O MON IV POWER STATION

RAPID CLIMATE CHANGE THREAT & VULNERABILITY ASSESSMENT

Socialist Republic of Vietnam:
O Mon IV Combined Cycle Power Plant

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ABBREVIATIONS

ADB	Asian Development Bank
AR4	Assessment Report 4
AWI	Air-Water Interface
BOT	Build-Operate-Transfer
CAM	Climate Change Adaptation & Mitigation methodology
GCM	Global Circulation Model
CCGT	Combined Cycle Gas Turbine
CO_2	Carbon Dioxide
CSAG	Climate Systems Analysis Group
CTTP	Can Tho Thermal Power Company
CW	Cooling Water
DARD	Department of Agriculture and Rural Department
DFO	Distillate Fuel Oil
DOIT	Department of Industry and Trade
DSM	Demand Side Management
EIA	Environmental Impact Assessment
ENSO	El Nino/La Nina Southern Oscillation
EVN	Electricity Viet Nam
GHG	Greenhouse Gas
GOV	Government of Viet Nam
ha	hectares
HGPI	hot gas path inspection
HRSG	Heat Recovery Steam Generators
ICEM	International Centre for Environmental Management
IPCC	Intergovernmental Panel on Climate Change
LHV	Lower Fuel Heating Value
masl	metres above sea level
mcm	million cubic metres
MMBTU	Million British Thermal Units
MONRE	Ministry of Natural Resources and Environment
MOIT	Ministry of Industry and Trade
NAO	North Atlantic Oscillation
NPV	Net Present Value
NTP	National Target Program
KfW	KfW Bankengruppe
PECC2	Power Engineering and Consulting Company No. 2
PECC3	Power Engineering and Consulting Company No. 3
PDP	Power Development Plan
PPC	Provincial People's Committee
RIAM	Rapid Impact Assessment Framework
SCGT	Simple Cycle Gas Turbine
SEA	Strategic Environmental Assessment
SEA START	Southeast Asia Global Change System for Analysis, Research & Training Centre
SPS	Safeguard Policy Statement, ADB
SRES	Special Report on Emissions Scenarios
TIT	Turbine Inlet Temperature
ToR	Terms of Reference
VSD	Variable Speed Drive

CONTENTS

EXECUTIVE SUMMARY

The objective of the study is to undertake an initial and rapid assessment of the potential threats and impacts of climate change to the O Mon IV combined cycle power station. In doing so, the study assesses the vulnerability of plant design, infrastructure and operations and sets priority areas for adaptation response.

The main findings for climate change impacts and adaptation priorities include:

IMPACTS The climate change impacts on the O Mon IV power plant are expected to be:

- **Performance losses:** the current system design will experience significant losses in efficiency and production and increases in fuel consumption. Over the 25 year design life these losses will cost USD 10.9million in present value terms, based on:

  i. A loss in power output of 827.5GWh, worth an estimated USD 9.36million at present value.
  ii. A net reduction in plant efficiency of 0.28%.
  iii. An increase in fuel consumption equivalent to USD 1.5million at present value.

- **Structural damage:** the impact on structural damage will not be significant:

  i. There is sufficient freeboard within existing design such that the flood and stormwater management systems will be able to cope with the increased flooding and rainfall expected by 2040.
  ii. Bank erosion will become an increasingly important threat to the plant over the design life, exacerbated by both climate change and reduced sediment loads in the Mekong River due to hydropower development, but requires further study

ADAPTATION Priority in adaptation response should be placed on the following:

1. **Improving performance of the gas turbine cycle:** Adaptation options are focused on the gas turbine technology and revolve around pre-treatment of the intake air to reduce temperature or redesigning the topping cycle technology to accommodate a warming climate.

2. **Improving performance of the cooling water cycle:** adaptation options are focussed on reducing the intake water temperature, or increasing the performance of the CW system pumps and heat exchangers.

3. **Improving management of the coolant discharge:** adaptation options are focussed on reducing the proportion of coolant feedback at the water intake structures and improving mixing of the coolant plume in the Hau River water column

There are four main entry-points for integrating adaptation planning into the project life-cycle:

1. the current design phase,
2. replacement of the gas turbine (~mid-way through the project),
3. replacement of other major equipment (3 times evenly spaced over the design project life),
4. end of the design economic life when refurbishment and life-time extension are being considered

Adaptation to climate change for the O Mon IV plant can be delayed to integrate with future maintenance schedules. A concept note should be prepared for treatment of cooling water (CW) prior to discharge to ensure continued long-term compliance with Vietnam National regulations on CW discharge temperature.

In designing and building large infrastructure projects investors and engineers utilise safety margins to factor in an acceptable level of risk. This characterisation of risk is fundamental to plant management and represents a sensitive balance between ensuring a desired level of safety, optimising performance and minimising the cost of investment. Design risk characterisation relies on detailed statistical analysis of historic time-series data to understand the surrounding hydro-geophysical conditions and set key design parameters (e.g. ambient temperature, maximum water levels, earthquake incidence). To date infrastructure, like O Mon IV, has been designed with the assumption that the average and extreme conditions observed in the past will continue throughout the design life of the plant (Biggs et al, 2008). In fact over the long term, many of these parameters will change in response to climate change - affecting the performance of the plant, the cost of maintenance and the life of plant components. The design of critical infrastructure must better reflect an increasingly dynamic and uncertain future.

The challenge then is to determine which climate change threats pose *tangible* risks to the integrity, efficiency or output of the plant, what adaptation response is required, and how best to phase adaptation to minimise the incremental investment required. This study focuses on adaptation of the O Mon IV plant. Also, it presents significant insights for other power stations in the O Mon complex and throughout Viet Nam by developing and testing a methodology for the climate proofing of future investments.

The cumulative impacts of the threats expected with climate change will result in changes to the hydro-metrological regime which underlies the design parameters selected by the O Mon IV project engineers during the design and feasibility stages. These include changes to intake air temperatures, river water temperatures, flood levels and flow velocities.

In order to understand how these design parameters may change, the O Mon Rapid climate change threat and vulnerability study addresses three major questions related to plant operations and assets:

i. what are the direct biophysical climate change threats the plant is *exposed* is to,
ii. what is the projected magnitude and duration of this exposure; and
iii. which operational, management and infrastructure components of plant design are *sensitive* to climate change.

In answering these questions the study assesses the impact of climate change on the O Mon IV power plant, quantifying the plants vulnerability, qualifying the need for adaptation and identifying priority areas of response.

O Mon IV represents a USD 778 million dollar investment and is expected to be built by 2015. It has a planned economic design life of 25 years and will be operational until at least 2040. Project planning for O Mon IV is at the detailed planning phase. ADB together with KfW are in the process of completing due diligence on plant design and financing in preparation for investment. It is intended that the outputs of this rapid climate change assessment will link into the project development at the investment phase and prior to procurement.

THE TIME-SLICE FOR ANALYSIS

The time-slice chosen for the assessment is 2040 in order to synchronise with the current plant design economic life, so that findings directly target investments currently under consideration. Climate change is a non-linear and complex phenomena and the use of a longer-term time-slice would result in a greater magnitude of threat posed by a warming climate and consequently more dramatic impacts.

THE ENVIRONMENTAL CONTEXT

O Mon IV is part of the O Mon power complex (160ha) which is situated on a low-lying (0.8 – 1.0masl) island of the Hau River at Phuoc Thoi and Thoi An ward, O Mon district, Can Tho City. The complex is approximately

80km from the coast and 17km upstream of Can Tho City. At the site, the Hau River is a straight channel 760m wide and up to 22-23m deep. This region has complex hydrodynamics with the combination of the Mekong River flood pulse and tidal influences reversing the direction of flow in the river channel and varying water levels by an average 2.46m annually. Historically, the surrounding land use has been predominately agriculture with growing industrial and urban sectors.

O Mon IV will be built to an elevation of 2.7masl, which requires the plant pad be raised by 1.7 – 1.9m. The elevation of the plant pad is the primary protection measure against overbank flooding and other riverbank hydraulic processes. In addition a revetment system will be installed in order to protect the bank from erosion and is capped with concrete protruding 0.2m above the elevated pad level. Each major component in the plant also sits on a concrete footing, providing a further 0.5m freeboard, such that the majority of plant equipment sits at 3.2masl or approximately 1.0m above the historic P1% flood event.

THE POWER PLANT

O Mon IV is a Combined Cycle Gas Turbine (CCGT) thermal power station with a design capacity of 750 MW. Under normal conditions the plant has a net efficiency of 56.4% and is expected to generate 4,500GWh of electricity per year. Construction is scheduled to begin in 2013 with the plant expected to come online in the fourth quarter of 2015. The plant is one of 5 projects under preparation within the O Mon power complex. O Mon I is a 660 MW conventional twin turbine plant which utilises distillate fuel oil (DFO) as the fuel source and has been operational since December 2009. O Mon II, III and IV are under design and each have a capacity of 750 MW, while O Mon V is under consideration with no firm plans.

CCGT plants can be considered as the combination of two conventional gas-fired and one steam-rankine turbines, which is typically known as a 2-2-1 configuration. As a CCGT power plant, O Mon IV uses natural gas, oxygen and water to generate electricity via two key thermal processes:

1. the gas turbine cycle (*'topping cycle'*), and
2. the steam turbine cycle (*'bottoming cycle'*)

Both processes convert thermal energy (combustion) into mechanical energy at the turbine and subsequently electrical energy at the generator. Each process is supported by a particular cooling process designed to remove heat from the system. Detailed analysis of plant processes revealed that there are three processes which are critical to power production and which directly rely on the surrounding environment (air and water) for inputs. Due to their direct connection to the environment, these processes are more sensitive to climate change:

A. **Gas turbine cycle (topping cycle):** air is drawn from the atmosphere into a compressor and then injected under pressure into the combustion chamber together with natural gas where it is ignited to produce a high temperature and high pressure gas. In the turbine these gases are then converted to work which drive the turbine connected to a generator for electricity production.
B. **Steam turbine (bottoming cycle):** the CCGT process recycles the remaining energy in the exhaust gas to drive a secondary or *bottoming* cycle, by piping the exhaust gas through a heat recovery steam generation system (HRSG). The steam is used to drive a single steam turbine connected to a generator for electricity production
C. **Cooling water cycle:** in order to extract heat from the bottoming cycle a *once-through* cooling water system is employed. Untreated river water is pumped through a heat exchanger to cool steam after it leaves the turbine, and then is discharged back into the Hau River. The cooling water exits the heat exchanger at a higher temperature than the inlet and under normal operations the discharge temperature below +7°C above the ambient river water temperature.

ASSESSMENT METHODOLOGY

The rapid assessment methodology utilised in this study adapts the ICEM CAM – Climate Change Adaptation and Mitigation methodology. At the core of the approach are four key principles:

1. **Confidence in impact:** the study will focus on those threats which can be *directly* linked to key design parameters of O Mon IV, and for which trends in those parameters can be quantified with confidence.
2. **Identify levels of uncertainty:** acknowledging the uncertainty in climate science can better characterise exposure and build confidence in assessment findings. The study utilised a number of different climate downscaling methods and a number of Global Circulation Models (GCMs) to reflect the range in future prediction
3. **Comparable methodology:** for ease of comparison similar methodologies are employed in the study as those used by design engineers to set design parameters.
4. **Phasing Adaptation response:** the impact of climate change on O Mon IV will extend over the entire plant life. Some adaptation may be required at the design phase; others may be introduced during the plant economic life, while others can be postponed until the end of the current economic life, at the point of major system refurbishment. By considering the timing of adaptation response, investors and operators can economise the cost of adaptation without comprising effectiveness.

The approach is built around two critical starting points – the surrounding environment and the plant design:

A. **The surrounding environment** defines the hydro-geo-physical context of the plant against which design parameters and conditions are set and through which the threat of global climate change will influence plant operations. *The surrounding environment characterises the threat of climate change to O Mon IV*.
B. **The plant design** defines the sensitivity of the plant to change and is based on the type and design of infrastructure which makes up the plant (the material assets) and the type and design of the operational and maintenance processes which are utilised in electricity production. *The plant design characterises the sensitivity of O Mon IV to climate change.*

APPROACH TO MODELLING

Threats are reviewed at the global, basin-wide, delta-region and site-specific levels to identify direct threats. These direct threats are then overlayed on existing plant design focussing on areas of sensitivity to assess the impact of climate change on O Mon IV. The synthesis of these elements defines the vulnerability of the plant. Conclusions are then made on the need and adaptive capacity of O Mon IV followed by recommendations on which components and plant processes should be the focus of adaptation response. The level of detail is sufficient for economists to take the study findings and make preliminary "ball-park" estimates of responding to climate change compared to doing nothing.

Simulation is an essential component of predicting future changes in complex systems. This study has developed a number of models and utilised a number of approaches to simulate future conditions which are realistic over the economic design life:

A. Climate downscaling: In order to predict future climate at Can Tho, the results of 8 global circulation models (GCMs) were used to generate predictions for two different time scales (2036-2045, 2045-2065) and for two different IPCC emissions scenarios (A2 and B2). Results utilised two downscaling techniques (statistical and dynamical) in order compare the influence of the methodology on the results. The observed and modelled baselines were compared using statistical techniques resulting in the selection of the NOAA Geophysical Fluid Dynamics Laboratory GCM (gfdl_cm2_0) as the most appropriate model platform for the study. Model results were then used for statistical analysis of meteorological parameters (air temperature, precipitation). The climate downscaling employed in this study represents the most up-to-date evidence base for climate change assessments available at the time of the study.

B. **Hydrological modelling:** The IWRM model was then used to incorporate climate change into the Mekong hydrological regime by modelling the entire Mekong Basin in order to establish the boundary conditions at Kratie. Then, delta-wide flood mapping was undertaken to map the change in depth and duration of flooding using the boundary conditions provided by the IWRM model and the predictions for sea level rise defined in the official scenario of the Government of Viet Nam.

C. **3D hydrodynamic & temperature modelling:** a detailed 3-dimensional model was set up for the area in the immediate vicinity of the O Mon complex. The model domain (50m x50m grid resolution) included an approximate 15km reach of the Hau River network centred on the complex, as well as the associated floodplains. The 3D modeling takes into account both horizontal and vertical flow and thermal distribution across the water column allowing for detailed computation of: water levels, flow velocities (in-channel and at the bed and banks), and water temperature. The results can be used to assess: heat exchange at the air-water interface (AWI), thermal stratification and mixing dynamics, flood onset, recession dynamics and erosion and the fate and transport of the coolant discharge plume in the dry season. Simulations were undertaken for two representative water years under baseline and climate change conditions: (i) Year 1997 – an average hydrological year, and (ii) Year 2000– a hydrologically extreme year. In addition a Cyclone Linda magnitude storm episode was simulated for a shorter period for both years in order to analyse extreme storm surge situation

D. **Plant performance simulations:** In order to understand how the plant would respond to changing air and river water temperature, the study team together with PECC3 – Power Engineering Consulting Company No.3 undertook simulations of plant power output and efficiency with increasing river and water temperature. The simulations used the design and machinery specifications as given in the Technical Design Document for O Mon IV (PECC3, 2009), and varied the design temperature by increments of 0.5°C between 25-36°C.

Three scenarios were explored and the results were then compared to other plant performances through a literature review of published results in Singapore, Brazil, Turkey, and North America:

	Air temperature	River water temperature	Impact on performance
A	Increasing by increments of 0.5°C between 25-36°C	Held constant at design temp	Increasing air temp
B	Held constant at design temp.	Increasing by increments of 0.5°C between 25-36°C	Increasing river water temp
C	Increasing by increments of 0.5°C between 25-36°C	Increasing by increments of 0.5°C between 25-36°C	Cumulative impact

DRIVERS OF CHANGE

A -CLIMATE CHANGE

Five key threats were identified as being of greatest significance to the O Mon IV plant (see below). The nature of exposure and impact of these threats varies. Some, like air and river water temperature threaten day-to-day performance of plant operations, while precipitation and flooding can affect maintenance schedules and downtime. Erosion and flooding were identified as the two potential threats which could cause damage to planned infrastructure.

Direct threat		Sensitivity of O Mon IV plant
Air temperature	→	Gas turbine cycle performance
River water temperature	→	Steam turbine cycle + coolant water cycle performance
Direct precipitation	→	Performance of gravity-driven stormwater management
Flood Depth + Duration	→	Asset damage + plant downtime
Erosion	→	Asset damage

B -UPSTREAM DEVELOPMENT

By 2015 the number of hydropower projects on the Mekong River and its tributaries will increase from 16 to 46, providing the capacity to retain 44,415 million cubic metres of wet season flow in their reservoirs for release during dry season electricity production. This represents an important driver of change to the Mekong hydrological regime. In the order of 10% of wet season flows will be stored resulting in an average 20-50% increase in dry season flows at Kratie and the Mekong Delta.

By 2015, upstream hydropower development will also halve the sediment load of the Mekong River (ICEM, 2010). Sediment levels play an important role in erosion and deposition processes, regulating ground water levels as well as controlling the depth of light penetration and hence influencing the temperature gradient of the water column. Higher sediment loads trap more light and heat at the surface increasing warming, while reduced loads and enhanced light penetration allows for warming to influence deeper layers of the water column.

For this rapid study, assessment of the impacts from upstream development has been undertaken as a sensitivity analysis overlayed on top of modelled future flows with climate change through the generation and use of a rating curve for the Hau River.

OVERVIEW OF RESULTS

The impact of climate change on O Mon IV is one of reduced performance and compromised operating processes, not damage or loss in assets. The most significant climate change threats predicted include rising air and river water temperature. The components most vulnerable to reduced performance are the gas and steam turbines, the air compressors and the circulating water pumps. These components are central to plant power production and are flagged as the highest priority for adaptation response. Most other components are expected to have minor vulnerability to climate change.

The O Mon study considered two kinds of climate change impacts: (i) loss in revenue (due to decreased output) and (ii) increase in fuel cost (due to efficiency change). The former is a change in economic benefit, while the latter is a change in the economic cost. The study shows that climate change will result in both a decrease in benefit and an increase in cost.

VULNERABILITY TO AIR TEMPERATURE

Air temperature is the critical link between the topping cycle and the surrounding environments. In a CCGT 2-2-1 plant, the two gas turbines contribute approximately two thirds of the power production, while the steam turbine contributes the remaining third. Typically for CCGT plants, power output and energy efficiency decrease as air temperature increases – primarily through losses in the gas turbines. Gas turbines utilise air as a working fluid and are therefore vulnerable to changes in ambient temperature, because an increase in air temperature reduces air density and hence mass flow of air intake to the compressor. These losses result in reduced gas turbine power output and a reduction in the pressure ratio within the turbine with a subsequent reduction in energy efficiency.

THREAT OF INCREASING AIR TEMPERATURE

The O Mon IV project is designed for an ambient air temperature of 30°C. The selection of the design temperature reflects an optimisation of plant productivity, operational and capital cost based on historical temperature trends. A higher design temperature would require greater capital cost as components would need to be resized, while a lower design temperature would adversely impact plant power production under current climate conditions.

The historic average annual ambient temperature is 26.7°C at Can Tho. There is little monthly or seasonal variation in average daily temperatures, with a slight seasonal reduction in the order of 1-2 degrees. On a daily time-step temperatures can vary by on average 6 -7°C during a day, peaking in the mid-30s and dropping to the low-20s overnight. With climate change there will be an average 3.1°C increase in daily ambient temperatures in the Mekong Delta with a range of 2.8 – 3.4°C. The average daily temperature will rise to 29.9°C while the variability in daily temperature will slightly reduce.

These changes will reduce both power output and net efficiency affecting plant performance. On a day-to-day level these changes are likely to be minor but over an annual production year and over the entire design life the plant will experience a significant loss of performance representing a loss of 8.4% of the initial investment cost.

SENSITIVITY TO INCREASING AIR TEMPERATURE

With each 1°C increase in temperature after 30°C net CCGT power output drops by 0.3-0.6% and net efficiency drops by less <0.1% and is driven by impacts on the topping cycle (Kelhofer et al, 2009; Brooks et al, 2000; Drbal et al, 1995).

Consistent with international experience, the net plant efficiency under the PECC3 simulations peaked at 29°C

(ε = 55.55%) and then underwent a gradual linear decrease in efficiency of 0.01% with further increases in temperature. Power output of O Mon IV showed a strong and decreasing linear trend due to increasing temperature with an approximate 0.57% decrease in power output for each degree increase in air temperature.

IMPACT OF INCREASING AIR TEMP

The study estimated the changes in power output and fuel consumption over a typical year and over the design life. Based on this analysis, the impact of increasing air temperature will have a significant effect on plant power output, but only a minor impact on net efficiency. With climate change annual power output in 2040 will decrease by 74.0GWh due to changes in air temperature alone or a 1.7% reduction in annual power output.

VULNERABILITY TO RIVER WATER TEMPERATURE

River water temperature is the critical link between the O Mon IV bottoming (steam) cycle and the surrounding environment – primarily through the cooling water system. The once-through cooling system employed at O Mon draws in untreated water from the Hau River and uses the temperature differential between the cooling water (CW) and the working fluid (steam) to condense the steam and return it to the HRSGs. The cooling system has a fundamental influence on the efficiency of the steam process. The greater the difference between river water and coolant temperatures the greater the efficiency of heat transfer. Reductions in efficiency will occur through increases in the river water intake temperature and a 1°C increase in river water temperature will result in a 0.1% reduction in both power output and efficiency for CCGT.

THREAT OF INCREASING RIVER WATER TEMPERATURE

The cumulative impacts of climate change and plant operations have the potential to reduce the difference between the CW and coolant by increasing the CW average temperature through two heat transfer mechanisms:

A. Feedback from the O Mon complex discharge channels, and
B. Increased heat exchange at the air-water interface (AWI)

A - FEEDBACK FROM THE O MON COMPLEX DISCHARGE CHANNELS

Coolant feedback is not a climate change threat, however, it must be considered as part of the background environmental context within which rising river water temperatures are assessed. The shared O Mon III/IV intake structure is located in between the O Mon III and IV plant sites. Two discharge channels with a combined capacity of 110m^3/hr are located 750m downstream of the complex. Assessment of existing conditions of coolant heat dissipation undertaken as part of the O Mon IV EIA have indicated that, with existing natural river water temperatures, the impacts of coolant feedback will be within acceptable limits for both the receiving environment and the design criteria set at the O Mon III/IV intakes (Vattenfall,2008; ADB, 2010).

The behaviour of the coolant plume is seasonally dependent:

- **During high-tide and low flow events** the flow direction in the Hau River is reversed causing the warmer plume of coolant outflows to 'blowback' past the O Mon III/IV intakes and past the O Mon River mouth. Coolant waters pool along the right-hand bank of the Hau River within the vicinity of the complex and 1-2km upstream of the O Mon complex. Further upstream and downstream of the complex the river channel widens slowing flow velocities and inducing greater mixing of the water column. In low-flow conditions coolant blowback can be significant, with an average of 15 - 20% of the baseline intake water originating from the coolant discharge channel (maximum 40 – 50%).

- **During the high flow season** there is minimal feedback of coolant waters at the O Mon IV intake as the magnitude of flow dominates the system dynamics even under high tide situations.

With climate change, feedback of coolant to the O Mon IV intakes will periodically increase. The increase will be minor for the average fraction of coolant in intake water (in the order of 1%), however, for maximum conditions, the fraction of coolant water at the O Mon IV intake is expected to increase by in the order of 10% as a result of sea level rise and changes to the flow regime due to changes in precipitation in the upper catchment (from 50 up to 68%).

The threat of climate change at the O Mon III/IV intake must be considered in the context of the increasing importance of coolant feedback on near bank water temperatures in a warming climate.

B - INCREASED HEAT EXCHANGE AT THE AIR-WATER INTERFACE (AWI)

The direct threat of climate change to the intake water temperature for the once-through cooling system is to increase the natural water temperatures through greater heat exchange between a warming atmosphere and the river system.

The cumulative impacts of natural heating and the coolant plume will exacerbate increases in river water temperature during the dry season and wet season, being more pronounced during the dry season when water levels and sediment concentrations are lower and flow velocities are slower allowing for greater penetration of light into the water column.

The impact of storm surge and more intense flooding with climate change is to marginally increase both mixing and water levels and hence reduce the areas with elevated water temperatures during these events. It should be noted that in reality the temperature variation is expected to be higher because of varying wind conditions and ambient water temperature. In this study constant average values have been used.

The main impacts of climate change on the river water temperature include:

1. 3-6% increase in the range and variability of intake water temperatures during average years;
2. 5-10% decrease in the range and variability of intake water temperatures during extreme/wet years;
3. Increase in the average intake temperature in the order of 3.5 – 4.0°C;
4. 2^{0}C fluctuations of temperature at the water surface due to the influence of tidal-induced flow reversal;
5. Significant decrease in the proportion of year when river water temperature is at or below the design temperature of 29.2°C. Under historic average and extreme flood years, the water temperature at the O Mon IV intake will be equal or below the design temperature for 46 – 70% of the year, with climate

change influences, the average river water temperature will rarely reach below the design temperature of 29.2°C.

SENSITIVITY TO INCREASING RIVER WATER TEMPERATURE

For river water temperatures greater than 25^0C, there is an approximately negative parabolic relationship between water temperature and efficiency. The reduction in efficiency is due to the reduced mass flow rate of warmer, less-dense river water. This affects efficiency of the bottoming cycle through two antagonistic impacts:

i. Reduced efficiency of heat transfer from coolant to CW– reduced mass in the CW will *reduce* the ability of the same volume of CW fluid to absorb heat from the working fluid

ii. Reduced power consumption at the CW pumps – with less mass to transport through the CW system and for the same flow rate; electricity consumption of the CW pumps will also *reduce* for water temperatures less than 30^0C, with only minor changes for temperatures 30 - 36^0C.

THE IMPACT OF INCREASING RIVER WATER TEMPERATURE

The impact of increasing river water temperature must be considered at the two points which connect the plant to the river: the intake and discharge structures:

- **At the water intake structure:** The impact of increasing river temperature will have a significant effect on plant power output (though lower than the impact expected for increasing air temperature). With climate change annual power output in 2040 will decrease by 0.6%.

  Nett efficiency losses are dominated by increasing river water temperature and will decrease by 0.3% down to 55.2%. Actual annual fuel cost of inputs relative to power generation is expected to increase by USD 0.11 million at present value by 2040.

- **In the coolant discharge system:** A key impact of climate change on the O Mon IV plant is to reduce the effectiveness of the plant coolant discharge system. The hydrodynamic modelling indicates that the combination of climate change and coolant feedback will have important implications for the receiving aquatic environment and for compliance with environmental guidelines and standards.

  Temperatures in the coolant plume are expected to remain within 7°C of the natural river water temperatures and continue to satisfy ADB environmental compliance criteria. The increased natural water temperatures of the Hau River will result in near 40 °C temperatures in the plant coolant plume, covering substantial areas of the Hau River channel during the dry season. The elevation of the discharge plume temperatures will: (i) approach the Vietnamese government standard, which stipulates that the maximum temperature of water discharged into a receiving environment should be ≤ 40°C[1] (ADB, 2010); and (ii) be harmful to the receiving ecosystem and cause high mortality for aquatic organisms (Rajagopal et al. 1995).

  A detailed modelling study focussed coolant discharge dynamics in the context of climate change is required to properly assess this impact on the receiving environment and also the long-term compliance with the Vietnamese national standard.

VULNERABILITY TO PRECIPITATION AND STORM WATER

O Mon IV incorporates a gravity stormwater collection system designed to manage precipitation falling directly onto the pad, through an underground drainage network. Central to the effectiveness of the stormwater

[1] c.f. Vietnam environmental standard: QCVN 24/2009/TNMT

system is the determination of suitable diameters for the conveyance pipe network, which also presents a design area of sensitivity to climate change.

THREAT OF CHANGING PRECIPITATION

The rainfall regime of the project site is dominated by two distinct seasons, with 80% of precipitation occurring during the wet season. Based on historic trends between 1978 – 2004, the average annual rainfall is 2,057mm with an average of 197 rainy days in the year. Average monthly rainfall fluctuates between 6.7mm during the peak of the dry season (February) and 329.8mm in August, while average monthly maximum rainfall values can reach 493.1mm during particularly wet years. The major impact of climate change is an approximate 15% increase in annual precipitation with a comparable increase (16%) in the number of rainy days. The combination of increased precipitation and rainfall days is likely to result in negligible change in the daily rainfall intensity.

SENSITIVITY TO CHANGING PRECIPITATION

The O Mon IV stormwater drainage system relies on gravity to collect, convey and discharge rainfall from the site. A small pump is available for emergency dewatering and designed to cope with 1 day of rainfall. The system is designed to manage rainfall events with intensities less than ~6mm/hr – approximately a maximum daily event with a P1% frequency of occurrence. For more intense shorter duration events, it is expected that plant staff will utilise the back-up pump system to speed up dewatering of the plant pad.

IMPACT OF CHANGING PRECIPITATION

The impact of climate change on precipitation is likely to see a 15-16% increase in both the annual rainfall volumes as well as the number of rain days in the year. The plant stormwater system is sensitive to changing average *rainfall intensities* which are not expected to change significantly by 2040 with climate change. Therefore the implications of climate change on the day-to-day operations of the plant stormwater system are expected to be negligible. For extreme rainfall events the plant back-up pump will remain suitable for managing dewatering of extreme events under climate change. Pump utilisation is likely to increase with climate change to prevent long periods of ponding with a subsequent minor implication on fuel consumption and maintenance schedules.

VULNERABILITY TO OVERBANK FLOODING

Plant operations can be severely affected by downtime associated with flooding and the damage caused to infrastructure. Vulnerability to flooding was assessed by quantifying the changes in water levels in the Hau River with climate change and then assessing the capacity of the existing flood protection works in managing these changing levels.

THREAT OF OVERBANK FLOODING

Water levels in the Hau River are driven by channel flow, tidal forcing and overland flow during the flood season. Under baseline conditions water levels fluctuate by 2.46m annually and 3.8m during extreme events. With climate change, the maximum water level is only 0.13 – 0.2m higher than baseline conditions. The floodplains surrounding the O Mon complex will experience increased flood water levels of 40-50% above current level, while the duration of flood events will increase by up to 80%. Climate change will also increase the proportion of the year experiencing high water levels.

The combination of climate change and upstream development will have seasonally distinct impacts on water levels in the Hau River. During the wet season the increased discharge and water levels predicted by the climate change modelling will be partially off-set by upstream regulation. During the dry season, upstream hydropower will superimpose and additional 20% increase in seasonal water levels in the Hau River.

SENSITIVITY TO CHANGING OVERBANK FLOODING

Most equipment and plant components of the plant have been raised to an elevation of +1.0m above the P1% historic flood event. A considerable safety margin is already incorporated into the design. This is a combination of an elevated pad and the utilisation of a concrete footing and represents the primary protection measure against inundation.

IMPACT OF CHANGING FLOODING

The flood protection measures proposed in the current design will be sufficient to manage the increase in flooding risk associated with climate change.

The threat of overbank flooding will increase with climate change, as water levels in the Hau River will increase in the order of 0.2m. These changes, though significant for the surrounding area, will not jeopardise the integrity of the current design pad elevation of 2.7masl on an annual basis – utilising ~20% of the existing freeboard, but still provide protection against annual flooding events and an acceptable level of risk for extreme events. For the surrounding floodplain, flooding times will increase significantly for the low-lying areas, increasing the need of effective water management. This may have implications for plant assets outside the main pad, including access roads.

For the O Mon IV plant, flooding of the plant pad is predominately a wet season risk. The antagonistic nature of wet season climate and development impacts reduces the CC -induced risk of plant flooding during the economic design life, confirming the suitability of the proposed flood management works.

VULNERABILITY TO EROSION AND CHANGING MORPHOLOGY

Riverbank erosion is a function of river flow velocity, soil structure and bank stability. Due to the river planform, erosion in the vicinity of the power plant is concentrated on the right-hand bank and immediately upstream of the O Mon River complex (1-2km upstream of the complex). Erosion problems could be exacerbated by intensive land clearing of the riparian zone and the docking of large vessels on the river bank (e.g. for sand mining or freight transport).

THREAT OF EROSION

Stream competence defines the ability of the river to entrain and transport solid particles and increases as a power of velocity. The 3D model was used to simulate flow velocities in the river benthic layer under baseline and climate change hydrological regimes. Flow velocities will not change significantly in the climate change scenarios, with average flow velocity decreasing slightly in the river channel and increasing in the floodplain. This implies that future flow velocity induced erosion will not change in response to climate change.

SENSITIVITY TO EROSION

The main protection measure against erosion is the installation of a revetment system along the Hau River bank involving interlocking metal sheets sunk 10m below the surface. The revetment system acts as a stabilising curtain to protect the pad from movement and erosion. Efforts made to stabilise the waterfront between the revetment and the river through planting of trees and reeds would improve the long-term effectiveness of the revetment system.

IMPACT OF CHANGING EROSION PATTERNS

By 2040, it is not expected that climate change will significantly alter flow velocities at the Hau River bed and banks and consequently there is not likely to be any increased threat from climate change on the existing revetment system. A full assessment of erosion potential including reduced sediment loading remains to be undertaken and is an important component of plant risk management as upstream changes to sediment transport will have a significant impact on the rates of erosion along the Hau River posing a direct threat to the O Mon complex.

SYNERGISTIC AND CUMULATIVE VULNERABILITY

An assessment was then made of the impact for all parameters combined, and the cumulative impact across the design economic life of the plant. The cumulative impact assessment assumes: (i) a non-linear and accelerating trend in climate change, with minimal impacts at the start of the design life rising to a maximum impact in 2040 proportional to a power function, (ii) an annual discount rate of 10%. Both of these assumptions have a significant impact on the total cost of climate change.

In summary, climate change will reduce performance of the O Mon power station through reduced efficiency and power output and increased fuel consumption. Over the economic design life of the plant, this reduction in performance would cost USD 10.9million in present value terms.

PLANT EFFICIENCY

Changes in plant efficiency are dominated by the bottoming cycle: The O Mon IV plant is expected to experience a 0.32% reduction in net efficiency in response to increasing river water temperature, with a marginal 0.02% increase in efficiency due to increasing air temperature. Combining the impact of both rising air and water temperature, there is a decrease of 0.28% in net efficiency.

POWER PRODUCTION

Changes in plant productivity are dominated by the topping cycle: By 2040, climate change will incur a total combined annual reduction of power output in the order of 99.3GWh or 2.5% of annual plant production. With a nominal electricity purchase price of US 6.78 US cent/kWh, the combined loss in power output would amount to a reduction in 2040 annual revenue in the order of USD 6.73 million in present value terms.

Over the life-cycle of the plant (25years), total power output will reduce by approximately 827.5GWh, with effects more severe in later phases of project operations. This represents a loss in power output of 0.8 % and a loss in revenues of USD 9.36million in present value terms.

FUEL CONSUMPTION

Reductions in electricity production will result in a slight reduction in fuel consumption. By 2040, electricity self consumption[2] is expected to decrease by 0.77 GWh due to air and river water temperature increase, with the greatest impact from air temperature increase to the equipment of the plant. This represents a minor benefit for the plant. [3]

Reduction in net efficiency will result in a relative increase of annual fuel cost of USD 0.1million in present value terms. Over the 25 year economic life, the total increased fuel cost is estimated at USD 1.5million (present value).

VULNERABILITY OF THE GREATER O MON COMPLEX

O Mon IV is one of five existing and proposed power stations in the O Mon complex. The vulnerability of the O Mon complex represents the cumulative vulnerabilities of each plant. Issues and costs identified for the O Mon IV plant should also be considered in relation to how they will upscale to the wider context of the complex. The key issues which increase in importance when going to scale include:

1. Cumulative losses in power output due to climate change represent a supply-side integrity issue with consequences for the regional energy sector.

[2] electricity consumption of all equipments of the plant
[3] The performance simulations used in this study have taken this minor improvement into account in the quantification of the overall impact.

2. With climate change the effectiveness of the coolant discharge system in dissipating heat energy will be reduced which will affect other plants in the O Mon complex
3. Given the similarity of impacts, there is a potential for shared cost of adaptation.

PREPARING FOR ADAPTATION

The O Mon IV power plant is currently at the investment phase of project development. Detailed design has been undertaken and an EPC is currently under tender. Given the level of development of the project, it remains possible but difficult to make major changes to detailed design.

The critical climate change impacts are performance related. It is recommended that adaptation response for O Mon IV prioritise:

A. Losses in power output & efficiency – due to increases in air and river water temperature
B. Increased fuel consumption – due to increase in river water temperature
C. Reduced efficiency of coolant discharge system – due to increased river water temperature

The first step in adaptation response is the preparation of detailed Climate Change Adaptation Plan. Given the commonality in impacts and aspects of operation, there is the potential for this document to be an integrated plan for the O Mon complex, covering all 5 power plants. A preliminary review of the types of adaptation options was made, including consideration of their suitability and phasing.

SCOPING OF ADAPTATION OPTIONS

A – TOPPING CYCLE + INCREASING AIR TEMPERATURE

Over 86% of the total economic impact of climate change is felt through a drop in power output of the power plant. Adaptation options are focused on the gas turbine technology and revolve around pre-treatment of the intake air or redesigning the topping cycle technology to accommodate a changed environment:

- **Customisation of turbine technology**: The most suitable adaptation option to maintain productivity of the gas turbine system is to explore suitable technology modifications with turbine suppliers. It is likely that the custom alterations to the design specifications can be negotiated – pending existing progress against project scheduling.

- **Installation of inlet air cooling:** the addition of a pre-inlet refrigeration air cooler could reverse the climate change trend of increasing air temperature by cooling the air before use.

- **Upgrading the compressor:** can compensate for the reduced air density by increasing the flow rate as this can maintain the design mass flux.

B – BOTTOMING CYCLE + CC-RELATED INCREASING RIVER WATER TEMPERATURE

The magnitude of performance impacts on the bottoming cycle are half the magnitude of the topping cycle, but the variety and relative simplicity of adaptation options prove attractive for adaptation. There are three groups of adaptation options for improved performance of the bottoming cycle: (i) reducing the intake water temperature, (ii) increasing the performance of the CW system pumps and heat exchangers, or (iii) improving management of the coolant discharge plume. For each of these, a number of potential adaptation options need to be considered, including:

- **Reducing the water intake temperature:** cooling of intake waters before use could partially reverse the climate change trend of increasing intake water temperature. These can be refrigerated or 'free-cooling' (i.e. non-refrigerated). A detailed study is required to source potential heat sinks for the free-cooling option, including nocturnal air temperature.

- **Increasing the performance of the CW system:** while increasing river water temperature will reduce performance of the CW system, there exist a number of options to improve system performance through alterations to other components. Two important options are the heat exchanger and the CW pumping system. Pumping options rely on three possibilities for increasing the flow rate and hence improving the mass-flux through the system:

    i. **Upgrading the heat exchanger:** increasing the size of the heat exchanger would allow a greater surface area contact between condensate and coolant, improving the performance of the CW process.

    ii. **Change existing pump management:** There is some capacity under the existing design to increase the flow rate by fully opening the globe valves, which control flow rates in the CW pumps. This may partially mitigate the loss in performance expected with climate change

    iii. **Add a back-up pump unit:** an additional pump could be used to satisfy the incremental flow demand required to restore the design mass-flow rate; and when used in conjunction with re-adjustments to the globe valves may not need year-round use (use may be limited to the dry season and periods of low flow, or during high tides when coolant feedback is peaking).

    iv. **Change to variable-speed drive pumps (Hydro-coupling):** a potential adaptation option for the O Mon IV project is to switch from fixed-speed to variable-speed CW pumps which are much more effective in maintaining efficiency and minimizing fuel consumption under varying temperature conditions

C – BOTTOMING CYCLE + COOLANT DISCHARGE RELATED INCREASING RIVER WATER TEMPERATURE

Coolant feedback at the water intakes is a key phenomenon exacerbating the impact of climate change-induced river water temperature increases. 3D modeling of the combined impact of coolant feedback and CC-related heating of river water could jeaopardise future compliance with Vietnamese regulations for water temperatures downstream of discharge channels. In light of this potential compliance issue, options for reducing the temperature of CW should be a priority in the medium-term.

