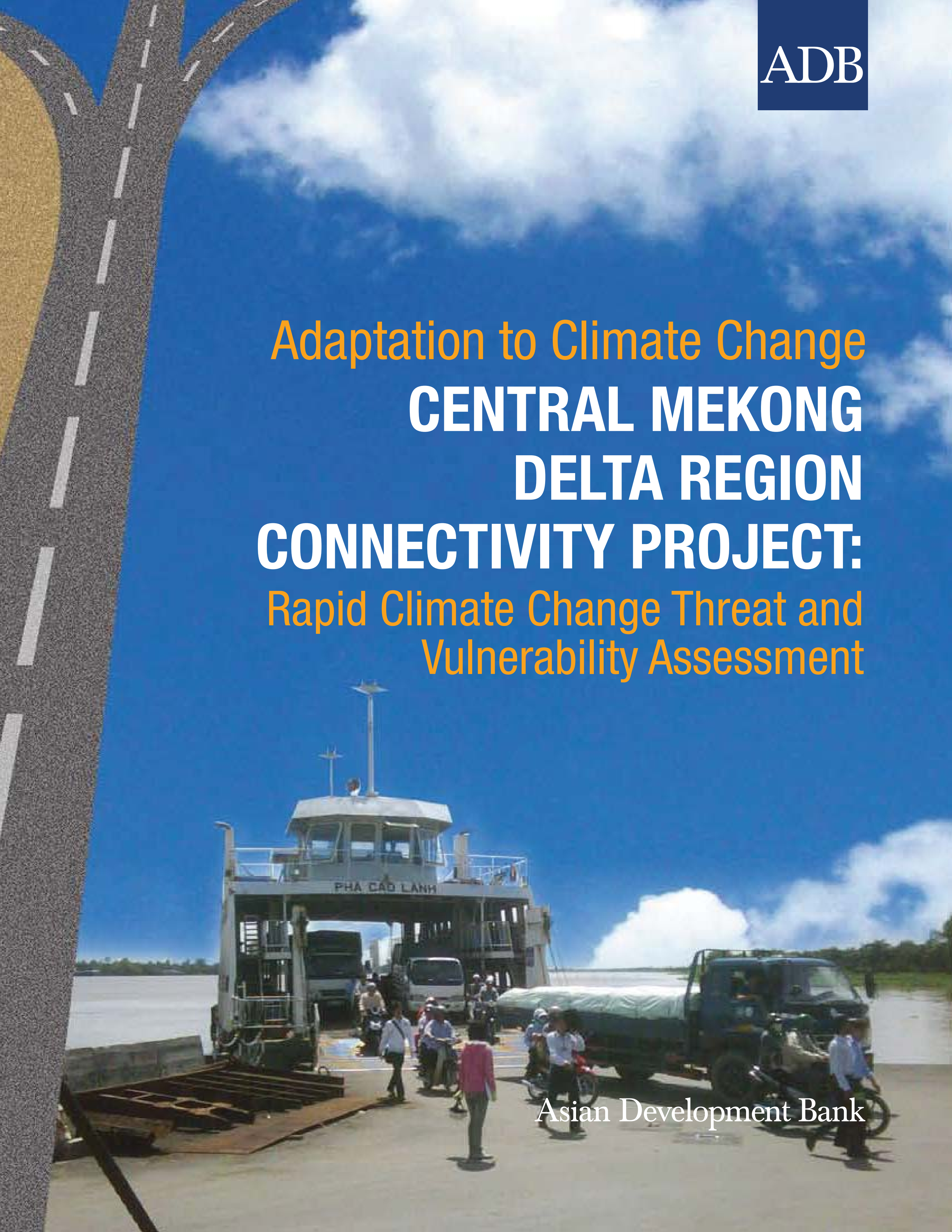

ADB

Adaptation to Climate Change

CENTRAL MEKONG DELTA REGION CONNECTIVITY PROJECT:

Rapid Climate Change Threat and Vulnerability Assessment

Asian Development Bank

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APRIL 2014

Asian Development Bank

Printed in the Philippines.

ISBN 978-92-9254-556-7 (Print), 978-92-9254-557-4 (PDF)
Publication Stock No. RPT146546-2

Cataloging-in-Publication Data

Asian Development Bank.
Central Mekong Delta Region Connectivity Project: Rapid climate change threat and vulnerability assessment
Mandaluyong City, Philippines; Asian Development Bank, 2014.

