Environmental Impact Assessment

Project Number: 41924-014
July 2015

Nam Ngiep 1 Hydropower Project
(Lao People's Democratic Republic)

Climate Change Impact Assessment

CLIMATE CHANGE IMPACT ASSESSMENT OF THE NAM NGIEP 1 HYDROPOWER PROJECT

FINAL REPORT (FR)

29th April 2015
Prepared for NAM NGIEP 1 POWER
COMPANY LTD

icem
Climate Change | Biodiversity
Water | Integrated Assessments

DOCUMENT HISTORY

Revision

Revision no	3.0 (revised submission, including NNP1PC and ADB comments)
Author/s	Tarek Ketelsen, Peter Ward, Peter-John Meynell, Jorma Koponen, John Sawdon, Julia Winter, Viet Anh Nguyen, Phaknakhone Rattana, Aphone Viengkhamhak

Distribution

Issue date	29th April 2015
Issued to	Mr. Shoji TSUTSUI Deputy Managing Director, Technical – Power Plant Nam Ngiep 1 Power Company (NNP1PC) Pakxan Office Unit 8, Ban Mixay, Pakxan Dist, Bolikhamxay Province, Lao PDR Tel: +856-54-280183; Fax: +856-54-280169
Citation	ICEM. 2015. Climate change risk and vulnerability assessment for the Nam Ngiep 1 hydropower project: Final Report. ICEM, Hanoi Viet Nam, 29th April, 2015
Disclaimer	This report is intended for public distribution and does not disclose data considered sensitive by Nam Ngiep 1 Power Company. Specifically, the quantitative results of the analysis of economic impacts of climate change have been shared with the Company and with ADB Private Sector Operations Department (PSOD) but are not published herein.

ABBREVIATIONS

ADB	Asian Development Bank
BL	Baseline
BOT	Built Operate Transfer
CAM	Climate Change Assessment Methodology
CC	Climate Change
CRVA	Climate change risk and vulnerability assessment
DEB	Department of Energy Business
EDL	Electricite du Laos
EE	Excess Energy
EGAT	Electricity Generation Authority of Thailand
ERC	Excess Rule Curve
FSL	Full Supply Level
GCM	Global Circulation Models
GOL	Government of Lao PDR
IFC	International Finance Corporation (World Bank Group)
IPCC	The Intergovernmental Panel on Climate Change
LRC	Lower Rule Curve
MEM	Ministry of Energy and Mines
MOL	Minimum operating level
NEM	New Economic Mechanism
NNP1	Nam Ngiep 1 Hydropower Project
NNP1PC	Nam Ngiep 1 Hydropower Power Company
NWL	Normal Water Level
PE	Primary Energy
PPA	Power Purchase Agreement
PSOD	Private Sector Operations Division
RCP	Resource Concentration Pathway
SE	Secondary Energy
SRES	Special Report on Emissions Scenarios
URC	Upper Rule Curve

Contents

EXECUTIVE SUMMARY

THE NAM NGIEP 1 HYDROPOWER PROJECT

Nam Ngiep 1 (NNP1) is a hydropower generation facility under development in the lower Nam Ngiep Basin - a tributary to the Mekong River joining the northern extent of the Annamites with the mountainous headwaters of the Vientiane plain. NNP1 was first identified in the early 1990s with feasibility studies completed in 1991 and 1998-2002. In 2013 the Nam Ngiep 1 Power Company (NNP1PC) was formally established as a joint venture between the project investors: KANSAI Electric of Japan, EGAT International of Thailand and Lao Holding State Enterprise. Additional financing was also sought from the Asian Development Bank through the Private Sector Operations Department (PSOD) and approved in August 2014. In 2014, the project commenced construction starting with preparation of worker's camps, access roads and the foundations of the re-regulating reservoir.

The NNP1 project has been designed to take advantage of the hydro-geological characteristics of the Nam Ngiep basin, with the main dam positioned within a steep natural canyon in the lower part of the catchment. This canyon allows the developer to build a large 148 m high dam with a total storage volume of 2.2 billion cubic meters and the capacity for seasonal regulation. The large storage volume and head, combined with a significant wet season flow allows for an installed capacity of 272 MW.

The project is designed for daily peaking operation (16 hours on and 8 hours off) for six days of the week with a design annual energy output of 1,515 GWh which is destined for export to Thailand under a Power Purchase Agreement (PPA) agreement with EGAT. NNP1 is a highly efficient dam extracting energy from 95% of the water that passes through the main dam each year.

The decision to operate NNP1 as a peaking project will result in rapid fluctuations in downstream water surface elevations. As a result, NNP1PC has included a re-regulation reservoir as part of the design. While the site conditions for the main dam are highly favourable, the site conditions for the re-regulating reservoir presented a greater challenge for design engineers as downstream of the main dam site the river enters a large, flat floodplain which eventually drains into the Mekong near Pakxan. Because of the low-lying topography, the re-regulating dam required an additional earth-filled saddle dam/dyke to block a historic bifurcation channel and prevent avulsion of the regulated river flow into its old channel. The re-regulating reservoir will operate under continuous mode and a powerhouse house has been installed with a capacity of 18MW, and the electricity generated destined for the domestic market.

In general, the NNP1 project is a robust structure with a significant amount of redundancy built into the design of the main dam and spillway which offer the project a high safety margin against variation in climate conditions. This safety margin has been included in response to the highly variable and poorly understood baseline hydrology of the NNP1 catchment but also provides a level of resilience to future climate change.

CHANGES IN THE NAM NGIEP CATCHMENT HYDROLOGY

The Nam Ngiep catchment is the primary asset of the NNP1 plant comprising 3,700 km^2 of rugged mountainous terrain with extensive remaining forest cover. The main assets of the watershed to NNP1 are; the large drop in catchment elevation (2,650 m) between the headwaters and the dam outlet; and, the high water productivity of catchment with a total average volume of 4.7 billion cubic meters flowing past the dam site each year at a mean annual flow rate of 148.4m^3/s

The catchment's water abundance and the hydrological process that govern it fate and transport are the fundamental characteristics that determine a hydropower reservoirs energy production potential. These processes are themselves sensitive to changes in climate, starting with increasing temperatures which will manifest changes in all aspects of the catchment's water cycle.

Climate change will induce substantial increases in atmospheric temperatures in the Nam Ngiep catchment by 2050, with average daily temperatures increasing by 1.6°C in the wet season and by 2.1°C during the dry season. By 2050, there will be a 26% increase in the proportion of the year when temperatures exceed an average daily maximum value of 34°C (up to 66% of the year compared to 40% in the baseline); and average daily maximum temperatures would exceed 44°C a phenomena unheard of under baseline conditions.

These increases in temperatures will have implications for linked catchment processes such as evaporation, evapotranspiration, humidity and precipitation, which are all expected to increase affecting water availability within the catchment. By 2050 average annual precipitation will increase by 16.5% from 1,845mm to 2,149mm; with 95% of this increase falling during the wet season. Increases in seasonal precipitation are heterogeneous given the complex interplay of atmospheric and orographic forcings in the Nam Ngiep catchment and the largest seasonal increases will occur in the northern, upland areas, where wet season precipitation increases will reach 21-25% relative to baseline levels, compared with 16-20% in the lower NNP1 catchment and 9-15% downstream of the NNP1 dam.

Characteristic of monsoon climates, inter-annual variability is large for the NNP1 catchment. Under baseline conditions seasonal rainfall can vary by +100/-50% in the dry season and +40/-25% in the wet season. With climate change, the wet season distribution shows a significant increase in the variability of precipitation with a greater proportion of periods of both intense and low wet season rainfall. In particular, wet seasons with precipitation greater than 2,500mm – an extremely rare event under baseline conditions – would occur 30% of the time under the future climate regime.

A similar trend is observed for the intensity of rainfall events, with peak rainfall events also increasing in both magnitude and frequency and exceeding daily rainfall totals of 160mm/day. These projected changes in precipitation are expected to be further exacerbated by an increasing frequency of cyclone and extreme storm events hitting the catchment, which was not modelled by the ICEM team. The exclusion of specific modelling of future cyclone dynamics omits quantification of one of the main drivers of precipitation change in the Nam Ngiep catchment, and given a consensus at the IPCC that cyclones in the west pacific are going to become more intense and more frequent, means that the CC projections utilised in this study are likely to underestimate future changes of precipitation magnitudes and intensities.

Increases in rainfall intensity will induce a major increase in hillslope erosion processes, with a 100-200% increase in erosion in the high sediment yield central areas and 200-400% increase in erosion rates for the moderate-yield northern catchment areas. This increase in erosion coupled with an increased river transport capacity (i.e. stream power) will nearly triple the annual sediment inflow to the NNP1 reservoir from 1.1 MT/yr to 2.5Mt/yr. In 50 years of operations, this would amount to an increased sediment inflow of 89.5MCM compared to 38.5MCM under baseline conditions and a loss of 7.5% of the main reservoirs active storage which amounts to a reservoir head loss of 0.8m.

Floods are regular and highly variable phenomena in monsoon catchments like the Nam Ngiep. Climate change will dramatically increase the frequency and magnitude of flood events. The 1 in 10 year event will become a 1 in 2 year event while the 1 in 100 year event will become a 1 in 5-10 year event such that by 2050 significant overbank flooding will become an almost biannual feature of the basin's hydrological regime, compared to the current situation where overbank flooding is an intermittent phenomenon. For the extreme flood events, the 1 in 1,000- ear event (used to size much of the flood management infrastructure) will become as frequent as a 1 in 20 – 100year event with a 1-5% chance of occurring each year under climate change.

The Probable Maximum Flood (PMF) represents the largest possible flood event in the catchment and was calculated by NNP1PC to be 8,890m^3/s using historic climate conditions. As part of the dam safety review (DSRP), NNP1PC revised the PMF estimate up to 9,050m^3/s. This estimate is significantly higher than the ICEM baseline estimates. With climate change the ICEM projections estimate the CC-PMF would reach 9,010 m^3/s (under the average CC scenario) and 11,560m^3/s (under the upper CC scenario) representing up to a +27% variation from the NNP1PC PMF. This upper estimate represents a significant increase in flood risk for the NNP1 project, commensurate with the dramatic increases in precipitation projected for the basin and represents an inflow volume greater than 1,000MCM within the first 40hours of the PMF event, compared to 831MCM under the NNP1PC baseline. It should also be noted that the findings of the CC-modelled PMF do not take into account changing intensity dynamics of the rainfall hydrograph at sub-daily time-steps, with the cc-projections assuming no change in the hourly rainfall hydrograph from the baseline. In reality, there is likely to be an increase in sub-daily rainfall intensity as well – especially if changing cyclone dynamics are taken into account.

The Nam Ngiep catchment has a high technical-potential for hydropower development along the river and its tributaries. Currently, there are four hydropower projects under development in the catchment and 1 project is under consideration. The three projects upstream of Nam Ngiep 1 (Nam Ngiep 2, Nam Ngiep 3A and Nam Chiane) are situated relatively high in the headwaters of the catchment and predominately rely on large elevation drops in the topography, not large river flow, for their electricity production. As such the upstream projects do not exert a substantial control over inflows to the NNP1 reservoir with a combined capacity to command ~20% of the NNP1 catchment. In all cases the upstream projects rely on an inter-tributary transfer of water to maximise the potential energy conditions between the reservoir and the turbines. NNP2, NNP3A and Nam Chiane have installed capacities of 180 MW, 44 MW, and 104 MW respectively, and reservoir storage varying from 13.8MCM (Nam Chiane), 23.12 MCM (NNP3A) to 151.8MCM.

NAM NGIEP ASSETS AND SENSITIVITIES TO CLIMATE CHANGES

In order to understand the impacts of climate change the projected changes in CC-threats need to matched with the relevant assets of the NNP1 facility that are sensitive to these changes. In this report an asset is used broadly to define physical infrastructure, equipment, plant components (e.g. main dam, agricultural lands) as well as plant processes (e.g. energy production). Nine major assets were identified in the NNP1 project which are potentially sensitive to climate change, they include:

1. **Main Reservoir**: With a surface area of 66.9km2 and a storage volume of 2,238MCM (1,200 MCM active) the NNP1 reservoir is the largest in the basin. Due to the surrounding topography the reservoir has a long narrow shape with the main reservoir volumes divided between two impoundments – a lower impoundment extending upstream from the dam wall and comprising predominately of dead storage, and an upper impoundment extending downstream from the reservoir headwaters and comprised almost exclusively of active storage. The two impoundments are connected by a narrow, confined section of reservoir running between a steep-gorge like section in the river.

    The main assets of the reservoir to the project are its large active storage which governs its capacity for seasonal regulation (and hence the project's ability to generate electricity during the dry season) as well as the project's capacity to store and safely pass flood events. The reservoir storage capacity is sensitive primarily to changes in sediment inflows which can reduce capacity through sedimentation. The reservoir is also sensitive to temperature induced changes in thermal stratification and the potential for deteriorating water quality associated with anoxic conditions within the reservoir water column which could have adverse implications for downstream releases.

2. **Main dam and spillway gates**: The main dam is a concrete gravity roller dam with a crest level at 323.5 masl. The penstocks are covered in concrete and embedded within the left side of the dam with intakes located about 43 m below the NOL. In order to pass flood flows, the main dam has four radial gate spillways which are mounted on the top of the main dam and capable of controlled opening. The gates discharge onto a curved concrete apron with energy dissipation structures at the foot of the apron. The main assets of the main dam are: (i) it's height which is determines the storage capacity and has been bolstered by NNP1PC through the inclusion of a parapet wall that raises the dam height to 323.5masl (3.5 m above the NOL); and (ii) the capacity of the spillway gates which are designed to pass flows of 5,210m^3/s (the baseline 1 in 1,000yr event).

   Both of these assets are sensitive to increases in the design and peak flood events which if exceeding the capacity of the main dam could result in over-topping, and if safely managed within the reservoir will result in increased wear-and-tear to the spillway structure.

3. **Main powerhouse**: The main powerhouse is a semi-underground structure located at the foot of the main dam and confined by the steep gorges of the site. Ground elevation is set at 193masl or 0.9m above the 1 in 1,000 year flood level. In addition the main power house is protected by an outer concrete wall-casing 17m high and an inner wall of double-thickness. Within the power house are two vertical shaft Francis turbines each with a rated capacity of 140.5MW.

   Because of its location at the foot of the dam and the confined gorge configuration, the powerhouse is highly sensitive to over-topping of the main dam which could send floodwaters cascading directly onto the structure damaging equipment and resulting in power outages. It is also moderately sensitive to potential backwater inundation from elevated levels in the downstream re-regulation reservoir, while the efficiency of the Francis turbines are mildly sensitive to changes in water density resulting from increases in temperature.

4. **Re-regulation reservoir, dam and spillway:** The re-regulation reservoir has a surface area of 1.27km^2 with a capacity of holding up to 7MCM of water. The dam comprises of a concrete gravity dam and includes an un-gated labyrinth type spillway which has been designed to maximise spill capacity equivalent to the 1 in 1,000 year event.

   The reservoir and spillway are, like the main dam and main spillway, sensitive to increases in the design and peak flood events which could result in elevated water levels within the reservoir and have knock-on implications in terms of inundation of the power house and overtopping of the re-regulation saddle-dam.

5. **Re-regulation reservoir powerhouse**: located on the left bank downstream of the re-regulation dam, comprising of one bulb turbine designed for low head flows.

6. **Re-regulation reservoir saddle-dam (dyke)**: 508m long earth-filled structure designed to compensate for low-line topography on the south-west perimeter of the re-regulation dam. The dam has a crest level of 189.4masl giving a total height of 14.4m above ground level.

   The saddle-dam is sensitive to over-topping which if happens repeatedly or if a construction defect is present could result in collapse of the structure. If infrequent, collapse is not likely but over-topping would still result in uncontrolled flows exiting the reservoir into the downstream environment.

7. **Transmission lines**: There are two separate transmission lines. A 230kV line extends 145km from the main dam powerhouse to the Na Bong substation, while an 115kV line extends from the re-regulation dam powerhouse to the Pakxan substation.

The transmission lines have a minor sensitivity to changes in air temperature which will reduce the efficiency of transmission and result in lost power delivery through phenomena such as the corona effect.

8. **Watershed**: The NNP1 watershed comprises 3,700km^2 of mountainous catchment with a total drop in elevation of 2,600m and a mean annual flow volume of 4.7 billion cubic meters. Land cover is 35% deciduous forest, 37% fallow land, 6% evergreen forest and 6% bamboo. The geological formation leads to very small landslide risk, but the steep topography coupled with a weathered lateritic soil structure presents a high risk of hillslope failure – especially in degraded landscapes – which contributes to the moderate sediment yield of the catchment.

   The watershed is sensitive to increases in rainfall intensity and magnitudes, which will alter the proportion of rainfall passing over the catchment as runoff (currently about 67% of rainfall) as well as the frequency of and rates of hillslope erosion, as well as the sediment transport capacity (stream power) of the river to transport sediments into the reservoir.

9. **Resettlement area**: The resettlement area designed for some 3,000 people includes 6,000 ha of land. Of these, the main assets investigated includes 420ha of irrigated paddy rice fields, 150ha of upland rice and 400 ha or rubber and other commercial trees.

   These assets are sensitive to increases in temperature and rainfall which will improve productivity of crops up to threshold values before further increases in precipitation and temperature begin to reduce productivity and hence yield. Due to its location in the floodplain immediately downstream of the saddle-dam, the paddy rice fields are also sensitive to the PMF event and over-topping of the saddle dam structure which could result in crop damages or loss, as well as damages to agricultural infrastructure.

IMPACTS OF CLIMATE CHANGE AND CASCADE HYDROPOWER ON THE OPERATIONS AND INTEGRITY OF NNP1

The combination of the nature of the threat (magnitude, frequency, duration etc) and the specific characteristics of the asset (design, material strength, siting, aspect etc) result in a unique exposure and sensitivity signature which characterises the impact. The coupling of relevant threats with specific assets results in a large amount of impact assessments. These pairings were screened with technical specialists from the NNP1PC and ICEM teams to help identify the most significant threats, and most critical assets to consider. In doing so, the team was able to refine the impact assessment and better focus on those threat-asset pairings considered most critical. This process, conducted during the field mission, resulted in the identification of 12 priority impact pathways of potential interest to the operation of the Nam Ngiep 1 plant. The main findings from the 12 impact assessments are summarised below:

1. **Due to the size of changes projected in the NNP catchment hydrology, climate change represents both a significant risk and an opportunity to the assets and processes of NNP1. Taking advantage of the potential benefits and avoiding some of the most significant risks will require dedicated adaptation response from NNP1PC, though some adaptation initiatives can be phased for implementation during future phases.** Of the ten climate change impact pathways identified as a priority, one offers an opportunity for increased electricity production, and one pathway was identified as priority adverse impact in need of an adaptation response. An additional four impact pathways all present significant risks that need a response, but there is potential for that response to be phased to avoid front-loading capital investment at the project outset.

2. **The most significant CC-benefit to NNP1 is a projected increased energy production potential,** with future climate change conditions likely to enhance the project's capacity to produce energy by increasing the year-round water availability. In an average year, energy production is expected to increase by several percent. This prediction is based on conservative estimates for climate change and so represents a lower estimate with likelihood that benefits could exceed this.

   ➢ *During the dry season and the shoulder seasons to the flood*, increased water availability is projected to increase seasonal energy production. The existing infrastructure would be capable of harnessing this additional energy production with existing turbines running at rated capacity for a longer portion of the year.

   ➢ *During the flood season*, increased water availability is projected to increase seasonal energy production. However, the additional potential to generate will, with the existing infrastructure, remain a foregone or wasted benefit, as the turbines will not be able to make use of the additional flows which will result in increased spillage.

3. **However, NNP1PC baseline energy production estimates assume a quantum of energy production which cannot be replicated by the ICEM suite of models, because the NNP1PC modelling presents a wetter dry season than the ICEM work. This suggests that any potential production benefits predicted with climate change would only compensate for over-estimates by the NNP1PC** with benefits above the quoted production capacity not occurring until later in the 35year time slice. The NNP1PC energy modelling assumes a baseline hydrology that is 32% wetter than the ICEM modelling in the dry season and 3% lower during the wet season. Consequently ICEM annual estimates for primary and secondary energy production are 3% and 16% lower respectively. With climate change, energy production will eventually exceed the NNP1PC baseline estimate amounting to an average increase of several percent 2050.

4. **The most significant impact of climate change is a dramatic increase in the frequency of spillway usage which will over the design life accelerate wear-and-tear of the spillway apron and scour of the riverbed as waters exit the spillway structure**: Under average flow conditions, the four-fold increase in the frequency of usage of the spillway coupled with an associated increase in spillway stream power will accelerate the rate of scour of the river bed at the foot of the spillway apron Stream power is directly proportional to discharge; given an approximate 7% increase in the size of the design flood discharge with climate change and relative to the NNP1PC design flood estimate of 5,210m3/s, the spillway landing zone is expected to experience a comparable 7-10% increase in stream power resulting only in a minor increase in erosion potential. This increase will accelerate the rate of erosion of the river bed alluvial layers but will not appreciably increase erosion of the underlying CH-bedrock.

5. **A number of climate change impacts are also considered moderate which do not need immediate adaptation, but could trigger significant impacts or an accumulated impact during the operating life. Preventative measures could build resilience in these areas and risk threshold monitoring could identify appropriate timing for future adaptation.**

   ➢ *Reduced active storage capacity of the main dam*: Increasing rainfall intensities will enhance rates of hillslope erosion and river stream power, tripling the sediment load entering the main dam. Over 50 years of operation, some 89.5MCM of sediments will flow into the main dam preferentially depositing in the important active storage zone and reducing the active storage capacity by up to 7.5%. This will reduce the regulating capacity of the main dam, increasing spillage during the wet season and storing a smaller water volume into the dry season with implications for foregone and lost energy production.

> *Increased risk of reduced productivity of the agricultural lands of the resettled community*: Climate change will increasing the temperature, evaporation and precipitation conditions for rain-fed rice, rubber and other commercial crops planned for the resettlement area (970ha). In some cases these increases will result in a minor improvement in specific aspects of the crop calendar. However, in general, the dominant impact is to push conditions further beyond the threshold for optimal suitability with a moderate decrease in suitability.

> *Reduced oxygen levels and water quality of dam releases*: Increasing air temperatures at the reservoir surface will increase reservoir water temperatures strengthening stratification in the water column and reducing dissolved oxygen (DO) levels with a knock-on potential for anoxic releases and poor water quality issues downstream of the main dam. The reservoir geometry would dampen this solar forcing and also partially dampen overturning of the thermocline, while the relatively-high position of the penstock intakes would moderate the frequency of anoxic releases reducing the severity of impact. These issues are likely to be more significant for water quality in the re-regulating reservoir (adjacent to the resettled community) than those downstream of both dams as the re-regulating reservoir spillway has capacity for further aeration.

6. A number of impacts with potentially very dramatic consequences were assessed and found to be of very low or negligible impact, these include:

   a. **Over-topping of the main dam**: Increases in rainfall projected with climate change will result in a potential 27% increase in the size of the PMF event reaching a peak inflow of 11,560m³/s. Modelling analysis by the NNP1PC found that there is sufficient safety-margin in the design of the main dam and its spillway to prevent over-topping of the structure, though wave action would intermittently cause some spill over the dam wall.

   b. **Over-topping of the re-regulation saddle-dam during the future PMF event routing uncontrolled flows through the agricultural lands of the resettled community:** With climate change the PMF event will increase the size of spillway releases to a maximum of 7,590m³/s. These releases will induce a rise in the re-regulation reservoir water levels up to 188.5 which is still 0.9m below the crest elevation of the re-regulation saddle dam. Consequently, there is confidence that even with the upper CC projections adopted in this study, over-topping of the re-regulation reservoir saddle dam is unlikely.

7. **Due to the small size and small command catchments of the upstream cascade, the three other projects in the NNP basin do not present any major risk to NNP1 operations under normal operations and a moderate risk under extreme climate conditions**. Concerns of the implications of upstream regulation on normal operations are unwarranted given the small size of the upstream projects (IP11). In addition catastrophic failure of upstream projects presents only a moderate risk to NNP1 and does not jeopardize the safety of main dam water levels, though without warning or coordination such events would present a major concern for operators attempting to manage the event.

ECONOMIC IMPLICATIONS OF CLIMATE CHANGE IMPACTS

Access to economic and financial information was not possible for the ICEM team, which greatly limited the capacity for an assessment of the economic impacts of climate change. Published literature estimates for energy production data and crop damages from other projects in the region were used to monetize two impacts – and then only as order-of-magnitude estimates. The main findings are:

1. **Economic impact of climate change on energy production**: the projected increased in Primary and Secondary energy production will result in an increase of several percent in annual average revenues.

2. **Economic impact of baseline uncertainty on energy production**: The ICEM model estimates an annual power output of, on average, 43.3 GWh less of primary energy and 30.5 GWh less of secondary energy than the NN1PC model, primarily due to lower PE and SE in the period April – August. The economic implication of this is that annual revenues under the ICEM baseline are less than the NNP1PC projections.

3. **Economic impact of damages to paddy rice crops:** Assuming a flooding event affects the whole pre harvest crop along the river banks over an area of 420 ha, economic losses of crop damage would occur for each peak flood event.

RECOMMENDED ADAPTION PRIORITIES

The recommendations are split into three sections: (i) monitoring measures that are required to identify thresholds which would trigger the need to proceeds with future adaptation measures; (ii) implementation of works that introduce adaptation measures now or preserve the capacity for phase adaptation in the future; and (iii) additional Technical Assistance (TA) studies and inputs that serve to confirm the scope and need for critical adaptation interventions.

A - THRESHOLD MONITORING MEASURES

For a number of impacts relating to downstream water quality issues and the impacts of increased spillage on lost energy potential as well as damage to the spillway structures, there is a need for improved certainty on the timing of when these CC impacts will become significant for NNP1. This means a phased approach to adaptation is required. The main objective of the first phase is to reduce this uncertainty through the implementation of a monitoring program of relevant hydro-climate, environmental and infrastructure condition monitoring. The first phase is considered a priority for implementation as part of project operations after commissioning. The second phase would be triggered once critical thresholds in any monitoring parameter have been triggered. The table below summarises the threshold monitoring required as part of the first phase.

NNP1 Asset	Monitoring parameter	Potential frequency of monitoring	Potential trigger value	Consequence
Reservoir water quality	Vertical-depth monitoring of temperature profile	Monthly	TBD	Explore the feasibility of one or more of Adaptation options 1-5
	DO monitoring	Monthly	Based on GOL regulation	
DO content of turbine discharges	**DO monitoring at outlet**	**Monthly**	**Based on GOL regulation**	**Explore the feasibility of one or more of Adaptation options 1-5**
	Odour monitoring at resettlement community residential area	Monthly	Human levels of detection for sulphurous compounds	
Spillway apron and downstream landing zone	Monthly discharges and volumes of spillage	Daily (aggregated at monthly time-step)	TBD	Explore the feasibility of Adaption option 14, 17
	Site inspection of scour conditions of the two structures	Annually during the dry season	TBD	
Energy production	Monthly discharges and volumes of spillage	Daily (aggregated at monthly time-step)	TBD	Explore the feasibility of Adaption option 15, 17

B - ADAPTATION INTERVENTIONS

The following adaptation options should be built into the design and construction phase of project development:

1. **Preventative measures for catchment sediment conservation:** site and develop preventative measures such as check dams and constructed wetlands that allow for increased sediment loads to be trapped within the landscape before they reach the headwaters of the reservoir. These measures should target erosion hotspots in the NNP1 catchments and be developed as part of the NNP1 watershed management plan. In addition efforts to rehabilitate degraded forest areas to enhance soil conservation should also be included as part of the watershed management plan.

2. **Build adaptive capacity for increased wet season electricity production**: inclusion of a blank manifold and provision for an additional penstock should be considered whilst the main dam is still under construction.

C - ADDITIONAL TECHNICAL ASSISTANCE

The CRVA identified the need for a number of additional TA inputs which would enhance the resilience of the NNP1 project and serve to provide greater clarity on the magnitude and timing of risks. These are summarised below:

1. **Rapid catchment condition appraisal and feasibility assessment for a Payment for Ecosystem Services scheme for catchment soil conservation**: A number of adaptation measures identified rely on the identification of erosion hot and sweet spots within the catchment; with the erosion hotspots considered as those areas producing the greatest amounts of hillslope erosion and sweet spots as those areas of forest providing the most important soil conservation services.

   Additional TA would be needed to undertake a GIS-based assessment of hot and sweet spots including an estimation of the sediment conservation potential. This assessment would need some field work to ground truth the findings of the GIS assessment and to identify sites and undertake a rapid feasibility assessment for a network of check dams and constructed wetlands.

   In parallel an institutional assessment would need to be undertaken to review the potential for piloting a Payment for Ecosystem Services (PES) initiative as enshrined in the new national water law for Lao PDR. The institutional assessment would need to include a review of government and community stakeholders and recommendations on the scope, mechanisms and modalities for implementation of the watershed soil conservation measures. Both components would need to be completed in close working cooperation with the NNP1 Watershed management plan.

2. **Technical and institutional feasibility assessment for the establishment of a Nam Ngiep Emergency Response Centre (ERC), including a coordinated Early Warning System**: A number of adaptation options point towards the need for a coordinated response to flood management, including coordination of spillway releases and an EWS, coordination of additional precipitation and stream gauge monitoring by cascade operators and flood forecasting measures as well as the coordination of the sharing of information sharing generated by these measures. Ultimately the responsibility for such coordination lies beyond any individual hydropower operator and requires an active and leading role from the Government of Lao PDR (GOL). An additional TA is needed to support relevant agencies within the GOL and operators of the NNP cascade to design and implement a coordinated response as outlined in adaptation options 18, 19 and 20.

   The main components of this TA would include an institutional review of government agencies and policies for watershed, flooding, disaster and climate change management resulting in a set of

recommendations on the appropriate institutional mechanisms, scope and membership of an ERC. A technical review undertaken in parallel would make recommendations on: (i) optimal siting for additional precipitation and stream gauge monitoring, (ii) appropriate technologies for monitoring stations, (iii) the potential for remote sensing information to inform monitoring and/or flood forecasting efforts, (iv) the need and role for a shared catchment hydrological model, and (v) scope of management guidelines and directives which are used to ensure communication and coordination during flood events.

3. **Hydrological analysis:** In the design of the PMF and its review through the DSRP and CRVA process, NNP1PC has undertaken due diligence to build a robust PMF that makes best use of all available data, compares with existing regional information and PMF estimates of hydropower projects in neighbouring basins such that even under the upper CC projections of this study, there is sufficient confidence in the project's inbuilt safety margin.

However, there remains a regional problem for hydrological analysis as experienced by NNP1 and neighbouring projects – that of highly variable precipitation dynamics resulting from multiple forcings in a poorly gauged context. As noted above, additional monitoring is an essential component in a strategy to fill this gap but will take many years to build the long time series needed for extreme event analysis. Therefore, this study recommends additional hydrological analysis to be undertaken to improve understanding of flood dynamics and support better and more responsive flood management in the Nam Ngiep and other basins of Lao. The main components of the additional assessment are summarised below.

Given the geographical scope of the additional analysis, the findings would be of benefit to a large number of stakeholders; consequently, it is recommended that the Government of Lao PDR with support from Development Partners should take the lead in undertaking the hydrological analysis and consolidating information which can be provided to relevant developers:

a. ***Regionalised frequency analysis*** of hydro-climate event frequencies (precipitation and flooding) that pools data from a wide number of stations and performs statistical analysis to extend the temporal scale of observation data sets which can be used for improved site-specific frequency distributions. This component would result in four main outputs:

   i. a set of improved precipitation frequency estimates for all existing precipitation stations in the area;
   ii. a set of improved flood frequency estimates for all existing hydrological stations in the area;
   iii. precipitation regional growth curve that can be used to calculate precipitation frequencies for sites with no station data; and
   iv. a flood regional growth curve that can be used to estimate flood frequencies for ungauged catchments. These outputs would build confidence in the magnitude and frequency of flood events which are being used to design the NNP1 project and presents potentially, the highest impact adaptation measure of all as it will build confidence in the existing or determine a more robust need for changes in the design of the dams and spillway structures.

b. ***Assessment of correlation between meso-scale phenomena and catchment precipitation dynamics***: An improved understanding of the correlation of the Southern Oscillation Index (SOI) with peak rainfall events in the NNP catchment would allow a potential long-term forecasting option for the basin which assessing the timing of each flood season relative to the wax and wane in the el nino/la nina phenomena. This information could give at the seasonal time-scale a level of alert or readiness when a particular flood season is expected to be high or extreme.

c. ***Simulation of event intensities under baseline and future cyclone conditions***: new methods using Regional Circulation Models (RCMs) such a RegCM developed by NCAR are emerging which can simulate cyclone tracks to derive detailed event rainfall patterns and peturb them to predict changes in extreme events that may occur under a range of future CC projections. This component would involve identifying the most significant cyclone event to hit the NNP catchment over the past 50 years and use the RegCM model to estimate how sub-daily rainfall intensities would change under a range of future climate scenarios. This component would give much better estimations of changing hourly rainfall dynamics within the catchment which are critical to robust PMF estimation and could be used to confirm or adjust the accepted PMF used in the design of NNP1.

1 INTRODUCTION AND BACKGROUND

1.1 CLIMATE CHANGE AND HYDROPOWER INFRASTRUCTURE

Hydropower infrastructure development represents a substantial investment, both as an upfront capital cost and in on-going maintenance. These investments are made on the understanding that the structures will have long design lives (20-100years) allowing their benefits to countries and economies to accrue over decades of use. In order to safeguard these investments, engineers are asked to design for and manage risk over the project life span which requires a compromise between the desired level of safety, performance optimisation and cost minimisation.
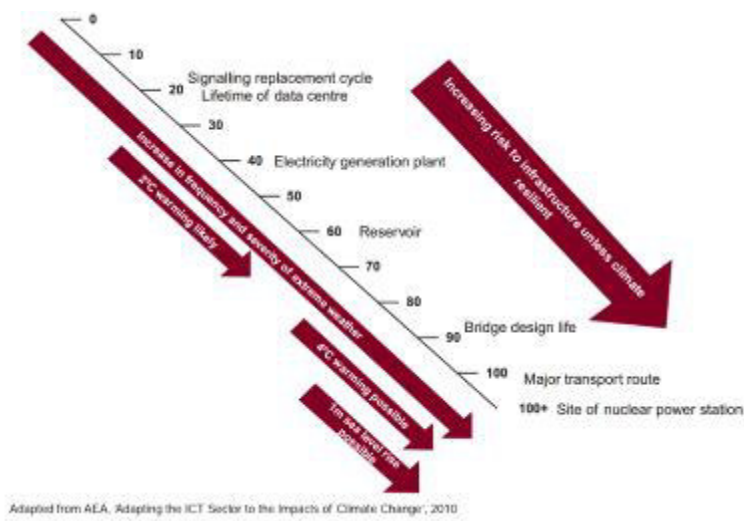
Figure 1 - Comparison between life span of infrastructure projects and climate change projections (Source: AEA, 2010)

Traditionally, risks have been characterised based on historical data records with engineers analysing spatio-temporal trends and variations in key risk-inducing parameters such as floods, droughts, storm events, heat waves and landslides. However, the documented evidence of climate change and its impact on the water cycle has made clear that the idea of hydro-meteorological processes being stationary and fluctuating within an unchanging envelope of variability can no longer be the design assumption for water management infrastructure (Milly et al, 2008). There are clear and quantifiable signals of change within hydro-meteorological parameters which are changing the characteristics of the atmosphere and water cycle within periods of decades; and which require a fundamental rethinking about how we characterise risks.

Anthropogenic emissions of greenhouse gases are expected to lead to significant changes in climate over the next century (IPCC, 2013). Many of the design parameters defined during the design phase will change in response to global climate change. This will have implications for the design, operation and viability of hydroelectric power stations[1].These risks can be summarized as follows:

- **Performance risks:** hydropower projects are carefully designed based on historical hydro-climate information and the performance of the plant is sensitive to changes in these parameters. For example, electricity output is highly sensitive to changes in flow passing through the turbine and so reservoir inflows. It is also sensitive to changes in operating head which will be affected by changes in seasonal water availability and draw down during the dry season. Changes in rainfall and evaporation rates will alter the daily, weekly and seasonal water available for electricity generation ultimately

---

[1] In some global studies, a 10% reduction in rainfall can result in a loss of hydropower generation by 25 to 50%. Simultaneously an increase in temperature of a few degrees might result in substantially higher evapotranspiration having a severe impact on hydropower as well, while year to year climate variability may well lead to a lower energy security in general. In general, climate change and its impacts pose several generic risks to hydroelectric dams and reservoirs.

affecting the performance of the project. In some cases globally, these changes can result in a positive benefit to electricity generation with increases in dry season flows allowing for more regular stream flow and greater production during the dry season.

- **Reservoir life risk:** With long operation design lives (50-60years) hydropower operations are sensitive to the ongoing capacity of the reservoir to store waters. Increasing sediments loads enhance deposition in the reservoir reducing both the dead and active storage and hence the useful operating life.

- **Safety risks:** Flood management is a large component of risk for a hydropower facility. Hydropower projects manage floods by allowing for buffer storage within the reservoir and by sizing the spillway discharge structures at sufficient size to pass the design flood event without overtopping. Climate change is in general anticipated to increase the magnitude of flood quantiles due to increasing atmospheric moisture retention capacity and precipitation intensity, and likely increasing frequency of extreme events. Flood magnitudes will also be influenced by potential changes in catchment conditions. Ensuring the integrity of the dam structure and safe passage of the design flood event is critical for both the generation potential of the plant as well as the safety of downstream inhabitants and the capacity for a project to manage changes in flood magnitude and intensities is one of the critical climate change issues for the sector.

- **Secondary risks of climate change:** changing climate conditions will induce changes in the frequency, magnitude and intensity of secondary catchment risks such as hillslope failure and landslides. Increasing landslides can exacerbate issues of dam failure and reduced storage capacity (when occurring direct into the reservoir) or block upstream channels reducing inflows and increasing the chance of flash flood flows when the upstream blockage is breached. Sediment trapping in the reservoir will lead to the loss of sediment to the downstream of the dam.

- **Environmental Risks:** Water temperature is crucial for the physical, chemical and biological dynamics of the rivers and lakes. Water temperature can affect both the chemical (e.g., dissolved oxygen concentration) and biological (e.g., fish growth) processes occurring in the water body. Increased air temperatures will lead to increased reservoir water temperatures which can cause impacts on the composition and richness of this ecosystem. These impacts can compromise compliance of the hydropower facility with its environmental and social safeguards and national regulatory frameworks and affect the success of benefit sharing initiatives.

- **Risks due to changing patterns of water demand:** Warmer climates will increase the demand for evapo-transpiration, in particular increasing demand for irrigation which may present a conflict to hydropower generation in some locations, or include the need for irrigation of agricultural lands established as part of a resettlement program.

Managing these risks requires interventions during the design, operations and maintenance phases of the infrastructure life-cycle. These interventions are often costly and need to be based on robust science comparable in methodology and accuracy with the original design calculations.

1.2   THE LAO CONTEXT FOR HYDROPOWER SECTOR VULNERABILITY

The People's Democratic Republic of Lao (Lao PDR) is a landlocked, water resource-rich country positioned between the energy hungry economies of China, Thailand and Viet Nam. During the 1990s the Government of Lao (GOL) adopted the New Economic Mechanism (NEM) a policy designed to accelerate national economic growth by fostering more open policies for investment – especially in the power, industrial, services, agriculture and commercial sectors (DEB, 2014). This new policy environment has seen a dramatic expansion of large hydropower in Lao PDR with 13 projects existing and 29 under construction and 49 planned (MRC, 2011; ICEM, 2013). The majority of these investments are private-sector led under a Built-Operate-Transfer (BOT) model, with in the order of 80-90% of the electricity production destined for export to a neighbouring country, and a small allocation of production reserved to meet domestic demand. The model allows investors to connect energy resources to the main economic markets, with the GOL benefitting during the concession period from taxation, and then finally owning the infrastructure after the concession period is completed (typically 20-30years for hydropower in Lao PDR).

Accounting for the impacts of climate change over the operational life of hydropower projects is critical for Lao PDR given the rapid pace of development in the sector and the country's high level of climate variability (ICEM, 2013). Without robust risk assessments and responsible adaptation responses there is potential for climate change to reduce the economic benefits from these projects and induce some or all of the risks listed above.

1.3 OBJECTIVES OF THE STUDY

With a strong commitment to environmental and social safeguards, and cognizant of the need for an informed science-based consideration of climate change NNP1PC has commissioned ICEM to undertake a climate change risk and vulnerability assessment (CRVA) of NNP1. The purpose of this study is to work with the NNP1PC design engineers and decide on how to integrate the CC-induced changing hydro-climatic conditions into the infrastructure design process. The success of the Climate Risk and Vulnerability Assessment (CRVA) relies in its ability to build a credible scientific evidence base which quantifies change in the design parameters most important to design engineers. This means going beyond an assessment of how temperature and precipitation is changing and converting global climate change into changes in flooding, landslide potential, river flow and design event return periods.

The NNP1 CRVA is the first comprehensive assessment of climate change impacts to a hydropower facility in Lao PDR and the Mekong Region. It is also one of the first few comprehensive studies worldwide[2], positioning the NNP1PC as a regional leader in project risk management.

The overall objective of the study is to assess the climate risk of the proposed Nam Ngiep 1 Hydropower Project (NNP1) in Lao PDR, and to identify measures to increase its climate resilience.

This study will be conducted in two separate phases: Phase 1 – a climate change impact assessment, and Phase 2 – a climate change adaptation assessment. In the course of Phase 1, the study will: (i) develop an inventory of key assets and functions of the NNP1 facility, (ii) assess impacts of climate variability and projected climate change on the performance and integrity of these assets and functions; (iii) estimate the potential costs of these impacts; and (iv) present the results of the assessment to the Borrower, ADB and other relevant stakeholders on the implications of the impacts of climate change on the project and seek agreement on the need for Phase 2. During contract negotiations the NNP1PC also requested the ICEM team to simulate and assess the impacts of upstream hydropower projects within the Nam Ngiep basin on the operations and safety of NNP1. In the course of Phase 2, the study will identify concrete adaptation options to climate change prioritizing options that address the most critical climate change impacts.

1.4 DESCRIPTION OF THE NNP1 PROJECT

Nam Ngiep 1 Hydropower Project is a hydropower generation facility under development in the lower Nam Ngiep Basin, a tributary to the Mekong River (Figure 2). The Nam Ngiep 1 project was first identified in the early 1990s with feasibility studies completed in 1991 by Sogreah, and 1998-2002 by Nippon Koei (Kansai, 2013). In 2013 the Nam Ngiep 1 Power Company (NNP1PC) was formally established as a joint venture between the project investors, KANSAI Electric of Japan , EGAT International of Thailand and Lao Holding State Enterprise. Additional financing was also sought from the Asian Development Bank through the Private Sector Operations Department (PSOD) and approved in August 2014. In 2014, the project commenced construction starting with preparation of worker's camps, access roads and preparations for the foundation of the re-regulating reservoir.

The catchment area is 4,533 km2 at the Mekong confluence, and 3,700 km2 above the dam site. Precipitation over the catchment is estimated at roughly 1,870 millimetres per year (mm/year)[3]. The catchment is hilly, with

---

[2] The International Finance Corporation (IFC) has undertaken two CRVA for hydropower facilities in Zambia and Nepal, and there were some pioneering assessments of climate change impacts on the North American hydropower sector in the mid-2000s.

[3] There are few rainfall gauging stations within the Nam Ngiep catchments and estimates of annual rainfall vary dramatically, this estimate is provided by NNP1PC, while Ministry of Energy and Mines (MEM) estimates mean catchment rainfall to be in the order of 2,400mm/yr making it one of the wettest catchments in Lao PDR.

elevations ranging from 157 meters above sea level (m.a.s.l..) near the outlet to over 2,800 m.a.s.l.. in the headwaters. Annual mean inflow to the proposed reservoir is estimated at 148.4 cubic meter per second (m^3/sec), based on a relatively short systematic flow gauging record. This is equivalent to approximately 1,265 mm/year, or roughly 67% of estimated precipitation input to the catchment.
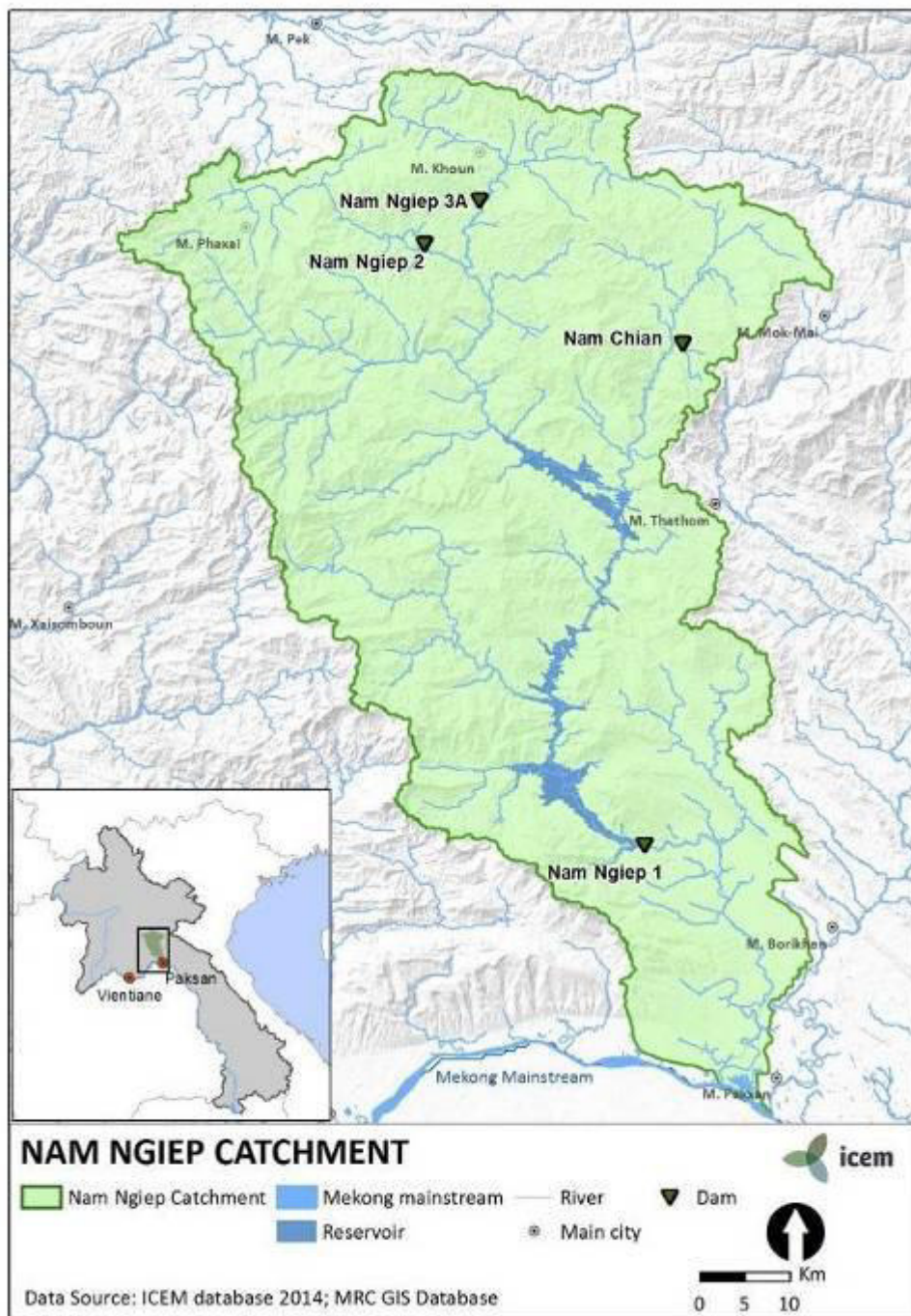
Figure 2 – The Nam Ngiep catchment and location of the hydropower projects

Primary components of the Project are a concrete gravity dam, storage reservoir, main power station and re-regulation power station; and power regulation and transmission facilities. The NNP1 project has been designed to take advantage of the hydro-geological conditions of the Nam Ngiep basin, with the main dam positioned within a steep natural canyon in the lower Nam Ngiep catchment. This canyon allows the developer to build a large head reservoir with a total storage volume of 2.2 billion cubic meters with the capacity for seasonal regulation, which combined with a significant wet season flow allows for an installed capacity of

272MW. The project is designed for daily peaking operation (16hours on and 8 hours off) for six days of the week with a design annual energy output of 1,515GWh which is destined for export to Thailand under a Power Purchase Agreement (PPA) agreement with EGAT.

The decision to operate NNP1 as a peaking project will result in rapid fluctuations in downstream water surface elevations. As a result, NNP1PC has included a re-regulation reservoir as part of the design. While the site conditions for the main dam are highly favourable, the site conditions for the re-regulating reservoir presented a greater challenge for design engineers as downstream of the dam site the river enters a large, flat floodplain which eventually drains into the Mekong near Pakxan. Because of the low-lying topography, the re-regulating dam required an additional earth-filled saddle dam/dyke to block a historic bi-furcation channel and prevent avulsion of the river flow into its old channel (Figure 3). The re-regulating reservoir will operate under continuous mode and a powerhouse house has been installed with a capacity of 18 MW, and the electricity generated destined for the domestic market.
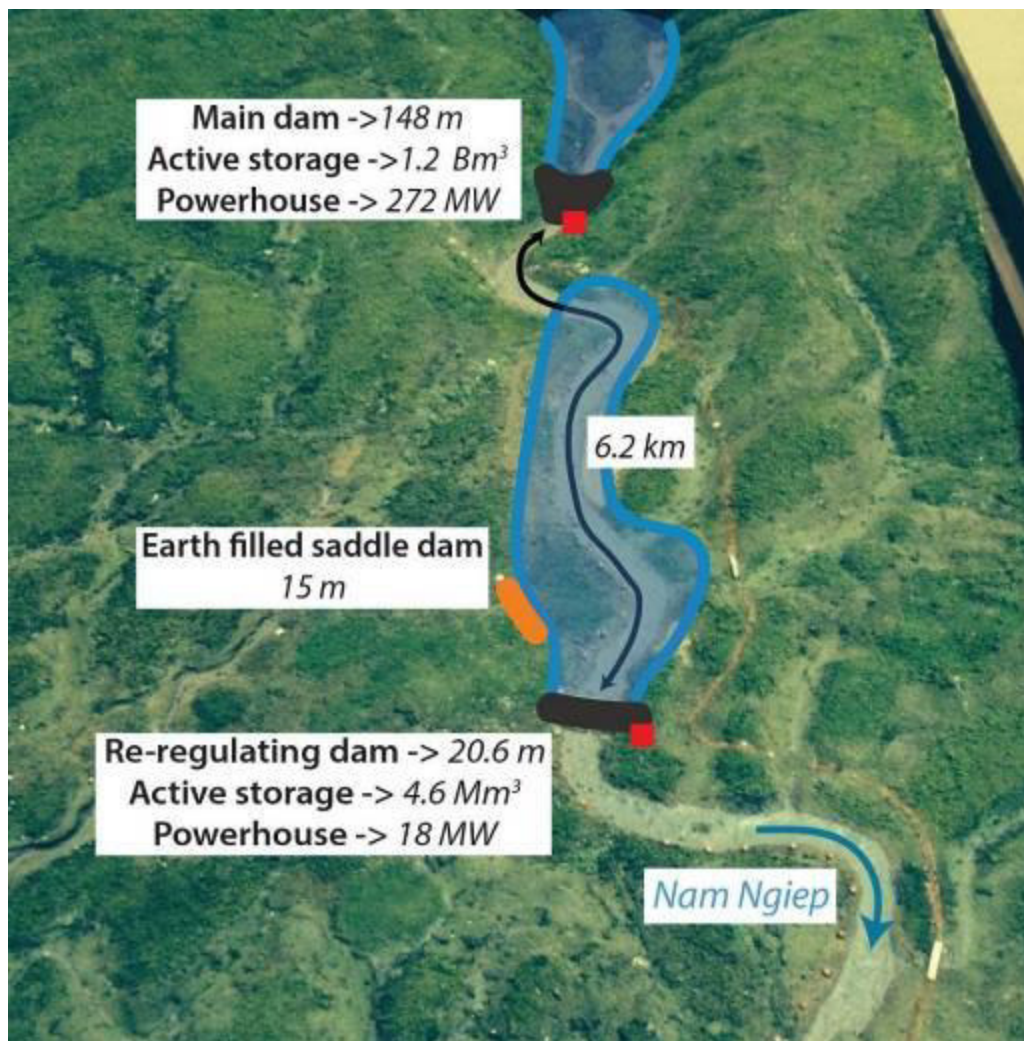
Figure 3 – Siting of the Nam Ngiep 1 main dam and re-regulating dams: *the main dam is positioned within a natural canyon providing favourable conditions for a reservoir; the re-regulating dam is located at the start of the Nam Ngiep floodplain within flat topography providing some challenges for containing the re-regulation reservoir. (Photograph is of a 3D physical model of the NN catchment)*

The Project is designed as a single-use facility, and the main dam and reservoir are not designed for flood control. Flood waves are routed through the reservoir (any vacant storage can be occupied by floodwaters, but no flood pool is maintained). The normal water level (NWL), equivalent to flood level, is 320.0 m.a.s.l. and the minimum operating level (MOL) is 296.0 m.a.s.l.. The maximum height of the dam is 323.5 m.a.s.l., which is

achieved through the inclusion of a 1.5 m parapet above the top of the dam wall. After commencement of operation, the environmental flow rate will be augmented to 27m³/s released from the re-regulation dam.

1.4.1   Overview of project operations

Figure 4 below illustrates the hydraulics of flow within NNP1. Water from the main reservoir is taken to the Frances turbines in the main powerhouse 148 m below and downstream of the main dam. Discharge from the powerhouse and spillage from the main dam then flows along the length of the 6.2 km re-regulation reservoir. The re-regulation dam was built to regulate discharge from the main dam and powerhouse before releasing downstream river. Water from the re-regulation dam is taken through a bulb turbine located in a powerhouse next to the re-regulation dam. The reservoir is expected to be highly efficient in terms of energy production due to the dam's large storage capacity relative to average flood conditions. This means that during long term operations the reservoir is likely to have a spillage factor of 5-7%.[4]
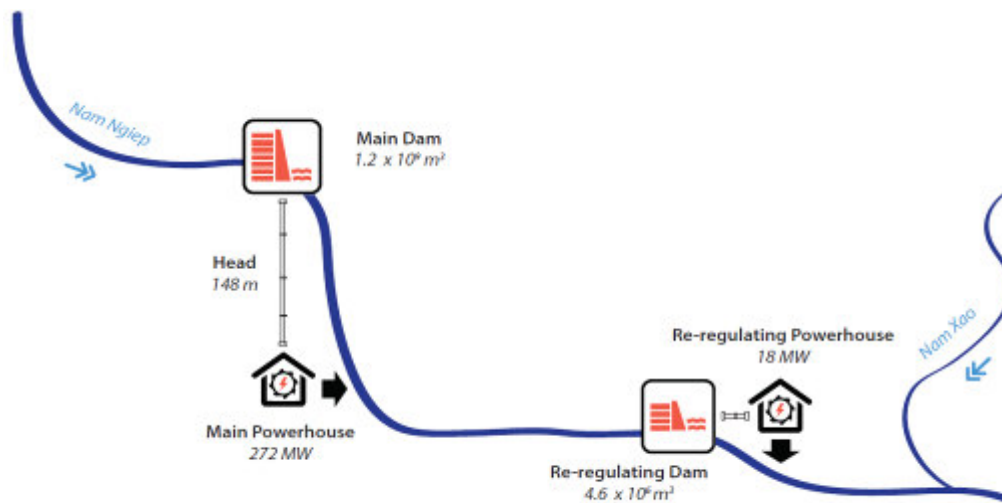
Figure 4 - Schematic diagram of hydraulic flow at NNP1

 To secure the storage volume of the re-regulating reservoir, NNP1 will also construct a saddle-dam/dyke toward the valley upstream of re-regulation dam. The resettlement area will be located downstream of the dyke. In total the resettlement area is designed for close to 3,000 people and includes 5 villages and nearly 1,400 ha of farmland – primarily for cultivation of rice.

