TAAS-0045: Adaptation to Climate Change in the Hydro-electricity Sector in Nepal

Final Report

Submitted by:

Nepal Development Research Institute (NDRI)-Nepal

in collaboration with:

Practical Action Consulting (PAC), Nepal

Global Climate Adaptation Partnership (UK) Limited (GCAP)

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This project, TAAS-0045: Adaptation to Climate Change in the Hydroelectricity Sector in Nepal, is undertaken at the request of the Government of Nepal, and is supported by Climate and Development Knowledge Network (CDKN).

The work is led by Nepal Development Research Institute (NDRI)-Nepal in collaboration with: Practical Action Consulting (PAC), Nepal and Global Climate Adaptation Partnership (UK) Limited (GCAP).

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Acronyms:

AEPC:	Alternate Energy Promotion Centre
amsl:	above mean sea level
CBA:	Cost Benefit Analysis
CC:	Climate Change
CCD:	Climate Compatible Development
CCKP:	Climate Change Knowledge Portal (WBG)
CDF:	Cumulative Density Function
CDKN:	Climate and Development Knowledge Network
CGIAR:	Consultative Group of International Agricultural Research
CIAT:	International Centre for Tropical Agriculture
CMIP5:	Coupled Model Intercomparison Project Phase 5
COP:	Conference of Parties
CRA:	Climate Risk Assessment
DFID:	Department for International Development
DHM:	Department of Hydrology and Meteorology
DOED:	Department of Electricity Development
DP:	Development Partner
DWIDP:	Department of Water Induced Disaster Prevention
ε^P:	Precipitation elasticity of runoff
ε^Q:	Runoff elasticity of a performance indicator
ε^T:	Temperature elasticity of runoff
E_o:	Potential Evapotranspiration (PET)
ETFC:	Electricity Tariff Fixation Commission
EIRR:	Economic Internal Rate of Return
ET:	Actual Evapotranspiration
EWS:	Early Warning System
FAO:	Food and Agriculture Organization
FIRR:	Financial Internal Rate of Return
GCAP:	Global Climate Adaptation Partnership
GCM:	Global Circulation Model (a.k.a. General Climate Model)
GDP:	Gross Domestic Product
GFDRR:	Global Facility for Disaster Reduction and Recovery
GHG:	Green House Gases

GLOF:	Glacial Lake Outburst Flood
GoN:	Government of Nepal
GW:	Giga Watt
GWh:	Giga Watt hour (energy)
GWP:	Global Water Partnership
H:	Head of power station (m)
HEP:	Hydroelectric plant
HP:	Hydropower
IBN:	Investment Board of Nepal
IC:	Installed Capacity
ICIMOD:	International Centre for Integrated Mountain Development
ICRM:	Iterative Climate Risk Management
IFF:	Investment and Financial Flow
INPS:	Integrated Nepal Power System
IPCC:	Intergovernmental Panel on Climate Change
IPPAN:	Independent Power Producers Association of Nepal
IRR:	Internal Rate of Return
ISET:	Institute for Social and Environmental Transition
IWRM:	Integrated Water Resources Management
IWMI:	International Water Management Institute
LAPA:	Local Adaptation Plans of Action
LCE:	Levelised Cost of Energy
LDOF:	Landslide induced Dam Outburst Flood
MoA:	Ministry of Agriculture
MoAC:	Ministry of Agriculture and Cooperative
MoAD:	Ministry of Agricultural Development
MoEn:	Ministry of Energy
MoPE:	Ministry of Population and Environment
MoSTE:	Ministry of Science, Technology and Environment
MW:	Mega Watt
NAP:	National Adaptation Plan
NAPA:	National Adaptation Programme of Action
NASA:	National Aeronautics and Space Administration (USA)
NAST:	Nepal Academy of Science and Technology

NCCKMC:	Nepal Climate Change Knowledge Management Centre
NDRI:	Nepal Development Research Institute
NEA:	Nepal Electricity Authority
NERC:	Nepal Electricity Regulatory Commission
NPC:	National Planning Commission
NPV:	Net Present Value
NSDRM:	National Strategy for Disaster Risk Management
NWP:	National Water Plan
OECD:	Organisation for Economic Co-operation and Development
O&M:	Operation and Maintenance
P:	Precipitation (mm)
PACN:	Practical Action Consulting, Nepal
PAC:	Project Advisory Committee
PDA:	Power Development Agreement
PES:	Payment for Ecosystem Services
PET:	Potential Evapotranspiration (Eo)
PI:	Performance Indicator
PMF:	Probable Maximum Flood
PMP:	Probable Maximum Precipitation
PPA:	Power Purchase Agreement
PPCR:	Pilot Project for Climate Resilience
PRoR:	Peaking Run-of-River
PTA:	Power Trade Agreement
Q:	Runoff, streamflow (m3/s or mm/year)
RCM:	Regional Climate Model
RCP:	Representative Concentration Pathways (CMIP5)
RDM:	Robust Decision Making
RoR:	Run-of-riveR (power plant)
SPCR:	Strategic Programme for Climate Resilience
SRES:	Special Report on (GHG) Emission Scenarios
TOR:	Terms of Reference
TYP:	Three-Year Plan
UNDP:	United Nations Development Programme
UNFCCC:	United Nations Framework Convention on Climate Change

USGS:	United States Geological Survey
WASP:	Wien Automated System Planning
WECS:	Water and Energy Commission Secretariat
WRS:	Water Resources Strategy

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Summary

At the request of the Government of Nepal, the Climate and Development Knowledge Network (CDKN) funded this study on the 'Adaptation to Climate Change in the Hydroelectricity Sector in Nepal'. The work is led by Nepal Development Research Institute (NDRI) - Nepal, working in collaboration with Practical Action Consulting (PAC), Nepal and the Global Climate Adaptation Partnership Limited (GCAP)-UK. The objectives of the study are to:

- Develop a solid evidence base on the vulnerability of the hydroelectricity-sector to climate change
- Identify viable adaptation options that enhance resilience;
- Understand and address the challenges of mainstreaming adaptation in the sector;
- To build capacity and help enable adaptation action amongst policy makers and the private sector.

Assessing the future impacts of climate change on the hydro-electricity sector in Nepal is very challenging due to the complex climate and hydrology, as well as the very large changes in elevation that occur across the country. Projections of future climate change show very high uncertainty, with large differences across future scenarios and between climate models.

To address this problem, the study has adopted an iterative climate risk management methodology (Figure 0-1) that specifically addresses the main objectives of the study using three iterative steps:

Step 1- Vulnerability Assessment using the Climate Risk Assessment (CRA) approach;

Step 2- Identification of Adaptation Options using the Adaptation Pathways approach and;

Step 3- Understand and address mainstreaming of adaptation in the sector through Institutional Analysis and identification of entry points and barriers.

This has been complemented with extensive stakeholder engagement, with government, the regulator, developers and the private sector with the aim to build capacity for policy makers and the private sector for adaptation.

A Climate Risk Assessment (CRA) methodology based on a "bottom up" decision-scaling approach is used to test the vulnerability of the hydroelectricity sector in Nepal to climate change. This starts by assessing the sensitivity of Nepal's present hydropower systems – and their performance - to the current climate and then assesses how future climate change could affect this.

The method identifies key performance indicators (PI) significant for hydro-energy generation that may be sensitive to climate and thus puts the initial emphasis on understanding how the present meteorological and hydrological variability affect current operations and planned investments. This has the advantage of focusing the analysis on what matters! It can then look at future climate change, including uncertainty, and see how important future changes could be and how these key PI are affected.

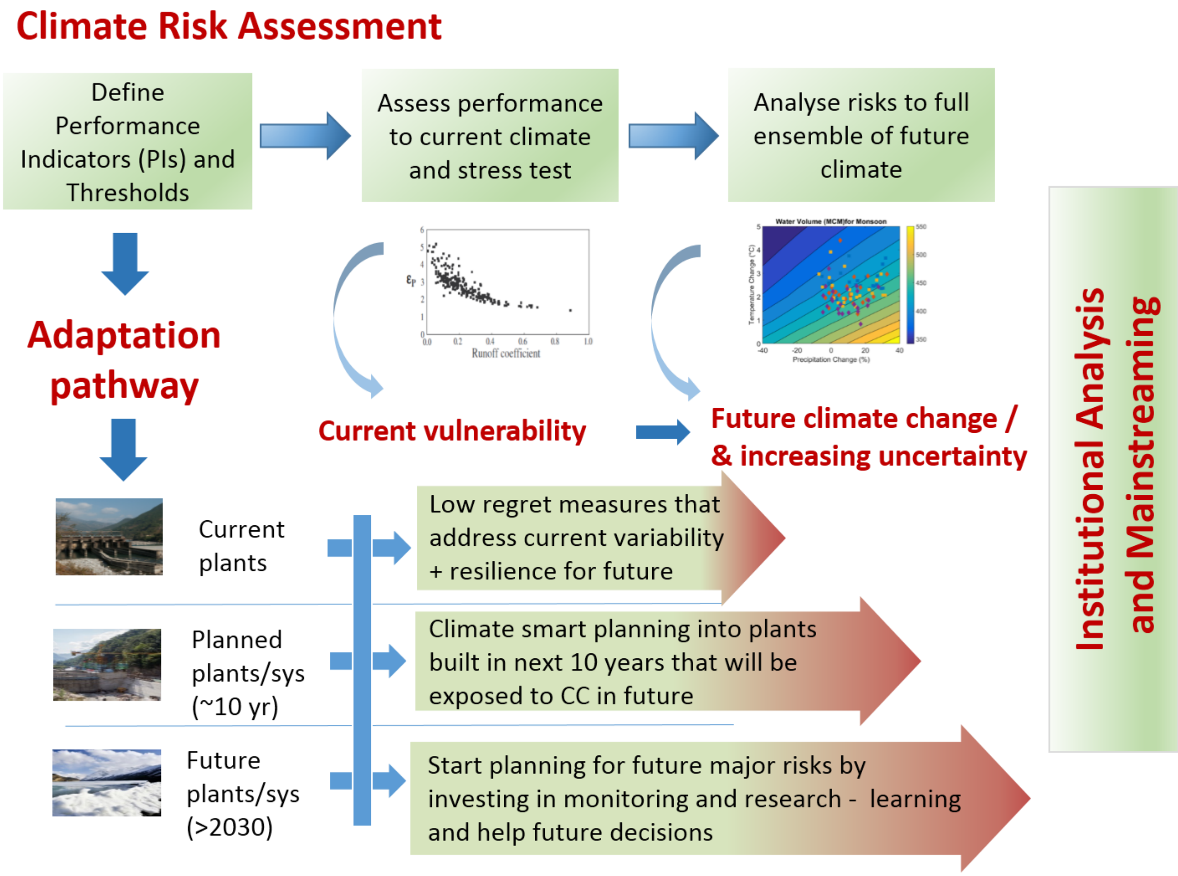

Figure 0-1: Iterative Climate Risk Management (ICRM) Approach of the Study

The CRA has been linked to an iterative adaptation pathways approach, to use this risk information to build up possible adaptation responses under uncertainty.

Critically this has adopted a policy centred approach, which aims to provide information for policy makers and the private sector to implement near-term adaptation. It has also included a strong consideration of the economic justification for adaptation, noting the challenges of uncertainty and discounting.

The method has identified three types of adaptation where decisions, investment or policy could be taken over the next five to ten years, and which will provide information to help address both current climate variability and long-term climate change. These are

1. Immediate actions that address the current risks of weather and climate extremes (the adaptation deficit) and build resilience to future climate change. This includes early low- and no-regret actions, which provide immediate economic benefits as well as future benefits under a changing climate. These activities are focused on current hydro-power plants.

2. The integration of adaptation into immediate decisions or investments with long life-times (climate smart planning), focusing on the new (planned or candidate) hydro-electric plants that will be built over the next decade or so. These plants will be exposed to future climate change but these changes are in the future and uncertain. This therefore involves a greater emphasis on low cost design or flexible or robust options that perform well under uncertainty.

3. Early monitoring, research and learning to start planning for the future impacts of climate change. This includes the investing in information and learning, to help future decisions (through the value of information and option values and learning).

The three interventions can be considered together in an integrated adaptation strategy, often termed an adaptation pathway or portfolio.

To capture uncertainty, the CRA uses multi-model climate projections ensembles and looks at the impacts of climate change on water resources to the time-period of the mid-century. It can therefore consider preparedness for a range of possible futures, and provide information that includes uncertainty.

This is fed into the adaptation analysis, which considers the possible options to address the current and future risks (and the impact on PIs), and then prioritises these based on the costs, benefits and other key criteria.

As the focus of the study is on providing analysis and information to enable current and future adaptation action of risks and opportunities amongst policy makers and the private sector, i.e. with implementation in mind, the study has also built up an extensive understanding of the current policy landscape with institutional mapping.

Key findings of the study are presented below.

Climate risk assessment

1. **A key finding is that current climate and hydrological variability is a major challenge for Nepal's hydro- sector**

The first key finding is that the performance of Nepal's existing hydro-electric plants – and especially smaller run-of-river (RoR) plants - is heavily affected by current climate variability. This leads to a high current vulnerability for the overall hydropower system, and causes high economic impacts.

There are large financial costs to operators of individual plants, from low flows, high floods and sediment load, and geo-hazards (reducing revenue and incurring penalties), as well as high economic costs at the system (national) level, with major power outages and unmet electricity demand.

However, there is a large variation in this vulnerability. It is influenced by catchment elevation, size of catchment and location, as well as the type of plant. To expanid:

- Higher variability is observed in smaller catchments than larger catchments;
- Seasonal and Inter-annual variations are higher in rain-fed catchments than in snow-fed catchments;
- Run-of-river (RoR) projects are more affected than storage type projects due to flow variability;
- Base flow[1] is more dominant in the dry winter season (Dec – Feb) whereas snow melt becomes important in the pre-monsoon season (Mar – May) season;

[1] Baseflow is the portion of river flow that comes from "the sum of deep subsurface flow and delayed shallow subsurface flow".

- Glacier melt currently starts from May/June onwards and the share of glacier melt (in river flow) in these months are reduced due to the onset of monsoon rain.

Furthermore, there is additional vulnerability from a number of geographical-specific risks:

- Sediment levels are high generally in Nepal, but particularly high in some catchments like Marsyangdi, Kali Gandaki, Tamor catchments;
- Power plants in upper catchments with glacier lakes are potentially more vulnerable to Glacial Lake Outburst Floods (GLOF) risks, especially those within 50 to 100 km of potentially dangerous glacial lakes[2];
- Hydropower projects located downstream of degraded watersheds and geologically weak hill slopes are at higher risk from geo-hazards such as landslide induced dam outburst floods (LDOFs);
- Very high and intense rainfall during the monsoon can lead to high peak flows, and these are a high risk to hydropower projects.

2. The impacts of future climate change on hydro-electric plants and the sector are uncertain: this requires a different approach

The lack of reliable and long-term hydro-meteorological data in Nepal is a key limitation to hydrological analysis and modelling work. There is insufficient coverage of hydro-meteorological stations across different catchments, and a particular lack of data for higher elevations. This makes understanding current risks as well as future changes challenging.

This is compounded by the high uncertainty when modelling future climate change in Nepal. There is inherent uncertainty in modelling climate change due to the range of possible future scenarios and the variation in climate model outputs. However, this is exacerbated in Nepal due to the complex climate and hydrology, as well as the very large changes in elevation that occur across the country, leading to high heterogeneity. Projections of future climate change show very large differences (even in sign) across future scenarios, climate models, and across the country (i.e. by elevation and catchment).

Rather than ignore this uncertainty, the climate risk assessment approach addresses it directly. It looks at the range of scenario and climate models (using multi-model ensembles) from the Coupled Model Intercomparison Project Phase 5 (CMIP5) that were used in the latest IPCC report, to assess how the envelope of future climate change will affect the key performance indicators. It can therefore help prepare for the range of possible futures, and help with decision making under uncertainty.

Observational trends show that the climate of Nepal is already warming. Trend analysis of observed temperature data from Climate Research Unit (CRU) for period of 1961-2013 in

[2] The peak discharge generated by GLOF events are attenuated by almost half and 80% in 50 km and 100 km, respectively, from such lakes. The hydro plants located after such distances are found to be normally designed for flood discharge higher (due to the size of the plant catchment area) than the GLOF generated peak discharge. In the case of plants located within 50 to 100 km from potentially dangerous glacial lakes, the peak discharge generated by GLOFs could be higher than the hydrological design flood. Hence, these plants located within 50 to 100 km of potentially dangerous lakes are potentially more vulnerable to GLOF risks.

Nepal shows increasing trend of temperature at the rate of 0.01˚C - 0.04˚C per annum though it varies across the country. Future climate projections show temperature will increase further and this is a robust finding across all the models. GCM model projections show that temperature will increase in monsoon months on an average by about 2˚C in RCP 4.5 scenario and by about 2.6˚C in RCP 8.5 scenario; and in the winter months by about 2.7˚C in RCP 4.5 and by about 3.4˚C in RCP 8.5 scenarios in 2040-2059. However, there is a wide range in the level of warming across different scenarios and GCM models.

Unlike temperature, there is no clear observed trend in precipitation. Future climate projections show wetter monsoon. While about 80% of models agree on increase in monsoon precipitation, their magnitude varies from 6% decrease to 33% increase. They show that, on an average, monsoon precipitation increases by 10.3% in western Nepal and by 7.6% percent in eastern Nepal in RCP 4.5 scenario, and by 15.2% in western Nepal and by 10% in eastern Nepal in RCP 8.5 scenario. There is no agreement regarding winter precipitation. Like for temperature, there is wide range of projections for precipitation across different scenarios and GCM models.

Similarly, precipitation extremes (maximum 1-day precipitation and maximum 5-day precipitation) are projected to increase. Even though, precipitation extremes changes are from 8% decrease to 52% increase, majority of models agree on increase of extremes, on an average, from 8 to 16% across Nepal.

3. **Future climate change will have most impact on hydroelectricity sector by increasing climate induced hazards, i.e. sediment, floods and geo-hazards including GLOFs and LDOFs, rather than overall annual average generation**

As the majority of climate models project increased average precipitation, this implies a positive gain might be expected in overall energy generation. However, this is driven by the increase in monsoon precipitation: the models are uncertain on the magnitude and sign of winter precipitation change.

Based on projections of water availability, hydropower generation - especially for medium and large projects– will be robust to future climate scenarios (2040-2059). The financial performance (in terms of Internal Rate of Return (IRR)) of these projects are found to be within the performance threshold for projected change in water availability due to change in precipitation and temperature. This is particularly true for the current and planned medium and large hydropower projects that are designed under the current tariff and power purchase agreement (PPA) regime.

Rising temperatures will affect snow hydrology and glacier melt and may impact hydro plants with substantial catchments above the snow line (i.e. the winter snow line of > 3000m elevation and the year-round snow line > 5000m elevation) but will have little or negligible impact on plants at lower elevations.

In terms of the national level, 44% of the 69 current and planned ROR/ PRoR projects reviewed in this study are in snow-dominated, higher elevation (H) catchments (with more than 80% of the catchment area above 3000m), 17% are in medium elevation (M) catchments (60-80% above 3000m), 19% are in low elevation (L) catchments (40-60% above 3000m) and 20% are in rain-dominated (R) catchments (less than 40% above 3000m).

In the case of 20 current and planned storage projects, the majority (65% or 13 of the 20), are in more rain dominated catchments (R), with one (5%), two (10%) and 4 (20%) in the H, M and L catchments, respectively.

The study has assessed the impacts of climate change on these different types of plants. This takes account of the complex interaction of hydrological elements like snowfall, snowmelt and evapo-transpiration (ET) from Precipitation (P) and Temperature (T) changes. The study has assessed a range of temperature and precipitation scenarios, to understand how performance varies across the uncertainty envelope.

For a more extreme (worst case) climate change scenario (20% reduction in P and +3^{o} rise in T by the 2050s), runoff decreases for all types of catchment, but the magnitude is greater in lower catchments. This is because evapo-transpiration (ET) losses increase more in hotter, lower catchments. In the pre-monsoon, higher catchments actually gain due to the complex interplay between ET and snowmelt (though the effect varies with the catchment area at higher elevation). Catchments with higher areas above 3000m and 5000m see increased snow and glacier melt but also ET increases. All of these changes are more significant in smaller catchments.

Run-of-river projects that are designed for higher dependable flows are less vulnerable to flow reductions than those designed for higher design discharge but lower dependable flows. This is because higher design flows leads to more energy variations with flow variations. Out of the 69 existing and planned ROR projects. 7% are designed for flows that are equal to 90% dependable flow (Q90), 10% are designed for flows between Q60 and Q90, 62% are designed for flows between Q40 and Q60 and 21% are designed for flows higher than Q40 (or less dependable flows).

Reservoir projects with more live storage lead to better regulation, but they can be more impacted by flow reductions due to climate change during the monsoon period. Out of 20 current and planned storage projects reviewed, 10% have live storage of more than 70% of monsoon (MS) runoff, 10% have from 50% to 70% of MS runoff, 30% have between 25% to 50% of MS runoff, and 50% have less than 25% of MS runoff. This also means that the majority of planned storage projects do not have high seasonal regulation potential.

Increased climate induced hazards – sediment, extreme floods and, GLOFs and LDOFs– are likely to be a more important risk and will be exacerbated by climate change. The climate projections agree on an increase in extreme rainfall events (higher intensity and frequency). This is likely to increase sediment load, floods and geo-hazards.

Sediment loads can be high in Nepal and this can reduce turbine lifetime and increase operational downtime (when loads are high). Sediment yields vary from basin to basin with geological conditions, rainfall, landcover and other natural factors. Hydro-power plants can use sediment handling measures to address these risks, though these depend on location and type of plant.

Another major risk is from Glacial Lake Outburst Floods (GLOFs). These can have major impacts on hydro-electric plants, particularly located near the critical glacial lakes. There have been seven major GLOFs over the past fifty years and one of these led to the loss of a multi-million dollar hydropower facility in 1985.

Hydropower plants that are located within 50-100 km downstream of potential glacier lakes are expected to be more affected by potential GLOF events. This is because the peak discharge generated by GLOF events within such distances can be higher the design flood values of the hydro plants. However, runouts from GLOFs are reported to travel up to 200 km in the Himalayan river. The heavy sediments and debris flows from GLOFs can create problems in these downstream projects. Critical glaciers lakes within Nepal are most densely located in Koshi and Gandaki Basins. There are no critical lakes in the Karnali basin (ICIMOD, 2011). The Dudh Koshi sub-basin includes 9 critical lakes, and the Arun and Tamor sub-basins have 3 critical glacial lakes each. Tsho Rolpa glacial lake lies in Tama Koshi sub-basin. Other glacial lakes are in Gandaki Basin. Breaching of glacial lake dams from a close distance posehigh risks to hydro projects, a case in point is the flood damage in Bhote Koshi Project on 5 July 2016 from a GLOF originating from Tibel, China.

Recently, there have been cases of landslide-induced damming and impounding of large volume of water behind these dams (for example, the Jure landslide in Sun Koshi River in August 2014) impacting hydro plants downstreamLandslide in Myagdi District of Nepal, the area which was affected by April and May 2015 earthquakes, blocked the large Kali Gandaki river impounding water approximately up to 3 km upstream (USGS, 2015). The landslide induced dam breached catastrophically but, fortunately, no human casualties occurred. The impact of hydropower projects downstream are not known.

The higher monsoon peak flows could increase the risks of extreme flows and floods, leading to damage of hydro-electricity plants, with the costs of repair and lost revenues. As an example, there have been recent losses of smaller hydro plants (e.g. Khudi hydropower plant) due to floods.

The expected rise in high flows due to climate change does have implications for the design of hydropower projects and flood design standards. Private developers for smaller/medium ROR projects are currently adopting design flood standards for shorter return periods (e.g. floods with probability of occurrence of 1in100 years, or 1 in1000 years) compared to NEA RoR projects which are designed for higher return periods (e.g. 1 in 10,000 years). Storage projects with substantial storage volume are however designed for a return period of1 in10,000 years or probable maximum floods (PMF). To a large extent, this practice may be attributed (at least partly) to the contractual/regulatory requirement that the ownership of the hydro plants developed by private developers will be transferred to the government after 30 years of their operation. The shorter the period that the plants can be owned and operated by private developers the smaller is the incentive to design and build the hydro plants for a higher flood intensities (i.e., with a higher return periods). In the event that the 30 year period for the plant ownership is to be retained, the regulatory control in terms of more stringent design standards to require the hydro plant construction to with stand the floods with a return period of 1:10,000 or higher must be strictly implemented.

4. **<u>The current power system suffers from an inefficient power mix and mismatch of supply and demand of electricity leading to high economic costs at the system (national) level</u>**

The current power system of Nepal is constrained by severe deficit in supply compared to the electricity demand. Considerable import of power from India and concerted load management by NEA is barely able to avoid load shedding. Inappropriate power mix and lack of capacity in the peak hours and dry season but surplus power in non-peak hours and wet season leads to significant loss to NEA.

One insight from the analysis is that existing and planned future projects are being designed at the project level under the current regime (pricing, market and regulatory policy) without fully considering systems requirements or possible changes in the regime. For example, more than 80% of the ROR projects are designed at discharges with 40% or lower dependability, which are “optimal” under the current pricing regime. Storage capacity of most reservoir projects are also limited, with only 24% storing more than 50% of the average monsoon runoff (June to Sep.) and only 45% generating more than 30% of the total annual energy in the 5 dry months from December to April.

Investment planning carried out under the study shows that more storage type reservoir projects are required to meet the current and future power demand of the Integrated Nepal Power System (INPS). The optimal (i.e., cost minimizing) share of storage hydropower projects in total installed generation capacity required to meet the projected domestic power demand is found to be increasing over time: That is, the share of capacity of both ROR and storage plants will be more or less equal to the order of 46 or 47% in the future. Similarly, with the available type of candidate plants, the energy mix will stabilize at 72% for ROR plants and 18-22% for storage projects.

A limitation of the present investment planning analysis using the WASP model is that it cannot consider the differences between RoR and PRoR hydro plants explicitly. It would be important from the policy and investment planning perspective to determine the optimal mix of RoR, PRoR and reservoir power plant capacities as well as their energy generation mix. This limitation is an issue for future research

The investment planning exercise was also carried out for an adverse hydrological condition of 20% reduction in precipitation and 3^{o}C rise in temperature. The probability of such an extremely dry hydrological condition happening in the next 30 years has a very low likelihood. Such an analysis was made to “stress test” the investment planning with the objective of testing the sensitivity of the key system-level performance indicators such as optimal capacity and energy mix requirement, levelized cost of energy as well as total investment cost.

Thermal generation would increase in adverse hydrological condition compared to Base Case. This is because generation from the ROR hydropower plants would decrease especially in the dry season and more thermal generation or import from India would be required to meet the energy needs. It is found that ROR plants are preferred to storage plants due to the former’s lower cost and high plant factor. Generation from storage plants would decrease while that from ROR plants would increase in some years which is partly attributed to earlier commissioning of the ROR plants in adverse hydrological condition.

The capacity factor of the power projects are defined as the ratio of the actual output and potential output at full capacity. The capacity factor in adverse hydrological condition is less compared to Base Case because higher plant capacity would be required to meet the energy needs in some of the very dry hydro conditions. The investment requirement, production cost and the levelized cost of energy generation increases by 12 % (8% is attributed to lower energy and 4% to additional adaptation cost for climate-proofing from adverse extreme hazards). A note of caution is that such hydrological condition would gradually occur over the next 3 decades so the impact may not be as much in the first one to two decades. On the other hand, the life of hydropower plants is much longer (50 to 60 years or even longer) as compared to the investment planning period of 30 years that has been considered in the study; however, this study has not considered hydrological changes for such a longer period (i.e., beyond

2050).The optimal power mix ratio adopted for the base case is however expected to perform satisfactorily in the case of an adverse hydrological condition as well. The above findings are based on the presently available projects in Nepal, and on 10-12% discount rate used which is closer to the private sector than from a public sector perspective.

5. **The impact of climate change on hydropower sector is additional to other factors and uncertainties**

Nepal's hydropower sector is affected by a multitude of issues and uncertainties. Climate change is therefore an additional emerging risk that the sector needs to adapt to.

In the short-term, for current plants, and for new planned plants, built in the next decade, the effects of current climate variability (baseline), climate-induced geo-hazards and particularly the uncertainty regarding institutional and regulatory issues are likely to be more important, with issues related to tariffs and pricing, export opportunities, construction costs (and the risks of delays and over runs) and project financing.

For future plants built later than this (after 2030 and beyond), the impacts of climate change could be much more significant. However, the design of these plants does not have to be finalised now: there is the opportunity to learn more about emerging trends and changes, and adjust these investments. This does require some preparation and action today, nonetheless, to allow the learning to provide future information and reduce uncertainties, for example by enhancing hydro-met data with monitoring to gather information and investing in downscaled modelling.

Adaptation

6. **Adaptation pathways can help address the challenges of adapting the hydro-electricity sector**

The climate risk assessment highlights that Nepal's current hydropower system has a current adaptation deficit, which leads to major impacts for the sector. Furthermore, it finds that future climate change will have additional potential impacts. These current and future risks can be reduced or avoided with adaptation.

The challenge of climate change is not insurmountable for the hydropower sector in Nepal and there are options that can address all the climate and future risks identified. However, the more difficult issue is to identify which adaptation options it makes sense to implement, given the balance of costs and benefits. This challenge arises because:

- Retrofitting options to reduce the risks of climate variability on current plants is often a very expensive option and is further complicated by existing power purchase agreements.
- It is possible to over-design new plants to mitigate against all possible risks, e.g. to design to cope with the most extreme climate scenarios, but this is unlikely to make sense in financial terms.

These decisions are complicated by the nature of climate change and the economics of investment decisions. This is because the impacts of climate change, and thus the benefits of adaptation, primarily arise in the future. Early action to address future climate change risks (such as with immediate retrofit or new plant over-design) will incur costs in the short-term, but provide economic benefits in the medium to long-term. This rarely makes sense from a financial perspective.

Compounding this, future climate change is associated with high uncertainty. This makes it difficult to plan exactly what to do when. Even if early action is taken, it is likely it will under- or over-estimate the actual risks that emerge.

Early adaptation (to future climate change) has the potential to increase the costs of capital or operation of hydropower plants, and therefore affects the rate of return (and the cost of electricity produced). The benefits of these adaptation investments may, however, only arise in the longer-term, towards the end of the concessionary period of the project and may be very small when compared to the up-front costs in present value terms: from the private perspective, they are unlikely to provide an early payback on investment (unless these are somehow reflected in the performance contract). This is exacerbated by the high uncertainty around future climate change risks and there is a question mark if future impacts will occur, and thus whether early adaptation will lead to actual medium- to long term benefits.

To address these challenges, the project adopted the iterative climate risk management approach highlighted earlier. This has two critical aspects. First, it focused on what action to take now over the next five to ten years to address current climate variability and future climate change. Second, it identified options that are economically attractive and justify implementation, despite the challenges around timing and uncertainty above. The approach used the three complementary building blocks presented in the earlier figure. At the system or policy level, the three interventions can be considered together in an integrated adaptation strategy, often termed an adaptation pathway or adaptation portfolio, as well as information for decisions on individual plants). Importantly, these pathways work with the CRA methodology, and thus look to see where interventions are justified, taking account of the outcomes (and uncertainty) from the climate projections.

It is stressed that there are important differences in adaptation across these three areas, due to the lifetime and economics of different decisions. This means that at the overall level, a set of complementary options in different applications will be needed.

7. <u>Adaptation needs to be designed to the specific context, plant and vulnerability</u>

The adaptation assessment has taken on board a key finding from the climate risk assessment: vulnerability is location, size and plant specific. The vulnerability of different plants varies with:

- Type of decision, i.e. decisions on current plants, planned (next decade) plants or long-term plants.
- Type of plant (small, medium, large, RoR vs storage)
- Design parameters like design discharge dependability for RORs or live storage capacity for reservoir projects.
- Catchment (snow fed versus rain fed).
- Sediment loading.
- GLOF and LDOF risk.
- Policy, regulatory and financial agreement.

This means that the vulnerability of any individual plants, and the system as a whole, is very heterogenous. This leads to an obvious but key finding: a suite of options is needed to adapt the hydro-power sector of Nepal, i.e. it is not a case of one size fits all.

The study identified a long list of adaptation options to the various risks identified. The list of adaptation options considered included:

- Technical options. These involve technical or engineering options (hard options) related to infrastructure, equipment, etc. noting these options were assessed in terms of their applicability to the typology above (i.e. current, planned or future) for different climate risks.
- Non-technical options. These involve alternative approaches, such as capacity building, the provision of information or, changes in management (soft options).

The analysis also considered policy or regulatory options, which include the means to implement some of the options above (e.g. changing guidance or PPA incentives). This list of options was then mapped according to the decision criteria and risk. The assessment therefore then set out to prioritise adaptation, both for interventions in general, and the choice of individual options (specifically).

