Environmental Impact Assessment

October 2018

India: Assam Power Sector Investment Program Tranche 3

Annex 8 of the EIA Report

Prepared by Assam Power Generation Corporation Limited (APGCL), Government of Assam for the Asian Development Bank. This is an updated version of the draft originally posted in April 2018 available on https://www.adb.org/projects/documents/ind-47101-004-eia

Final Report – Climate Risk and Vulnerability Assessment – Lower Kopili Hydropower Project, Assam Power Project, India

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Contents

List of Abbreviations

ADB	Asian Development Bank
APGCL	Assam Power Generation Corporation Limited
ASAPCC	Assam State Action Plan for Climate Change
ASDMP	Assam State Disaster Management Plan
a.s.l	above sea level
CEIA	Comprehensive Environmental Impact Assessment
ESIA	Environmental and Social Impact Assessment
EMP	Environmental Management Plan
FSL	Full surface level
GCMs	Global climate models
GoI	Government of India
IMD	Indian Meteorological Department
IPCC	Intergovernmental Panel on Climate Change
LKHEP	Lower Kopili Hydro-Electric Project
MCM	Million cubic meters
MoEF&CC	Ministry of Environment, Forests and Climate Change, GoI
N / A	Not applicable
NEEPCO	North East Electricity Power Company
RCMs	Regional climate models
SPS	ADB Safeguard Policy Statement (2009)

1. Background

1.1 Project Context

The Assam Power Project (46470-001) was approved by the Asian Development Bank (ADB) in June, 2014 to fund the Assam Power Sector Investment Program, a multi-tranche investment facility focused on the upgrading of power generation and distribution systems, including the construction of a 120-megawatt hydropower plant (LKHEP); the financing of new energy efficient power generation equipment at existing plants; new distribution lines and substations; and financial management training and other support for staff of state power companies (the Assam Power Generation Corporation and Assam Power Distribution Company). The ADB Assam Power Investment Program – Tranche 3 (loan 3140 – IND, approved 11 July, 2014) has particular focus on supporting the construction of the Lower Kopili Hydro-Electric Project (LKHEP) run-of-river hydropower plant in central Assam (see Figure 1), that will help the state avoid over 530,000 tons per annum of carbon dioxide emissions that would otherwise be produced by fossil fuel-driven generation. Also, by cutting power outages in the state, the program is benefiting over 2.7 million consumers.

1.2 Project Area

The Kopili River originates in the state of Meghalaya and flows through Assam before joining the Brahmaputra River. This region lies within the eastern ranges of the Himalayan foothills. The drainage area up to the proposed LKHEP lies between longitudes 92°11’41.12” - 92°49’19.47” E and latitudes 25°08’20.31” - 25°40’40.82” N. There are two other reservoirs located upstream of the proposed LKHEP site. They are at the Umrong dam and the Khandong dam. The reservoir at the Khandong dam has a surface area of 17.65 km^2 and is located at an elevation of 600 m asl. The second reservoir at Umrong dam has a surface area of 9.34 km^2. A map showing the watershed and the reservoirs, including the LKHEP site, is presented in Figure 1. Figure 2 shows the natural habitat context of the LKHEP location within the watershed (a combination of forest and hilly agricultural land).

This region receives the world’s highest rainfall amounts, and about 30% of India’s total rainfall. This area may be characterized as a tropical monsoon rainforest climate. A typical year may be divided into winter (November-February), spring (March-April), summer (May-August) and autumn (September-October). The summer period receives heavy monsoon rainfall; spring and autumn receive moderate rainfall, whereas the winter is dry and doesn’t receive much rainfall at all. Typically, shifting agriculture (referred to as *jhum cultivation*) is practiced in the forested region, with terrace farming in the hilly areas.

1.3 Overview of Climate Change in Assam (Past Trends and Future Projections)

Assam is temperate, with a Tropical Monsoon Rainforest climate (summer maximum of 35 – 39 °C and a winter minimum of 5 – 8 °C). The area experiences heavy rainfall and high humidity. The climate is characterized by heavy monsoon downpours, which reduce summer temperatures, and enable formation of foggy nights and mornings in winter. There is moderate rainfall and temperature in the spring (March – April) and autumn (September – October). For ascertaining long-term climate trends, State level climate data for the period 1951 to 2010 were analyzed by the India Meteorological Department.[1] In Assam, the analysis is based on data collected from 6 stations for temperature and 12 stations for rainfall. The analysis indicates that the mean temperature in the State has increased by +0.01 ^oC/year. There has also been an increase in seasonal temperatures across seasons, with pronounced warming in post-monsoon and winter temperatures. The annual rainfall has also decreased by -2.96 mm/year during the same period (see Table 1 below).

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[1] Assam State Action Plan on Climate Change. 2015. Department of Environment, Government of Assam.

When future climate projections are examined, it appears that Assam will continue to experience increasing temperatures, although at a slow rate. There is a less clear future trend in rainfall, with slight increases expected in most areas, but the smallest rainfall increase (and possibly a decline) to be expected in the northwestern part of Assam (see Table 1 below; future projections are discussed in more detail later in this report).

Figure 1. Kopili River watershed map.

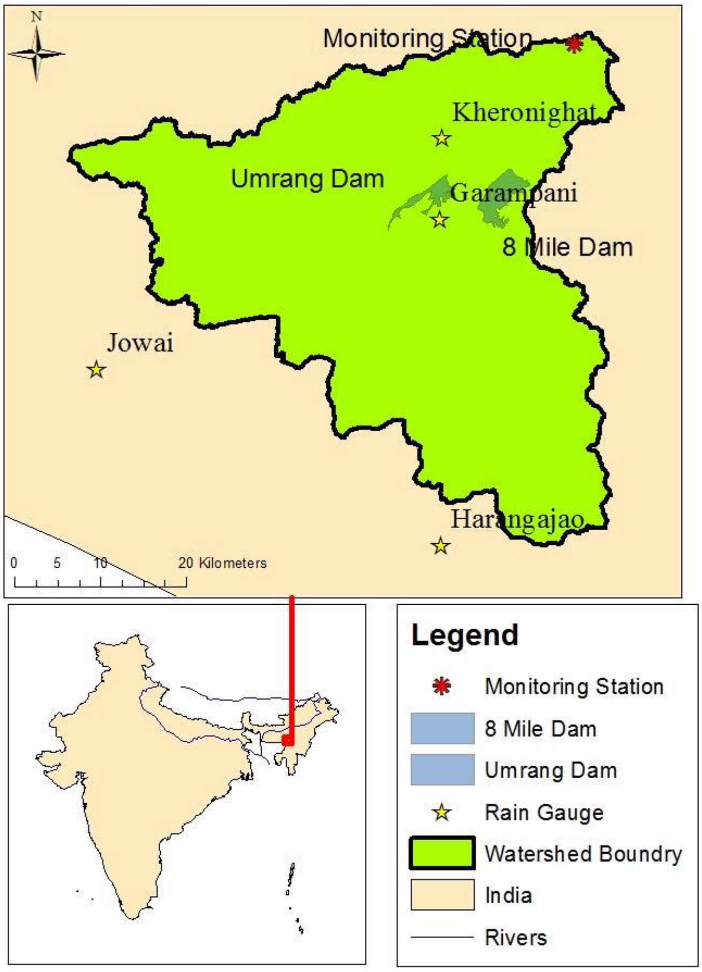


Figure 2. LKHEP location within the watershed.

Table 1: Past climate trends: 1951-2010.

	Annual	Winter	Summer	Monsoon	Post Monsoon
Mean Max Temp (oC/yr)	+0.02	+0.01	No trend	+0.01	+0.02
Mean Min Temp (oC/yr)	+0.01	+0.02	+0.01	+0.01	+0.02
Mean Temp (oC/yr)	+0.01	+0.01	No trend	+0.01	+0.02
Rainfall (mm/yr)	-2.96	+0.08	-0.56	-2.19	-0.75

Table 2: Future climate trends, to 2050.

	2021-2050 wrt BL	Remarks
Mean Temperature	1.7-2.0°C	All across Assam
Annual Rain fall	-5 to 5%	North western districts
	5-10%	North Eastern districts
	10-25%	Central, South Eastern Districts
Extreme rainfall days	5-38%	Rainfall >25 to 150 mm
Drought weeks	-25% to >75%	Southern districts show marginal reduction in drought weeks but rest of the district show an increase by more than 75% wrt BL

1.4 Project Components

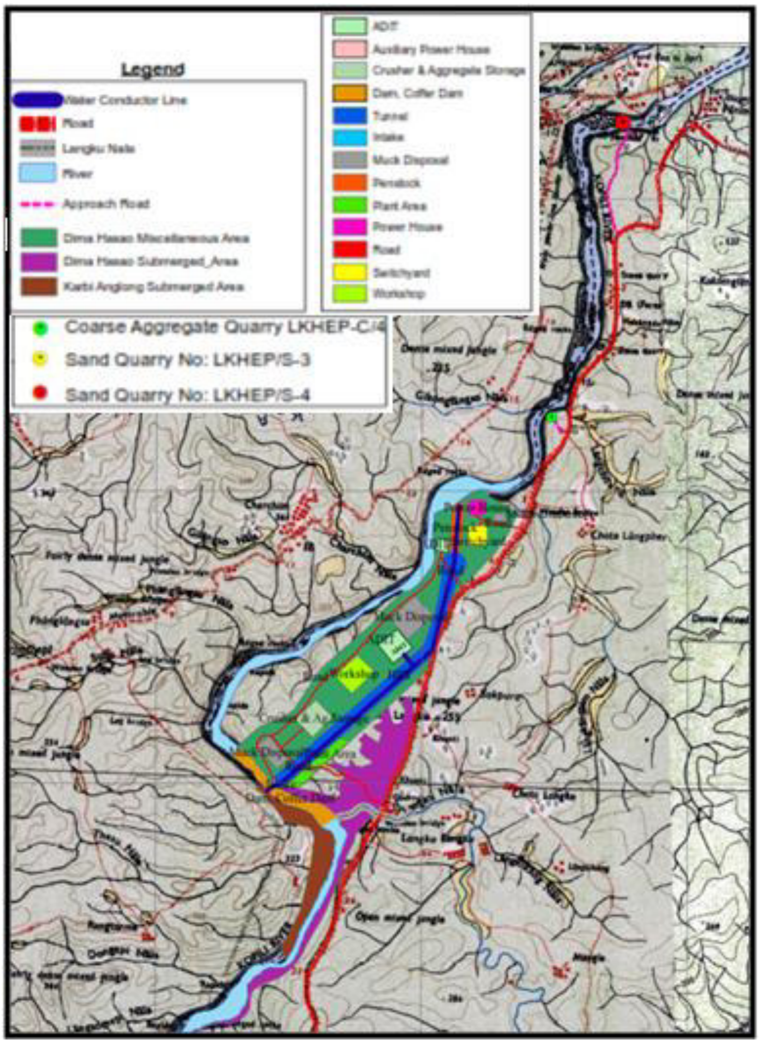
There are three main elements associated with the LKHEP: the dam/powerhouse complex; the project access roads; and, the transmission lines required for power evacuation. These all may have some vulnerability to climate change, to varying extents. These project components are briefly described below.

Dam/Powerhouse Complex:

LKHEP will comprise a 70-m concrete gravity dam across the Kopili river at Longku, about 20 km downstream from the Kopili HEP Stage-I powerhouse. There will be a water conductor system comprising an intake structure, headrace tunnel, surge shaft, penstock, and a surface main powerhouse with installed capacity of 110 MW, utilizing the inflow from a catchment area of about 2,076 km^2. An auxiliary powerhouse with installed capacity of 10 MW is proposed for the toe of the dam for additional power generation. Environmental flow, to maintain a wetted area below the dam, will come from the auxiliary powerhouse. The proposed layout of the project is shown in Figure 3.

The proposed project will receive water from: (i) tailrace water released from the existing Kopili power plant further upstream; (ii) incremental flow from the river catchment area between the Khandong dam and the proposed LKHEP dam; and, (iii) any reservoir spill from the Khandong and Umrong reservoirs. The dam will create a reservoir at Longku with a spread of 620 ha, with a live storage of 77 million m^3 (see Figure 4). The maximum operating level of the LKHEP dam will be 226 m above Mean Sea Level (MSL).

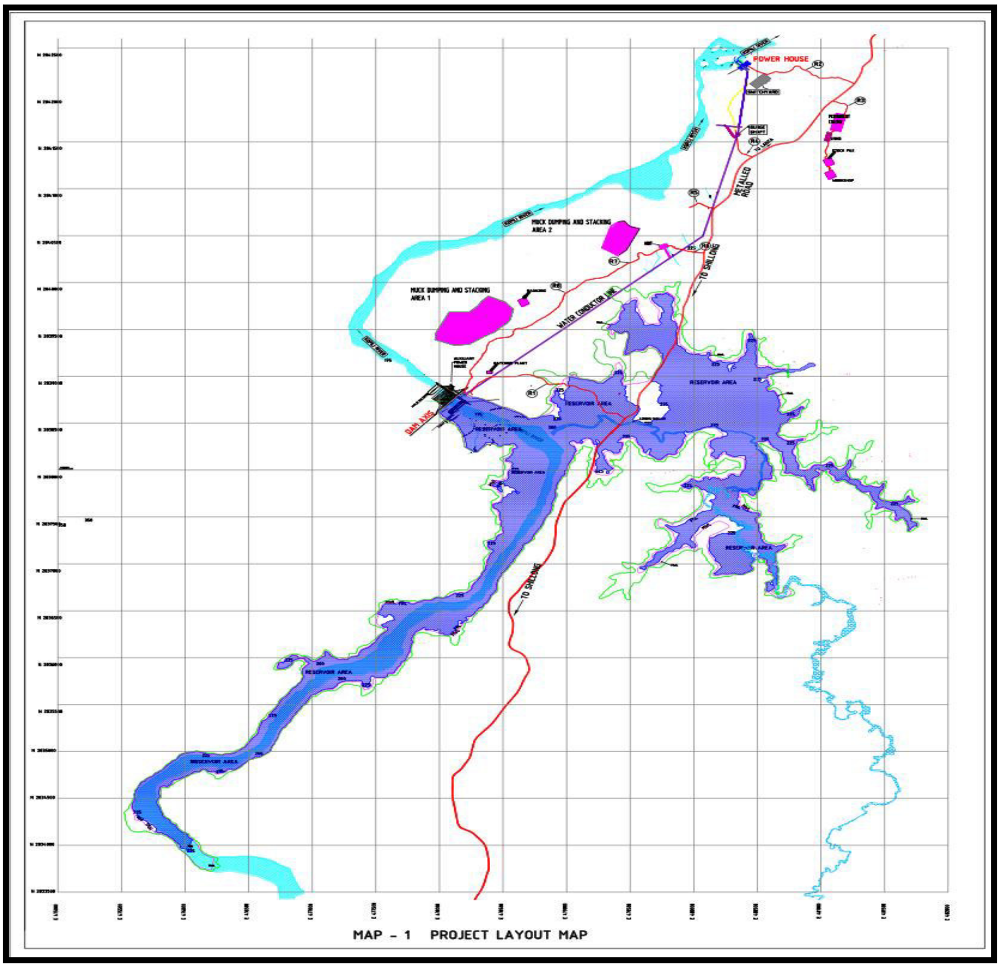
Figure 3. Main project infrastructure.



Transmission Lines:

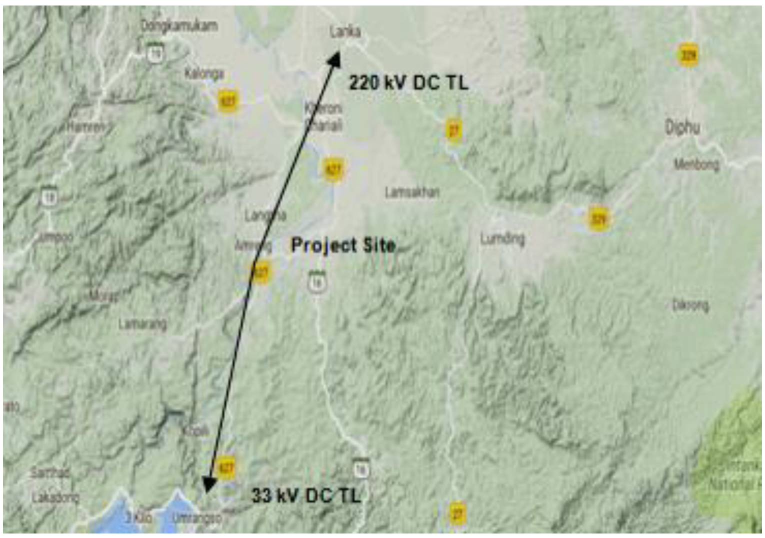
Power generated at the LKHEP powerhouse will be transferred to the Lanka substation (S/S) located at Shankerdev Nagar (see Figure 5) through a new 220 kV double circuit (DC) transmission line. This transmission line will be about 50 km long and will use a new right-of-way from LKHEP to Lanka. The existing S/S at Lanka is presently rated at 132 kV, so this S/S will be upgraded and expanded to 220 kV to receive power from the project. Power received at Lanka from the project will be partly used to serve customers and regions presently served by the Lanka S/S. The balance of power from the project will be transferred to an upstream network through the Lanka-Misa transmission lines.

Figure 4. Reservoir flooding area.



Power generated at the 10 MW auxiliary powerhouse will be transferred to Umrangso, along a new double circuit 33 kV line, 20 km long, to be built under the project (see Figure 5). There is an existing 132 kV S/S at Umrangso, where two new bays will be built to receive the new line from the project. There will be a 33 kV connection from the auxiliary powerhouse to the main powerhouse, to provide auxiliary power and back-up power, to ensure the ability to start the main powerhouse, in case the Lanka S/S is de-energized during a transmission network outage in the Lanka-Misa area.

Figure 5. Generalized transmission line corridors.



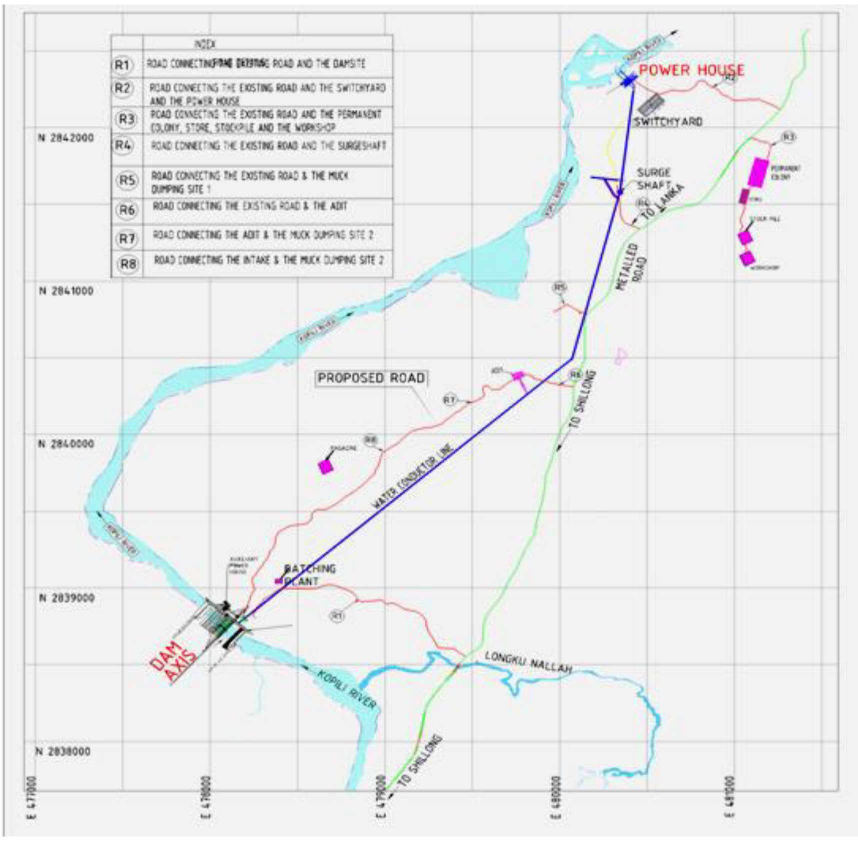
Project Access Roads:

The project site can be reached by road from Guwahati on the National Highway (NH-52) up to Lanka (a distance of approximately 180 km). From Lanka up to the dam site area, a State Highway exists (for 33 km) which further up becomes the PWD road (Longku-Garampani) that will serve as the main access road to the project. The total length from Lanka to the project site is 48 km. Several smaller access roads are required from the PWD road to various project infrastructure areas and worksites (see Figure 6), for example the dam and powerhouse areas. The total length of these roads will be approximately 13.1 km (see table below).

Table 3. New access roads required for LKHEP.

Lanka Garampani road to dam site and rehabilitation area, dyke and intake shaft top, including existing road diverted.	5.52 km
Explosives magazine road.	0.84 km
Lanka Garampani road to powerhouses	1.21 km
Approach road to colonies	0.37 km
Road to rock quarry areas	1.19 km
Road to dumping areas	0.61 km
Road to adit portals.	1.22 km
Road to hydro-mechanical workshop.	0.10 km
Road to electro-mechanical workshop.	0.03 km
Road to surge shaft.	1.85 km
Road to proposed bridge.	0.16 km
Total	**13.1 km**

Figure 6. Proposed project access roads.



1.5 Environmental Due Diligence and Climate Risk and Vulnerability Assessment Requirements

The LKHEP project is categorized as "A" under ADB guidelines, which means that it has gone through a full EIA process, including more than two public consultations to determine public concerns about the project and to benefit from local community observations of the natural environment in the project zone of influence. All environmentally sensitive areas within the project influence areas were carefully analyzed to assess the extent and significance of possible impacts. An associated Environmental Management Plan (EMP) and Monitoring Program were designed to address mitigation measures required for the identified impacts and to monitor their effectiveness. Government of India guidance also categorizes this project as "A" (a HEP greater than 50 MW). This also requires a comprehensive EIA and EMP, consistent with the ADB requirements, and an Environmental Clearance before any construction activity (this was obtained for LKHEP in September 2013).

Hydropower projects, since they are linked to natural water systems, are automatically considered to be medium or high risk with regard to vulnerability to climate change. As such, LKHEP is obligated to go through a climate risk and vulnerability assessment (CRVA), which is documented here. The purpose of the CRVA is to quantify the specific risks and identify adaptation options that can be integrated into project design, assuming they are technical feasible (using engineering measures and appropriate staff tasks) and economically viable (not significantly affecting the accepted profitability of the hydropower project). This study is intended to inform any such subsequent design analyses and changes, which may be due to changes in rainfall (affecting power potential and efficiencies, as well as sediment deposition in the reservoir) or temperature (as it affects evaporation, and subsequently the amount of stored water).

Adaptation options for hydropower projects (depending on the specific issues) can include: adjusting the dam height and thickness; adjusting spillway capacities and accommodation of sediment flushing; modifying turbine numbers and design to handle higher suspended sediment loads; adjusting headrace tunnels to handle variable flows; implementing rigorous discharge monitoring and hydrological forecasting; and developing basin-wide management strategies to handle increased risks of sediment erosion.

In response to the requirements noted above, the first Project CEIA study was conducted in September, 2015 (WAPCOS, 2015a; WAPCOS, 2015b), and has subsequently been updated by a revised ESIA, with EIA, SIA and EMP volumes (WAPCOS, 2016a; WAPCOS, 2016b; WAPCOS, 2016c). The revised EIA and EMP documents have received additional review attention, over November, 2016 – February, 2017, from an ADB environmental safeguards technical assistance team, with the intention of input to a further updated ADB Project ESIA (now completed with additional analytical reports on cumulative impacts, water quality management, and integrated water resource management). The revised ESIA (WAPCOS, 2016a) and EMP (WAPCOS, 2016b) documents have provided supporting data to assist the current CRVA. The Detailed Project Report (DPR) (Lahmeyer India, 2015a; Lahmeyer India, 2015b; Lahmeyer India, 2015c) also provided data on the Project engineering design and supporting technical studies, which have been equally valuable in support of the current study and report.

1.6 Climate Risk and Vulnerability Assessment

Based on an initial climate risk screening assessment of the project (Ji, 2015) (discussed below), the performance of the proposed investment is likely to be affected by future changes in climate conditions and their impacts, including: temperature increase; precipitation decrease (but changing rainfall patterns); flood; and landslide risk. To achieve the impact and outputs of the proposed investment, a climate risk and vulnerability assessment (CRVA) is required to provide a detailed and focused risk and vulnerability assessment that will identify and, to the extent possible, quantify risks to the project from climate change and variability, and provide corresponding adaptation measures. Outputs of the CRVA will be used to finalize the Project detailed design, and to strengthen the existing design to ensure that the proposed investment is climate-proofed to the extent feasible.

