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

Significance of dams in climate change adaptation and mitigation

Dr J. Chandrashekhar Iyer, Former Chairman Central Water Commission

Mr. Kofi Annan, the erstwhile Secretary-General of the UN remarked in 2015…….

- *"The world is reaching the tipping point beyond which climate change may become irreversible. If this happens, we risk denying present and future generations the right to a healthy and sustainable planet - the whole of humanity stands to lose".*

The Paris Agreement 2015……

- *framed during the twenty-first Conference of Parties (COP21), called on all nations to collectively limit global warming to 2°C below pre-industrial levels (1850-1900) and to pursue efforts to limit the increase to 1.5°C.*

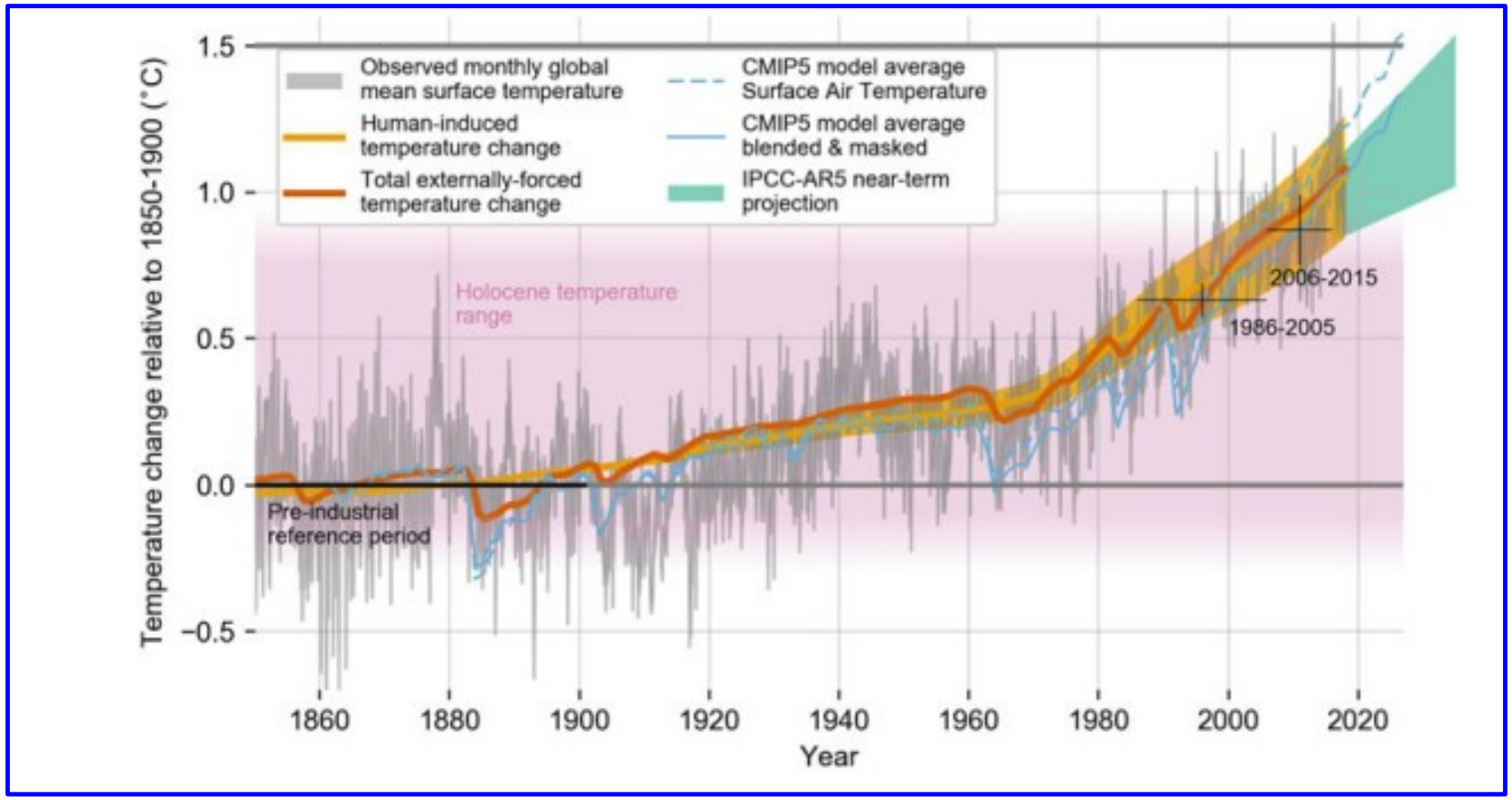
GLOBAL SCENARIO

As per the report of the UN's Intergovernmental Panel on Climate Change (2021)

- *The emissions of greenhouse gases (GHGs) from human activities are responsible for ~1.1°C of warming since pre-industrial times.*

- *Further, limiting global warming to close to 1.5°C or even 2°C over pre-industrial levels will be "beyond reach" without "immediate, rapid and large-scale reductions" in greenhouse gas emissions.*

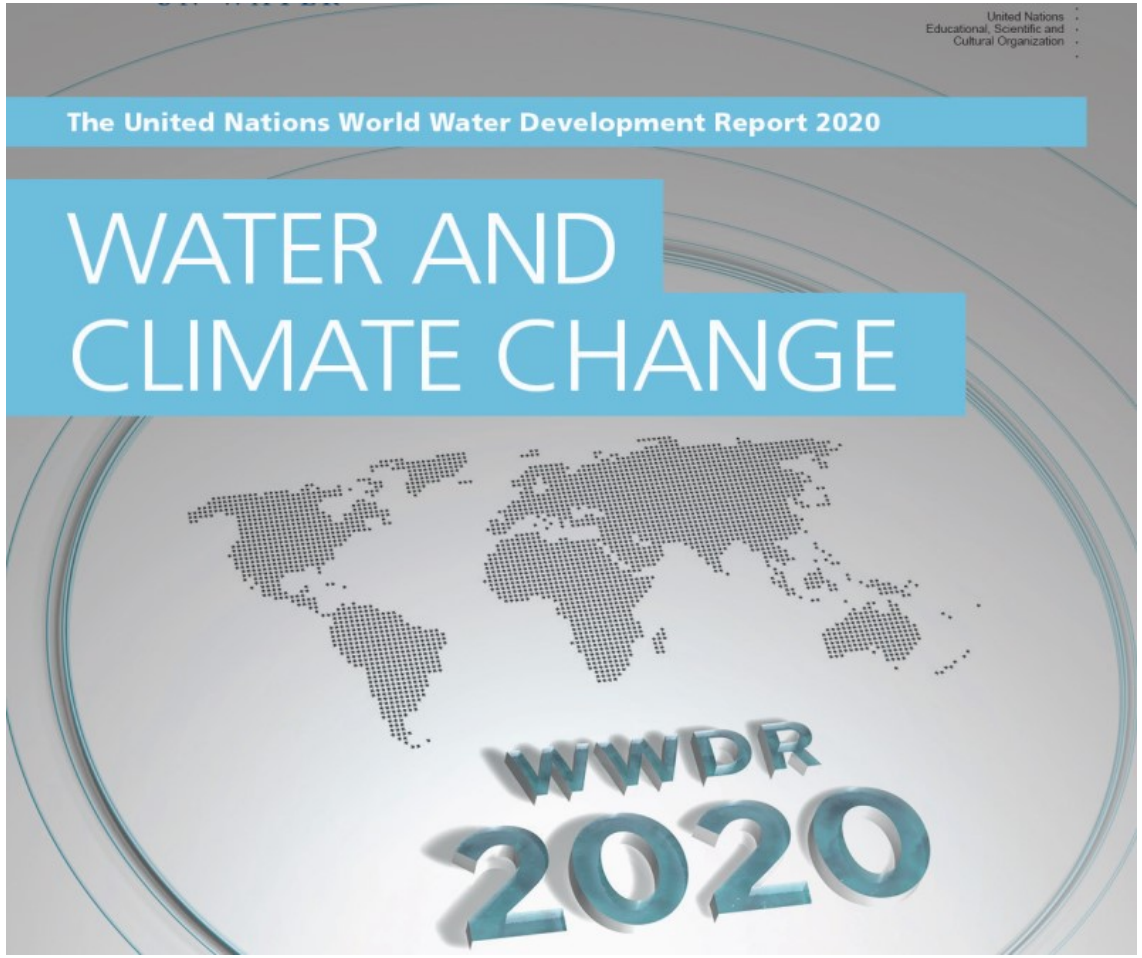
Evolution of global mean surface temperature (GMST) over the period of instrumental observations.



Source : IPCC - AR5

GLOBAL SCENARIO

- As per UN World Water Development Report 2020, Climate change will affect the availability, quality and quantity of water for basic human needs
- Climate change will make extreme events more severe by altering the timing, intensity and duration of their occurrences
- Alteration of the water cycle will also pose risks for energy production, food security, human health, economic development and poverty reduction



Indian Scenario

Indian Meteorological Department…….

