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

Adaptation Pathways Report

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Table of Contents

This project, TAAS-0045: Adaptation to Climate Change in the Hydroelectricity Sector in Nepal, is being 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 Adaptation Partnership (UK) Limited (GCAP).

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Acronyms:

ADB:	Asian Development Bank
AEPC:	Alternate Energy Promotion Centre
CC:	Climate Change
CCD:	Climate Compatible Development
CDKN:	Climate and Development Knowledge Network
CIAT:	International Centre for Tropical Agriculture
CMIP3:	Coupled Model Intercomparison Project Phase 3
CMIP5:	Coupled Model Intercomparison Project Phase 5
COP:	Conference of Parties
CSAG:	Climate Systems Analysis Group
DFID:	Department for International Development
DHM:	Department of Hydrology and Meteorology
DOED	Department of Electricity Development
EIRR	Economic Internal Rate of Return
ET:	Actual Evapotranspiration
FAO:	Food and Agriculture Organization
FIRR:	Economic Internal Rate of Return
GCAP:	Global Climate Adaptation Partnership
GCM:	Global Circulation Model
GDP:	Gross Domestic Product
GFDRR:	Global Facility for Disaster Reduction and Recovery
GLOF:	Glacial Lake Outburst Flood
GoN:	Government of Nepal
GW:	Giga Watt
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
IPPAN:	Independent Power Producers Association of Nepal
ISET:	Institute for Social and Environmental Transition
LAPA:	Local Adaptation Plans of Action
masl	Meters above sea level
MoA	Ministry of Agriculture
MoAC	Ministry of Agriculture and Cooperative
MoAD:	Ministry of Agriculture Development
MoEn:	Ministry of Energy
MoSTE:	Ministry of Science, Technologyand Environment
MW	Mega Watt
NASA	National Aeronautics and Space Administration (USA)
NAPA	National Adaptation Plans of Action
NCCKMC:	Nepal Climate Change Knowledge Management Centre
NDRI:	Nepal Development Research Institute
NEA"	Nepal Electricity Authority
NPC:	National Planning Commission

NPV	Net Present Value
NSDRM:	National Strategy for Disaster Risk Management
NWP:	National Water Plan
O&M:	Operation and Maintenance
PAC:	Practical Action Consulting
PDA:	Power Development Agreement
PES:	Payment for Ecosystem Services
PET	Potential Evapotranspiration
PI	Performance Indicator
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
PPCR:	Pilot Project for Climate Resilience
PROR:	Peaking Run-of-river
PTA:	Power Trade Agreement
RCM	Regional Climate Model
RCP	Representative Concentration Path (CMIP5)
ROR:	Run-of-river (power plant)
SPCR:	Strategic Programme for Climate Resilience
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
WECS:	Water and Energy Commission Secretariat
WRS:	Water Resources Strategy

Summary

At the request of the Government of Nepal, the Climate and Development Knowledge Network (CDKN) is funding 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 Global Adaptation Partnership (UK) Limited (GCAP).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.

This report presents the initial analysis of adaptation options. To do this it uses an iterative climate risk management approach (adaptive management). This first considers the potential risks of climate change, starting with current climate variability and then considered future climate change, taking account of the high uncertainty of projections in Nepal. It then considers the possible timing and sequencing of adaptation options to address these risks using iterative adaptation pathways building the analysis around three key types of intervention.

i. Immediate actions that address the current adaptation deficit and also build resilience for the future. This involves early capacity-building and the introduction of low- and no-regret actions as these provide immediate economic benefits. These actions are focused on existing hydro-electricity plants / system in Nepal.

ii. The integration of adaptation into immediate decisions or activities with long life-times, notably new infrastructure and planning decisions. This requires different issues to the actions above, because infrastructure/plans will be exposed to climate change in the future, noting the high uncertainty. It involves a greater focus on risk screening, the risks of lock-in, and the identification of flexible or robust options (rather than optimal ones). These actions are focused on the siting and design of new hydro-plants that will be built over the next 5 – 10 years.

iii. Early planning for the future impacts of climate change, noting uncertainty. This includes a focus on the value of information and future options/ learning. This includes action that will help inform the future hydro-electricity sector, i.e. to help improve future decisions, particularly around enhanced monitoring and research.

The three categories can be considered together as an integrated adaptation strategy or an adaptation pathway.A key justification for this approach is that it addresses the economic challenge of adaptation, i.e. the need to consider up-front adaptation costs against future discounted benefits. The study has mapped a long list of potential adaptation options using this pathways approach and undertaken initial analysis on their potential costs and benefits. It has also considered how integrate these into existing entry points, and mainstream (i.e. to integrate) adaptation into the hydro-electricity sector of Nepal.

The analysis has then considered the results of the vulnerability assessment. This confirms the need to focus on current climate variability as the starting point and particularly the

issues around low season flows (Dec-Mar), due to the load shedding and unmet demand. It also highlights that an additional set of options need to be developed that focus on current data hydro-met gaps, i.e. supporting information to provide the enabling environment for better hydro-planning.

In terms of the design of plants with future climate in mind, the vulnerability report highlights that any design or adaptation option should be project and system specific, depending on factors such as location, size, type, hydrological design parameters, installed capacity and live storage (in the case of storage projects).

Finally, the vulnerability report highlights the need to address early planning and monitoring to start preparing for the long-term climate induced hazards identified by stakeholders as the key risk to hydro projects: these include potential glacial lake outburst floods, sediment load and extreme flood events.For GLOFs in particular, additional options have been identified around risk management strategy such as early warning or design of key structures above the hazard levels or even underground structures. More analysis of these options will be undertaken.

Moving forward, the results of the vulnerability assessment report will be used to refine the adaptation options considered in this report, adding additional options and providing a greater differentiation between types and elevation of plants. The adaptation options identified will be discussed with expert group consultations and consultation with other stakeholders in Nepal, and local information (and costs) investigated. These will be used on an existing adaptation cost-benefit model run by the team to derive indicative estimates for adaptation and it is proposed to test this on a selected number of case studies to look at some of the promising adaptation options to help prioritise potential options. Finally, the analysis will consider the potential for these options in Nepal, i.e. the practicality and acceptability of options, and the issues in implementation (e.g. whether effective, policy costs, etc.). This will consider the entry points and potential barriers to adaptation and look to see how they could be introduced into the hydropower sector of Nepal.

1 Introduction

1.1 Introduction to the study

At the request of the Government of Nepal, the Climate and Development Knowledge Network (CDKN) is funding 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) and Nepal Global Adaptation Partnership (UK) Limited (GCAP).

The study builds on the previous assessment of the Economic Impacts of Climate Change in Nepal (IDS, 2014). The primary objectives for this 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;
- Build capacity and help enable adaptation action amongst policy makers and the private sector.

This report summarizes the initial findings of the adaptation pathways analysis.

Chapter 2 presents the overall conceptual framework, the approaches and methodologies.

Chapter 3 describes the analysis of risk and options and proposes early adaptation pathways.

Chapter 4 covers the potential integration into policy.

Chapter 5 outlines the next steps, drawing on the findings of the vulnerability assessment.

2 Conceptual Framework for Adaptation Pathways

This chapter outlines the conceptual framework for the adaptation pathways approach used in the study. It starts with a discussion of the two key challenges facing adaptation – uncertainty and economics. It then goes on to describe the adaptation pathways approach and how it integrates with the wider Climate Risk Assessment method in the overall study. .

2.1 Uncertainty

While considerable investment has been made in climate modeling and downscaling of global climate models over recent years, and projections of future climate change, the confidence in the results remains low. This limits the use of these models for informing investment and policy choices.

This is mainly because of the large uncertainty associated with future climate, which has two components. First, future greenhouse gas emissions – and thus the level of climate change that will occur over time - are uncertain. It is currently not clear whether the world will implement the emission reductions (mitigation) needed to limit global warming to 2 degrees relative to pre-industrial levels (the 2°C goal) and many commentators consider higher emission scenarios towards a 3 or 4°C warmer world are more likely. The future emission path makes a large difference to future warming and changes in other climate parameters, such as precipitation, especially post 2050.

Second, even when a future emission scenario is defined, there are still large variations projected from different climate models. This arises because of the structure and sensitivity of the models, the regional and seasonal changes associated with global temperature, and the difficulty in projecting complex effects such as rainfall. As a result, different climate models often give very different results, even for the same scenario and same location.

Much of the existing literature ignores these issues, and typically runs one or more climate model projections, and then assesses the potential impacts and then adaptation options. Such impact-assessment based studies do not take account of uncertainty, because they are highly stylized and focus on individual climate projections and then consider adaptation as a response to this defined future projection. They analyse the idealised response to an individual future projection, even if they subsequently repeat this calculation for a number of alternative simulations (one-at-a-time). This predict-and-optimise approach presents information on how adaptation responses might change across a range of future projections, but it does not inform the policy maker on what to do now, given this future uncertainty exists (and is large).

Critically, the uncertainty when multiple scenarios and climate model projections are considered 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, they are unlikely to even describe the limits of the range of possible climate changes. Perhaps most importantly, climate projections have the least skill in the variables that are most important for water resources projects, such as hydrological variability (inter- and intra-annual variations) and extremes (e.g., floods and drought). Often, the results of a climate change analysis present a wide range of possible future mean climates, with no insight on hydrological variability and climate extremes, and as a result, the project planner faces a difficult path forward.

As a consequence, project planners in the hydro sector are ill-equipped to i) incorporate climate information and all its uncertainties within a broader assessment of a project's probability of success, and ii) make intelligent modifications to the project design to reduce its vulnerabilities to failure. Given that climate science is not in the position to present a likely future of limited and reasonable range, a different approach to project assessment and decision making is needed.

2.2 The economics of adaptation

The most important impacts of climate change are likely to arise in the future. Indeed, the climate signal (the change) from climate change over the next thirty years is generally low, and it is only in the second half of the century that major changes occur.