8. <u>There are low regret adaptation opportunities for the hydropower sector in Nepal</u>

The adaptation pathways approach was used to help identify the timing and sequencing of adaptation, ensuring options were designed to fit the relevant decision contexts.

This analysis used a number of case studies, with data from real hydropower projects in Nepal (flow conditions, construction costs, operating performance and finances), and then used these to 'test' different adaptation options (in both current and future planned examples). This analysis helped link adaptation to the key performance indicators.

It included an indicative economic and financial analysis of options, assessing the costs against the potential benefits of adaptation in reducing revenue loss (from lower generation from changes in flow) and for climate induced disasters, revenue loss from increased downtime and damage. For major storage plants there was also the consideration of safety and wider economic effects.

Discussion on promising options was also undertaken with key experts in Nepal, and this identified additional options as well as concrete examples of the inclusion of options in existing or planned plants.

Based on the overall analysis, a number of general findings emerge.

First, it does not make sense to over-design the whole hydro-power sector in Nepal for all possible future climate risks today. In many cases, the high cost of retrofit (existing plant) or high costs of over-design (future plant) did not provide sufficient benefits to justify investment, or else proved to be less cost-effective compared to alternative options (e.g. lower cost investment or alternative approaches to addressing risk, such as insurance).

Second, from testing different options in different case studies, it is clear that the applicability, suitability and financial performance of adaptation options is plant and project specific (linked to the factors on the previous page). There is a danger in providing general recommendations on 'good' adaptation.

However, it was possible to identify a set of interventions that look very promising, i.e. the third key finding is that there are low regret adaptation options for the hydropower sector in Nepal, which have wide applicability, noting these differ across all three building blocks. These are discussed below.

Institutional analysis

9. <u>Understanding the institutional context and barriers is critical for effective adaptation</u>

A wide range of stakeholders have a vested interest in hydropower generation and safety, and thus in adaptation.

This includes Government policy makers and regulators, International Financial Institutions (IFIs) and Development Partners (DPs), the private sector, domestic and foreign developers, foreign regulators (for exports) and others such as civil society.

Importantly, these stakeholders are involved at different stages of hydropower development, from policy decision makers, to developers and consumers: this also maps onto their potential role in risk assessment, adaptation strategy and implementation.

The study undertook an institutional mapping analysis and reviewed the roles and responsibilities of different actors in hydropower development, their exposure to climate change risks, the various mechanisms through which they could support or implement adaptation, and their influence.

The ability to influence or implement adaptation also depends on stakeholder's adaptive capacity (e.g. their access to information, finance, etc.). This has been explored through a series of workshops and stakeholder consultation in the project.

The study has also considered how to mainstream (to integrate) adaptation into the institutional and policy landscape. Mainstreaming is the integration of climate change into existing policy and development, rather than implementing measures as a stand-alone activity. The focus is therefore to include climate in existing activities, e.g. to make it climate-smart.

Recommendations

Finally, the study has identified key recommendations:

Addressing current vulnerability

The priority is for Nepal's hydropower system to address current climate variability and geo-hazards, as this would improve current performance and produce immediate benefits, while also .will build resilience to future climate change for the medium to long-term.

Individual plants are often not designed to cope with current risks, but addressing these risks will help financial performance, help to protect assets, and will help offset the future risks of climate change.

At the system level, the current balance of plants does not perform well today against seasonal and inter-annual levels of climate variability. Looking at the balance of plants on the system to address current variability now will have a major benefit in strengthening the sector to address the risks of future climate change in the future.

Hydro-met

While positive initiatives are happening, notably the Pilot Program for Climate Resilience (PPCR) initiative, further strengthening of hydro-meteorological information is critical. The information on water catchments about 3000 m is identified as a particular gap, but greater hydro-met and sediment monitoring across the country is a priority.

These investments in information provide the foundation for current and future adaptation, i.e. they will improve current and future investment decisions and produce a very high benefit from improving decisions (the value of information).

The potential for on-line and real-time monitoring, and enhanced dissemination of hydro-met information is a key priority for investment, though there is also a need to ensure better data is communicated to end-users, in a form that is timely and usable. There is considerable potential for plant management and efficiency as well as system optimisation from this information in more detailed plant management and system management.

Further work on the weather value chain for hydro-power would be useful, along with stakeholder consultation to understand end-user needs, and to help identify data but also information pathways to maximise the effective use.

Risk assessment, best practice and awareness

There are barriers to plant operators adopting early low regret measures including information gaps, finance and institutional. These can be targeted to create the enabling environment for early adaptation for developers.

To address this, it would be useful to use the vulnerability work and undertake risk assessments for existing plants. This would provide key information for operators on the risk they face. This could be complemented with good practice examples (from Nepal) on the application of promising low regret options, with benefit and cost information, to raise awareness, highlighting financial benefits.

Large hydropower plants generally have high design standards. The main capacity and awareness gap is therefore with smaller developers, thus the priority here is for adjusting design standard and enhancing best practice in smaller plants.

Climate risk screening and design standards

Following on from the analysis above, there is a need to mainstream climate risk assessment into the development project cycle (the application, approval and financing arrangements).

The priority would be to ensure that plants are addressing current climate variability effectively, but also help operators to consider if there are additional areas where climate change might justify additional investment, noting that this needs to consider the balance of costs and benefits.

The priority is again likely to be for smaller plants. A similar approach of providing support information and case study material for the development of new plants (good practice examples) would be particularly useful.

System planning

More efficient capacity mix (optimal (cost minimizing) equal share (46-47%) of ROR and storage type reservoir projects) is required to meet the current and future power demand of the Integrated Nepal Power System (INPS). Noting that at present the share of storage plant capacity is about 10% only, these results indicate inadequacy of storage power plant capacity in the existing INPS generation system (hence an inefficient capacity mix) besides the total system capacity itself being inadequate.

System planning is also constrained by insufficient number of variations in projects types and size including limited number of storage project inventory. It is recommended that project feasibility studies and hydropower/river basin master plans (under preparation by Water and Energy Commission Secretariat (WECS)) undertake a more varied options assessment considering both current hydrology and future changes, and likely changes in policy, regulatory and pricing regime.

At present system planning is being carried out for one particular future power demand scenario (which is based on a particular GDP growth scenario). As there are uncertainties in future GDP growth and the associated future power demand growth paths, the implications of climate change for system planning and costs are unlikely to be fully reflected. Also, analyses of the implications for capacity and energy generation mixes of climate change are mainly limited to assess the roles of RoR andstorage plants; however, they do not sufficiently and systematically differentiate the future roles of RoR, PRoR plants in long term systematic planning. It is recommended that system planning also consider these issues for a more comprehensive assessment of the nature and scale of climate change adaptation involved in hydropower development in the country over a long run.

Invest to learn

Finally, there is a need to invest, with monitoring, research and pilots, to improve future decisions and planning (learning).

This could include further work to improve the modelling of climate change in Nepal, but also a greater focus on observations and monitoring (e.g. building on the existing monitoring of GLOF risks).

The need to build capacity in the sector is paramount, with more focus on awareness raising and information, along with supporting research. One important aspect is to develop the institutional research landscape and ensure information is disseminated.

Finally, there is a need for institutional strengthening on climate change in Government and across the major agencies involved in the hydro-sector, as well as for the private sector. A planned programme of technical assistance support would enable all the other key recommendations, and would help the hydro-power sector to mainstream climate change and develop future sector development plans and policies to ensure they are climate smart.

1 Introduction

Current climate variability and extreme events already cause major impacts and economic costs in Nepal. A recent study of the economic impacts of climate change in Nepal - published by the Government of Nepal on the 28th of April 2014 - estimated that the annual costs of the current climate and water resources variability is equivalent to 1.5% to 2% of current GDP. The study also found that climate change could aggravate these impacts, leading to potentially larger costs in the future.

A key risk of climate change identified in the above study concerned the hydroelectricity sector. The risk may increase with climate change, and is thus critically important as Nepal has a very large potential for hydroelectricity. Moreover, the development of the hydroelectricity sector is a key part of future development plans and crucial for domestic and export growth, with planned investments of billions of dollars in the near-term.

Against this background and at the request of the Government of Nepal, the Climate and Development Knowledge Network (CDKN) funded this study on 'Adaptation to Climate Change in the Hydroelectricity Sector in Nepal'. The work is led by Nepal Development Research Institute (NDRI) - Nepal, working in collaboration with Practical Action Consulting (PAC), Nepal and the Global Climate Adaptation Partnership Limited (GCAP) (UK). The objectives of the study are to:

- Develop a solid evidence base on the vulnerability of the hydro-sector to climate change:
- Identify viable adaptation options that enhance resilience;
- Understand and address the challenges of mainstreaming adaptation in the sector;
- To build capacity and help enable adaptation action amongst policy makers and the private sector.

The expected key outputs from the Technical Assistance are:

- Evidence of impacts of climate change in the hydroelectricity sector
- Defined adaptation pathways for the hydro-electricity sector with viable adaptation options
- Identified opportunities and challenges for mainstreaming Climate Compatible Development (CCD) in the hydro-electricity sector

These outputs are expected to contribute to (i) increased understanding of Key Stakeholders (Government and private sector) and objective acceptance backed by a strong evidence of the vulnerability of hydro-electricity sector to climate change in Nepal, (ii) greater use of no- regret, low cost adaptation options by the Government/ private sector for addressing current climate variability and long term climate change and (iii) increased capacity through knowledge gained by key stakeholders (Government and private sector) to address climate risks.

A series of knowledge products including a project flyer, several blogs, technical notes and policy briefs, and presentations in national and international fora were prepared during the course of the Project (www.ndri.org/projects/ccandhydro).

This Final Report is prepared summarizing the full process, the project approach, background and key findings of the two-year project.

2 The hydro-electricity sector in Nepal: current and future

Being the most important energy resource of the country, hydropower development is closely linked with the economic growth and development of Nepal. This is because of the important roles that electricity can play in development of agriculture, transport and industry sectors in the country. In addition, the well being and livelihood of a large number of people would depend upon increasing the people's access to electricity.

Nepal's topography and abundant water resources create immense potential for hydroelectric power. Although overall energy needs (more than 85%) are predominately met from traditional bio-mass, the nation's current electricity generation is heavily reliant on hydroelectricity, providing more than 90% of the nation's electricity (OECD, 2003; WECS, 2011; NEA, 2016).

2.1 Current, Construction and Candidate Plants

In this study hydropower plants are classified into three categories: 1) Current (existing) plants 2) Committed plants and 3) Candidate plants. Current plants are hydropower plants in operation above 5 MW capacities. Committed plants are those that are expected to be operation in near future (under-construction and with PPA contract). Candidate projects are planned projects. We studied 89 hydropower projects of which 20 are existing projects[3], 30 are committed and 39 are candidate projects. These hydropower projects are shown in Figure 2-1.

Current Plants

Currently the Nepal Electricity Authority (NEA) dominates power generation in Nepal but there are also a large number of independent power producers (IPPs), as well as inter-connections to India. Out of total available electric energy of 5005.7 GWh, NEA contributed about 47% while IPP and import from India had shares of 23% and 27% respectively in 2015 (NEA, 2016). There are 11 major NEA hydro plants (over 5 MW) with the total capacity of 459.15 MW as well as 18.78 MW of small hydropower plants (of which 4.5 MW is isolated). Total number of IPP-owned projects that are in operation has reached 50 with their combined installed capacity of 324.45 MW, hence totaling 802.38 MW of hydro capacity (NEA, 2016).

Existing plants are located in Koshi and Gandaki basin. Except Kulekhani storage hydropower, they are either run-of-river (RoR) or peaking RoR (pRoR) type. Depending upon the location, catchment of these plants varies from highly snow dominated to rainfed[4]. Six projects with capacity of 185 MW are snow dominated while six projects of 198 MW with including Kulekhani storage are rain-dominated or rainfed. The country's largest projects - Kali Gandaki A (144 MW) and Marsyandgi (69 MW) projects have medium snow dominated catchments. Only five plants have head more than 250m. Besides, plants in Kali Gandaki and Marsyangdi river in Gandaki Basin that lie in Tibetan Sedimentary Zone; and also in middle mountain rainfed catchment like Kulekhani and Jhimruk are facing high sediment induced impacts. Most of current hydropower plants (12 out of 20) are designed in flow with exceedance probability of 40% (Q40). Only three projects are designed in Q90.

Future Plants: Committed and Candidate Plants

Committed Plants

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[3] Kulekhani I and II are considered as one project. Upper Marsyangdi A was under construction during time of study. Only projects above 14 MW are considered for committed and candidate projects.

[4] Categorization of catchments: a) High snow dominated : Catchment area (CA) above 3000m is greater than 80% b) Medium snow dominated: CA above 3000m is between 60-80% c) Low snow dominated: CA above 3000m is between 40-60% d) Rain dominated : CA above 3000m is 20-40% e) Rainfed: CA above 3000m is less than 20%.

NEA and its sister companies have eleven hydropower projects with installed capacity of 1047 MW under construction which are expected to be operational by 2025. Upper Tamakoshi hydropower project (456 MW), developed by Upper Tamakoshi Hydropower Limited is expected to commission within two years. Likewise, 91 projects of IPPs with their combined capacity of 1721.532 MW are under construction after financial closures. 44 projects of IPPs with their combined capacity of 783.8 MW are in their various stages of development.

Like current condition, those projects under construction are RoR and pRoR plants. Hence, they are expected to influence by seasonal skewness of flow in rivers. In the study, out of 30 hydropower projects only one project is storage project. 14 out of 30 projects are highly snow dominated including Upper Tamakoshi HPP. 6 projects are lowly snow dominated while 3 are medium. 7 projects are rain dominated / rainfed. Like in existing projects, half of them are located in Gandaki basin and none in Karnali Basin. 15 RoR/ pRoR projects have head greater than 250m. Likewise, 15 projects are designed in Q40 flow; 6 projects in Q30; 2 projects in Q65 and none in Q90.

Candidate Plants

Many basin level studies like Gandaki River Basin Power Study (1979), Medium Hydropower Study Project (1997), Master Plan Study for Water Resources Development of The Upper Karnali River and Mahakali River Basin (1993), Study of Koshi River Hydro-electric Power Development Project (1984) and Nationwide Master Plan Study on Storage type Hydroelectric Power Development in Nepal (2014) have identified different promising storage and RoR/PRoR projects all over Nepal. Most of the candidate plants are from those studies like existing and under-construction plants. NEA has planned and proposed nine projects of 2177 MW capacity out of which 3 projects are storage with 1470 MW capacity. This included DudhKoshi Storage, Tamor Storage and Uttar Ganga Storage HEPs. Even projects like Budhi Gandakiand Nalsyaugad Storage HEPs are candidate plants.

In this study, 39 candidate projects are studied out of which 18 are storage projects with capacity of 26393 MW and 21 RoR/pRoRs of 4905 MW capacity. Most of the storage projects are in Gandaki and Karnali Basin while only two are in Koshi Basin. Only six projects have more than live storage (LS) more than 40% of total monsoon inflow and seven projects have less than 20% of total monsoon inflow. Most of storage projects have less storage capacity in compare to monsoon inflow which is almost 80% of total inflow. Likewise, 10 storage projects are rainfed or rain-dominated while only one is highly snow dominated. In case of RoR/PRoR candidate projects, more than half are highly snow dominated; 4 are medium ; 3 are low snow dominated and only 2 are rain dominated. 14 out of 21 RoR/ PRoR projects of them are located in Koshi Basin while 5 projects are in Gandaki Basin and remaining two projects are in Gandaki Basin. 11 of those projects have head higher than 250m. Only eight of these projects are designed for Q_{40} flow.

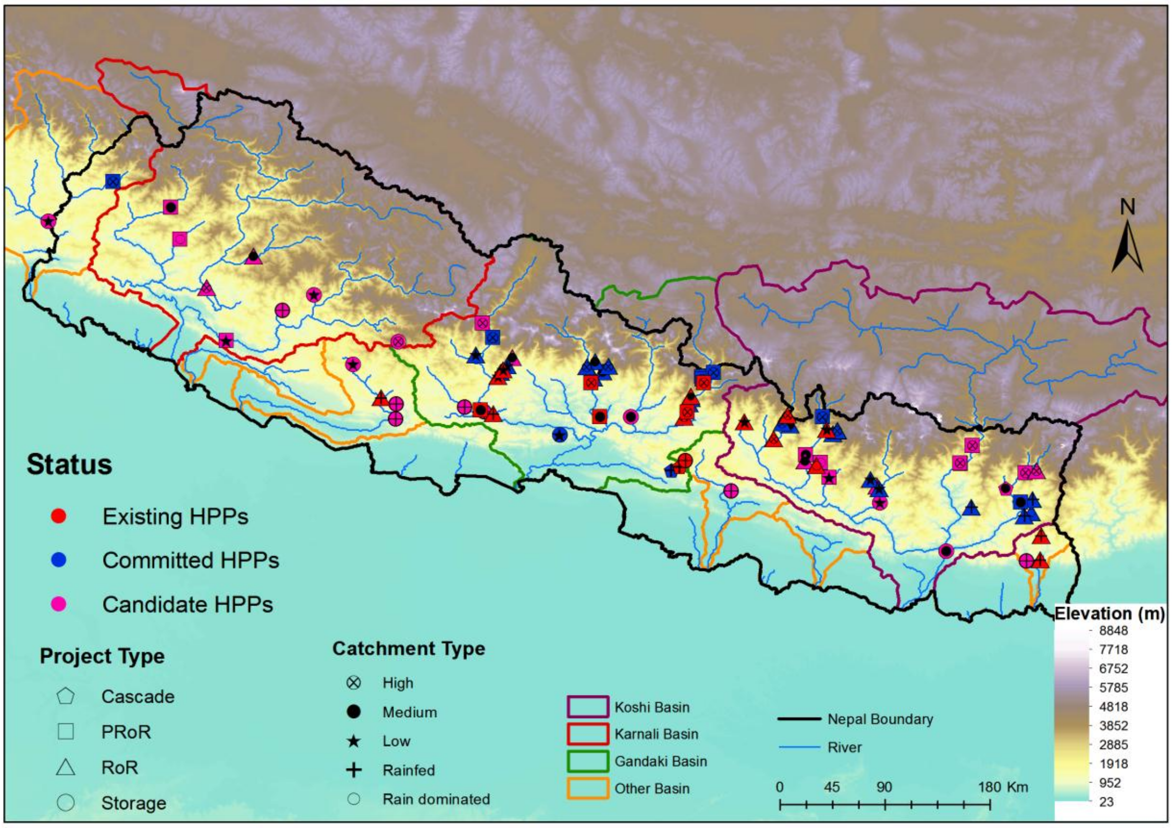


Figure 2-1: Hydropower projects in Nepal

2.2 Current Electricity Consumption and Load Forecast

Current Electricity Consumption

The total electric energy consumption of Nepal is around 3% of the total energy of 475,000 terra joules in 2015 (MOF, 2015). Domestic sector and industrial sector are major consumers of electric energy. In 2015, electricity sales were approximately 3744 GWh, of which 1813 GWh (45%) was to the domestic sector and 1352 GWh (36%) to the industrial sector. Other sectors using electric energy are commercial, water supply and irrigation, transport, street lights, community sales; and religious places.

Current supply and demand

The current supply is 856MW including supply from NEA (hydro and thermal), IPPs and import from India. The peak demand in 2015 was 1291 MW and is 1385 MW in 2016 (NEA, 2016) which normally occurs between 17:00 to 20:00 hours. Since, total supply is only 856 MW, the rest of demand is unmet resulting in load shedding.

Load Forecast

The NEA (2014) and Vernstrom et al. (2013)[5] have carried out load forecast up to 2050. NEA uses econometric methods for load forecasting. The electrical energy demand is assumed to increase at a compound annual rate of 7.8% during 2022- 2032 and 7.1% after 2032 in NEA's forecast and at

[5] A report prepared for Investment Board Nepal by Vernstrom et al. (2013)

6.8% in that of Vernstrom et al (2013')[6] which were extended out to 2050.The peak load and energy forecasts are presented In **Figure 2-2**. By 2050, the load (MW) and the Energy (GWh) required will have risen significantly.

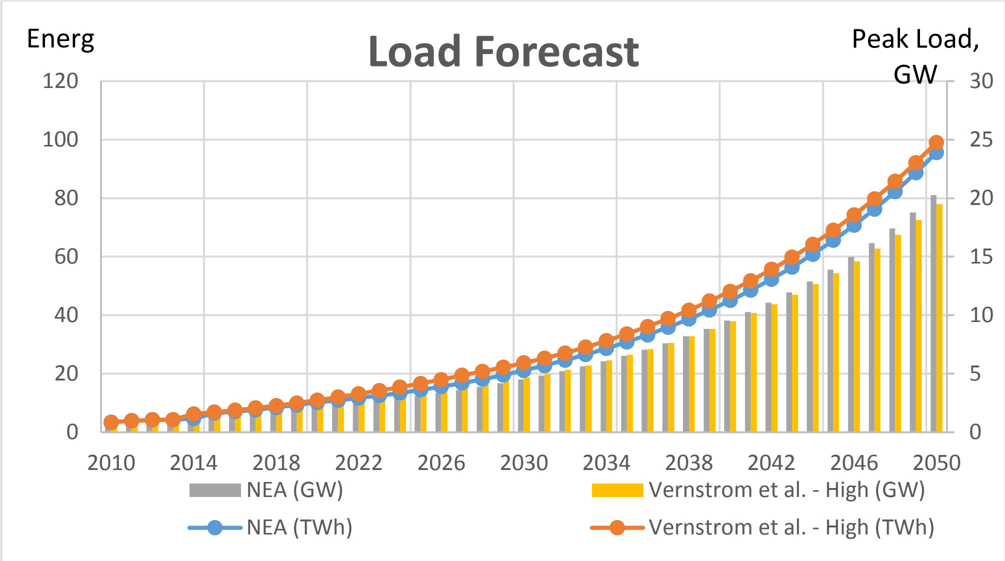


Figure 2-2: Load forecasts for Nepal (source: NEA, 2014; Vernstrom et al., 2013)

Note that these load forecasts do not take account of the future impacts of climate change on temperatures. In context of Government of Nepal's target to graduate the country from least developed country (LDC) to developing nation by 2022, National Planning Commission (NPC) (2014) estimated annual GDP growth rate of 9.2 percent during 2013-2022. This is quite high compared to rate used by NEA (2014) and Vernstorm et al (2013) to forecast the load. This suggests substantial higher load demand by the order of 30 to 36 percent.

Future Supply

As stated earlier, there are a number of committed (under construction) plants by NEA, its sister organizations and IPPs with the combined capacity of 2,768.5 MW. Upper Tamakoshi hydropower project (456 MW) is expected to be operational within two years. Likewise, Chameliya and Upper Trisuli 3A are expected to be commissioned in mid of 2017. Kulekhani III is expected to be commissioned by end of 2016. From IPPs, so far till FY 2015/16, the total number of PPAs concluded has reached 185 with their combined capacity of 2829.78 MW (NEA, 2016).

NEA (2016) has listed nine projects with a total capacity of 2,177 MW as planned and proposed projects. Three storage projects, namely Dudh Kosi Storage, Uttar Ganga Storage and Tamor Storage, are included in the list. Likewise, the feasibility study of Budhi Gandaki Storage Project (1200 MW) has been concluded and is in the process of distribution of compensation to affected people. Likewise, Project Development Agreements (PDAs) have been signed for the development

[6] There is also another set of load and energy forecasts up to the year 2032, which is prepared by NEA/JICA (2012). According to that , the energy demand in 2032 would be 17921 GWh in Low case and 22166 GWh in High case, whereas the peak load would grow to 3934 MW in Low case and 4866 MW in High case.

of two export oriented projects, namely Arun 3 with Satluj Jal Vidyut Nigam Limited (SJVN) and Upper Karnali with GMR, both which are of 900 MW capacity.

2.3 Institutions, Policy and Regulations

2.3.1 Regulatory Framework

Water Resources Act 1992 is the umbrella legislation for water resources development in Nepal. The act vests ownership of water in the state; prioritizes order of water use and establishes a system of licensing. Regarding hydropower sector in Nepal, the governing act is the Electricity Act 1992 and its regulations, the Electricity Rules 1993 and the Electricity Tariff Fixation Rules, 1994. The act governs the use of water for hydropower production; establishes a system of licensing and sets the powers, functions and duties of a license holder. The Electricity rules sets out the procedure for obtaining license, deals acquisition of house and land and compensation. The Electricity Tariff Fixation Commission (ETFC), formed under the Electricity Act 1992, is responsible for fixing and also reviewing electricity tariff. Both the acts also mandate the environmental study for hydropower. Likewise, The Environment Protection Act (1996) and Regulation (1997) contains provisions on the environmental safeguards to be applied on hydropower projects; and mandates environmental study.

The Project Development Agreement (PDA) is a legal concession agreement between the Government and developers for the use of water resources for hydropower generation in Nepal. It lays out obligations and risk sharing between the government and the developers in constructing, operating and managing the hydropower plant for the duration of the concession agreement. Likewise, Power Purchase Agreement (PPA) is a legal agreement on electricity purchase rates between developers and off-takers. It also defines the penalties to be paid by hydropower operators for failing to meet the committed energy. Generally, the hydrological risks are also incorporated in PPA rates.

The government has recently formulated the '*Rastriya Urja Sankat Nibaran tatha Bidhyut Bikash Dasak Samdandhi Abadharana Patra, 2072*' which sets out the power purchase rate for storage, RoR and pRoR projects. This has also extended the defined period of dry season from four months to six months, where the rates are higher. It has also defined the nature of storage and PRoR projects based on the ration of dry season and wet season energy generation and peaking capacity.

Based on Interim Constitution of Nepal 2007, GoN has proposed a draft Electricity Act 2065 (not yet ratified by the Parliament). The proposed act is more comprehensive in electricity development than the prevalent act. It is more focused towards rapid hydropower-development in Nepal. Likewise, it is providing right to a new regulatory body, the proposed Nepal Electricity Regulatory Commission to fully regulate the power sector beyond just economic regulation currently carried out by Electricity Tariff Fixation Commission (ETFC).

2.3.2 Policy

National Policy: There are short-term national development goals within the Government's Three Year Plan (TYP). The previous TYP also has introduced the concept of climate resilient planning, particularly in the policy and strategy of infrastructure projects promoting climate adaptation. The Nepal Development Vision (2030) sets out the longer-term aspiration for Nepal becoming a middle income country over the next decade and an upper middle-income country by 2030. This foresees high average annual GDP growth rate of 9% with a structural shift that makes electricity, gas and water one of the prominent sectors, and a key driver for growth from the production of hydro-power.

Climate Policy: The National Adaptation Programme of Action (NAPA) (2010) addresses water related sectors through the promotion of community-based adaptation and the integrated management of agriculture and water. Nepal has also prepared Local Adaptation Plan of Actions (LAPAs) supporting water- based resilience at the community level. With aim to facilitate integration of climate change adaptation into development processes; the Ministry of Population and Environment (MoPE) launched the National Adaptation Plan (NAP) formulation process in September 2015 with water and energy sector as one of seven thematic groups.

The Climate Change Policy (2011) sets out the risks associated with climate change and proposes a range of priority thematic areas. For the water sector, these include improved systems for glacial lake monitoring, and the development of early warning systems for water-induced disasters. A Strategic Program for Climate Resilience (SPCR 2011) under Pilot Project for Climate Resilience (PPCR) contains water related components addressing water-induced disasters, water supply and irrigation in mountain areas and climate proofing of hydro-power facilities.

Water and Hydropower Policy: The 2002 Water Resources Strategy (WRS) of Nepal sets out a comprehensive approach to water planning in water supply and sanitation (WSS), irrigation and hydro-power, as well as a range of institutional, legal and environmental issues. The strategy sets out a short (5 years), medium (15 years) and long-term (25 years) vision. The National Water Plan (NWP) (2005) acts as the implementation plan of the Water Resources Strategy (WRS). The NWP recognises the objectives of the WRS and lays down short-, medium- and long-term action plans for the water resources sector, including investments and human resource development. The Rural Energy Policy (2006) sets out the approach to delivering energy to off grid communities through a range of technologies such as biogas, biomass, solar, and productive energies. These technologies also include micro and small hydropower. The Subsidy Policy for Renewable Energy (2013) stipulates the schemes for subsidies provided to promote the development of renewable technologies by making renewable technologies affordable to the low income households (AEPC, 2013).

The main policy framework governing the sector remains the Hydro-power Development Policy (2001), which identifies 42,000 MW of technically and commercially realisable capacity in the country. The policy recognises a range of benefits, which include the downstream benefits of flood control. While primarily targeted at medium and large projects, the Policy also sets out the basis for mini (100 kW to 1000 kW) and micro-hydro (<100kw) projects development. The policy does not have any reference to the potential impacts of climate change on hydrological flows or competing water demands, but does make provision that if hydrological conditions are more adverse than anticipated when the license was granted, the licence term may be extended by up to 5 years as compensation.

There have been a number of further planning documents issued since 2006. For example, the WECS produced a review of documents prepared for 'Nepal's Long Term Vision on Water Resources and Energy Sectors 2050 AD', but this also does not explicitly make reference to climate change.

2.3.3 Institutions

Overall institutions involved in hydropower sector can be grouped in four categories.

Government Institutions: The Ministry of Energy (MoE) and its Department of Electricity Development (DoED) have jurisdiction over the hydroelectricity sector in Nepal. The ministry has been entrusted with the task of developing policies and plans for the conservation, regulation and utilization of energy. The Department of Electricity Development (DoED) functions as the chief coordination unit for promotion and development of the hydropower sector. It performs regulatory duties and is primarily responsible for awarding licenses to hydropower projects.

The National Planning Commission (NPC) and The Water and Energy Commission (WEC) was established as an advisory bodies of the government for the formulation of policies, plans and programmes. WEC focuses in the water resources and energy sector. The Commission and its secretariat, the Water and Energy Commission Secretariat (WECS), are responsible for formulating and assisting in developing policies and strategies in the water resources and energy sector, and for providing suggestions, recommendations and guidelines in developing irrigation, hydropower, and drinking water projects.

The Ministry of Population and Environment (MoPE) formulate and implement the policies, plans and programmes that contribute to minimize the impact of climate change, environment sustainability, preservation of natural resources, promotion of sustainable practices and technologies, and management of climate change induced risks. The Department of Hydrology and Meteorology (DHM) has a mandate from GoN to conduct all the hydrological and meteorological activities in Nepal.

The Nepal Electricity Authority (NEA) is a government-undertaking organisation that has primary objective to generate, transmit and distribute adequate, reliable and affordable power by planning, constructing, operating and maintaining all generation, transmission and distribution facilities in Nepal's power system both interconnected and isolated. The NEA is the only energy off-taker in Nepal. The Electricity Tariff Fixation Commission (ETFC) is an independent body, created in 1994, responsible for tariff fixation. The Investment Board Nepal (IBN) is entrusted to promote economic development of the country by creating an investment-friendly environment.

International Financiers and Development Partners: The World Bank Group, Asian Development Bank, Japan International Cooperation Agency, UK Department for International Development (DFID), USAID/MCC, EU/ European Investment Bank, Denmark and Norway major international financiers and development partners that have been investing in development projects in Nepal including hydropower sector. In hydropower sector, these agencies have focused on hydroelectric power generation, enhancing transport connectivity, and improving the business environment.

Currently, hydropower development committee have been established to develop storage hydropower projects, like Budhigandaki and Nalsinggad, in Nepal.

Domestic Developers: Independent Power Producers' Association (IPPAN) is association of Nepalese private hydropower developers. It works to encourage private sector investment in hydropower in Nepal and to act as a link between the private sector and government organizations involved in developing hydropower in the country. In 2015, the capacity of IPPs hydropower plants is almost 38% of total capacity of the country (NEA, 2016). Likewise, Nepal Hydropower Association (NHA), association of individuals those working in hydropower sector, lobbies and advocates on helping create better enabling environment for hydropower development; provide capacity building support to hydro professionals, and investors.

Academic and Research Institutions: Many international and national institutions are actively supporting the research on water and energy; climate change thus providing key inputs for planning and development of water resources in the country. International Centre for Integrated Mountain Development (ICIMOD), Institute of Engineering (IOE), International Water Management Institute

(IWMI), Nepal Academy of Science and Technology (NAST), Hydro LAB, Nepal Development Research Institute (NDRI) are some of these institutions.

3 Study Method

3.1 Introduction

Assessing the future impacts of climate change on the hydro-electricity sector in Nepal is very challenging due to the complex climate, hydrology and geology, as well as the very large changes in elevation that occur across the country. This is further compounded by the lack of reliable and long-term hydro-meteorological and sediment data in Nepal.