---

[4] The spillage factor reflects the proportion of inflows which will not pass through the turbines and instead passes through the spillway. The factor was computed based on a 30-year daily simulation of reservoir operations, undertaken by NNP1PC with their TANK model and shared with the ICEM team.

Location of future re-regulating dam and subsidiary powerhouse

River section between main dam and re-regulation dam contains significant in-channel deposits and features

Location of future main dam to span canyon

Nam Xao river – confluence located downstream of re-regulation dam

Figure 5 – Site conditions at main project features of the NN1 project

1.4.2   Project layout and design

The project is situated on Nam Ngiep River with two main construction areas: the main power station with its reservoir of 66.9 km² and the re-regulation power station located 6.2 km downstream of the main dam. The project also has 507.5 m long dyke on the right bank of the Nam Ngiep River and upstream of the re-regulation dam to protect a low elevation area which could have once been the original course of the river.

A – MAIN POWER STATION

The main power station includes the reservoir, main dam, spillway, powerhouse and turbines. Figure 6 shows the location of these facilities; intakes, penstocks, and a spillway are built inside the dam body. A 230 kV transmission line will also be constructed to transfer energy production from the main powerhouse to Nabong Substation. All of this energy production will be exported to Thailand.
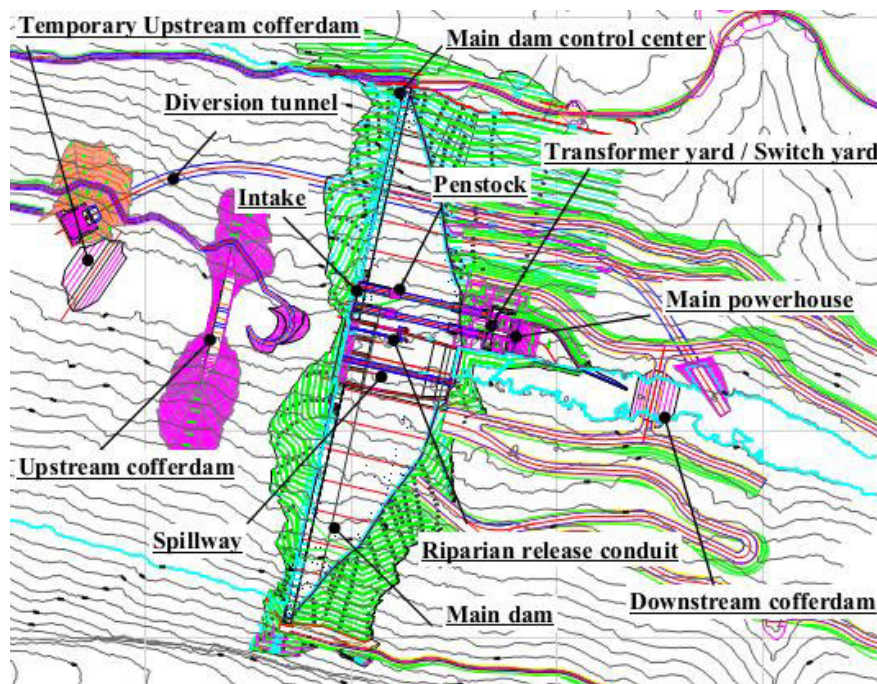
Figure 6 - Layout of the main dam facilities *(Source: Technical report on NNP1, 2013)*

The main specifications of the main power station are shown in Table 1 below.

Table 1 - Main parameters of the main power station

Facility	Facility description	Specifications
Main reservoir	Flood/Normal water level	EL. 320 m
	Minimum water level	EL. 296 m
	Reservoir surface area	66.9 km^2
	Effective storage capacity	1,192 x 10^6 m^3
	Catchment area	3,700 km^2
	Average annual inflow	148.4 m^3/s
Main dam	Type	Concrete gravity dam (Roller-Compacted Concrete)
	Dam height	148 m
	Crest length	530 m
	Crest level	323.5 m
Spillway	Gate type	Radial gate
	Number of gates	4
	Design flood	5,210 m^3/s (1,000-year)
Intake	Discharge capacity	230 m^3/s
Penstock	Type	Covered by concrete and embedded
	Number	2
	Length	185 m
	Diameter	5.2 m
Powerhouse	Type	Semi-underground
	Dimension (L x W x H)	25 x 62.5 x 47.2 m
Turbine and generator	Maximum plant discharge	230 m^3/s
	Effective head	130.9 m
	Type of turbine	Francis
	Rated output	272 MW (at Substation)
	Annual power generation	1,515 GWh (at Substation)

B – RE-REGULATION POWER STATION

The re-regulation power station facilities include the re-regulation dam and powerhouse as seen in Figure 7. The re-regulation dam is located 6.2 km downstream of the main dam and was designed to store the outflow from the main power station which operates for 16 hour peak generation and to release it to the downstream evenly on 24-hour basis. An un-gated spillway was selected to allow overflow during flood event, the spillway has a labyrinth structure to maximise discharge during flood events and so minimise back-water head rise within the reservoir. There is also a saddle dam (dyke) on the right bank upstream of the re-regulation dam. This dam protects the downstream resettlement area from water inundation due to over-topping of the re-regulation reservoir.

Energy generation from the re-regulation powerhouse will be transmitted to Paksan station providing electricity to Paksan. The main specifications of the re-regulation power station are shown in Table 2 below.
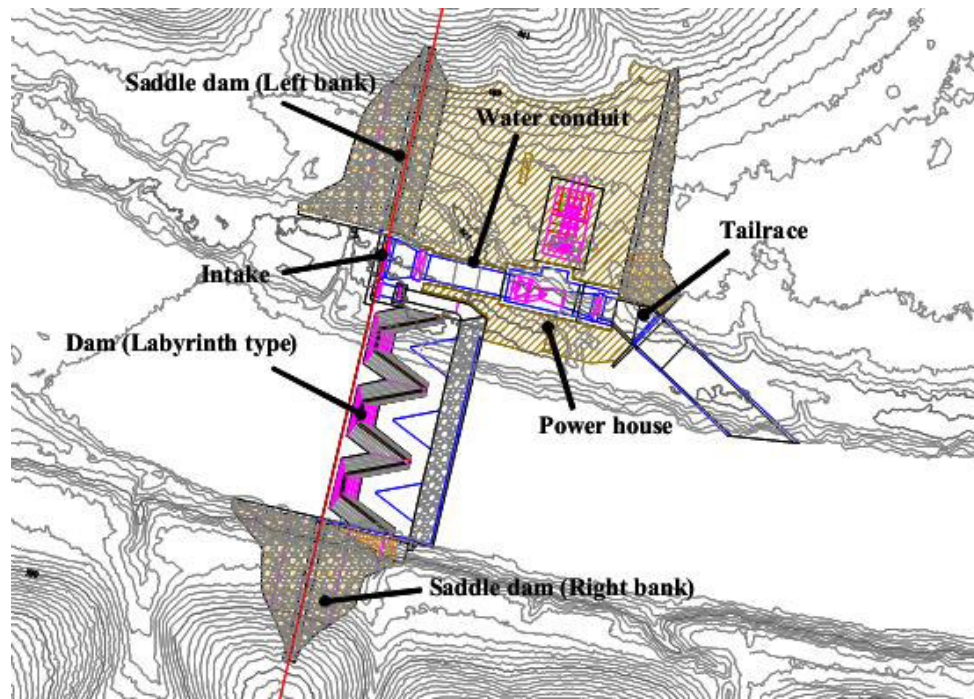
Figure 7 – Layout of re-regulation dam facilities *(Source: Technical report on NNP1, 2013)*

Table 2 - Main parameters of the re-regulation power station

Facility	Facility description	Specifications
Re-regulation reservoir	Flood water level	EL. 185.9 m
	Normal water level	EL. 179 m
	Minimum water level	EL. 174 m
	Reservoir surface area	1.27 km^2
	Effective storage capacity	4.6 x 10^6 m^3
	Catchment area	3,725 km^2
Re-regulation dam	Type	Earth dam
	Dam height	22.1 m
	Crest length	90 m
Spillway	Gate type	Un-gated spillway (Labyrinth type)
	Design flood	5,210 m^3/s (1,000-year)
Intake	Discharge capacity	160 m^3/s
Powerhouse	Type	Semi-underground
	Dimension (L x W x H)	46.4 x 22.05 x 49.1 m
Turbine and generator	Maximum plant discharge	160 m^3/s
	Effective head	12.7 m
	Type of turbine	Bulb
	Rated output	18 MW (at Substation)
	Annual power generation	105 GWh (at Substation)
Saddle dam (Dyke)	Type	Earth dam
	Crest length	507.2 m
	Dyke height	14.4 m

C – RESETTLEMENT AREA

The resettlement area of Houay Soup is close to the dam site on the right bank of the Nam Ngiep, encompassing an area more than 6,000 ha. It will consolidate into one village administration the 4 villages from the zone 'Lower Reservoir Area' (zone 2LR) and 1 village from the Construction area (zone 3), consisting of *circa* 3,000 people. It gets its name from two tributaries to the Nam Ngiep, Houay Soup Gnai and Houay Soup Noi. The bigger of the two Houay Soup Rivers runs 8 km from the mountain slopes to the southwest of the resettlement site. The flatter lands along both banks of the Houay Soup River will provide more than 400 ha of irrigated paddy fields as well as upland rice fields, grassed areas, cash crops, and commercial tree plantations. The population distribution by ethnicity shows that the 3 main ethnic groups in the project area are Lao Loum, Hmong, and Khmu.

In discussions with Project Affected Persons (PAPs), the initial concepts of the land use for the 6,000 ha were expressed as follows in the Table and Figure below.

Table 3 – Initial concepts for land use for the resettlement area

Use	Area (ha)
Irrigated paddy rice fields	420
Upland field rice	150
Other cultivated land	820
Pasture land	600
Forest for firewood	300
Community facilities	50
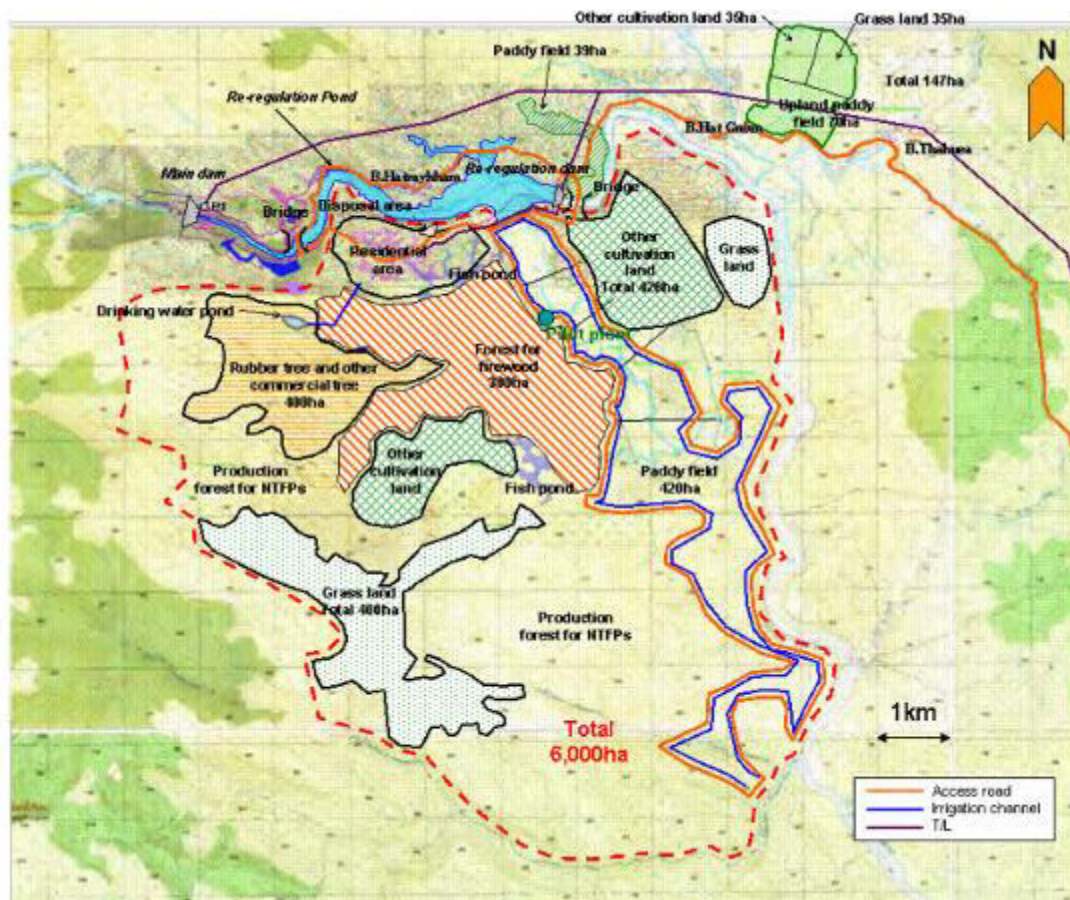
Figure 8 - Land demarcation plan discussed with PAPs

The upland rice fields would be located in a mountainous area north of the confluence of the Nam Ngiep River with the Nam Xao River, whereas the paddy rice fields would be located, as previously mentioned, along Houay Soup River all the way down to the Nam Ngiep confluence and river bank.

A resettled community is a complex system and in its complexity many entry points for a climate change impact assessment can be found, tackling issues such as health and disease of the inhabitants, of the animals and flooding of the area. For the sake of simplicity this study will focus on the suitability in terms of location and productivity of the chosen agricultural land, and on its proposed irrigation system. Such an impact assessment will allow the safeguarding of resettled people and will ensure that future benefits are not threatened.

1.4.3   Operation rules

A – MAIN POWER STATION

The main power station is planned to operate 16 hours on a weekdays (Monday through Saturday) from 6 am to 10 pm as peak energy generation and Primary Energy (PE) production. The off-peak generation is conducted only when surplus water is available.

i.   **Lower Rule Curve (LRC)** – PE will only be produced when water level in the reservoir is higher than the LRC. When the water level falls below LRC, the plant will stop operating.

ii.   **Upper Rule Curve (URC)** – when water level in the reservoir is higher than URC, the plant will operate to produce PE and Secondary Energy (SE).

iii.   **Excess Rule Curve (ERC)** - When the water level of the reservoir is higher than ERC, the plant will operate to produce PE, SE and (Excess Energy (EE).

Figure 9 – Rule curves of the main reservoir *(Source: Technical report on NNP1)*

B – RE-REGULATION POWER STATION

The re-regulation reservoir will store outflow from the main reservoir for 16 hours of operation then regularly release water downstream on a continuous 24 hour basis. The re-regulation power plant aims to operate 24hours however water released from re-regulation will be controlled gradually depending on water a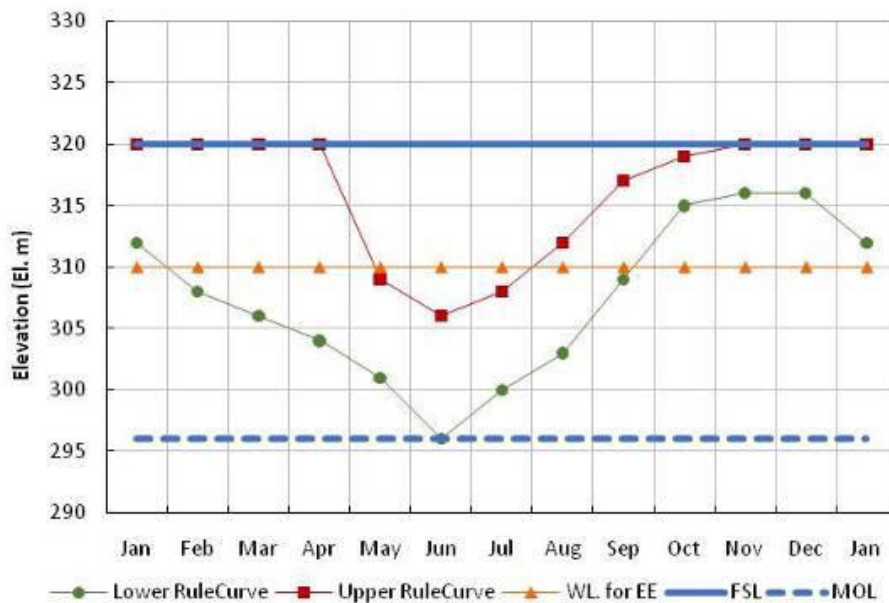vailable in the re-regulation reservoir. Water released downstream also needs to meet with a minimum 27 m^3/s for riparian release.

1.4.4   Assets

The main assets of NNP1 project are listed in Table 4 below. These assets will be the main focus for assessing climate change impact and vulnerability.

Table 4 – Main assets of NNP1 project

No	Asset	Facility description	Quantities
1	Main reservoir	Reservoir surface of 66.9km^2 with the capacity of holding up to 2,238 MCM of water	1
2	Main dam	Concrete gravity dam (Roller-Compacted Concrete)	
		Bell-mounted intake on the main dam body with sill level at EL. 276.1 m	2
		Penstock embedded in concrete over a length of 185m and located on the left side of the dam	2
		Radial gated spillway is mounted on the top of the main dam	4 gates
3	Main powerhouse	Semi-underground powerhouse with the ground level set at EL. 193 m (1000 year flood water level is 192.1 m)	1
		Vertical Francis turbines	2
4	Re-regulation reservoir	Reservoir surface of 1.27 km^2 with the capacity of holding up to 7 MCM of water	1
5	Re-regulation dam	A concrete gravity dam	1
		Un-gated labyrinth type overflow spillway	1
		Bell-mounted intake on the dam body	1
6	Re-regulation powerhouse	Powerhouse is located on the left bank downstream of the re-regulation dam	1
		Bulb turbines	1
7	Dyke	earth –fill structure associated with the re-regulation dam to compensate for low-line topography on the south-west perimeter of the re-regulation reservoir	1
8	Transmission lines	230 kV transmission line connecting the main powerhouse to Nabong Substation	1
		115 kV transmission line connecting the re-regulation powerhouse to Pakxan station	1
9	Watershed	- Size: 3,700 km^2 - Drop in elevation: over 2600 m - Land cover: 35% deciduous forest, 37 % old and young fallow land, 6%, evergreen forest , 6% bamboo - Sediment production: 1.07 Mt/year - Average annual flow at dam site: 4.7 billion m^3	1
10	Resettlement area	Four assets:	1

No	Asset	Facility description	Quantities
		- 420 ha of irrigated paddy rice fields - 150 ha of upland rice fields - Rubber plantation - Irrigation system	

1.5   CASCADE HYDROPOWER DEVELOPMENT IN THE CATCHMENT

As one of the wettest catchments in the Lower Mekong Basin and host to some of the highest peaks in Lao PDR, Nam Ngiep catchment has a high technical-potential for hydropower development along the river and its tributaries. Currently, there are four hydropower projects under development in the catchment and 1 project is under consideration (Figure 10). The three projects upstream of Nam Ngiep 1 are situated relatively high in the headwaters of the catchment and predominately rely on large elevation drops in the topography, not large river flow, for their electricity production. In all cases the upstream projects rely on an inter-tributary transfer of water to maximise the potential energy conditions between the reservoir and the turbines:

i. **NNP1** is the most downstream dam on Nam Ngiep River considered in this study and about 50 km from Pakxan. The NNP1 reservoir will be a biggest reservoir within Nam Ngiep catchment with capacity of holding 2,237.83 MCM of water. Its catchment covers over 81% of the Nam Ngiep total catchment area.

ii. **Nam Ngiep 2 (NNP2)** is on Nam Sen River – a tributary of the Nam Ngiep River and about 94 km upstream of the NNP1 dam site. The NNP2 powerhouse is about 10 km away from NNP1 reservoir. It has a storage capacity of 151.8 MCM which is 6.8% the volume of the NNP1 reservoir. The project includes an inter-basin transfer between the Nam Sen and Nam Siam rivers and a diversion tunnel to supply the reservoir during the dry season from the headwaters of the Nam Ngiep.

iii. **Nam Ngiep 3A (NNP3A)** is on Nam Ngiep river and about 100 km upstream of NNP1 dam site and directly upstream of NNP2. It has a small reservoir with storage capacity of 13.8 MCM, that is. only 0.6% of the NNP1 reservoir volume.

iv. **Nam Chiane project** is on the Nam Tong River, a tributary of the Nam Ngiep River and about 74 km upstream of the NNP1 dam site. It has a storage capacity of 23.12 MCM which is 1% of the NNP1 reservoir volume.

v. **Nam Pot** project is located on Nam Pot River directly downstream of NNP2. This proposed project is small (capacity of 15 MW) and still under consideration. Given that no firm plans or details were available for the Nam Pot and that the project lies downstream of NNP1, it was not considered further in the CRVA.

The main features of cascade hydropower projects upstream of NNP1 are summarised in Annex I.

Although small compared to NNP1, these upstream projects will influence the inflow hydrology into the NNP1 reservoir, altering the timing of inflows under normal operating conditions and especially contributing to the NNP1 flood risk during extreme events depending on how flood waters are stored or passed through the upstream reservoirs.
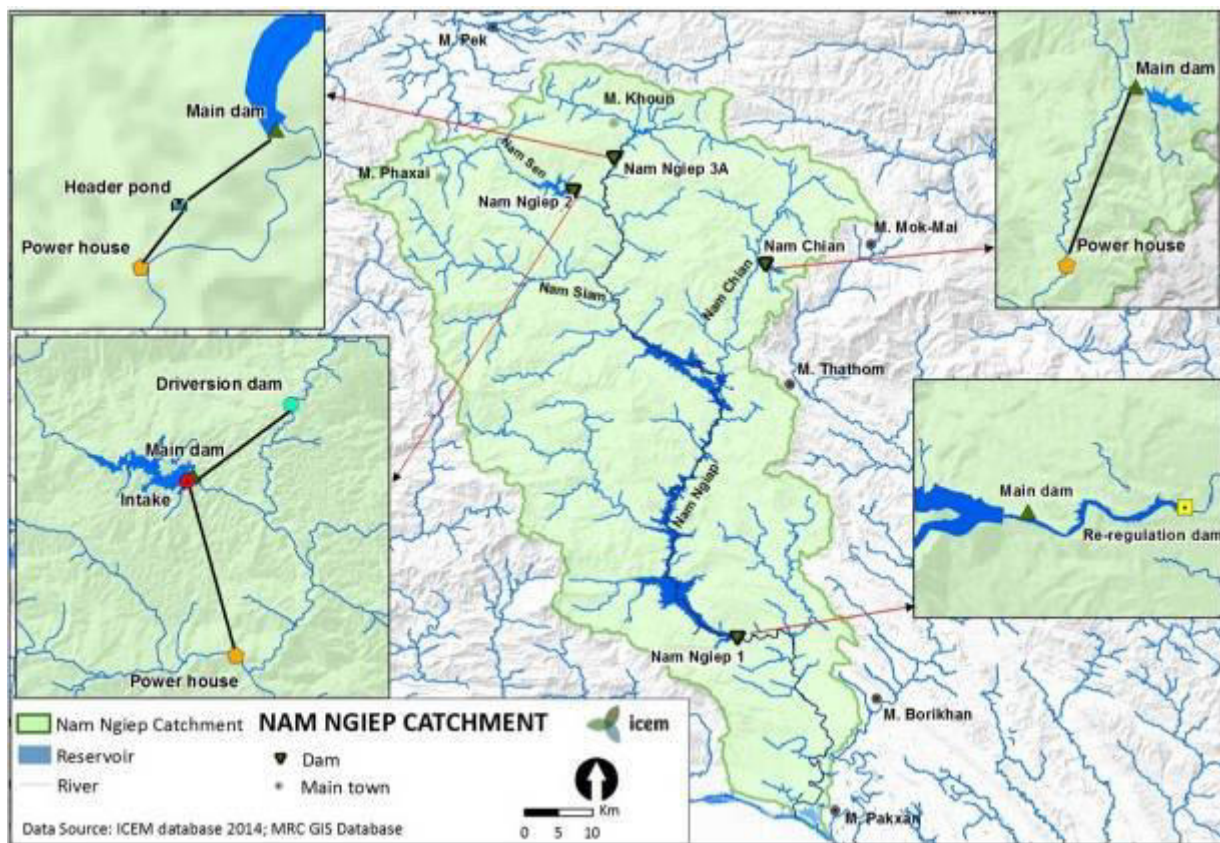
Figure 10 – Cascade hydropower in the Nam Ngiep catchment

Focussing on the implications of the cascade on NNP1, an assessment of the future flow and water levels in the Nam Ngiep River will need to incorporate the changes of flow due to the operation of this upstream hydropower. Therefore, to assess the incremental change associated with upstream hydropower development, the following two scenarios have been selected:

1. *Scenario A:* Change in flow to NNP1 when all upstream cascade hydropower are in operation

2. *Scenario B:* Dam break of the upstream project - routing of downstream flood wave due to failure of the earth dam associated with undiscovered construction defect releasing the whole contents of the reservoir into the NNP1 reservoir in the post-flood season.
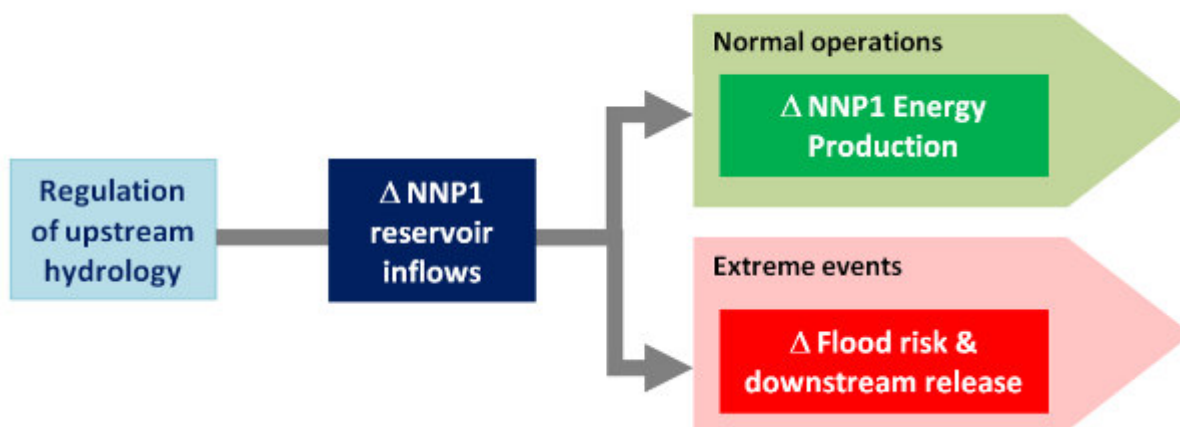
Figure 11: Influence of the Nam Ngiep upstream cascade on NNP1 energy production

25

2   ASSESSMENT METHODOLOGY

2.1   APPROACH TO THREAT ANALYSIS

A review of recent global and regional climate modelling, and recent studies of climate change impacts on the Lower Mekong Basin indicate that the region may become more than 2^0C warmer compared with the average for the period from 1970 to 1999 by mid-century (ICEM, 2013). Existing projections also indicate that the basin will most likely experience moderate increases in precipitation in the wet season, and potentially a more prolonged dry season. However, impacts on basin runoff are more uncertain, with many recent studies projecting changes in discharge of between -15% and +15% of current annual discharge. AA rapid desktop assessment undertaken by ADB Regional and Sustainable Development Department (RSDD) recommended that a hydrologic simulation study should be conducted to explore the impacts of climate change on the Nam Ngiep Catchment with a primary objective to identify critical thresholds at which alterations in discharge are likely to affect the reliability of power generation, and the likelihood that such conditions might be encountered over the design life of the project. The modelling approach below was designed in direct response to this.

Changes in river discharge will directly affect the operations and management of the hydropower plant. A reduced or increased river flow could lead to the loss or gain in energy production; an increase or reduction in sedimentation in the reservoir; or an increase in spillage which the spillway may or may not have capacity to cope with. Therefore, in order to assess the impact of climate change to NNP1, it is important to understand the hydrological conditions and quantify river discharge changes for the whole catchment under climate change.
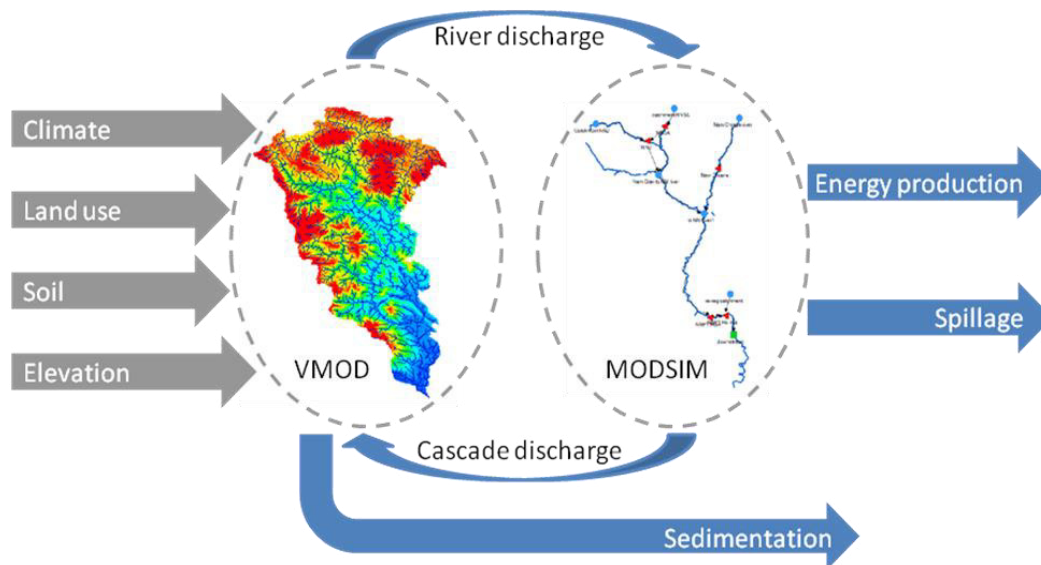
Figure 12 - Linkages between models

As there are four hydropower projects being developed in the upstream of the Nam Ngiep catchment, changes in river discharge to NNP1 will not only be affected by climate change but potentially also by the operations of these cascade hydropower projects. To tackle both issues, our study will apply two nested models. VMOD is a a distributed hydrological model that is used to model a single river basin and MODSIM is a generalised river basin Decision Support System (DSS) and network flow model. The VMOD model computes river discharges at different locations in the catchment based on time series of climate data, land use, soil and elevation. The resulting discharges are used as input data for the MODSIM model which simulates the upstream cascade hydropower projects, by considering their operation rules and storage volumes (Figure 12). The aim is to quantify the incoming water discharge at the Nam Ngiep 1 project. MODSIM also computes the energy production and the spillage discharges of NNP1 according to its current operation rules. Furthermore, the

resulting value of the discharge to NNP1 is inserted into the VMOD model to calculate the changes in sedimentation and other catchment processes for the NNP1 reservoir. In addition to provision of river discharge information for MODSIM, the VMOD model is also able to quantify spatially-disaggregated conditions in the NNP catchment, including estimates of changes in hillslope erosion, hillslope failures and land slide potential.

Figure 12 characterises the linkages between the models used in the study. These models rely on a process of data analysis and modelling which constitute the main inputs to the modelling approach and which are described in detail in sections 2.1.1 to 2.1.6. These steps culminate in the quantification of the climate change threats facing the Nam Ngiep catchment and which constitute a key input into the future impact and vulnerability analysis.

2.1.1   Climate change model scenarios

There are various emission scenarios which project the level of radiative forcing in the atmosphere as a consequence of GHGs impacts on atmospheric dynamics. Figure 13 shows the variation of emission levels and surface warming of the 6 SRES scenarios. The IPCC scenario A1b – a moderate emissions scenario – and B1 – a low emissions scenario – have been selected to determine future climate projections for this study. Scenario selection was based on the best-available downscaled climate data and drew upon previous work by ICEM in the USAID-funded Mekong ARCC project in 2011-2012. The scenarios selected (A1b and B1) constitute already out-dated projections for the future climate with the new CMIP 5 projections having been released since the existing projections were downscaled. However, given the finite resources available for the CRVA it was not possible to undertake a novel set of downscaling for the catchment. In addition, it should be noted that the observational data collected in the 15 years since the SRES scenarios were identified have proven that global GHG emissions are increasing faster than even the most extreme SRES scenario A1F1 (ICEM, 2013). Therefore, the projections utilized in this study could be improved if additional resources are available to incorporate, downscale and process more up to date RCPs.
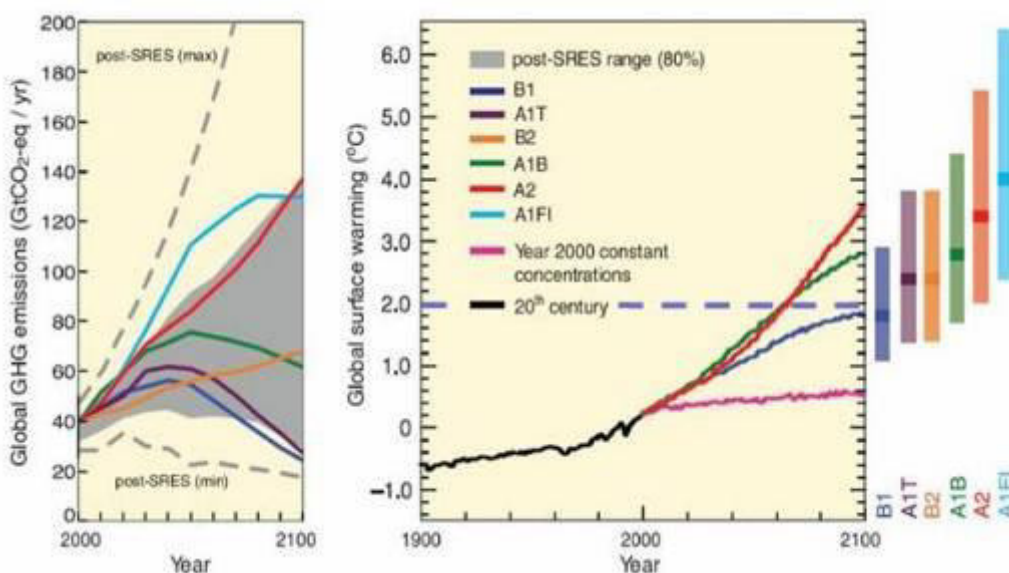

Figure 13 - Global emission and surface warming in the 6 illustrative SRES scenarios (A1B, A1T, A1FI, A2, B1, B2). *Source: IPCC Special Report: Emissions Scenarios (SRES), 2000*

IPCC scenario A1B represents a world of rapid economic growth, an introduction of more efficient technologies, the global population peaking by 2050 and a balance between fossil intensive and non-fossil

energy sources. IPCC scenario B1 corresponds to a low population growth and strong convergence between regions, but with faster introduction of clean and resource-efficient technologies than A1[5].

2.1.2 *Climate change downscaling*

Primary evidence for the nature and magnitude of future climate change is provided by the GCMs, which are mathematical models of the coupled earth-ocean-atmosphere system. GCMs resolve the earth spatially at between 100 and 300 km; and do not fully represent many features important in shaping local climate, such as topography. The varying description of physical approaches leads to varying accuracy for any given GCM over any given area. Because of this variability in results international best-practice in climate change assessment strongly recommends multi-model approaches to climate change modeling (MacSweeney et al, 2011). The use of multiple GCMs allowed the study team to explore the suitability of different GCMs to the Mekong region; the impact of model architecture on climate change results; and focus resources on components contributing the greatest uncertainty to results (i.e. GCMs not scenarios).

The study adopted six GCMs that best simulate the historic climate conditions of the Mekong Basin. These GCMs were selected based on a statistical review of past studies to determine the suitability of the 17 GCMs which have been applied to the Mekong Basin over the past 10 years. (Eastham et al, 2009; Cai et al, 2008). The review focused on comparing the ability of the GCMs to simulate historic precipitation data in the Mekong Basin. This is because Mekong precipitation dynamics are complex involving two monsoon systems and a global hot-spot for cyclones. The six GCMs that exhibited the best agreement for the LMB precipitation regime are:

   i.   ccma_cgcm3.1 (CCCMA Canada),
   ii.   cnrm_cm3 (CNRM France)
   iii.   ncar_ccsm3_0 (NCAR USA)
   iv.   miroc3_2_hires (CCSR Japan)
   v.   giss_aom (GISS USA)
   vi.   mpi_echam5 (MPI Germany)

From these six, an assessment of precipitation changes projected for the Nam Ngiep were assessed and three GCMs were identified to represent the high (MPI_echam5 scenario A1b), average (giss_aom scenario B1) and (ncar_cssm3_0 scenario B1). The selection of these three simulations allows the project to compare the impact of climate change under cautious, representative and conservative projections (Box 1).

Statistical downscaling was undertaken for these GCMs by the Free University of Amsterdam and Aalto University and utilized in previous CRVAs[6]. Statistical downscaling was selected as computationally less expensive than other downscaling approaches and it is well suited to downscaling data to point level where long historic records exist. Statistical downscaling relies on the premise that local climate is conditioned by large-scale (global) climate and by local physiographical features such as topography, distance from the ocean, and vegetation, such that at any specific location there is a link between large-scale and local climatic conditions.

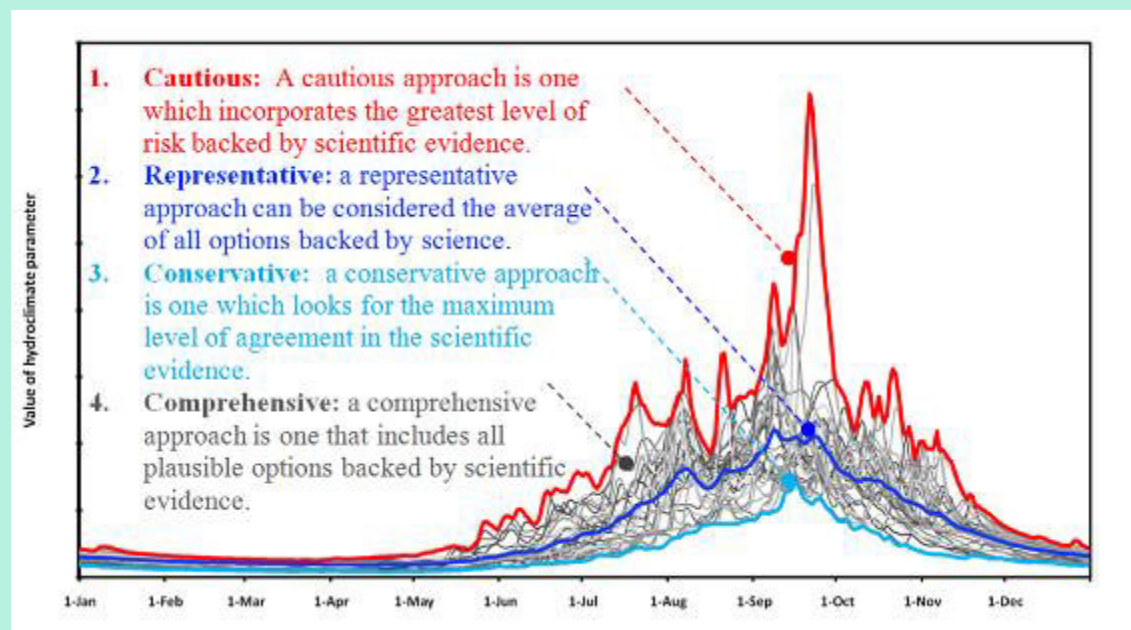---

[5] IPCC Special Report: Emissions Scenarios (SRES), 2000

[6] ICEM/ADB (2012): Mekong Delta Central Connectivity Project – Rapid Climate Change and Vulnerability Assessment. Financed through RETA 6420: Climate Change Adaptation in Asia and the Pacific; (ICEM, 2013): Mekong Adaptation and Resilience to Climate Change (Mekong ARCC) Synthesis Report. U.S. Agency for International Development

BOX 1:
APPROACHES TO RECONCILING VARIABILITY IN CLIMATE CHANGE PROJECTIONS

Climate Change threat assessments culminate in the production of very large databases of information, which need to be consolidated in order to be useful for vulnerability assessments. In this study a single scenario (A1b) multi-model ensemble (six GCMs) was used to establish climate change threat. This means that in the order of 650 years of daily data was generated for 30 hydroclimate parameters covering some 159,000 grid cells. Presenting this information to the impact assessment teams required the team hydrologists to consolidate this information into projections which focused on the trend signal and the range in results.

There are a number of options for reconciling the results of the six GCMs, depending on the study's acceptable level of risk and confidence in the climate modeling (see figure below). A cautious approach may use the highest results whereas a conservative approach may use the lower level of GCM results. A representative approach would use the average of GCM results and a comprehensive approach would take into account all the results applying statistical measures to fit a distribution to the large data set.

1. **Cautious:** A cautious approach is one which incorporates the greatest level of risk backed by scientific evidence.
2. **Representative:** a representative approach can be considered the average of all options backed by science.
3. **Conservative:** a conservative approach is one which looks for the maximum level of agreement in the scientific evidence.
4. **Comprehensive:** a comprehensive approach is one that includes all plausible options backed by scientific evidence.

2.1.3 Ground-truthing climate change projections

The climate change projections generated by the work flow above are available for 166 precipitation and temperature stations within temperature stations within the Mekong Basin. In some countries like Viet Nam and Thailand, the station coverage is reasonable., coverage is reasonable., However, for Lao PDR station density is on average one station for every 10,388 km2 (Table 5). Given the highly variable rainfall dynamics this coverage is poor and it is expected that baseline simulations for areas far from stations will vary significantly from historical baselines. Consequently, this study uses the simulated baselines and future projections to quantify the relative change for each meteorological parameter at each cell within the catchment and then superimposes this relative change on top of the observed historical data sets (

Figure 14). In this way the nature of the climate change is captured but the projections remain grounded to a physical, observed data set.

Table 5 – Spatial distribution of meteorological monitoring stations used in the climate change downscaling

LMB Country*	No. Precipitation stations	No. Temperature Stations	Station Density (km²/station)
Cambodia	6	6	13,090
Lao PDR	16	4	10,388
Thailand	98	12	1,714
Vietnam	7	8	4,481
Total	*127*	*30*	*7,418*

* Note, this table only shows stations within the Lower Mekong Basin, a number of stations in the Upper Mekong Basin and the surrounding catchments were also used in the modelling but have not been included in calculating densities
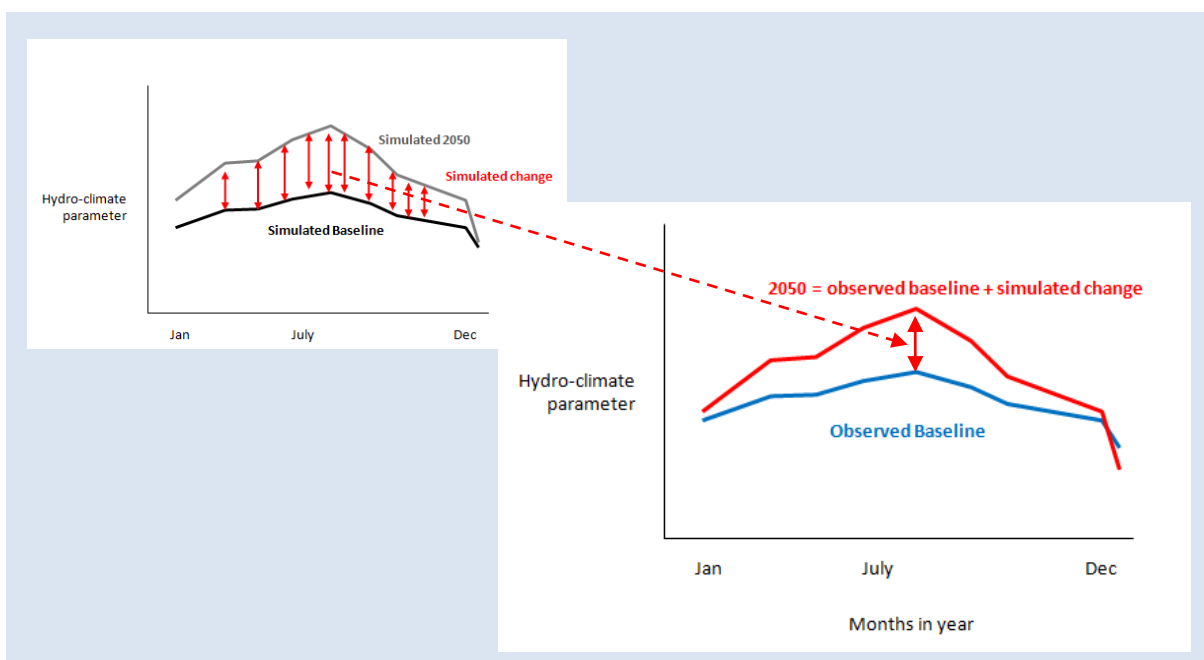
Figure 14 – Approach to ground-truthing climate change projections to observed data sets

2.1.4   Hydrological model

The VMOD model is a distributed hydrological model that is used to model a single river basin. This model will be used to spatially interpolate historical and downscaled climate data between monitoring stations and to simulate the hydrological regime of the basin using a water balance approach. VMOD is a physically based model which simulates the actual physical processes of the Mekong basin hydro-climate for 5 x 5 km grid cells and for daily time steps. The climate interpolation and hydrology simulation are based on a suite of parameters including elevation and weather information as well as soil and vegetation properties, evaporation, filtration, surface runoff, subsurface runoff, and groundwater flow (see Figure 15 for the computation for every grid cell of the model). Being based on the actual physical processes, the model is able to accommodate changes to one or more of these parameters and to quantify the impacts on the processes of the hydrological regime – qualifying as suitable for climate change assessments. GIS analysis was used to analyse and visualise the various model outputs.

Figure 15 - Physically based model - computations for every grid cell

Observed data is used for the calibration of the simulated data for the baseline period 1998 -2011. The future daily flow is computed over the period 2038 – 2062 using six GCMs, providing a total of 56 hydrological years of daily data. For each GCM, the 14 year future data set is then coupled with the 14-year historic baseline and then daily maximum flows each year from these data sets are fitted with the EV1 distribution to calculate magnitudes and return periods.
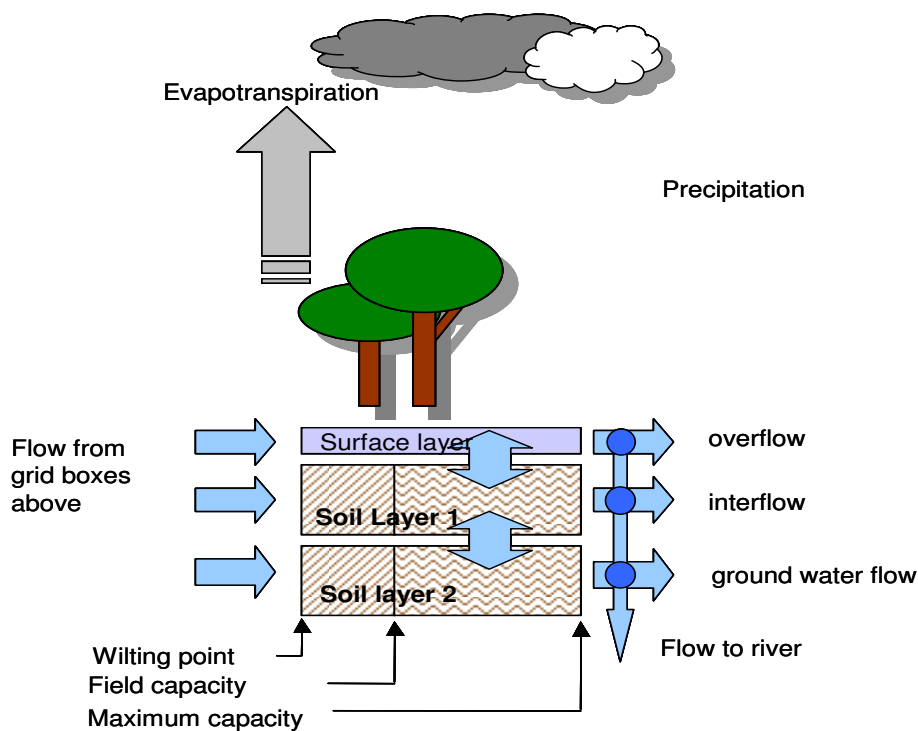
The frequency analysis uses probabilities to express the likelihood of an event occurring by fitting statistical distributions to time series data. Return periods express the likelihood that a certain value will be exceeded – for example the P1% or 1 in 100 year flood, indicates that there is annually a 1% chance of a flood exceeding or equal to that flood. The study focuses on establishing the 1 in 1000 year flood event and on analysing the water availability in the dry season, period in which the need for a minimum 27 m^3/s riparian release could not be met due to insufficient water.

2.1.5 Cascade model

MODSIM is a generalised river basin Decision Support System and network flow model. It is designed for highly complex and constantly evolving river basin management environments. Operation rules, storage volumes and power generation capacity of upstream reservoirs/dams are important inputs to the model in order to quantify the flood discharges and seasonal water availability at NNP1 reservoir.

The MODSIM model also computes energy production and spillage for NNP1 under normal and flooding conditions based on the operation rule curve and the water availability at the reservoir.

2.1.6 Quantifying the direct threats

The future changes in climate are assessed with 6 global climate models as described in Section 2.1.2 above. The model results, in most cases, presented are the average or maximum values for a parameter. The statistical techniques used to asses change in the hydro-metrological parameters include:

- **Daily curves** present daily data so that small-time scale fluctuations in a parameter can be picked up. For this study, daily data represents the averaged value for a given day based on the two time-periods: 1998-2011 and 2045 – 2058.

- **Seasonal curves** collapse daily data sets into monthly averages over a particular time-period so that the broad seasonal trends in a typical calendar year can be understood. For this study the time periods are 1998-2011 for historical data and 2045 – 2058 for future predictions.

- **Percentage change plots** can be used to provide clear summaries of major seasonal and annual changes in a parameter due to climate change. The plots are generated by expressing the difference between the climate change scenario and the baseline as a percentage of the initial baseline value. By expressing the change as a percentage of the baseline (rather than an absolute value) it is possible to assess the relative magnitude of change which provides a simple indicator of how accurate a chosen design specification may be.

- **Frequency histograms** organise the dataset to present the frequency of occurrence for particular events or outcomes. This is useful in predicting how the likelihood of a particular event changes, and how the statistical parameters of the distribution (mean, max, min, standard deviation, skew, median) change.

- **GIS maps** illustrate model results seasonal and annual changes in a parameter due to climate change. The maps are generated using the result from the VMOD model as baseline, average climate change scenario and percentage change between the two.

2.2   APPROACH TO VULNERABILITY ANALYSIS

The framework used is the ICEM Climate Change Assessment and Adaptation Methodology (the CAM). The method has been built up by ICEM from more than five years of field testing and development in thirteen countries in Asia and the Pacific across different sectors (Figure 16). It draws from and simplifies the original concepts and approaches of the International Panel on Climate Change and subsequent tools and methods prepared by other organisations. It addresses the need for a flexible and integrated approach to adaptation planning that can be tailored to any development project or any system.
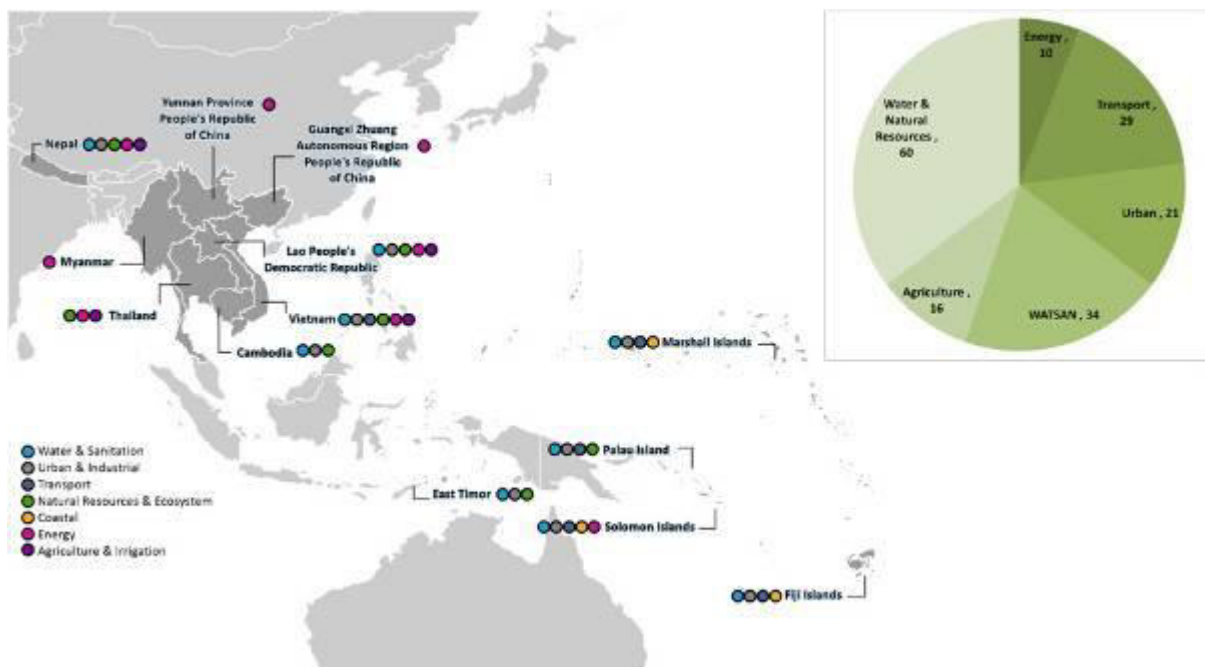

Figure 16 - ICEMs geographical experience implementing CRVA in the Asia-Pacific Region

The CAM process has four main phases (Figure 17) – vulnerability assessment, adaptation priorities, adaptation planning and then adaptation implementation. Those phases are intended to be integrated with

government development planning and budgeting cycles – for example, socio-economic plans, sector development plans, area wide plans, down to project specific planning and the environmental impact assessment process.

