



**CLIMATE-RESILIENT DAMS AND
HYDROPOWER INFRASTRUCTURE
INTEGRATING
ENVIRONMENTAL SUSTAINABILITY
IN PLANNING AND DEVELOPMENT**

**Climate-Resilient Pumped Storage Hydropower Development in the
Western Ghats**

*Integrating Climate Risk Assessment, Dam Safety and Sustainable Design for Off-
River Closed-Loop PSH*

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Background & Context

- Rapid growth of **solar and wind** increases need for grid flexibility
- Pumped Storage Hydropower (PSH) is the most mature large-scale energy storage solution
- Climate change is introducing uncertainty in **hydrology, geotechnics, and operation**
- Conventional PSH designs rely on **historical hydrology and deterministic safety** margins, which are increasingly inadequate under climate non-stationarity



Why Western Ghats?

- Steep terrain → excellent **elevation differences** for PSH
- High monsoonal rainfall and **flashy small catchments**
- Complex geology and **environmentally sensitive region**
- Increasing frequency of **extreme rainfall, landslides, slope failures**
- Strong need for **climate-informed** planning and design



Problem

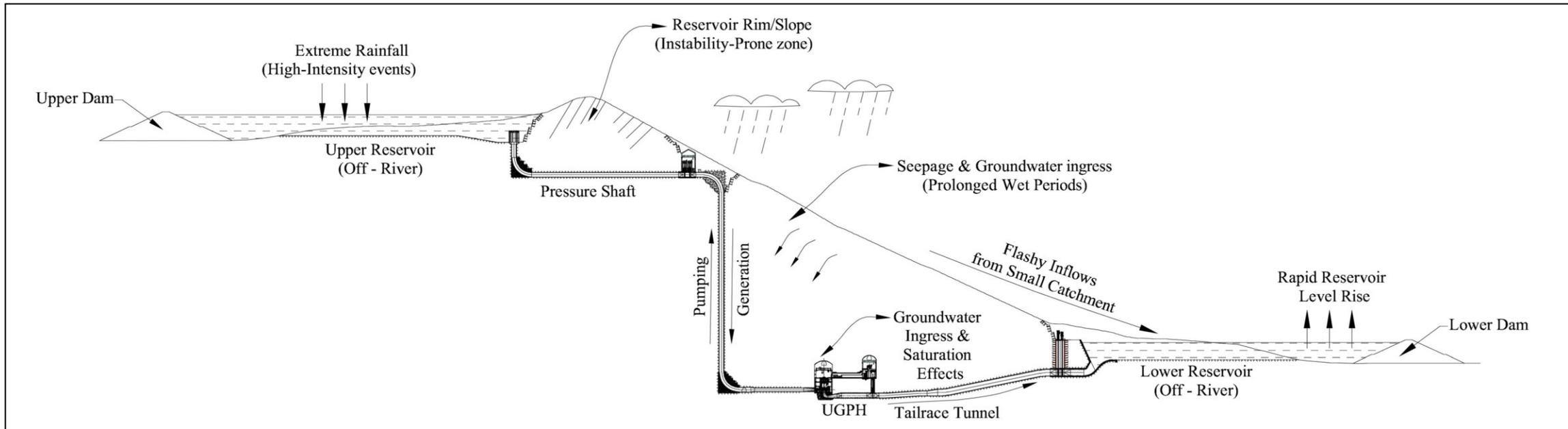
- Most PSH projects do not explicitly integrate climate risk assessment
- Climate-induced risks extend beyond floods to:
 - Slope instability and landslides
 - Reservoir rim and abutment failures
 - Groundwater ingress into underground caverns
 - Operational disruptions during extreme events
- Need for a structured, risk-informed framework

Objectives of the Study

- Develop a **climate-resilient framework** for pumped storage projects
- Focus on **off-river, closed-loop PSH** systems
- Integrate:
 - Climate risk assessment
 - Risk-informed dam safety
 - Sustainable design and environmental safeguards
 - Adaptive operational strategies
- Need for a structured, risk-informed framework

Off-River Closed-Loop PSH Concept

- Upper and lower reservoirs located away from rivers
- Minimal impact on downstream hydrology and aquatic systems
- However, systems remain exposed to: Direct extreme rainfall, Rapid reservoir level rise, Slope instability around reservoirs, Seepage and flooding of underground structures
- Climate risks must be explicitly addressed