Using the discount rates conventionally used in developing countries (12%) -or the typical internal rate of return expected on a project - future adaptation benefits in the medium term and beyond are extremely small when expressed in current terms (e.g. in present value terms). This contrasts with early adaptation actions that cost money today (such as in the over-design of hydro-electricity plants to address future climate change).

This mismatch between the timing of benefits and costs is critical from an economic perspective (OECD, 2015). It difficult to justify in economic or financial terms that major actions should be taken for changes that are decades away, especially due to the issue of uncertainty (which means that potential risks may not even occur anyway).

This is critical because it means that many adaptation options will not pass an economic cost-benefit analysis. Where public investment is funding adaptation, the limited resources available in Nepal will thus be spent elsewhere (i.e. to give more immediate societal benefits).

Similarly, in financial terms, where private investment is involved, it will make little sense for a project developer to increase project costs (and borrow more) for future adaptation to provide possible benefits in the long-term. Depending on the forms of project financing, contractors face different incentives to protect and efficiently manage their assets against future climate risks depending on whether they own them, or simply operate them. For example, under a Build Operate Own and Transfer (BOOT) arrangement, during the concession period the private company owns and operates the facility with the prime goal to recover the costs of investment and maintenance while trying to achieve higher margin on project projects. Concession agreements typically last 30-35 years, with assets being transferred to the Government where the project is located after the end of the concession period.

2.3 Iterative risk management and adaptation pathways

As a response to the challenge of uncertainty and economics, there has been a shift to consider the timing and phasing of adaptation. This has been captured in the literature through frameworks or principles. Examples include Ranger et al., (2010); Watkiss and Hunt (2011); Fankhauser et al. (2013). These shifts were captured in the IPCC 5th Assessment Report using the term 'iterative climate risk management' (IPCC, 2012: 2014) – also known as adaptation pathways (Downing, 2012).

Recent examples (DFID, 2014: Watkiss, 2014) apply these concepts to more practical decision making. They frame climate change risks starting with current climate variability and then look to future climate change, including uncertainty. The focus is on policy relevant decisions, i.e. those needed and justified (in economic terms) in the next decade, both now and in the future. Three broad types of adaptation decisions are identified for early adaptation, each with different needs in terms of economic assessment.

I. Immediate actions that address the current adaptation deficit and also build resilience for the future. This involves early capacity-building and the introduction of low- and no-regret actions as these provide immediate economic benefits. These actions are focused on existing hydro-electricity plants in Nepal but also include the wider electricity system (e.g. transmission and demand).

II. The integration of adaptation into immediate decisions or activities with long life-times, such as infrastructure or planning, which will be exposed to climate change in the future, noting the high uncertainty. This requires different tools and methods to actions above. It involves a greater focus on climate risk screening, identification of the risks of lock-in, and the identification of flexibility or robustness to deal with uncertainty. These actions are focused on the design of new hydro-plants and the system that will be built over the next 5 – 10 years.

III. Early planning for the future impacts of climate change, noting uncertainty. This includes a focus on adaptive management, the value of information and future options/ learning, especially when decision life-times are long or future risks are very large or irreversible. This is focused on early actions to help inform the future hydro-electricity sector, i.e. to help improve future decisions,particularly around enhanced monitoring and research..

The three categories can be considered together in an integrated adaptation strategy or an adaptation pathway. This approach has been adopted in this study.

2.4 Integration with the Climate Risk Assessment Method

The Climate Risk Assessment method used in the study follows the same type of thinking as the adaptation pathways approach, and therefore aligns to the overall analysis.

The CRA method proposed for the study does not follow a 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 Climate Risk Assessment (CRA) methodology based on a "bottom up" decision-scaling approach. This starts with assessing the sensitivity of the performance of Nepal's present and future hydropower systems to future climate changes ("stress test") and then assesses how likely climate changes are that could significantly impact the systems' performance.

The Climate Risk Assessment (CRA) methodology focuses primarily on identifying potential climate hazards to infrastructure through the analysis of the sensitivity to changes in river runoff of performance indicators significant for hydro-energy generation. The reason is to first put the emphasis on understanding the present meteorological and hydrological variability, the current water resources and hydro-energy generation systems, the planned investments and their sensitivity to climate variations. This starting point on the current aligns to the adaptation pathways approach above.The key advantage is that decision-scaling focuses on those futures for which a project has demonstrated vulnerabilities, reducing the level of effort.

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. It makes the best use of the available climate information, which is typically highly uncertain, and focuses on key areas that are likely to be of high relevance for policy. Available climate projections generally demonstrate a large uncertainty in individual climate projections and it is thus important to consider all available GCM projections, rather than building this CRA on the projections of only a few selected GCMs and RCMs. Also, climate models (including RCMs) which performed well for the present climate conditions do not necessarily give the same good performance for future conditions. It has been observed that GCMs performing equally well for the present climate may provide very different projections for the future. Multi-model ensembles are thus found to be the appropriate approach for assessing the impacts of climate change on water resources. This helps reducing the effects of model errors in one particular model and effects of the natural variability in any particular run. 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. This consideration of future uncertainty also aligns to the adaptation pathway approach.

2.5 Policy Integration and mainstreaming

Most of the earlier literature on adaptation on the economics of adaptation - including in the hydro-electricity sector – have used scenario-based ‘impact assessment’ (see UNFCCC, 2009). Such studies adopt a logical, scientific and sequential approach, starting with future socio-economic scenarios and climate model projections, then assessing future impacts and costs from climate change. The analysis of adaptation is then considered as the final step in this chain, with the potential consideration of costs and benefits, and even an analysis of the optimal response. Such an approach has been termed a science-first approach (Ranger et al, 2010: Wilby, 2012).

However, there is a considerable literature (e.g. Füssel and Klein, 2006; Ranger et al; 2010; Watkiss and Hunt, 2011) that identifies problems with this classic approach, especially for informing policy makers. This is because:

- The studies have insufficient consideration of immediate and short term time-scales of relevance for early adaptation,
- They do not consider wider (non-climatic) drivers and existing policy - including baseline policies and programmes of relevance to current and future climate risks;
- They focus on a narrow set of technical (engineering) adaptation responses, excluding the diversity of adaptation options;

- They ignore the factors determining the adaptation process itself, including socio-institutional policy context, actors and governance.

A conclusion is that such studies, on their own, do not provide the necessary information for practical- and policy orientated adaptation, i.e. for early implementations such as the focus of this project. This is particularly a problem for adaptation in developing countries, where the focus is on the short-term, the wider non-climatic drivers usually dominate, and the policy context is critical for successful implementation.

As a result, more policy-orientated studies put more focus on adaptation as the objective, rather than considering it at the end of a classic science-first, impact-assessment study. This shift, where the study objective is considered from the perspective of informing adaptation – has been termed a 'policy-first' or decision-first approach (Ranger et al., 2010). Critically, this requires a greater understanding of current drivers, non-climate policy and existing adaptation. This focus on a policy first approach also aligns with the CRA method, which assesses what is important for hydro-electricity.

A second shift, particularly at national level is towards mainstreaming adaptation. The recent National Adaptation Plan (NAPs) guidance recommends the mainstream of adaptation (LDC expert group, 2012).

While there is still no formal definition of mainstreaming (in the IPCC), the term is used interchangeably with 'integration', i.e. the integration of adaptation into existing policies and decision-making, rather than through implementation of standalone adaptation policies, plans or measures. The focus on mainstreaming is synergistic with the policy-first approach outlined above, in that it considers existing policy and objectives, non-climate drivers, multiple objectives and ancillary costs and benefits. It also puts greater emphasis on understanding the context for an intervention and the current decision-making process.

A critical step for mainstreaming is to find relevant entry points (UNDP, 2011), that is, opportunities in the national, sector or project planning process where climate considerations can best be integrated. Critically, these will differ with each adaptation problem. This makes it is essential to understand and integrate adaptation within the existing socio-institutional landscape, especially as adaptation will be one of many policy objectives, and not necessarily the dominant one.

Mainstreaming also requires a good understanding of the individual organisations, networks and processes for making relevant decisions, recognising these will differ with sector and application.

A key part of the adaptation pathways approach is therefore to consider a policy-first (or decision first) approach and to identify entry points for mainstreaming.

3 Adaptation Pathway Analysis

3.1 Identification of climate risks

The study inception report identified the key issues for the hydropower sector, both for the current risks of climate variability and the future risks of climate change. These were summarised as:

- The current impact of runoff variability on run-of-river plants during the dry season, and associated load shedding, and continued or increased risks under climate change.
- The impact of current and future climate variability on the hydropower system development
- The current risks of damage from floods during the monsoon period, and the potentially high increases in peak flows under climate change.
- The existing problems of sediment deposition and high sediment concentration, due to soil erosion from heavy rainfall and flooding, and its potential increase under climate change.
- The current and future risks of damage from Glacial Lake Outburst Floods (GLOFs).
- The effects of climate change on the cryosphere and snow and glacial melting, affecting the timing and quantity of river flows, and how these might change under future warming.
- The sensitivity and vulnerability of hydro-energy generation and infrastructure of existing, under construction and planned hydropower systems in the context of future climate change.
- The effects of climate change on electricity demand, both in Nepal and India (as a key export market).

More detail on these risks are given in the vulnerability report. What is clear is that these have potential to affect hydropower plant and system development and performance, as well as wider aspects in relation to load shedding and the mismatch between demand and generation of hydro-energy. There are also important issues on risks and safety. For the adaptation analysis, the aspects above can be summarised in terms of the table below.

Effectively there are three main climate-induced risk categories affecting hydropower generation: revenue loss, safety, and sedimentation. Power plants designers, owners, and operators will adapt to reduce such risks if the benefits of doing so are higher than the costs; and typically if the incentives of adapting are built into contracts and legal obligations.