Projections of future climate change show very high uncertainty, with large differences across future scenarios and between climate models. Though considerable investment has been made in climate modeling and downscaling of GCMs with hoped-for benefit to decision makers, a recent study of the World Bank's Independent Evaluation Group (IEG, 2012) found that "climate models have been more useful for setting context than for informing investment and policy choices" and "they often have relatively low value-added for many of the applications described." The lack of success in the use of climate projections to inform decisions is not due to lack of effort in translating model outputs to be relevant to decision makers. The uncertainty associated with future climate is largely irreducible in the temporal and spatial scales that are relevant to water resources projects. As a result, climate science-led efforts typically do not reduce the uncertainty of future climate, and in fact, are unlikely to describe the limits of the range of possible climate changes. Perhaps most important, climate projections have the least skill in the variables that are most important for water resources projects, such as hydrologic extremes (e.g., floods and drought). Often, the results of a climate change analysis present a wide range of possible future mean climates, no insight on climate extremes, and the sense that this is only the tip of the iceberg for climate uncertainty. As a result, the project planner faces a difficult path forward.

To address these challenges, the project has adopted an iterative climate risk management approach. This type of approach was highlighted in the IPCC SREX and 5th Assessment Report (IPCC, 2012: 2014). Recent examples (DFID, 2014) apply these concepts to more practical decision making and such an approach has been applied in this study. This approach is also consistent with the recent World Bank's Decision Tree (DT) Framework on confronting climate uncertainty in Water Resources Planning and Project Design (Ray and Brown, 2015).

The adopted methodology (Figure 3-1) specifically addresses the main objectives of the study using three iterative steps: Step 1- Vulnerability Assessment using the Climate Risk Assessment (CRA) approach; Step 2- Identification of Adaptation Options using the Adaptation Pathways approach and Step 3- Understand and address mainstreaming of adaptation in the sector through Institutional Analysis and identification of entry points and barriers. Close stakeholder consultations and participation, and dissemination of knowledge products have been used to build capacity for policy makers and the private sector for adaptation,

3.2 CRA Approach

The Climate Risk Assessment (CRA) method does not follow a traditional top-down, scenario-led impact assessment, i.e. where a climate model produces a future projection, which is used in a hydrological model and then in a water resources system or impact model to quantify future impacts, and finally to consider potential adaptation responses. Instead it uses a methodology based on a "bottom up" decision-scaling approach. This starts by assessing the sensitivity of Nepal's present hydropower systems – and their performance - to the current climate and then assesses how future climate change could affect this. Figure 3-2 shows the differences in the two approaches.

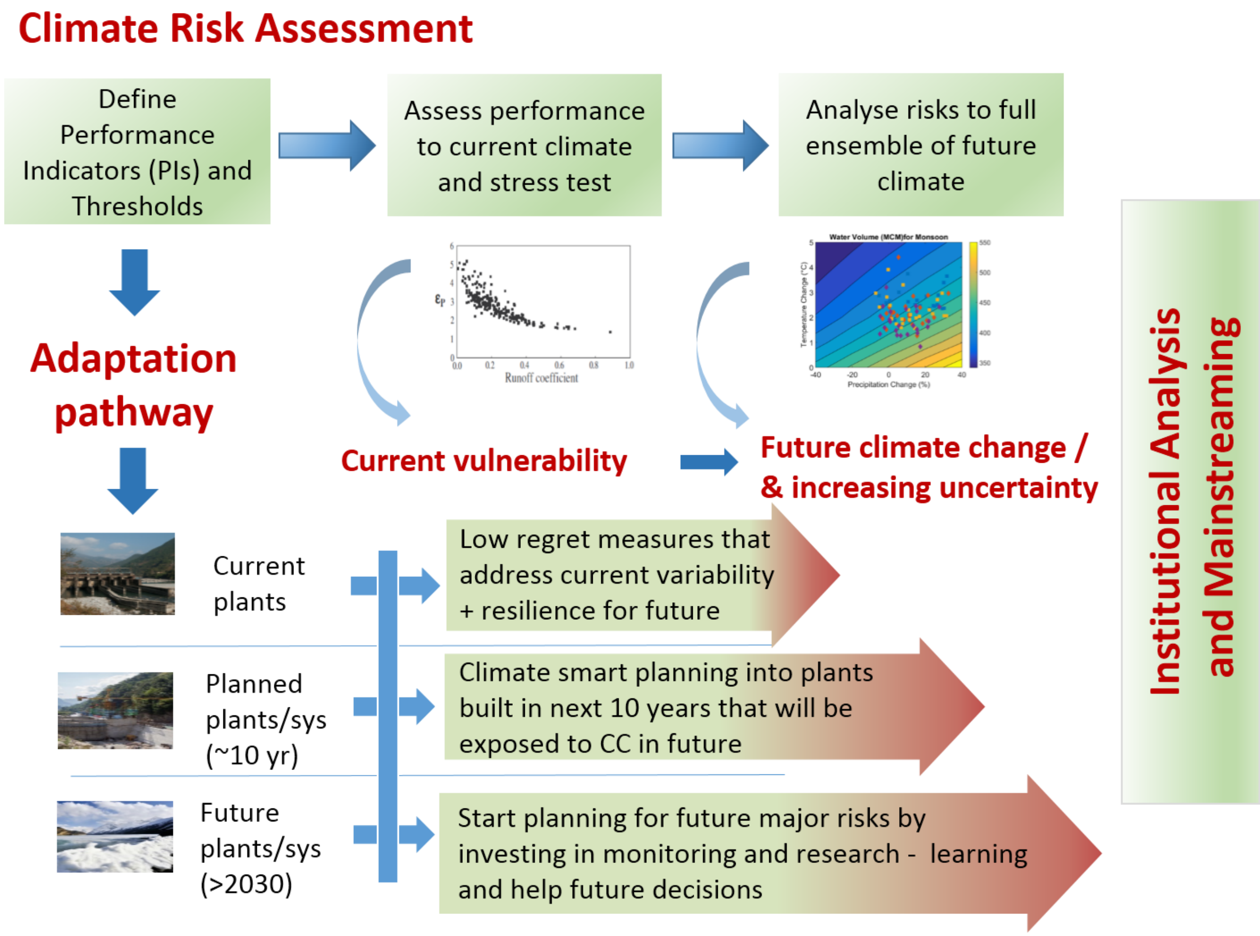
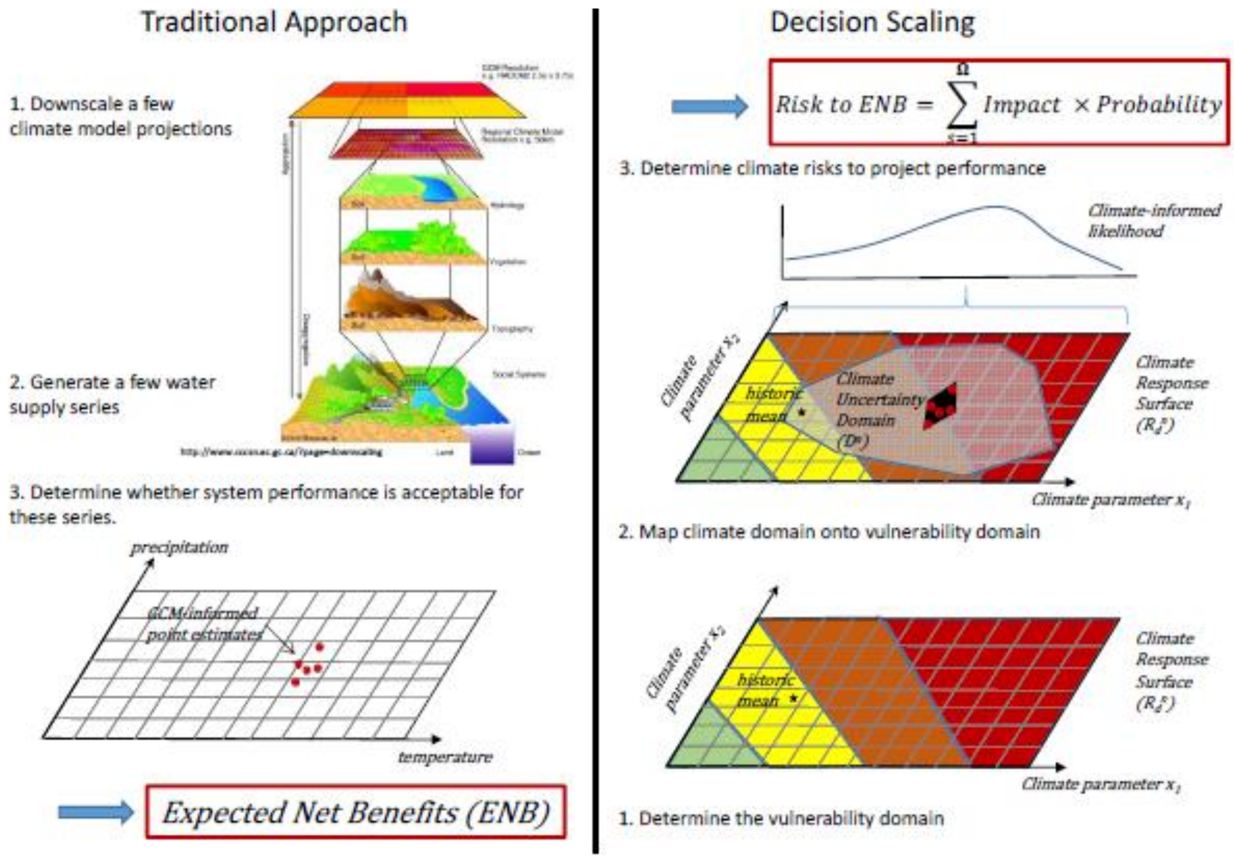


Figure 3-1: Iterative Climate Risk Management (ICRM) Approach of the Study

The decision-scaling approach used in CRA is a bottom-up, robustness-based approach to water system planning, making use of a stress test for the identification of system vulnerabilities, and simple, direct techniques for the iterative reduction of system vulnerabilities through targeted design modifications. Rather than building this CRA on the projections of only a few selected GCMs and RCMs, the CRA approach therefore considers preparedness for a range of possible futures, an important ideological shift from previous scenario based approaches, which tend to focus on a small subset of defined future scenarios and models.

The method identifies key performance indicators (PI) significant for hydro-energy generation that may be sensitive to climate and thus puts the initial emphasis on understanding how the present meteorological and hydrological variability affect current operations and planned investments. This has the advantage of focusing the analysis on what matters! It can then look at future climate change, including uncertainty, and see how important future changes could be and how these key PIs are affected.



Source: García, L.E. et al., 2014; Ray & Brown, 2015

Figure 3-2: Comparison of Traditional Top-down Approach and Bottom-up Decision Scaling

The main difference between the two approaches is how and when the climate projections data are used. The top-down approach starts with downscaling, bias collection and use of one particular GCM projection in the hydrological model to simulate the changes in hydrology and, subsequently, assessing the impacts on the water resources system. The bottom-up approach also uses climate projections, but it does this later in the process and looks at multimodel ensemble data, not a few individual climate model projections. The bottom-up approach starts with mapping of vulnerability domain of key performance indicators and the multimodel ensemble of climate projections are used to check the plausibility of such climate conditions occurring that would make the project or system risky.

The key steps used for CRA are (Figure 3-3):

- Define Performance Indicators (PIs) and acceptable thresholds with close stakeholder consultation
- Assess performance to current climate variability and "stress test"
- Analyse vulnerability and risks to PIs from full ensemble of future climate

3.2.1 Key Performance Indicators

This first stage of the CRA process is to identify the potential hazards to the system that result from changes in climate, where hazard implies the impact of a climate change but not its probability. Risk is defined as the product of impact and probability, an expected value of the loss. The process begins ideally with stakeholder discussions to identify the relevant performance indicators of the water resources system under consideration, and also, if appropriate, thresholds of acceptable decreases in performance levels. For this study, critical performance indicators were discussed with multiple stakeholders through focused discussion with stakeholders and workshops including:

- Inception Workshop on 20 Feb 2015
- Mini-workshop on "Climate Change and Hydropower Policy" on 19 August 2015
- Mini-workshop on "Private Sector engagement in adaptation to climate change" on 31 Aug 2015

Selected performance indicators of concern were *inter alia:*

i. Total dry season and annual energy generation and firm power
ii. EIRR and NPV of individual projects
iii. Sediment load (design concerns) and its impacts on energy generation
iv. Extreme flood events, its management and design concerns
v. Hydropower investment plans and "appropriate" power mix
vi. Water induces hazards and its management such as GLOFs, landslides
vii. Basin level plans and "appropriate" sizing such as installed capacity, reservoir live storagel
viii. System indicators such as investment cost, levelized cost of energy (LCE), mix of storage and RoR projects (capacity and energy)

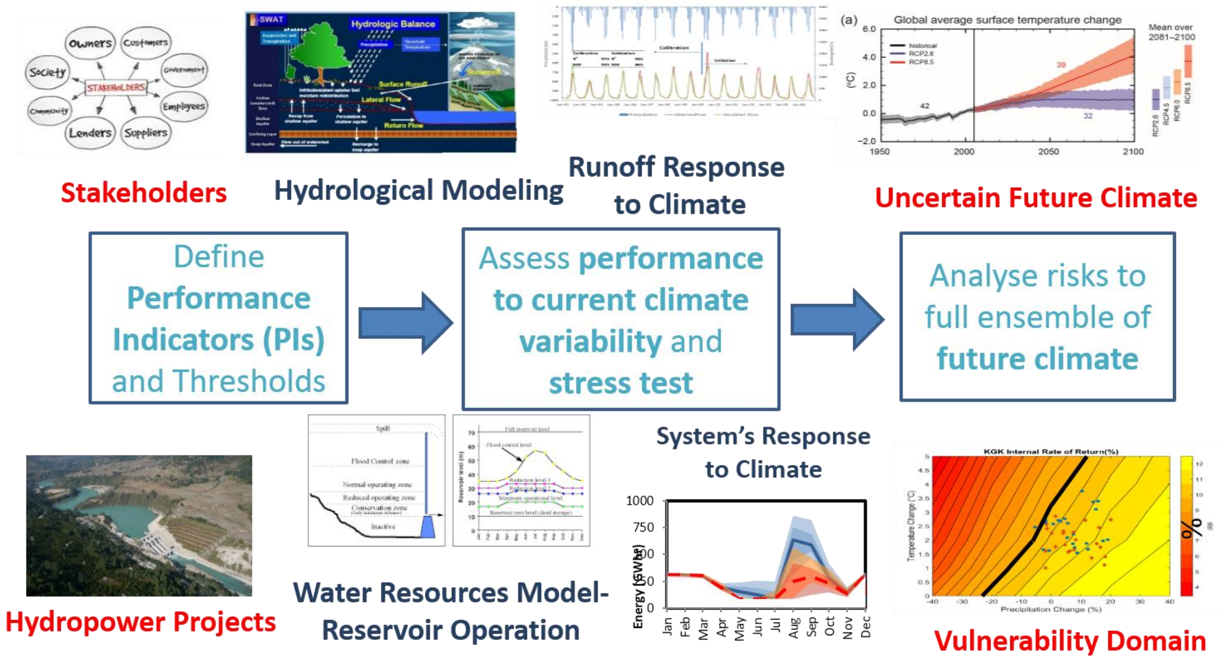


Figure 3-3: Key Steps of the CRA Approach

3.2.2 Vulnerability Assessment and Stress Test

Following the definition of performance metrics and thresholds, the next step is to seek an understanding of how runoff responds to changes in climate, and how the water resources or hydro-electricity system responds to changes in runoff. It also identifies runoff (and climate) conditions that may cause unacceptable system performance, defined as the “vulnerability domain” in the Bottom-up approach shown in Figure 3-2.

We used two methods to do so. The first was the analytical approach using the concept of elasticity (Grijsen, 2014), through:

i.) Modeling the response of selected performance indicators to relative (%) changes in basin runoff, by the application of a water resources system or reservoir operation model, yielding the runoff elasticity[7] (ε_Q^{PI}) of performance indicators (PI); and
ii.) Linking the response of basin runoff to changes in precipitation and temperature by regression and analytic models, yielding the precipitation elasticity and temperature sensitivity[8] (respectively ε_P^Q and S_T^Q) of runoff, which synthesize the climate sensitivity of basin runoff.

This approach is the one recommended by Ray and Brown (2015) to carry out the rapid project scoping as part of Phase 2 of the Decision Tree Framework. The concept of elasticity for evaluating the sensitivity of streamflow to changes in climate was introduced by Schaake (1990), who defined the climate elasticity of stream flow by the proportional change (%) in streamflow (Q) divided by the proportional change (%) in a climate variable. No hydrological modeling is required to assess the climate elasticities of runoff, when sufficient observed hydro-meteorological data are available, and one is mainly interested in seasonal/annual runoff volumes in relation to the storage capacity available in a basin or in seasonal hydro-energy generation rather than in extreme events of short duration. While in most of the analyses the present inter-annual flow variability can be maintained, it may also be tested how the performance of infrastructure could be affected by an increase in inter-annual flow variability, e.g. an increase with 20%.

As some of the performance indicators of interest require us to assess the intra-annual variability at a monthly or at a daily scale, we also applied hydrologic modeling using SWAT semi-distributed, physically based hydrologic model to evaluate the monthly and within-year runoff response to climate change. The runoff conditions for future climate changes were determined using the hydrologic model by parametrically varying the precipitation (P) and temperature (T) over a range informed by the different GCM models analysed. These runoff conditions were then used in the water resources/hydropower systems models to determine the systems' response to climate (the vulnerability domain).

Ray and Brown (2015) and others have used the weather generator to produce a number of stochastic time series based on the statistical characteristics of the historical record. They then systematically change parameters to produce new sequences of weather variables (e.g. precipitation) that exhibit a wide range of change in their statistical characteristics (variability). We have not used such weather generators to produce different time series but have produced runoff time series for changes in P and T (as informed by the GCM models) using the hydrological model.

This process of running hydrological and water resources/hydropower system model for the entire period (30 years) for each of the hydropower project or system under consideration constitutes the "stress test" for different climate conditions. The performance of each proposed project or system (plan) is evaluated for a range of future climate states and the results for each performance indicator

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[7] The runoff elasticity of a performance indicator defines the response of an indicator to changes in runoff. For example, a runoff elasticity of 1.3 indicates that a 10% decrease in runoff causes a 13% decrease in performance.

[8] The precipitation elasticity of runoff defines the response of runoff to changes in precipitation and the temperature sensitivity defines runoff response to changes in temperature (due to changes in evapotranspiration). A precipitation elasticity of $\varepsilon_P^Q = 2.5$ indicates that a 10% decrease in rainfall causes a 25% decrease in runoff. A temperature sensitivity of $S_T^Q = -3\%$ indicates that a 2 ^{0}C increase in temperature causes 6% decrease in runoff.

(PI) are presented on a climate response map (Ray and Brown, 2015). The performance evaluation is carried out using different tools such as the excel based models developed for energy computations of ROR projects, reservoir operation simulation models for energy computations of storage reservoir projects, cost-benefit analysis for computation of internal rate of return (IRR), present value of net benefits and levelized cost of energy (LCE). Acceptable thresholds of PIs are then used in the vulnerability domain (system response map) to determine the unacceptable climate domain (conditions).

The scope of our study was not limited to one particular project but the whole hydro-electricity sector in Nepal. Climate vulnerability of all types (ROR, PROR, Storage) and size of projects located in different climate and catchment regimes needed to be assessed. A database of 89 hydropower projects (69 ROR/PROR and 20 storage projects) was compiled and analyzed to assess the climate vulnerability across projects with different design concepts (types, size) and located in different catchments. Our assessment started with the vulnerability assessment under current climate variability of the existing and planned projects before testing the vulnerability to future climate changes.

Several additional tools and methods were also needed to evaluate the performance of the identified PIs. The climate change impact from extreme events such as floods, sediment and geo-hazards (including Glacial Lake Outburst Floods (GLOFs)) required case studies and hazard mapping. Performance of system level indicators such as investment cost required for generation expansion, appropriate mix of ROR, PROR and Storage projects and levelized cost of energy required the use of system planning models like WASP IV.

3.2.3 Climate Informed Risks: Estimating the plausibility of climate conditions and hazards

The next step in the CRA process is the determination of the plausibility (or relative likelihood) of the climate and runoff conditions identified as critical in previous steps. It is where the best available climate information is incorporated into the risk assessment process. The risk of violating the initially assessed thresholds regarding system performance can be assessed by using available climate projections from tools such as the Climate Wizard (climate wizard) and the Climate Change Knowledge Portal (Climate Portal); the latter also uses the projections provided by the Climate Wizard. The International Center for Tropical Agriculture (CIAT) operates the Climate Wizard (CW) tool, which was initially developed (Girvetz et al, 2009). Using the output of the latest CMIP5 projections, this tool is now being updated[9] for 23 GCMs and two Representative Concentration Pathways scenarios (RCP4.5 and RCP8.5), thus providing 46 bias-corrected climate projections for the 21st century (for 2030, 2050 and 2080) for user defined areas at 0.5^0 grid resolution. Since any CMIP5-RCP scenario could well reflect the ultimate climate future for the 21st century, all available climate projections were treated as one ensemble, consisting of a mix of projections for all available GCMs and RCPs.

Other sources of climate projects are the World Bank's Climate Change Knowledge Portal (CCKP) and those provided by NASA (https://cds.nccs.nasa.gov/nex-gddp).

3.2.4 Stress tests for other uncertainties

Ray and Brown (2015) point out that, whilst climate-related risks are quantified in the process of climate (change) risk assessment, it remains unclear in most cases whether the effects of changes

[9] Results for CMIP5 are not yet publicly available on the Climate Wizard, but were provided for this study through the kind cooperation of Dr. Evan Girvetz of CIAT, Nairobi.

in climate on a certain water resources project are significant relative to the impacts of changes in other non-climate factors (such as demographic, technological, land use, and economic changes).

The project level cost-benefit analysis model developed was thus used to test the performance of key economic indicators to non-climate indicators such as cost overruns, delays in construction, discount rate, and unanticipated future changes in the socio-economic and financial environment in which the project is placed. These uncertainties add to the total uncertainty about project outcomes, which may at times be more important than uncertainties about the future climate, particular in the case of climate resilient interventions. The model was also used to evaluate the economic performance of the project to different adaptation options including upfront or phased adaptation cost, and suite of technical and non-technical options.

3.3 Adaptation Pathways

3.3.1 Introduction

The previous section outlines how the study method and Climate Risk Assessment (CRA) methodology, which is based on a "bottom up" decision-scaling approach. It has identified key performance indicators (PI) that are significant for hydro-energy generation and that are sensitive to climate and thus puts the initial emphasis on understanding how the present meteorological and hydrological variability affect current operations and planned investments. This has the advantage of focusing the analysis on what matters. It then looks at future climate change, including uncertainty, and assesses how important future changes could be and how these key PI are affected.

Once these risks are identified, the next step is to identify potential adaptation options, to reduce or remove these impacts. As the hydropower sector has been developed with existing variability and different climate and hydrological risk levels, the challenge of climate change is not insurmountable and there are options that can address nearly all the climate and future risks that have been identified to mid-century (e.g. see IDS Nepal, 2014). It is therefore technically possible to address or design adaptation for Nepal's hydropower sector.

However, a more difficult challenge is to identify which adaptation options make sense to implement, and whether to remove risks completely or just reduce them, i.e. the balance of costs and benefits.

While it is possible to retrofit measures to reduce the risks of existing climate variability on current plants, this is often a very expensive option. This is made more challenging in Nepal by existing power purchase agreements and the high cost of borrowing. There is also the issue that the climate is already changing, and a question of how much retrofitting to do (noting that the historic hydrological patterns (or average and extremes) is no longer a good predictor of the future under climate change).

Looking forward, it is possible to over-design new plants to mitigate against all possible future climate change risks, e.g. to design to cope with the most extreme climate scenarios, this is also unlikely to make sense in economic and financial terms. However, this investment is complicated by the nature of climate change and how this affects the economic justification of adaptation investments for two reasons.

First, the impacts of climate change, and thus the benefits of adaptation, primarily arise in the future. Early action to address future climate change risks (such as with up-front retrofit or over-design) will incur costs in the short-term, but provide economic benefits in the medium to long-term. This rarely makes sense from an economic or financial perspective.

Second, and compounding this, future climate change is associated with high uncertainty. This makes it difficult to plan exactly what to do when. Even if early action is taken, it is likely that it will under- or over-estimate the actual risks that emerge, leading to high impacts later (if climate change turns out to be more severe) or investments are made with costly adaptation that are not actually needed (if for example, positive or more modest change occurs).

Early adaptation (to future climate change) has the potential to increase the capital or operating costs of hydropower plants, and therefore affects the rate of return and the cost of electricity produced. The benefits of these investments will, however, only arise in the longer-term. This is a particular issue for private plants in Nepal, as any benefits of medium to long-term adaptation will occur towards the end of the concessionary period of the PPA (30 years). Even for public projects, the future benefits of adaptation will be very small when compared to the up-front costs in present value terms. These issues are exacerbated by the high uncertainty around future climate change risks and there is a question mark if future impacts will occur, and thus whether early adaptation will lead to any actual medium- to long term benefits. The box below provides more detail.

Box 3-1: Discounting and future adaptation benefits

When comparing $costs and $benefits in different time periods, it is important to make sure that values are presented in equivalent terms, reflecting the fact that people prefer to receive goods and services now rather than later ('time preference'). For the private sector, this time preference is associated with the interest rate on money, and the payback or return, which is then reflected in the internal rate of return (the IRR). In public project appraisal, social discount rates are used to convert all costs and benefits to 'present values'.

In Nepal, public appraisal of hydropower projects uses a 12% social discount rate. This means that future impacts from climate change – and thus future adaptation benefits from reducing these impacts - are small when presented in present value terms. This can be seen in the figure. A $1 adaptation benefit that arises in 25 years (e.g. around 2040) has a present value today of $0.06 and even a $1 adaptation in 15 years (i.e. around 2030) a present value of $0.18.

The main impacts of climate change on the hydropower sector happen towards mid-century, thus a plant operating or built today will experience these impacts in the long-term (towards the right of the figure). This means the payback on expensive retrofits today is difficult to justify (as money has to be invested or borrowed to undertake these works). The incentive will be therefore to delay or put off this investment. Likewise for a new plant this is designed today, under a Build Operate Own and Transfer (BOOT) arrangement in Nepal, where a private company owns and operates the facility with the goal to recover the costs of investment and maintenance within concession period of 30-35 years, there is little incentive to increase the captial costs and reduce profits now for benefits (reduced impacts and maintenance of revenues) that will arise at the very end of the concession period.

3.3.2 Adaptation pathways

To address these challenges, the project adopted an iterative climate risk management approach aligned to the climate risk assessment. This has two critical aspects. First, it focuses on what action to take now over the next five to ten years to address current climate variability and future climate change. Second, it identifies options that are economically attractive and justify implementation, despite the challenges around timing and uncertainty highlighted above.

This aims to provide practical information to support adaptation decisions (or policy) over the next five to ten years and aligns to the approach and findings from the CRA, i.e. for current climate variability and future climate change including uncertainty. It uses three complementary building blocks for addressing climate risks in the hydroelectricity sector of Nepal. These are

1. Immediate actions that address the current risks of weather and climate extremes (the adaptation deficit) and build resilience to future climate change. This includes early low- and no-regret actions, as these provide immediate economic benefits and can help reduce future impacts under a changing climate. These activities are focused on current hydro-power plants.
2. The integration of adaptation into early investments (climate smart planning), focusing on the new (planned or candidate) hydro-electric plants that will be built over the next decade or so. Given their long life-times, these plants will be exposed to future climate change, but these changes are uncertain. This therefore involves a greater emphasis on low cost design or flexible or robust options that perform well under uncertainty.
3. Early monitoring, research and learning to start planning for the future impacts of climate change. This includes the investing in information and learning, to help inform future decisions, through the value of information and option values.

At the individual plant level, that there are important differences in adaptation across these three areas, with different types of investments (i.e. reflecting decision context and challenges). Importantly for the study, this means there is not one single type of adaptation problem for the hydropower sector, and a different approach and different options are appropriate for each of the three typologies.

At the system or policy level, the three interventions can be considered together in an integrated adaptation strategy, often termed an adaptation pathway or adaptation portfolio (Downing, 2012), though the pathways concepts can also be applied for future decisions for individual plants.

This adaptation pathways approach has been used in this study to help with the timing and sequencing of adaptation, and to help in the early scoping and prioritisation of adaptation options.

The adaptation study has therefore taken the multi-model climate projections and vulnerability results from the CRA, and used the adaptation pathways approach to work up a list of possible adaptation options, for each of the three categories identified above.

The assessment developed a long list of adaptation options with a focus on identifying adaptation options that addressed risks to the key performance indicators, in relation to different climate risks, thus linking the analysis to the CRA. As an example, it considered how the impacts of a GLOF would affect a power plant (the immediate damage, the loss of generation and revenues from initial downtime and repair, etc.) and then identified possible options – both technical and non-technical - to reduce or avoid these costs.

The final step was then to prioritise these adaptation options, both for interventions in general, and the choice of individual options (specifically). The selection of promising early adaptation options has made using a combination of quantitative and qualitative analysis. This included analysis of costs and benefits along with a wider multi attribute analysis and expert elicitation, the latter focused on identifying options that were Nepal specific.

An initial economic / financial analysis was undertaken using real hydrological and financial data from a number of existing plants in Nepal. The analysis has then introduced climate scenarios – looking at the envelope of change from the models - to see how this affected the net present value (NPV) and internal rate of return (IRR). The final step was to analyse the costs and benefits of adaptation options, and to see how these affect the underlying financial and economic performance criteria, and thus to understand the costs and benefits of adaptation.

This was used to identify promising options, which were then considered with respect to their implementation (taking account of the institutional landscape) and the barriers to adaptation

3.4 Institutional analysis and mainstreaming

A wide range of stakeholders have a vested interest in hydropower generation and safety, and thus in adaptation.

This includes Government policy makers and regulators, International Financial Institutions (IFIs) and Development Partners (DPs), the private sector, domestic and foreign developers, foreign regulators (for exports) and others such as civil society.

Importantly, these stakeholders are involved at different stages of hydropower development, from policy decision makers, to developers and consumers: this also maps onto their potential role in risk assessment, adaptation strategy and implementation.

The study undertook an institutional mapping analysis and reviewed the roles and responsibilities of different actors in hydropower development, their exposure to climate change risks, the various mechanisms through which they could support or implement adaptation, and their influence.

The latter centres on their role in the project cycle in Nepal, and the point at which they influence or act, i.e. planning, design, construction, operation.

The ability to influence or implement adaptation also depends on stakeholder's adaptive capacity (e.g. their access to information, finance, etc.). This has been explored through a series of workshops and stakeholder consultation in the project.

The study has also considered how to mainstream (to integrate) adaptation into the institutional and policy landscape. Mainstreaming is the integration of climate change into existing policy and development, rather than implementing measures as a stand-alone activity (OECD, 2015). The focus is therefore to include climate in existing activities, e.g. to make it climate-smart.

One of the first activities of mainstreaming is to identify relevant entry points (UNDP, 2011), that is, to identify the existing framework and opportunities in the national, sector or programme plans and activities where climate adaptation can be integrated.

To enable this, the study assessed the existing regulatory framework for the electricity sector and hydro-electricity as well as for climate change adaptation. This provides the baseline onto which adaptation options or interventions can be considered.

Finally, there are a number of barriers to adaptation (Cimato and Mullan, 2010) that make it harder to plan and implement. These include a range of economic, social and institutional factors, including market failures, policy failures, governance failures and behavioural barriers.

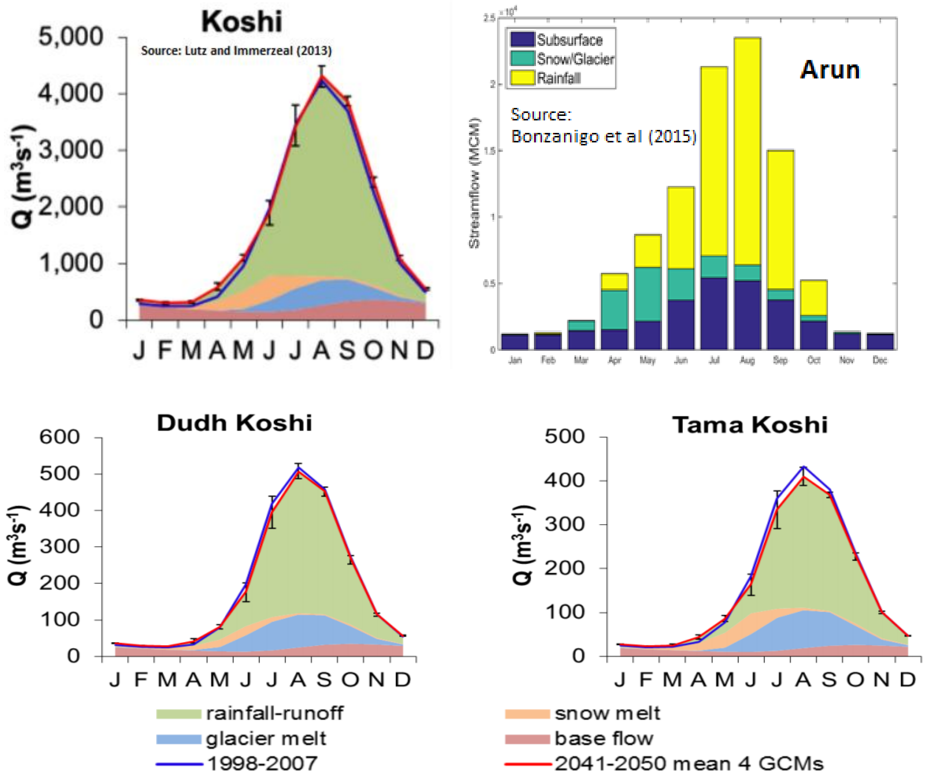
Addressing these barriers is critical to successful adaptation, especially for medium to long-term decisions such as for hydro-power. The study has therefore assessed the barriers to adaptation for the hydropower sector in Nepal.