- *Monitors the climate parameters and provides annual climate statement to the country, WMO and IPCC.*
- *The year 2024 is termed by WMO as the warmest year in the 175-year observational record with a global mean surface temperature of 1.55±0.13 °C above the 1850-1900 average.*
- *This marked the warmest year since nationwide records began in 1901, surpassing the previous highest temperature observed in 2016.*

Source: IMD Annual report

Indian Scenario

"Assessment of Climate Change over the Indian Region" (2020)

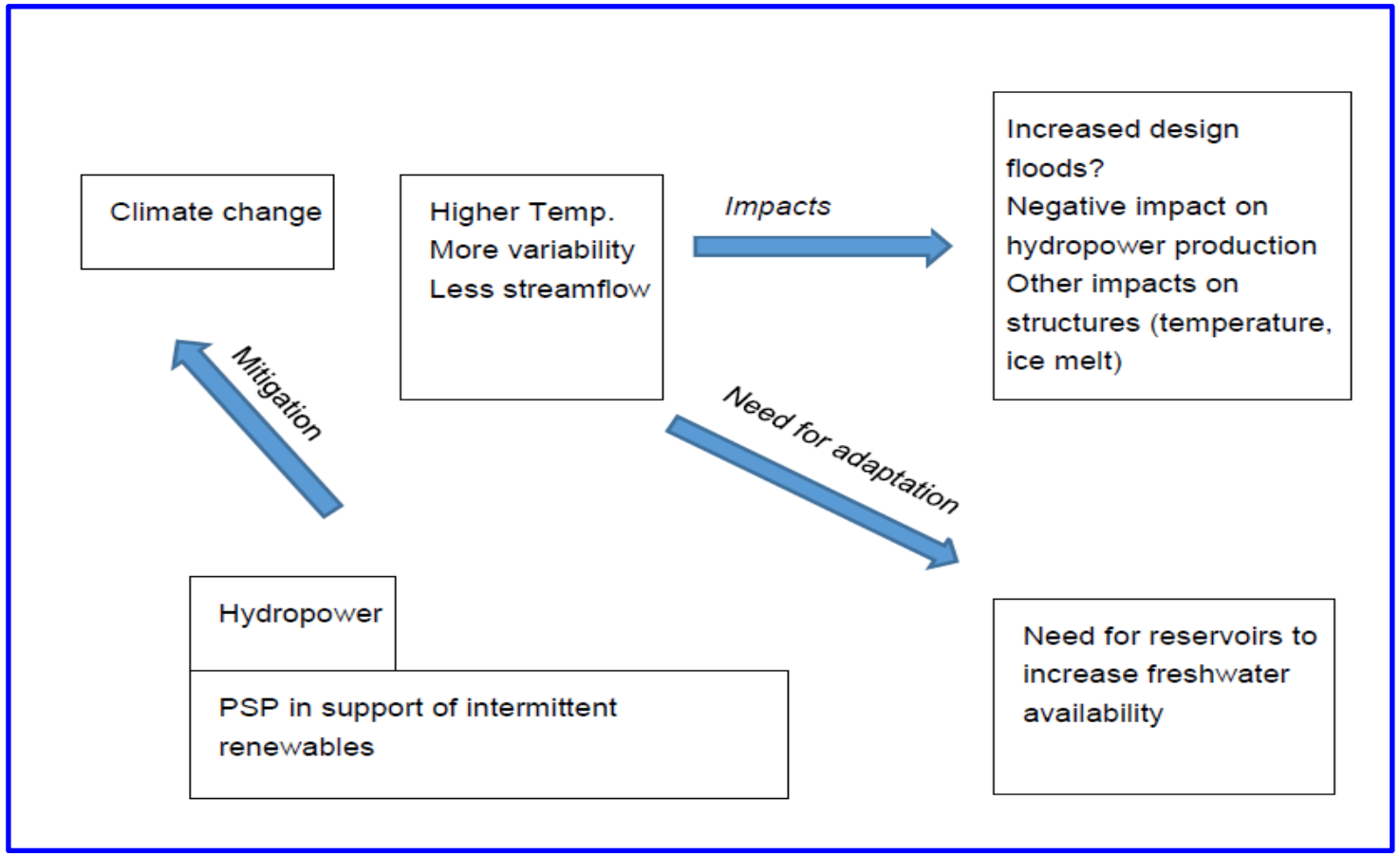
Relevant Extracts from a report of the Ministry of Earth Sciences, Government of India …….

Since the middle of the twentieth century, India has witnessed

- *rise in average temperature;*
- *a decrease in monsoon precipitation;*
- *a rise in extreme temperature, droughts, and sea levels;*
- *as well as increase in the frequency and intensity of severe cyclones.*

By the end of the twenty-first century, average temperature over India is projected to rise by approximately 4.4°C relative to the recent past (1976–2005 average), under the RCP 8.5 emission scenario

Impacts-Adaptation-Mitigation



Source : ICOLD

Impact of Climate Change on Droughts

"Assessment of Climate Change over the Indian Region" (2020).....Relevant Extracts

DROUGHTS

- *The frequency and spatial extent of droughts over India have increased significantly during 1951–2015. An increase in drought severity is observed mainly over the central parts of India, including parts of Indo-Gangetic Plains (high confidence). These changes are consistent with the observed decline in the mean summer monsoon rainfall.*

Impact of Climate Change on Floods

"Assessment of Climate Change over the Indian Region" (2020).....Relevant Extracts

FLOODS

- *Flood frequency and associated risk are projected to increase over the major river basins of India, with a higher risk for the Indus-Ganges-Brahmaputra river basins in a warming climate.*

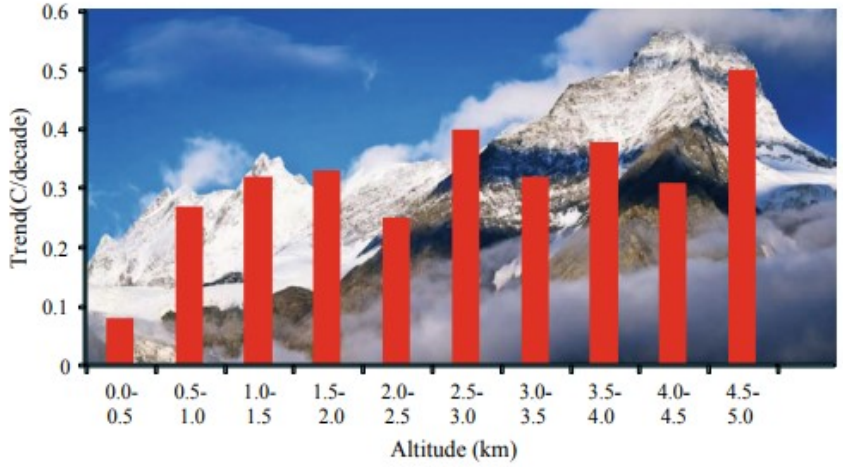
- *The enhanced flood risk is likely due to increasing stream flow and run-off associated with the projected increase in frequency of extreme rainfall events over the major Indian river basins and is compounded by glacier and snowmelt over the Indus-Ganges-Brahmaputra.*