Potential risks of climate change on hydro-electricity

Potential climate change	**Impact**
Increases in intense precipitation events, and extreme events (floods)	• Possible increase in generation • Increase sediment and debris may block dam spillways, damage important structural components (turbines), or reduce live storage (and power generation) in the medium- and long-term. • Extreme flood volumes may exceed dam design limitations, over-topping dam walls and increasing the risk of structural failure. • Extreme floods storms may force dams to release water to prevent over-topping, resulting in highly destructive downstream floods and water surges.
Changes in seasonal precipitation patterns	• "Run-of-river" dams can experience a direct reduction in hydropower production in response to reduced dry season discharge; and for these facilities, "excess" inflows would be spilled without added energy production. • Large reservoir systems have the capacity to store inflows and are less affected as they provide some buffering against increasing variability of annual inflows.
High temperatures and extreme events (droughts)	• Reduce the amount of water available (river discharge, reservoir storage volume) to produce electricity. Run-of-river facilities are particularly vulnerable. • Firm power contracts for electricity sales from hydropower plants typically assume that production targets will be met 95-98% of the time. Power shortfalls due to recurrent drought would significantly undermine such contractual obligations. • Trade-off between alternative water usages (agriculture vs power) put higher pressure on generation • Change in soil moisture during dry/wet season impacts on runoff • Evaporisation, reducing the volume and elevation of water available for electricity generation in all types of dams.

In these cases, they will take action with the objective:

- To maintain the project/system performance (e.g. GWh produced, storage capacity);
- To ensure the project/system's safety, and safety of the population ;
- To manage water resources efficiently (e.g. water management plans that take into account the alternative use of water for irrigation/drinking purposes; and environmental considerations).

3.2 Previous adaptation assessments

Many previous studies have simply assumed that the best way to address the risks above is to over-design plants, using information from climate projections to adjust current design criteria, for example, increasing spillway dimensions to take account of future higher flood events. However, such studies rarely consider the economic and financial implications of such actions. Increasing the costs of design (and the cost of capital) incurs a large additional cost today, which must be borne by the investor or public finances, and this will affect the rate of return of the project. The problem is exacerbated by the high uncertainty with future climate change, and the question of exactly how much over-design to build in.

Traditionally, dam and reservoir design relies heavily upon historic observations of rainfall and temperatures. However, as acknowledge by the ICOLD Committee on Global Climate Change and Dams, Reservoirs and the Related Water Resources[1], the hydro community is beginning to realize that climate change may challenge this strategy: past records are not comprehensive enough for accurate analysis of future conditions (ICOLD, 2010), i.e. the past is no longer a good predictor for the future.

There is a range of tools available to mainstream climate change risk into hydropower design. Most developers continue to use historical trends and work with some optimistic and pessimistic scenarios based on those trends *('What if'* scenario). No probability is associated with these scenarios. However, some designers integrate their analysis with supplementary information readily available and of relatively easy interpretation. For example, the World Bank Climate Change Knowledge Portal is a central hub of information, data and reports about climate change around the world.

ICOLD (2010) describes two additional types of risk assessment methods that can be used to model future climate risks: the use of deterministic scenarios based on GCM outputs; and the use of probabilistic scenarios – also based on GCM outputs – which use probability density functions for air temperature and precipitations, and use them together with response functions of water resources to climatic variations. Although less used amongst project designers, these two methods have found some applications in academic and scientific studies.

Maass et al. (1962) use classical decision rules and payoff matrix (e.g. maximin and minimax regret) to water resources planning; and Byer et al. (2012) show how the same methods can be applied to decision making on hydropower development.

Methods such as robust decision making (RDM) under uncertainty, real option analysis (ROA), and adaptive management have been used in the literature to show the advantages of flexible and dynamic decision making in dealing with climate change uncertainty, also in the context of hydropower design and planning (see Nassopoulos et al. 2013; Hallegatte et al., 2012; Mittal, 2004; Byers et al., 2011; Jeuland and Dale Whittington, 2014).

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[1] In 2008, the International Commission on Large Dams (ICOLD) created the Committee on Global Climate Change and Dams, Reservoirs and the Associated Water Resources in order to demonstrate the seriousness with which ICOLD approaches climate change and its effects on water resources. The Committee was formally constituted a year later in Brasilia, where its founding meeting took place with the mission to provide technical support to the international dam community by developing guidelines that support international climate change recommendations.

These methods allow for the decision making to incorporate attitudes toward risks and uncertainties and assumptions, at least implicitly, about the likelihood of future scenarios. With real option analysis, for example, flexibility can be built into the design to adjust to changing circumstances (Byer et al. 2012). The adoption of these decision-making tools could help hydro plants planners and designers incorporate climate change into investment decisions.

However, these examples are currently highly academic in nature. Moreover, the difference in methods often leads to different results.

For example, as part of the World Bank's Enhancing the Climate Resilience of Africa's Infrastructure (ECRAI) project, Cervigni et al. (2015) simulated the economic performance of hydro infrastructure[2] in dry and wet scenarios, and found that dry scenarios would lead to revenue losses in the order of 10% to 60% of baseline values, with Zambezi, Senegal and Nile (equatorial lakes region) basins most affected. Wet scenarios resulted in potential revenue increase in the order of 20% to 90% (with Volta, Niger and Eastern Nile as the basin with larger gains). The findings of the ECRAI report show that the effects on individual countries tend to be much larger than power pool average: the dry scenario potential losses in Malawi, Burundi and Sierra Leone, is estimated to be as large as three, two and one half halftimes larger than the no-climate change baseline. Other vulnerable countries include in Eastern Africa, Ethiopia (40% increase); and in Western Africa Guinea and Mali, which are in the 40% to 60% range of increase. However, as explained by the authors, gains are only be potential and could not materialise since the option of dispatching excess energy to the market might not be foreseen in the power trading agreements. Conversely, losses under dry scenarios might well materialise, as energy that is not produced through hydro will need to be made up typically through more expensive power sources such as diesel generators.

Interestingly, the study also showed that in some cases the benefits and revenues of hydro projects are so high that even in extreme future climates the risk of the project being economically unfeasible (negative NPV) is low. This is because variables/assumptions such as price and demand for power or water have a stronger effect on net returns than climate variations. Nevertheless, the ECRAI study also found that the maximum regret risk faced by project developers when using existing design can be cut by 30% or more by modifying selected design parameters in anticipation of climate change.

Cole et al. (2014) estimated how well matched the current plans for dam building appear to be with predictions of river flow over time under two different climate change scenarios, one under large and one under small warming. The authors found that dam building is fairly well matched with river-flow predictions. However, predictions of an increase in extreme events and reduced rainfall for certain countries mean that there are still viability concerns for certain planned hydropower investments. For example, countries such as Nigeria and Uganda are found to be likely to experience large increase in the variance of rainfall, with years of plentiful rainfall and years of possible drought (Cole et al. 2014).

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[2] The study includes seven major river basins (the Nile, Niger, Volta, Senegal, Congo, Zambezi, and Upper Orange), and four power pools (Eastern, Western, Southern, and Central African Power Pools).

Sediments reduce the (live) storage capacity of reservoirs, and damage turbines. Sediments management is already a challenge for project developers and climate change may exacerbate sedimentation issues even further. Lempiere (2006) states that a reduction of storage of 0.3% per year means a reduction of power of much less than 0.1% of production, or less than 10% in a century. According to the ICOLD Bulletin on Sedimentation (2009) globally there is an average sedimentation rate of 0.8% per year and a weighted average sedimentation rate of 0.7% per year.

3.3 Adaptation options

The focus of this study – and the use of adaptation pathways – is to allow consideration of the more advanced decision making under uncertainty approaches within a real policy environment. The pathways approach offers flexibility, in that it can consider whether flexibility or robustness might be appropriate for new plants – and can then further use different decision-support approaches to analysis analytically. However, the key issue is to frame the overall analysis to allow these various approaches. The study has therefore assessed potential adaptation options with the overall adaptation pathways approach in mind, and considered flexible and robust options, as well as more conventional approaches.

The study has started with a review of potential adaptation options to address the key climate variability and future climate change risks.

Risk 1. Loss of Revenues

Revenue generation is potentially reduced by low stream flows, and during periods of drought. The impacts will vary depending on the type of hydro plant considered: for example, losses will be more significant for run of the river plants vs. storage plants – as the latter are able to store water and provide some buffering to flows variability. However, some projects have multiple purposes and 'competing' water users. For example, if a dam is used for irrigation and hydropower, during large draught periods government authorities may prioritise the use of water for irrigation purposes and require dam operators to lower reservoir levels, in some cases below the minimum level that allows the operation of the turbines. Loss of generation can also be an effect of evaporation and evapotranspiration phenoma, which can affect storage plants generation capacity. Finally, revenue loss may also incur when dealing with sedimentation and safety issues, which are operations that require stopping the plant for a certain period of time (as explained further below).

In storage reservoirs, one engineering (hard) measure to minimize the impacts of lower stream flows can be the increase of the reservoir storage capacity. Besides the raising of dams, a good solution to increase the reservoir storage is to install fusegates on the sill of existing spillways, allowing an increase to the normal water level while maintaining the dam's safety level[3]. Fusegates may be included in the design and construction of new dams or integrated into existing dams. They also make the dam more secure by enhancing its

[3] Fusegates are essentially a technical method to increase the maximum water level without structural dam heightening. They increase spillway capacity without sacrificing existing reservoir storage. In fusegates system, gates are placed side-by-side to fill in the original spillway width. In case of normal floods, they act as a free-sill spillway.

capacity to discharge major floods and by providing support in case of human or technical error resulting in gate malfunction.

Another possible solution to face lower stream flows at a certain site is to divert some flows from an adjacent watershed into the reservoir. This involves the construction of diversion and water conveyance structures, hence requiring higher capital costs, with potentially significant environmental impacts.

Soft measures include improving weather forecasts systems to optimise the reservoir operations; improving cooperation between different plants particularly if the operate in a cascade fashion in the same basin; and enhance interconnection between different (e.g. regional) systems to allow for transfer of energy in the case for example of draught. The latter would require great institutional will, capacity, and coordination between the relevant institutions.

Higher rainfall might also increase generation capacity, if surplus water is not spilled but contribute to energy production. Adaptation in this case might entail reducing the flows spilled through the spillway; or in some case repowering the plant with bigger turbines.