With regard to scope of work, the current CRVA study first defined the scope of climate risk and vulnerability assessment through literature review, in close consultation with the ASB SARD mission leader and the project team for Assam Power System Investment Program (ADB, 2016c). The focus was then upon the delivery of the following detailed tasks and outputs (ADB, 2016c): review all available relevant project documents and, in close consultation with the SARD mission leader and/or project team of the Assam Power System Investment Program (Tranche 3) – Lower Kopili Hydroelectric Project (LKHEP), define the scope of the climate risk and vulnerability assessment as required by the project, as follows:

i) **Collate, organize, and review available baseline** biophysical, environmental, demographic, socioeconomic, and policy data and information relevant to climate risk management within the context of the project;

ii) **Review existing studies**, data, and information on current and projected climate change risks and vulnerability for the proposed LKHEP on the Kopili River at Longku village in the east of Karbi Anglong district of Assam in India; the specific geographic area(s) and sector(s) covered by the project;

iii) **Develop detailed scenarios of climate change** variables as required for future time horizons pertinent to the project, including documentation of scenario methods, data sources, uncertainties, and caveats;

iv) **Identify climate risks and vulnerabilities and potential adaptation options** and practices as inputs to modeling and/or assessment of climate change impacts on relevant aspects of the project;

v) **Identify and discuss the implications of projected climate change impacts** and associated uncertainties for the design and operation of the project;

vi) **Conduct technical and economic assessments of potential climate risk and vulnerability** adaptation (climate proofing) options and practices relevant to the project;

vii) **Within the context of the project, assess existing policies, laws and regulations**, and/or institutional framework for adaptation and identify ways to enhance the enabling environment (if necessary); and,

viii) **Submit a comprehensive report on the potential risks of climate change** to the project and possible adaptation interventions, including practical advice on the use of the CRVA results for project design and operation.

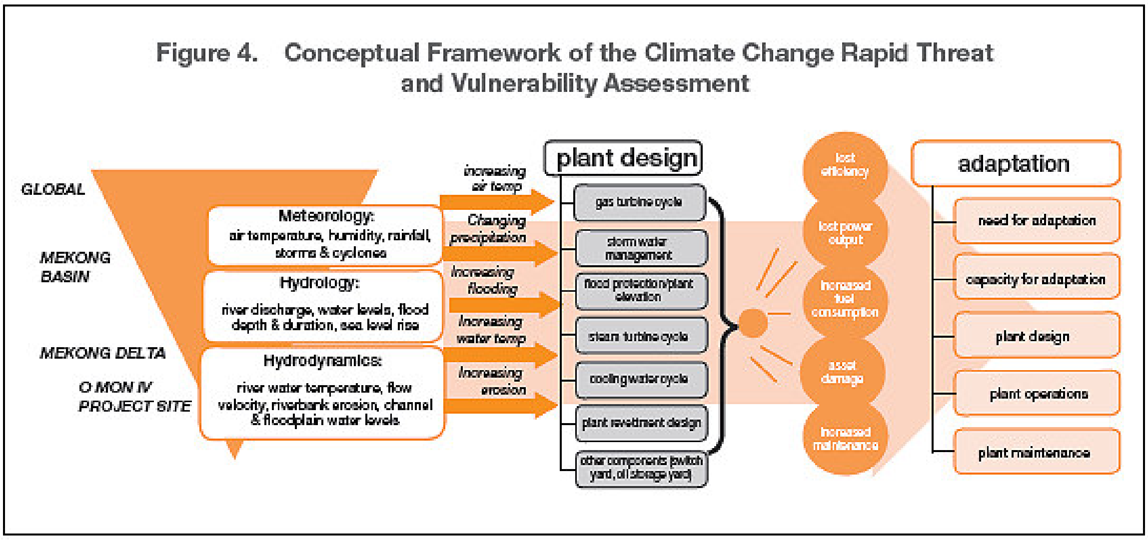
2. Review of Existing Studies

2.1 Climate Risk and Vulnerability Assessment Methodology

Climate risk and vulnerability assessment (CRVA) requires a convergence of detailed climate modeling (future projections for the region of interest), understanding of how these expected climate changes may impact biophysical features in a given project area, identification of project features which could be affected by the changing biophysical features (with some sense of the probability, or risk, of these vulnerabilities occurring), and description of technical options for adapting the project to meet the risks, or at least not be significantly affected by them. All institutions and agencies which engage in climate risk and vulnerability assessment generally follow this hierarchy of analysis (World Bank, UN agencies, and ADB). None of these steps can be avoided, if an effective project-specific climate change adaptation strategy is to be developed. As such, the ADB guidelines on CRVA have been used for this study. They are described below. Note that, while climate modeling has been done for Assam (for the Climate Change Action Plan, referred to previously), and vulnerabilities have been identified at the state-wide level, that document is not site-specific enough to address potential climate change issues with the LKHEP (hence the requirement for this study). In general, the common limitations of all CRVA work can be the lack of site-specific baseline data for the biophysical features of interest, and the vagaries or even conflicting results from climate modeling. Fortunately, in the LKHEP case, a climate risk assessment has already been done, rationalizing the climate models for the region, and the baseline survey work for the LKHEP EIA has provided quite specific data for the biophysical features of interest.

ADB's refined CRVA approaches are based on a series of climate risk and adaptation case studies within Vietnam (ADB, 2012a; ADB, 2013a) with a focus on Power Sector investment and development. These documents assist with an outline of a conceptual approach to climate change and vulnerability assessment (shown in Figure 7). This outlines the risk assessment methodology which can also be applied to the LKHEP case study. It involves major steps to assess: the likely climate change "downscaling" from global analysis to the site; the likely impact of meteorological, hydrological and hydro-dynamic conditions on the project site; the "knock-on" impacts of these changed conditions on plant design and plant performance; and, the adaptation actions needed to mitigate these changes.

Figure 7. Conceptual approach to this climate change assessment.



Source: Figure 4 - (ADB, 2012a)

As further noted by (ADB, 2012a), and detailed in Figure 8, the critical steps are: threat analysis; vulnerability analysis; and adaptation planning.

The main objective of the **threat analysis** is to define and quantify the changes in spatial–temporal dimensions of climate variability. This includes the changes in incidence, magnitude, and duration of hydro-meteorological events. This analysis normally uses downscaled GCM modeled projections of future climate and projects changes in the hydrological regime, given the projected future climate (ADB, 2012a).

The **vulnerability assessment** combines aspects of conventional engineering feasibility assessments with life cycle analysis. It relies on two assessment phases: (i) the sensitivity of the plant design to climate variability; and, (ii) the combination of the quantified direct threat and plant sensitivity to determine the impact over the design life (ADB, 2012a). A detailed assessment is then made of the plant design by reviewing plant design parameters and identifying potentially vulnerable processes and components of the plant. An infrastructure inventory is compiled to determine the physical assets most at risk of damage and their value. Then an assessment is made of all plant processes to identify those that may be enhanced or compromised by climate change. This defines the sensitivity of the plant design to the threats of climate change. Functional links are then established between the vulnerable processes and assets, and the direct threats are identified during the threat analysis phase. This impact analysis overlays each climate change threat projected by the modeling on the vulnerability of specific plant components, using identified functional links. Based on these relationships, an assessment is then made of the magnitude of the climate change impact over the design life, quantifying the scale of the risk posed by climate change to the project design and the level of climate change response needed (ADB, 2012a).

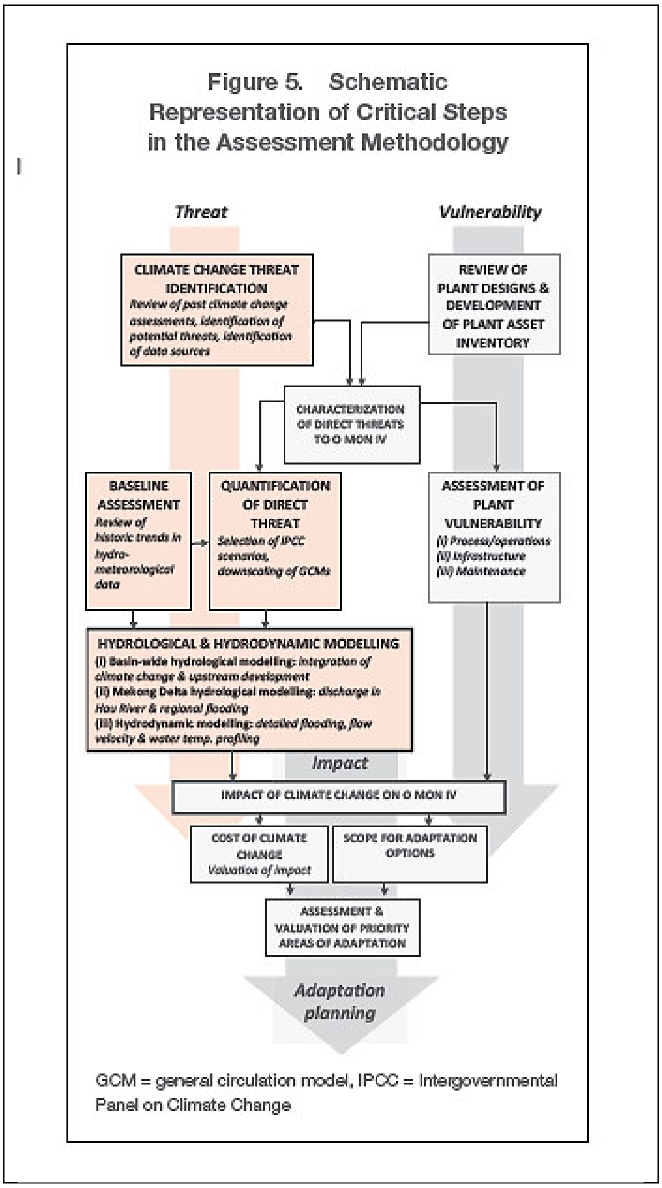
Once the magnitude of the impact and the need for adaptation are understood, a rapid assessment is made of the **adaptive capacity** of the plant's design, and priority areas of response are identified along with a number of corresponding potential adaptation options. These adaptation options are intended to establish the framework for comprehensive adaptation planning (ADB, 2012a).

Based on the early sectoral case studies as noted above, ADB has followed-on to develop a series of generic sectoral guidelines for climate risk and adaptation and climate-proofing investments. The relevant guidelines for the Power Sector are respectively (ADB, 2012b) and (ADB, 2013b). Building on the methodology details outlined in such studies, the power sector climate-proofing guideline as outlined in Table 4 notes six activities steps which are needed in climate risk and vulnerability assessment and adaptation in relation to the project cycle. These steps are: the risk screening and scoping in the project identification stage; the impact, vulnerability and adaptation assessment in the project feasibility stage; and implementation arrangements, monitoring and evaluation in the project implementation stage.

The power sector climate-proofing guideline has further outlined in Table 5 the 20 detailed steps which are needed to implement the six activities in relation to the project cycle. This guideline adds detail on the project screening and scoping steps not outlined in previous documents. The screening and scoping analysis uses a project risk screening tool (presented in Appendix 1 of (ADB, 2013b). The tool screens for risks from both climate change and natural hazards, and is of interest at the stage of identifying and assessing project feasibility. The impact, vulnerability and adaptation assessments in Table 5 add a further step-wise definition to the assessment methodology outlined in Figures 7 and 8.

The power sector climate risk and adaptation guideline offers further insight into general and specific risks of power sector developments, which also appear to apply suitably to the LKHEP study. The power sector is noted to be vulnerable to projected changes in many dimensions of the climate, including likely increases in the frequency and intensity of extreme weather events, higher air and water temperatures, changes in rainfall and river discharge patterns, and sea level rise (ADB, 2012b). With specific regard to hydropower developments, ADB has provided generic analysis of likely climate change impacts, as outlined in Figure 9.

Figure 8. Schematic outline of critical steps in the assessment methodology.



Source: Figure 5 - (ADB, 2012a)

Table 4. Assessing Adaptation Needs and Options: 6 Sets of Activities.

Project Cycle	Set of Activities
Project identification	1. **Project risk screening and scoping**: How is the proposed project (project characteristics) vulnerable to the impacts of climate change over its life span? What are the climate parameters of most interest to the project? Is sufficient information available to undertake an assessment? Who are the main stakeholders?
Feasibility study, PPTA implementation	**2. Impact assessment**: What are the current and historical trends in climate? How is climate projected to change in the future and in what ways? How will this affect natural and human systems of interest? What are the root causes for predicted impacts? What reasonable assumptions (quantitative and qualitative) can be made about climate change and its impacts?
	3. Vulnerability assessment: How have people historically coped with heavy rainfall, floods, landslides, drought, storm surges, and other weather events? Where are the most vulnerable areas? Who are the most vulnerable populations? What climatic conditions are limiting?
	4. Adaptation assessment: What adaptation solutions are technically feasible to address projected climate vulnerabilities? What are the costs and benefits of these options? What is (are) the preferred option(s) in the context of the project?
Project implementation	**5. Implementation arrangements**: Who has the capacity to implement the selected adaptation option(s)? Are there additional key stakeholders that need to be brought into the project? Is there a need for additional capacity building?
Monitoring and evaluation	**6. Monitoring and evaluation**: How can progress toward vulnerability reduction be measured? How can monitoring be used for learning? How will lessons be collected, assimilated, and used to improve future agriculture investment projects?

Source: (ADB, 2013b)

Table 5. Assessing Adaptation Needs and Options: 6 Sets of Activities and 20 Steps.

Set of Activities	Steps
1. Project screening and scoping	Step 1: Screen the project for exposure to climate change Step 2: Establish the adaptation objective Step 3: Survey existing information and knowledge Step 4: Identify and engage stakeholders Step 5: Identify methodology and data needs Step 6: Identify the required expertise
2. Impact assessment	Step 7: Construct climate change scenarios Step 8: Estimate future biophysical impacts Step 9: Assign probabilities to identified impacts
3. Vulnerability assessment	Step 10: Identify vulnerabilities Step 11: Identify biophysical drivers of vulnerabilities Step 12: Identify socioeconomic drivers of vulnerabilities
4. Adaptation assessment	Step 13: Identify all potential adaptation options Step 14: Conduct consultations Step 15: Conduct economic analysis Step 16: Prioritize and select adaptation option(s)
5. Implementation arrangements	Step 17: Establish arrangements for implementation Step 18: Identify needs for technical support and capacity building

6. Monitoring and evaluation	Step 19: Design monitoring & evaluation plan, including suitable performance indicators Step 20: Feedback into policy-making and knowledge management processes

Source: (ADB, 2013b)

With regard to adaptation options, ADB has further noted that hydropower plants are normally robust; as such, an increase in the strength or frequency of storms or cyclones only marginally increases the risk of destruction. Nonetheless there are various measures to better adapt hydropower systems to climate change (ADB, 2012b):

- increase dam height and/or build small dams upstream (where flow is expected to increase);
- design more robust dams and infrastructure for heavier flooding and extreme events;
- construct or augment water storage reservoirs;
- modify spillway capacities and install controllable spillway gates to flush silted reservoirs;
- modify the number and type of turbines that are better suited for expected water flow rates and more resilient to performance reductions and turbine lifetime due to higher suspended sediment loads;
- modify canals or tunnels to better handle changes in water flows;
- allow for increased flows from glacier melting if they are likely to persist over the technical lifetime of the system's increased capacity;
- develop improved hydrological forecasting techniques and adaptive management operating rules;
- develop basin-wide management strategies that take into account the full range of downstream environmental and human water uses; and,
- restore and better manage upstream land, including afforestation to reduce floods, erosion, silting, and mudslides.

The climate-proofing guideline adds further guidance (Table 6) on potential adaptation options which are of relevance for the hydropower development sector.

A recent guideline (ADB, 2016e) has added guidance for a system to track and report the climate financing which is invested in the climate change risk, vulnerability and adaptation activities outlined above, and in the follow-up implementation of climate-proofing adaptation plans. The approach follows a methodology of tracking and reporting climate finance that the multilateral development banks (MDBs) have jointly developed ("the joint MDB approach").[2] ADB and other MDBs having used this approach since 2012 for jointly reporting their annual climate finance.[3]

[2] The group of MDBs involved in the climate finance tracking initiative consists of the African Development Bank, the Asian Development Bank, the European Bank for Reconstruction and Development, the European Investment Bank, the Inter-American Development Bank Group (Inter-American Development Bank and the Inter-American Investment Group), and the World Bank Group (International Finance Corporation, Multilateral Investment Guarantee Agency and the World Bank (International Bank for Reconstruction and Development and the International Development Association)).

[3] http://www.adb.org/documents/joint-report-mdbs-climate-finance-2015.

Figure 9. Key climate change impacts and adaptation – Hydropower.

Table 5 Key Climate Change Impacts and Adaptation—Hydropower

Climate Variable	Physical Components	Key Impacts	Adaptation Options
• Precipitation • Temperature • Extreme events	• Dam and other structures (intake, penstock) • Power station (turbines and generators)	• Indicated below for specific climate changes	• Develop improved hydrological forecasting techniques and adaptive management operating rules • Develop basin-wide management strategies that take into account the full range of downstream environmental and human water uses • Restore and better manage upstream land including afforestation to reduce floods, erosion, silting, and mudslides • Analysis to estimate likely range of projected climate variations over hydro lifetime • Identify cost-effective designs (new plants) and modifications (existing plants) to deal with specific risks identified for the site
• Precipitation (including drought)	• Dam and other structures • Power station	• Changing annual or seasonal patterns can affect river flows and water levels behind dams, either reducing or increasing power output • Siltation can reduce reservoir storage capacity • Increased uncertainty in water flows can affect power output and generation costs	• Increase dam height and/or build small dams upstream (if flow is expected to increase) • Construct or augment water storage reservoirs • Modify spillway capacities and install controllable spillway gates to flush silted reservoirs • Modify number and type of turbines more suited to expected water flow rates • Modify canals or tunnels to handle expected changes in water flows • Optimize reservoir management and improve energy output by adapting to changes in rainfall or river flow patterns
• Extreme events (glacier melting, floods)	• Dam and other structures • Power station	• Floods and glacial lake outburst floods can damage or destroy infrastructure	• Design more robust dams and infrastructure for heavier flooding and extreme events • Design for increased flows from glacier melting
• Higher air temperature, wind speeds, and humidity	• Dam and other structures	• Can increase surface evaporation, reducing water storage and power output.	• Construct or augment water storage reservoirs

Source: Table 5 - (ADB, 2012b).

Table 6. Potential Adaptation Options for Climate Change in the Energy Sector.

Climate Change	Potential Adaptation Options
Hydropower	
Precipitation (including drought)	• Develop improved hydrological forecasting techniques and adaptive management operating rules. • Develop basin-wide management strategies that take into account the full range of downstream environmental and human water uses. • Restore and better manage upstream land including afforestation to reduce floods, erosion, silting, and mudslides. • Analysis to estimate likely range of projected climate variations over infrastructure lifetime. • Identify cost-effective designs (new plants) and modifications (existing plants) to deal with specific risks identified for the site.
	• Increase dam height and/or build small dams upstream (if flow is expected to increase). • Construct or augment water storage reservoirs. • Modify spillway capacities and install controllable spillway gates to flush silted reservoirs. • Modify number and type of turbines more suited to expected water flow rates. • Modify canals or tunnels to handle expected changes in water flows. • Optimize reservoir management and improve energy output by adapting to changes in rainfall or river flow patterns.
Extreme events (glacier melting, floods)	• Design more robust dams and infrastructure for heavier flooding and extreme events. • Design for increased flows from glacier melting.
Higher air temperature, wind speeds, and humidity	• Construct or augment water storage reservoirs.

Source: Table 6 - (ADB, 2013b).

2.2 Project Risk Screening and Scoping

Following the ADB project climate risk screening and scoping template (ADB, 2012a), the first step (Activity 1), involving project climate risk screening and scoping (Tables 4 and 5) had been conducted for LKHEP and reported (Ji, 2015) in December, 2015. This initial LKHEP climate risk screening report used an ensemble of Global Climate Models (GCMs) to assess the 2050 climate projections for the Project area. In summary, the GCM modeling up to 2050 (under the rcp8.5 scenario) has predicted:

- **temperature trend -** a mean annual temperature increase of 2.48 ^{0}C from the average annual baseline of 21.1^{0}C, with the highest temperature rise projected to occur in December (>2.75^{0}C) and the lowest in July (<2.19^{0}C);
- **rainfall trend -** total annual rainfall increase of 206 mm (7.6 % increase), which would predominantly be comprised of a monsoon season (May – Oct) rainfall increase of 190 mm (8.8% increase), offset by a slight dry season (Jan – Apr) rainfall decrease.

Based on the above climate risk projection, a climate risk and natural hazard screening was conducted with output as summarized in Table 7. Disregarding the risks that are not related to climate (i.e., earthquake-related risks) and risks which do not apply to the LKHEP site (cyclone surge, tsunami and

GLOF), the remaining risks shaded yellow are climate-related and may have an effect on the LKHEP site. These risks thus fall within the scope of the current CRVA. These risks are all connected by one inter-linked chain of climate change driven processes, i.e. temperature rise, rainfall changes (increased rainfall, increased storms and cyclones, change in rainfall temporal distribution), hydrological change and impacts of subsequent hydrological changes.

The evaluation of LKHEP flood risk notes that the state of Assam regularly experiences very high rainfall in the summer season, 'including extreme events like cloud bursts often leading to catastrophic hydro-meteorological hazards, mainly floods and flash floods, …..with the basin experiencing the highest number of floods in India during the monsoon rains and suffers flood damages on an annual basis'. This evaluation of the flood situation, however, appear to refer to the Brahmaputra basin and floodplain, and would not apply to the upper Kopili river basin, where APGCL staff have alternatively noted that the Kopili basin never experiences flash floods (*pers.comm*. APGCL staff, November, 2016). With regard to the climate change impact on floods, however, (Ji, 2015) rightfully noted that one of the most pronounced effects of climate change is the increase in heavy rainfall with higher intensity. Under the conditions of rising temperatures, precipitation is more likely to arrive in the form of heavy rains accompanied by an increase in flood risk (Allen and Ingram, 2002; Goswami *et al*., 2006; Min *et al*., 2011; Trenberth, 1998; Trenberth *et al*., 2003). Regional empirical research has in fact shown that the trend of heavy precipitation (>100 mm) events in the last 50 years in India is increasing, compared to precipitation events less than 100 mm (Goswami *et al*., 2006).

In the evaluation of LKHEP drought risk, (Ji, 2015) alternatively notes that droughts may present the most obvious threat to hydroelectric generation, as they reduce the amount of water available to produce electricity. With regard to LKHEP climate change impact, (Ji, 2015) noted that 'increased precipitation intensity and variability are projected to increase the risk of drought in many areas (IPCC, 2007). Soil moisture loss through evapotranspiration is also projected to increase as a result of the projected increase in annual mean temperature (2.5^{0} Celsius by the 2050s), which may also reduce catchment wetness and river flows.

Table 7. ADB LKHEP Climate Risk Screening Report – Risk Assessment Output.

Type of Risk	**Overall Risk / Hazard**	**Climate Impact**	**Climate Variables / Confidence**
Earthquake	High	N / A	
Landslide triggered by earthquake	Medium	N / A	
Landslide triggered by precipitation	Medium	High	Increased monsoon intensity – medium
Forest fire	Low	Medium	Rising temperatures – low
Flood	High	High	Increased monsoon intensity – medium
Drought	Medium	Low	Rising temperatures – high Precipitation – low to medium
Cyclone wind	Medium	High	Increased cyclone intensity - low[4]
Cyclone surge	None	High	Increased cyclone intensity – low
Tsunami	None	N / A	
River Bank Erosion	High	Low	Rising temperatures
Glacial Lake Outburst Flood (GLOF)	None	High	Rising Temperatures - Accelerated Melting of Glaciers

[4] The confidence level is low due to the fact that there exists a large degree of uncertainty regarding the future scenarios of cyclone activities within the North Indian Ocean.