Performance of the bottoming cycle could be improved by reducing the proportion of coolant waters entering at the water intake. There are a number of options for achieving this:

- **Redesign the O Mon III/IV intake***:* By moving the intake structure further into the centre of the river channel (e.g. through the adoption of the O Mon I intake tower design), it is possible to reduce the percentage of coolant waters entering the intake by as much 40-50%, which will reduce the temperature of the intake waters.

- **Improvements to discharge channel:** Discharging further downstream or further into the centre of the river channel would improve mixing of coolant waters and avoid the concentration of coolant waters along the right-hand bank at the O Mon complex.

- **Increased retention time in the discharge channel:** a longer retention time in the coolant discharge system could allow for greater reduction in coolant water temperatures before entering the Hau River system. This would require significant space as increased retention time would result in a longer discharge channel or the inclusion of a retention facility with a large surface area

ADAPTATION PHASING AND ENTRY-POINTS

Entry points for adaptation arise at different stages of the project time-line. Ideally, adaptation planning should be initiated at the feasibility/design phase of a project because this allows for the greatest capacity for integration. However, adaptation entry-points also exist at later stages in the project, including the construction and operations phases.

- **2011 – Investment planning phase:** opportunity to make modifications to design elements which could restore plant performance in a warming climate. This entry-point would suit all adaptation options, but would be critical for redesign of civil works at this stage, as infrastructure will typically have longer design lives and so fewer entry-points further along the timeline.

- **2027 – Gas turbine replacement:** the gas turbines are one of the major plant components and also flagged as the most vulnerable to climate change. The replacement of the turbines mid-way through the design life offers an opportunity for customization or redesign to suit the ambient temperature profile in a warming climate.

- **2022, 2028, 2034 – major equipment replacement:** typically major plant equipment is replaced once every 7-10years. These dates offer suitable entry points for bottoming cycle adaptation – especially those relating to the CW pumping system or heat exchangers. It is suggested that the potential compliance issue for water temperatures downstream of the discharge channel be synchronized with these entry points in the operational life.

- **2040 – Refurbishment and life-time extension (LTE):** the end of the design economic life offers the opportunity for major redesign of the plant, many components will need replacement or LTE refurbishment.

- **Financial entry-points:** In addition to these, there may also be financial entry-points for adaptation defined by the projected investment return schedule. This would apply to adaptation options which require the purchase of additional plant components (e.g. coolers, and pumpsets).

- **Management & maintenance entry points:** management entry points are the most flexible and are present throughout the project life cycle. Opening the CW pump valves is one example of a management response. Entry-points also exist for non-replacement maintenance (e.g. major overhauls, repairs). Typically the benefit of these forms of adaptation is likely to be smaller than other options.

1 INTRODUCTION & BACKGROUND

This study was undertaken to assist the Can Tho Power Company (CTTP) and the Asian Development Bank (ADB) integrate climate change into the design and operation of the proposed O Mon IV power station. It is part of ADB RETTA 6420 and seeks to quantify how the threats posed by climate change will impact the plant design, performance and maintenance of the power station over the design life; and set priority areas for future exploration of adaptation response.

To date infrastructure, like O Mon IV, has been designed with the assumption that the average and extreme conditions observed in the past will continue throughout the design life of the plant (Biggs et al, 2008). As the threat and impact of climate change becomes better understood, it is increasingly clear that this assumption is contested and that there is a complex feedback loop with the impact of climate change affecting the energy sector and posing risks to future infrastructure investments within design lifetimes. In a warming climate engineers and urban planners need to acknowledge that the design of critical infrastructure must better reflect an increasingly dynamic and uncertain future. The challenge then is to determine which climate change threats pose *tangible* risks to the integrity, efficiency or output of future investments, what adaptation response is required, and how best to phase adaptation in order minimise the incremental investment required. In this context, this study of the O Mon IV plant presents significant insights to other power stations in the O Mon complex and throughout Viet Nam by developing and testing a methodology for the climate proofing of future investments.

O Mon IV is expected to be built by 2015 and, with a planned economic design life of 25 years, will be operational until at least 2040. The O Mon IV plant represents a USD 778 million dollar investment and is part of a 5-phase power development complex servicing Can Tho, Long An, Tien Giang, Vinh Long and Dong Thap province. In total, the O Mon complex will provide 17.5billion kWh of energy annually, contributing in the order of 4% of the projected national demand by 2030 (PECC3, 2009).

During the lifetime of the plant, Can Tho City and the Mekong Delta areas are expected to experience significant impacts from climate change (Dasgupta et al, 2007; CTU, 2009). Sea levels and ambient temperatures are expects to rise, while rainfall will become more variable. Wet seasons will get wetter, while droughts will occur with greater frequency and severity. Extreme events are likely to become more frequent as storms and cyclones track further south hitting the Mekong Delta with increasing frequency. Change in the Mekong Delta's hydrological regime coupled with increased use of groundwater will exacerbate land subsidence issues (Doyle et al, 2010). On top of this, the Mekong Basin has begun a period of intensive hydropower development with some 46 large storage hydropower projects currently existing, under construction or under firm planning in the up-stream reaches and tributaries of the Mekong River by the time O Mon IV comes online. Together these 46 projects would have the capacity to significantly regulate the flow regime of the Mekong River, storing in the order of 44,415 mcm (~10%) of wet season flow for release during the dry season, thereby reducing the characteristic seasonal variability and affecting the delta flooding regime. These projects are also expected to halve the sediment load in the Mekong River – exacerbating erosion effects and increasing light penetration into the water column. An additional 40 projects are also being considered for completion by 2030. The cumulative impacts of these expected threats will result in changes to the hydro-metrological regime which underlies the design parameters selected by the O Mon IV project engineers during the design and feasibility stages. These include changes to intake air temperatures, river water temperatures, flood levels and design flood events, and flow velocities.

In order to understand how these design parameters may change, the O Mon Rapid climate change threat and vulnerability study will address three major questions related to plant operations and assets:

1. what are the direct biophysical climate change threats the plant is *exposed* is to,
2. what is the projected magnitude and duration of this exposure; and

3. which operational, management and infrastructure components of plant design are *sensitive* to climate change.

This approach to vulnerability is adapted from the ICEM CAM approach (2010) and broadly consistent with the definitions of vulnerability recommended by the IPCC (2009).[4] In answering these questions the study will assess the impact of climate change to the O Mon IV power plant, quantifying the plants vulnerability, qualifying the need for adaptation and identifying priority areas of response.

Project planning for O Mon IV is at the detailed planning phase and ADB together with KfW are in the process of completing due diligence on plant design and financing in preparation for investment. It is intended that the outputs of this rapid climate change assessment will link into the project development at the investment phase and prior to procurement.

The time-slice chosen for the assessment is 2040 in order to synchronise with the current plant design economic life. After 2040, O Mon IV will require refurbishment in order to remain operational. In reality combined cycle power stations can typically remain operational for 30-40 years (Kelhoffer et al, 2009). However, 2040 was chosen for this assessment because the end of the design economic life: (i) allows the study to assess the vulnerability of investments made based on current equipment specifications and designs, and (ii) offers a key milestone in the maintenance schedule at which point further climate proofing assessments can be made and integrated into refurbishment activities. Climate change is a non-linear and complex phenomena and the use of a longer-term time-slice would result in a greater magnitude of threat posed by a warming climate and consequently more dramatic impacts.

In order to better understand the impact of climate change on the plant, the study takes a life-cycle analysis approach considering the cumulative impact of change from the start (2015) to the end (2040) of the current economic design life. This approach allows for an incremental quantification of climate change and the 25year time slice also allows for the identification of key entry points into the plant life around which adaptation options can be phased for optimal effectiveness and economy of investment.

1.1 OBJECTIVES OF THE STUDY

The objective of the study is to undertake an initial and rapid assessment of the potential threats posed by climate change to O Mon IV power plant and assess the vulnerability of plant design, infrastructure and operations to these threats.

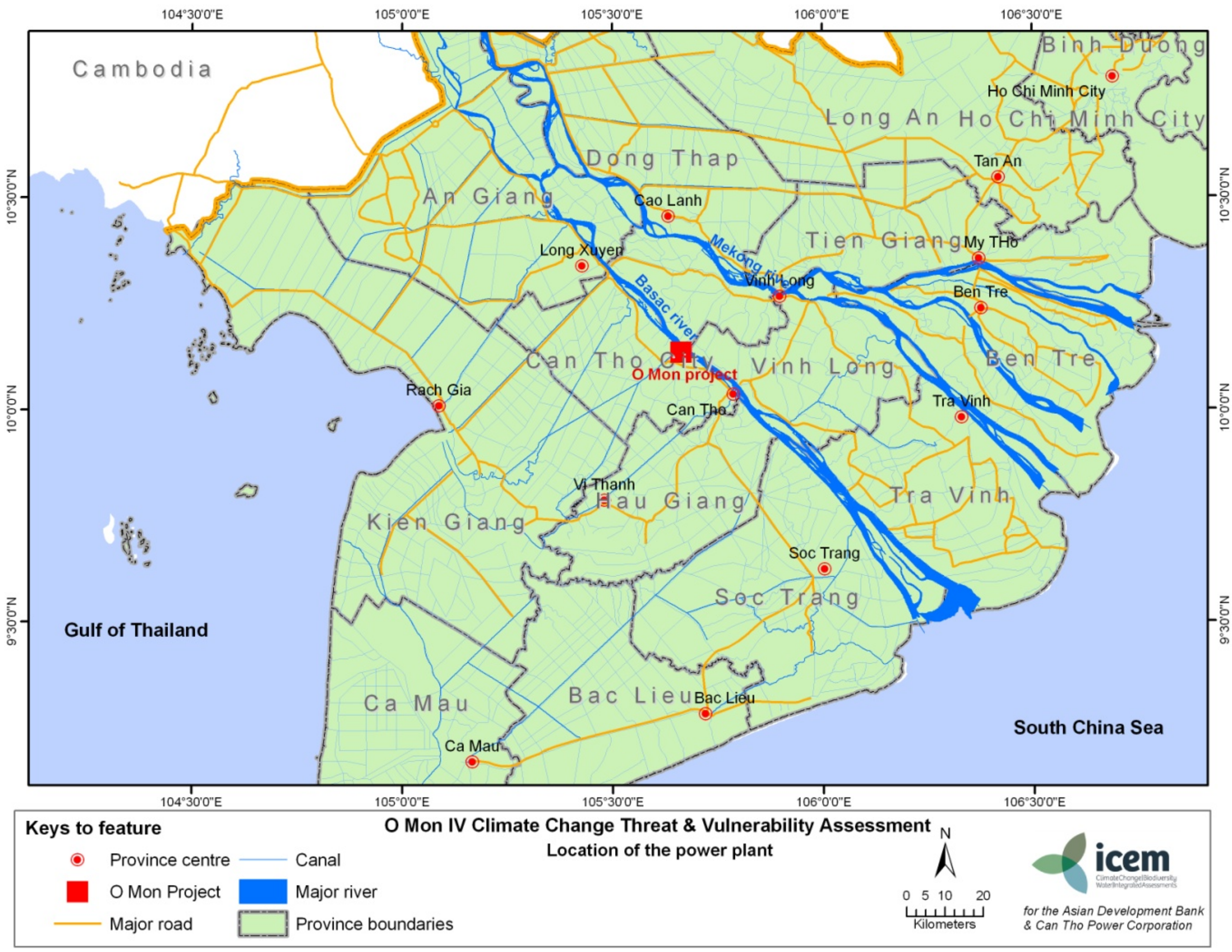
1.2 DESCRIPTION OF THE SURROUNDING ENVIRONMENT

O Mon IV is one of 5 power plants in the O Mon power complex (“the complex”) which is situated at Phuoc Thoi and Thoi An ward, O Mon district, Can Tho City (Fig. 1). The complex lies in the heart of the Mekong Delta on the right-bank of the Hau River, approximately 80km from the coast and 17km upstream of Can Tho City. This region has complex hydrodynamics with tidal influences reversing the direction of flow in the river channel and shifting water quality from fresh to brackish, while the Mekong’s seasonal flood pulse varies water levels by 2.46m annually and 3.8m during extreme years.

The project area is flat with loose primary and secondary soil structures of clay and alluvial deposits underlying a tertiary layer approximately 3m below the natural top soil. The complex covers an area of approximately 160 ha of a low-lying island in the Hau River floodplain and is surrounded by the Hau River, the O Mon River, the Vam creek and the Chanh creek with a natural ground elevation of on average 0.8 – 1.0m above sea level. At the site, the Hau River is a straight channel 760m wide and 22-23m in the deepest part, while the two creeks are 6-7m deep (ADB, 2010). Historically, the surrounding land use is predominately agriculture with growing industrial and urban sectors. A summary table of the surrounding environment is included in Annex 1.

[4] CAM – Climate Change Adaptation & Mitigation

Figure 1 Location of the O Mon Power Complex



1.3 DESCRIPTION OF THE POWER PLANT

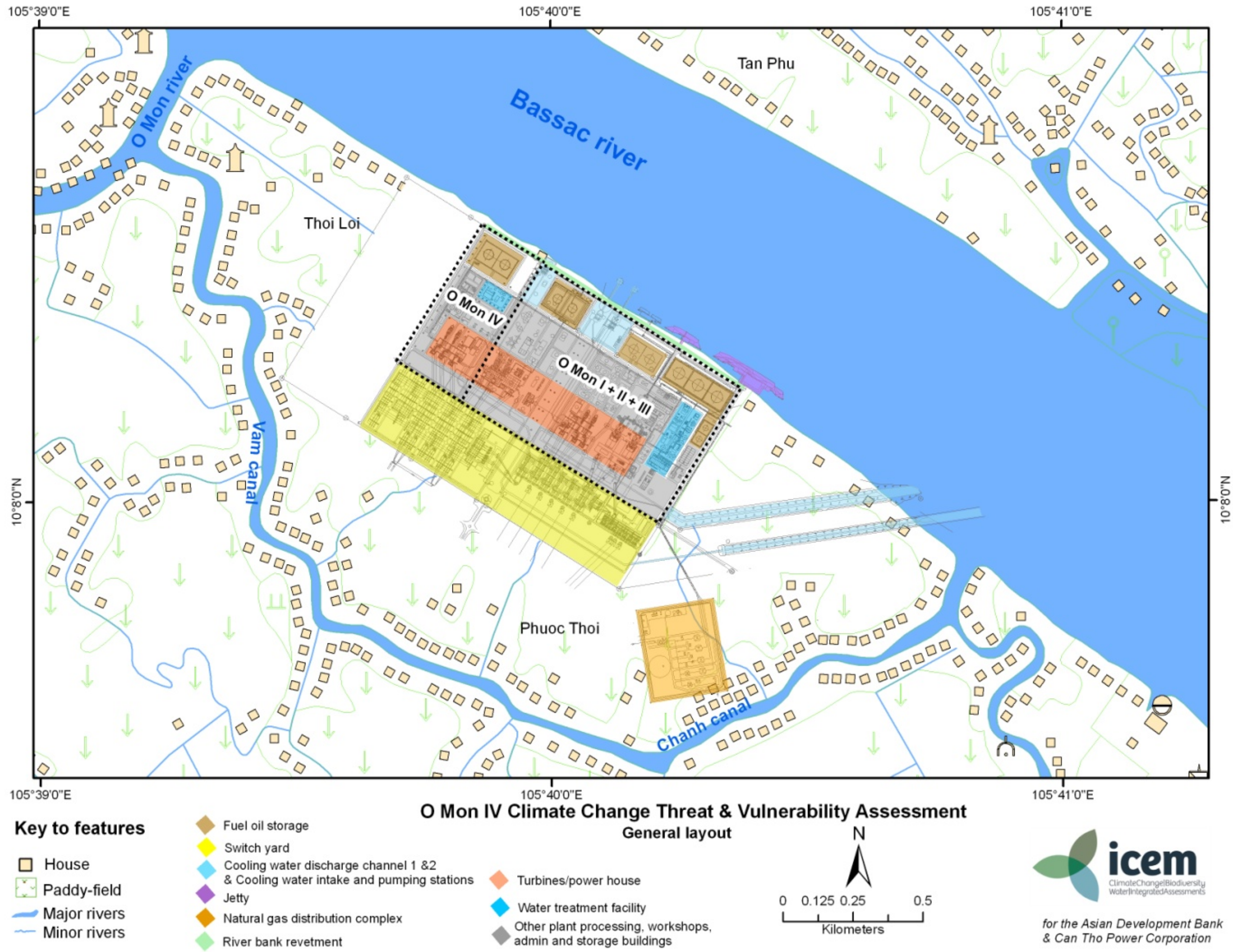
O Mon IV is a Combined Cycle Gas Turbine (CCGT) thermal power station with a design capacity of 750 MW. Under normal conditions the plant has a net efficiency of 56.4% and is expected to generate 4,500GWh of electricity per year, with fuel supply coming via a pipeline from the Block B&52 gas fields in the Gulf of Thailand.[5] Construction is scheduled to begin in 2013 with the plant expected to come online in the fourth quarter of 2015. To date, the following works and activities have been undertaken:

- The Feasibility Study and Detailed Design was approved by EVN on July 27, 2006 and August 26, 2009 respectively
- EIA Report (prepared by PECC3) was approved by MONRE on December 20, 2007
- Access road No.2 is now under construction
- Gas pipeline is now under construction
- Land clearing and filling work is now underway to prepare the O Mon IV pad (figure 3)
- A temporary earthen dyke has been built to protect the river bank at the project site (Figure 3)
- The EIA report was redrafted for the ADB by an independent consultant in September, 2010
- Tenders for detailed design are currently under review

[5] The assessment of climate change impacts on the gas fields and pipeline lies beyond the scope of the present study, The study team recommend that a separate rapid assessment be undertaken for the pipeline as the plant's vulnerability is strongly contingent on ensuring a secure and reliable fuel supply.

O Mon IV is one of 5 projects under preparation within the O Mon power complex (Figure 2). O Mon I is a 660 MW conventional twin turbine plant which utilises distillate fuel oil (DFO) as the fuel source and has been operational since December 2009. It is anticipated that O Mon I will also switch to natural gas in the near future. O Mon II, III and IV are under design and each have a capacity of 750 MW, while O Mon V is under consideration with no firm plans. The 5 plants will share a switchyard, jetty and gas storage facility. O Mon I and II also share water intake, treatment and discharge infrastructure, while O Mon III and IV will have a similar shared arrangement for water intake, treatment and discharge infrastructure (Figure 2).

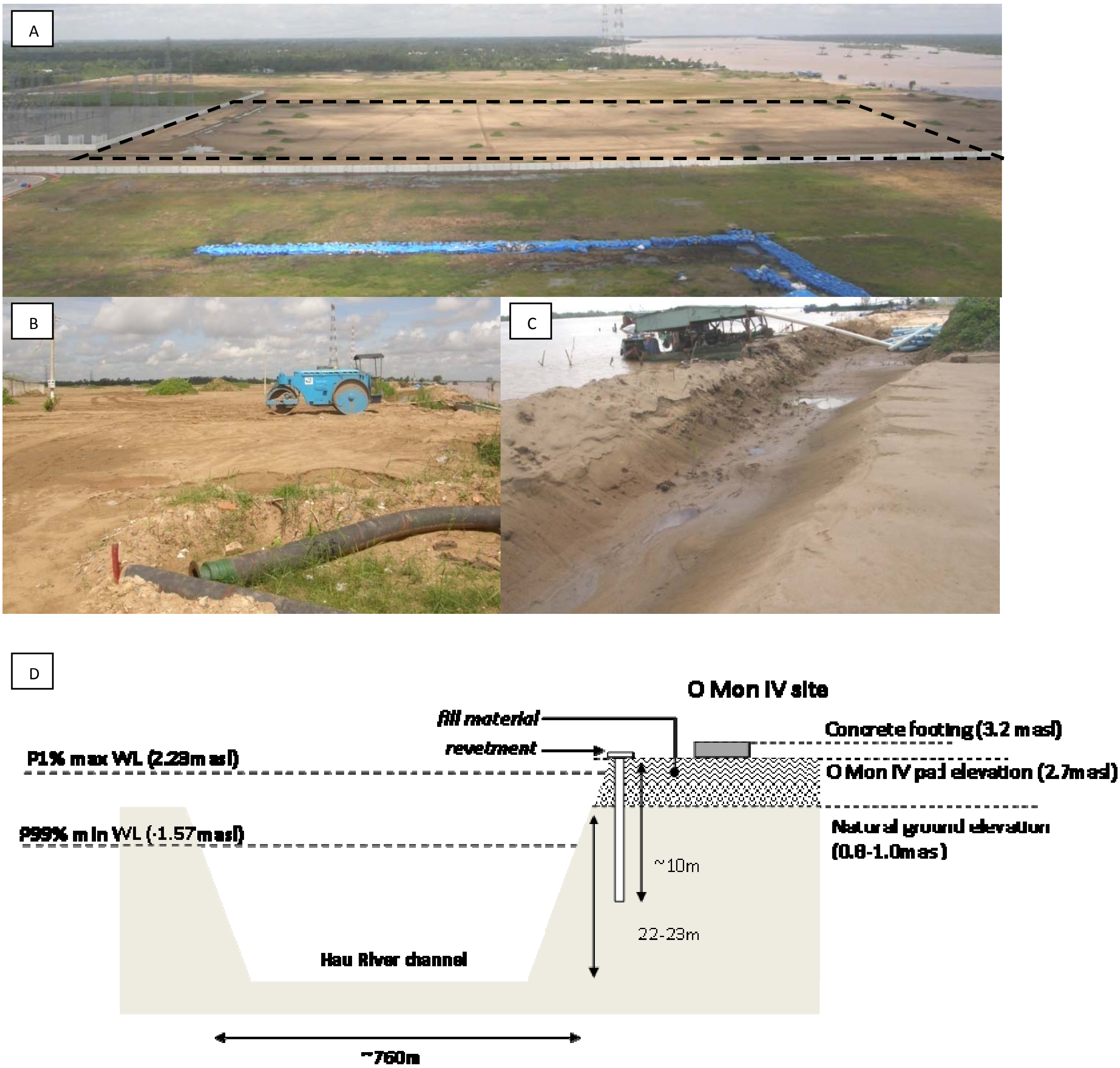
Figure 2 General Layout of the O Mon Power complex



1.3.1 Protection works

O Mon IV will be built to an elevation of 2.7 masl, which requires the plant pad be raised by 1.7 – 1.9m (Figure 3). The fill for the pad is primarily derived from sands extracted further upstream and will require in the order of 250,000m^3 after compaction. The elevation of the plant pad is the primary protection measure against overbank flooding and other riverbank hydraulic processes. In addition a revetment system will be installed involving interlocking metal sheets sunk 10m below the surface along the Hau River bank, in order to protect the bank from erosion (Annex 1). The barrier is capped with concrete protruding 0.2m above the elevated pad level. Each major component in the plant also sits on a concrete footing, providing a further 0.5m freeboard, such that the majority off plant equipment sits at 3.2masl or approximately 1.0m above the historic P1% flood event (Figure 3).

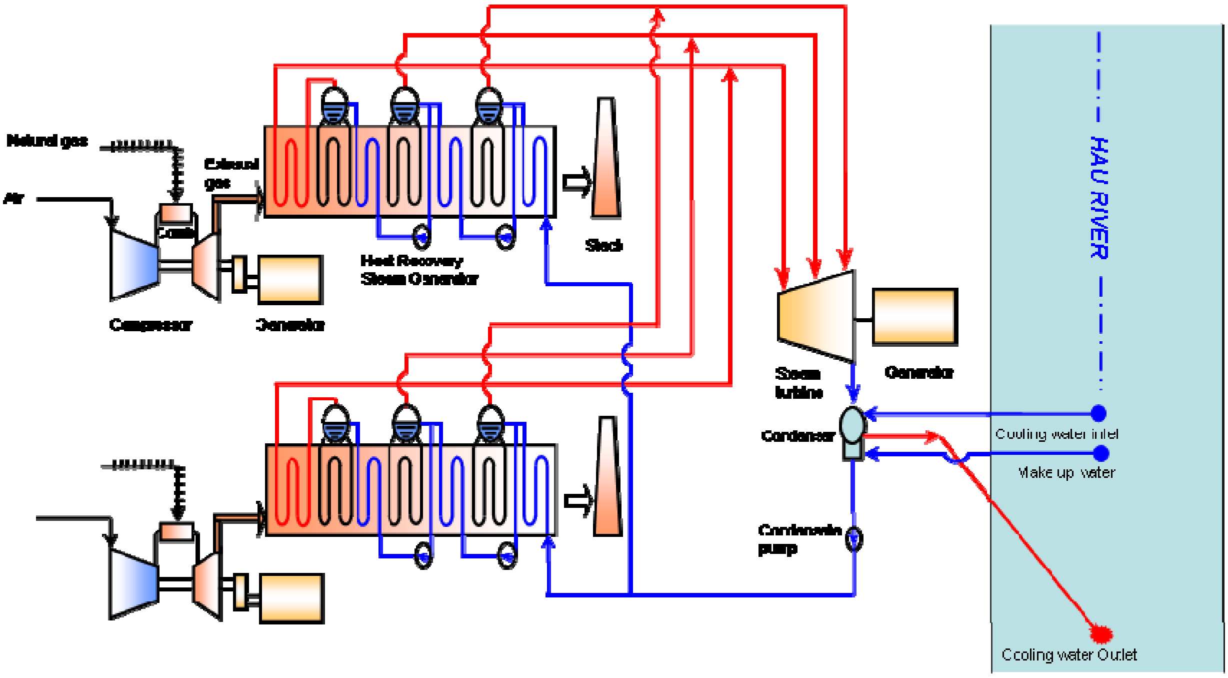
Figure 3 Current condition of the O Mon IV site: *(**A**) O Mon IV pad (dashed area/middle ground) has been cleared and work has begun to raise and level the pad to design elevation of 2.7 masl. The site is bordered by the Hau River, the O Mon complex switchyard, O Mon III (foreground) and proposed O Mon V site (background); (**B**) pad preparation works include the transport of fill material by boat and the compaction of fill material using heavy machinery; (**C**) clearing of the riparian vegetation has left the river bank exposed to erosion and a temporary earth dyke has been built and continuously maintained to protect the O Mon IV pad from flooding & erosion; (**D**) Schematic cross-section of O Mon IV elevation compared to historic river water levels (not to scale)*



1.3.2 Plant processes

As a CCGT power plant, O Mon IV uses natural gas, oxygen and water to generate electricity via two key thermal processes – the gas turbine cycle and the steam turbine cycle – both of which convert thermal energy (combustion) into mechanical energy at the turbine and subsequently electrical energy at the generator. Each process is supported by a particular cooling process designed to remove heat from the system. CCGT plants can be considered as the combination of two conventional gas-fired and one steam-rankine power cycle, which is typically known as a 2-2-1 configuration. Two gas-fired turbines comprise the *topping cycle*, and the waste heat produced is then recycled into a second *bottoming cycle* comprised of one steam turbine (Figure 4). A 2-2-1 configuration is typical for CCGT plants because it is found that the exhaust heat from two gas turbines is needed to provide sufficient energy for one steam cycle. The main advantage of the CCGT system is a cumulative system efficiency greater than either a conventional gas or steam power station (Kelhofer et al, 2009).

Figure 4 Schematic diagram of O Mon IV combined cycle plant



There are three processes which are critical to power production and which directly rely on the surrounding environment (air and water) for inputs. These processes are summarised in figure 4 and described below:

A - GAS TURBINE CYCLE

In the O Mon IV *topping cycle,* air is drawn from the atmosphere into a compressor and then injected under pressure into the combustion chamber together with natural gas where it is ignited to produce a high temperature and high pressure gas. The turbine inlet temperature (TIT) typically reaches in the order of 1200°C. In the turbine these gases are then converted to work which drive the turbine connected to a generator for electricity production. Each gas turbine has a design power output of 260-290MW and design efficiency in the order of 40%.

B - STEAM TURBINE CYCLE

Exhaust gasses from the gas turbines remain at very high temperatures (638°C), the CCGT process recycles the remaining energy in the exhaust gas to drive a secondary or *bottoming* cycle. This is achieved by piping the exhaust gas through a heat recovery steam generation system (HRSG) to heat treated river water for the generation of steam. In O Mon IV two HRSGs are proposed with a combined capacity of 714 tons/hour.

Under normal operations, 84m^3/hr of raw water is drawn from the Hau River and undergoes treatment including: sedimentation, primary and secondary filtration with activated carbon and demineralisation. The purified water is then passed through the HRSGs and utilising the heat in the topping cycle exhaust gas is converted into steam. The steam from both HRSGs is forced through the throttle to drive a single steam turbine connected to a generator for electricity production. The steam turbine has a design power output of 264-289MW and efficiency in the order of 30%.

After the steam expands through the turbine, it is piped through a heat exchanger to convert the steam back into water (condensate). This condensate is then returned to the HRSG through high-pressure feed pumps for reuse.

C – COOLING WATER CYCLE

In order to convert the steam expelled from the turbine back into a condensate, heat must be extracted. In O Mon IV this is achieved using a *once-through* cooling water cycle. The source of the cooling water (CW) is the Hau River, where water is drawn by gravity into an underground pit via a screened 30m-wide intake. Two CW pumps with a combined design capacity of 18m^3/hr then draw water from an inlet 5m below the surface and pump the CW into the heat exchanger. The external surface of the heat exchanger is exposed to pumped cooling water, while the expelled steam flows within. This transfers heat energy from the steam flowing inside the pipes to the CW outside cooling the steam back to water.

The cooling water exits the heat exchanger at a higher temperature than the inlet and is circulated to an underground tank before being discharged back to the Hau River via an open channel. The increment of temperature increase can be controlled by altering the pumped flow rate by partially opening or closing the globe valves immediately downstream of the CW pumps. A higher flow rate will result in lower discharge temperature for the CW but will require greater fuel consumption at the CW pumps. Under normal operating conditions the valves are 70-80% open with total energy consumption in the CW pumps of 4,114kW and a discharge temperature below +7°C above the natural river water temperature (Vattenfall, 2008; PECC3, 2007).

These three processes are characterised by the range and average daily temperatures of the working media – air and river water.

1.3.3 Plant layout & design

O Mon IV is situated on a 575mx240m rectangular block on a southwest-northeast axis. The block backs onto the Hau River to facilitate transportation of fuel and other plant materials. The pad can be divided into 5 main areas based on their function and the type of infrastructure (Figure 5). The location of the 5 areas within the pad is broadly consistent with the other O Mon plants.

AREA 1. *Main Equipment:* Area 1 is at the south-western end of the pad and contains the main equipment used in the production of electricity and the control of plant operations, including: the turbine hall which contains 02 gas turbines and the steam turbine, auxiliary equipment and also a crane with a capacity to lift all the components inside the turbine hall. The area also contains 02 natural circulation HRSGs (either horizontal or vertical) with a 40 m high emissions stack; generators and step-up transformers; the administration building and the control room. Connections of the generators and transformers to the 500 kV transmission line are made through the 500 kV switchyard which is located adjacent to Area 1.

AREA 2. *Workshops & administration*: contains lower value infrastructure such as security buildings, workshops, canteen and parking facilities.

AREA 3. *Water treatment system*: is in the central section of the O Mon pad and contains the plant components utilised for treatment of intake river water for use in plant processes (settling, demineralisation, water supply pump stations and fire protection pump stations), together with water storage tanks for filtered and demineralised water.

AREA 4. *Wastewater treatment:* adjacent to the O Mon III pad, this area will house the domestic and central waste water treatment systems, oil-water separator with connections to discharge points. This area is also used during maintenance and repair of plant components

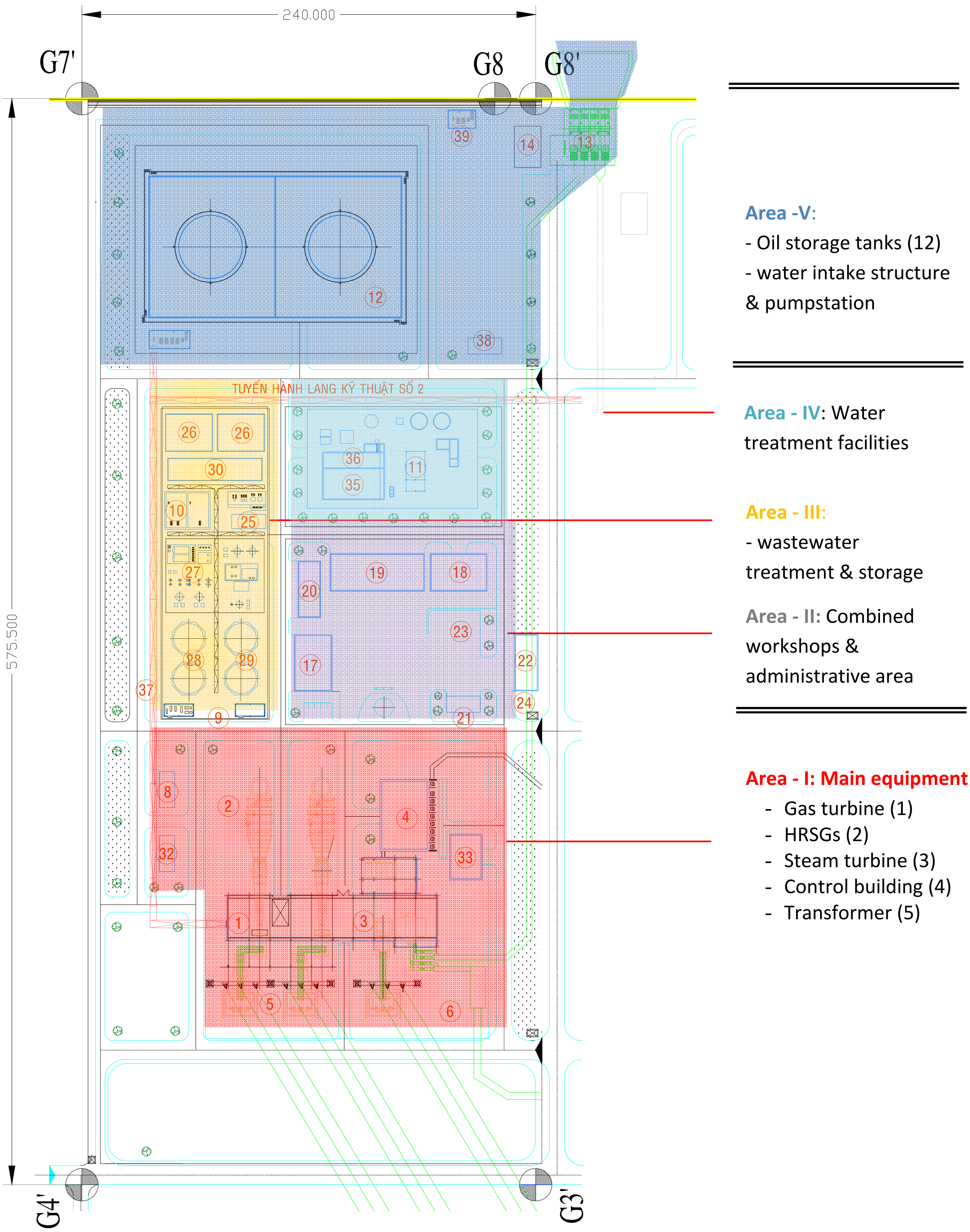
AREA 5. *Oil storage & water intakes*: immediately adjacent to the Hau River, the area will house key components of the raw water intake system including cooling water (CW) pumping facilities, chlorine dosing station as well as storage and pumping facilities for back-up DFO.

The detailed schedule and other key parameters of O Mon IV are provided in Table 1.

Table 1: Main parameters of O Mon IV (Source: ADB, 2010)

No	Description	O MON IV power plant
A	**Technical parameters**	
1	Installed capacity	750 MW
2	Technology	Combined cycle with a configuration of 2-2-1
3	Fuel	- Gas from Block B&52, *and* - DFO as back up fuel
4	Cooling water	- Water source: Hau River - Intake: 18 m^3/s
5	Feed water	Fresh water taken from Hau River and to be treated before supplied to the power plant.
6	Power output	4.5 billion kWh
7	Annual operating hours	- average: 6,000 hours - max: 6,500 hours
8	Net efficiency	56.4%
9	Lifetime	25 years
B	**Design parameters**	
1	Design air temperature	30 Deg C
2	Humidity	85%
3	Design water temperature (inlet)	30 Deg C
4	Design water temperature (outlet)	Inlet + 7deg
5	Design elevation of the plant pad	2.7 masl
6	Design elevation of most plant equipment	3.2 masl
C	**Implementation schedules**	
1	EPC contract signing	Quarter I/2013
2	Operation gas turbine No. 1	Quarter I/2015
3	Operation gas turbine No. 2	Quarter I/2015
4	Commercial operation of the plant	Quarter IV/2015

Figure 5 O Mon IV plant layout: key components of the CCGT plant



1.3.4 Assets

Total investment in the O Mon IV plant is expected to require USD 778 million (CTTP, 2010). The most up-to-date financial breakdown provided by CTTP account for VND 10,704,175 billion (approximately USD 550 million), of which VND 1 billion is for plant infrastructure and construction works; VND 7.9 billion are for main plant equipment and VND 0.375 billion is for shared facilities with O Mon III, with the remainder estimated for access roads and staff apartments.

Main assets of O Mon IV power plant are listed in Table 2 where information was available, with a more detailed list of base costs provided in Annex 2.

