches, and backup batteries above projected coastal flood levels, and deploy remote management tools that allow engineers to reconfigure and reboot facilities when physical access is cut off by high water. • **Corrosion Proofing & Subsea Cable Protection.** Use corrosion-resistant hardware and salinity-resistant cabling, seal conduits against saltwater, and bury beach-landing cables below erosion zones.	• **Site Screening & Slope Stabilization.** Identify geohazard exposure through site screening and avoid building towers or hubs on active slide paths or unstable soils. Use vegetation for landslide protection where appropriate, alongside basic surface drainage and retaining structures to prevent soil movement. • **Flexible Cables & Tower Foundations.** Use flexible conduits and reinforced mast foundations to absorb ground settlement without shearing cables or tilting antennas. • **Network Redundancy & Access.** Build redundant fiber routes along separate corridors so traffic bypasses landslide-damaged links. Maintain emergency access plans for road washouts.

Continued on the next page.

Climate Risk & Resilience Matrix: ICT Assets (continued)

Blue = Resilience Table addition, not drawn from the World Bank Toolkit.

	Extreme cold / snow and ice build up / permafrost melt	Extreme heat / rising temperatures	Drought / water scarcity / ground shrinkage	Wildfire
Impacts	• **Ice Loading & Falling Ice.** Ice builds up on aerial cables, antennas, and trees, disrupting radio signals and bringing down lines, poles, or towers. Ice shed from tall masts can crush shelters and generators below. • **Cold-Weather Equipment & Power Failures.** Extreme cold causes electrical and mechanical failures and sharply reduces backup battery capacity. Long winter grid outages drain batteries and generators, cutting service. • **Permafrost Thaw & Frost Heave.** Thawing permafrost and seasonal freeze-thaw cycles make towers and poles sink or tilt and can crack conduits and snap buried fiber. • **Blocked Winter Access.** Snow and ice block remote access roads, delaying repairs and generator refueling.	• **Cooling Strain & Equipment Failures.** Increased heat puts additional demand on cooling requirements, raising energy costs and straining HVAC systems. Equipment at data centers and base stations can malfunction or fail above design temperatures, especially if cooling systems trip during heatwaves. • **Hardware Degradation & Signal Loss.** Heat shortens cable and battery life and can reduce wireless coverage. • **Grid, Water & Maintenance Constraints.** Heatwaves strain local power grids and limit water available for evaporative data-center cooling, while extreme outdoor temperatures restrict safe working hours for repair crews.	• **Data-Center Cooling & Dust Strain.** Water shortages can limit water-based cooling at data centers. Prolonged dry conditions increase windblown dust that clogs air filters and cooling vents at base stations and cabinets. • **Ground Shrinkage, Erosion & Cable Damage.** Drier, shrinking ground can cause subsidence that damages underground cables and destabilizes tower foundations. Reduced precipitation can also cause land heave and expose underground cables through erosion. • **Grid Power Limits.** Drought-driven hydroelectric shortfalls or utility electricity rationing can trigger grid outages and voltage drops, forcing telecom sites onto backup power.	• **Direct Fire & Heat Damage.** Wildfire can damage masts, antennas, wooden poles, shallow buried conduits, above-ground cables, and data-center power facilities, and cut off access for repairs and refueling. • **Grid Outages & Preventative Shutoffs.** Wildfire can damage transmission and distribution lines and equipment, and utilities may cut power preventively in extreme fire weather. Because ICT networks depend on grid power, these outages directly threaten connectivity. • **Smoke & Ash.** Heavy smoke and ash clog HVAC and cabinet air filters, causing equipment to overheat. • **Emergency & Evacuation Blackouts.** Losing fiber links or cell sites can cut emergency calls and alerts during evacuations.
Potential Solutions	• **Ice & Snow Hardening.** Specify equipment, towers, and cables rated for low temperatures and ice loads, strengthen poles, and manage trees along aerial routes. Install ice shields over shelters and cable trays below tall masts. • **Winterized Backup Power.** Install backup power with extended fuel storage for prolonged outages, winterize generators and fuel supplies, and house batteries in insulated, heated enclosures. • **Permafrost & Frost Protection.** Design foundations for permafrost conditions in northern regions; use burial depths, backfill and slack that tolerate frost heave. • **Winter Access & Remote Monitoring.** Plan snow clearing for remote access roads, and monitor fuel levels and site temperatures remotely.	• **Cooling & Passive Heat Protection.** Install redundant cooling at switching centres and data centers, with temperature alarms, and use water-efficient or air-cooled systems. Improve airflow management, clean HVAC units before peak summer, and use heat-reflective coatings or sunshades on outdoor cabinets. • **Hardware & Cable Resilience.** Specify components with higher operating-temperature ranges. • **Power & Operational Planning.** Provide reliable backup power and reduce grid dependence (e.g., through microgrids). Plan for future temperature projections, include heat warnings in contingency and operational procedures, and adjust outdoor maintenance hours to protect worker safety during heatwaves.	• **Water-Efficient Cooling & Storage.** Provide greater on-site water storage or standby cooling, and select cooling technology suited to a drier climate where evaporative cooling may become unfeasible. Plan for water availability over the asset life. • **Ground Shrinkage & Erosion Protection.** Use buried-cable designs that tolerate ground movement, inspect poles and buried routes in shrink-swell soils, and compact backfill properly. Maintain ground cover where dry soils could expose buried cables. • **Dust Control & Backup Power Readiness.** Service air filters more often and seal enclosures against dust. Maintain backup power for grid rationing.	• **Defensible Space & Site Hardening.** Trim vegetation near power and communication lines, clear brush to maintain defensible space around cell sites and towers, and use gravel ground cover, fire-resistant shelters and fire-resistant pole wraps. • **Undergrounding & Network Redundancy.** Bury fiber in conduit through high fire-risk areas, build diverse fiber routes, and enable emergency roaming during evacuations. • **Smoke Filtration & Backup Power.** Use extra filtration for fresh-air cooling in high-wildfire-risk areas. Provide backup power and fuel reserves at cell sites to ride through preventive shutoffs. • **Rapid Recovery Deployment.** Keep portable equipment, transportable antennas, and mobile generators ready to restore emergency coverage quickly.