Risk 2. Safety

Extreme rainfall/run-off or change in flood return period and peak intensity may exceed dam design limitations, over-topping dam walls and increasing the risk of structural failure. Heavy precipitations can cause flood events, which lead to damage costs (repair costs and loss of generation revenues during repair), major catastrophic events with loss of assets and damage for downstream population, and wider economic costs for lost load.

In the design of overflow structures of new and existing dams some allowance is considered to deal with extreme precipitation events. Spillways are structures that either form part of a dam, or are found just beside one; and they are used, when a reservoir is full, to pass floodwater safely, and in a controlled way, over a dam, around it or through it.

The overflow capacity of existing dams can be increased through raising the dam crest, and/or the construction of auxiliary spillways, or through changes on the existing spillways to increase their discharge capacity. As mentioned above, a cost-effective solution to increase the discharge capacity of reservoirs is to install gates, fusegates, or fuse plugs, which allow to keep the same full supply level or even to raise it. Compared to the alternative of widening existing spillways, the installation of fuse gates reduces significantly the amount of excavation works, and has a lower environmental impact

Structural changes to increase discharge capacity might be costly, though oftentimes they are mandatory to reduce the public risk related to a dam failure in the event of extreme floods. As a matter of fact, many dams designed in the past were designed to stand lower flood standards than current levels, and therefore have now upgraded their standard to meet new safety regulations. When engineering upgrades are not mandatory or needed, non-structural alternatives could include reducing reservoir levels before the heavy rain/flood season (although this might result in generation losses), or introducing periodic and mandatory safety reviews (low regret). For example, in order to increase safety, during floods, authorities may ask operators to lower the normal reservoir level to keep free some reservoir volumes for flooding and ensure downstream protection. Lower reservoir level means lower heads and therefore less energy generated.

For dams under design, adaptation could entail allowing space in the design for future increase in spillway capacity, and introducing or improving warning systems for water triggered landslides and floods (low regret). For long-term planning, watershed monitoring and data collection could be undertaken with a view to improving information to inform future investment decision (the value of information).

Risk 3. Sedimentation

Increase sediment and debris may block dam spillways, damage important structural components (turbines), or reduce live storage (and power generation[4]) in the medium- and long-term. Most of the dams have been designed with a design life approach, i.e. by assuming that after a certain period that structure is replaced, and in a lot of these projects no measures to deal with sedimentation were properly implemented. Only by adopting a life cycle approach, do designers take into account the long term sustainability of reservoirs subject to sedimentation[5].

Sediment management is an issue already common to many dam operators under the existing climate, and will be exacerbated by future climate change. In many developing countries, the progressive deforestation and cultivation of steep slopes is the only survival option for the rural poor, and about 10% of the world's population cultivates steeply sloping soils. Other man-made activities upstream the reservoir and in the catchment area (e.g. mining) increase the amount of debris in rivers. These increase soil erosion and sediments. Watershed management measures involving local communities are considered useful, but alone are insufficient to solve the issue, and often are difficult to implement as they require great institutional effort.

Reservoir sedimentation is not a simple problem with easy solutions. Measures to deal with sediments increase the initial costs of a project (e.g. for the construction of larger outlets, diversion tunnels, check dams); and sediment management measures adopted during operation in most cases reduce the energy output by imposing a non-operation period to deal with sediments. The following diagram shows possible measures that can be considered to deal with reservoir sedimentation.

All these measures can be retrofitted. However, retrofitting comes at a higher cost than building them into the design of the dam. Generally, solutions that imply works on the dam and reservoir, like bypass tunnels or dam heightening, tend to be more expensive if built later on in the life of the plant, or if their late construction was not initially foreseen. The difference in costs is related with the site installations (e.g. mobilization/ demobilization, temporary roads), river diversion during works, and loss of revenues during the non-operation periods required for the completion of the works.

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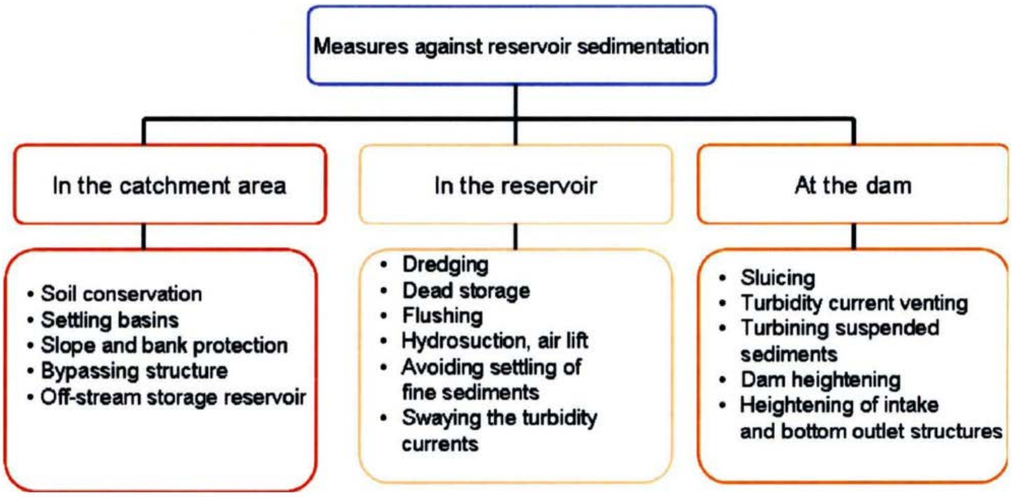
[4] Loss of reservoir capacity does not reduce the energy generation in the same proportion. A reduction of storage of 0.3 percent per year means a reduction of power of much less than 0.1 percent of production.(In 2009 ICOLD Bulletin Sedimentation and Sustainable Use of Reservoirs and River Systems).

[5] With a design life approach the sediments are stored in the reservoir until will be completely full. With a life cycle approach the sediments are not stored in the reservoir and therefore can last much longer.



(Schleiss and Oehy, 2002)

If located outside the reservoir, measures can be more easily built after dam completion (e.g. check dams, debris basins or reservoirs upstream to trap eroded sediments). However, these measures have high costs (civil works and land acquisition), and require maintenance. When structures are in the reservoir area, it is cheaper to build them as part of the same building contract as that of the dam. Even though it is difficult to give an estimate with certainty – mainly because every project is different - engineers believe that sediment structures in the reservoir area could cost double if retrofitted after dam construction rather than built within the same contract as the main dam.

Measures such as dredging and hydrosuction have high costs - up 10 €/m^3 – and are generally considered as a last resort. Operators may find cost effective to undertake localised interventions to keep the area surrounding the power intake clear and allow maintaining power generation during the operations.

Some of the techniques to bypass sediments through the reservoir imply the loss of water for energy production and sometimes also the reservoir draw down. Flushing operations, for example, require emptying the reservoir for a few days (2-3 days) and the replenishment may take up to 3 weeks, with a consequent loss of revenues for the time the turbines are not in operation. It has been estimated that loss of revenues equates approximately 5% of the power generated annually. It should be noted that this technique is adopted if the reservoir capacity/mean annual runoff is less than 0.2, which is currently a problem for less than 25% of the dams in the world (ICOLD 2009).

Soft measures include changing operating rules to allow sediments to pass through the dam, though this solution might impose lower water levels and therefore reduce energy production. However it would prolong the useful life of the reservoir in the long-term. For log-term planning, sediments monitoring will be important to gather information for future plants.

3.4 Analysis of adaptation pathways

The options above have been considered in terms of the adaptation pathways approach, and the timing and phasing of adaptation. This follows the framework set out in the table below.

Adaptation Pathways for Hydro-electricity

Timing of risk	Type of plant	Timing of adaptation	Costs and benefits
Type i) Current climate	Current plant	Do now	Ideally identify low regret options
Type ii) Future with climate change, e.g. 2030	Existing plant	Retrofit later	As above, noting the need for investment in information to allow effective redesign (VoI)
	Plant being built in next 5- 10 years	Change design to take account	Trade-off future benefits versus early costs
		Include flexibility in design	Trade-off future benefits versus early costs.
Type iii) Future climate change 2020 -2050	System design and plants to be future> 10 years	What do now to help improve decisions in 10 years	Value of information (VoI)

The table below maps a range of adaptation measures against the iterative framework.

A more detailed analysis of these options, and the potential costs and benefits, is set out in Appendix 1.

Analysis of adaptation options mapped against the iterative adaptation pathways approach

	Climate Risk/Timing	**Issues**	**Soft measures**	**Hard measures**
Existing Plants	Existing climate variability (now), plus early climate trends over next decade or two.	High cost of retrofit Operational flexibility needed This is reactive adaptation hence all strategies are likely to be no-regret options that deliver benefits now and against early risks	• Enhanced monitoring (also community-based) • Insurance and other financial instruments • Soil and water conservation programs to improve reservoir management • Slopes stability monitoring • Run turbines at lower/higher capacity in the case of increased/decreased precipitation; or for less/more hours if the reservoir can provide some storage • Insurance • Use of district royalties to regions and districts to improve monitoring, install warning systems • Demand-side management ($benefits from reduced peak and loss of load) • Reservoir management • Weather forecast systems to optimise reservoir operations	• Increasing storage: dam heightening or increasing the full supply level (e.g. through installation of fuse gates) • New auxiliary spillways or increase of the capacity of the existing ones, if confirmed climate changes may lead to larger flows • Removing sediments to increase reservoir capacity (dredging, flushing) and improve sediment management (build sediment trapping structures, and sediment routing structures) • Retrofit of turbines before end of turbine lifetime (40 years) if damaged by sediments or to respond to higher flows. • Strengthen transmission lines to improve resilience to load fluctuations, and reduce risk of disruption (e.g. using barriers to protect from landslides) • Interconnection of energy systems within the same country and across regions to build resilience
Planned schemes currently at scoping/ design	Future changes (>2030). Potential for changes in generation (kWh) and revenues, but also risks of low flow and security of supply/risks of damage from high flows o	Risks occur towards the end of economic lifetime of plant. Discounted and uncertain future benefits (>2030) versus costs today. High uncertainty on future changes.	• Improve understanding of current adaptive gaps and system performance under current climate (no regret) • Awareness campaigns, e.g. on risk of floods, to improve disaster risk-preparedness (no regret) • Develop integrated water management plans (no regret) • Investigate options for diversifying energy mix: risk diversification, e.g. different balance of RoR and storage, micro versus large hydro; solar and hydro. • Improve data collection (low regret): site screening to	• Climate risk screening • Consider different alternative for design, i.e. pumped storage plants • Low-cost incremental over-design, e.g. extra design contingency for high flows, increase flood storage capability • Robustness: • Consider number/size of turbines that perform well across a range of streamflow scenarios (high