Table 2 Main assets of O Mon IV power plant

Main equipment	Main specification	Quantities	Value ($USD mill)[6]
Gas turbine	Indoor, air cool; capacity 260-290 MW/unit Generators: 300-340 MVA/unit, 50 Hz Power factor: 0.85 (lagging), 0.9 (leading)	2 units	
HRSG	Natural circulation, Horizontal type, three pressure levels Evaporation: about 714 T/h	2 units	
Steam turbine	Capacity: 260-290 MW/unit Generators: 310-340 MVA/unit, 50 Hz Power factor: 0.85 (lagging), 0.9 (leading)	1 unit	
Step-up transformer			1.57
- For gas turbines	15.75 (21)/510±10%x1.25% kV Rated output: 300-340MVA, 50 Hz	2 units	
- For steam turbine	15.75 (21)/510±10%x1.25% kV Rated output: 310-340 MVA, 50 Hz	1 unit	
Intake tower and pumping station	30m wide intake with bar screens		2.0
Discharge channel	650mm lining Design flow rate 54m³/hour Bank-slope m = 1.5 Channel depth 8.92m Max WL +2.28masl Min WL -1.6masl		8.9
Main buildings			47.0
500 kV switchyard		1 unit	1.0
DFO tanks	10,000 m^3	2 units	2.1
Pumping station, fire fighting piping system, fire fighting trucks			3.65
Access road No 2			5.05

1.3.5 Equipment life-cycle

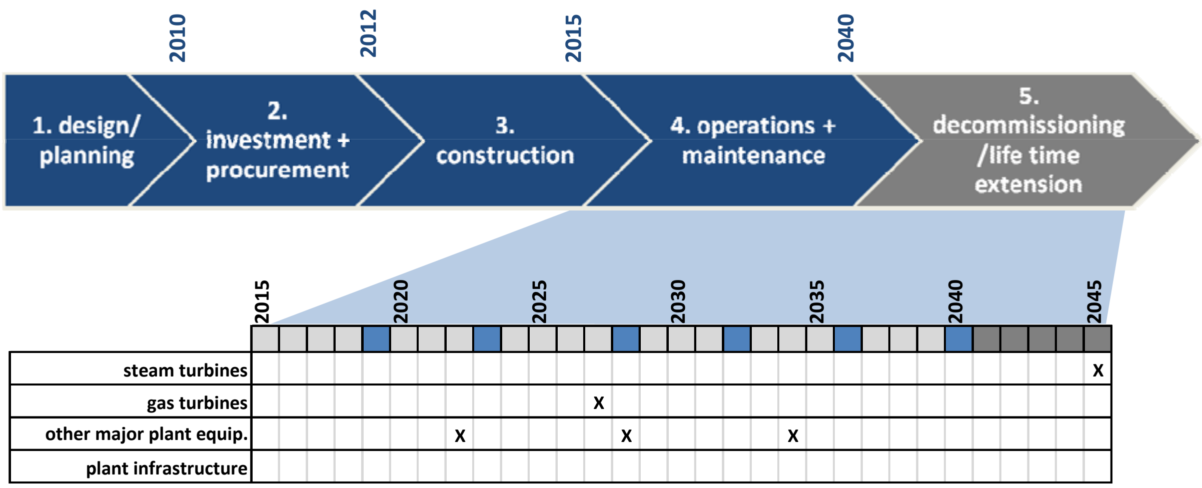
The life-cycle of the O Mon IV plant is divided into 5 main project phases (figure 6):

1. Design/planning
2. Investment and procurement
3. Construction
4. Operations and maintenance
5. Decommissioning/life-time extension

The plant is designed to operate at base load but able to respond to changes of load and endure regular start/stop operations. The average annual hours of operation is estimated at 6,000hours with a maximum of 6,500hours.

[6] Values are included where available

Figure 6 O Mon IV indicative project timeline



Component	hours	years	months
maintenance			
minor	8,000	1.3	16
major	16,000	2.7	32
major overhaul	32,000	5.3	64
replacement			
steam turbine	180,000	30.0	360
gas turbine	72,000	12.0	144
major plant equip	42,000	7.0	84

X	replacement
	operations + repairs
	major overhaul
	decommissioning/lifetime extension

Each component of the plant has its own life-cycle within the project time line determined by the plant operating regime. The individual component life-cycle includes a series of periodic maintenance following the detailed guidance of equipment suppliers. Typically, three types of maintenance interventions are stipulated: minor repair, repair and overhaul (figure 6).

For gas turbines, these are equivalent to inspection of combustion (usually after 8,000 hours or once every 16months of normal operation); inspection of stack or hot gas part inspection (HGPI) (usually after 16,000 hours or once every 32 months of normal operation), and overhaul (usually after 32,000 hours or once every 65.5months of normal operation), respectively.

The replacement schedule of the main plant equipment is an important consideration for adaptation planning as together with design and construction phase they define the entry points for adaptation response. Under base load operations, most plant infrastructure will need to be replaced at least once during the design economic life – the exception being the steam turbine which typically has a life of 25-30years in tropical environments (OECD, 2000; Heinzel, 2009). The gas turbines will need to be replaced or undergo a major life-time extension overhaul approximately mid-way through the design economic life, while other major plant equipment (pumps, compressors, HRSGs, heat exchangers etc) would require replacement every 7-10years (figure 6). Actual replacement scheduling depends on equipment specifications, actual plant operations and effectiveness of maintenance.

1.4 UPSTREAM DEVELOPMENT AND FUTURE CHANGES TO THE FLOW REGIME

Over the past several thousand years the Mekong River has reached a state of dynamic equilibrium characterised by a flood pulse hydrograph (MRC, 2005). In the past 15 years the Mekong Basin has been undergoing dramatic change as the Mekong countries of Lao PDR, Thailand, Viet Nam, Cambodia and China (Yunnan Province) seek to develop the basin's immense potential for hydropower. By 2015 the number of hydropower projects on the Mekong River and its tributaries will increase from 16 to 46, increasing installed capacity from 3,136 MW to 19,918 MW (Table 4, Figure 8). These 46 projects will have the capacity to store

44,415 million cubic metres of wet season flow in their reservoirs for release during dry season electricity production. With an average annual flow of 495,000 mcm, this represents the capacity to store in the order of 10% of wet season flows resulting in an average 20-50% increase in dry season flows at Kratie (Figure 7).

Upstream hydropower projects planned for 2015 will also halve the sediment load of the Mekong River (ICEM, 2010). At present the average annual sediment load at Kratie is 165 million tonnes. A proportion of this is deposited on the Tonle Sap and Mekong Delta floodplains of Cambodia and Vietnam. The remainder (approximately 63%) travels down the main river channels of the Mekong (Hau and Tien Rivers) before deposition at the river mouth and near coastal shelf. Based on the distribution of flows between the Hau and Tien Rivers it is expected that 18 million tonnes of sediment are transported past the O Mon complex. Sediment levels in the Hau River play an important role in erosion and deposition processes regulating ground water levels as well as controlling the depth of light penetration and hence influencing the temperature profile of the water column. Higher sediment loads trap more light and heat at the surface increasing warming, while deeper light penetration allows for warming to influence deeper layers of the water column.

Table 3: Hydropower development in the Mekong Basin & predicted increase in total active storage (Source: ICEM, 2010)

Mekong Basin country	No. of dams		Total active storage (mcm)		Total installed capacity (MW)	
	2000	2015	2000	2015	2000	2015
Lao PDR	8	20	5,593	17,166	621	3,502
Thailand	6	6	3,276	3,276	245	245
Cambodia	0	1	0	0	0	1
Viet Nam	1	13	779	2,619	720	2,284
China	1	6	257	23,193	1,550	15,450
TOTAL	***16***	***46***	***9,906***	***46,254***	***3,136***	***21,482***

For O Mon IV, an assessment of the future flow and water levels in the Hau River by 2040 will need to incorporate this regulation of seasonal flows in the basin and loss of sediment load. For this rapid study this has been undertaken as a sensitivity analysis overlayed on top of modelled future flows with climate change through the generation and use of a rating curve for the Hau River. This allows for the study to assess the incremental change associated with upstream hydropower development.

Figure 7: Change in Mekong Hydrograph (Kratie station) by 2015 due to hydropower development: *(left) average daily discharge at Kratie in 2000 and 2015 based on 14year time series; (right) average percentage change in daily discharge at Kratie between 2000 and 2015 – dry season flows increase by 20-50%, while wet season flows will decrease in the order of 10% due to storage of wet season flows. During dry years, the changes will be much more pronounced* (Source: MRC, 2009)

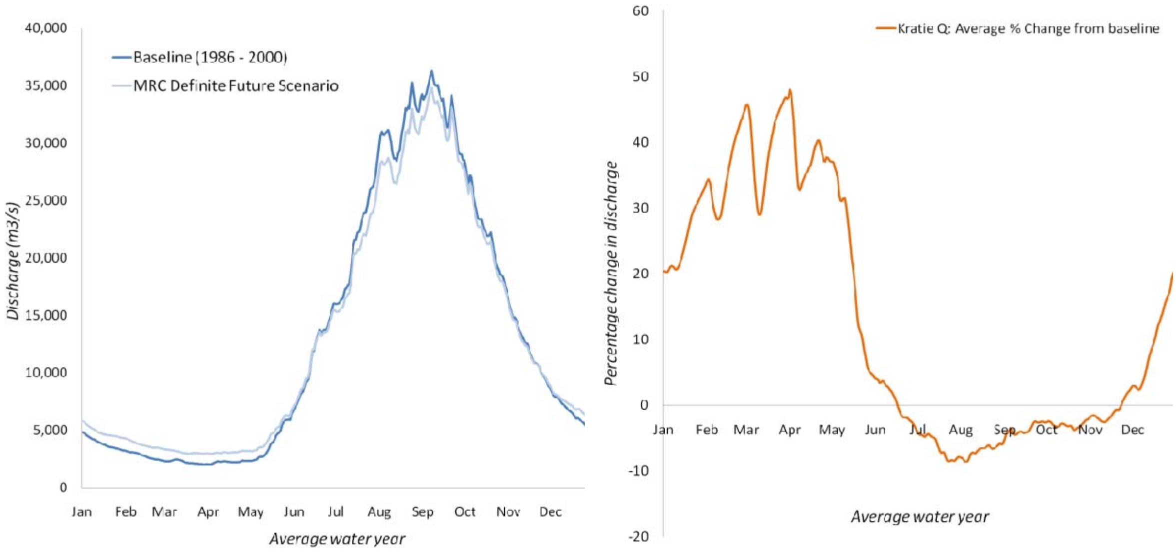
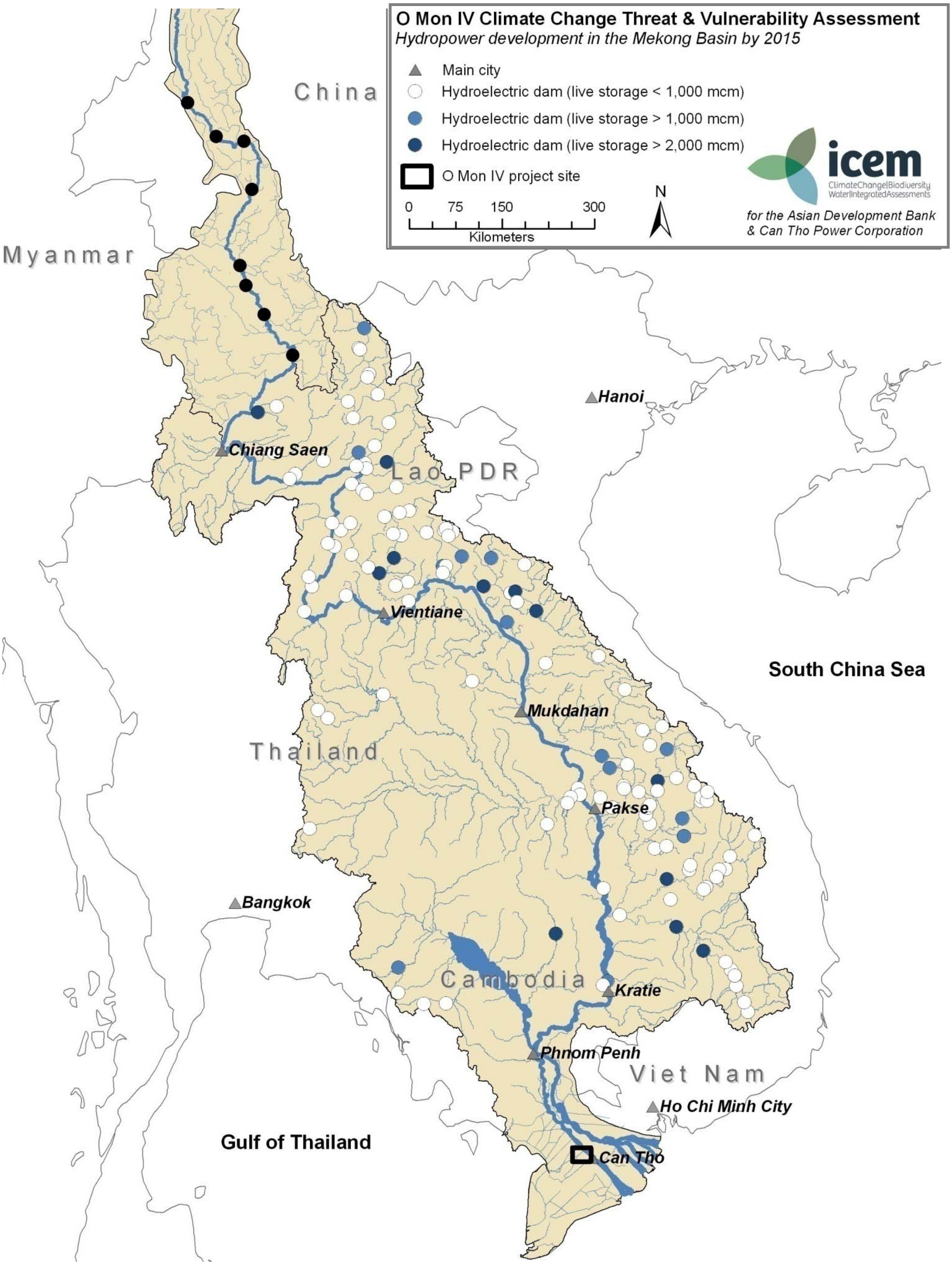


Figure 8: Hydropower development in the Mekong Basin by 2015: *projects identified represent those that exist, are under construction or have achieved a firm level of planning by 2015.* (Source: MRC, 2009)



2 ASSESSMENT METHODOLOGY

In designing and building large infrastructure projects investors and engineers utilise safety margins to factor an acceptable level of risk into project design – freeboards are included in flood protection works, ranges of variability are built into operating processes and performance curves are developed for particular infrastructure components. This characterisation of risk is fundamental to plant management and represents a sensitive balance between ensuring a desired level of safety, optimising performance and minimising the cost of investment. Typically, larger safety margins require greater cost. For example, the foundations for the O Mon IV gas turbine are raised 0.5m above the pad elevation and amount to an investment of ~USD 1.5 million, further raising the freeboard (height of the foundation) would result in a substantial increase in this cost and require considered assessment of the risk and associated costs. By convention, methods such as hydro-economic analysis and composite risk analysis are used to: (i) optimise the capital cost and the risk of failure from extreme events, (ii) forecast the current and future loading on plant infrastructure and define plant capacity within the acceptable level risk (Chow et al, 1988).[7]

The characterisation of risk for large infrastructure relies on detailed statistical analysis of historic time-series data to understand the surrounding hydro-geophysical conditions and set key design parameters (e.g. ambient temperature, max. water levels in the Hau River, earthquake incidence). In the long term, many of these parameters will change in response to climate change - affecting the performance of the plant, the cost of maintenance and the life of plant components. Predicting the exact magnitude of changes to hydro-metrological parameters is a complex process, highly dependent on the modelling approach used and also the projections made concerning future global GHG emissions.[8] So, while a "no-action" approach on climate change will increase the risk for O Mon IV, incorporating climate change into the plant's design could increase both design uncertainty and the cost of investment and requires a rigorous scientific evidence base in order to proceed.

The rapid assessment methodology utilised in this study adapts the ICEM CAM methodology to characterise the threat, assess the plant's vulnerability to, and recommend priority areas for adaptation response for climate change over the plant's design life. At the core of this approach are four key principles:

1. **Confidence in impact:** the study will focus on those threats which can be *directly* linked to O Mon IV design. Direct threats are those which affect a key design parameter of the plant and for which change in trends for that parameter can be quantified with confidence. The concept of *directness* is an important element of the methodology to reduce the level of uncertainty which the climate change analysis introduces into the design.
2. **Identify levels of uncertainty:** acknowledging the uncertainty in climate science can better characterise exposure and build confidence in assessment findings. In this study the methodology will assess two different IPCC future climate scenarios SRES A2 and B2 and 8 different GCMs to explore a range of impact based on the range of threats predicted by international scientific consensus.[9] Where necessary, reporting has followed these ranges to better characterise threat.
3. **Comparable methodology:** where possible similar methodologies are employed in the study as those used by design engineers to set the design parameters. This allows results to be compared with calculations undertaken under conventional design phases.

[7] Hydroeconomic analysis estimates the damage and probability of occurrence associated with a particular hydrologic event and uses this to optimise the design return period against capital cost of infrastructure, composite risk analysis accounts for the risks which arise from multiple sources of uncertainty by fitting probability distributions to plant loading and capacity and estimating the likelihood of loading exceeding capacity. These are common practice for large infrastructure design:

[8] A number of modelling steps are required to quantify how increases in GHGs affect the earth's climate, the knock-on effects on the global water cycle and the hydrological regime of specific river systems. Computational approaches can be analytical or statistical, and at each stage a number of assumptions are built into the modelling architecture. Similarly, a number of future climate change scenarios have been developed by the IPCC, reflecting different trends in global CO2 emissions, each scenario results in different impact estimates with increasing divergence for longer projections.

[9] IPCC. 2000. Special Report on Emissions Scenarios (SRES). Cambridge University Press, Cambridge

4. **Phasing response:** the impact of climate change on O Mon IV will extend over the entire plant life. Some adaptation will be required at the design phase, others can be introduced during the plant economic life, while others can be postponed until the end of the current economic life, at the point of major system refurbishment. By considering the timing of adaptation response, investors and operators can economise the cost of adaptation without comprising effectiveness.

Figure 9 outlines the conceptual approach to this climate change assessment. The approach is built around two critical starting points – the surrounding environment and the plant design:

A. **The surrounding environment** defines the hydro-geo-physical context of the plant against which design parameters and conditions are set and through which the threat of global climate change will influence plant operations. The surrounding environment characterises the *threat* of climate change to O Mon IV.
B. **The plant design** defines the sensitivity of the plant to change and is based on the type and design of infrastructure which makes up the plant (the material assets) and the type and design of the operational and maintenance processes which are utilised in electricity production. The plant design characterises the *sensitivity* of O Mon IV to climate change.

Threats are reviewed at the global, basin-wide, delta-region and site-specific levels to identify direct threats, which are then overlayed on top of existing plant design focussing on areas of sensitivity to define the impact of climate change on O Mon IV. The synthesis of these two elements defines the vulnerability of the plant. Conclusions are then made on the need and adaptive capacity of O Mon IV followed by recommendations on which components and plant processes should be the focus of adaptation response. The level of detail is sufficient such that economists can take the study findings and valuate the cost of *"doing nothing"* and then develop and compare with preliminary "*ball-park*" estimates of responding to climate change.

2.1 APPROACH TO THREAT ANALYSIS

Figure 10 details specific components of the assessment methodology and their inter-relation. The main objective of the threat analysis is to define and quantify the changes in spatio-temporal dimensions in climate variability. This includes the changes in incidence, magnitude and duration of hydro-metrological events. The study has considered threat at four geographical scales: (i) global, (ii) Mekong Basin, (iii) Mekong delta area, and (iv) the O Mon IV project site; and over a 80 year period (50 years to the present and 30 years into the future).

The threat analysis takes a modelling approach to downscale Global Circulation Models (GCMs) predictions for future climate, and then predicts changes in the hydrological regime. 8 GCMs were used together with 2 different downscaling techniques (dynamical and statistical). The ICEM IWRM model was then used to incorporate climate change into the Mekong Basin hydrological regime and establish the boundary conditions at Kratie. The next phase in the modelling was to determine the delta-wide changes in flooding downstream of Kratie using the boundary conditions provided by the IWRM model and the predictions for sea level rise defined in the official scenario of the Government of Viet Nam. This modelling utilised Hydro-GIS as developed by MONRE and presented a picture of future regional changes to flood duration and depths for the delta as well as defining the water level and discharge boundary conditions for the next phase of detailed hydro-dynamic modelling.

The final modelling phase was the development of a detailed three dimensional model of the channel network surrounding O Mon IV including the Hau and O Mon rivers, and the Vam Cong and O Mon complex discharge canals including the surrounding floodplains. This phase modelled: (i) heat-exchange at the air-water interface (AWI) to predict changes in the river water temperature profile at the O Mon IV inlet structures, (ii) changes in flow velocity and erosion potential, and (iii) water levels of the Hau River and surrounding canals under climate change. Importantly, the hydro-dynamic modelling also incorporated an assessment of the potential of the coolant feedback loop from the plant discharge channels to 'blow back' and exacerbate increasing river water temperatures at the inlet site.

Lastly, the threat analysis assessed the future changes in the Mekong hydrological regime due to intensified upstream hydropower and irrigation development to quantify their impacts during the design life of the project. Though not attributable to climate change upstream hydropower development represents a key driver of hydrological change in the basin, for some plant parameters, upstream development has the potential to offset the threats posed by climate change, exacerbating threats for others.

2.2 APPROACH TO VULNERABILITY ANALYSIS

The vulnerability assessment combined aspects of conventional engineering feasibility assessments with life-cycle analysis. It relied on two assessment phases – the sensitivity of the plant design to climate variability and the combination of the quantified direct threat and plant sensitivity to determine the impact over the design life. First an assessment was made of the hydro-physical conditions of the O Mon IV site with a focus on bank stability; geomorphic conditions of the immediate channel reach and pad elevation/stability. Then a detailed assessment was made of the plant design by reviewing plant design parameters and identifying vulnerable processes and components of the plant. An infrastructure/equipment inventory was compiled to determine the physical assets most at risk to damage and their value. Then an assessment was made of all plant processes to identify those that may be enhanced or compromised by climate change. This defined the sensitivity of the plant design to the threats of climate change. Functional links were then established between the vulnerable processes and assets of O Mon IV and the direct threats identified during the threat analysis phase.

The impact analysis overlayed each climate change threat predicted by the modelling on the vulnerability of specific plant components, using identified functional links. Based on these relationships, an assessment was then made on the magnitude of the climate change impact on O Mon IV over the design life, quantifying the scale of the risk posed by climate change to the design and what level of climate change response is needed.

2.3 APPROACH TO ADAPTATION SCOPING

Once the magnitude of the impact and the need for adaptation has been understood, a rapid assessment was made of the adaptive capacity of the O Mon IV design, setting priority areas of response and flagging a number of corresponding potential adaptation options. These adaptation options are intended to establish the framework for comprehensive adaptation planning.

Figure 9: Conceptual framework of the climate change rapid threat & vulnerability assessment, based on ICEMs CCAM – Climate Change Adaptation & Mitigation methodology

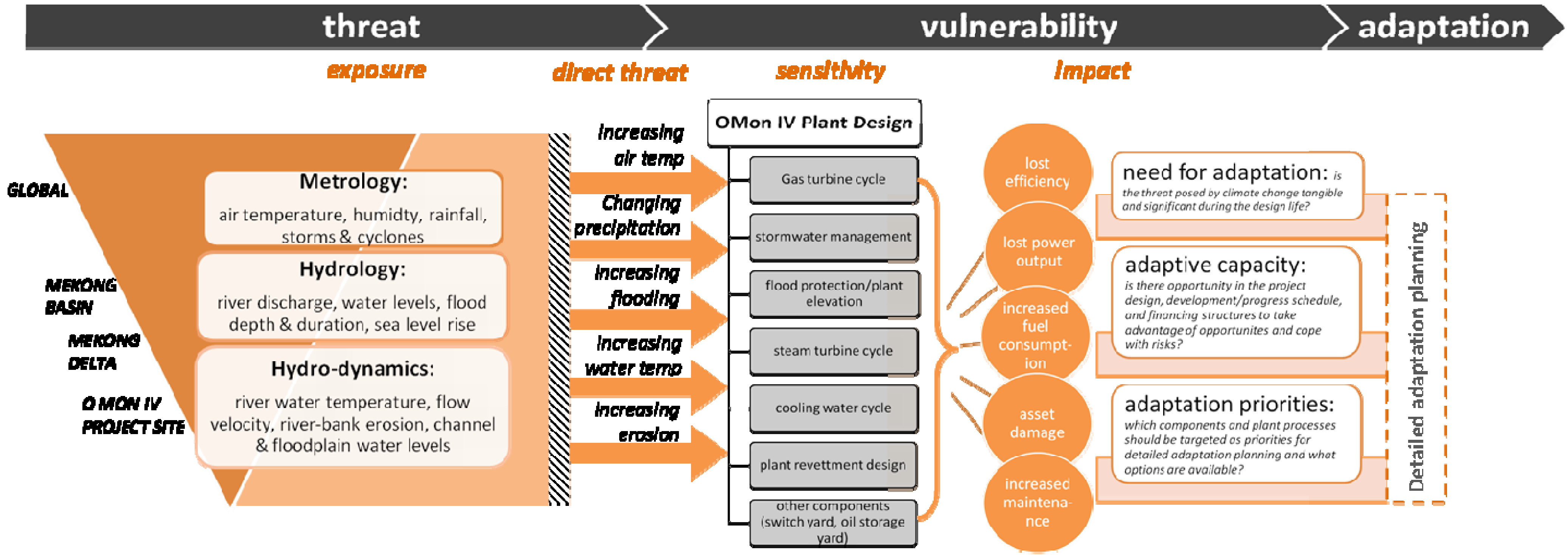
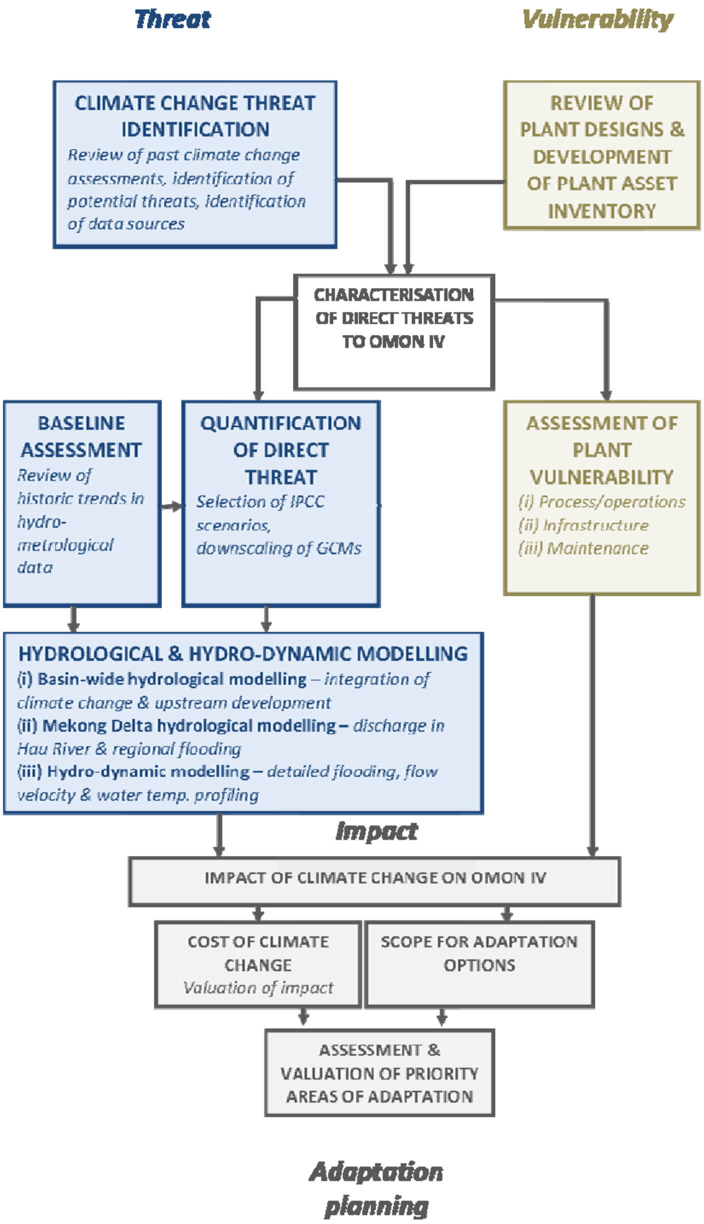


Figure 10: Schematic representation of critical steps in the assessment methodology



3 THE VULNERABILITY OF O MON IV TO CLIMATE CHANGE

Five key threats were identified as being of greatest significance to the O Mon IV plant:

Direct threat		Sensitivity of O Mon IV plant
Air temperature	→	Gas turbine cycle performance
River water temperature	→	Steam turbine cycle + coolant water cycle performance
Direct precipitation	→	Performance of gravity-driven stormwater management
Flood Depth + Duration	→	Asset damage + plant downtime
Erosion	→	Asset damage

The nature of exposure and impact of these threats varies. Some like air and river water temperature threaten day-to-day performance of plant operations, while precipitation and flooding can affect maintenance schedules and downtime. Erosion and flooding were identified as the two potential threats which could cause damage to planned infrastructure.

Following the CCAM methodology (figure 9, 10), the study team characterised the direct threats and linked them to associated plant components or processes. In this way, the vulnerability of the O Mon IV plant is specific to the prevailing hydro-physical environment of the site and the specific parameters and design specifications of the O Mon IV plant. Unless stated otherwise, details of plant design were obtained from CTTP, PECC3 or the field mission.

3.1 QUANTIFYING THE DIRECT THREATS

The future changes in climate are assessed with global climate models. GCMs are typically built with a coarse resolution of 2.25°x3.75° (~300km^2 grid cells) because current computers have insufficient computational power to model the entire earth-system with finer resolution. Because of the coarse resolution of the global models their results are downscaled to local level with different techniques. The models differ in terms of their resolution (number of cells representing the Earth), assumptions, data and processes they describe. Consequently an ensemble of models are typically used to reveal probable range of future climate change impacts. This approach has been also adopted in the study.

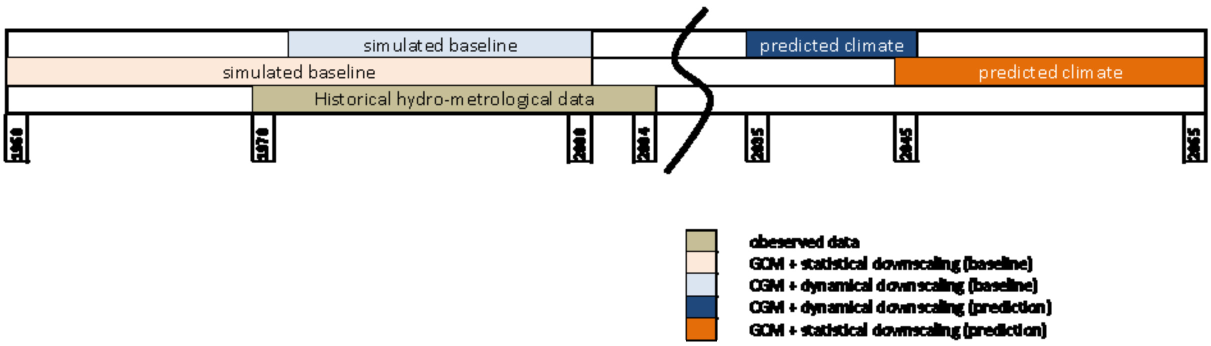
In order to predict future climate at Can Tho, the results of 8 global circulation models (GCMs) were used to generate predictions for two different time scales (2036-2045, 2045-2065) and for two different IPCC emissions scenarios (A2 and B2)(table 5). Higher resolution results were obtained using two downscaling techniques (statistical and dynamical) in order compare the influence of the methodology on the results. Results from a dynamical downscaling model with a full description of atmospheric physics were obtained from SEA START using the PRECIS platform, while results from a statistical downscaling approach were obtained from CSAG at the University of Cape Town. The two approaches differ in that the statistical approach does not need a full analytic description of all atmospheric processes, and works empirically, by identifying large scale statistical relationships between circulation patterns and local climate conditions. The two time periods were selected because the GCMs utilised are not designed for short-term climate forecasts and cannot adequately predict phenomena such as ENSO and North Atlantic Oscillation (NAO) which can induce multi-decadal variability in climate – this is particularly relevant for statistical approaches (SEI, 2009).

There is typically considerable margin for error in downscaled results from GCMs due to: (i) the coarse resolution of the CGM, and (ii) error introduced through the downscaling methodology. In order to extricate error from the model predictions, the GCM models were used to replicate historical data which was available for Can Tho City (~20km from the project site). The historical data available covered the time period 1978 – 2004 (26 years) and the simulated baselines had similar ranges of 20 – 40 years (figure 11).

Table 4 Key features of the climate modelling utilised

GCM ID	GCM source	Downscaling methodology	Source of downscaled data	Baseline time slice	Future time-slice	IPCC SRES scenario
ccma_cgcm3_1	Canadian Centre for Climate Modelling & Analysis	Statistical/ empirical	CSAG[10]	1961 – 2000	2045 – 2065 (Future A)	A2
cnrm_cm3	Meteo-France, Centre National de Recherches Meteorolgiques	Statistical/ empirical	CSAG	1961 – 2000	2045 – 2065 (Future A)	A2
csiro_mk3_0	Australian Commonwealth Scientific & Industrial Research Organisation	Statistical/ empirical	CSAG	1961 – 2000	2045 – 2065 (Future A)	A2
csiro_mk3_5		Statistical/ empirical	CSAG	1961 – 2000	2045 – 2065 (Future A)	A2
gfdl_cm2_0	NOAA Geophysical Fluid Dynamics Laboratory	Statistical/ empirical	CSAG	1961 – 2000	2045 – 2065 (Future A)	A2
giss_model_e_r	NASA Goddard Institute for Space Studies	Statistical/ empirical	CSAG	1961 – 2000	2045 – 2065 (Future A)	A2
ipsl_cm4	Institut Pierre Simon Laplace	Statistical/ empirical	CSAG	1961 – 2000	2045 – 2065 (Future A)	A2
mpi_echam5	Max Planck Institute of Meteorology (Germany)	Statistical/ empirical	CSAG	1961 – 2000	2045 – 2065 (Future A)	A2
		PRECIS (dynamic)	SEA START[11]	1980 - 2000	2036 – 2045	A2, B2

Figure 11 timescales for data simulation, prediction and calibration



The observed and modelled baselines were compared resulting in the selection of the NOAA Geophysical Fluid Dynamics Laboratory GCM (gfdl_cm2_0) as the most appropriate model platform for the study (figure 12).[12] Most other models performed well with the exception of: (i) csiro_mk3_5 which significantly under-estimated wet season average temperatures, and (ii) echam4_PRECIS which did not accurately replicate the historical data and was on average between 1.3 – 4.7 °C above the observed data (figure 12). [13]

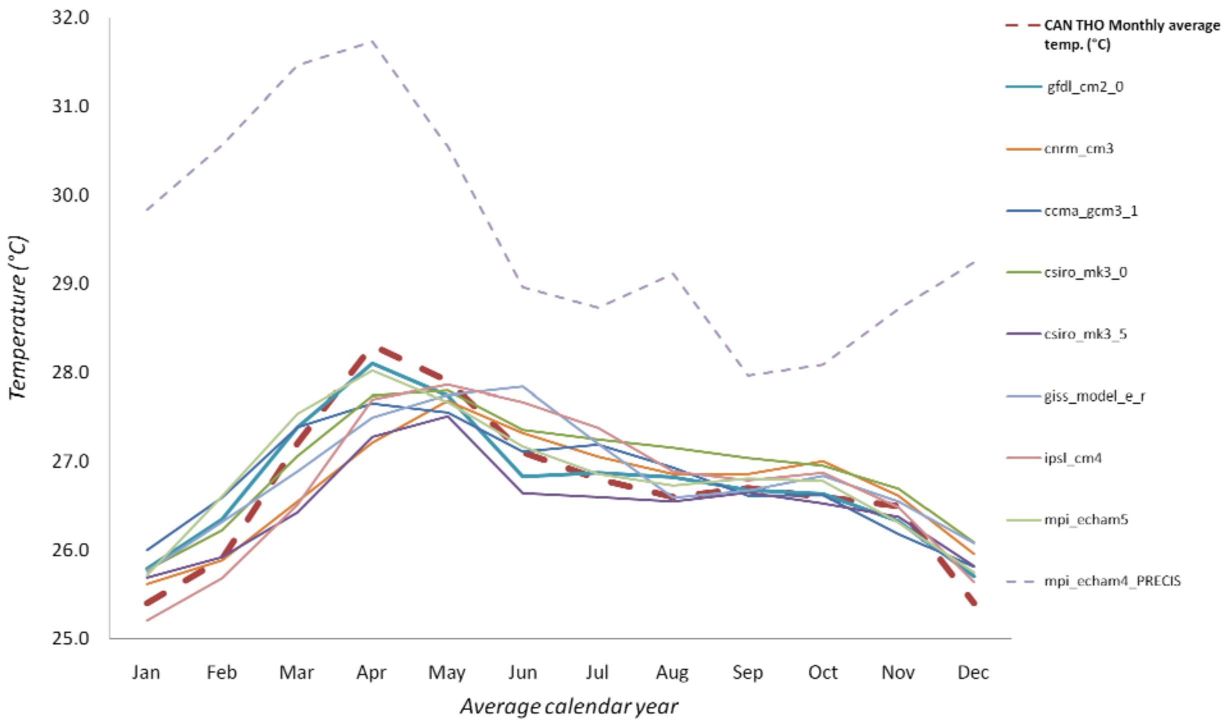
[10] CSAG is the Climate Systems Analysis Group of the University of Cape Town. CSAG DATA was obtained from the "WeAdapt" joint project between CSAG and the Stockholm Environment Institute (SEI) www.weadapt.org

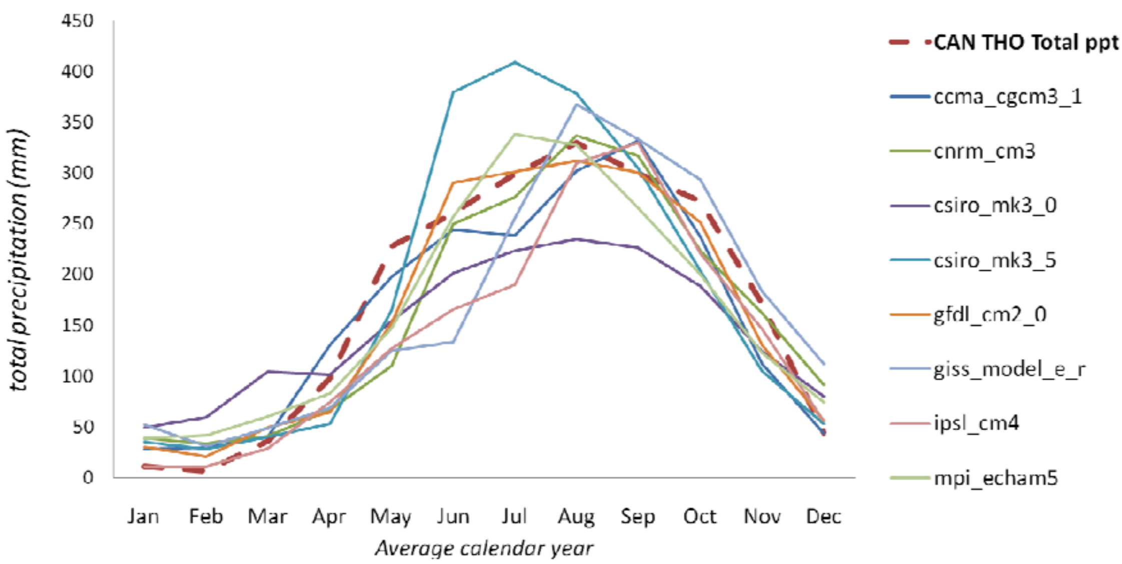
[11] SEA START is the Southeast Asia branch of the Global Change System for Analysis, Research and Training Centre based in Bangkok Thailand www.start.or.th

[12] Comparison of modelled and observed data used the Sum of Squared Errors (SSE) to select the GCM of best fit.

[13] PRECIS downscaling has since been updated subsequent to the finalisation of this study.

Figure 12 Comparison of 9 model baselines from 9 different GCMs for average monthly meteorology of the Mekong Delta: *(top) average monthly temperature, (bottom) total monthly precipitation. Based on the GCMs ability to reproduce the historical data set (dashed bold red line) a suitable GCM - gfdl_cm2_0 (turquoise solid line) from NOAA Geophysical Fluid Dynamics Laboratory was selected for use in the study. The greatest divergence was observed for the dynamical downscaling utilising ECHAM 4 and the PRECIS platform, while the cnrm_cm3 model from Meteo-France also produced a simulated baseline with good comparability to the historical data set.*





A similar assessment was undertaken for precipitation for which the GCM gfdl_cm2_0 also performed well, confirming suitability for the study (figure 12).

