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

GLACIAL LAKE OUTBURST FLOOD HAZARD ASSESSMENT FOR A HIMALAYAN HYDROPOWER PROJECT: A CASE STUDY FROM THE LOHIT BASIN, INDIA

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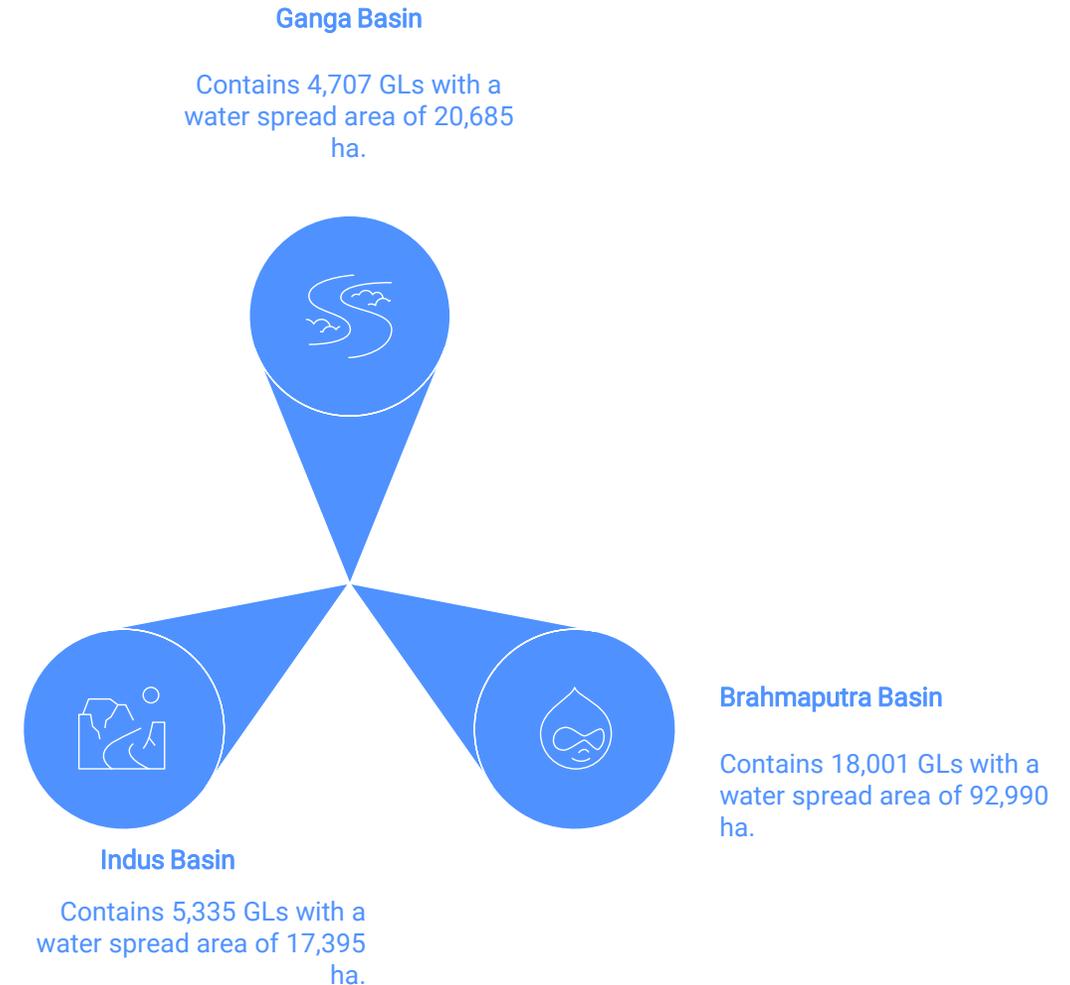Sreeja A.S., Assistant Director-II, CWC

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CONTENTS

Glacial Lake Expansion and GLOF Risks: Implications for Himalayan Hydropower Projects

- Global mean surface air temperature increased by ~0.85 °C (1880–2012)

- Himalayan region warming rate: ~0.15–0.60 °C per decade (last 3 decades)

- Glaciers are melting at an accelerated and unprecedented rate

- Formation of numerous glacial lakes (GLs)

- National Remote Sensing Centre (NRSC) has prepared atlases for three Himalayan basins

- The instant release of stored water on breaching of glacial lakes with very high velocity is known as Glacial Lake Outburst Flood i.e. GLOF.

Ganga Basin

Contains 4,707 GLs with a water spread area of 20,685 ha.

Brahmaputra Basin

Contains 18,001 GLs with a water spread area of 92,990 ha.

Indus Basin

Contains 5,335 GLs with a water spread area of 17,395 ha.