Lightning	High	Medium	Temperature rise – low

Source – adapted from natural hazard assessment of (Ji, 2015)

In the evaluation of cyclone risk, (Ji, 2015) assesses the project area as prone to cyclone wind hazards from the Bay of Bengal. He reports that according to BMTPC cyclone zonation, the north-west districts of Assam (including Karbi Anglong and Dima Hasao in the Kopili river basin) are in a zone of high damage risk, where wind speed can reach up to 47m/s. The districts very close to Bangladesh (i.e. Karimganj, Hailakandi and Cachar), which lie to the south of the Kopili river basin, are in a very high damage zone due to close proximity to the Bay of Bengal, where wind speed can reach up to 55 m/s and result in large-scale damage (ASDMA, 2016). On the analysis of a climate change impact on cyclone frequency, (Ji, 2015) has recorded that a predicable trend does not exist. It is noted that 'most studies (Webster *et al*., 2005; Niyas *et al*., 2009; Habib, 2011; Hussain *et al*., 2011) for the North Indian Ocean agree that the frequency of tropical cyclones is declining, while the intensity of cyclones has been observed to have increased. It is extremely difficult to confirm whether the impact of climate change has exceeded the natural variability and has manifested a detectable signal. In terms of historical tropical cyclone activity, a 2010 WMO assessment of tropical cyclones and climate change concluded that "it remains uncertain whether past changes in tropical cyclone activity have exceeded the variability expected from natural causes." This conclusion applies to all basins around the globe[5]. (Ji, 2015) further notes that according to (IPCC, 2007), "there is less certainty about the changes in frequency and intensity of tropical cyclones on a regional basis than for temperature and precipitation changes… however, extreme rainfall and winds associated with tropical cyclones are likely to increase in South Asia". Simulations (Unnikrishnan *et al.*, 2011) of tropical cyclones in the Bay of Bengal from the regional climate model (PRECIS) show an increase in the frequency of cyclones in the Bay of Bengal under the A2 scenario compared to the baseline (1961-1990). The risks of higher wind velocities could be expected to increase in the future.

In a final summary of the likely impacts on the project of the evaluated hydro-climatic changes, (Ji, 2015) concluded that the LKHEP hydropower generation-specific climate risks would be: changes in the pattern of electricity generation[6]; sediment impacts on storage capacity and equipment[7]; and, equipment corrosion due to increased acid mining drainage mobilization[8]. Under the GHG emission and indirect impacts, (Ji, 2015) further assessed that the LKHEP will have a high positive impact on GHG emissions (a reduction), however, on the negative side, there will be indirect risk of dam-induced downstream flood[9]. In the final overall summary of the LKHEP screening results, (Ji, 2015) concluded that the project was at high risk in regard to a multi-hazard index[10] and climate impact, with the listing of earthquake, landslide, sedimentation, cyclone winds, lightning and flash flood as the main natural hazard and climate threats to LKHEP. To address these risks, (Ji, 2015) proposed various actions (see Table 8), which may be classed as tentative adaptation measures.

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[5] http://www.gfdl.noaa.gov/global-warming-and-hurricanes

[6] Due to variability in river flow and increased rainfall variability.

[7] Due to increased precipitation intensity, increased sediment loads, accelerated wearing of turbines, reduced storage capacity, shortening of operating life of hydropower plant.

[8] Due to increased precipitation and more effluents to the storage reservoir.

[9] Negative impact of downstream floods has already been reported due to the NEEPCO operation of the upstream dams. The Upper Kopili dams have reportedly changed the character of flood in the river downstream, for the worse. Before the construction of the Kopili dam, floods occurred mainly during the monsoon season. Increase in water volume due to heavy rains used to be the reason for flooding. There used to be normal floods which occurred not more than two or three times a year; however, after the construction of the upper dams, the number of artificial floods occurring in a year had gone up to 5-6 times. These floods mainly occurred from the month of August to the first two weeks of November. This impact has in past submerged 65 ha of cultivation land, and such a downstream impact assessment is a problem in Assam, as the state has witnessed huge protests against dams due to lack of proper downstream impact assessment and a neglect to use safe dam operation procedures.

[10] i.e., including non-climate related seismic risk assessment.

Table 8. LKHEP Climate Risk Screening Report – Required Action.

Natural / Climate Risk	Adaptation
Earthquake	In order to prevent the uncontrolled rapid release of water from the reservoir of a storage dam during a strong earthquake, the dam must be able to withstand the strong ground shaking from even an extreme earthquake, which is referred to as the Safety Evaluation Earthquake (SEE) or the Maximum Credible Earthquake (MCE). Large storage dams are generally considered safe if they can survive an event with a return period of 10,000 years, i.e. having a one percent chance of being exceeded in 100 years.
Landslide	The project site is prone to a medium risk of landslides. Slope stabilization should be implemented to protect all physical structures (such as powerhouses, dams, access road, pylons, etc.). Regular monitoring of the watershed is also recommended.
Sedimentation	A detailed study on the sediment generation and load within each sub-basin needs to be conducted. Acid coal mine discharge is a detrimental problem within the watershed. Sustainable watershed management including the restoration of ecosystems within the watershed needs to be practiced. The Himalayan rivers often transport sand with a high Quartz content, so particular attention must be given in the design of the structural arrangements, which will reduce the risks as much as possible of entrainment of such material into the turbine flow. This aspect is of prime importance if the project designers intend to use desanding structures for this purpose (incorporate in the dam design possibilities of future structural modifications to alleviate the sedimentation problems). For run-of-river plants, efficient sediment flushing arrangements are also necessary.
Cyclone Winds	The overhead transmission lines must be able to withstand strong winds. A minimum overhead clearance of transmission lines must be maintained for safety. Material to reduce thermal sag (e.g., aluminum conductor composite core – ACCC) may need to be specified at the project design stage.
Lightning	Lightning protection must be installed for the power supply component of the project. Lightning surges may cause serious damages to the expensive equipment in the power system. Lightning protection must be implemented.
Flashflood	Flood risks must be taken into account during project design. Spillways and flood outlets should be designed to safely convey major floods to the watercourse downstream from the dam. They are selected for a specific dam and reservoir on the basis of release requirements, topography, geology, dam safety, and project economics. The design spillway capacity of the proposed Lower Kopili project with catchment of 2,106 km^2 is 16,110 cubic meters. Compare this with the spillway capacity of the upstream Khandong dam on the same Kopili river with catchment area of 1,256 km^2 being 15,471.3 cubic meters. It is clear that the design spillway capacity of the proposed Lower Kopili Project is inadequate. Considering future risks of flash floods on dam safety, it is recommended that an allowance be added to the volume to cope with the projected increase in peak flow. This allowance should be estimated using projected climate change scenarios.

As outlined in a separate ADB Climate Change: Project Adaptation Action Report (ADB, 2016a), the LKHEP is classed to have a Medium Climate Change Classification (ADB PCS: Mitigation or Adaptation Classification). A summary of this climate risk screening has projected differing changes under an A2 scenario (by 2050) of a ~ 2.2^{0}C (annual mean) temperature rise and ~ 120 mm (annual) or 5% precipitation rise (mm). The reason why this report is projecting differing climate change trends than that of (Ji, 2015) is uncertain. In the absence of more detail on the assessment methodology of the ADB Climate Change: Project Adaptation Action Report (ADB, 2016a), the current CRVA assessment will adopt the climate screening findings of (Ji, 2015), assumed to be more reliable.

2.3 Climate Impact Assessment

In follow-up to the initial climate risk screening and scoping of (Ji, 2015), the second climate impact assessment activity (noted in Tables 4 and 5) was conducted for LKHEP in October, 2016, in the form of an 'assessment of the effect of climate change on the hydrology and sediment loadings' (ADB, 2016d). The major objective of the study was to assess the impact of climate change on the hydrological regime of the Kopili River, as well as the sediment erosion and its loading into the LKHEP reservoir, using different climate change scenarios.

As with the LKHEP climate risk screening and scoping study (Ji, 2015), the impact assessment study again used an ensemble of Global Climate Models (GCMs) to assess the 2040 – 2070 climate projections (i.e. mid-century time horizon) for the project area. The study notes that in order to assess the impact of climate change on the water resources regime, the climate change projections are generated using general circulation models (GCMs). However, since these GCMs are simulated on a very coarse resolution, these data cannot be used directly either at the precipitation gauge station or at the watershed level. Therefore, the climate data projections from GCMs are downscaled, using either statistical downscaling methods or dynamic downscaling using Regional Climate Models (RCMs)[11]. Six different Regional Climate Models (RCMs) - HadGEM3-RA, RegCM-V4, SNU-MMS, SNU-WRF-V3, YSU-RSM-V3, and SMHI-RCA-V4, were used to provide climate input into two GCM's - HadGM2-AO and SMHI as model ensembles. The multi-model approach helps in assessing the uncertainty in the climate change projections resulting from their inherent assumptions. For each of the models, three scenarios (historical[12], rcp 4.5 and rcp 8.5 scenarios[13]) were used to assess the impacts.

Precipitation models and performance: With the mid-century (2040 – 2070) temperature change projections provided by the scenarios (rcp4.5 = a 1.4°C increase; rcp8.5 = a 2.0°C increase), the study focused on a review of the modeled rainfall outputs. It was noted that the data output from the different regional model ensembles varied significantly, with average annual precipitation for LKHEP varying between 2,594 mm and 2,780 mm for the historical period. Average monthly precipitation was then output from the different models for historical and future (rcp4.5 and rcp8.5 scenarios) periods, and it was noted that the projected data from most of the models for the historical period were very consistent[14]. It was concluded the climate models were performing consistently, regardless of the differences in their formulations. The average monthly precipitation for the rcp 4.5 and rcp 8.5 scenarios for the months Jan – Mar and Nov-Dec is significantly less than the precipitation during the months of April – October.

Modeled precipitation projections: The modeled findings on average accumulated precipitation during the non-monsoon months (all precipitation, added from November to March inclusive) were found to vary between 156 mm and 249 mm (i.e., the total rain that fell during the lean season). During the monsoon period (all precipitation added from April to October inclusive) the total precipitation (modeled results) varied between 1,652 mm and 4,326 mm. Most models yielded average annual precipitation within the range of 2,400 mm – 3,600 mm. In terms of projected change in precipitation, the study concluded that the annual average precipitation was in general projected to increase by ~ 10% (i.e. under rcp4.5 and rcp8.5 future scenarios versus historical). Of these increases, the monsoon precipitation was found to be significantly increasing[15]. The monthly average precipitation during the

[11] (ADB, 2016d) notes that the study made use of the data from climate change projections generated under an international effort referred to as Coordinated Regional climate Downscaling EXperiment (CORDEX). Under the CORDEX program, the Kopili River watershed falls under the East Asia (EAS) and West Asia (WAS) regions.

[12] Obtained from model, not the observed climate data.

[13] Representative greenhouse gas concentration trajectories adopted by the IPCC for its fifth assessment report (AR5) in 2014. RCP4.5 projects a 1.4°C and 1.8°C global warming temperature increase for 2046 – 2065 (mid Century) and 2081 – 2100 (end Century). RCP8.5 projects a 2.0°C and 3.7°C global warming temperature increase for 2046 – 2065 (mid Century) and 2081 – 2100 (end Century).

[14] Except for the June output for one model – SNU-MM5.

[15] (ADB, 2016d) outputs for monthly rainfall simulations found the June – July rainfall for historical periods fell at 500 mm / month for 4 of 5 model outputs. The RCP4.5 output varied much more widely for June and July, with rainfall between 400 – 800 mm / month for 4 of 5 models (i.e., did not show significant or consistent increase versus historical). The RCP8.5 output also varied widely for June and July, with rainfall between 600 – 800 mm / month for 4 of 5 models (i.e., did suggest a significant increase versus historical).

non-monsoon period, however, was found to have mixed response; i.e., some models have predicted future precipitation to be higher and other models have predicted the reverse.

Modeled temperature projections: All the models predict that the temperatures in the region will increase, and in general the average annual temperature is predicted to increase by about 2°C by 2070. Only the HADGEM3-RA model suggested that temperatures will be reducing during the monsoon months for the rcp4.5 emission scenario. The HADGEM3-RA model corresponding to the rcp4.5 emission scenario indicates temperatures in the region increasing in the range of 3.5 to 5.5°C during the non-monsoon season (by 2070).

River flow, evapotranspiration and sediment models: To assess the hydrological conditions in the watershed, and to assess the climate change impacts on the hydrological regime and hydropower potential, the study developed a watershed simulation model to assess the hydrological and sediment regime under current and future conditions, as projected by climate change models. A semi-distributed watershed model, the Soil and Water Assessment Tool[16] (SWAT) (Arnold *et al.*, 1998) was implemented. The model was set up with three main layers of GIS data, namely DEM, land use, and the soil map, which were obtained from the SWAT India database (Narasimhan, 2012)[17]. These data were later corrected for catchment land cover using Google Earth observations[18]. The model required input also of climate data (precipitation, temperature, wind, humidity, etc.)[19]. Once set up, the model was calibrated against the observed river discharge data in the lower Kopili river[20]. The study then took the monthly average rainfall outputs from the six RCM – GCM model ensembles discussed above, corrected the bias in rainfall output versus observed rainfall data, and input these data into the SWAT runoff model to obtain historical and future (rcp4.5 and rcp8.5 scenarios) projections of river flow, evapotranspiration, and sediment yield.

Modeled river flow projections: From the SWAT modeling outputs, the study found that the average annual flows estimated using the projected climate conditions for both rcp 4.5 and rcp 8.5 scenarios, when compared to the historical period, were found to show a flow increase for all the models, with the exception of the SMHI-RCA4-V4 model projections, which suggested that average annual flows would reduce by about 50% (with a reduction mostly in the monsoon period flows)[21]. This is consistent with

[16] A model which requires geographical data of the watershed on landscape themes, i.e.: digital elevation model (DEM), soils, land use and other spatial features in the form of Geographical Information System (GIS) layers. Also requires climate data, i.e.: precipitation, temperature, wind, humidity, etc.

[17] Reference not provided, nor could be found in Google scholar search.

[18] The coarse resolution dataset of the Narasimhan study showed the LKHEP catchment to be all forest. But it is known that the shifting agriculture (locally called "Jhum cultivation") is a predominantly practiced approach in this region. After verifying sources, such as Google Earth maps, a new land use file was created by verifying the actual aerial picture for the entire watershed.

[19] Observed rainfall data from four catchment rain gauges were processed and assessed (i.e. Garampani, Jowai, Kheronighat and Harangajao) with data coverage from 1977 to 2006. These data were found to exhibit unusual variations between stations and there were many data gaps, so they were not used for the modelling. To improve the dataset, the (ADB, 2016d) study used the half degree gridded precipitation data developed by the India Meteorology Dept. (IMD), obtained from http://swat.tamu.edu/conferences/2012/; developed from rainfall stations with daily precipitation data from Jan 1, 1971 until Dec 31, 2005. With regard to the needed temperature, wind velocity, humidity, and solar radiation data input, (ADB, 2016d) reports that no data were found for the LKHEP catchment area. Thus, the data were generated using the weather generator embedded in the SWAT software.

[20] (ADB, 2016d) notes that the model was calibrated and validated using a monthly time-step, using the observed streamflow data. The Nash-Sutcliffe Efficiency for the calibration and validation for the SWAT model simulations for the monthly simulations were 0.75 and 0.65, respectively.

[21] This differing SMHI-RCA4-V4 model prediction was consistent with the model's prediction of a 50% reduction in the annual precipitation for rcp 8.5 scenario compared to historical period, with similar precipitation reductions observed for rcp 4.5 scenarios as well. The precipitation from the SMHI model differed from all others showing

the 50% reduction in the annual precipitation for the rcp 8.5 scenario, compared to historical period projection by the SMHI-RCA4-V4 model. Similar reductions are observed for rcp 4.5 scenarios as well. With a focus on the monthly river flow predictions, (ADB, 2016d) found that versus the historical conditions, the precipitation and the corresponding streamflow patterns, the monsoon flows are not of concern, whereas the non-monsoon flows could be of concern, as the non-monsoon modeled flow variations were mixed; i.e., with some models showing future flow increases and others showing flow decreases. (ADB, 2016d) concluded that there would be a significant increase in the monsoon (Mar- Oct) monthly rainfalls and river discharge, however mixed response in regard to non-monsoon monthly rainfall and flows, with a predominant prediction of a decreased precipitation and river discharge in the non-monsoon season.

Modeled evapotranspiration projections: The study found the annual average ETs for the historical period for all the climate models were estimated to be within the range of 583 – 672 mm. The same for the rcp4.5 and rcp8.5 scenarios were estimated to vary between 519 – 723 mm and 623 – 697 mm, respectively. These annual estimates of ET are typically about 20-25% of the average annual precipitation. The SNU-The ET was found to increase for historical and future periods for both rcp4.5 and rcp8.5 scenarios. The majority of models predicted that the ET would be increasing by 15 – 50 mm for the rcp4.5 scenario, and 25 – 54 mm for rcp8.5 scenario[22]. These increases in ET corresponded to a 10-15% increase, versus the historical period climate.

Modeled sediment yield projections: From the output of the SWAT model (ADB, 2016d) concluded lastly that there would be no predicted change in sediment loading in the LKDEP project due to the buffering effect of the upstream dams.

2.4 Other Studies

2.4.1 Assam State Disaster Management Plan (ASDMP)

The 2016 Assam State Disaster Management Plan (ASDMA, 2016) provides an alternative risk assessment to that presented by the ADB documents noted above. Listed according to the main risks that were considered, the following conclusions were made:

- **Earthquake** – A review of the ASDMP assessment of earthquake risk is already presented in (Ji, 2015). ASDMP confirms that 'according to the Global Seismic Hazard Assessment Programme (GSHAP) data, the state of Assam lies in a region with high to very high seismic hazard'. Plus, 'as per the 2002 Bureau of Indian Standards (BIS) map, this state also falls in the highest risk Zone-V'. The ASDMP earthquake peak ground acceleration mapping placed the LKHEP Karbi Anglong, Dima Hasao and adjacent Meghalaya districts in the moderately high PGA 2 -3 m/sec class.
- **Flood Hazard** - The 1998 – 2007 flood hazard map of Assam state shows the Kopili basin area downstream of LKHEP in the Hojai and Lanka township areas to have a low to very low flood hazard, with the two Districts of Karbi Anglong and Dima Hasao also having the lowest population densities in the state, at around 180 persons / km^2.
- **Landslide Hazard** – The ASDMP landslide incidence mapping only designates areas in the 35% - 40% slope range to have a moderate landslide risk. As shown in Figure 10 and on the ASDMP landslide risk map, these areas are very sparse in the upper Kopili basin in Dima Hasao district on the Meghalaya border (only on the steep slopes of some mid- to upper catchment incised river valleys).
- **Erosion Risk** – The ASDMP mentions only generally that an Assam land-use board study (2003) had found that high rainfall (more specifically high intensity rainfall) has been found to be another

that the non-monsoon period precipitation would increase, whereas the monsoon period precipitation would decrease.

[22] The SNU-MM5 model differed, with projections for rcp4.5 scenario indicating that the annual average ET would reduce by 115 mm, and for the rcp8.5, there would be a reduction of 22 mm.

important factor causing erosion in almost all the districts with higher gradients/slopes. Loss of topsoil through surface run-off under heavy precipitation and humid climatic conditions is the most common type of soil erosion (known as gully erosion) in the entire state. The ASDMP makes no mention of the upper Kopili basin or Dima Hasao district presenting any notable erosion risk (the focus is more upon river bank erosion along the Brahmaputra river).

- **Wind and Cyclone** - A review of the ASDMP assessment of cyclone and wind risk was presented in (Ji, 2015). Parts of Assam are exposed to cyclones that sweep through the Bay of Bengal, generally between April and December, with the main peak season for cyclones generally being May and November. The ASDMP indicates that each year about 60% of the State may experience cyclone force winds, with speeds up to 50-55 m/s. The LKHEP project area is just slightly west of the main cyclone tracking area for recent cyclones that have moved up from Bangladesh. For example, in December 2010, the project area was affected by severe winds associated with a cyclone.
- **Fire** – The ASDMP mapping of fire risk in the Dima Hasao upper Kopili Basin indicates a low fire risk.
- **Climate Variability and Climate Change** – ASDMP notes that the north-eastern region of India is expected to be highly prone to the consequences to climate change. The annual mean maximum temperatures in the region are rising at the rate of +0.11°C per decade. The annual mean temperatures are also increasing at a rate of 0.04°C per decade in the region. The State of Assam is very much a part of the regional warming trend. However, there is no significant trend in rainfall for the region as a whole; i.e., rainfall is neither increasing nor decreasing appreciably for the region as a whole. However, for a part of the region comprising Nagaland, Manipur, Mizoram, Tripura and parts of the Barail Hills, making one of the 36 meteorological sub divisions of the country, a significant change in seasonal rainfall has been observed. The summer monsoon rainfall is found to be decreasing over this region significantly during the last century at an approximate rate of 11 mm per decade. This would appear to suggest that the upper Kopili basin, for the most part, is experiencing little change in rainfall levels, whereas the upper catchment to the south east (Barail Hills) may be experiencing a monsoon rainfall decrease.
- **Climate Modeling Study -** ASDMP further noted a recent study which has evaluated the possible impacts of climate change on water resources of the river basins in India (Gosain *et al.*, 2011). The report mentions that the majority of the Indian river systems show an increase in precipitation at the basin level, with only the Brahmaputra, Cauvery and Pennar river basins showing a marginal decrease in precipitation under the Mid Century (MC) scenario, and an associated decrease in water yield. Similarly, the majority of the river systems in India show an overall increase in sediment load at the basin level, yet the Ganga, Brahmaputra, Krishna, Pennar and Cauvery having sub-basins which show a reduction in sediment load under the MC scenario. Under the End Century (EC) scenario, the Ganga system shows a significant increase in sediment load in a majority of its sub-basins, whereas some areas of the Krishna, Pennar and Brahmaputra basins show a reduction in sediment load, again under the EC scenario. There are also a few sub-basins of the Ganga, Brahmaputra, Krishna, Cauvery and Pennar that show some decrease in the peak flow magnitudes. Under this assessment, the LKHEP Kopili basin, in falling within the Brahmaputra basin, may also be experiencing decreased rainfall, water yield, sediment load, and peak flow (flood) magnitudes.
- **District Level – Vulnerability Assessments** -
  - **Karbi Anglong**: The Karbi Anglong District is situated in the central part of Assam. This district has dense tropical forest-covered hills and flat plains. Karbi Anglong is a predominantly tribal district, and the local population's dependency on natural resources is very high. Except for the valleys, the people in this region practice step cultivation. This district has minimum exposure to flood hazard risk and moderate exposure to wind storms. The building vulnerability is quite high in this region. This confirms the state risk assessment of very low flood risk hazard, yet moderate wind hazard, in the LKHEP areas of Karbi Anglong.

- **North Cachar Hills (Dima Hasao):** The Dima Hasao district is primarily a hilly region with highly varying terrain. This is a least developed district in Assam. It is predominantly a forest area and agricultural practices of paddy cultivation are done in a Jhum cultivation system in dry hilly land in the plain terrain areas, depending mainly on rainfall. The average annual rainfall of the district is 3,399 mm, but due to the nature of the terrain, this district hardly experiences any problem of flooding. The urban population is highest (> 30%) in this district (after Kamrup Metro district), with the lowest population density. Only 44 people reside per sq. km. Per capita income is comparatively better in this district and much higher than the state average. In this district more than 80% buildings have a wall type of Category I. This indicates that the households are highly vulnerable to cyclonic wind storms. This confirms the state risk assessment of very low flood risk hazard and very low population density, yet ongoing vulnerability to wind storms in the LKHEP areas of Dima Hasao.