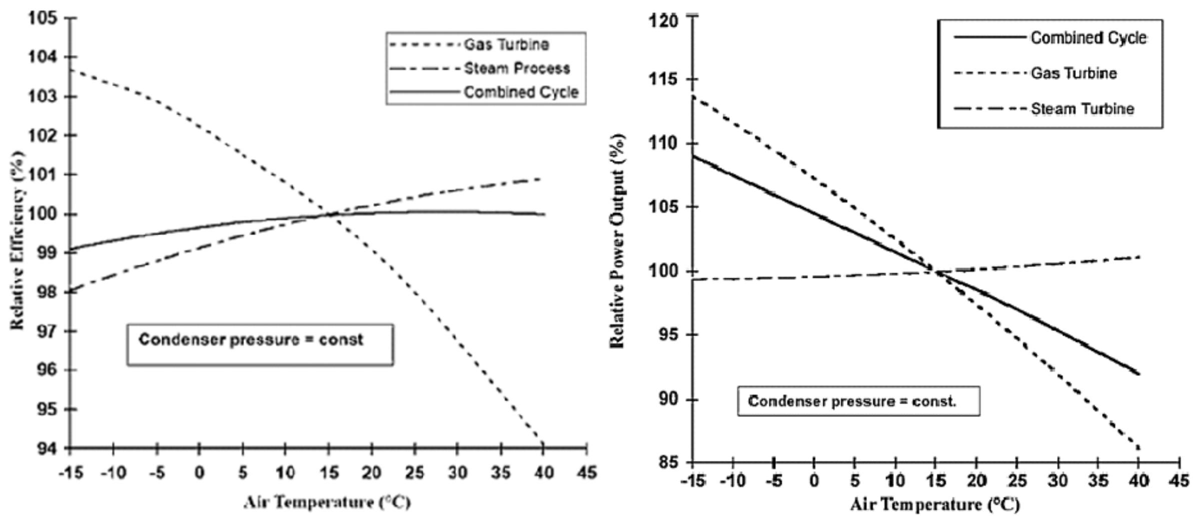
In most cases results presented are the average values for a parameter, as it is the average from which operational design specifications of the plant are determined. The statistical techniques used to asses change in the hydro-metrological parameters include:

- **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: 1961-2000 and 2045-2065.
- **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 1961-2000 for historical data and 2045 – 2065 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.

3.2 VULNERABILITY TO AIR TEMPERATURE

O Mon IV has a 2-2-1 configuration consisting of 2 gas turbines, 2 HRSG (Heat Recovery Steam Generators) and one steam turbine (Section 1). The first electricity production phase in the plant consists of two air-cooled gas turbines, which utilise air as a working fluid and are therefore vulnerable to changes in ambient temperature (Figure 13). Typically for CCGT plants, power output and energy efficiency decrease as air temperature increases. This is because an increase in air temperature reduces air density and hence mass flow of air intake to the compressor and a subsequent reduction in heat transfer efficiency of the air cooling system. These losses result in reduced gas turbine power output and a reduction in the pressure ratio within the turbine with a subsequent reduction in energy efficiency. To compensate for this, plants can restore the mass flow by increasing the flow rate through the compressors; however this will also increase the specific power consumption of the compressor. Variation in other climate factors (pressure, humidity) can also affect performance but to a significantly smaller degree and have not been identified as direct threats (Erdem et al, 2005). Based on gas kinetics and turbine performance, it is expected that climate change will increase temperatures and so have a negative impact on gas turbine electricity production and efficiency (figure 13).

Figure 13: Theoretical relative efficiency & power output of gas, steam and combined-cycle processes as a function of air temperature: *(left) Change in relative efficiency - the effect of changing air temperature is greatest on the gas turbine cycle; (right) Change in relative power output* (Source: Kehlhofer et al, 2009)



In a CCGT plant, gas turbines contribute approximately two thirds of the power production, while the steam turbine contributes the remaining third. The dominance of the gas-cycle for power production results in greater comparability between the CCGT and gas turbine power output curves (i.e. a sharp and approximately linear drop in relative output), and it is expected that changes to air temperature will have more significant impact on plant power output.

For temperatures greater than 15°C, the net efficiency of a CCGT is comparable with the steam process, increasing with rising air temperature until approximately 30°C and then decreasing as the ambient temperature continues to rise. The comparability of the CCGT efficiency with the steam process reflects the greater energy inputs of the steam cycle and that this process is not significantly affected by rising ambient temperatures (Section 3.3).

For CCGT plants in colder climates a warming surface air temperature may have positive implications for relative plant efficiency (figure 13). The O Mon IV plant is currently designed for the peak efficiency for CCGT plants (29-30°C) which will decline with additional temperature increases.

By quantifying the change in ambient air temperature predictions can be made on the loss in efficiency and power output, combined with change in fuel consumption over the plant's design life.

3.2.1 Threat of increasing air temperature

The historic average annual ambient temperature is 26.7°C at Can Tho (table 7). There is little monthly or seasonal variation in average daily temperatures, with a slight seasonal reduction in the order of 1-2 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 mid-30s and dropping to the low-20s overnight.

Table 5 Can Tho average monthly temperatures (1978 – 2004) (Source: PECC3, 2009)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	*Year*
mean temp. (°C)	25.4	25.9	27.2	28.3	27.9	27.1	26.8	26.6	26.7	26.6	26.5	25.4	*26.7*
max temp. (°C)	33.5	34.7	36.0	36.6	36.7	35.2	34.5	34.2	34.1	33.6	33.5	33.0	*34.6*
min temp. (°C)	17.8	18.4	17.7	21.8	22.0	21.4	21.4	21.1	22.2	21.2	19.3	17.0	*20.1*

For plant operations it is the variability in daily temperatures together with the longer term monthly averages which define the design air temperature. The O Mon IV project is designed for an ambient air temperature of 30°C. This design temperature is on average 3.3 °C above the long-term monthly average, however the intra-daily variability in temperatures means that the design temperature is regularly exceeded for short periods of the day. The selection of the design temperature reflects an optimisation of plant productivity, operational and capital cost based on historical trends. A higher design temperature would require greater capital cost as components would need to be redesigned, while a lower design temperature would adversely impact plant production under current climate conditions.

Figure 14: Computed change in averaged ambient temperature bands with climate change: *comparison of average daily temperature under baseline and climate change scenarios. Design temperature dotted, shaded area reflects the typical range in average monthly temperature with blue shading = baseline, bronze = with climate change; (bottom) difference in average daily temperature between baseline and climate change scenarios.* The greatest increase in temperature is expected for the end of the wet season.

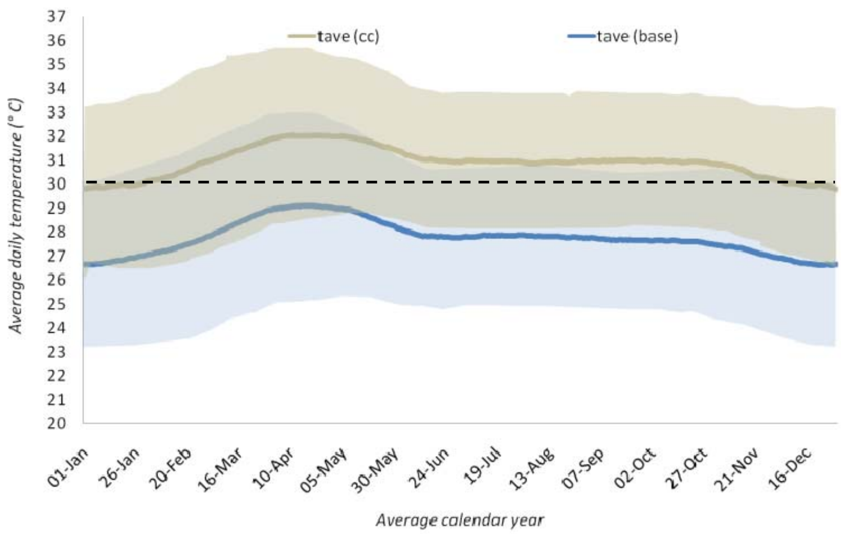


Figure 15 Difference averaged ambient temperature with climate change: *difference in average daily temperature between baseline and climate change scenarios.* The greatest increase in temperature is expected for the end of the wet season.

To explore the climate change impacts on the plant, the selected GCM outputs were analysed for minimum, maximum and average daily temperature. The daily time-step was chosen so that detailed temperature distribution profiles could be developed for typical years under baseline and climate change conditions. These were used to predict how power production, plant efficiency and fuel consumption would change. Summary findings are presented below, with a full set of graphs and tables in Annex 4.

With climate change there will likely be an average 3.1°C increase in daily ambient temperatures in the Mekong Delta with a range of 2.8 – 3.4°C (Figure 14, Table 8). The average daily temperature will rise to 29.9°C while the variability in daily temperature will slightly reduce. Figure 15 presents histograms for baseline and future temperature distribution in comparison to the O Mon IV design temperature of 30°C.

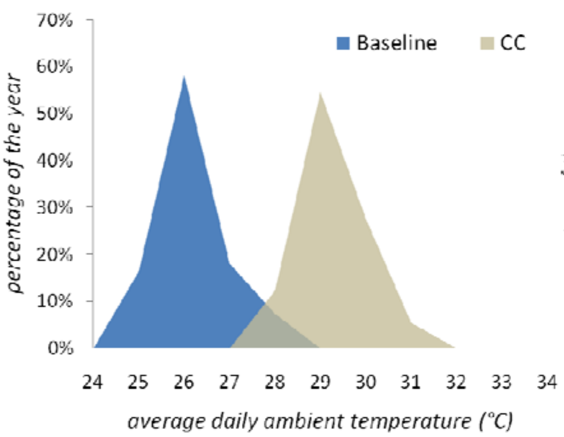
Table 6 Modelled average ambient temperatures under baseline and Climate Change scenarios

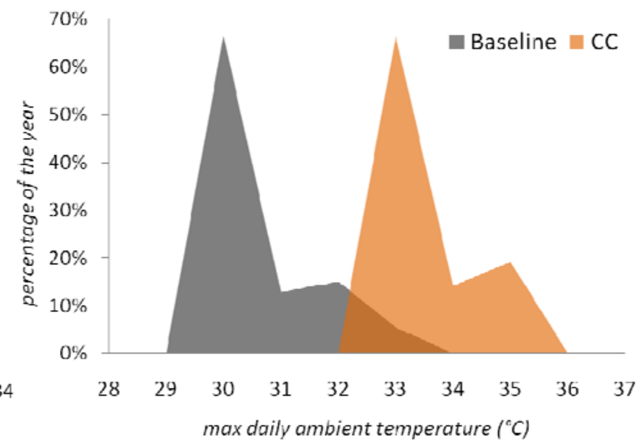
STATISTICAL PARAMETER	BASELINE	CLIMATE CHANGE	DIFFERENCE	
			Absolute	(%)
Average Temp (°C)	26.8	29.9	3.1	11.8%
Average Max Temp (°C)	31.1	34.1	3.0	9.6%
Average Min Temp (°C)	24.4	27.8	3.3	13.6%
Range in average temp (°C)	2.5	2.2	-0.3	-
Range in max. temp (°C)	3.0	2.5	-0.5	-
Range in min. temp (°C)	2.2	2.3	+0.1	-

Under typical historic conditions 66% of the year experiences max daily temperatures below the plant design temperature while the average daily temperature remains below 30°C year round. By the end of the plant economic design life, the maximum daily temperature will exceed 30°C year round reaching temperatures of up to 35.6°C (Figure 15). Some 5.5% of the year will experience average daily temperatures greater than the plant design temperature with climate change (Figure 15).

These changes will push both power output and net efficiency further along their performance curves - reducing plant performance. On a day-to-day level these changes are likely to be minor but over an annual production year and over the entire design life this will compound towards a significant loss of plant performance.

Figure 16: Frequency distribution curves of daily temperatures under baseline and B2 climate change scenarios: *(left) Average Daily Temperatures: there is an increase in the mean temperature of 3.1°C with slight reduction in annual variance; (right) Max. Daily temperatures: with climate change the max. daily temperature will exceed the design temperature for a significantly greater proportion of the year. Full details are in Annex 3.*





3.2.2 Sensitivity to increasing air temperature

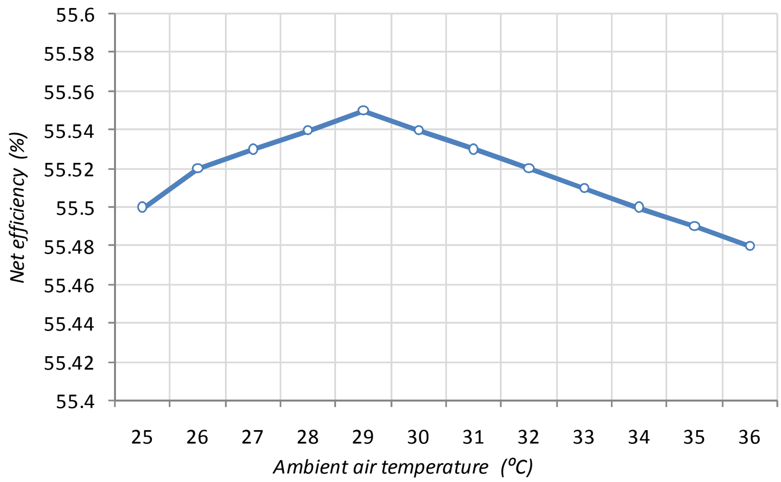
Figure 13 presented theoretical results for power production and net efficiency for generic power plants. In order to understand how the O Mon IV plant would respond to changing air temperature, the study team together with PECC3 undertook simulations of plant power output and efficiency with increasing air temperature. The simulations used the design and machinery specifications as given in the Technical Design Document for O Mon IV (PECC3, 2009), and varied the design temperature by increments of 0.5°C between 25-36°C. Results were then compared to other plant performances through a literature review of published results in Singapore, Brazil, Turkey, and North America (Figure 17; Annex 4).

According to the literature, with each 1°C increase in temperature after 30°C, power output of the gas turbines drops by 0.5 – 1.02%, while efficiency drops by ~0.24% (Kelhofer et al, 2009; Brooks et al, 2000; Drbal et al, 1995). Steam turbine power output and efficiency are not significantly changed by changing air temperature, while net CCGT power output drops by 0.3-0.6% and net efficiency drops by less than 0.1% (Kelhofer et al, 2009; Brooks et al, 2000; Drbal et al, 1995).

Consistent with the theoretical curves and the literature review, the net plant efficiency under the PECC3 simulations peaked at 29°C (ε = 55.55%) and then underwent a gradual linear decrease in efficiency with further increases in temperature (figure 17). This relationship can be approximated as linear for temperatures greater than 29°C with a 0.01% decrease in efficiency with each 1°C increase in temperature (Equation 1). This is consistent with the upper limit expected in the literature.

$$\varepsilon = -0.01\,T + 55.84 \qquad \text{-- (1)}$$

Figure 17 Change in net plant efficiency with air temperature (Data Source: PECC3, 2010)

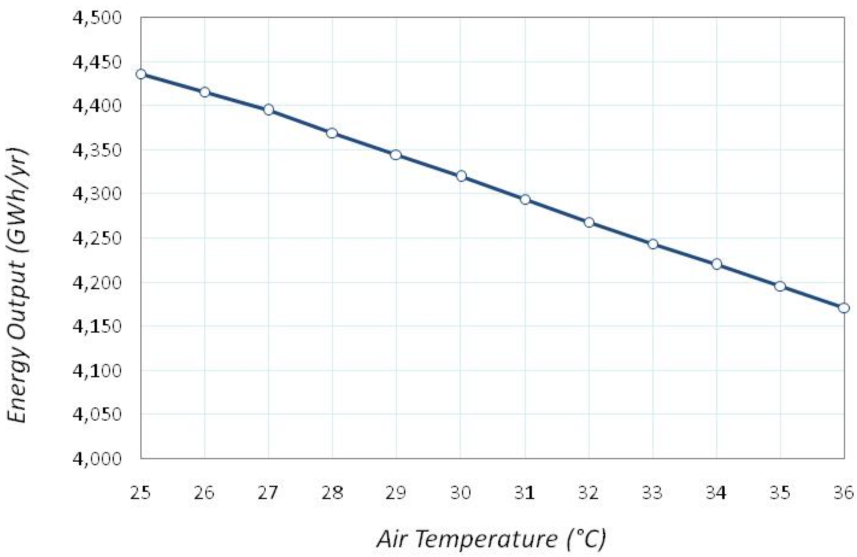


Power output of O Mon IV showed a strong and decreasing linear trend (R^2 = 0.999) according to the following equation (Equation 2, Figure 17):

$$P(T) = -24.54T + 4465.6 \qquad \text{-- (2)}$$

Based on this trend, there is an approximate 0.57% decrease in power output for each degree increase in air temperature.

Figure 18 Change in net plant power output with air temperature (Data Source: PECC3, 2010)



3.2.3 Impact of increasing air temperature

Figures 17 and 18 serve as a guide for climate change impact and present the trends in power output and efficiency based on changing average temperatures with the assumption that other parameters of the statistical temperature distribution (standard deviation, skew) remain unchanged. GCM simulation results (figure 15) indicate that we can also expect the nature of the distribution to be affected and so a more nuanced assessment of the impact on power output needs to be undertaken.

It was then possible to estimate the changes in power output and fuel consumption over a typical year and over the design life, using; (i) the results of the PECC3 simulations for efficiency, (ii) the changes to the ambient temperature distribution curve as represented in figure 15, (iii) an average of 6,000 annual operating hours and a gas price of USD 7.5/MMBTU[14].

First, the energy output (E) can be calculated by integrating power output over the temperature range observed in the temperature distribution curve:

$$E_{Tm} = \sum_{T=28}^{T=37} f(T) * P(T) * 6000 \quad \text{-- (3)}$$

Where: T_m is the average temperature;
P(T) is the power output at temperature T;
f(T) is temperature distribution curve for temperature T, and
6000 is the average number of hours of full power per year.

Fuel cost is then estimated by adding the efficiency (η(T)) at each temperature bin and gas price to equation (3). This is repeated for the climate change scenario with results detailed in Annex 4 and summarised below.

Table 7 Summary changes in plant performance due increasing air temperature

	baseline	climate change
Energy output (GWh)	4,338	4,264
change from baseline		*-74.0*
Energy input (GWh)	7,812	7,675
change from baseline		-136.8
Energy input (MBTU)	26,661,109	26,194,352
change from baseline		*-466,756*
Fuel cost (Mill US$)	200.0	196.5
change from baseline		*-3.5*
Average efficiency (%)	55.53%	55.56%
change from baseline		*+0.03*

Based on this analysis, the impact of increasing air temperature will have a significant effect on plant power output, but only a minor impact on net efficiency. With climate change annual power output in 2040 will decrease by 74.0GWh due to changes in air temperature alone or a 1. 7% reduction in annual power output. The reduction in power output will result in a commensurate decrease the plant's revenue stream for the year 2040.

There is a slight increase in net efficiency resulting in a minor reduction in relative fuel cost. Actual fuel cost of inputs relative to power generation is expected to marginally decrease by 2040.

[14] The quoted gas price is based on the latest information available from the Gas Purchase negotiation between EVN and PVN. This is significantly above global market prices for gas. Other supply arrangements within Viet Nam also reflect lower prices – for example the prices quoted for Bach Ho oil field (Vietnam) was set at around 2.2 USD/MBTU with 2% increase per year from 2005 onwards (long term contract) while natural gas from Nam Con Son gas field was set at 3.2 with annual increase of 2% applied from 2005.

3.3 VULNERABILITY TO RIVER WATER TEMPERATURE

While air temperature is the critical link between the plant topping cycle and the surrounding environment, it is river water temperature which connects the bottoming cycle. Exhaust heat from the topping cycle is used to produce steam in the HRSGs which are then used to drive a steam turbine. After passing through the turbine chamber, the steam needs to be cooled back to a liquid so that in can be transported back to the HRSGs and re-heated.

The once-through cooling system employed at O Mon draws in untreated water from the Hau River and uses the temperature differential between the cooling water (CW) and the working fluid (steam) to condense the steam and return it to the HRSGs. The cooling system has a fundamental influence on the efficiency of the steam process, which can be described by the theoretical Carnot efficiency, η:

$$\eta = 1 - \frac{T_C}{T_H} \qquad \text{-- (4)}$$

Where:

T_C is the absolute temperature of the cold source (river water), and
T_H is the absolute temperature of the hot source (coolant), and

The greater the difference between river water and coolant temperatures the greater the efficiency of heat transfer. Since the temperature of the coolant is not expected to change, reductions in efficiency will occur through increases in the river water intake temperature with an approximately negative linear trend.

According to the literature, a 1°C increase in river water temperature will result in a 0.1% reduction in both power output and efficiency for CCGT (Annex 4).

3.3.1 Threat of increasing river water temperature

The combined impacts of climate change and plant operations have the potential to reduce the difference between the CW and coolant by increasing the CW average temperature through two heat transfer mechanisms:

A. "Blowback" of coolant from the O Mon complex discharge channels to the CW inlet, and
B. Increased heat exchange at the air-water interface (AWI) due to climate change

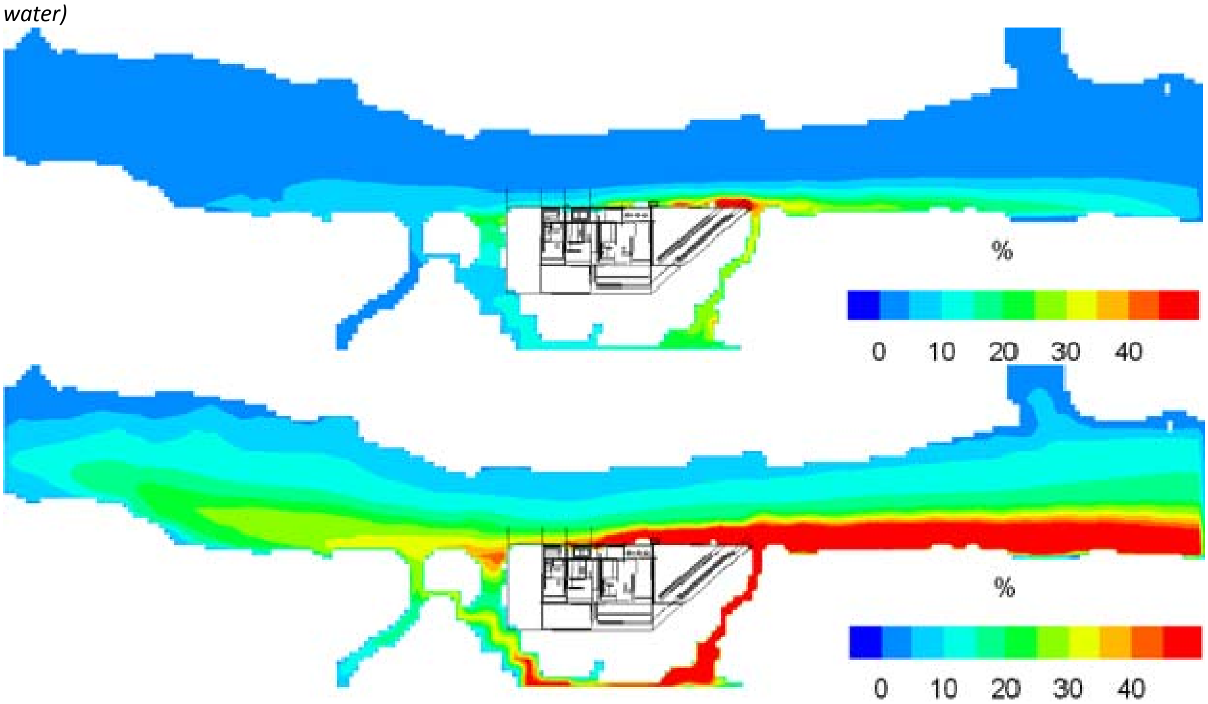
A – FEEDBACK FROM THE O MON COMPLEX DISCHARGE CHANNELS

Coolant feedback is not a climate change threat, however, it must be considered as part of the background environmental context within which rising river water temperatures are assessed. Assessment of existing conditions of coolant heat dissipation undertaken as part of the O Mon IV EIA have indicated that with existing natural river water temperatures, the effect of coolant feedback will be within acceptable limits for both the receiving environment and the design criteria set at the O Mon III/IV intakes (Vattenfall,2008; ADB, 2010). There are a number of limitations with the existing modelling of the O Mon coolant plume (Annex 3), which required additional modelling to be undertaken as part of this study in order to understand the system dynamics.

The O Mon III/IV intake structure is located in between the O Mon III and IV plant sites. Two discharge channels with a combined capacity of 110m^3/hr are located 750m downstream of the complex. The rate of cooling in the discharge channel can be considered a function of; air temperature, flow velocity, turbulence, channel dimensions, wind, and other atmospheric conditions. The temperature of the coolant will vary depending on plant operation but will be kept within 7°C of the natural river water temperature (ADB, 2010). [15]

During high-tide and low flow events the flow direction in the Hau River is reversed causing the warmer plume of coolant outflows to 'blowback' past the O Mon III/IV intakes to a distance of 1-2km upstream. Using three-dimensional modelling of the project area, the fate and transport of the coolant plume was simulated under constant wind conditions for wet and dry season in average and extreme flood years and then an additional model run was undertaken to incorporate storm surge (Annex 3).[16] Results were collected for both the average proportion of coolant in the middle of the water column at the intake and for the maximum coolant proportion and are presented below for the 1997 dry season which represents average baseline conditions (figure 19).

Figure 19 Fraction of coolant water in the Hau River water column in 1997 dry season conditions: *(top) Average middle water column coolant water fractions (% of water); (bottom) Maximum total water column coolant water fractions (% of water)*



In low flow conditions coolant water recirculation to water intake (coolant feedback) can be significant. Under baseline conditions an average of 15 - 20% of the intake water will originate from the discharge channel with a maximum of 40 – 50% (Figure 19). The location of the discharge outlet and the prevailing current dynamics under low-flow conditions pools coolant waters along the right-hand bank of the Hau River within the vicinity of the complex. Upstream and downstream of the complex the river channel widens slowing flow velocities and inducing greater mixing of the water column.

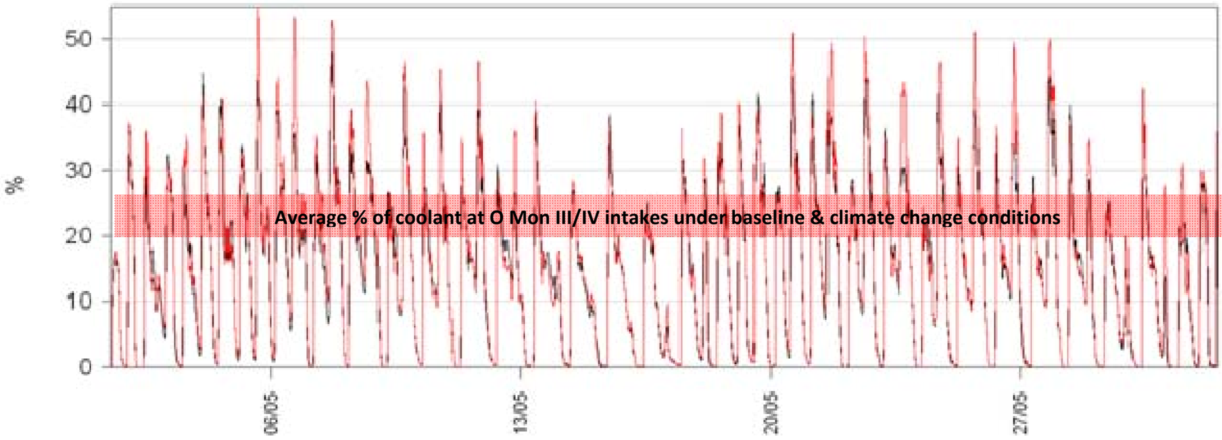
Figure 20 shows the typical coolant discharge feedback time series for the O Mon IV water intake. The oscillations observed in figure 20 reflect the tidal pattern of influence for the Hau River. As the tide wanes, upstream flow drives the coolant plume downstream of the discharge channels and the fraction of coolant water at the O Mon III/IV intake drops to zero. With the rising tide, there is sufficient downstream hydraulic gradient for backwater dispersion of coolant along the right-bank of the Hau River for 1-2km upstream of the O Mon complex. During the high flow season there is no feedback of coolant waters at the O Mon IV intake as the magnitude of flow dominates the hydraulics even under high tide situations. The changes in flow predicted under climate change will periodically increase the feedback of coolant to the O Mon IV intakes. The increase

[15] The O Mon IV EIA estimated that at the outlet of the channel the cooling water temperature would be a max of +5.75°C above ambient river water conditions (PECC, 2008), however, no information is presented on how this change in temperature differential was calculated nor is it obvious from first principles. This study used the +7°C at the channel inlet as the outlet temperature.

[16] Analysis of historic hydrological data at Can Tho and in the Mekong Delta reveals that 1997 was an average year.

will be minor for the average fraction of coolant in intake water (in the order of 1%), but will be significant for maximum conditions. With climate change the maximum fraction of coolant water at the O Mon IV intake is expected to increase by up to 10% as a result of sea level rise and changes to the flow regime due to changes in precipitation in the upper catchment (up to 68%).

Figure 20 Feedback of coolant discharge at O Mon III/IV intake: *percentage of coolant in the intake water, under: (black line) under baseline conditions; (red line) with climate change; (red bar) average % based on a typical water year*



The threat of climate change to the temperature of water at the O Mon III/IV intake must be considered in the context of coolant feedback and its increasing importance on near bank water temperatures at the intake.

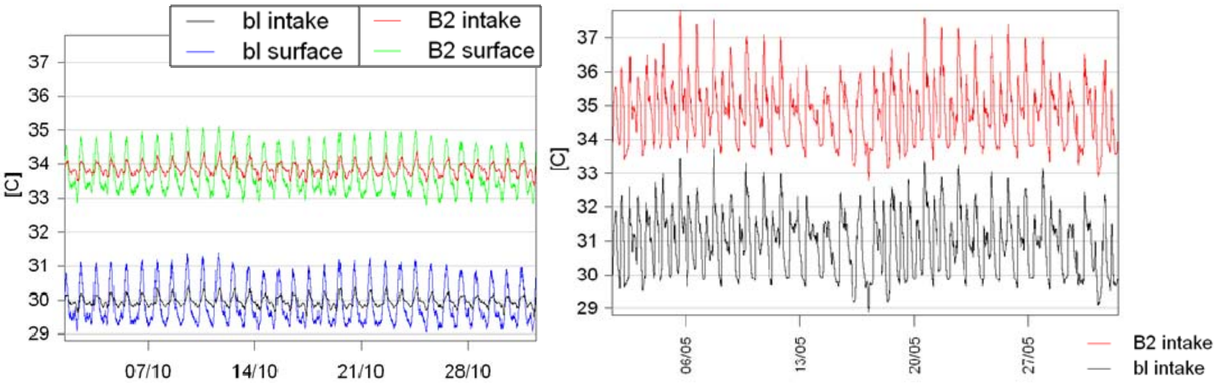
B – INCREASED HEAT EXCHANGE AT THE AIR-WATER INTERFACE (AWI)

The direct threat of climate change to the intake water temperature for the once-through cooling system is to increase the natural water temperatures through greater heat exchange between a warming atmosphere and the river system.

As the ambient air temperature increases, more heat will be transferred to the water column increasing the temperature of the river water. The cumulative impacts of natural heating and cooling water will exacerbate increases in river water temperature during the dry season and wet season, being more pronounced during the dry season when water levels and sediment concentrations are lower and flow velocities are slower allowing for greater penetration of light into the water column. Based on the predicted changes in air temperature simulations were undertaken for two representative water years to quantify the change in average, maximum and minimum water temperature both at the surface and at the O Mon III/IV water intake. Simulations were undertaken for two representative water years under baseline and climate change conditions: ("(i) Year 1997 – an average hydrological year, and (ii) Year 2000– a hydrologically extreme year. In addition a Cyclone Linda magnitude storm episode was simulated for a shorter period for both years in order to analyse extreme storm surge situation.[17] The impact of storm surge and more intense flooding with climate change is to marginally increase both mixing and water levels and hence reduce the areas with elevated water temperatures during these events. It should be noted that in reality the temperature variation is expected to be higher because of varying wind conditions and ambient water temperature. In this study constant average values have been used.

[17] Cyclone Linda struck the Ca Mau peninsula in 1997 and represents one of the most significant storm events to hit the delta in recent history. Sufficient hydro-metrological data is available from this event to replicate the storm event in the modelling, simulating a 'direct hit' on the Hau River mouth.

Figure 21 O Mon IV intake water temperatures: *(left) Wet season temperatures - blue and black are baseline surface and intake level temperatures respectively, red and green are surface and water intake temperatures with climate change; (right) Dry season water temperatures at the intake – black is under baseline conditions and red is with climate change.*



The main impacts of climate change on the river water temperature include:

1. 3-6% increase in the range and variability of intake water temperatures during average years (table 8)
2. 5-10% decrease in the range and variability of intake water temperatures during extreme/wet years (table 9)
3. Increase in the average intake temperature in the order of 3.5 – 4.0°C (figure 21, table 9) and near 39°C temperatures will be reached quite frequently in the dry season; this can have significant consequences for plant efficiency, reliability and;
4. The influence of tidal-induced flow reversal is evident in both baseline and climate change scenarios resulting in 2^{0}C fluctuations of temperature at the water surface.
5. Significant decrease in the proportion of year when river water temperature is at or below the design temperature of 29.2°C. Under historic average and extreme flood years, the water temperature at the O Mon IV intake will be equal or below the design temperature for 46 – 70% of the year (table 9). With climate change influences, the average river water temperature will rarely reach below the design temperature of 29.2°C (table 9).
6. in low flow conditions coolant water recirculation to water intake (coolant feedback) can be significant; as this affects plant efficiency and reliability especially in the future climate conditions alternative coolant intake solutions should be investigated

Table 8 Impact of climate change on average daily temperature ranges at the O Mon IV intake: *for average and wet years with and without storm surge events*

	Average Daily temperature range		% of year ≤ 29.2°C	
	baseline	climate change	baseline	climate change
Average year	30.5 °C (28 - 34.8 °C)	33.9 (31.5 - 38.7 °C)	46.5%	~0%
Extreme wet year	30.3 (28 – 34 °C)	33.8 (32 - 38.2 °C)	51.5%	~0%
Average year storm surge episode	29.8 (29 - 30.9 °C)	33.4 (32.8 - 34.7 °C)	69.8%	~0%
Extreme wet year storm surge episode	29.7 (29 – 31 °C)	33.5 (32.8 - 34.8 °C)	67.2%	~0%

Figure 22 Frequency distribution curves of average daily river water temperatures under baseline and B2 climate change scenarios: *there is an increase in the mean temperature with comparable annual variance*

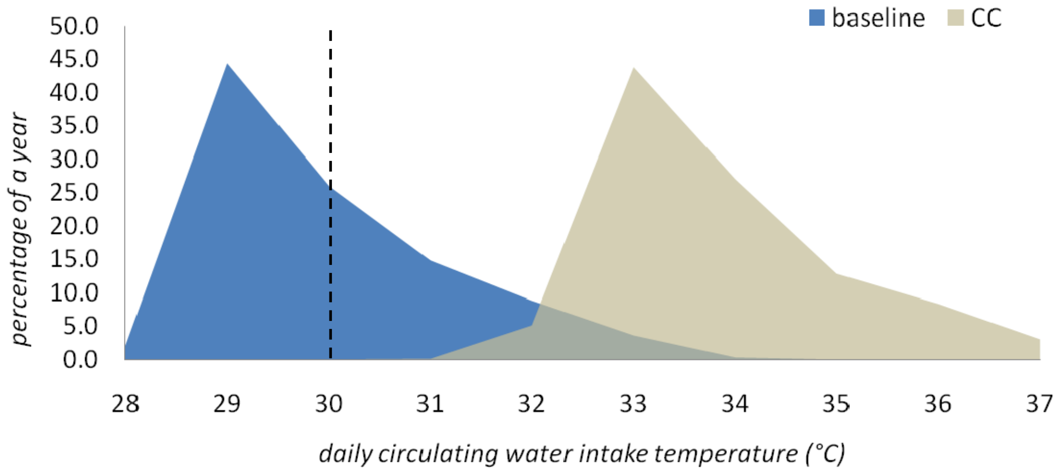
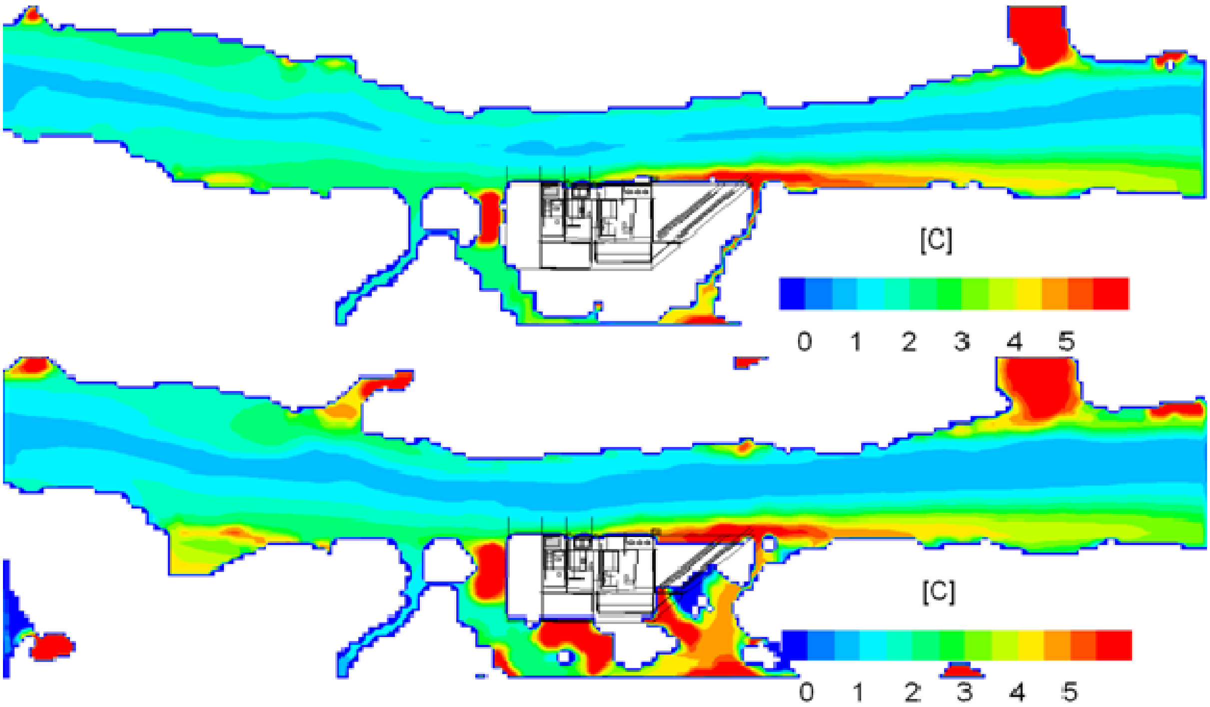


Figure 23 Maximum temperature increase in the whole water column compared to ambient 30°C water temperature: *(top) Baseline conditions, (bottom) with climate change*



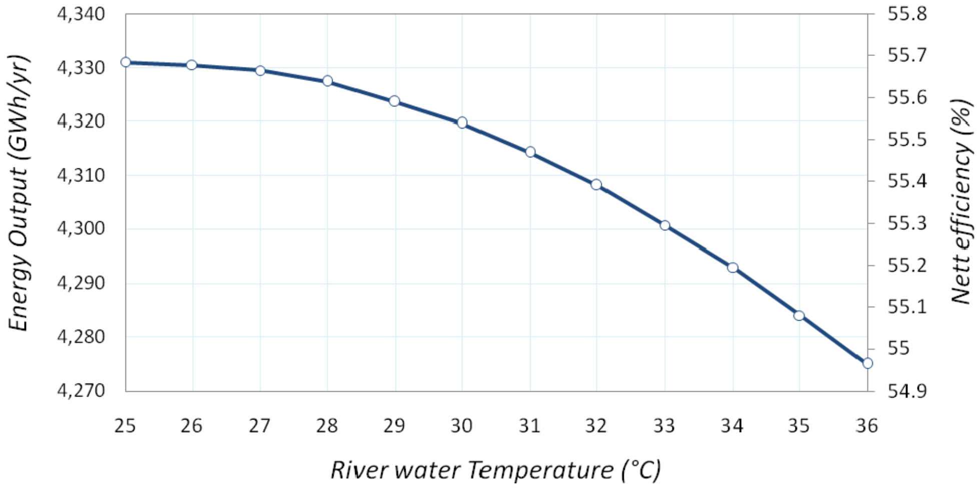
3.3.2 Sensitivity of increasing river water temperature

In order to assess the specific impacts these predicted changes in river water temperature will have on the plant, detailed simulations were undertaken for O Mon IV using the technical specifications in the Technical Design Document (PECC3, 2009). These simulations varied the temperature of river water at the intake structure assessing the sensitivity of the plant design. Figure 24 shows the relative efficiency as a function of river water temperature. For river water temperatures greater than 25^0C, there is an approximately parabolic relationship between water temperature and efficiency (equation 5, figure 24):

$$\varepsilon = -0.006\, T_{river}^{2} + 0.2988\, T_{river} + 51.96 \quad \text{-- (5)}$$

Where, T_{river} is the river water temperature in degrees Celsius.