- Recorded GLOF events in the Himalayas:
  - **296 events from 109 GLs since 1950** (Zhang et al., 2021)
  - **179 events** reported in Karakoram valleys (1533–2020) (Bazai et al.2022)
- Indian states with highest GLOF hazard:
  - **Jammu & Kashmir**, followed by **Arunachal Pradesh, Sikkim, Himachal Pradesh, Uttarakhand** (Mal et al., 2021)
- Major recent GLOF disasters in IHR:
  - **2013 Chorabari GLOF (Kedarnath):** large-scale devastation and loss of life(Allen et al., 2016)
  - **2023 South Lhonak Lake GLOF (Sikkim):** 178 fatalities; severe damage to **Teesta hydropower projects** (Zhang et al.,2025)
- **Urgent need** for GLOF hazard assessment
  - Mitigation measures and early warning systems
  - Safety evaluation of high-altitude hydropower projects
- Present study: GLOF assessment of **Lohit River Basin** to evaluate potential impacts on **Kalai-II HEP, Arunachal Pradesh**


04-10-2023

Earlier

TEESTA 3 DAM
BEFORE & AFTER

Source: South Asia Network on Dams, Rivers and People

GLOF Modelling Methodology
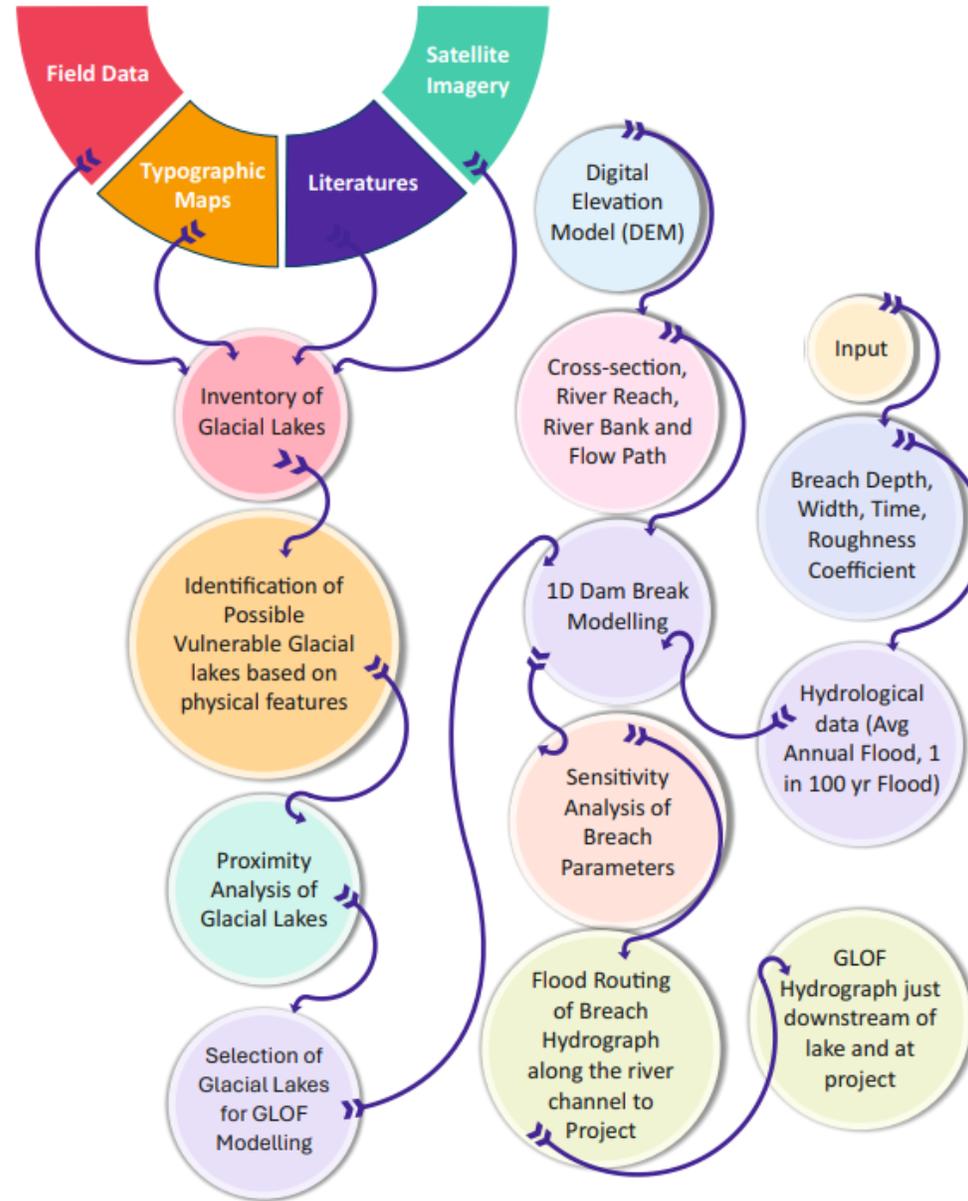
Study Area-Lohit River Basin

- **Major left-bank tributary of Brahmaputra**

- **Origin:** Southern slopes of **Kangri Garpo Range, Tibet** at **6,190 m** elevation

- Primary glacier source: Ata Kangla Glacier

- Enters India near **Kibitoo (Arunachal Pradesh)**

- Characterized by steep mountainous terrain, narrow valleys, deep gorges, rapids, and boulder-strewn channel

- Major tributaries in India: Dau, Dalai, Tidding, Lang, etc.