4 The current and future climate vulnerability of the hydro sector and identification of key performance indicators

4.1 Current Climate Variability and its impacts

Hydro-meteorological characteristics of river basins in Nepal (the upper Ganges Basin) are mainly influenced by complex topographical variation and monsoon precipitation. Sharp changes in precipitation and climate occur from low to high altitudes within short spatial distances, including dominant orographic effects causing higher precipitation in foothills of the Himalayas. As such, this shapes the climatology and hydrology of the region. In addition to topography, the southwest monsoon governs the summer precipitation in Nepal and westerlies influence the winter precipitation. Since the southwest monsoon is dominant and generates almost 80% of the total rainfall in a span of four months from June to September, the temporal rainfall distribution is heavily skewed. Such spatial and temporal variation of precipitation and climate influences the hydrological characteristics of the Nepalese Himalayan catchments.

The flow hydrograph is single peaked (in July or August) with almost 75-80% of annual flow in monsoon months. Runoff in the Himalayan catchments is composed of glacier melt, snow melt rainfall-runoff, and base-flow (groundwater). Rainfall-runoff constitutes the major volume of flow hydrograph. Lutz and Immerzeel (2013) estimated that rainfall-runoff contributes about 66% of total runoff in Upper Ganges basin; which is followed by 13.9% from base flow,11.5% from glacier melt and 8.6% from snow melt. This is in contrast with Upper Indus basin where 40.6% is contributed by glacier melt and 21.8% by snow melt. Rainfall- runoff and base flow only constitutes 26.8% and 10.8%, respectively, in Upper Indus.



(Source: Lutz and Immerzeel 2013; and Bonzanigo et al 2015)

Figure 4-1: Composition of flow hydrograph in Upper Ganges basin (Koshi and its tributary basins)

Figure 4-1 shows the temporal distribution of above components and their significance. In monsoon, the rainfall-runoff dominates the hydrograph even though the glacier melt is higher in those months in compare to other months. In pre-monsoon months (April-May), the snow melt approximately have equal or more share in contribution in comparison to rainfall-runoff and base flow. In these months, the glacier melt just begins and has minimal contribution. In the case of the post-monsoon (October -November), rainfall-runoff still constitutes a major portion with increased base flow. In these months, the contribution of glacier is higher in higher elevation catchments as Dudh Koshi and Tamakoshi than compared to the whole Koshi basin. This is because a high percentage of snow and glacier area in those sub-basins. But still, rainfall- runoff is major component in post monsoon. In case of dry seasons (December - March), base flow is prominent to other components. Snow/glacier melt is significant in pre-monsoon months for snow fed rivers.

Besides, elevations of 3000m and 5000m are important benchmarks in examining the climate and flow characteristics. Below 3000m, hydrology is driven dominantly by rainfall. Likewise, threshold of 5000m is considered as permanent snow line. The transition area between 3000m and 5000m has major influence in hydrology as snow accumulation and melting process occurs in this area.

It is observed that annual water yield has increasing trend as percentage area above 3000m increases up to 20 percent and then has decreasing trend thereafter (left chart in Figure 4-2). Similar trend is observed with dry season yield too. Similar nature is found with the percent area greater than 5000m with point of inflection at 10 percent (right chart in Figure 4-2). With this reference, the value of percentage of catchment above 3000m and supported by the different values of range of water yields, we have categorized the catchments into five groups, These area) Highly snow dominated higher elevation catchments with catchment area (CA) above 3000m is greater than 80% b) Medium snow dominated with CA above 3000m between 60-80% c) Low snow dominated with low elevation catchments with CA above 3000m between 40-60% d) Rain dominated catchments with CA above 3000m between 20-40% e) Rain-fed catchments with CA above 3000m less than 20%.

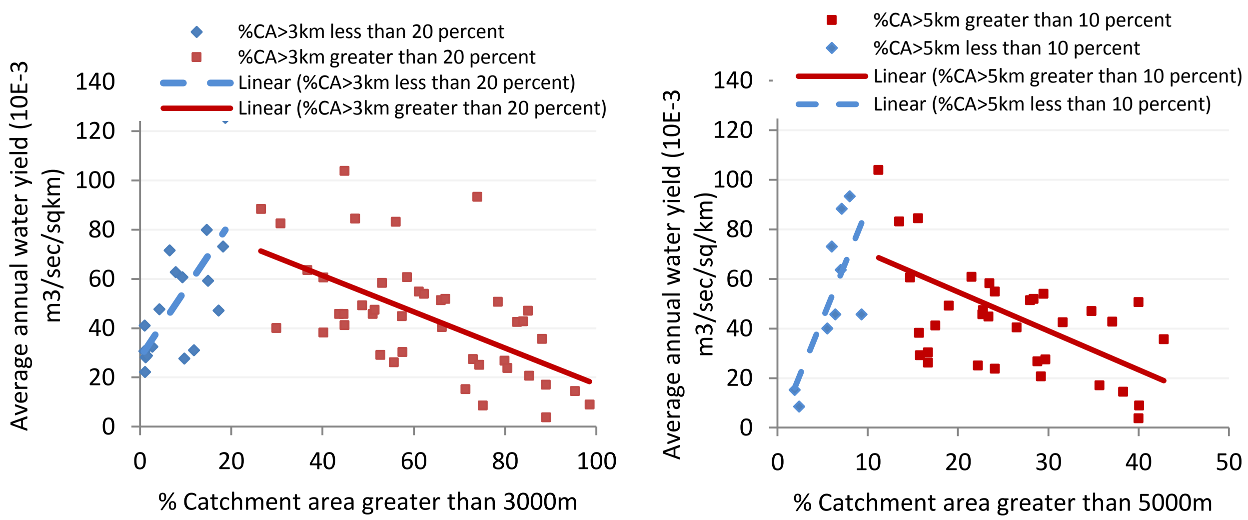


Figure 4-2: Variation of Average Annual water yield along with percentage of area greater than 3000m and 5000m elevation

Coefficient of variation (CV) of flow is high for rain-fed and rain dominated catchments than snow dominated catchments. This can be observed across the catchments in Figure 4-3. This is because of storage of rainfall as snow/glacier and their gradual melt in the snow dominated catchments. It is also observed that the coefficients of variation in pre-monsoon period in highly snow dominated catchment are comparatively higher because of the snow melt. The influence of the monsoon precipitation causes high CV in monsoon months for all the catchments. In case of rain-fed and rain dominated catchments, high CV values in dry season can be attributed to variation in monsoon rainfall. Likewise, CV of flow is high for smaller catchment than for larger catchment. In high catchments, due to tradeoff of effects of different hydrological processesdue in different spaces (lumping) causes lower coefficient of variation. In contrast, in smaller catchments, those processes are specific resulting in high coefficient of variation depending upon the nature of the catchment.

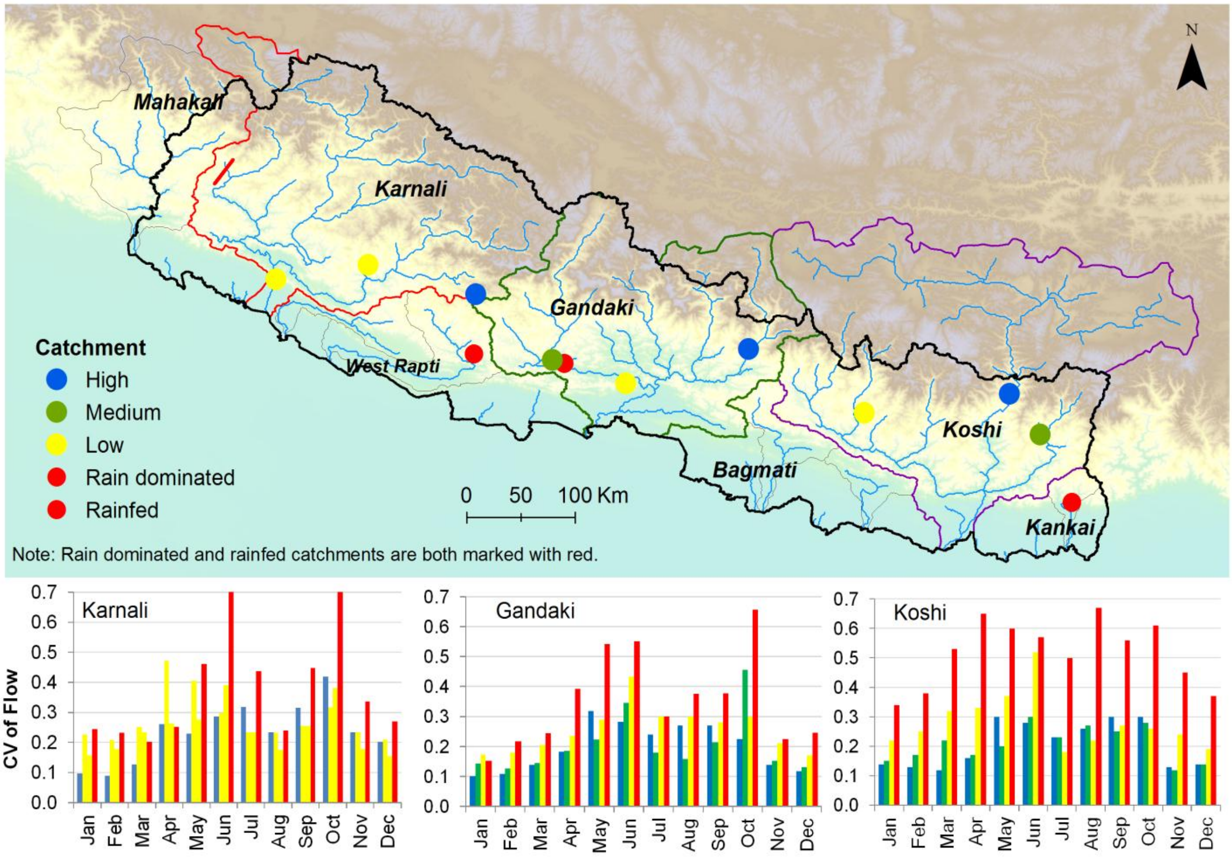


Figure 4-3: Coefficient of variation of the flow across different catchments

4.1.1 Energy Variability

The excel-based hydro-energy generation computation is used to compute the monthly energy variation of hydro projects. Energy variation is mainly dependent upon catchment type (based on catchment categorization described in Section 4.1 above), size, head, sediment load, live storage capacity for storage projects etc. Catchments with higher elevations are more snow fed which contribute to pre monsoon flows. Energy generation in smaller catchments are more variable as there is more variation in flow in inter-annual and seasonal. Snow fed and larger catchments have less variable in flows and hence in energy. Figure 4-4 presents current, committed and planned hydropower projects categorized by project and catchment type.

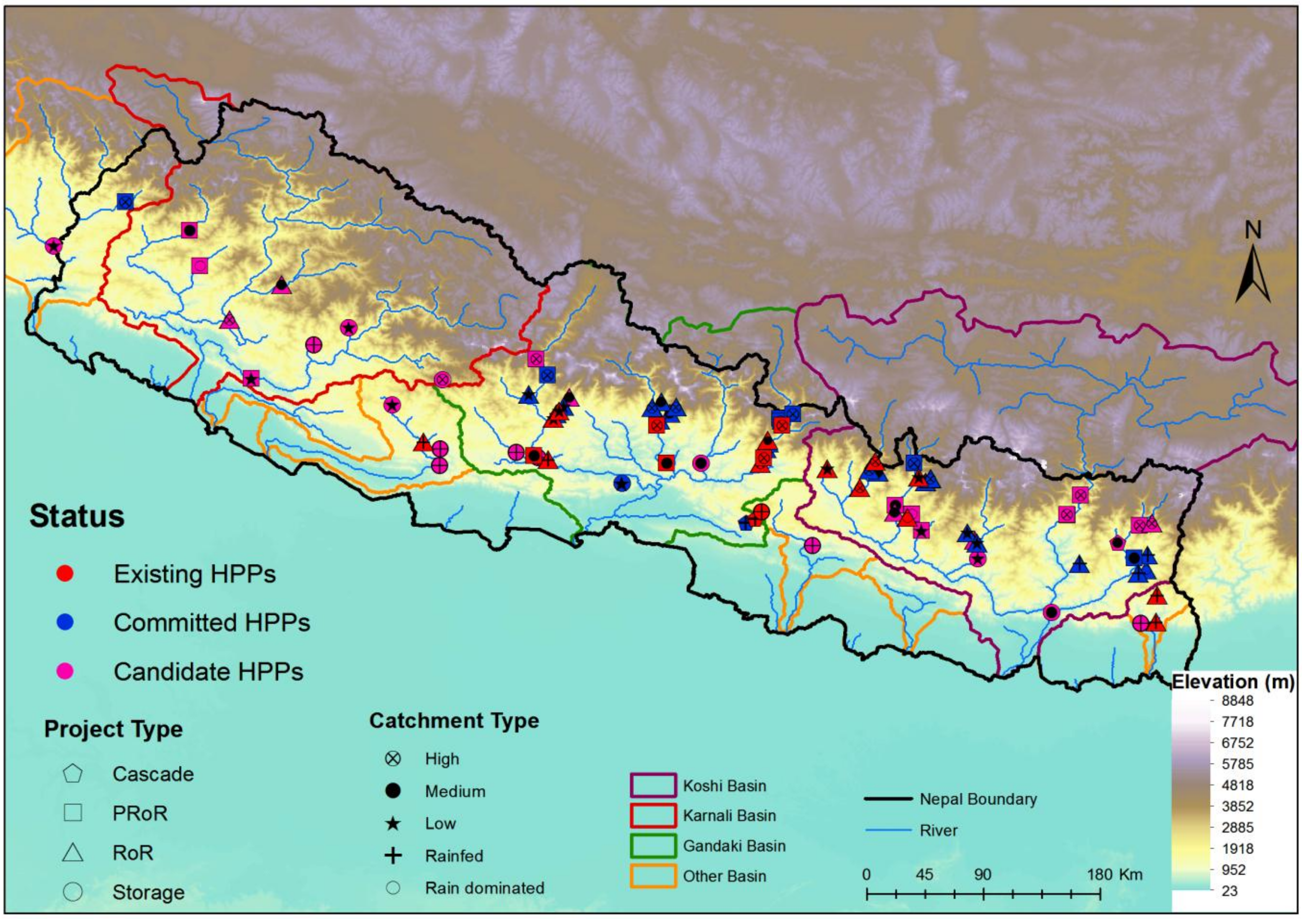
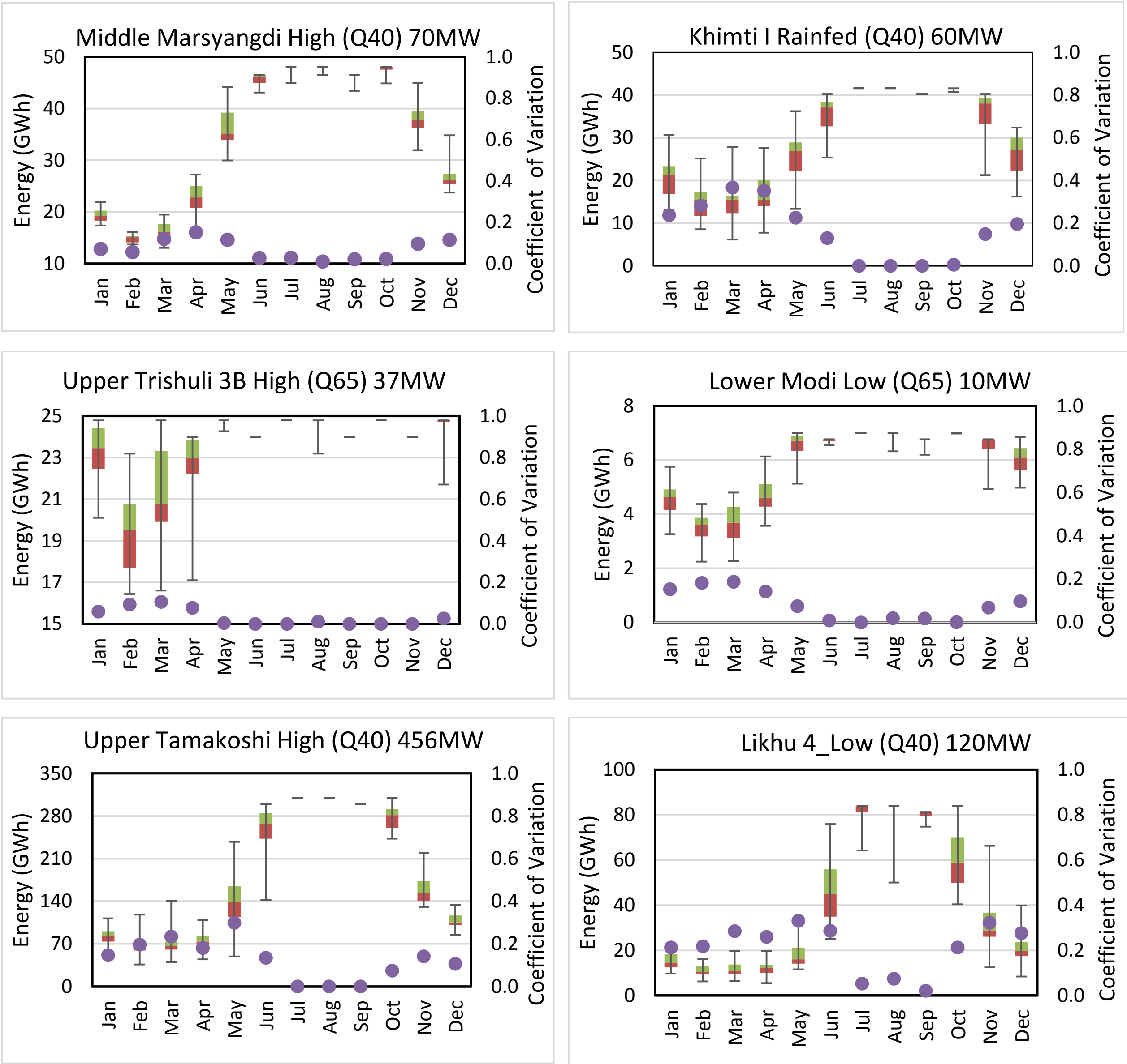


Figure 4-4: Hydropower projects, their type and catchment conditions

4.1.1.1 ROR projects

More than 75% (69 out of 89) projects reviewed in the study are RoR and PRoR projects with different status, catchment types and design flows with varying flow dependability The projects are designed from 20% to up to 90% of flow dependability (exceedance probability). More than 50% of the projects are designed with flow with 40% exceedance probability and 44% of them lie in the high snow dominated catchments. The results of the computation on the energy generation show that variation is more dependent on type of catchment and dependable design discharge. Figure 4-5 shows energy variation of projects in snow fed and rainfed catchments with design discharges of different probability of exceedence. Projects in rain-fed catchments with design discharge with low probability of exceedance have more inter and intra-annual energy variability than projects in rain-fed catchment designed for discharge with high probability of exceedance. Energy variation in snow fed catchments is less compared to projects in rain dominated or rain-fed catchments Snow fed catchments has comparatively stable base flow so the energy variation is less.



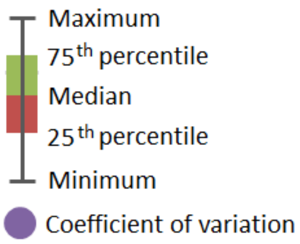


Figure 4-5: Energy Variation in different catchment with different design capacity (RoR Projects)

4.1.1.2 Storage projects

Twenty storage projects are considered in this study with one existing (Kulekhani I and II 92 MW) and one under construction (Upper Seti (Tanahu): 140 MW). The ratio of live storage capacity to average monsoon (June – September) runoff of these 20 projects varies from 6% to 87%. Only 10% of the 20 storage projects have live storage- monsoon runoff ratio more than 70% and 50% of the projects have live storage capacity less than 25% of monsoon runoff. Projects with high live storage have better control and better flow regulation in dry season so dry season energy generation is robust to flow variations.

Figure 4-7 shows the storage projects (one existing and others planned) across the river basins. Rain dominated and rain-fed catchments are marked as blue dots. Black circles show the reservoir capacity of the storage projects with respect to monsoon flow.

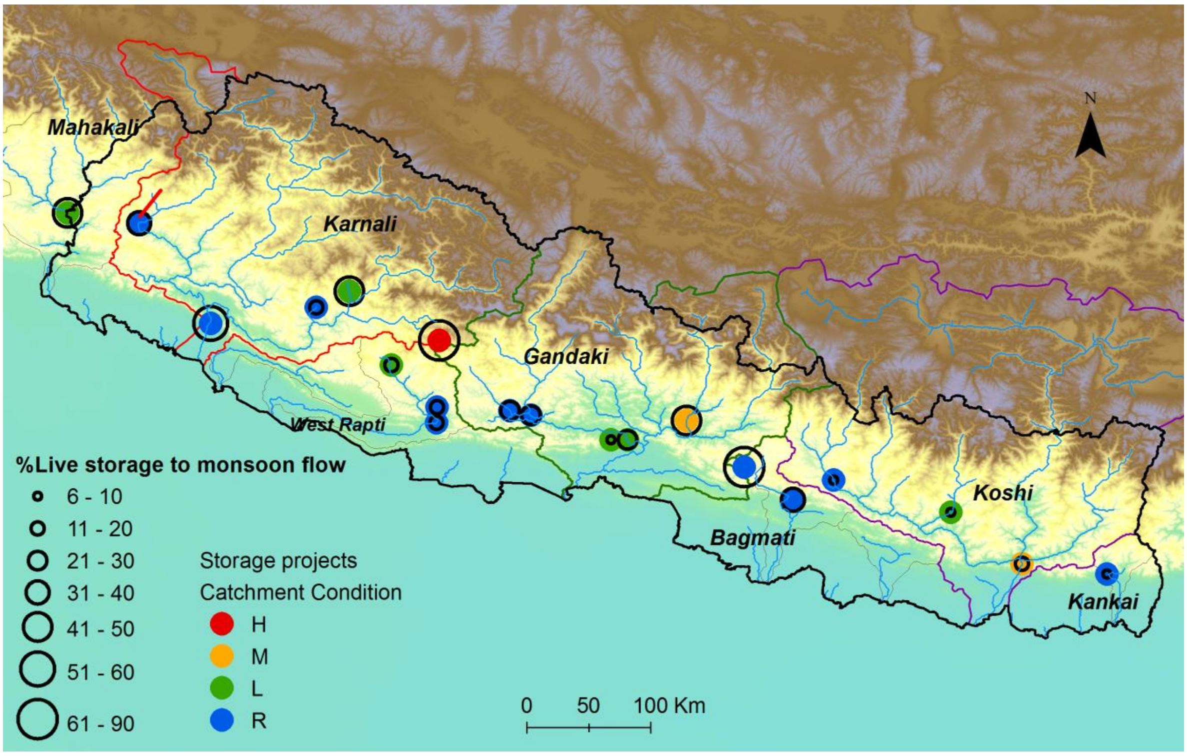


Figure 4-6: Storage projects with their percentage of live storage to monsoon flow and catchment condition

Excel based reservoir simulation model was used to simulate the energy generation for different design parameters such as storage capacity, monthly plant factor and reservoir operation policy. The flows stored in the wet season are used to generate firm energy in the dry season. As the storage capacities of the reservoir projects are substantially lower than the average monsoon runoff, the dry season energy is more or less stable for these storage projects. Energy is generated in the wet season using a reservoir operation policy of filling the reservoir at the end of the wet season (September/October). Secondary energy is generated up to the maximum installed capacity when the flows are high instead of spilling the extra flows that cannot be stored.

Error! Reference source not found. shows the energy generation pattern of two projects with different live storage capacity in terms of % of average wet season runoff. It is clear that dry season energy is stable (firm) for a storage project with larger live storage than one with smaller storage. The wet season energy generation in a storage project with larger live storage varies more as the generation is more as secondary energy when higher flows occur in some years. In the case of storage projects with smaller live storage, the wet season energy generation variation is less because the project stores only a small part of the monsoon runoff and energy is generated in its full capacity with the available being less the design discharge capacity every year. The pre-monsoon and post-monsoon energy generation variation is mainly due to secondary energy generation when reservoir water levels exceed the desired reservoir levels in these months according to the operation policy (rule) adopted.

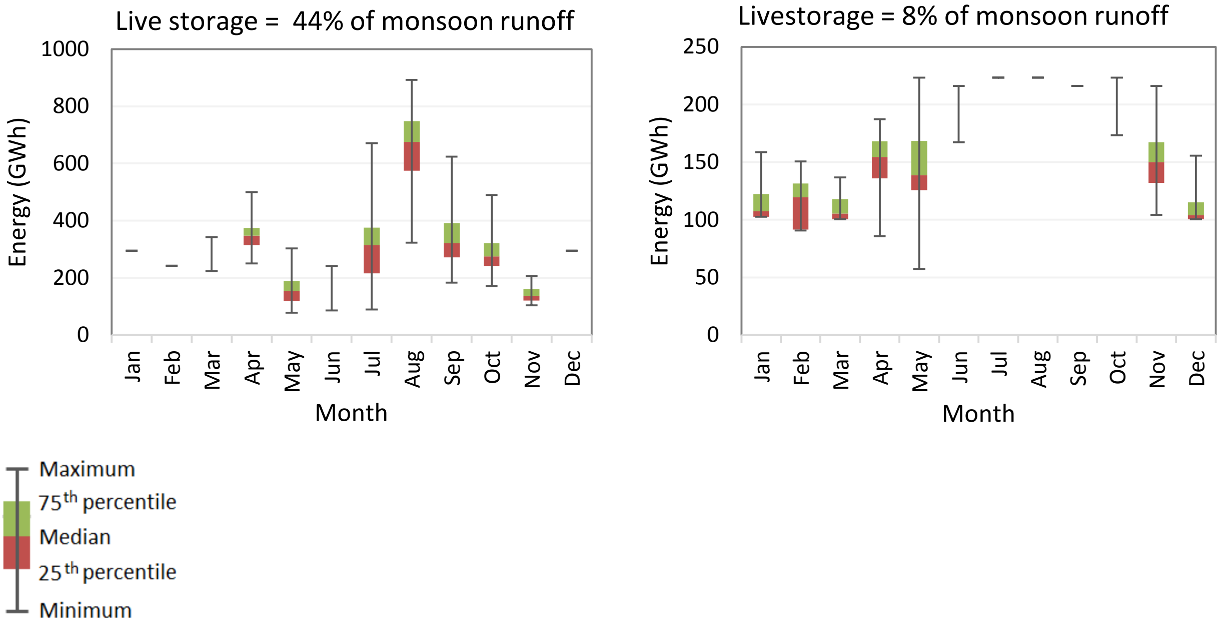


Figure 4-7: Energy Variation with different live storage capacity to monsoon runoff of Storage Projects

4.1.2 Sediment Variations

4.1.2.1 Sediment induced impacts on RoR/ PRoR projects

Wear and tear of both civil and hydro-mechanical structures is the key sediment related problem causing outage and higher O&M cost. Because of the high velocity and transport of bed load (boulders, gravels, and pebbles), spillways, bed load passages such as undersluice, gravel traps of RoR headworks are usually subjected to substantial wear and tear. For instance spillways and bed load passing passages at headworks of Middle Marsyangdi HEP (70 MW) in Nepal have been severely damaged due to floods of each year. Similarly, turbines and accessories (guide vanes, stay vanes, face plates, nozzle of impulse turbines) of most of the RoR hydropower projects in Himalayas are severely damaged due to suspended sediment. Severe wear and tear have been reported in Jhimruk HEP as well as Middle Marsyangdi HEP, Nepal The wear and tear of turbines and accessories cause loss of efficiency of turbines resulting in loss of power output. The loss of efficiency varying between 4% (at full plant capacity) and 8% (at partial load condition) has been reported in Jhimruk Hydropower plant after the operation of plants for mere 72 days. Choking of conveyance due to floating debris, bed load and sometimes due to coarse suspended particles are most common problem for RoR/ PRoR projects in Nepal. It causes reduced generation; due to decreased discharge or significant headloss in the trashrack.

4.1.2.2 Sediment induced impacts on Storage projects:

Contrary to RoR/ PRoR plants, both the conveyance and generating units and accessories do not suffer from wear and tear and choking at least during early years of generation. However, it will cause loss in effective storage in later years of operation. Loss of live storage of reservoir has been witnessed in the Kulekhani hydropower project, the only existing reservoir project in Nepal. It has lost about 20.4 million cubic meters (mcm) (23.9%) of 85.4 mcm total storage (14 mcm (19.1%) of 73.3 mcm live storage) in about 25 years of operation (1985 - 2010) due to sedimentation, especially due to a major extreme flood and sediment event in 1993.

Box 4-1: Effect of sedimentation in Budhigandaki Hydroelectric Project

Budhigandaki Hydroelectric Project (BGHEP) is one of the promising and priority storage projects of Nepal. The project is located on the Budhi Gandaki River approximately 2 km form its confluence with Trisuli river at Benighat. According to the feasibility and detailed design report of BGHEP (Phase III), the mean annual energy generated will be 3383 GWh/year, out of which 1408 GWhr will be generated during the winter period of 5 months from mid-December to mid-May. The project cost is estimated to be 2592 million USD (US$ 2160 per KW).

Loss of storage due to sedimentation: BGHEP is storage plant with design capacity of 1200MW, dam height of 263m and gross storage volume of 4467 million cubic meters (mcm) at FSL of 540m. Minimum Operating Level (MOL) is 496m with an inactive storage volume of 2241.6 mcm, and the live storage of 2225.7 mcm. Estimated sediment yield of BG catchment is 9.8 million cubic metres per year equivalent to 2720 tonnes/sq.km/year. According to the DPR, the live storage will decrease by 3.7% after 25 years, 6.4% after 50 years and 12.5% after 100 years. The figure below shows the estimated loss of storage with relative depth of reservoir after 25 years in the case of given sedimentation condition (blue curve), and in the case of increased sedimentation (red curve). The latter case is based on assumption of 20% increase in sedimentation due to increase in monsoon flow (resulting from 10-20% increase in monsoon precipitation as projected by GCM results) and its linear response in loss of storage.

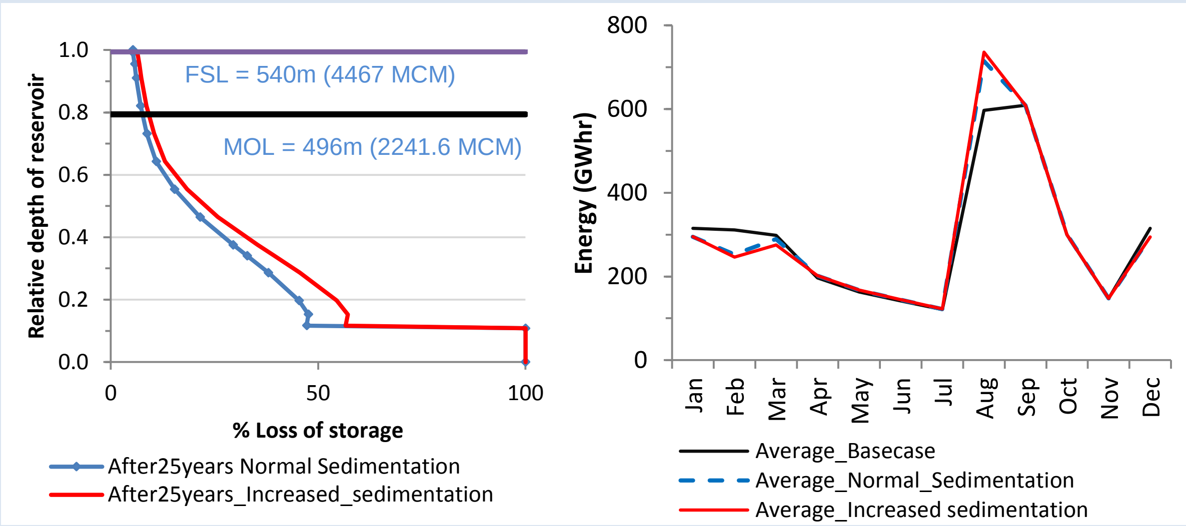


Figure: (Left) Loss of storage with respect to relative depth of BG reservoir (right) Loss of energy after 25 years due to sedimentation

Loss in energy due to sedimentation: An excel-based reservoir simulation of BGHEP was carried out in this study with the purpose to access the changes in energy in different climate scenarios and in increased sedimentation condition. Results show an decrease of 2.9% of total energy (7.1% of dry energy from December to April) after 25 years in case of given sedimentation condition (Dashed blue curve in Figure above) from the commissioning year (black line). In the case of increased sediment condition, results show the decrease (loss) of energy by 3.5% of total energy (8.6% of dry energy) (red curve). The results also show increase in wet energy as more water is spilled due to reduced storage capacity due to additional sedimentation.