2.4.2 Assam State Action Plan on Climate Change

The 2012 - 2017 Assam State Action Plan on Climate Change (ASAPCC) (Department of Environment and Forest, 2016) provides an alternative climate change and vulnerability assessment to that presented in the ADB documents above. The ASAPCC notes as follows:

- **Vulnerability Assessment -** The state suffers from a high risk of natural hazards, being highly vulnerable to floods, river bank erosion, sand casting, landslides, cyclonic storms, as listed in the ASDMP. The exposure to such hazards is also aggravated because of the location of the State in the northeastern region which is one of the most seismically active regions in the world. Assam also receives high torrential rainfall ranging from 248 cm to 635 cm which also contributes to the flooding of the Brahmaputra River. The state also suffers socio-economic vulnerabilities as discussed in Section 2.5.4.
- **Rainfall trend –** The region receives rainfall during the summer and winter months from both the south-west and north-east monsoons. The region is characterized by high rainfall, but analysis of long-term trends in the annual rainfall indicates a slight decline in the total rainfall received in the region (Das *et al*., 2009; Mirza *et al*., 1998; Tiwari, 2006; ASTEC, 2011). Pre-monsoon and post-monsoon thundershowers are very dominant over the region due to orography and the humidity available for convection. (Kandalgaonkar *et al.*, 2005), in their study to address the relationship between thunderstorm activity and rainfall over different regions of India, also showed that over the North Eastern region, the probability of an association of thunderstorms with rainfall is quite high when compared to other regions. Also, months with high rainfall have been observed to have more thunderstorms. Thunderstorms in the post-monsoon season have been observed to occur with higher intensities than during the pre-monsoon season.
- **Temperature trend** - The 20th century has observed a warming trend of 0.51°C in India, with accelerated warming observed from 1970 onwards. The Assam region has also experienced an increase in the annual mean maximum temperatures, with an increase at the rate of +0.11°C per decade, and annual mean temperatures at a rate of 0.04°C per decade.
- **Modeled Projections** – There are very few studies that have done a thorough analysis of the trends of changes in the climate for the region that can be used to draw conclusions. Projections provided by experts on changes in the climate have been done using different outputs either available at coarser resolution, or based on single model outputs for a particular scenario. These studies, while indicative in the very broadest sense of the changes that are likely in the climate, do not help in capturing the uncertainties associated with the various projections, indicating the need for further research on these aspects. The few studies that are available for the north east region conclude as follows:
  - (Kulkarni *et al.*, 2010), using the IPCC-AR4 model outputs over the Indian region, concluded that there will be a substantial increase in the amount of summer monsoon season rainfall

over the north east region until 2100. These models had a coarse resolution, and hence there was significant spatial variability over the region;

- (Rajendran and Kitoh, 2008), using a high resolution MRI general circulation model with a 20 km mesh grid, showed that the monsoon variability is well represented in the baseline, and the future changes over the region showed reduction in rainfall over the Assam region for the SRESA1B scenario, whereas the extreme events were found to increase;
- The regional climate model assessments over the Indian region using HADRM2 indicate that India's initial national communication (NATCOM, 2004), using the Regional climate projections of HadRM2, suggest that the seasonal mean rainfall (over the 2080s time period) increases over the north east region, and also there is a possibility of an increase in the number of rainy days over the region (NATCOM, 2004);
- (Kumar *et al.*, 2006), in their study using the PRECIS (Providing REgional Climate for Impact Studies) model, showed that the temperature is likely to increase by 2.5°C- 4°C in the A2 scenario over the Indian region, with pronounced warming over the northern and northeastern parts of India. The percentage increase in rainfall is also suggested to increase over the Assam region during 2080s, when compared to 2030s and 2050s.
- (INCCA, 2010) **-** High resolution regional climate model (PRECIS) simulations, using lateral boundary forcing from three QUMP (Quantifying Uncertainties in Model Projections) runs, in a recent report prepared by MoEF for the A1B scenario for 2030's, indicate an all-round warming over the Indian Subcontinent.
    - **Summary of temperature variations.** The annual temperatures are set to increase from a minimum of 26.8 ^{0}C to a maximum of 27.5 ^{0}C in the 2030's. The rise in temperature with respect to the 1970's (climatology) shows a range between 1.7 to 1.8 ^{0}C. Seasonal temperature for all the three QUMP simulations also are projected to rise from 1.5 to 2.2^{0}C, with the monsoon months of June, July, August and September showing a maximum rise amongst all the seasons.
    - **Summary of rainfall variations.** The mean annual rainfall is projected to increase in the region and was found to vary from a minimum of 940 ± 149mm to 1,330 ± 174.5 mm. The rate of increase in rainfall over Assam, while projected to increase, is projected to be slightly less when compared to the state of Arunachal Pradesh and some parts of North Assam adjoining Arunachal Pradesh. Overall, the number of rainy days is projected to decline in Assam, but intensities could increase. From the observations, it was concluded that an increase in the rainfall in the pre-monsoon and post-monsoon months might be associated with an increased number of thunderstorms in the region.
    - **Extremes**: Changes in rainfall patterns and increasing variability in the future may have some regions experiencing scarcity of rainfall and others an increase. Drought-like conditions might prevail, given the climatic variations expected. A projected increase in rainfall, rainfall intensities and accelerated summer flows may produce more frequent conditions of floods and flash floods in the Brahmaputra valley.
    - **Uncertainty**: An increased number of observations is essential for further validation of models and climate variability over the region. Changes in extreme events of rainfall and temperature might have direct or indirect impacts on different sectors in the region. There may also be changes in the hydrological response of the basins, including impacts on glaciers.

- **Assam's Emissions Profile** - According to estimates conducted in 1990, the State's total GHG emissions from anthropogenic activities amounted to 19.9 MT carbon dioxide equivalents (CO2e). This was comparatively low, compared to most of the other states and ranked 14th while accounting for just under 2% of India's total emissions. The estimates further saw a modest increase in 1995 and amounted to 20.9 MT CO2e. However, the state still ranked 14th and accounted for only 1.7% of India's total emissions. These estimates were made in the context of India's first National Communication to the UNFCCC.

- **Climate Change Impacts – Existing Policy Response and Gaps**
  - **Power Sector** - As of 2007-2008, Assam has an installed electricity capacity of just over 1,000 MW (BEE, 2009); however, CEA estimates the installed electricity capacity at 700 MW. This may be primarily due to plant retirements. The 2007-2008 total consumption was listed as 2,544 GWh with peak demand is at 848 MW with the state operating at a peak deficit of -9.7% (BEE, 2009). The current energy mix, based on CEA 2008 values of Assam installed electricity capacity, sees the primary energy supply come for gas 59%, hydropower 22.4%, steam 13.4%, diesel 4.6% and renewable sources, which include solar, wind, microhydel and biomass, totaling 0.5%. Thermal power for electricity generation from fossil fuels comes exclusively from natural gas, being 1,125 GWh (44% of total consumption), which interestingly has one of the lowest plant load factors (PLF) in India (20%) when compared to the all-India PLF of 72%. This would suggest a lower level of efficiency within existing thermal power generation capital, highlighting it as an area for significant improvement, or a re-focusing of electricity generation towards other available options.
  - **Water Resources -** Climate change will also negatively impact the water resources sector by increasing freshwater scarcity, which is already a problem for Assam in the winter. The predicted increase in average temperature and decrease in the number of rainy days due to climate change will further stress water resources. This problem is compounded by high levels of groundwater extraction, which can be expected to continue given Assam's growing population and reliance on agriculture. Assam's water resource policies are distributive rather than proactive and there is a dearth of programs promoting water harvesting and water conservation or storage.
  - **Forest Resources -** The northeast region has the highest forest cover in India, which provides a number of adaptive advantages. Forests can reduce soil erosion and runoff, regulate flooding and temperature and mitigate climate change. However, Assam has the lowest forest cover in the region at 35.5% and reports indicate that it is decreasing.[23] This has serious implications for the disaster management sector. A reduction in forest cover may also amplify the effects of mean temperature rise, impacting agriculture, water resources and the composition of the remaining forestland. Apart from the goal of afforestation, conversion of wastelands into forests and management of jhum cultivation should also be prioritized. A sustainable land use policy for the State with appropriate regulatory measures is a critical requirement for effective management of the natural resources of the State.

2.5 Available Baseline Data

2.5.1 Relevant Baseline Data and Identified Data Gaps

The mission TOR (ADB, 2016c) have stressed a need to collate, organize, and review available baseline biophysical, environmental, demographic, socioeconomic, and policy data and information relevant to climate risk management within the context of the project (see Section 1.6). Focus on this task commenced during the November, 2016 field visit to Guwahati and the LKHEP project site, with a focus on the collation and review of biophysical and environmental baseline data considered essential to assess the climate, hydrology, landscape condition, engineering design and catchment development trends and threats. The key LKHEP documents, the CEIA (WAPCOS, 2016a) and DPR (Lahmeyer India, 2015a), were first reviewed, and then also the LKHEP data archives of the APGCL. As outlined in the risk assessment methodology of Figures 7 and 8, the CRVA review aimed to assess the baseline data holdings of the project which would assist in characterizing the risk posed by climate change-induced

[23] Forest Survey of India. 2005. State of the Forest Report. Available from http://www.fsi.nic.in/sfr_2005.htm.

temperature increase, precipitation increase or variability, floods, droughts and landslides, and the likely impact of these upon project structures and project operation.

An early conclusion from the baseline data review was that, other than the hydro-climatic and catchment physical information provided in the hydrology chapters of the CEIA (WAPCOS, 2016a) and DPR (Lahmeyer India, 2015a), the focus of project documents in regard to all other supporting baseline data, and virtually all site maps, was upon the project footprint and the near-catchment surrounds only. No baseline data of any kind were found to describe the larger western area of the lower Kopili intermediate catchment within the Myntiang river basin which extends into Meghalaya state (see Section 2.5.1); plus, there was little baseline data of any kind for the large upper Kopili river catchment above the Khandong and Umrong dams (see Section 2.5.1). The most conspicuous baseline data absence in project documents (CEIA and DPR) were: i) an updated land cover mapping of the total upper Kopili basin above the LKHEP site; ii) a systematic assessment of development trends and catchment threats in the upper Kopili basin (besides the acid mine waste drainage problem); and, a review of catchment management or conservation plans for the upper Kopili basin.

The November, 2016 baseline data review of LKHEP project documentation and APGCL archives concluded on the need for a specific data collection focus from:

- **NEEPCO (North Eastern Electricity Power Company):**
  - Time series data on the monthly storage volumes (or levels versus FSL) of the Umrong and Khandong dam storages since commissioning in the 1970's (or for the last 10 -15 years at least);
  - Time series data on the pattern of dam flow releases to the lower Kopili river from the Umrong and Khandong dams over the same time period
- **Forests Department, Assam (& Meghalaya)**
  - Recent[24] map of forest and other land cover types (agriculture, plantations, grasslands, scrublands, settlements, water bodies etc.) within the upper Kopili river basin;
  - Land use and forest cover areas or % tables for the sub-catchments within the upper Kopili river basin; and
  - Any data on land degradation, soil erosion or landslide risk surveys or assessments within the upper Kopili river basins.
- **Regional Meteorology Department, Assam (& Meghalaya)**
  - Map of the locations and names of rainfall stations throughout Assam and Meghalaya states;
  - Map of the locations and names of climatology stations throughout Assam and Meghalaya states (i.e. which record temperature, relative average humidity, solar radiation, wind speed and direction, and pan evaporation);
  - Tables of the monthly and annual average rainfall levels for the mapped rainfall stations (and coordinates of locations, and periods of data collection) within the Kopili and adjacent river basins;
  - Tables of the monthly or annual average climatology data for the mapped climatology stations (and coordinates of locations, and periods of data collection) within the Kopili and adjacent river basins;
  - Any data on general Potential Evapotranspiration (PET) estimates, or actual evaporation estimates for land cover, water bodies and forests (i.e. FAO Penman Montieth calculations or equivalent) for any sites in Assam or Meghalaya states;
  - Any information on long term climate studies within Assam or Meghalaya states with a focus on empirical or modeled studies of:

[24] Within the last 5 years, preferably.

- climate change (temperature and rainfall) effects;
- influence of cyclonic events on state rainfall total and cyclone incidence;
- influence of the ENSO cycle (El Nino / La Nina) on state rainfall totals and rainfall seasonality (i.e. monsoon timing);
- influence of the IOD cycle (Indian Ocean Dipole) on state rainfall totals and rainfall seasonality (i.e. monsoon timing); or
- long term rainfall or temperature trends and decadal cycles.

A summary description of the available baseline information and data of the LKHEP site and upper and lower Kopili basins (i.e., the project area) is outlined as follows.

2.5.2 Biophysical

Geology and Landscape

With regard to the larger-scale biophysical context, (ASDMA, 2016) note that plate tectonics show Assam to be in the eastern-most projection of the Indian Plate, where the plate is thrusting underneath the Eurasian Plate, creating a subduction zone and the Himalayas (hence the high earthquake risk). In overall landscape character, Assam possesses a unique geomorphic environment, with plains, dissected hills of the South Indian Plateau system and with the Himalayas all around its north, north-east and east edges (ASDMA, 2016). The LKHEP project area and upper Kopili river basin in turn lie within the hills of Karbi Anglong and North Cachar, now eroded and dissected, which were originally parts of the South Indian Plateau system (ASDMA, 2016). Figure 10 shows an outline of the upper Kopili river basin landscape which lies within the Central Assam Hills physiographic zone (ASDMA, 2016), and ranges from < 400 m elevation at the LKHEP site downstream end to elevations > 1,400 m in the western catchment uplands in Meghalaya state, and up to > 1,600 m elevation in the North Cachar Hills in the south east. Figure 11 shows the distribution of slope classes in the landscape, with most the basin dominated by gentle to moderately undulating landscape (5 to 15% slope class), and only a few sites where river valleys have incised the plateau and in the far southeast watershed, where slope classes are steep to very steep (30% to > 50% slope).

Geologically, the landscape comprises the ancient Gniessic Complex of Meghalaya (Archaen – Proterozoic) and Shilong Group (Paleoproterozoic – Mesoproterozoic) igneous and metamorphic rock formations[25] to the west of the basin into Meghalaya state; and, the Jaintia Group[26] (Paleocene – Eocene) and Barail Group[27] (Eocene – Oligocene) sedimentary rock formations in the upper Khandong dam catchment to the southeast (Geological Survey of India, 1998). (WAPCOS, 2016a) records the LKHEP dam site and river bed to lie on metamorphic rocks, comprised mainly of leucocratic grey and pink granite gneisses belonging to the Archaean Gneissic Complex that have been traversed by younger intrusives of porphyritic and normal granites, pegmatite and quartz veins. The granite gneiss occurs mainly on or along the river bed and at times on the steep valley slopes. Sporadic exposures of Cherra sandstones occur on the abutments. The sandstones are overlying the granite gneissic rock as a cap.

River Basins and Hydrology

The LKHEP is proposed to be located on the Kopili River at Longku in the east of Karbi Anglong District of Assam. The longitude and latitude of the dam site are 92° 46′ 53.62′′ E and 25° 39′ 57.39′′ N, respectively. The upper Kopili river basin lies on the southern watershed of the Brahmaputra river basin, straddling the border between the Assam and Meghalaya states, as shown (circled red) in Figure 12. The

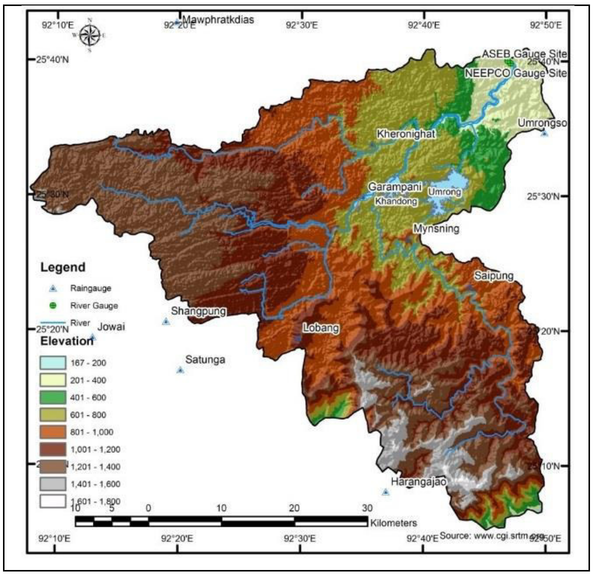
[25] Precambrian gneissic complex comprising para- and orthogneisses and migamatites, and Shilong Group comprised mainly of quartzites. They are both intruded by basic and ultrabasic intrusives and late tectonic granite plutons (ref. megdmg.gov.in/features.html).
[26] Cretaceous – Tertiary sedimentary rocks, including the Jaintia Group (calcareous facies) – limestones (ref. megdmg.gov.in/features.html).
[27] The Oligocene Barail group coals and shales of the North Cachar Hills.

upper Kopili catchment drainage area, above the proposed LKHEP site, lies between longitude 92°11’41.12” - 92°49’19.47” E and latitude 25°08’20.31” - 25°40’40.82” N (ADB, 2016d). The upper Kopili river basin, shown in Figure 12, has a total catchment area of 2,076.62 km^2 above the LKHEP site. This area is sub-divided further into: i) an intermediate catchment of 788 km^2 for the LKHEP reservoir below the upper dam catchments (Figure 12 – between the lower and upper green lines); and ii) the upper catchment of the Khandong and Umrong upper dams of 1,318 km^2 (Figure 12 – above the upper green line), which is sub-divided further between the small 62.0 km^2 catchment of the Umrong dam, and the much larger 1,256 km^2 catchment of the Khandong dam. The Umrong and Khandong[28] reservoirs are respectively recorded by NEEPCO to have live storage of 51.53 MCM at FSL 609.6 m a.s.l and 129.5 MCM at FSL 719.30 m a.s.l[29]. This compares to the live storage of 77.29 MCM[30] at FSL 226.0 m a.s.l which is planned for the LKHEP reservoir. The Khandong reservoir at FSL has a reservoir surface area of 13.36 km^2 and the Umrong Dam at FSL has a reservoir surface area of 15.99 km^2.

Climate

This Northeast region receives the world’s highest rainfall and about 30% of India’s total rainfall. Figure 13 shows Assam state to fall mostly in the 2,000 – 4,000 mm / year rainfall zone, with the upper Kopili basin falling between this zone and a 1,000 – 1,200 mm rain / year zone to the east. The LKHEP site and eastern Kopili basin appear to fall within the latter lower rainfall zone, which appears to be a rain shadow on the leeward side of the Borail and Khasi and Jaintia Hill ranges to the south and west.

Figure 10. Landscape of the Upper Kopili River Basin.



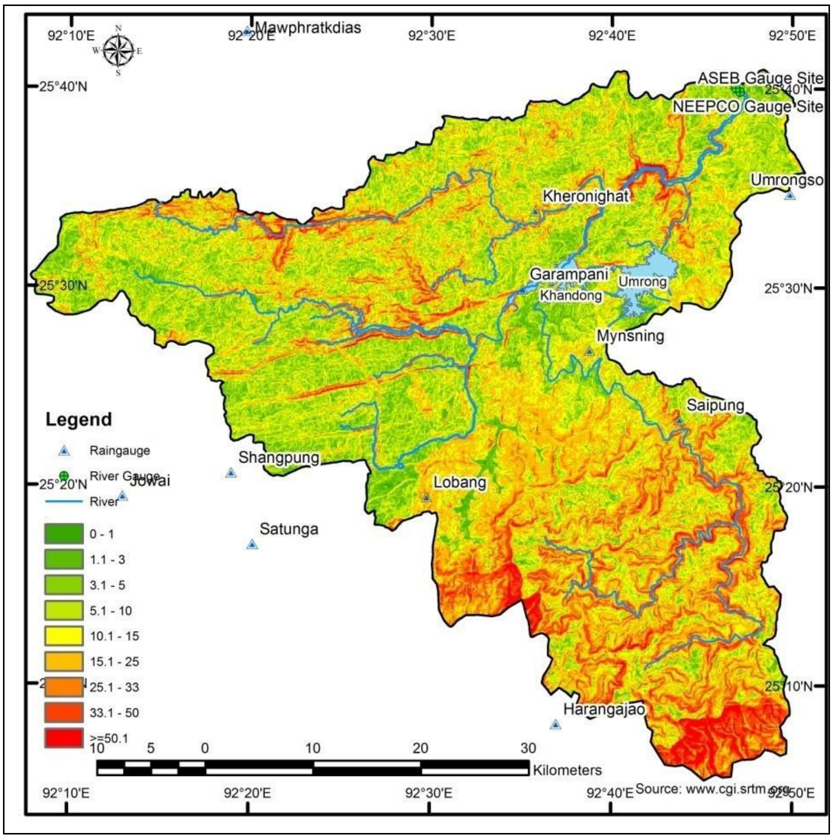
Source – Figure 5.2 – (WAPCOS, 2016a)

Figure 11. Landscape Slope Classes of the Upper Kopili River Basin.

[28] Project commissioned in 1984, with a concrete gravity dam 66 m high, with a last stage finished in 1988, and last stage extension in 1997.

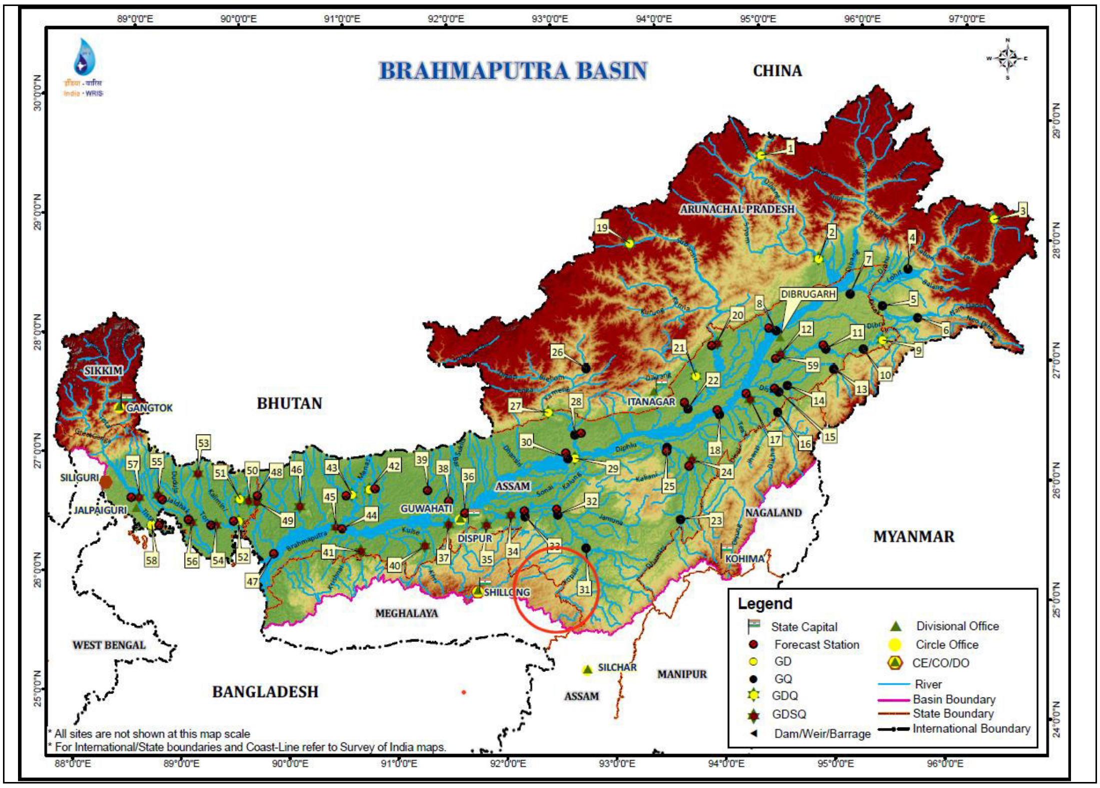
[29] A planned radial gate installation at Khandong Dam will raise the FSL to 739.33 m a.s.l, and the reservoir live storage will rise to 666.0 MCM.

[30] Total storage capacity of 106.39 MCM with drawn down level to 202.0 m a.s.l.



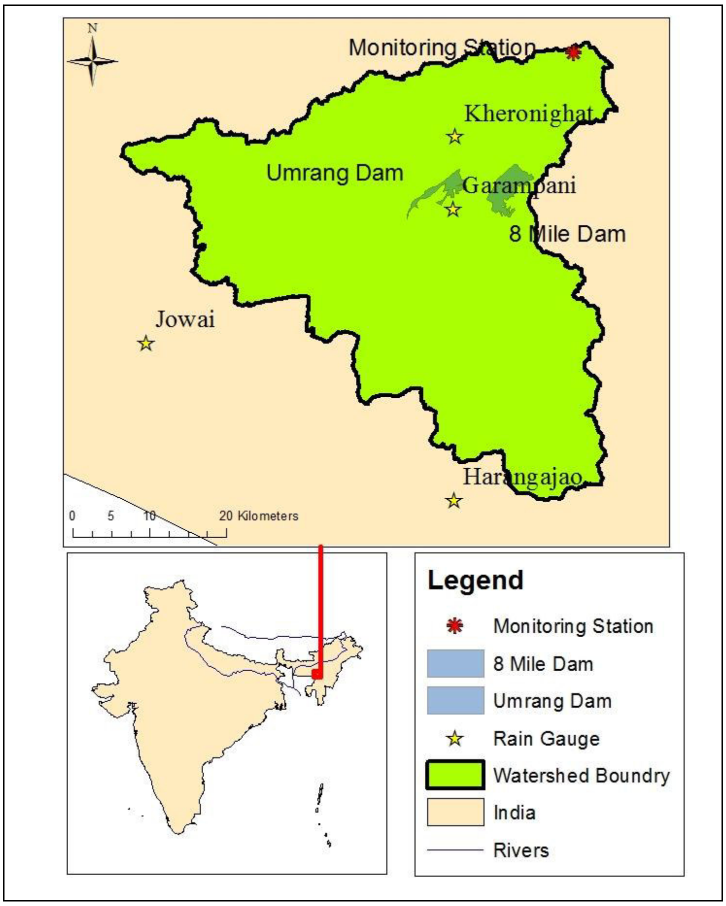
Source – Figure 5.3 – (WAPCOS, 2016a)

Figure 12. Upper Kopili river catchment basin within the Brahmaputra river basin.



