



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

**Sustainable and Climate-resilient Design and Operation  
of Hydropower Projects: Lessons From Extreme Flood  
Events In Himachal Pradesh, India**

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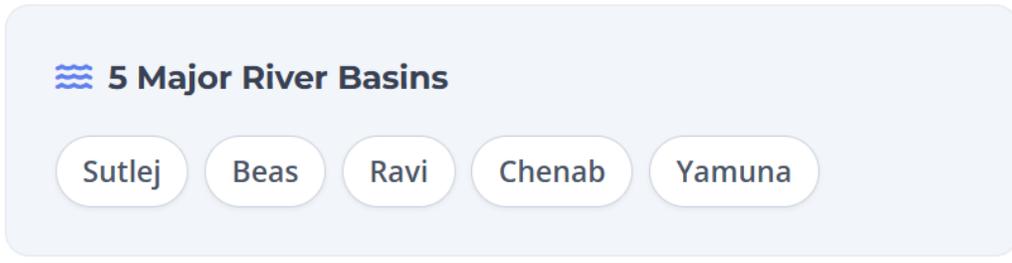
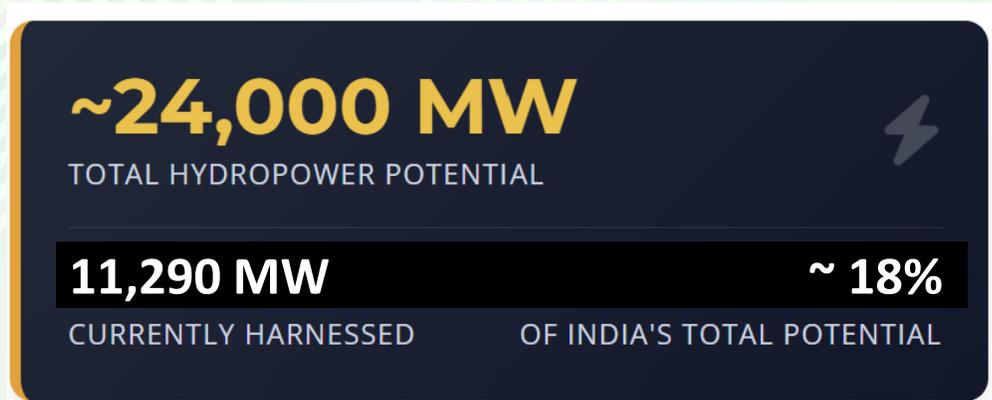
- Total assessed hydropower potential: ~133.4 GW (large hydro)
- Pumped Storage Potential (PSP): >176 GW
- Installed capacity: ~51 GW (~38% harnessed)
- Major potential regions: Himalayan states, North-East India, Western Ghats
- Strategic importance: Baseload + peaking power, grid stability, RE integration.



# Hydropower in Himachal Pradesh

## Scale & Significance

- ✓ High Head Terrain: Steep gradients offer immense energy generation potential.
- ✓ Perennial Flows: Fed by both glaciers and monsoon rainfall.



**Challenge:** While offering huge energy benefits, rapid expansion in fragile geology has altered hill slopes, drainage networks and increased sediment risks.

## Rainfall anomalies exceeding 60% above normal within 72 hours.

Cloudbursts in Kullu and Mandi generated flash floods and landslides.

### Damage to Larji Hydro Electric Project

- Extensive damage when floodwaters from the Beas River inundated the powerhouse in July 2023.
- Historical high flood discharge comparison August 3, 1953 (3838.37 cumecs) vs. July 2023 (5600 cumecs).

### Damage to Malana-II HEP Project

- Was filled with debris and silts causing its overflow
- Chocking of gates and breach in the dam abutment slope.

# July 2023 Flood Event



Malana Dam 2- Chocking of Gates (Source-  
The economic times)

Malana Dam 2- Overtopping of dam (Source-  
Twitter-HP Govt.)

2<sup>nd</sup> Sequence of intense rainfall caused extreme flows in the **Malana, Parbati, and Beas basins**, leading to widespread damage to hydropower infrastructure.