This study will be conducted in two separate phases (Phase 1 and Phase 2). In the course of Phase 1, the study will (i) assess impacts of climate variability and projected climate change on key parameters of the Project, including infrastructure, future run-off, sedimentation, dam safety, over-topping of concrete dam and earth-fill, and energy production; (ii) estimate the potential costs of these impacts; and (iii) present the results of the assessment to the Borrower, ADB and other relevant stakeholders on the implications of the impacts of climate change on the project and seek agreement on the need for Phase 2.

Conditional upon the findings of the impact assessment and consultation conducted in Phase 1, a Phase 2 may take place. In the course of Phase 2, the study will identify concrete adaptation options to climate change for the Project. In the course of Phase 2, adaptation options will be prioritized on the basis of a cost-benefit analysis.
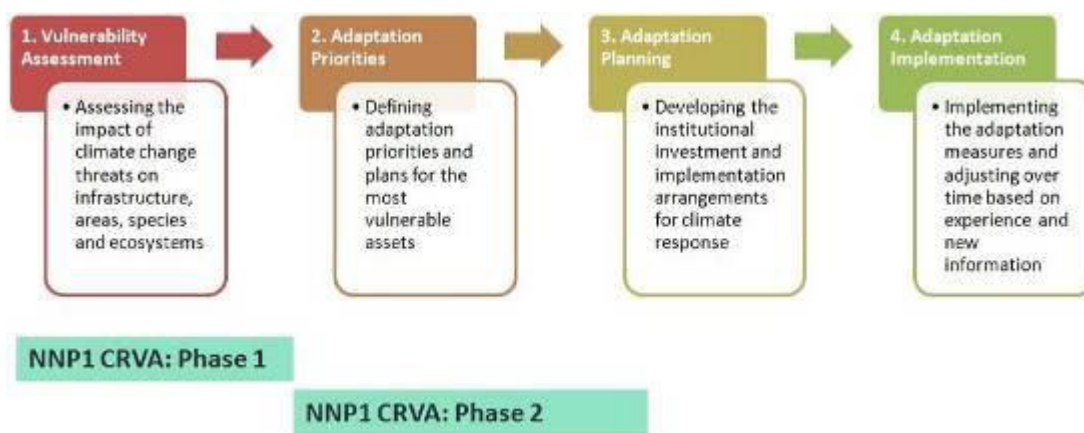
Figure 17 - Steps of the CAM process: The NNP1 CRVA will undertake steps 1 and possibly 2 of the CAM process.

The vulnerability assessment (NNP1 CRVA: Phase 1) has steps and tools to help understand and document in a systematic way the causal linkages between the climate change threats to the different environmental, economic and social assets and services (e.g. a road or bridge, an endangered species or protected area, agricultural fields or a school) (Figure 18).

Figure 18 - Vulnerability assessment steps

The method considers four important factors in assessing vulnerability of the target system and its components to the climate change threats: *exposure*, *sensitivity*, *impact* and *adaptive capacity*.

➢ **Exposure** is the extent to which a system is exposed to the climate change threat.

> **Sensitivity** is the degree to which a system will be affected by, or responsive to climate change exposure.
> The potential **impact** (or level of risk) is a function of the level of **exposure** to climate change induced threats, and the **sensitivity** of the target assets or system to that exposure.
> **Adaptive capacity** is understood in terms of the ability to prepare for a future threat and in the process increase resilience and the ability to recover from the impact.
> When impact and adaptation capacity are considered a measure of relative **vulnerability** can be defined (Figure 19).
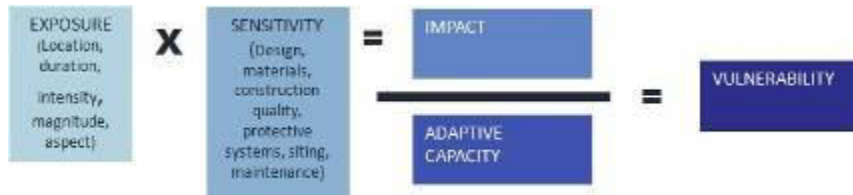
Figure 19 - Computation of vulnerability

Therefore, once the asset has been identified and its related climate change threat understood, its exposure and sensitivity can be investigated according respectively to the issues of location, duration, intensity, magnitude, aspect and to the matters of design, materials, construction quality, protective systems, siting, and maintenance.

The CAM rating system for all parameters uses a scoring from very low to very high and is applied based on expert judgement drawing from the best available scientific and factual evidence and where appropriate community knowledge and experience (Figure 20).

Figure 20 – **Determining impact and vulnerability**

The potential impacts of climate change are illustrated in Figure 21, which suggests how climate change can impact a particular infrastructure investment through multiple pathways, with each characterized by a degree of inherent uncertainty. It follows that the assessment of many of these risks is difficult in the context of a desk study of the proposed Project, particularly as observational data are limited and very little climate simulation modelling of the Nam Ngiep catchment, encompassing hydrology and ecology, has been performed. This study will mainly focus on the two risks judged to be of greatest potential significance, climate change impacts on project performance; and impacts on flood risk.
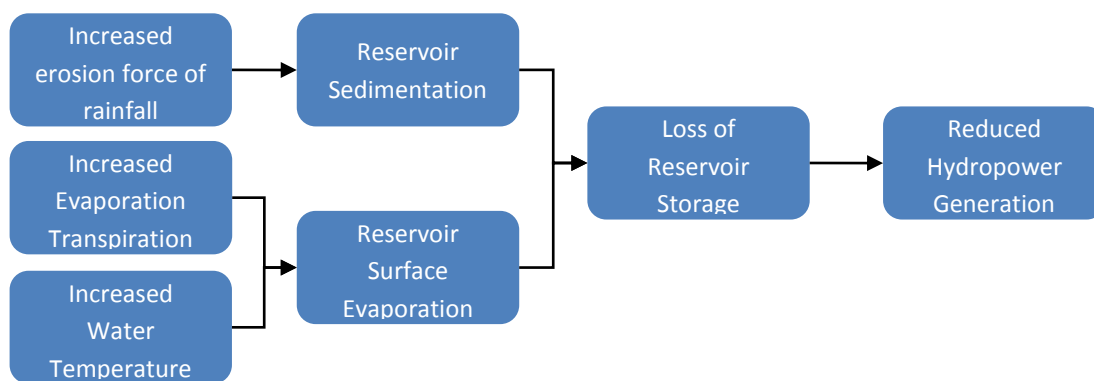
Figure 21 - Example of a climate change impact pathway for hydropower

2.3   APPROACH TO ADAPTATION SCOPING

Adaptation to climate change refers to actions that can be taken in response to the potential impacts of climate change. These options are designed to enhance an asset by reducing its sensitivity and/or exposure to climate change, as well as through building the adaptive capacity. It can include actions taken to prevent, avoid or reduce the risks of those impacts (proactive adaptation), or in response to impacts as they happen (reactive adaptation). Adaptation includes taking advantage of the opportunities that may arise due to climate change, as well as responding to negative impacts. It involves developing a range of adaptation options for each of the main impacts you determined during your vulnerability assessment and then determining priorities for implementation that are built into an integrated adaptation plan. With limited resources it is not possible or necessary to do everything at once; choices must made on what is feasible and necessary now and what can be left to later planning cycles. Adaption planning has three main steps (Figure 22): (i) defining the options; (ii) setting priorities among them; and (iii) preparing adaptation plans and integrating them into established plans and budgets.
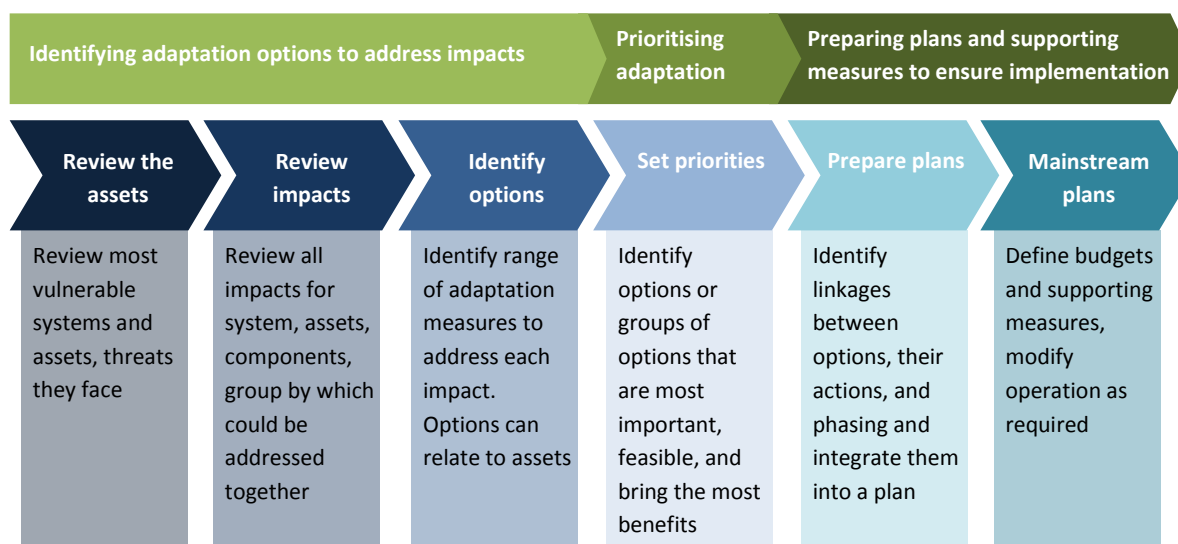
Figure 22 – Adaptation planning process

The scoping process is designed to employ a transparent logic to setting adaptation priorities based on the following criteria:

   i.   Existing conditions at the target assets.
  ii.   The climate change threats.
 iii.   The potential impacts on the assets being assessed.
 iv.   The capacity of the designed system to recover from the impact.

3   IMPACT ANALYSIS

Impact analysis is a well-established methodology in environmental assessments, designed to characterise the nature and magnitude of change experienced by a given system subject to a specified threat or pressure. In climate change assessments the threats/pressures are the result of changing CO_2 concentrations and the impact of this on the earth's meteorological and hydrological systems. It has become standard practice to express impacts in terms of system "exposure" and "sensitivity" to the threat (see for example UNDP, 2006; IPCC, 2007; ICEM, 2010). There is considerable debate regarding the meanings of these terms, however, in this study we adopt the definitions presented in Section 2, and which are best explained with a simple example.

Figure 23 describes the impact of climate change on three houses built on a river floodplain. In this case, the threat of climate change is felt as an increase in river level during large flood events. Each of the three houses below will experience the same threat in different ways and a comparison of the houses reveals the distinction between exposure and sensitivity:

- **Characterising exposure: (house A and A'):** During the same flood event houses A and A' will be *exposed* to the flood waters in different ways, based on their location. House A lies on the river bank at the river level, while House A' is elevated above the water level sitting on the river's flood plain. Because of this difference in location, the magnitude and duration of flooding experienced by each house will be different, with A' having a lower level of exposure.

- **Characterising sensitivity (house A and B):** Comparing house A and B, it can be seen that both houses have the same exposure to the flood threat, because they are both located along the river bank. However, they are made of different materials and so their sensitivity to the same level of exposure is different. House A is made of weak materials, likely to be easily damaged by flood waters, while House B is made of stronger materials (e.g. concrete) and also elevated on stilts which will reduce its sensitivity. In this example, houses A and B will have the same exposure, but house A will have a higher sensitivity to an increasing flood threat, which will result in a higher impact for house A.
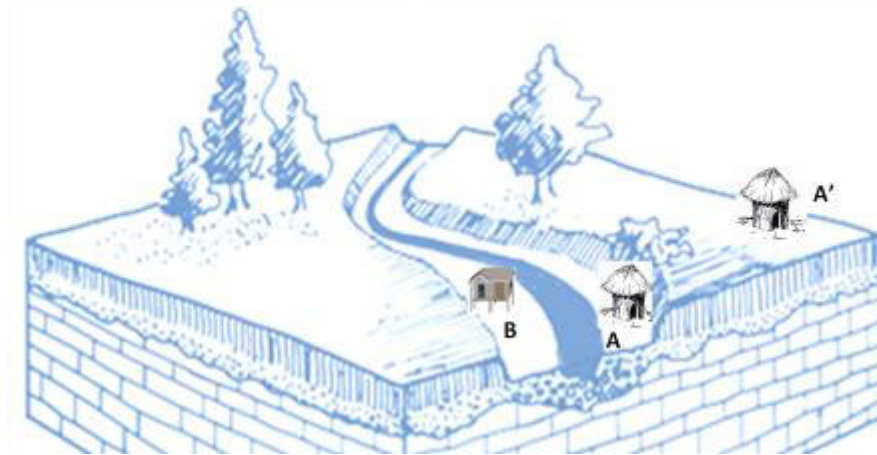
Figure 23 - Characterising impacts using exposure and sensitivity

Impact is then the product of the exposure and the sensitivity of a system and a function of both the nature of the CC threat as well as the properties of the system/asset under threat. This is shown in Figure 24 where the threat is shown to target an asset. The combination of the nature of the threat (magnitude, frequency, duration etc) and the specific characteristics of the asset (design, material strength, siting, aspect etc) result in a unique exposure and sensitivity signature which characterises the impact. Linking the characterisation of impact to analysis of how a system responds to a quantified threat also strengthens the scientific basis of the impact assessment which is important for building confidence in recommended response measures.
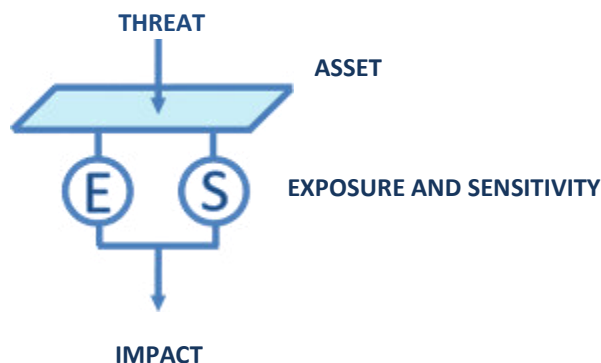
Figure 24 – Node representing the impacted asset (blue layer) and the evaluation of its exposure and sensitivity to the incoming threat.

Adopting this approach, the starting point for the CRVA is the identification of which threats projected as likely in the Nam Ngiep basin future climate are of relevance to the 10 assets identified as being of key value in the inventory of equipment, infrastructure, components and processes of the NNP1 facility.

The threats can be largely distinguished between threats due to changes in the water cycle and threats due to changes in the Nam Ngiep cascade management. The first are related to the modelled changes projected for the future climate and can be grouped under the following drivers of change: (i) air temperature, (ii) precipitation (intensity and magnitude), and (iii) flood frequency. These threats are strictly correlated since the assumed increase of the CO_2 concentration in the atmosphere triggers a series of consequences that perpetuate through the hydrological cycle and start with an increase in the air temperature, the consequent increase in precipitation and therefore of the magnitude of the PMF.

The second group of threats are linked to the effects of the presence of upstream projects and how these projects will change the timing and magnitude of inflows into NNP1 during normal and extreme operations. As noted in section 1, the characterisation of these threats is based on two scenarios, simulating the normal functioning conditions of all hydropower projects in the catchment, and the dam break of the Nam Ngiep 2 structure. Each of the threats may affect different assets in various ways, and, also, the same asset may respond differently to these variations due to its changing exposure and sensitivity. For instance, air temperature might threaten the conductivity along the transmission lines and lead to the loss of energy delivered to the Nabong Substation, while it might also affect, differently, the quality of the water by strengthening thermal stratification within the reservoir and so lead to the disruption of the aquatic ecosystem downstream of the project. Therefore, each evaluated asset is considered in terms of its exposure and sensitivity specifically to the threat in question.

Table 6 - Establishing causal linkages between threats and assets: scope of the threats and assets considered

THREATS	NNP1 SYSTEM ASSETS
Variability in the water cycle 1. Air temperature 2. Precipitation (intensity & magnitude) 3. Flood event **Cascade management** 4. Normal cascade operations 5. Cascade emergency flood management	**Infrastructure and physical assets** 1. Reservoir (main dam and re-regulation dam) 2. Dam wall (main dam, re-regulation dam & saddle dam) 3. Spillway structures (main dam and re-regulation dam) 4. Intake & penstock (main dam and re-regulation dam) 5. power house (main dam and re-regulation dam) 6. turbine and generators (main dam and re-regulation dam) 7. Watershed condition and productivity 8. Resettlement area productivity **Processes** 9. Energy production 10. safeguards and regulatory compliance

THREATS	IMPACT PATHWAY

$[CO_2]$

AIR TEMPERATURE
- IP1: WATER QUALITY - DOWNSTREAM AQUATIC ECOSYSTEM
- IP2: TRANSMISSION LINES - ENERGY LOSSES

PRECIPITATION
- IP3: RESERVOIR SEDIMENTATION - STORAGE CAPACITY
- IP4: RESERVOIR SEDIMENTATION – REGULATION CAPACITY
- IP5: SEASONAL WATER AVAILABILITY - INCREASE ENERGY PRODUCTION
- IP6: INCREASED SPILLAGE – DAMAGE TO SPILLWAY

PROBABLE MAXIMUM FLOOD
- IP7: OVERTOPPING MAIN DAM- INUNDATION OF POWERHOUSE
- IP8: ELEVATED REREGULATION WATER LEVELS - FLOODING OF POWERHOUSE FROM BACKWATER
- IP9: OVERTOPPING MAIN DAM - SADDLE DAM BREACH
- IP10: REDUCED OR DAMAGED AGRICULTURE PRODUCTION AT RESETTLEMENT AREA

HYDROPOWER PLANTS CASCADE
- IP11: DAM BREAK SCENARIO OF NAM NGIEP 2 HYDROPOWER PROJECT
- IP12: OPERATION OF ALL THE UPSTREAM HYDROPOWER PROJECTS IN THE CATCHMENT

38

The coupling of relevant threats with specific assets results in a large amount of impact assessments. These pairings were screened with technical specialists from the NNP1PC and ICEM to help identify the most significant threats, and most critical assets to consider. In doing so, the team was able to refine the impact assessment and better focus on those threat-asset pairings considered most critical. This process, conducted during the field mission, resulted in the identification of 12 priority impact pathways of interest to the operation of the Nam Ngiep 1 plant. Each pathway is illustrated as shown in Figure 25 and the process of assessing exposure (E) and sensitivity (S) for each of the impacted assets affected by the cascade effects is exemplified in each chart by the following node symbol (Figure 24). The impact pathways are individually described in the following sections preceded by a description of the relevant hydro-meteorological threat and the general overview can be seen in Figure 25. There are nine impact pathways generated by the climatic threats and two linked to the management of the upstream cascade. For each impact pathway, the analysis starts with a short overview of the causal sequence of impacts (in an orange box) which summarises how the specific threat might impact the NNP1 project. The analysis then goes on to determine the magnitude, timing and significance of the impact pathway based on the design details for the project and the modelling results. A detailed description of each impact pathway is also shown in Annex III using the ICEM CAM matrix template.

3.1   IMPACTS OF THE INCREASE IN AIR TEMPERATURE

3.1.1   Threat of increasing air temperature

The historic average annual ambient temperature is 27.1°C at Ban Hat Gnium station downstream of NNP1 project (Table 7). There is little monthly or seasonal variation in average daily temperatures, with a slight seasonal reduction in the order of 2-3 degrees during the wet season when cloud cover inhibits solar radiation and a peak in temperature at the end of the dry season. On a daily time-step temperatures can vary by on average 6 -7°C during a day, peaking in the low-30s and dropping to below 20s overnight in the dry season.

Table 7 – Ban Hat Gnium average monthly temperature (1998 – 2011)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean temp. (°C)	23.8	25.3	28.1	29.7	29.0	28.8	28.5	28.2	27.7	27.5	25.2	23.0	*27.1*
Max temp. (°C)	30.3	31.9	34.4	35.4	33.6	32.9	32.4	32.0	31.6	32.2	30.7	29.1	*32.2*
Min temp. (°C)	17.2	18.7	21.7	24.1	24.4	24.6	24.6	24.4	23.8	22.8	19.6	16.9	*21.9*

Temperature varies also between locations in the catchment depending on their topography. For example, NNP3A project site is
NNP3A project site is located approximately 81 km north of Ban Hat Gnium and more than 600 m higher than Ban Hat Gnium. NNP3A's
Ban Hat Gnium. NNP3A's location and topography result into a 5°C difference from Ban Hat Gnium as seen in

Figure 26. In order to account for elevation induced changes in temperature throughout the catchment, spatial interpolation methods were used to develop temperature profiles for all points in the catchment between all observation stations.
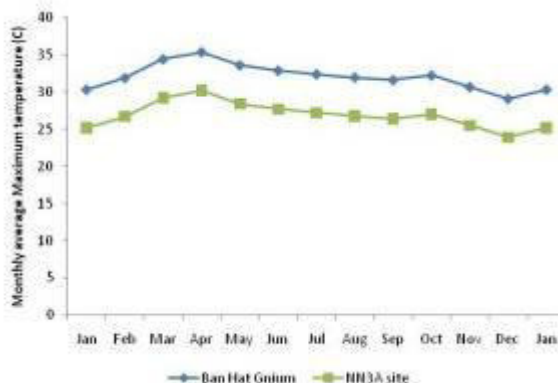
Figure 26 – Historical average monthly maximum temperature at Ban Hat Gnium and NNP3A site

To explore the climate change impacts on the project, downscaled daily temperature data were obtained for stations within the Nam Ngiep catchment, these selected GCM outputs were analysed for average and maximum daily temperature. In 2050, there will likely be an average 1.6°C increase in maximum temperatures of the catchment in the wet season and 2.1°C in the dry season, as seen in Figure 27 and Figure 28. With the temperature increase in both seasons, evaporation, precipitation and humidity are expected to increase affecting water availability within the catchment.
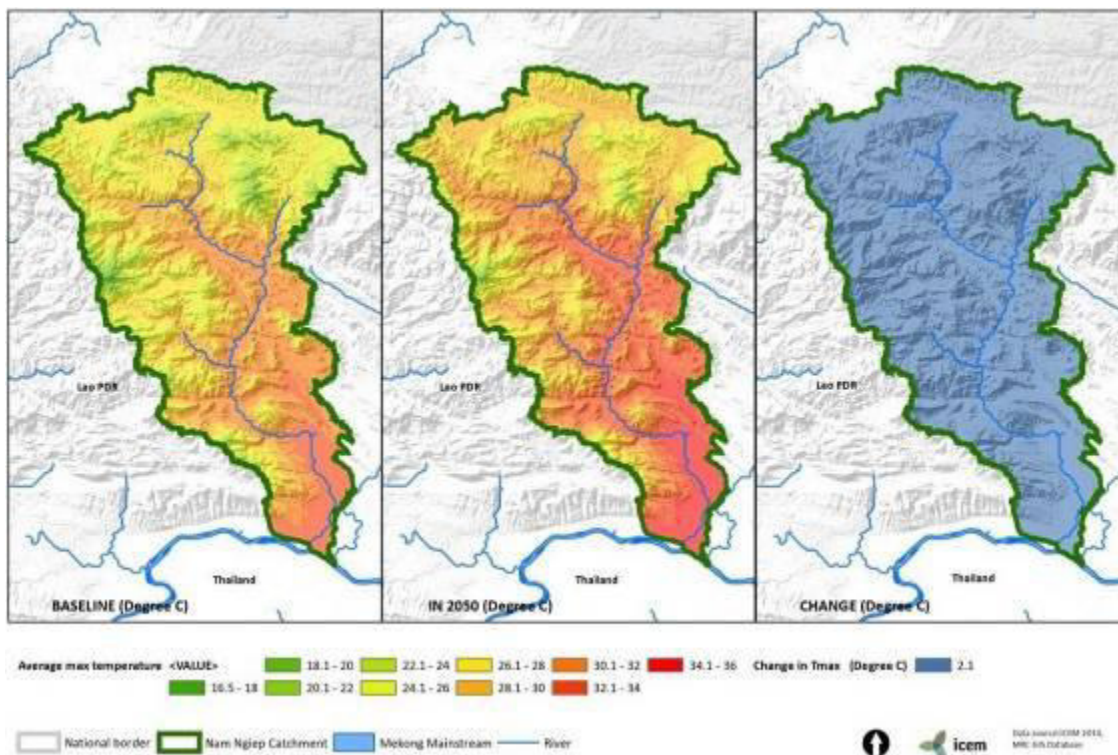
Figure 27 - Average Maximum Temperature changes in dry season
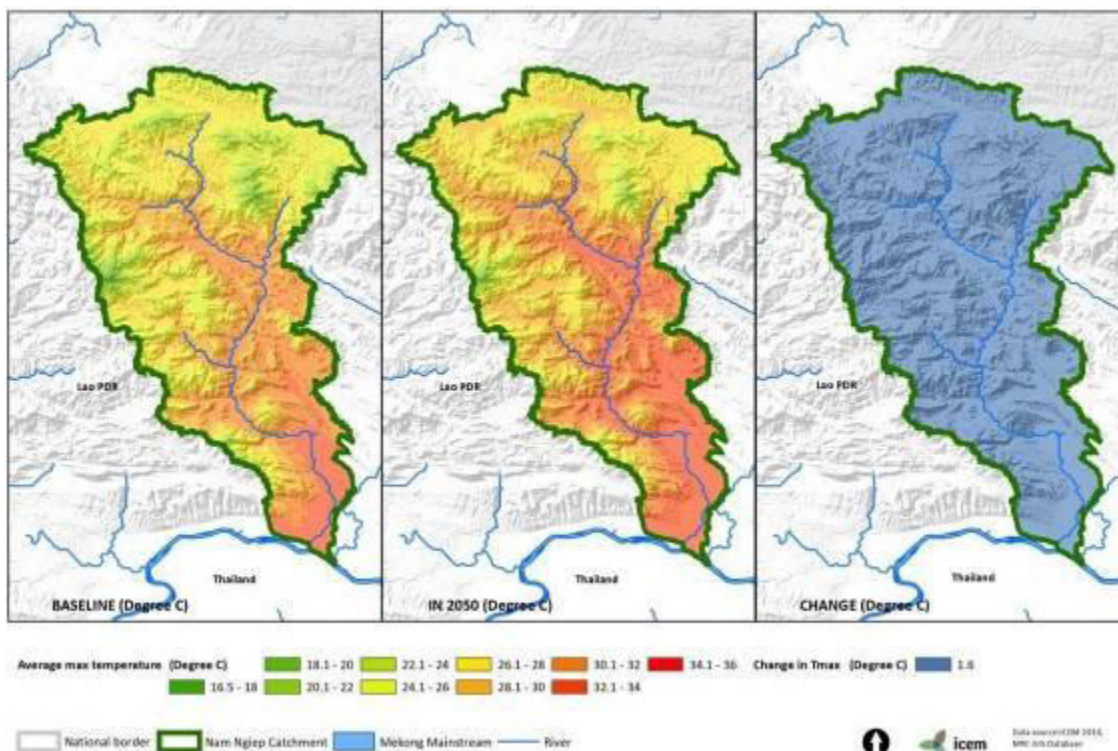
Figure 28 - Average Maximum Temperature changes in wet season

The impact of climate change on the temporal variability of temperatures was assessed using frequency analysis. Figure 29 presents histograms for baseline and future temperature distribution at Ban Hat Gnium station. The graphs project a shift in the mean of the distribution with minor changes in the variance. This means that maximum daily temperatures will become hotter, with 66% of the year experiencing temperatures greater than 34°C compared to 40% of the year under baseline conditions. In addition, the new climate regime will expose the catchment to temperatures up to 44°C which were not part of the historic climate regime.
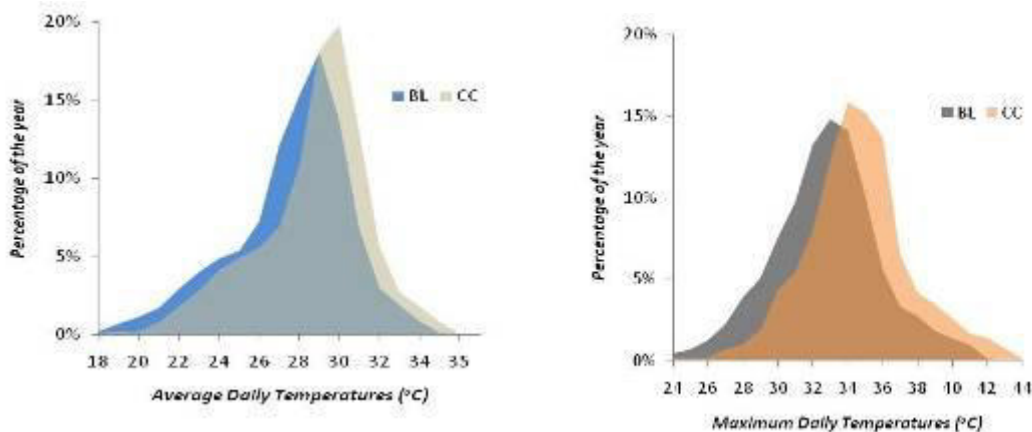
Figure 29 - Frequency distribution curves of daily temperatures under baseline and climate change scenarios: *(left) Average Daily Temperatures: there is an increase in the mean temperature of 2°C with slight increase in annual variance; (right) Max. Daily temperatures: with climate change the max. daily temperature also increase in annual variance and shift to the right by 2°C.*

3.1.2   Impact on downstream aquatic ecosystem (IP1)

Threat: *increasing air temperatures*
Impact pathway: *An increase of the air temperature will increase the water temperature in the reservoirs. An increase in water temperature will strengthen the stratification of the lake leading to a reduction of dissolved oxygen in the water. This increases the chances of fish kill, odour and deterioration downstream of the plant. Changes in downstream water quality may weaken the effectiveness of environmental and social safeguards adopted by NNP1 and lead to issues of compliance with government and investors.*
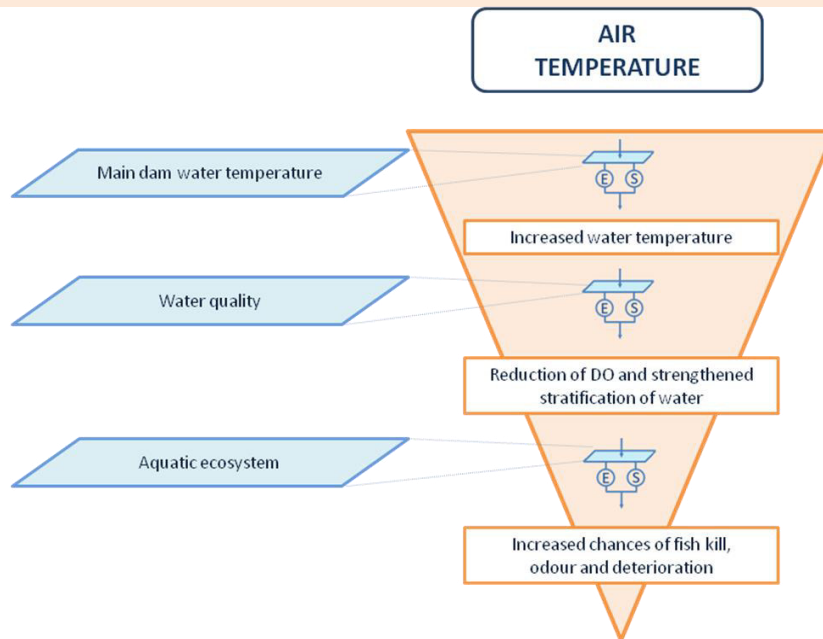
Figure 30 – Impact Pathway 1: the threat of an increase in air temperature affects the main dam water temperature, the water quality and finally the aquatic ecosystem.

Water temperature is crucial for the physical, chemical and biological dynamics of lakes. Water temperature plays a key role in influencing the aquatic ecosystem of lakes, which are usually adapted to a specific range of physical and environmental conditions. Changes in temperature will affect both the chemical (e.g., dissolved oxygen concentration) and biological (e.g., fish growth) processes occurring in the water body (e.g., Wetzel, 2001). Temperature is the primary driver of vertical stratification in slow moving water bodies, and thus directly affects vertical exchanges of mass, energy and momentum within the water column.

Water temperature in lakes and reservoirs follows complex dynamics and is the result of a combination of different energy fluxes which makes predicting the future trend of surface water temperature challenging. Air temperature is a significant index of the overall meteorological conditions, and can be reasonably assumed as the main variable influencing the heat balance of the surface layer of the lake (Livingstone and Padisák, 2007). Long-term, high-resolution air temperature observational datasets are in general available, and since water temperature measurements are far less available, several simple models have been formulated that use air temperature to estimate the surface water temperature of lakes.
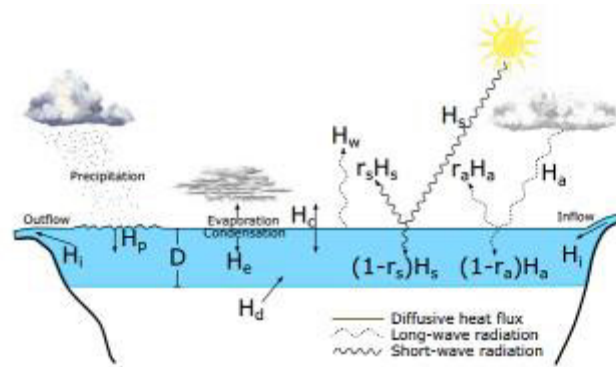
Figure 31 – Scheme of the main heat exchange processes between air and surface layer. Source: Piccolroaz S. et al (2013)

An increase in air temperature will affect the temperature of the water in the reservoirs of the Nam Ngiep 1 project. The significant increase in average and extreme air temperatures at the reservoir surface (Figure 29) will increase the energy flux across the boundary surface heating the top layer of the reservoir. The strength of this solar forcing is a function of the shape of the reservoir. Nam Ngiep 1 main reservoir is largely contained within a deep-set V-shaped canyon which results in a long, thin reservoir with a medium surface area to volume ratio. The dimensions of the reservoir are therefore likely to dampen the efficiency of thermal exchange at the reservoir-atmosphere boundary; however, the net effect will be strengthened reservoir stratification because of the significant increase in the frequency of hot days projected. The increase of the temperature of the water would lead to a strengthened stratification of the reservoir water, i.e. a raise in the hypolimnion and a more stable thermocline. This would lead mainly to a reduction of Dissolved Oxygen (DO) since warm water holds less oxygen than cool water, so it may be saturated with oxygen but still not contain enough for survival of aquatic life. It is likely that stratification will increase in the dry season when temperatures are highest, and that if overturn of thermocline is going to occur it will be at the start of the rainy season when colder water will be running off into the top end of the reservoir. However, the shape of the reservoir is such that wind action cannot be effective along the full length of the reservoir, and this may reduce the risk of full over turn throughout the reservoir.

In terms of downstream releases, water quality is a function of both the strength of stratification and the position of the thermocline relative to the penstock intake structures. In the case of Nam Ngiep, the intake structures of the penstocks are placed at a level for which the risks of taking in low quality water are moderate.

In conclusion, likelihood of climate change exacerbating water quality issues for releases from the Nam Ngiep main reservoir are moderate. The shape of the reservoir will reduce exposure to increased solar forcing and dampen overturning of the thermocline at the start of the wet season; these two factors, in combination with a relatively high-set intake structure will results in moderate likelihood of increasing the frequency of anoxic releases to the downstream aquatic ecosystem (Annex III – Aquatic ecosystem). These issues are likely to be more of an issue for water quality in the re-regulating reservoir (adjacent to the resettled community) than those downstream of both dams as the re-regulating reservoir spillway has capacity for further aeration.

3.1.3 Impact on efficiency of generation and transmission (IP2)

Threat: *increase in air temperatures*
Impact pathway: *An increase in the air temperature will affect the energy supply by reducing the turbinated power and the efficiency of the transmission lines in delivering energy to the substation. This may lead to a loss of income, which will accumulate during the operating life of the plant.*
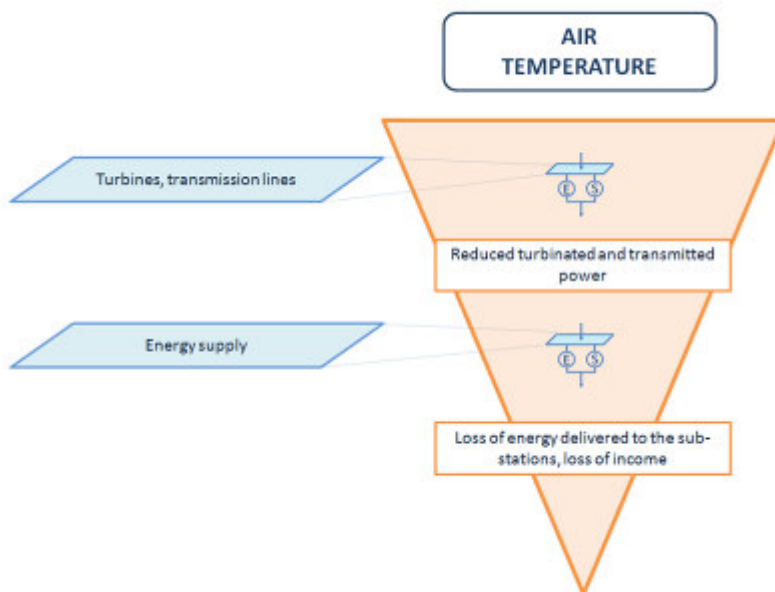
Figure 32 - Impact Sequence 2: the threat of an increase in air temperature affects the conductivity of the transmission lines and therefore the energy supply to Nabon substation.

High temperature limits the power rating of overhead lines, underground cables, and transformers but does not cause immediate faults (Ward, 2010). The expected higher air temperatures and air humidity affect the transformers and cables of the transmission lines delivering the energy to the substations through decreased conductivity along the lines and partial discharge of electrical energy through the *Corona effect* at the insulators. Consequently, the incoming power at Nabong Substation for export to Thailand could be less than envisioned due to these distributed losses. According to literature review, the resistance of the cables increases circa 0.4% per 1 °C rise. [7,8] Under CC, average air temperature of the catchment would increase by 2.1°C in the dry season and 1.6°C in the wet season. This would cause a transmission line loss change of 0.84% (2.1 multiplied by 0.4%). The current calculated loss of the transmission lines of the NNP1 project is 5% of the water power available output. The loss in future climate change can be calculated as:

$$CC_{Loss}= 5* (1+ 0.0084) = 5.042 \%$$

Instead of 95% of the water energy being passed through the transmission lines, 94.958% of the energy will be passed through.

Along this line of thought, the change in energy relative to the turbinated flow can be evaluated by looking at how the water density is affected by an increase in temperature. According to literature, water at 32°C has a density of 995.03 kg/m³ and at a temperature increased by two degrees, it is 994.37 kg /m³. The difference is 0.66 kg/m³, which is a 0.066% decrease in density. So it can be concluded, that under climate change, with slightly less dense water, the turbinated power sent to the generator would be lower by 0.066 %.

According to these findings, the rated output of 272 MW expected at the substation will be decreased by 0.066% due to reduced turbine efficiency, this will be compounded by a loss of 0.042% loss during transmission, amounting in total to a 0.11% reduction in power output or a rated power of 271.7 MW. We can conclude that changes associated with the temperature component of climate change will have negligible impact on energy delivered by the NNP1 project.

---

[7] Asian Development Bank (2012) Climate Risk and Adaptation in the Electric Power Sector. Asian Development Bank publication ISBN 978-92-9092-730-3
[8] European Commission (2011). The Impact of Climate Change on Electricity Demand. www.adamproject.eu, http://ec.europa.eu/environment/integration/research/newsalert/pdf/223na4.pdf

3.2   IMPACTS OF THE INCREASE IN PRECIPITATION INTENSITY AND MAGNITUDE

3.2.1   *Threats of increasing precipitation intensity*

Historical precipitation data was collected from four stations within the catchment – Xiang Khouang, Tha Viang, Hat Gnium and Pakxan station from 1971 to 2013.[9] Detail on precipitation variation between stations and the modelling calculation are described in the Annex II. The annual mean precipitation for the whole catchment is estimated by the model at 2,053 mm. Daily precipitation fluctuates from 0 to 150mm as seen in Figure 33. Precipitation of the catchment varies also between seasons. The catchment is dominated by the Southwest monsoon, which occurs during the northern hemisphere summer and results in heavy precipitation over the western slopes of the Annamite mountains, with highest average precipitation totals occurring near Nam Ngiep. The heaviest precipitation occurs between May and September. The Northwest Monsoon (October – April) contributes far less precipitation since the basin lies in the rain shadow of the Annamite mountains. Therefore, there are two distinct seasons in the catchment: the dry season from November until April and the wet season from May until October.
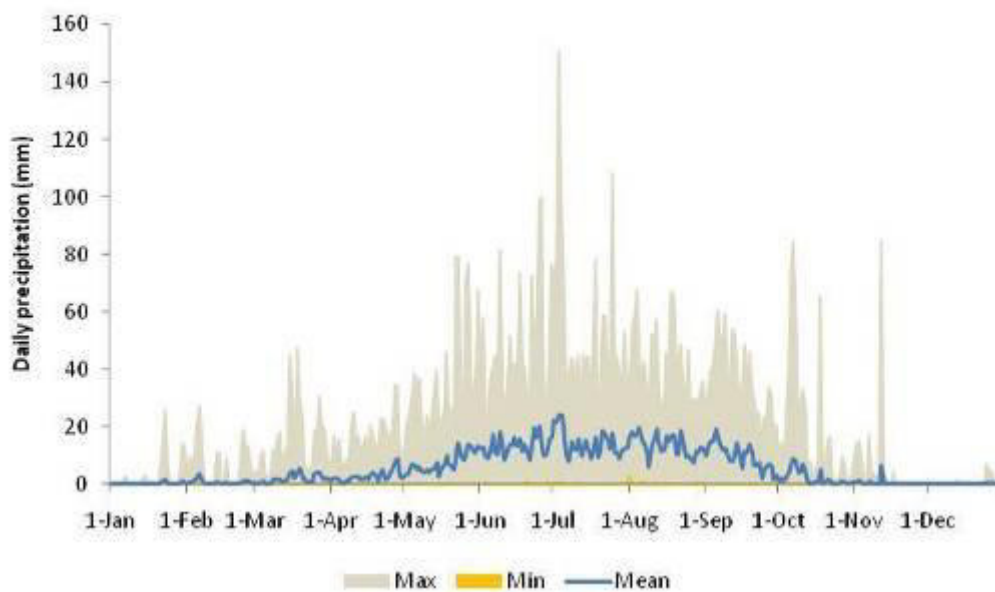
Figure 33 – Baseline daily precipitation of the catchment: *computed data taken at the central point of the catchment i.e. on NNP1 reservoir area.*

In addition, due to its relative proximity to the coastline to the South China Sea, the catchment is subject to cyclone events during the wet season. Cyclones originate in the western Pacific Ocean and are driven westward across the Vietnamese coastline in response to the earth rotation. Over the past 50 years more than 100 tropical storms and cyclones have crossed into the Lower Mekong Basin (UNOCHA, 2011). In northern Lao these cyclones can occur during a wide window stretching from July to October. The majority of cyclones hitting northern Lao occur in the northern-most limits of the Annamite ranges, where the Annamites are closest to the coast– especially in the Nam Theun, Nam Hinboun catchment. These catchments have had up to 30 cyclones over the past 50 years, making cyclones a regular occurrence with multiple events in a single wet season in extreme cases. In contrast the Nam Ngiep catchment has experienced 6 cyclones in the past 50 years; most of these cyclones enter the Nam Ngiep catchment from neighbouring Nam Theun with weakened intensity, fewer cyclones enter further north as the area is shielded by the Vietnamese landmass and also to some extent by Hainan Island (Figure 34). These cyclones play a dominant role in the extreme hydrology of the catchment and hence characterise the magnitudes and frequency of flood risk.

---

[9] Note: the record is not complete at all stations for the period specified
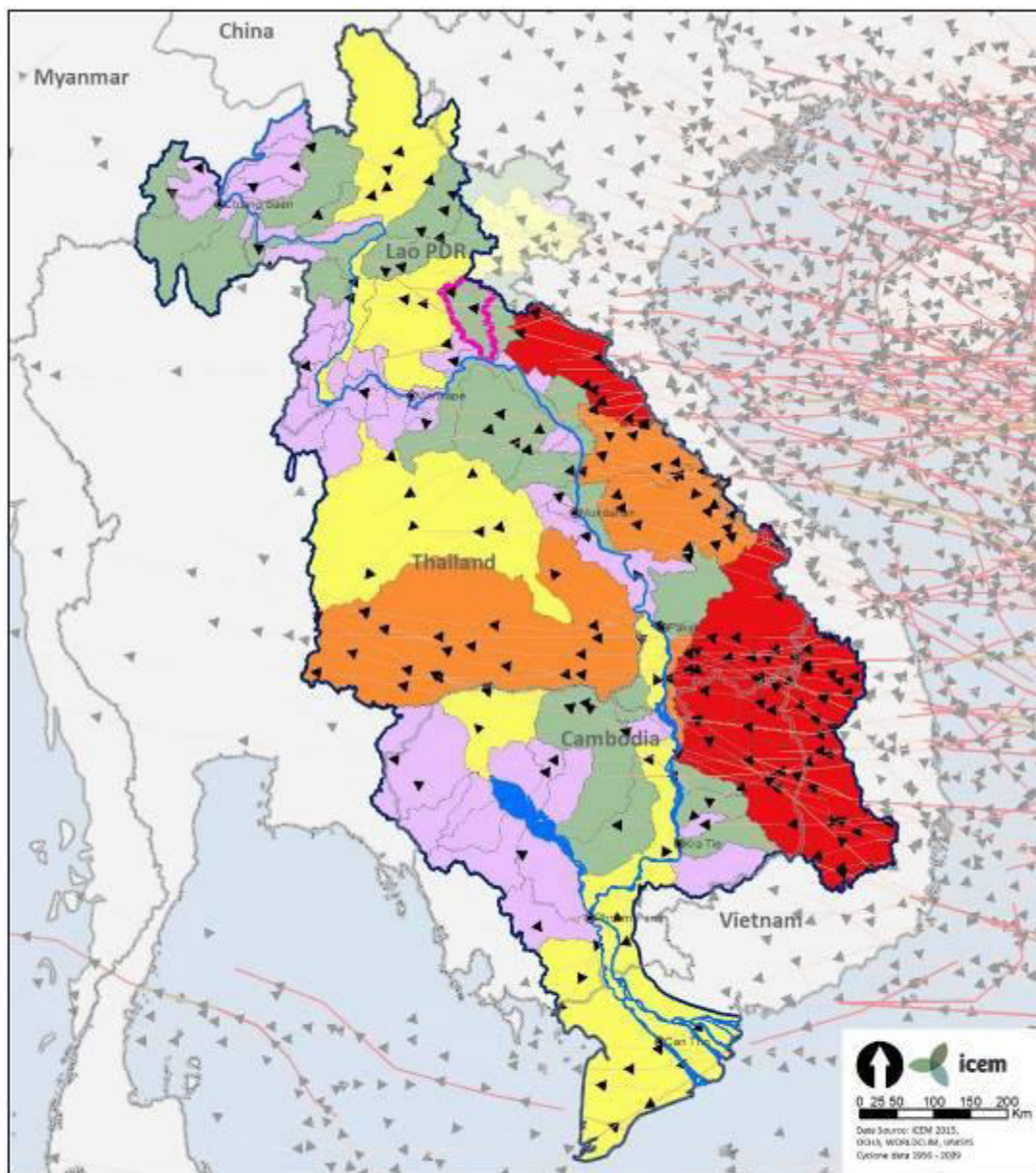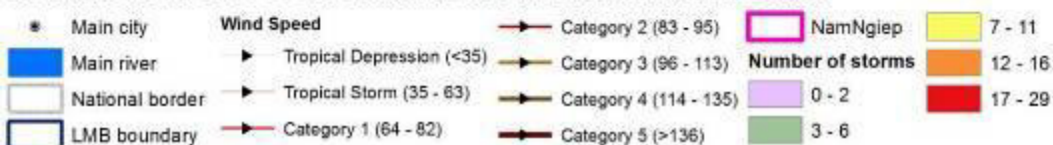
Figure 34: Cyclone incidence for the Lower Mekong Basin and the Nam Ngiep catchment

With climate change, the model results indicate that average precipitation will increase by 17.8%. Peak rainfall events will also increase in magnitude with future rainfall intensities in the catchment reaching 160mm/day and a greater incidence in daily rainfall exceeding 100mm/day (Figure 35). Although modelling of future cyclone dynamics was beyond the scope of this project, there is confirmation in the literature that high intensity cyclone events will increase in frequency for the Lower Mekong Basin (ICEM, 2013). An increased intensity of cyclones making landfall in northern Viet Nam will increase the frequency with which cyclones hit Nam Ngiep catchment as strong cyclones can penetrate further into the continental land mass, meaning that more cyclones will retain sufficient energy as they pass over Nam Theun basin to induce storm conditions in the Nam Ngiep. This changing cyclone fate and dynamics of cyclones into the Nam Ngiep catchment remains a major area of uncertainty in predicting future extreme rainfall conditions and requires further work.
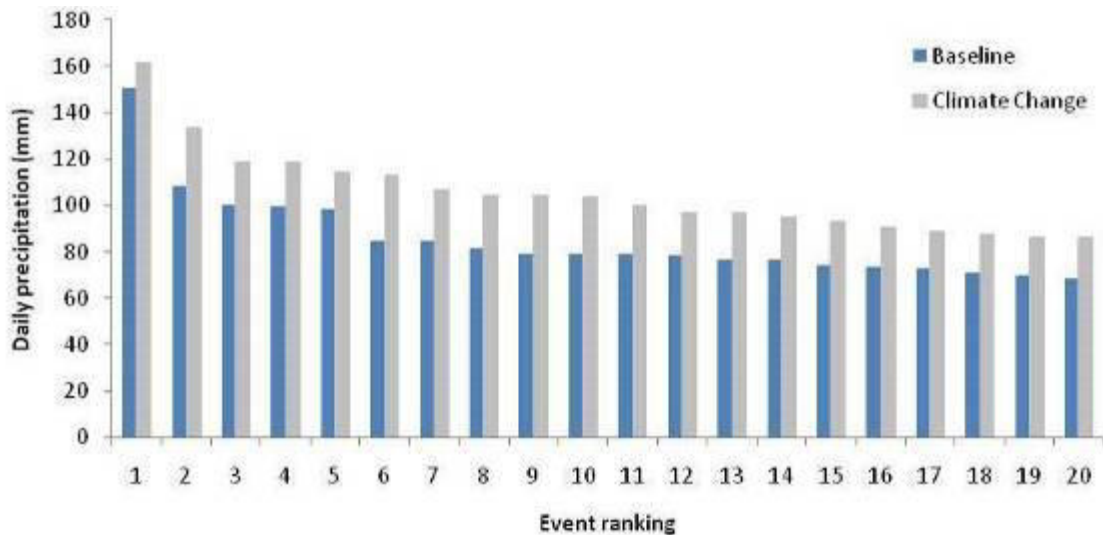
Figure 35 - The top 20 ranked of maximum rainfall events: *with climate change, the 1st ranking event, maximum daily precipitation would increase by 6.7% at 160mm. With 10th ranking event, daily precipitation would increase by 30.8% i.e. from 79mm to 99.7mm.*

3.2.2   Threats of increasing precipitation magnitude

Under climate change, annual precipitation of the catchment will increase from 2,053mm to 2,418mm. Precipitation increases in both dry and wet seasons, however the major increase is in the wet season accounting for a 95% increment in precipitation. Figure 36 shows average precipitation changes in the catchment in the dry and the wet season. By 2050, dry season precipitation in the upper catchment is 300 mm which is 13-14% more than its current precipitation, while precipitation of the lower catchment is about 350mm which corresponds to a 6-10% increase. By 2050, wet season precipitation in the upper catchment is 1,800 – 2,000mm which is a 21-25% increase from the current precipitation and precipitation at the lower catchment is increased by 16-20% at 2,600mm.

Aggregating for the whole catchment, baseline mean precipitation is estimated as 186mm for the dry season and 1,868mm for the wet season. With climate change, mean precipitation would increase by 10% in the dry season and 19% in the wet season. This can be seen in the shift to the right of the precipitation frequency distributions.

Characteristic of monsoon climates, inter-annual variability is large for the Nam Ngiep catchment. Under baseline conditions seasonal rainfall can vary by +100/-50% in the dry season and +40/-25% in the wet season. This variability affects power production in the plant and is an important driver behind spillage flows during the wet season and also reduced operating head in the dry season. The wet season distribution shows a significant increase in the variability of precipitation with a greater proportion of periods of both intense and low wet season rainfall. In particular, wet seasons with precipitation greater than 2,500 mm – an extremely rare event under baseline conditions – would occur 30% of the time under the future climate regime.