			reduce extreme risks • Adopting a river basin approach with respect to monitoring climate risks • Promote cooperation between different plants operating in a cascade fashion (low regret) • Smart licensing along the river basin to account for cascade effects • Develop guidelines for developers on what climatic info should be used for EIA, minimum environmental flows etc. • Monitor extreme flows and develop warning systems for water-triggered landslides/floods • Payments for ecosystem services to improve watershed management upstream • Periodic and mandatory safety review (low regret) • Changes in maintenance regime to address drying out of reservoir basins and embankment structures • Reducing reservoir levels before non-flood seasons (non-structural option) • Wide consultation during EIA • Insurance • Environmental and social safeguards (i.e. requirement applying to EIA, minimum environmental flows) • PPA and concession agreement requirements	cost) • Consider parallel outlet tunnels in the design phase (to deal with sediments) • Consider options for conjunctive ground surface water storage (high cost) • Flexibility: • Plan for dam raising and create buffer zones around the reservoir limiting land use to allow dam raising in the future • Plan for supplementary spillway capacity • Plan for additional spillways and by-pass tunnels
Future potential plants that will be needed on system (2020 to 2050)	Major non-marginal changes in flows or major systematic shifts in risk by 2050, e.g. transformation rainfall, ENSO shifts	Unlikely to be addressed through BAU. Very high costs, but very high uncertainty, risk of major costs for impacts that do not happen.	• Iterative plans: • Maintain and/or create monitoring systems of the watershed (weather an gauge stations) • Enhanced monitoring schemes to track changes in risks (e.g. monitoring GLOF, R&D) • Portfolios of options/plant changes linked to key performance thresholds or limits.	• System mix of future plant (type and size):

4 Consideration in Nepal context and policy

4.1 Key issues for Nepal

The previous chapter set out the general aspects in applying the adaptation pathways. This chapter considers the practical application to Nepal.

Nepal's electricity generation relies mostly on the run-of-river type hydro power plants, and a particularly issue is that during the dry season, Nepal is currently unable to produce sufficient energy to meet its demand. Low river flows and low installed (peaking) capacity lead to planned rolling blackouts (often referred to as 'load shedding' in Nepal) and this has a high cost of lost load. Further outages can be exacerbated in low rainfall years, primarily in the dry season, but also because of the variability of the monsoon and the consequent filling-upof reservoirs, such as the Kulekhani reservoir.

Earlier studies (USAID-SARI, 2003) have highlighted the high economic costs of the poor quality of electricity delivery in Nepal. This study reported that approximately 8% of the industrial sector demand was not met due to planned and unplanned interruptions, and that the industrial sector losses in Nepal attributable to unplanned interruptions averaged at 0.49 US$/kWh and 0.14 US$/kWh for planned outages. The outages were estimated to lead to an economic loss in Nepal's industrial sector amounting to US$ 24.7 million a year, which was equivalent to 4.4% of the industrial sector GDP or 0.5% of national GDP in 2001. Recent analysis has also highlighted that these issues continue (Shrestha, 2010) and have macro-economic impacts on the country.Power outages are likely to continue for the next 3-4 years (NEA, 2012), as demand is projected to exceed supply, and during the dry season planned interruptions ('load shedding')is projected at 12-14 hours per day per consumer.

There are also some risks from extreme events. Hydro-electric plants are also subject to the risks of floods including the risks from Glacial Lake Outburst Floods (GLOFs). Indeed, there was the loss of a multi-million dollar hydro-power facility (which had capital cost of approximately NPR 45 million) in 1985 due to a GLOF event (OECD, 2003) and more recent loss ofmicro-hydro plants from floods (Paudyal, 2011).

Rivers in Nepal are known for their high sediment loads. In ROR projects, high sediment concentrations in the rivers result in abrasion of turbine runners, higher maintenance cost and higher generation losses due to plant shut down. Abrasion of turbines leads to a reduction in turbine generation efficiency which in effect means less energy generation at the same discharge and head. In storage type projects, annual sediment deposits reduce the capacity of the reservoirs resulting in less live storage for seasonal regulation, leading to reduced lean season energy generation.It has been reported that sediment concentrations as high as 24,400 PPM passed through the turbines of Jhimruk Hydropower Plant (owned by the Butwal Power Company) in a single event on July 31, 1996. The cost of its damage was estimated to be about ten times the generated revenue (WECS, 2011). Nepal's only reservoir project Kulekhani lost more than 25% of its total capacity (1982- 2004). Kali Gandaki A has lost about 50% of its pondage capacity in 10 years of operation. All three turbines of Kali Gandaki were replaced after the first few years of operation due to wear and tear of the turbines due to high sediment loads. Most ROR plants are facing severe problems of sediment-induced wear and tear after a few years of operation.

These issues highlight the high importance of addressing current risks, and therefore the high economic benefits of addressing the adaptation deficit.

High priority should thus be given to the monitoring of the present status of the country's water resources, current runoff trends, minimum flows and similar metrics. Actual precipitation (and runoff) data are required for more enhanced and more accurate future analyses of rainfall – runoff relationships and hydrological modelling. Therefore, it is recommended to revive, upgrade and expand existing hydro-meteorological networks in Nepal, with particular emphasis on the collection of runoff data. Equal priority should be given to the preparation of a comprehensive and nation-wide data base of already available hydro-meteorological data. Thus, in support of the development of the hydro-sector, and other sectors such as agriculture, there is an urgent need to develop and operationalize a comprehensive Hydrological or Water Information System (HIS/WIS) for Nepal.

Looking forward, the previous CDKN funded study (IDS, 2014) looked at the future impacts of climate change on hydroelectric power and combined hydrological model runs with a hydro-electricity optimisation system (VALORAGUA and WASP), to consider the changes in river flows and energy generated. There were large differences found in the projections of different climate models and the study, therefore, compared two different data sets. The first model projected lower dry season flows and lower energy availability. The additional capacity needed to meet future demand under this scenario (2800 MW by 2050) was estimated at an additional generation expansion costs of US$2.6 billion (present value) for the period through to 2050. This scenario also leads to an increased level of thermal plantsin the system, with increasing GHG emissions. However, the second model, which projected higher river flows in the dry and wet seasons, led to increased energy availability and avoided the need for additional plants, thus leading to a reduction of generation expansion costs of -US$170 million (present value) over the period to 2050 compared to the baseline (i.e. a benefit).The findings indicate that climate change could potentially have a major impact on future generation and investment, but the uncertainty necessitates an iterative response. These highlight the potential costs of climate change could be large.

The study above focused on generation. There are, however, additional risks to hydro-electricity generation in Nepal from increased high flows (i.e. from increased heavy precipitation during the monsoon) and the risks of damage to hydro-electricity plants from floods. Heavy precipitation and increased soil erosion can result in higher sediment flows in the river, which can reduce the lifetime of storage projects. It can also damage run-of-river projects, as the desanding basins (sediment traps) provided to control the sedimentation may not be able to control the sediment flow passing through, leading to increased wear and tear of the turbine blades. This results in not only increased down-time for more frequent maintenance but also reduction in turbine generation efficiency, leading in turn to lower energy generation for the same discharge and head.There are limited quantitative assessments of the future impacts of GLOFS. However, some planned projects are located near the headwater regions of the Himalayas and several of the projects include reservoirs. Consequently, their vulnerability to GLOFs is likely to increase significantly (Matambo and Shrestha, 2011).

These provide key future issues of focus.

There are also other studies that are advancing work in this area, and it will be important to link to these. The World Bank funded "Building Resilience to Climate-Related Hazards Project (BRCH)" is undertaking technical modernization of hydrological networks (74 hydrological stations). These include, among other activities, installation of weather radar, upgrading and expansion of automated weather stations for aviation safety (total 100 stations), surface meteorological and lightning detection networks, glacier and snow monitoring and establishment of a calibration facility

The World Bank is also funding Technical Assistance for a “Programmatic Approach (PA) to Impacts of Climate Risks on Water, Hydropower and Dams in Nepal”, which focuses on a case study for the Upper Arun Hydropower Facility. The main objective of the PA is to assess various scientific methods of screening climate change and disaster risks and methods of integrating appropriate resilience measures in water, hydropower and dam investment projects. Whereas this PA study focuses on the Upper Arun basin as a case study, and our present study will cover the entire hydropower sector and all river basins of Nepal, the importance of a close coordination between both interventions is evident. This includes analysis (activity 1) of Investment Decision Making under Deep Uncertainties.

The inception and vulnerable reports have mapped out the current hydro-electric plants in Nepal, the near-term planned plants under construction or in planning, and the potential long-term expansion plans. These align to the different phases of adaptation in the pathways approach.

4.2 Mainstreaming and entry points

The important aspect of this study is to mainstream (i.e. to integrate) adaptation into the hydroelectricity sector of Nepal. As well as raising awareness and building capacity, the study is investigating the entry points for mainstreaming relevant institutional issues.

In the inception phase, the team carried out an institutional analysis and reviewed the regulatory framework regulating the sector with a view to understanding the roles and responsibilities of different actors in hydropower development, their exposure to climate change impacts, the various mechanisms through which they do or could support adaptation, and their influence. During the first phase of consultation the team also started gathering information regarding different stakeholders’ needs with respect to climate change adaptation, and their interest and attitude towards this study more generally. As the work on adaptation pathways is progressed, we will look for ways to integrate into policy.