1. Climate change adaptation. 2. Central Mekong Delta. 3. Connectivity Project. I. Asian Development Bank.

Note: Unless otherwise explicitly indicated, all figures and tables in this report are sourced from International Centre for Environmental Management. 2013. *Central Mekong Delta Region Connectivity Project: Rapid Climate Change Threat and Vulnerability Assessment*. Prepared for the Asian Development Bank. Ha Noi. Viet Nam.

In this publication, “$” refers to US dollars.

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Printed on recycled paper

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Foreword

Many of the projected impacts of climate change are likely to adversely affect critical infrastructure assets within the region. The Asian Development Bank (ADB) is committed to helping its developing member countries to better understand the risks posed by climate change and to manage these risks effectively. To this end, ADB is developing a suite of tools, resources, and guidance materials to support comprehensive, rapid, and cost-effective climate risk management at sector and project levels. These resources include preliminary rapid risk screening tools, improved access to climate change projections, technical notes providing guidance for climate proofing investments in critical development sectors, and case studies illustrating approaches to climate risk assessment and identifying appropriate and promising adaptation responses.

This publication is an important contribution to the case study literature on adaptation. The transport sector is potentially among the most vulnerable to projected changes in climate variables, and this report illustrates the use of a rapid climate impact assessment on how climate change is likely to influence the performance of a transport link in the Mekong Delta. It also discusses a number of adaptation options that the project may utilize to address the potential impacts of climate change.

This publication has been jointly produced by ADB's Regional and Sustainable Development Department and Southeast Asia Department under the regional technical assistance project Building Resilience to Disasters and Climate Change Impacts (RETA 7608) financed by ADB's Technical Assistance Special Fund.

This report was prepared by Rustam Ishenaliev (transport specialist, Southeast Asia Department) and Benoit Laplante (environmental economist, consultant) on the basis of the study Central Mekong Delta Region Connectivity Project: Rapid Climate Change Threat and Vulnerability Assessment prepared by the International Centre for Environmental Management (ICEM) under the regional technical assistance project, Promoting Climate Change Adaptation in Asia and the Pacific (RETA 6420) funded by the governments of Japan and the United Kingdom.

The ICEM study team comprised Jorma Koponen (team leader), Tarek Ketelsen, Jeremy Carew-Reid, To Quang Toan, John Sawdon, Pertti Kaista, Tran Thanh Cong, and Tranh Thi Thanh. The ICEM study team wishes to thank the following individuals for their support: Duong Tuan Minh, Au Phu Thang, Tran Van Thi, Tranh Anh Duong, Nguyen Van Cong, Cam Vu Tu, Truong Hong Hai, Rustam Ishenaliev, John Cooney, Brian Barwick, Anthony Green, Nihal Alagoda, Ha Quoc Dong, Nguyen Huu Thien, and Nguyen Bich Ngoc.

The study was guided and coordinated by Charles Rodgers, former senior environment specialist (climate change adaptation), Regional and Sustainable Development Department (RSDD) and Cinzia Losenno, senior environment specialist (climate change adaptation), RSDD. Invaluable assistance was provided by Lorie Rufo, environment officer (climate adaptation), RSDD, and Agatha Diaz (consultant), RSDD.

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Abbreviations

ADB	Asian Development Bank
GCM	general circulation model
ICEM	International Centre for Environmental Management
IPCC	Intergovernmental Panel on Climate Change
km	kilometer
km^2	square kilometer
km^3	cubic kilometer
Lao PDR	Lao People's Democratic Republic
m^3/sec	cubic meter per second
m	meter
masl	meters above sea level
MONRE	Ministry of Natural Resources and Environment
MRC	Mekong River Commission
SRES	Special Report on Emissions Scenarios
TEDI	Transport Engineering Design Incorporated

Notes
All temperatures reported are in degrees Celsius.

Executive Summary

Viet Nam is projected to be among the developing countries most impacted by climate change, especially as it pertains to sea level rise, storm surges, floods, and the intensification of extreme weather events. Given its low altitude, the Mekong Delta (located in Southern Viet Nam) is particularly exposed to these projected changes. Severe flooding has occurred numerous times in the delta in recent decades, especially when strong rain events coincide with high tides. The flood of 2000 is historically the worst of the last 75 years: 600 deaths, up to 170,000 hectares of paddies and 94,000 hectares of fruit and industrial tree plantations affected, and approximately 1,273 kilometers of national interprovincial road and 9,737 kilometers of smaller town roads submerged. Estimates of total damages to the national road transport infrastructure from predicted changes in temperature, precipitation, and flooding range between $4 billion and $9 billion over the period 2010–2050.