Figure 36 - Average precipitation of Nam Ngiep catchment: *the top figure presents average precipitation in the dry season and the bottom figure presents average precipitation in the wet season. Both have the first map showing baseline data, the middle maps showing climate change in 2050 and the last map showing percentage change between baseline and climate change data.*
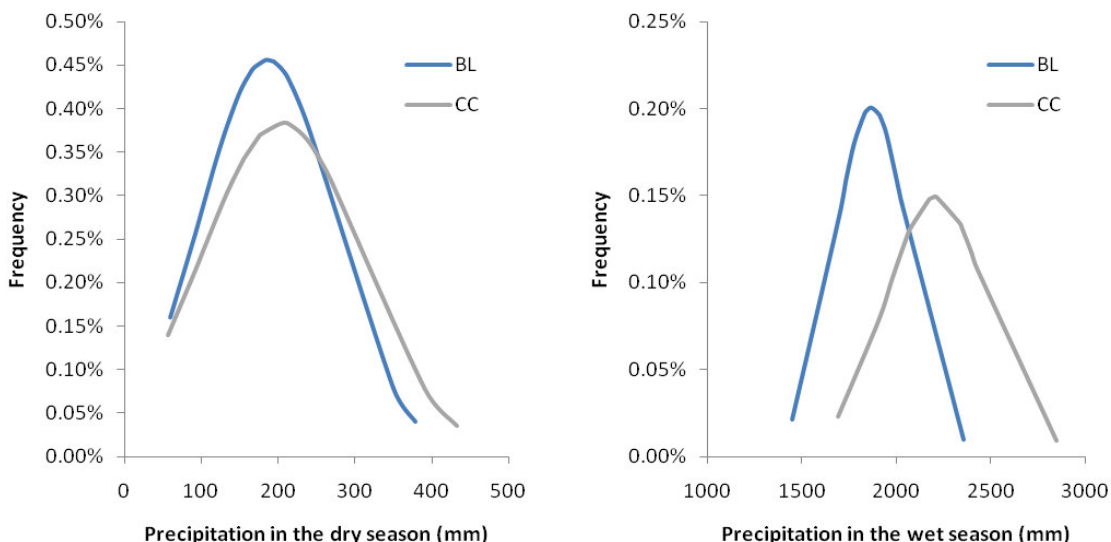
Figure 37 – Precipitation frequency of NNP1 catchment: *(left) precipitation in the dry season: with climate change, there is a 10% increase in the mean precipitation; (right) precipitation in the wet season: mean precipitation also increase and shift to the right by 400mm.*

3.2.3   Threat of increasing erosion and sediment transport

Precipitation intensity affects the runoff and soil erosion condition within the catchment. A prolonged dry season followed by intensive precipitation at the start of the wet season would lead to higher sediment runoff within the catchment. Slope stabilisation and erosion risk were also modelled under climate change. The results show a major increase in erosion within the catchment, largely due to the project increases in precipitation intensity. The most substantial increases with climate change will be in the northern upland areas of the catchment where increases in rainfall intensity, coupled with steep slopes will alter the erosion dynamics and increase rates of hillslope erosion by more than 200% (Figure 38).
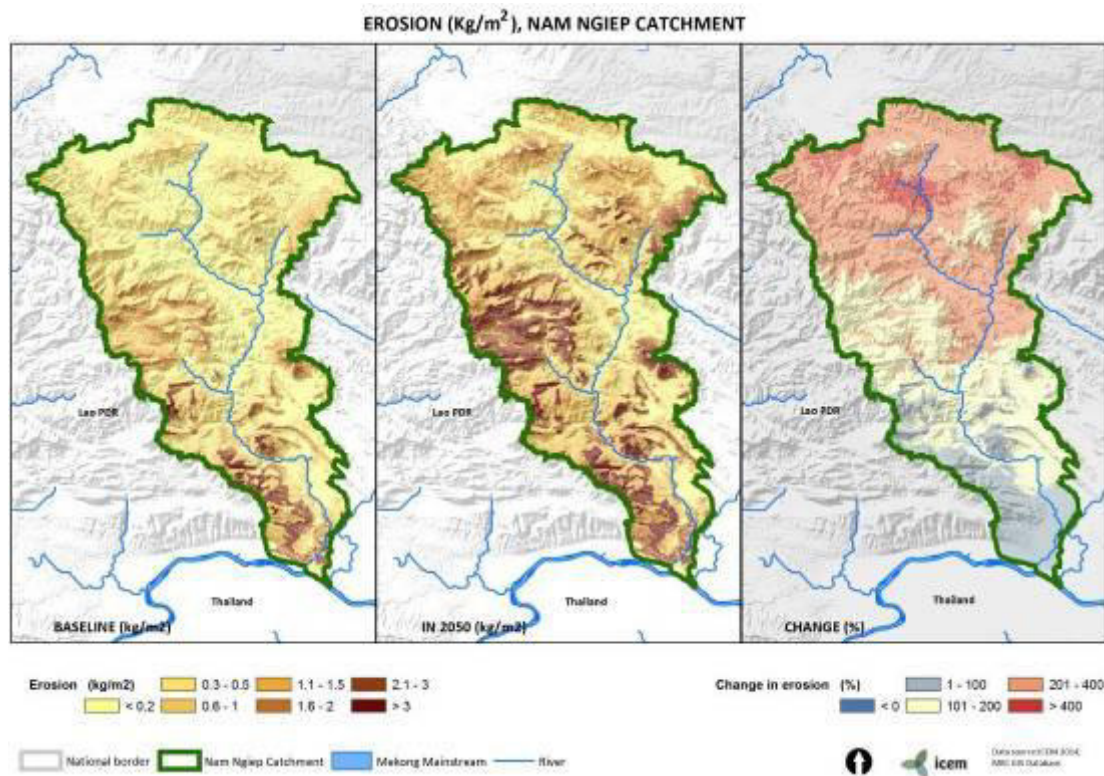
Figure 38: Erosion within Nam Ngiep catchment

Historically, the highest rates of erosion (1-2 kg/m²) have been in the mid-western catchment area, where slopes are high and deforestation has been most extensive. Under the future climate regime these areas will experience erosion rates between 2-3 kg/m². The net result of these dramatic increases in erosion in the western and northern areas of the catchment is that there will be a major increase in the mobilisation of sediments into the main streams and channels of the Nam Ngiep Catchment.

Sediment transport is a complex process and dependent on a number of important factors. In the case of the NNP1 command catchment, climate change will induce a major increase in hillslope erosion, and also increase the stream power of the river channel by increasing the frequency with which bank full discharge is reached. The increase in the erosion rate coupled with increased river transport efficiency will lead to an increase in sediment load entering the Nam Ngiep 1 reservoir. Some of this increasing load will be trapped behind the reservoirs of the upstream cascade, but as their command catchments account for less than 20% of NNP1 catchment, the majority of the increased sediment load will over time pass downstream to the NNP1 reservoir.

Baseline sediment loads into the reservoir were estimated as 0.915 Mt/yr (NNP1PC) and 1.07 Mt/year (this study) (Table 8). In the future the annual sediment load will increase to 2.516 MT/yr or a tripling of the historic loading.

Looking broadly at the gross sediment transport into NNP1, under the current condition, sedimentation within the reservoir after 50 years of operation would reach a total volume of 38.6 MCM. This estimated volume is only 3.7% of the reservoir's dead storage volume and 1.7% of the reservoir's storage capacity. Under future climate change, sedimentation the reservoir after 50 year would be 89.5 MCM which is 8.5% of the reservoir's dead storage volume and 4% of the reservoir's storage capacity.

Table 8 – Gross properties of sediment yield in NNP1 catchment and sedimentation trap in the reservoir: *comparison between sedimentation estimate by NNP1 and VMOD model results for baseline and climate change scenarios*

	Suspended sediment yield (Mt/yr)	Bedload sediment yield (Mt/yr)	Total sediment yield (Mt/yr)	Total sediment yield volume (MCM/yr)	Total sedimentation in the reservoir over 50 years (MCM)
NNP1PC estimate			0.915	0.762	35
ICEM Baseline	0.891	0.178	1.070	0.820	38.6
ICEM Climate change	2.097	0.419	2.516	1.940	89.5

In gross terms, the rates of sedimentation do not pose a major threat to reservoir operations. However, reservoir sedimentation is as much an issue of the dynamics of where sediment is deposited as it is the total loading. This is because dam operations are much more sensitive to sedimentation in the active storage zone of the reservoir than sedimentation in the dead storage. In order to understand the distribution of sedimentation within the reservoir a rapid assessment of reservoir geometry and settling hydraulics was undertaken.

The total reservoir volume is 2,238 MCM with more than half (~1,200 MCM) comprised of active storage. Because of the surrounding topographical conditions the main reservoir can be considered as two distinct impoundments connected by a narrow gorge within which the reservoir is confined to within the river channel (Figure 39).
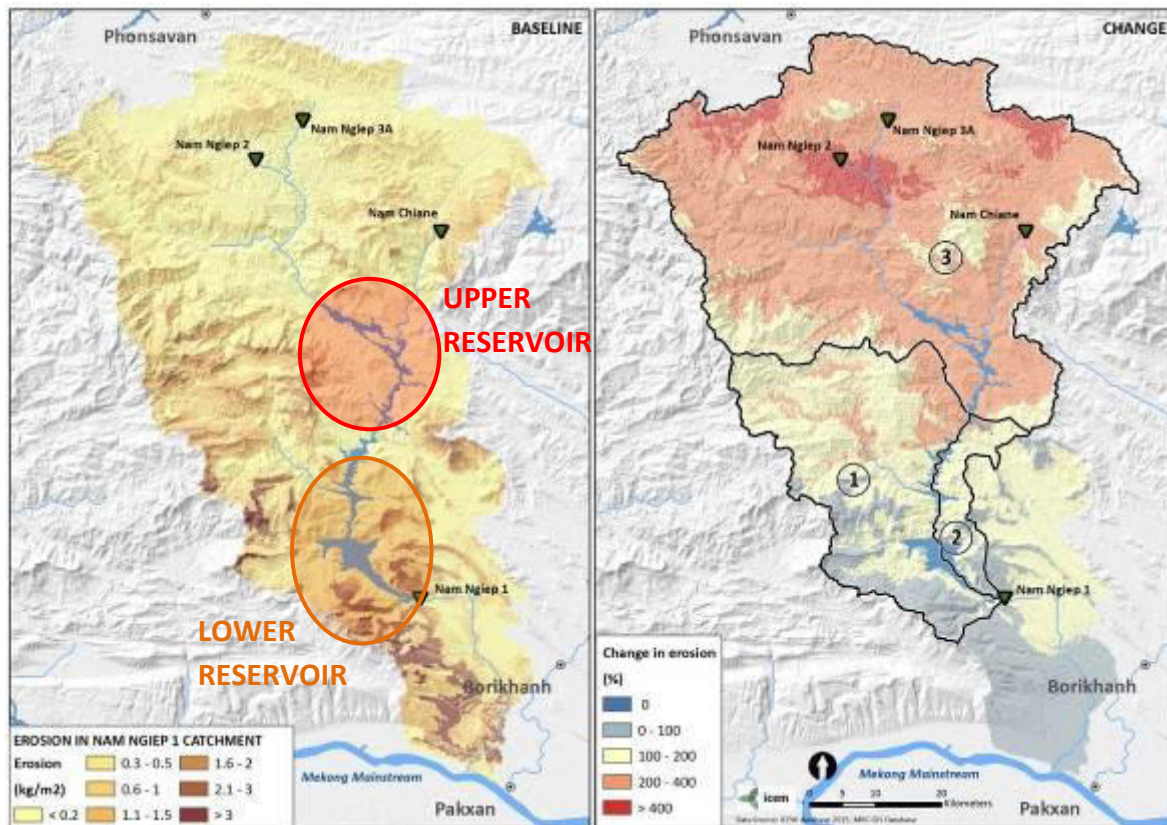
Figure 39 - Erosion rate within the sub-catchments of NNP1 – *the division of NNP1 reservoir into upper and lower reservoir overlay baseline erosion rate of the catchment (figure on the left) and the division of erosion sub-catchments overlay % change of erosion under climate change (figure on the right)*

THE NNP1 LOWER IMPOUNDMENT AREA

The lower impoundment extends 35 km from the dam wall upstream into the mid-section of the NNP1 catchment. It constitutes the deepest part of the NNP1 reservoir and therefore also comprises predominately dead storage. The total volume of the lower impoundment is 1,800 MCM of which 54% is dead storage, which constitutes about 95% of the total dead storage of the NNP1 reservoir.

Sediment inflows to the lower impoundment originate in sub-catchments 1 and 2 (see Figure 39Figure 38). Sub-catchment 1 includes the highest sediment yield areas of the NNP1 basin with rates of hillslope erosion exceeding 3 kg/m2 in some areas. Therefore, under baseline conditions the majority of sediments from sub-catchments 1 & 2 would be transported into the lower impoundment depositing primarily in the dead storage zone. The baseline sediment load for the lower impoundment is averaged as 0.689 Mt/yr or 25.25 MCM over 50 years. Under climate change conditions this sediment load will double to 1.55 Mt/yr or 56.48 MCM over 50 years. Even with climate change this constitutes ~3% of the total storage volume of the lower impoundment resulting in a low sensitivity of the lower impoundment to the high risk of increasing sediment load. Due to the hydraulics of sediment transport in reservoirs a large proportion of this sedimentation will occur within the active storage volume of the reservoir with sedimentation forming deltas where rivers and streams enter the lower impoundment. For the lower impoundment the impact of 50 years of sedimentation with climate change will induce a maximum loss of the total NNP1 reservoir active storage (1,200 MCM) of between 3-4.5%.

THE NNP1 UPPER IMPOUNDMENT AREA

The upper impoundment constitutes the top 25 km of the NNP1 reservoir and has a storage volume of 413.7 MCM. In contrast to the lower impoundment, the upper impoundment volume is 90% comprised of active

storage. In gross terms, the active storage in the upper impoundment amounts to 31% of the total active storage of the NNP1 reservoir.

Sediment inflows into the upper impoundment originate in sub-catchment 3 which includes the northern mountainous areas of the NNP1 command catchment. This area experiences moderate rate of erosion under baseline conditions, however, will experience the greatest increase in hillslope erosion with climate change. Significant pockets of the Nam San tributary catchment and the area near the Nam San-Nam Ngiep confluence experience increases in rates of erosion of >400%, while the majority of the catchment experiencing increases of 200-300% (Figure 39). All three of the upstream projects are located in this sub-catchment. The increased rates of erosion and enhanced transport capacity of the sub-catchments' waterways will result in a tripling of the sediment inflows of the upper impoundment from 0.38 Mt/yr to 0.97 Mt/yr with climate change. Over 50 years of operation this means that the total sediment accumulated in the upper reservoir would amount to 33 MCM or 8% of the storage capacity of the upper impoundment. Sedimentation in the upper impoundment will preferentially deposit in the active storage zone because of the sharp drop in hydraulic transport capacity when streams and reservoirs enter the high water levels of the impoundment. Consequently the impact of sedimentation in the upper impoundment over 50years of operation would be to reduce the total active storage capacity of the NNP1 reservoir by 2-3%. Table 9 summarises the sedimentation findings for the upper and lower impoundments.

Table 9 – Sedimentation between upper and lower reservoir for baseline and climate change condition

	Upper impoundment			Lower impoundment		
	Total sediment yield (Mt/yr)	*50 years accumulated sediment (MCM)*	*% of storage capacity*	*Total sediment yield (Mt/yr)*	*50 years accumulated sediment (MCM)*	*% of storage capacity*
Baseline	0.381	13.32	3%	0.689	25.29	1%
Climate change	0.965	32.98	8%	1.552	56.48	3%

3.2.4   Impact on reservoir sedimentation-storage capacity (IP3)

Threat: *increased hillslope erosion and sediment transport*
Impact pathways: *Increased precipitation intensity will affect the soil catchment cover through an increased erosion and consequent sediment mobilisation. Increased river flows will also enhance the sediment transport capacity of the Nam Ngiep River with both factors combining to exacerbate sediment inflows to the reservoir. The main reservoir will fill up with sediment and the reduced active storage capacity of the reservoir will affect energy production and regulation capacity.*
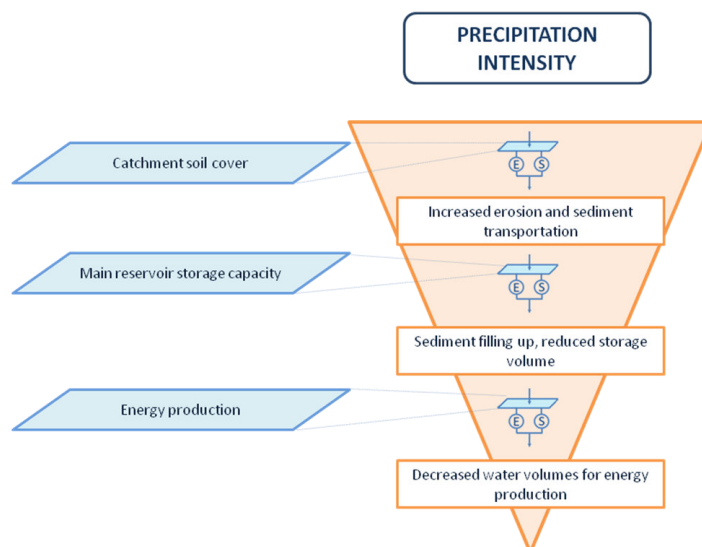
Figure 40 - Impact Sequence 3: the threat of an increase in precipitation intensity affects the catchment soil cover, *the main reservoir storage capacity and consequently the regulation capacity during big flood events*

The watershed is not typically considered an asset for a hydropower plant; however, the soil and vegetative cover of a catchment are the fundamental factors in determining the quotas of rainfall which either infiltrate the ground, evaporate or runoff towards the reservoir as well as the rates of soil erosion on the hillslopes. The catchments water abundance and the hydrological process that govern it fate and transport through the catchment therefore determine the energy production potential of NNP1. These processes are themselves sensitive to changes in climate.

An intensification of the storm events and also the increase in their frequency threatens to enhance hillslope erosion through the washing away of the finer soil material inhibiting water infiltration and causing eventually slope instability, these processes are nonlinear and can be dramatically exacerbating by changing land use conditions in the catchment – especially in the parts of the Nam Ngiep catchment that are mountainous with steep slopes. While the underlying geology is not expected to result in high land slide risk, significant portions of the catchment do possess a risk of hillslope failure, because of highly degraded slopes in some areas of the catchment with weathered lateritic soils.   As noted in the description of the threat above, the results of the climate change modelling show 100-400% increase in soil erosion in parts of the catchment and a tripled cumulative sedimentation yield over 50years compared to the current estimated sedimentation. Such an increase in soil erosion will lead to the transportation of the material into the reservoir and its consequent silting up. The length of the reservoir and size of the active storage relative to the dead storage would mean that most of the incoming sediments would settle out within the reservoir active zone. This scenario would affect the energy production of the power plant since there would be a decrease in seasonal storage capacity and the water available for use as turbinated flow.

Based on the model projections, the combined impact of reduced active storage in the lower and upper impoundments due to sedimentation is a 5-7.5% reduction in the total reservoir active storage volume. Under average hydrological conditions, this reduced active storage volume would see wet season water levels in the reservoir rise by ~0.8m which would increase the amount of spillage during the wet season and reduce by a proportionate volume the amount of water carried through to the following dry season. This spillage reflects a reduced regulation capacity of the reservoir but also a foregone quantum of energy production, amounting in a medium climate change impact. In addition, the increased spillage will also increase wear-and-tear on the spillway structures which were not designed to be used so frequently (c.f. IP6).

3.2.5   Impact on reservoir sedimentation- Regulation capacity (IP4)

Threat: *increased hillslope erosion and sediment transport*
Impact pathways: *An increase in precipitation intensity and hillslope erosion will lead to an increased sedimentation in the main reservoir due to increased sediment transport into the reservoir. The loss of active storage will cause the reservoir to be more sensitive to an incoming PMF due to a smaller regulation capacity.*

As described in the previous impact pathway, the deposition of 89.5 MCM of sediments into the NNP1 active storage will impact on the reservoirs approach to managing normal extreme flood events. The 89.5 MCM of lost storage, which translates into a water level change of 0.8 m will under normal flood conditions result in a larger volume of water passing through the spillway structures reducing the seasonal regulatory capacity.

Under extreme flood events, the lost active storage corresponds to the PMF flood volume during the first 4 hours of the event or one-third of the inflows during the rising limb of the PMF flood hydrograph. This lost storage therefore strengthens the need for a rapid response to the PMF event and the need for early warning detection of its manifestation through the catchment to ensure the reservoir manages the PMF flood safely. These values are considered as having a medium impact on the regulation capacity towards probable maximum floods (Annex III – Reservoir storage volume).
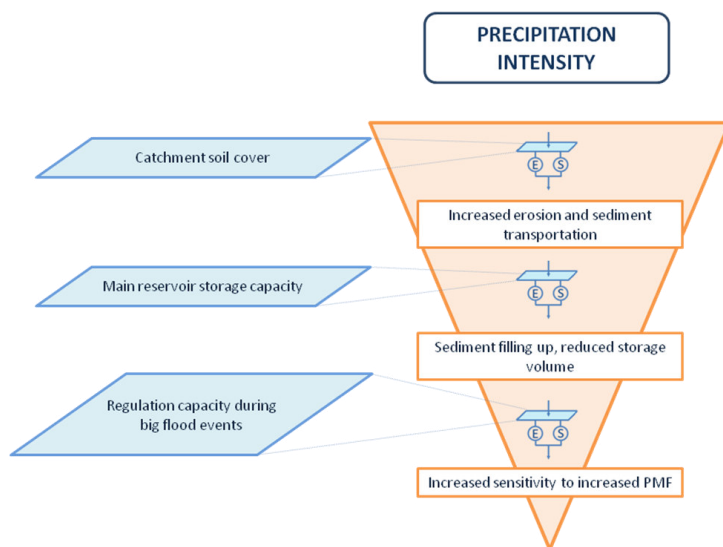
Figure 41 - Impact Sequence 4: the threat of an increase in precipitation intensity affects the catchment soil cover, the main reservoir storage capacity and consequently the energy production

3.2.6 Impact on Seasonal water availability - increase energy production (IP5)

Threat: *increased water availability*
Impact pathways: *An increase in overall precipitation magnitude will provide longer and earlier onset of the monsoon. The additional water will be used for energy production and the powerhouse will operate at full capacity more frequently.*
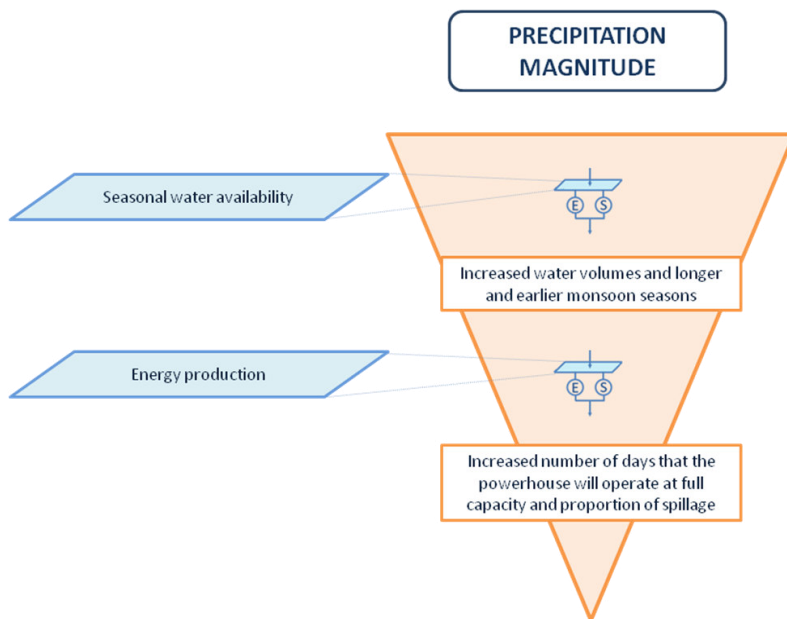
Figure 42 – Impact Sequence 5: the threat of an increase in precipitation magnitude affects the seasonal water availability and therefore the energy production

A change in the precipitation regime would induce both positive and negative threats to power production. Gross energy production of the NNP1 reservoir is dependent on the reservoirs ability to store water during the wet season when inflows are abundant and release them during the dry season when natural inflows are scarce. This is the main function of the active storage volume. In the case of NNP1, the active storage of the

main reservoir is too small to accommodate large variations in flow and therefore to keep production constant and unaffected by variations in precipitation.

POSITIVE IMPACTS OF INCREASED PRECIPITATION ON ENERGY PRODUCTION

The year-round increase in precipitation resulting from the model, which is on average 10% increase in the dry season and 19% increase in the wet, implies an increase of water availability in general. During the dry season and dry years, the monsoon will have an earlier onset and will last longer. The energy production will therefore be strengthened as the number of days the turbines can operate at full capacity will increase. The lengthening of the monsoon and a general increase in precipitation will also increase water availability during the wet season, which will also enhance energy production – especially in the onset and falling limb of the flood.

The calculated increase is shown in Figure 43; the average annual energy production is estimated to increase by 2050, the distinct increases are 7 % in the dry season and 16% in the wet season. These increases represent substantial benefits to the project, which will continue to accrue during the operating life. The impact on the power production is considered high (Annex III – Energy production).
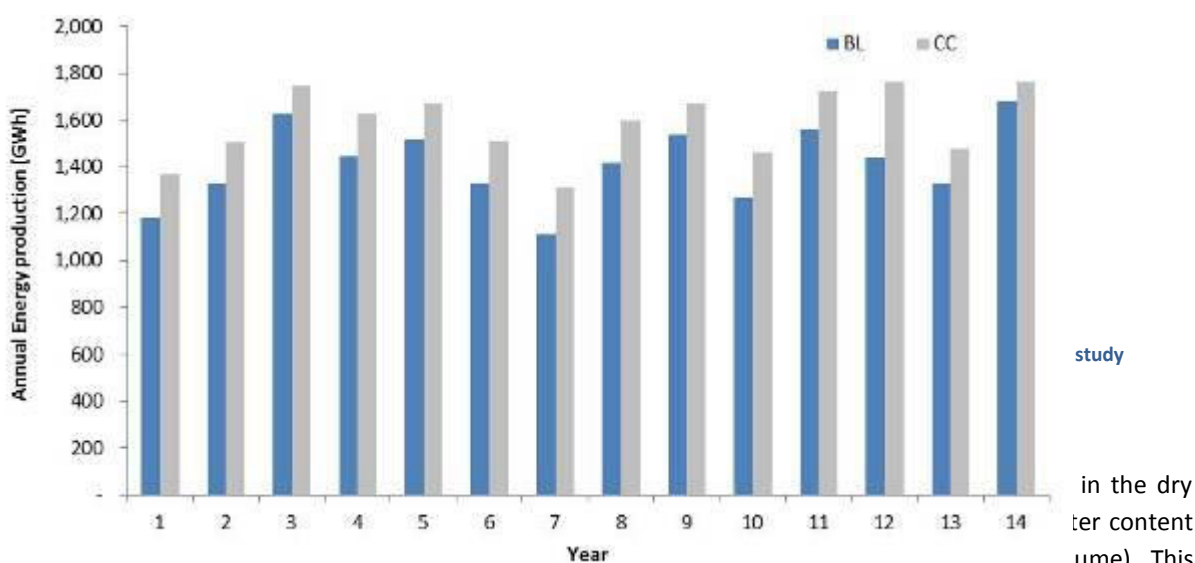
substantial increase in spillage would not result in reduced power production, because turbines would be producing at full capacity during spill events, however it does highlight a reduced water efficiency of NNP1 under the future climate regime, where an associated quantum of energy is foregone over the spillway and not utilised by the project.

3.2.7   Impact on increased spillage – damage to spillway (IP6)

Threat: *increased wet season inflows*
Impact pathways: *An increase in seasonal water availability will lead to increased spillage due to excess of water, which would represent a foregone energy generation opportunity. The use of the spillways may lead to their damage and increased costs for maintenance.*

The increase in reservoir spillage described above, translates to an increase in the average spillage discharge, of 2,253 m^3/s under climate change compared with 1,374 m^3/s under baseline conditions. In addition the design spillway event is the 1,000-year flood which will increase marginally from 5,210 m^3/s to 5,550m^3/s.

The spillway discharges directly onto the river bed with no energy dissipation or protection works at the landing zone. Leaving the spillway apron, spill waters are directed by two chutes onto a landing zone identified through modelling analysis by NNP1PC (Figure 44). The two chutes are angled to direct spillage to the base of

the right-side valley in order to keep discharged waters clear of the power house, reducing the sensitivity of the powerhouse to damage from spillway releases.
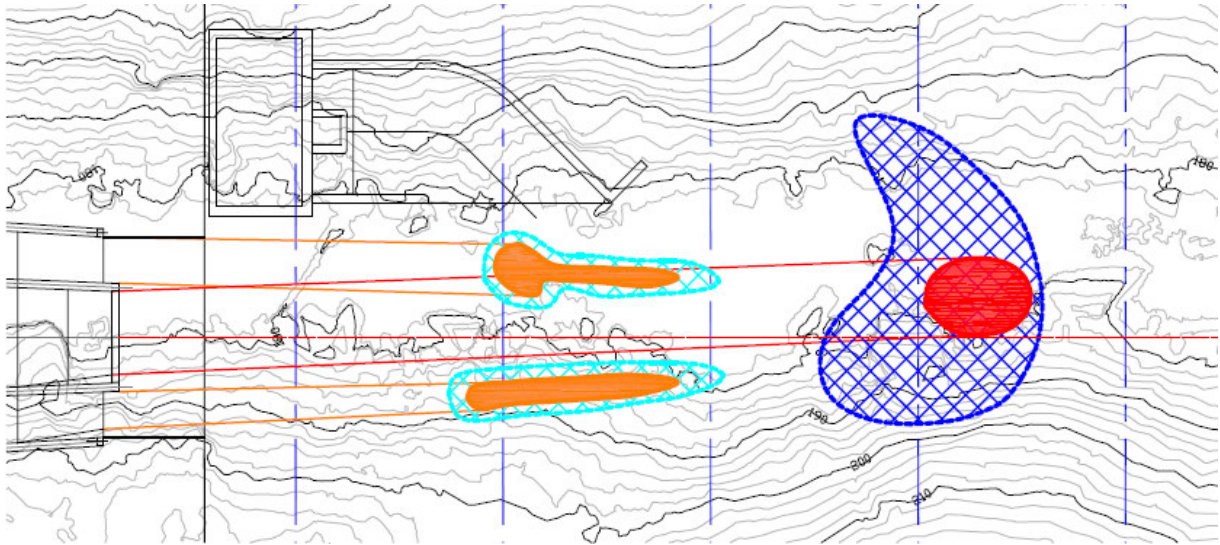
Figure 44: Layout of the spillway apron, chutes and landing zone

Analysis was undertaken by NNP1PC of the bed conditions at the landing site which determined that there was 10 m of sediments and sands underlain by CH-rock. Based on standard industry engineering methods (Annandale et al, 2006), NNP1PC calculated the landing zone's Erodibility Index which is given as:

$$K = M_s * K_b * K_d * J_s$$

Where:
M_s = mass strength number;
K_b = block size number;
K_d = discontinuity bond shear number; and
J_s = relative ground structure number

Then an estimate of the spillage stream power was made for the design flood (5,210m3/s) using the equation:

$$P = \gamma * U * h * S$$

γ: unit weight of water = 104 m^3/s/m
U: flow velocity = 46.1 m/s
h: water depth = 2.3 m
S: hydraulic energy grade line slope = 0.016

Based on these equations, NNP1PC estimated the Erodibility index of the bed rock to range from 4,904 to 19,780, with a design flood stream power of 177 kN/m^2. These estimates place the landing zone bed rock within the non-eroded zone (Figure 45).
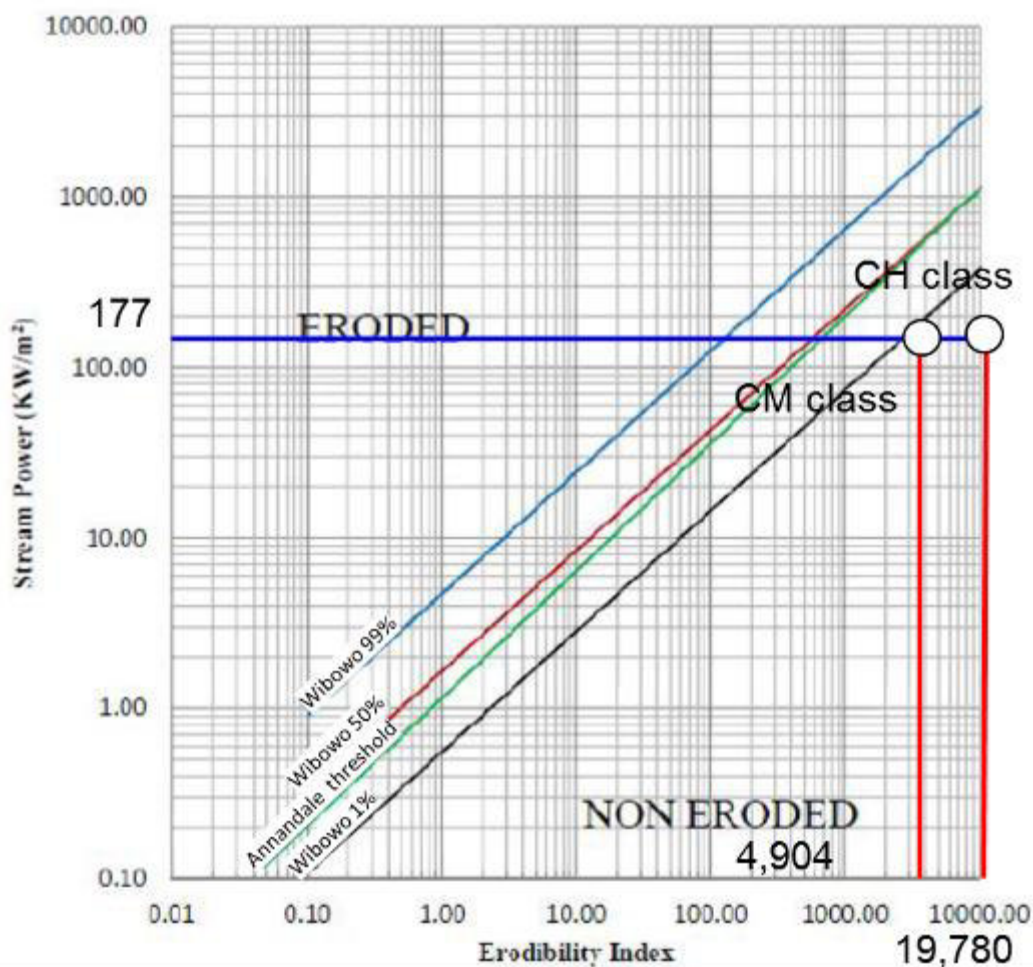
Figure 45: Assessing the Erodibility index of NNP1 landing zone

However, as shown in the diagram the landing zone is relatively close to the erodible thresholds. Stream power is directly proportional to discharge; given an approximate 7% increase in the size of the design flood discharge with climate change and relative to the NNP1PC design flood estimate of 5,210 m³/s, the spillway landing zone is expected to experience a comparable 7-10% increase in stream power with climate change, resulting only in a minor increase in erosion potential. This increase will accelerate the rate of erosion of the river bed alluvial layers but will not appreciably increase erosion of the underlying CH-bedrock, or push the area into the erodible zone. The low change in stream power projected during the design flood event, coupled with the fourfold increase in frequency of spillway usage will result in a moderate exposure of the landing zone to increased erosion, while the good quality bed rock 10 m below the river bed will result in moderate sensitivity resulting in a net moderate impact (Annex III – Spillways).
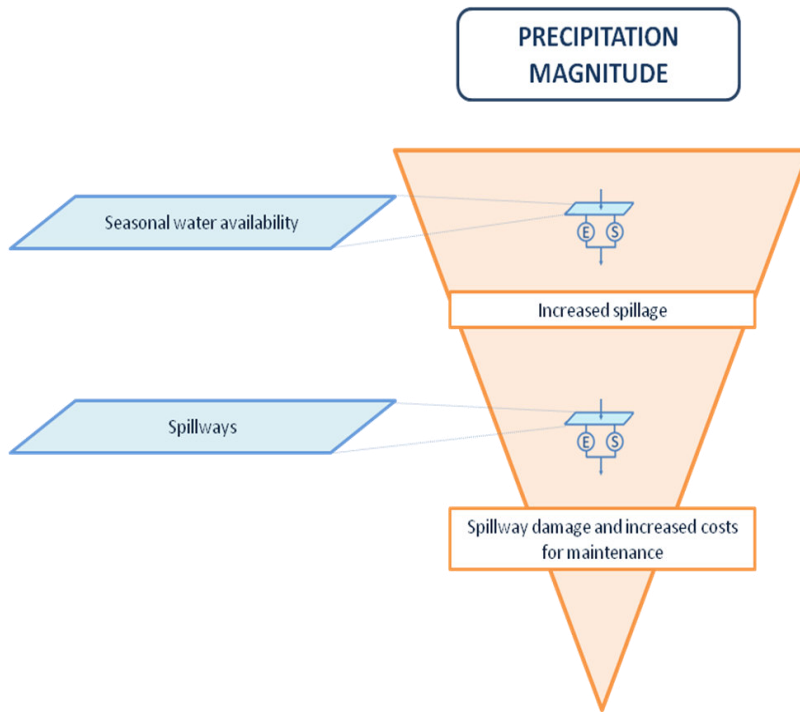
Figure 46 - Impact Sequence 6: the threat of an increase in precipitation magnitude affects the seasonal water availability and therefore increases the spillage which affects the maintenance necessary for the spillways

3.3   IMPACTS OF THE INCREASE IN FLOOD FREQUENCY

3.3.1   Threats to increasing flood frequency

The increase in precipitation leads to a change in the flood regime. Flood discharges for various return periods were calculated using modelling results to quantify changes. Figure 47 shows the flood return periods for the baseline data compared with the results from the average of all climate change scenarios and the high climate change scenario (out of the six selected scenarios). The likelihood of occurrence of the baseline 1000-year flood will increase, becoming a flood with a 90-year return period for the average climate change scenario or a 30-year return period for high climate change scenario. While the 1 in 10 year flood event will become a 1 in 2 year event for the Nam Ngiep River.
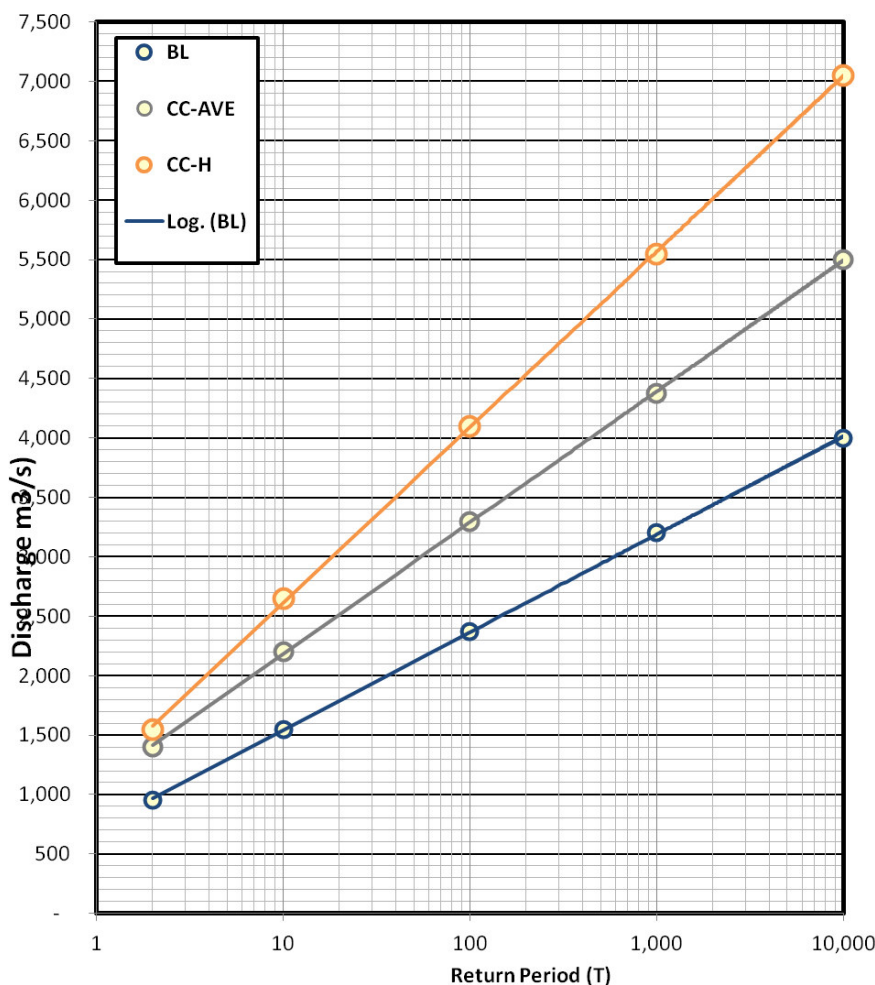
Figure 47 – Flood return period: *calculated based on VMOD model results which incorporated various precipitations from different locations in the catchment. Flood return period was estimated using Best-fit method, the cumulative frequency distribution based on the Gumbel, and Log-Pearson distribution.*

INCREASES IN THE 1 IN 1,000 YEAR DESIGN FLOOD

The NNP1 project, in particular the spillway gates, was designed with a design flood discharge of 5,210 m^3/s which is the estimation of the 1000-year flood from observed discharge data at Muong Mai station located 20 km downstream of Hat Gnium. This station has notably higher precipitation than the amount of precipitation estimated for the whole catchment leading to higher discharges recorded at Muong Mai than at the dam site. Discharge information is recorded at the station only twice each day, making it sufficient for estimation of the mean daily discharge at the station. However, with only two readings recorded daily it is likely that the monitoring will not pick up peak daily discharges – which are needed for flood frequency analysis. In response to this, NNP1PC applied a scalar conversion factor of 1.2 to the estimated mean daily discharge in order to approximate the peak daily discharge. The results from the VMOD model estimated that the baseline 1000-year flood discharge is only 3,200 m^3/s which is 39% less than the design flood discharge. Under the average of all climate change scenarios, the 1000-year flood discharge is 4,375 m^3/s which is 16% less than the designed flood discharge, while the higher estimate would reach 5,550 m^3/s exceeding the design flood discharge by 7%.

Under the high climate change scenarios used in this study, the increased size of the design flood (would exceed the discharge capacity of the spillway structure inducing a backwater effect and causing the reservoir water levels to rise. However, reservoir storage has been designed to accommodate the PMF flood event (substantially larger than the 1 in 1,000-year event) such that the rise in reservoir water levels during a 1 in 1,000-year event can be maintained with the reservoir without overtopping.

INCREASES IN THE 1 IN 10,000-YEAR FLOOD

The frequency analysis undertaken by the ICEM team was then extrapolated to estimate the 10,000 year event with findings shown in Table 10.

Table 10: ICEM modelling estimates for extreme flood events

Return Period (T)	Event discharge (m³/s)		
	BL	CC-AVE	CC-H
2	950	1,400	1,550
10	1,550	2,200	2,650
100	2,375	3,300	4,100
1,000	3,200	4,375	5,550
10,000	4,000	5,500	7,050

INCREASES TO THE PROBABLE MAXIMUM FLOOD (PMF)

The NNP1 project calculated the probable maximum flood (PMF) to be 8,890 m³/s. The PMF represents the largest possible flood event in the catchment and was calculated using a deterministic method based on rainfall data at Pakxan station which is 50 km downstream of NNP1 dam and situated within a wetter climate. Modelling by the NNP1PC demonstrated that the PMF can safely be passed without overtopping of the parapet wall (RL323.5 m.a.s.l.[10]) at the main dam, with a maximum water level of 321.94 m.a.s.l reached 19 hours after the onset of the event (Figure 48).
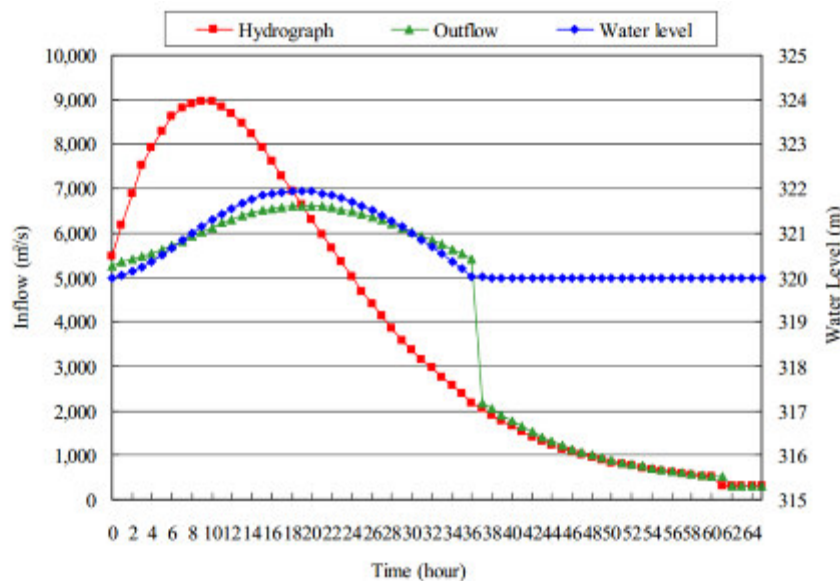
Figure 48 - Flood routing of the Probable Maximum Flood *(Source: NNP1 Technical report)*

In engineering design, efforts at estimating the PMF typically adopt a deterministic approach such as the one utilised by NNP1PC. Another approach is to use probabilistic methods and flood frequency analysis to estimate the 10,000-year event and then to extrapolate using frequency factor formulas to derive estimates for the PMF (Zhou et al, 2008). The probabilistic approach is historically not favoured because it extends a comparatively short data set (even if 100 years of data is available) to estimate events with very large return periods. While

---

[10] In February, 2015 NNP1PC confirmed that the dam crest level including the additional parapet was increased to 323.5 compared to the 322.0masl quoted in the 2014 Technical Report. All assessments of climate change impacts have been revised to ensure this new level is taken into account.

there are accuracy issues with a probabilistic approach, there are also acknowledged limitations to the deterministic approach in the literature, and neighbouring hydropower projects within Lao PDR have reported a 50% variation in the size of the PMF when different methodologies are used (DSRP Meeting Report, 2015).

The probabilistic method developed by Zhou et al was used in the CRVA for three reasons:

(i) **Given baseline and projections data availability, the CRVA could not provide a more confident deterministic PMF estimate than NNP1PC:** the ICEM approach to CC projections and simulations produces data commensurate with a frequency analysis approach but cannot, given resource limitations[11], provide estimates for sub-daily rainfall intensities with climate change which are essential if the deterministic approach is to be updated to include climate change; in addition, after review of the NNP1PC approach to estimating the PMF, it was concluded that the company has made a robust estimate taking into account all available data, comparing with regional studies and also those of hydropower projects in neighbouring basins.

(ii) **Efforts therefore focus on comparing with another approach:** a probabilistic approach linking the 10,000-year and PMF event will offer a point of comparison with the deterministic PMF.

(iii) **The approach developed by Zhou et al (2008) is built on an established theoretical link between the two events, and draws on a large data set from two separate studies:** Seminal work by Hershfield (1961) was used drawing on 2,600 rainfall stations and 95,000 station data years, coupled with research on 11,518 annual floods from 490 catchments by Merz et al (2003) to establish the correlation.

The approach employed is described in Annex IV. The results show that average PMF of the modelled climate change scenarios is 9,200 – 9,400 m³/s and PMF under high climate change scenario is 11,800 – 11,950 m³/s. Average PMF of all climate change scenarios is 3% greater than the current NNP1's estimated PMF, while PMF under high climate change scenario is 27 - 30% higher than the current NNP1's estimated PMF. This represents a significant increase in flood risk for the NNP1 project, commensurate with the dramatic increases in precipitation projected for the basin. It should be noted that the findings of the cc-modelled PMF do not take into account changing intensity dynamics of the rainfall hydrograph at sub-daily time-steps, with the cc-projections assuming no change in the hourly rainfall hydrograph from the baseline. However, it is expected that the sub-daily rainfall intensity will likely increase with climate change which would affect the magnitude of the result PMF.

The increasing size of the PMF represents a significant increasing risk to the project. Modelling work by the NNP1PC as part of the DSRP demonstrated that the main dam and its spillway could accommodate a 25% increase in the PMF up to 11,500 m³/s without overtopping. During this event the water levels would be right at the dam crest level such that wave action would likely induce intermittent overtopping of the structure, which was deemed to be acceptable by the DSRP given the extreme nature of the event. The average and upper climate change estimates fall within a range comparable to the magnitude of the PMF assessed by NNP1PC and deemed to be manageable by their in-house modelling efforts (Figure 49). The results demonstrates that even under a scenario comparable with the upper climate change estimate, the project can safely pass the PMF without overtopping of the parapet wall at the main dam. Using the same flood routing model developed by NNP1PC, Figure 50. shows the inflow and outflow hydrographs for the main dam and

---

[11] ICEM explored the possibility of replicating the deterministic method using future climate change simulated data, however resources were not available for new CC dynamic downscaling and it was requested by NNP1PC that ICEM use the existing downscaled data as developed for the Mekong ARCC project. This set of existing data did not give any projections for sub-daily rainfall data – i.e. it does not provide new estimates for rainfall intensity, which is one of the key input requirements for PMP estimation. Without updating the rainfall intensity data for the CC scenario, recalculating the PMP was considered not appropriate. This meant that a thorough recalculation of the PMP and PMF would be applying a methodology much more accurate than the input data available.

corresponding dam water levels. The results confirm that with climate change the maximum water surface level in the main reservoir will reach 323.4 m with a maximum spillway release of 7,591 m^3/s. Water level in the reservoir will be drawn down to NOL within 46 hours of PMF events as showed in Figure 50.

In February 2015, before the results of the PMF modelling were released, the NNP1PC clarified with the ICEM team that the height of the parapet wall on the main dam has been raised such that the maximum stored water level is 323.5 m, which means that the main dam could safely accommodate and pass the potential 25-30% increase in the PMF. The findings indicate that the CC-PMF would be at the top-most limit of the dam to store the PMF, however, was deemed as acceptable given the uncertainty in the PMF estimate and also the extreme rarity of the event.
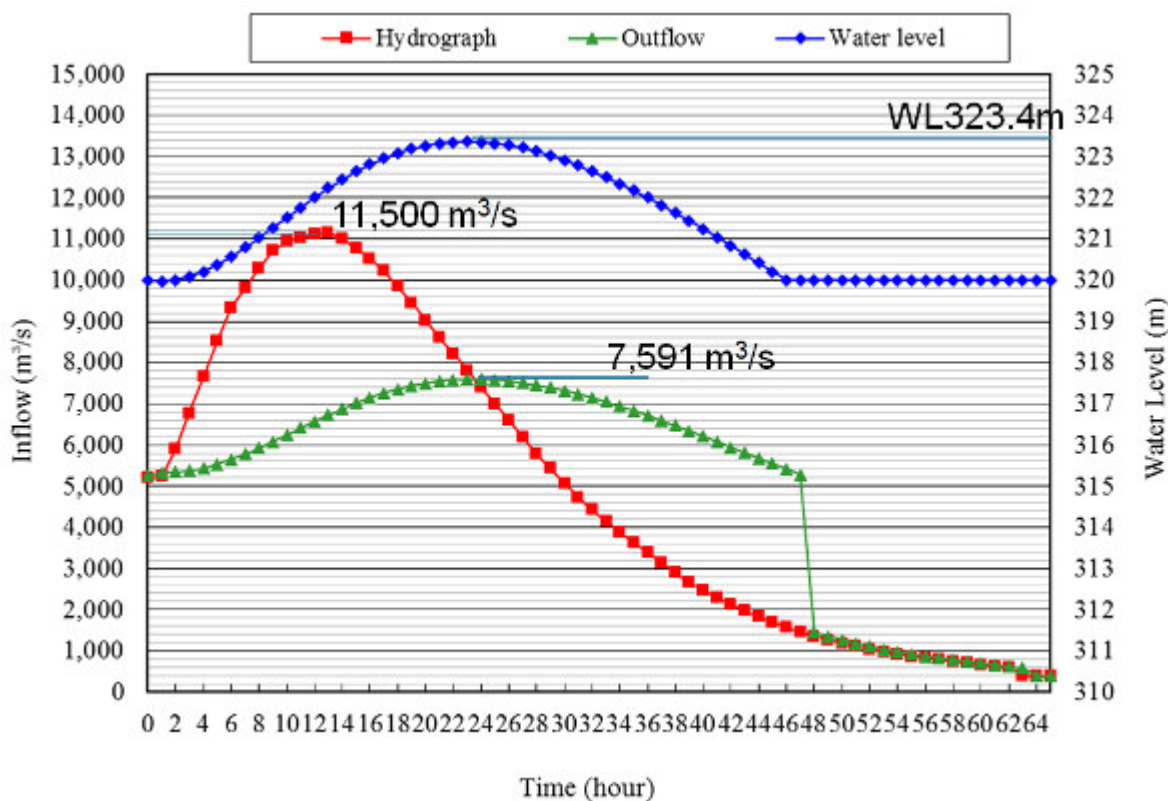
Figure 49: Flood routing of the Probable Maximum Flood under high climate change scenario *(Source: NNP1PC, 2015)*

3.3.2   Impact on Overtopping main dam-Inundation of powerhouse (IP7)

Threat: *increase in the size of the design flood.*
Impact pathways: *An increase in the PMF flood event will increase the volume of flood waters that need to be stored and passed through the spillway of the main dam. In the worst case scenario the increased PMF magnitude would exceed the capacity of the main dam resulting in over-topping and uncontrolled releases over the main dam wall. Over-topped flows would be concentrated in the downstream canyon leading to the inundation of the powerhouse from an overflow. A power outage may follow due to the flooding of the electrical facilities, as well as damage to equipment, the control room and penstock protection works.*

Figure 50 - Impact Sequence 7: the threat of an increase in the probable maximum flood affects both the main reservoir storage and the main spillway discharge capacity, consequently the main powerhouse and the energy production.

The impacts on the NNP1 project due to an increase in the probable maximum flood would be determined by the combined characteristics of the main reservoir and of the main spillway. The reservoir storage capacity together with the main spillway discharge capacity would contribute to accommodate and release the incoming volumes of water. The combination of a diminished storage capacity and an exceeded spillway discharge capacity would establish the occurrence of the main dam being overtopped by the incoming PMF, which would result in a cascade of significant impacts on the project and downstream, which are each assessed separately. In this scenario the impacted asset is the main powerhouse which is located adjacent to foot of the dam on the left slope. This section along the river is an optimal choice for locating the dam wall since the valley is V shaped and easily blocked. However, the steep canyon configuration induces a high sensitivity of the powerhouse to overtopping as the steep canyons could lead to the creation of a concentrated flow of overtopped water as the canyon funnel the waters, hitting the powerhouse and damaging the structure itself, the penstock protection and the control room (Figure 51). The inundation of the powerhouse would lead to the power outage of the plant and to a loss of income for its prolonged inactivity.
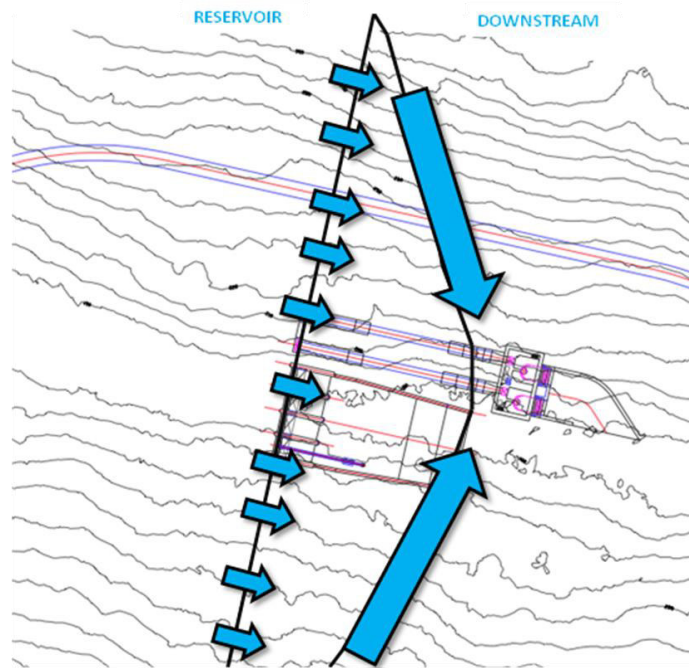
Figure 51 - Indicative flow directions in the event of dam overtopping, highlighting the funnelling of flood flows into the v-shaped valley and onto the powerhouse

The results from the modelling show that the PMF could increase by up to 30% with climate change and that the height of the parapet wall has been raised to 323.5 m which would allow the reservoir to accommodate the projected increase in the PMF even if the reservoir was at FSL when the PMF event occurs. However, there remains no appreciable safety margin above this estimate such that a further small increase in the design PMF would result in over-topping. The impact scoring consequently show a very high exposure to an increasing design flood associated with the wetter catchment, however, because of the over-design in the existing reservoir and spillway, NNP1 has a low risk of overtopping even under a future climate regime. For the power house this low risk of overtopping translates to a moderate level of exposure, although the sensitivity of the powerhouse remains high due primarily to its location at the foot of the dam. These factors lead to a moderate impact score (Annex III – Reservoir storage, Spillway, Main powerhouse, Energy production).