It is envisaged that this will be through national and sector development planning. Consideration will be given to the national planning process (led by National Planning Commission (NPC)) and sector energy policies and plans currently under revision (led by the Ministry of Energy). The study will also consider entry points provided by cross-cutting climate policies and measures led by the Ministry of Science, Technology and Environment (MoSTE).

However, for the hydro sector, there are additional key stakeholders involved – and additional entry points - associated with the financing of hydro development (e.g.International Financial Institutes (IFI), development partners), whether public (large-scale) or increasingly with the private sector. The Investment Board Nepal (IBN) dealing with larger hydropower plants (above 500 MW) will be another key stakeholder. The involvement of these other stakeholders involves additional policy relevant entry points, for example through the climate safeguard systems of the lenders, through the process of strategic environmental assessment (policy) or environmental impact assessment (projects), and through contractual agreement template (PDA).

At the project level, there will be entry points for mainstreaming recommendations into new hydro-plant design. This could be through guidance for design or as part of environmental impact assessment, whether for large or small hydro. The relevant entry points for this will be explored to ensure that any guidance made can be influential to decisions.

Finally, across all these issues, there are important barriers to adaptation. These were summarized in the inception report and will be further investigated as the policy work advances.

5 Linking to the Vulnerability Assessment

This report sets out the initial mapping of adaptation pathways for hydro-electricity. This provides the basic information for the analysis of adaptation in the study, and notably the use of the vulnerability report to progress.

5.1 Results of the vulnerability assessment

The results of the vulnerability assessment have been considered, based around the adaptation pathways approach.

First, the vulnerability report confirms the key performance indicators of concern to the government and private sector as:

i. Dry season and annual energy generation, its variability and reliability

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 induced hazards and its management such as GLOFs, landslides

vii. Basin level plans and "appropriate" sizing such as installed capacity, reservoir live storage.

It also provides information of relevance across the three building blocks of the adaptation pathways approach, outlined below.

Current climate variability

The existing and planned hydropower projects in Nepal are of three types, (i) pure run-of-river (ROR) hydropower projects (with no storage capacity) that generate energy with the instantaneously available flow up to the maximum available generation capacity (installed), (iii) peaking ROR projects that have a small pondage capacity that can be used to generate peaking power during the dry season for some hours in a day and (iii) storage projects with reservoirs that can store monsoon flows and regulate to generate higher energy in the dry season.

However, most hydropower plants in Nepal are run-of-river (R-o-R) installations and are thus severely affected by the existing seasonal variations in river flows. While much of the hydropower potential of the country remains as yet undeveloped, insufficient generation capacity during the winter season leads to frequent load shedding and high associated economic costs from unmet electricity demands. Hence, Nepal's current hydropower system is ill-prepared to even address the current variability of flows, let alone the any hydrological changes due to climate change.

Most RoR projects generate to the full capacity in the monsoon months and any excess water cannot be utilized. The live storage capacities of the seasonal storage projects are also much less than the average annual flows or even the average monsoon (June - September) flows. The current electricity tariff offered by the electricity utility to private developers are about two times higher in the four dry seasons months of mid Dec to mid-Apr than in the other eight months of the year. These mean that any changes in the total annual flows which is mostly monsoon flows (about 75-80% of annual flows are in four monsoon months) is less important than the changes in the dry season months.

This highlights there is a major adaptation deficit currently, and immediate adaptation options to address the current deficit through a mixture of supply and demand measures is warranted.

Near-term design

Globally, a warmer world is projected to bring more precipitation, and the consensus projection indicates that this will also happen in Nepal. Most models project a wetter (and hotter) future (2040-2059) for Nepal. All models agree on a much warmer future (2040-2059), mostly in the range of 2 0C to 3 0C, depending on the location and RCP scenario.

In case of monsoon months, projection for increase in precipitation is clear in both scenarios RCP 4.5 and RCP 8.5 for all regions and it is 7-11% and 9-15% respectively for upper regions. In case of winter months, there is decrease in change in mean precipitation from 5.11% to 0.03% expect for region 6 in RCP 4.5 scenario and from 4% to 6.5% in RCP 8.5 scenario. In absolute terms projected precipitation changes for the low flow season are minimal, but overall 85% of the projections show a significant increase in monsoon rainfall.

The storage projects (one existing and 16 proposed) are designed for a range of live storage capacity. About half (8 out of 17 reviewed) have live storage less than 20% of the average monsoon (June-September) flows and only 3 out of 17 have live storage more than 50% of average monsoon flows. A higher percentage of live storage means better regulation which makes them more suitable for adapting to climate induced runoff changes (particularly for reduction in dry season energy in the power system).

The consideration of these changes could be made in the near-term design of new hydropower plants in Nepal, noting that there are a large number of proposed projects. This could draw on the list of various design options highlighted in this report, both with respect to over-design, flexible and more robust options.

Indeed, Chapter 6 of the vulnerability report highlights some potential design options that could be considered (for Sediment Handling) and provides a baseline case to assess the potential benefits (and compare to the costs of different options) for sediment reduction.

However, a key finding of the vulnerability report is that reliable long-term hydro-meteorological data (for at least a 30-year period) is not available to plan and design the hydropower projects even in relation to the current climate and hydrological regime. Hence, some of the problems faced by the projects such as lower than expected energy generation (which lead to private developers facing penalties and losses) are due to a lack of data and study than for other reasons. This is particularly problematic for small projects for multiple reasons, as the hydrology of smaller catchments are more erratic and variable.Even in the case of availability of long-term data, assumption of "stationarity" in defining the hydrological design parameters is problematic as the historical regime may have changed due to upstream interventions and diversions if not for climate change. Again this is more critical for smaller projects than for larger ones,

This highlights a key adaptation priority is to source better data on the current hydrological regime and on tracking recent changes, i.e. a clear priority is for better hydro-met information. This is a low-regret options that has the benefit that it will improve future decisions.

Another key aspects highlighted in the vulnerability report is the different climate and flow conditions that occur at different altitudes in Nepal, due to the combination of higher temperature increase at higher elevation and the influence of precipitation and snow/glacier melt. The vulnerability report categorised projects according to elevation as (i) High catchment with 80% area>3000m, (ii) Medium catchment with 60% -80% area >3000m, (iii) Low catchment with 20%-40% >3000m and (iv) Rainfed catchment with 0% -20%>3000m.

There is therefore a need for the adaptation analysis to follow this differentiation and look to see if adaptation options need to alter according to the type of plant and the location.

Future risks

The vulnerability report also highlights that as well as changes in precipitation and temperature, hydropower plants are threatened by precipitation-induced natural disasters, notably floods, landslides, and severe erosion and sedimentation problems associated with the summer monsoon. Moreover, there is an increasing risk of Glacial Lake Outburst Floods (GLOFs) due to accelerated glacier melt caused by increasing temperatures and the subsequent retreat of glaciers. It is these threats that stakeholders fear may increase in the future due to an increasing variability of precipitation and increasing temperatures. A stronger focus on monitoring and assessment of these variables, and early planning to see how to respond to them, is therefore a priority to start preparing for future climate change.

Summary

Overall, the results of the vulnerability assessment confirm the need to focus on current climate variability as the starting point and particularly the issues around low season flows(Dec-Mar), due to the load shedding and unmet demand[6]. They also highlight that an additional set of options need to be developed that focus on current data hydro-met gaps, i.e. supporting information to provide the enabling environment for better hydro-planning.

In terms of the design of plants with future climate in mind, there is a stronger focus on differentiating between three types of plant (RoR, small pondage, storage) and three altitudinal locations (noting there is some overlap between these). The vulnerability report highlights that any design or adaptation option should be project and system specific, depending on factors like location, size, type, hydrological design parameters, installed capacity and live storage (in the case of storage projects).

[6]Nepal's electricity generation is insufficient to operate important plants during the dry season. This leads to planned rolling blackouts – these are often referred to as 'load shedding' in Nepal (noting the definition of load shedding is different in other countries)-and this has a high value of lost load.

Finally, there is a need to address early planning and monitoring to start preparing for the long-term climate induced hazards identified as a key risk to the hydro projects. These include potential glacial lake outburst floods, sediment load and extreme flood events.

For GLOFs in particular, hydro project within 50 -100 km from potential GLOFs are recommended to have a risk management strategy such as early warning or design of key structures above the hazard levels or even underground structures. More analysis of these options will be undertaken.

5.2 Next steps

The vulnerability assessment report will be used to refine the adaptation options considered in this report, adding additional options and providing a greater differentiation between types and elevation of plants. The analysis will also investigate the potential to look at adding adaptation options into the economic rate of return analysis (the IRR and NPV). It will also assess non-technical options associated with providing better information for both current and future risks, and with a greater focus on additional GLOF specific options.

The adaptation options identification will be discussed with expert group consultations and consultation with other stakeholders in Nepal.

The pathways team has developed an adaptation cost-benefit model that can look at indicative estimates for adaptation and it is proposed to test this on a selected number of case studies to look at some of the promising adaptation options.

This will allow a prioritisation of options. This will allow an initial ranking of their potential effectiveness and their costs, along with other attributes (e.g. in relation to poverty reduction, environmental or social co-benefits, etc.).

Finally, the analysis will consider the potential for these options in Nepal, i.e. the practicality and acceptability of options, and the issues in implementation (e.g. whether effective, policy costs, etc.). This will consider the entry points and potential barriers to adaptation and look to see how they could be introduced into the hydropower sector of Nepal.