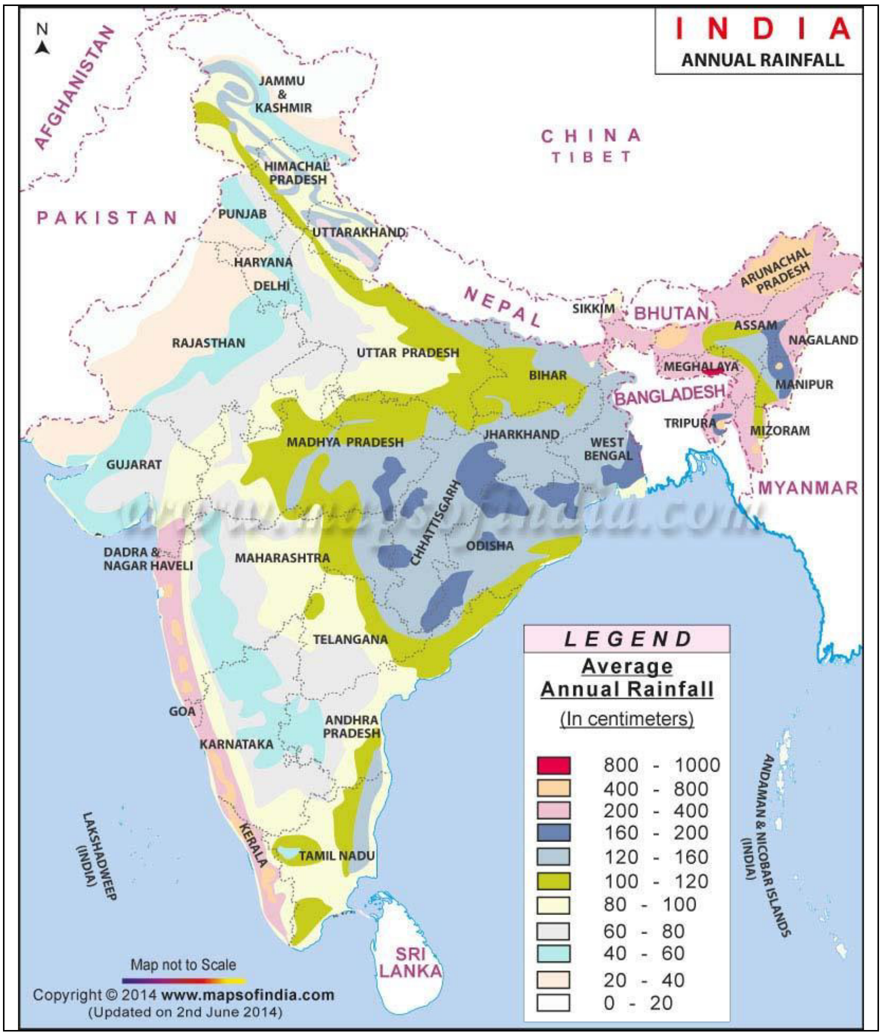
Source – http://india-wris.nrsc.gov.in/wrpinfo.

Figure 13. The Upper Kopili River Basin and LKHEP, Umrong and Khandong dam catchment areas.



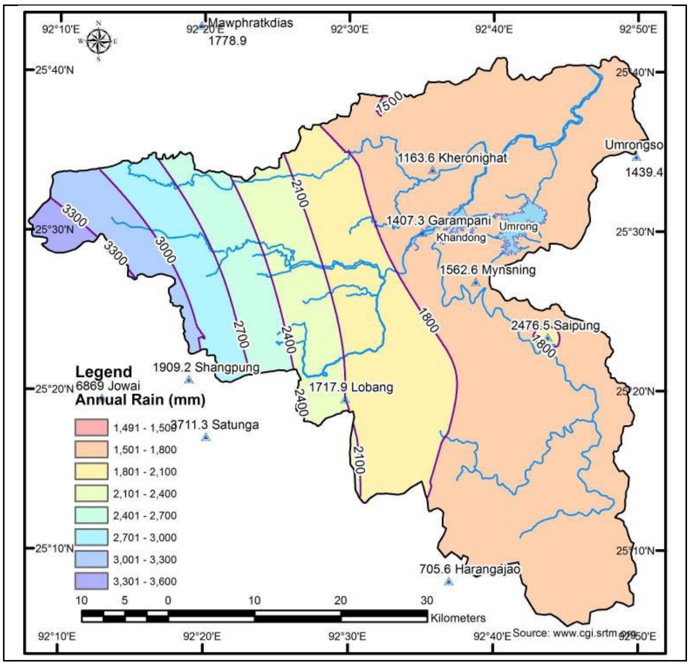
Source – ADB, 2016d

Figure 14. Rainfall zonations of India.



Source – www.mapsofindia.com

Figure 15. Rainfall zonations of the Upper Kopili Basin.

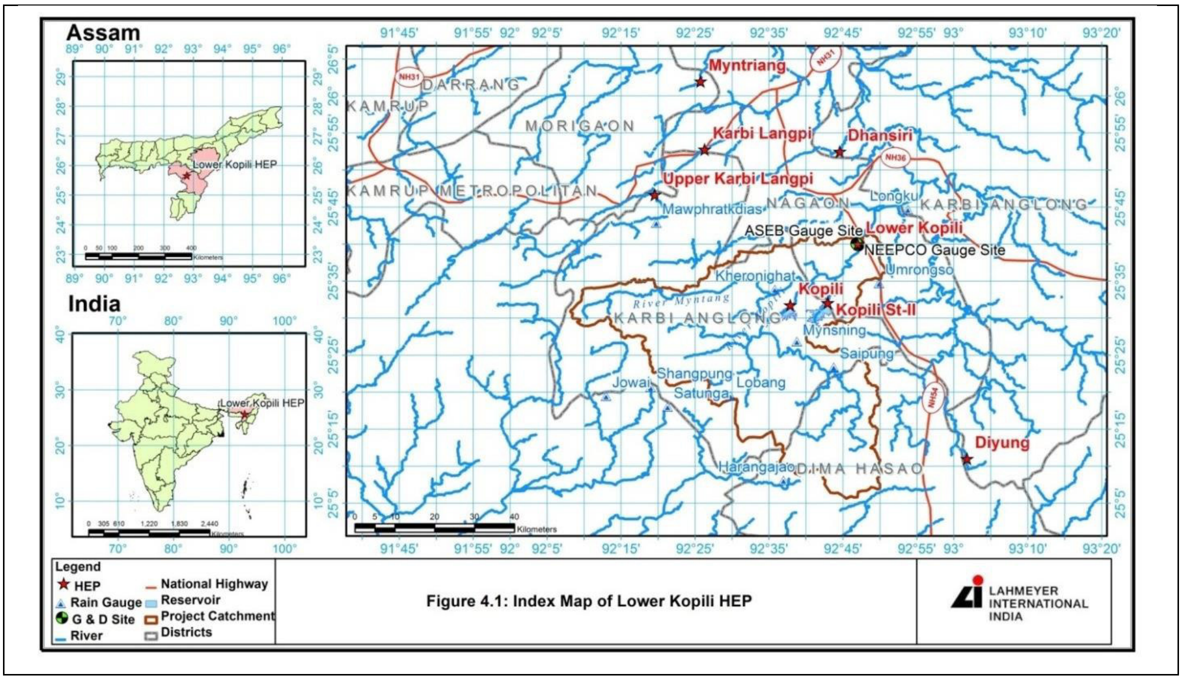


Source – Figure 5.6 - (WAPCOS, 2016a)

Figure 15 above alternatively shows the upper Kopili basin rainfall to vary from 1,500 – 1,800 mm / year across the east and southeast basin, rising sharply in rainfall level in Meghalaya state to > 3,000 mm / year in the far western basin. The upper Kopili area is characterized to have a humid sub-tropical (warm summer) climate. The summer (May-September) period receives heavy southwest monsoon rainfall; the pre-monsoon (Apr-May) and post monsoon (Oct- early Nov) periods receive moderate rainfall and the winter (late Nov-Mar) is dry with no or little rainfall. The region experiences heavy rainfall from cyclonic storms and the southwest monsoon from May to October, which is about 90% of the annual rainfall in the region (WAPCOS, 2016a).

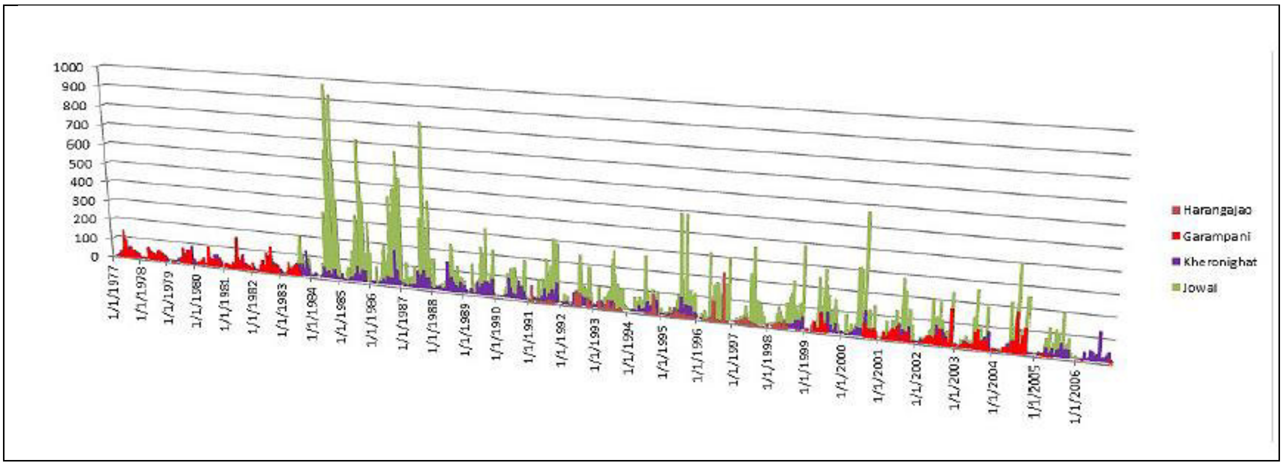
The mean annual rainfall over the upper Kopili basin has been computed as 1,946 mm, using an interpolation across the average annual rainfall of the eight rainfall stations which are found in or near the catchment (Figure 16). These rainfall stations are Shangpung, Satunga, Mawphratkdias, Saipung, Garampani, Lobang and Myntriang ordinary rainfall stations, and the Umrongso rain station immediately below the Khandong reservoir, as listed by (WAPCOS, 2016a). The project DPR (Lahmeyer India, 2015a) alternatively records 12 rainfall stations to occur in or near the upper Kopili basin, adding the four stations, Jowai, Harangajao, Khernighat and Longku.

Figure 16. Rainfall stations in the Kopili River Basin.



Source – Figure 5.1 - CEIA (WAPCOS, 2016a)

Figure 17. Observed monthly rainfall within the Kopili river basin – 4 stations -1977 – 2006.



Source – Figure 4 - (ADB, 2016d)

The annexes of the DPR (Lahmeyer India, 2015a) present monthly rainfall records of the 12 rainfall stations which outline data records for: eight stations to run from 1962 – 63 to 1981 – 86; three stations (Jowai, 1983; Khernighat, 1977; and Harangajao, 1991) to start more recently; and one station Garampani to run from 1963 – 2006. The (ADB, 2016d) study has provided a visualization of the inter-annual variability in the observed rainfall at four stations, Jowai, Harangajao, Khernighat and Garampani, over the period 1977 – 2006 (in Figure 17). The plot shows the monthly rainfall to vary from monsoon season peaks of 100 – 200 mm at most in three stations (Harangajao, Khernighat and Garampani), and an unusually high rainfall (up to 800 – 950 mm / month) and larger variation at the Jowai station.

With regard to other climatic parameters in the upper Kopili river basin, the maximum temperature observed in summer ranges between 23°C and 32°C, and the minimum temperature observed in winter ranges between 6°C and 14°C, with average relative humidity varying between 73% and 84% throughout the year (WAPCOS, 2016a). The (ADB, 2016d) study has confirmed that while there are climate observation stations in or near the upper Kopili basin, data are not collected for daily temperature, humidity, wind speed, pan evaporation, or solar radiation. As a result, climate modeling for this specific region has had to rely on the SWAT weather generator model, to allow daily weather inputs to the climate models referred to in ADB (2016d).

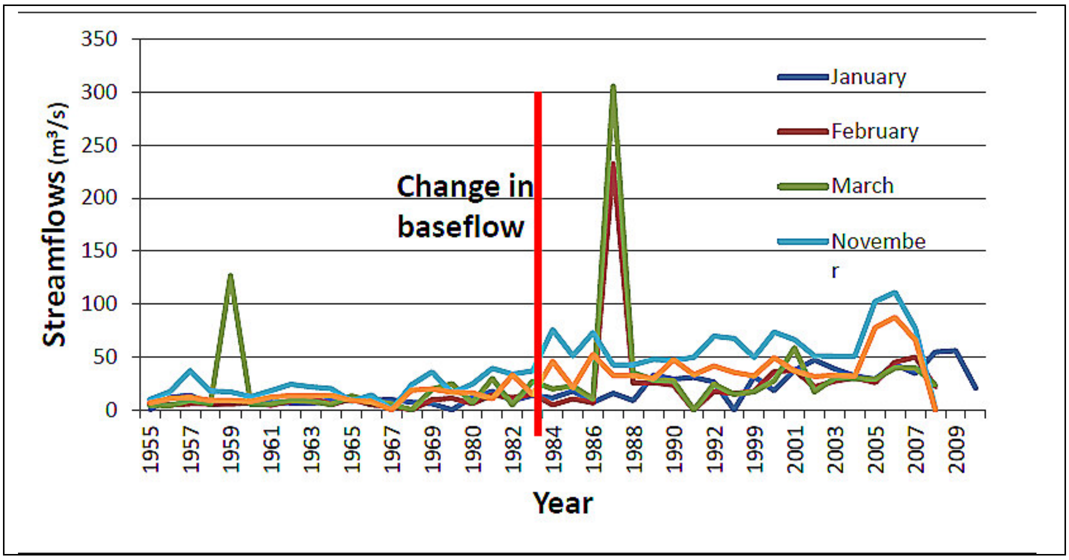
Hydrology

The project DPR (Lahmeyer India, 2015a) records that four river discharge gauges have existed in the upper Kopili river basin over differing periods of time: the Garampani gauge, established by the Central Water and Power Commission (CWPC) in 1955, with catchment area of 1,256 km² above the Khandong dam site, and a data record over 1955–69 and 1976–79, kept by NEEPCO; the Longku gauge, established in 1979 by ASEB, about 1.5 km upstream of the proposed LKHEP dam site, 2.5 km below the Kopili powerhouse, with data record from 1979 – 92 (station closed in 1992); the Longku gauge, established by NEEPCO, 3km downstream of the Kopili powerhouse, with data record from 1998–2004, and a catchment of 2,019 km² (mapped in Figure 16); the LKHEP dam site gauge, established in 2004 by APGCL, with data record from 2004-10. The long term hydrological analysis of the DPR (Lahmeyer India, 2015a) has utilized discharge data at the Longku dam site which has been generated from discharge data at Garampani using catchment area proportion, to scale-up the discharge to the 2,076.62 km² catchment area of the LKHEP.

The (ADB, 2016d) study has utilized the generated discharge data to analyze the pattern of Kopili river dry season baseflow discharge at the Longku gauge and LKHEP site (Figure 18), and to characterize the inter-annual pattern of observed river discharge (Figure 19). The dry season (Nov – Jan) baseflow analysis shows a definite shift in hydrological pattern post-1982, with an increase in dry season baseflow caused by the regulation of the catchment upstream with the commissioning of the Khandong dam.

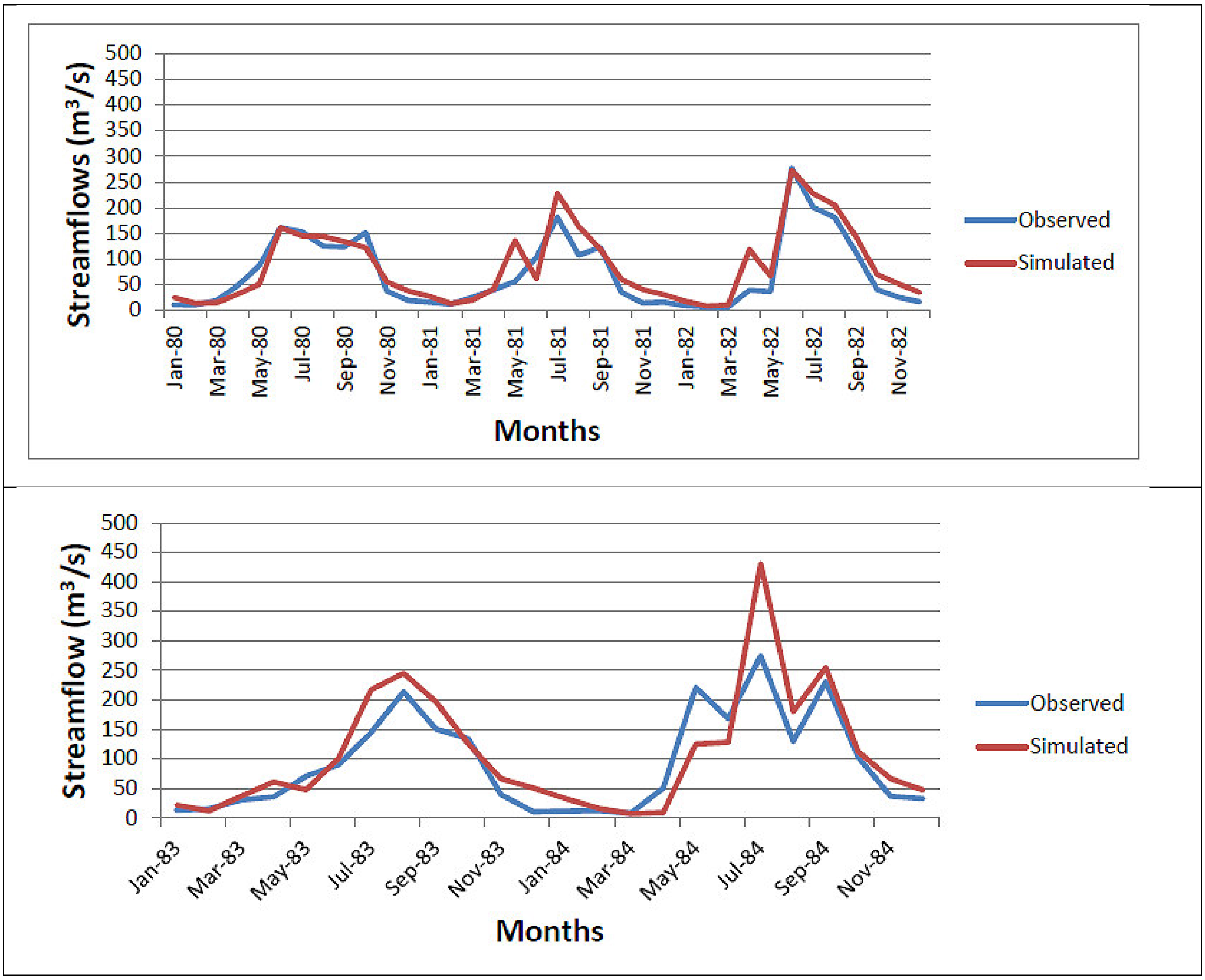
Figure 19 shows the river flow time series at the LKHEP site post Khandong dam commissioning, with the average monthly flow peaking in the lower Kopili River to reach 150 to 250 m^3/sec, mostly during the May – September southwest monsoon period. Table 9 in turn shows the average annual discharge pattern of the lower Kopili river at the LKHEP site, with the hydrological year starting in January with minimum flows of 19.9 m^3/sec, rising to a peak flow of 222 m^3/sec in June during the monsoon period, before dropping gradually in flow each month over July – December to reach again the January low flow.

Figure 18. Observed dry season baseflow in the Kopili river at Longku gauge site – 1955 – 2009.



Source – Figure 5 - (ADB, 2016d)

Figure 19. Observed monthly discharge of the Kopili river at Longku gauge site – 1980 – 2006.



Source – Figure 8 - (ADB, 2016d)

Table 9. Average monthly discharge of the Kopili river at Longku gauge site as derived from the Garampani gauge – 1951 – 1969.

Table 1: Average monthly streamflows at the LKHEP site

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average Discharge (m^3/s)	19.9	23.6	29.3	34.7	85.7	222	174	146	138	107	44	27.2

Land Cover and Land Use

The LKHEP site and upper Kopili basin lie in the mosaic of forest and shifting cultivation land cover (green shaded) which characterize the hill country of southern Assam and Meghalaya, as distinct from the heavily cultivated plains of the Brahmaputra valley and lower eastern landscape of Karbi Anglong district (grey shaded) (Figure 20). A land cover mapping of the upper Kopili basin by (ADB, 2016d) (Figure 21) shows that only a small area of the intermediate catchment above the LKHEP site is forested (mainly over-grown teak forest plantations), whereas the upper catchment above the upper dams is dominated by a mix of cropland, shifting cultivation, re-growth woodland and abandoned shifting cultivation. As noted by (ADB, 2016d), typically shifting agriculture, referred to as Jhum Cultivation, is practiced in the forested region, with terrace farming in the hilly region.

The (WAPCOS, 2016a) CEIA and DPR (Lahmeyer India, 2015a) mention erroneously that the total 2,076 km^2 upper catchment area above the LKHEP site is nearly 95% covered with forest and about 5% under cultivation. This assessment is very misleading, and has been proved wrong by field reconnaissance in the upper catchment by the current CRVA assessor, where the landscape was found to more closely resemble the rough land cover mapping provided by (ADB, 2016d) in Figure 20.

2.5.3 Environmental

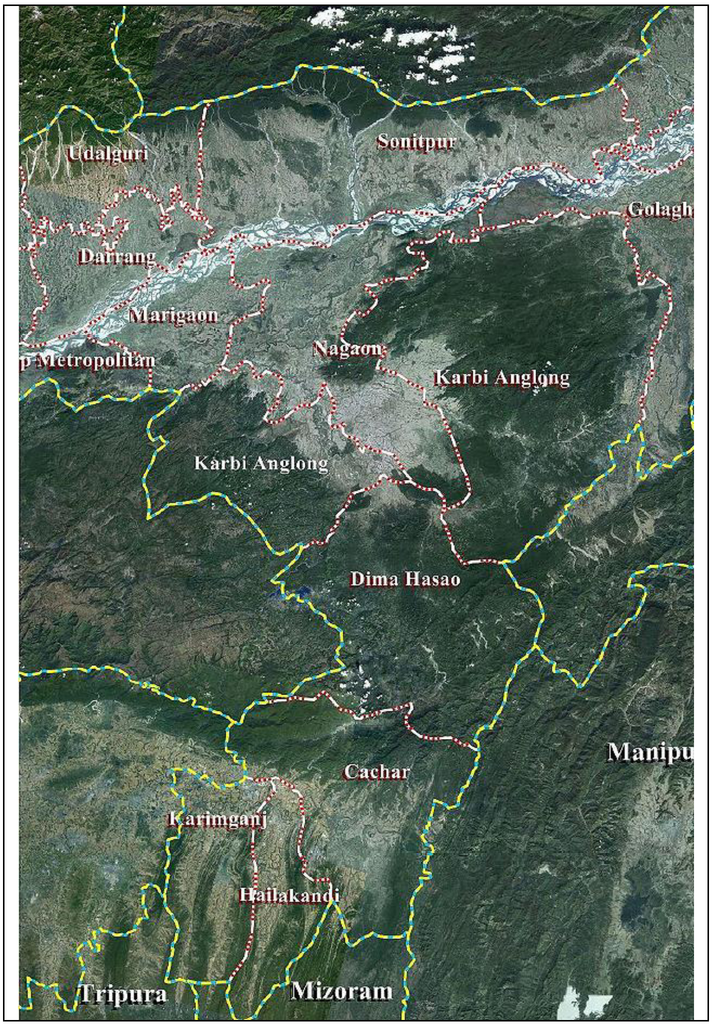
The most serious environmental issues in the LKHEP area are acid drainage from coal mining and coal stock-piling sites in the catchment of the upper dams, which has resulted in very low pH levels in the Kopili River and an absence of fish in the main river at the dam and powerhouse sites (however, there are fish in the tributaries of the Kopili River).

With regard to biodiversity and protected areas, the DPR (Lahmeyer India, 2015a) and EIA (WAPCOS, 2016a) note that although wildlife are occasionally observed in the area, the only endangered species reported in the area are elephants, which have been seen crossing the river above and below the proposed dam site, and Chinese pangolins, which are noted in anecdotal reports. There are no protected areas, such as a National Park or a Wildlife Sanctuary, located in the vicinity of the Lower Kopili HEP.