4.1.2.3 Sediment variation over Nepal

Sediment load is higher in the river basins like Kali Gandaki and Marsyangdi in Gandaki Basin (lying in the Tibetan Sedimentary Zone). These areas generally produce annual sediment yields of more of than 7000 ton/sq.km/year. Sediment loads in high glacierized area as in Arun sub-basin and Tama Koshi sub-basin in Koshi Basin are less than 1500 ton/sq.km/year. Areas in the middle mountains, rain-fed catchments, such as Kulekhani and Khokhajor also have high yield of around 5000 t/sq.km/year. Sediment loads as high as 25,000 ppm are regularly recorded in major rivers such as the Narayani in Nepal (Carson, 1985). Sediment load up to 50,000 parts per million (ppm) has been frequently observed on smaller rivers like the Jhimruk in Nepal (Basnyat, 1997, Pradhan 2004). Figure 4-8 show the sediment yield map of Nepal Map is prepared based on literature review.

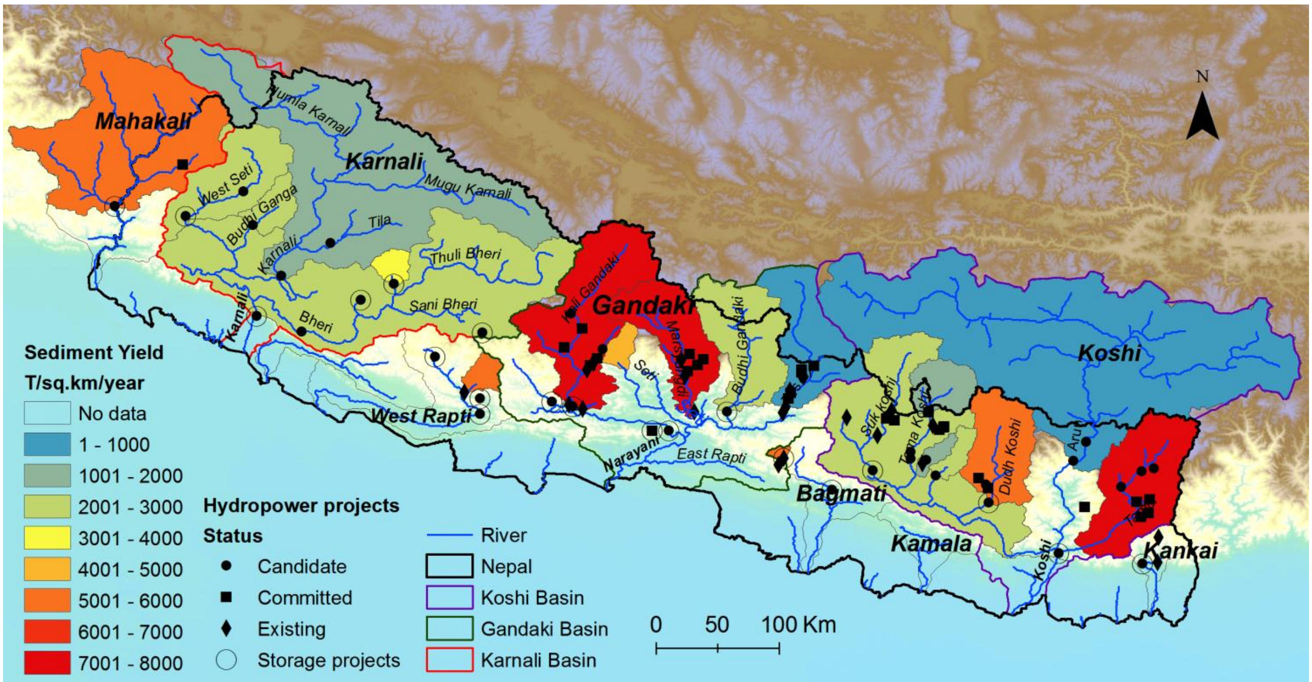


Figure 4-8: Sediment yield of different river catchments of Nepal

4.1.3 GLOF Risks

Temperature rise in the Himalayan watershed has contributed to the formation and expansion of glacial lakes which is closely associated with increased risk of glacial lake outburst flood (GLOF). Sudden release of stored water and associated debris due to breach in the glacier moraine dam is known as GLOF. They are characterized by high peak discharge, high velocity, and very high sediment/debris load. Twenty four GLOF events have been documented in Nepal by ICIMOD (2011) with its origin both in Nepal and China. Fourteen GLOF events in Nepal were reported between 1935 and 1991 (ICIMOD, 2007).

High discharge volume within a short time interval causes catastrophic damage to hydropower infrastructures. Namche Small Hydro project was destroyed by the Dig Tsho GLOF in August 1985 (ICIMOD 2011, Yamada and Sharma 1993) with an estimated loss of US$ 1.5 million (NHA, 2015). Likewise, Zhangzangbo GLOF in July 1981 caused significant damage to diversion weir of Sunkoshi Hydropower plant (NHA, 2015). Besides the peak discharge (floods), the high magnitude of sediment it carries is the major threat to hydropower and other structures, not to mention the communities living downstream of such lacks. Numerical modeling of Tam Pokhari (Sabai Tsho) GLOF in September 1998 done by Osti and Egashira (2009) estimated 440,000 m^3 of sediments/ debris was deposited along the downstream distance of 14 km. GLOF in Nagma in 1980 caused an increase in sediment load from 2000-6000 ppm to 8000-12000 ppm in Tamor river at Mulghat.

ICIMOD (2011) modeled the breach of three critical glaciers- Tsho Rolpa, Thulagi Lake and Imja Tsho lakes-

Tsho lakes- using hydrodynamic models.

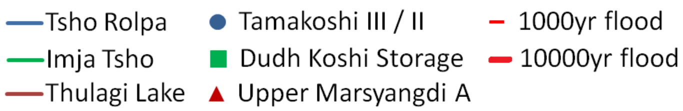


Figure 4-9 shows the computed magnitude; time of travel and distance travelled by peak flood in the case of three GLOFs modelled.

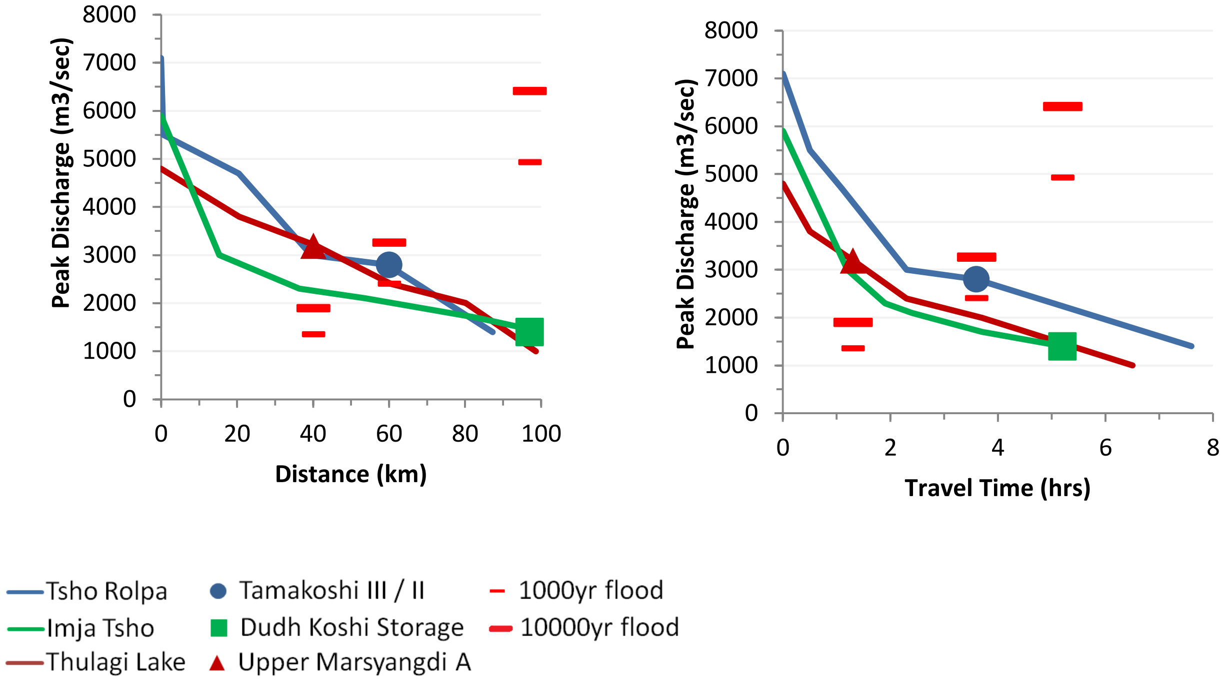


Figure 4-9: Distance and time of travel by flood waves in three critical glaciers (Source: ICIMOD 2011)

GLOF flood waves (equivalent to nearly instantaneous dam break floods) rapidly attenuate on their way down the mountain valleys. ICIMOD (2011) modelling results show that peak flows (varying between 5000 m^3/s and 8000 m^3/s at the site of the dam break for the above mentioned 3 relatively large lakes) attenuate rapidly up to half the magnitude in around 50 km over a period of about 3 hours. In about 100 km, the maximum flow is damped to about 20% of the initial peak flow, i.e. about 1,200 m^3/s for the above 3 cases. The expected hydrological floods of 1:1000 and 1:10,000 year return periods of three projects downstream of these lakes are also shown in the figure. It can be observed that the projects located after about 60 km from the lakes have 1:1000 year flood estimate about equal or more than peak discharge from the GLOFs at these locations. This provides some general guidance on the peak flood attenuation of GLOFs expected as the flood wave traverses along the river.

From the above three case studies by ICIMOD (2011), peak discharge of GLOF hazards are seen to be reduced by almost half in about 50 km and by about 80% in about 100 km (measured along the valley or river axis) from the potential glacial lakes. However, a more detailed dam break analysis and hydro-dynamic modeling for the GLOF events would however be required for each GLOF case to determine the exact impacts of such events. While the above case studies by ICIMOD deal with the flood discharge, the high sediment concentration and debris load that these GLOFs bring with them can be a matter of more concern to hydropower projects and other assets located downstream of these dangerous lakes. Runouts from GLOFs have been reported up to 200 km in the Himalayan region. Another important consideration of assessing GLOF risks on hydropower projects is to compare the peak flood from GLOF and the hydrological design flood that is used to design the hydraulic structures. The estimated design flood with high return periods (e.g. 1:10,000 years) for projects downstream of potential glacial lakes, like the proposed Arun 3 run-of-river project and the proposed Budhi Gandaki reservoir project, are found to be higher than the potential peak discharges from the GLOFs, if they were to occur. For example, peak flood from GLOF and Landslide induced outburst flood (LDOF) for the Budhi Gandaki Gandaki project is estimated to be 3000 m^3/s and 5200 m^3/s, respectively. The 1:10,000 year hydrological flood is estimated as 6,200 m^3/s and the Probable Maximum Flood (PMF) is estimated as 9,800 m^3/s.

ICIMOD (2011) has categorized 21 glaciers in Nepal as potentially dangerous glacial lakes for GLOF based on size and rapid expansion; increase in water level and other geological conditions. These lakes were mapped along with the existing and planned hydropower projects in Nepal. It can be seen that most of these dangerous lakes are located in the Koshi Basin and the Gandaki Basin (see Figure 4-10). There were no critical lakes identified in the Karnali basin in the study by ICIMOD in 2011. In the Koshi Basin, the Dudh Koshi sub-basin consists of 9 such critical lakes followed by Arun and Tamor sub-basins with 3 critical glacial lakes each. Tsho Rolpa glacial lake lies in Tama Koshi sub-basin. Other glacial lakes are in Gandaki (Narayani) Basin.

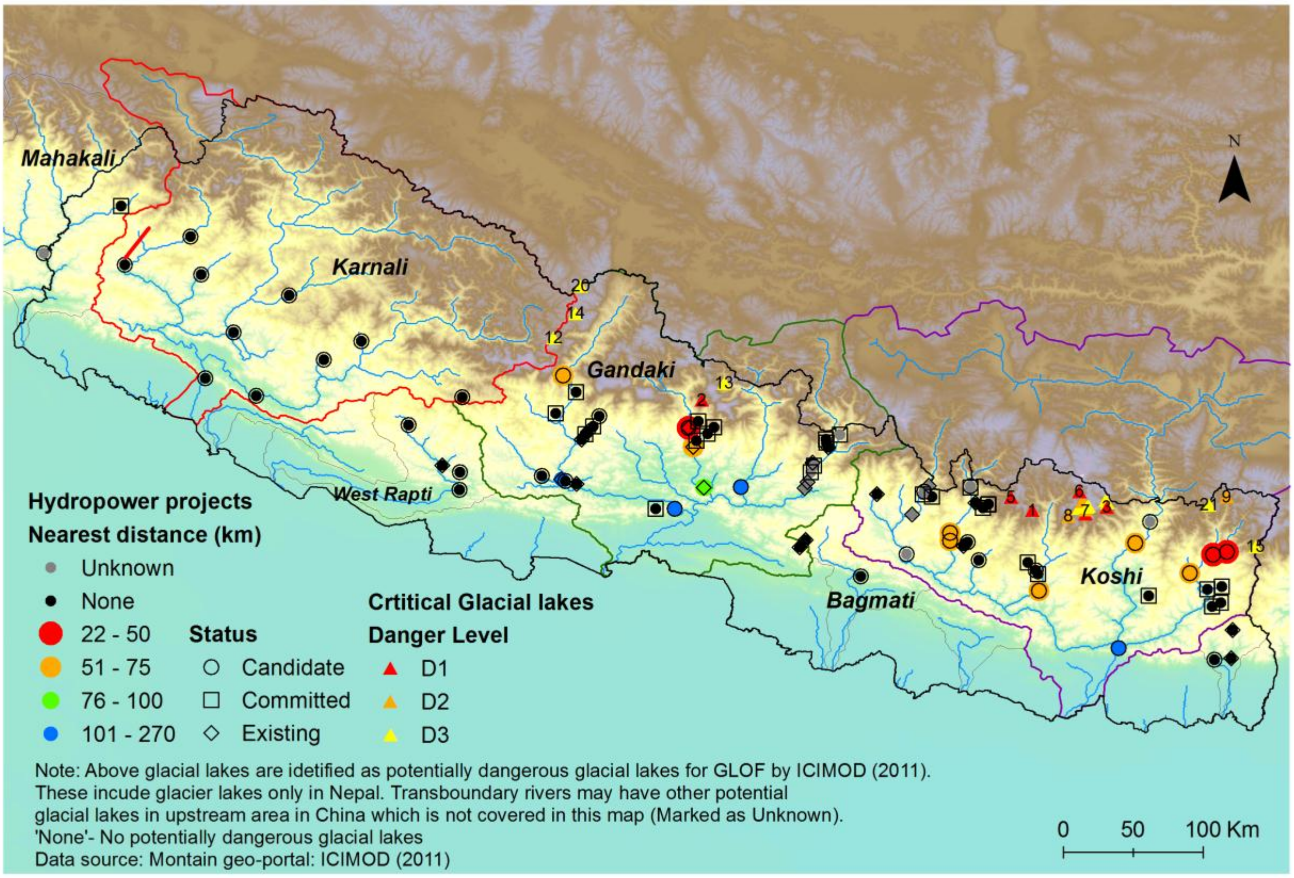


Figure 4-10: Location and approx. distance of hydropower projects with respect to critical glacial lakes identified by ICOMOD (2011)

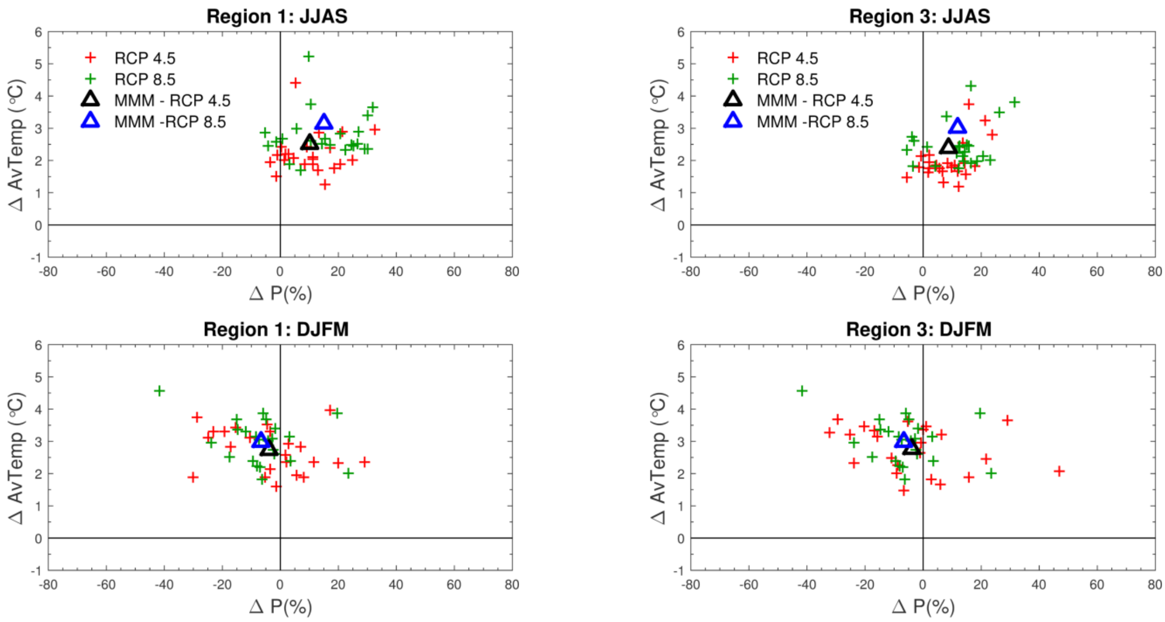
Figure 4-10 delineates the distance of the hydropower projects from the dangerous lakes identified by ICIMOD (2011). Based on the above case studies, hydropower projects located within 50-100 km from such dangerous glacial lakes can be considered at more risk from GLOF impacts than those further downstream. Given similar topography and river hydrography across the river systems, this can be a guidance to hydropower engineers and planner to initially assess the risks of GLOFs on hydropower projects. One limitation of the map is that glacier lakes in the Chinese (Tibetian) catchments are not mapped.

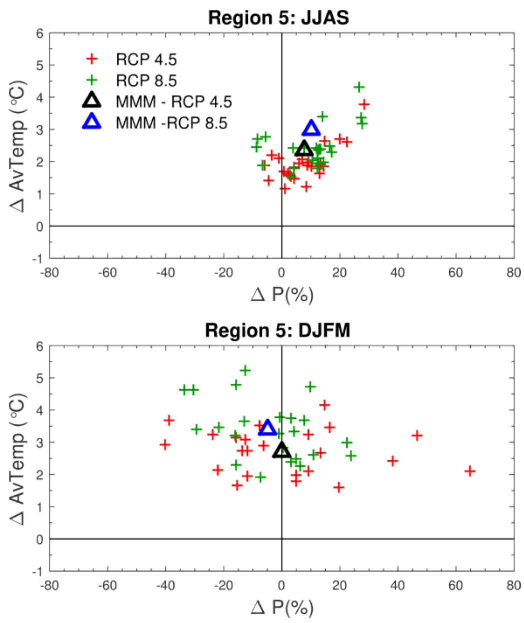
4.2 Future climate risks

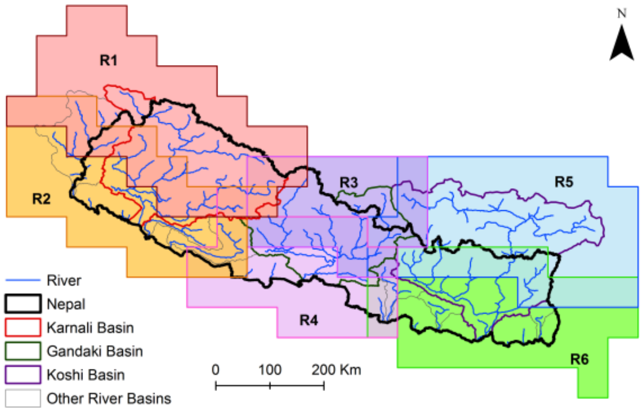
4.2.1 Climate Projections and Uncertainty

We have used 23 Coupled Model Intercomparison Project Phase 5 (CMIP5) climate model projections for Nepal for the 2050 time horizon (2040 – 2059), as available from the Climate Wizard[2] (Girvetz et al, 2009) for two climate scenarios RCP 4.5 and RCP 8.5. Representative Concentration Pathways (RCPs) are used by Intergovernmental Panel on Climate Change (IPCC) to describe the future scenarios. They are atmospheric greenhouse gases (GHG) concentration trajectories that are pursued over time, from present day to 2100, in order to stabilize radiative forcing to specified value along the trajectory. There are four such scenarios, viz, RCP2.6, RCP4.5, RCP6.0 and RCP8.5 that represent four different levels of radiative forcing at the end of 2100 AD which are 2.6, 4.5, 6.0 and 8.5 Watt/m^2, respectively. The base period is 1960-1991.

Selection of study area: Owing to the topography and precipitation, we have divided the study area (Nepal) into six hydro-meteorological regions (as shown in Figure 4-11**)**. It is divided vertically into two regions at elevation range above (upper) and below (lower) approximately 1000m. Region 1, Region 3 and Region 5 constitute upper regions representing the Himalayan region, with medium to high altitudes. Region 2, Region 4 and Region 6 represent the lower altitudes in the Terai region and are more rain-dominated. These divisions also commensurate with the three major river basins in Nepal: Koshi River basin in Eastern Nepal, Gandaki River basin in Central Nepal and Karnali River Basin in Western Nepal.







Study regions for climate change analysis

(Note: MMM represents multiple model mean)

Figure 4-11: Changes in average temperature and precipitation in 2040-2059 from base case

The 23 model results in changes in precipitation and temperature from the base case period (1960 – 1991) to the 2050s (2040 – 2059) is shown in scatter plots (Figure 4-11)

Uncertainty in model projections in temperature

The models show quite a large variation in projected temperature ranges for different seasons and months. The 23 GCM models even though are consistent in projecting warmer future in 2040-2059; they vary in degree of projected changes Figure 4-11 .For monsoon months, in RCP 4.5 scenario, more than16 models predict temp rise between 1˚C to 2˚C (except region 1) whereas more than 13 models predict temperature rise between 3˚C to 4˚C in RCP 8.5 scenario. For winter months, about two-third of the models project more than 2˚C in RCP 4.5 scenario and more than 3˚C in RCP 8.5 scenario.

Uncertainty in model projections in precipitation

The ranges of precipitation changes are high. The change in monsoon precipitation across upper Nepal is projected from -5.8% to +32.7% in the RCP 4.5 scenario and from -8.9% to +31.8% in the RCP 8.5 scenario for the same time period. In winter months (DJFM), the projected precipitation change ranges from -40% to +66% in the RCP 4.5 scenario and from -37% to +24% in the RCP 8.5 scenario by mid-century. Ranges of changes are higher in case of pre-monsoon and post monsoon months.

About 19 models agree on the increase in precipitation in monsoon months in RCP 4.5 and RCP 8.5. But different model results show different range of those increases (Figure 4-11). However, there is no agreement among models regarding winter precipitation. More than half of the models show a decrease in winter precipitation.

4.2.2 Hydrological Modeling- Runoff response to climate

The future projections from climate models show changes in temperature (T) and precipitation (P) which can influence changes in hydrologic regime by affecting key hydrological processes like evapotranspiration(ET), snow-rainfall ratio and melting time and amount of snowmelt. Hence, the semi-distributed, physical based SWAT hydrological model was used in this study to assess the changes in runoff with changes in Precipitation and Temperature. The runoff-response to changes in average P and T for three outlet locations (from upstream to downstream) of Jamu basin in Karnali River Basin is presented in Figure 4-12**.** The catchment characteristics of these outlets are given in Table 4-1.

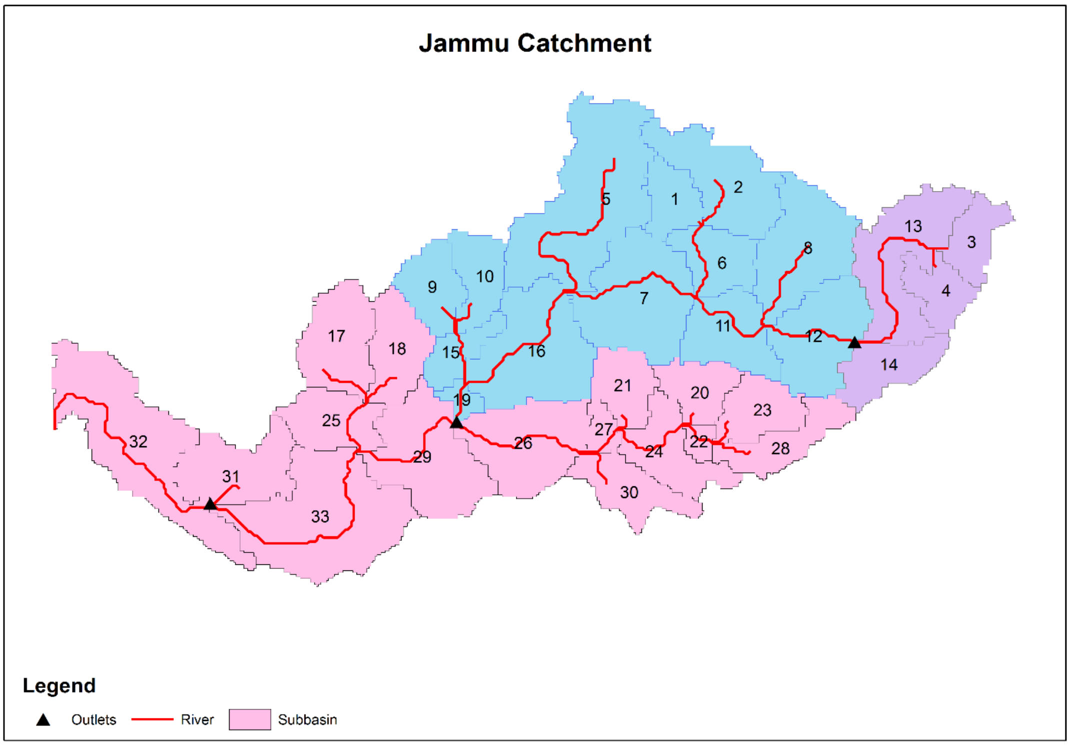


Figure 4-12: Catchment map with outlets under analysis

Table 4-1: Catchment Characteristics of Basin Outlets (Jammu)

Outlet	Classification	Catchment Area- CA (km^2)	CA > 3000m		CA > 5000m	
			Area (km^2)	%	Area (km^2)	%
Upper	H	1032	1032	100%	417	40%
Middle	M	6902	5706	83%	696	10%
Lower	L	13247	6726	51%	696	5%

Change in precipitation and temperature impacts snowfall, snowmelt, ET and subsequently the yield. With the increase in temperature, the snowfall, snowmelt and yield decreases in annual scale. When analyzed seasonally, yield generally decreases with rise in T due to increased ET except in winter and pre-monsoon season in snow dominated catchments. In the winter (DJFM) months, the increase in yield is observed with rise in temperature. This is due to the complex interaction of snow melt and ET in the hydrological cycle which attributes to earlier and increased snowmelt. The effect is milder in mid outlet (Thuloveri) and downstream outlet (Jammu) due to lesser snow and higher rain dominated regime. In pre monsoon (AM) there is an elbow in upstream catchment (outlet 13) which shows that yield increased upto 3^0C increase but yield decreases with further temperature increment. The snow melt compensates the increase in ET up to 3 ^{0}C but beyond 3^0C rise, the ET dominates thus decreasing the water yield. The total snow melt runoff increases up to 3^0C then decreases as the snowfall also declines as more precipitation falls as rainfall which further aids the ET which increases with temperature. This effect is less prominent in mid catchments category as mid catchment has lesser area above 5km than upstream catchment (u/s). In monsoon (JJAS) months, the decrease in water yield is higher for upstream (u/s) catchment but, for mid and downstream (d/s) catchments, the change is not significant as the increase in ET is not significant. In post -monsoon (ON) months, the decrease in water yield is higher for U/S catchment than for mid and D/S catchment. The impacts of P and T changes in these hydrological processes are shown in Figure 4-13 and Figure 4-14

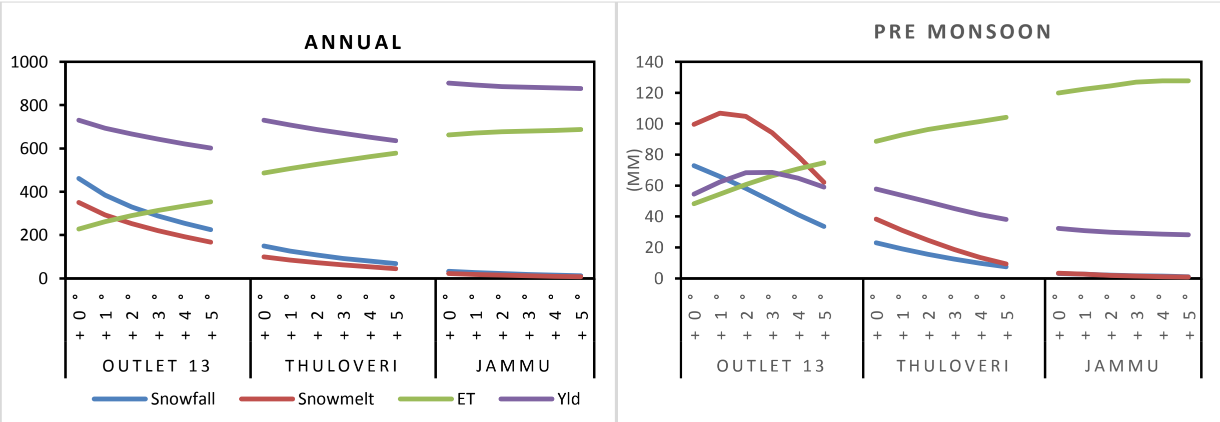
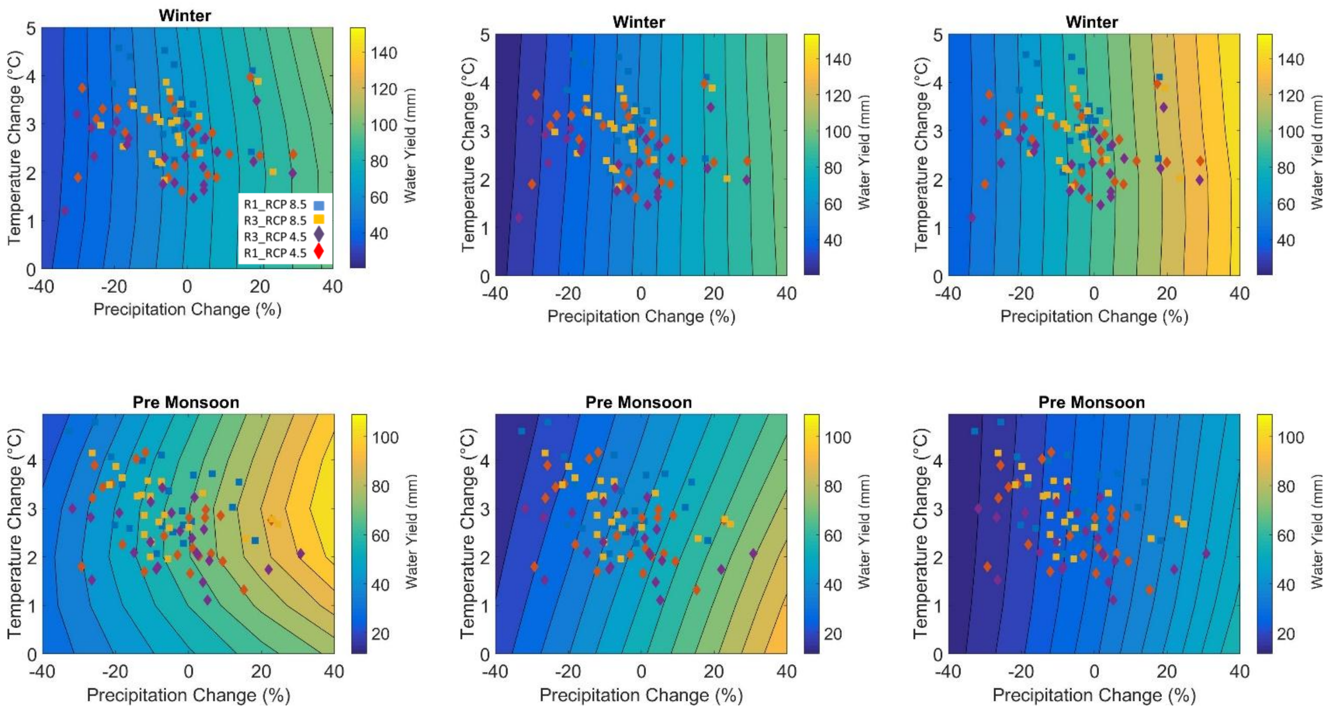