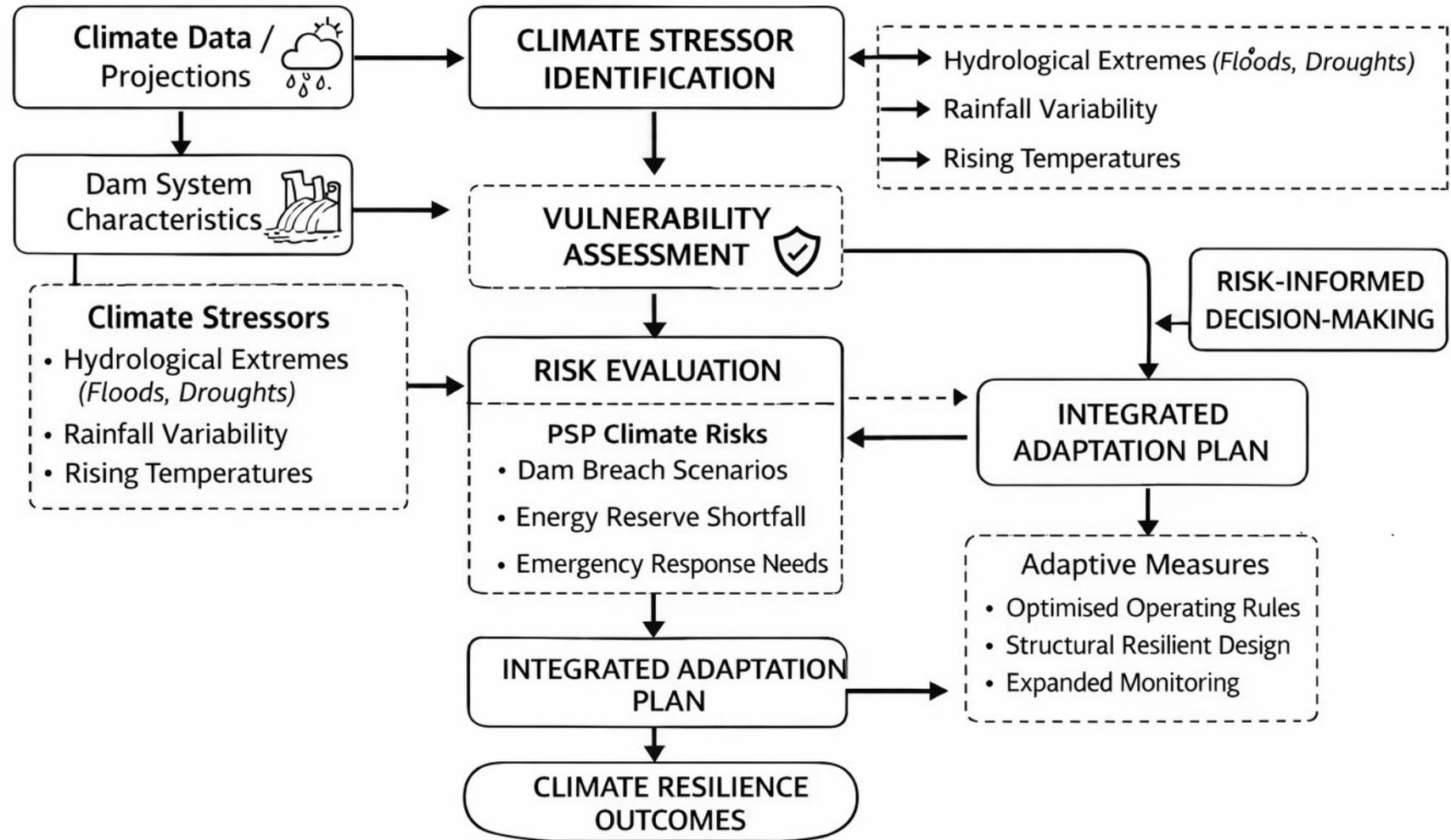
Climate Change Stressors & Components

Climate Stressor	Affected Component	Potential Impact
Intense short-duration rainfall	Small catchments	Flashy inflows, rapid level rise
Extreme rainfall	Reservoirs, spillways	Rapid level rise, overtopping risk
Rainfall variability	Reservoir operation	Reduced predictability
Slope saturation	Dam abutments, slopes	Instability, landslides
Prolonged wet periods	Tunnels, caverns	Increased seepage
Rising temperature	Reservoirs	Increased evaporation

Climate Risk Assessment Framework

Stepwise approach:

1. Climate stressor identification
2. Component-based vulnerability assessment
3. Consequence-based risk evaluation
4. Prioritisation of adaptation measures



Climate Risk Matrix – PSH

Climate Hazard	Likelihood	Consequence	Risk Level	Key Adaptation Measures
Extreme rainfall	Medium	Very High	High	Revised PMF, spillway capacity
Reservoir rim instability	High	High	High	Slope stabilisation, drainage
Landslides	High	Medium	High	Monitoring, bioengineering
Tunnel flooding	Medium	High	Medium–High	Drainage, seepage control
Operational disruption	Medium	Medium	Medium	Adaptive operating rules

DAM SAFETY AND STRUCTURAL RESILIENCE

Dam Safety Aspect	Climate Driver	Potential Failure Mode	Mitigation / Compliance Reference
Spillway capacity	Extreme rainfall	Overtopping	Revised PMF; CWC flood guidelines
Reservoir stability rim	Saturation	Localised failure	Slope stabilisation; drainage
Embankment integrity	Prolonged periods wet	Internal erosion	Filters; instrumentation
Underground works	High groundwater	Flooding, instability	Drainage; rock support
Emergency response	Extreme events	Delayed intervention	EAP; Dam Safety Act, 2021 (Section 30)

Sustainable Design and Environmental Safeguards

- Off-river PSH reduces riverine impacts, but climate risks remain
- Climate-responsive safeguards include:
 - Footprint optimization
 - Catchment treatment and erosion control
 - Bio-engineering and nature-based solutions
 - Controlled surface drainage
- Integrated with **EIA and long-term environmental monitoring**



Adaptive Operation & Decision Support



- Static operating rules are inadequate under climate variability
- Climate-resilient operation requires:
 - Real-time rainfall, reservoir and seepage monitoring
 - SCADA-based decision support systems
 - Updated Emergency Action Plans (EAPs)
- Enhances safety and operational reliability

Conclusions & Way Forward

- Climate change introduces multi-dimensional risks to PSH systems
- Deterministic, historically based designs are increasingly inadequate
- Integrated framework links:
 - Climate risk assessment
 - Risk-informed dam safety
 - Sustainable design
 - Adaptive operation
- Provides a robust and transferable approach for climate-resilient PSH development



Thank You