2.5.4 Demographic

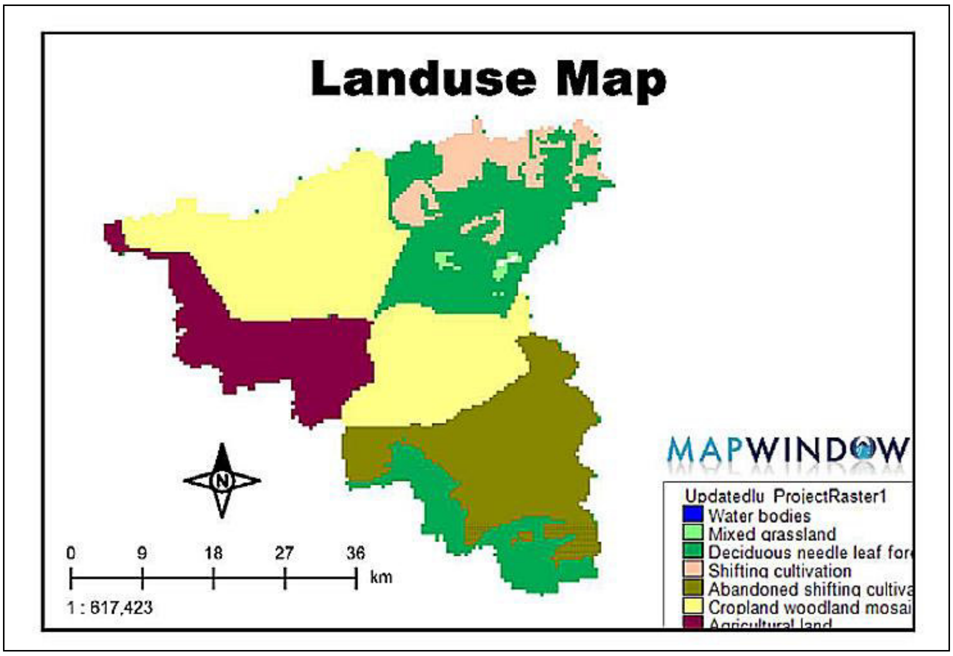
The total population of Assam State is 31.17 million (2011 Census), with the population having grown steadily from 3.29 million in 1901, reaching levels of 6.70 million (1941), 14.63 million (1971), 22.41 million (1991) and 26.66 million (2001) before reaching the current population level. The current state-wide average population density is 396.8 persons/km^2. The population literacy rate, as per the 2011 census, is 73.18% (ASDMA, 2016). Compared to the high state population density, Dima Hasao and Karbi Anglong districts which cover the LKHEP project area have the lowest population densities in the state, at < 180 persons / km^2 (ref. flood risk mapping, (ASDMA, 2016)).

Figure 20. Land cover of Kopili River Basin and Assam and Meghalaya State Surrounds.



Source – Figure 3 - (ASDMA, 2016) - Google Earth image from 2012

Figure 21. Land cover of the Upper Kopili River Basin.



Source – Figure 2 - (ADB, 2016d) - interpretation of Google Earth 2016 image

Karbi Anglong 2011 census data[31] record a total population of 956,313 persons for the District, with a population increase of 17.58% compared to the previous 2001 census, and a district population density in 2011 of 92 persons / km^2. Dima Hasao 2011 census data[32] record a total population of 214,102 persons for the District, with a population increase of 13.84% compared to the previous 2001 census, and a district population density in 2011 of 44 persons / km^2. The Project SIA volume of the CEIA (WAPCOS, 2016c) provides no data on the demographics or socioeconomic status of the 'host community' of LKHEP in the surrounding Districts and Sub-Districts of the upper Kopili river basin. The focus of the baseline data is solely on the project affected people (PAP).

2.5.5 Socioeconomic

As noted by (ASDMA, 2016), the economy of Assam state continues to be predominantly agrarian. The contribution of the agriculture sector to the State Domestic Product was more than 25 per cent during 2009-10. The chief agricultural products of the state are varieties of rice, tea, jute, mustard, pulses, sugarcane, potatoes, oranges, pineapples, coconut, areca nut, black pepper, citrus fruits, banana, papaya, turmeric, spices, flowers, medicinal and aromatic plants, besides many types of vegetables, thus contributing significantly towards the food and nutritional security of the State. (ASDMA, 2016) also note that the livestock and tree plantation sectors play an important role in the state's economy, with socioeconomic relevance to the upland hill communities of the upper Kopili river basin. (ASDMA, 2016) note a total of 7,762,572 Indigenous Cattle and 446,185 Crossbreed Cattle, recorded in the State during 2009-10, as reported by State Animal Husbandry and Veterinary (AH&V) Department. With regard to tree plantations, (ASDMA, 2016) note that the tea industry, rubber plantations, sericulture and bamboo plantations all play a significant role in the state's socioeconomy.

The ASAPCC (Department of Environment and Forest, 2016), however, notes that Assam remains one of the poorest states in India. Despite recent acceleration of its economic growth, disparity against the national average income has still been widening (Asian Development Bank, 2010). In terms of poverty, Assam has more than a third of its population (36.09%) under the poverty line (Assam Human Development Report, 2003). The percentage of poor in Assam is the highest amongst the northeastern states. Poverty in Assam is more widespread in the western, southern and the hill districts. Related to this, the Assam Human Development Report (2014) notes that the average unemployment rate in Assam is 13.4%, with female unemployment being at 33.9%, and youth unemployment (15 to 24 year olds) at 37.7%. Further, 20% of the people in the State own 70% of the cultivable land, which is a significant inequality. Child malnutrition is quite high in the State (Assam Human Development Report, 2014).

2.5.6 Policy

Directly over-lapping with the focus of ADB's climate and natural hazard risk assessment (see Section 2.2 and (ADB, 2012a), Appendix 1) the Assam State disaster risk assessment also covers earthquake, flood and landslide hazard, erosion, wind, cyclone, and fire (ASDMA, 2016). With regard to the legal and policy basis for disaster management (DM) planning in the state of Assam, Section 23 of the (national) Disaster Management Act 2005 provides that there shall be a Disaster Management Plan for every state, and that the State Plan shall be prepared by the State Executive Committee and shall be approved by the State Authority. The authority in the case of Assam State is the Assam State Disaster Management Authority[33] (ASDMA), Department of Revenue and Disaster Management. The Assam State Disaster Management Plan (ASDMP) plan is prepared by ADSMA, and allied State Departments, under the provisions outlined in the national Disaster Management Act 2005 and Section 5 (State Plan) of Assam

[31] See www.census2011.co.in
[32] See www.census2011.co.in
[33] The state level ASDMA falls under the National Disaster Management Authority, and is supported from below by the District Disaster Management Authority and Local Authorities below that (Panchayati Raj, Municipality and Urban authority levels) (ASDMA, 2016).

State Disaster Management Rules 2010. In accordance with this Act and Rules, the plan must include the following:

- Identify the vulnerability of different parts of the State to different forms of disasters;
- The measures to be adopted for prevention and mitigation of disasters;
- The manner in which the mitigation measures shall be integrated with the development plan and projects;
- The capacity-building and preparedness measures to be taken;
- The roles and responsibility of each department of the Government of the State in relation to prevention, mitigation, preparedness, capacity building, response and rehabilitation;
- The roles and responsibilities of different departments of the Government of the State in responding to any threatening disaster situation or disaster; and,
- The roles and responsibilities of community based organizations, international and national non-governmental organizations in activities of capacity building, response and relief.

A review of Assam state and national policy with regard to forests, abatement of pollution, national conservation strategy, environment and development, environment, water, wildlife conservation, hydropower development and small hydropower has been provided by the updated Project CEIA (input from the ADB environmental safeguards team). These policies do not appear to relate to natural hazard and climate risk, vulnerability or adaptation.

3. Vulnerability Assessment

3.1 Scenarios of Climate Change

3.1.1 Re-Assessment of Climate Trends

Temperature - There would appear to be little debate or contradicting evidence with regard to climate change projections of temperature change in the northeast India region. The GHG impact on global and regional temperature increase has been exhaustively studied by the IPCC and others, and the science is relatively mature. Hence, the GCM and RCM model predictive outputs are assumed to be relatively reliable, and empirical estimates even more reliable. The assumption of relative reliability rests upon the fact that temperature is a parameter which is spatially and temporally reasonably stable (i.e., it does not widely or abruptly vary), and as such is easier to predict across wide spatial areas with a minimum number of ground observation points as input. Hence, it is not surprising that the previous ADB LKHEP modeled climate change temperature projections do not vary widely in magnitude or trend, compared to the predictions made by other regional empirical and modeled studies. The comparative findings of the ADB LKHEP climate change temperature modeling predictions versus regional studies are:

- **(Ji, 2015) models** - LKHEP GCM climate risk screening modeling to mid-century (2050), under the rcp8.5 scenario, predicted average annual temperature increase of 2.48 ^{0}C, and dry season (December) and monsoon season (July) maximum temperature rise of >2.75^{0}C and <2.19^{0}C, respectively;
- **(ADB, 2016d) models** - LKHEP GCM and RCM climate impact assessment modeling to mid-century (2040 - 2070), under rcp4.5 and rcp8.5 scenarios, found all models predicted a temperature increase, most models suggesting an increase of about 2°C. One model (HADGEM3-RA) under rcp4.5 scenario predicted an increase between 3.5 to 5.5°C in the non-monsoon season;
- **(ASDMA, 2016) empirical data** – ASDMP state risk assessment notes that annual mean and annual mean maximum temperatures in the northeast region are rising respectively at a rate of +0.04°C and +0.11°C per decade (i.e., 0.16°C mean annual and 0.44°C mean maximum temperature rise by mid-century);
- **(Department of Environment and Forest, 2016) empirical data** – The ASAPCC climate change assessment records a warming trend of 0.51°C in India, with accelerated warming observed from 1970 onwards. The Assam region has experienced an increase in the annual mean maximum and mean annual temperatures at the rate of +0.11°C and 0.04°C per decade;
- **(Department of Environment and Forest, 2016) modeled studies** – The ASAPCC climate change assessment reviewed modeling studies which gave consistent results with regard to temperature trends:
  - (Kumar *et al.*, 2006), using the PRECIS RCM model showed that the temperature is likely to increase by 2.5°C- 4°C in A2 over the Indian region, with pronounced warming over the north and northeastern parts of India;
  - (INCCA, 2010) **–** using the PRECIS RCM found an all-round temperature warming over the Indian Subcontinent; the annual average temperature is expected to rise between 1.7 to 1.8 ^{0}C versus the 1970s temperature; the corresponding seasonal temperature is expected to rise from 1.5 to 2.2^{0}C, with monsoon months (June – September) showing a maximum rise amongst the seasons.

Rainfall – The case of climate change rainfall prediction varies significantly from that of temperature. There is much debate and contradicting evidence with regard to climate change projections of precipitation change in the northeast India region. The link between GHG and global warming predictions and rainfall change is much weaker, and the science is both less mature and confronted with considerable difficulties. Hence, the GCM and RCM model predictive outputs are assumed to be not particularly reliable versus the empirical estimates which are assumed to be much more reliable. The assumption of relative unreliability of modeled results rests upon the fact that rainfall is a parameter which is spatially and temporally highly variable (i.e., it does vary both widely and abruptly), and as such is considerably more difficult to predict across wide spatial areas with a low number of ground observation points as input. Hence, it is not surprising that the previous ADB LKHEP and regional study modeled climate change rainfall projections do vary widely in magnitude and trend, versus regional empirical studies. The comparative findings of the ADB LKHEP and regional study modeled climate-change rainfall predictions versus regional empirical studies are:

- **(Ji, 2015) models** - LKHEP GCM climate risk screening modeling to mid-century (2050), under rcp8.5 scenario, predicted a total annual rainfall increase of 206 mm (7.6 % increase); monsoon season (May – Oct) rainfall increase of 190 mm (8.8% increase); and, a slight rainfall decrease in the dry season (Jan – Apr);
- **(ADB, 2016d) models** - LKHEP GCM and RCM climate impact assessment modeling to mid-century (2040 - 2070), under rcp4.5 and rcp8.5 scenarios, predicted an annual average precipitation increased by ~ 10%, with monsoon precipitation to significantly increase, yet non-monsoon precipitation shows a mixed result between models (some increases and some decreases);
- **(ASDMA, 2016) empirical data** – The ASDMP state risk assessment notes there is no significant trend in rainfall for the region as a whole, i.e., rainfall is neither increasing nor decreasing appreciably for the region as a whole. However, part of the region comprising Nagaland, Manipur, Mizoram, Tripura and parts of the Barail Hills show a significant change in seasonal rainfall, with summer monsoon rainfall found to be decreasing significantly during the last century at an approximate rate of 11 mm per decade (i.e., a 44 mm decrease by mid-century, a 5% to 2% decrease depending on rainfall zone[34]);
- **(Department of Environment and Forest, 2016) empirical data** – The ASAPCC climate change assessment records that long-term trends in the annual rainfall indicate a slight decline in the total rainfall received in the region (Das *et al*., 2009; Mirza *et al*., 1998; Tiwari, 2006; ASTEC, 2011);
- **(Department of Environment and Forest, 2016) modeled studies** – The ASAPCC climate change assessment warns that the modeling studies relevant to the northeast region, although indicative in the very broadest sense of the likely climate changes, do not help in capturing the uncertainties associated with the various projections and indicate the need for further research on these aspects. The studies reviewed suggested mixed results with regard to rainfall projections:
    - (Kulkarni *et al.*, 2010), with a coarse resolution model of the Indian region, concluded that there will be a substantial increase in the amount of summer monsoon rainfall over the northeast region until 2100;
    - (Rajendran and Kitoh, 2008), with a fine resolution model, concluded that future changes would show a reduction in rainfall over the Assam region, whereas the extreme events were found to increase;
    - (NATCOM, 2004), using an RCM, found that the monsoon seasonal mean rainfall (up to 2080) would increase over the northeast region, with also the possibility of an increase in number of rainy days;
    - (Kumar *et al.*, 2006), using the PRECIS RCM model, showed that a larger percentage increase in rainfall over the Assam region up to 2080s, compared to the 2030s and 2050s;
    - (INCCA, 2010) **–** using the PRECIS RCM, concluded that the rate of rainfall over Assam is projected to increase, with the number of rainy days projected to decline, but rainfall intensities to increase. They slso concluded that the regional rainfall in pre-monsoon and post-monsoon months may be associated with an increased number of thunderstorms. It was also concluded that increasing variability and changes in rainfall patterns may have some regions

[34] i.e. 1,000 – 2,000 mm / year rainfall zones, and assuming 90% annual rainfall in the monsoon season.

experiencing scarcity of rainfall and others an increase. Drought-like conditions might prevail, given the climatic variations expected.

There appears to be a distinct dichotomy of rainfall prediction results between the ADB and regional modeled studies and the regional empirical studies. The modeled studies all predict the annual rainfall to increase (~7.6 to 10%), with most suggesting that the increase will be larger in the monsoon season (> 8.8%); but, there is no clear trend for the non-monsoon season, as rain days may increase or decrease, and rain intensities and thunder storms may increase. By contrast, the empirical studies suggest that regional rainfall has historically shown no trend or a slight decrease across the region, yet a more significant 2 – 5% decrease in monsoon season rainfall in specific sub-regions (e.g. Barail hills near the LKHEP). The empirical findings appear largely opposed in rainfall trend compared to that predicted by the models.

There are various caveats which need to be considered with regard to the reliability of GCM and RCM climate-change precipitation predictions, which relate to the interaction model reliability and the scale of model resolution, the topographic complexity and rainfall patterns of the Assam state.

As acknowledged by the (ADB, 2016d) study (Section 2.3), GCM models 'are simulated on a very coarse resolution, these data cannot be used directly either at the precipitation gauge station or at the watershed level'…..the climate data projections from GCMs need to be downscaled using statistical downscaling methods or RCMs'. This caveat puts the modeled precipitation findings of (Ji, 2015) mostly in doubt.

The findings of the down-scaled RCMs, however, have further reliability concerns. The highly varied monthly seasonal rainfall predictions of the (ADB, 2016d) RCM results are a case in point. The fact that the RCM model did not use observed rainfall data and opted to use the input of the half degree gridded precipitation data developed by the India Meteorology Department (IMD) is a data input reliability concern with regard to modelling precipitation change in the Assam hills. The weak point as found by the (ADB, 2016d) study is that the density of rain gauges in the hills is low, and reliability of their data may be suspect; this versus the higher complexity of rainfall pattern in the hills due to topographic variations (i.e., aspect, elevations, orographic and rain shadow effects). The result is that the rainfall modeling input from a low density of rain gauges in complex hill topography is usually very unreliable when using observed data. As stressed by the Assam Regional Meteorology Centre meteorologists in Guwahati, this results in the rainfall reliability of the half-degree gridded precipitation data developed by IMD to also be unreliable in the hills of Assam, as the gridded data are largely developed from the much larger density of rain gauges in the Brahmaputra plain, and thus do not reliably represent the hill conditions (*pers. comm.*, regional meteorologists, Assam Regional Meteorology Centre, Guwahati, November, 2016). In this case, the modeled predictions of the (ADB, 2016d) RCM outputs may also be in doubt due to 'unreliable' rainfall data input.

Lastly, all models, RCM or otherwise (e.g. SWAT), will have problems in prediction of rainfall trends when rainfall patterns are dominated by highly spatially and temporally variable convective rainfall systems (i.e., thunder storms). As opposed to temperate frontal and tropical monsoonal rainfall systems which have much more predicable behavior spatially and temporally, tropical and sub-tropical and arid thunder storms-based rainfall systems are almost random in their spatial and temporal pattern. This makes them very difficult to model or predict rainfall magnitude or pattern. As found by (Kandalgaonkar *et al.*, 2005) the northeast region of India and Assam show that pre-monsoon and post-monsoon thundershowers are very dominant over the region, due to orography and the humidity available for convection, with thunderstorms in the post-monsoon season observed to be with higher intensities than during the pre-monsoon season. This pattern of rainfall will be very difficult for any model GCM (RCM or otherwise) to replicate and predict (hence, another reason for doubt to be expressed in modeled rainfall predictions in Assam, and particularly in the hills).

In view of the above challenges and short-comings of rainfall modeling, the findings of the regional empirical studies are chosen as providing the more reliable rainfall projections, and the trend in annual average rainfall is assumed to be slightly negative, with the monsoon season rainfall trend more negative at a rate of 44 mm decrease to 2050. The findings of the (Jain and Kumar, 2012) India-wide review suggest that the annual rainfall of the Brahmaputra river basin is slightly decreasing at -0.85% by mid-century (per 50 years), and rain days decreasing at – 1.9% by mid-century (per 50 years). Numerous studies were also quoted from other parts of India (e.g. (Goswami *et al*., 2006)), as noted by (Ji, 2015), that extreme rainfall events (> 100 mm) are increasing along with trends of decreasing annual rainfall and rain days. This trend would make conceptual sense in view of the increasing temperature trends.

3.1.2 Revised Climate Change Scenarios

Temperature - In view of the findings in Section 3.1.1 with regard to scenario methods, data sources, uncertainties, and caveats, the CRVA climate change conclusion regarding climate change-induced temperature change is that temperatures will increase at the LKHEP site by the mid-century (2050). The predicted rate of increase, however, varies widely in the modeled predictions, with mean annual increases of 1.7 – 4.0^{0}C, monsoon season increases from 2.2 – 2.75^{0}C and non-monsoon season increases from 2.19 – 5.5^{0}C. The relative temperature increase predicted by regional empirical studies is more modest, with a 0.16^{0}C mean annual and 0.44^{0}C maximum seasonal temperature increase by the mid-century (2050). In view of the relative strength and reliability of empirical versus modeled studies, it is suggested the temperature change scenario at the LKHEP site will be closer to the increase of 0.16^{0}C mean annual temperature increase and 0.44^{0}C maximum non-monsoon season temperature increase, compared to the > 2.0 ^{0}C increase suggested by the GCM and RCM models.

Rainfall - In view of the findings in Section 3.1.1 with regard to scenario methods, data sources, uncertainties, and caveats, the CRVA climate change conclusion regarding the climate change-induced rainfall change will follow the findings of the regional empirical studies rather than the modeled studies. Accordingly, the upper Kopili by mid-century (2050) is expected to experience a 0.85% decrease in average annual rainfall, a larger 2% - 5% decrease in monsoon season rainfall, a 1.9% decrease in rain days and an increase in extreme rainfall intensity (> 100 mm) rainfall events associated with thunderstorms, particularly in the pre-monsoon and post-monsoon seasons. These conclusions are summarized in the table below.

Table 10. Summary of findings from review of climate change scenarios.

Parameter	Historical	Current View of Future Climate Trend in the Project Area
Temperature	0.66 ^{o}C increase in mean annual temperature from 1951 to 2010.	Continuing minor increase in mean annual temperature (a further 0.16 ^{o}C by 2050, with temperature increases greater during the non-monsoon season).
Rainfall	178 mm/yr decrease in total annual rainfall from 1951 to 2010.	Continuing minor decrease in total annual rainfall (0.85% less in 2050, compared to now). Fewer rain days and less rain in the monsoon. However, an increase in the rainfall intensity during extreme weather events (so, ultimately less rain annually, in fewer but more intense rainfall events).

3.2 Climate Risks and Vulnerabilities

3.2.1 Revised Climate Risk Assessment

The above analysis updates and quantifies the scenarios of climate change induced temperature and rainfall change. The current section updates the assessment of the likely 'knock-on' climate and natural hazard risks which may impact on the LKHEP project structures and operation, in view of the trends in temperature increase, rainfall decrease, and changed rainfall patterns. These climate secondary risks will, in turn, be influenced by three factors:

i) the baseline conditions of the climate, hydrology and landscape;

ii) the driving process of hydrological change; and

iii) the moderating or exacerbating influence of catchment land cover, land management, and land degradation upon the expected hydrological and climate changes.

The LKHEP site baseline conditions have been reviewed in Sections 2.3 and 2.4 above and form a starting point for the analysis of baseline risk levels prior to climate change.

The hydrological implications of the climate change scenarios may be easily assessed qualitatively with little or no advantage to be had in repeated hydrological or hydro-dynamic modeling assessment[35]. The reduced rainfall and rain day trend, increasing extreme event rainfall intensities, and rising temperatures (i.e. increased evaporation), will be translate into reduced monsoon season average river flows, reduced dry season river flows, increased magnitude of storm flood peaks, and increased slope erosion and sediment transport, due increased rainfall intensity and large flood peaks.

The additional influence of catchment land cover, land management, and land degradation, is a driver which is seldom integrated into the climate and hydrological risk assessment, yet it does have a large influence in either moderating / buffering or exacerbating the climate change induced hydrological changes. The driving influence is a process called the 'infiltration trade-off effect' (Bruijnzeel, 1988; and Bruijnzeel, 1989), which is a tropical landscape catchment conceptual process which until recently was not widely recognized and largely confined to academic debate. With increasing recent tropical catchment studies with a focus on hydrology and soil condition, it is now evident that the conceptual process does in fact occur in reality, within wet tropical landscapes particularly. The driver chain process is land cover change which reduces the soil surface infiltration rates over periods of years to decades due to the advancement of soil degradation. The reduced soil infiltration reaches a tipping point where progressively more rainfall is translated into surface runoff, with less infiltrating into the groundwater. This results in changed river basin hydrology – with a trend of increasing flood peaks and decreasing baseflow resulting in the catchment rivers. The existence of a trend in soil degradation, or the reverse of improved or stable soil conditions, can make the hydrological effects of climate change much worse, or can moderate / mitigate them. In the spectrum of land cover types which trigger land degradation and soil infiltration reductions, natural forest is the best case; arable agriculture is worse; and, villages and settlements (impermeable surfaces) are worst.

Combining an assessment of baseline conditions, climate change impact and land cover / land degradation impact, a revised climate risk assessment for the LKHEP is outlined in Table 11.

Table 11. Revised LKHEP Climate Risk Assessment.

Type of Risk	Overall Risk / Hazard	Climate Impact	Land Cover Impact	Climate Variables / Confidence
Landslide triggered by precipitation	Low	Low	Medium	Increased pre-monsoon and post-monsoon rainfall intensity – medium
• **Evaluation:** The ASDMP baseline landslide incidence mapping only designates areas in the 35% - 40% slope				

[35] Minus improved rainfall data (i.e., longer time series, fewer gaps and less suspect data and more rain gauges), and minus updating land cover data across the whole upper Kopili basin above the LKHEP site, there would be little or no advantage in re-conducting hydrological modeling, as the results will not improve from the climate risk impact analysis already conducted by (ADB, 2016d) with the SWAT model. The only advantage would be to quantify the likely impacts of rainfall reduction on low flows, and more intense rainfall upon the pattern of flood peaks. However, in view of the need to identify small changes in baseflow and average flow due to rainfall reduction, and increased flood due to extreme daily rains, a monthly time step model such as implemented by (ADB, 2016d) with SWAT, is inadequate to model these changes. A daily time step model, such as HEC-RAS, would be the appropriate modeling approach to achieve a characterization of the hydrology change.