Inspections at **Malana-I, Malana-II, Parbati-III, Sumez, and Beas Kund HEPs** showed:

- **Main dams and powerhouses remained structurally stable**
- **Severe damage to auxiliary works**, including:
  - Loss of approach roads and bridges
  - Riverbank erosion and failure of protection works
  - Boulder/debris deposition at intakes and barrages
  - Siltation of water conductor and tailrace systems
  - Damage to electrical and monitoring systems
- **Downstream habitations** affected by flooding, property loss, agricultural damage, and connectivity disruption

# July-August 2024 Flood Event

## Summary Table on Hydro Projects Affected by Cloudburst/ Flashflood Disaster on July 31- August 01, 2024.

Source: <https://sandrp.in>

SN	Project Name	Capacity	COD	Company Name	River Basin
1	Jirah HEP	4 Mw	Jan. 2011	Kapil Mohan Hydro Pvt Ltd	Tosh nullah, Parbati river Beas Basin
2	Raskat Mini HEP	800 Kw	Aug. 2001	Indushree Power (P) Ltd.	Raskat nullah, Parbati river, Beas Basin
3	Brahma-ganga HEP	5 Mw	April 2008	Harisons Hydel Power Project	Brahmaganga nullah Parbati river, Beas Basin
4	Malana II HEP	100 Mw	July 2012	Everest Power Private Ltd	Malana stream, Parbati river, Beas Basin
5	Malana I HEP	86 Mw	July 2001	Malana Power Company Ltd	Malana stream, Parbati river, Beas Basin
6	Upper Nanti HEP	13.5 Mw	2018	Greenko Hydro Energy Pvt Ltd.	Nanti stream, Sutlej basin
7	Kurmi HEP	8 Mw	March 2014	Kurmi Energy Pvt Ltd	Nanti stream, Sutlej basin
8	Lower Nanti HEP	14 Mw	2013	Suryakant Hydro Energy Pvt. Ltd	Nanti stream, Sutlej basin
9	Ghanvi I HEP	22.5 Mw	Dec. 2000	HP State Electricity Board Ltd.	Ghanvi stream, Sutlej basin
10	Ghanvi II	10 Mw	Nov. 2014	HP State Electricity Board Ltd.	Ghanvi stream, Sutlej basin
11	Greenko Sumez HEP	14 Mw	2012	Greenko Sumez Hydro Energy Pvt Ltd	Sechi stream, Sutlej Basin
12	Sechi HEP	4.5 Mw	Feb. 2011	Ascent Hydro Projects Ltd	Sechi stream, Sutlej Basin

Repeated cloudbursts during **June–August 2025** triggered catastrophic flash floods

- **Complete destruction** of small HEPs, including **16 MW Patikari** and **1 MW Jiwa HEP**
- **Major operational HEPs critically damaged:**
- **Malana-I (86 MW):** Cofferdam collapse (second consecutive year), loss of heavy equipment.
- **Parbati-II (800 MW):** Debris reaching Powerhouse outfall ; all four units disabled.
- **Under-construction projects** such as **Indira Priyadarshini (Kangra)**, severely affected.



Muck and debris near Sainj HEP (Source: Sandrp.in)



Power House damaged: Indira Priyadarshini HEP (Source: Sandrp.in)

# June-August 2025 Flood Event



Patikari Hydro Project in Himachal  
(Source: Sandrp.in)



Jiwa hydro project (Source:  
Sandrp.in)



Cofferdam at Malana Dam-1 collapsed  
(Source- tribune India)



Debris reaching NHP's Parbati II HEP powerhouse  
premises (Source: Sandrp.in)



## Impact on downstream villages

These structures might fail during heavy rain and put downstream villages at risk.

## Media influence

Circulation of images and videos intensified fear about downstream safety and project reliability.

## Altered natural river flow paths

hydropower construction activities had altered natural river flow paths and slope stability, thereby increasing flood intensity and debris movement



☰ 🔍 Sun, Jan 11, 2026 | New Delhi 17°C

Hindustan Times 100

Home E-Paper IND Vs NZ Live Have Your Say! **NEW** WPL 2026 Horoscope 2026 **Cricko**

Updated on: Jul 13, 2023 1:09 AM IST

By Chetan Chauhan/ Gaurav Bisht/Naresh K Thakur , NEW DELHI/SHIMLA/DHARAMSHALA



Massive devastation happened in the areas having high infrastructure development such as hydel project, hill cutting for widening of roads and destruction of forest cover for infrastructure projects (PTI)

dition

## DownToEarth

Health Agriculture Water Waste Climate Air Africa Data Centre Video Gallery Food

### Himachal cloudbursts: Are hydropower projects to blame?

*Four of the 6 places where cloudbursts occurred last week were locations of hydro projects*