Impact of Climate Change in the Himalayas

"Assessment of Climate Change over the Indian Region" (2020)……..Extracts

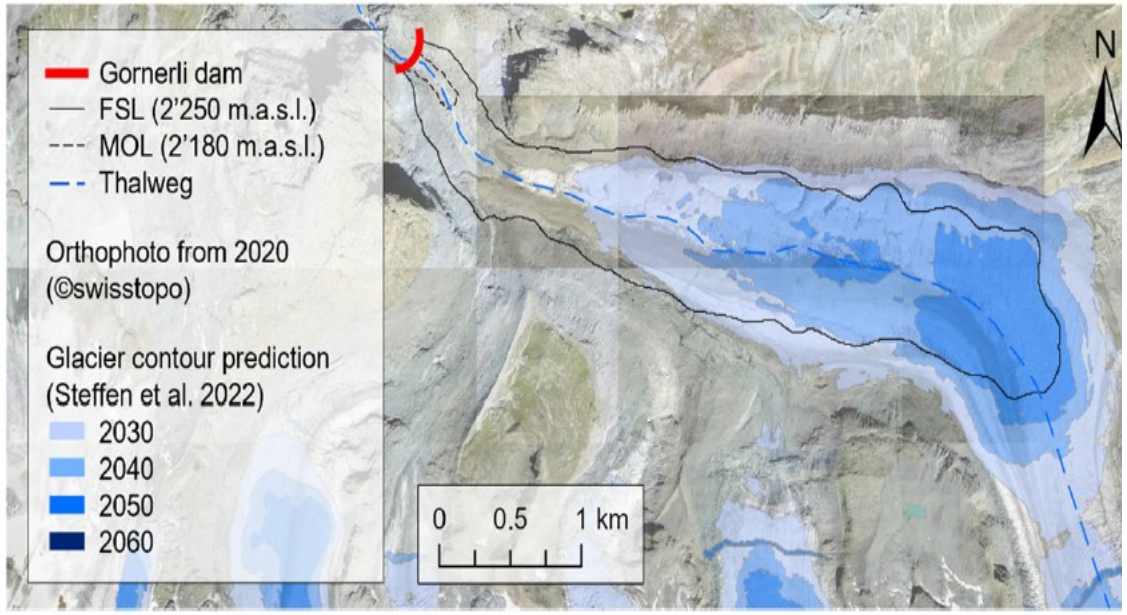
Climate Change in the Himalayas

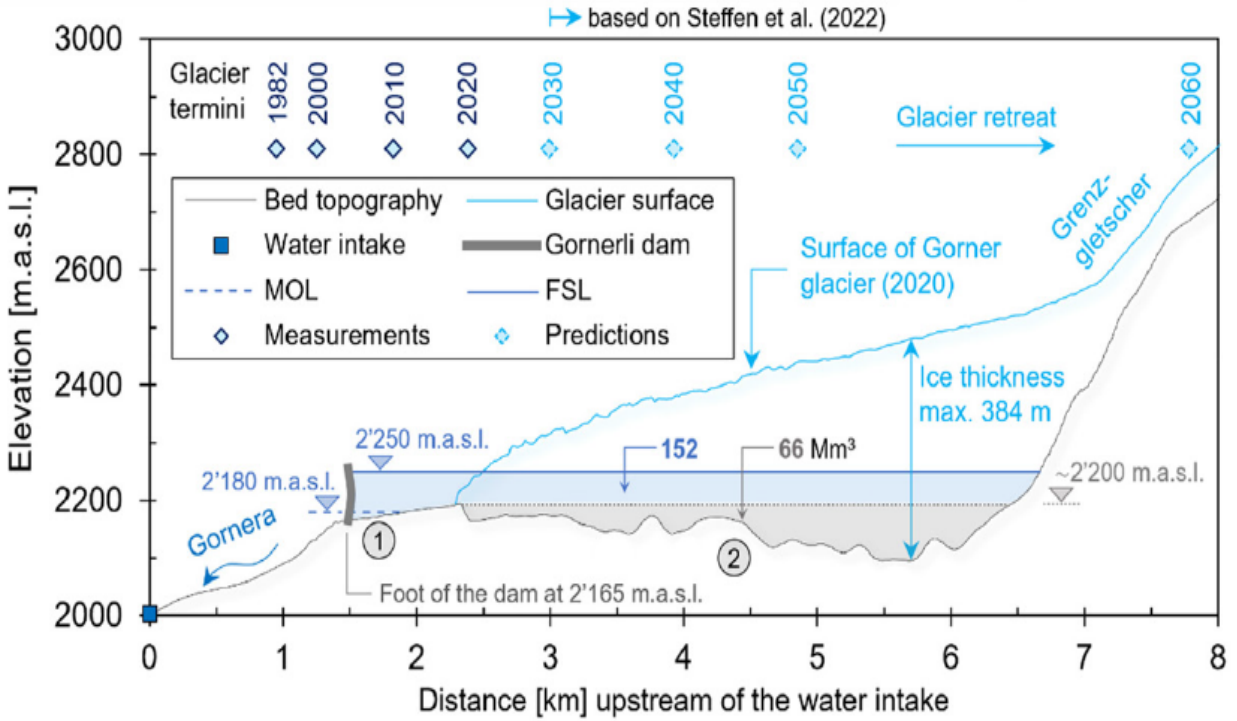
- *The annual mean surface-air-temperature in the Hindu Kush Himalaya (HKH) increased at a rate of about 0.1 °C per decade during 1901–2014, with a faster rate of warming of about 0.2 °C per decade during 1951–2014, which is attributable to anthropogenic climate change (High confidence).*
- *Several areas in the HKH have exhibited declining trends in snowfall and retreating glaciers during the recent decades.*
- *Future climate projections suggest warming of the HKH region in the range of 2.6–4.6 °C by the end of the twenty-first century.*



GORNERLI DAM AT THE TOE OF GLACIER

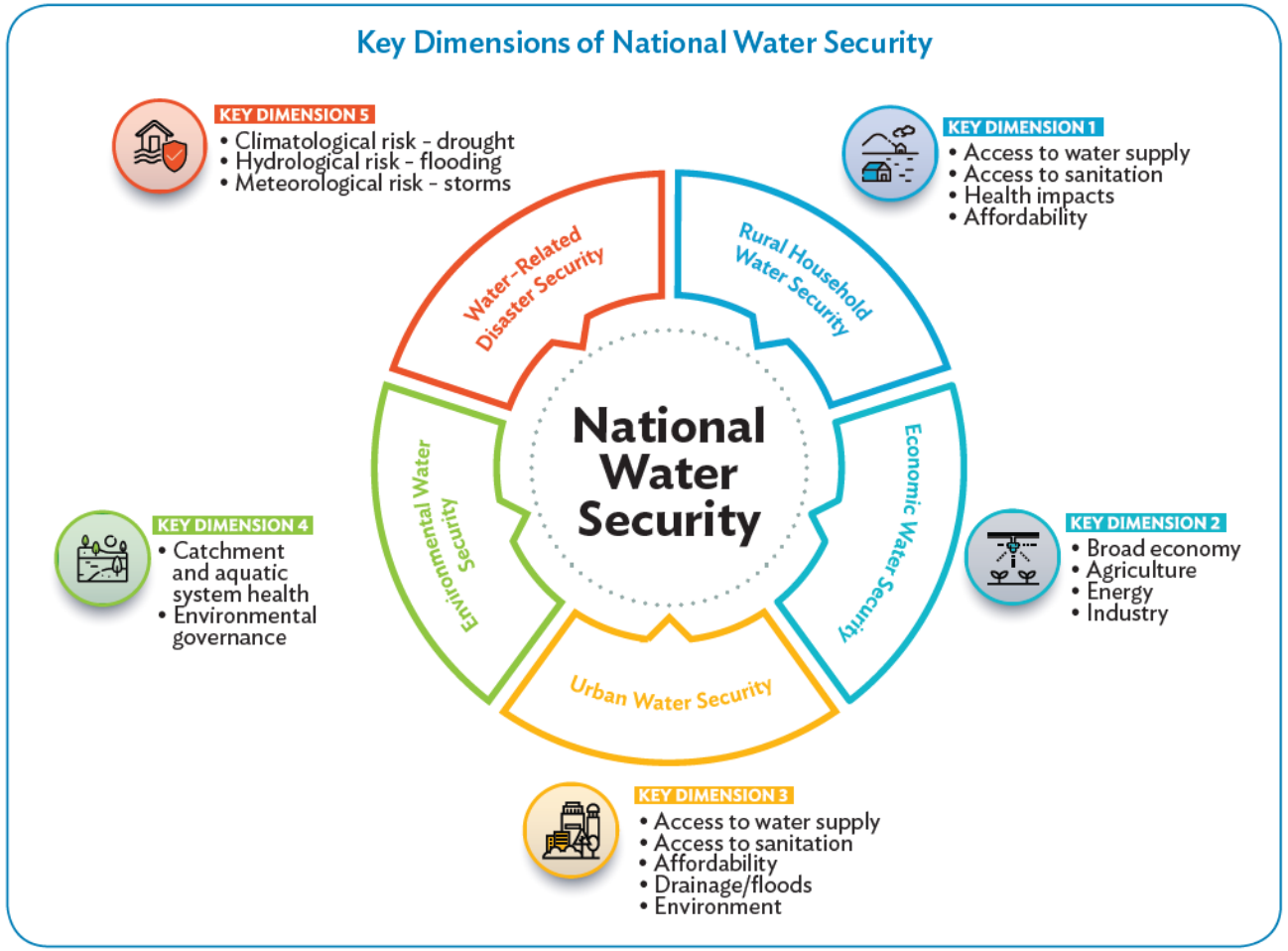
(Case Study from the Alps, Switzerland)





Source : Julien ROEDER et al. (2025)

Impact of Climate Change on Water Security



Source: ADB : Asian Water Development Outlook 2020

Sector-wise Future Demand Scenario (BCM)

Sector	Probable Water Demand as Projected by NCIWRD (1999)	
	2025	2050
Irrigation	**611**	**807**
Domestic	**62**	**111**
Industry	**67**	**81**
Energy	**33**	**70**
Others	**70**	**111**
Total	**843**	**1180 ***

Against utilizable water resources of 1121 BCM

- ***Basin-wise water availability has wide variations.***
- ***Climate change impacts unevenly spread out.***
- ***Construction of water storages and developing regional or national water grid.***

NATURAL DISASTERS

- *Climatological events (extreme temperature, drought, forest fire)*
- *Hydrological events (floods, mass movement)*
- *Geophysical events (earthquake, tsunami, volcanic activity)*
- *Meteorological events (tropical storms, extra-tropical storms, convective storm, local storm)*

- Historic, Monster Winter Storm.
- Weather Emergency declared.
- Power Grid Operators working hard to avoid rotating blackouts.

US storm cancels 10K flights, 850,000 homes lose power

Reuters
letters@hindustantimes.com

WASHINGTON: More than 850,000 customers in the US as far west as New Mexico were without electricity and over 10,000 flights were cancelled on Sunday during a monster winter storm that paralysed eastern and southern states with heavy snow and ice.

As snow, freezing rain and dangerously frigid temperatures swept into the eastern two-thirds of the nation on Sunday, the number of power outages continued to rise. As of 10.47am EST (1547 GMT) on Sunday, more than 850,000 US customers were without electricity, according to PowerOutage.us, with 290,000 in Tennessee and over 100,000 each in Mississippi, Texas and Louisiana. Other states affected included Kentucky, Georgia, Virginia and Alabama.

More than 10,200 U.S. flights scheduled for Sunday were cancelled, according to flight tracking website FlightAware. Over 4,000 flights were cancelled on Saturday. Washington DC's Ronald Reagan National Airport said airlines had cancelled all flights at the airport on Sunday.