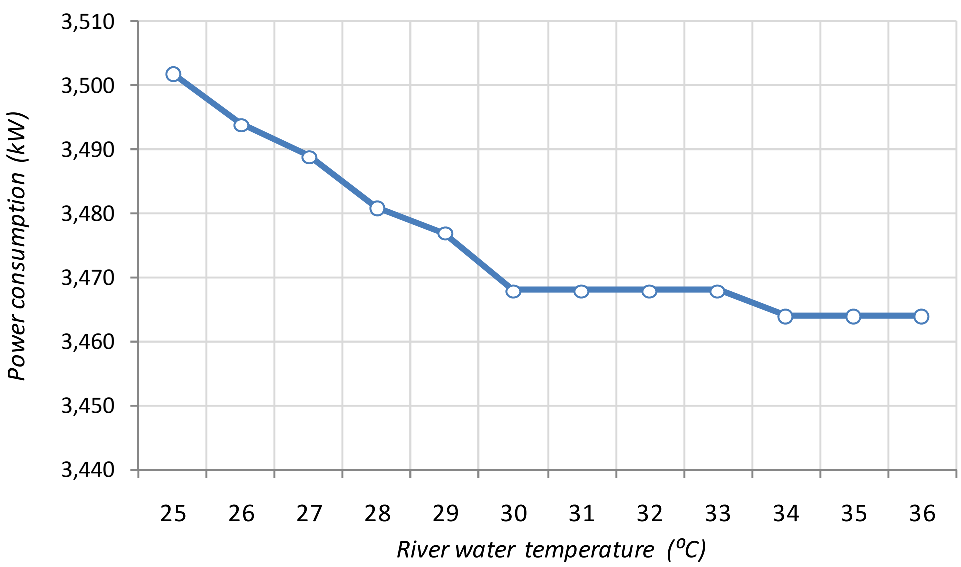
Figure 24 Relative efficiency & energy output of O Mon IV as a function of river water temperature (Data Source: PECC3, 2010)



Increasing river water temperature and reduced efficiency will also have an adverse effect on energy output (figure 24). The magnitude of this reduction will be in the order of 30% of the reduction expected for increased air temperature.

The reduction in efficiency can be partly explained by the reduced mass flow rate of warmer river water which in turn reduces the efficiency of heat transfer from coolant to CW and hence efficiency. However, decreasing density of warmer water has a positive impact on power consumption at the CW pumps. With less mass to transport through the CW system, electricity consumption of the CW pumps will reduce (figure 25). There is a steady linear decrease in CW pump electricity consumption for water temperatures less than 30^{0}C, with only minor changes for temperatures between 30 - 36^{0}C. With climate change and a 3-4^{0}C increase in average river water temperature, power consumption of the CW pumps will decrease marginally and fluctuate less during operating years – remaining constant at 3,470KW.

Figure 25 Change in Circulating Water (CW) pump electricity consumption with increasing river water temperature (Source: PECC, 2010)



3.3.3 Impact of increasing river water temperature

The impact of increasing river water temperature must be considered at the two components which connect the plant to the river: the intake and discharge systems:

A – AT THE WATER INTAKE STRUCTURE

Using the same approach as outlined in Section 3.2.3, the temperature distributions (figure 22) can be combined with the detailed simulation methodology of Section 3.3.2 to predict the impact of increasing river water temperature on plant performance.

Table 9Summary changes in plant performance due increasing air temperature

	baseline	climate change
Energy output (GWh)	4,338	4,313
change from baseline		*-25.3*
Energy input (GWh)	7,812	7,812
change from baseline		0
Energy input (MBTU)	26,661,109	26,660,533
change from baseline		*-575*
Fuel cost (Mill US$)	200	200
change from baseline		*0*
Average efficiency (%)	55.53	55.21
change from baseline		*-0.32%*

Based on this analysis, the impact of increasing river temperature will have a significant effect on plant power output, though lower than increasing air temperature. With climate change annual power output in 2040 will decrease by 25.3GWh due to changes in river water temperature alone or a 0.6% reduction in power output. Nett efficiency will also decrease by 0.3% down to 55.2%. Actual fuel cost of inputs relative to power generation is expected to increase.

This will influence the financial balance of the project, reducing the revenue of the plant (as less energy will be produced) and increasing the cost (fuel cost will increase).

B – IN THE COOLANT DISCHARGE SYSTEM

A key impact of climate change on the O Mon IV plant is to reduce the effectiveness of the plant coolant discharge system. The hydrodynamic modelling indicates that the combination of climate change and coolant feedback will have important implications for the receiving aquatic environment and for compliance with environmental guidelines and standards. Temperatures in the coolant plume are expected to remain within 7°C of the natural river water temperatures and continue to satisfy ADB environmental compliance criteria. However, the Vietnamese government standard stipulates that the maximum temperature of water discharged into a receiving environment should be ≤ 40°C[18] (ADB, 2010). The increased natural water temperatures of the Hau River (which is also the coolant water supply) will result in near 40 °C temperatures in the plant coolant plume which during the dry season will spread over substantial areas of the Hau River channel. These temperatures will be harmful to the receiving ecosystem and cause high mortality for aquatic organisms (Rajagopal et al. 1995). A more detailed modelling study of the coolant discharge dynamics in the context of climate change is required to properly assess this impact on the receiving environment and also compliance with the Vietnamese national standard.

[18] c.f. Vietnam environmental standard: QCVN 24/2009/TNMT

3.4 VULNERABILITY TO PRECIPITATION & STORMWATER

O Mon IV incorporates a gravity stormwater collection system designed to manage precipitation falling directly onto the pad and mitigate the potential for flooding by conveying stormwater away from the plant. The proposed system divides the O Mon IV pad into 7 areas and uses constructed gradients in ground elevation to direct rainfall into a network of gutters connected by pipes 400mm below the surface.

Central to the effectiveness of the stormwater system is the determination of suitable diameters for the conveyance pipe network, which also presents a design area of sensitivity to climate change. Combining the rational method and Manning's equation for pipe flow dynamics, the piper diameter required for a given storm water system can be related to rainfall intensity according to the following equation (Chow et al, 1988):

$$D = \left(\frac{3.21 \times C \times n \times A \times i}{\sqrt{S_o}}\right)^{3/8} \quad \text{—(5)}$$

Where:

D = pipe diameter (mm)
n = Manning's coefficient for concrete surfaces
C = run-off coefficient
A = Area of O Mon IV plant pad
S_o = bed slope of the pipe
i = rainfall intensity (mm/hr)

By assessing future rainfall statistics under climate change scenarios, it is possible to quickly relate the implications of changing rainfall on stormwater capacity and the potential for delays in dewatering of the plant pad after larger rainfall events.

3.4.1 Threat of changing precipitation

The rainfall regime of the project site is dominated by two distinct seasons. The wet season (May – Oct) accounts for more than 80% of annual rainfall total. Based on historic trends between 1978 – 2004, the average annual rainfall is 2,057mm with an average of 197 rainy days in the year. Average monthly rainfall fluctuates between 6.7mm during the peak of the dry season (February) and 329.8mm in August. Average monthly maximum rainfall values can reach 493.1mm during particularly wet years.

Table 11 presents the size of extreme rainfall events. The P1% event can result in almost 200mm falling within an hour.

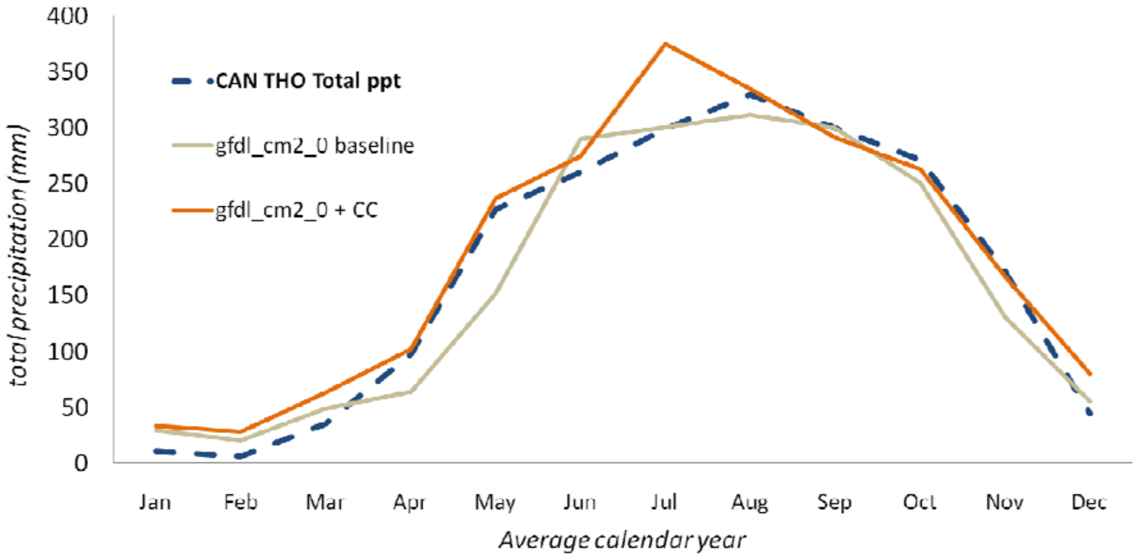
Table 10 Baseline precipitation & intensity statistics (Source: PECC 3, 2010)

		Precipitation (mm)			intensity (mm/hr)		
P(%)	days	20min	1hr	1 day	20min	1hr	1 day
1	4	67.0	132.2	196.7	201.0	132.2	7.9
3	11	56.8	111.6	167.0	170.4	111.6	6.7
5	18	51.8	102.0	153.0	155.4	102.0	6.1
10	37	45.0	88.1	133.1	135.0	88.1	5.3
25	91	35.5	69.2	105.6	106.5	69.2	4.2
50	183	27.6	53.4	82.6	82.8	53.4	3.3

A GCM was used to simulate the historic rainfall patterns (figure 26). The model was successful in predicting wet season precipitation but showed considerable variance from the observed data for the dry season and the shoulder seasons and over a typical water year, the model under-estimated the historic rainfall regime by

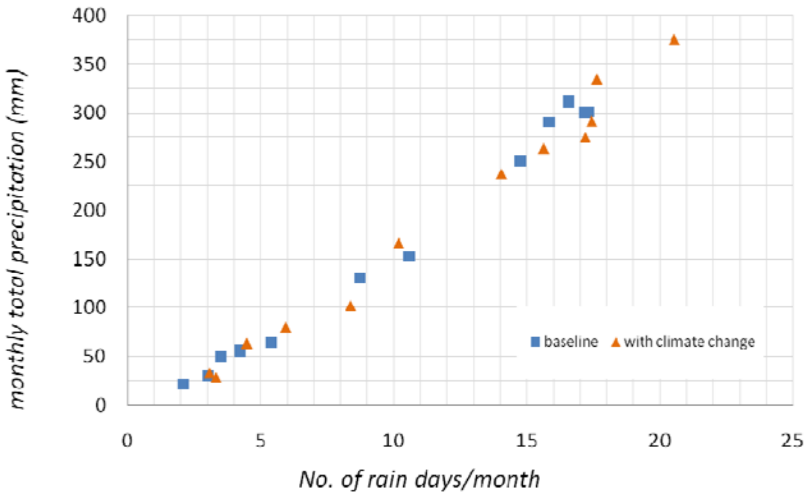
~4.5%. Given that the direct threats expected from precipitation will focus on changes to extreme wet season events, the model was considered suitable for this application.

Figure 26 Can Tho precipitation regime: *(dashed blue line) observed average monthly rainfall 1978 – 2004; (beige line) GCM modelled historic trend in average monthly precipitation; (orange line) GCM modelled future precipitation with climate change. (Source: CTTP, 2010; SEI, 2009)*



The major impact of climate change is an approximate 15% increase in annual precipitation with a comparable increase (16%) in the number of rainy days. The combination of increased precipitation and rainfall days is likely to result in negligible change in the daily rainfall intensity (figure 27). During the wet season the timing of the peak rainfall events is likely to occur earlier in the season (July).

Figure 27 Correlation between average total monthly precipitation & no of rainfall days: *under both baseline and climate change situations. The increase in both precipitation and no of rainfall days suggests that climate change will not have a major impact on average daily rainfall*

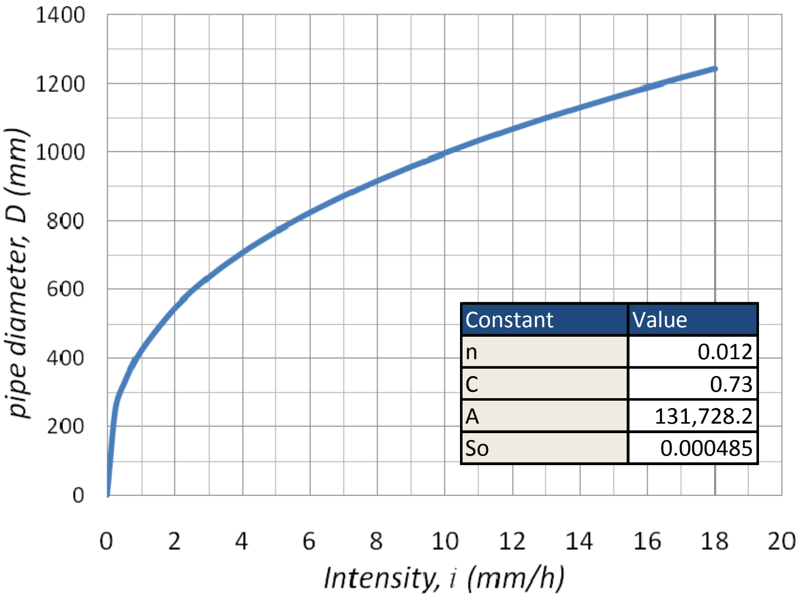


intensities.

3.4.2 Sensitivity to changing precipitation

The O Mon IV stormwater drainage system is USD 270,000 inter-connected network of D600 (600mm) buried collection pipes which feed into two D800 conveyance pipelines discharging into the Hau River (Annex I). There are 167 drains distributed throughout the pad. The system relies on gravity to collect, convey and discharge rainfall, utilising a max change in ground elevation of ~0.2 m over the ~550m length of the site. A small pump is available for emergency dewatering and designed to cope with 1 day of rainfall.

Figure 28 O Mon storm water system pipe diameter requirements for changing rainfall intensities: *based on a theoretical derivation of pipe capacity (equation 5) with constant values as shown below.*[19]



Based on equation 5, design pipe capacity and historic data, the current stormwater system is designed to manage rainfall events with intensities less than 6mm/hr. This corresponds to a maximum daily event with a P1% frequency of occurrence (figure 28, table 11). For more intense shorter duration events, it is likely that plant staff will utilise the back-up pump system to speed up dewatering of the plant pad. And increasing rainfall intensity would result in a greater reliance on the dewatering pump with increases in associated costs.

3.4.3 Impact of changing precipitation

The impact of climate change on precipitation is likely to see a 15-16% increase in both the annual rainfall volumes as well as the number of rain days in the year. The plant stormwater system is sensitive to changing average rainfall intensities which are not expected to change significantly by 2040 with climate change. Therefore the implications of climate change on the day-to-day operations of the plant stormwater system are expected to be negligible.

For extreme rainfall events the plant has a back-up pumping option. The pump is expected to remain suitable for managing dewatering of extreme events under climate change and will not need to be resized. It is likely that plant operators will need to use the pump more frequently with climate change to prevent long periods of ponding with a subsequent minor implication on fuel consumption and maintenance schedules.[20]

3.5 VULNERABILITY TO OVERBANK FLOODING

Flooding is a significant management issue for the Mekong Delta, with on average 1.7million ha affected each year, primarily due to the low elevation and pulsing river hydrograph (ICEM, 2010). While some land-use options have the potential to *"live with floods"*[21] large-scale infrastructure like the O Mon complex does not, and plant operations can be severely affected by downtime associated and flood damage to infrastructure due to continual water logging. Options available to design engineers include; building a dyke to isolate the area

[19] constants were derived from plant drawings and the site visit
[20] potential increases in fuel consumption associated with the storm water system have not been factored into simulations of changes in efficiency and plant performance
[21] The MARD Water Resources Management Strategy 2005 – 2010 is built on the principle that flooding plays an important role in the agriculture-based economy of the Mekong Delta and the driving consideration is not exclusively flood prevention but also better utilisation and management of average seasonal variations in water availability for agriculture and other human needs.

from the surrounding hydrological regime, or elevating the plant equipment above the flood levels. For the O Mon complex, the engineers have chosen to elevate the entire pad for the 5 power plants above the P1% flood level.

Vulnerability to flooding was assessed by quantifying the changes in water levels in the Hau River with climate change and then assessing the capacity of the existing flood protection works in managing these changing levels.

3.5.1 Threat of changing overbank flooding

A two-step approach was required to model the changes in flooding for the O Mon project site. First, a regional delta-wide model (HydroGIS) was uses to provide boundary data for the project site. For HydroGIS the modelled area was divided into *flood cells* that are hydrologically linked to the river channel network by overland flow in the flood season. The model includes a comprehensive description of all existing water control infrastructure in the Mekong Delta (Annex 3).

The model was then run for both baseline and climate change scenarios under average (1997) and extreme flood years (2000). Storm surge was included as an additional set of model runs, by synthesising an event equivalent to 1997 Cyclone Linda hitting the Hau River mouth in combination with a spring tide (figure 29).

The study also utilised the official sea level rise scenarios for Viet Nam as published by MONRE, which indicate a 23-24cm rise in sea levels by 2050 under B2 and A2 scenarios. Using these factors future water levels were then numerically approximated according to equation 6:

$$Z = SLR + Z_{baseline} \sum_{i=1}^{N} a_i b^i \qquad --(6)$$

Where:

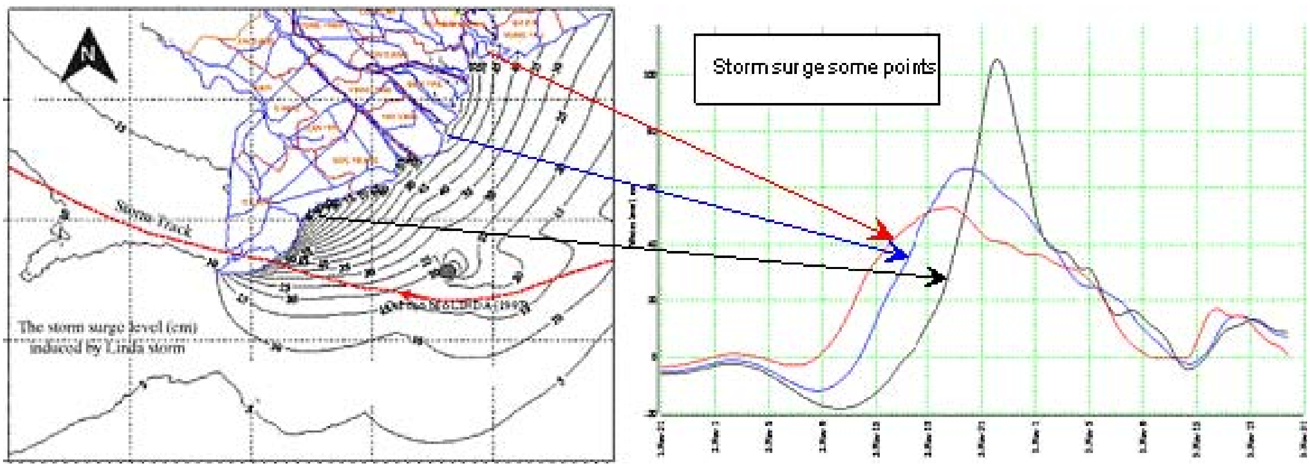
Z = future water level (masl)

SLR = sea level rise

a_i = change in amplitude of tidal wave, *i* as induced by SLR

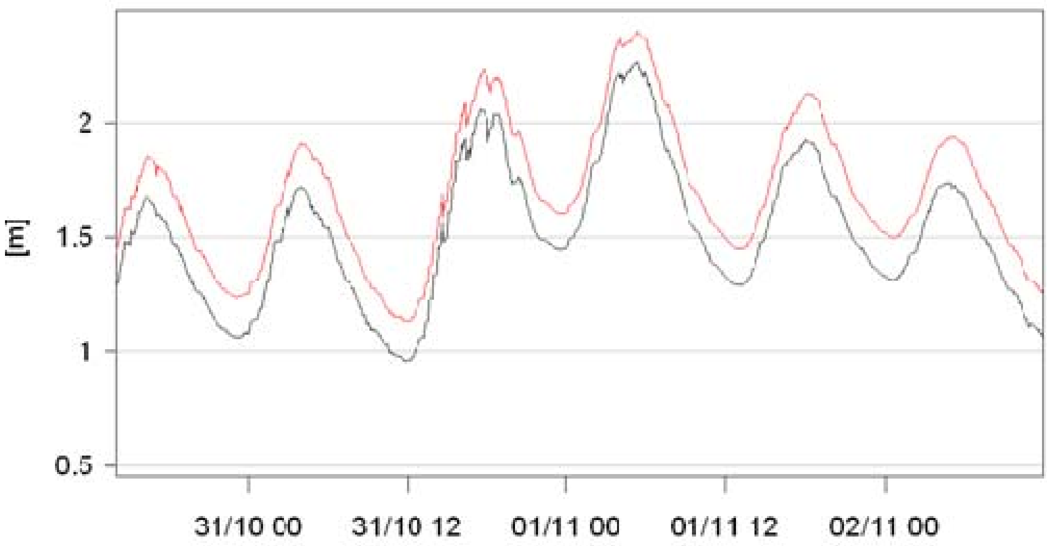
b = portion of tidal wave *i* over the entire tidal spectrum

Figure 29 Simulation of storm surge at the Mekong River mouth (blue line)



Using the boundary values obtained from HydroGIS a 3D model for water levels in the plant vicinity was established (Annex 3). Of the studied cases (dry year, wet year and storm surge) the maximum water levels are obtained during the storm surge situation. There is only minimal difference between the dry and wet year storm surge maximum water levels. The time series for the storm surge baseline and climate change scenario water levels at the Omon IV water intake are presented in figure 30. The maximum water level is only 13 cm higher in the climate change scenario and, in general, the water level changes are below 20 cm (table 12).

Figure 30 Max. water levels at the O Mon IV project site: *(black) average baseline water levels for an extreme flood year with storm surge; (red) average water levels for an extreme flood year with storm surge under climate change*

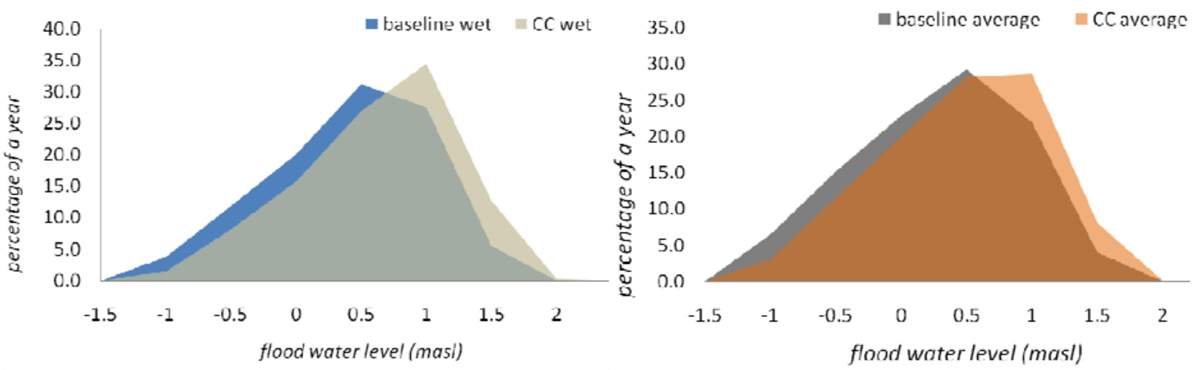


With climate change the area immediately surrounding the O Mon complex will experience increased flood water levels of 40-50% above current level, while the duration of flood events will increase by up to 80% (Annex 4). Climate change will also increase the proportion of the year experiencing high water levels (figure 31), though even with climate change on average less than 2 days a year will experience water levels greater than 2.0masl and the current design pad elevation of 2.7masl is not likely to be breached on an annual basis.

Table 11 Minimum, maximum and average water levels for different periods in the baseline and climate change scenarios

WATER LEVEL	min		max		average	
dry year	**bl**	**CC**	**bl**	**CC**	**bl**	**CC**
May	-1.03	-0.83	1.12	1.36	0.04	0.27
October	0.43	0.54	1.94	2.11	1.26	1.36
Storm surge	0.48	0.64	2.27	2.40	1.51	1.69
Whole year	-1.04	-0.83	1.96	2.13	0.54	0.71

Figure 31 Frequency distribution curves of average daily water levels under baseline and B2 climate change scenarios: *(left) under typical wet year; (right) under typical average year*



3.5.2 Sensitivity to changing overbank flooding

The entire O Mon IV pad has been raised to an elevation of 2.7masl, on top of this an additional 0.5m freeboard has been incorporated to most major plant components by setting equipment on an elevated concrete footing (Figure 3). These protection measures were designed for the P1% historic flood event with an additional safety margin of ~1.0m. The considerable safety margin already incorporated into the design (+1.0m) result in an existing flood management design capable of accommodating the expected increase in water levels associated with climate change.

Separate to the main pad, the O Mon complex drainage channels are protected by a 6m-wide shoulder embankment elevated to the same level as the plant pad (2.7masl). On top of this, there is an additional embankment with a maximum crest elevation of 3.7masl which skirts the drainage canal.

3.5.3 Impact of changing overbank flooding

The threat of overbank flooding will increase with climate change, as water levels in the Hau River will increase in the order of 0.2m. This is driven by the inter-play of sea level rise increases and changes to Mekong flow. With these assumptions and within the episodes studied the maximum water levels reach 2.4 m which is still below the plant ground level 2.7 m. For the surrounding floodplain, flooding times will increase significantly for the low-lying areas, increasing the need of effective water management. This may have implications for plant assets outside the main pad, including access roads.

There is considerable uncertainty in the magnitude and speed of sea level rise which is the dominant forcing determining future water levels at the O Mon power plant. Estimates used in this study remain within the official Government projections under the NTP, and are conservative.

3.6 VULNERABILITY TO EROSION AND CHANGING MORPHOLOGY

Figure 32 Upstream Hau River morphology: *a channel constriction ~1km upstream from the O Mon complex with a minor left-ward meander indicates that flow velocities on the right-bank are greater than those on the left bank suggesting an increasing risk of erosion migrating downstream towards the O Mon complex.*

Riverbank erosion is a function of river flow velocity, bank soil complex and bank stability. The O Mon complex is located on a reach of the Hau River ~1.2km downstream of a channel constriction where the average river width decreases from 1.2km to 750m. The constriction reduces the cross-sectional area of flow and so increases flow velocity in the river past the complex. A slight left-ward dog-leg in the river planform will result in increased flow velocities on the right-hand bank near the O Mon River mouth – making this side of the river more prone to erosion (figure 32). This could be exacerbated by intensive land clearing of the riparian zone and the docking of large vessels on the river bank (e.g. for sand mining or freight transport).

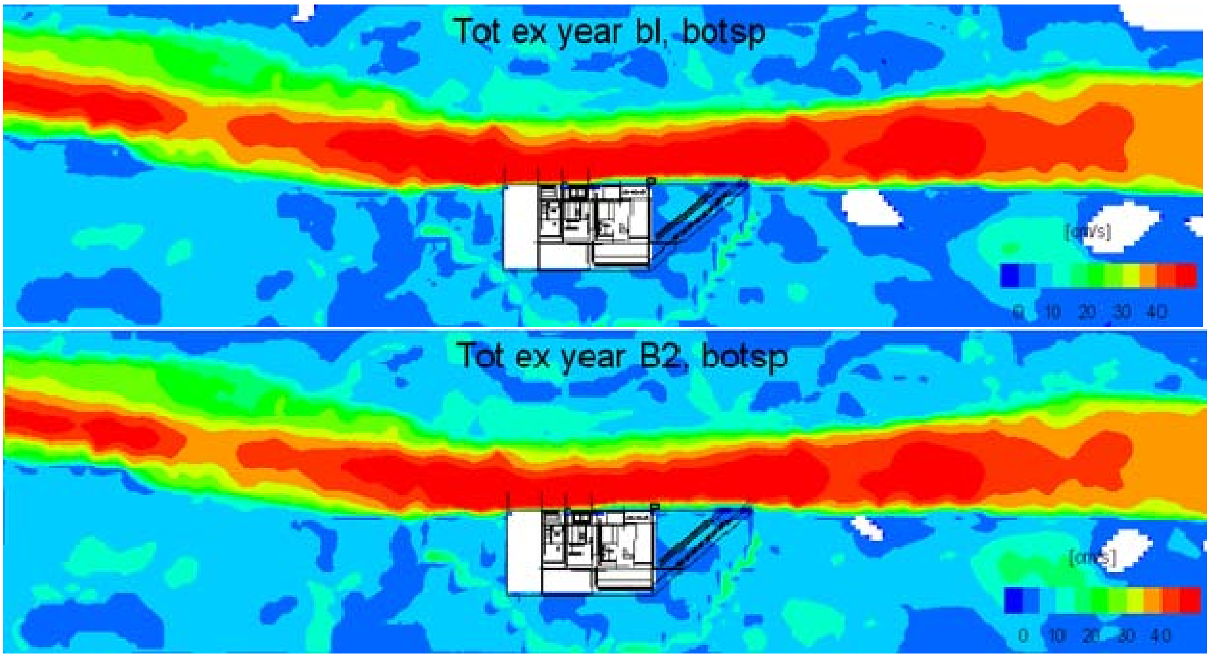
3.6.1 Threat of erosion

The 3D model was used to simulate flow velocities in the river benthic layer under baseline and climate change hydrological regimes.

Stream competence defines the ability of the river to entrain and transport solid particles and increases as a power of velocity. Consequently, entrainment and transport is likely to be focused on the wet season, when flow velocities are higher and also when most of the sediment load enters the Mekong. Flow velocities will not change significantly in the climate change scenarios as can be seen in figure 33. The average flow velocities will decrease slightly in the climate change scenario in the river channel and will increase in the floodplain. In front of the power plant bottom flow speed will stay practically the same. This implies that future flow velocity induced erosion will not change in response to climate change.

The reduced sediment loads as a consequence of upstream hydropower will increase erosion issues in the vicinity of the O Mon complex – in particular the 1km reach between the O Mon River mouth and the O Mon V plant pad. In the long-term, this erosion hotspot will migrate downstream towards the O Mon complex. The implications of reduced sediment loads on erosion lies outside the scope of this study, though it remains an important piece of assessment for ensuring the longevity of the plant life because the projects responsible for the reduced sediment load are all likely to be in place by 2015 when O Mon IV begins operations.

Figure 33 Average near bottom flow speed with and without climate change: *(top) baseline conditions: the channel constriction 1-2km upstream of the O Mon complex induces greater velocities at the bed and banks of the river channel. Red is equivalent to flow velocities in the order of 0.5m/s; (bottom) climate change conditions: similar flow dynamics to baseline condition with slightly increased overland velocities in the surrounding floodplain.*



3.6.2 Sensitivity to erosion

Figure 3 and Annex 1 illustrate key features of the O Mon IV revetment design. The flood management strategy adopted for the plant requires the substantial elevation of ground levels above natural levels of the O Mon flood plain and the revetment system acts as a stabilising curtain to protect the pad from movement and erosion. The revetment is inserted into the ground ~5m from the river bank (figure 34). Efforts made to stabilise the waterfront between the revetment and the river through planting of trees and reeds would improve the long-term effectiveness of the revetment system.

Figure 34 Revetment design for O Mon I plant

3.6.3 *Impact of changing erosion patterns*

By 2040, it is not expected that climate change will significantly alter flow velocities at the Hau River bed and banks and consequently there is not likely to be any increased damage threat from climate change on the existing revetment system. A full assessment of erosion potential remains to be undertaken and is an important component of plant risk management as upstream changes to sediment transport will have a significant impact on the rates of erosion along the Hau River posing a direct threat to the O Mon complex.

3.7 SYNERGISTIC & CUMULATIVE VULNERABILITY

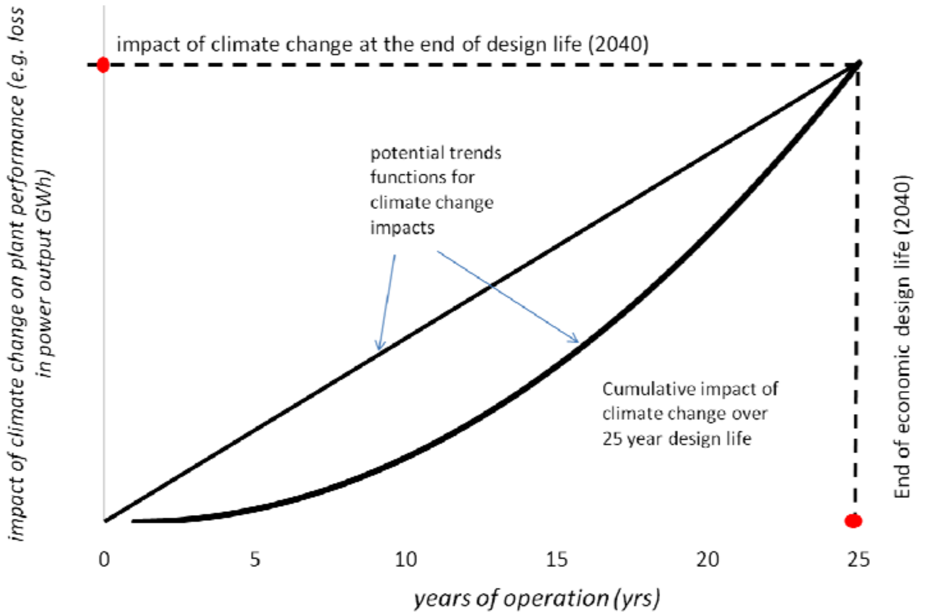
The performance impacts reported in Section 3.2 – 3.3 quantify the expected annual impact at the year 2040 for changes in individual parameters. This section adds to the analysis by: (i) synthesizing a total impact for all parameters combined, and (ii) assessing the cumulative and combined impact across the design economic life of the plant. The former is a relatively simple exercise involving the superposition of multiple impacts which can either compound an impact or nullify it, while the latter requires further understanding of shorter-term climate change trends between now and 2040.

Quantifying short-term trends in climate through the use of GCMs is difficult (Section 3.1). For this study the cumulative impact of climate change on performance is made based on the following assumptions:

(i) The rate of change in impact is expected to start slowly and increase over time;
(ii) Consequently, the project start date represents operations with no climate change impact, while the year 2040 represents the max impact expected over the economic design life;
(iii) The rate of increase is climate change impact is expected to be non-linear;

Based on these assumptions, the cumulative impact can be considered as the integral of a climate change polynomial impact function over the design life (figure 35). A linear trend was not considered representative of the rates of change in climate and impacted systems. A linear trend also provides a higher estimate of the cumulative losses over the design life, so the selection of non-linear polynomial function also presents a more conservative estimate of the impact. The combined and cumulative impacts on plant power output and energy consumption were assessed using this methodology. As part of the synergistic trends, a sensitivity analysis was also undertaken of the flooding impact to development of hydropower in the Mekong Basin.

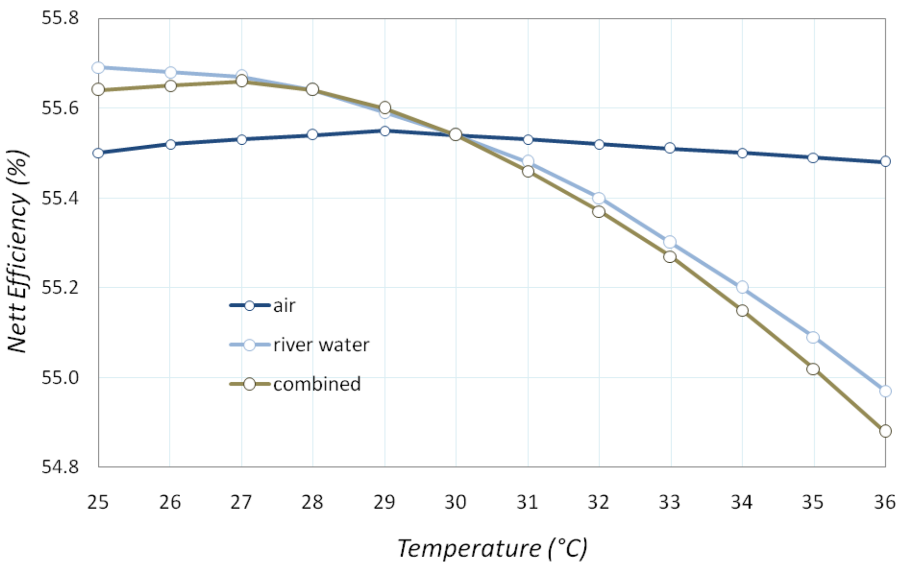
Figure 35 Assessing the cumulative impacts of climate change over O Mon IV design life: *predicting short-term cumulative impacts of climate change is difficult but essential for climate proofing investments in O Mon IV. This study compares both a linear and an accelerating non-linear trend in climate change increasing with design life. The cumulative impact is then the integral of the trend line or the area under the graph which can vary significantly depending on the impact function selected.*



3.7.1 Plant efficiency

The O Mon IV plant is expected to experience a 0.32% reduction in net efficiency in response to increasing river water temperature, with a marginal 0.02% increase in efficiency due to increasing air temperature. The results indicate that changes in efficiency are dominated by the steam cycle with a net drop of 0.3% efficiency expected during the plant economic life (figure 36).