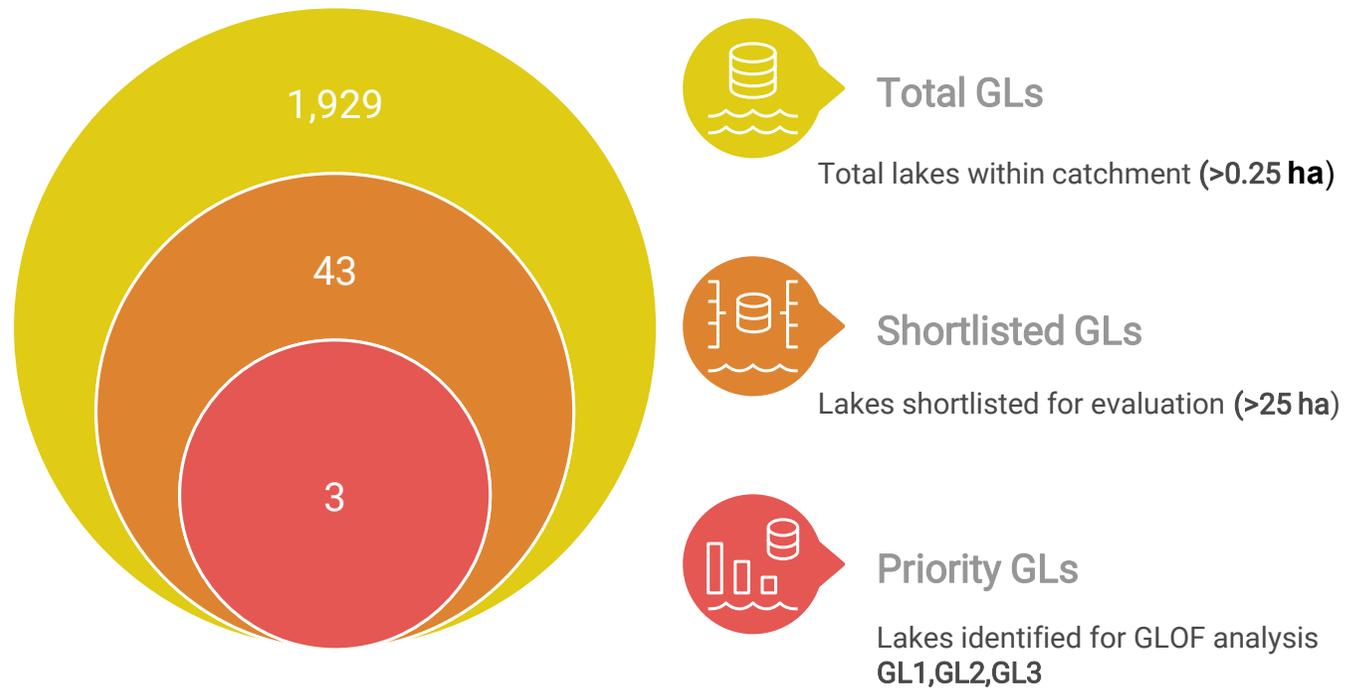- Length in India: **433 km**, joins Brahmaputra near Sadia
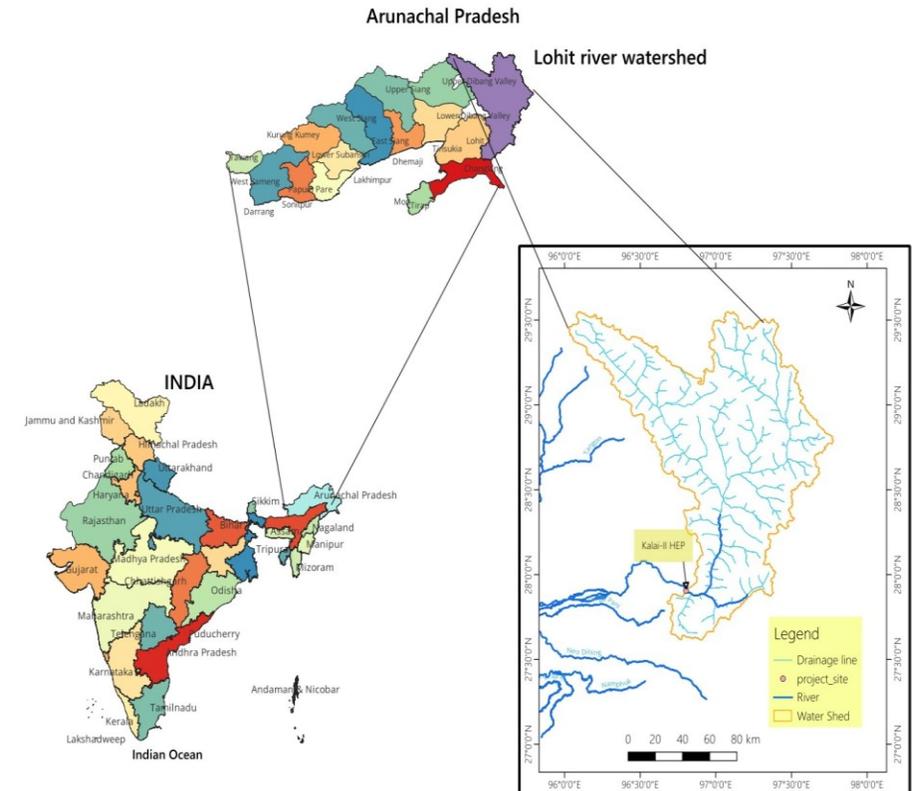
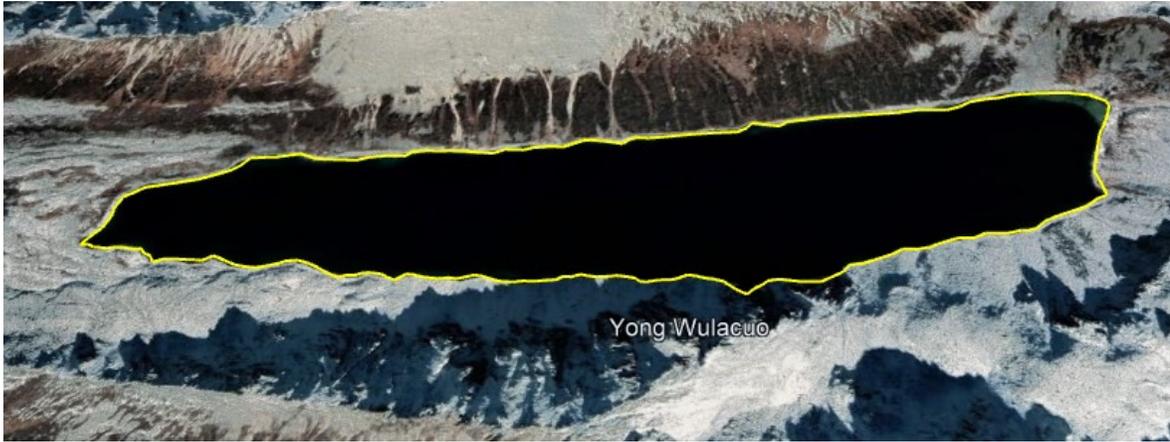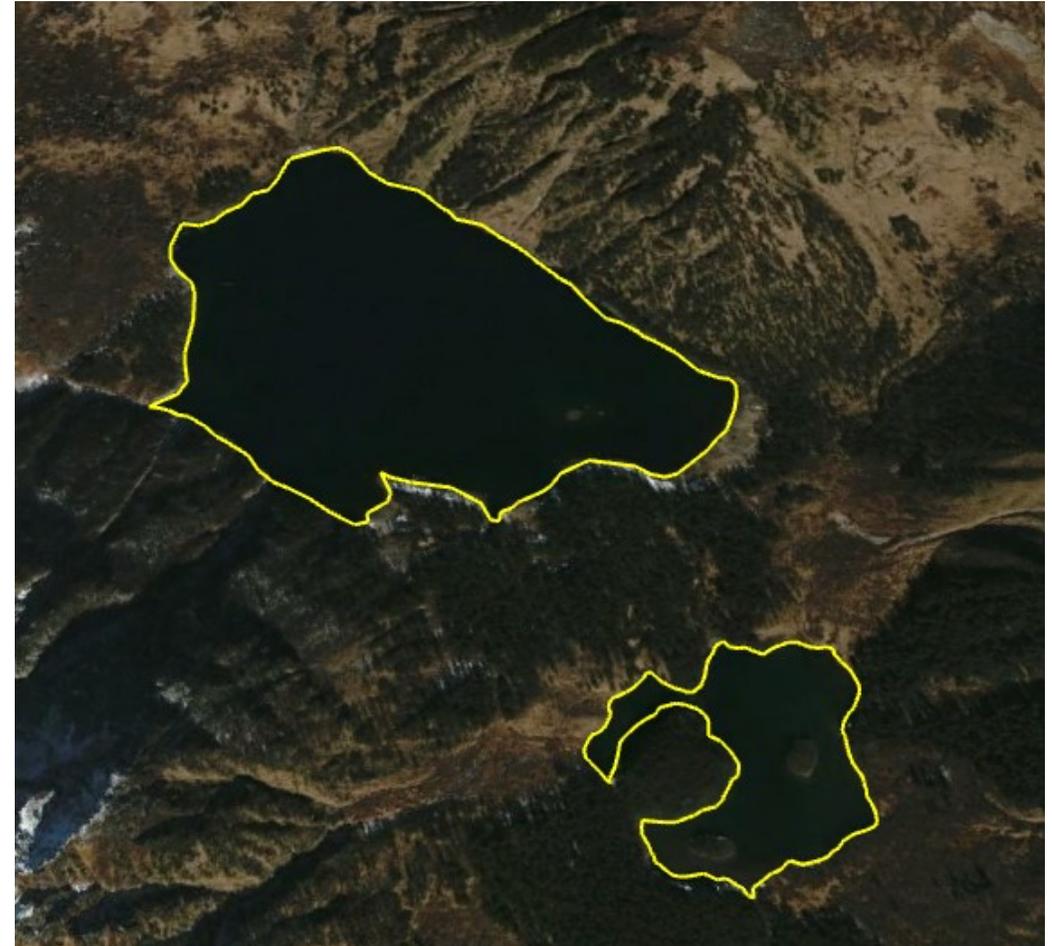**Catchment area map of Kalai-II HEP.**