In the context of climate change, it is usually not economical or technically possible to completely climate proof infrastructure against all possible climate change projections. Engineers, together with climate scientists, need to establish a clear evidence base of how climate change may impact the assets and surrounding environment and then assess what level of additional risk is acceptable. This determination of acceptable risk is as much a function of economic and political considerations as it is a technical one—especially given the novelty of climate change assessments. This case study is a clear illustration of the interaction of these interfaces in assessing and addressing climate risk vulnerability in the context of a specific investment project in Viet Nam.

The Central Mekong Delta Region Connectivity Project is cofinanced by the Asian Development Bank, the Government of Australia, and the Government of the Republic of Korea with an estimated total financial cost of $860 million in 2013. It consists of two bridges and an interconnecting road that will form part of a strategic transportation link connecting provinces of the delta to Ho Chi Minh City. Currently, the route crosses the Tien River and Hau River by ferry, which represents a significant bottleneck, extending journey times considerably. Projected increases in traffic flows would necessitate expansion of ferry capacity (in terms of both the number of boats and of ferry landings).

With the projected increase in precipitation and sea level rise as well as more frequent and stronger storm surges due to climate change, project stakeholders raised concerns as to the impacts that climate change may have on the project bridges, approach roads, and interconnecting road. While the original project feasibility study used projections of sea level rise adopted by the Government of Viet Nam, concerns were raised as to the possible incremental impacts of the intensification of storm surges and changes in rainfall patterns in the Mekong River Basin.

The study described in this publication was commissioned to provide an additional assessment of the potential risks posed by climate change to the bridges and roads, and to suggest adaptation options that may be incorporated into the detailed designs. Specifically, the study aimed to

(i) test a climate change threat and vulnerability assessment methodology for use in transport infrastructure projects;
(ii) improve understanding of climate change risks among key stakeholders, including the detailed design team and policy makers;
(iii) quantify climate change impacts on the infrastructure, performance, maintenance, and legal compliance of the bridges and roads; and
(iv) prioritize specific adaptation options that are technically sound, realistic, and economically viable.

The assessment process used a multi-model ensemble of six general circulation models, two global emissions scenarios, statistical downscaling techniques, and a suite of modeling tools developed for the Mekong over the past 15 years to build an evidence base of climate change vulnerability. Results between GCMs and scenarios vary and study findings have been developed to reflect these ranges and select conservative estimates of future change.

The study showed that the 1-in-100 year floodplain water level may increase by 0.6 meters (m) over a 100-year design life. While preliminary design from the feasibility study recommended a 1-in-100 year 2.82 m above sea level, results from this study suggested that peak water levels in the floodplain will reach 3.47 m above sea level, and 3.10–3.60 m above sea level at the project site. It was found that without adaptation, the future one-in-hundred year event will raise water levels approximately 0.1 m above the embankment freeboard, presenting a situation of risk. It was also identified that the left bank of the Cao Lanh bridge site will experience a significant increase in bed scour and bank erosion during large flood events. On the other hand, the study found that navigation clearance should not be significantly affected.

While potential risks were clearly identified, the consensus on the magnitude and scope of adaptation was only reached through continued dialogue and weighing response options and costs. Given the location, nature, scale, and investment needed, parties have agreed to a phased approach in which, as a first phase, the height of the embankments would be raised above levels which would otherwise have been considered appropriate. This raising was achieved at an additional cost of $4.5 million.

This study provides (i) a deeper understanding of climate change threats generally in the Mekong basin as well as how the infrastructure will be affected by extreme climate change events; (ii) a better appreciation of the need to incorporate climate change risk assessments and generate a body of knowledge over time; and (iii) a consensus-building tool for project financiers and the government of Viet Nam to adapt a better strategy for climate change response.

In particular, the study illustrates that a constrained time frame and limited resources may not be a significant impediment to the undertaking of climate risk vulnerability assessment, which can provide valuable information at the project design stage to increase the climate resilience of large investment projects.