Figure 36 Change in efficiency of O Mon IV with changing air temperature and river water temperature and the combined influence of both (Data Source: PECC3, 2010)[22]



[22] Variations in temperature we considered for both air and river water according to the following scenarios:

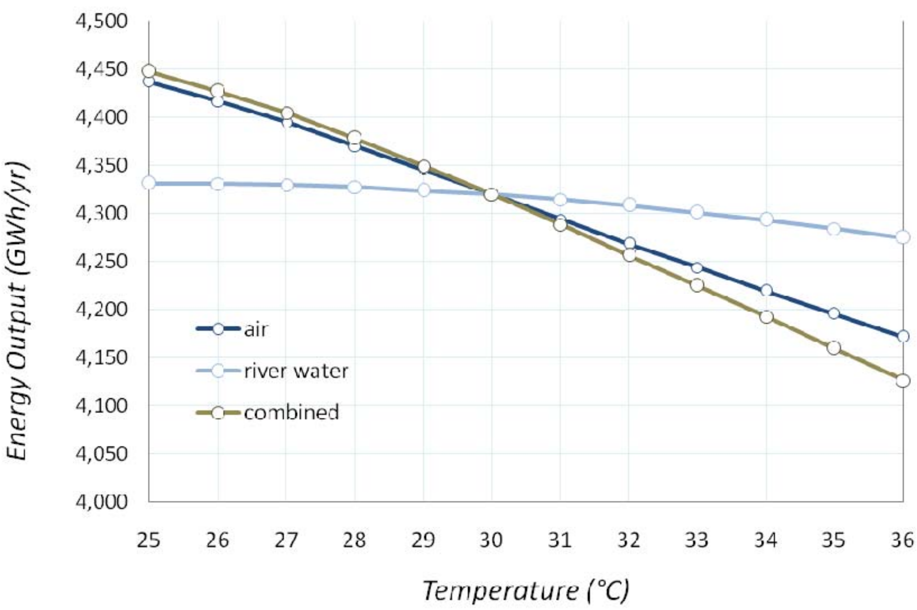
Scenario A. *AIR:* increasing air temperature 25-36°C + constant river water temperature
Scenario B. *RIVER WATER:* increasing river water temperature 25-36°C + constant air temperature
Scenario C. *COMBINED:* increasing air temperature 25-36°C + increasing river water temperature 25-36°C

3.7.2 Power production

The O Mon IV gas turbines contribute approximately 66% of the electricity output of the plant; similarly the losses in power output are dominated by the impact of climate change on the topping cycle (figure 37). Changes in ambient air temperature can have a significant effect on the performance of the topping cycle reducing annual power output by 74GWh or 1.7% of the total. Increasing river water temperature will also reduce annual power output by 25.3GWh under climate change – providing a total combined annual reduction of power output in the order of 99.3GWh or 2.5% of annual plant production by 2040.

With a nominal electricity purchase price of US 6.78 US cent/kWh, the combined loss in power output would amount to a reduction in 2040 revenue. Using a discount rate of 10% p.a., lost power output would amount to a revenue reduction of USD 0.62 million in the year 2040 in present value terms.

Figure 37 Change in power output of O Mon IV with changing air temperature and river water temperature and the combined influence of both (Data Source: PECC3, 2010)



Over the life-cycle of the plant, the combined impacts of climate change on power output are presented in table 13. Total power output will reduce by approximately 827.5GWh over the 25year economic design life with effects concentrated in later phases of project operations. Over the design life of the plant this represents a loss in power output of 0.8 %.

Table 12 Combined and cumulative impacts of climate change on power output

CC vulnerability	Increasing air temperature	Increasing river water temperature	Combined annual loss	Cumulative loss over economic life	% loss of total power output over plant life	Discounted aggregated loss in revenue
Loss in power output (GWh)	74.0	25.3	99.3	827.5	0.8 %	USD 9.36 million

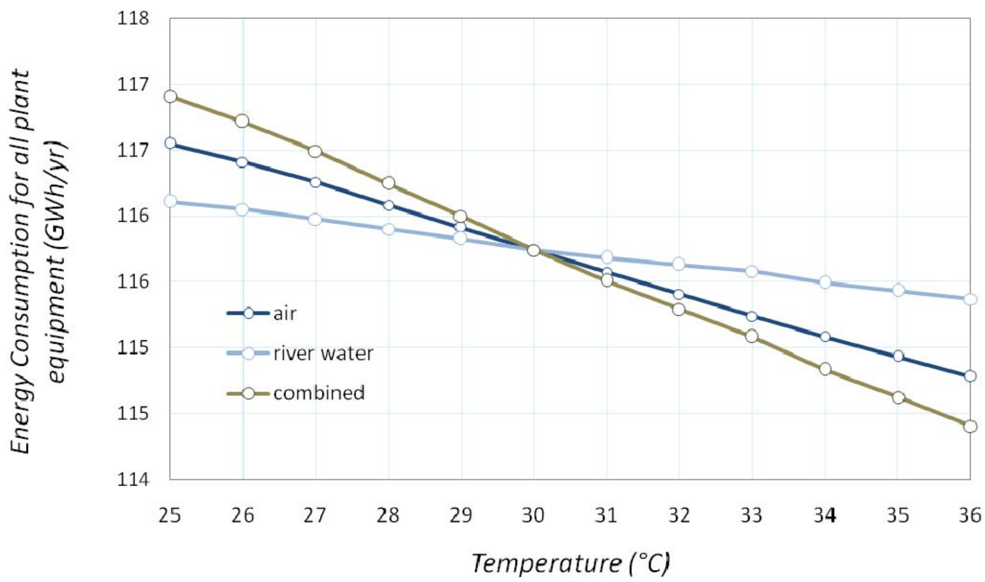
With a nominal electricity purchase price of US 6.78 US cent/kWh, and an assumed nonlinear climate impact trend, the combined and cumulative loss in power output would amount to a reduction in revenue over the economic design life in the order of USD 9.36 million in present value terms.

3.7.3 Fuel consumption

Reductions in electricity production will result in a slight reduction in fuel consumption. By 2040, electricity self consumption[23] is expected to decrease by 0.77 GWh due to air and river water temperature increase. The decreased fuel consumption due to air temperature increase is 0.52 GWh compared with 0.24 GWh from river water, implies the greatest impact is from air temperature increase to the equipment of the plant.

This represents a benefit for plant performance from climate change, but it is of substantially smaller magnitude to the reduction in the output of the plant over the same period. The performance simulations used in this study have taken this minor improvement into account in the quantification of the overall impact.

Figure 38 Change in fuel consumption of O Mon IV with changing air temperature and river water temperature and the combined influence of both *(Data Source: PECC3, 2010)*



The analysis shows that there is a slight increase of 0.02% in net efficiency due to air temperature increase and there is a decrease of 0.3% in net efficiency due to river water temperature increase. This results in a relative increase of fuel cost by 2040. The discounted aggregate loss over the 25 years economic lifetime is estimated at USD 1.5million.

Table 13 Combined and cumulative impacts of climate change on life-cycle fuel consumption

CC vulnerability	Increasing air temperature 2040	Increasing river water temperature 2040	Combined annual loss 2040	Cumulative loss over economic life
fuel cost increase at present value (USD million)	(0.008)	0.11	0.1	1.5

3.7.4 Quantifying the total impact of climate change

The aggregated economic losses predicted due to the influence of climate change on performance and fuel consumption are highly dependent on the nature of the climate impact function and the discount rate applied.

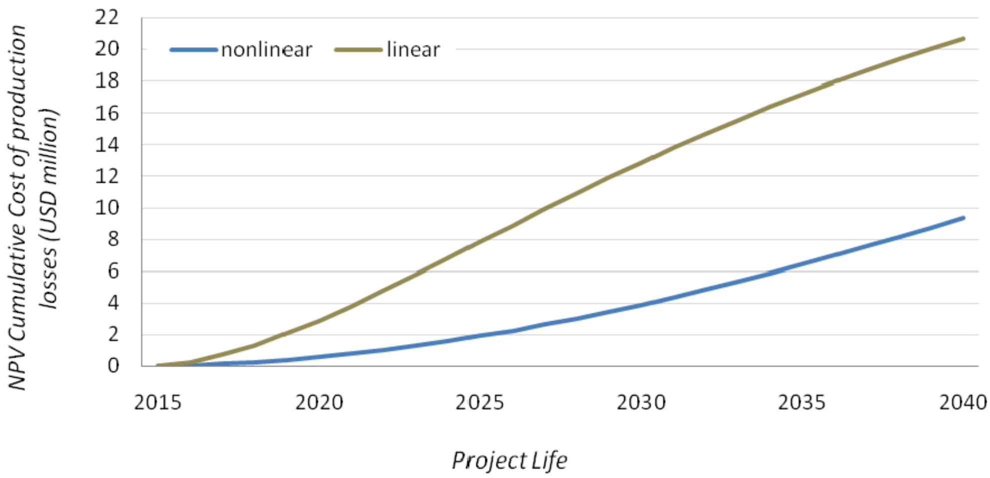
Specifying the impact function

[23] electricity consumption of all equipments of the plant

The total cost of climate change over the design economic life due to lost production or increased fuel cost is the cumulative sum of the annual cost of climate change from 2015 to 2040. The study assessed the cumulative cost of climate change by estimating the incremental cost at the end of the design life (2040) and then "back filling" for the period 2016-2039 assuming that there was no impact of climate change in 2015 when the project comes online.

Using this methodology, the total cost of climate change over the plant's 25 year design life depends on the rate at which climate change impacts are expected to accumulate. Section 3.7 describes two potential impact functions, linear and nonlinear, and concludes that a nonlinear accelerating function is likely to better represent the physics of change in the global climate system. This assumption introduces some error into the cost of climate change on the O Mon IV plant. The nonlinear accelerating assumption represents the lower bound of potential cumulative impact (figure 39). A conservative estimated was adopted because it represents an impact for which the study has sufficient confidence in its occurrence. Using a linear climate change impact function would have resulted in a net loss of revenue over the design economic life of USD 20.7million in present value terms compared to the loss associated with a nonlinear accelerating function of USD 10.9 million (figure 39).

Figure 39 Calculating the cumulative cost of climate change with two incremental impact functions: *NPV cumulative cost of production losses directly associated with climate change are strongly dependent on how climate change impacts are expected to accumulate over the design life.*



Setting the discount rate

The formula for converting an amount of money (F) in a given future year (n) at a given discount rate (i) to present value is given by:

$$P_{pw} = \sum_{t=1}^{n} \frac{F_t}{(1+i)^t} \quad \text{-- (7)}$$

For this study a discount rate of 10% was selected, such that every dollar spent in 2040 is equivalent to USD 0.092 in 2015. The selection of another discount rate would change the net present value of the cumulative climate impact.

3.7.5 Synergistic flooding impacts with upstream development

Upstream development is expected to decrease wet season flows by on average 10% as water is stored during the wet season for release during the dry season. When released this will increase dry season flows by an average 30%. The combination of climate change and upstream development will have seasonal distinct impacts on water levels in the Hau River. During the wet season the increased discharge and water levels predicted by the climate change modelling will be partially off-set by upstream regulation (figure 40). During the dry season, climate change and upstream hydropower will have a complementary relationship both acting to increase seasonal water levels in the Hau River.

For the O Mon IV plant, river water levels are of concern in regard to flooding of the plant pad, which is predominately a wet season risk. The antagonistic nature of wet season climate and development impacts reduces the CC-induced risk of plant flooding during the economic design life, confirming the suitability of the proposed flood management works.

Figure 40 Combined impacts of climate change and upstream development on water levels at the project site: *(left-axis) illustrates changes in average monthly water levels of the Hau River under key individual drivers (upstream hydropower development and climate change) and under the combined influence of both drivers; (right-axis) illustrates the changes in water levels predicted for the combined impact of climate change and upstream hydropower development*

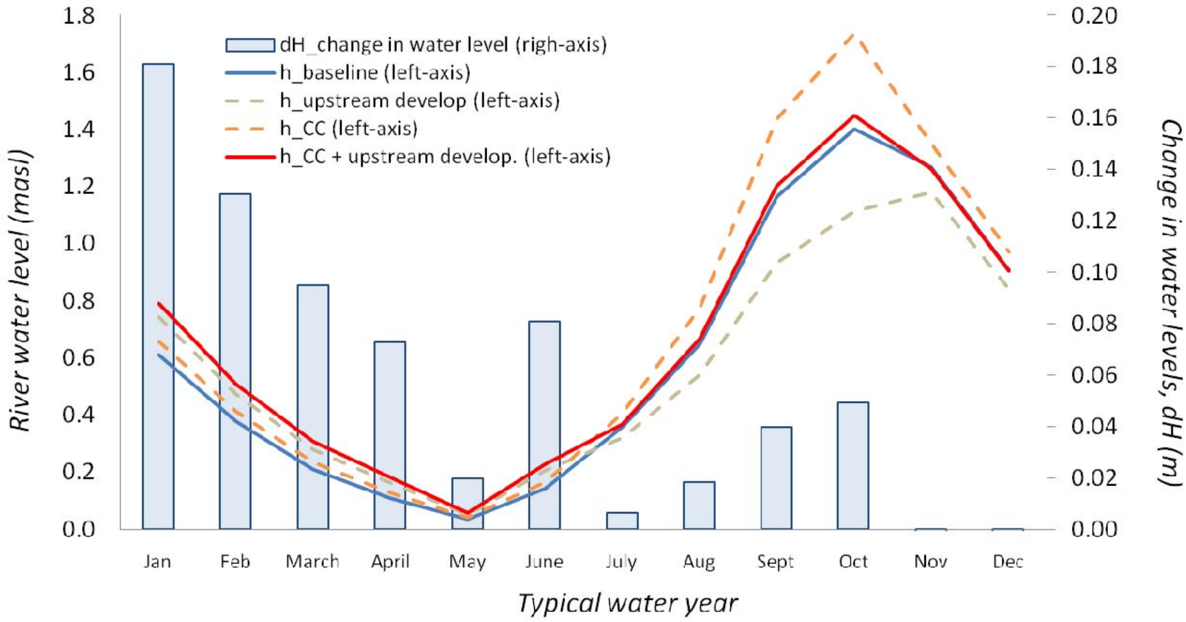


Table 14 Synergistic changes in Hau River water levels with climate change and upstream hydropower development

	Q_baseline	Q_CC + upstream develop.	h_baseline	h_CC + upstream develop. (left-axis)	dH_change in water level (right-axis)
Jan	4,893	6,850	0.610	0.8	0.18
Feb	2,744	3,841	0.376	0.5	0.13
March	1,558	2,182	0.210	0.3	0.09
April	978	1,370	0.108	0.2	0.07
May	1,215	1,701	0.036	0.1	0.02
June	3,440	4,816	0.145	0.2	0.08
July	7,778	7,778	0.358	0.4	0.01
Aug	11,579	11,579	0.649	0.7	0.02
Sept	15,529	15,529	1.164	1.2	0.04
Oct	16,895	16,895	1.400	1.4	0.05
Nov	13,584	13,584	1.267	1.3	0.00
Dec	8,372	8,372	0.909	0.9	0.00
Average	7,380	7,875	0.603	0.7	0.06
Min	978	1,370	0.036	0.1	0.00
Max	16,895	16,895	1.400	1.4	0.18

3.7.6 Vulnerability of the greater O Mon complex

O Mon IV is one of five existing and proposed power stations in the O Mon complex. The five plants share similar designs and in the case of O Mon I/II and O Mon III/IV share plant infrastructure (Section 2). The threats quantified for O Mon IV are directly relevant to the other modules in the O Mon complex, the sensitivity of plant components defined for O Mon IV are also similar for other modules and the vulnerability of the O Mon complex represents the cumulative vulnerabilities of each plant. Issues and costs identified for the O Mon IV plant should also be considered in relation to how they will upscale to the wider context of the complex. The key issues which increase in importance when going to scale include:

1. **Cumulative losses in power output due to climate change represent a supply-side integrity issue with consequences for the regional energy sector:** O Mon IV constitutes in the order of 20% of the power output from the O Mon complex and is expected to experience a loss in power output of ~0.7%. Under the same threats and with similar components, the cumulative loss in power output for the O Mon complex due to climate change could become both a financial issue for plant operators and an energy sector supply issue for the region.

2. **With climate change the effectiveness of the coolant discharge system in dissipating heat energy will be reduced:** the distance between the O Mon III/IV intakes and the coolant discharge channel will not be sufficient to prevent warmer coolant waters re-entering the cooling water cycle and effecting performance of both plants. The combination of coolant temperatures and climate change could elevate water temperature levels close to 40°C in the plume and these warmer waters can constitute the majority (up to 68%) of the water entering the intakes during the dry season.

3. **Potential for shared cost of adaptation:** The shared assets between O Mon III and O Mon IV (e.g. water intake structures) present an opportunity for sharing the cost of adaptation and suggest that adaptation planning for O Mon IV is better undertaken as part of integrated adaptation planning for the larger O Mon complex.

4 SETTING PRIORITIES FOR ADAPTATION

4.1 RANKING CLIMATE CHANGE IMPACTS

The total impact of climate change on the O Mon IV power plant is estimated at USD 10.9 million at present value over the economic design life. In order to assist the CTTP and ADB in setting priorities for adaptation, the O Mon study team utilised an assessment matrix framework to characterise and rank the direct threats facing O Mon as well as the key strategic vulnerabilities of the plans.

The methodology is simplified from the RIAM methodology and scores the impact for each *threat-sensitivity* coupling according to table 16 (Pastakia, 1995). Scores for individual couplings range from -3 (major dis-benefit) to +3 (major benefit). These are then tallied to give totals for: (i) each threat, and (ii) for each sensitive plant component, with results presented in table 17. This methodology allows for a weighted indicator of priority for each threat and for each plant component.

Table 15 Ranking scales for identifying key areas of vulnerability

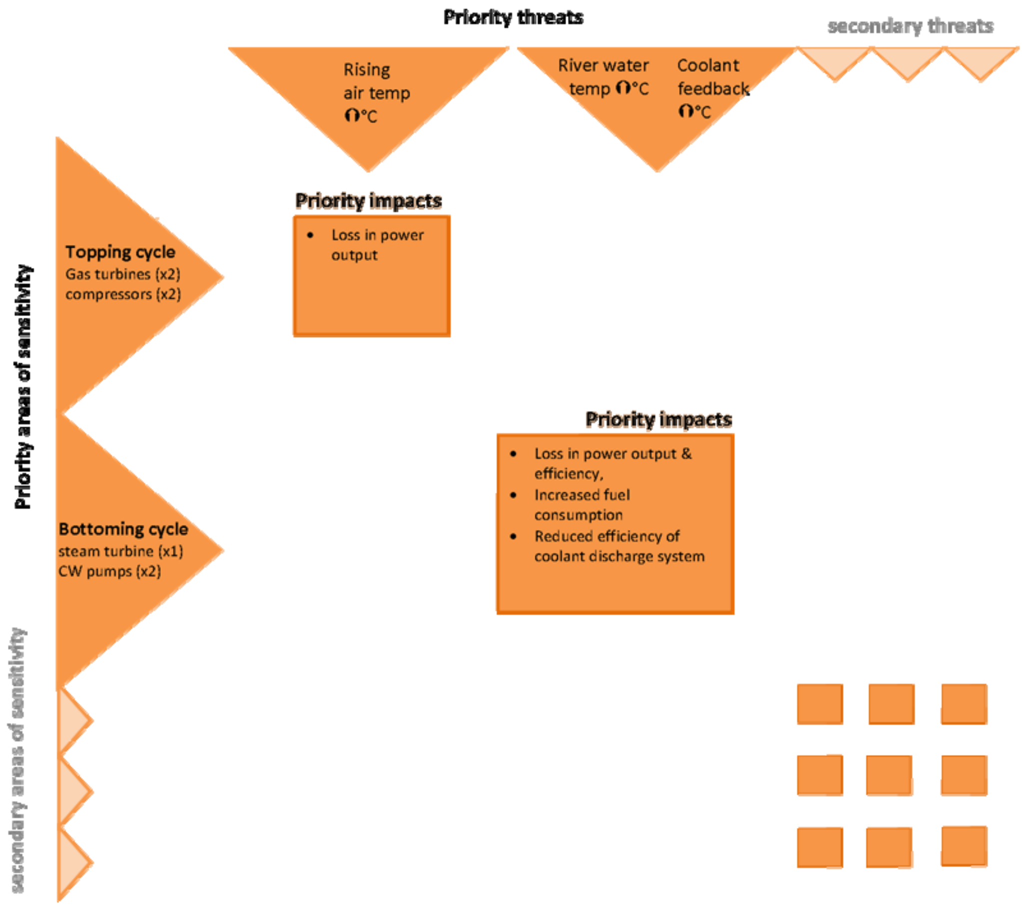
MAGNITUGE OF THREAT	MAGNITUDE OF CUMULATIVE THREAT	
+3 = major positive benefit	> +6	= major positive impact
+2 = significant improvement in status quo	> + 4	= significant positive impact
+1 = improvement in status quo	> + 2	= improvement in the status quo
0 = no change/status quo	- 1 to + 1	= no change/status quo
-1 = negative change to status quo	< - 2	= negative change to the status quo
-2 = significant negative dis-benefit or change	< - 4	= significant negative dis-benefit
-3 = major dis-benefit or change	< - 6	=major negative dis-benefit

Figure 41, condenses the findings of the ranking matrix into the priority areas of threat and sensitivity and summarises the impact. The most significant threats predicted include rising air and river water temperature. The impact of climate change on O Mon IV is one of reduced performance and compromised processes, not damage or loss in assets. The components most vulnerable to reduced performance are the gas and steam turbines and the air compressors. These components are central to plant power production and are flagged as the highest priority for adaptation response. The CW pumps are also significantly vulnerable to climate change. Most other components are expected to have minor vulnerability to climate change in comparison.

Table 16 Rapid climate change vulnerability summary matrix: *bottom row gives ranking for direct threats; right-most column ranks vulnerability of plant components*

	CLIMATE CHANGE THREAT	No. units	Air Temp. (°C)	River water Temp. (°C)	Coolant discharge Feedback (°C)	flood water levels (m)	flood volumes (m)	Climate change threat score (CCS)
	PLANT COMPONENT							
I.	**I. Gas turbine**							
i	compressor (X2)	2	-3	0	0	0	0	-6
ii	gas turbines (x2)	2	-3	0	0	0	0	-6
iii	generators (x2)	2	0	0	0	0	0	0
iv	step-up transformers (x2)	2	0	0	0	0	0	0
v	Controlling equipment	1	0	0	0	0	0	0
II.	**II. Steam turbine**							
i	HRSGs (x2)	2	1	0	0	0	0	2
ii	steam turbine (x1)	2	0	-2	-2	0	0	-6
iii	generator (x1)	1	0	0	0	0	0	0
iv	condensate pump (x1)	1	0	-1	-1	0	0	-2
v	Controlling equipment	1	0	0	0	0	0	0
III.	**III. Coolant cycle**							
i	Intake structure	1	0	0	0	0	0	0
ii	pumping system	2	0	-1	-2	0	0	-6
IV.	**IV. Storm water management**							
i	culverts & drains(conveyance)	1	0	0	0	0	-1	-1
ii	discharge outlets	2	0	0	0	0	-1	-2
V.	**V. Closed cooling water system**							
ii.	inlet structure	1	0	0	-1	1	0	0
	Discharge channel	1	0	0	0	0	0	0
VI.	**VI. Oil storage tank**	1	0	0	0	0	-1	-1
	VII. 500 kV switchyard	1	0	0	0	0	-1	-1
			-5	-5	-6	1	-4	

Figure 41 Vulnerability of O Mon IV: priority threats, sensitivities and impacts of focus: *the impact of climate change on O Mon IV will be felt in the performance and processes of power production, not in damage to assets.*



4.2 CAPACITY FOR ADAPTATION

The majority of the climate change costs (~86%) represent lost opportunity costs of reduced power output, while the remaining 14% comprises increased fuel consumption due to reduced efficiency. These impacts will be felt incrementally throughout the design economic life. Adaptation response will require an increase in capital investment costs, particularly at the beginning of the project which may take an order of years to recover.

The O Mon IV power plant is currently at the investment phase of project development. Detailed design has been undertaken and an EPC is currently under tender. Given the level of development of the project, it remains possible but difficult to make major changes to detailed design and this could present some limitations to the capacity for incorporating adaptation.

4.3 PRELIMINARY SCOPING OF ADAPTATION OPTIONS

The strategic climate change impacts identified in this study relate to reduced performance of the plant and its processes. This section provides a scoping of potential technological and management solutions, providing comment on their suitability for O Mon IV.

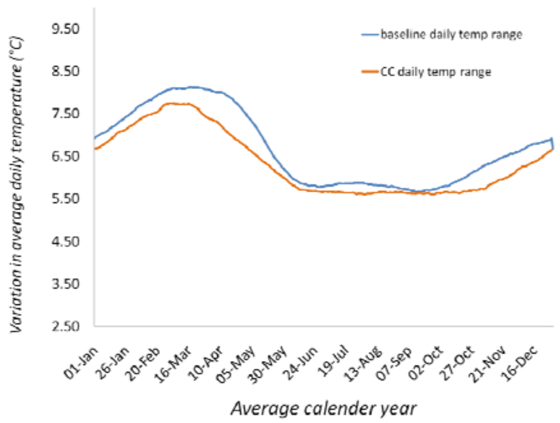
4.3.1 Rising air temperature

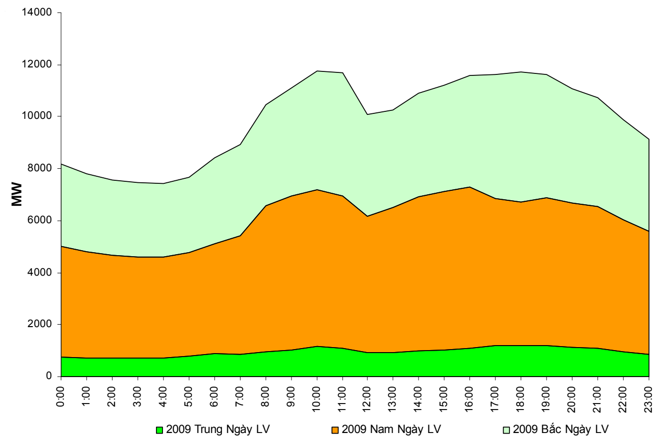
GENERAL OPERATIONAL PRINCIPLES

Power production from O Mon IV could be re-scheduled to target peak periods of the day when ambient air temperatures are lower and demand is higher. CCGT plants are normally designed for base load operation, however, they have the capacity to alter production scheduling to target specific times in the day**.** The load curve for southern Vietnam typically displays two peaks in demand: (i) the morning peak (10:00 – 11:00) is caused mainly by industrial loading, while (ii) the evening peak (18:00 – 19:00) (figure 42). Both of these peaks correspond to periods of moderate temperatures (figure 42).

A1. **Development alternative production schedule**: Detailed production simulations should be undertaken to explore the potential for O Mon IV to maximize power output in lower temperature periods.

Figure 42 Daily scheduling of power production: *(left) Average daily fluctuation in air temperature at O Mon IV, (right) Vietnam load curve for 2009 – blue = north region, orange = southern region, green = central region*





GAS TURBINE & COMPRESSORS

The biggest impacts are experienced in the topping cycle making it the highest priority for adaptation. However, the adaptation for the topping cycle requires a commitment early in the design process. There are several options for adaptation, which revolve around pre-treatment of the intake air or redesigning the topping cycle technology to accommodate a changed environment:

A2. **Customisation of turbine technology**: fabrication of gas turbines is typically customisable to each project, manufacturers will be able to alter generic products to better suit design specifications provided in the EPC. An effective adaptation response is to redesign the gas turbines cognizant of climate change.

Technically, this is likely to be the most suitable adaptation option to maintain productivity of the gas turbine system, though may be difficult to implement given the level of project development. If redesign of the gas turbines is not an option, then there are other options which attempt to mitigate the lost performance with reducing level of effectiveness:

A3. **Installation of inlet air cooling:** This option attempts to reverse the climate change trend of increasing air temperature by adding a cooling process before use. The two most common options for inlet cooling in gas turbine applications are evaporative cooler and refrigeration chillers.

- *Evaporative coolers* are more effective for hot, low-humidity climates and would not be suitable for O Mon IV due to average year-round humidity levels of 83% reaching average monthly maximums of 99% (PECC3, 2009; Loud, 1991).

- *Refrigeration/chiller coolers* are not constrained by ambient humidity. The operating principle is similar to the CW heat exchangers proposed for the steam turbine cycle. It works by directing air flow past a heat exchanger filled with colder fluid which causes condensation in the air flow and a reduction in temperature. Issues for consideration with this approach include:

i. The technology is effective and could improve performance to a greater degree than the expected losses with climate change (i.e. improved performance from the baseline design)

ii. Capital cost is substantial for the unit, but the refrigeration process will also increase fuel consumption for the plant

iii. Chiller coolers are substantial pieces of equipment and would command a sizeable area of the O Mon IV pad to house it. This would be a major hindrance for this option given the size of the O Mon IV pad.

iv. Critical to the performance of a chiller cooler is the availability of a suitable cool water source. Detailed simulations are required to assess the feasibility of using the Hau river water source for this purpose and what level of treatment is required for this.

v. Given the high humidity levels at the project site, the use of a chiller would also require a drift eliminator to be installed downstream of the cooling coils to eliminate excessive water ingestion in the turbines (Loud, 2009)

A4. **Upgrading the compressor:** a third adaptation option is to compensate for the reduced air density by increasing the flow rate as this can maintain the design mass flux. This can be achieved by upgrading the compressor to a larger model. Detailed engineering calculations are required to size the required compressor for this option. As with the other options this would represent a significant investment in both capital and operational costs.

STEAM TURBINE

Increasing air temperature exerts a minor positive influence on the power output of the steam turbine and does not require adaptation.

4.3.2 Rising river water temperature

STEAM TURBINE

The magnitude of performance impacts on the bottoming cycle are approximately half the magnitude of the topping cycle, but the variety and relative simplicity of adaptation options prove more attractive for adaptation. Increasing river water temperature has a significant influence on the efficiency of the steam turbine and power output. A number of adaptation options are available:

A5. **Use of free-cooling option:** Free-cooling systems are non-refrigerated cooling systems which rely on a nearby heat sink as a source of cooling. They operate in a similar manner to a heat exchanger in that lower nocturnal air temperatures (the heat sink) are used to reduce the temperature of a working fluid. Other heat sinks also include deep sea water and high-altitudes.

The system operates by introducing an additional step in the CW circuit before its use. Assessment of historic and projected daily ambient temperatures indicates that daily fluctuations in temperature are in the order of 5.5 – 8.0°C (figure 41), with an average daily minimum temperature of 24.4°C (27.7°C with climate change). This is not likely to be a suitable option as the drop in nocturnal temperatures is not likely to produce sufficient cooling potential. Another option would be to modify a chiller for this (c.f. A1). This would have similar issues as raised in A2.

A6. **Upgrading the heat exchanger:** increasing the size of the heat exchanger would allow a greater surface area contact between condensate and coolant, improving the performance of the CW process.

Increase of flow rate: increasing flow rate at the CW pumps would pass a greater mass of fluid through the exchangers increasing heat transfer capacity. This could be done by through a number of different alterations to the CW pumping system. Each of these pumping options would first require a pipe dynamics assessment of the CW system to ensure that an increased flow rate does not lead to excessive frictional in the pipe network losses (i.e. reduced efficiency):

A7. **Retain the existing pump design and open the throttle:** flow rates in the two proposed CW pumps are controlled by a globe valve at their outlet. The aperture size of the valve can be used to alter the flow rate in the CW system. According to operational behavior in O Mon I, these globe valves are normally kept at 70-80% open in order to satisfy the design flow rates for the CW system. There is some capacity under this system to increase the flow rate by fully opening the globe valves, which may partially mitigate the loss in performance expected with climate change.

A8. **Add a back-up pump unit:** a second option, offering greater flexibility whilst still adhering to the original design is to add an additional smaller pump to the CW system. This pump could be designed to satisfy the incremental flow demand required to restore the design mass-flow rate; and when used in conjunction with re-adjustments to the globe valves may not need year-round use (use may be limited to the dry season and periods of low flow, or during high tides when coolant feedback is peaking).

Additionally, the back-up pump may not be needed at the outset of the plant life due to the non-linear and accelerating nature of climate change impact. The design CW pumps could be installed and utilised exclusively in the first years of operation, whilst undergoing continual performance monitoring. Then 5-10 years after commencement, a review could be made of project operations and the decision be made as to whether an additional unit is required. A detailed pump sizing study for a number of different operating regimes would be required in order to size the pump and assess the associated life-cycle costs.

A9. **Convert to hydro-coupling:** the CW pumps planned for O Mon IV are fixed-speed drive pumps designed for optimal performance at a single speed. Traditionally these pump units have been used widely in southern Viet Nam, because the relatively constant year-round temperatures do not require intensive monitoring and adjusting of flow rates so that the pump can be sized against the design flow rate with confidence that there will be limited variance under day-to-day operations. In Northern Viet Nam there is significant seasonal and even monthly variation in temperatures which have resulted in a preference for hydro-coupling or variable-speed drive (VSD) pumping systems. These pumpstations are much more flexible than the fixed-drive units and allow the operator to optimize pump efficiency over a range of working flow rates.

A potential adaptation option for the O Mon IV project is to switch from fixed-speed to variable-speed CW pumps. In selecting this adaptation option it should be noted, that:

i. VSDs are considerably more expensive than fixed speed pumps, though they can last up to 20-30 years, while fixed-speed units have an average life of 5-6 years;[24]
ii. a switch to VSDs would see a greater proportion of project costs required as up-front investment, whilst the existing CW pumps allow this investment cost to be spread out over the plant life-time via increased maintenance and replacement;
iii. sound design of the VSD could eliminate other capital costs associate with fixed-speed pumps (e.g. control valves, by-pass lines).

[24] Variable-speed pumps in the Vung An power station (Ha Tinh province) have been operating for decades. The longer design life is primarily due to the pumps ability to constantly adjust output to remain within the optimal ranges on its pump curve. Fixed-speed drives typically spend a significant proportion of their operation away from the optimal range

Revise management of coolant discharge: coolant feedback at the water intakes is a key phenomenon exacerbating the impact of climate change-induced river water temperature increases. Performance of the bottoming cycle could be improved by reducing the proportion of coolant waters entering at the water intake. There are a number of options for achieving this:

A10. **Redesign the O Mon III/IV intake***:* the current design places the intake close to the river bank and conveys the water into an underground pit through a 30m-wide screened opening. Figure 23 illustrates that the transport of the coolant plume during high-tide periods tracks closely to the river bank. Approximately 40-50% of the water at the bank is coolant blowback, dropping to 20% 100-120m out from the bank. By moving the intake structure further into the centre of the river channel (e.g. through the adoption of the O Mon I intake tower design), it is possible to reduce the percentage of coolant waters entering the intake by as much 40-50%, which will reduce the temperature of the intake waters. There would be considerable financial implications of this decision, but the O Mon I tower would offer performance data and detailed cost estimates which could inform the decision-making process.

Moving the existing intake structure to the upstream edge of O Mon IV would increase the distance between the discharge outlet and plant inlet by ~250m. This option would complicate the ability for O Mon III to utilise the same intake and would reduce the proportion of coolant water at the intake by less than 5%.

Redesign of the discharge structure: the current open-channels discharging coolant waters from the O Mon complex enters the Hau River approximately 750m downstream of the O Mon I plant and immediately adjacent to the Vam Co creek. Effective adaptation options for coolant management at discharge, include those that: increase coolant temperature drop in the conveyance channel prior to intercepting the Hau River; increase mixing of coolant into the Hau River water column, or those that increase the distance between the discharge outlet and the intakes:

A11. **Improvements to discharge channel:** downstream of the discharge channel the river channel widens considerably. Discharging further downstream or further into the centre of the river channel would improve mixing of coolant waters and avoid the concentration of coolant waters along the right-hand bank at the O Mon complex. In practice this would be difficult to achieve, may interfere with other river uses and would need a scoping study to assess options like submerged pipe outlets, extension of the discharge channel groin amongst others.

A12. **Increased retention time in the discharge channel:** a longer retention time in the coolant discharge system could allow for greater reduction in coolant water temperatures before entering the Hau River system. This would require significant space as increased retention time would result in a longer discharge channel or the inclusion of a retention facility with a large surface area.

There are two groups of adaptation options for the bottoming cycle - management of coolant plume to reduce elevated water temperatures at the intake, or change the flow rate and pumping regime of the CW system to compensate for increased temperatures. The former would require redesign and civil works, while the latter would require additional expenditure on equipment and alterations of operational management

4.4 PHASING ADAPTATION RESPONSE

Entry points for adaptation arise at different stages of the project time-line. Ideally, adaptation planning should be initiated at the feasibility/design phase of a project because this allows for the greatest capacity for integration. However, adaptation entry-points also exist at later stages in the project, including the construction and operations phases.

Based on figure 6, the following potential adaptation entry points have been identified for O Mon IV. The specific years mentioned should be considered indicative but will change based on up-to-date project scheduling and life-cycle advice from equipment manufacturers:

- **2011 – Investment planning phase:** Before an EPC has been awarded and procurement begins, there remains opportunity to make modifications to design elements which could restore plant performance in a warming climate. This would suit all adaptation options listed in section 4.3. It would be critical to consider adaptation options which require redesign of civil works at this stage, as they will typically have longer design lives and so fewer entry-points further along the timeline.

  Also critical to this entry point is the preparation of a detailed adaptation plan. This could be undertaken separately for O Mon IV or as an integrated plan for the entire O Mon complex.

- **2027 – gas turbine replacement:** the gas turbines are one of the major plant components and also flagged as the most vulnerable to climate change. The replacement of the turbines mid-way through the design life offers an opportunity for customization or redesign to suit the ambient temperature profile in a warming climate.

- **2022, 2028, 2034 – major equipment replacement:** typically major plant equipment is replaced once every 7-10years. These dates offer suitable entry points for bottoming cycle adaptation – especially those relating to the CW pumping system or heat exchangers

- **2040 – refurbishment and life-time extension (LTE):** the end of the design economic life offers the opportunity for major redesign of the plant, many components will need replacement of LTE.

- **Financial entry-points:** In addition to these, there may also be financial entry-points for adaptation defined by the projected investment return schedule. This would apply to adaptation options which require the purchase of additional plant components (e.g. coolers, and pumpsets).

- **Management & maintenance entry points:** management entry points are the most flexible and are present throughout the project life cycle. Opening the CW pump valves is one example of a management response (A6). Entry-points also exist for non-replacement maintenance (e.g. major overhauls, repairs). Typically the benefit of these forms of adaptation is likely to be smaller than other options.

Comprehensive adaptation response for O Mon IV can be phased to synchronise with these entry points. For example, adaptation to increasing river water temperatures could be phased using the above entry points. This would allow sufficient time to studies required for optimal selection of adaptation option. From an impacts perspective, it would be acceptable to defer response to the first major replacement of CW pumps as the incremental rise in river water temperature over the next 10-12 years will be smaller than in the following 15-18years of operation. A detailed adaptation schedule would form one of the major outputs from comprehensive adaptation planning.

5 CONCLUSIONS & RECOMMENDATIONS

5.1 OVERALL CONCLUSION

There is a clear and present need for the O Mon IV plant design to consider adaptation with substantial cost implications if no action is taken. In a warming climate the current system design will experience significant losses in efficiency and production and increases in fuel consumption which, over the design life, represent economic losses of USD 10.9million in present value terms (table 17). Through an overall rapid estimate of potential costs and the scoping of adaptation options, it is likely that some climate change impacts can be avoided or mitigated through the appropriate phasing of adaptation response.

There are only minor climate change impacts on the integrity of plant infrastructure and the effectiveness of flooding and rainfall management systems.