Delta Air Lineson said that it intended to operate on a reduced schedule "subject to real-time frozen precipitation and afternoon storm conditions."

The airline had adjusted its schedule on Saturday, with additional cancellations in the morning for Atlanta and along the East Coast, including in Boston and New York City, and said it would move experts from cold-weather hubs to support de-icing and baggage teams at several southern airports.

The National Weather Service's latest forecast for Sunday through Monday morning calls for heavy snow from the Ohio Valley to the Northeast, including up to 18 inches in New England. Much of the Southeast and parts of the Mid-Atlantic are expected to get rain and freezing rain.

Forecasters predicted "bitterly cold temperatures and dangerously cold wind chills" from the southern plains to the Northeast in the wake of the storm, bringing "prolonged hazardous travel and infrastructure impacts."

Calling the storms "historic," President Donald Trump on Saturday approved federal emergency disaster declarations in South Carolina, Virginia, Tennessee, Georgia, North Carolina, Maryland, Arkansas, Kentucky, Louisiana, Mississippi, Indiana, and West Virginia. "We will continue to monitor, and stay in touch with all States in the path of this storm. Stay Safe, and Stay Warm," Trump wrote in a post on Truth Social.

Seventeen states and the District of Columbia have declared weather emergencies, the Department of Homeland Security said. DHS Secretary Kristi Noem on Saturday warned Americans to take precautions.

"It's going to be very, very cold," Noem said. "So we'd encourage everybody to stock up on fuel, stock up on food, and we will get through this together."

The Department of Energy on Saturday issued an emergency order authorising the Electric Reliability Council of Texas to deploy backup generation resources at data centres and other major facilities, aiming to limit blackouts in the state.

On Sunday, the DOE issued an emergency order to authorise grid operator PJM Interconnection to run "specified resources" in the mid-Atlantic region.

US electric grid operators on Saturday stepped up precautions to avoid rotating blackouts.

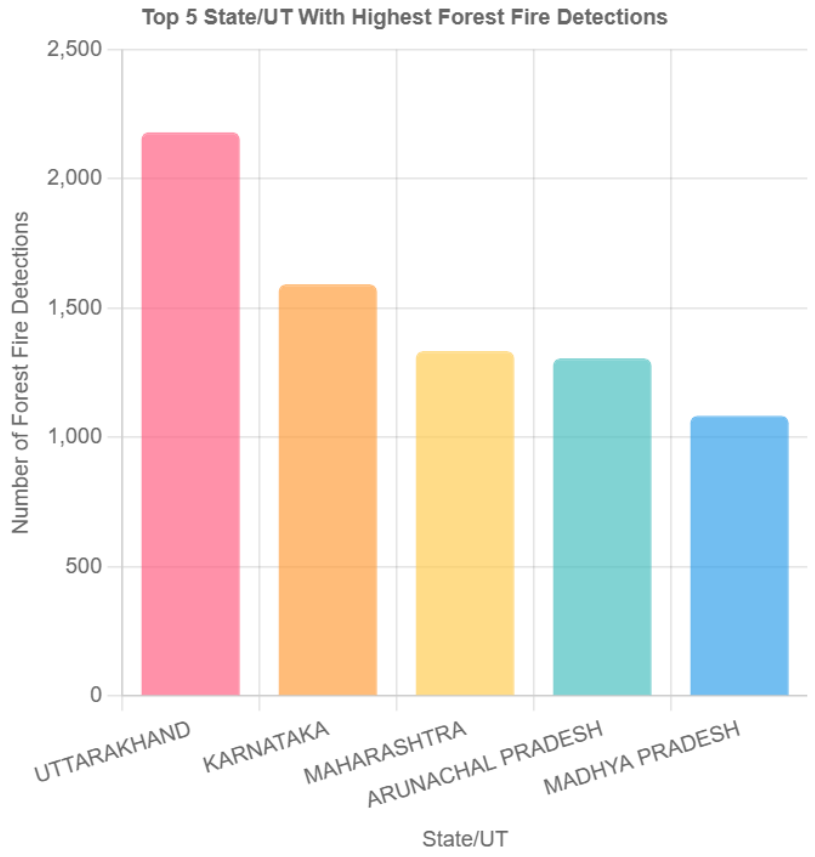
Weather fits climate forecasts of more 'freak storms,' less total snow

Researchers told the News that Sunday's snowstorm was unusually large and followed larger climate patterns in which more extreme weather is predicted.

By David Liu | 3:28 a.m., January 28, 2026
Contributing Reporter

FOREST FIRES

Top 5 States With Highest Forest Fire Detections (2025-26)



Source : Forest Survey of India

IMPACT OF FOREST FIRES

Wildfires can have significant impacts on the occurrence and frequency of landslides in several ways:

- ***Loss of Vegetation:*** ***Without this root system to stabilize the soil and rocks, there is an increased likelihood of rockfalls and debris flow.***
- ***Loss of Soil Stability:*** ***Heat from wildfires can alter soil properties, making it more prone to erosion and destabilization.***
- ***Changes in Hydrological Patterns:*** ***Wildfires alter the infiltration rate of a catchment. This can lead to increased erosion and can change the catchment flood hydrology.***
- ***Changes to Rock Mass:*** ***Intense heat from wildfires can cause thermal stress and expansion in rocks, leading to fractures and weakening of rock.***
- ***Increased Weathering Processes:*** ***Wildfires can accelerate weathering processes including chemical weathering from altered soil conditions and physical weathering from increased freeze-thaw cycles.***

Forest Fire and High Debris Flow

(Case Study of Wenner Lake Dam, USA)

- Lightning started several forest fires which eventually burned around 1000 sq km of forest in Washington State USA. High runoff flows along with debris flows blocked the dam spillway. Interesting facts to note are:
- Rainfall in the watershed was of the order of only a 5-year event.
- Estimated flows from the fire event were 7 to 8 times larger than the predicted flows from a 1000-year local storm event.
- Approximately 10-fold reduction in surface infiltration.
- As a result of this flood and the failure, the Washington State DSO recommended dam safety protocols for **burned watershed hydrology calculations.**

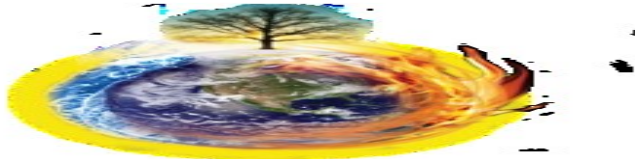
Rabel Dam (Wenner Lake No.4) spillway blocked by debris flow during the 2014 wildfire and rainfall event

Timothy MOTE et al. (2025)

Climate Change - Impacts on WR

Decline in the glaciers in the Himalayas

Increased drought & flood events – same amount of rainfall in shorter duration



Increased saline intrusion of coastal & island aquifers due to rising sea levels

Impact on Water Quality

Impact on Dam Safety

ADAPTATION

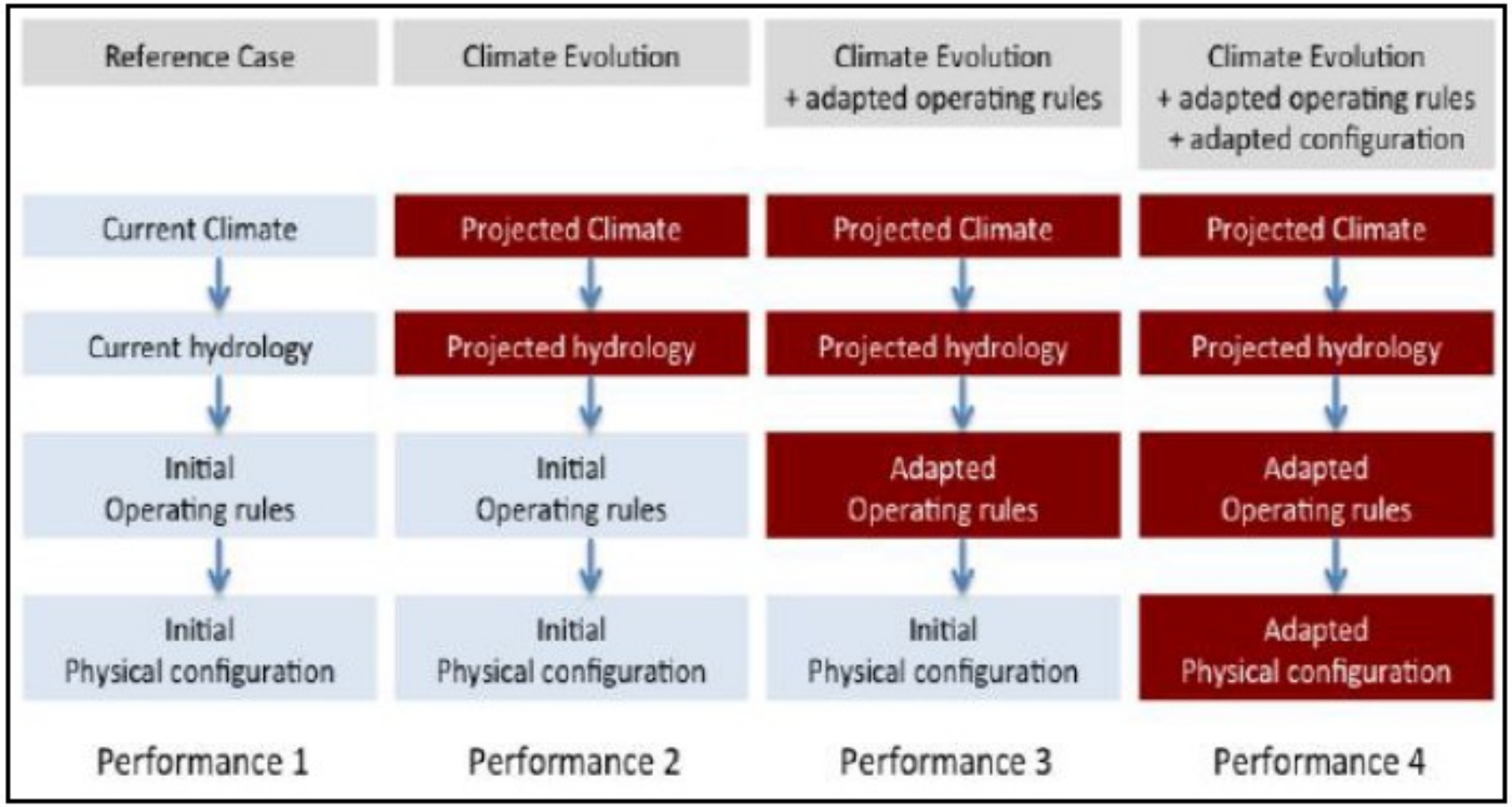
SIGNIFICANCE OF DAMS IN ADAPTATION AND MITIGATION