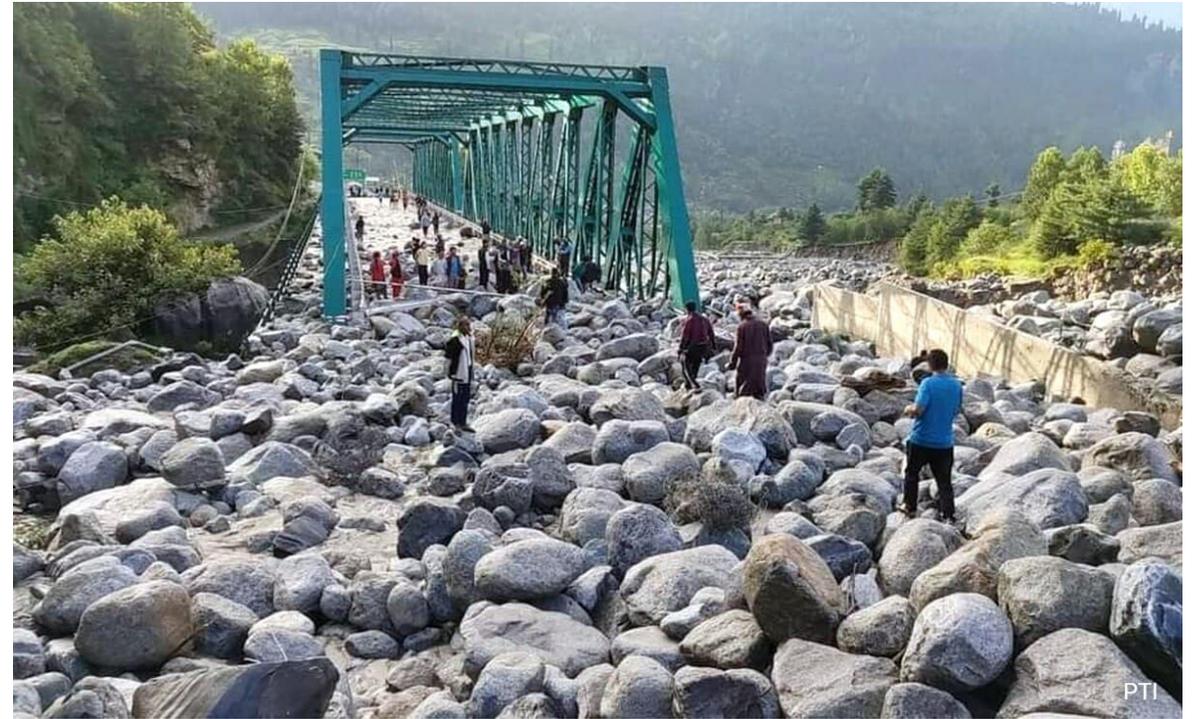


Scene after cloudburst in Shimla's Samej village, with relief workers engaged in rescue work. Photo provided by: Rohit Parashar.

# Flood Events: Damages to Infrastructure



Damaged Chandigarh-Manali  
(Source- Indian express)



The Manali-Leh Highway blocked (Source- NDTV)

# Flood Events: Damages to Infrastructure



Damaged Chandigarh-Manali  
(Source- Hindustan Times)



Damaged Foot Bridge-Kullu  
(Source: Infra.com)

## Climate-Responsive Design flood Philosophy

- Recent extreme rainfall, cloudbursts, and floods show **increasing frequency of hydrological extremes**
- Traditional **stationary flood estimates** based on short records may under-represent current risks
- Design floods must account for **changing trends and drivers**

*Non-stationary flood frequency analysis recommended to avoid unsafe designs.*

## Sediment Management

- Cloudbursts and flash floods cause rapid erosion and sediment surge from steep Himalayan catchments
- Repeated extreme events (2023–2025) lead to accelerated reservoir sedimentation
- Reduced opportunity for natural flushing and consolidation

*Sediment-bypass tunnels sized for monsoon peaks, Adaptive sluicing and flushing operations and Catchment treatment: check dams, terracing, afforestation*