Kalai–II HEP Catchment Lake Evaluation
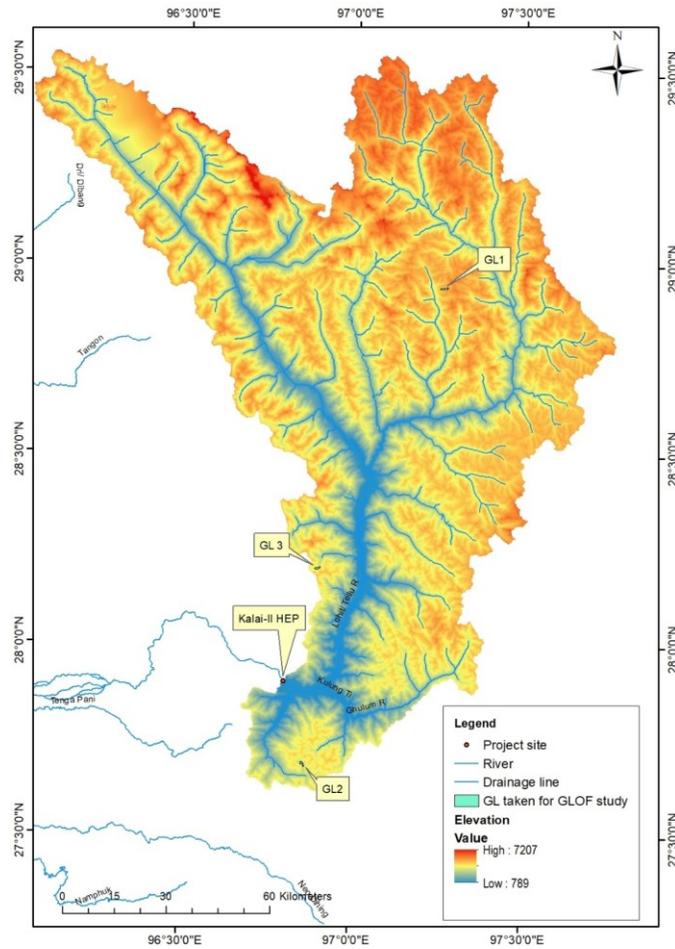
Locations of GL1, GL2 and GL3 in the project catchment area