1. Economic development objectives :– irrigation, hydropower, navigation, tourism, recreation, navigation.
2. Climate Risk mitigation :– Building resilience against flood and drought impacts, Absorb the hydrological shocks, Key role in energy transition through Hydro/PSH.
3. Human health objectives :– drinking water supply, wastewater treatment and sanitation
4. Ecological protection and enhancement – protecting and/or restoring wetlands, rivers, flood plains and riverine environments, ground water recharge
5. Inter-Basin transfer of water, Regional or National Water Grid

Adaptation to Climate Change

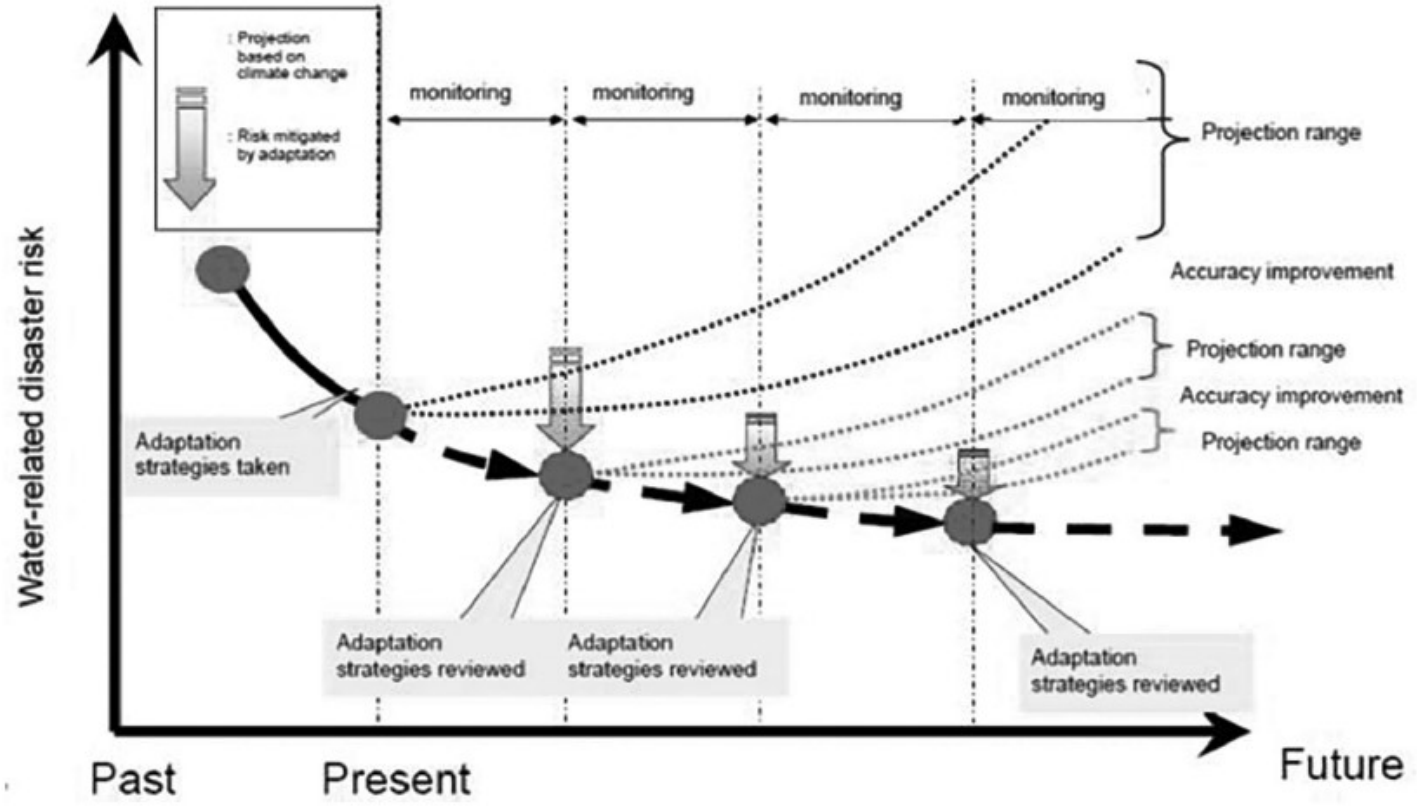
- Climate Change poses challenge to water, dam and hydropower professionals introducing uncertainty in future hydrological assessments.
- Future projections cannot provide the decision-makers with precise information regarding the rate of future changes. The information however is of immense use that could serve initial assessment.
- Informed Adaptive Management is the key.

CLIMATE CHANGE ADAPTATION FRAMEWORK



Source: ICOLD BULLETIN 169

CLIMATE CHANGE ADAPTATION



No regrets approach for adaptive management

Source: ICOLD BULLETIN 169

Functional Adaptation Measures

SELECT INTERVENTIONS

- Developing or improving hydrological forecasting tools including the development and application of appropriate measures to deal with extreme hydrological events.
- Developing of improved technologies to evaluate the performance of projects and to identify ways of operating them under modified climatic conditions.
- Bringing changes to operating rules such as revised reservoir level limits in order to provide an increased flood storage buffer.
- Improvements to the communication and decision-making process used by various stakeholders.
- Carrying out studies directed at identifying the impacts of climate change upon the various users of water within a watershed.
- Creation of regulatory bodies that are mandated to develop and apply improved operating strategies.
- Promotion of educational efforts that are targeted with informing citizens of the impact of climate change, with the hope of finding adaptive measures that would compensate for the impacts and reduce negative impact on dams and reservoirs.
- Improvement of mathematical models to evaluate the impact of climate changes.
- Restricting the development of land within the zones susceptible to flooding.
- Modification of engineering design practices so that non-structural adaptation can be considered as an integral part of the design process which must be considered in conjunction with proposals for structural change.

Source: ICOLD BULLETIN 169

Structural adaptation measures

SELECT INTERVENTIONS

- Increase in the capacity of the spillway works and/or the provision of emergency spillways.
- Change the number and type of water control gates, both for flood management and water release requirements.
- Add controllable gates to free overflow spillways in order to provide greater regulation of flood peaks.
- Modify the dimension of canals or tunnels that are for water transfer.
- Create new upstream storage reservoirs and re-consider the multi-purpose potential of new reservoir projects.
- Modify the active storage capacity of reservoirs by increasing the height of the storage dam and/or raising the sill level of the overflow works.
- Increase the amount of freeboard above top water level in order to accommodate predicted increases in flood rise and wave surcharge values.
- Replace or reinforce upstream slope protection such as riprap to provide satisfactory erosion protection under increased dynamic loading from waves.