3.3.3 Impact of elevated water levels in re-regulation reservoir - Flooding of Powerhouse from backwater (IP8)

Threat: *increase in the size of the PMF*
Impact pathways: *An increase in the PMF flood event will increase the volume of flood waters that need to be stored and passed through the spillway of the main dam. If the dam is able to contain the PMF without over-topping, then water levels in the reservoir would rise increasing the discharge flows through the spillway. These increased discharges could increase the inflow of waters to the re-regulation dam which could result in two potential impacts: (A) the re-regulating reservoir contains the incremental flood volume leading to elevated levels and back-water inundation of the power house leading to power outage and a loss of income, and/or (B) the incremental flood volume exceeds the capacity of the re-regulating reservoir resulting in over-topping of the re-regulating dam and dyke structures, flooding downstream reaches and communities. Impact pathway (A) is assessed in this section, with (B) addressed in the next section.*
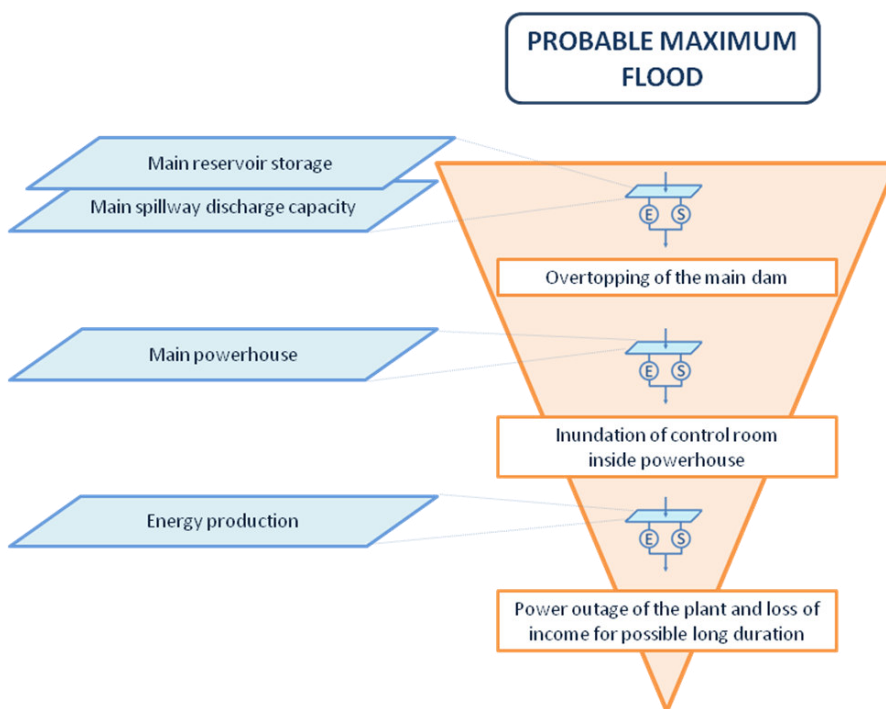
Figure 52 - Impact Sequence 8: the threat of an increase in the probable maximum flood affects both the main reservoir storage and the main spillway discharge capacity, consequently the re-regulation storage capacity, the main powerhouse and so the energy production.

In the likely event that the main dam is not over-topped during the PMF with climate change, the increased flood volume stored behind the dam wall will increase the discharge flows through the spillway. This will result in spillway discharge exceeding 7,000 m³/s for more than 20 hours during the peak of the PMF event and peaking at 7,590 m³/s (Figure 49), whereas under baseline PMF conditions spillway discharge never exceeds 7,000 m³/s. This increased inflow would lead to a more than 20% increase in the flood volume entering the re-regulating reservoir during the first 40 hours of the PMF event, which corresponds to a flood inflow volume of more than 1,000 MCM compared to 831 under the baseline PMF.

The re-regulation reservoir has a storage capacity of 11 MCM above the NOL, with a spillway designed to pass 5,210 m³/s. The re-regulation reservoir is an un-gated spillway which commences spilling once water levels at the re-regulation dam exceeds 187 m.a.s.l. Conditions in the re-regulation reservoir are comparable to the dynamics of a river with water levels varying along the re-regulation reservoir length in response to topography. The main power house floor elevation is located at 193 m.a.s.l. or 0.9m above the maximum water level in the re-regulation reservoir during the baseline 1 in 1,000-year event (192.1 m.a.s.l.). In addition, the main power house design also includes a concrete curtain[12] 17 m high which raises the protection of the power house against inundation to 210 m.a.s.l.; and the inner walls of the electrical and control rooms are doubled to prevent water leak.

In a future 1,000-year flood with climate change case, the water levels reached in the re-regulation dam would reach 192.6 m.a.s.l. which is below the floor elevation of the powerhouse. For the levels to reach the foot of the powerhouse would require 5,800 m³/s which is 5% larger than the future 1000-year event with climate change, however, substantially smaller than the estimated releases under both the baseline PMF (over 6,500 m³/s c.f. Figure 48) and the CC-PMF (over 7,500 m³/s c.f.Figure 50). Using the upper estimate for the CC-PMF would result in a maximum water level in the re-regulation reservoir capable of reaching the foot of the main power house but not exceeding the height of the concrete curtain.

The impact scores related to this threat are rated moderate because of the high likelihood of increased spillway releases during the PMF and the very low sensitivity of the power house to inundation due to the

---

[12] The 'concrete curtain" is actually extruded cement panels comprising the exterior wall of the power house (NNP1PC, 2014).

robust existing protection measures (Annex III - Reservoir storage, Spillway, Main powerhouse, Energy production).

3.3.4 *Impact of elevated water levels in re-regulation reservoir - Saddle dam breach (IP9)*

Threat: *increase in the size of the PMF*
Impact pathways: *An increase in the PMF flood event will increase the volume of flood waters that need to be stored and passed through the spillway of the main dam. If the dam is able to contain the PMF without over-topping, then water levels in the reservoir would rise increasing the discharge flows through the spillway. These increased discharges could increase the inflow of waters to the re-regulation dam which could result in two potential impacts: (A) the re-regulating reservoir contains the incremental flood volume leading to elevated levels and back-water inundation of the power house leading to power outage and a loss of income, and/or (B) the incremental flood volume exceeds the capacity of the re-regulating reservoir resulting in over-topping of the re-regulating dam and dyke structures, flooding downstream reaches and communities. Impact pathway (B) is assessed in this section, with (A) addressed in the previous section.*
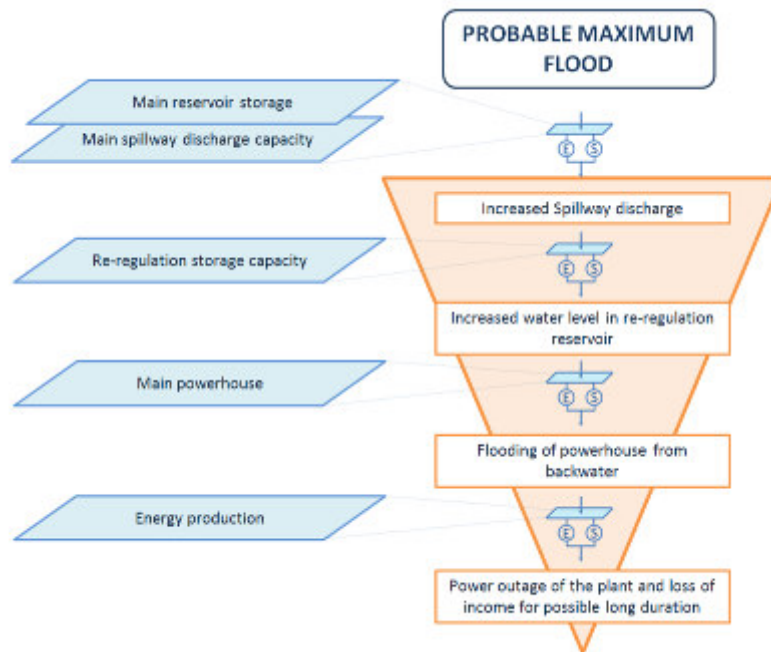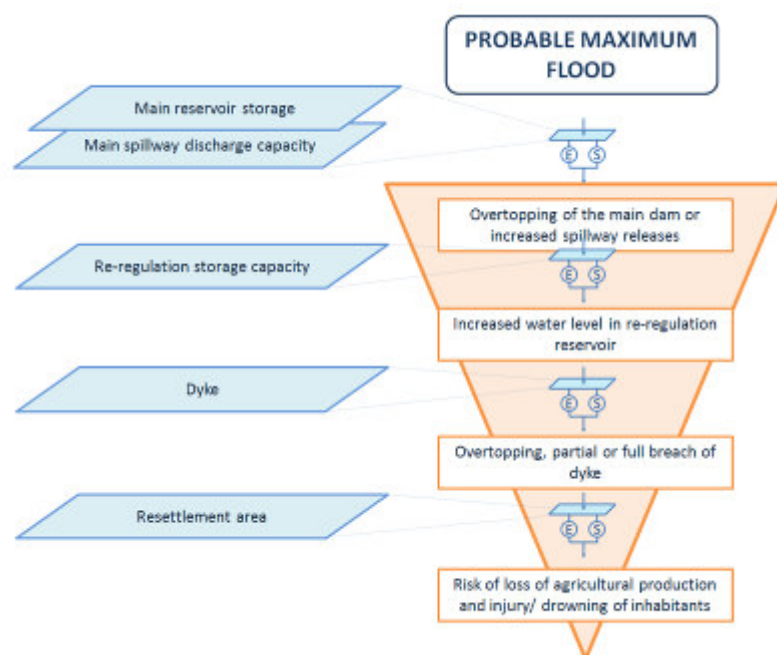

Figure 53 - Impact Sequence 9: the threat of an increase in the probable maximum flood affects both the main reservoir storage and the main spillway discharge capacity, consequently the re-regulation storage capacity, the saddle dam and finally the resettlement area.

As noted under IP8, the PMF event under baseline and future CC conditions will result in increased discharge from the main dam into the re-regulation dam. In the worst-case scenario these increases will occur in the event of an (unlikely) overtopping of the main dam, however, a more likely scenario is that spillway releases are elevated above 7,000 m³/s for a 20 hour period during the PMF hydrograph peak, substantially increasing the volume of water entering the re-regulation reservoir and exposing the saddle-dam to potential overtopping.
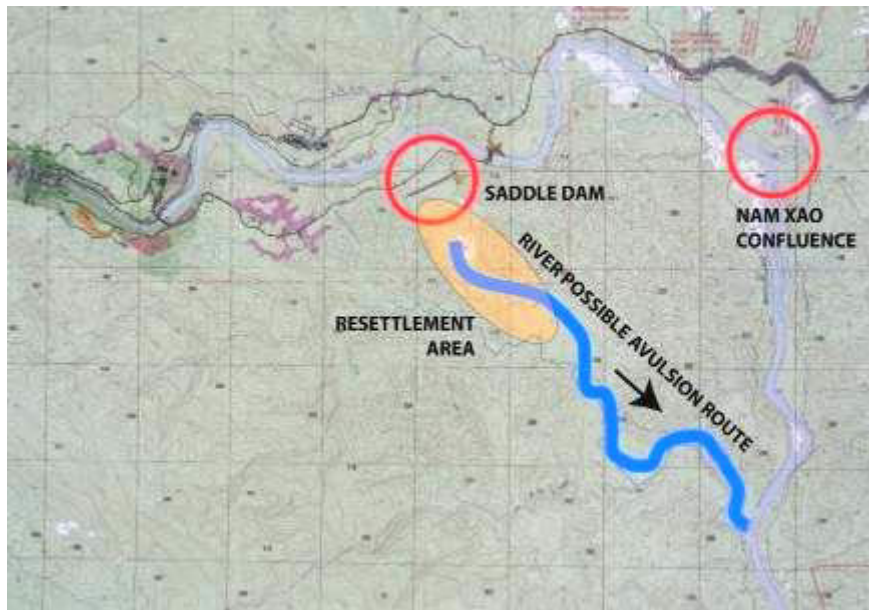
Figure 54 - Aerial view of the saddle dam relative to the re-regulation dam, Nam Xao confluence, and resettlement area.

As noted in section 1, the saddle-dam prevents waters in the re-regulation reservoir following an old river channel of the Nam Ngiep. Although the residential area of the resettled communities lie at a higher elevation site to the immediate southwest of the saddle-dam, large areas of the proposed agricultural land – especially paddy rice lie within the low lying areas of the old river channel. A partial or full breach of the saddle dam could result in substantial flows into the low elevation area and damage to crops and farming infrastructure. A factor possibly contributing to the rising of the water levels in the re-regulation reservoir is the confluence of the Nam Ngiep with the Nam Xao 5 km downstream, where a sediment wedge at the confluence could cause a partial blockage of the river upstream and therefore increase the levels also upstream of the re-regulation dam (Figure 54).

The crest elevation of the saddle-dam is 189.4 m.a.s.l.[13]. In the proximity of the saddle dam the level in the reservoir with the current 1000-year design flood (5,210 m³/s) is estimated at 186.2 m.a.s.l.; with the high scenario of the 1 in 1,000-year event with climate change the level is expected to reach 186.4 m.a.s.l. if a proportional increase is calculated based on the rating curve available within proximity of the power house[14].

Considering the PMF, NNP1PC used a simple reservoir routing model to compute the water levels at the saddle-dam under the baseline PMF, concluding that the maximum water level under that event would reach 187.7 m.a.s.l., some 1.7 m below the revised crest elevation.

Using upper estimate for the CC-PMF and extending the NNP1PC rating curve derived from the reservoir routing model, reveals that maximum water level in the re-regulation reservoir at the saddle dam site is 188.5 m.a.s.l., which is 0.9 m below the maximum crest elevation of the saddle dam. Therefore under the upper estimate for the CC-PMF water levels in the re-regulation reservoir will not over top the saddle dam and there is a very low exposure of the downstream agricultural lands to uncontrolled flood flows from the re-regulation reservoir.

The implication of this impact sequence is broken down and described in two phases, first the impact on the saddle dam and then the implications for the resettled community.

---

[13] At the final CRVA project workshop in February, NNP1PC noted the following: "…*NNP1PC is committed to ensuring the safety of the downstream areas and communities and a decision has been made to raise the height of the re-regulation dyke to increase the free-board and level of safety...*" this level of 189.4 is therefore 2.4m higher than reported in the 2014 technical report..

[14] The rating curve at the powerhouse is ~200m from the dam wall and 4-5km distant from the saddle-dam. The curve also only extends up to an inflow of 6,000m³/s.

For the saddle-dam, the size of increase in the threat is substantial (30% increase in the PMF resulting in a commensurate increase in flood inflow volume to the re-regulation reservoir with a 30% increase in the max spillway discharge). The potential impact of over topping ranges from uncontrolled releases into the downstream floodplain to damage or failure of the saddle-dam structure – depending on the sensitivity of the saddle-dam. The location of the saddle dam means that the structure's exposure to this threat is very high. In terms of sensitivity the saddle dam is an earth-filled dam anchored on both sides by small hills. Earth-filled dams are sensitive to over-topping and globally the majority of dam failures are associated with earth-filled dams. However, the structure is also designed to a higher level of safety than typical for earth dykes (i.e. the PMF event) reducing the sensitivity of the structure by significantly as the dam height is able to accommodate even the CC-PMF. When failure does occur it is often the result of exposure to regular extreme conditions possibly exacerbating a structural defect originating during construction. In the case of the re-regulation reservoir saddle-dam, the sensitivity of the structures materials and construction techniques are largely compensated for by the high design standard of safety, and hence a very low likelihood of dam failure resulting in a low sensitivity and consequently a low impact score.

The low impact of the CC-PMF on the saddle dam translates into a low exposure of the downstream resettled community to flood waters associated with over-topping of the saddle-dam. Based on the proposed resettlement plans (Figure 8), the assets most exposed to potential over topping are the 420 ha of paddy field proposed within the floodplain of the former alluvial channel of the Nam Ngiep reservoir. The residential area is located on higher ground and set back from the flow path of over-topped flows and the other land use in the vicinity is also slightly raised comprising forest for firewood/NTFPs and other cultivation lands. Given that the damages are likely to be in terms of lost annual crops and damage to irrigation infrastructure and not loss of life, dwellings or long-term cultivation practices such as commercial trees, the sensitivity is scored as low. Consequently the impact score for the resettled community is low (Annex III - Reservoir storage, Saddle dam, Resettlement area).

3.3.5 Impact of rising temperatures, increased water availability and increased flood risk on resettled community (IP10)

Threat: increased temperatures, increased precipitation and increased flood risk.
Impact pathways: *Rain-fed crops are sensitive to changes in water availability especially changes in precipitation, temperature and rates of evaporation. Increases in temperature below a threshold level can increase growth of plants enhancing yield, however, after threshold levels are reached increases in temperature will exacerbate water availability issues through increases in evaporative rates. Similarly, increases in rainfall can also enhance growing conditions up to a threshold value before excess water begins to have negative effects through, for example, water logging of soils resulting in root rot, and flooding resulting in damage and in some cases total crop failure.*

A hydropower project has significant environmental and social impacts within the locality especially downstream of the dam; these require management and mitigation measures to be in place to ameliorate the adverse impacts of the project on the receiving and downstream ecosystems and communities. This represents both an obligation and a legal requirement for hydropower projects in Lao PDR and companies will invest substantially in resettlement, environmental monitoring and mitigation measures as well as livelihood programs. NNP1PC has completed studies of both ESIA and resettlement and defined a program of investments and activities which themselves represent a substantial investment by the company amounting to some USD 52.5 million over the first 27years of operation, of which some USD 21 million is allocated to resettlement site development and livelihood restoration costs (NNP1 EIA, 2014). These investments are an asset of the NNP1 facility and the success of these proposed measures are in some cases also vulnerable to climate change. As described in Section 1, the resettled community includes 3,000 people. The resettled area is estimated at 6,000ha located within the elbow of the Nam Ngiep River stretching from the main dam to ~ 7 km downstream of the Nam Xao confluence. The majority of this land allocation is for agriculture and forestry with 420 ha of irrigated paddy rice, 150 ha of upland rice, 600 ha of pasture land, 400 ha of rubber and

commercial trees amongst others. Of this land allocation, three zones were identified as being sensitive to climate change.
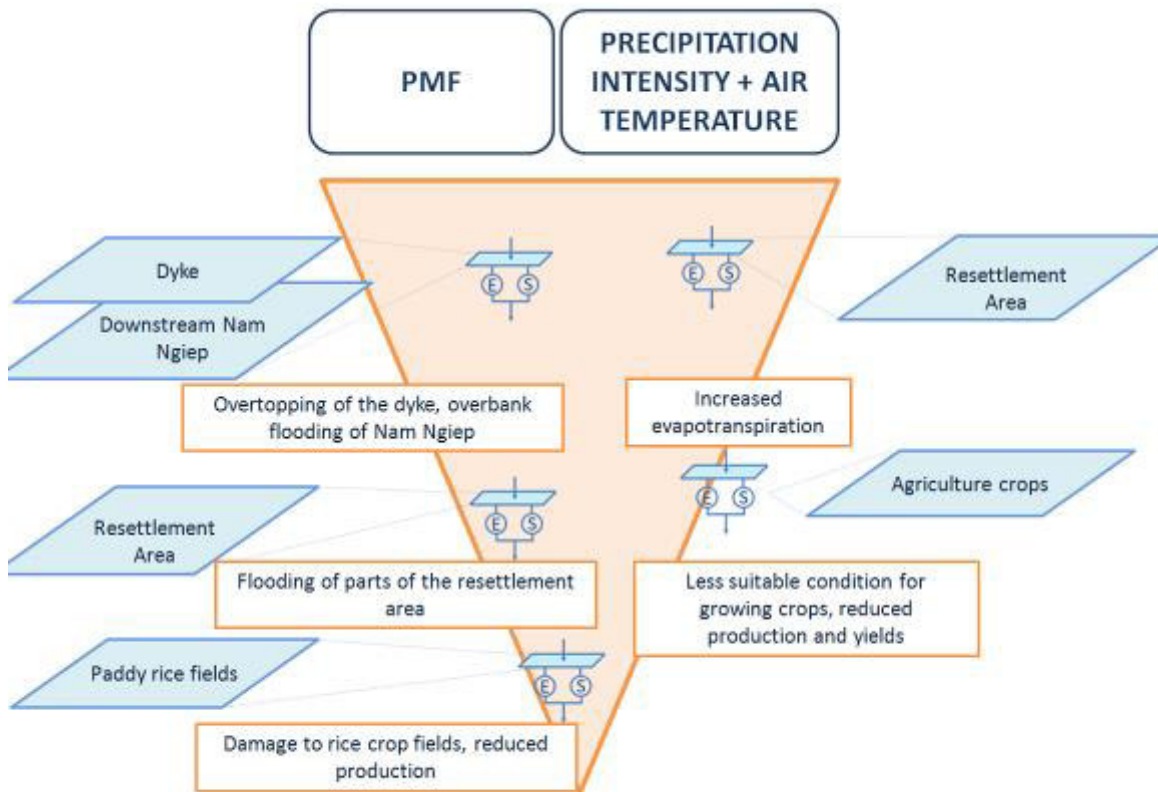
Figure 55 - Impact Sequence 9: the threat of an increase in the probable maximum flood and changes in hydroclimate variables affects the agricultural productivity of rice, rubber and other commercial farm lands planned for the resettled community.

ZONE A - RUBBER AND COMMERCIAL TREES (400 HA)

In the moderate elevation areas immediately south of the main dam, ~400 ha of rubber and commercial trees are earmarked for cultivation. These crops play an important role in the economic earning capacity of the resettled community, but are vulnerable to changes in temperatures and surface water availability during different periods in the agricultural calendar.

As the exact nature of the other crops was not known the CC impact assessment focussed on rubber. Based on field work by FAO in Viet Nam and the Mekong Region in the 1990s, crop suitability for a given area was classified into four classes: most suitable, moderately suitable, moderately unsuitable and not suitable. This data, specific to crop type, was used by FAO and Government of Viet Nam to classify agro-ecological zones and also as the primary input by IRRI for their Land Use Suitability Evaluation Tool (LUSET) which was modified by ICEM in 2010 for application to the river basin scale. For the productivity of commercial rubber trees it was identified that it is most sensitive to three hydro-climate factors: (i) Annual rainfall total, (ii) mean daily maximum temperature and (iii) mean daily temperature. At the resettlement site, baseline conditions would present ideal or near ideal conditions for rubber cultivation (Most suitable or moderately suitable), with moderate suitability arising from a slightly too wet baseline climate and slightly excessive temperature maximums. These characteristics reflect a moderate sensitivity of rubber to climate change. In terms of exposure, climate change will see annual rainfall increase by 16.4% pushing rubber from the most suitable to moderately suitable; while mean and maximum temperatures will increase by 1.4 °C and 2.6 °C respectively, with the increase in max temperatures inducing a similar impact as the increasing rainfall and the increase in

mean temperature having no significant impact on suitability. The net result is a moderate exposure to climate change. The impact of climate change would be to reduce the suitability of each of these parameters, such that by 2050 rubber would only be moderately suitable for maximum temperatures and annual rainfall (Figure 56). Based on these exposure and sensitivity scores an impact score of medium was determined for the rubber growing areas.
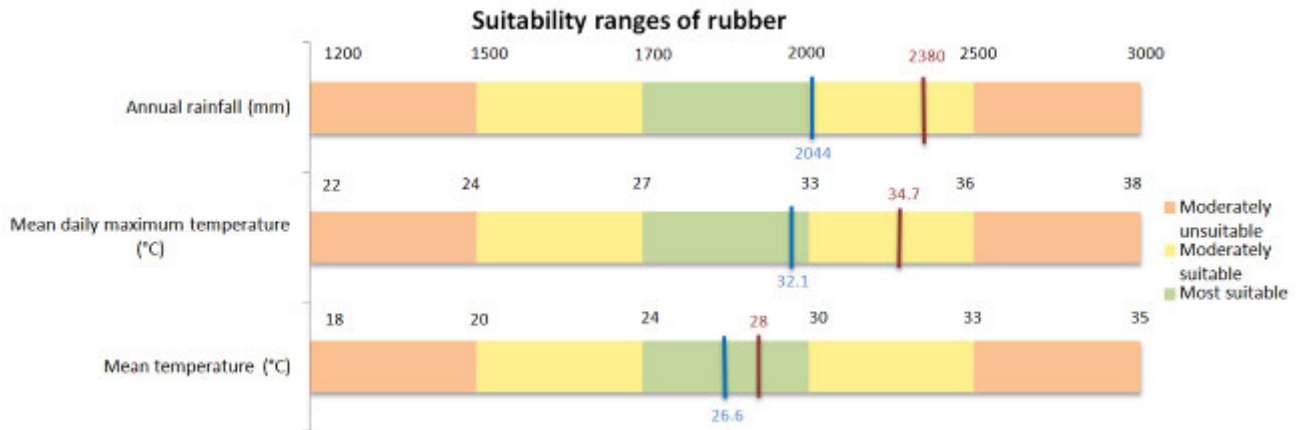
Figure 56 - Suitability ranges for rubber at the Nam Ngiep site: *(BLUE BAR) baseline conditions, (RED BAR) future CC estimates.*

ZONE B - UPLAND RICE (150 HA)

A smaller area of upland rice is planned for a moderate elevation area on the right bank of the Nam Xao – immediately upstream of the confluence with the Nam Ngiep. The area is not planned to be serviced with irrigation infrastructure, with one rain-fed rice crop per year and planting typically at the start of the wet season (mid-June) and harvesting six months later at the end of the calendar year. Six hydro-climate parameters were identified as most significant for rain-fed rice as shown in Figure 57. Under baseline conditions the area presented moderate or high suitability for rain-fed rice, with most sensitivity scores falling at the lower limit or below the limit of high suitability, such that they were moderately sensitive to increasing temperatures and rainfall, but that changes in the parameters would generally produce more favourable conditions. In terms of exposure, increasing temperatures will see the four key temperature parameters increase by 0.3 – 1.6 °C. The increases in temperature during the growing cycle will have an appreciable benefit of rice cultivation, with the other temperature parameters having only a minor effect. In terms of precipitation, the projected 30.3% increase in rainfall during the ripening stage will have a significant impact on rice production improving suitability from the lower limit of moderately unsuitable to moderately suitable. However, the significant increases in rainfall at the start of the wet season (20% increase) will start to reduce the suitability of rice in these areas by pushing suitability towards the upper limit of the optimal suitability class. The combined result is a low exposure rating. Based on these exposure and sensitivity characteristics, an impact score of medium was determined for rain fed rice within the resettlement site.
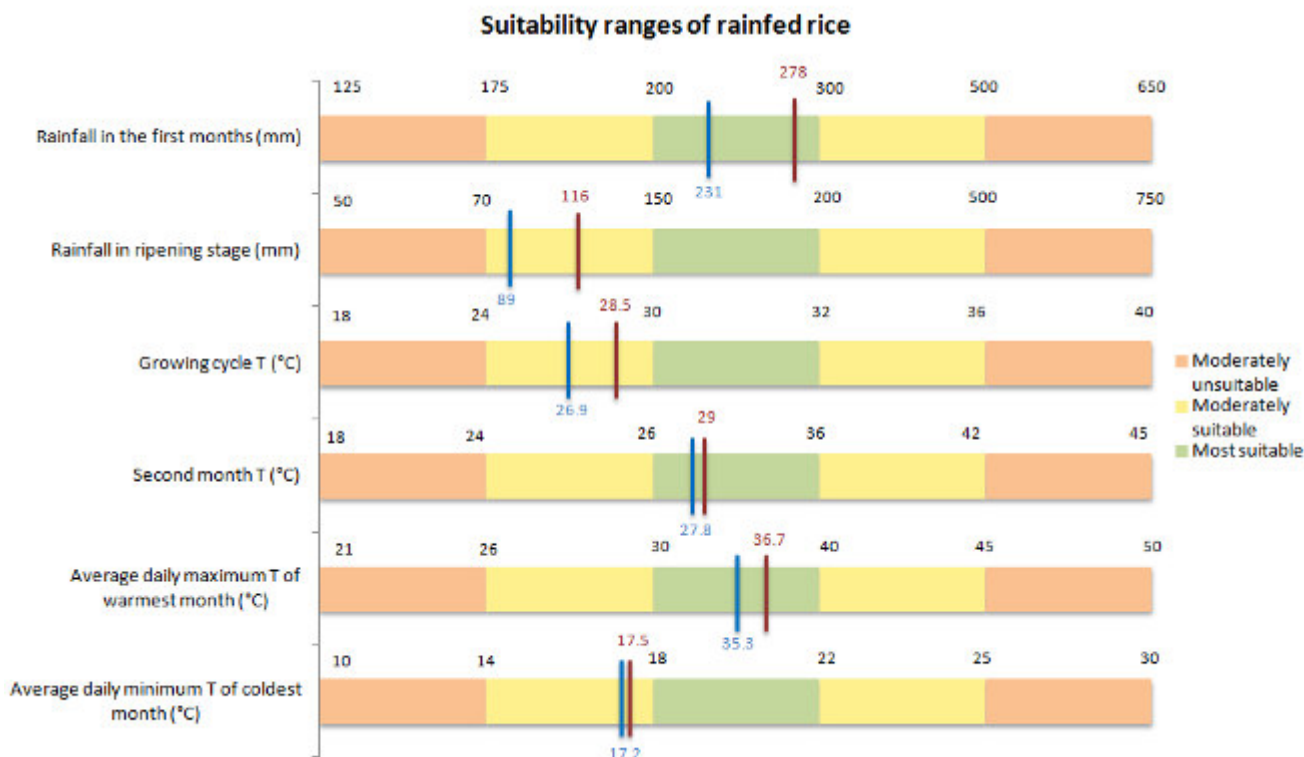
Figure 57 - Suitability ranges for rainfed rice at the Nam Ngiep site: *(BLUE BAR) baseline conditions, (RED BAR) future CC estimates*

ZONE C - PADDY RICE (420 HA)

A large area of paddy rice is planned for development within a low-lying flat area. This area corresponds to the alignment of the former river channel of the Nam Ngiep and its former floodplain and lies directly downstream of the re-regulation reservoir saddle dam. A commitment has been made by NNP1PC to design and build an irrigation system for this area to ensure farmers are able to grow two rice crops per year (rain-fed in the wet season and irrigated during the dry season).

The exposure, sensitivity and impact of climate change on the rain-fed rice crop matches the assessment covered in section 3.3.5(b) above with a final impact score of medium.

The additional major risk to the paddy rice area is the risk of crop damage due to flooding. Floods would typically occur mid-calendar for the rain-fed rice and the experience in the region is that they can cause failure of the rice crop through by: (a) drowning the plant with too rapid increase in flooded depth, (b) damage to infrastructure used to control surface waters (e.g. dykes and polders), or (c) physical damage to the crop through the force of flood flows. The majority of the paddy rice area lies within the natural floodplain of the Nam Ngiep River, however, according to NNP1PC field observations after the 2011 cyclone there was no flooding of the paddy area during that event, which has been classified as an approximately 1 in 30 year storm.. According to model results for flood inflows to the NNP1 reservoir, a baseline 1 in 30year event (1,800 m^3/s) is likely to shift to being a 1 in 5-year event by 2050. This represents a dramatic increase in exposure of the paddy rice area to overbank flooding whereby a phenomena which might occur once over a 30year operating life would occur once 2-3 times during the operating life. Nonetheless, assessment of baseline flooding in the Nam Ngiep for the 100 year event by the Ministry of Public Works and Transport (MPWT) reveals that even under that event, only minimal areas of the paddy field areas are likely to be inundated (Figure 58). The regulatory capacity of the NNP1 main dam would serve to reduce this increasing exposure resulting in an overall exposure scoring of low.
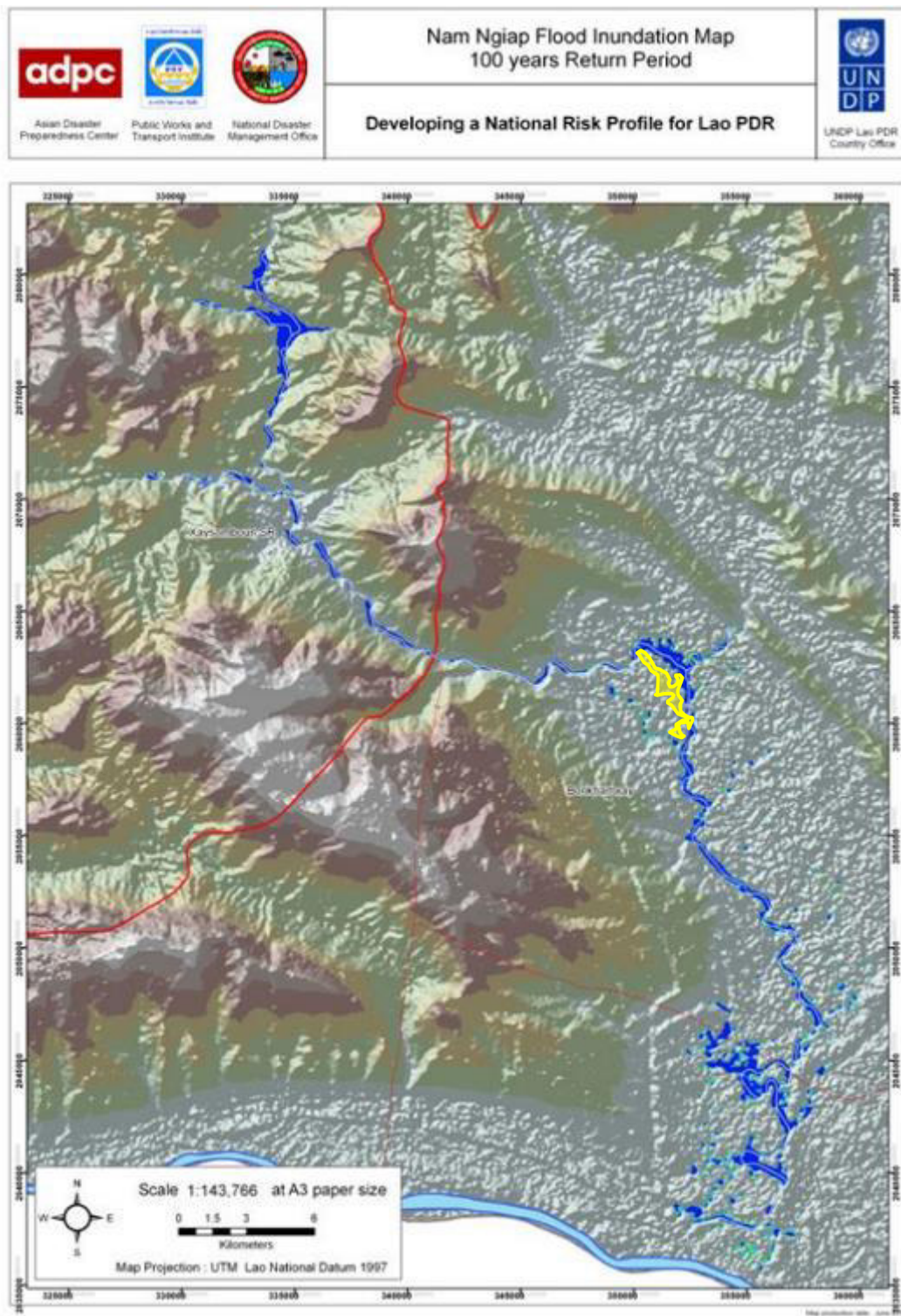
Figure 58: Baseline flooding for the NNP catchment during the 100 year event: *the approximate location of the paddy fields is shown in yellow* **(***Source: MPWT, 2010***)**

In terms of sensitivity, the location of the paddy rice produces a very low flood risk, which could be compounded by the type of rice grown. In Lao PDR it is typical for new rice ventures to plant high yield rice strains which are capable of producing the greatest benefit for farmers per unit area under cultivation. However, these rice varietals are more sensitive to flood depth and rates of water level change. The net result is a sensitivity score of medium and an overall impact score for paddy rice of low.

3.4   HYDROPOWER CASCADE THREAT ANALYSIS

CASCADE MANAGEMENT UNDER NORMAL OPERATIONS

3.4.1   Threats to NNP1 operation from upstream hydropower projects in the catchment

The operations of upstream hydropower could affect operation of NNP1. The three upstream projects will each seek to optimise their water usage based on their design characteristics and their power generation requirements. Depending on how they are managed these projects could have a positive or adverse impact on daily and seasonal water availability within NNP1.

The magnitude of influence exerted by the upstream projects on Nam Ngiep is proportional to the proportion of catchment runoff which is under their control. Using results from the modelling, Figure 59 shows that approximately 19% of the NNP1 catchment runoff is controlled by the upstream projects. The importance of this upstream control on NNP1 varies between normal operations and under extreme events.
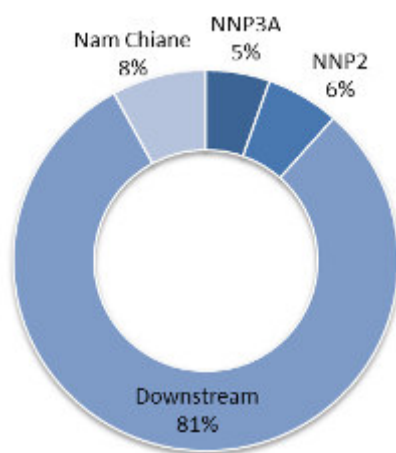
Figure 59 – Runoff contribution to NNP1 catchment

Under normal operations, the operation of three upstream hydropower projects will have a regulatory influence on seasonal flows retaining some water from the wet season to the dry season. Peaking operations would create a short-time step (sub-daily) variation in the hydrograph. Under extreme conditions, the impact on the magnitude and timing of inflows into the NNP1 reservoir depends on how the upstream projects plan and manage flood events. Given the size of the reservoirs it is expected that the upstream projects would pass flood waters as they arrive.

In the worst case scenario a dam break or major unplanned release could escalate flood inflows into the NNP1 reservoir through the discharge of the reservoir contents in a short period of time.

A more realistic (and moderate) scenario could result as a consequence of the unique precipitation dynamics of the Annamites mountain range, whereby reservoirs filling at the start of the wet season (mid-June), could reach FSL by August. In September – October the wet season rainfall is bolstered by the advent of the cyclone season where erratic cyclones and tropical storms originating in the western Pacific dump a large volume of rainfall in the catchment over a short time period at a time. Cyclones occurring at this time would likely coincide with reservoirs are already fully stocked by the monsoon. In such circumstances, operators will have a matter of hours to clear storage space within their reservoirs in order to safely attenuate the impending cyclone-induced flood event. In such circumstances, experience within Lao PDR has shown that, operators can increase 100-fold the spillway releases in a short period of time, giving downstream projects very little time to respond. As noted in section 1, only the extreme dam break scenario is explored in this study.

3.4.2   Impact of normal cascade operations on NNP1 energy production (IP11)

Threat: *Management of releases from upstream cascade of hydropower projects under normal operating conditions.*

Impact pathway: *daily changes in inflow hydrology due to normal operations of the upstream cascade, which would in turn affect power production and the reservoir capacity to cope with extreme flood event.*

The annual daily mean flow is estimated at 138.9 m³/s. The model confirms that there are no changes to daily mean inflow at NNP1 between the cascade and no-cascade scenarios. The model also confirms that there are no seasonal changes in NNP1 inflow between the cascade and no-cascade scenarios. However there are daily fluctuations in water inflows to NNP1 which show minor variations of -95 to +90m³/s (Figure 60). These variations occur due to the storage of water in upstream reservoirs. As the flow increases in the wet season, it will be used to fill upstream reservoirs instead of flowing straight into NNP1; hence daily discharge to NNP1 is reduced for some days during the season. When upstream reservoirs are full during peak flow, water will start to spill out of these reservoirs and into NNP1. An increase in inflow into NNP1 reservoir would be caused by these spillages plus the release of water from upstream hydropower generation. These variations amount to a +/- 15% variation in daily inflows when the upstream reservoirs are filling or spilling.
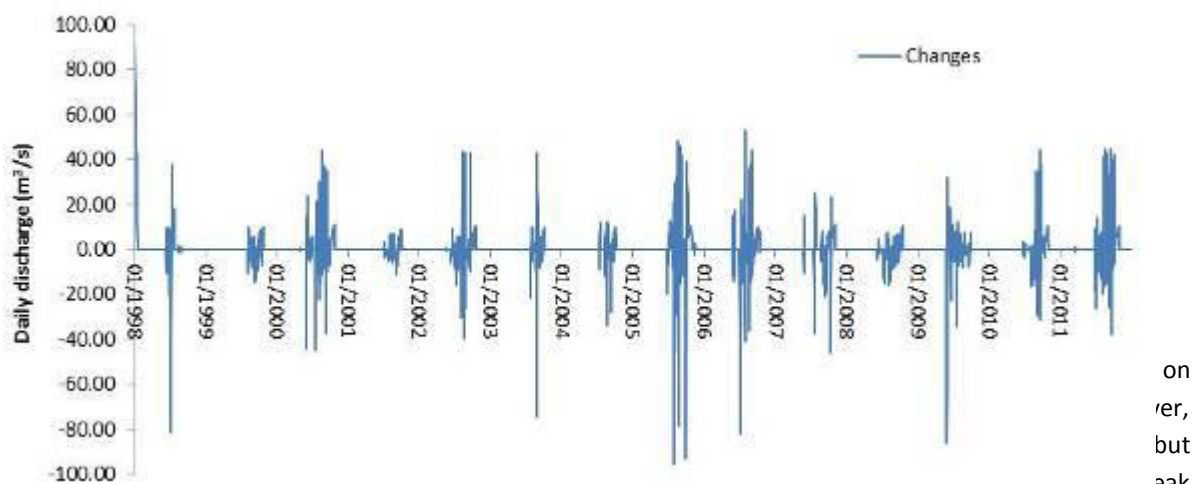
flood flow due to the operation of cascade. This will result in a minor increase in the proportion of spillage from the reservoir, though no appreciable impact on energy production. The very low exposure and very low sensitivity result in an impact score of very low.

The figures computed in this study are based on the estimates derived from our modelling work and which are lower for the Nam Ngiep catchment than those assumed by NNP1PC. An assessment of the sensitivity of energy production to variations in the historic rainfall which compares the ICEM and NNP1PC values is presented in Section 4.2.

CASCADE MANAGEMENT UNDER EMERGENCY OPERATIONS

3.4.3   Impact of NNP2 dam break on NNP1 reservoir water levels and overtopping (IP12)

Threat: *structural failure in the NNP2 dam and sudden release of NNP2 reservoir volume into NNP1 reservoir*

Impact pathway: *a NNP2 dam break would send a major flood wave downstream into the NNP1 reservoir which could cause overtopping of the dam structure and an array of knock-on impacts such as, drowning out and damage of the power house, over-topping of the saddle dam and damage to the agricultural lands of the resettled community.*

As a worst-case, hypothetical scenario, the study assumed a failure of the NNP2 reservoir. Based on a review of global experience with earth dam failures, it was concluded that such failures, if they occur, are most often the result of an undiscovered construction defect which is exacerbated over time by large flood events. In such circumstances, failures would typically occur years into the operating life in the period following a heavy wet season, when the reservoir is fully stocked and the water body works against the fault in the dam structure inducing a collapse. The exposure would be substantially worse if the scenario considered the dam failure to occur concomitant with a peak flood event.

The total volume of the NNP2 reservoir is 157.7 MCM. During the post-flood season the reservoir is full with a daily inflow rate at 173.53 m^3/s[15]. NNP2 dam site is 28km upstream of the NNP1 reservoir headwaters, and the NNP1 reservoir is itself 60 km long. Assuming NNP2 dam break is completed in a relatively short period of time (Figure 61), this section determines how long it would take for the contents of NNP2 reservoir storage to reach NNP1 reservoir and the implications of the subsequent inflow rate of the flood wave on dam water levels.
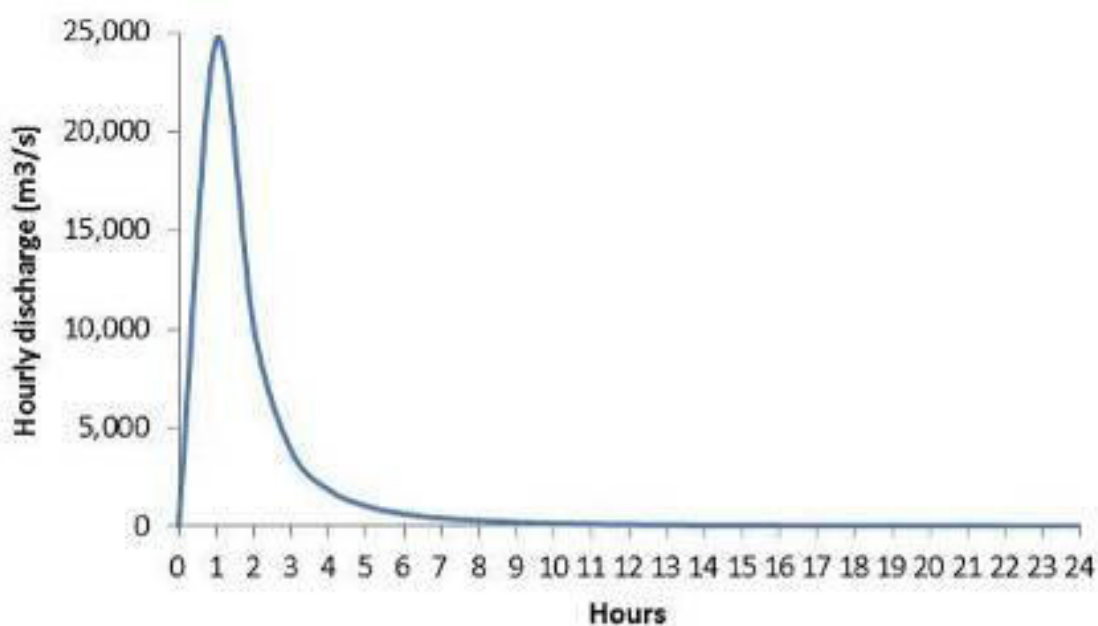
Figure 61 – Discharge from NNP2 reservoir after the dam break

Time-dependent flood wave propagation downstream of a breached dam is a function of site-specific parameters including reservoir capacity and breaching characteristics for the dam under review, e.g. the progressive erosion of an embankment. The advance of flood wave across the floodplain will in turn be governed by a future range of determinants, many difficult to replicate in a mathematical model e.g. different terrain and surfaces including the influence of land use change (P. Novak, 2011). There are sophisticated commercial software available for dam break analysis such as DAMBRK, FLD-WAV and HECRAS, however, for this study, the floodwave to NNP1 reservoir has been estimated using a simpler method to explore whether NNP1 reservoir can contain the volume of NNP2 storage during the dam break event. Details of the calculation are described in Annex II. The results show that within 24 hours after the dam break, most of the NNP2 reservoir waters will discharge to Nam Ngiep River. Discharge rate is high in the first 2 hours (see Figure 61) with 79% of the reservoir volume released downstream. The NNP2 dam break scenario discharges 157.7 MCM into the NNP1 reservoir, which amounts to ~17.3% of the PMF event (~907 MCM). However, the dynamics of the NNP2 dam break event are faster, with almost all of the volume released within 3 hours, while the PMF event would take more than 5 hours to release the same volume, resulting in the NNP2 dam break being a smaller magnitude but more concentrated risk to NNP1.

---

[15] This is baseline average daily inflow to NNP1 reservoir in October

Based on modelling of the Nam Ngiep catchment, average discharge velocity within the reach from NNP2 dam to NNP1 reservoir is 3 m/s with the peak flood at 9 m/s[16]. Assuming discharge velocity from NNP2 dam to NNP1 in the dam break scenario is equal to the peak flood i.e. 9 m/s, it will take less than an hour (52 minutes) for the water wave from NNP2 to reach NNP1 reservoir, resulting in a high exposure of the NNP1 reservoir to a dam break flood wave. As the water flows into the reservoir of 60 km long and flat at its normal operation level of 320 m, energy in the flood wave would dissipate through the reservoir water column and the dam-break water would move as a rising water level, rather than a breaking wave within NNP1 reservoir. The spillway gates of the main dam are considered fully open until the water level in the main reservoir reaches again the normal operating level of 320 m.a.s.l.
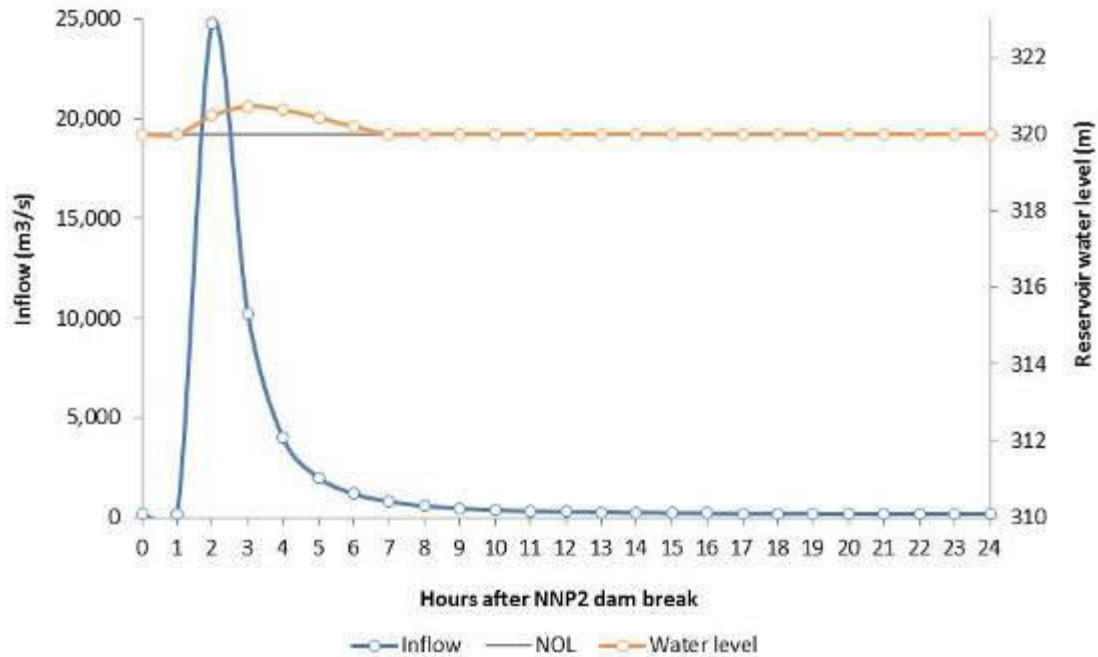
Figure 62 – NNP1 reservoir's inflow and water level of changes within 24 hours of NNP2 dam break

Maximum flood level of NNP1 reservoir is 320 m however NNP1 dam height is 322 m with a 1.5 m parapet on the dam (making the total height of 323.5 m) to increase the storage capacity of the reservoir for extreme flood event. The results shows that with floodwave from NNP2 dam break, water level at NNP1 will rise up maximum to 320.7 m during the second hour and water level will stay above normal operation level for the next 4 hours. With continuous discharge from the spillway and the powerhouse, and the reduction of water flow from NNP2, the water will be drawn down to NOL within 7 hours of dam beak. Figure 62 shows the calculation results for NNP1 water level with detail of calculation and assumption can be found in Annex II. The relatively large size of the NNP1 reservoir active storage compared to the volume released from a NNP2 dam break results in a very low sensitivity of the structure to the resulting flood wave from a dam break. The long reservoir will be able to dissipate the energy of the flood wave, while the reservoir volume and spillways will be able to contain and safely pass the flood downstream, even though the intensity is higher than the PMF. The combination of a high exposure and very low sensitivity results in a moderate impact score.

---

[16] Results from VMOD model running with baseline climate data over 14 years

3.5   UNCERTAINTY IN IMPACT ASSESSMENTS

There is a fundamental uncertainty in understanding of the hydrological regime of the Nam Ngiep catchment which arises from the poor coverage of observational records in precipitation and to a lesser extent discharge. In total there are four existing precipitation stations within the basin with daily time series records for 14 years.

In addition the precipitation dynamics of the region are highly heterogeneous and complex with the interplay of two monsoons, an off-shore cyclone system and local orographic forcings producing widely varying precipitation conditions within small areas, such that rainfall stations in nearby locations cannot be used to estimate rainfall conditions within the catchment.

Consequently there is substantial variation between NNP1PC, ICEM and Government of Lao estimates for rainfall with estimates of annual rainfall for the catchment varying between 2,400 mm/yr (GOL), 1,870 mm/yr (NNP1PC) and 1,845 mm/yr (ICEM). These variations produce a range of uncertainty in baseline conditions for two important parameters for NNP1: (i) flood magnitudes, and (ii) seasonal water availability.

In general, the NNP1PC modelling assumes wetter baseline catchment conditions because of the use of downstream stations outside the NNP1 catchment that are located in wetter areas of the Mekong Basin. This approach was adopted by NNP1PC because the data records outside the catchment were longer and generally of better quality. The ICEM approach was to use a combination of stations from within and outside the basin and to automate a spatial interpolation algorithm into our distributed hydrological model to estimate daily precipitation between stations.

Without better observational data from within the catchment it is difficult to identify which is the better approximation, but the net result is that NNP1PC tends to overestimate both the flood risk and the seasonal water availability. The overestimation of the flood risk is the main reason for the high safety margin built into the NNP1 design; however, the overestimation of water availability could also over-estimate the energy production capacity of NNP1 under baseline conditions.

BASELINE FLOOD MAGNITUDES

There is substantial variation between the flood magnitudes predicted by this study compared with other estimates. These discrepancies are primarily due to: (i) a paucity of reliable long time series precipitation and discharge data within the NNP1 command catchment, and (ii) the reliance of estimates on different station data and differing methodologies. These differences all stem from a variation in the estimate of catchment rainfall, and are summarised in the table below.

For the key parameters of the 1 in 1,000-year flood event the ICEM projections with climate change are -14.7 to +6.5% relative to the NNP1PC baseline estimates. While the ICEM projections for the PMF with climate change are 3 to + 30% of the NNP1PC baseline estimates. The increasing size of the PMF is considered a conservative estimate and represents a significant increasing risk to the project. Although the study also demonstrates that even under high climate change scenario, the project can safely pass the PMF without overtopping of the parapet wall at the main dam primarily because the height of the parapet wall above the main dam has been raised to 323.5 m, sensitivity analysis revealed that there remains very little room for uncertainty within the PMF calculation and any increase above the CC estimates of this study would result in overtopping of the dam.