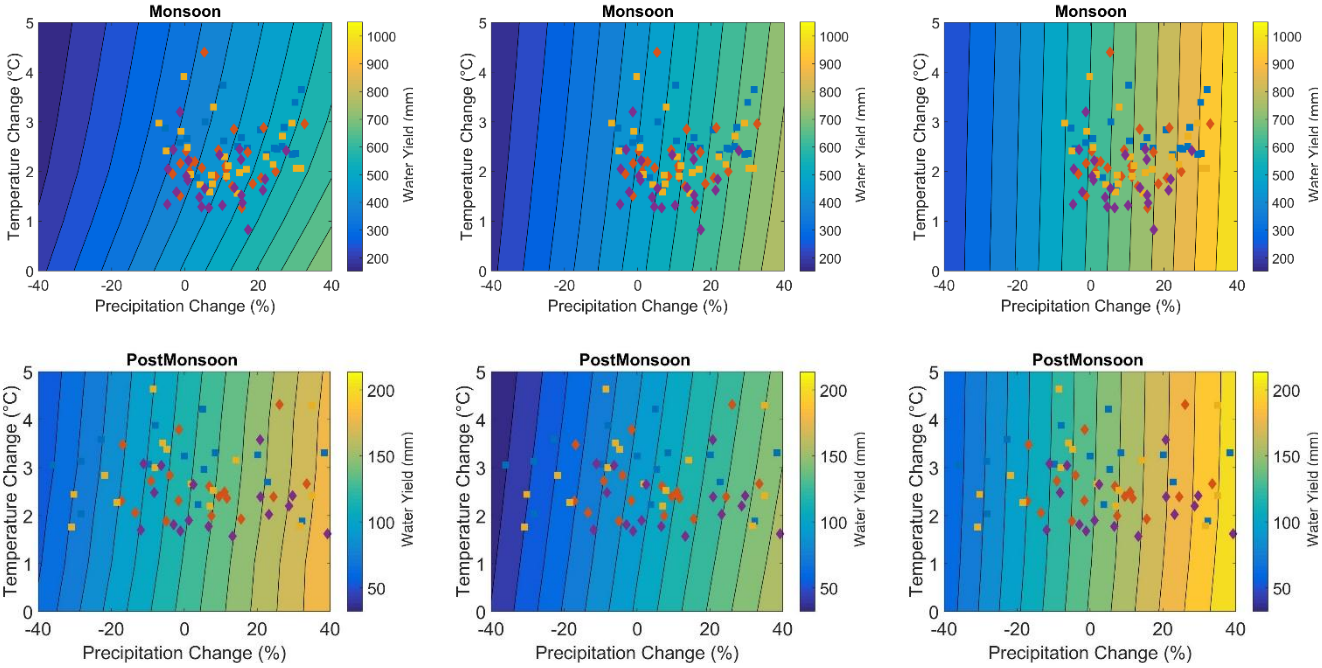
Figure 4-13: Variation in hydrological parameters with temperature change

Upstream Catchment — **(H) Outlet 13**

Mid Catchment — **(H) Thuloveri**

Downstream Catchment — **(R) Jammu**





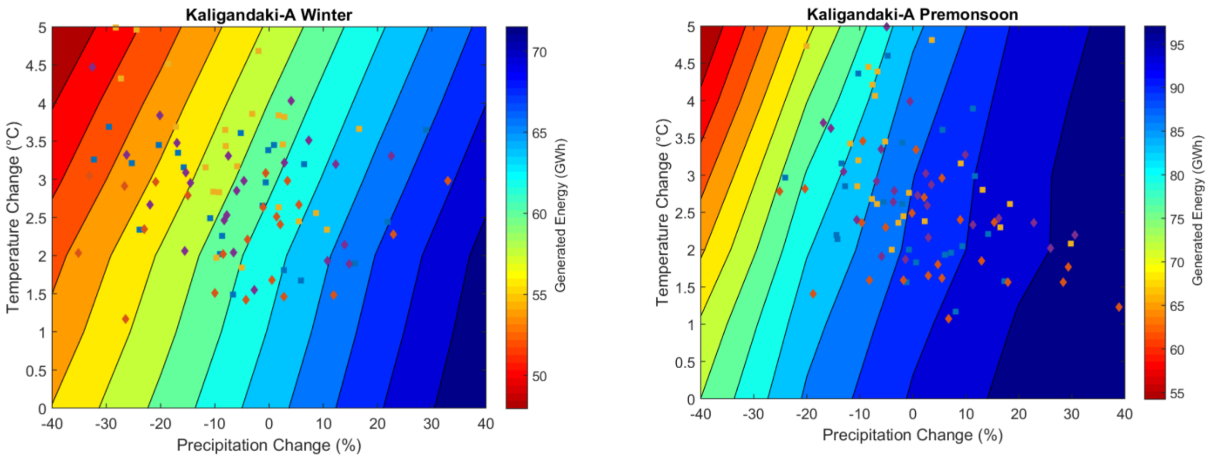
Note: H = >80% CA above 3km elevation M =60%-80% above 3km elevation L =60%-40% above3k elevation , R = <40% CA above 3k elevation

Figure 4-14: Seasonal Water Yield at all catchments of Jammu for changes in P and T

4.2.3 System Response to Climate

4.2.3.1 Energy Generation

The simulated flows for different precipitation and temperature changes (runoff response to climate described in the previous sub-section) were used to simulate the energy generation in different hydrological runoff conditions (system response to climate) An example of Kali Gandaki ROR Project of 144 MW is presented in Figure 4-15. The dots shown in the surface (figure) are the projections of P and T changes of different CMIP5 models for 2050s.



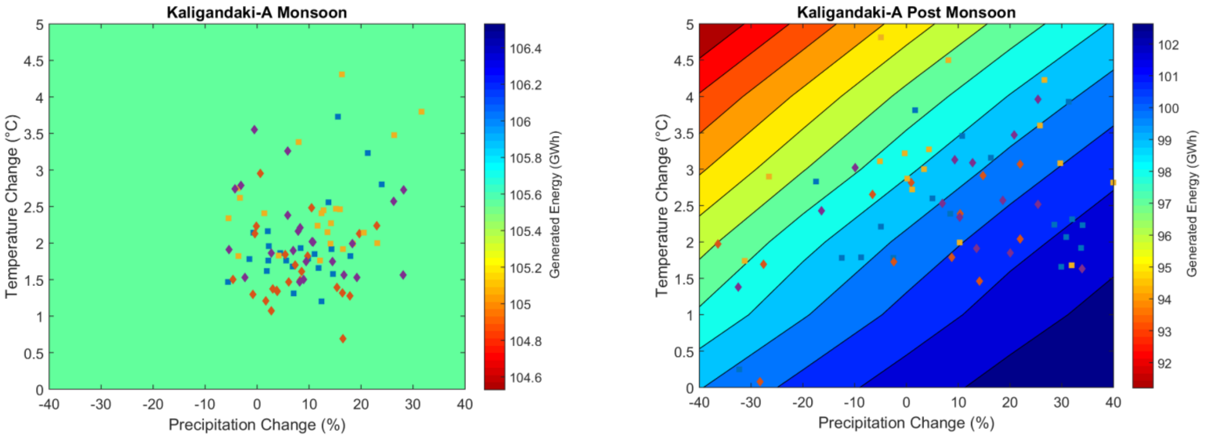
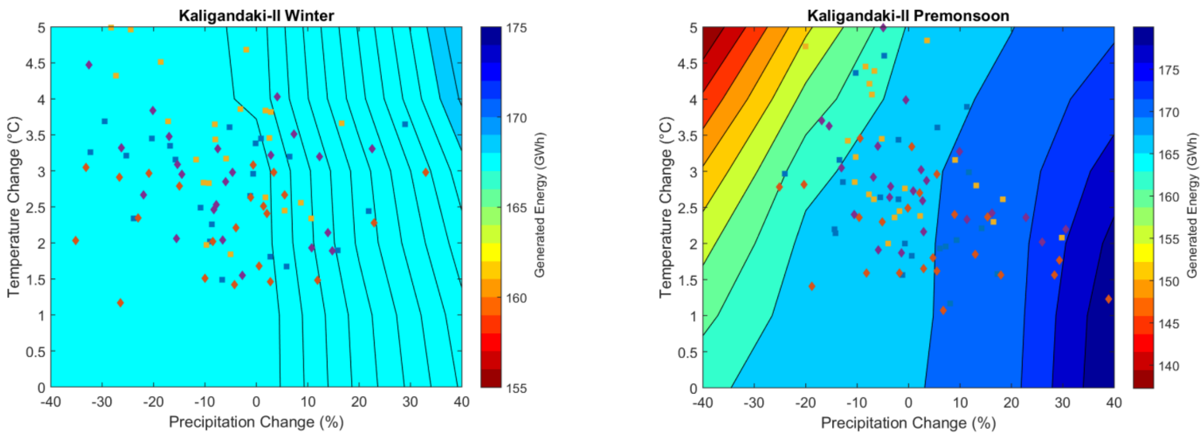


Figure 4-15: Energy Response to Changes in P and T

We can see from Figure 4-15 that any changes in flows in the monsoon period do not impact the energy generation as the flows in these months are much higher than the design discharge for the 144 MW installed capacity. In other months, this is not the case, as any increase or decrease of flows will impact energy generation as available flows are less than the design discharge.

In the case of seasonal storage projects like Kali Gandaki II with 660MW, the flows stored in the wet season are used to generate more energy in the dry season. Hence, any changes in flows due to changes in P and T will have less impact on the energy generation especially on the firm energy generation in the dry season for large reservoirs. Energy generation in the wet season may however be affected as secondary energy will be generated up to the maximum installed capacity instead of spilling the extra flows that cannot be stored. Figure 4-16 shows the energy generation response (surface) to changes in P and T.



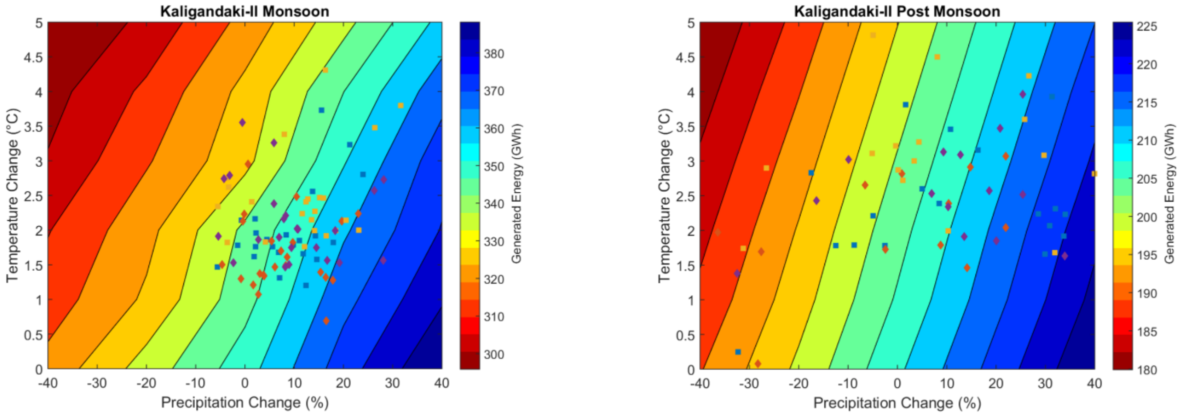


Figure 4-16: Energy Response to Changes in P and T (Storage Project Example)

4.2.3.2 Economic and Financial Indicators

A cost-benefit analysis (CBA) model was used to test the sensitivity of economic/financial indicators like Internal Rate of Return (IRR), Net Present Value (NPV) and Levelized Cost of Energy (LCE) to changes in climate and non-climate factors. The purpose of this exercise is to demonstrate the approach for climate risk analysis to compute economic or financial performance indicators. Cost benefit analysis of selected small and medium ROR projects were carried out. Results of Hewa (14,9 MW) and Kabeli B1 (25 MW) (Rain-dominated catchments), Rahughat (32 MW) (low snow-fed) and Kaligandaki Koban (180 MW) (high-snow-fed) hydroelectric projects are discussed here (Table 4-2) It can be seen that changes in IRR for rain-dominated projects like Hewa and Kabeli B1 are higher compared to KGK and Kabeli B1 for the expected changes in energy generation within a wide range of P and T changes (Figure 4-17). This shows that snow-fed projects are more robust than more rain-fed catchment ROR projects,

Table 4-2: List of CBA performed Projects

Projects	**IC (MW)**	**Status**	**Area (sq.km)**	**% A<3k**	**%A 3K-5K**	**% A>5K**	**Catchment Condition**
Kali Gandaki Koban	180	Candidate	3474	2%	53%	44%	High
Rahughat	32	Committed	305	56%	44%	8%	Low
Kabeli B1	25	Committed	710	69%	31%	0%	Rainfed
Hewa A	14.9	Committed	208	90%	10%	0%	Rainfed

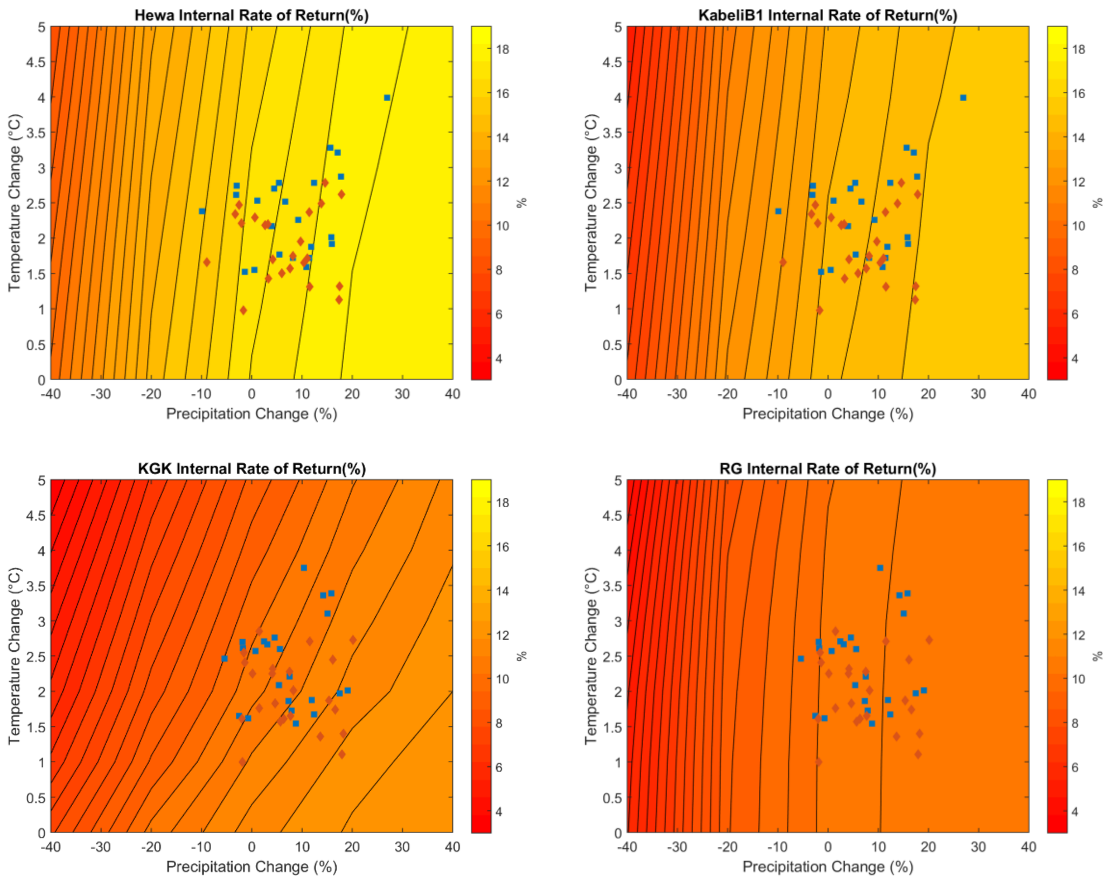


Figure 4-17: Internal Rate of Return (IRR) Response to Climate

Vulnerability to Non-climate factors

The vulnerability of hydropower projects to other non-climate factors such as Cost Over-run, Time Over-run, Discount Rate and O & M were also assessed using the CBA models. Cost over-run and discount rates are found to be the most sensitive factors affecting IRR and NPV of any project.

4.2.3.3 Climate Change Impacts on Investment Planning

Investment planning study was carried out to meet the electricity demand of Nepal for the 30 year period from 2020 to 20150 using the WASP IV model. The power demand (or “load”) in the future is based on the forecast (for domestic demand only) carried out by Nepal Electricity Authority (NEA) (Figure 4-18).

The study was carried out mainly for two scenarios i.e. Base Case (historical hydrological condition) and an extreme Climate Change (CC) hydrological case (Adverse Case). Base Case is business as usual scenario where generation is based on the historical flows and no change in energy generation due to climate change is considered. In the extreme hydrological condition, 20% reduction in precipitation and three degree Celsius rise in temperature is considered. The adaptation cost considered in the study is the additional upfront (capital) cost to manage (design) for higher floods and higher sediment load. In principal, the adaptation cost (or losses) for higher floods and sediments would be two types (a) cost of structural design changes and (b) loss of revenue due to plant shut down for more frequent O & M requirements or forced outages.

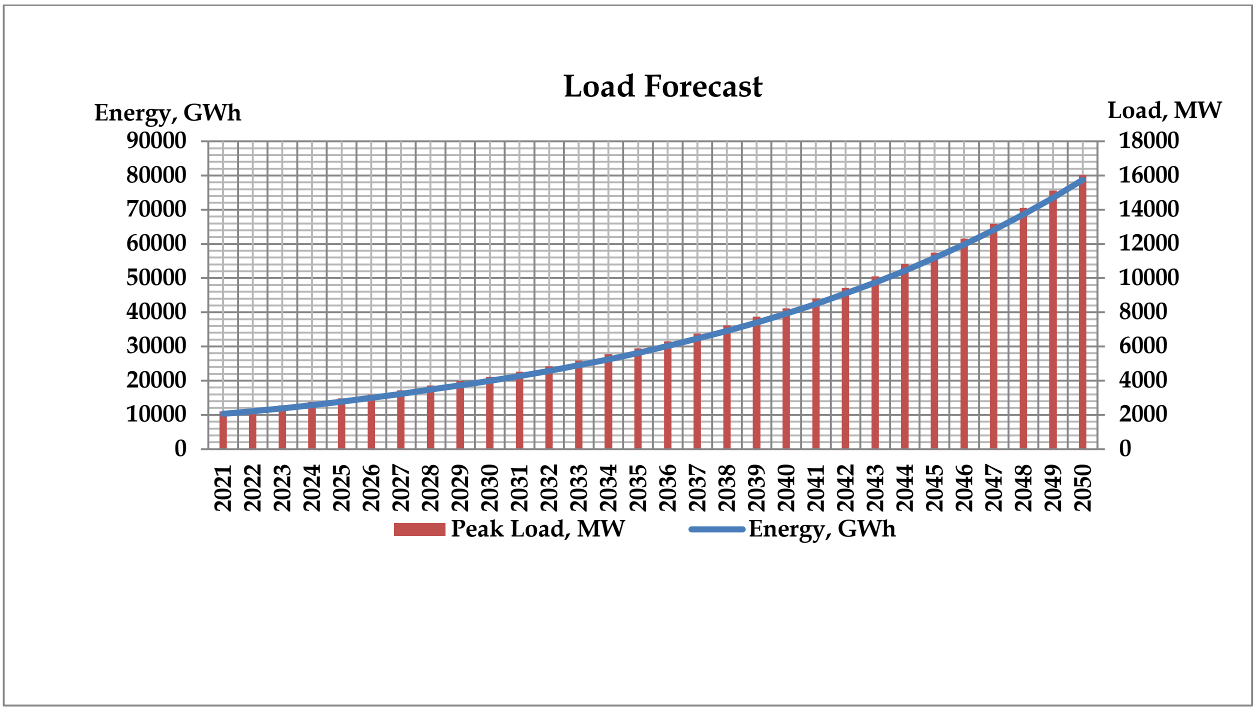


Figure 4-18: Load Forecast

Eighty nine existing, committed and candidate hydro power projects were considered in the analysis. To provide sufficient number of plants to the program, some dummy plants similar to the available plants were also considered in the study. The methodology and components of the WASP model are as shown in Figure 4-19.

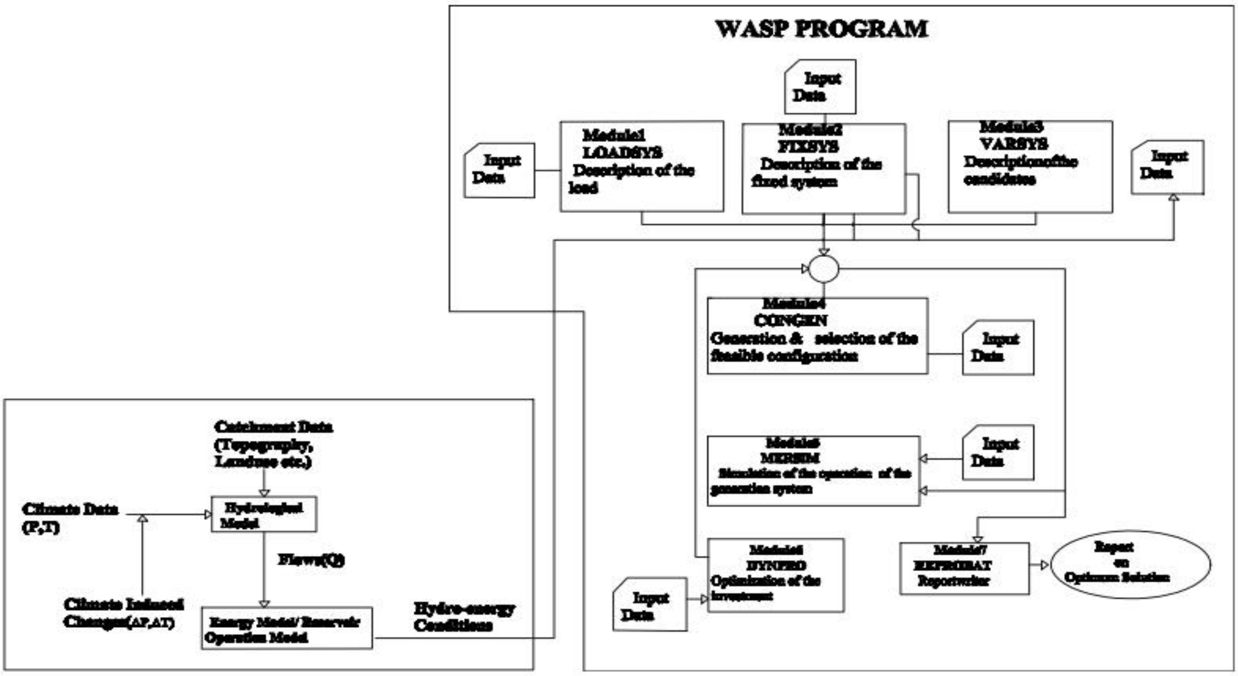


Figure 4-19: Block Diagram of Methodology

The key findings are as follows:

1. More storage type reservoir projects are required to meet the current and future power demand of the Integrated Nepal Power System (INPS). The optimal (i.e., cost minimizing)

share of storage hydropower projects in total installed generation capacity required to meet the projected domestic power demand is found to be increasing over time: That is, the share of capacity of both ROR and storage plants will be more or less equal of the order of 46 or 47% in the future. Similarly, with the available type of candidate plants, the energy mix will stabilize at 72% for ROR plants and 18-22% for storage projects. Noting that at present the share of storage plant capacity is about 10% only, these results indicate inadequacy of storage power plant capacity in the existing INPS generation system (hence an inefficient capacity mix) besides the total system capacity itself being inadequate.

2. The investment planning exercise was also carried out for an adverse hydrological condition of 20% reduction in precipitation and 3ºC rise in temperature. The probability of such an extremely dry hydrological condition happening in the next 30 years is highly unlikely. Such an analysis was made to "stress test" the investment planning with the objective of testing the sensitivity of the key system-level performance indicators such as optimal power mix requirement, levelized cost of energy and total investment cost.
3. Thermal generation has increased in adverse hydrological condition compared to Base Case. This is because dry season generation from hydro plants has reduced and more thermal generation (or import from India) is required to meet the energy needs. It is found ROR plants are preferred to storage plants due to their low cost and high plant factor. In the adverse hydrological condition, the generation from storage plants has decreased while that of ROR plants has increased in some years which is attributed to earlier commissioning of the ROR plants in the adverse hydrological condition.
4. The capacity factor of the power projects are defined as the ratio of the actual output and potential output at full capacity. The capacity factor in adverse hydrological condition is lower than in the Base Case because higher number of plants were added to meet the energy needs in some of the very dry hydro conditions. The levelized cost of energy generation increases by 12 % (8% is attributed to lower energy and 4% to additional capital cost for climate-proofing from adverse extreme hazards)
5. Similarly, in the adverse hydrological condition, the investment and production cost increases by 12% (again 8% is attributed to lower energy and 4% to additional capital cost for climate-proofing from adverse extreme hazards). A note of caution is that such hydrological condition would gradually occur over the next 3 decades so the impact may not be as much in the first one to two decades. The optimal power mix ratio adopted for the current hydrological condition (base case) is however expected to perform satisfactorily in the case of an adverse hydrological condition as well.
6. Size, type, capacity and cost of the project makes considerable impact on the performance of the system. System can benefit from power exchange i.e. importing electricity during peak time and dry season and exporting during wet season.
7. The above findings are based on the presently available projects in Nepal. About 89 projects including 20 storage projects were considered in the investment planning analysis. Out of which, 28 ROR/PROR projects are committed (under construction) and 41 are candidate hydropower projects (28 ROR/PROR and 19 storage type projects). Existing as well as planned hydropower projects are all found to be designed under the current pricing, market and regulatory regimes without fully considering the power system requirements nor do they consider any likelihood of future changes in these regimes. For example, more than 80% of the ROR projects are designed at discharges with 40% or lower dependability, found to be "optimal" under current pricing regime. Storage capacity of most reservoir projects are also limited, with only 20% of them storing more than 50% of the average monsoon runoff (June

to September) and only 45% generating more than 30% of the total annual energy in the 5 dry months from December to April.

8. System planning is, hence, constrained by insufficient number of variations in projects types and size including limited number of storage project inventory. The limited number of candidate storage projects with sizable live storage can be a limitation to achieve an “optimal” power mix of the system. This could also be the reason for not so significant change in power mix requirement between the historical hydrological condition and the adverse hydrological condition.

4.2.4 Summary of risks to projects and sector

Based on the vulnerability assessment, the key risks to the hydropower projects and the sector can be summarized as follows:

1. **Low flows:** Run-of-river (ROR) and peaking ROR projects are adversely impacted by any reduction in flows in the dry season (December – March), the pre- (April- May) and post-monsoon (October – November) periods. These are less impacted from flow changes in the wet season (June – September) as the design discharge capacity of these projects are less than the available monsoon flows. Moreover, the price of electricity is higher (two times at current rates) in the winter/dry season months (mid Dec to mid-April) than other eight months. Apart from the seasonal variations, inter-annual variation of low flows is also important as it impacts the reliability of the electricity generation. Vulnerability assessment of the ROR/PROR projects to future climate changes shows that that projects in rain-fed, smaller catchments are more vulnerable than projects in snow-fed and larger catchments to any reduction in precipitation and rise in temperature due to climate change. Storage projects with larger storage capacity can help firm up dry season energy. Dry season energy generation from storage projects with larger live storage are generally robust to climate change. However, storage projects with large live storage can be impacted by any reduction in monsoon flows.
2. **Floods-** Climate projections show that extreme precipitation and monsoon flows are expected to increase in the future although the magnitude of change is uncertain. Hydropower projects therefore are more at risk from climate induced hazards than from changes in water availability. Projects in more rain-fed catchments receive higher floods (in terms of flood magnitude per unit catchment area) as catchments below 3000 mm receive more intense rainfall compared to higher elevations,
3. **Sediments**- sediment loads are generally higher in Nepal and some river systems such as Kali Gandaki and Marsyangdi are more prone to higher sediment loads and concentration. More intense rain due to future climate changes are expected to aggravate the sediment problems. Other man-made interventions and watershed degradation are also expected to worsen the situation putting hydropower projects at more risk due to sediment related problems.
4. **Geo-hazards** including GLOFs and LDOFs along with extreme floods and sediments are the most important risk from climate change for the hydropower projects in Nepal.

More details on the findings of the vulnerability assessment are described in Chapter 7.

5 Adaptation options and pathways

5.1 Introduction

The previous chapter outlined the findings of the climate risk assessment (CRA). It reports that current climate and flow variability is a key challenge for Nepal's current hydropower system and that this leads to major impacts for the sector. It also found that future climate change will have potentially large additional impacts by increasing climate induced hazards, though there is a large uncertainty around these future risks.

At the same time, the vulnerability analysis presented shows that the challenge of climate change is not insurmountable. The analysis reports that based on projections of water availability only hydropower generation of smaller and rain-fed ROR projects are more vulnerable than medium and large projects to future climate scenarios (2040-2059). Indeed, the CRA findings indicate that future climate change will have most impact by increasing climate induced hazards, i.e. sediment, floods and geo-hazards including GLOFs, rather than average generation.

It also finds that Nepal's hydropower sector is currently dominated by other issues affecting the power sector, such as institutional factors, regulatory issues and pricing. The CRA also reports that in general, current climate variability and future climate change are more of an issue for small plants, especially Run-of-River, and for these plants there are additional risks from climate change affecting dry season winter flows, higher flash floods, sediment and debris load. These findings form the basis for the adaptation assessment. As highlighted in the method section, there are adaptation options that can address the climate and future risks that have been identified to mid-century. It is therefore technically possible to address or design adaptation for Nepal's hydropower sector. The key issue is to identify which adaptation options make sense to implement, and whether to remove risks completely or just reduce them, i.e. the balance of costs and benefits. This is compounded by the fact that there are different parties and that what 'makes sense' for Government might be different to what makes sense for private investors, in which case the key is to design adaptation policies which align the interest of the Government to that of the private sector. For example, adaptations hat looks at the financial aspects only will implicitly represent the taking the private investors/developers point of view and not necessarily of the government.

To help do this, this study has used the adaptation pathways approach set out in Chapter 3 (method). This aims to provide practical information to support adaptation decisions (or policy) over the next five to ten years and uses three complementary building blocks for adapting the hydro-sector of Nepal. These are

1. Immediate actions that address the current risks of weather and climate extremes (the adaptation deficit) and build resilience to future climate change. This includes early low- and no-regret actions, as these provide immediate economic benefits and can help reduce future impacts under a changing climate. These activities are focused on current hydro-power plants. These are relevant and meet the interest of both private investors (with short pay back goals) and the Govt (long-term vision, and interested in social/environmental aspect as well).

2. The integration of adaptation into early investments (climate smart planning), focusing on the new (planned or candidate) hydro-electric plants that will be built over the next decade or so. Given their long life-times, these plants will be exposed to future climate change, but these changes are uncertain. This therefore involves a greater emphasis on low cost design or flexible or robust options that perform well under uncertainty. It is in the interest of

the Government to have a climate-smart system of hydro plants and this should be Government-led.

3. Early monitoring, research and learning to start planning for the future impacts of climate change. This includes the investing in information and learning, to help inform future decisions, through the value of information and option values. This is also in the interest of the Government to start planning for the future impacts and should be Government-led.