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APPENDIX 1. CLIMATE CHANGE IMPACTS AND ADAPTATION OPTIONS FOR HYDRO

Increases in Intense Precipitation – High flows, changing extreme return periods *Solutions that imply works on the dam and reservoir, like new spillways, dam raising, bypass tunnels tend to be more expensive.*

Current climate variability and Future Climate Change	**Impact on infrastructure operation – and potential benefits (avoided impacts)**	**Plant type**	**Timing of adaptation**	**Possible adaptation measure**	***Cost of adaptation ($)measures / cost of 'flexibility' incorporated at design stage***	**Potential size of benefits**	**Comments**
1) HEAVY PRECIPITATION							
A) Extreme rainfall/run-off, or change in flood return period and peak intensity, may exceed dam design limitations, over-topping dam walls and increasing the risk of structural failure.							
Type i) Current weather (2015) and heavy rainfall/flood	Leading to • Physical damage (repair costs) and down-time and reduced generation (loss of revenue) from repair. • Risk of catastrophic structural failure (major irreversible loss of asset) • Downstream impacts from water surges (secondary impacts). • Wider economic costs of lost load. During floods, authorities may ask to lower the normal reservoir level to keep free some reservoir volumes for flood, to ensure some sort of downstream protection. The lower reservoir level, means lower heads and therefore less energy generated.	Current plants	*What to do now – and whether this is low or high regret.*	Increase of the Dam Spill Capacity. • Building new auxiliary spillway to add extra discharge capacity to the dam, or/and • Modifying existing spillways to increase their discharge capacity. - Changes on the weir crest to increase its hydraulic performance (Labyrinth or PKW weirs). This type of solutions are also usual for new spillways. - Gates, fuse gates, or fuse plugs allow to keep the same full supply level or even to raise it and at the same time increase the discharge capacity for extreme events. - Raising of the dam crest allows to increase the head above the spillway crest and therefore its discharge.	These costs are generally high, but they are mandatory to reduce public risks related with a dam failure due to the spillway lack of capacity.	How much is risk reduced by this measures. The spillway structures are designed to pass a certain flow. If it is found that a dam only can pass 100 year flood and with a new spillway shall be able to pass the 10000 year flood, the risk is reduced 100 times.	A lot of dams in the past were designed with floods smaller than current standards and most of these works would be required anyway, even without climate changes. What is advisable is to design these new works with some allowance to take into account possible climate changes. Spillways waterways and stilling basins should also be changed For the "new" design flow.
				Insurance			Increased insurance to cover risks (assume already some insurance)

				Temporary flood storage, could include ecosystem based adaptation upstream flood plains			
				Cooperation between the different reservoirs along the basin.	Low cost Installation of the Monitoring and communications systems between the different reservoirs of a basin + Weather forecast systems to help on the decisions.	Optimize response activities	In large basins with multiple reservoirs large flood releases should be carefully planned.
				Periodic and mandatory safety reviews (low regreat)	Low cost		
				Revised flood control procedures	Low cost		
				changed maintenance regime to address drying out of reservoir basins and embankment structures			
				Reducing reservoir level before flood season (non-structural alternative)			This should be seen as a temporary solution.
Type ii) Future climate change [2030 and later) – Increase heavy events/ flood	As above	Existing plant on system (no adaptation)	*What do in the <u>future as retrofit</u>*	See options above	See options above	See above	See discussion above
		New plants (built now – 2015 – 2020)	*What do now during the <u>design phase for the future</u>*	Over-design and build additional spillway capacity.	Increase the project cost to face future incertitude, which could also affect the project feasibility.	This measure would reduce the risk related with future incertitude	
				Allow space in the design for future increase in spillway capacity	Flexibility for additional new spillways capacity added later on, with not so high costs.	This measure would reduce costs in the future with relatively small cost at the present.	

Type iii) Long-term risks, e.g. 2025 - 2050	As above but also Major non-marginal changes in flows or major systematic shifts in risk by 2050, e.g. transformation rainfall, ENSO shifts	New plants (built in future >2020	*What do now to prepare for future*	Maintain or/and create a monitoring system of the watershed. (Weather and gauge stations).	Medium cost. Installation and maintenance of the stations and data records.	Value of information	Long flow series are vital for the design. Are also quite useful for the assessment of climate changes.
				Develop warning systems for water-triggered landslides/floods and GLOFS			

Current climate variability and Future CC	Impact on infrastructure operation – and potential benefits (avoided impacts)	Plant type	Timing of adaptation	Possible adaptation measure	***Cost of adaptation ($)measures / cost of 'flexibility' incorporated at design stage***	Potential size of benefits	Comments
1) HEAVY PRECIPITATION							
B) Increase sediment and debris may block dam spillways, damage important structural components (turbines), or reduce live storage (and power generation) in the medium- and long-term. Most of the dams have been designed with a *design life approach*, assuming that after a certain period that structure is replaced, and in a lot of these projects no measures to deal with sedimentation properly were implemented. This approach needs to change to a *life cycle approach* in order to ensure the sustainability of reservoirs subject to sedimentation. Sedimentation is already a problem which climate change tends to get worst.							
Type 1) Current weather (2015) and sediment increase	Leading to • Lost generation during sediment control. [(1)] • Loss of generation capacity due to the loss of reservoir storage[(2)] • Turbine damage (repair costs) and reduced generation (loss of revenue) from repair. • Earlier turbine replacement. [(1)] Some of the techniques to bypass sediments through the reservoir imply the loss of water for energy production and sometimes also the reservoir draw down. [(2)] Loss of reservoir capacity does not reduce the energy generation in the same proportion. A reduction of storage of 0.3 percent per year means a reduction of power of much less than 0.1 percent of production. (In 2009 ICOLD Bulletin Sedimentation and Sustainable Use of Reservoirs and River Systems)	Current plants	*What to do <u>now</u> – and whether this is low or high regret.* *<u>Sustainable Management of the Reservoir</u>*	Mechanical Removing Reservoir dredging; Hydrosuction, Trucking	Expensive measures.	Useful for localized interventions to keep the vicinity of the power intake clear to allow to keep the plant operation.	Should be seen as last resort.
				Reservoir flushing and Sluicing;	These are less costly solutions to deal with sediments, however the turbine operation needs to be interrupted during the time of these operations. This "cost" of nonproduction can be considered as an O&M cost for the sediment management. Based on some examples, flushing operations would not allow turbine operation roughly during 5% of the year.	When possible to be adopted, these are sustainable measures to face reservoir sedimentation.	These techniques only can be adopted in some special circumstances. For instance, flushing is generally adopted when the reservoir capacity/mean annual runoff is less than 0.2., less than 25% of the dams in the world (ICOLD 2009). These techniques demands high capacity outlets, which are better to be built initially with the dam, however there are examples where those were built later (Sanmenxia Dam in China)

				Density Current Venting.	Low cost solution which does not required the lowering of the reservoir even if some water are lost through the bottom outlet.	When possible to be used, these technique allows to release a good portion of the sediments, increasing the useful life of the reservoir. For example, at Bajiazui Dam in China, the density current venting provides an average release ratio of 46% .	Complicated technique which dependent of a lot of factors. It may help to have various outlet at different levels.
				Operating Rules There are some operation related with gates, reservoir levels and outlets which allows to pass some of sediments through the dam.	Low costs. Can imply to impose lower water levels in the reservoirs which would reduce energy production.	Allows to pass some of the inflow sediments and therefore extend the useful life of the reservoir.	
			Lost Storage Replacement	Dam heightening or building a new and higher dam downstream of the existing one.	High costs related with raising/new dam and the larger area affected to the reservoir. Power intakes and low levels outlets my also needed to be raised.	In the long term period it is not a solution for the sediment problem.	In arid regions, this solution seems to be a cost-effective method to compensate the storage loss due to sedimentation.
			Preventing Sediment Inflow into the reservoir	Prevent erosion through some soil conservation measures in the watershed (changes in land usage, etc)	High costs, which cannot be fully affected to the plant. The advantages of these measures are not only related with the sediment yield reduction.	This measures can reduce the sediment load but do not stop it. There are some examples (Mangla dam in Pakistan) even, where the reduction was not the expected.	In large basin these measures demands a lot of institutional effort for a long period of time.
				Check dams, debris basin or other reservoirs upstream to trap eroded sediment.	These structures are costly to build (civil works+land acquisition) and demand maintenance.	This measures can reduce the sediment load but they demand maintenance to ensure their sustainability.	

				Bypass Tunnels	Costly. It requires a sediment check dam located upstream of the reservoir and a long bypass tunnel around the reservoir.	When possible to be adopted, this is sustainable measure to face reservoir sedimentation.	These solution is being used for some in Japan and Switzerland.
Type ii) Future climate change [2030 and later) – Increase heavy events/ flood	As above	Existing plant on system (no adaptation))	*What do in the* <u>*future as retrofit*</u>	See options above	See options above	Avoids all future risks / impacts.	See discussion above
		New plants (built now – 2015 – 2020)	*What do now during the* <u>*design phase for the future*</u>	When possible, new dams should be designed with a *life cycle approach* in order to ensure the sustainability of reservoirs subject to sedimentation. Besides the measures listed above also off-stream storage can be considered during the design phase.	Higher initial Costs Structures to deal with sediments (tunnels, check dams, multiple outlets) should be design and build together with the dam. Measures do deal with sediments may reduce the energy output by imposing non-operation periods, which would reduce the viability of some hydropower project.	Sustainability of the reservoirs can be ensured for a long period.	Correct sediment load estimations are essential during the design stage, so the correct measures could be adopted. Those measures should start to be used right from the beginning of the exploration and not wait until it is a serious problem difficult to solve.
Type iii) Long-term risks, e.g. 2025 - 20505	As above but also Major non-marginal changes in flows or major systematic shifts in risk by 2050, e.g. transformation rainfall, ENSO shifts	New plants (built in future >2020	*What do now to prepare*	Sediments monitoring to help the estimations during the design stage.	Low cost		
				Soil conservation measures in the watershed.	High Costs The advantages of these measures can bring more benefits then the sediment yield reduction.	It will be possible to follow the reduction of sediment yield due to soil conservation measures.	As said, in large basin these measures demands a lot of institutional effort for a long period of time.

Change in seasonal rainfall patterns

Current climate variability and Future Climate Change	**Impact on infrastructure operation – and potential benefits (avoided impacts)**	**Plant type**	**Timing of adaptation**	**Possible adaptation measure**	***Cost of adaptation ($)measures / cost of 'flexibility' incorporated at design stage***	**Potential size of benefits**	**Comments**
2) CHANGE IN AVERAGE AND MONTHLY RAINFALL							
A) Changes in flow from altered precipitation, run-off, river flow, snow melt patterns, evaporation, evapotranspiration, etc.							