Table 11 - Variability in baseline hydrological estimates for the Nam Ngiep Catchment

Hydroclimate parameter	NNP1 baseline estimates	ICEM estimates		Other baseline estimates
		Baseline	*2050 with climate change*	
Average annual rainfall (mm/yr)	1,870	1,845	2,149	2,400[17]
Total sediment inflow (Mt/yr)	0.915	1.070	2.516	NA
Average annual discharge (m³/s)	148.4	139.9	178.1	NA
1 in 1,000-year discharge (m³/s)	5,210	3,186	4,348 – 5,562	NA
Probable Maximum Flood (m³/s)	8,890	NA	9,350 – 11,985	NA

BASELINE SEASONAL WATER AVAILABILITY

The daily inflow into the NNP1 reservoir is the main determinant of the reservoirs energy production potential. As noted above, there is a significant 6% discrepancy in the inflow hydrograph between the ICEM and NN1PC modelling (Table 11, Figure 63). Disaggregating for season and the NNP1PC dry season estimates are 60% larger than the ICEM estimates while the ICEM estimate is 2% larger in the wet season.
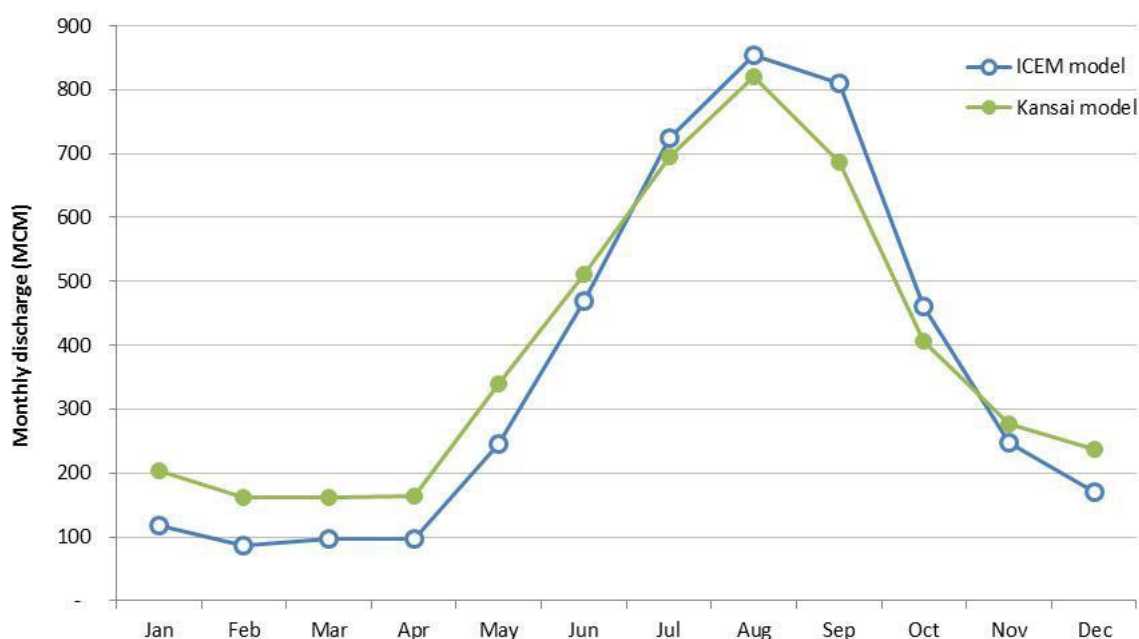
Figure 63 - Comparison of baseline average inflow hydrograph of the NNP1 dam site.

NNP1 has calculated energy production using a water balance model applying its operation rule curve. ICEM has used a MODSIM model which also incorporates the operation rule curve. A comparison was made of the two methods using the same input data sets which revealed less than 1% discrepancy between the two methods, indicating that the variation in input data induces an order of magnitude greater variability in the results than the selection of either method. As seen from the figure and table below, there is a significant decrease in the energy production (both PE and SE) in the dry season.

---

[17] Estimate comes from Government of Lao PDR
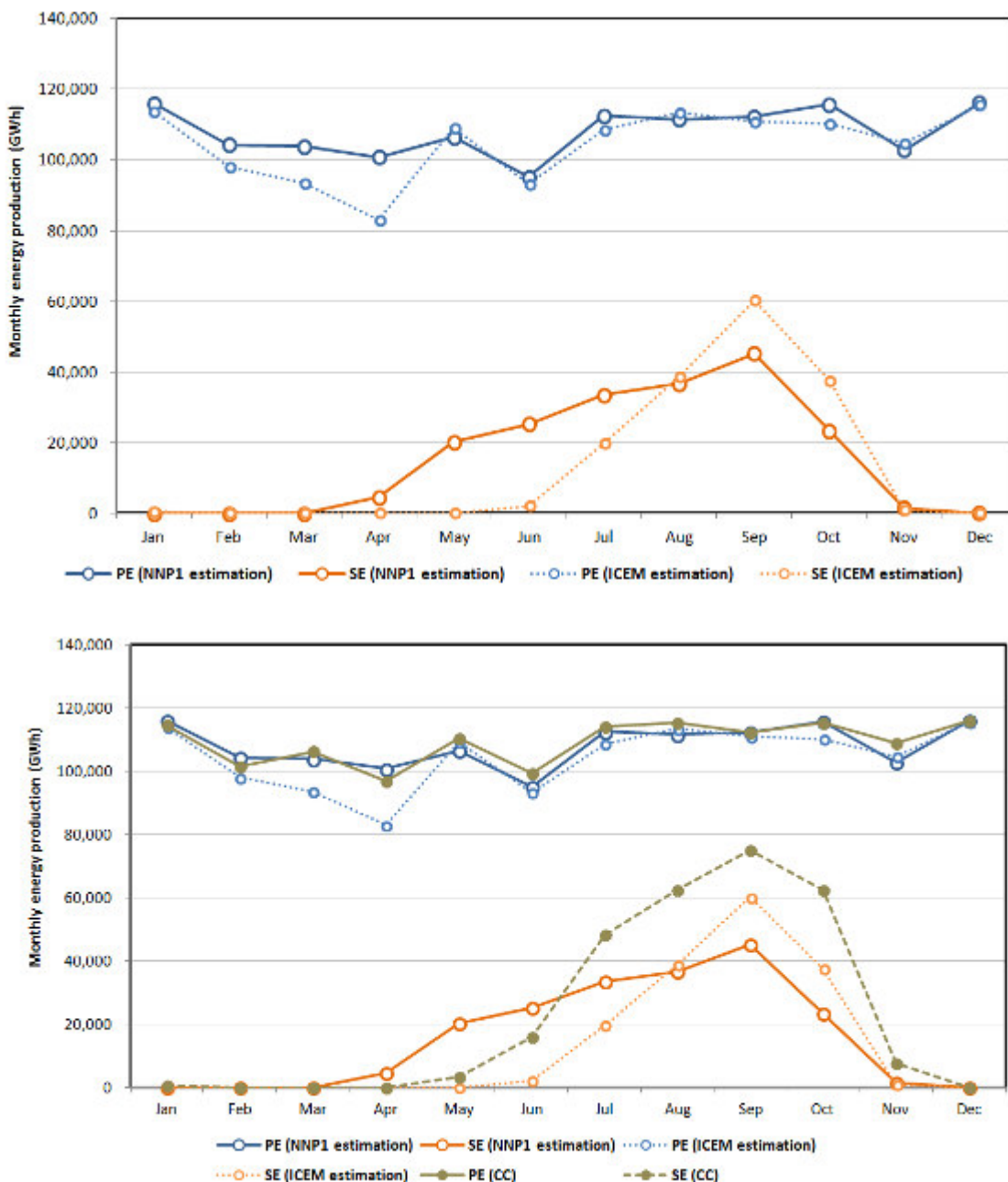
Figure 64 - Variation in seasonal energy production estimates for NNP1: *(TOP) Primary and secondary baseline energy production, and (BOTTOM) including climate change estimates.*

In the dry season, average PE production estimated by ICEM is 5% less than estimated production by Kansai; while in the wet season; average PE production estimated by ICEM is 1% less than the estimation from Kansai. Annual average SE production estimated by ICEM is also 16% less than the estimation from Kansai. Overall, the annual mean energy production estimated by ICEM is 5% reduction from Kansai's estimation.. More detail is also presented under Annex II.

4 CUMULATIVE IMPACTS OF CLIMATE CHANGE

4.1 CUMULATIVE IMPACTS

The impacts in section 3 were established to analyse causal pathways through which climate change and upstream hydropower will impact on the functioning and integrity of the NNP1 project. Table 12 summarises the results of the impact assessment for each impact pathway. Based on these results the following conclusions can be drawn:

1. **Due to the size of changes projected in the NNP catchment hydrology, climate change represents both a significant risk and an opportunity to the assets and processes of NNP1. Taking advantage of the potential benefits and avoiding some of the most significant risks will require dedicated adaptation response from NNP1PC, though some adaptation initiatives can be phased for implementation during future phases.** Of the ten climate change impact pathways identified as a priority, one offers an opportunity for increased electricity production, and one pathway was identified as priority adverse impact in need of an adaptation response. An additional four impact pathways all present significant risks that need a response, but there is potential for that response to be phased to avoid front-loading capital investment at the project outset.

2. **The most significant CC-benefit to NNP1 is a projected increased energy production potential,** with future climate change conditions likely to enhance the project's capacity to produce energy by increasing the year-round water availability. In an average year, energy production is expected to increase by several percent. This prediction is based on conservative estimates for climate change and so represents a lower estimate with likelihood that benefits could exceed this.

   ➢ *During the dry season and the shoulder seasons to the flood*, increased water availability is projected to increase seasonal energy production by 7%. The existing infrastructure would be capable of harnessing this additional energy production with existing turbines running at rated capacity for a longer portion of the year.

   ➢ *During the flood season*, increased water availability is projected to increase seasonal energy production by 16%. However, the additional potential to generate will, with the existing infrastructure, remain a foregone or wasted benefit, as the turbines will not be able to make use of the additional flows which will result in increased spillage.

3. **However, NNP1PC baseline energy production estimates assume a quantum of energy production which cannot be replicated by the ICEM suite of models, because the NNP1PC modelling presents a wetter dry season than the ICEM work. This suggests that any potential production benefits predicted with climate change would only compensate for over-estimates by the NNP1PC** with benefits above the quoted production capacity not occurring until later in the 35year time slice. The NNP1PC energy modelling assumes a baseline hydrology that is 32% wetter than the ICEM modelling in the dry season and 3% lower during the wet season. Consequently ICEM annual estimates for primary and secondary energy production are 3% and 16% lower respectively. With climate change, energy production will eventually exceed the NNP1PC baseline estimate amounting to an average increase of 12% by 2050.

4. **The most significant impact of climate change is a dramatic increase in the frequency of spillway usage which will over the design life accelerate wear-and-tear of the spillway apron and scour of the riverbed as waters exit the spillway structure**: Under average flow conditions, the four-fold increase in the frequency of usage of the spillway coupled with an associated increase in spillway stream power will accelerate the rate of scour of the river bed at the foot of the spillway apron. Stream power is directly proportional to discharge; given an approximate 7% increase in the size of

the design flood discharge with climate change and relative to the NNP1PC design flood estimate of 5,210 m³/s, the spillway landing zone is expected to experience a comparable 7-10% increase in stream power resulting only in a minor increase in erosion potential. This increase will accelerate the rate of erosion of the river bed alluvial layers but will not appreciably increase erosion of the underlying CH-bedrock.

5. **A number of climate change impacts are also considered moderate which do not need immediate adaptation, but could trigger significant impacts or an accumulated impact during the operating life. Preventative measures could build resilience in these areas and risk threshold monitoring could identify appropriate timing for future adaptation.**

   ➢ *Reduced active storage capacity of the main dam*: Increasing rainfall intensities will enhance rates of hillslope erosion and river stream power, tripling the sediment load entering the main dam. Over 50 years of operation, some 89.5 MCM of sediments will flow into the main dam preferentially depositing in the important active storage zone and reducing the active storage capacity by up to 7.5%. This will reduce the regulating capacity of the main dam, increasing spillage during the wet season and storing a smaller water volume into the dry season with implications for foregone and lost energy production.

   ➢ *Increased risk of reduced productivity of the agricultural lands of the resettled community*: Climate change will increasing the temperature, evaporation and precipitation conditions for rain-fed rice, rubber and other commercial crops planned for the resettlement area (970ha). In some cases these increases will result in a minor improvement in specific aspects of the crop calendar, however, in general the dominant impact is to push conditions further beyond the threshold for optimal suitability with a moderate decrease in suitability.

   ➢ *Reduced oxygen levels and water quality of dam releases*: Increasing air temperatures at the reservoir surface will increase reservoir water temperatures strengthening stratification in the water column and reducing dissolved oxygen (DO) levels with a knock-on potential for anoxic releases and poor water quality issues downstream of the main dam. The reservoir geometry would dampen this solar forcing and also partially dampen overturning of the thermocline, while the relatively-high position of the penstock intakes would moderate the frequency of anoxic releases reducing the severity of impact. These issues are likely to be more significant for water quality in the re-regulating reservoir (adjacent to the resettled community) than those downstream of both dams as the re-regulating reservoir spillway has capacity for further aeration.

6. A number of impacts with potentially very dramatic consequences were assessed and found to be of very low or negligible impact, these include:

   a. **Over-topping of the main dam**: Increases in rainfall projected with climate change will result in a potential 27% increase in the size of the PMF event reaching a peak inflow of 11,560 m³/s. Modelling analysis by the NNP1PC found that there is sufficient safety-margin in the design of the main dam and its spillway to prevent over-topping of the structure, though wave action would intermittently cause some spill over the dam wall.

   b. **Over-topping of the re-regulation saddle-dam during the future PMF event routing uncontrolled flows through the agricultural lands of the resettled community:** With climate change the PMF event will increase the size of spillway releases to a maximum of 7,590 m³/s. These releases will induce a rise in the re-regulation reservoir water levels up to 188.5 m.a.s.l. which is still 0.9 m below the crest elevation of the re-regulation saddle dam.

Consequently, there is confidence that even with the upper CC projections adopted in this study, over-topping of the re-regulation reservoir saddle dam is unlikely.

7. **Due to the small size and small command catchments of the upstream cascade, the three other projects in the NNP basin do not present any major risk to NNP1 operations under normal operations and a moderate risk under extreme climate conditions**. Concerns of the implications of upstream regulation on normal operations are unwarranted given the small size of the upstream projects (IP11). In addition catastrophic failure of upstream projects presents only a moderate risk to NNP1 and does not jeopardize the safety of main dam water levels, though without warning or coordination such events would present a major concern for operators attempting to manage the event.

Table 12 - Summary of climate change and cascade impacts and impact scores

	SYSTEM		IMPACT SUMMARY	IMPACT SCORE
IP5	**Threat:**	Impact on seasonal water availability	**Climate change increases wet and dry seasonal water availability increasing the capacity of the NNP1 reservoir to generate electricity and offering opportunities to enhance energy production.** *A change in the precipitation regime would induce both positive and negative threats to power production; because energy production of the NNP1 reservoir is dependent on the reservoirs ability to store water during the wet season when inflows are abundant and release them during the dry season when natural inflows are scarce. The increasing wetness of the NNP1 catchment in both the wet and dry season will result in a 7% increase in dry season energy production and a 16% increase in wet season energy production, representing a substantial benefit to the project which will continue to accrue during the operating life.*	**HIGH (+)**
	Asset:	Energy production	*At the same time, increased precipitation in the wet season will reduce the water efficiency of the NNP1 project by increasing spillage from 5% to 17%.This substantial increase in spillage would not result in reduced power production, but it does represent a substantial quantum of energy potential which is foregone over the spillway and not utilised by the project.*	
IP6	**Threat:**	Increased wet season flows	**Climate change increases the rate and velocity of spillway releases increasing issues of wear-and-tear and the spillway apron and accelerating scour at the foot and anchor of the energy dissipation structure** *Under average flow conditions, the four-fold increase in the frequency of usage of the spillway coupled with the five-fold increase in average spill velocity will represent a threat to structural components of the spillways – especially in relation to scour at the foot and anchor of the energy dissipation structure downstream and the spillway surface, resulting in an impact score of high.*	**MODERATE (-)**
	Asset:	Spillway structure		
IP9	**Threat:**	Increased peak flood magnitudes => increased spillway discharge from main dam	**Climate change increases the volume and rate of spillway discharge during peak flood events, elevating water levels in the re-regulating reservoir causing over-topping and/or failure of the saddle dam.** *The high risk of an increasing PMF will result in a high risk of increased spillway releases during the PMF. With climate change these releases will exceed 7,000 m³/s for a period of 20hours during the peak in the PMF hydrograph. The increased spillway releases will substantially increase the flood volume entering the re-regulation reservoir raising the maximum water levels as the un-gated re-regulation spillway attempts to pass the PMF flood inflows. These elevated levels are manageable by saddle dam meaning the structure has very low risk to the threat of over-topping, which would route substantial flood flows along an old river channel of the Nam Ngiep which is now proposed for agricultural land of the resettled community.*	**LOW (-)**
	Asset:	Re-regulation reservoir capacity=>	*The magnitude of the threat will result in re-regulation reservoir water levels 0.55-0.9m below the maximum crest elevation of the saddle dam making the likelihood of over-topping during the PMF event very low. In general, earth-*	

	saddle-dam integrity		*filled saddle dams are sensitive to over-topping, however the very high design safety level (the PMF is the design event for the saddle dam) compensates for the higher sensitivity of the materials and construction techniques resulting in a low likelihood of dam failure and a moderate sensitivity which when combined with the very high exposure results in a high impact score.*	
	Threat:	Saddle dam breach	**Climate change increases the volume and rate of spillway discharge during peak flood events, elevating water levels in the re-regulating reservoir causing over-topping and/or failure of the saddle dam, and consequently flooding and damage to the resettled community.**	**LOW** **(-)**
	Asset:	Flooding of downstream resettlement area	*The low impact of the CC-PMF on the saddle dam translates into a low exposure of the downstream resettled community to flood waters associated with over-topping of the saddle-dam. However, only agricultural lands lie within the potential impact zone of the dam breach floods which would result in damage to agricultural infrastructure and a lost rice crop, but would not impact on the residential areas where most people are located. The low exposure and low sensitivity result in a low impact score of the resettled community to a saddle dam breach.*	
IP10	**Threat:**	Increased flood risk => reduced agricultural productivity & crop failure	**Climate change will increase the frequency of overbank flooding in the Nam Ngiep River turning major flood events from a 1 in 30-year phenomena to a 1 in 5-year phenomena, however the resettled area lies predominately outside the historic NNP floodplain and so are not expected to cause damages to the agricultural lands of the resettled community.**	**VERY LOW** **(-)**
	Asset:	Agricultural land for the resettled community	*Climate change will produce only a very low level of expose for the 402 ha of paddy rice proposed as part of the resettlement plans. Increases in rainfall will increase the frequency of floods capable of overtopping the river banks and flooding the natural floodplain areas – including the paddy rice land; however, the topography and location of the farmland means that it will rarely flood.*	
	Threat:	Increased temperatures, & rainfall intensities => reduced agricultural productivity	**Climate change reduces productivity of rain fed rice, rubber and other commercial crops planned for the resettlement area.** *Climate change will increasing the temperature, evaporation and precipitation conditions for rain-fed rice, rubber and other commercial crops planned for the resettlement area. In some cases these increases will result in a minor improvement in specific aspects of the crop calendar, however, in general the dominant impact is to push conditions further beyond the threshold for optimal suitability with a moderate decrease in suitability.*	**MEDIUM** **(-)**
	Asset:	Agricultural land for the resettled community		
IP8	**Threat:**	Increased	**Climate change increases the volume and rate of spillway discharge during peak flood events, elevating water**	**LOW**

		peak flood magnitudes => increased spillway discharge from main dam	**levels in the re-regulating reservoir and drowning out the power house due to back-water effects.** *The high risk of an increasing PMF will result in a high risk of increased spillway releases during the PMF. With climate change these releases will exceed 7,000 m³/s for a period of 20 hours during the peak in the PMF hydrograph. The increased spillway releases will substantially increase the flood volume entering the re-regulation reservoir enhancing the back water effect and raising the maximum water levels as the un-gated re-regulation spillway attempts to pass the PMF flood inflows; inducing a moderate exposure of the powerhouse to backwater inundation for the re-regulation reservoir. However, the powerhouse has a very low sensitivity to backwater inundation because of: (i) the relatively high elevation of its floor, and (ii) the inclusion of a 17 m high concrete extruded outer wall. Consequently the impact is scored as low with minimalchance of the powerhouse being flooded, equipment damaged and power outages experienced.*	**(-)**
	Asset:	Re-regulation reservoir capacity=> main power house		
IP12	**Threat:**	Upstream dam break and downstream flood wave propagation	**Major failure in the upstream cascade causes the uncontrolled release of an intense, large volume flood wave impacting water levels in NNP1 and causing over-topping of the main dam with knock-on implications for the re-regulation reservoir and downstream assets.** *In the worst-case scenario, the rapid collapse of upstream dams would discharge 157.7 MCM downstream in a matter of hours. The ensuing flood wave would travel at up to 9m/s reaching the headwaters of the NNP1 reservoir within an hour. The flood inflow from the dam break is only 17.3% of the baseline PMF (~907 MCM), however the dynamics of the release are faster with the flood inflows arriving in about half the time of the PMF making the event a smaller magnitude but more concentrated risk of which the NNP1 exposure is high. The relatively large size of the NNP1 reservoir active storage compared to the volume released from a dam break results in a very low sensitivity of the structure to the resulting flood wave. The long reservoir will be able to dissipate the energy of the flood wave, while the reservoir volume and spillways will be able to contain and safely pass the flood downstream, even though the intensity is higher than the PMF. The combination of a high exposure and very low sensitivity results in a moderate impact score.*	**MEDIUM (-)**
	Asset:	NNP1 water levels & overtopping of the main dam		
IP7	**Threat:**	Increased peak flood magnitudes	**Climate change increases the size of the probable maximum flood (PMF) over-topping the main dam and causing inundation, damage and power outage to the powerhouse.** *The high risk of an increasing PMF coupled with a low sensitivity of the reservoir to over-topping produces a moderate exposure of the main power house to inundation by reservoir waters; however, the steep V-shaped canyon configuration induces a high sensitivity of the power house to inundation as over-topped flows would be concentrated onto the power house site damaging the structure, equipment and the penstock protection works; resulting in a final impact score of medium.*	**MEDIUM (-)**
	Asset:	Reservoir and spillway capacity => main power house		
IP3	**Threat:**	Increased hillslope	**Climate change reduces the active storage capacity of the main reservoir increasing wet season spillage and the proportion of water not producing electricity.**	**MEDIUM**

		erosion & river transport capacity (stream power)	*The combined impact of sedimentation in the NNP1 reservoir is a 5-7.5% reduction in the total reservoir active storage volume. This reduced active storage volume would see wet season water levels in the reservoir rise by ~0.8 m which would increase the amount of spillage during the wet season and reduce by a proportionate volume the amount of water carried through to the following dry season. This spillage reflects a foregone quantum of energy production in both the wet and dry season, amounting in a medium climate change impact. In addition, the increased spillage will also increase wear-and-tear on the spillway structures which were not designed to be used so frequently.*	**(-)**
	Asset:	Watershed sediment yield => reservoir active storage => energy production		
IP4	**Threat:**	Increased hillslope erosion & river transport capacity (stream power)	**Climate change reduces the active storage capacity of the main reservoir reducing the capacity of the main reservoir to store flood waters during peak flood events.** *Under extreme flood events, the lost active storage corresponds to the PMF flood volume during the first 4 hours of the event or one-third of the inflows during the rising limb of the PMF flood hydrograph. This lost storage therefore strengthens the need for a rapid response to the PMF event and the need for early warning detection of its manifestation through the catchment to ensure the reservoir manages the PMF flood safely. These values are considered as having a medium impact on the regulation capacity towards probable maximum floods (Annex III – Reservoir storage volume).*	**MEDIUM (-)**
	Asset:	Watershed sediment yield => reservoir active storage => flood regulation		
IP1	**Threat:**	Increasing air temperatures	**Climate change reduces DO content of reservoir releases adversely impact downstream ecosystems and water supply.** *The likelihood of climate change exacerbating water quality issues for releases from the Nam Ngiep 1 main reservoir is moderate. The shape of the reservoir will reduce exposure to increased solar forcing and dampen overturning of the thermocline at the start of the wet season; these two factors, in combination with a relatively high-set intake structure will results in moderate likelihood of increasing the frequency of anoxic releases to the downstream aquatic ecosystem. (Annex III – Aquatic ecosystem). These issues are likely to be more of an issue for water quality in the re-regulating reservoir (adjacent to the resettled community) than those downstream of both dams as the re-regulating reservoir spillway has capacity for further aeration.*	**MEDIUM (-)**
	Asset:	Water quality of reservoir & releases =>downstream ecosystems		
IP2	**Threat:**	Increasing air temperatures	**Climate change reduces the efficiency of transmission and turbines resulting in a reduced power output for the plant.**	**VERY LOW**

	Asset:	Rated power output	*Increases in air temperature will induce a marginal reduction in the efficiency of power production through: (i) 0.042% efficiency drop in power transmission and, (ii) 0.066% drop in turbine efficiency, which will by 2050 reduce the rated capacity of NNP1 to 271.7 MW. This is considered a very low/negligible impact of climate change on the rated power output.*	
IP11	**Threat:**	Management of upstream cascade releases	**Management of releases from the upstream cascade under normal operations affects the seasonal and daily timing of water availability in NNP1 reservoir, affecting energy production.** *The small size of the three upstream reservoirs means the projects will not have an appreciable impact on annual or seasonal inflows into the NNP1 reservoir. However, during the wet season at times of filling and spilling from the upstream projects there will be a daily influence of +/- 90 m³/s or ~15% variation in the average wet season inflow for short periods, which will results in a very minor variation in energy production. Under extreme flood conditions, spillway releases from the upstream cascade are likely contribute in the order of 100 m³/s to the peak flood flows with a minor influence on spillage.*	**VERY LOW**
	Asset:	NNP1 reservoir levels => Energy production		

4.1   ECONOMIC IMPLICATIONS

The implications of climate change for the NNP1 project can be characterised through their individual pathways, as resulting in cumulative impacts on the performance of the project, and broader environmental and social externalities. The financial and economic assessment of climate change impacts is, in principle, assessed on the basis of the cumulative impact categories of infrastructure damage, energy production, and environmental and social externalities.

However, in the case of this project access to economic and financial information of the project was not possible and so only indicative quantitative analysis has been conducted for the implications of climate change for energy production. The economic and financial implications of climate change for damage to plant infrastructure, and environmental and social externalities have not been quantitatively assessed; we restrict comments on these two categories of cumulative impact to the conclusion of this section.

4.1.1   Energy production

The threat assessment identified five major impact pathways through which energy production could be affected, namely increased transmission line losses (IP2), reduced reservoir storage capacity due to increased sedimentation (IP3), changes in seasonal water availability and consequent changes in energy production (IP4), overtopping of main dam and damage to the powerhouse (IP7), elevated regulation reservoir levels and power house flooding (IP8). The assessment also identified two potential impact pathways associated with the hydropower cascade, including an upstream dam break and impacts on the flow regime from the operation of the upstream cascade.

The impact assessment indicates that of these impact pathways only increased line losses due to increased ambient temperatures (IP2) and changes in seasonal water availability (IP4) are likely to be realised within the time horizon of this study. Increased line losses due to factors attributable to climate change are estimated to be less than 0.1% of power output, these are therefore deemed negligible. Therefore we only consider changes in seasonal water availability. Similarly, for potential impacts due to the operation of the cascade only changes in the flow regime is likely to alter expected power production. We deal with each of these three impacts of power production in turn before concluding.

SEASONAL WATER AVAILABILITY - INCREASED ENERGY PRODUCTION

The impact assessment has shown that given the assumed climate change scenario, water availability over the year is likely to change considerably with climate change. This in turn will lead to changes in energy production. Energy production is divided into primary energy (PE) and secondary energy (SE). PE supplies peak electricity demand for 16 hours per day between 6:00 am and 10:00 pm from Monday to Saturday. PE is produced throughout the year when the reservoir water level is above the lower rule curve (see Figure 9). As a peaking plant NNP1 has been designed to maximise PE production. SE is produced in the off-peak hours on weekdays and on Sundays. SE is produced when the reservoir water levels exceed the upper rule curve (see Figure 9). SE is produced predominantly during the wet season when sufficient water is available. Excess energy (EE) is also identified in the operating rules for the project, but this has not been modelled in the impact assessment.

Figure 65 (below) shows how average monthly PE and SE output are expected to vary over the year for baseline and climate change scenarios. Overall, greater water availability under the climate change scenario is expected to enable an increase in average annual energy production from 1,413 GWh in the baseline of approximately 12% to 1,585 GWh by 2050. This is composed of an increase of PE production by about 57 GWh or 5% of the baseline figure and an increase of SE production by 116 GWh or 72%.
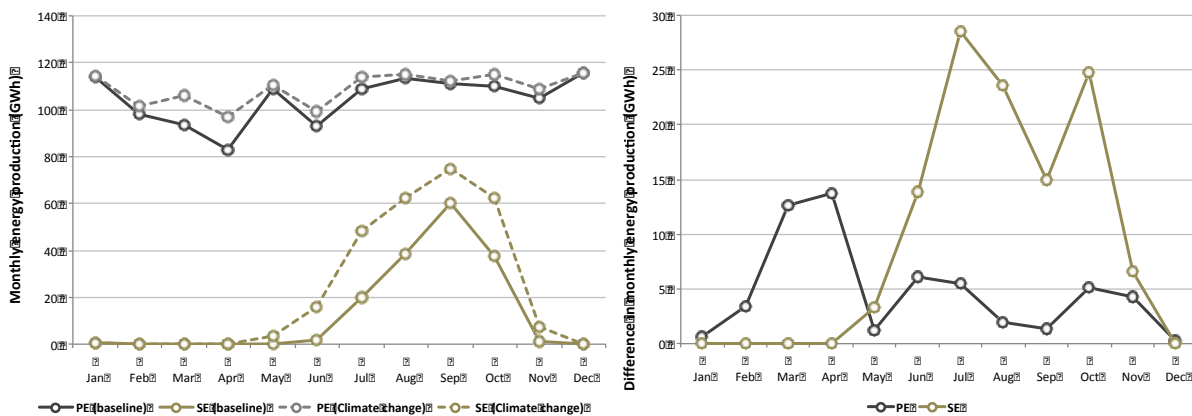
Figure 65 - Average monthly primary and secondary energy production in baseline and climate change scenarios

SEASONAL WATER AVAILABILITY – DIFFERENCES IN ESTIMATION OF WATER AVAILABILITY

Climate change aside it is important to re-emphasise the uncertainty that remains relating to current hydrological conditions in the river basin, and the performance of the project based upon this. As noted above, modelling used by NN1PC and ICEM for the catchment produced differing results in terms of annual and seasonal output of primary and secondary energy, these differences are reported in Figure 66 below. The ICEM model estimates an annual power output of, on average, 43.3 GWhless of primary energy and 30.5 GWh less of secondary energy than the NN1PC model.
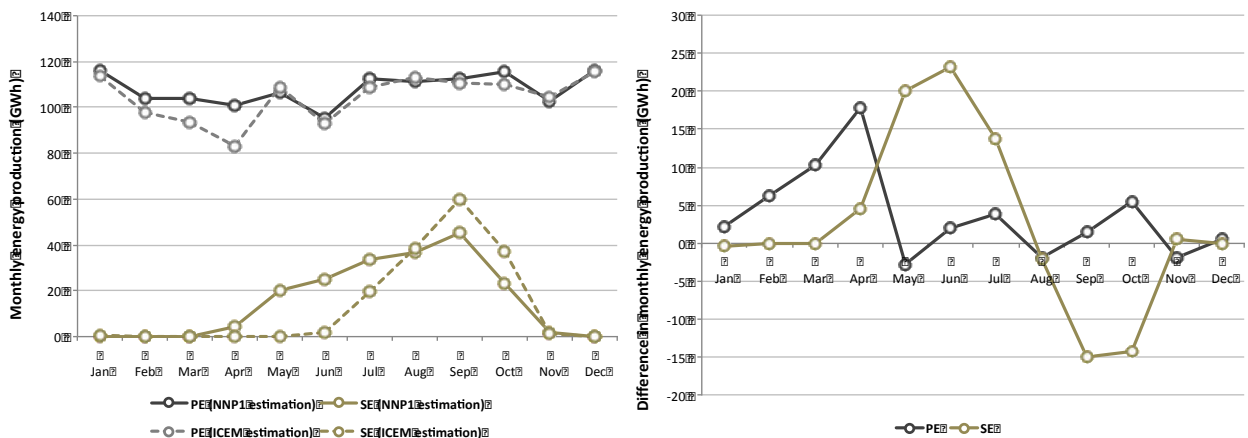
Figure 66 - Differences in estimated power output based upon NN1PC and ICEM modelling of catchment hydrology: *showing estimated output of primary and secondary energy by month (left) and difference in estimated output of primary and secondary energy per month (NNPC model output – ICEM model output)(right)*

4.1.2   Damages to paddy rice crops

Based upon a farm gate price for rice of approximately LAK 2,000/kg (USD 0.25/kg) in 2013, (see Newby et al 2013), and an average yield of 1,689 kg/ha (this is the mean value calculated by Newby et al 2013, and is well below the official target of 4,000 kg/ha), then the average value of crops per ha would amount to approximately LAK 6.7 billion /ha (US$ 422).

Assuming a flooding event affects the whole pre harvest crop along the river banks over an area of 420 ha, this would lead to losses of approximately US$ 177,000. However, timing of the maximum flood will be critical in terms of whether this damage would be realised.

It is expected that the flood damages to agricultural infrastructure will also be important adding significantly to the maintenance burden on the project throughout operation,

4.2 ECONOMIC CONCLUSIONS

The economic analysis has focused upon changes in expected revenue levels due to changes in energy production in respect to climate change. Increase precipitation and water availability due to climate change is expected to increase energy production.

Moreover, these figures include only revenues, given data access it has not been possible to arrive at estimates for additional damage to the plant due to climate change. The impact assessment report makes clear elsewhere that additional wear and tear can be expected due to climate change, this may imply additional variable O&M costs. These need to be borne in mind when assessing the economic implications of climate change. Nevertheless, as fixed O&M costs increases are not likely to be significant (with the analysis showing a low risk from climate change to most of the project components), it is highly likely that the overall impact of climate change on the economic and financial case for the NNP1 project is positive.

Environmental and social externalities may also change with climate change. There is an increased likelihood of fish kills with climate change implying potential losses for fishing communities and in possibly a decline in biodiversity. While these both undoubtedly have economic value it is not possible at this point to quantify this. Other potential impacts from dam overtopping or breach are unlikely to be realised due to climate change and therefore are not considered further.

4.3 NNP1 ADAPTIVE CAPACITY

In some cases the climate change impacts identified above are partially ameliorated by the NNP1 assets to respond to increasing risks. This capacity to respond in the face of a risk is termed adaptive capacity. Below is a summary of the adaptive capacity of each asset as relevant to the main impacts.

4.3.1 Downstream water quality

The relatively high level of the intake for the power house gives a certain degree of adaptive capacity of the project to cope with poor quality water being entrained in the turbined water under normal circumstances. However, if the stratification of the reservoir intensifies and then overturns suddenly, the poor quality water released is still likely to pass through turbines, despite the high level of the intake. The adaptive capacity to be able to cope with this is low, because of the fixed infrastructure.

4.3.2 Reduced regulation capacity

The adaptive capacity of the project to limit the losses of active storage are low because of the volume of active storage is fixed by the reservoir design and the reservoir geometry preferentially encourages deposition in the active zone. Soil erosion in the catchment largely determined by the conditions of soil type, slope, land use and vegetation cover. The only aspects of these conditions that may be changed is the land use and vegetation cover. One factor which may reduce sediment reaching the Nam Ngiep 1 reservoir is likely to be sediment accumulation in the other reservoirs upstream.

4.3.3 Flood damages

As summarized in section 4.1, the flood risk for NNP1 will lead to damages in the spillway structure and the 420 ha of paddy rice identified for the downstream floodplain. The adaptive capacity for each asset is summarised below:

1. **Main dam, reservoir and spillway**: These assets have a high adaptive capacity to deal with an increasing flood risk because they were designed with considerable safety margin allowing for additional storage and discharge which results in a capacity to manage the most extreme PMF event envisioned under climate change.

2. **Spillway release and energy dissipation structures**: These assets have a low adaptive capacity because they cannot respond to an increasing scour risk without redesign in the shape and materials of the structure. The existing capacity for adaptation lies mainly in the maintenance and refurbishment schedule which has not yet been finalised.

3. **Re-regulation reservoir, spillway and saddle dam:** these assets have a low-moderate level of adaptive capacity because they were designed with sufficient safety margin to deal with all but the upper limit of the projected CC-PMF. The labyrinth-type spillway maximises spillway capacity but as it is uncontrolled there is little flexibility for the operator to increase spill during peak events, and the reservoir has a small storage volume relative to the size of the incoming event resulting in the risk of over-topping of the saddle dam. The adaptive capacity of these assets results in a significant risk of over-topping but it also limits this risk to being an extremely infrequent event which avoids the compounding risk of saddle-dam failure.

4. **Downstream agricultural lands:** the adaptive capacity of the 420 ha of paddy rice area is unknown at this stage given insufficient detail on the design of the farming system and associated infrastructure. It is known that the area will be serviced by irrigation infrastructure, which depending on the design, could also help to drain and pass floodwaters during extreme events which would increase adaptive capacity. Also, as is the case for paddy rice development in other parts of the Mekong, it is assumed that the area will be serviced by a network of canals, embankments and earthen dykes. Depending on the dimensions and material strength of these structures they could provide additional adaptive capacity of the paddy rice area to manage the increasing frequency of over-bank flooding of the Nam Ngiep River, though they would not provide any capacity to manage the larger, infrequent risk of over-topping of the saddle-dam.

4.3.4   Agricultural productivity

As summarized in section 4.1, increasing temperatures and rainfall will have a moderate adverse impact on agricultural productivity of the rubber, rain-fed rice and commercial tree areas of the resettled community.

The adaptive capacity of the 420ha of irrigated rice will be moderate-high to these impacts of changing climate conditions, primarily because of the plan for an irrigation system. The irrigation system would allow farmers to compensate high temperatures and evaporation rates as well as water deficits associated with erratic rainfall.

Present understanding is that the upland rice area (150ha) and the rubber/commercial trees (400ha) would not include an irrigation system and so farmers would have a low adaptive capacity.

4.3.5   Energy production

As summarized in section 4.1, the main impacts of climate change is increasing seasonal water availability and a greater potential to generate electricity, of substantial value to the operator.

The adaptive capacity of the Nam Ngiep 1 power plant to take advantage of the increases in rainfall projected by climate change is **moderate** and determined primarily by the design capacities and flows of the turbines. The project includes two 140.5 MW verticals-shaft Francis turbines to give a total rated power output of the project of 272 MW. Francis turbines are well suited to a wide range of head and discharge conditions, and the current configuration is capable of a theoretical power output ~5% greater than the project rated output (i.e.

280 MW). These turbines would have been sized based on a flow marginally higher than the mean annual flow of the Nam Ngiep River at the dam site, and are likely slightly oversized to provide the operator with flexibility given the highly variable hydrology of the catchment.

During the dry seasons the two turbines will operate below their optimal efficiency rating as both operating head and discharge through the penstocks drops in response to the reduced water availability. The impact of climate change would be to push the dry season operating efficiency closer to the theoretical optimal thus increasing power production and resulting in a high adaptive capacity to harness increasing dry season flows. Given the size of the NNP1 turbines they have a high capacity to take advantage of this increase in dry season flows, allowing the benefit to accrue to the developer with no adaptation investment in infrastructure.

For NNP1 to take advantage of the increased wet season water availability it would require that the current infrastructure could accommodate larger flows through the penstocks and turbines. As noted above the turbines have a capacity for a small, in the order of 5% increase in capacity which would allow NNP1PC to partially capitalise on the increases in wet season flows. However, given the size of the projected increase the majority of the additional wet season generation potential would not be available to the NNP1PC without significant alteration in the design of the turbines and intake structures resulting in a low adaptive capacity.

The combination of a high dry season adaptive capacity and a low wet season capacity results in an overall moderate capacity of the NNP1 project to respond to the increased energy generation potential of the catchment.

4.4 IMPLICATIONS ON REGULATORY COMPLIANCE

There are a number of regulations which the project must comply with, including dam safety, water quality, flood management and watershed management planning.

Under the concession agreement, regular safety checks and inspections are required, and these should include both the integrity of the dam, the spillways and associated mechanical and electrical equipment to open the spillway gates. In the event of increased usage of the spillways, routine maintenance is expected to increase and increased internal safety checks may also be required. Safety measures also include early warning and emergency preparedness plans to be in place and regularly tested and staff trained.

The water passing through the turbines and being discharged downstream needs to satisfy the water quality standards applicable for maintaining aquatic life in Lao PDR. Regular monitoring of the waters needs to be carried out and the results of analysis provided to MONRE.

Flood management measures should be shared with local agencies within the Nam Ngiep river basin. Since there are a number of hydropower projects upstream, flood management should include joint planning and communications with all the projects, especially providing enough warning of when the spillways are to be brought into operation. This is especially important for Nam Ngiep 1 being the most downstream hydropower plant. This could be coordinated through a River Basin Committee in the future if one is established for the Nam Ngiep.

There is now a requirement within the EIA regulations for all hydropower projects to provide a watershed or catchment management plan. Since increased sedimentation is to be expected under climate change projections, the watershed management plan should be strengthened to reduce the risks of soil erosion and include collaboration with the other hydropower projects upstream of Nam Ngiep 1. This could also be coordinated through a Nam Ngiep River Basin Committee.

5   SETTING PRIORITIES FOR ADAPTATION

The purpose of this section is to shift the focus from impact analysis to adaptation response. The adaptation options are presented for the main issues encountered in the project which are the following:

1. Water quality
2. Watershed
3. Spillage
4. Overtopping
5. Energy production
6. Agricultural production in resettlement area

The adaptation options presented in this section are an edited long-list of potential adaptation measures, from which Section 6 distils a clear program of recommendation adaptation options which are consistent with the principle of prioritising today only those adaptation options which are essential and phasing to future milestones in the operation life those adaptation options responding to impacts that accumulate over time. Where possible an economic estimation of the adaptation options are also presented, noting the lack of economic and financial data made available to the ICEM team.

In addition, it should be noted that each adaptation option presented in Section 5 will have implications for the surrounding social and environmental context, with some having the potential to burden the project with a great environmental or social impact. Therefore, before endorsement to proceed on any adaptation option is given an Adaptation Impact Assessment (AIA) is needed as part of the adaptation scoping process to ensure that the adverse impacts are avoided or mitigated.

5.1   WATER QUALITY

The poor water quality release due to sudden overturn of the reservoir is expected to be an occasional or rare event. If poor quality water release and fish kills prove to be a regular occurrence after the reservoir conditions have stabilised, there are a number of options that can be considered.

The adaptation options to tackle the problem of water quality are the following:

1. **Multiple intake tower**: installation of a multiple intake tower which allows water to be drawn into the intakes from a number of levels would allow for mixing of better quality water from above the thermocline with that from below the thermocline. This is a high cost adaptation measure which would require substantial redesign and investment in a new intake tower.

2. **Downstream weir structure**: As has been installed in Nam Theun 2, a weir structure with a large cross-sectional area could aerate the turbine outflows and mitigate the poor DO levels. The structure could probably be installed downstream of the re-regulation reservoir.

3. **Mechanical aeration**: Similar to how lakes are aerated in Australia, Europe and North America a mechanical aerator which essential mixes the water column could be used to break up the thermocline. The flow in time in the re-regulation dam is quite fast so for an effective treatment there might be the need for multiple units, such as paddlewheel aerators.

4. **Floating aeration (in re-regulation dam):** again coming from the experience of water quality management of lakes, the use of air compressors to pump air below the thermocline and let it bubble up through tubes to aerate the poorer quality water.

5. **Hypolimnetic aerator:** this type of aerator forces water from the hypolimnion upwards to the surface where it goes through a degassing chamber before being sent back down the pipe. This method avoids algal bloom.

Indicatively the degassing chamber (separator box) should have the dimensions of 5.8 m long x 3.1 m wide x 2.1 m in depth. The separator box has openings at either end on the bottom to support the inlet and outlet tubes. The inlet tubes could be of 1.5 m in diameter, and 12.0 m in length. The outlet tube instead, 1.85 m in diameter and 9.5 m in length. The measured inlet tube velocity of water would be in the range of 0.5-0.7 m/s, which would generate an induced aerator flow of roughly 1.25 m^3/s. This equates to a daily hypolimnetic water volume of 216,000 m^3 being pumped through the aerators. The system should be powered by a circa 37 kW compressor.

It is unclear what capacity of equipment would be needed in this case. However, indicative costs for an aerator with a treatment capacity of 216,000 m^3 of water per day cost around US$ 470,000 in 2007. Updated figures are not available for this equipment in the region. Inflated to 2013 values this would amount of approximately US$ 528,000. Detailed O&M costs have also not been available however, a unit this size would require a 37 kW compressor, which could imply a power consumption need of approximately 324 MWh per year, at a cost of UD$ 0.03 /kWh this would amount to power costs of around US$ 9,720 per year.

The methane reduction achieved from aeration may represent significant emissions reductions and may suggest that the CDM or other emissions reduction crediting mechanism could potentially be available for such a project. At the moment there is no approved CDM methodology for this type of project. Moreover, depending on the power density of the hydropower project, it is also likely to be eligible for CDM funding, it is unclear whether this would preclude additional funding for emissions reduction activities such as reservoir aeration.

6. **Threshold DO monitoring (thermocline, DO water, DO turbinated water):** Deteriorating water quality conditions projected within the study embody a certain level of uncertainty – in terms of when and how frequent anoxic waters are released from the reservoir. In some circumstances periodic monitoring of the issue can help to better establish the need for adaptation and hence ensure optimal efficiency in adaptation response. The approach promoted is for a program of threshold monitoring by which key parameters are measured downstream – in this case, this could include, level of reservoir stratification, DO content of turbine discharges, odour monitoring at the resettled community re-regulation site, and environmental monitoring of fish kills. For each monitoring parameter identified an acceptable threshold would be set, such that if the threshold is exceeded beyond an acceptable frequency, the need for one or more of the adaptation measures identified above would be triggered. Such monitoring should be carried out at least once a month, and perhaps more often until the patterns of stratification and overturn in this reservoir are understood, and warning can be provided when it is likely to occur. This adaptation option would therefore focus on installing DO monitoring downstream of the re-regulation reservoir. This approach might work well with options (3) and (4) which have high ongoing operational costs, which would be expensive under continuous operations, but less costly if they are only operated every few years when there is an extremely dry year with high temperatures.

5.2   WATERSHED

The watershed section tackles tow issues, first the issue of erosion and increased sedimentation in the reservoir; second the issue of uncertainty in understanding the baseline hydrology.

5.2.1   Erosion and sedimentation

The adaptation options can be divided into prevention measures and response measures (Figure 68).

Prevention measure – i.e. measures that control the amount of sediment entering the reservoir:

7. **Constructed wetlands in the reservoir head waters:** A pilot project designed to build constructed wetlands in the Theun Hinboun Expansion reservoir (Nam Gnouang) has shown that these wetlands can act like check dams, storing sediments entering the reservoir. If these constructed reservoirs are installed upstream of the NOL, then sediments could be trapped before entering the reservoir's active storage. A GIS and field-based assessment would be needed to identify potential sites that have suitable geometry and that are also situated downstream of the high sediment yield areas of the catchment.
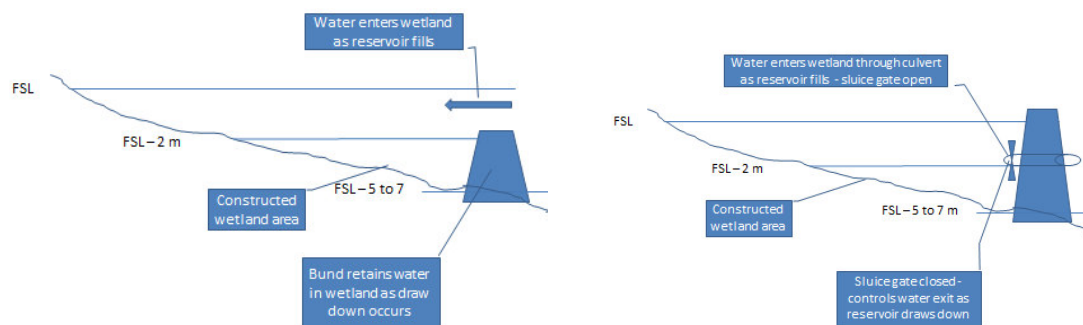
Figure 67: Example of a constructed wetland located in the headwaters of the reservoir: *A check dam across a reservoir tributary would create a wetland which would also trap sediments above the NOL level reducing the accumulation of sediment in the reservoir active storage.*

8. **Check dams:** another option is to install check dams in suitable areas of catchment where the highest increase in erosion is expected to take place. This would be a complementary measure to the constructed wetlands and given the size of each measure relative to the overall sedimentation problem combined implementation of a network of both check dams and constructed wetlands are likely to be more effective.

9. **Protection of existing forest:** the watershed management plan which NNP1 is creating should survey the catchment to determine forest areas worth protecting as part of a biodiversity offset plan for the forest area inundated by the reservoir. Forest conservation for existing forests on steep slopes could play an important role in reducing sediment production. This could also be linked into a PES system for watershed management, which the Government of Lao is beginning to trial.

10. **Reforestation:** If the watershed management plan also surveys were to identify areas for reforestation, this could enhance the sediment conservation element of the plan and reduce the sediment load into the river. To be most effective the survey would need to include an element of slope analysis so that reforestation is focused on the most highly erosive slopes.

Response measures – measures to manage the sediment once in the reservoir. These measures are drawn from the experience of large reservoirs in south and Southeast Asia.

11. **Dredging:** this method may be used in any place in the reservoir where sediments have accumulated. it consists the periodic use of heavy machinery and pumps to mechanically extract accumulated sediment deposits. A variation of this is the regular augmentation of gravel below a dam in order to replace sediment lost and prevent downstream bank erosion.

12. **Sediment flushing or routing:** the flushing of sediments happens by regularly using bottom outlet gates, and occasionally through draining the reservoir down. This method will clear the sediments that have accumulated close to the dam and bottom outlets, but not those further back into the reservoir. The suggestion is to start the wet season with the reservoir drawn down so that the incoming flood would pass through a reservoir with semi-restored riverine conditions which will enhance mobilisation of the delta and move sediments further down as the reservoir is filling up.

Other options were considered such as density current venting, where the natural sediment transport pathways through the reservoir are identified and a proportion of the flow is diverted, and sediment by-pass channels which divert sediment-laden water into a tunnel just upstream of the reservoir to discharge it back into river below the dam. These options were discarded because highly dependent on the hydraulic head and the velocity characterising the reservoirs. The geometry and gradients in this case were not suitable.

Figure 68 - Sediment management options in a reservoir. (Source: Meynell and Zakir 2014, adapted from Tetsuya Sumi)

5.2.2 Uncertainty in rainfall estimation in data-scarce basins

In the design of the PMF and its review through the DSRP and CRVA process, NNP1PC has undertaken due diligence to build a robust PMF that makes best use of all available data, compares with existing regional
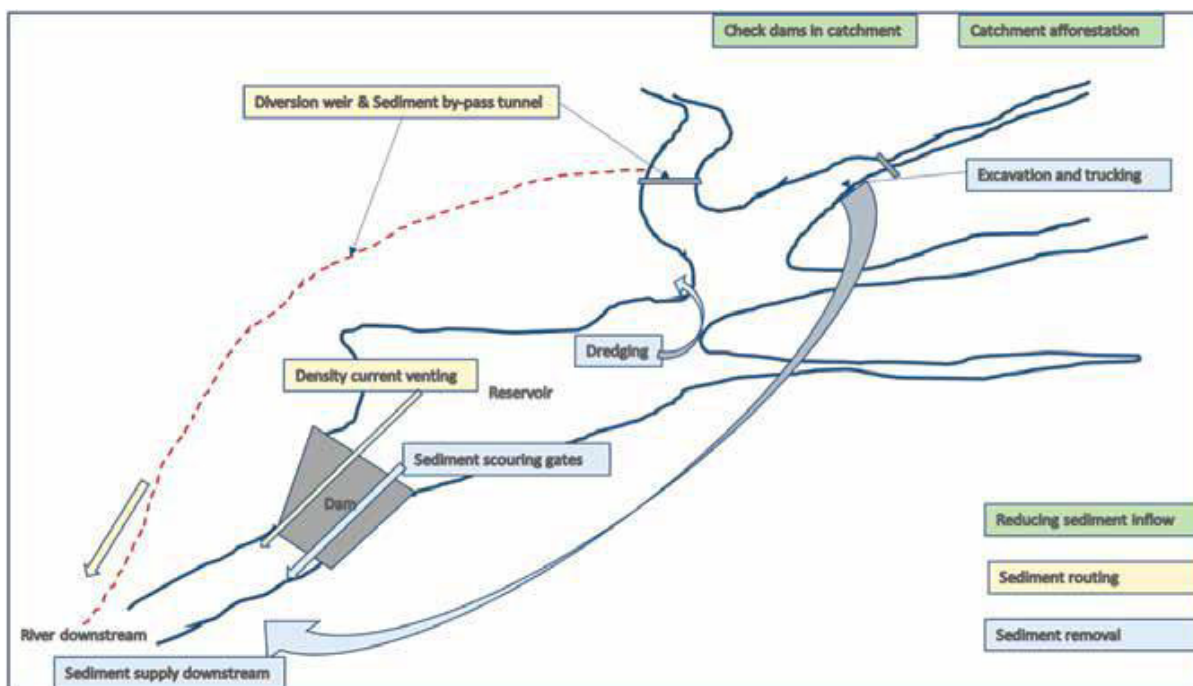
information and those of hydropower projects in neighbouring basins such that even under the upper CC projections of this study, there is sufficient confidence in the project's inbuilt safety margin.

However, there remains a regional problem for hydrological analysis as experienced by NNP1 and neighbouring projects – that of highly variable precipitation dynamics resulting from multiple forcings in a poorly gauged context. Regionalisation techniques provide an opportunity for extending the period of record for available hydro-climatic stations and providing estimates for ungauged catchments. It is recommended that a regionalised precipitation and flood frequency study be undertaken to improve estimation of precipitation and flood frequencies for the design of planned hydropower investments in the region, and to assist regional governments in water and power planning.

Regional frequency analysis is a statistical approach to calculating hydro-climatic event frequencies by pooling data from several sites located within a region. It can be used to improve the frequency estimation at sites with poor data or for estimation of frequencies at sites with no stations. Regional frequency analysis assumes that the frequency distribution for all the sites within a region are the same except for a site-specific scale factor. This enables the scaled frequency information from all the sites within a region to be combined in order to produce a regional frequency distribution. By using information from multiple sites to improve the estimation of frequency distribution, the method effectively substitutes space for time. Improved site frequency distributions can then be obtained from the regional frequency distribution by reapplying the site-specific scale factor.