Source: ICOLD BULLETIN 169

MITIGATION

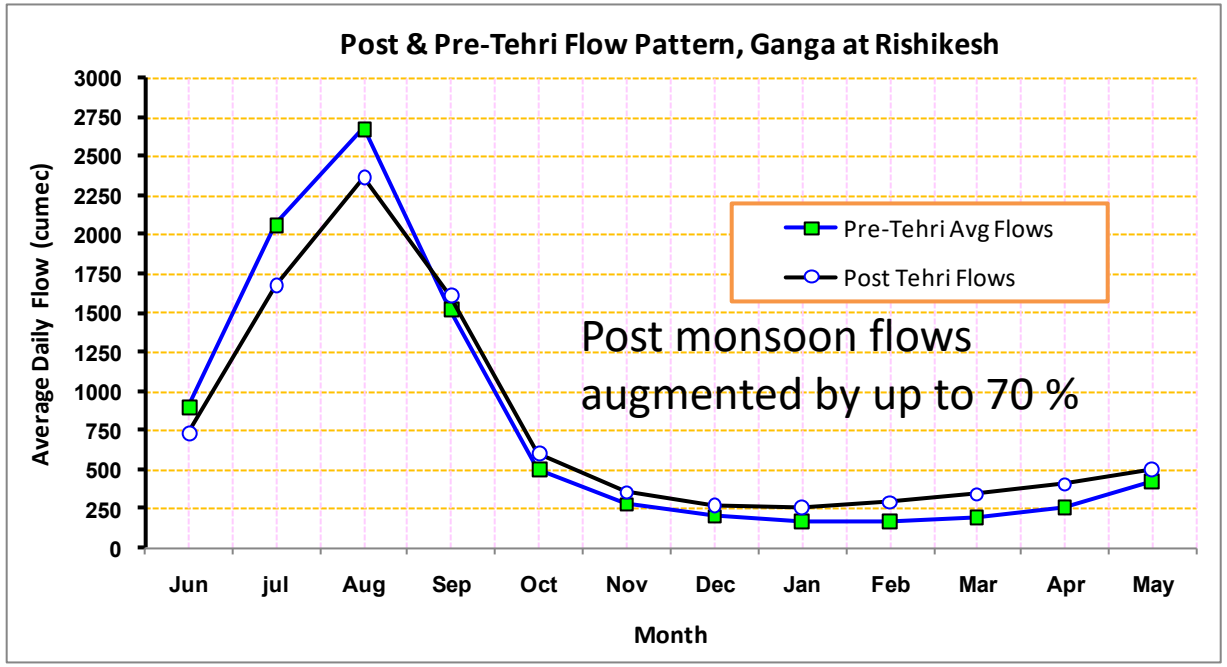
Snapshot of the floods during 2005-2019

YEAR	REGION/FLOODS
2005 (JULY)	MUMBAI
2007(AUGUST)	BIHAR
2008(AUGUST)	BIHAR
2012(JUNE)	BRAHMAPUTRA
2013 (JUNE)	UTTARAKHAND
2013(JULY)	BRAHMAPUTRA
2014(SEPTEMBER)	KASHMIR
2015(JUNE & AUGUST)	ASSAM
2015(JULY)	GUJARAT

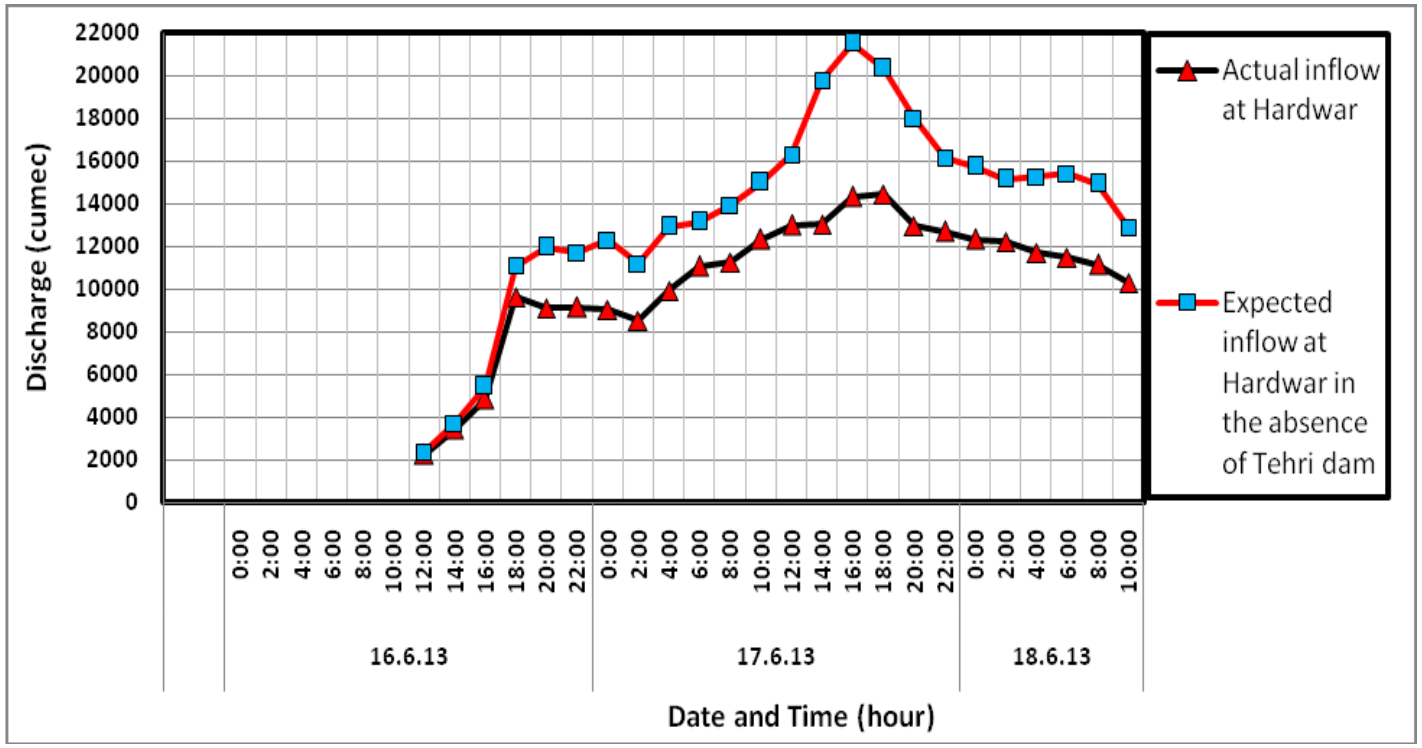
YEAR	FLOOD
2015(NOVEMBER)	CHENNAI
2016(JULY)	ASSAM
2017(JUNE & JULY)	NORTH-EAST
2017 (JULY)	BIHAR
2017(JULY)	WEST BENGAL
2017 (JULY)	GUJARAT
2017(AUGUST)	MUMBAI
2018(AUGUST)	KERALA
2019 (JULY, AUGUST, SEPTEMBER)	WIDESPREAD OVER THE ENTIRE COUNTRY

TEHRI DAM, UTTARAKHAND

Tehri dam commissioned in July 2006, Multipurpose project (3.54 BCM Gross, 2.615 BCM live storage, provision of 2.70 lakh ha additional irrigation, stabilization of 6.04 lakh ha command in U.P., Drinking water 162 MGD to Delhi, 108 MGD to U.P., 1000 MW power



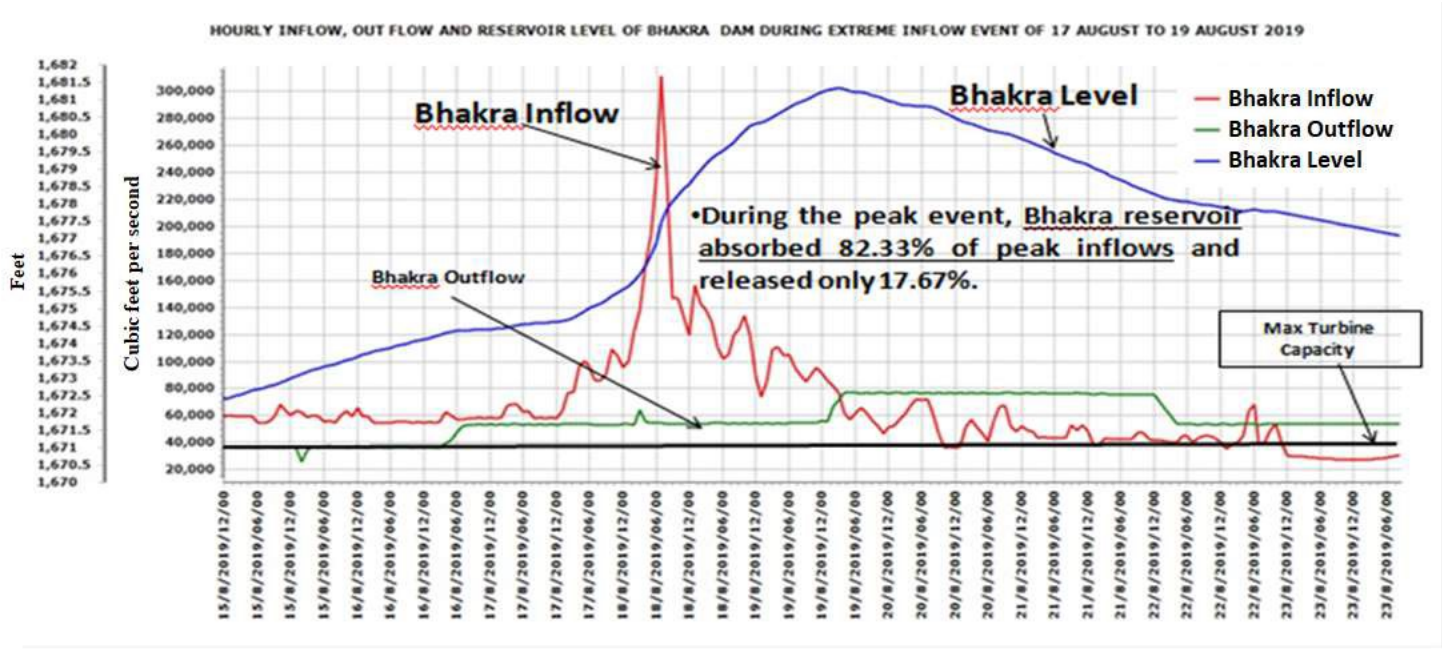
Flood Mitigation by Tehri dam (2013 Flood)