Note: Failure at one ICT site can overload surviving assets, reduce service quality, and disrupt dependent systems across emergency response, public safety, transport, and economic activity. Operators should establish geographically separated disaster-recovery facilities, server virtualization, system backups, and business-continuity protocols; account for workforce commute disruptions during extreme events; maintain early-warning links and recovery coordination with meteorological and local authorities; and set up infrastructure sharing, carrier mutual-aid, emergency roaming, and rapidly deployable temporary cell or satellite links.

In addition, climate-driven shifts in animal, insect, and plant ranges expose ICT infrastructure to damage from rodents, birds, insects, and mold in newly affected areas. Operators can respond with armored cabling, fine mesh over vents, bird guards, mold-resistant seals, rigid conduit for buried lines, and vegetation clearance around facilities.

Source: *World Bank Group. 2023. Climate Toolkits for Infrastructure PPPs: ICT Sector. Washington, DC: World Bank. Summarized and adapted by Resilience Table; text in blue is a Resilience Table addition, not drawn from the Toolkit. This summary is not a World Bank Group publication and has not been reviewed or endorsed by the World Bank Group. Draft for consultation (v0.9), November 2026 ·* *Summary and additions © Resilience Table · Free for non-commercial use with attribution (CC BY-NC-ND 4.0)*

References

World Bank Group. 2022. Climate Toolkits for Infrastructure PPPs. Washington, DC: World Bank. https://www.worldbank.org/en/topic/sustainableinfrastructurefinance/brief/climate-toolkits-for-infrastructure-ppps

World Bank Group. 2023. Climate Toolkits for Infrastructure PPPs: Water Production and Treatment Sector; Road Sector; ICT Sector; Hydropower Sector; Renewables Sector. Washington, DC: World Bank. https://www.worldbank.org/en/topic/sustainableinfrastructurefinance/brief/climate-toolkits-for-infrastructure-ppps

World Bank Group. 2023. "The World Bank Group's Climate Toolkits for Infrastructure PPPs." Brief, May 19, 2023. https://www.worldbank.org/en/brief/2023/05/19/climate-toolkits-for-infrastructure-ppps

Saralegui, G., K. Weekes, and M. Silva Zuniga. 2023. "Introducing the sector-specific climate toolkits for infrastructure PPPs." World Bank Blogs, June 20, 2023. https://blogs.worldbank.org/en/ppps/introducing-sector-specific-climate-toolkits-infrastructure-ppps

World Bank Group. 2021. Resilience Rating System: A Methodology for Building and Tracking Resilience to Climate Change. Washington, DC: World Bank. http://hdl.handle.net/10986/35039

World Bank. 2019. "$4.2 Trillion Can Be Saved by Investing in More Resilient Infrastructure, New World Bank Report Finds." Press release on Lifelines: The Resilient Infrastructure Opportunity, June 19, 2019. https://www.worldbank.org/en/news/press-release/2019/06/19/42-trillion-can-be-saved-by-investing-in-more-resilient-infrastructure-new-world-bank-report-finds

Mahul, O., B. Adam, and S. Hallegatte. 2025. "Disaster protection: How public-private insurance programs can make low-income countries more resilient." World Bank Blogs, May 22, 2025. https://blogs.worldbank.org/en/psd/disaster-protection--how-public-private-insurance-programs-can-m

GFDRR. ThinkHazard!. https://thinkhazard.org

IFC. Building Resilience Index. https://www.resilienceindex.org

Global Infrastructure Facility, Aon, IFC and MIGA. 2026. Underwriting the Future of Resilience: Developing Insurable and Bankable Infrastructure. https://www.globalinfrafacility.org/knowledge/underwriting-future-resilience-developing-insurable-and-bankable-infrastructure