There are many regionalisation methods available for hydro-climatic frequency analysis. It is recommended that the L-moments regional frequency analysis approach, developed by Hosking and Wallis (1997), be adopted for this study. The L-moment approach has been demonstrated to perform competitively with the best available statistical techniques for regional frequency analysis. In the United States the approach was tested against the U.S. 1982 Interagency Advisory Committee on Water Data Bulletin 17B procedure, the current United States standard for calculating flood frequencies for ungauged catchments. The comparison showed the L-moments approach to be more effective in identifying homogeneous regions, and more coherent in fitting statistical distributions (Lim and Voeller, 2009).

13. There are three main steps to be undertaken for a regional frequency analysis using the L-moments approach, the steps are similar for analysis of precipitation and flood frequencies:

> **Step 1. Data collection, collation and screening:** Precipitation and discharge time series for stations in the area are collected and analysed to identify annual maxima and the date of annual maxima. Station information can be augmented by products such as Tropical Rainfall Measuring Mission19 (TRMM) or Asian Precipitation – Highly-Resolved Observational Data Integration Towards Evaluation of Water Resources20 (APHRODITE). The annual maxima series are tested for discordancy using L-moment statistics. The discordancy test aims to identify sites that are incompatible with the other sites of a group and screen out incorrect data values or outliers that may affect later stages of the analysis.

> Data on catchment characteristics is also required for regional flood frequency analysis to delineate regions which may be hydrologically homogenous.

> **Stage 2. Forming and testing homogenous regions:** The aim of this stage is to form groups of sites that approximately satisfy the condition of homogeneity. This means that the annual maxima frequency distribution of the sites should be close to identical except for at-site scale factors. L-moment heterogeneity tests should be used to assess whether a group of sites can be treated as a homogenous region. Depending on the number of available sites and the

---

[19] http://trmm.gsfc.nasa.gov/
[20] http://www.chikyu.ac.jp/precip/

geographic area to be covered, this stage may identify one or more homogenous regions. Separate regions may need to be developed for precipitation and flood frequency analysis.

➢ **Stage 3. Choosing a regional frequency distribution and developing the regional growth curve:** In this step L-moment statistics are used to scale the annual maxima for each site, combine the scaled site data into a regional dataset and fit a frequency distribution to the regional dataset. A goodness-of-fit measure based on L–moments statistics is used to test whether selected frequency distributions are acceptable and to find the best-fitting distribution. The best fitting probability distribution is used to develop a regional flood frequency curve, or regional growth curve. The regional growth curve provides a single standardized regional frequency curve that is applicable, after rescaling, anywhere in the region. Separate regional growth curves would need to be developed for precipitation and flood frequency.

The output of the study would include: i) a set of improved precipitation frequency estimates for all existing precipitation stations in the area; ii) a set of improved flood frequency estimates for all existing hydrological stations in the area; iii) precipitation regional growth curve that can be used to calculate precipitation frequencies for sites with no station data; and iv) a flood regional growth curve that can be used to estimate flood frequencies for ungauged catchments. These outputs would build confidence in the magnitude and frequency of flood events which are being used to design the NNP1 project and presents potentially, the highest impact adaptation measure of all as it will build confidence in the existing or determine a more robust need for changes in the design of the dams and spillway structures.

5.3   SPILLAGE

An increased spillage, as predicted through the modelling, will increase the wear and tear of all mechanical parts involved as well as scour on the built surfaces of the downstream spillway and energy dissipation structures. The adaptation options should focus upon strengthening the regular monitoring of the equipment functioning, and revising the schedule for routine maintenance and repair of the spillways and gates to cater for the increased usage of the spillway.

The adaptation options for the increased spillage are the following:

14. **Increased frequency of maintenance**: the simplest method to address this is to increase the maintenance frequency. Undertake 2-yearly or 5-yearly monitoring of the wear and tear of the spillway apron to analyse the rates of erosion on the concrete. Once every 10 years it would be advisable to assess the actual amount of water spilled.

15. **Increase turbine capacity**: adding extra turbine capacity would be a good way to reduce spillage. Given that procurement is already finalised for the existing turbines this would mean adding additional units (as opposed to sizing up the existing ones). Extra turbines (i.e. one smaller unit) would also work better in the dry season where existing turbines can run at full capacity and the additional turbine is switched off. Given the relative size of the increase in wet season water availability the additional turbine would need to be in the order of 30-50% of the size of the existing turbine to be most efficient.

At this stage in project implementation, an additional turbine may not be warranted during construction, however a manifold and provision in the dam civil works to allow for an additional penstock should be considered at this stage.

16. **Threshold monitoring:** both options (1) and (2) are expensive and as is the case for water quality impacts, the timing and frequency of increasing spillage embody a certain level of uncertainty. A phased approach to adaptation would include a program of threshold monitoring that monitors the volume of water passed over the main dam spillway and visibly inspects the level of deterioration in the civil works

associated with the spillway apron and the energy dissipation structures. For each of these parameters an acceptable threshold value and frequency would be set, with the need for option (1) or (2) triggered only if these limits are exceeded,

17. **Cascade coordination of spillway releases:** In moderate flood events, coordination with upstream projects would allow NNP1 to optimise spillage from the main dam. This option is discussed in more detail under section 5.4

5.4   OVERTOPPING

Rising levels in the main and the re-regulation dam threaten to lead to an overtopping of the saddle dam releasing uncontrolled flood volumes into the downstream agricultural land of the resettled community. The adaptation options for addressing this risk are:

18. **Early warning system (EWS) and Emergency Response Centre (ERC):** an early warning system (EWS) would help predict: (i) wetness of the next season and (ii) incoming cyclones at the end of the season. This is ideally done in cooperation and total communication with other basins, for example the Nam Theun basin as well as a level of coordination by the Government of Lao PDR. Based on international experience, such an effort could include the establishment of an Emergency Response Centre (ERC) which would be led by the Dept. of Meteorology and Hydrology and involve active engagement of other key departments as well as representatives from each operator in the NNP cascade. The main function of the ERC would be to coordinated management directives in the cascade during extreme flood events and also to coordinate and strengthen flood monitoring and forecasting efforts by operators and GOL in the NNP basin.

As this would be the first EWS/ERC in Lao PDR, it would require technical assistance that draws in international experience to support NNP cascade operators and GOL in designing the working modalities, protocols, technologies and regulatory environment for implementation.

19. **Coordination with other dams:** jointly establish the value of a threshold flood. Once this has been reached all hydropower projects enter a flood control mode, i.e. a high alert mode, for which there would be the requirement for hourly communication about operations. A stand-by mode would also be advisable, triggered by a particularly wet monsoon season for which all reservoirs reach FSL level early in the wet season. During the stand-by mode daily communications between reservoirs are advised. Note that coordination relates to informing projects about how the dam is being managed, not about enforcing changes on that management regime. It would also involve a coordinated approach to designing additional precipitation and stream gauge monitoring which each project and the GOL might undertake to ensure the most effective monitoring and forecasting for the basin. Ideally this measure would be a sub-component in option (1).

20. **Flood buffer:** this is an easy option to implement further along the life-span of the project. It involves changing the elevation of the Normal Operating Water Level to increase the flood storage buffer. This essentially, comes down to changing the operating regime and rule curves. The need for this adaptation is highly dependent on the validity of the PMF and design flood estimates made by NNP1PC and ICEM and would require the undertaking of the regional flood and precipitation frequency analysis identified in Section 5.2.2 to confirm the need or otherwise. In addition, it is suggested to conduct a rule curve review every 5 years to have a better understanding of the inflow variability and the dynamics of large flood routing through the reservoirs. The current data set is relatively short and would benefit from a longer time-series.

> ## Box 2: Case of the Srinagarind Dam
>
> *Experience at some dam sites in Thailand has been that modifications were needed after a few years of operation. At one Electricity Generating Authority of Thailand (EGAT) high hazard site, Srinagarind dam, a review of hydrological conditions in the Khwae river basin led to recommendations by the expert engineering team to operate flood season reservoir levels more conservatively than had been the case in the past to provide a larger flood buffer (Champa et al 1988, SNC Lavalin 1999, Ward et al. 2013).*

21. **Extension of parapet wall along half the dam above the power house:** This measure would not prevent over-topping but it would direct over-topped flows away from the powerhouse which would limit the damage to equipment and power outages. The rest of the dam wall could be left open to provide extra spillage capacity in the event of an extreme CC-PMF. Such a measure would need to be considered as part of an integrated system including the raising the saddle-dam crest elevation.

22. **Flood protection measures for downstream assets:** Another potential adaptation measure is to ensure flood protection measures are included as part of the proposed agricultural infrastructure destined to support the 420 ha of paddy rice.

23. **Improved understanding of meso-scale phenomena in the catchment's precipitation dynamics:** As noted in the report the baseline estimates of catchment precipitation and therefore the future CC projections are highly dependent on a number of meso-scale atmospheric processes that are not well understood at present. These include: (i) the Southern Oscillation Index (SOI) and other global scale phenomena that affect the monsoon, as well as (ii) dynamics of the West-Pacific cyclone system. Previous studies at the basin-scale have shown there are correlations between flood risk and the timing and cycles of the SOI (see for example Räsänen et al, 2014). An improved understanding of the correlation of the SOI with peak rainfall events in the NNP catchment would allow a potential long-term forecasting option for the basin which assessing the timing of each flood season relative to the wax and wane in the *el nino/la nina* phenomena. This information could give at the seasonal time-scale a level of alert or readiness when a particular flood season is expected to be high or extreme.

   In addition, new methods using Regional Circulation Models (RCMs) such a RegCM developed by NCAR are emerging which can simulate cyclone tracks to derive detailed event rainfall patterns and perturb them to predict changes in extreme events that may occur under a range of future CC projections (see for example, Benn, Wylde and Green, 2014). The methodology would involve identifying the most significant cyclone event to hit the NNP catchment over the past 50 years and use the RegCM model to estimate how sub-daily rainfall intensities would change under a range of future climate scenarios.

5.5   ENERGY PRODUCTION

In order to take advantage of the increased rainfall and thus increase power production, the main tool that can be used is the regular monitoring of reservoir levels according to the operational rule curve. It may be necessary to revise the rule curve in the light of increases in rainfall and the experience of high and low rainfall years.

The adaptation options to take advantage of the additional water that would be lost due to increased spillway operation are more limited and could involve major investments. It could be useful even at this stage in the project to carry out some design calculations to estimate how much additional water could be used and how to

accommodate this within the existing design or layout of the plant. For example is there enough space for the construction of an additional turbine, or are there opportunities for increasing turbine size at an appropriate stage during the project. Obviously in both of these instances, the increases in water availability would have to be confirmed and economic justifications for the added costs demonstrated. A cost-effective solution could be to add a blanked manifold where the intake of the penstock is to make space in the future for a new turbine as suggested in Section 5.3 option 4.

5.6   AGRICULTURAL PRODUCTION IN THE RESETTLED AREA

The inclusion of an irrigation system would greatly enhance the capacity of the upland rice area (150 ha) to manage variations in monthly water availability which are shown to be important during the growing cycle of rice. It is understood that an irrigation system is currently not proposed for the upland rice area, but that recommended that a pumped irrigation system would give farmers secure water delivery regardless of the changing hydro-climate wetness.

5.7   EROSION AT THE SPILLWAY LANDING ZONE

Erosion at the outlet of spillway structures is a common problem for hydropower projects. In the case of the NNP1 project, the landing zone for spillway releases is unprotected and it is expected that a scour hole 10 m deep will form as spillway releases erode the overlaying sediment deposits in the river bed. Below 10 m geotechnical surveys identify that the underlying CH bed rock which is considered resistant to erosion, such that the scour hole will not progress below 10m.

However, the erosion potential calculated by NNP1PC lies at the upper limit of the non-erodible zone. In other hydropower projects, such as the Kariba dam in Zimbabwe, which is underlain by Gneiss rock, scour in the land zone is much more pervasive than anticipated during the design (Figure 73), such that dam operators now need to undertake regular underwater efforts to reinforce the scour hole with concrete to ensure the scour hole does not undermine the dam structure.
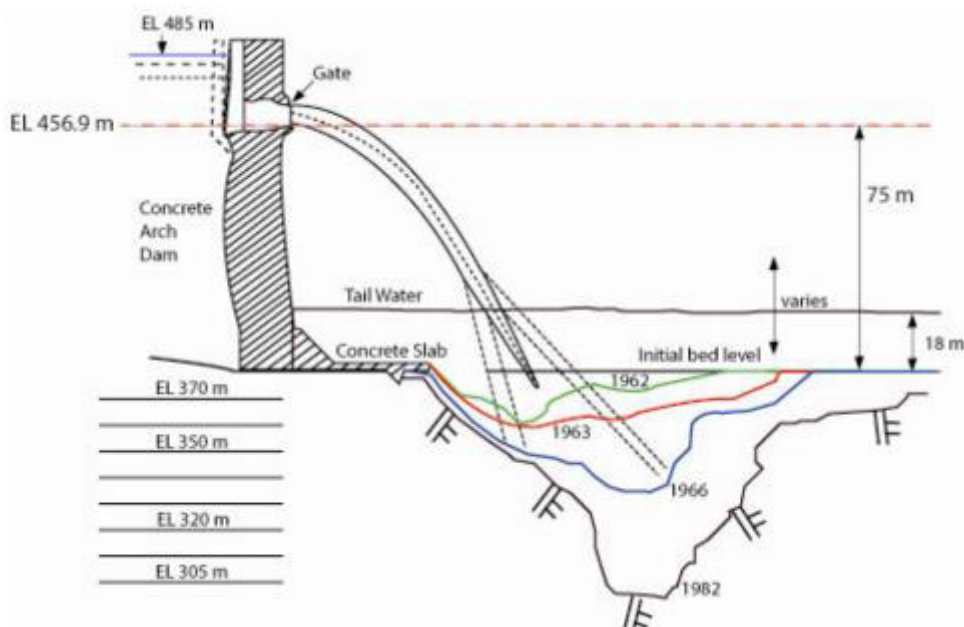

Figure 69: Progressive scour lines at the Kariba Dam 1959-1982 *(source: USSD, 2008)*

 For NNP1, no immediate adaptation measures are needed for the scour hole, however, it is recommended that the development of the scour hole is monitored, once bed rock is exposed a threshold is established to trigger remedial efforts if scour progresses into the bed rock.

6 RECOMMENDATIONS

The main conclusions of the impact assessment are presented in section 4.1. Coupling these findings with the results from the review of the NNP1 adaptive capacity (4.3) and the targeted long-listing of potential adaptation options in Section 5 results in the following recommendations for adaptation.

The recommendations are split into three sections: (i) monitoring measures that are required to identify thresholds which would trigger the need to proceeds with future adaptation measures; (ii) implementation of works that introduce adaptation measures now or preserve the capacity for phase adaptation in the future; and (iii) additional Technical Assistance (TA) studies and inputs that serve to confirm the scope and need for critical adaptation interventions.

6.1 THRESHOLD MONITORING MEASURES

For a number of impacts relating to downstream water quality issues and the impacts of increased spillage on lost energy potential as well as damage to the spillway structures, there is a need for improved certainty on the timing of when these CC impacts will become significant for NNP1. This means a phased approach to adaptation is required. The main objective of the first phase is to reduce this uncertainty through the implementation of a monitoring program of relevant hydro-climate, environmental and infrastructure condition monitoring. The first phase is considered a priority for implementation as part of project operations after commissioning. The second phase would be triggered once critical thresholds in any monitoring parameter have been triggered. The table below summarises the threshold monitoring required as part of the first phase.

Table 13 – Proposed threshold monitoring required as a first phase of adaptation to the issues of reduced downstream water quality, increased spillage and the implications to spillway infrastructure damage and lost energy potential.

NNP1 Asset	Monitoring parameter	Potential frequency of monitoring	Potential trigger value	Consequence
Reservoir water quality	Vertical-depth monitoring of temperature profile	Monthly	TBD	Explore the feasibility of one or more of Adaptation options 1-5
	DO monitoring	Monthly	Based on GOL regulation	
DO content of turbine discharges	DO monitoring at outlet	Monthly	Based on GOL regulation	Explore the feasibility of one or more of Adaptation options 1-5
	Odour monitoring at resettlement community residential area	Monthly	Human levels of detection for sulphurous compounds	
Spillway apron and downstream landing zone	Monthly discharges and volumes of spillage	Daily (aggregated at monthly time-step)	TBD	Explore the feasibility of Adaption option 14, 17
	Site inspection of scour conditions of the spillway and scour hole	Annually during the dry season	TBD	
Energy production	Monthly discharges and volumes of spillage	Daily (aggregated at monthly time-step)	TBD	Explore the feasibility of Adaption option 15, 17

6.2 ADAPTATION INTERVENTIONS

The following adaptation options should be built into the design and construction phase of project development:

1. **Preventative measures for catchment sediment conservation:** site and develop preventative measures such as check dams and constructed wetlands that allow for increased sediment loads to be trapped within the landscape before they reach the headwaters of the reservoir. These measures should target erosion hotspots in the NNP1 catchments and be developed as part of the NNP1 watershed management plan. In addition efforts to rehabilitate degraded forest areas to enhance soil conservation should also be included as part of the watershed management plan.

2. **Build adaptive capacity for increased wet season electricity production**: inclusion of a blank manifold and provision for an additional penstock should be considered whilst the main dam is still under construction.

6.3   ADDITIONAL TECHNICAL ASSISTANCE (TA)

Last, the CRVA identified the need for a number of additional TA inputs which would enhance the resilience of the NNP1 project and serve to provide greater clarity on the magnitude and timing of risks, these are summarised below:

1. **Rapid catchment condition appraisal and feasibility assessment for a Payment for Ecosystem Services scheme for catchment soil conservation**: A number of adaptation measures identified above rely on the identification of erosion hot and sweet spots within the catchment; with the erosion hotspots considered as those areas producing the greatest amounts of hillslope erosion and sweet spots as those areas of forest providing the most important soil conservation services.

   Additional TA would be needed to undertake a GIS-based assessment of hot and sweet spots including an estimation of the sediment conservation potential. This assessment would need some field work to ground truth the findings of the GIS assessment and to identify sites and undertake a rapid feasibility assessment for a network of check dams and constructed wetlands.

   In parallel an institutional assessment would need to be undertaken to review the potential for piloting a Payment for Ecosystem Services (PES) initiative as enshrined in the new national water law for Lao PDR. The institutional assessment would need to include a review of government and community stakeholders and recommendations on the scope, mechanisms and modalities for implementation of the watershed soil conservation measures. Both components would need to be completed in close working cooperation with the NNP1 Watershed management plan.

2. **Technical and institutional feasibility assessment for the establishment of a Nam Ngiep Emergency Response Centre (ERC), including a coordinated Early Warning System**: A number of adaptation options point towards the need for a coordinated response to flood management, including coordination of spillway releases and an EWS, coordination of additional precipitation and stream gauge monitoring by cascade operators and flood forecasting measures as well as the coordination of the sharing of information sharing generated by these measures. Ultimately the responsibility for such coordination lies beyond any individual hydropower operator and requires an active and leading role from the Government of Lao PDR (GOL). An additional TA is needed to support relevant agencies within the GOL and operators of the NNP cascade to design and implement a coordinated response as outlined in adaptation options 18, 19 and 20.

   The main components of this TA would include an institutional review of government agencies and policies for watershed, flooding, disaster and climate change management resulting in a set of recommendations on the appropriate institutional mechanisms, scope and membership of an ERC. A technical review undertaken in parallel would make recommendations on: (i) optimal siting for additional precipitation and stream gauge monitoring, (ii) appropriate technologies for monitoring stations, (iii) the potential for remote sensing information to inform monitoring and/or flood forecasting efforts, (iv) the need and role for a shared catchment hydrological model, and (v) scope of

management guidelines and directives which are used to ensure communication and coordination during flood events.

3. **Hydrological analysis:** In the design of the PMF and its review through the DSRP and CRVA process, NNP1PC has undertaken due diligence to build a robust PMF that makes best use of all available data, compares with existing regional information and those of hydropower projects in neighbouring basins such that even under the upper CC projections of this study, there is sufficient confidence in the project's inbuilt safety margin.

However, there remains a regional problem for hydrological analysis as experienced by NNP1 and neighbouring projects – that of highly variable precipitation dynamics resulting from multiple forcings in a poorly gauged context. As noted above, additional monitoring is an essential component in a strategy to fill this gap but will take many years to build the long time series needed for extreme event analysis. Therefore, this study recommends additional hydrological analysis to be undertaken to improve understanding of flood dynamics and support better and more responsive flood management in the Nam Ngiep and other basins of Lao. The main components of the additional assessment are summarised below. Given the geographical scope of the additional analysis, the findings would be of benefit to a large number of stakeholders; consequently, it is recommended that the Government of Lao PDR with support from Development Partners should take the lead in undertaking the hydrological analysis and consolidating information which can be provided to relevant developers:

a. *Regionalised frequency analysis* of hydro-climate event frequencies (precipitation and flooding) that pools data from a wide number of stations and performs statistical analysis to extend the temporal scale of observation data sets which can be used for improved site-specific frequency distributions. This component would result in four main outputs:

   i. a set of improved precipitation frequency estimates for all existing precipitation stations in the area;
   ii. a set of improved flood frequency estimates for all existing hydrological stations in the area;
   iii. precipitation regional growth curve that can be used to calculate precipitation frequencies for sites with no station data; and
   iv. a flood regional growth curve that can be used to estimate flood frequencies for ungauged catchments. These outputs would build confidence in the magnitude and frequency of flood events which are being used to design the NNP1 project and presents potentially, the highest impact adaptation measure of all as it will build confidence in the existing or determine a more robust need for changes in the design of the dams and spillway structures.

b. *Assessment of correlation between meso-scale phenomena and catchment precipitation dynamics*: An improved understanding of the correlation of the Southern Oscillation Index (SOI) with peak rainfall events in the NNP catchment would allow a potential long-term forecasting option for the basin which assessing the timing of each flood season relative to the wax and wane in the el nino/la nina phenomena. This information could give at the seasonal time-scale a level of alert or readiness when a particular flood season is expected to be high or extreme.

c. *Simulation of event intensities under baseline and future cyclone conditions*: new methods using Regional Circulation Models (RCMs) such a RegCM developed by NCAR are emerging which can simulate cyclone tracks to derive detailed event rainfall patterns and peturb them to predict changes in extreme events that may occur under a range of future CC projections. This component would involve identifying the most significant cyclone event to hit the NNP

catchment over the past 50 years and use the RegCM model to estimate how sub-daily rainfall intensities would change under a range of future climate scenarios. This component would give much better estimations of changing hourly rainfall dynamics within the catchment which are critical to robust PMF estimation and could be used to confirm or adjust the accepted PMF used in the design of NNP1.

.

REFERENCES

Asian Development Bank (2012) **Climate Risk and Adaptation in the Electric Power Sector**, Asian Development Bank publication ISBN 978-92-9092-730-3

Adrian, R., O'Reilly, C. M., Zagarese, H., Baines, S. B., Hessen, D. O., Keller, W., Livingstone, D. M., Sommaruga, R., Straile, D., Donk, E. V., Weyhenmeyer, G. A., and Winder, M.: (2009) **Lakes as sentinels of climate change**, Limnol. Oceanogr., 54, 2283–2297.

Champa S., B. Mahatharadol and A. Suthinsak (1988). **Spillway Operation of Srinagarind Dam and Khao Laem Dam.** Commission Internationale des Grands Barrages. 16th Congress San Francisco. pp. 521-533.

European Commission (2011). **The Impact of Climate Change on Electricity Demand.** www.adamproject.eu, http://ec.europa.eu/environment/integration/research/newsalert/pdf/223na4.pdf

Gill M.A. (1979) **Sedimentation and Useful Life of Reservoirs**, Journal of Hydrology, 44, 89-95.

Hulme, M. , Neufeldt, H., Colyer, H., Ritchie, A. (2009). **Adaptation and Mitigation Strategies: Supporting European Climate Policy. The Final Report from the ADAM Project. Revised June 2009.** Tyndall Centre for Climate Change Research, University of East Anglia, Norwich, UK

Hosking, J.R., Wallis, J.R., 1997. Regional frequency analysis. Cambridge University Press, United States of America

Kansai (May 2013). **Technical report on Nam Ngiep 1 Hydropower Project.**

Lim, Y., Voeller, D., 2009. Regional flood estimations in Red River using L -Moment-Based Index-Flood and Bulletin 17B Procedures. J. Hydrol. Eng. 14, 1002–1016

Livingstone, D.M. and Padisak, J. (2007). **Large-scale coherence in the response of lake surface-water temperatures to synoptic-scale climate forcing during summer**, Limnol. Oceanogr., 52, 896–902.

Mackay, M.D., Neale, P.J., Arp, C. D., Domis, L.N.D.S., Fang, X., Gal, G., Joehnk, K.D., Kirillin, G., Lenters, J.D., Lithcman, E., Macintyre,S., Marsh, P., Melack, J., Mooij, W.M., Peeters, F., Quesada, A., Schladow, S.G., Schimd, M., Spence, C., and Stokes, S.L. (2009). **Modelling lakes and reservoirs in the climate system**, Limnol. Oceanogr., 54, 2315-2329.

Meynell, P.J. and Nazia, Z. (2014). **EIA Guidelines for Large-Scale Hydropower In Pakistan**. Islamabad: IUCN Pakistan. 136 pp.

Piccolroaz, S., Toffolon M., Majone B. (2013) **Air to water temperature in lakes.** Hydrology and earth system sciences, 17, 3323-3338

SNC Lavalin (1999). **Report of Expert Review Committee on Dam Safety at Srinagarind and Vajiralongforn Dams.** For Electricity Generating Authority of Thailand.

USGS, 1982. Guidelines for determining flood flow frequency. Bulletin 17B of the Hydrology Committee. United States Geological Society, Reston, VA, United States of America

Ward, D. (2010). **Vulnerability of electricity grid systems to climate change and extreme weather events.** Presented at Joint ICTP-IAEA Workshop on Vulnerability of Energy Systems to Climate Change and Extreme Events. Abdus Salam International Centre for Theoretical Physics. Trieste. 19–23 April.

Ward, P.R.B., Räsänen, T. A., Meynell, P.J., Ketelsen, T. (2013). *Flood control challenges for large hydroelectric reservoirs: Nam Theun-Nam Kading Basin, Lao PDR. Project report: Challenge Program on Water & Food Mekong project MK3 "Optimizing the management of a cascade of reservoirs at the catchment level*. ICEM – International Centre for Environmental Management, Hanoi Vietnam, 2013

Wetzel, R. G. (2001) **Limnology: Lake and River Ecosystems**, Academic Press, San Diego, 3rd Edn.

Zhou, R.D., Donnelly, C.R., Judge, D.G. (2008) *On the relationship between the 10,000yr flood and the Probable Maximum Flood*, conference paper at Hydrovision 2008, Denver Colarado.

ANNEX II: MODELLING VERIFICATION AND RESULTS

A – HYDROLOGICAL & HYDRODYNAMIC MODELLING

The modelling objective is **provision of quantitative information on the threats** under future climate conditions and under the operation of hydropower cascades. In general modelling helps in identifying CC risks and understanding CC related processes that impact the plant operation.

A1. VMOD Model set up

The VMOD distributed hydrological model was used to estimate water discharge within Nam Ngiep catchment. Figure 70 shows how the model is constructed. Elevation, land use and soil cover layers were inputted into the model as grid cell file. These are the base layers to simulate the flow within the catchment.
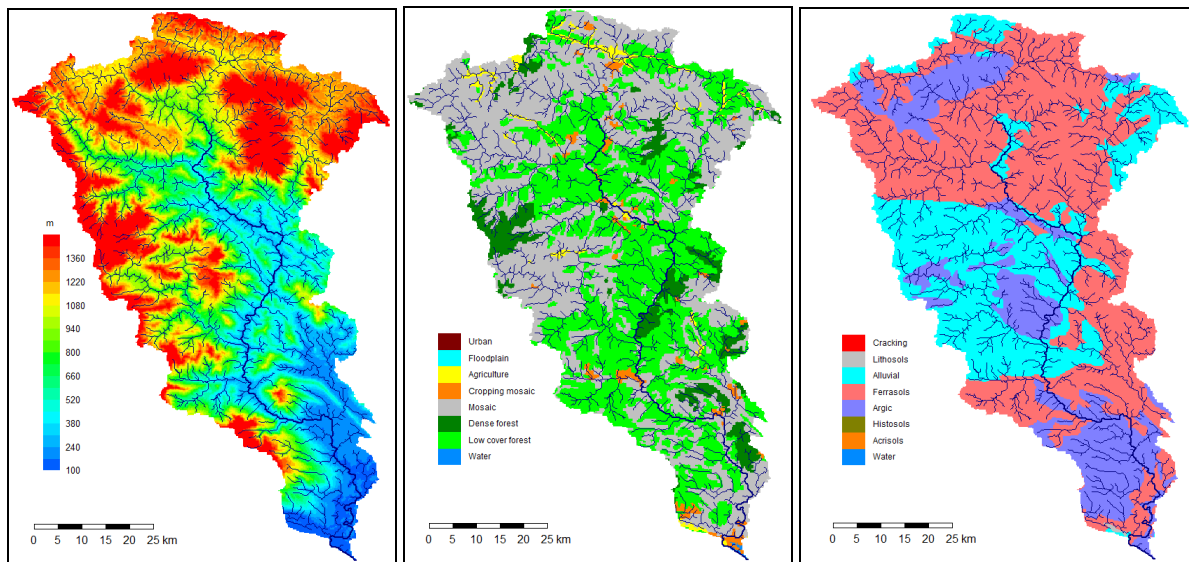
Figure 70 – VMOD model set up: *showing elevation grid 90x90m (left), 2010 landuse layer (middle), and soil layer (right)*

The model has incorporated rainfall data collected from four stations within the catchment. The data covers the years from 1971 to 2013 and it was used as baseline data for the study. Rainfall is variable between stations; the upper catchment is much drier than the lower catchment as seen in Figure 71.

1. Xiengkhouang station – the north upstream station has average annual rainfall between 1,000 - 1,200 mm with the maximum value of 2,500 mm.

2. Thaviang station - the central upstream station also has average annual rainfall between 1,000 - 1,200 mm with the maximum value of 2,500 mm.

3. Hat Gnium station - the central downstream station has average annual rainfall of 1,500 mm with the maximum value of 3,000 mm

4. Paksan station – the downstream station has average annual rainfall of 2,980 mm with the peak of 4,590 mm
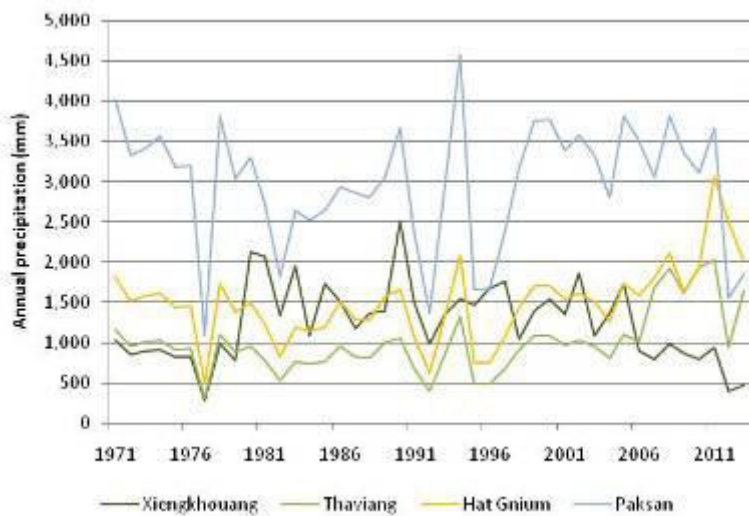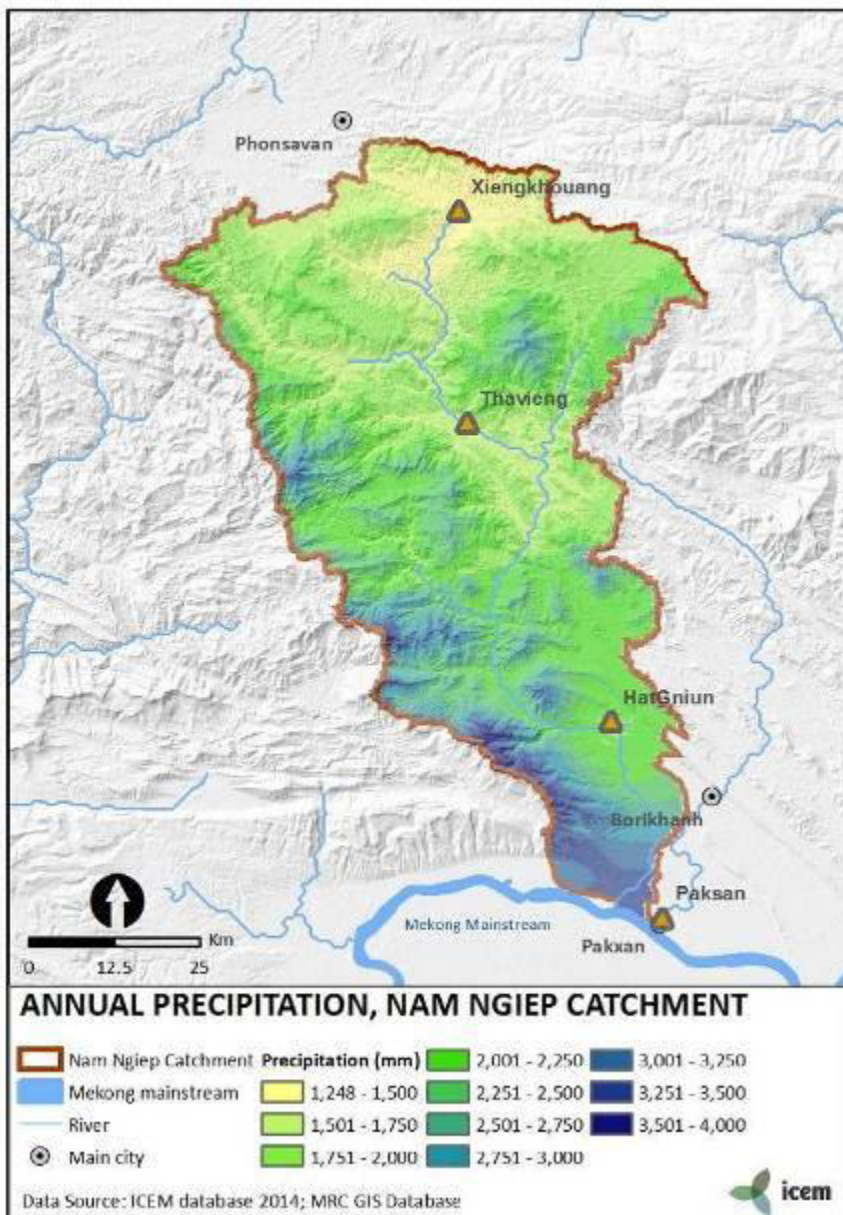
Figure 71 – Rainfall data input for the model: *location of four stations within the catchment (top) and annual rainfall variability at the four stations (bottom).*

The whole catchment was divided into grid cells as seen in Figure 72 and river discharge was computed depending on the terrain, land use and soil properties.
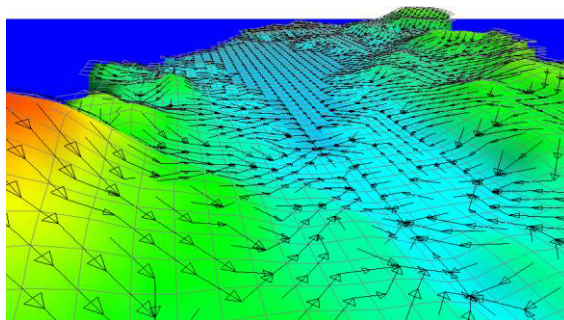
Figure 72 – Computing water flow within a typical catchment

The computed and measured river discharges at Hat Gnium have been used to calibrate the model. Figure 73 shows the variance between VMOD computed and observed discharges within given years. The results show that the modelled discharges are not too far off from the measured data. Overall, the computed average flow is 145 m³/s compared to a measured value of 142 m³/s.
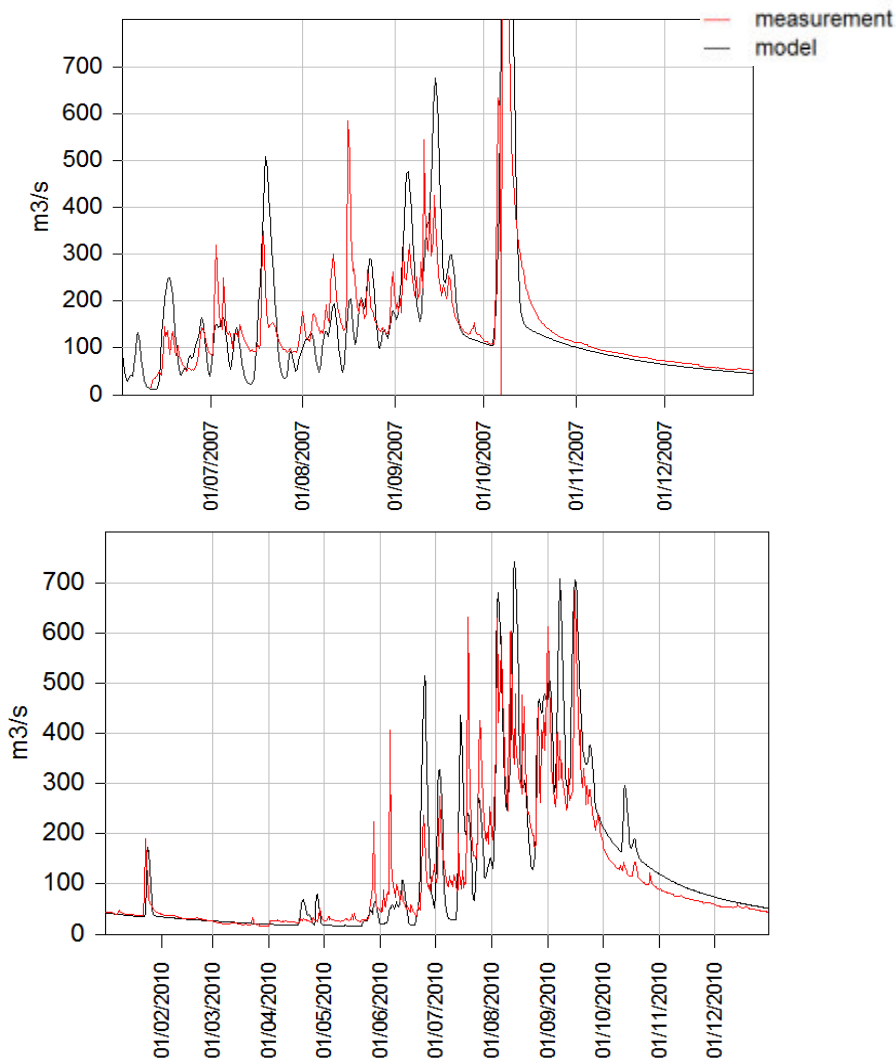
Figure 73 – VMOD simulated river discharges compared to observed data at Hat Gnium, year 2007 and 2011

A2.   MODSIM model set-up

The MODSIM model was used by the study to simulate the changes of river discharge when all hydropower projects within a cascade are in operation. The model was set up with input data on reservoir storage capacity, operational levels and rules, power generation capacity and operation hours for each of the hydropower project. Inflow to each hydropower project was calculated based on discharge output from VMOD model. Figure 74 shows the flow network for the cascade and input data for the model. The model calculates downstream discharge from powerhouse, spillage and energy production at each hydropower project throughout different scenarios. Comparison between scenarios was conducted to quantify the impact of hydropower cascades in Nam Ngiep catchment.

Figure 74 – MODSIM model set-up: *flow network through reservoir and hydropower (left); and capacity and operation rule of NNP1 input to the model (right)*

Computed results from MODSIM model was compared with the modelled results supplied by NNP1PC for the design. Figure 75 shows the difference in energy production between MODSIM model and NNP1 model. Both of the models were run with the same inflow data from 1984 to 2013, this data was obtained from NNP1 technical report. The results show that overall the difference on annual energy production between MODSIM and NNP1 model is 0.93% with variation between years. Thus the model is in an acceptable range.

Figure 75 – MODSIM simulation energy production compared with NNP1PC's modelling results

A3.   Limitation of the models

Both of the models used in this study have some limitation due to data availability. With an inconsistent available period of rainfall data between stations, the models could only run with a completed dataset for 14 years from 1998-2011. 14 year period might not be long enough to capture the natural variability in catchment rainfall and flood dynamics.

MODSIM model can only incorporate the lower operation rule curve for NNP1, the upper rule curve was ruled out by assuming the plant will operate to produce PE and SE when water level in the reservoir is higher than the LRC. There was not a significant change in energy production due to this limitation of the model as showed in the above comparison.

Daily precipitation input data is recorded and computed and cannot be used to estimate flow intensity hourly, 12-hr, 24-hr, 48-hr and 72-hr for extreme flooding events.

B – SEDIMENTATION ESTIMATION

B1.   Sediment loads

A large proportion of suspended and bed load transported by the Nam Ngiep river networks rivers are expected to deposit within the reservoir. Suspended Load (SL) is the portion of the sediment that is carried in the body of the flow with sufficiently velocity that it remains predominately entrained in the water column. SL (kg/s) was computed in VMOD model based on runoff of the catchment. Bed Load (BL) consists of the larger sized sediments which cannot be maintained in suspension by turbulent forces in the water column and are mobilised by saltation. Unlike suspended sediments, bed load can take many hydrological seasons to migrate downstream accumulating in the riv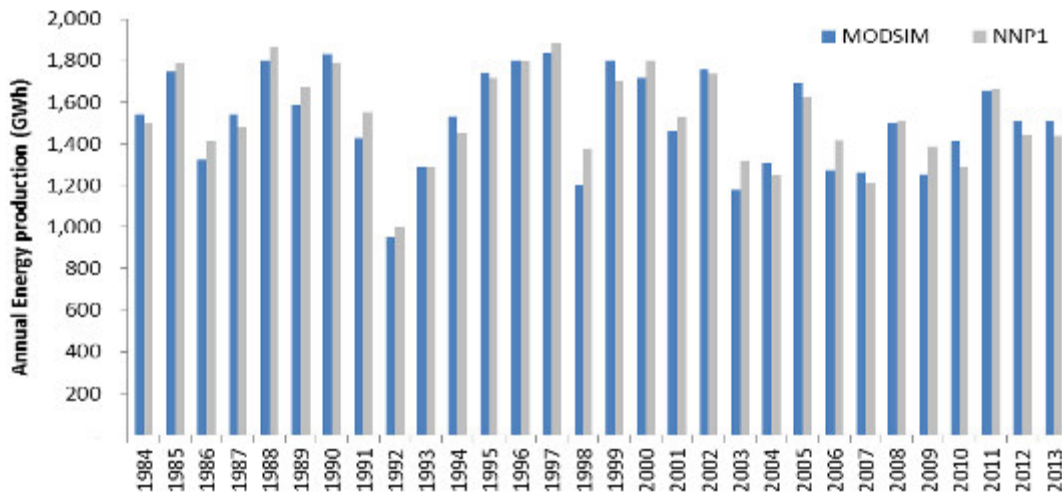er channel and then moving downstream in large discrete movements under peak or extreme flow conditions. Because of the dynamics of bed load transport and lack of monitoring data, it is difficult to model BL transport. Thus in this study, an empirically-derived relationship for bed load which estimated bed load as being 20% of the total suspended load was used. Total sediment load to the reservoir is the sum of suspended load and bed load assuming its specific gravity is 1,300kg/m^3.

B2.   Sedimentation in the reservoir

The amount of sediment deposited within the reservoir depends primarily on the amount of sediment inflow, the type of sediments and the reservoirs geometry. The most informative description for reservoir

sedimentation estimation is trap efficiency. Trap efficiency equations from Gill (1979) have been used for this study.

Median Curve for Medium Sediments Morris and Wiggert (1972):

$$T_e = \frac{\left(\frac{C}{I}\right)}{\left[0.012 + 1.02\left(\frac{C}{I}\right)\right]}$$

Where T_e is trap efficiency, C/I is capacity inflow ratio (C is volume of the reservoir, I is the flow/discharge rate).

The result shows that 95-96% sediment load will be trapped in the reservoir.

With the relationship between sedimentation rates T_e, specific weight of sediment deposited, the sedimentation volume in the reservoir for a given period Δt was estimated using the following equation:

$$\Delta S = \frac{GT_e \Delta t}{\gamma}$$

Where, ΔS is sedimentation volume, G is characteristic weight of annual sediment inflow, Δt is a short interval of time in years and γ is specific weight of sediment deposited. The specific weight was assumed to be equal to 1,300kg/m^3 for the study. As the project life time is 50 years, therefore Δt was set at 50 years to calculate accumulated sedimentation in the reservoir after 50 years.

C – DAM BREAK ANALYSIS

The hydraulics of dam break and the propagation of its flood wave to the downstream is extremely complex. The cause of NNP2 dam failure is not the focus of this study. This study assumes the worst scenario as the NNP2 dam breaks completely, the whole contents of NNP2 reservoir will spill downstream into NNP1 reservoir. For analysis, NNP2 dam break can be treated like weir system. Therefore discharge out of NNP2 reservoir is calculated using Bazin's formula.

$$Q = \mu LH\sqrt{(2gH)}$$

Where Q is the volume discharge per unit of time, μ is empirical coefficient (in this case 0.3 was used), L is the length of crest of the dam, H is the head different between water behind the dam and water in front of the dam, g is acceleration by gravity.

Using this equation, discharge rate and volume for every second after the dam break is calculated. After 24 hours, most of NNP2 volume has released downstream.

The result from VMOD model indicates that average discharge velocity within the reach from NNP2 dam to NNP1 reservoir is 3 m/s with the peak flood at 9m/s. Assuming discharge velocity from NNP2 dam to NNP1 in the dam breaking scenario is equal to the peak flood which mean it will take 52 minutes for the water wave from NNP2 to reach NNP1 reservoir given the distance between NNP2 dam to NNP1 reservoir is approximate 28km (28,000/9 = 3,111 second ≈ 52 minutes). As the water flows into the reservoir of 60 km long and flat at its normal operation level of 320m, this dam-break water would move as a slowly rising water level, rather than a breaking wave within NNP1 reservoir. To estimate water level rise in NNP1 reservoir 24 hours after NNP2 dam break, the follow assumptions have been applied:

- Constant flow from NNP1 catchment at 173.53m^3/s into the reservoir in addition of the inflow from NNP2 dam break

- The spillway will fully open when the flood wave arrives to the reservoir and close when water in the reservoir drawn down to NOL

- Time step for the calculation is 1 hour

Using the same approach which used by NNP1 in calculating discharge out of the reservoir during PMF event, discharge from the spillway for each hour after the NNP2 dam break is calculated using the following equation:

$$V_{sp} = nC'BH^{3/2}$$

Where V_{sp} is outflow volume discharge from the spillway, n is the number of spillways, C' is the discharge coefficient which various with different level of water in the reservoir, B is the width of overflow crest, H is the height different between water level in the reservoir and the height of the spillway. Therefore, volume of water remains in the reservoir every hour is:

$$V = V_{in} - V_{sp}$$

Where V_{in} is inflow volume from NNP1 catchment and NNP2 floodwave, V_{sp} is outflow volume discharge from the spillway, and V is the volume remain in the reservoir. Reservoir water level was estimated based on V and the volume curve below.
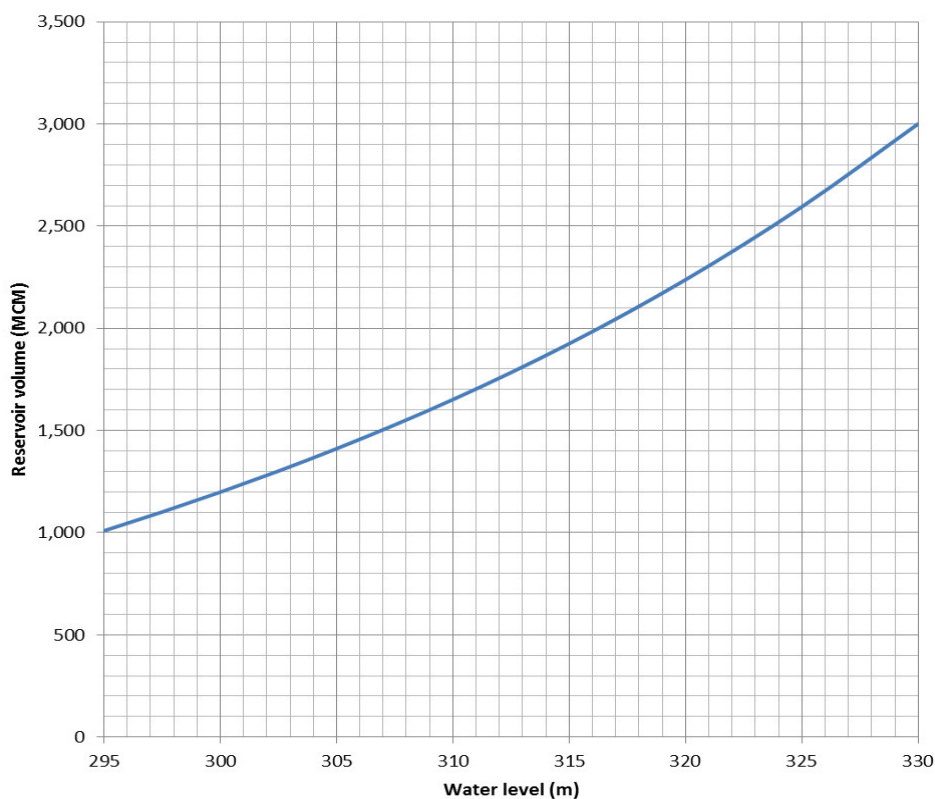
Figure 76: Volume and water level relationship curve for NNP1 reservoir

The computed results are shown in the table below.

Time (hr)	Inflow (m³/s)	V (MCM)	Water level (m)	V_{sp} (MCM)
0	173.53	2,238,455	320.00	5,257
1	173.53	2,220,153	320.00	5,170
2	24779.66	2,290,747	320.00	5,501
3	10250.56	2,307,847	320.49	5,734

4	3986.44	2,301,554	320.73	5,782
5	2014.15	2,287,990	320.64	5,687
6	1200.20	2,271,837	320.44	5,548
7	803.98	2,254,758	320.20	5,394
8	588.22	2,237,458	320.00	5,251
9	460.75	2,220,212	320.00	5,170
10	380.64	2,202,970	320.00	5,089
11	327.77	2,185,828	320.00	5,009
12	291.48	2,168,845	320.00	4,929
13	265.74	2,152,057	320.00	4,850
14	246.98	2,135,486	320.00	4,772
15	232.98	2,119,144	320.00	4,696
16	222.33	2,103,041	320.00	4,620
17	214.08	2,087,180	320.00	4,545
18	207.59	2,071,563	320.00	4,472
19	202.41	2,056,192	320.00	4,400
20	198.23	2,041,066	320.00	4,329
21	194.82	2,026,182	320.00	4,259
22	192.01	2,011,540	320.00	4,191
23	189.68	1,997,135	320.00	4,124
24	187.72	1,982,966	320.00	4,058

D – SENSITIVITY OF ELECTRICITY PRODUCTION TO VARIATIONS IN PRECIPITATION DATA

D1. Hydrological of the basin from various precipitation data

NNP1PC used low flow analysis to estimate their annual energy production. The low flow analysis has been done by estimating basin mean precipitation from observed data available within and outside of the basin. Only 5 years of observed precipitation data was available for the 3 stations inside the basin, therefore Kansai have applied the Thiessen method by using precipitation data from peripheral sites to calculate basin mean precipitation where long-term data is available i.e. from 1971 to 2000. Data from the 3 inside stations also have been used to calibrate and adjust mean precipitation calculation. The annual basin mean precipitation was estimated at 1,870mm.

Discharges to NNP1 reservoir was calculated by applying Tank model method using the basin mean precipitation data. This method calculates runoff using different infiltration levels with assumptions at each tank level as seen in Figure 77. The tank output was calibrate and adjusted based on 14 year observed flow data at Muong Mai station (1998-2011) and over 2 year observed flow data at Ban Hat Gnium (from September 1998 to December 2000). As the result, annual mean flow of the basin is estimated at 148.4 m^3/s.

Using a different approach, ICEM has used observed precipitation data (1971-2013) from four stations within the basin (Xiengkhouang, Thaviang station, Hat Gnium, and Paksan station) to estimate precipitation distribution within the basin. Observed data were input into VMod model where it precipitation was computed based on the terrain. The results indicated that the computed annual precipitation in the middle of the catchment is 2,053 mm. Discharge to NNP1 was computed using the distribution of precipitation throughout the NNP1 catchment as described in the previous section. The annual mean flow to NNP1 reservoir in this case is 138.9 m^3/s which is 6% different from the NNP1 report.
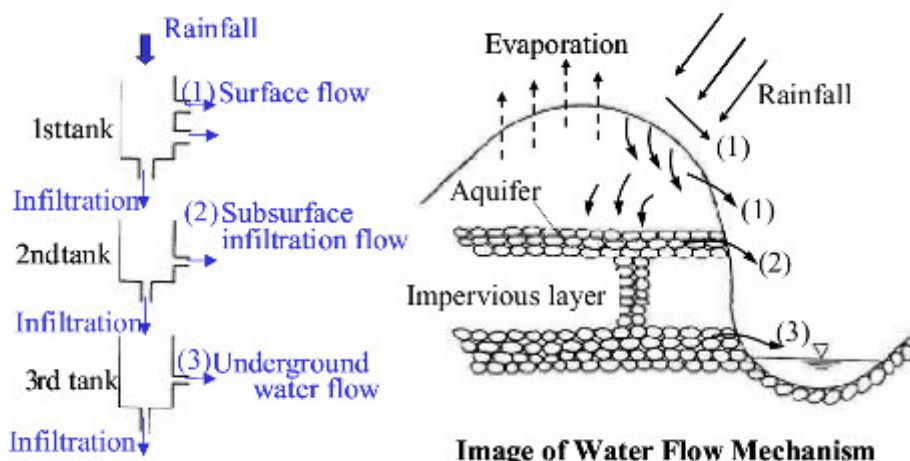
Figure 77: Tank model method *(Source: NNP1 Technical report)*

Although there is only 6% difference in annual mean flow to NNP1 reservoir, the different between the two computed results in the dry season is significant. Figure 78 shows Kansai estimated discharge to NNP1 reservoir in the dry season is 1.6 times higher than our estimated discharge while in the wet season, it is 2% less than ICEM estimated data. These different would lead to the change in energy production estimated using to different methods.