- Source: **Glacial Lake Atlas of Brahmaputra Basin (NRSC)**

Total GLs

Total lakes within catchment (**>0.25 ha**)

Shortlisted GLs

Lakes shortlisted for evaluation (**>25 ha**)

Priority GLs

Lakes identified for GLOF analysis
GL1,GL2,GL3

1,929

43

3

Google satellite imagery of GL 1 (93.63 ha)

Google satellite imagery of GL 2 (49.45 ha) and GL 2a (9.16 ha)


Google satellite imagery of GL 3 (67.30 ha)

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Lake Volume Estimation

- Christian Huggel (2002) → Canadian Inland Water Directorate → Khanal et al. (2015) – MRD → Cook & Quincey (2015)

| Sl No	ID_No as per NRSC Inventory	Lat	Long	Area (Ha)	Elevation (m)	Distance to project site (km)	Vol of GLs (MCM)	Breach Vol adopted (MCM)
(GL1)	10591H051447	28.9395	97.2616	93.63	4412	172.81	31.40	23.55 (75%)
(GL3)	10591D160698	28.2022	96.898	67.30	3731	81.44	19.49	14.62 (75%)
(GL2)	10592A142163	27.6897	96.8603	49.45	3373	48.98	12.50	10.625 (85%)

GLOF Modelling

- ➤ **Selection of Glacial lakes** for GLOF modelling
- ➤ **Cross-sections** extracted from SRTM 30 m DEM at 2-5 km intervals
- ➤ **Input:** Breach depth, width, time, roughness coefficient
- ➤ **Initial Conditions**
- • Hydraulic routing performed under **two initial flow scenarios**:

Annual Average Flood
- 885 m³/s

100 year Flood
- 11,582 m³/s
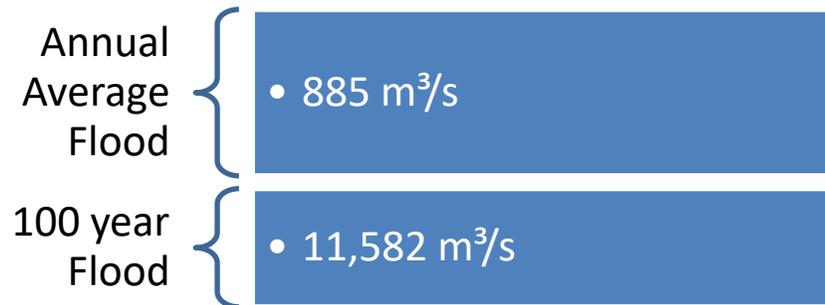
- • Routed hydrographs represent **combined flood + GLOF response**
- • **GLOF ordinate** at any section =**Total flood ordinate-Initial flood discharge**

Modelling Approach: GLOF as a Dam-Break Problem

- GLOF conceptualized as a **dam-break under unsteady flow conditions**

- **Moraine dams** behave like **unconsolidated earthen embankments**

- Failure mechanisms include: **Overtopping, Piping etc.**

- Two-stage GLOF analysis**: Dam-breach hydrograph generation & Hydrodynamic routing**

- Estimation of peak discharge, attenuation & arrival time at Kalai-II HEP

- Numerical tool used**: MIKE 11 (DHI)**

- Model governed by **Saint-Venant continuity & momentum equations**

- Model domain includes **glacial lake (reservoir), dam-break structure, and downstream channel network**