Table 17 Summary of performance related impacts of climate change

Impact of climate change	
Air temperature	
Energy output (GWh)	- 25.3
NPV Fuel cost (USD million)	+ 0.11
River water temperature	
Energy output (GWh)	- 73.9
Fuel cost (USD million)	- 0.09
Cumulative in 2040	
Energy output (GWh)	- 99.3
NPV Fuel cost (USD million)	+ 0.1
Cumulative over economic design life	
Energy output (GWh)	-827.5
NPV Fuel cost (USD million)	+ 1.5 million
NPV of reduced performance (USD million)	+ 10.9

The performance losses expected over the economic design life, represent the cumulative impact of three main threats and two main plant processes which can be directly linked via the design specifications and parameters used in detailed design:

A. CC-related increases air temperature + topping cycle
B. CC-related increases in water temperature + bottoming cycle
C. Coolant discharge-related increases in water temperature + bottoming cycle

The impact of these threat-sensitivity couplings is summarised for three critical performance parameters for which quantifiable changes were available: net plant efficiency, power production and fuel consumption.

5.1.1 Plant efficiency

Changes in plant efficiency are dominated by the bottoming cycle: The O Mon IV plant is expected to experience a 0.32% reduction in net efficiency in response to increasing river water temperature, with a marginal 0.02% increase in efficiency due to increasing air temperature. Combining the impact of both rising air and water temperature, there is a decrease of 0.28% in net efficiency.

5.1.2 Power production

Changes in plant productivity are dominated by the topping cycle: By 2040, climate change will incur a total combined annual reduction of power output in the order of 99.3GWh or 2.5% of annual plant production. With a nominal electricity purchase price of US 6.78 US cent/kWh, the combined loss in power output would amount to a reduction in 2040 annual revenue in the order of USD 0.62 million in present value terms.

Over the life-cycle of the plant (25years), total power output will reduce by approximately 827.5GWh, with effects more severe in later phases of project operations. This represents a loss in power output of 0.8 % and a USD 10.9 million reduction in revenue at present value.

5.1.3 Fuel consumption

Reductions in electricity production will result in a slight reduction in fuel consumption. By 2040, electricity self consumption[25] is expected to decrease by 0.77 GWh due to air and river water temperature increase, with the greatest impact from air temperature increase to the equipment of the plant. This represents a minor benefit for the plant. [26]

Reduction in net efficiency will result in a relative increase of fuel cost of 0.1 million USD in 2040. Over the 25 year economic life, the total increased fuel cost is estimated at USD 1.5 million at NPV.

5.2 PRIORITIES FOR ADAPTATION

Project development for O Mon IV has proceeded to the investment phase and aspects of the design may be difficult to change. However, there remain a number of important entry points for adaptation in the plant life cycle which must be considered. These include: (i) the current planning phase, (ii) replacement of the gas turbine (~12 years), (iii) replacement of other major equipment (3 times over the design project life), (iv) end of the design economic life when refurbishment and life-time extension are being considered.

Adaptation response should focus on three critical impact areas which drive the loss in performance:

A. Losses in power output & efficiency – due to increases in air and river water temperature
B. Increased fuel consumption – due to increase in river water temperature
C. Reduced efficiency of coolant discharge system – due to increased river water temperature

Over 86% of the total economic impact of climate change is felt through a drop in power output of the power plant. Adaptation options are focused on the gas turbine technology and revolve around pre-treatment of the intake air or redesigning the topping cycle technology to accommodate a changed environment.

The magnitude of performance impacts on the bottoming cycle are half the magnitude of the topping cycle, but the variety and relative simplicity of adaptation options prove attractive for adaptation. There are three groups of adaptation options for improved performance of the bottoming cycle: (i) reducing the intake water temperature, (ii) increasing the performance of the CW system pumps and heat exchangers, or (iii) improving management of the coolant discharge plume.

Coolant feedback at the water intakes is a key phenomenon exacerbating the impact of climate change-induced river water temperature increases. Performance of the bottoming cycle could be improved by reducing the proportion of coolant waters entering at the water intake.

Separate and above the economic arguments for adaptation, the study identified one potential legal compliance issue which should be prioritised for adaptation response. Modelling in this study indicates that there is a plausible threat that the combined impact of both rising river water temperatures due to climate

[25] Electricity consumption of all equipment in the plant

[26] The performance simulations used in this study have taken this minor improvement into account in the quantification of the overall impact.

change and coolant discharge could result in downstream river water temperatures above the 40°C stipulated in the Vietnamese regulation. The study recommends: (i) detailed 3D modelling is needed of heat exchange from coolant passing through the discharge channel and into the Hau River, and (ii) preparation of a concept note for assessment of adaptation options for cooling coolant waters prior to discharge.

5.3 VULNERABILITY OF THE GREATER O MON COMPLEX

O Mon IV is one of five existing and proposed power stations in the O Mon complex. The vulnerability of the O Mon complex represents the cumulative vulnerabilities of all plants taken together. Issues and costs identified for the O Mon IV plant should also be considered in relation to how they will upscale to the wider context of the complex – for example, the effectiveness of the coolant discharge system in dissipating heat energy will affect all 5 plants.

It is expected that the cumulative impact of climate change on the O Mon complex will elevate impact from one of financial performance of the plants to a wider regional issue for the energy sector and downstream consumers. Performance losses will be greatest during the dry season which coincides with times of higher demand.

Consideration of the greater O Mon complex as whole will provide opportunity for an integrated and more efficient adaptation.

5.4 IMMEDIATE NEXT STEPS

The following immediate next steps are recommended:

1. **Consultations:** Undertake a program of consultations with CTTP, MOIT and Can Tho DOIT staff to disseminate and discuss the threat and vulnerability assessment findings.

2. **Undertake comprehensive adaptation planning:** A detailed Climate Change Adaptation plan needs to be initiated for the greater O Mon complex to provide a management framework for the scoping, planning and implementation of adaptation into the design and operations of each plant. However, given the imminent scheduling of the O Mon IV plant (EPC contracts are under consideration) a separate – O Mon IV specific – adaptation plan should be prepared and costed as part of that process. O Mon IV is sufficiently advanced in project development that a plan for decisions on adaptation strategies will be needed. For the other plants still in the design phase a full integration of adaptation can be achieved at the outset, which is the most desirable and economical approach.

   The plan should also include detailed costings of favoured adaptation options. An accurate valuation of adaptation is not possible outside the detailed adaptation planning process. The planning team should work closely with CTTP, PECC3, DOIT and investment partners (ADB, KfW). Overlap with the vulnerability assessment phase is also important to successful planning.

   Part of the adaptation planning process will include undertaking a number of important additional studies.

   i. **Coolant discharge dynamics**: A dedicated modelling study of the coolant discharge dynamics in the context of climate change is required to properly assess this impact on the receiving environment and also compliance with the Vietnamese national standard. The study would need to include separate scenarios for relevant adaptation options listed in this report to quantify the changes in coolant mixing and the proportion of coolant water feedback at the intakes of the plant.

ii. **Adaptation concept note for coolant cycle**: As identified in Section 5.2 a concept note for the scoping of potential options to reduce coolant temperatures at the river outlet should be prepared during the current investment phase.

iii. **Sediment transport dynamics:** a dedicated modelling study is required of the Hau River channel to assess the morphological implications of climate change and reduced sediment loading due to upstream hydropower development. The high seasonal variability in water levels and the planform of the river in the vicinity of the plant suggest that erosion will become an increasingly relevant issue for the site during the design economic life – particularly from bank erosion and bank collapse.

3. **Extend the climate change rapid threat and vulnerability assessment:** the current assessment focussed on the O Mon plant and its operations. Further assessment is needed to assess the vulnerability from source to user, including studies for:

   i. **The O Mon complex gas supply pipeline –** detailed climate change impact assessment of the gas fields and the gas supply pipeline

   ii. **Regional energy sector climate change assessment –** the O Mon complex represents a major component of regional energy supply. A sector wide climate change assessment is required for the southern Vietnam energy sector to assess vulnerability and upscale and integrate adaptation at the site level to the sector level.

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ANNEX I: KEY FEATURES & ASPECTS OF O MON IV DESIGN & SURROUNDING ENVIRONMENT

Table 18 presents a summary of the surrounding conditions of the complex and O Mon IV site.

Table 18 Summary of the O Mon IV geospatial context (Source: ADB, 2010; PECC3, 2010)

Environmental characteristic	Description
topography	• Low-lying floodplain island
geology	• Primary layer: 1.5 – 1.7 m predominantly silty deposits from overbank siltation • Secondary layer: • Tertiary layer:
geohazard	• Located on the Hau & Tien Rivers fault line • Weak earthquake risk, with a max severity capable of overturning furniture • Max credible earthquake risk M = 6.1 on Richter Scale
climate	• Monsoonal climate with two distinct seasons o Dry season: November – April o Wet season: May – October • Average air temperature: 25.4 – 28.3 °C • Average max air temperature: 33 – 36.7 °C • Average min air temperature: 17 – 21.8 °C
surface water	• Rainfall average 2,057 mm/yr • P1% max water level (WL): 2.23masl • P99% min water level: -1.57masl • Extreme annual fluctuation in WL ~3.8m • Average Hau river water temperature: 29.2 °C
Groundwater	• Two aquifers • Superficial aquifer lies 0.5 – 2.5m below the natural surface and is hydrologically connected to the Hau River
River morphology & condition	• River channel is straight and wide, with deep clearance. • Riverbanks are predominately vegetated with strong evidence of erosion in reaches cleared for access or land use. • Upstream channel shows constriction and Right-bank shows a clear left-ward meander indicating that in this reach erosion occurs on the right-bank with the site of erosion progressing downstream towards the complex • Sand-mining and clay excavation for the construction sector are believed to be exacerbating erosion on the Hau River
Land use	• Predominately farming with increasing industrial use
River use	• Fishing, • Small, medium & large river transport. • Evidence of sand mining

ANNEX II: DETAILED ASSET INVENTORY AND VALUE

Proposed Equipment for O Mon-IV

Source: CTTP (September 2010)

Component / Subcomponent		Description	Base Cost (VND million)
1.1a	EPC Package, Construction	Turbine building	70,386
		Gas turbine foundation	27,405
		Steam turbine foundation	11,682
		HRSG foundation, blowdown tank and chimney foundation.	47,067
		Pipe rack foundation	3,664
		Main transformer, auxiliary transformer and gantry tower foundations	14,372
		Garage	2,067
		Control building	12,389
		Warehouse	9,252
		Mechanical and electrical workshop building	7,256
		Diesel plant	4,880
		Motor car garage	242
		Motor-bike garage	447
		Canteen	2,713
		500 kV Sub-station	25,169
		Cable trench system	10,128
		Primary water tank	6,287
		Cooling water system (pipe, siphon pit, discharge culvert)	16,963
		Chlorination building	1,844
		Water treatment plant	2,665
		Water treatment area	25,051
		Fire station	0
		D.O. tanks area - 2 x 10,000m3	32,903
		Oil pump station	374
		Gas distribution station	1,389
		Hydrogen plant	367
		Pipeline bridge	6,409
		Storm water drainage system	5,265
		Foundation of fire-fighting pipe	1,076
		Internal road	20,448
		Landscaping	3,667
		Fence, gate and gate house	3,944
		Reinforcing wall of foundation pit	21,191
		Piling test	2,084
		Materials cost for main buildings	593,887
		Temporary roads for construction works	1,718
		Warehouse for equipment	1,345
		Temporary fence	119
		Water supply for construction works	3,740
		Inside - EPC package	9,986
		Outside - EPC package	2,746
1.1b	EPC Package, Equipment	Main equipment of the plant	7,899,273
		Main equipment of the plant - testing and installation	184,797
		Technology transfer	89,110

		Water supply for construction	3,801
		Other costs	58,564
1.2	Common Facilities	Administration building	9,236
		500kV Switchyard	15,561
		Intake tower and pumping station	31,125
		Discharge tunnel	142,211
		Discharge open channel No.2	111,825
		Road from O Mon-III to O Mon-IV	7,033
		Pump station, fire fighting piping system, fire fighting trucks	58,334
2	Road No. 2 to O Mon Center	Access Road No.2	80,801
3	Land filling	Land filling	31,659
4	Staff apartments	Staff apartments	57,268
7	Project management	Project management	49,015
8.2	Design and studies	Design and studies, in-house	3,717
15/6	Fuel for testing of equipment	Fuel Oil for Testing and Commissioning	188,769
		Gas for Testing and Commissioning	92,586
19	Detection and destruction of explosive materials	Detection and destruction of explosive materials	1,161
20	Clearance, compensation and resettlement	Clearance, compensation and resettlement	218,850
	Other costs	Appraisal costs for FS	344
		Permit fees	755
		Preparatory production	42,200
		Financial and other fees	21,100
			10,413,684

	Consultant services	EPC package, national	1,328
		EPC package, international	241,366
		Designs and studies	27,815
		DED for staff apartments	1,765
		Construction supervision of staff apartments	861
		Audit and balance sheet of project cost	1,383
		Independent monitoring and env. audits	15,973
			290,490
			10,704,175

ANNEX III: MODELLING APPROACH & VERIFICATION

A – HYDROLOGICAL & HYDRODYNAMIC MODELLING

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

A1. Modeling overview

The modeling has two scopes and scales:

I. Regional and basin-wide hydrological/hydrodynamic model providing boundary values for the local model
II. 3D hydrodynamic and thermal model for plant impact assessment.

The computed discharge are used as water levels in the first model are used in the second one as boundary values. There are three options for setting up the boundary values: (i) water levels are prescribed on both upstream and downstream boundaries, (ii) water levels are used in both boundaries or (iii) water level is used on one boundary and discharge on the other one. The two models are fundamentally different in their computation and it was found out that they are basically incompatible:

i. if water levels are used on both boundaries the flows in the 3D model are too low
ii. if flows are prescribed on both boundaries the water levels and flooding are unrealistic
iii. if water level is used on one boundary and flow on the other the flow needs to be adjusted to get realistic water levels.

Resolving the incompatibility was not possible within the project scope. Instead the third option was used and boundary flow adjusted to 40% of the original one. This provided also compatible flow with the measured average and maximum flow in Can Tho gauging station 1978 - 2004. The measured average and maximum flows are 2440 m^3/s and 8000 m^3/s and the corresponding adjusted computed flows for the year 1997 2952 and 7200 m^3/s. For the year 2000 the adjusted flows are 3700 m^3/s and 8040 m^3/s. Minimum flows are not represented well by the adjustment: the measured minimum flow is 800 m^3/s and the adjusted ones 185 m^3/s and 423 m^3/s.

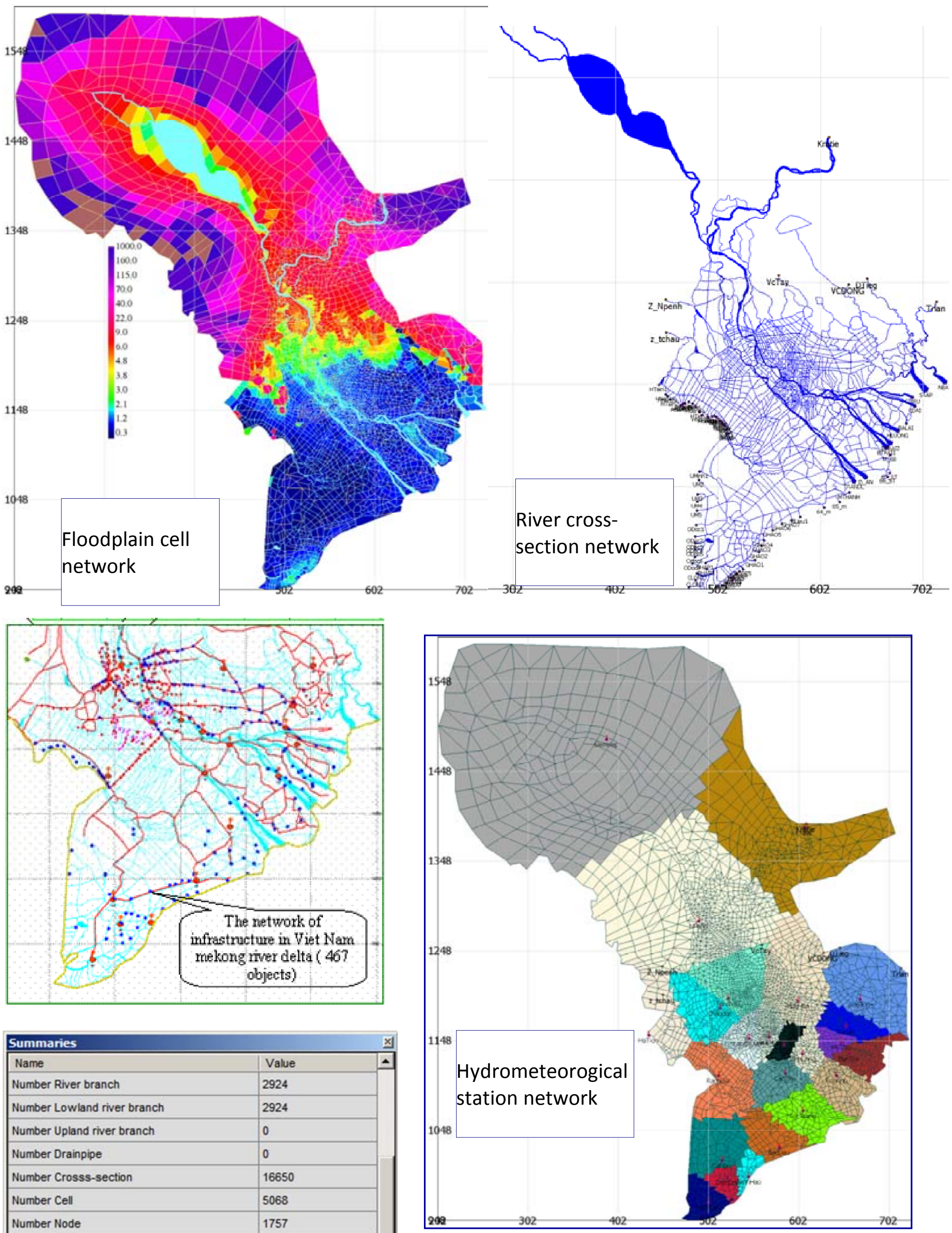
Both relatively dry and extreme flood years were studied in the project (1997 and 2000). In addition the impact of the Linda storm was studied for both years. The whole year statistics and characteristics were analyzed as well as the driest month May and wettest month October. The corresponding periods and episodes were then studied in climate change conditions, that is with predicted 2040 change in Mekong upstream flow, precipitation and sea level rise.

A2. Regional hydrological model

The purpose of the HydroGis application is to provide boundary data for the local O Mon 3D flow, water level, flood and temperature model.

Figure 1 shows how model is constructed. The modelled area is divided into *flood cells* that are filled by *river and channel network* during flood season. Main *infrastructure* (gates, dyke, bridges etc.) controls flow. *Meteorological data* (precipitation, evaporation) are obtained from hydrometeorological network. The year 2040 scenarios have been simulated with an adapted grid that takes into account proposed adaptation measures for climate change and sea level rise (Figure 42).

Figure 43 1HYDROGIS model set-up: *showing floodplain cells (upper left), river network (upper right), infrastructure points (middle left) and hydro-meteorological stations (lower right)*



Summaries

Name	Value
Number River branch	2924
Number Lowland river branch	2924
Number Upland river branch	0
Number Drainpipe	0
Number Crosss-section	16650
Number Cell	5068
Number Node	1757
Number Lowland node	1757
Number Upland node	0
Number Node of Drainpipe	0
Number Upstream Boundary	7
Number Downstream Boundary	82
Number Hydromet Station	24
Number Geo-point	14916
Number Observation point	26
Number Dam(Bridge)	194
Number Dike	214
Number Sewer	61

HydroGis has been tested on 12 case studies recommended by European hydraulic experimental labs including comparision with analytic solutions, numerical stability and approximation, sensitivity of numerical algorithms and mass conservation.

The model has been tested by comparing model results with measurement data in 4 Vietnamese river deltas:

- River delta with strong tidal forcing (the Thi Vai River, Vung Tau city);
- River delta with minimal tidal forcing (the Cai River, Nha Trang city)
- River delta with strong tidal and upstream forcing (the Mekong River)River delta with lot of control structures (the Sai Gon-Dong Nai River, south Vietnam).

The computed and measured water levels and discharges are shown for two measurements points near the Cambodian border (Tan Chau and Chau Doc) in Figure 43. The points are located in the Mekong and Bassac branches of the Mekong River. Figure 5 shows the computed and monitored water levels in 3 main channels west of the Bassac River.

Figure 44 HydroGIS simulated water levels and discharges compared to observed data in the Mekong River mainstream near the Cambodian-Vietnamese border. Year 2001

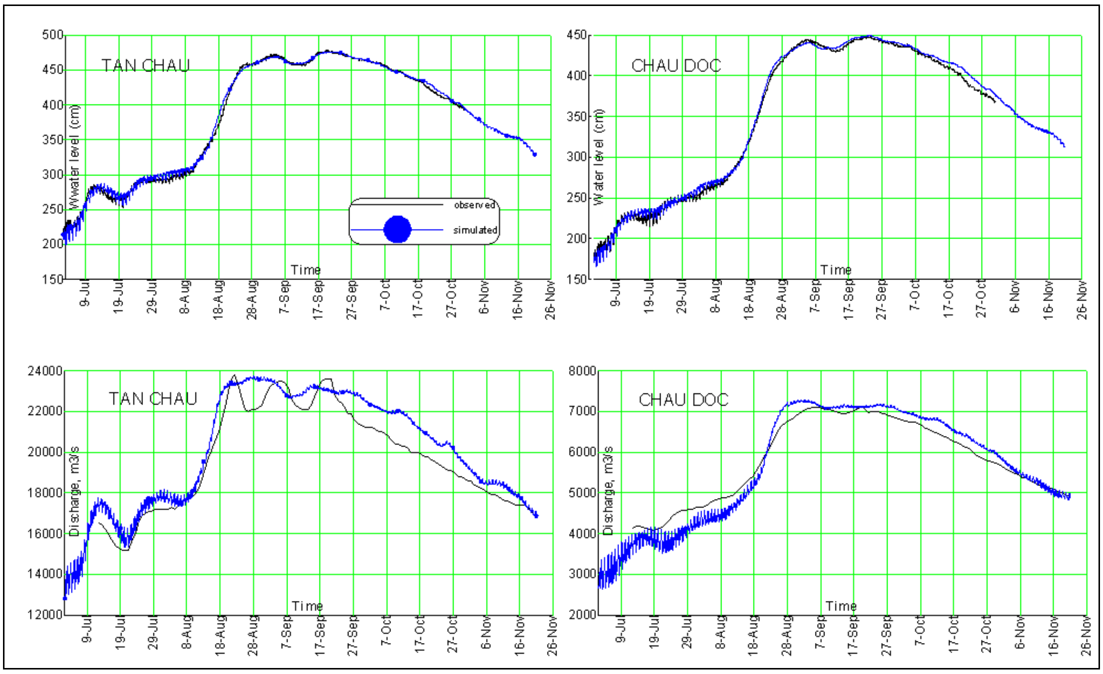


Figure 45 Location map of the hydrologic stations near the O Mon power station. From: Location map of hydrologic stations in the Lower Mekong Basin, Mekong River Commission 2005.

Figure 46 Can Tho: comparison of modelled and observed water levels

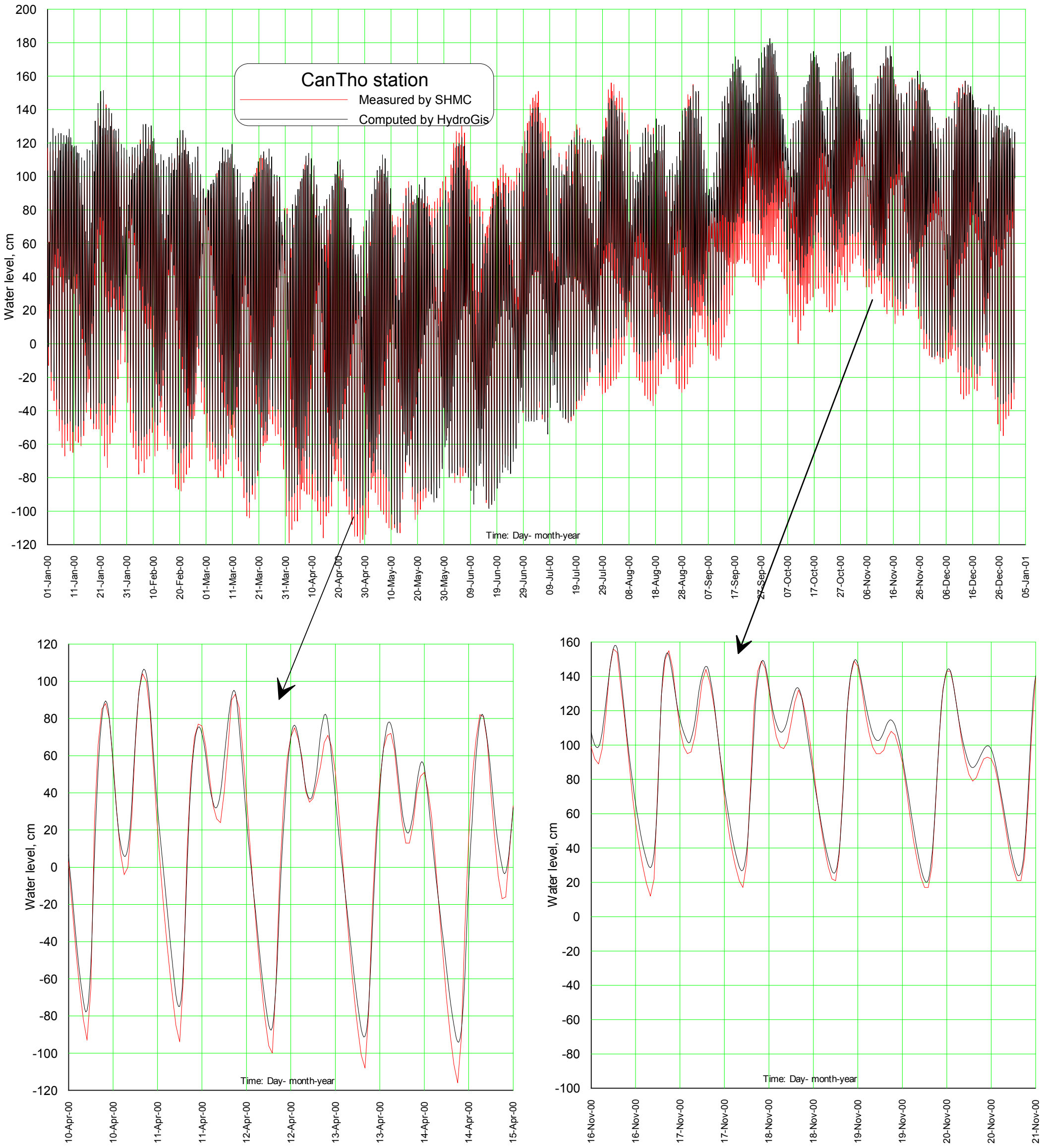
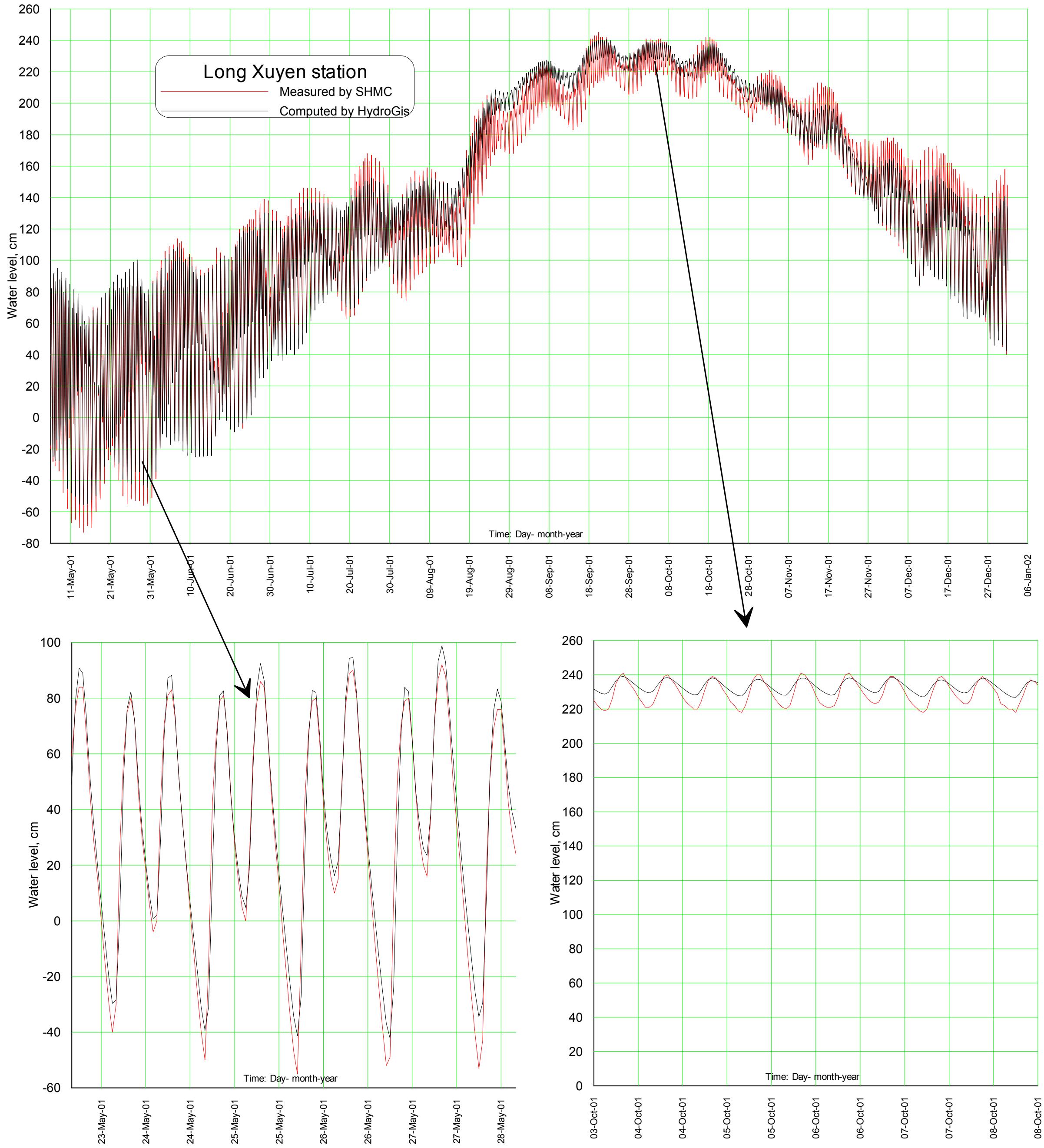


Figure 47 Long Xuyen: comparison of modelled and observed water levels



A3. 3D hydrodynamic and temperature model

3D modeling is required for simulation of the river flow and plant thermal releases. 3D modeling takes into account both horizontal and vertical flow and thermal distribution. The coolant water tends to stratify on the surface and the flow near the shore is very different from the flow in the middle of the river channel and deeper parts. These effects can't be described with a 1D or 2D model. Also flooding requires at least 2D model approach.

The EIA 3D model has been used in the study. The model has been used in more than 300 projects since 1982. Large number of projects have been dealing with cooling water discharges from conventional and nuclear power plants. During 2001 - 2010 the model has been used in South East Asia for 8 areas. In Vietnam applications have included whole Delta and high resolution applications in Plain of Reeds, Tan Chau and Tan Tieu River mouth including coastal areas (reference Mekong River Commission and National Mekong Committees). The EIA 3D model characteristics are:

1. spatial description in 3-dimensions (requirement to obtain horizontal and vertical distributions; also proper description of stratification, turbulence and other parameters requires 3D model)
2. calculation of density (temperature, salinity)
3. calculation of sediment related processes, that is transport, sedimentation, resuspension, erosion, bed load etc.
4. advanced turbulence calculation for vertical mixing and flow properties (in EIA model several options including most universal k-e model)
5. ability to combine high-resolution near-field calculation with far-field simulation for large sea impact through sea currents and wind, wave and tide induced circulation (in EIA model nesting with varying resolution is used, for instance 1 - 200 m resolution)
6. accurate description of small-scale features important for flow such as bottom channels and jetties
7. description of momentum advection
8. wave modelling
9. inclusion of tides in the calculation
10. accurate flooding description.

A4. 3D model set-up

Figure 1 and 2 show the 3D model grid used in the project. The grid resolution (grid box size) is 50 m. The area covers both the river system and floodplains around the plant. The three plant outlets for the complete plant complex are shown near the middle part of the grid. The coolant outlet is near the narrow river channel downstream (right hand side) junction.

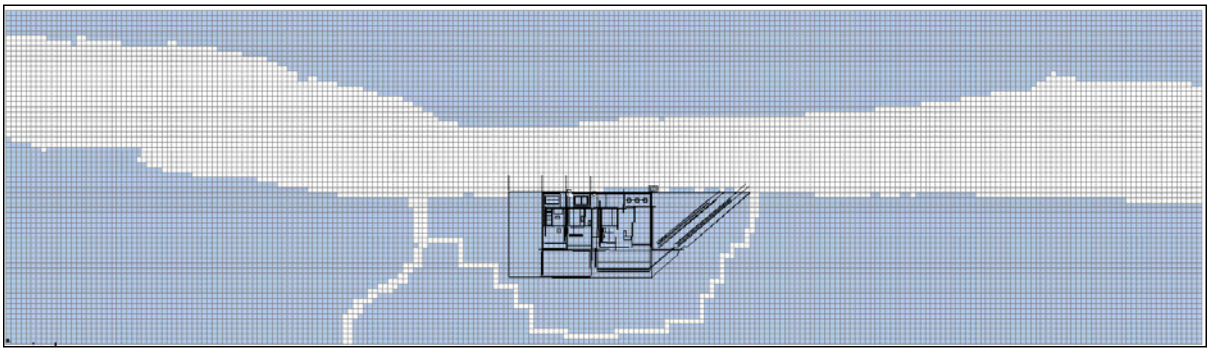


Figure 1. 3D model grid. Blue color shows river channels. Grid resolution is 50 m.

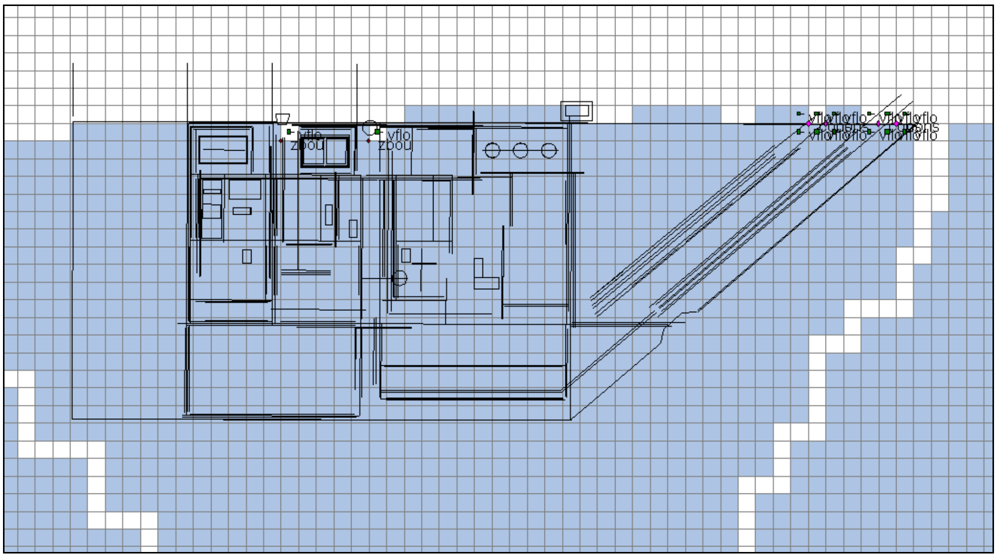


Figure 2. 3D model grid zoomed to the power plant. Coolant discharge outlets are to the right of the plant and intakes in the middle part of the plant.

Figure 3 shows the grid elevations in the mean sea level reference system. The elevations are based on MRC Hydrographic Atlas data and Vietnamese data.

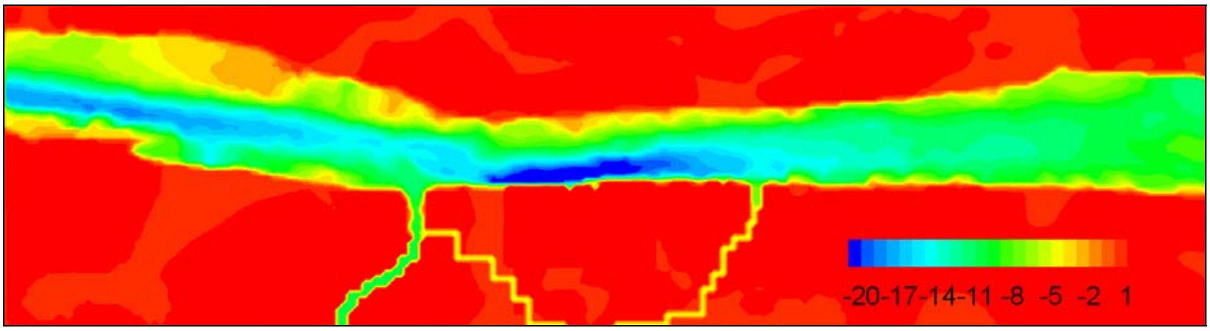


Figure 3. Pilot model elevations. Red color above mean sea level (0 m), dark blue color -20 m or lower. The plant ground elevation is 2.7 m.

Considering the limited scope of the project the model set-up needed to be simplified. Instead of using full weather and climate data sets the following has been assumed:

- constant wind from west 3.6 m/s (average wind speed, typical wind direction part of the year)
- average constant air temperature, pressure, humidity and cloudiness
- average constant incoming water temperature without taking into account daily or seasonal variability
- average constant sediment concentration and Secchi depth (light penetration)
- no land use data taken into account in the simulations.

There is no other reason using the these approximations other than the time and costs of obtaining and processing of full data sets. Many important aspects for the plant operation such as thermal coolant feedback in different conditions can't be included in the project scope and need to be covered with future work. More thorough model calibration and verification would be needed for technical planning of for instance power intakes and outlets.

The air temperature used for the baseline is 27 °C, pressure 1016 mbar, relative humidity 85% and cloudiness 0%. These values (except for cloudiness) correspond to average atmospheric conditions. In the future climate change scenarios air temperature has been raised to 30.3 °C. The value is based on 10 global climate models that have been downscale to the Ho Chi Minh City area. The range of temperature increases from the downscaled models are:

- May max temperature 2 - 4 °C
- May min temperature 2.7 - 3.7 °C
- October max temperature 2.7 - 4.5 °C
- October min temperature 2.7 - 4.2 °C

Based on these ranges the most probably temperature increase in the future 2040 - 2065 scenario is 3.3 °C.

The incoming water temperature was calculated with the water temperature model. The value was set to 30 °C which corresponds to average river water temperature at Can Tho. Water temperature model was calibrated using this temperature and average atmospheric conditions. When the calibrated model was applied for the future climate conditions the incoming water temperature was found out to be 30.9 °C.

The sediment concentrations affect light penetration into the water mass. The average sediment concentration from measurements is 30 mg/l which corresponds to about 50 cm Secchi depth. In the future scenario Mekong dams will trap most of the sediments and sediment concentration will be much lower. However only a modest 10 mg/l change in sediment concentration was used and the corresponding Secchi depth estimated to be 100 cm. The Secchi depths are obtained from a curve based on simultaneous measurement of Mekong water sediment concentration and Secchi depth (MRC WUP-FIN).