Figure 78: ICEM and Kansai estimated m

D2.   *Energy production estin*

NNP1 has calculated energy pro
has used a MODSIM model wh
section, the two methods give s
same data set. Therefore the different in energy production between NNP1 and ICEM estimation is mainly resulting from the two different computed discharge datasets. As seen from the figure and table below, there is a significant decrease in the energy production (both PE and SE) in the dry season.

In the dry season, average PE production estimated by ICEM is 5% less than estimated production by Kansai; while in the wet season; average PE production estimated by ICEM is 1% less than the estimation from Kansai. Annual average SE production estimated by ICEM is also 16% less than the estimation from Kansai. These result from the 60% and 2% decrease of discharges in the dry and wet season respectively of the two datasets. Overall, the annual mean energy production estimated by ICEM is 5% reduction from Kansai's estimation.
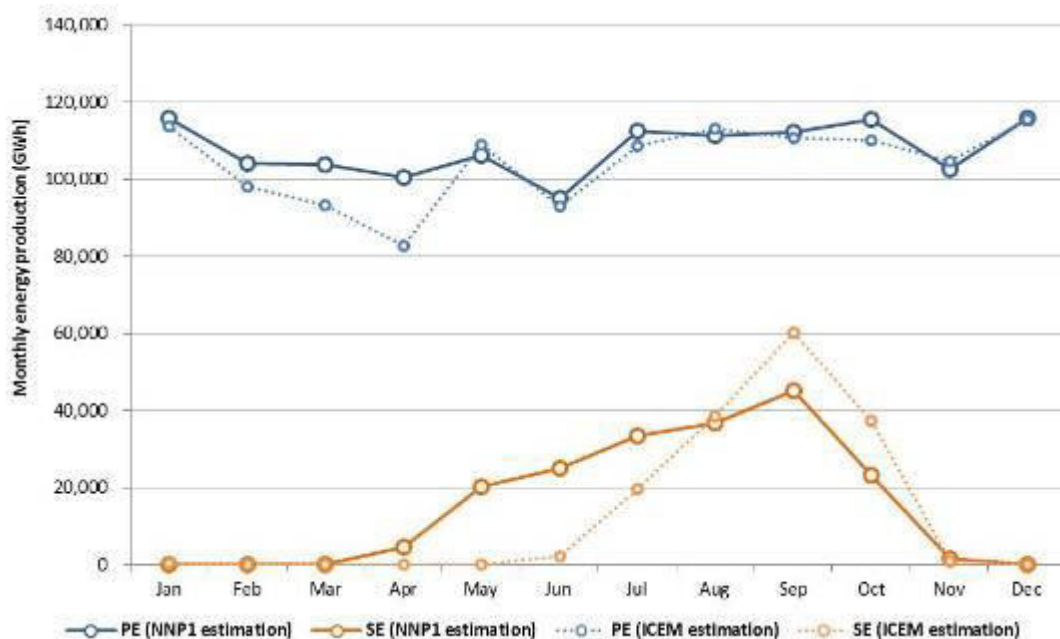
Figure 79: ICEM and Kansai estimated monthly mean PE and SE production

Table 14 – Comparison between NNP1 estimated and ICEM modelled results for energy production

Year	NNP1 calculation	ICEM calculation
1998	1,377.71	1,180.08
1999	1,701.88	1,331.72
2000	1,799.77	1,623.21
2001	1,524.88	1,447.26
2002	1,735.87	1,515.44
2003	1,316.13	1,332.69
2004	1,245.83	1,111.39
2005	1,628.67	1,415.73
2006	1,418.13	1,539.72
2007	1,212.32	1,270.85
2008	1,514.11	1,559.37
2009	1,387.96	1,439.56
2010	1,290.42	1,330.10
2011	1,661.42	1,682.39
Average	**1,486.79**	**1,412.82**

With various rainfall datasets and methods for calculating runoff, energy productions are expected to increase or decrease depending on available water within the basin. Given that there were only 14 years of data to work with, longer period of data would be better for comparison between the two approach methods.

ANNEX III: CAM DETAILS

AQUATIC ECOSYSTEM

Aquatic Ecosystem					
THREAT					**IMPACT**
Change and shift in regular climate	*Written description of the threat*	Exposure	Sensitivity	Impact	*Written explanation of what the impact is and reasons for score*
Temperature	i. Under CC, average air temperature of the catchment would increase by 2.1°C in the dry season and 1.6°C in the wet season ii. Maximum daily temperature would reach 44°C (in April) iii. 66% of the year the maximum daily temperature is over 34°C which is 26% increase compare with the baseline maximum temperature	H[21] 22	L[23]	M	The oxygen content of the reservoir water is essential for ensuring the water quality and the necessary environmental conditions for aquatic life. An increase of the air temperature would lead to an increase of the water temperature in the upper layers which would result into a strengthened stratification of the reservoir water, i.e. a raise in the hypolimnion, a more stable thermocline. This would lead mainly to a drastic reduction of Dissolved Oxygen (DO) in the water which could increase the chances of fish kill, odour and deterioration in downstream water quality due to the anoxic water. It is likely that stratification will increase in the dry season when temperatures are highest, and that if overturn of thermocline is going to occur it will be at the start of the rainy season when colder water will be running off into the top end of the reservoir. However, the shape of the reservoir is such that wind action cannot be effective along the full length of the reservoir, this may reduce the risk of full over turn throughout the lake.

---

[21] Reservoir exposed to dramatic increase of sustained high temperatures with significant increase of portion of the year with temperatures above 34 0C (from less than half to2/3). It is expected that the water temperature will rise in response to sustained higher temperatures rather than to occasional hotter days. Frequency rather than magnitude.
[22] Water temperature also depends upon the degree of insolation. It is not clear whether under climate change we will have more clear days, when insolation is greater. If we have more cloudy days then the importance of insolation in heating the water will be less
[23] Intake structure is high

Aquatic Ecosystem					
THREAT		IMPACT			
Change and shift in regular climate	*Written description of the threat*	Exposure	Sensitivity	Impact	*Written explanation of what the impact is and reasons for score*
					With a high intake, the risks of taking in low quality water are reduced under normal operation, and the risks of full overturn are also low.

ENERGY SUPPLY – EFFICIENCY OF GENERATION AND TRANSMISSION

Energy supply – Efficiency on generation and transmission					
THREAT					*IMPACT*
Change and shift in regular climate	*Written description of the threat*	Exposure	Sensitivity	Impact	*Written explanation of what the impact is and reasons for score*
Temperature	i. Under CC, average air temperature of the catchment would increase by 2.1^{o}C in the dry season and 1.6^{o}C in the wet season ii. Maximum daily temperature would reach 44°C iii. 66% of the year the maximum daily temperature is over 34°C which is 26% increase compare with the baseline maximum temperature	L	VL	VL	The expected higher air temperatures and air humidity could affect the cables of the transmission lines delivering the energy to the substations. The threat of increased temperatures would affect the conductivity along the cables and lead to an increased Corona effect at the insulators. Consequently, the incoming power at Nabong for export to Thailand could be less than envisioned due to these distributed losses. The change in energy relative to the turbinated flow can be evaluated by looking at how the water density is affected by an increase in temperature. The rated output of 272 MW expected at the substation will be decreased by 0.042% due to the transmission changes and by 0.066% due to the turbines.

CATCHMENT SOIL COVER

Catchment soil cover					
THREAT					IMPACT
Change and shift in regular climate	*Written description of the threat*	Exposure	Sensitivity	Impact	*Written explanation of what the impact is and reasons for score*
Precipitation intensity	i. Annual mean precipitation for the whole catchment is estimated at 2,053mm. With CC, precipitation would likely to be increased by 17.8%. ii. Maximum daily precipitation would increase by 6.7% at 160mm. iii. The number of event that daily precipitation is over 100mm would be triple under CC	L	H[24]	M	The contributing catchment is not often considered an asset for a hydropower plant, however, the soil and vegetative cover of a catchment is a fundamental factor in determining the quotas of rainfall which either infiltrate the ground, evaporate or runoff towards the reservoir as well as the rates of soil erosion on the hillslopes. An intensification of the storm events and also the increase in their frequency threatens to enhance hillslope erosion through the washing away of the finer soil material inhibiting water infiltration and causing eventually slope instability and consequently forest cover loss. Parts of the Nam Ngiep catchment are mountainous presenting steep slopes sensitive to such intense rainfall events. - With climate change, erosion will increase of between 2-4% in the West of the lower catchment reaching the annual value of 1.8 kg/m^2 sediment yield within the catchment will likely to be of 698 tonnes/ km^2/ year which is triple the current load at the rate. This will have significant implications for the storage capacity of the reservoir (see storage capacity).

[24] The Nam Ngiep catchment is highly sensitive to soil erosion. Sensitivity is likely to increase with steep hillside cultivation.

STORAGE CAPACITY

Storage capacity					
THREAT					**IMPACT**
Change and shift in regular climate	*Written description of the threat*	Exposure	Sensitivity	Impact	*Written explanation of what the impact is and reasons for score*
Precipitation intensity	i. Annual mean precipitation for the whole catchment is estimated at 2,053mm. With CC, precipitation would likely to be increased by 17.8%. ii. Maximum daily precipitation would increase by 6.7% at 160mm. iii. The number of event that daily precipitation is over 100mm would be triple under CC iv. In the dry season, in 2050, precipitation of the upper catchment is 300 mm which is 13-14% more than its current precipitation, while precipitation of the lower catchment is about 350mm which corresponds to a 6-10% increase v. The mean is set at 186mm for the dry season. With climate change, this mean precipitation would increase by 10%	H[25]	L[26]	M	During dry seasons instead, the siltation of the reservoir would lead to a decreased power production due to the less water availability. However based on our calculation: - BL: Sedimentation volume of the reservoir is 38.6 MCM after 50 years of operation, the life time of the project. This estimated volume is only 3.7% of the reservoir's dead storage volume and 1.7% of the reservoir's storage capacity. - CC: Sedimentation volume within the reservoir after 50 year would be 89.5 MCM which is 8.5% of the reservoir's dead storage volume and 4% of the reservoir's storage capacity - The loss of active storage capacity is likely to take place at the top end of the reservoir as a delta forms where the rivers flow into the reservoir.

[25] The exposure of increased precipitation leading to increased soil erosion and the consequent sedimentation is high as explained in the previous section
[26] The sensitivity to this increased sedimentation is likely to be low because the dead storage capacity is quite large (1040 MCM)

Storage capacity					
THREAT					**IMPACT**
Change and shift in regular climate	*Written description of the threat*	Exposure	Sensitivity	Impact	*Written explanation of what the impact is and reasons for score*
Design Flood	i. The likelihood of occurrence of the baseline 100-year flood could increase, becoming a flood with a 19-year return period for average climate change scenario or a 10.5-year return period for extreme climate change scenario ii. the average of all climate change scenarios, the 1000-year flood discharge is 4,348m^3/s which is still 14.7% less than the designed flood discharge iii. In the worst case of climate change scenario, the 1000-year flood discharge would reach 5,562m^3/s which is higher than the designed flood discharge	H[27]	M[28]	M	A change in the intensity of the storm events could lead to an increased sediment runoff from the catchment. In reaching the reservoir, stream power would reduce dramatically causing the larger sediment fractions to deposit and contribute to the progressive siltation of the active storage zone of the reservoir. This would entail a loss in the regulation capacity of the reservoir during big flood events.

---

[27] The exposure here is High, because there is a significant increase in the frequency of the return period maximum flood.
[28] The sensitivity of the system to this is related to the increased loss of active storage capacity

ENERGY PRODUCTION

Energy production					
THREAT					**IMPACT**
Change and shift in regular climate	***Written description of the threat***	Exposure	Sensitivity	Impact	***Written explanation of what the impact is and reasons for score***
Precipitation magnitude	i. In the dry season, in 2050, precipitation of the upper catchment is 300 mm which is 13-14% more than its current precipitation, while precipitation of the lower catchment is about 350mm which corresponds to a 6-10% increase ii. The mean is set at 186mm for the dry season. With climate change, this mean precipitation would increase by 10% i. Precipitation in the wet season also increase by 19%	H	H	H	- Under CC, annual energy production would likely to be increased by 12%, from 1,413GWh to 1,585GWh - Energy production in the dry and wet season would likely to be increased by 7% and 16% respectively An expected change in the precipitation regime could represent a threat to power production. The active storage of the main reservoir is too small to accommodate large variations in flow and therefore to keep production constant and unaffected by precipitation. A year-round increase in precipitation will imply an increase of water availability in general. Extreme dry years will have an earlier onset of the monsoon (wet season) and will last longer. The energy production will therefore be strengthened as the number of days of the turbines operating at the full capacity will rise. During wet years the inflows may exceed the turbines' capacity and therefore entail higher spillage volumes.

Energy production					
THREAT					**IMPACT**
Change and shift in regular climate	*Written description of the threat*	Exposure	Sensitivity	Impact	*Written explanation of what the impact is and reasons for score*
Precipitation intensity	ii. Annual mean precipitation for the whole catchment is estimated at 2,053mm. With CC, precipitation would likely to be increased by 17.8%. iii. Maximum daily precipitation would increase by 6.7% at 160mm. iv. The number of event that daily precipitation is over 100mm would be triple under CC v. With climate change, erosion will increase of between 2-4% in the West of the lower catchment reaching the annual value of 1.8 kg/m2 vi. sediment yield within the catchment will likely to be triple the current load at the rate of 698 tonnes/ km2/ year vii. Sedimentation volume within the reservoir after 50 year would be 91 MCM which is 8.8% of the reservoir's dead storage volume and 4.1% of the reservoir's storage	H[29]	L[30]	M	Energy production decrease due to sediment filling up and reduced active storage volume of the reservoir. The loss of active storage means a loss of flexibility in the use of that water during dry season months. It does not matter so much in the wet season. The economic implication of this is the loss of potential peak power production during the dry season.

[29] Exposure is high because the significant increase in precipitation intensity and erosion
[30] Sensitivity is low because the volume of active storage taken up is relatively small in 50 years

Energy production					
THREAT					**IMPACT**
Change and shift in regular climate	**Written description of the threat**	**Exposure**	**Sensitivity**	**Impact**	**Written explanation of what the impact is and reasons for score**
	capacity				
Design Flood	i. The likelihood of occurrence of the baseline 100-year flood could increase, becoming a flood with a 19-year return period for average climate change scenario or a 10.5-year return period for extreme climate change scenario ii. the average of all climate change scenarios, the 1000-year flood discharge is 4,348m3/s which is still 14.7% less than the designed flood discharge iii. In the worst case of climate change	H[31]	M	H	An increase in the probable maximum flood can affect the energy production: in case of an overtopping of the dam or filling up of the re-regulation pond, the inundation or flooding from backwater of the powerhouse would take place which would result into the power outage of the plant and consequently into a loss of income.

---

[31] The exposure is High, because there is a significant increase in the frequency of the return period maximum flood.

Energy production					
THREAT		**IMPACT**			
Change and shift in regular climate	*Written description of the threat*	Exposure	Sensitivity	Impact	*Written explanation of what the impact is and reasons for score*
	scenario, the 1000-year flood discharge would reach 5,562m3/s which is higher than the designed flood discharge				

SPILLWAY

Spillway					
THREAT					**IMPACT**
Change and shift in regular climate	***Written description of the threat***	Exposure	Sensitivity	Impact	***Written explanation of what the impact is and reasons for score***
Precipitation magnitude	i. In the dry season, in 2050, precipitation of the upper catchment is 300 mm which is 13-14% more than its current precipitation, while precipitation of the lower catchment is about 350mm which corresponds to a 6-10% increase ii. Precipitation in the wet season also increase by 19%	H	M[32]	H	- Under CC, the reservoir, on average, would spill 17% of its water content. It would spill 5% of its water content under operational baseline conditions - Daily maximum spillage over 14 years of modelling would be 2,253m^3/s under CC while the baseline condition is only 1,374m^3/s An increase in the precipitation magnitude entails for a higher spillway use rate during the year. The higher use of the gates and spillways would result in an increase of erosion leading to the necessity to do more maintenance. All the same, the increased spillage use will affect energy production in the sense that water spilled is a loss of water potentially destined to power generation.

---

[32] The sensitivity of the system shows that the spillway use would increase from 3% (baseline) to 13% (climate change) of water volume

Design Flood	i. the average of all climate change scenarios, the 1000-year flood discharge is 4,348m3/s which is still 14.7% less than the designed flood discharge ii. In the worst case of climate change scenario, the 1000-year flood discharge would reach 5,562m3/s which is higher than the designed flood discharge	VL	H	L	An increase of the probable maximum flood could result into the overtopping of the dam. This event would damage the spillway structures and the gates. It should be noted that increased use of spillways may lead to malfunction of one or more of the gates which may then lead to overtopping during a maximum flood.

MAIN POWERHOUSE

Main powerhouse					
THREAT					**IMPACT**
Change and shift in regular climate	***Written description of the threat***	**Exposure**	**Sensitivity**	**Impact**	***Written explanation of what the impact is and reasons for score***
Probable Maximum Flood	i. the average of all climate change scenarios, the 1000-year flood discharge is 4,348m3/s which is still 14.7% less than the designed flood discharge ii. In the worst case of climate change scenario, the 1000-year flood discharge would reach 5,562m3/s which is higher than the designed flood discharge	L	H	M	In case of an increase of a major flood event and therefore in the potential case of the overtopping of the dam because of spillway inadequacy to such discharges, the steep canyon configuration could lead to the creation of a concentrated flow of overtopping water hitting the powerhouse and damaging the structure itself, the penstock protection and the control room. The value of 5,562 m3/s is higher than the design flood but the spillway itself is designed to discharge up to 9,000 m3/s without a rise in the level higher than the parapet wall along the crest of the dam. In such worst climate change case scenario of a flood discharge of 5,562 m^3/s, the water levels reached in the re-regulation dam would not exceed the 193 m.a.s.l., the elevation of the floor of the powerhouse. In fact, the level in the reservoir in the proximity of the main dam with such discharge is of 192.6 m.a.s.l., and the associated discharge to the level of 193 m.a.s.l. is of 5,800 m^3/s. The system is able to attenuate the incoming probable maximum flood, even in a situation of a completely full reservoir during the wet season or full operating mode.

SADDLE DAM

Saddle dam					
THREAT					**IMPACT**
Change and shift in regular climate	*Written description of the threat*	Exposure	Sensitivity	Impact	*Written explanation of what the impact is and reasons for score*
Probable Maximum Flood	i. Average PMF of the modelled climate change scenarios is 9,350m³/s and PMF under high climate change scenario is 11,985m³/s ii. PMF under high climate change scenario is 30% higher than the current NNP1's estimated PMF	H	M	H	The saddle dam is placed on the right bank of the Nam Ngiep River to protect a low elevation area which could have once been the original course of the river. The threat of increased flood intensity would put the system under stress since the river is likely to re-open its bifurcation channel. With climate change these releases will exceed 7,000m³/s for a period of 20hours during the peak in the PMF hydrograph, re-regulation reservoir water levels could reach 0.55m below the max crest elevation of the saddle dam which would not result in over-topping and posing a risk of failure for the earth-filled saddle dam

RESETTLEMENT AREA

Resettlement area – cultivation					
THREAT					IMPACT
Change and shift in regular climate	*Written description of the threat*	Exposure	Sensitivity	Impact	*Written explanation of what the impact is and reasons for score*
Temperature	i. The annual mean temperature is 28 °C ii. The mean daily maximum temperature with climate change will be of 34.7 °C iii. For rice the growing cycle temperature is 28.5 °C, second month temperature is 29 °C, average daily maximum temperature of warmest month is 36.7 °C and average daily minimum temperature of coldest month is 17.5 °C	L	L	L	Rice and rubber: Overall conditions in 2050 will still be optimal for the cultivations intended for the resettlement area, with each of the parameters chosen for the impact assessment remaining within suitability. The parameters and their ranges are taken from the Mekong ARCC, project in which the Land Use Evaluation Tool (LUSET) model developed by IRRI (CGIAR-CSI 2006) was used. The parameters for temperature are the following. RICE : growing cycle temperature, second month temperature, average daily maximum temperature of warmest month, average daily minimum temperature of coldest month RUBBER: mean daily maximum temperature and mean temperature

Resettlement area – cultivation					
THREAT					**IMPACT**
Change and shift in regular climate	*Written description of the threat*	Exposure	Sensitivity	Impact	*Written explanation of what the impact is and reasons for score*
Precipitation	i. Annual mean precipitation for the resettlement area is estimated at 2,380mm. ii. Rainfall in the first months for upland rice cultivation (May and June) is 278 mm iii. Rainfall in the ripening stage for rice (October to December) is 116 mm	L	L	L	Rice and rubber: Overall conditions in 2050 will still be optimal for the cultivations intended for the resettlement area, with each of the parameters chosen for the impact assessment remaining within suitability. The parameters and their ranges are taken from the Mekong ARCC, project in which the Land Use Evaluation Tool (LUSET) model developed by IRRI (CGIAR-CSI 2006) was used. The parameters for precipitation are the following. RICE : rainfall in the first months, rainfall in ripening stage. RUBBER: annual rainfall.
Flood	i. Average PMF of the modelled climate change scenarios is 9,350m^3/s and PMF under high climate change scenario is 11,985m^3/s ii. PMF under high climate change scenario is 30% higher than the current NNP1's estimated PMF	H	L	M	Under high CC, a maximum spillway discharge at the main dam is 7,597m^3/s leading to the rising of WL up 0.55m below the current maximum crest elevation of the saddle dam. Water will therefore not over top the saddle dam nor routing flood flows over the agricultural lands of the resettled communities.

ANNEX IV: SENSITIVITY ASSESSMENT OF THE PMF TO CLIMATE CHANGE

A – PROBABLE FLOOD DISCHARGE AND PROBABLE MAXIMUM FLOOD

Probable Maximum Flood (PMF) is the flood hydrograph resulting from the Probable Maximum Precipitation (PMP) coupled with the worst flood producing catchment conditions that can be realistically expected in the prevailing meteorological condition (Novak. P et al, 2007). PMF estimation is one of the most important tasks in dam design, the dam should be designed to cope with PMF event.

NNP1 has estimate the Probable Maximum Flood (PMF) based on the following estimations:

- Probable Maximum Precipitation (PMP) was calculated using long term observed rainfall data (1972-2011) at Paksan station located 50 km downstream of the dam site,

- Rainfall intensity curve was derived from observed data at Thaviang station during August 1998 – December 2000 and September 2007-December 2009. This station is located at the centre of Nam Ngiep Basin,

- Runoff coefficient was estimated using land use of Nam Ngiep basin.

Unit hydrograph method (modified by Snyder equation) was applied to estimate PMF, details of the estimation can be found in NNP1 Technical report. PMF for the project was estimated at 8,980 m^3/s. The blue line on Figure 80 shows PMF and flood discharges for return period using unit hydrograph method. The red line on Figure 80 shows Probable flood discharge which has been calculated using observed discharge data at Muong Mai station 20 km downstream of the dam site. Figure 80 also demonstrate that Probable flood discharge and PMF using different estimation methods have shown similar results for flood discharges. Thus there is relation between Probable flood discharge and PMF.
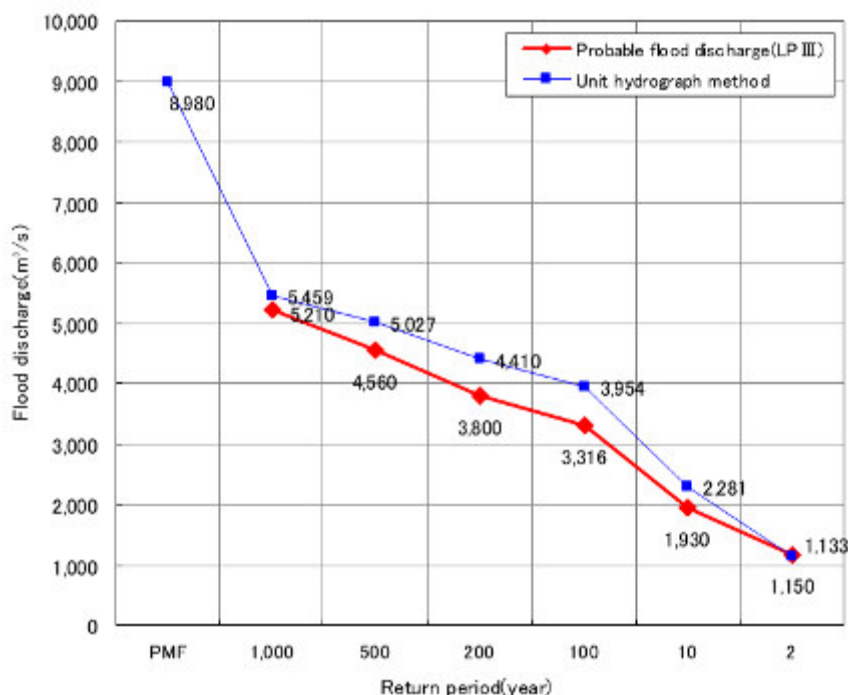

Figure 80: Probable flood discharge and PMF *(Source: NNP1 Technical report)*

B – PROBABLE MAXIMUM FLOOD FOR CLIMATE CHANGE

NNP1 has calculated PMF using well established methods which provided an estimate of the baseline PMF magnitude and also established a relationship between the baseline PMF and the baseline design flood.

ICEM explored the possibility of replicating this method using future climate change simulated data, however there were two technical factors which hindered this approach. First resources were not available for new CC downscaling and it was requested by NNP1PC that ICEM use the existing downscaled data we developed as part of the Mekong ARCC work. This set of existing data did not give any projections for sub-daily rainfall data – i.e. it does not provide new estimates for rainfall intensity, which is one of the key input requirements for PMP estimation. Without updating the rainfall intensity data for the CC scenario, recalculating the PMP was considered not appropriate. Second, both the baseline and future CC projections time series are short. The combination of both of these factors meant that a thorough recalculation of the PMP and PMF would be applying a methodology much more accurate than the input data available.

Instead the ICEM approach was to utilise two methodologies that develop relationships between the design flood and the PMF and to scale the PMF based on how the CC-design flood (1,000 year flood) changed in relation to the baseline design flood, using the following formula:

$$Q(ccpmf) = Q(bpmf) \text{ X } (Qccdf/Qbdf)$$

> *Q(ccpmf) = climate change PMF*
> *Q(bpmf) = baseline PMF*
> *Q(ccdf) = CC design flood*
> *Q(ccbdf) = baseline design flood*

This approach looks at the relative change in the PMF event based on the best available information on the relative change CC is inducing on baseline data.

Method 1 – recalculating the PMF with revised input data and no conversion factor

The hydrology of NNP1 catchment has been calculated using various precipitation data, with explanations on that data and methods used included in Annex II Section D. This results in different value for Probable flood discharge as shown in Figure 81. Due to the baseline discharges from VMOD model are smaller than discharges from NNP1 estimation, average 1,000-year flood under CC will be as high as the 1000-year flood estimated by NNP1 and 17% less than the design flood of the project. However 1000-year flood under high CC scenario will be 5,562 m^3/s which is 7% higher than the design flood.
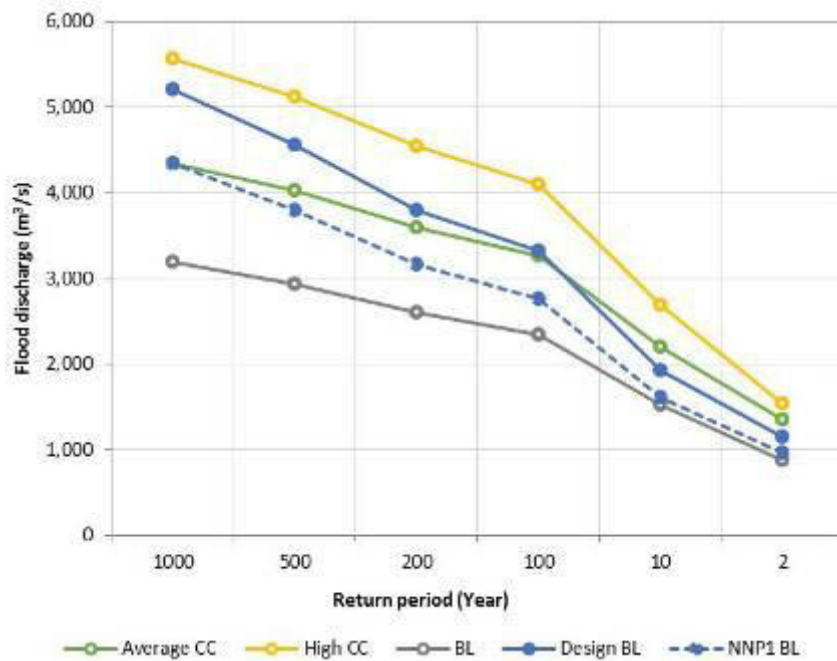
Figure 81: Probable flood discharge for various precipitation data: *NNP1 BL line represents probable flood discharge which is calculated by using rainfall data from Muong Mai station; Design BL line represents probable flood discharge which is calculated from NNP1 BL multiply with 1.2 safety factor; BL line represents the baseline Probable flood discharge that is calculated using VMOD model; Average CC and High CC lines represent average probable flood discharge for the six climate change scenarios and probable flood discharge for high climate change scenario (these were calculated using VMOD model)*

Because of the clear relationship between Probable flood discharge and PMF as established by NNP1PC (Figure 80), the PMF could was re-calculated using Probable flood discharge under climate change, based on the assumption that the change in PMF under climate change would be related to the change in flood discharge. In this case, 1,000-year flood discharge has been selected to estimate PMF. Thus the following equation was used:

$$Q_{CC-PMF} = Q_{PMF} \times (Q_{CC-1000}/Q_{1000})$$

Where Q_{CC-PMF} is PMF under climate change, Q_{PMF} is the current PMF, $Q_{CC-1000}$ is 1000-year flood discharge under climate change, and Q_{1000} is the current 1000-year flood discharge.

Figure 82 shows the correlation between Probable flood discharges estimated for average and high CC scenarios and the NNP1 Unit hygrograph results (from 2-year to 1000-year flood discharges). Thus, Q_{CC-PMF} can be calculated from Q_{PMF} = 8,980 m³/s, $Q_{CC-1000}$ = 5,562 or 4,348 m³/s, and Q_{1000} = is 5,459 m³/s (1000-year flood discharge estimated using unit hydrograph method).

The results show that with average PMF for all climate change scenarios is 12,132 m³/s which is 34% higher than the current PMF; and PMF under high climate change scenario is 15,520 m³/s which is 71% higher than the current PMF.
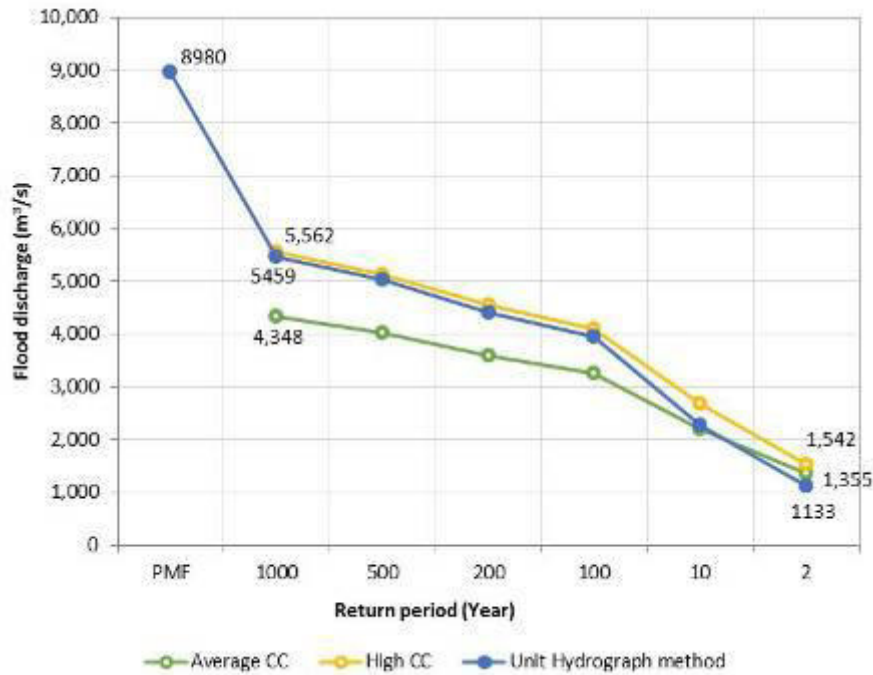
Figure 82: Climate change Probable Flood discharges and the current PMF

Method 2- estimating the PMF based on established literature relationships between the 1 in 10,000year event and the PMF

Method 1 above, is a simple linear scaling approach that links the 1 in 1,000-year event with the PMF event, based only on data from one catchment. This approach is not commonly used in hydrological risk analysis. More common – especially for infrastructure design – are attempts to find correlation between the PMF and the 1 in 10,000-year event, which has resulted in a common rule of thumb that the PMF is generally in the order of twice the 10,000-year flood (Zhou et al, 2008).

Zhou et al (2008) derived a theoretical relationship between the 10,000-year and the PMF event applicable for the Gumbel and Generalized Extreme Value Distributions. The approach draws on Hershfield's procedure for estimating the PMP (1961) which can be expressed as:

$$P_{pmp} = P_{max} + K_{pmp} \; x \; S$$

Where:

P_{pmp} is the PMP estimate,

P_{max} is the mean annual rainfall maxima for a given time-series,

S is the standard deviation of that time-series, and

K_{pmp} is the Hershfield frequency factor for the PMP.

This equation is combined with a frequency factor formula used in the frequency analysis of extreme storms as developed by Chow (1951) and given by:

$$P_{10,000} = P_{max} + K_{10,000} \; x \; S$$

Where:

P_{max} is the mean annual rainfall maxima for a given time-series,

S is the standard deviation of that time-series, and

$K_{10,000}$ is the frequency factor for the 10,000 year event

Dividing the two equations and substituting the coefficient of variation as, $C_v = \dfrac{S}{P_{max}}$ gives the following ratio:

$$Ratio = \frac{P_{pmp}}{P_{10,000}} = \frac{P_{max} + K_{pmp} \; x \; S}{P_{max} + K_{10,000} \; x \; S} = \frac{1 + K_{pmp} \; x \; C_v}{1 + K_{10,000} \; x \; C_v}$$

With $P_{10,000}$ and $K_{10,000}$ calculated with formula specific to the specific distribution used in the frequency analysis. A full description of the methodology can be found in Zhou et al (2008), the main conclusions relevant to the project are:

- K_{pmp} typically varies between 13 – 19 and should be less than 15 for very wet catchments or catchments where rainfall event duration was less than 24hours.
- Based on 2,600 rainfall stations and 95,000 station years of data, taken predominately from North America, it was shown that 90% of the stations had a Cv which varied between 0.3-0.4 (Hershfield, 1961)
- Based on 11,518 annual floods from 490 catchments (Merz et al, 2003), the average Cv = 0.494 for long rain floods, 0.456 for short rain floods, and 0.457 for flash floods
- For Cv ranging between 0.2 – 1.5, and Kpmp ranging between 13-19, Zhou et al showed that the ratio ranges between 1.53 – 2.66, with the most common ratio being approximately 2.
- Specifically for a Cv of 0.4 (i.e. as could be expected for intense, wet catchments) and a Kpmp of 15, the ratio is given as 1.896
- If kpmp is reduced to 13 to suit the wet/intense catchment conditions, and Cv is increased to 0.46 to match long, short and flash flood catchments, then the ratio becomes approximately 1.7. That is, the PMP is approximately 1.7 x the 10,000-year event

Using this approach, ICEM extrapolated its frequency analysis to extend up to events with a return period of 10,000 as shown in the figure below.
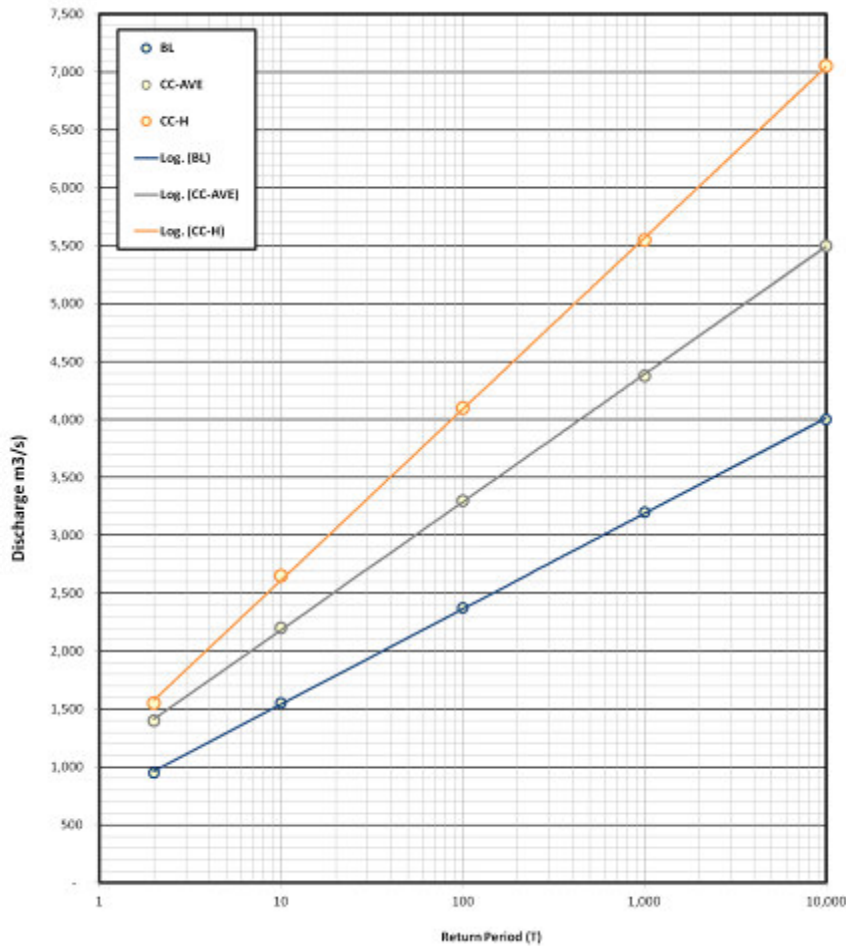
These estimates for the 10,000 year event under baseline and CC conditions were then combined with the ratio of 1.75 to estimate the PMP flood event as shown in the table below:

Qpmf [Zhou method] (method 2)	T	BL	CC-AVE	CC-H
Cv=0.2, Kpmp=13	1.53	6,120	8,415	10,787
Cv=0.4, Kpmp = 13	1.7	6,800	9,350	11,985
Cv=0.4, Kpmp = 15	1.896	7,584	10,428	13,367
Most common	2	8,000	11,000	14,100
Cv = 1.5, Kpmp=19	2.66	10,640	14,630	18,753
Qpmf(NNP1 scaled) (method 1)			12,13	15,520
Figures adopted for the report		**6,800**	**9,350**	**11,985**
Qpmf(NNP1)	9,050		0.75	1.03	1.3

Using this method the baseline PMF was estimated as 6,630 m3/s (75% of the NNP1PC baseline estimate) and the future CC PMF was estimated as 9,010 – 11,560 m3/s (1-30% more than the NNP1PC baseline estimate).

The estimates derived from method 2 are much lower than those obtained from method 1. Given the uncertainty the ICEM team will adopt the lower estimates, namely:

➢ CC-PMF(ave) = 9,350 m3/s = 1.03 x NNP1PC baseline PMF

➢ CC-PMF(high) = 11,985 m3/s = 1.3 x NNP1PC baseline PMF

C – WATER LEVEL AT MAIN DAM DURING CLIMATE CHANGE PMF EVENT

To assess how changes in PMF might affect the risk of overtopping the dam, the water level in the reservoir was calculated under climate change PMFs. The same method and equations used by NNP1 has been applied to estimate water level in this study.

The results show that maximum water level will reach the height of 321.815 m with the maximum discharge of 6,525 m³/s during the average climate change PMF. With PMF event under high climate change scenario, water level will reach the maximum height of 323.4 m with the maximum discharge of 7,591 m³/s (see Figure 83 for details). This is a 1.43 m increase in water level in the reservoir compared with water level rise under the current PMF, however this will not overtop the dam as the dam height with its 1.5 m parapet is at 323.5 m. Water level in the reservoir will rise above NOL during PMF event but with continuous discharge, water level will be drawn down to NOL within 36 and 47 hours during the average CC PMF event and the high CC PMF respectively.
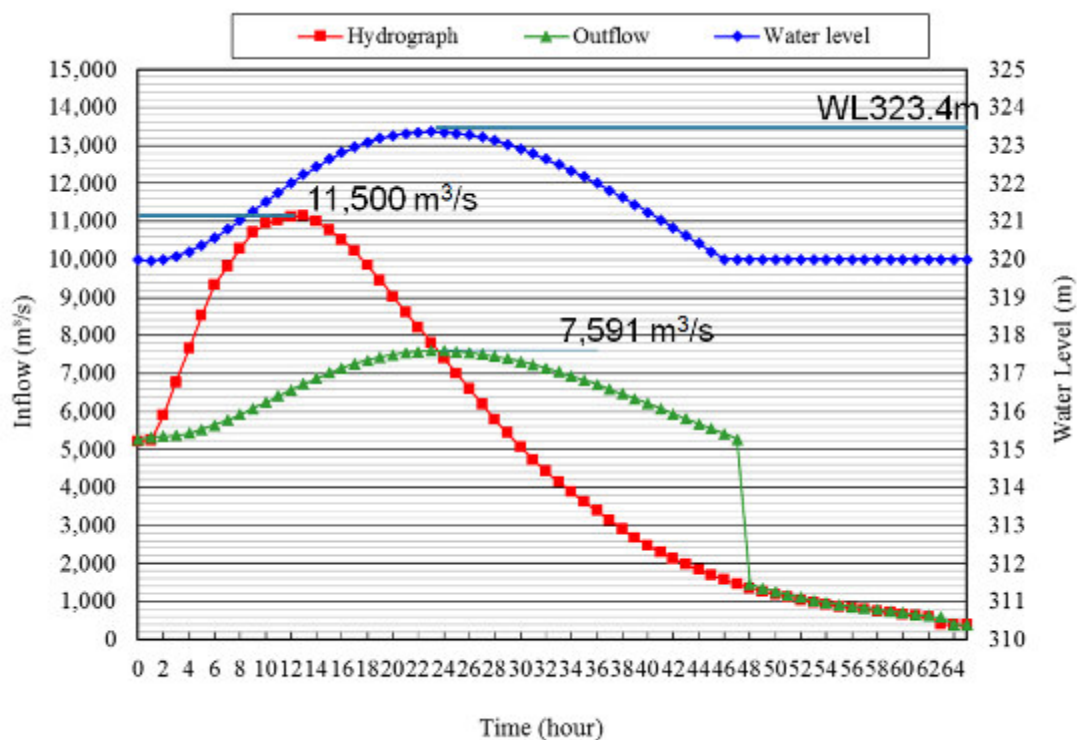

Figure 83: Hydrograph during PMF event: *high climate change scenario (figure on the bottom)*

The NNP1PC modelling study demonstrates that even under the higher climate change estimate, PMF can pass without overtopping of the parapet wall at the main dam. The maximum water level will reach the maximum height of 323.4 m which only gives 0.1m of clearance left in the reservoir before being overtopped.

D – WATER LEVEL AT THE SADDLE DAM DURING CLIMATE CHANGE PMF EVENT

During the current PMF event, the maximum spillway discharge from the main dam will be 6,596 m³/s which would make water level at 200 m downstream of the main dam rise to 193.9 m. This was calculated by extending the NNP1 rating curve between discharges and water elevations as seen in Figure 84 below. The relationship between discharges and water elevations above NOL of re-regulation reservoir can be estimated using the flowing equation:

$$E = 7.3788\ln(D)+129.04$$

Where, E is water elevation at 200 m dam axis, D is the spillway discharge from the main dam.
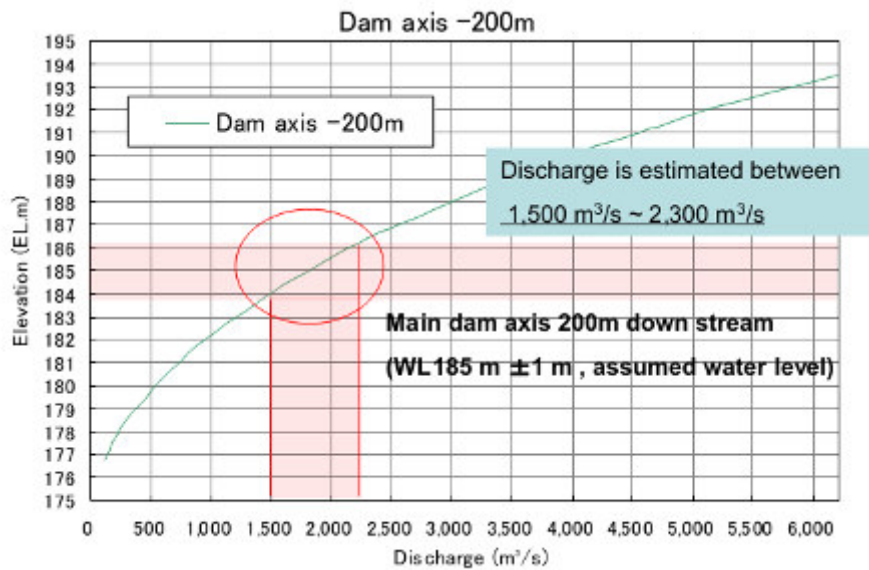

Figure 84: Flow analysis vs water elevation at 200m downstream of the main dam *(Source: NNP1 Technical Report)*

The same equation was used to estimate water elevation during CC-PMF. With 25% increase in PMF under CC, water level at 200 m downstream of the main dam will raise up to 195.08 m which is 1.15 m increase from the baseline PMF.

NNP1 has estimated that water level at the saddle dam will reach 187.7 m during baseline PMF. Under climate change PMF event, water level at the saddle dam could have the same proportional increase as the increase of water level at 200 m downstream of the main dam i.e. 1.15 m. Therefore, the maximum water level at the saddle dam during CC-PMF event is 188.85 m (187.7 m + 1.15 m) which is 0.55m below the current maximum crest elevation of the saddle dam. Thus under the upper estimate for the CC-PMF water levels in the re-regulation reservoir will over top the saddle dam routing flood flows over the agricultural lands of the resettled communities.

NNP1PC have computed their own estimation of the water level at the saddle dam for the same event and found the max water level to reach 188.5 m which is 0.9 m below the saddle dam crest level.

Nam Ngiep CRVA (ICEM)

NNP1PC's Comments on Final Report

	Recommendations in Final Report	NNP1PC's Comments
		The design methods for the structures of the NNP1 hydropower project are in conformity with current codes and standards, and are based on the hydrological data which are evaluated for reasonableness by means of theoretical analysis and thorough calibration.
		NNP1PC have carried out reasonable and economical design of the structures and, as a result of this CRVA, it was confirmed by us that the structures had enough redundancy to accommodate future climate change.
		Some risks and implications of climate change impacts are reported in this Final Report, and several recommendations have been made to the NNP1 Project and are stipulated in this report.
		NNP1PC make comments on these recommendations as below.
1	Page 8 The recommendations are split into three sections: (i) monitoring measures that are required to identify thresholds which would trigger the need to proceeds with future adaptation measures; (ii) implementation of works that introduce adaptation measures now or preserve the capacity for phase adaptation in the future; and (iii) additional Technical Assistance (TA) studies and inputs that serve to confirm the scope and need for critical adaptation interventions. **A - THRESHOLD MONITORING MEASURES** For a number of impacts relating to downstream water quality issues and the impacts of increased spillage on lost energy potential as well as damage to the spillway structures, there is a	NNP1PC has implemented its Environmental Management Plan (EMP), which have been developed as guidelines for minimizing environmental impacts from specific activities of the Project. The EMP will be updated and/or revised, both for the construction and the operation phases, to adapt the measures to the prevailing conditions taking account of additional impacts monitored during construction. The EMP includes regular monitoring of water quality at selected sites upstream from the reservoir, in the reservoir, and downstream from the dams during the operating period. Monitoring and inspection of the structures, including spillway structures, are scheduled be implemented during the operating period.

	need for improved certainty on the timing of when these CC impacts will become significant for NNP1. This means a phased approach to adaptation is required. The main objective of the first phase is to reduce this uncertainty through the implementation of a monitoring program of relevant hydro climate, environmental and infrastructure condition monitoring. The first phase is considered a priority for implementation as part of the first phase of operations. The second phase would be triggered once critical thresholds in any monitoring parameter have been triggered.	Monthly discharges and volume of spillage will also be monitored and recorded continuously. NNP1PC will pay attention to the monitoring data, and if critical thresholds in any monitoring parameter have been triggered, adaptation measures will be considered.

2	Page 9, **B – ADAPTATION INTERVENTIONS**
	The following adaptation options should be built into the design and construction phase of project development:
	
	    1. **Preventative measures for catchment sediment conservation:** site and develop preventative measures such as check dams and constructed wetlands that allow for increased sediment loads to be trapped within the landscape before they reach the headwaters of the reservoir. These measures should target erosion hotspots in the NNP1 catchments and be developed as part of the NNP1 watershed management plan. In addition efforts to rehabilitate degraded forest areas to enhance soil conservation should also be included as part of the watershed management plan.
	
	    2. **Build adaptive capacity for increased wet season electricity production**: inclusion of a blank manifold and provision for an additional penstock should be considered whilst the main dam is still under construction.
		1. **Preventative measures for catchment sediment conservation**
		
		Even in the climate change scenario, the volume of sedimentation in the reservoir for 50 years is estimated to be approximately 89.5 million m^3, and this volume is quite small compared to the effective storage volume of the reservoir of 1,192 million m^3.
		There seems to be minor impacts on the NNP1 Project during climate change, since the reservoir has no function of flood control and the rule curves of the reservoir can be adjusted in response to the changing conditions in the future.
		
		In the EMP and the Watershed Management Plan of NNP1PC, occasional monitoring of the land use in the watershed and the slopes and a vegetative buffer around the reservoir are scheduled to be conducted during the operating period in order to determine areas of greater risk of erosion and sedimentation.
		NNP1PC will pay attention to the monitoring results, and once the risk of erosion and sedimentation have been actualized,

		preventative measures will be considered and developed with the support of GOL.
		2. Build adaptive capacity for increased wet season electricity production
		NNP1PC have no plan to modify the current conceptual design of structures at this moment, but will re-consider adjustment of the rule curves of the reservoir in response to the changing condition in the future.
	Page 9 to 11, **C - ADDITIONAL TECHNICAL ASSISTANCE** Last the CRVA identified the need for a number of additional TA inputs which would enhance the resilience of the NNP1 project and serve to provide greater clarity on the magnitude and timing of risks, these are summarised below: 1. **Rapid catchment condition appraisal and feasibility assessment for a Payment for Ecosystem Services scheme for catchment soil conservation**: A number of adaptation measures identified above rely on the identification of erosion hot and sweet spots within the catchment; with the erosion hotspots considered as those areas producing the greatest amounts of hillslope erosion and sweet spots as those areas of forest providing the most important soil conservation services. Additional TA would be needed to undertake a GIS-based assessment of hot and sweet spots including an estimation of the sediment conservation potential. This assessment would need some field work to ground truth the findings of the GIS assessment and to identify sites	**1. Rapid catchment condition appraisal and feasibility assessment for a Payment for Ecosystem Services scheme for catchment soil conservation.** Please see the above comment of 1. above (Preventative measures for catchment sediment conservation). NNP1 PC agree with the concept of PES and would like to closely follow up with the development of this scheme by GOL. **2. Technical and institutional feasibility assessment for the establishment of a Nam Ngiep Emergency Response Centre (ERC)** NNP1PC agree the concept of the establishment of an ERC on the initiative of the GOL, and we would like to cooperate with other developers in the basin and support the operation of the ERC with them.

and undertake a rapid feasibility assessment for a network of check dams and constructed wetlands.

In parallel an institutional assessment would need to be undertaken to review the potential for piloting a Payment for Ecosystem Services (PES) initiative as enshrined in the new national water law for Lao PDR. The institutional assessment would need to include a review of government and community stakeholders and recommendations on the scope, mechanisms and modalities for implementation of the watershed soil conservation measures. Both components would need to be completed in close working cooperation with the NNP1 Watershed management plan.

2. **Technical and institutional feasibility assessment for the establishment of a Nam Ngiep Emergency Response Centre (ERC), including a coordinated Early Warning System**: A number of adaptation options point towards the need for a coordinated response to flood management, including coordination of spillway releases and an EWS, coordination of additional precipitation and stream gauge monitoring by cascade operators and flood forecasting measures as well as the coordination of the sharing of information sharing generated by these measures. Ultimately the responsibility for such coordination lies beyond any individual hydropower operator and requires an active and leading role from the Government of Lao PDR (GOL). An additional TA is needed to support relevant agencies within the GOL and operators of the NNP cascade to design and implement a coordinated response as outlined in adaptation options 18, 19 and 20.

The main components of this TA would include an institutional review of government agencies and policies for watershed, flooding, disaster and climate change

3. **Hydrological Analysis**

The approach adopted in this study was an analytical approach with a highly detailed distributed model, reflecting a range of findings for a wide number of variables (temperature, rainfall, runoff, groundwater recharge, hillslope erosion, sediment transport).

As a result of this analysis, NNP1PC has confirmed the robustness of the structures for the climate change impacts.

Proposed further hydrological analysis and consolidating information led by the GOL would be useful for a large number of development stakeholders in the Nam Ngiep and other basins of Lao PDR.

NNP1PC will be able to contribute to the understanding of flood dynamics and support better and more responsive flood management of the Nam Ngiep river through the provision of hydrological data measured by the project.

management resulting in a set of recommendations on the appropriate institutional mechanisms, scope and membership of an ERC. A technical review undertaken in parallel would make recommendations on: (i) optimal siting for additional precipitation and stream gauge monitoring, (ii) appropriate technologies for monitoring stations, (iii) the potential for remote sensing information to inform monitoring and/or flood forecasting efforts, (iv) the need and role for a shared catchment hydrological model, and (v) scope of management guidelines and directives which are used to ensure communication and coordination during flood events.

3. **Hydrological analysis:** In the design of the PMF and its review through the DSRP and CRVA process, NNP1PC has undertaken due diligence to build a robust PMF that makes best use of all available data, compares with existing regional information and those of hydropower projects in neighbouring basins such that even under the upper CC projections of this study, there is sufficient confidence in the project's inbuilt safety margin.

However, there remains a regional problem for hydrological analysis as experienced by NNP1 and neighbouring project – that of highly variable precipitation dynamics resulting from multiple forcings in a poorly gauged context. As noted above, additional monitoring is essential component in a strategy to fill this gap but will take many years to build the long time series needed for extreme event analysis. In addition, the study recommends additional hydrological analysis to be undertaken to improve understanding of flood dynamics and support better and more responsive flood management in the Nam Ngiep and other basins of Lao.

| | | The main components of the additional assessment are summarised below. Given the geographical scope of the additional analysis, the findings would be of benefit to a large number of stakeholders; consequently, it is recommended that the Government of Lao PDR with support from Development Partners should take the lead in undertaking the hydrological analysis and consolidating information which can be provided to relevant developers.: | |