Tehri dam mitigated flood peak by 7000 cumec and saved Rishikesh and Haridwar from flood devastation

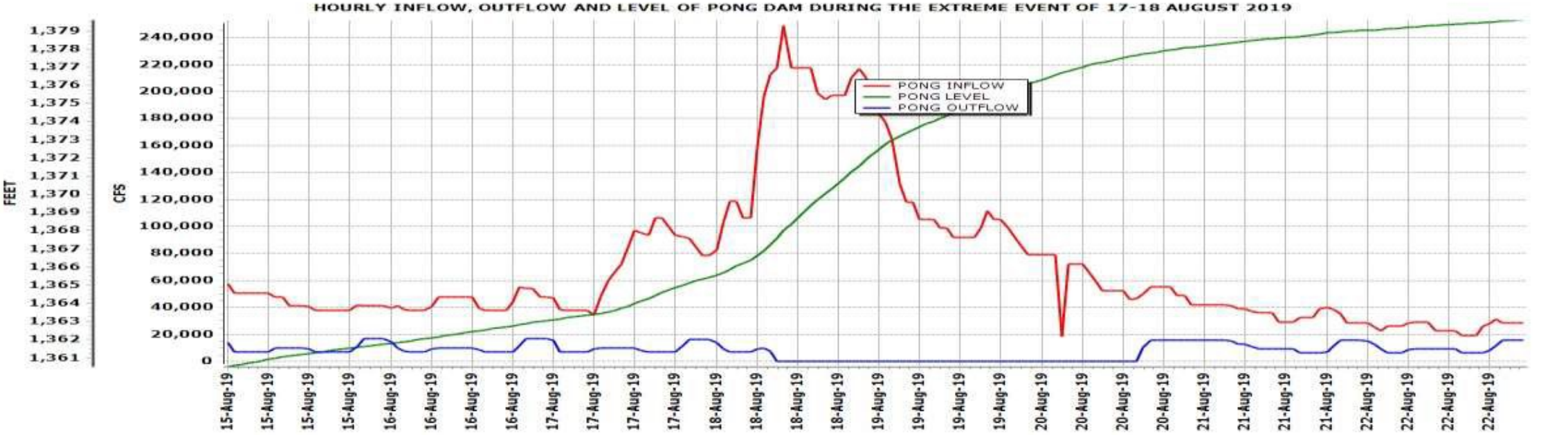
FLOOD MITIGATION BY BHAKRA DAM (AUGUST 2019 FLOOD)

Operation of Govind Sagar reservoir of Bhakra dam during flood event of 17-18 August



FLOOD MITIGATION BY PONG DAM (AUGUST 2019 FLOOD)

Operation of Maharana Pratap Sagar reservoir of Pong Dam during flood event of 17-18 August 2019



Conference of Parties to the UNFCCC (COP26)

At the Conference of Parties to the UNFCCC (COP26) in Glasgow, India has made the following announcements to be achieved by the year 2030.

i) *India will reach its non-fossil energy capacity to 500 GW.*

ii) India will meet 50% of its energy requirements from renewable energy.

iii) India will reduce the total projected carbon emissions by one billion tonnes.

iv) India will reduce the carbon intensity of its economy by less than 45%.

v) India's commitment to net-zero emission by 2070.

Installed Generation Capacity (Fuel-wise) in India (as on 30.11.2025)

	Category		Installed Generation Capacity (MW)	% Share in Total
Fossil Fuel	Coal		2,19,610	43.1%
	Lignite		6,620	1.3%
	Gas		20,122	3.9%
	Diesel		589	0.1%
	Total Fossil Fuel :		**2,46,942**	**48.4%**
Non-Fossil Fuel	RES (Incl. Hydro)		2,54,021	49.8%
	Hydro	50,415		9.9%
	Wind, Solar & Other RE	2,03,607		39.9%
	Wind	*53,986*		*10.6%*
	Solar	*1,32,848*		*26.1%*
	BM Power/Cogen.	*10,757*		*2.1%*
	Waste to Energy	*857*		*0.2%*
	Small Hydro Power	*5,159*		*1.0%*
	Nuclear		8,780	1.7%
	Total Non-Fossil Fuel :		**2,62,801**	**51.6%**
	Total Installed Capacity (Fossil Fuel & Non-Fossil Fuel)		**5,09,743**	**100%**

Source: CEA

Chengdu Declaration on Dams and Reservoirs for Energy Transition and Adaptation to Climate Change

Chengdu Declaration on

Dams and Reservoirs for Energy transition and Adaptation to Climate Change

Approved on 3rd October 2024, at the 92nd ICOLD Annual Meeting in New Delhi by the International Commission on Large Dams (ICOLD)

In addressing the multifaceted challenges posed by climate change the role of dams and reservoirs is indispensable. Water storage is up to date providing food security, flood control, resilience to droughts and generation of low carbon energy, which is a critical component of our efforts to address climate change and energy transition. Meeting the climate change-induced rising demands for water supply, addressing the heightened risks of extreme flood and drought events and balancing the intermittent renewable energy sources call for safer, smarter and more eco-friendly dams towards a significant increase in global water storage capacity and hydropower generation.

A CHANGING WORLD

Population growth. The world's population has skyrocketed from around one and a half billion in the early 20th century to nearly 8 billion today. It is expected to grow to around 10.4 billion by 2100. This steady rise in population directly impacts global need for water.

Global water demand has reached 4,600 km3 per year and is expected to increase by 20% to 30% by 2050. Currently, roughly 70% of total water use worldwide irrigates 20% of total cultivated land which produces 40% of total produce. Feeding a population of around 9.7 billion by 2050 and 10.4 billion by 2100 is a fundamental yet most challenging task. Climate change adversely affects water demand jeopardizing food security.

Unless more fresh water is stored by 2050, 3.6 to 4.6 billion people worldwide, and approximately 1 in 4 children, will be living in water stress areas. If all identified future dams were constructed and contribute to irrigation along with other uses, they would secure food for more than 600 million additional people. More dams are needed for providing global water and food security.

Climate change. Human activities, mainly through greenhouse gas emissions, have unequivocally caused global warming, with global surface temperature reaching an increase of 1.1°C above 1850-1900 levels in the past decade (2011-2020). Historical and current greenhouse gas emissions continue to rise, stemming from unsustainable fossil fuel energy, land-use changes, lifestyles and global consumption patterns.

The IPCC AR6 report has issued alarming forecasts on global climate change, warning of increasing temperatures, extreme weather events and rising sea levels. The uncertainty in spatial and temporal distribution of water resources is highlighted as a critical impact. Changes in precipitation patterns, increased evaporation rates and melting glaciers are expected to exacerbate water scarcity in many regions. The timing, duration, and intensity of climate crisis occurrences remain uncertain.

Clean energy transition is the top priority for meeting COP commitments, since energy is the main source of carbon emissions. According to the International Energy Agency (IEA), total global electricity generation in 2050 will be 2.5 times the current level. To achieve the goal of reaching carbon neutrality by the middle of the present century, the share of renewable energy in primary energy consumption must increase significantly. To achieve 100% carbon free electricity generation by the middle of the present century, coal, oil and gas units' capacity will need to be reduced globally at a rate of 100 GW per year. This requires complete transformation of energy production and consumption.

Hydropower is the solution. Hydropower schemes, including pumped storage plants, through low-carbon dispatchable technologies, need to step in as 'guardians of the electricity grid' for energy transition. Dams having reservoirs with long duration energy storage are the lead provider of grid flexibility and will be the backbone of reliable, safe, and decarbonized power systems. To achieve the energy transition goal, currently installed hydropower capacity has to be doubled for net zero scenarios by the middle of the present century.

Extreme events aggravated by Climate Change call for more water storage capacity in reservoirs towards a climate-resilient water supply, food, and agricultural production and environmental protection. Additional freeboard for flood control in existing and future reservoirs is required to assure higher safety levels, thus losing useful volumes of water for other uses. Ecological flows, reducing climate impacts on downstream river reaches and deltas, ecosystems and biodiversity, require additional regulated water volumes, against aggravating irregularity and uncertainty of inflows and competing water uses. Larger volumes of water storage are required to manage inland water resources in the context of climate induced water scarcity, severe droughts and increasing vital water needs of a growing population. More water storage in large reservoirs is a solution towards climate change resilience to water-related hazards, to be considered in integrated river basin management along with other options.

Maintenance and rehabilitation of existing dams, including increasing their capacity, efficiency and safety is paramount. The new conditions imposed by climate change and the demographic growth pose major challenges to the safety management of existing dams. ICOLD is committed to strengthening and improving dam safety management, rehabilitation and refurbishment, to enhancing dam and levees resilience and ensuring the safe, sustainable, reliable and environmentally friendly operation and maintenance of more than 64,000 large dams supporting human needs worldwide.

Role of Dams and Reservoirs for Energy Transition

Dams, as part of hydro-storage schemes, make energy transition viable. The penetration of intermittent renewables and the withdrawal of thermal plants cause greater complexity in the operation of the electricity system, resulting in spills and rapid variations in generation and frequency. By storing and releasing water, hydropower can ramp up and down quickly and precisely especially with artificial intelligent operation technologies, improving regulation of the response to frequency variations as needed for rapid adaptation of high voltage grid networks. Energy storage in form of water is inescapable for renewables to replace fossil fuel sources and a key to meet the climate commitments.