- River network defined along **main channel and tributaries**

- **Upstream boundary condition:** Lateral inflow hydrograph at reservoir

- **Downstream boundary condition**-Normal depth/ Stage-Discharge relationship
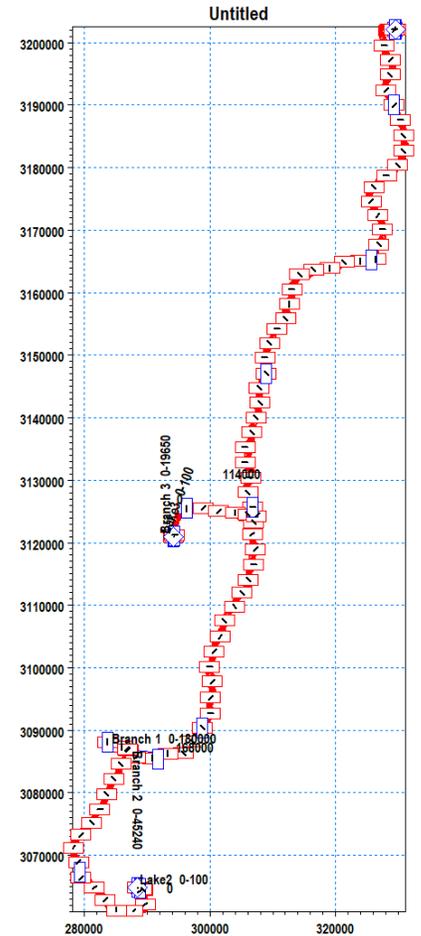
MIKE 11 Model setup

Breach Parameters

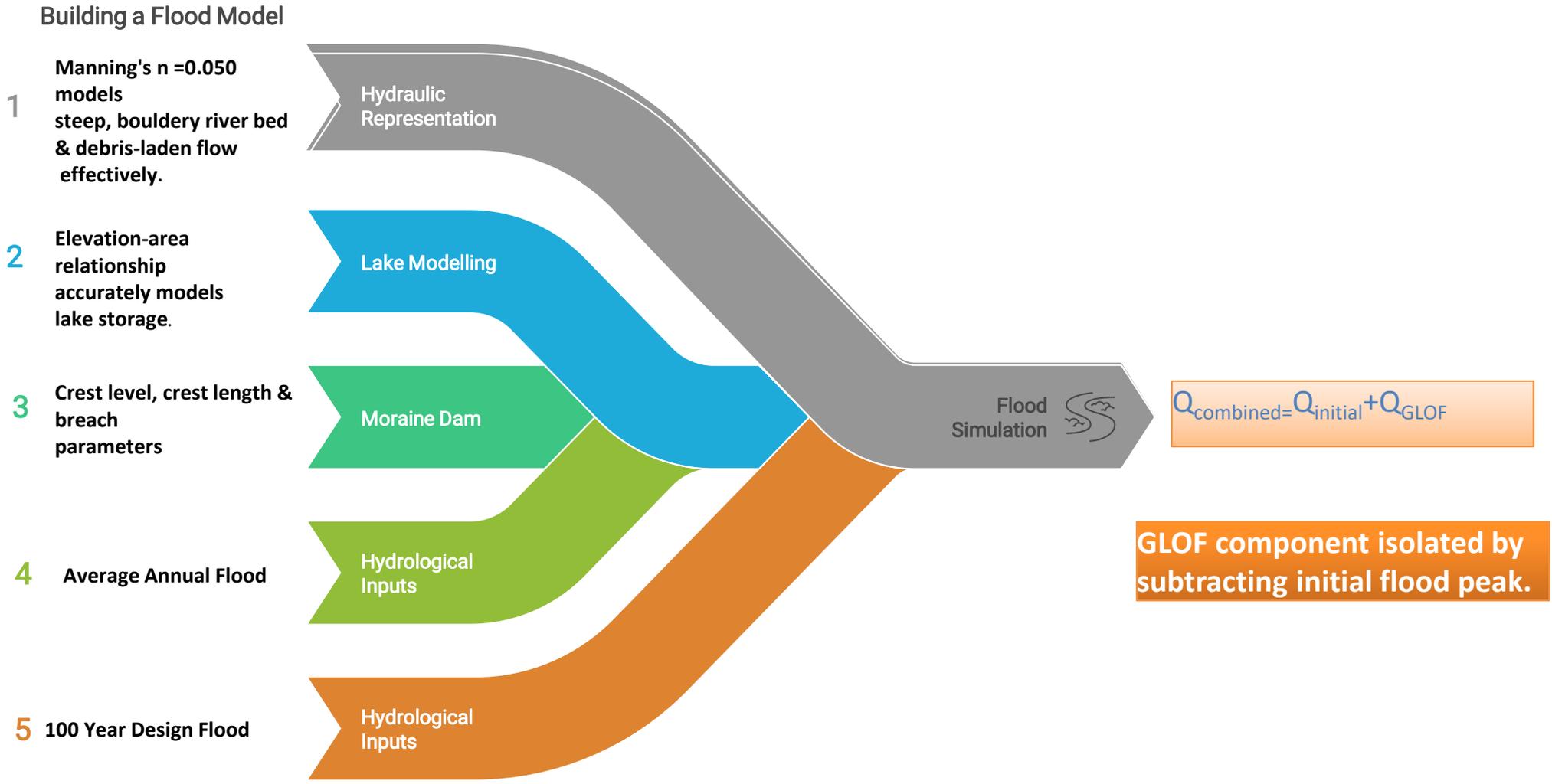| Lake	Lake Elevation (m)	Breach Volume (MCM)	Breach Depth (m)	Avg. Breach Width (m)	Bottom Breach Width (m)	Top Breach Width (m)	Side Slope	Development Time (min)
GL1	4412	23.55	25	92	67	117	1H : 1V	60
GL2	3373	10.62	22	73	51	95	1H : 1V	45
GL3	3731	14.62	22	80	58	102	1H : 1V	45
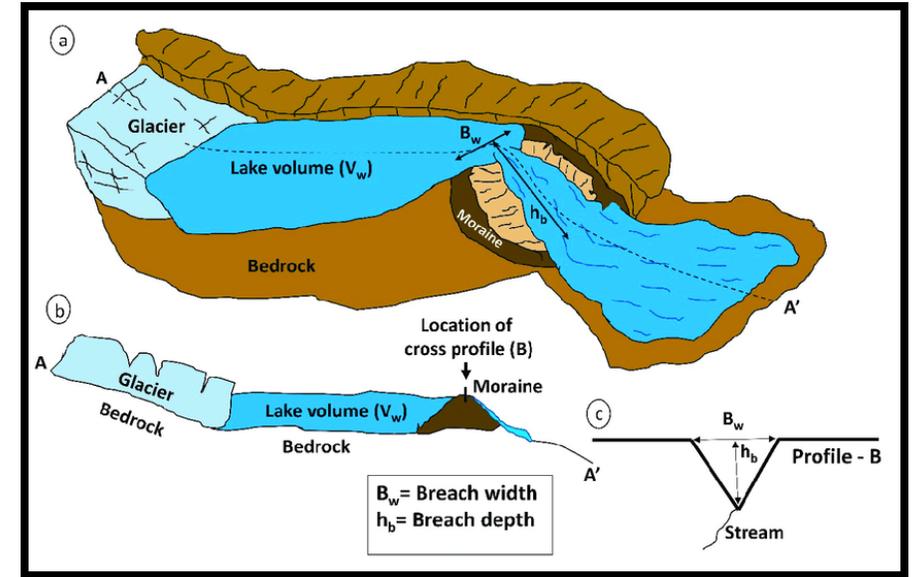
Source: Sattar & Goswami (2020)