5.2 Mapping Adaptation Options to Key Risks in Nepal

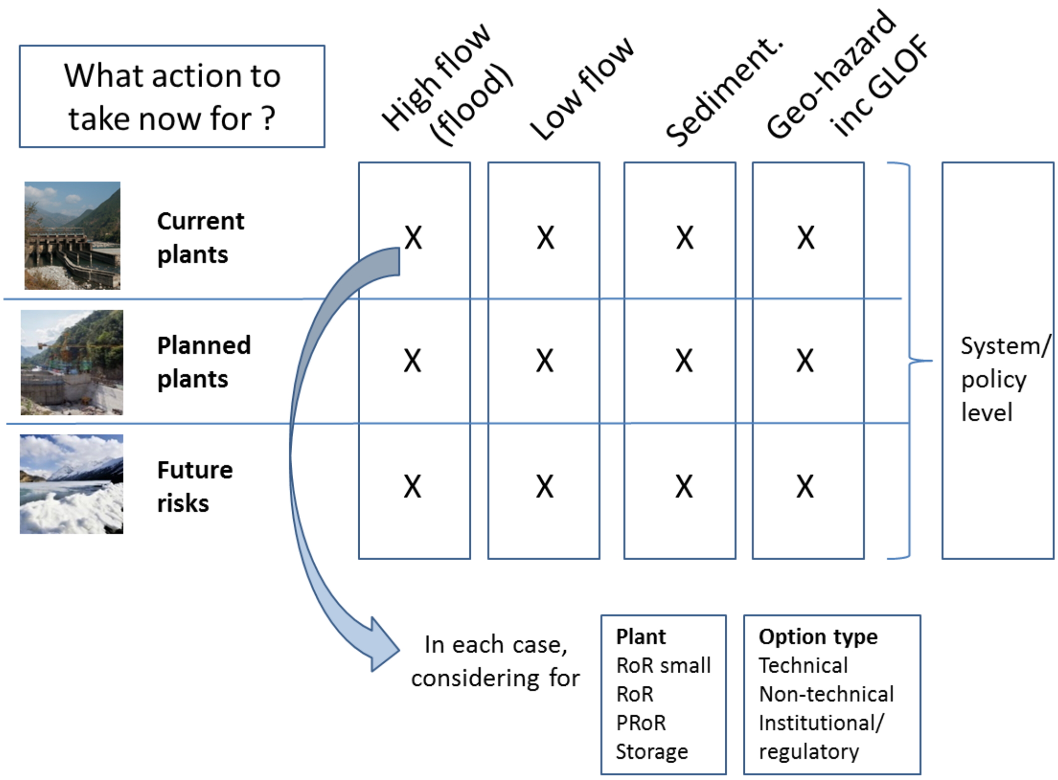
The first key task in the assessment was to link the adaptation pathways approach to the findings of the CRA. However, a critical finding from the latter is that the vulnerability of different plants in Nepal – in different locations - varies, both to current climate variability and future risks. It also varies according to the performance indicator used, for example indicators relevant at the project and system level. The findings indicate:

- Smaller projects are likely to be more affected by climate change as they are affected more by variable flow conditions.
- Hydro plants with high elevation and low elevation (snow fed or rain fed) will be affected differently.
- Run-of-river projects that are designed for higher design discharge but lower dependable flows are more vulnerable to water availability than those designed for higher dependable flows.
- Reservoir projects with more live storage lead to better regulation and more reliable (firm) dry season energy, but they can be more impacted by flow reductions due to climate change during the monsoon period.
- Sediment yields vary from basin to basin, but are very high in some basins. Sediment yield is expected to increase with climate change and the future impact will also vary with catchment location, type and size and also the project parameters.
- Dam break analyses by ICIMOD (2011) in three glacial lakes in Nepal show attenuation of peak flow by approximately half after travelling 50 km and by approximately 80% after 100 km. Hydropower plants that are located more than 50-100 km downstream of potential glacier lakes are expected to be less affected by potential GLOF events due to dampening of peak flow, though heavy sediments and debris flows can create problems in these downstream projects. Runout distances of more than 200 km have been reported for Himalayan GLOFs (Reynold, 2014). This has to be verified by comparing with the design flood of individual hydro plants. There is also a difference in the number and distributional pattern of critical glaciers lakes across high catchments in Nepal.
- The higher monsoon peak flows could increase the risks of extreme flows and floods, but the level of increase is projected to differ by river catchment. It will also affect plants differently due to the variation in design standards (e.g. return periods of design flood) between smaller and larger plants.
- The vulnerability at the system level can be more critical than at the project level because the former is based on “cost minimization” objective while the latter is on “revenue maximization” objective.

This leads to two key conclusions. First, a suite of adaptation options will be needed to address different risks for different plants, both in relation to current and future. Second, the vulnerability to current variability and future climate change will be highly site (location), plant (design parameters), and system specific. This means the exact adaptation options for an individual project or system will vary with the specific drivers of vulnerability (e.g. low or high sediment levels, risk of GLOF events, small or large RoR, system level indicators such as investment cost and LCE etc.). It is therefore clear that in Nepal, it will not be a case of 'one size fits all'. Adaptation will generally need to be location, risk and plant specific, even for individual risks. Complementing this, there will also need to be adaptation at the system level, which addresses these risks to the operation of the system as a whole.

To help address this, the study therefore developed an adaptation matrix that used the adaptation pathways approach (and the three building blocks), combined with the set of key climate risks identified in the CRA. This is shown in Figure 5-1. The assessment used this matrix and developed a long list of adaptation options to populate all the cells. The list of options was compiled by a review of the literature (international and in Nepal), expert elicitation and stakeholder consultation.

The focus on was on identifying adaptation options that addressed risks to the key performance indicators, in relation to each of the climate risks, thus linking the analysis to the CRA. As an example, it considered how the impacts of a geo-hazard (a Glacial-induced Lake Outburst Flood (GLOF) or landslide induced (LLOF) would affect a power plant (the immediate damage, the loss of generation and revenues from initial downtime and repair, the impact of high debris and sediment, etc.) and then identified possible options to reduce or avoid these costs.



Note: For details refer to Adaptation Option Matrices Sections 5.3

Figure 5-1: Adaptation Options Matrix

The options were further categorized into:

- Technical options. These involve technical or engineering options (hard options) such as new auxiliary spillways, sediment removal technology, settling basins, underground powerhouses, etc. noting these options were assessed in terms of their applicability to the three typologies above (i.e. current, planned or future), for each individual climate risk.

- Non-technical options. These involve alternative approaches, such as capacity building, the provision of information, changes in management (soft options) such as early warning systems, insurance, etc. again separating these out by decision type and climate risk.

It also considered policy or regulatory aspects, which include the means to implement some of the options above, noting these could include different ways to achieve the same objectives, e.g. changes in guidance that affected design standards for individual plants or changes in pricing regimes and incentives through PPAs).

This led to a very large number of adaptation options: indeed, the assessment identified over a hundred possible interventions across the range of decisions, risks and plants. However, a key focus was to find examples of current practice or potential options in Nepal, to get more context specific information. The assessment therefore then set out to prioritise these adaptation options, both for interventions in general, and with respect to the choice of individual options for particular risks/contexts.

5.3 Prioritising Promising Adaptation Options

The prioritisation of adaptation options is challenging, because of the site-specific nature of hydro-electricity plants, as well as the complexities involved with climate risk and uncertainty. However, the adaptation pathways approach can help to overcome many of these challenges by considering the timing and sequencing of adaptation and helping to identify promising, low-regret options.

The study developed this approach, capturing promising options across all three building blocks. To do this, the study took the long list of adaptation options and started to assess their costs and benefits by quantitative and qualitative analysis, along with a wider multi attribute analysis and expert elicitation, the latter to help draw out options that were Nepal specific.

A key part of this analysis was to use existing Nepal hydropower plants and existing hydrological data in case studies, to explore the potential costs and benefits of options, for both current and planned plants. A model was developed to allow analysis of how increased costs (from adaptation) changed the net present value and rate of return. Sensitivity analysis was then used to examine how changes in costs affected performance and revenue, both for current and future climate scenarios, thus allowing information on adaptation costs and benefits.

Box 5-1: Analysing the costs and benefits of adaptation

The costs and benefits of adaptation options will be plant and project specific, depending on factors like location, size, type, hydrological design parameters, installed capacity and live storage. Given the wide range of these variables, it is difficult to undertake detailed analysis except for specific plants with detailed hydrological data. However, there is information available which helps to allow analysis of the relative performance of options.

The study reviewed information from existing plants, and elicited views from experts, to estimate the potential costs of different adaptation options. This provided valuable information in sorting the relative cost of different options (and the potential benefits). What was clear is that many low cost options exist, which are a low proportion of capital costs. This contrasts to the larger-scale overdesign options, which are often 5% of capital cost or even more.

The results are shown in the table below, including the plant for which data were taken noting the caveats above.

Indicative costs of different adaptation options, relative to total project costs

Option	Cost
High flow floods	
Detailed risk assessment	+
Hydro met monitoring (at the plant)	+
Early warning system	+
Low cost protection of key infrastructure	+
Fusegates	n/a
Auxiliary spillway	+
Insurance	++
Increasing gate size (e.g. Khimtill)	++
Additional gates	n/a
Over design (e.g. to 1 in 10000 or max probable flood)	+++++
Low flows	
(On line /real time monitoring) Weather forecast/operational optimization	+
Reservoir management	+
Turbine upgrade (e.g. Andhi Khola)	Variable
Sediment	
Real time sediment monitoring (e.g. Middle Marsyangdi)	+
Turbine recoating	+
Continuous flushing	n/a
Sloping intake (withdraw higher level) (e.g. Kulekhani)	+
Hydro-cyclones	++++
Vortex separation (e.g. Upper Marsyangdi A)	++++
Bypass tunnel (Kali Gandaki Koban)	+++++
GLOFs	
Early warning system for GLOFS (e.g. Bhotekoshi	+
Smart tail gates (Khimti-1)	+
Insurance	++
Underground power house (e.g. Upper Tamakoshi)	+++++
Glacier Lake draining (Imja and also Tsho Rolpa)	$3 Million/lake

Key

+less than 1% of total project cost (construction and other)

++ or the order of 1%

+++ 1 to2%

++++2 to 3%

+++++>3%

The study then took this information and tested the costs and benefits of adaptation using case studies

The study did this by choosing a range of different existing plants (RoR, PRoR, Storage) in different locations (and subject to different risks) and using historical hydrological and sediment data, and existing cost and financial information to understand the financial performance and the impacts of current climate and hydrological variability. The analysis then looked at different options to address these current impacts, to see how this affected the net present value (NPV) and internal rate of return (IRR). The analysis has focused on the direct loss of generation and revenues, as well as direct damage and loss of revenues (from the downtime) from climate induced hazards. In the financial analysis, it has included consideration of the potential revenues under existing PPA and penalties, which affect the financial performance of hydropower schemes.

The analysis was then repeated using a range of future climate scenarios, looking at the envelope of change from the models. This provided information on whether these options also built resilience to future climate change.

Finally, the study took these case studies, and used them as exemplars to examine new planned plants, i.e. to take them and consider what would be the additional options if being designed today, allowing more consideration of new options that could be included in design. The analysis also used switching values to assess the thresholds when cost increases affected key performance indicators. This provided some analysis in cases where cost data was broad or uncertain (e.g. allowing an analysis of how high the costs had to be before the NPV or IRR was negatively affected). It also allowed an analysis of soft options.

Based on the overall analysis, a number of general findings emerge.

First, it does not make sense to over-design the whole hydro-power sector in Nepal for all possible future climate risks today. In many cases, the high cost of retrofit (existing plant) or high costs of over-design (future plant) did not provide sufficient benefits to justify investment, or else proved to be less cost-effective compared to alternative options (e.g. lower cost investment or alternative approaches to addressing risk, such as insurance).

Second, from testing different options in different case studies, it is clear that the applicability, suitability and economic performance of adaptation options is plant and project specific (linked to the factors on the previous page). There is a danger in providing general recommendations on 'good' adaptation.

However, it was possible to identify a set of interventions that look very promising, i.e. the third key finding is that there are low regret adaptation options for the hydropower sector in Nepal, which have wide applicability, noting these differ across all three building blocks. These are discussed below.

5.3.1 Low-regret options for existing plants

For current hydro-power plants (and the current system), the key focus was to address no- and low-regret options[10] that address current risks of climate variability, i.e. that are good to do anyway, but also will help address the early signals from future climate change and thus help build resilience.

The most promising options provide immediate (net) economic benefits. These include an emphasis on options that have low costs, particularly non-technical options and capacity building. Examples include:

- Improved hydro-met data,
- Real-time sediment monitoring (for high sediment laden catchments),
- Early warning systems, for high risk plants at risk of high flows or geo-hazards (including GLOFs).
- Information that helps manage or address risks, such as operational management, detailed flood risk assessment.
- Insurance, which generally costs around 1% (per annum of plant costs).

However, it is highlighted that while these options are low cost, they often involved opportunity or transaction costs associated with their implementation and effectiveness.

There are also some retrofit options that are no- or low-regret, such as putting low-cost protective structure around key infrastructure, turbine recoating, etc. In some cases additional options, such as turbine retrofits also fall into this category. However, in all cases, promising options are primarily addressing current variability albeit also offering greater resilience for early climate change trends.

[10] These are sometimes defined as options that generate net economic benefits, irrespective of whether or not climate change occurs, but in this assessment, a broader definition was used (DFID, 2014) that focused on general low-regret characteristics.

It maybe that the best approach is from combinations (portfolios) of options, combing various hard and soft options to cover different risks. For example, low cost protective measures to protect against more routine high flows combined with early warning, complemented with insurance to cover the risk of low probability high impact events.

In Nepal, many of these various types of low-regret options are forms of good practice, and they have not been implemented due to current barriers. The reason they have not been implemented, therefore, is due to the barriers to adaptation (see later discussion). They also provide greater resilience to the future changes expected from climate change, e.g. the increase in climate induced hazards. The study looked for existing examples of these options, and gathered information on their effectiveness and costs, as case studies.

For plants that are exposed to high current impacts of variability (e.g. high sediment loads) there may also be more expensive options that can be justified (e.g. more advanced sedimentation management) because of the high current baseline costs. However, larger and more costly retrofit options that involved major infrastructure and works were generally not found to be low-regret (there maybe cases where they are justified, but application is highly context specific). What is clear is that it makes little sense to build expensive retro-fits now for future climate change (which may emerge in 20 years' time).

At the system level, a general finding was that a major gap is around the availability of hydrological and meteorological information, and thus there is a need for enhanced monitoring, data availability and use. The lack of data for higher altitude catchments (above 3000m) was identified as a particular gap, but also more information on sediment flows was considered a key priority. A further priority (institutional) identified is the need to consider hydropower, and thus hydrological risks, with integrated water resource management.

The table below provides key examples identified in the study.

Adaptation options[11] for current and under-construction plants

		Non-technical	Technical (low regret)	Technical (higher costs)
High flow (flood)	IF a vulnerable area	Enhanced hydro-met (including on line /real time monitoring) Detailed flood risk assessment Early warning Insurance Reservoir management (Kulekhani storage project)	New auxiliary spillway Modifying existing spillways to increase discharge capacity. Fusegate/plugs Protect key infrastructure, e.g. intake structure, power house	Raising the dam crest/ dam heighten [storage] (limited scope in existing system). Bypass tunnels for flood Temporary flood storage, upstream flood plains
Low Flow (dry, winter) including inter-	IF a vulnerable area	Enhanced hydro-met (including on line /real time monitoring) Weather forecast/operational optimization	Turbine upgrade during retrofit to improve efficiency	Turbine replacement (Both upgrading and efficiency improvement of new machines) Divert flows (conveyance structures) (for e.g.

[11] The costs and benefits of adaptation options will be plant and project specific, depending on factors like location, size, type, hydrological design parameters, installed capacity and live storage. Given the wide range of these variables, it is difficult to prioritise the options applicable to all plants. Box 5.2 provides a guidance on analysing the costs and benefits of adaptation to allow analysis of the relative performance of options.

		Non-technical	Technical (low regret)	Technical (higher costs)
annual variability		Plant management Insurance Plant co-operation (especially cascade) Cascade management (Kulekhani I, II and III; Tamakoshi III and V) Reservoir management (Kulekhani)		Rolwaling diversion to UTK 456 MW increases dry season generation)
Sediment	IF a high sediment laden river (e.g. Kali Gandaki and Marsyangdi Rivers)	Sediment monitoring (on-line) Slope stability monitoring Plant shut down above agreed threshold concentration Upstream watershed management	Sloping intake for Kulekhanu (already implemented after 1993 flood) (Re)Coating of turbines Retrofit sediment management Check dams in upstream watershed (e.g. Kulekhani project) Hydrocyclones especially for high head plants e.g: Thapa Khola HEP (14MW) under-construction in Mustang)	Flushing (operation rule for reservoir operation/ flushing for pRoR) (e.g. Middle Marsyangdi but constrainted by system intervention) Bypass or diversion tunnels for sediment flushing/routing (e.g. proposed Kali Gandaki Koban) Dredging (plants in high sediment laden rivers like Kaligandaki A, Middle Marsyangdi , Jhimruk HEP) Hydrosuction Check dams Upstream traps Sloping intake for storage projects (implemented in Kulekhani after 1993 flood event) Density Current Venting (storage only)
Geo-hazards (including Landslide induced Dam Outburst floods (LDOF) and GLOFs	If projects located within 100 km from dangerous glacial lakes as GLOF hazards# If projects located near weak and degraded slopes/ watersheds	Detailed geo-hazard risk mapping and assessment Early warning Insurance Upstream watershed management/conservation (for all plants especially smaller plants)	Protect key infrastructure, e.g. intake structure, power house	Underground power house (.e.g. Upper Tama Koshi) Glacier Lake dewatering (e.g. Imja Lake) and Landslide induced dams dewatering and controlled breaching before burst in case of occurrence

(due to peak flows) expected to be reduced by 100 km (to be verified against design flood plant-wise)

The linkages to the institutional aspects and system planning are presented below.

	Institutional	**System**
High flow (flood)	Revise design standards (projects designed in different standards) Prepare design guidelines Safety reviews Awareness raising Capacity building	Better hydro-met data System risk assessment and planning
Low Flow (dry, winter)	PPA revision to incentivise (take or pay for energy supplied up to threshold dependability e.g. 90% dependable) Revision of penalty clause in PPAs of smaller and projects in more rain-fed catchments[12] Revise design standards Guidance Relax penalty clause Awareness raising Capacity building	System level intervention- more storage projects to augment dry season energy generation (More diverse power mix) Better hydro-met data Integrated water resource management Demand reductions PPA revision Transmission efficiency Interconnectors Prioritize high head RoR projects as they are less sensitive to low flow variation.(financially more viable)
Sediment	Revise design standards Guidance Build capacity of design engineers/firms Include innovative design options such as Hydrocyclones for high and medium head projects and vortex chamber extractor for low head plants in Engineering curriculum	Better hydro-met data Watershed management (e.g. afforestation, SWC)
Geo-hazard	Mandatory components (e.g. EWS) Revise design standards	Glacier Lake Monitoring data Research Glacier Lake draining (e.g. Imja Lake) and Landslide-induced dam management (dewatering and controlled breaching) in case of occurrence

5.3.2 Climate smart options for planned plants

The second building block in the adaptation pathway is the integration of adaptation into new hydropower plants, i.e. planned and near-term candidate plants that will be designed over the next five to ten years, involves different issues. As well as designing for current variability, these plants will be exposed to future climate change, especially towards the end of their economic lifetime.

The focus is therefore on making these new hydropower plants ‘climate-smart’. This necessitates different thinking to current plants (above), because it also includes the timing of adaptation, the trade-off between additional up-front costs and long-term benefits, and uncertainty.

First, the low regret-options identified for current plants are also applicable for future design. The focus on non-technical options, e.g. monitoring, early warning, information is still as relevant and are a priority for these plants as well as they ensure current climate variability will be addressed and generally build resilience to early future climate change.

[12] Government is already proposing removal of penalty for projects under 10 MW.

Second, there is also the opportunity to include additional options that address current climate variability more effectively today in new design. Indeed, many of these options will help build future resilience, especially in cases where the case of the likely trend of future climate change is more certain. As an example, for rivers with high sediment load, advanced and efficient sediment equipment can actually lead to lower costs than gravity settlement today, and provide extra resilience given climate change is likely to increase sediment loads in the future.

Third, there are additional options which make more sense at the design phase for addressing future climate change. However, the identification and applicability of these is more complex to assess. The key issue here is that while these plants will come on stream in the next ten years or so, the major changes projected from climate change will happen in the far future (2040 – 2060) and are uncertain.

The question is therefore around what additional options might be justified to include in the design today, given this will be cheaper than retrofitting later. In general, four promising areas emerged.

- There are some very low-cost over-design options that can be incorporated to help build future resilience. An example is fuse-gates or fuse-plugs for storage projects. These contrast to a general over-design (larger structure, additional spillways).
- There is the potential to include flexibility in the design to allow later upgrades at lower cost. An example would be to include the space for adding additional spillways later (should these be needed).
- There are some options that are robust, i.e. that perform well under a range of future scenarios. This could include the choice of turbine/s, selecting equipment that provides better performance over a range of flows (reflecting changes under climate change), rather than optimally to one flow regime.
- In many cases, however, the most economically efficient option is to wait, with a phased approach, but with the caveat that this should be as adopted as part of an iterative risk management approach at the plant level that enables learning and adaptive management.

Thus, while there is the opportunity to include some early climate smart elements, the main focus should be on a cycle of monitoring, evaluation and review over time, to bring in additional options if needed (or delay if not). This has the advantage that adaptation only takes place if needed, and furthermore, costs are borne later, and thus are closer to the stream of adaptation benefits (improving the economic return).

One condition of this approach, however, is that there must be investment in monitoring and planning to allow this approach to work (which itself has a cost, albeit low). This can be seen as an investment in information (the value of information).

In practice, the exact adaptation option will vary with the risk level, the exact costs and benefits, the risk preferences of the investor, etc. It is therefore difficult to provide firm recommendations, i.e. that any particular option is the answer. This leads to a general recommendation that more focus on climate risk assessment and adaptation analysis is needed during the design and planning of hydropower.

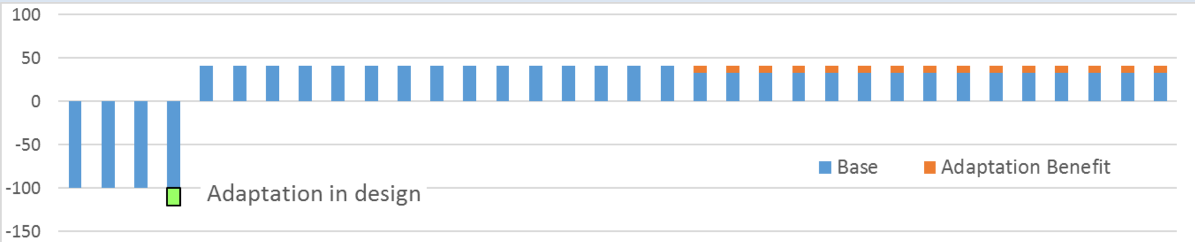
Box 5-2: Illustration of the adaptation economic challenges

The analysis has taken information on current plants, along with historic data and future climate projections to examine the complex trade-off between costs and benefits of adaptation on new plants. This box provides an example.

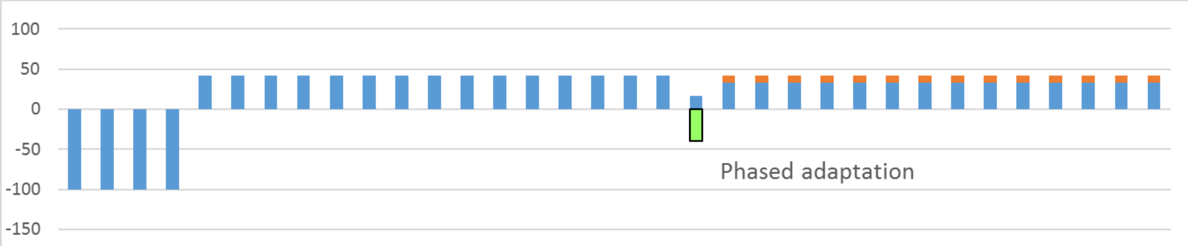
In the case where climate change involves a reduction in future revenues, then there are important differences in approach to adaptation that can be taken, especially when faced with uncertainty. These choices are illustrated below, using the results from the case study model. The issues are illustrated using a plant with a four year construction period, at a cost of $400 million and a 30 year revenue period (note for simplicity, revenues are provided as being constant: for the model, the actual 30 year period and full variability has been assessed), shown in blue.

A climate stress test is introduced (for illustrative purposes) with a 20% reduction in revenues after 15 years due to climate change. In practice this level of change would be at the higher range of early possible futures.

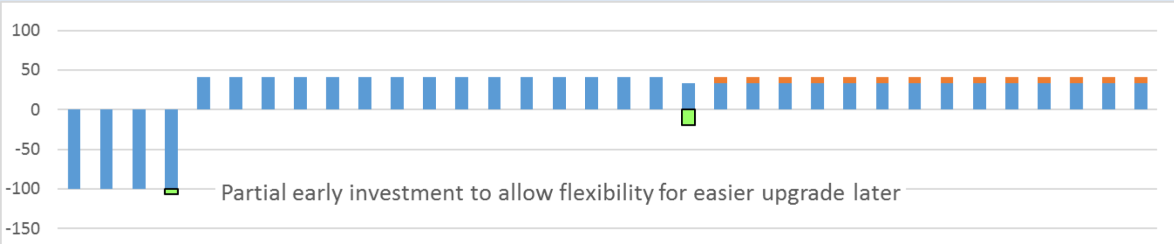
In the first case, adaptation is included in the design phase, with a 5% increase in total project costs (reflecting a higher cost option, see earlier table). In this case the adaptation costs are incurred during the construction period, but although climate change impacts are completely reduced, these adaptation benefits occur much later in time, thus benefits are low when expressed in present value terms. This means the economic benefits of adaptation may not justify the costs (or in financial terms, the IRR may be lower than the do-nothing scenario, meaning that the developer would be worse off and it would be better financially to bear the losses). The effect of adaptation on the key performance indicators varies depending on the cost, benefits and the timing of adaptation. If adaptation costs are lower, or impacts occur earlier, then the IRR will improve: however, if future benefits are lower or later, then adaptation actually leads to a lower IRR than the do-nothing scenario. More importantly, it is not possible to know how much adaptation to implement during the design phase, i.e. because of the uncertainty over future climate change. This means there is a chance that the benefits will not arise, in which case the costs of adaptation are a wasted investment leading to a much lower IRR, or else climate change turns out to be more severe, in which case revenues will drop along with the IRR.



This is contrasted with phased adaptation, where information is collected about the changes occurring s climate change evolves, and the adaptation response is made with this information. In such a case, there will be a cost penalty from retro-fitting, as this is more expensive than including adaptation at the design stage (in the figure, for illustration, twice as expensive, and it also includes a loss in revenues during the retrofit). Nevertheless, the IRR can often be higher (i.e. phased adaptation performs better than adaptation in design), because the costs are incurred closer to when the benefits arise. Furthermore, in this scenario, the main benefit is that uncertainty is reduced, because the level of adaptation is targeted to the level of impacts (thus regrets are minimised). The other advantage is the adaptation can be brought forward or delayed, as the evidence emerges, thus the IRR increases even more. However, the benefits of this approach depend on how much higher the costs of retrofit are, as well as the length of downtime needed to retrofit later, noting this can run into additional problems in relation to contract penalties.



A variation on this is to introduce some flexibility to upgrade later in design, i.e. whereby an initial investment is made which makes it cheaper to upgrade later on with phased adaptation. This can lead to a higher IRR than the adaptation in design, and has the advantages again of minimising uncertainty (and regrets). The relative IRR compared to the phased approach depends on the relative costs of early and phased adaptation.



A further variation is to include robust options in design, i.e. those that perform well over a range of climate futures, rather than optimally to one future. This again reduces the impact of uncertainty, but it can have a penalty in the short-term, i.e. because it is likely to lower revenues relative to the optimal solution. If this reduces revenues in early years, this can have a major impact on the IRR (or economic present value). There is therefore a trade-off that will depend with the size of this penalty versus the future benefits under uncertainty

Finally, the introduction of no-regret options, i.e. those adaptation options that provide immediate economic benefits, as well as enhancing resilience against future climate change, generally perform best of all.

This includes options that provide early benefits (similar to the low regret options for current plants above). It can include additional over-design, or options that provide flexibility or robustness, to address future climate impacts, but only when the costs are low. As with the discussion above, low cost- non-technical options that provide information are low regret, and can be extended to provide additional information (e.g. with continuous monitoring) to help inform later upgrades or retrofits and the modelling indicates this is one of the most effective options.

It is noted that in cases where the future risks are potentially very high, and retrofits are very expensive, there may also be a case for over-design, notably because of safety issues and where plants are important in relation to national electricity generation and therefore could have wider economic impacts. This applies notably to larger storage projects. However, in Nepal these plants are usually already designed for the maximum probable event and would not be sited in high geo-hazard risk sites.

Adaptation options for planned plants[13]

		Non-technical,	**Technical (low regret)**	**Technical (higher costs)**
High flow (flood)	IF a vulnerable area	Enhanced hydro-met (including on line /real time monitoring) Siting	Space for future auxiliary spillway Fusegate/plugs [storage]	Over-design the dam crest/ dam so that higher [storage]. Additional spillways

[13] Please refer to Footnote 11 and Box 5.2 on analyzing costs and benefits of adaptation options.

		Non-technical,	Technical (low regret)	Technical (higher costs)
		Detailed flood risk assessment Early warning Insurance Reservoir management (storage projects) Design standard enforcement by regulator (no consistent standard exists)	Protect key infrastructure, e.g. intake structure, power house	Changes on the weir crest to increase its hydraulic performance (Increase flood storage capacity Bypass tunnels for flood Build powerhouse underground Dam structure (concrete gravity versus rock filled)) Larger foundations to allow dam heightening in the future
Low Flow (dry, winter)	IF a vulnerable area	Enhanced hydro-met (including on line /real time monitoring) Siting Weather forecast/operational optimization Plant management Insurance Plant co-operation (especially cascade) Reservoir management	Number and size of turbines (perform to wider flow regime, noting trade off) Multiple outlet height to cope with variability	Increase storage Over-design the dam crest/ dam so that higher [storage]. Divert flows (conveyance structures) (Space for future turbines Larger foundations to allow dam expansion in the future System level intervention- more storage projects to augment dry season energy generation Prioritize high head RoR projects as they are less sensitive to low flow variation.
Sediment	IF a high sediment laden river	Siting Sediment monitoring (on-line) Slope stability monitoring Design guidance (on more efficiency approaches) Plant shut down above agreed threshold concentration Upstream watershed management	Enhanced trapping devices, e.g. centrifugal separation, hydrocyclones for medium & high head plants, vortex basins (low head plants) (Upper Marsyangdi) Larger outlets for flushing Continuous flushing mechanism Bypass or diversion tunnels for sediment flushing/routing	(Advanced settlement routing) Parallel outlet tunnels Check dams Upstream traps Sloping intake (storage) (e.g Kulekhani)
Geo-hazards (including Landslide induced Dam Outburst floods (LDOF) and GLOFs	If within 100 km from dangerous glacial lakes as GLOF hazards # If near weak and degraded slopes/ watersheds	Siting Detailed geo-hazard risk mapping and assessment Early warning Insurance Upstream watershed management (including green engineering in roads and other interventions)	Protect key infrastructure, e.g. intake structure, power house Set back or raise structure Smart tailrace gates (close when GLOF warning) Khimti-1 has considered measures to check backflow from Tamakoshi when GLOF expected	Underground (e.g. powerhouse) Upper Tamakoshi HEP (456 MW) Underground settling basin Puwa Khola (7MW) Additional spillway

(due to peak flows) expected to be reduced by 100 km (to be verified against design flood plant-wise)

The institutional and system wide categories are very similar to presented in the earlier table. These are also discussed further in the next chapter.

As with the current plants above, the lack of hydro-met data is a major problem, as the decision analysis on what to do cannot be made unless good existing information is available. The priority is to invest in monitoring and information. The provision of this information to small hydro developers is particularly important, because of their higher vulnerability, though this also requires capacity building to help them use this information effectively. As with current risks, these actions are strengthened from institutional strengthening in hydropower planning as well as integrated water resource management.

At the system level, a more robust system development with appropriate mix of projects (RoR/PROR and storage) is also a constraint to meet the system demand of the country. Lack of variations in the portfolio of projects is also a barrier for robust system planning, not only to address the current climate regime but also future climate changes.

5.3.3 Early actions to address future risks

The final category involves different concepts again. It is focused on future major risks from climate change with the critical difference that it involves plant design that will be take place in the future. This would include, for example, the next generation of planned plants (those designed after 2025). In this case, there is no need to make a firm decision now and there is time to learn. This therefore involves a set of options that provide the information to help make better decisions and planning in the future. This is a key priority given the large uncertainty around future climate change in Nepal (as identified in the CRA).

This includes a set of activities around monitoring, research and planning, to provide information for the hydropower sector, e.g. for sector development plans and national system planning.

The example of existing glacial lake monitoring is a good example of this type of early action, providing information that will help to identify emerging risks. This could be extended, for example, with a monitoring and research programme to include other high flow risks.

Research to help the modelling of climate change in Nepal is also a priority, as well as pilot and evaluation projects to test new adaptation options.