Pumped storage plants allow displacement of energy from off-peak to peak hours by pumping water from lower to an upper reservoir. Off-river, closed system, pumped storage plants do not depend on hydrology of the site and are versatile in terms of their location. Renewable pumped storage plants can employ existing reservoirs, preserving flood control functions and energy transport infrastructure, to minimize environmental impact. They can synergize new consumptive uses with current uses thereby minimizing generation as well as operation and maintenance (O&M) costs.

Investments. Hydropower asset owners and managers, as well as other stakeholders, make financial and economic decisions based on the projected value of their production assets. Multiple factors delay decisions and implementation of these much-needed facilities. Hindering the desired acceleration of development of new hydro as well as pumped storage schemes are the uncertainty of financial sustainability of the investment, the lack or ambiguity of regulatory framework for energy storage, pricing, and lagging administrative procedures for permitting and granting concessions. A clear, consistent regulatory framework, and administrative reforms to simplify and expedite procedures for granting concessions are essential to achieve the required hydropower development pace.

Role of Dams and Reservoirs in Climate Change Adaptation

Floods and extreme events

Floods cause huge financial losses, environmental catastrophes, and fatalities. Climate change is expected to increase the frequency and intensity of floods in the coming decades in many regions worldwide. Storage reservoirs mitigate the risk of flooding and reduce the frequency and extent of inundations. Early warning systems and land management with non-structural measures reinforce and enhance the key role of dams and levees in flood control.

Higher demand for water supply are demanded by society due to uncertainty in the frequency and intensity of floods in climate change conditions, land use changes and larger population exposure downstream. These require enhanced design of new dams increased dam quality through artificial intelligent construction, and continuous efforts to upgrade dam resilience operation both for existing and new dams.

Drought events are also expected to occur more frequently and are likely to be more persistent and geographically widespread. Annual and interannual storage and proper reservoir management along with other measures at the river basin scale are required to mitigate droughts' effects on human uses and the aquatic ecosystems. Thus, reservoirs provide resilience, addressing environment vulnerability against droughts. Artificial reservoirs often developing into valuable wetlands host important wildlife and support biodiversity.

River basins with large reservoir regulations are often more adaptable to temporal and spatial changes in water resources, making them less vulnerable to climate change. Creating new storage by constructing sustainable dams is important since around 0.5% of storage capacity is being lost annually due to reservoir sedimentation. The rate of sedimentation is expected to rise in many areas where erodibility will worsen under climate change, unless reservoir management and watershed measures are implemented.

Integrated river basin management

More reservoir volume is needed for integrated water resources management, especially in the light of climate change. Annual and interannual storages are required to ensure climate-resilient water supply for irrigation and food security, safe drinking water, energy generation, flood regulation, drought mitigation, and other uses. The volume of water stored in reservoirs must increase to meet traditional needs and climate change challenges.

Multipurpose dam projects support holistic river basin management and sustainable development. They allow for downstream ecological releases, and shape flood regimes allowing risk mitigation across river systems, floodplains, deltas and coastal areas. To address climate-related reduction in mean annual flow or increased hydrologic variability and heightened risk and uncertainty, reservoir storage capacity increase must be considered as a major option and smart operation be adopted. Overall, dams make an important structural component within integrated river basin planning and management aligning with techno-economic and environmental considerations.

Dams for water supply and irrigation

Dams provide a reliable source of raw water which is treated and supplied to towns, cities, large metropolitan areas and megacities concentrating more and more population. Reservoirs supplying drinking water systems provide enhanced resilience against drought through annual and interannual storage.

Increased temperature due to global warming raises water demand for crops, while food security of a growing population also requires more production, with expected reduction of rainfed crops.

An increasing proportion of irrigated land will need new regulating infrastructure including dams, and water conservation to attend to this unavoidable function.

Dams and the Environment

Carbon footprints and ecological impacts of dams need to be managed. Habitat loss, methane emission from reservoirs, disruption of river ecosystems, relocation of communities, etc. should be evaluated and properly addressed in Environmental Impact Assessment and Environmental Management Plans. Despite certain adverse impacts, overall, dams and their reservoirs are an important tool, alongside other measures, for energy transition and climate change adaptation. It is noted that hydropower has one of the lowest carbon intensity factors of all electric power generation technologies.

ICOLD strongly recommends the following actions:

i) Development of storage capacity worldwide: Per capita storage capacity has been steadily declining since the 1960s due to population growth, sedimentation in reservoirs, and a decline in dam construction pace. New storage is needed for energy transition and to maintain the traditional benefits of dams under the new challenging conditions shaped by climate change.

ii) Awareness of Hydroelectric development: Policy makers and civil society to focus on sustainable pumped storage, storage based hydro-schemes, to balance growth and energy transition towards the net zero pathway.

iii) Development of hydroelectric potential, especially in developing world, in regions where only 10 to 25 percent of hydroelectric potential has been harnessed, demands significant efforts, cooperation and cooperation amongst main stakeholders such as international organizations, governments, relevant institutions, NGOs, and civil society.

iv) Introduction of energy storage as a new official use of reservoirs in water acts and permitting regulations, to facilitate effective energy transition and modern water management adapted to current needs.

v) Establishment of a clear and stable regulatory framework for energy storage that includes additional tariffs for energy storage. Urgent policy reforms are needed to enable energy transition, and to ensure equity in energy access, guaranteeing the financial feasibility of storage-based hydropower and pumped storage projects, as keys for the energy transition commitment.

vi) Administrative reforms to be carried out urgently to simplify and expedite procedures for granting concessions for new hydroelectric and pumped storage projects, especially concerning environmental authorization and grid access. Concessional financing needed to boost long duration energy storage in reservoirs. Mandates and targets for development of dams and hydropower have to be clearly defined.

vii) Highlighting the positive environmental impacts of dam and reservoir projects contributing to water needs and energy transition, recognizing that in many cases, the positive impacts can outweigh other negative impacts.

viii) Strengthening dam safety management through rehabilitation and upgrading, including surveillance, real time flow forecast and early warning systems to enhance resilience, optimized reservoir management operation, smart regulation, and capacity building, in face of extreme events exacerbated by climate change.

ix) Promoting sustainable water and sediment management is essential to preserve the functions of dams and reservoirs, considering techno-economical, environmental and/or regulatory constraints.

x) Promoting research and development into new technologies that facilitate climate change mitigation and adaptation efforts. This includes exploring the implementation of hybrid hydro-battery systems, virtual power plants, automated data systems using artificial intelligence, and comprehensive information system architecture, as well as advanced materials for sustainable dam construction and rehabilitation.

"Storing Water, Secures the Future. Dams and Reservoirs Empower a Resilient World. Adaptation to Climate Change needs Safe and Sustainable Dams".

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International Hydropower Association
International Energy Agency
International Commission on Irrigation and Drainage
World Water Council
Institut Méditerranéen de l'Eau

Chengdu Declaration on Dams and Reservoirs for Energy Transition and Adaptation to Climate Change

Extracts from select Recommended Actions (5/10):

1. New storage is needed for energy transition and to maintain the traditional benefits of dams under the new challenging conditions shaped by climate change.
2. Policy makers and civil society to focus on sustainable pumped storage, storage based hydro-schemes, to balance growth and energy transition towards the net zero pathway.
3. **Introduction of energy storage as a new official use of reservoirs** in water acts and permitting regulations, to facilitate effective energy transition and modern water management adapted to current needs.

Chengdu Declaration on Dams and Reservoirs for Energy Transition and Adaptation to Climate Change

4. **Urgent policy reforms** are needed to enable energy transition, and to ensure equity in energy access, guaranteeing the financial feasibility of storage-based hydropower and pumped storage projects, as keys for the energy transition commitment.

5. **Strengthening dam safety management** through rehabilitation and upgrading, including surveillance, real time flow forecast and early warning systems to enhance resilience, optimized reservoir management operation, smart regulation, and capacity building, in face of extreme events exacerbated by climate change.

CLIMATE RISKS AND SUSTAINABLE FINANCE

"Physical risk[7]" means the economic costs and financial losses resulting from the increasing severity and frequency of:

- **Acute Physical Risks**

Extreme climate change-related weather events such as floods, heatwaves, landslides, storms and wildfires.

- **Chronic Physical Risks**

Longer-term gradual shift of the climate such as changes in precipitation, extreme weather variability, ocean acidification, and rising sea levels and average temperatures

- **Indirect effects of climate change:**

Loss of ecosystem services (e.g. water shortage, degradation of soil quality, or marine ecology).

DAMS : KEY TO CLIMATE CHANGE ADAPTION AND MITIGATION AND SECURING THE HYDRO GIGAWATTS

- Apart from the conventional benefits, dams play a significant role in providing resilience against the impacts of climate change, adapt and mitigate the extreme events of floods, droughts and other hydrological shocks.

- Dams are vital for water, food, energy and health security of the country.

- In order to add the targeted GW of hydro and pumped storage capacity by the year 2030 and 2050 to fulfill the announced energy transition goals, storage, run-of-river and pumped storage dams would have a significant part to play.


Thank You