- **Breach geometry estimation empirical relationships**:
  - Froehlich (1995b, 2008a, 2017a)
  - Federal Energy Regulation Commission (1987)
 - Von Thun & Gillette (1990)

GLOF Simulation

Building a Flood Model

1. Manning's n =0.050 models steep, bouldery river bed & debris-laden flow effectively. — Hydraulic Representation

2. Elevation-area relationship accurately models lake storage. — Lake Modelling

3. Crest level, crest length & breach parameters — Moraine Dam

4. Average Annual Flood — Hydrological Inputs

5. 100 Year Design Flood — Hydrological Inputs

Flood Simulation

$Q_{combined} = Q_{initial} + Q_{GLOF}$

GLOF component isolated by subtracting initial flood peak.

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CENTRAL BOARD OF IRRIGATION & POWER
ESTD. 1927
NEW DELHI

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Summary of Results

| Sl No. | Case | Location | Initial Condition in the river for GLOF Simulation (Cumec) | | | | Distance from Lake in km |
| | | | Avg Annual Flood | | 100 year Flood | | |
			GLOF (cumec)	Travel time	GLOF (Cumec)	Travel time	
1	GL1	At d/s of Lake	6323	0	6323	0	0
2		Kalai-II HEP	1773	7 h 30 min	2413	5 h 10 min	172
3	GL2	At d/s of Lake	5374	0	5374	0	0
4		Kalai-II HEP	2854	55 min	3574	45 min	49
5	GL3	At d/s of Lake	5882	0	5882	0	0
6		Kalai-II HEP	1747	3 h 39 min	2755	1h 54 min	81