A key priority is also the need for general capacity building (across the different actors in the sector) and for institutional strengthening, to provide the enabling environment for the future. A.

These options do have an economic value, known as the value of information, as they enable more effective decisions in the future which reduces costs and increases benefits. They also provide information that can help keep future options open (quasi option value). While these options may not be as large or as costly as the options above, they are important and need to be prioritised: if no action is taken, no learning will occur, and future decision will be uninformed.

5.4 Discussion

The key findings of the analysis are summarized below.

Adaptation pathways can help address the challenges of adapting the hydro- sector. The challenge of climate change is not insurmountable for the hydropower sector of Nepal, and technical options exist. What is more difficult is to identify what makes sense given the high uncertainty, and the trade-off between future benefits (from adaptation) and immediate or early costs. This study has used an iterative climate risk management approach. This aligns directly to the CRA and provides practical information to support adaptation over the next five to ten years. It identified three complementary building blocks (an adaptation pathway) for addressing climate risks in the hydro-sector of Nepal for current, planned and longer-term plants.

Adaptation needs to be designed to the specific context, plant and vulnerability. Given the heterogeneity of vulnerability, a suite of options is needed to adapt the hydro-power sector of Nepal, i.e. it is not a case of one size fits all. This means adaptation needs to be plant, location and vulnerability specific. The ‘best’ adaptation options need to take account of context-specific risks, assessing what works for the project finances. It does not make sense to over-design the whole hydro-power sector for all possible future risks. The study identified a large number of possible adaptation options, and then mapped these to a matrix of adaptation decision versus risks. It used economic analysis to test different options and identified technical and non-technical options, as well as regulatory approaches, that could help address risks to the key performance indicators.

A key finding is that there are many low regret adaptation options that can help address current climate variability and future climate change risks, across the range of risks and climate induced hazards, for different types of plant.

- For current plants, the priorities are for low-regret options, i.e. those with low costs and immediate benefits, particularly non-technical options and capacity building. Examples include improved hydro-met data, early warning systems, low cost protective structures, better sedimentation management, turbine recoating, insurance, etc. These contrast with more costly retrofit options, which have potential in some but not most cases. Many of these low-regret options are forms of good practice, and they have not been implemented due to current barriers.
- For planned plants, the priority is for climate smart design, but considering the trade-off between early adaptation costs and future benefits. While there are additional opportunities to include options at the design phase, interventions also need to consider the high climate change uncertainty. The focus is still on the options identified for current plants above. However, there are also some additional low-cost interventions which can help reduce future risks, and some potential options which offer flexibility or robustness.
- Finally, in relation to future major risks, a set of information needs, monitoring and research activities to enable learning were identified to help the planning and design of the next generation of candidate plants and system planning.

One additional finding is that other factors are more important in the economic and financial analysis than climate change, notably the tariff used (the electricity generation price) and the discount rate/rate of return threshold. This reinforces the point that adaptation should be integrated (or mainstreamed) into existing sector policy and planning – not the other way around.

The key recommendations from the analysis are included in Chapter 7.

6 Towards implementation

A wide range of stakeholders have an interest in hydropower generation and safety, and thus in adaptation.

This includes Government policy makers and regulators, International Financial Institutions (IFIs) and Development Partners (DPs), the private sector, domestic and foreign developers, foreign regulators (for exports) and others such as civil society.

Importantly, these stakeholders are involved at different stages of hydropower development, from policy decision makers, to developers and consumers: This also maps onto their potential role in risk assessment, adaptation strategy and implementation.

The study undertook an institutional mapping analysis and reviewed the roles and responsibilities of different actors in hydropower development, their exposure to climate change risks, the various mechanisms through which they could support or implement adaptation, and their influence.

The latter centres on their role in the project cycle in Nepal, and the point at which they influence or act, i.e. planning, design, construction, operation. This is shown in the figure below.

The ability to influence or implement adaptation also depends on stakeholder's adaptive capacity (e.g. their access to information, finance, etc.). This has been explored through a series of workshops and stakeholder consultation in the project.

Project cycle phase	Decision makers and relevant parties	In Nepal:
Planning	Government, Planners, Regulators, Developers, Local communities	Ministry of Energy, Department of Electricity Development (DOED), Water and Energy Commission Secretariat (WECS), National Planning Commission (NPC), Nepal Investment Board, Concerned Ministries, Ministry of Population and Environment, Department of Hydrology and Meteorology (DHM), Nepal Electricity Authority (NEA), Electricity Tariff Fixation Commission (ETFC)
Design	Developers, Designers, Government, Financiers (Domestic as well as international), Local communities	Domestic and international consultants, Independent Power Producers (IPP) – Independent Power Producers Association, Nepal (IPPAN) and Nepal Hydropower Association (NHA), NEA and its sister organizations; World Bank, ADB, JICA, DFID, USAID/ Millennium

Project cycle phase	Decision makers and relevant parties	In Nepal:
		Challenge Corp. (MCC), European Investment Bank, and other partners
Construction	Developers, Owners, Financiers, Insurers (Domestic and international), Local communities	Banks, Insurance agencies; and same as above
Operation	Owners, Operators, Financiers, Insurers, Local communities	Same as above

Non-technical or soft options like developing enhanced hydro-met, management of water-related disaster through risk mapping, Integrated river basin management with river basin organization; development of water related information system are common adaptation measures across all nature of hydropower projects. These options are basically related to the planning and management aspect and at the national level. For instance, we can consider the National Water Plan 2005 which have already defined these aspects as targets to achieve by 2027. As such, for these common soft measures, common key entry points are basically enforcement or implementation the existing policy by overcoming the existing barriers through inter- institutional cooperation, allocation of appropriate budget, enhancing skills / manpower and stakeholder participation. This will not only make hydropower sector but also overall water related sector climate resilient.

As for technical options, they are more specifically to be incorporated into design standards and guidelines by regulating authorities; and followed by developers. These should include the climate requirements (climate risks) and these should be considered at project level and system level. In reality, most of these options are “good practice” options.

At project level implementation, following are general interventions that support the identified adaptation options:

- Develop guidelines for developers on climate information
- Develop guidelines on risk screening
- Climate risk screening in NEA approval process (and also for power trading institutions and financiers)
- Change contract to incentivize adaptation (e.g Lower royalty or lower equity stake (to recognize climate resilient) or lower free electricity level
- Revise design standards for floods and geo-hazards
- Incorporate periodic mandatory safety rules and compliance

At system level implementation, following are general interventions that support the identified adaptation options:

- Policy and strategy for diversifying energy mix; risk diversification
- Environment and social safeguards (requirement applying to EIA, minimum environmental flows)

- Regional grid and focus on power trade/exchange for better hydro-thermal coordination (eg. more thermal during dry hydrological years and more hydro during wet hydrological years)
- Proposed National Energy Regulatory Commission (NERC) to be mandated with full regulatory authority including climate and non-climate screening unlike only economic regulatory mandate of ETFC
- Risk sharing arrangement by private and public sector
- Payment for ecosystem services to improve watershed management upstream
- Change tariff and pricing structure in PPA with greater differentiation on seasonal and daily variation .e.g to incentivize storage and PRoRs rather than RoR
- Appropriate penalty regime considering climate variability at present and in the future

It is also noted that there may sometime be opportunities to mainstream, when plants are upgraded, or infrastructure is being replaced.

Finally, there are a number of barriers to adaptation that make it harder to plan and implement. These include a range of economic, social and institutional factors, including market failures, policy failures, governance failures and behavioural barriers.

Addressing these barriers is critical to successful adaptation, especially for medium to long-term decisions such as for hydro-power. There are ways to reduce or overcome these barriers; however, this requires their consideration from the start of the adaptation planning process.

6.1 Implementation and responsibility for adaptation options

Adaptation Type	Entry Point	Barriers	Responsibility
High Flows (Flood)			
Technical options (engineering design) such as: Existing plants - retrofitting e.g. new auxiliary spillways, fusegates/plugs, protection of key structures	Technical audit including design and new data analysis and economic evaluation of options	Site and design constraints; lack of economic incentives	Project Owner and Regulatory Authority (DOED and proposed NERC)
Planned plants – flexible design such as space for auxiliary spillways, fusegates/plugs, larger foundations for future upgrading, by-pass tunnel, upstream flood retention; Over design such as additional spillways, higher design flood standards, free flood space in storage reservoir project	Prepare design standards and guidelines (currently projects designed in different standards)	No "design standards" enforced Lack of reliable hydro-met data Developers' interest are more short-medium term (for the duration of the concession period) Institutional capacity for due diligence by regulators and lending agencies	Regulatory Authority (DOED and proposed NERC) Developers Lending agencies (Banks)
Non-technical options: Enhanced hydro-met (including on line /real time monitoring and forecasting)	Improvement of data collection and modelling; additional stations in high	Lack of adequate budget and priority	

Adaptation Type	Entry Point	Barriers	Responsibility
Detailed flood risk assessment Early warning systems Insurance Reservoir management of storage projects Upstream watershed management	elevations; Cooperation with Neighboring countries for data sharing (e.g. glacier lakes in Tibet/China_ Part of project royalty to be provided enhancement of hydro-met services Design standards and guidelines Payment of environmental services (PES) and use of part of project royalty for watershed conservation	Institutional capacity Lack of regulations Lack of watershed/river basin agencies	DHM, DOED, Ministry of Soil Conservation, Insurance companies WECS, River Basin Organizations (new but not active) Local Government and Community management of watershed
Technical options (storage) include raising the dam crest, new auxiliary spillways, fusegates, or fuse plugs. For RoR./pRoR can retrofit (protect) vulnerable structure such as intake. Non-technical options include early warning systems to allow shutdown to protect, reservoir management, insurance.	As left though also options for flexible design (bigger foundations for later dam heightening, space for later supplementary spillway capacity) and design, e.g. choice of dam material, as well as burying or protection key structures.	Enhanced system planning and modelling (site and plant selection) Enhanced hydro-met data collection. Integrated water resource management	The technical and non-technical options should be included in the hydropower design guideline. Which should include structural design with minimum climate-proof standards. Designers, Planners, Owners, Financers and

Adaptation Type	Entry Point	Barriers	Responsibility
			Insurance Company would be responsible to implement it. The project operator should be able to implement the non-technical options which includes early war
Low flows including variability			
Technical (engineering design) Divert flows (conveyance structures) (for e.g. Rolwaling diversion to UTK 456 MW increases dry season generation) Appropriate power mix of ROR/PROR and Storage (including pumped storage) and other supply options to enhance dry season energy reliability Interconnection with regional grid to benefit from coordination of hydro and thermal generation **Non-technical options:** PPA revision to incentivise	Feasibility studies and river basin planning and management System planning and appropriate pricing regime (incentivizing in PPAs) Regional grids with neighboring countries, power trading agreements	Lack of river basin organizations and plans Inter-sectoral and inter-regional conflict Institutional shortcomings – overlapping roles, no regulatory authority, no authority undertaking system planning, NEA's conflict of interest Lack of institutional capacity	WECS, NPC. Min of Energy Proposed NERC River Basin Organizations NEA, Developers, Design Firms

Adaptation Type	Entry Point	Barriers	Responsibility
(take or pay for energy supplied up to threshold dependability e.g. 90% dependable) Revision of penalty clause in PPAs of smaller and projects in more rain-fed catchments[14] Revise design standards Guidance Capacity building			
Sediments			
Technical options Existing plants: retrofitting including Turbine upgrading/ recoating Enhanced trapping devices, e.g. centrifugal separation, hydrocyclones for medium & high head plants, vortex basins (low head plants) (Upper Marsyangdi) Larger outlets for flushing Continuous flushing mechanism Bypass or diversion tunnels for sediment flushing/routing	Technical audit including design and new data analysis and economic evaluation of options Prepare design standards and guidelines (currently projects designed in different standards)	Site and design constraints; lack of incentives for developers No “design standards” enforced Lack of reliable historical and current (after plant operation) sedimentation data Institutional capacity	Project Owner and Regulatory Authority (DOED and proposed NERC) Regulatory Authority (DOED and proposed NERC) Developers

[14] Government is already proposing removal of penalty for projects under 10 MW).

Adaptation Type	Entry Point	Barriers	Responsibility
Non-technical: Siting Sediment monitoring (real time) Slope stability monitoring Design guidance (on more efficiency approaches) Upstream watershed management Plant shut down above agreed threshold concentration	Improvement of sediment data collection and modelling; Design standards and guidelines Payment of environmental services (PES) and use of part of project royalty for watershed conservation System scheduling by Off-taker (Load Dispatch Center of NEA) Appropriate power mix with adequate reserve margin, coordinated operation with other plants	Lack of adequate budget and priority Institutional capacity and overlapping mandate/roles Lack of regulations Current mis-match between supply and demand Lack of system planning by current institutions	DHM, DOED, Ministry of Soil Conservation, WECS, River Basin Organizations (new but not active) Local Government and Community
Geo-hazards including LDOFs and GLOFs			
Technical options: Siting Protect key infrastructure, e.g. intake structure, power house Set back or raise structure	Design standards and guidelines Feasibility studies	Lack of data/information (hazard and risk maps) Institutional capacity and preparedness	Developers, design firms

Adaptation Type	Entry Point	Barriers	Responsibility
Smart tailrace gates (close when GLOF warning) Underground power house (.e.g. Upper Tama Koshi) Glacier Lake dewatering (e.g. Imja Lake) and Landslide induced dams dewatering and controlled breaching before burst in case of occurrence		Lack of institution and DRM policy Lack of guidelines and regulations	DHM, DOED, DWIDP
Non-technical: Detailed geo-hazard risk mapping and assessment Early warning and forecasting Upstream watershed management (including green engineering in roads and other interventions) Insurance	River basin disaster risk management plan	No clear responsibility or authority assigned no any current institution	River Basin Organization/Authority, WECS Department of Soil Conservation and Watershed Management

6.2 Entry Points and Barriers

One of the first activities of mainstreaming is to identify relevant entry points, that is, to identify the existing framework and opportunities in the national, sector or programme plans and activities where climate adaptation can be integrated.

To enable this, the study assessed the existing regulatory framework for the electricity sector and hydro-electricity as well as for climate change adaptation. This provides the baseline onto which adaptation options or interventions can be considered.

In the context of hydro-electricity, this includes the Electricity Act and Regulations, which regulate the electricity sector by a system of licensing. To obtain a license for the survey, generation, transmission or distribution of electricity, an application form must be submitted to the Secretary of Ministry of Energy (MoEn) through Department of Electricity Development (DOED) along with a financial, technical and environmental study report. This provides a key entry point for adaptation.

For most hydropower projects, developers must conduct environmental assessments before implementation. Initial Environmental Examination (IEE) and Environmental Impact Assessment (EIA) reports are approved from the MoEn and Ministry of Population and Environment (MoPE). .

However, this study does not recommend mainstreaming climate change adaptation (CCA) in EIA, as this is generally too late in the process: normally by the time a project or programme gets to this point it is already developed and the opportunity to integrate is already lost. It is also largely ancillary to the core design and development.

A further opportunity for mainstreaming exists through the Project Development Agreement (PDA) which is the concession agreement. The PDA template contains provisions governing potential climate-induced risks, such as force majeure and the management of GLOFs, as well as provisions concerning the handover of the project. It mandates that companies should conduct a study of potential effects on the development of a GLOF and LDOF It also defines the roles and responsibility of the government and the developer. Recently approved projects, such as the Arun 3 and Upper Karnali, have used the new PDA template.

Upon completion of such study, a full and detailed report is submitted to the GoN. If the GoN in consultation with the technical review panel determines that the installation of an early warning system in respect of a GLOF is required, the company has to establish such a system (in consultation with GoN). This provides an existing example of how adaptation could be integrated into the PDA.

One of the most promising areas would be to include climate risk screening in the feasibility design guidance. This is being updated next year and this provides a concrete entry point for mainstreaming.

The National Adaptation Plan (NAP) currently under preparation by the Ministry of Population and Environment (MOPE) in cooperation with sectoral ministries including Ministry of Energy will be an important entry point to integrate (mainstream) the findings and recommendations of this study. Initial linkages and discussions with the NAP team have been made and the adaptation pathways prepared under the study can be used for the NAP in the hydroeletricity- sector.

Finally, there are a number of barriers to adaptation that make it harder to plan and implement. These include a range of economic, social and institutional factors, including market failures, policy failures, governance failures and behavioural barriers.

Addressing these barriers is critical to successful adaptation, especially for medium to long-term decisions such as for hydro-power. There are ways to reduce or overcome these barriers; however, this requires their consideration from the start of the adaptation planning process.

Some of the barriers to adaptation and how these could be overcome are as follows:

1. **Investment Barriers** - private sector is reluctant to spend upfront capital to implement the adaptation options as the benefits are achieved not now but at the end of the concession period. Domestic financial capacity is low, so domestic funds are usually directed towards small/medium projects. Nepal relies on foreign direct investment (FDI) and large institutional investors for large plants. Mandatory regulation can be a means but is not likely to succeed without incentivizing adaptation. One option to overcome this is to access available adaptation funds (eg. Global Climate Fund, Least Developed Countries Fund, Special Climate Change Fund etc.). Capacity building and awareness and options for different (small and large) investors to access these available funds is needed.
2. **Institutional and Governance Barriers** - lack of coordination among the various government entities, for example Ministry of Energy and Department of Soil Conservation and Watershed Management, is a barrier for watershed level adaptation recommended. The current institutions in Nepal are not prepared for climate change adaptation. Awareness and capacity building including relevant policy interventions recommended in the adaptation options are required to overcome this. Formation of Climate Adaptation Cell within Ministry of Energy in coordination with Ministry of Finance, Ministry of Forest and Ministry of Population and Environment is another recommendation to overcome the institutional barriers. There is also an issue of policy priorities as climate change is currently not at the top of the list for the government. Lack of a master plan for hydropower and weak licensing system is another barrier. Lack of a holistic approach to river basin management (which takes into account hydropower and other uses along the basin) and other water uses is affecting the sector. The government has recently started addressing these barriers. River basin and hydropower master plans are currently under preparation by the Water and Energy Commission Secretariat (WECS) with support from the World Bank, The licensing system is also expected to be revised using the river basin and hydropower master plans. The new licensing system should also change the current lengthy process for approval, which is a significant cost to developers in Nepal and that, if reduced, would benefit adaptation. High turnover of government staff is affecting the sector development in general, including adaptation.
3. **Power Purchase Agreement (PPA)** - the vulnerability assessment has clearly concluded that climate change impacts and adaptation will vary from project to project, from smaller to larger projects, in one catchment to another and from ROR to Storage projects. The new PPA policy (February 2017) of the government (and Nepal Electricity Authority, NEA) has extended the period for the dry season tariff rates from 4 months to 6 months (which is double the wet season tariff rate) and also proposed a new policy of higher rates for peaking ROR (pROR) and storage projects. The plant will need to generate certain percentage of the annual energy, and at certain capacity (MW) out of total installed capacity in the dry months, to qualify for the higher rates offered for pROR and storage projects. This can lead to the private developers also designing their projects with peaking capacity, which is currently not the case mainly due to no difference in peak and off-peak tariff rates. This new policy has also changed the power purchasing regime from “take and pay” to “take or pay”. There is also some relaxation on the penalty developers need to pay for not meeting the committed energy. These are positive steps that will benefit the developers considering current variability as well future climate change. However, there still remains the problems of plants

of smaller capacity, location and types that will not fully benefit from these changes. For example, most of the existing and currently designed pROR and storage projects do not meet the threshold criteria of dry season energy percentage to qualify for the higher PPA rates. This new pricing and PPA regime will require a revision of the design (including the installed capacity) of the planned plants to benefit from the changes. Hence, uniform PPA may not result on financial viability of the project if the adaptation options are to be implemented. PPA and Project Development Agreements (PDAs) should therefore be reviewed and adapted to make them adaptation friendly to the projects in terms of their financial viability.

4. **Poor adaptive capacity** - This includes, especially for small private developers and government representatives, the lack of access to and capacity in understanding and using complex climate and sedimentation models.
5. **Behavioral barriers -** These include inertia, e.g. sticking to the old methods of evaluating and assessing projects, as well as the idea that climate change is 'too difficult and too uncertain to address'. Improving data collection, and hydro-met data dissemination and access can help overcome these barriers.

7 Conclusions and Recommendations

7.1 Conclusions

The key findings of the study are summarized below.

Current variability is a major challenge for Nepal's hydro- sector. A key finding is that Nepal's hydropower sector is already affected by climate variability today, due to high seasonal and inter-annual variability. This leads to high levels of current economic costs for operators and the economy.

Vulnerability is highly heterogeneous. The study found that these impacts differ with catchment elevation and size, geographical and geological location, and plant type. Higher variability was found in smaller catchments, as well as in rain-fed catchments. Run-of-river (RoR) projects were found to be more vulnerable than storage projects. Risk of high peak flows, sedimentation levels, Landslide-induced Dam Outburst Flood (LDOF) and Glacial Lake Outburst Floods (GLOF) also varied widely.

The impacts of climate change on hydropower are uncertain. The lack of existing reliable and long-term hydro-meteorological and sediment data in Nepal makes hydrological analysis and modelling difficult. This is a key limitation to understanding current risks as well as future climate change. This is compounded by the high uncertainty associated with future climate change in Nepal. The projections from the climate models show a wide range of warming across scenarios and models, with changes of 1.2˚C to 5.2˚C by mid-century (with average increases of 2˚C and 2.6˚C for RCP4.5 and 8.5 scenarios in monsoon months; and with average increases of 2.7˚C and 3.4˚C in RCP 4.5 and RCP 8.5,respectively, in winter months). They also generally show an increase in monsoon precipitation and heavy rainfall events, though the range is wide. In contrast, there is no agreement regarding winter precipitation, for example with a projected change of-40% to +66% (RCP 4.5).

The current regime is not addressing current variability. One insight from the analysis is that existing and planned future projects are being designed at the project level under the regime that was very recently (February 2017) changed (pricing, market and regulatory policy) without fully considering systems requirements or possible changes in the regime. For example, more than 80% of the ROR projects are designed at discharges with 40% or lower dependability, which are "optimal" under the recently changed pricing regime. Storage capacity of most reservoir projects are also limited, with only 24% storing more than 50% of the average monsoon runoff (June to September) and only 45% generating more than 30% of the total annual energy in the 5 dry months from Dec. to April. The new PPA regime proposed by the government in February 2017 has made changes in the number of months of dry season tariff, higher tariffs for peaking ROR and storage projects meeting certain dry season generation thresholds, and adopted a "take or pay" principle for power purchase. This will mean that the design of the plants (including the installed capacity and design discharge) will need to be reviewed and revised, if necessary, to benefit from the new PPA regime. This shows how vulnerable hydro plants are to changes in pricing regime.

Smaller RoR plants are the most vulnerable to future climate change. Smaller RoR projects will be more affected by climate change, because they are affected most by variable flow conditions.. Rising temperatures will affect snow hydrology and glacier melt and may impact hydro plants with substantial catchments above the snow line (which is around 44% of current and planned RoR) but its overall impact on energy is low. Rising temperatures will have greater impacts on evapo-transpiration losses for lower catchments, resulting in decreasing dry season flow. Changes in rainfall will have more impact on rain-dominated catchments. Smaller ROR projects in rain-fed catchments are more vulnerable, especially those designed for low dependable flows, as these are more vulnerable to flow variations. Storage projects with higher storage can better manage flow variations and thus are more resilient to future climate induced changes.

The greatest impact of climate change is from increased climate induced hazard. It is the increase in climate induced hazards – sediment, extreme floods and geohazard (including GLOFs and LDOFs) – that are the most important additional risk from climate change (i.e. additional to current variability).

Increasing sediment loads could have important economic costs. Sediment loads are often high in Nepal, causing wear and tear and reducing turbine lifetime, or increasing operational downtime. Climate change may increase sediment loads, increasing impacts. Case study analysis estimated a 6% to 12% loss of energy from climate change is possible. Another major risk is from geo-hazards including LDOFs and GLOFs. Hydropower plants that are located more than 50-100 km downstream of glacier lakes are not at direct risk, as the design floods of plants at such locations are normally higher than peak discharge from GLOF events (to be verified against design flood plant-wise), but can still be affected by sediments and debris.

High flow and geohazards are likely to increase. Higher monsoon flows are likely to increase the risks of extreme flows and floods, leading to damage and downtime. The expected rise in high flows due to climate change is a factor for future design, especially for smaller RoR projects which currently have lower flood design standards.

Climate change impacts are additional to other factors (i.e. additional to current variability, institutional and regulatory issues). While climate change is potentially important, it is outweighed by other issues and uncertainties affecting the power sector. For current plants, the effects of current climate variability, institutional and regulatory issues and pricing are more important. For plants planned in the next decade, or so climate change generally has a modest impact and other factors are likely to be more important, such as the tariff received or the discount rate/rate of return. Climate change could be much more important for plants built later (>2030), but the design of these plants does not have to be finalised now: there is the opportunity to learn before decisions are made.

Adaptation pathways can help address the challenges of adapting the hydro- sector. The challenge of climate change is not insurmountable for the hydropower sector of Nepal, and technical options exist. What is more difficult is to identify, however, is what makes sense given the high uncertainty, and the trade-off between future benefits (from adaptation) and immediate or early costs. This study has used an iterative climate risk management approach. This aligns directly to the CRA and provides practical information to support adaptation over the next five to ten years. It identified three complementary building blocks (an adaptation pathway) for addressing climate risks in the hydroelectrcity-sector of Nepal for current, planned and longer-term plants.

Adaptation needs to be designed to the specific context, plant and vulnerability. Given the heterogeneity of vulnerability, a suite of options is needed to adapt the hydro-power sector of Nepal, i.e. it is not a case of one size fits all. This means adaptation needs to be plant, location and vulnerability specific. The ‘best’ adaptation options need to take account of context-specific risks, assessing what works for the project finances. It does not make sense to over-design the whole hydro-power sector for all possible future risks. The study identified a large number of possible adaptation options, and then mapped these to a matrix of adaptation decision and risks. It used economic analysis to identify promising technical and non-technical options, as well as regulatory approaches, that could reduce the risks to the key performance indicators.

There are low regret options to adapt the hydro- sector in Nepal. A key finding is that there are many low regret adaptation options that can help address current climate variability and future climate change risks, across the range of risks in Nepal and climate induced hazards, for different types of plant.

- For current plants, the priorities are for low-regret options, i.e. those with low costs and immediate benefits, particularly non-technical options and capacity building. One clear insight is that many smaller current projects have been designed with low design standards and with limited data. Therefore, there are immediate benefits from improved hydro-met data, early warning systems, retrofitting low cost protective structures, better sedimentation management, turbinerecoating and insurance. Many of these low-regret options are forms of good practice, and they have not been implemented due to current barriers. A "technical audit" of current plants, and information and technical assistance to help address these risks and barriers in the light of new data is therefore a priority. These low regret can be contrasted with costlier retrofit options, which have potential in some but not in most cases.
- For planned plants, the priority is for climate smart design. Howeve, while there are opportunities to include options at the design phase, these interventions need to consider the high uncertainty around future climate change and the balance between early adaptation costs (in design) and future adaptation. The inclusion of low regret options (as identified for current plants above) is still a priority, but there are also some additional low-cost interventions which can help reduce future risks, and some options which offer flexibility or robustness that take account of future uncertainty.
- Finally, in relation to future major risks, a set of information needs, monitoring and research activities to enable learning were identified to help the planning and design of the next generation of candidate plants and system planning.

The institutional and policy context is important for implementing adaptation. A range of stakeholders are involved in hydropower, with various roles and responsibilities, at different stages of development. The study undertook an institutional mapping analysis to understand these. One finding was that institutions are not currently prepared for climate change. The study then identified possible entry points in current policies and regulations where climate adaptation could be mainstreamed (integrated), to help make the sector climate-smart.

7.2 Recommendations

Finally, the study has identified key recommendations:

Addressing current vulnerability

The priority is for Nepal's hydropower system to address current climate variability. This will help build resilience to future climate change.

Individual plants are often not designed to cope with current risks, not least because the detailed hydrological data is not available. Ensuring that plants address current risks will help the economic and financial performance, it will help protect assets, and will build resilience that will help offset the future risks of climate change. The study finds, however, that the current vulnerability is highly heterogenous, and the choice of measures needs to reflect the individual risk.

At the system level, the current balance of plants does not perform well against today's seasonal and annual levels of climate variability. Looking at the balance of plants on the system to help address current variability will help to address the risks of future climate change on average and low season generation.

Hydro-met

While positive initiatives are happening, notably the PPCR initiative, further strengthening of hydro-meteorological information is critical. The lack of hydro-met data means that plants today are not being designed to the likely variability. The information on water catchments about 3000 m is identified as a particular gap, but greater hydro-met and sediment monitoring across the country is a priority.

This investment provides the foundation stone for current and future adaptation, and there is a very high benefit from investing (the value of information).

The potential for on-line monitoring, and enhanced dissemination of hydro-met information is also a critical area of investment, to ensure better data is communicated to end-users, in a form that is timely and usable. There is considerable potential for plant efficiency and system optimisation through the use of this information in more detailed plant management and system management.

Further work on the weather value chain for hydro-power would be useful, along with stakeholder consultation to understand end-user needs, and to help identify data but also information pathways to maximise the effective use.

Risk assessment, best practice and awareness raising (capacity building)

One of the key issues the study has identified is that there are barriers to plant operators adopting early low regret measures – to address current climate variability and build resilience to future climate change. There are, however, examples where operators have included some measures, thus there are Nepal case studies to learn from and to use as good practice.

These include information gaps, finance and institutional barriers. These barriers can be targeted to create the enabling environment for developers. To start this process, it would be useful to use the vulnerability work here and undertake risk assessments for existing plants. This would provide key information for operators on the risk they face (including the potential financial risk). A programme to collate good practice examples, with benefit and cost information, and to raise awareness of these initiatives would then help address the information barriers. At the same time, targeted material that highlighted the possible return on investment with concrete case studies would be useful to help address financial barriers.

A particular priority is for smaller plants. Large hydropower plants generally have high design standards, not least because they are financed by International Finance Institutions. The main capacity and awareness gap is therefore with smaller developers. The proposed programme should thus be focused on this group.

A similar initiative is needed for planned plants, though this links in with the latter recommendations on moving to climate risk screening.

Risk screening and design standards

Following on from the analysis above, there is a need to mainstreaming climate risk assessment into the development project cycle.

The priority would again be to ensure that plants are addressing current climate variability effectively, but also help operators to consider if there are additional areas where climate change might increase the incentive to act (e.g. to include additional measures), noting that this needs to consider the balance of costs and benefits.

As with above, the priority is likely to be for smaller plants. A similar approach of providing support information and case study material (good practice examples) would be particularly useful, though in some cases the design standards could be enhanced. Examples of the latter include the provision for higher design standard minimums to take account of the likely increase in return periods, or the requirement for early warning systems for plants at particular risk of geohazards.

It is stressed that the climate risk screening should be included in the design and feasibility stages, and not in the environmental impact assessment, as it will be most effective if incorporated into the main design and financial modelling.

System planning

There is a need to enhance system planning as projects are designed more at the project level without consideration of the system requirements. Investment planning shows that more storage type reservoir projects are required to meet the current and future power demand of the Integrated Nepal Power System (INPS). The optimal (i.e., cost minimizing) share of storage hydropower projects in total installed generation capacity required to meet the projected domestic power demand is found to be increasing over time: That is, the share of capacity of both ROR and storage plants will be more or less equal of the order of 46 or 47% in the future. Similarly, with the available type of candidate plants, the energy mix will stabilize at 72% for ROR plants and 18-22% for storage projects. Noting that at present the share of storage plant capacity is about 10% only, these results indicate inadequacy of storage power plant capacity in the existing INPS generation system (hence an inefficient capacity mix) besides the total system capacity itself being inadequate.

Size, type, capacity and cost of the project makes considerable impact on the performance of the system. System can be benefit from power exchange i.e. importing electricity during peak time and dry season and exporting during wet season.

System planning is constrained by insufficient number of variations in projects types and size. For example, the limited number of candidate storage projects with sizable live storage can be a limitation to achieve an optimal power mix of the system. It is recommended that project feasibility studies and river basin/hydropower master plans undertake a more varied options assessments considering both current climate and future changes, and likely changes in policy, regulatory and pricing regime.

Invest to learn

There is a need to invest to learn, with monitoring, research and pilots, to improve future decisions and planning.

This could include further work to improve the modelling of climate change in Nepal, but also a greater focus on observations and monitoring (e.g. building on the existing monitoring of GLOF risks).

The need to build capacity in the sector is paramount, with more focus on awareness raising and information, along with supporting research. One important aspect is to develop the institutional research landscape and ensure information is disseminated.

Finally, there is a need for institutional strengthening on climate change in Government and across the major agencies involved in the hydroelectricity sector, as well as for the private sector. A planned programme of technical assistance support would enable all the other key recommendations, and would help the hydro-power sector to mainstream climate change and develop future sector development plans and policies to ensure they are climate smart.

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