<table>
<tr><th>Type of Risk</th><th>Overall Risk / Hazard</th><th>Climate Impact</th><th>Land Cover Impact</th><th>Climate Variables / Confidence</th></tr>
<tr><td colspan="5">range to have a moderate landslide risk. The ASDMP landslide risk map shows very few areas in the upper Kopili basin in Dima Hasao district on the Meghalaya border (only on the steep slopes of some mid- to upper catchment incised river valleys) where there is some risk. The sandy soils on metamorphic, sedimentary and igneous rocks would also not be prone to landslips due to their well draining nature.
• Climate Change Assessment: Reduced rainfall, higher temperature and higher evaporation will lead to drier catchment conditions, which are not conducive to landslips (which are normally triggered by slope wetness).
• Catchment Management Assessment: Deforestation, poor agricultural land management and shifting agriculture on steep slopes of incised river valleys, and in the higher rainfall western (Meghalaya) areas of the LKHEP intermediate catchment may add some medium risk of landslips (but again the landscape slope classes, geology and soil conditions will reduce the risk of landslips under poor land management).</td></tr>
<tr><td>Forest fire</td><td>Low</td><td>Medium</td><td>High</td><td>Rising temperatures and evaporation – medium</td></tr>
<tr><td colspan="5">• Evaluation: The ASDMP baseline fire risk mapping for the Dima Hasao hills is low. With the upper Kopili catchment above the upper dams and the western catchment of the intermediate catchment of LKHEP under cropland / woodland mosaic and shifting cultivation, plus livestock grazing, it is assumed the fire risk is low because there will be little ground cover / fuel load to burn. The intermediate catchment forested areas, however, do have a low to medium fire risk, due to the dense ground cover and fuel load. This fire risk, however, will be under careful management by the Forest Department and their field staff, to protect the valuable teak plantations.
• Climate Change Assessment: Increasing temperatures, higher catchment evaporation, and slightly reduced rainfall and rain days will lead to greater catchment dryness. This will pose a medium risk upon the increased incidence of fires, in those areas which have enough fuel load to be susceptible.
• Catchment Management Assessment: Catchment land cover and management will have a high influence on the risk of fires, as this will determine the type of ground cover and density of fuel load to support the fires, and the activities of the local population, in conducting of their land use, will determine if fire is part of their traditional land management practice.</td></tr>
<tr><td>Flood</td><td>Medium</td><td>Medium</td><td>High</td><td>Increased daily extreme rainfall intensity and thunderstorms – medium
Slightly reduced rainfall and rain days, increased temperature and evaporation - increased catchment dryness – medium</td></tr>
<tr><td colspan="5">• Evaluation: The ASDMP state risk assessment, in the 1998 – 2007 flood hazard map of Assam state, shows the Kopili basin area downstream of LKHEP in the Hojai and Lanka township areas to have a low to very low flood hazard. The 2011 census data also shows the two Districts of Karbi Anglong and Dima Hasao also having the lowest population densities in the state, at 92 and 42 persons / km2, respectively. As part of integrated water resources management study an analysis of pre-dam and post-dam discharge have been undertaken in order to assess the impact of the Kopili dam on river flow and to establish before and after dam discharge scenario. The period from 1959 to 1983 was considered as pre-dam era while period from 1999 to 2016 was considered post-dam era. The analysis clearly observed that mean of monthly mean discharge increased from 84.55 m3/s to 89.49 m3/s in post dam era. As far as mean of monthly maximum is concerned, it has reduced significantly from 486.20 m3/s to 192.68 m3/s in post dam period while mean of monthly minimum was increased significantly in post dam period from 20.72 m3/s to 55.53 m3/s. Further analysis of the Kopili discharge data at Longkhu in year 2015 (as part of climate screening study) observed that discharge distribution during the months of Jan, Feb, Mar, November and December may be attributed to the base flow since there is no significant rainfall during these months. The stream flow pattern has changed after 1984. The division of two distinct periods is due to the increased flow releases during base flow periods as a result of reservoir releases from Kopili Hydropower plant located upstream of the LKHEP. In order to assess an impact KHEP to monsoon flows, an analysis was also carried out on the daily flow data. It can clearly be seen that the peak daily flows have reduced in the post-dam period compared to the pre-dam period. There is thus a low baseline risk of Kopili river flood peaks due to upstream dam releases.
• Climate Change Assessment: The increased flood peak risk in the Kopili river is assessed to be a medium</td></tr>
</table>

<table>
<tr><th>Type of Risk</th><th>Overall Risk / Hazard</th><th>Climate Impact</th><th>Land Cover Impact</th><th>Climate Variables / Confidence</th></tr>
<tr><td colspan="5">risk under the climate change influence as there are two climate scenario trends which are working against each other with regard to influence on flood peaks. The predicted increase of daily rainfall intensities and thunderstorms will have a high impact on increased incidence of flood peaks in the Kopili and intermediate catchment rivers. This, however, will be moderated by the drier catchment conditions caused by higher temperatures, higher evaporation and lower rainfall and fewer rain days. These climate changes result in a raising of the time to reach the threshold for catchment wetness to cause overland flow and flood generation in the smaller catchments, and hence the larger river. The higher flood risk from more intense rains should be reduced to medium risk by the increased catchment dryness.
Catchment Management Assessment: The influence of catchment land cover, land management and land degradation will be strong on the incidence of flood peaks in the river. Poor management of the upper high rainfall catchment areas, leading to land and soil infiltration degradation, will lead to a trend of increasingly larger flood peaks in the catchment rivers year by year. In the LKHEP intermediate catchment, the risk is medium, because of the larger area of forest cover, which helps prevent soil and land degradation, and will have an influence in buffering the flood peaks in the river system, and will not lead to a trend of increasing flood peaks year by year. If the forest is cleared, degraded, or burnt, however, there will be a large effect on the incidence of flood peaks.</td></tr>
<tr><td>Drought</td><td>Low</td><td>Medium</td><td>High</td><td>Rising temperatures and evaporation – high
Slightly reduced rainfall and rain days - increased catchment dryness - medium</td></tr>
<tr><td colspan="5">Evaluation: The ASDMP state risk assessment give no mention of an incidence of climatic or hydrologic drought in the upper Kopili basin or Dima Hasao or Karbi Anglong districts; hence it is assumed that the incidence of drought is currently low in the area. With regard to the lower Kopili river at the LKHEP site, the risk of hydrologic drought (i.e., low flows) would appear to be low, as a result of the hydrological buffering and regulating effect of the upstream Khandong and Umrong dam storages, which as shown by (ADB, 2016d) had resulted in a lower basin base flow increase in the Kopili river post-1984, after the upper Khandong dam commissioning.
Climate Change Assessment: The increase in hydrologic drought in the Kopili river basin overall is assessed to be a medium risk under the climate change influence. The predicted increase of daily rainfall intensities and thunderstorms will have some impact on increased incidence of flood peaks in the upper Kopili basin. Any increase in flood peaks generally leads to a proportional decrease in the baseflow fraction of the river which can be captured by water storage. The drier catchment conditions caused by higher temperatures, higher evaporation and lower rainfall and fewer rain days will also raise the time to reach the threshold for catchment wetness, which will support aquifer recharge and baseflow generation in the rivers, along with the slightly reduced annual and monsoon season rainfall overall. These climate change induced catchment and slight hydrological changes will create a medium risk of increased hydrological drought in the upper Kopili river basin.
Catchment Management Assessment: The influence of catchment land cover, land management and land degradation will be strong on the incidence of baseflow decline and low flows in the catchment rivers. Poor management of the upper high rainfall catchment areas, on steep slopes particularly, will lead to land and soil infiltration degradation, which will lead to a trend of reduced water infiltration to groundwater tables and reduced baseflow in the catchment rivers year by year. In the LKHEP intermediate catchment, the risk is medium, because of the area of forest cover that helps prevent soil and land degradation, and will have an influence in reducing the loss of soil infiltration and reduction of baseflow from the streams in this area of the catchment. The high rainfall in the western intermediate Myntiang river catchment in Meghalaya has cropland and shifting cultivation land cover which may lead to soil degradation and a baseflow reduction in the Myntiang river year by year. Also, if the forest areas in the near catchment are cleared, degraded or burnt, there will also be an effect on the catchment baseflows reduction as soil degradation and infiltration loss sets in, unless the forest is allowed to quickly regenerate as natural scrubland.</td></tr>
</table>

Type of Risk	Overall Risk / Hazard	Climate Impact	Land Cover Impact	Climate Variables / Confidence
Cyclone wind	High	Low	N / A	Increased cyclone intensity - low[36]

- **Evaluation:** The ASDMP state risk assessment of cyclones suggests that Dima Hasao and Karbi Anglong districts are at relatively high risk of medium to high winds speeds due to the infrequent tail-end passage of cyclones from the Bay of Bengal. In an evaluation of cyclone risk, (Ji, 2015) also assesses the project area as prone to cyclone wind hazard from the Bay of Bengal. (Ji, 2015) reports that according to BMTPC cyclone zonation, the northwest districts of Assam (including Karbi Anglong and Dima Hasao in the Kopili river basin) are in a zone of high damage risk where wind speed can reach up to 47m/s. The districts very close to Bangladesh (i.e., Karimganj, Hailakandi and Cachar), which lie to the south of the Kopili river basin, are in a very high damage zone, due to close proximity of Bay of Bengal, where wind speed can reach up to 55 m/s and result in large-scale damage (ASDMA, 2016). The base line risk of strong winds from cyclones thus remains high.
- **Climate Change Assessment:** On the analysis of a climate change impact on cyclone frequency, (Ji, 2015) has recorded that a predicable trend does not exist. It is noted that 'most studies (Webster *et al*., 2005; Niyas *et al*., 2009; Habib, 2011; Hussain *et al*., 2011) for the North Indian Ocean agree that the frequency of tropical cyclones is declining, while the intensity of cyclones has been observed to have increased. It is extremely difficult to confirm whether the impact of climate change has exceeded the natural variability and has manifested a detectable signal. In terms of historical tropical cyclone activity, a 2010 WMO assessment of tropical cyclones and climate change concluded that "it remains uncertain whether past changes in tropical cyclone activity have exceeded the variability expected from natural causes." This conclusion applied to all basins around the globe[37]. (Ji, 2015) further notes that according to (IPCC, 2007), "there is less certainty about the changes in frequency and intensity of tropical cyclones on a regional basis than for temperature and precipitation changes… however, extreme rainfall and winds associated with tropical cyclones are likely to increase in South Asia". Simulations (Unnikrishnan *et al.*, 2011) of tropical cyclones in the Bay of Bengal from the regional climate model (PRECIS) show an increase in the frequency of cyclones in the Bay of Bengal under the A2 scenario compared to the baseline (1961-1990). The risks of wind could be expected to increase in the future.

River Bank Erosion	Low	Medium	Medium	

- **Evaluation:** The ASDMP baseline river bank erosion risk analysis focuses upon the more serious problem of Brahmaputra river bank erosion, with no mention of this being a problem in the upland hills. Field assessment of the intermediate catchment river banks below the Khandong dam and in the LKHEP dam site reveals the Kopili river to be heavily incised into the plateau landscape, exposing the gneiss and granite bed rock in the river bed and along the river banks. Due to the abundance of rocky boulders and exposed bed rock along the Kopili river bank, and the lack of substantial areas of sediment deposit in the steep landscape and high gradient river, there is virtually no risk of river bank erosion.
- **Climate Change Assessment:** The predicted increase of daily rainfall intensities and thunderstorms will have a medium impact in increase of the flood peak flows in the catchment rivers. This may have a medium impact on possibility of river bank erosion.
- **Catchment Management Assessment:** The influence of catchment land cover and land management will be primarily upon the incidence of flood peaks in the river, which can cause river bank erosion. Poor management of the upper high rainfall catchment areas, leading to land and soil infiltration degradation, will lead to a trend of increasingly larger flood peaks in the catchment rivers year by year. This trend will have high risk of increasing river bank erosion in the susceptible sites. In the LKHEP intermediate catchment, the risk is medium, because of the larger area of forest cover, which protects from soil and land degradation, and will have an influence in buffering the flood peaks in the river system, and will not lead to a trend of increasing flood peaks year by year.

Erosion and Sediment	Medium	High	High	

[36] The confidence level is low due to the fact that there exists a large degree of uncertainty regarding the future scenarios of cyclone activities within the North Indian Ocean.
[37] http://www.gfdl.noaa.gov/global-warming-and-hurricanes

Type of Risk	Overall Risk / Hazard	Climate Impact	Land Cover Impact	Climate Variables / Confidence
Transport				

- **Evaluation:** The ASDMP baseline erosion risk analysis makes no mention of the Dima Hasao or Karbi Anglong districts, so assumedly the risk is low. General mention is made, however, of high rainfall (more specifically high intensity rainfall) being an important factor causing erosion from surface run-off in almost all the districts mainly due to higher gradient/slope. The upper, higher rainfall, western intermediate catchment (upper Myntiang river) and upper catchment will show higher risk of soil surface erosion under the cropland, shifting cultivation and cropland / woodland mosaic, particularly on the steeper (> 30% slope) valleys of the incised river valleys. The situation will be made worse if over-grazing from local cattle is allowed in these upper catchments. The eastern intermediate catchment, and along the Kopili river valley, is alternatively covered by over-grown teak forest plantations, with good understory and ground cover. These areas of the intermediate catchment offer low risk of erosion. In view of this there is a medium to high risk of soil surface erosion in the high rainfall upper catchment above the upper dams, which will lead to sediment mobilization in the rivers. This sediment, however, will be captured in the Khandong and Umrong reservoirs, and will not impact upon the LKHEP. In the intermediate LKHEP catchment there is a medium erosion risk in the higher rainfall western catchment in Meghalaya state, which will lead to sediment (mainly sand) mobilization from the Myntiang river catchment. Along the Kopili river banks there is much less risk of hill slope erosion due to the forest cover, however there is a build-up of sands along the river banks which could be mobilized during more extreme floods.
- **Climate Change Assessment:** The predicted increase of daily rainfall intensities and thunderstorms will have a high impact on the erosivity caused by rainfall in those areas of the catchment which are prone to erosion (noted above) and which have poor ground cover to resist the erosion impact. There is a high risk of increased soil surface erosion under the higher intensity rains. With regard to sediment, mainly sand, mobilization, the increase of the flood peak flows in the catchment rivers due to increased daily rainfall intensities and thunder storms will lead to a high risk of increased mobilization of sediments and sand. This, however, will be moderated by the dry catchment conditions caused by higher temperatures, higher evaporation and lower rainfall and rain days. The threshold for catchment wetness to cause overland flow, and flood generation from smaller catchments, will be higher.
- **Catchment Management Assessment:** The influence of catchment land cover, land management and land degradation will be strong on the incidence of flood peaks in the river and upon the transport of sediment and sand in the catchment rivers. Poor management of the upper high rainfall catchment areas, on steep slopes particularly, will lead to land and soil infiltration degradation, which will lead to a trend of increasingly larger flood peaks in the catchment rivers year by year. In the LKHEP intermediate catchment, the risk is medium, because of the larger area of forest cover, which helps prevent soil and land degradation, and will have influence in buffering the flood peaks in the river system, and will not lead to a trend of increasing flood peaks year by year. If the forest is cleared, degraded or burnt, however, there will be a large effect on the catchment flood peaks and sediment and sand transport into the LKHEP reservoir.

Lightning	High	High	N / A	Temperature rise – low Increase thunderstorms – high

- **Evaluation**: (Ji, 2015) assessed the lightning risk of the LKHEP project as high. It was noted that lightning is one of the most serious causes of over-voltage. Lightning can result in strikes to a phase-conductor and towers with no earth wire, and over-voltages. Transients or surges on the power system may originate from switching and from other causes, but the most important and dangerous surges are those caused by lightning. Lightning surges may cause serious damage to the expensive equipment in the power system (e.g., generators, transformers, etc.) either by direct strikes on the equipment or by strikes on the transmission lines that reach the equipment as traveling waves. Additionally, lightning-originated surges can also cause damage, depending on their amplitude and energy content, to the power components connected to the networks as well as the relevant electronic devices. One of the most significant losses that it may cause, as far as the industries are concerned, is the downtime.
- **Climate Change Assessment**: (Ji, 2015) noted that it is generally expected that lightning activity will increase in a warmer climate (IPCC, 2007) as numerous climate model simulations have shown. Although the parameterizations of lightning in the models are quite crude, the models nevertheless manage to duplicate the present global lightning climatology, and all of the model studies indicate that there could be

Type of Risk	Overall Risk / Hazard	Climate Impact	Land Cover Impact	Climate Variables / Confidence
fewer thunderstorms overall, but they could become more intense, which in turn may increase the amount of lightning by 10% for every 1 degree of global warming. The current climate scenario assessment, based on regional empirical studies, would suggest that thunderstorm activity is already high in Assam, in both pre-monsoon and post-monsoon seasons. With the prediction that thunderstorms and high intensity daily extreme rains will increase with a rise in temperature (as suggested by IPCC above), there is a high risk of an increase in lightning in the LHHEP area due to climate change.				

Table 12. Summary of perceived climate risks and "knock-on" effects.

Parameter	Expected Trends and Risks
Temperature	*Continuing minor increase in mean annual temperature (a further 0.16 °C by 2050, with temperature increases greater during the non-monsoon season).* • Increased evaporation rates (from the river/reservoir), especially during the lean season (non-monsoon), but almost negligible.
Rainfall	*Continuing minor decrease in total annual rainfall (0.85% less in 2050, compared to now). Fewer rain days and less rain in the monsoon. However, an increase in the rainfall intensity during extreme weather events (so, ultimately less rain annually, in fewer but more intense rainfall events).* • Somewhat reduced monsoon season river flows (average over the period). • Somewhat reduced dry season river flows (average over the period). • Increased magnitude of storm flood peaks (generally during the early and late monsoon). • Increased slope erosion and sediment transport due to increased rainfall intensity and larger flood peaks during the period April-October.
Winds	*Increased risk of high velocity winds due to extreme weather events (correlated with more intense rainfall during extreme weather events), but the frequency of such events is not well-forecast.* • Increased wind speeds can increase the risk of tree felling and subsequent soil erosion (where exposed). Also, increased risk of damage to infrastructure (such as transmission towers).
Lightning	*Apparent increased risk of lightning frequency, correlated with the increased intensity of extreme weather events (more apparent than an increased frequency of such events).* • Increased risk of lightning strikes on power infrastructure (such as transmission towers).

3.2.2 Revised Climate Vulnerability Assessment

Summary of main climate risks

The revised climate risk technical assessment above outlines that the three risks of landslide, river bank erosion and fires are low by baseline risk, are only moderately affected by climate change, and may be controlled most effectively by catchment land cover planning and land management (i.e., which will be implemented anyway to address the higher priority climate risks). These risks are assessed not to be a priority for LKHEP focus, as they will not impact on project vulnerability.

The climate risks which are a priority are:

- those with low to medium baseline risk, but have medium to high risk of increase due to climate change and poor catchment and land management – i.e. floods, droughts and erosion / sediment transport; and
- those with high baseline risk, either low to high risk worsening under climate change, and no linkage with catchment or land management – i.e. cyclone winds and lightning.

Project Vulnerability

In view of the climate change scenarios discussed in Section 3.1, the climate risk technical assessment in Section 3.2.1, the identified key induced risks which act as drivers of impact upon the project are the catchment function / hydrological change risks of floods, drought and sediment transport, and the climate risks of cyclonic winds and lightning. Both sets of factors could impact upon either the LKHEP project operation and/or structures.

Project Components

In review of the project structures which may be negatively impacted by the identified key climate risks, the main civil works of LKHEP, as defined by the DPR (Lahmeyer India, 2015a), are listed as follows:

a) Dam - A concrete gravity dam with sluice spillways, 345.15 m long, 70.13 m high across the Kopili River at Longku.

b) Intake Structure - An independent intake structure with trash racks located 30 m upstream of the Dam, to carry a discharge of 112.71 m^3/sec.

c) Head Race Tunnel - 6.65 m diameter, 3,619.62 m long, Modified Horse shoe section, with one adit 334 m long, 6.0 m diameter D-shaped.

d) Surge Shaft - 25.0 m diameter, 82.9 m total height with a restricted orifice of 3.6 m diameter provided as a riser shaft of 32.21 m height.

e) Valve House - The valve house is an underground cavern of size 19.90 m (L) x 11.50 m (W) x 17.25 m (H). An EOT crane is also provided inside the Valve house for installation and maintenance of the valve.

f) Pressure Tunnel - 5.20 m diameter, 703.8 m long up to the bifurcation at 75 m upstream of D-line in the Power House. The pressure tunnel is steel lined for its full length.

g) Penstock - 2 penstocks of 3.70 m diameter, fully steel lined, with lengths varying from 75 to 80 meters from the bifurcation point to the power house.

h) Power House - A Surface type power house is proposed to accommodate 2 units of 55 MW each. Power House building of size 77.55 m (L) x 21.50 m (W) at the elevation of the service bay, with a common EOT crane 230 / 40 t capacity over units and service bay. To be located on the Kopili River near Longku village of Lanka Taluk of Karbi Anglong district.

i) Draft tube gates - 2 draft tube gates at EL. 92.00 m are proposed.

j) Tail race channel - 26.3 m wide and 52.0 m long rectangular channel with reverse slope of 1 in 5, designed for carrying a discharge of 112.71 m3/sec.

k) Auxiliary Power House - A surface type power house is proposed to accommodate 2 units of 2.5 MW each and 1 unit of 5 MW total 10 MW. Power House building is located just downstream of dam on the right bank side.

l) Tail Race channel of the Auxiliary Power House is an open channel.

m) New access roads in the immediate project vicinity (13.1 km); upgrades of existing roads.

n) New transmission lines, north and south of the project area (total of 70 km); substation upgrades.

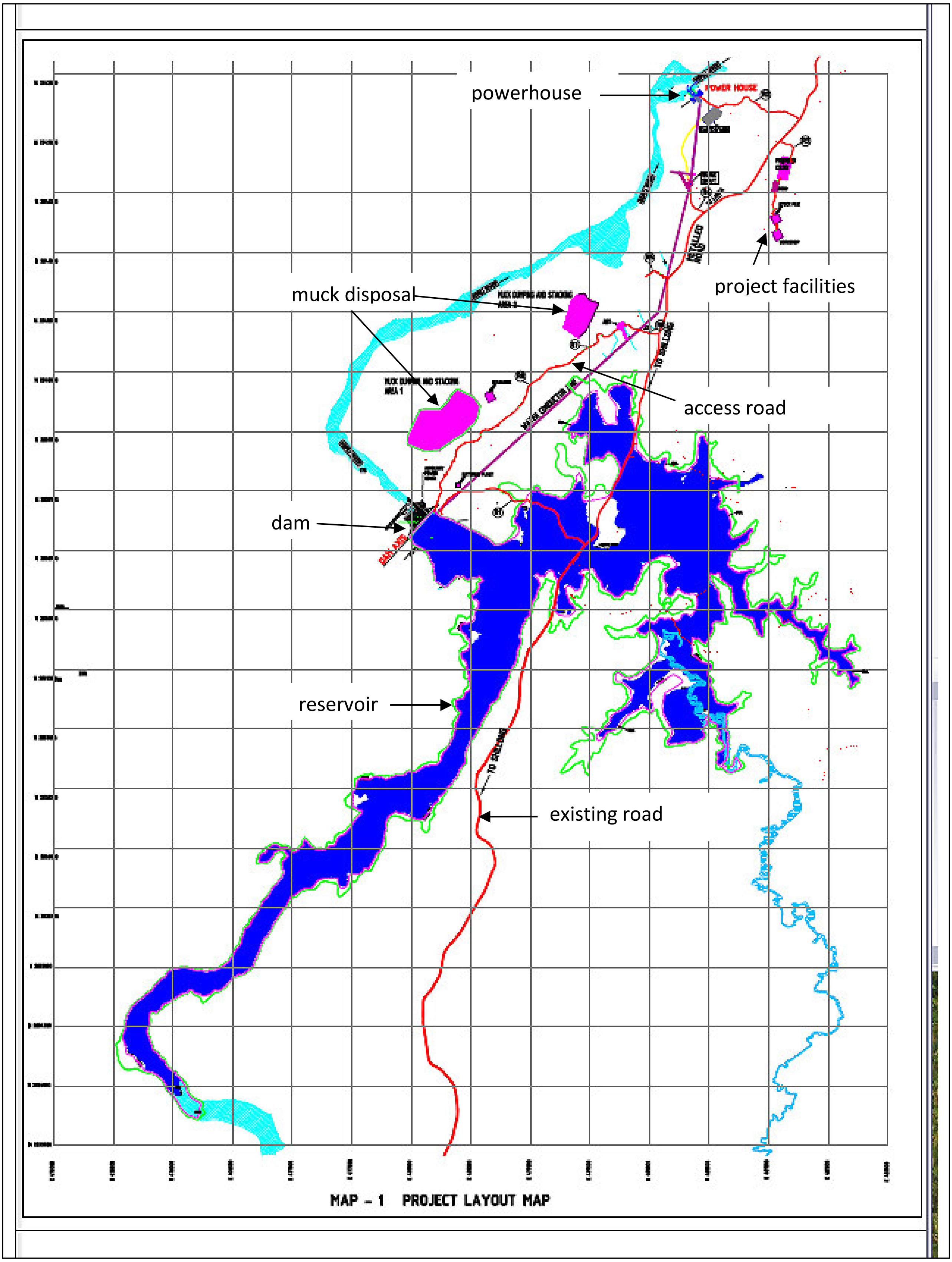
The LKHEP dam and electricity generation will be run as a 120 MW run-of-the-river system (with peaking power), with the project expected to run at its full capacity during the monsoon season, and as a supplementary station to offset the peak load requirements during the non-monsoon season. The dam construction will form a reservoir with a capacity of 106.29 Mm^3 at FSL of 226.0 m a.s.l, to give a live storage of 77.29 Mm^3, and a reservoir inundation surface area at FSL of 394 ha. There will be a design maximum water level of 229.60 m a.s.l. (giving some flood buffering capacity). An outlined in the project footprint in Figure 22, there also should be two or three bridges constructed to pass the current road over the reservoir.