Results
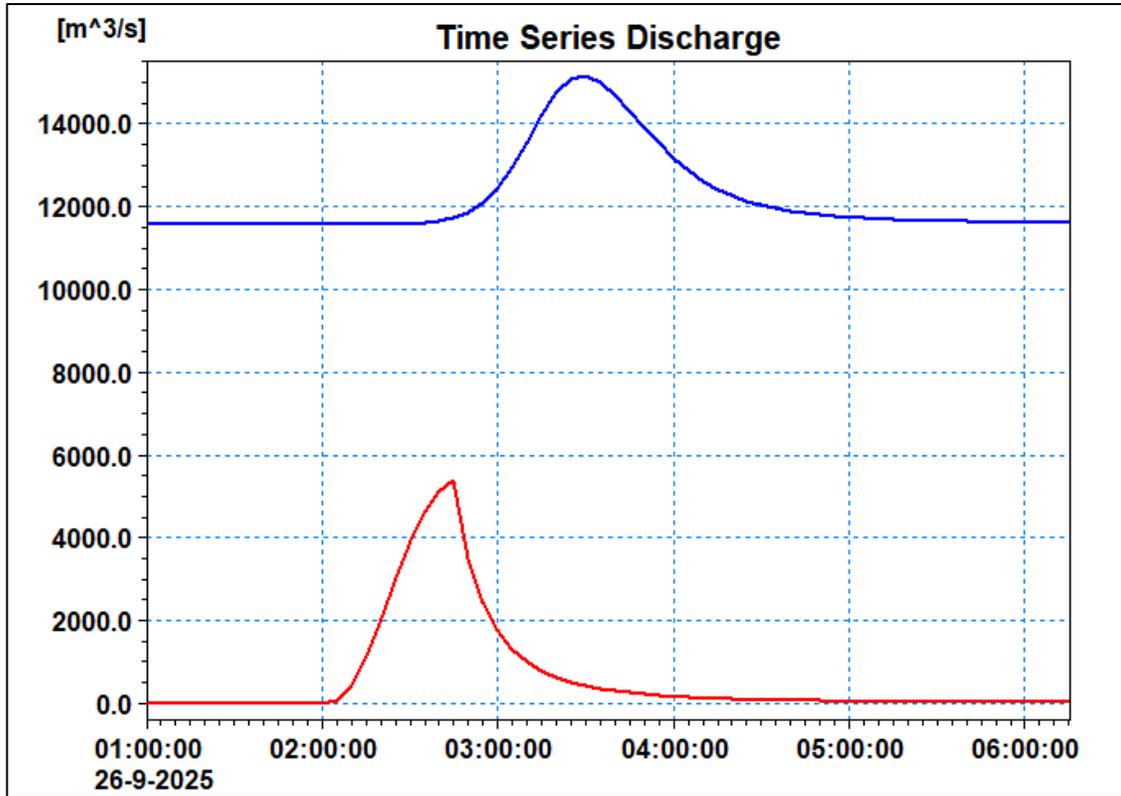
GLOF at just downstream of lake and at Kalai-II HE Project site along the river including 100 Year flood due to GL2 outbursts
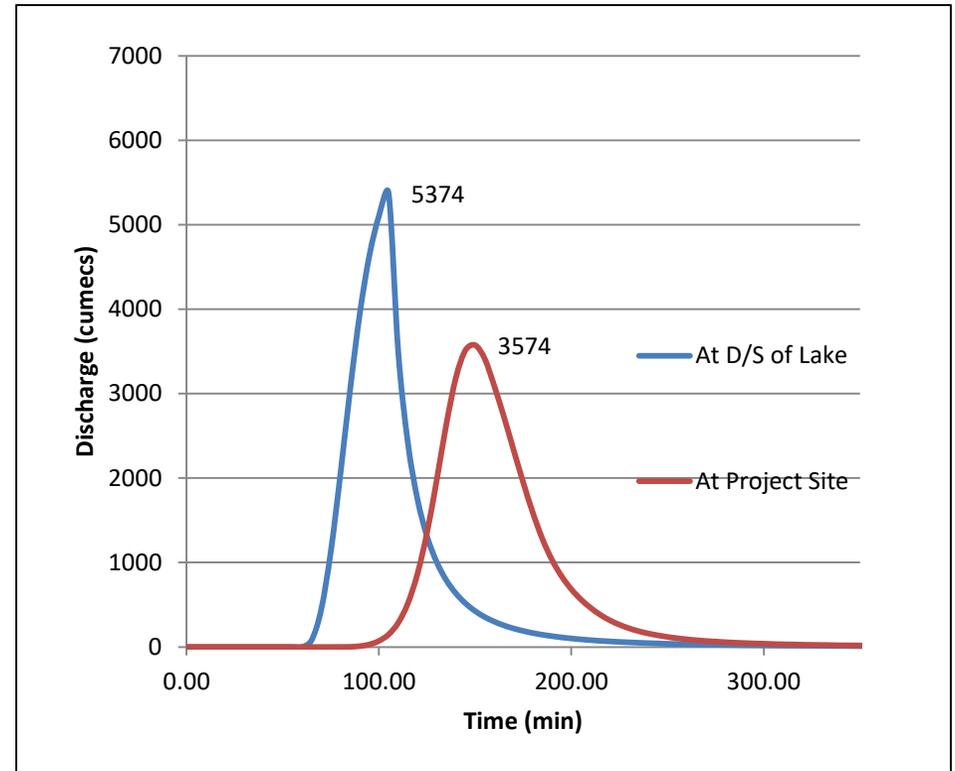
GLOF at just downstream of lake and at Kalai-II HE Project site along the river excluding 100 Year flood due to GL2 outbursts

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Assumptions and Limitations

- **Model assumptions:**
  - ✓ Based on Saint-Venant equations
  - ✓ Assumes incompressible, homogeneous flow, hydrostatic pressure, and long-wave conditions
- **Breach uncertainty:**
  - ✓ Breach width and depth are empirically estimated
  - ✓ Moraine dam failure mechanisms remain poorly constrained, influencing peak discharge and travel time
- **Excluded processes:**
  - ✓ Channel erosion and scour during high-velocity GLOF flows
  - ✓ Debris transport and temporary blockages at narrow sections
- **Despite limitations:**
  - ✓ Modelling provides a practical and reliable estimate of GLOF magnitude and downstream impacts

Conclusions

- ✓ GLOFs represent a credible threat to hydropower infrastructure in the Lohit River Basin
- ✓ The very first step in minimizing the threat can be to start the monitoring of vulnerable lakes more actively and regularly.
- ✓ The next step would be to carry out detailed studies and model simulation of potentially vulnerable lakes and to share the outcome with the concerned stakeholders.
- ✓ It is also important to closely assess the bathymetric changes of identified lakes, instead relying only on satellite and remote sensing data.
- ✓ Early Warning System (EWS): A transmitter station installed at glacial lake sites that receives signals from sensors and relays them to downstream and remote warning stations.
- ✓ An additional flood cushion may be provided during construction stage of projects to accommodate the increased discharge due to increase in size of glacial lakes.

Conclusions

- ✓ Various methods and techniques may be used to mitigate potential GLOF hazards in Lohit basin. If the environment permits, lowering the level of the lake water is usually considered the most effective mitigation measure.

- ✓ Modelling framework adopted in the present study is reproducible and transferable to other Himalayan basins

- ✓ Integration of GLOF risk assessment into hydropower planning, operation & emergency management is essential under changing climate conditions

CWC Guidelines for GLOF

Thank You