Land use data is usually used when modeling flood propagation. Land use (vegetation) defines the flow friction in different water layers and also has sheltering effect for wind. Because the model area has been restricted to a quite small area there was no reason to include the land use in the simulation.

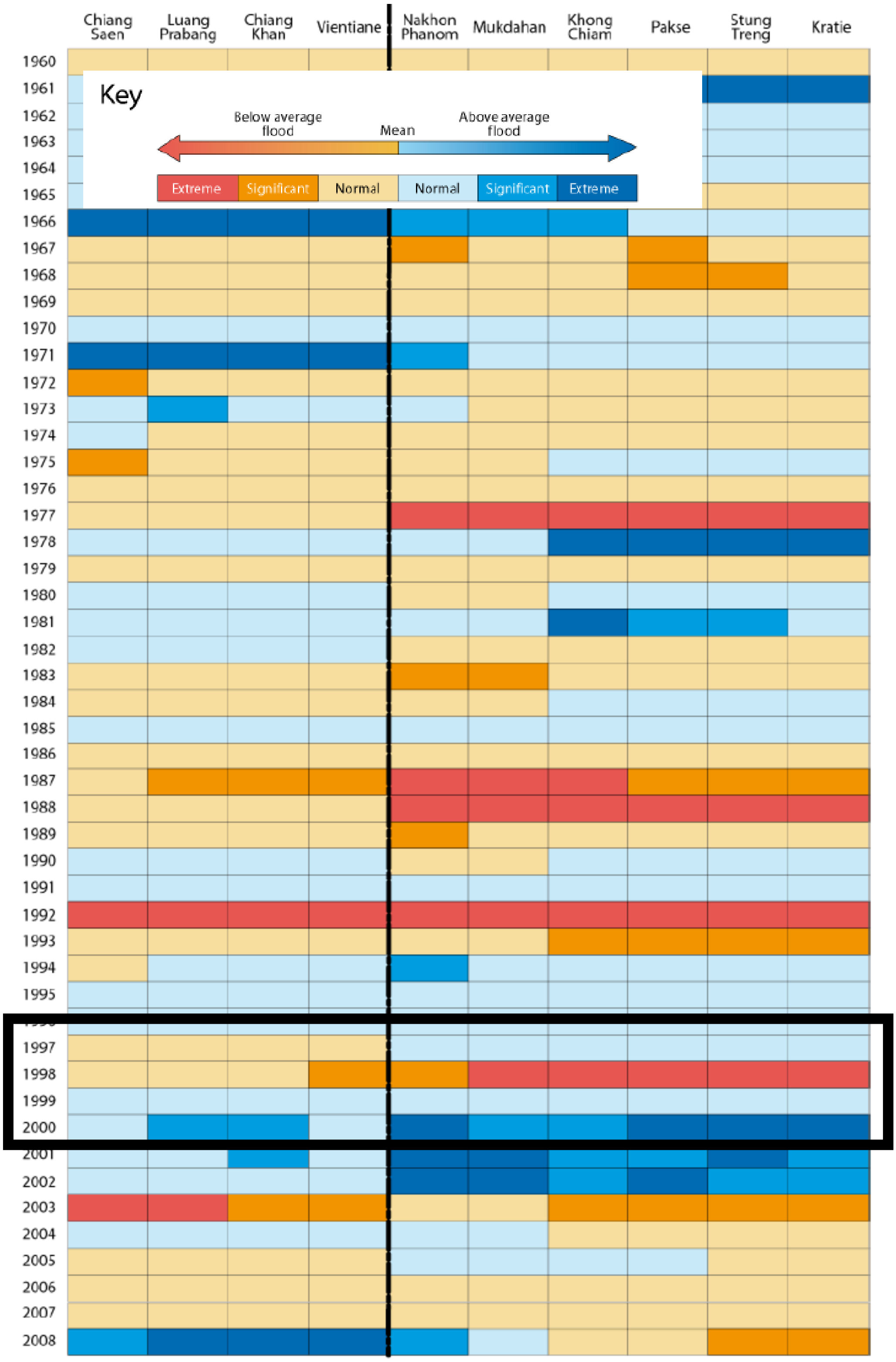
Other assumptions and model parameter values are:

- k-epsilon vertical turbulence model (the most general and physically accurate model available)
- constant horizontal turbulent viscosity 1 m^2/s
- wind drag coefficient 0.0012 (obtained from calibration for other model applications)
- square bottom friction coefficient 0.01 (obtained from calibration for other Mekong river channel areas)
- layer velocities are calculated directly instead of splitting into external/internal modes
- coolant water temperature increase is 7 °C
- all units are operational with total water intake 88 m^3/s and coolant discharge 85 m^3/s.

B – SELECTION OF CHARACTERISTIC WATER YEARS

Typical and extreme flood years were identified for particular attention in the modelling utilising statistical definitions for flood characteristics developed by the Mekong River Commission (MRC). Taking values for Kratie as the beginning of the Mekong Delta floodplain, the years 1997, 1998 and 2000 were chosen as being representative of the typical range of average, dry and wet years (Figure 35).

Figure 48 Statistical characterisation of flood years: *The selected years of 1997, 1998 and 2000 are representative of an average, dry and extreme wet years respectively for the Mekong River Delta area. (Source: MRC, 2009)*



C – DERIVATION OF A RATING CURVE FOR THE HAU RIVER CHANNEL

A rating curve relates river water levels to discharge or vice versa. The most common type of rating curve is power type equation:

$$Q = c(h + a)^b$$

where:

Q = discharge (m3/sec)
h = measured water level (m)

a = water level (m) corresponding to *Q* = 0
b, c = coefficients derived for the relationship corresponding to the station.

The rating curve was derived for the O Mon river area from the HydroGis model results. Monthly average values for computed water elevations and discharge were used. The unknown coefficients *a, b* and *c* were obtained by taking logarithm of the rating curve equation and using the least squares method for best fit with the HydroGis discharges. After the best fit was obtained the equation was turned around using logarithms to obtain function for the water elevations:

$$h = 10^{\frac{\log_{10}(Q) - \log_{10}(c)}{b}} - a$$

Three different rating curves were calculated for falling flood, early flood and raising flood. The corresponding coefficient values are presented in Table A.

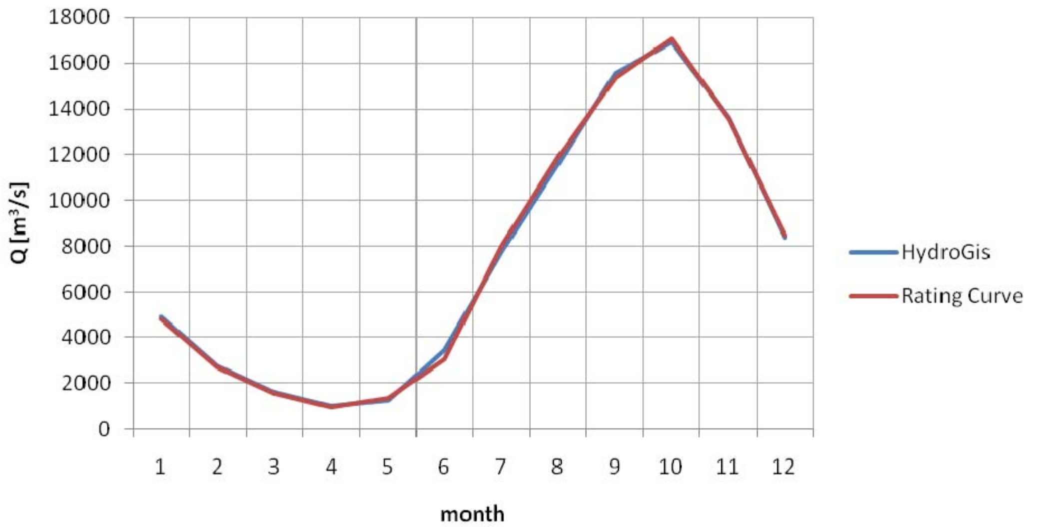
Table A. Rating curve coefficients for different months.

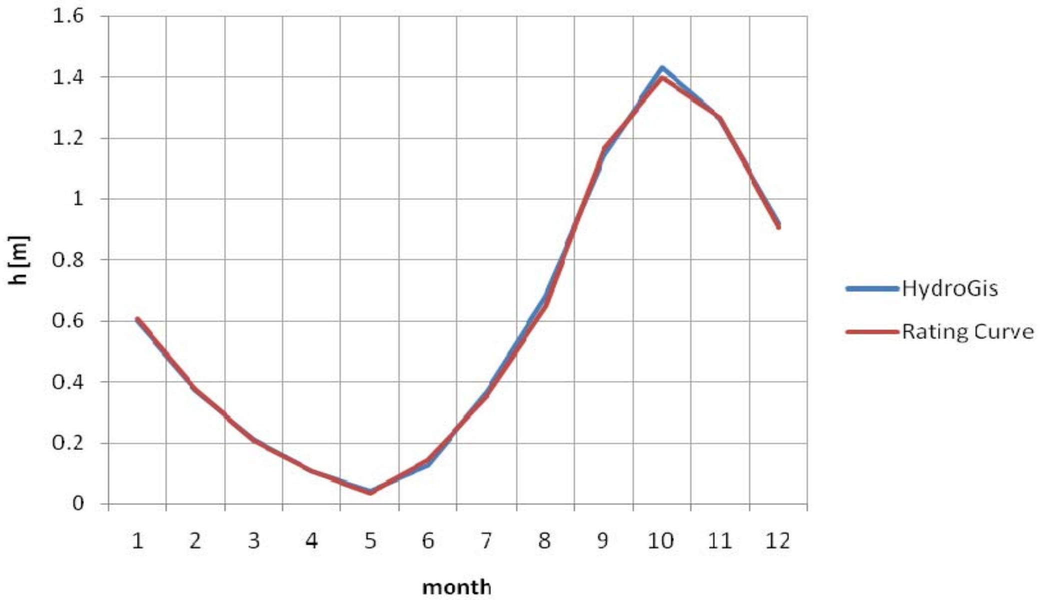
	a	b	c
Jan	0,231717	1,771256	6634
Feb	0,231717	1,771256	6634
March	0,231717	1,771256	6634
April	0,231717	1,771256	6634
May	0	0,744982	14521
June	0	0,744982	14521
July	-0,19628	0,38666	15726
Aug	-0,19628	0,38666	15726
Sept	-0,19628	0,38666	15726
Oct	-0,19628	0,38666	15726
Nov	0,231717	1,771256	6634
Dec	0,231717	1,771256	6634

Figure 3-F compares the HydroGis computed monthly average discharge and the corresponding discharge obtained from the rating curve using the HydroGis computed monthly average water level. Similarly Figure 2 compares the HydroGis and rating curve water elevations. It can be seen that the fit is very good and the rating curve can be used for obtaining water levels in changing flow conditions, at least on a more or less average basis.

The above analysis should be conducted with measured flow and discharge in the future and within the scope of a more detailed study.

Figure 3-F Comparison of modeled and rating curve obtained discharges (top) and water levels (bottom)





D – LIMITATIONS OF PREVIOUS HYDRODYNAMIC MODELLING

Two previous O Mon power plant thermal plume modeling studies exist: (i) Power Engineering & Consulting Company No.3 (PECC3)/ Environment and Computer Department, O Mon IV Thermal Power Plant Environmental Impact Assessment, May 2007 and (ii) Vattenfall, O Mon Thermal Power Plant Final Report, Environmental Impact Assessment, April 2008. These studies are referred here as PECC3 and Vattenfall.

The PECC3 is a 2D (2 dimensional) vertically integrated study. The model used in the study is SW-FAST2d version 2.5 2005. The model has at least two crucial limitations: (i) thermal plumes require 3D modeling because of thermal stratification, 2D models can't capture vertical density or velocity differences or stratification, (ii) based on the velocity fields in Figures 3-3 and 3-4 the simulated flow fields are not right showing highest velocities near the shore and dramatically diminishing towards the middle of the river; the reality is that the flows are vice versa because of much higher impact of bottom stress on the flow in shallow areas.

The Vattenfall modeling work is based on 3D approach applying MIKE3D model. The approach is more sound as it takes into account water density (warm water is more light) and vertical distribution of flow and temperature. The modeling work may be adequate as a rough scoping study for a EIA, but it is clearly inadequate for any technical planning purposes. The limitations of the study are:

1. The modeling doesn't include flooding (Mike3D can't model flooding). The flooding can spread the cooling water to a large floodplain area.
2. The channel system near the outlet, flooding around and thermal impacts are not included in the model.
3. The maximum tidal amplitude is about +- 1.5 m but the 3 m change in water level is not reflected in the model geometry as can be seen from figures 24 – 27. The near shore flow depends crucially on this water level change.
4. The coolant feedback into the intakes is not studied at all. Even a small rise in the coolant temperature can mean substantial amount of money.
5. There is an indication in Figure 27 that feedback can be significant but the distribution so much off the shore remains unexplained when expectation is more near shore distribution (maybe wind is pushing the plume?).
6. The very low vertical mixing of the coolant is unexplained as the expectation is to have more mixing in constantly changing tidal and wind conditions.
7. No time series analysis of the results is presented for some reason. The variability in different conditions would be crucial information.
8. The simulation period is very short, only one week, compared to the high variability of conditions.
9. No calibration or verification results for the model are presented so it is impossible to know the reliability of the results.
10. Impact of the massive sand mining is not modeled.
11. The potential natural thermal stratification of the river is neither discussed nor modeled. This would be crucial for plant coolant intake.

E – STATISTICAL SELECTION OF GCM

The study used the Sum of Squares method to quantify the variability between each GCM output and the baseline monthly temperature averages for Can Tho/

Month	CAN THO Monthly average temp. (°C)	ccma_gcm3_1	cnrm_cm3	**gfdl_cm2_0**	csiro_mk3_0	csiro_mk3_5	giss_model_e_r	ipsl_cm4	mpi_echam5	mpi_echam4_PRECIS
Jan	25.4	0.6	0.2	0.4	0.4	0.3	0.4	-0.2	0.3	4.43
Feb	25.9	0.7	0.0	0.4	0.3	0.0	0.4	-0.2	0.7	4.66
Mar	27.2	0.2	-0.6	0.2	-0.1	-0.8	-0.3	-0.7	0.3	4.26
Apr	28.3	-0.6	-1.1	-0.2	-0.6	-1.0	-0.8	-0.6	-0.3	3.43
May	27.9	-0.3	-0.2	-0.2	-0.1	-0.4	-0.2	0.0	-0.2	2.65
Jun	27.1	0.0	0.2	-0.3	0.3	-0.5	0.7	0.6	0.1	1.86
Jul	26.8	0.4	0.3	0.1	0.4	-0.2	0.4	0.6	0.1	1.93
Aug	26.6	0.3	0.3	0.2	0.6	-0.1	0.0	0.3	0.1	2.52
Sep	26.7	-0.1	0.2	0.0	0.3	-0.1	0.0	0.1	0.1	1.27
Oct	26.6	0.0	0.4	0.0	0.4	-0.1	0.2	0.3	0.2	1.49
Nov	26.5	-0.3	0.1	-0.2	0.2	-0.1	0.0	0.0	-0.2	2.22
Dec	25.4	0.4	0.6	0.3	0.7	0.4	0.7	0.2	0.3	3.84
Year	26.7	0.1	0.0	0.1	0.2	-0.2	0.1	0.0	0.1	2.88
ave diff		0.1	0.0	0.1	0.2	-0.2	0.1	0.0	0.1	2.9
max diff		0.7	0.6	0.4	0.7	0.4	0.7	0.6	0.7	4.7
min diff		-0.6	-1.1	-0.3	-0.6	-1.0	-0.8	-0.7	-0.3	1.3
absolut max diff		0.95	1.22	0.52	0.88	1.11	1.10	0.90	0.76	4.83
STDEV		0.41	0.47	0.24	0.34	0.41	0.44	0.40	0.28	1.20
SQUARED ERRORS										
Jan	25.4	0.354	0.046	0.148	0.141	0.081	0.130	0.038	0.099	19.658

Feb	25.9	0.483	0.000	0.194	0.102	0.000	0.172	0.048	0.497	21.721
Mar	27.2	0.036	0.422	0.034	0.020	0.601	0.096	0.476	0.112	18.124
Apr	28.3	0.416	1.188	0.040	0.314	1.051	0.656	0.366	0.078	11.736
May	27.9	0.119	0.048	0.027	0.010	0.152	0.024	0.002	0.055	7.037
Jun	27.1	0.000	0.048	0.073	0.068	0.212	0.548	0.319	0.004	3.472
Jul	26.8	0.152	0.063	0.005	0.202	0.040	0.156	0.331	0.004	3.736
Aug	26.6	0.112	0.068	0.048	0.308	0.003	0.000	0.081	0.017	6.333
Sep	26.7	0.007	0.024	0.001	0.116	0.003	0.001	0.007	0.011	1.604
Oct	26.6	0.000	0.160	0.001	0.126	0.006	0.055	0.076	0.032	2.207
Nov	26.5	0.102	0.012	0.031	0.038	0.017	0.002	0.000	0.038	4.929
Dec	25.4	0.168	0.308	0.090	0.469	0.172	0.462	0.055	0.119	14.754
SUM SQUARES		1.951	2.388	0.692	1.913	2.337	2.302	1.800	1.067	115.311

ANNEX IV: SUPPORTING RESULTS

This annex presents additional results and supporting data from the assessment as referred to in the report.

A - MODELLING RESULTS

Table 19 Coolant fraction frequency distribution in the water intake for 1997 May baseline and climate change scenarios

COOLANT FRACTION	0%	10%	20%	30%	40%	50%	60%
baseline	33.1	19.6	16.6	16.8	11.7	2.3	0.0
CC	30.4	21.4	16.9	14.7	11.2	4.4	1.0

Figure 49 Maximum flood depth in the wet (extreme flood) year. *Blue is less than 0.6 m depth and red more than 1.4 m. Baseline scenario*

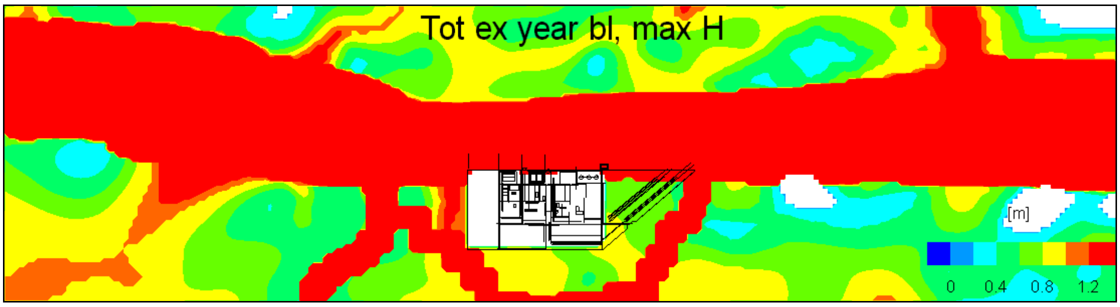


Figure 50 Maximum flood depth in the wet (extreme flood) year. *Blue is less than 0.6 m depth and red more than 1.4 m. Climate change scenario*

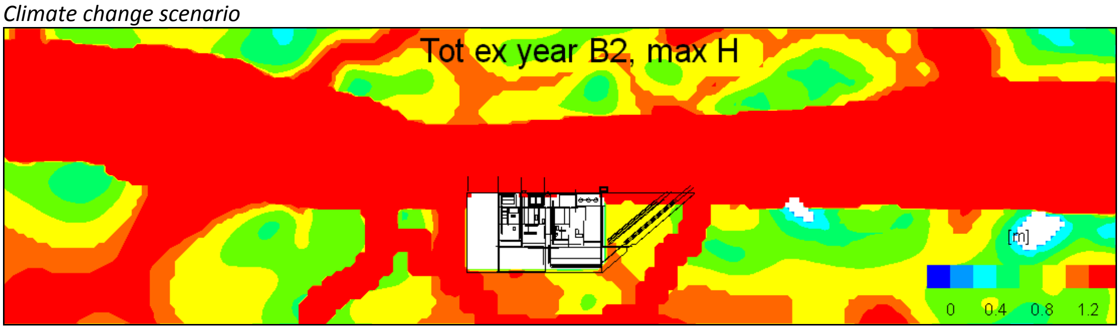


Figure 51 Change in maximum flood depth in the climate change scenario compared to baseline. *Red color is more than 80% change*

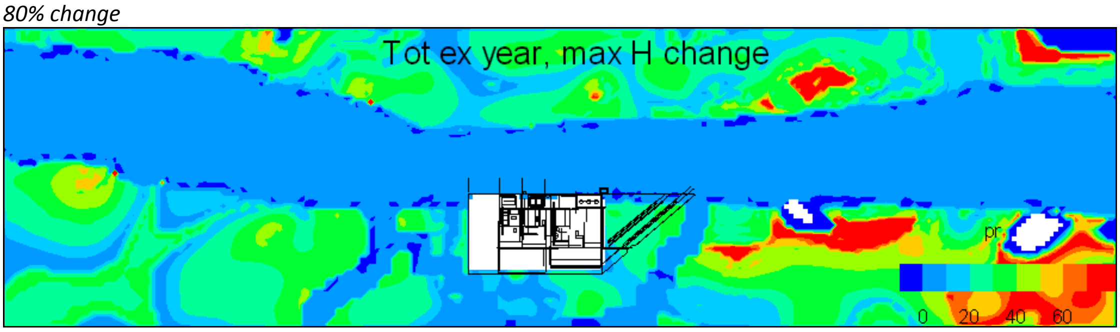
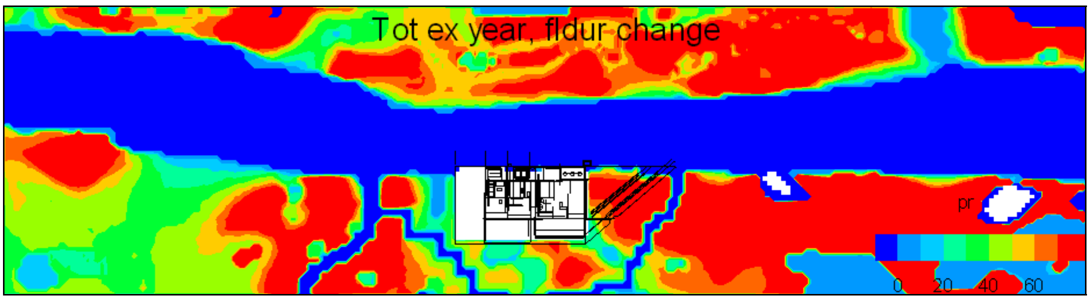


Figure 52 Change in flood duration. climate change scenario compared to baseline**.** *Red color is more than 80% change*



SIMULATED RIVER WATER TEMPERATURE WITH AND WITHOUT CLIMATE CHANGE

				summary stats						Histogram									
Model run	water year	season	scenario	n	sum	avg	std	min	max	28	29	30	31	32	33	34	35	36	37
May average year baseline	average	dry	baseline	7,442	232,305	31.22	1.42	28.24	34.61	2.0	25.3	16.5	21.7	22.4	10.5	1.6	0.0	0.0	0.0
May average year B2	average	dry	CC	7,442	260,503	35.00	1.37	32.13	38.73	0.0	0.0	0.0	0.0	3.2	26.7	19.1	26.8	16.7	7.5
October average year baseline	average	wet	baseline	7,442	222,420	29.89	0.55	29.08	31.34	0.0	65.2	32.2	2.6	0.0	0.0	0.0	0.0	0.0	0.0
October average year B2	average	wet	CC	7,442	250,950	33.72	0.55	32.82	35.05	0.0	0.0	0.0	0.0	1.7	67.7	30.4	0.2	0.0	0.0
Storm surge average year baseline	average	annual	baseline + storm surge	722	21,486	29.76	0.52	28.96	30.92	1.0	67.9	31.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Storm surge average year B2	average	annual	CC + storm surge	722	24,259	33.60	0.49	32.83	34.67	0.0	0.0	0.0	0.0	3.6	70.6	25.8	0.0	0.0	0.0
Total average year baseline	average	annual	baseline	87,567	2,666,600	30.45	1.17	27.99	34.74	2.1	44.4	26.0	14.8	8.8	3.6	0.3	0.0	0.0	0.0
Total average year B2	average	annual	CC	87,567	3,005,730	34.32	1.18	31.53	38.68	0.0	0.0	0.0	0.1	5.1	43.8	27.0	12.8	8.3	3.0
May extreme flood year baseline	extreme	dry	baseline	7,442	230,222	30.94	1.39	28.65	34.50	1.7	33.5	17.2	21.0	18.1	7.9	0.6	0.0	0.0	0.0
May extreme flood year B2	extreme	dry	CC	7,442	258,461	34.73	1.34	32.42	38.42	0.0	0.0	0.0	0.0	3.2	36.3	18.0	21.6	15.8	5.2
October extreme flood year baseline	extreme	wet	baseline	7,442	222,555	29.91	0.56	29.13	31.27	0.0	64.7	31.3	4.0	0.0	0.0	0.0	0.0	0.0	0.0
October extreme flood year B2	extreme	wet	CC	7,442	251,179	33.75	0.55	32.94	35.00	0.0	0.0	0.0	0.0	0.4	68.6	31.0	0.0	0.0	0.0
Storm surge extreme flood year baseline	extreme	annual	baseline + storm surge	722	21,482	29.75	0.58	28.96	31.02	0.8	66.3	32.4	0.4	0.0	0.0	0.0	0.0	0.0	0.0
Storm surge extreme flood year B2	extreme	annual	CC+ storm surge	722	24,294	33.65	0.58	32.77	34.82	0.0	0.0	0.0	0.0	7.8	61.6	30.6	0.0	0.0	0.0
Total extreme flood year baseline	extreme	annual	baseline	87,567	2,651,660	30.28	1.05	28.01	34.78	2.7	48.8	26.4	14.0	5.7	2.2	0.23	0.0	0.0	0.0
Total extreme flood year B2	extreme	annual	baseline	87,567	2,987,060	34.11	1.02	32.01	38.16	0.0	0.0	0.0	0.0	5.6	50.1	28.1	9.2	5.5	1.6

B - PECC3 EFFICIENCY & POWER OUTPUT SIMULATION RESULTS

Detailed modelling of plant energy output, consumption and efficiency were simulated for O Mon IV using actual design specifications of plant components as defined in the technical design document (PECC, 2009). Simulations were undertaken for three scenarios, with results reported below:

A. **Increasing air temperature + constant river water temperature:** air temperature was varied between 25 - 36°C, while river water temperature was kept constant. This allowed for the extraction of the specific impact of air temperature on plant performance;
B. **Increasing river temperature + constant air temperature:** river water temperature was varied between 25 - 36°C, while air temperature was kept constant. This allowed for the extraction of the specific impact of river water temperature on plant performance; and
C. **Combined increasing air temperature + increasing river water temperature:** both air and river water temperatures were varied between 25 - 36°C. This allowed for the quantification of the combined impact.

Scenario		Air Temperature	River water temperature	Plant Cross output (kW)	Plant Net output (kW)	Net efficiency (%)	Power consumption of CW pumps (kW)	Power consumption for all other plant equipment (kW)	Power consumption for all plant equipment (kW)					Energy consumption for all plant equipment (GWh/yr)	Change in energy output (GWh/yr)	Relative change in power output (%)
								Operating Loads	100%	90%	75%	60%	40%			
								Annual Hours at Load	1500	2200	2000	1300	600			
								Operating time equivalent to maximum power	1500	1980	1500	780	240			
								Operating time equivalent to maximum power (Tmax)	6000							
A	A1	25	30	758,806	742,641	55.5	3,468	12,697	16,165	15,827	15,249	14,524	13,502	116.55	4,436	2.70%
	A2	26	30	755,449	739,305	55.52	3,468	12,676	16,144	15,811	15,228	14,507	13,490	116.41	4,416	2.24%
	A3	27	30	751,820	735,700	55.53	3,468	12,652	16,120	15,793	15,205	14,489	13,478	116.26	4,395	1.74%
	A4	28	30	747,657	731,564	55.54	3,468	12,625	16,093	15,772	15,178	14,469	13,464	116.08	4,370	1.16%
	A5	29	30	743,501	727,434	55.55	3,468	12,599	16,067	15,751	15,153	14,447	13,451	115.91	4,345	0.59%
	A6	30	30	739,229	723,188	55.54	3,468	12,573	16,041	15,731	15,127	14,427	13,437	115.74	4,320	0.00%
	A7	31	30	734,894	718,878	55.53	3,468	12,548	16,016	15,710	15,101	14,407	13,423	115.57	4,294	-0.60%
	A8	32	30	730,568	714,577	55.52	3,468	12,523	15,991	15,690	15,075	14,387	13,409	115.40	4,268	-1.20%
	A9	33	30	726,474	710,506	55.51	3,468	12,500	15,968	15,670	15,050	14,366	13,396	115.24	4,244	-1.76%
	A10	34	30	722,424	706,478	55.5	3,468	12,478	15,946	15,651	15,026	14,347	13,382	115.08	4,219	-2.32%
	A11	35	30	718,381	702,458	55.49	3,468	12,455	15,923	15,633	15,002	14,328	13,369	114.93	4,195	-2.88%
	A12	36	30	714,350	698,449	55.48	3,468	12,433	15,901	15,616	14,978	14,309	13,356	114.78	4,171	-3.43%

	B1	30	25	741,184	725,098	55.69	3,502	12,584	16,086	15,777	15,176	14,480	13,492	116.11	4,331	0.26%
	B2	30	26	741,085	725,008	55.68	3,494	12,583	16,077	15,772	15,166	14,473	13,485	116.05	4,330	0.25%
	B3	30	27	740,908	724,836	55.67	3,489	12,583	16,072	15,761	15,155	14,462	13,472	115.98	4,329	0.23%
	B4	30	28	740,538	724,478	55.64	3,481	12,579	16,060	15,750	15,148	14,450	13,460	115.90	4,327	0.18%
	B5	30	29	739,896	723,843	55.59	3,477	12,576	16,053	15,742	15,135	14,441	13,451	115.83	4,324	0.09%
	B6	30	30	739,229	723,188	55.54	3,468	12,573	16,041	15,731	15,127	14,427	13,437	115.74	4,320	0.00%
B	B7	30	31	738,326	722,290	55.48	3,468	12,568	16,036	15,725	15,117	14,418	13,426	115.68	4,314	-0.12%
	B8	30	32	737,292	721,262	55.4	3,468	12,562	16,030	15,719	15,110	14,411	13,416	115.63	4,308	-0.27%
	B9	30	33	736,046	720,023	55.3	3,468	12,555	16,023	15,712	15,103	14,404	13,410	115.58	4,301	-0.44%
	B10	30	34	734,746	718,734	55.2	3,464	12,548	16,012	15,700	15,092	14,392	13,398	115.49	4,293	-0.62%
	B11	30	35	733,234	717,231	55.09	3,464	12,539	16,003	15,692	15,085	14,385	13,391	115.43	4,284	-0.83%
	B12	30	36	731,713	715,719	54.97	3,464	12,530	15,994	15,684	15,076	14,377	13,383	115.37	4,275	-1.04%
	C1	25	25	760,692	744,482	55.64	3,502	12,708	16,210	15,872	15,296	14,576	13,558	116.91	4,447	2.95%
	C2	26	26	757,269	741,090	55.65	3,494	12,685	16,179	15,851	15,266	14,553	13,539	116.72	4,427	2.48%
	C3	27	27	753,476	737,326	55.66	3,489	12,661	16,150	15,823	15,233	14,523	13,515	116.49	4,404	1.96%
	C4	28	28	748,970	732,856	55.64	3,481	12,633	16,114	15,792	15,200	14,491	13,488	116.24	4,378	1.34%
	C5	29	29	744,169	728,090	55.6	3,477	12,602	16,079	15,763	15,162	14,461	13,465	116.00	4,349	0.68%
	C6	30	30	739,229	723,188	55.54	3,468	12,573	16,041	15,731	15,127	14,427	13,437	115.74	4,320	0.00%
C	C7	31	31	733,982	717,972	55.46	3,468	12,542	16,010	15,704	15,091	14,397	13,412	115.51	4,288	-0.72%
	C8	32	32	728,621	712,640	55.37	3,468	12,513	15,981	15,677	15,059	14,369	13,389	115.29	4,256	-1.46%
	C9	33	33	723,268	707,317	55.27	3,468	12,483	15,951	15,651	15,027	14,343	13,369	115.08	4,225	-2.20%
	C10	34	34	717,898	701,982	55.15	3,464	12,452	15,916	15,620	14,991	14,312	13,343	114.83	4,193	-2.94%
	C11	35	35	712,348	696,462	55.02	3,464	12,422	15,885	15,595	14,959	14,286	13,324	114.62	4,159	-3.71%
	C12	36	36	706,780	690,926	54.88	3,464	12,390	15,854	15,569	14,927	14,258	13,302	114.40	4,126	-4.48%

C – PERFORMANCE IMPACTS OF CLIMATE CHANGE

WORKSHEET	**PERFORMANCE SUMMARY FOR RISING AIR TEMPERATURE**
PROJECT	***O MON Rapid CC VA***
UPDATED	14-Dec-10

INPUTS

Conversion factor	1 MBTU=	252,000	Kcal								
	1 kWh=	860	kcal								
Ambient temperature	24	25	26	27	28	29	30	31	32	33	34
Power output (MW)	745,977	742,641	739,305	735,700	731,564	727,434	723,188	718,878	714,577	710,506	706,478
Efficiency (%)	55.48	55.50	55.52	55.53	55.54	55.55	55.54	55.53	55.52	55.51	55.50
Hours of full power (hours)	6000										
Gas Price ($/MMBTU)	7.5										

OUTPUTS

Energy output (baseline)												
Frequency	0.000	0.164	0.581	0.181	0.074	0.000	0.000	0.000	0.000	0.000	0.000	
Energy output (GWh)	0.0	717.0	2522.2	781.4	317.9	0.0	0.0	0.0	0.0	0.0	0.0	**4338**
Energy input (GWh)	0.0	1291.7	4541.7	1406.8	572.2	0.0	0.0	0.0	0.0	0.0	0.0	**7812.3**
Energy input (MBTU)	-	4,408,038	15,499,519	4,800,928	1,952,623	-	-	-	-	-	-	**26,661,109**
Fuel cost (Mill US$)	0.0	33.1	116.2	36.0	14.6	0.0	0.0	0.0	0.0	0.0		**200.0**

Energy output (CC)												
Frequency	0.000	0.000	0.000	0.000	0.123	0.545	0.277	0.055	0.000	0.000	0.000	
Energy output (GWh)	**0.0**	**0.0**	**0.0**	**0.0**	**529.6**	**2328.6**	**1175.0**	**231.3**	**0.0**	**0.0**	**0.0**	**4264**
Energy input (GWh)	**0.0**	**0.0**	**0.0**	**0.0**	**953.2**	**4190.9**	**2115.0**	**416.4**	**0.0**	**0.0**	**0.0**	**7675.6**
Energy input (MBTU)	-	-	-	-	**3,253,137**	**14,302,305**	**7,217,888**	**1,421,022**	-	-	-	**26,194,352**
Fuel cost (Mill US$)	0.0	0.0	0.0	0.0	24.4	107.3	54.1	10.7	0.0	0.0		**196.5**

RESULTS

Difference (CC-Baseline) (absolute)	
Energy output (GWh)	-73.98
Fuel cost (Million US$)	-3.50
Actual fuel cost increase (Mill US$)	-0.09

Average efficiency	
Baseline	55.53%
Climate Change	55.56%

WORKSHEET	**PERFORMANCE SUMMARY FOR RISING WATER TEMPERATURE**
PROJECT	***O MON Rapid CC VA***
UPDATED	14-Dec-10

INPUTS

Conversion factor	1 MBTU=	252,000	Kcal							
	1 kWh=	860	kcal							
Temperature	28	29	30	31	32	33	34	35	36	37

Power output (MW)	724,478	723,843	723,188	722,290	721,262	720,023	718,734	717,231	715,719	714,199
Efficiency (%)	55.64	55.59	55.54	55.48	55.4	55.3	55.2	55.09	54.97	54.84
Hours of full power (hours)	6000									
Gas Price ($/MMBTU)	7.5									

OUTPUTS

Energy output (baseline)											
Frequency	0.021	0.444	0.260	0.148	0.088	0.036	0.003	0.000	0.000	0.000	
Energy output (GWh)	90.2	1927.6	1127.5	643.4	381.5	156.9	11.4	0.0	0.0	0.0	**4338**
Energy input (GWh)	162.2	3467.5	2030.0	1159.7	688.7	283.7	20.6	0.0	0.0	0.0	**7812.3**
Energy input (MBTU)	553,536	11,833,375	6,927,829	3,957,590	2,350,252	968,194	70,332	-	-	-	**26661108.6**
Fuel cost (Mill US$)	4.2	88.8	52.0	29.7	17.6	7.3	0.5	0.0	0.0	0.0	**200.0**

Energy output (B2)											
Frequency	0.000	0.000	0.000	0.001	0.051	0.438	0.270	0.128	0.083	0.030	
Energy output (GWh)	**0.0**	**0.0**	**0.0**	**2.2**	**220.6**	**1891.1**	**1164.1**	**551.6**	**355.8**	**127.7**	**4313.1**
Energy input (GWh)	**0.0**	**0.0**	**0.0**	**4.0**	**398.1**	**3419.7**	**2108.9**	**1001.3**	**647.3**	**232.9**	**7812.2**
Energy input (MBTU)	-	-	-	**13,739**	**1,358,638**	**11,670,344**	**7,196,954**	**3,417,084**	**2,209,101**	**794,673**	**26660533**
Fuel cost (Mill US$)	0.0	0.0	0.0	0.1	10.2	87.5	54.0	25.6	16.6	6.0	**200.0**

RESULTS

Difference (B2-Baseline) (absolute)	
Energy output (GWh)	-25.3
Fuel cost (Million US$)	0.0
Actual fuel cost increase (Mill US$)	1.164

Average efficiency	
Baseline	55.53%
Climate Change	55.21%

D – SUMMARY TABLES OF LITERATURE REVIEW

Table 20 Impact of increasing river and air temperature on power output

	1°C increase in the temperature of the coolant	1°C increase in the temperature of air
1. (Kelhofer et al, 2009)		
Gas turbine		Drop ~0.5%
Steam turbine		Increase ~0.06%
Combined cycle		Drops ~0.3%
2. (Frank , 2000)		
Gas turbine		Drop ~0.62%
Steam turbine		
Combined cycle		
3. (Lawrence, 2009)		
- Gas turbine		Drop ~1.02%
Steam turbine		
Combined cycle		
4. (KEMA, 2008)		
Gas turbine		
Steam turbine		
Combined cycle	Drops ~0.1%	Drops ~0.5%
5. Simulation of PECC3		
Gas turbine		
Steam turbine		
Combined cycle	Drops ~0.16%	Drops ~0.57%
Range	**0.1-0.16%**	**0.3-0.57%**

Table 21 Impact of increasing river and air temperature on power output

	1°C increase in the temperature of the coolant	1°C increase in the temperature of air
1. (Kelhofer et al, 2009)		
Gas turbine		Drop ~0.24%
Steam turbine		Increase ~0.04%
Combined cycle		Almost unchanged
4. (KEMA, 2008)		
Gas turbine		
Steam turbine		
Combined cycle	Drops ~0.1%	
2. Simulation of PECC3		
Gas turbine		
Steam turbine		
Combined cycle	Drops ~0.09%	Drops ~0.01%
Range	**0.09-0.1%**	**0-0.01%**