CLIMATE CHANGE IMPACT ASSESSMENT OF THE NAM NGIEP 1 HYDROPOWER PROJECT

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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

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EXECUTIVE SUMMARY

THE NAM NGIEP 1 HYDROPOWER PROJECT

Nam Ngiep 1 (NNP1) is an approximately 900 million USD 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 (45%), EGAT International of Thailand (30%) and Lao Holding State Enterprise (25%). 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 between a steep natural canyon in the lower part of the catchment. This canyon allows the developer to build a large 148m head reservoir 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 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. 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 bi-furcation 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 water shed to the NNP1 plant 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 catchments water abundance and the hydrological process that govern it fate and transport through the catchment are the fundamental characteristics that determine a hydropower reservoirs energy production potential. These processes are themselves sensitive to changes in climate starting with increasing in 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 of the catchment, 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 lead 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 under baseline conditions. This estimate is significantly higher than the ICEM baseline estimates. With climate change the ICEM projections estimate the CC-PMF would reach 8,584m^3/s (under the average CC scenario) and 10,980m^3/s (under the upper CC scenario) representing a -4% to +22% variation from the NNP1PC baseline. 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 of 1,008MCM 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.

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, but also to changing magnitude and timing of the inflow hydrograph. 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**: 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 17m 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.** Of the ten climate change impact pathways identified as a priority, one (IP5) offers an opportunity for increased electricity production, while two pathways (IP6 & IP9) were identified as priority adverse impacts in need of an adaptation response. An additional three impact pathways all present significant risks that need a response, but there is potential for that response to be phased to avoid front-loading of the capital 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 from 1,413 GWh to 1,585GWh amounting to a 12% increase. 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. **Baseline energy production estimates assume a quantum of energy production which cannot be replicated by the ICEM suite of models, suggesting that any potential production benefits predicted with climate change would off-set initial 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 CC-risk to NNP1 is the over-topping of the re-regulation saddle-dam during the future PMF event routing uncontrolled flows through the agricultural lands of the resettled community:** Increases in wet season rainfall will result in a potential 22% increase in the size of the PMF event. Though there is sufficient safety-margin in the design of the main dam and its spillway to prevent overtopping of that structure, the CC-PMF will dramatically increase the magnitude of spillway releases into the re-regulation reservoir with spillway discharges exceeding 7,500m^3/s for 11 hours, inducing a rise in reservoir water levels to 0.25m above the crest-elevation of the saddle dam and resulting in over-topping of the saddle dam and the routing of flood flows through some of the low-lying agricultural areas proposed for the resettled community. Though overtopping will occur, the infrequency of the CC-PMF is not likely to substantially increase the risk of failure or dam break for the earth-filled saddle dam.

5. **The second-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 at the foot and anchor of the energy dissipation structures**: 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 wear of the concrete lining on the spillway apron and scour at the foot and anchor of the energy dissipation structure downstream and the spillway surface.

6. **The third-most significant impact of climate change will be an increase in the frequency and magnitude of flooding of agricultural lands in the resettlement area**: Climate change will expose 402 ha of paddy rice proposed as part of the resettlement plans to a dual flood risk. On the one hand 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. On the other hand, the dramatic increase in the peak flood event (PMF) will introduce a new risk of overtopping of the saddle dam and the routing of a substantial volume of flood waters into the paddy rice areas (see bullet point 4). Both these flood risk will result in crop damages and an increasing maintenance burden on agricultural and irrigation infrastructure within the paddy area.

7. **A number of climate change impacts are 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 50years 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 rainfed 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.

8. **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 (5% and 72% respectively) will result in a 9% increase in annual average revenues of USD 80million up to USD 86.9million. Assuming a linear progression of climate change

and a standard ADB discount rate of 12% the Net Present Value (NPV) of climate change impacts on production revenues is approximately USD 12.87million.

2. **Economic impact of baseline uncertainty on energy production**: The ICEM model estimates an annual power output of, on average, GWh 43.3 less of primary energy and GWh 30.5 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 USD 3.5million (~4%) 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 reach in the order of USD 177,000 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 hydroclimate, 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.

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 energy dissipation structures	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. **Flood protection for agricultural lands:** Include flood protection measures and infrastructure for the 420ha of paddy rice planned in the low-lying flood plain downstream of the re-regulation reservoir saddle dam. The specific nature of these measures need to be designed in parallel with the design process for the irrigation infrastructure and the farm management practices currently under development by NNP1.

2. **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.

3. **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

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. **Hydrological analysis:** Adaptation options 13 and 23 identify the need for further analysis to enhance understanding of the complex catchment hydrology. Uncertainty in catchment hydrology has been identified as a critical factor governing the nature of flood risks within the basin and there is significant discrepancy between existing estimates to warrant further study and investigation. As noted in Section 5 the main components of this additional assessment would need to include:

    a. ***Regionalised frequency analysis*** of hydroclimate 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.

2. **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.

3. **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.