Type i) Current weather (2015) e.g. reduced rainfall	Lower rainfall leading to • Reduction in in-flows (reduced generation). • Possible deviation from optimal operation. • Downstream impacts from water reduction (secondary impacts). • Wider economic costs of lost load. Storage provides some buffering against increasing variability of annual inflows. Run-of-river plants could experience a direct reduction in hydropower production in response to reduced dry season discharge May also be effect of higher evaporation/evapotranspiration reducing run-off.	Current plants	*What to do now – and whether this is low or high regret.*	Weather forecast systems to optimize the reservoir operation.	Low costs	Maximization of the energy production.	
				Improved management and operation regimes. i.e. run at peak Cooperation between different plants operating in a cascade fashion.	Low costs	Use of available energy when is needed the most.	Within a cascade the operation of the plants can be made to optimize the output of the entire cascade or alternatively to maximize the output of a certain plant.
				Enhance interconnection between different systems.	This is an effort that needs to come from the governments of the different countries.	Climate change effects are not likely to affect all the regions the same way. With the different systems interconnected would be possible to provide energy to a systems more affect by a draught.	
				Increase reservoir storage capacity to reduce the volumes of water spilled through the spillway. •Dam Raising •Install fusegates on the sill of existing spillways, allowing an increase to the normal water level while maintaining the dam's safety level	High costs, especially if the possibility of the dam raising was not considered in the initial design.	Reduction of the water volumes spilled through the spillway. Increasing of the head.	Measures to remove sediments from the reservoir also increase the storage capacity.
				Divert some flows from an adjacent watershed into the reservoir.	High costs. This involves the construction of diversion and water conveyance structures.	This would allow to maximize the use of the full capacity of an existing plant.	This can only be an option only when natural conditions would allow it.
				Modifications to the intake arrangement so water can be abstracted from lower levels in the reservoir during periods of prolonged drought	High costs and limited benefits for hydropower. In storage reservoirs, lower levels means lower heads and eventually low efficiencies during turbine operation.	Increase of the storage capacity of the reservoir.	

				Change turbines (retrofit) to lower capacity	Low cost. After the turbine life-time it is found that its capacity is lower than required, then it can be replaced by lower capacity (and cheaper) machines.	New turbines would operate more efficiently for the "new conditions"	
				Insurance, e.g. index linked?			
				Demand-side management ($benefits from reduced peak and loss of load)			Campaigns to reduce energy consumption during droughts
				Integrated water resource management			
				conjunctive ground surface water storage ?			
				Smart licensing along the river basin to account for cascade effects			
	<u>Higher</u> rainfall might increase generation capacity. May lead to modest effects in relation to high volumes and sedimentation. For run of river facilities "excess" inflows may be spilled without added energy production.	Current plants	*What to do <u>now</u> – and whether this is low or high regret.*	Additional Power Capacity.	IRENA (2012) mentions that the cost of adding additional capacity (turbines) is about USD 500/K	Increase of the energy production, by reducing the flows spilled through the spillway. New turbines can be design for a larger range of flow and head scenarios.	Even if not related with climate changes, some HEP were or are being re-powered. (Ex: Cambambe (Angola), Cahora Bassa (Mozambique) Ruacana (Namibia).
Type ii) Future climate change [2030 and later)	As above for <u>lower</u> rainfall	Existing plant on system (no adaptation)	*What do in the <u>future as retrofit</u>*	See options above	See options above	See above	See discussion above

		New plants (built now – 2015 – 2020)	*What do now during the design phase for the future*	Plan for possible dam raising in the future. This planning is not only in the dam structure but also in the allowed use for the reservoir area. A "buffer" area around the reservoir should kept free.	This would increase the initial costs of the project. Ultimately the possibility of the dam raising in the future will constrain the solution chosen for the dam.	Lower costs in the future if confirmed the benefits of the raising of the dam.	Planned dam raising examples: Cambambe dam (Angola); Chicamba dam (Mozambique); Couga Dam (South Africa); Guri dam (Venezuela) "unplanned" dam raising examples: Kamuzu Dam (Malawi) San Vicente dam (USA) Spitallamm and Seeuferegg dam (Switzerland),
				Power plant designed to operate for a large range of flows and heads.	Higher initial costs. It could led to adoption of more turbines with less power, which is generally a more costly solution.	It would increase the flexibility of the plant operation to face future changes	
				If there is not big pressure from the demand side, power installation can be phased.	Initial lower costs. Lower initial power capacity.	Flexibility to adapt the turbine(s) installed later to the future conditions.	
			At the basin / system level	Plant siting			
				Design, i.e. run of river versus storage			
				Mix of large, medium and micro			
				Integrated water resource management			
	As above for higher rainfall			Additional space in powerhouse for the installation of a turbine in the future. Design waterways with some room for flow increase in future.	Increase initial construction costs	Cheaper repowering in the future if required.	The installation of the power capacity can be phased in time to adjust the investment to the demand. This strategy would also suit to monitoring eventual climate changes on the site.
				Insurance and other financial instruments			

	If can't predict, i.e. if not clear if higher or lower rainfall (UNCERTAINTY)		*What do now during the design phase for the future*	Change turbine design or flexibility, i.e. consider number/size of turbines that perform well across a range of streamflow and heads scenarios	Initial higher costs. More turbines, even if smaller increase the costs.	Better efficiencies and possibility to adapt to future conditions	Robustness
				If possible from the demand side phase turbine installation	Initial lower costs. Lower initial power capacity.	Flexibility to adapt the turbine(s) installed later to the future conditions.	
				Consider in the design the possibility for the dam raising. A "buffer" area around the reservoir should kept free.	This would increase the initial costs of the project. Ultimately the possibility of the dam raising in the future will constrain the solution chosen for the dam.	Lower costs in the future if confirmed the benefits of the raising of the dam.	
				Dam dimensioning under uncertainty	Smaller reservoirs to minimise sunk costs (but note cost penalty)		RDM
				Multiple output height to cope with variability			Robustness
Type iii) Long-term risks, e.g. 2025 - 20505	As above but also Major non-marginal changes in flows or major systematic shifts in risk by 2050, e.g. transformation rainfall, ENSO shifts	New plants (built in future >2020	*What do now to prepare for future*	Maintain or/and create a monitoring system of the watershed. (Weather and gauge stations).	Medium cost. Installation and maintenance of the stations and data records.	Value of information	Long flow series are vital for the design. Are also quite useful for the assessment of climate changes.
			At the basin / system level	Plant siting?			
				Design, i.e. run of river versus storage			
				Mix of large, medium and micro			
				Demand-side management ($benefits from reduced peak and loss of load)			
				Reduce transmission losses			

Drought (meteorological and hydrological)

Current climate variability and Future Climate Change	**Impact on infrastructure operation – and potential benefits (avoided impacts)**	**Plant type**	**Timing of adaptation**	**Possible adaptation measure**	***Cost of adaptation ($)measures / cost of 'flexibility' incorporated at design stage***	**Potential size of benefits**	**Comments**
3) EXTREME LOW RAINFALL (DROUGHT)							
A) changes in drought intensity and duration, in terms of low flows in rivers (streamflow drought) Note these changes may also affect water quality, which is a particular issue where draw off water for supply							
Type i) Current weather (2015) e.g. reduced rainfall	Meteorological or hydrological drought leading to • Deviation from optimal operation (reduced generation). • Reduce below optimal production to meet multiple needs (e.g. where serves for irrigation). • More extreme, lower the reservoir below the minimum level that allows the operation of the turbines • Downstream impacts from water reduction on other sectors e.g. agriculture (secondary impacts). • Wider economic costs of lost load. Additional impacts from evaporation reducing the volume and elevation of water available for electricity generation Storage provides some buffering against increasing variability of annual inflows. Run-of-river plants could experience a direct reduction in hydropower production in response to reduced dry season discharge. Loss of reservoir capacity does not reduce the energy generation in the same proportion. As above a reduction of storage of 0.3 percent per year means a reduction of power of much less than 0.1 percent of production.	Current plants	*What to do <u>now</u> – and whether this is low or high regret.*	Change operational regime, i.e. run peak only			
				Divert some flows from an adjacent watershed into the reservoir.	This involves the construction of diversion and water conveyance structures.		Inter-watershed transfer projects to move water between different river basins
				Enhance interconnection between different systems	This is an effort that needs to come from the government of the different countries.		Issues if interconnection of different systems useful to build resilience to climate changes effects.
				Modifications to draw-off arrangements so water can be abstracted from lower levels in the reservoir during periods of prolonged drought	Lower power intakes to compensate for lower head pond water levels		Cited in ICOLD
				Insurance			
				Demand-side management ($benefits from reduced peak and loss of load)			
				Reduced water allocations for irrigation to minimize evaporation losses and reduce environmental stress on 'low flow' river systems			

				changed maintenance regime to address drying out of reservoir basins and embankment structures			
				Reduce transmission losses			Beyond owner, system wide approach
Type ii) Future climate change [2030 and later)	As above	Current / plants (no adaptation)	*What do in the <u>future as retrofit</u>*	See options above	See options above	See above	See discussion above
		New plants (built now – 2015 – 2020)	*What do now during the <u>design phase for the future</u>*	Design larger dam for more water storage Increased over-year storage to compensate for longer term droughts	See 1A)	See 1A)	See 1A)
				Larger foundations to allow dam expansion in the future	See 1A)	See 1A)	See 1A)
Type iii) Long-term risks, e.g. 2025 - 20505	As above but Major non-marginal changes in flows or major systematic shifts in risk by 2050, e.g. transformation rainfall, ENSO shifts	New plants (built in future >2020	*What do now to prepare for future*	Extreme event monitoring			
			At the basin / system level	Plant siting			
				Design, i.e. run of river versus storage			
				Mix of large, medium and micro			
				Demand-side management ($benefits from reduced peak and loss of load)			
				Greater use of pumped storage for hydropower generation			