## Slope Stability and Geological Resilience

- Schist and gneiss formations with jointing demand robust geotechnical planning
- Designs must consider saturation, rapid drawdown, and groundwater effects.
- Conservative slope geometries, Surface and subsurface drainage, Reinforcement and erosion protection

*Rock anchors, soil nailing, and bio-engineering for long-term stability*

## Abrasion-Resistant Materials for Hydraulic Structures

- High-velocity, sediment-laden floods cause **severe hydro-abrasion** in spillways, Boulder and gravel impact leads to **progressive concrete degradation**.
- Structural performance and safety can be compromised if unaddressed
- Need for **high-performance, abrasion-resistant materials**.

*Concrete Innovations (SJVN–IIT Delhi) Development of M80-grade HPC and HPFRC Superior resistance to abrasion and impact under high-sediment flows*

## Diversion Arrangements

Diversion structures are **temporary in function but permanent in importance**

Failures due to:

- Unprecedented flood discharges,
- landslide-induced blockage, weak and sheared geology, and
- inadequate allowance for overtopping and sediment-laden flows.
- ✓ *Diversion tunnels should be checked for extreme floods, debris impact, and blockage conditions, with appropriate lining & support systems.*
- ✓ *Cofferdams should be designed as :*
  - *Controlled overtopping structures.*
  - *Capable of safely passing the project design flood above their crest without catastrophic erosion or failure, thereby flooding the area downstream*

## Reservoir and Gate Operation Protocols

- Review reservoir rules for gradual and predictable to ensure gradual and predictable releases during rapidly rising inflow conditions.
- Adopt DROM to adjust storage and releases using near-real-time inflow estimates.
- Use/Upgrade SCADA, instrumentation, communication, and backup power.

## River Training and Bank Protection

Existing river training works often inadequate under extreme floods

Designs must consider:

- ✓ Boulder impact
- ✓ Bed aggradation
- ✓ Lateral erosion
- ✓ Use drone mapping and bathymetric surveys for periodic assessment.

## Access Infrastructure and Appurtenant Works

- Roads, bridges, and footbridges highly vulnerable during floods
- Design upgrades needed for:
  - Improved drainage
  - Adequate freeboard
  - Erosion protection

*Reliable access essential for safe operation and emergency response*

## Emergency Preparedness & Public Safety

- ✓ Emergency Action Plans to be **regularly updated** and Strengthen downstream **warning and alert systems**
- ✓ Conduct periodic **mock drills** with authorities and communities.
- ✓ Clear roles and responsibilities during flood emergencies.

## Institutional Collaboration & Learning

Strong coordination among:

- ✓ Project authorities
- ✓ Disaster management agencies
- ✓ Local administration

Institutionalize **post-event forensic assessments.**

Integrate lessons into **design standards and O&M manuals**

## Safety Inspection of Dams

Nathpa Dam experience shows value of proactive inspections:

- ✓ Pre-monsoon readiness inspections.
- ✓ Post-monsoon damage assessments.
- ✓ Mandatory independent external inspections.

## Regulatory Compliance & Dam Safety Framework

Strict implementation of **Dam Safety Act, 2021**. Compliance with **NDSA guidelines**, including:

- ✓ Emergency Action Plans
- ✓ Instrumentation and monitoring
- ✓ Approved reservoir operation manuals

*Ensures structural integrity, operational safety, and public protection*



# Conclusions



- 01.** Extreme events during **2023–2025** confirm the growing impact of **climate variability** on Himalayan hydropower infrastructure.
- 02.** A shift to **climate-responsive design** is essential, including non-stationary flood estimation and provisions for sediment- and debris-laden flows.
- 03.** **Sedimentation, slope instability, and hydro-abrasion** must be addressed through integrated sediment management, robust geotechnical stabilization, and abrasion-resistant materials.
- 04.** **Diversion tunnels and cofferdams**, though temporary, must be designed with **permanent-structure rigor** to safely pass extreme floods.
- 05.** **Sustainable operation** requires adaptive reservoir and gate protocols, real-time monitoring, automation, and resilient river-training and access infrastructure.
- 06.** **Rigorous inspections, strong emergency preparedness, institutional coordination, and strict compliance with the Dam Safety Act, 2021** are critical to build back better and ensure safe, low-carbon hydropower.



**Thank You**

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