From the above analysis of the LKHEP civil works structures and site development it would appear that the structures and project operations vulnerable to the current assessed key climate risk impacts are the:

- dam, intake structure, reservoir, bridges and electricity generation and dam operating procedures – which will be vulnerable to the impact of the catchment hydrological change and changed catchment conditions (i.e., floods, droughts, erosion levels, and sediment transport); and,
- transmission lines and switching yard associated with the project (not listed in LKHEP project details in the DPR, but addressed in the updated EIA) – which will be vulnerable to the climatic risks (i.e., cyclone winds and lightning).

The effort towards development of adaptation options should thus be focused on these structures and operating procedures.

Figure 22. LKHEP Project Footprint.



3.3 Potential Adaptation Options

Dam: the dam will be primarily impacted by any increases in Kopili river flood peaks, and secondary consideration may need to be given to the possible adjustment of dam height to add reservoir storage volume to counter the projected increase in hydrologic drought. The apparent need for adaptation and potential adaptation measures are as below:

- **Flood peak increase:** (Ji, 2015), in the project risk screening assessment, has made comment that the LKHEP spillway flood capacity appeared under-designed versus the catchment size and risk of increase in flash floods. A re-analysis of the DPR (Lahmeyer India, 2015a) would suggest that the current spillway design, by baseline, is already adequate for the total catchment size. The DPR outlines the LKHEP spillway to be designed with 11,248 m^3/s maximum capacity as defined by a 500 year return design flood[38] (calculated using the empirical approach). Following the IS code for dam design, the DPR (Lahmeyer India, 2015a) outlines the inflow design flood for the dam should be the Probable Maximum Flood (PMF). The PMF in the Kopili River at the LKHEP site (calculated using the deterministic approach) is 11,030 m^3/s. This is less than the spillway design capacity above. The DPR explains that the calculation of the PMF has been made using a total catchment area of 2,076.62 km^2 above the LKHEP site, assuming that the upper catchment has no dams and is unregulated[39]. The assumption was made to yield safer flood design values for the LKHEP dam, whereas in reality, there will be flood moderation taking place due to the upstream dam storage volumes. In comparison to the maximum floods recorded from the hydrological record of the total upper basin, the DPR outlined an average maximum 10-day flood discharge in the Kopili River in the monsoon season of only 495.6 m^3/s, and in the non-monsoon season, only 184.3 m^3/s. These rather modest current Kopili River maximum floods are far below the current dam spillway design discharge for a 500 year return flood, and also far below the 25 year return flood value of 5,985 m^3/s. The CRVA analysis concludes that the dam and spillway thus appear already well designed to withstand any small or medium increases in flood peak magnitudes likely under the more intense rainfall and thunder storms projected by the climate risk analysis. The DPR also adds confidence to this by outlining that the PMF has already been designed using the Probable Maximum Precipitation (PMP) obtained from IMD for the catchment (i.e., 519 mm for a 1-day storm; and 799 mm for a two-day storm)[40]. These rainfall figures suggest that the PMP and dam spillway design are already adequate to cope with any small to medium climate change induced increases in rainfall intensity. Thus, no further adaptation measures are needed.
- **NEEPCO communication on flood control:** It would appear that beyond the potential impact of climate change on increased extreme rains and flood peak magnitudes and frequency, there is the question of NEEPCO upstream dam operation. Assessment by (Ji, 2015) of downstream flood damage, and increased flood incidences in the Kopili River, since the commissioning of the upstream dams, suggests that NEEPCO may be operating their dams in a way that increases flood risk. The DPR above has suggested that NEEPCO conducts no flood control or gate operation on their dams. As a flood adaptation measure, effective communication between NEEPCO and APGCL needs to be established, to confirm that the dam operation rules and actual operation conducted by NEEPCO with regard to flood control and dam releases will be correctly implemented. In the

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[38] The design flood for construction diversion works has alternatively adopted a 1/25 year flood of 720 m^3/s.

[39] The DPR outlines that this was done because both the Khandong and Umrong reservoirs are noted to be specifically designed for generation of hydropower only, without significant flood control. The Umrong is a pick-up reservoir, developed for power generation utilizing release from the Khandong reservoir. One of the reservoirs has an ungated spillway to pass floods, while the other operates with gates open. There is also no diversion for consumptive uses (Lahmeyer India, 2015a).

[40] The DPR also analyzed catchment rainfall data records for storm rainfall for the non-monsoon (November to May) season and found a peak value of 173 mm observed 13th Nov 2002 at Garampani (Lahmeyer India, 2015a).

event that NEEPCO is implementing dam flood release through gate operation, the implementation of releases needs to be communicated promptly to the APGCL dam operators downstream, so that they can take appropriate action to reduce flood impacts.

- **Hydrologic drought:** In view of the projected slight decreases in average annual and monsoon rainfall, a slight decrease in rain days and an overall increase in catchment dryness, there will be an increased risk of reduced low flow magnitudes and longer periods of low flows during the non-monsoon period. It is, however, assumed that the expected slight decrease in monsoon period river average flows will not affect the run-of-river operation for power generation from the dam. If the impact of less non-monsoon period power generation is considered serious, a consideration may be given to adapting the LKHEP project by raising the dam and spillway height to a higher FSL to increase the storage volume of the reservoir, to provide more storage capacity to counter the decrease in non-monsoon season river low flows, and longer low flow periods.
- **Catchment management:** Refer (below) to the generic discussion of catchment management required to moderate flood peaks, hydrologic drought, and sediment transport.

Reservoir: The reservoir will be impacted primarily by an increase in sediment (sand) transport which will reduce the live storage volume of the reservoir, and may also need to be adjusted in terms of design storage volume to counter the increase in hydrologic drought, as well as the maximum water level to add more flood buffering capacity. The apparent need for adaptation and potential adaptation measures are as below:

- **Flood peak increase:** In view of the fact that the current dam spillway design, as analyzed above, appears adequately adapted to cope with any climate change induced increase in flood peak magnitude and frequency, there would appear to be no need to consider an alteration in the design of the dam maximum water levels, and reservoir volumes or area, to cope with the increased floods.
- **Hydrologic drought:** See comments above under the dam section on the impact of hydrologic drought on the dam design and reservoir storage volumes. In summary, if the projected decrease in non-monsoon season LKHEP electricity generation is considered serious, a raising of the dam wall, spillway and reservoir FSL may need to be considered. As such the reservoir will increase in storage volume and inundation area.
- **Sediment transport:** There is an increased risk of sediment (mostly sand) transport due to climate change induced increases in extreme rainfall intensity and thunderstorms. This is expected to result in higher levels of catchment erosion and transport of finer sediments and sand into the river system, and a higher magnitude and more frequent flood peaks to increase transport of the eroded sand and finer sediments along the Kopili River from intermediate catchment sources into the reservoir. Over the long term, this will decrease the live storage volume of the reservoir, and the overall reservoir life. To some extent, the dams further upstream and their own related reservoir management can reduce the sediment load between those structures and the LKHEP reservoir (most of the sediments in the upper catchment are already being trapped in those upper reservoirs). Further, as most of the mobilization of sediments will occur during the monsoon, when discharge volumes in the Kopili are quite high, sluicing of water in the LKHEP reservoir from gates near the bottom of the dam could allow the accumulating sediment load in the reservoir to flush through, which, while adding a turbidity peak to the lower river system, will occur when natural turbidity levels are already quite high in the Kopili River. Further adaptation measures for sediment transport impact include the catchment management options outlined below.
- **Catchment management:** Refer (below) to the generic discussion of catchment management required to moderate flood peaks, hydrologic drought, and sediment transport.

Dam operating procedures: The LKHEP dam operation procedures may have to be adjusted in the face of increased magnitude and frequency of river flood peaks, and possibly in case of increased hydrologic drought. The apparent need for adaptation and potential adaptation measures are noted below:

- **Flood peak increase:** Given that the current dam spillway design, as analyzed above, appears adequately adapted to cope with any climate change induced increase in flood peak magnitude and frequency, there would appear to be no need to consider an alteration in the LKHEP dam operation procedures.
- **Hydrologic drought**: In view of the climate change induced risk of increased hydrologic drought discussed under the dam and reservoir sections above, one could consider adapting an altered non-monsoon dam operation procedure during non-monsoon low flow periods by reducing the environmental flow releases to the lower catchment. This would counter, to some extent, the loss of stored water and electricity generation due to extended low flow periods. However, this is **not** recommended, since eflow is a project environmental obligation and even more important if the river system is experiencing low flows anyhow during the lean season (downstream tributaries to the Kopili River, which are an essential part of the downstream river management plan, would also be experiencing lower discharges).

Intake structure: The intake structure will be vulnerable to catchment erosion levels and sediment (mostly sand) transport. The apparent need for adaptation and potential adaptation measures are noted below:

- **Sediment transport:** As note for the reservoir above, there is an increased risk of fine sediment and sand transport due to climate change induced increases in extreme rainfall intensity and thunderstorms. This is expected to result in higher levels of catchment erosion and transport of finer sediments and sand into the river system, and a higher magnitude and more frequent flood peaks to increase the transport of the eroded sand and finer sediments along the Kopili River from intermediate catchment sources into the reservoir. This may result in an increase of sand transport to the site of the intake structure, thus raising a risk that sand will pass into the intake structure and onward to the power house to cause damage to the turbines. Consideration should be given to intake siting and engineered protection barriers to halt sand transport into the intake tunnel (finer sediments, like suspended silt will just flow through). The only other adaptation for this impact is the catchment management option outlined below.
- **Catchment management:** Refer (below) to the generic discussion of catchment management required to moderate flood peaks, hydrologic drought, and sediment transport.

Bridges: The bridges will be vulnerable to any increase in magnitude and frequency of river flood peaks. The apparent need for adaptation and potential adaptation measures are noted below:

- **Flood peak increase:** Due to the projected increase in flood peak magnitude and frequencies due to increased daily rainfall intensities and thunder storms, attention should be given to review the design flood specification of these bridges to ensure they can safely withstand increased flood events and magnitudes. The other adaptation is to focus attention on catchment management to ensure that the trend in flood peak increase does not worsen over the long-term.
- **Catchment management:** Refer (below) to the generic discussion of catchment management required to moderate flood peaks, hydrologic drought, and sediment transport.

Electricity generation: The LKHEP electricity generation potential will be vulnerable in the short term to any increased hydrologic drought which will reduce electricity generation capacity, and in the long term to any increase in sediment (mostly sand) transport which will reduce the live storage volume of the reservoir and affect the projected dam and project life. The apparent need for adaptation and potential adaptation measures are noted below:

- **Hydrologic drought:** See the notes in the reservoir section (above) that outline the risk of impact of decreased non-monsoon season river low flows, and increases in the periods of low flow, which will impact on reservoir storage volumes and result in reduced electricity generation. The porposed adaptation is to consider an increase in reservoir storage volume, by raising the dam and spillway height. The other adaptation is to focus attention on catchment management, to ensure that the trend in low flow decrease does not worsen over the long term.

- **Sediment transport:** See the notes in the reservoir section (above) that outline the risk of impact of increased sediment and sand transport into the reservoir, which will impact operations by reducing reservoir live storage volume and result, in the long-term, in a reduced electricity generation. The only adaptation for this is to focus attention on catchment management, to ensure that the trend in catchment erosion and sediment transport to the river system, and sediment transport along the river system by increased flood peak magnitudes and frequency, will not worsen in the long-term.
- **Catchment management:** Refer (below) to generic discussion of catchment management required to moderate flood peaks, hydrologic drought, and sediment transport.

Generic Catchment Management Effort: To support and prolong the effectiveness of the engineering adaptation options suggested for the dam, reservoir, intake structure, electricity generation potential and bridges associated with the LKHEP, and guard against exacerbation of the predicted climate induced trends of increased floods, hydrologic drought, catchment erosion, and sediment transport, there will need to be a generic adaptation effort towards improved catchment management. The focus would be as follows:

- reducing the trends of deforestation, over-grazing and excessive livestock numbers, fires and unsustainable erosion-inducing shifting agriculture and cropping practices;
- most particularly in the higher rainfall catchment areas (> 2,000 mm / year) and on steep land with slopes > 33%; and,
- under these in cooperation with a broad range of local and state level stakeholder agencies, inclusive of the State and District Forest and Environment Department, State and District Disaster Management Authorities and the District Agriculture and Livestock and Veterinary Departments, District and local Panchayati Raj authorities and local communities and their traditional leaders.

The overall aim of this effort is to reduce the possibility of land degradation and the initiation of the 'infiltration trade-off effect' (discussed above in Section 3.2.1) which will lead to losses in surface soil infiltration capacity across the landscape, leading to a decadal trend of increased erosion, surface runoff, river flood peaks magnitudes, sediment transport and degradation of the river baseflow, low flows, and increased periods of low flow.

Revised hydrology modeling: An improved assessment of the potential changes in flood patterns, low flows and sediment transport may be needed to produce a finer modeling and/or assessment of possible climate change impacts on the relevant vulnerable aspects of the project (noted above). Notes on the required daily time step hydrologic or hydrodynamic modeling have been made under Footnote 35. The assessment most needed would be to further explore the impact of potential rainfall and rain day reductions on the river hydrology, and the impact of potential hydrologic drought on the monsoon and non-monsoon season electricity generation potential of LKHEP.

Transmission lines and switching yards: These structures are not detailed in the Project DPR (Lahmeyer India, 2015a; however they are addressed in the updated ESIA). They will clearly be necessary for LKHEP project function. The transmission lines and switching yard may be impacted by the high baseline and climate risk of lightning strike. The transmission line will also be exposed to the high baseline risk of strong cyclonic winds. In view of this risk, the adaptation comments previously made by (Ji, 2015) with regard to adaptive strategies (Table 6) are assessed by the CRVA to still remain relevant. These include:

- **Cyclone winds**: The overhead transmission lines must be able to withstand strong winds. A minimum overhead clearance of transmission lines (above vegetation) must be maintained for safety. Material to reduce thermal sag (e.g., aluminum conductor composite core – ACCC) may need to be specified at the project design stage (Ji, 2015). The ASDMP state risk assessment notes that the likely cyclone wind speed risk in Dima Hasao and Karbi Anglong would be 47 – 50 m / sec. The LKHEP structures and transmission lines should thus be designed to withstand these wind speeds.

- **Lightning:** Lightning protection must be installed for the power supply component of the project. Lightning surges may cause serious damage to the expensive equipment in the power system. The most commonly used devices for protection against lightning surges are: 1) earthing screen; 2) overhead ground wires; and 3) lightning arrestors or surge diverters (Ji, 2015).

The adaptation options detailed above are summarized below according to project component operational management requirements.

Table 13. Summary of climate change adaptation options for the various LKHEP components during the operation phase (during which climate change may be evident).

Project Component	Adaptation Options
Dam design and operation (including spillways, sluice gates, and intake structures)	• For the risk of slightly lower accumulated rainfall in the lean season (not so much a concern in the monsoon, which is very variable anyhow), a slight increase in the dam height to accommodate more storage to maintain planned power production levels. A few meters higher would not significantly increase the reservoir area. • Bottom-of-dam sluice gates for sediment evacuation during the monsoon (to accommodate the risk of increased sedimentation in the reservoir due to more extreme rainfall events).
Reservoir management	• Increase the storage capacity (slightly) to accommodate the risk of reduced river discharge (to maintain current planned power production potential). The slightly increased evaporation rate expected with a minor temperature increase would also be accommodated by slightly increased storage capacity. • Undertake sediment sluicing during the monsoon. • Consider regular sediment dredging in the upstream tail of the reservoir (as needed), to address the increased risk of sedimentation in the reservoir (and loss of storage capacity). • Maintain coordination with the dam and reservoir operations upstream to minimize the sedimentation risk in the LKHEP reservoir.
Access roads and bridges	• Road bed heights need to accommodate the highest expected water level during flood events (in the vicinity of the reservoir, which will have a maximum water level defined by both the dam and floodgate operation). • All roads in the vicinity of the LKHEP need adequate cross-road drainage with suitable culverts (correct frequency along the road ways and adequate diameter). • Bridges need adequate freeboard above all predicted flood levels and scouring protection for all bridge footings.
Transmission towers and lines	• Structural design to include suitable cross-braces and structure member thickness, as well as over-engineered tower-to-foundation connections, to accommodate the possible

Project Component	Adaptation Options
	increased frequency of cyclones in the LKHEP area. • Surge diverters and grounding schemes to reduce the risk of system damage due to lightning strikes (this is a standard procedure, in any case). • Adequate line height above vegetation (especially trees) to avoid the risk of line breaks during cyclone events.
Substations	• Adequate freeboard and berming/cross-drainage, to protect substations from an increased flood risk. • As above, surge diverters and grounding schemes to protect substations from an increased risk of lightning strikes.

3.4 Implications of Projected Climate Change Impacts

The major implication of the projected climate change impacts is a potential increase in hydrologic drought, which may reduce the LKHEP non-monsoon electricity generation potential. The seriousness of this reduction on project feasibility needs to be considered; best supported by revised hydrological modeling, at daily time-steps, to refine the understanding of the degree of this impact upon electricity generation schedules and potential. The engineering options to adapt to the increased hydrologic drought, which appear to only be a raising of the dam wall, spillway and FSL height, could be expensive in terms of project cost and added dam inundation impacts (mainly undefined social and resettlement impacts; however, expected to be slight if reservoir levels were to increase by only 2-3 meters). Hence, a decision will need to be made as to whether the level of loss in non-monsoon electricity generation warrants the expense.

The risk of flood impact appears to already be covered by the dam design (i.e., adequate PMF and spillway design flood specifications). Hence, this climate change risk appears as if it will not translate into any extra engineering adaptation costs. There will, however, be an institutional need to establish better communications between NEEPCO and APGCL, in order to ensure that the upstream Khandong and Umrong dams are operated in coordination with the LKHEP dam, in an effort to reduce the 'artificial' flood impacts on the Kopili River, which could overlay the underlying climate change induced increase in flood events and magnitudes.

The climate change induced impact of increased fine sediment and sand transport into the LKHEP reservoir, loss of live storage and possible damage to turbines, has few engineering adaptation options (apart from regular sluicing of accumulated sediments during the monsoon). Hence, the extra engineering cost to adapt to this trend will be modest (i.e., increased protection of the intake structure from sand input). The major cost to address the increased sediment transport impact will be improved upper catchment management (now defined in the watershed management plan; 2017).

As the suggested multi-stakeholder approach to improve catchment management may be both unfamiliar to APGCL and considered beyond the boundary of LKHEP project development, the message needs to be stressed to APGCL and the Assam State Government that their LKHEP investment may be put more at risk by the potential impacts of catchment degradation alone in increasing the flood peaks, decreasing the baseflows, and increasing sediment transport in the Kopili River. When combined with the negative effect of projected climate change impacts on the same catchment functions, the case for a combined adaptation program addressing both climate change and catchment degradation, will assume more urgency, particularly in view of the long-term negative impacts of hydrologic drought, sediment transport, and electricity generation reductions on the combined operations of the Khandong, Umrong, and LKHEP dams.

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Climate Models and Scenarios Referred to in this Document[41]

rcp 8.5 Scenario: Representative Concentration Pathways (RCP), with an emissions scenario in which the radiative forcing level reaches 8.5 W/m^2 (irradiance, in watts per square meter). This is characterized by increasing greenhouse gas emissions over time, representative for scenarios in the literature leading to high greenhouse gas concentration levels, over the period 2006 – 2100. RCP 8.5 was developed using the MESSAGE model and the IIASA Integrated Assessment Framework by the International Institute for Applied Systems Analysis (IIASA), Austria.

rcp 4.5 Scenario: As above, with projections for temperature showing the level of radiative forcing by greenhouse gas emissions stabilizing at 4.5 W/m^2 by 2100. RCP 4.5 was developed by the GCAM modeling team at the Pacific Northwest National Laboratory's Joint Global Change Research Institute (JGCRI) in the United States. It is a stabilization scenario, in which total radiative forcing is stabilized shortly after 2100.

PRECIS (Providing REgional Climates for Impacts Studies): Developed at the Hadley Centre at the UK Met Office, PRECIS is a regional climate modelling (RCM) system designed to run on a Linux-based PC. PRECIS can be applied to any area of the globe to generate detailed climate change projections. PRECIS is designed for researchers (with a focus on developing countries) to construct high-resolution climate change scenarios for their region of interest. These scenarios can be used in impact, vulnerability and adaptation studies, and to aid in the preparation of National Communications, as required under Articles 4.1 and 4.8 of the United Nations Framework Convention on Climate Change (UNFCCC).

IPCC-AR4: The fourth assessment report (2007) from the InterGovernmental Panel on Climate Change. A fifth assessment report has also been completed.

HadGEM3-RA: HadGEM3-RA is a regional version of the HadGEM3 global model (third version of the Global Environment Model, developed at Hadley Centre, UK Met Office). There are versions which apply to just the atmosphere, or also atmospheric/ocean (AO) interactions. HadGEM3-RA has the ability to reproduce small scale features more realistically than the HadGEM2-AO, due to its high resolution including complicated topography and coast lines, although it has small large-scale drift from lateral boundary forcing. For the surface air temperature and precipitation, HadGEM3-RA shows a similar pattern to projection by the HadGEM2-AO. However, it tends to underestimate warming trends of temperature and inter-annual variability of precipitation.

SMHI-RCA-V4: The RCA is a regional climate model (version 4) for the atmosphere and its exchange with the land surface, developed by the Rossby Centre (Swedish Meteorological and Hydrological Institute). The RCA has its origin from the numeric weather forecast model HIRLAM, based on daily evaluation at the weather forecast service at SMHI and other meteorological institutes in Europe. Both HIRLAM and RCA are hydrostatic models, performing calculations in a discrete grid net over a specified area. The RCA uses a soil surface scheme as well as parameterization of radiation, clouds, turbulence, and precipitation processes. Evaluations of the RCA show that the model, given realistic driving data, can re-create the main features of the observed climate (mostly in Europe) during recent decades with high confidence.

[41] This information has been extracted from the NOAA website, Wikipedia, and the various model generator websites. See the LKHEP Climate Change Risk Assessment Report (ADB, 2016d) for more specific details on the models used.

RegCM-V4: The Regional Climate Model system (RegCM, version 4), originally developed at the National Center for Atmospheric Research (NCAR), is maintained in the Earth System Physics (ESP) section of the ICTP (International Center for Theoretical Physic in Italy). The model is flexible, portable, and easy to use. It can be applied to any region of the World, with grid spacing of up to about 10 km (hydrostatic limit), and for a wide range of studies, from process studies to paleoclimate and future climate simulation.

SNU-WRF-V3: From the Seoul National University; Climate Change Impact Assessment for Hydrology Library (SNU-CAHL) was created to automate the task of updating the projections for climate change scenarios in hydrology. It is a collection of scripts that work together to automate tasks for hydrologic modeling and data management. Currently, available data are downscaled by the Korea Environment Institute and consist of ten time-series scenarios, a combination of two emission scenarios, RCP 4.5 and 8.5, and five Regional Climate Models, HadGEM2-AO, HadGEM3-RA, RegCMv4, RSMv3.1, SNU-MM5 v3, and WRF v3.4, with a special resolution of 1 km in daily and monthly time steps. These input data, are applied to two hydrologic models, IHACRES and GR4J.

YSU-RSM-V3: From Yonsei University, South Korea, a Regional Spectral Model, consisting of a gridded data tool (version 3) developed to process the outputs of regional climate models, including the COordinated Regional climate Downscaling EXperiment (CORDEX) data, with a focus on agriculture.

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