Introduction

Background

Over the last decade, Viet Nam has made significant advancements in the development of its transport infrastructure. In particular, approximately 30,000 kilometers (km) of roads were added to the network, and the amount of paved roads has increased five times in the last 7 years.

However, as Viet Nam continues to upgrade its transport infrastructure, it faces a number of important challenges, including climate change. Numerous studies have identified Viet Nam as being one of the developing countries most impacted by the rising sea (see Brecht et al. 2012; Dasgupta et al. 2011, 2009; and Nicholls and Cazenave 2010 among others). It has been estimated that a one-meter sea level rise may impact up to 10% of Viet Nam's land.

The transport sector will be among those most seriously impacted by climate change (ADB 2011). Between 2001 and 2005, extreme weather events caused D2,571 billion of damages to the transport sector. If mean sea level rises by one meter, it is estimated that 11,000 km of roads could be submerged and that up to 695 km of national highways are at risk of inundation (MONRE 2010). An estimated 4.3% of existing national and local roads would be permanently under water, including 574 km of dikes. Chinowsky et al. (2012) estimate total damage to the national road transport infrastructure from predicted changes in temperature, precipitation, and flooding ranging between $4 billion and $9 billion over the period 2010–2050.

Given its low altitude, the Mekong Delta is particularly exposed to climate change especially as it pertains to sea level rise, storm surges, and increasing precipitation (Neumann et al. 2012). The transport network of the Mekong Delta is arguably the most vulnerable to climate change. More than 70% of national highways in the delta are predicted to be permanently inundated by a one-meter rise in sea level (MONRE 2010). As such, existing and future capital investments in the transport sector in Viet Nam and particularly in the Mekong Delta stand to gain significantly from explicitly accounting for the possible impacts of climate change to ensure that these investments deliver the services and benefits for which they are undertaken.

The Project

The Central Mekong Delta Region Connectivity Project consists of two bridges and an interconnecting road that will form part of a strategic transportation link connecting the provinces of Dong Thap, An Giang, and Can Tho to the Second Southern Highway and Ho Chi Minh City (Figure 1).[1]

Currently, the route crosses the Tien River and Hau River by ferry, which represents a significant bottleneck, extending journey times considerably. Projected increases in traffic flows would necessitate expansion of ferry capacity (in terms of both the number of boats and of ferry landings). Relative to the "no project" scenario, the largest benefit accrues to ferry users by eliminating ferry waiting and crossing time.

The Cao Lanh Bridge (crossing the Tien River) is a cable-stayed bridge with spans 150+350+150m and approach bridges with a length of 682 m on both sides. The Vam Cong Bridge (crossing the Hau River) is a cable-stayed bridge with spans 210+450+210 m and approach bridges with lengths of 1,139 m and 960 m. The deck of the Cao Lanh Bridge will be constructed of precast concrete Super-T girders and the deck of the Vam Cong Bridge is of steel composite design. All approach bridges will be made using precast concrete elements. The road section on bridges is 24.5 m wide. Substructures will be constructed with cast-in-situ concrete. Both bridges will be founded on bored piles.

In consultation with the Mekong River Commission, the Government of Viet Nam has set a design constraint for bridge elevation based on providing a minimum navigation clearance of 37.5 meters (m) for the 1-in-20-year flood characteristics (also referred as the P5% flood, indicating a 5% annual probability of occurrence). This navigation clearance is set to allow future passage of 10,000 deadweight tonnage vessels upriver to Phnom Penh port.

The approach and connecting roads include 26 smaller bridges that will cross canals and rivers. The bridges are designed as precast concrete bridges with lengths between 34 m and 603 m. The openings of the bridges are designed to be adequate for design floods. The bridges will be founded on bored or driven piles. Bridge approach roads will have embankments set for the P1% event (flood characteristics recurring 1 in 100 years, or 1% annual probability of occurrence).

The project is cofinanced by the Asian Development Bank (ADB) and the governments of Australia and the Republic of Korea with an estimated total financial cost of $860 million in 2013. The two bridges with their respective approach roads and interconnecting road represent approximately 75% of the total investment; the remainder of the investment is for associated land acquisition, contingencies, and financial charges during implementation.

The Study

Numerous provinces of the Mekong Delta regularly experience flooding, including the Can Tho and Dong Thap provinces where the project is located.[2] In a large flood, inundated areas may encompass 1.6 million hectares, while elevated floodwater levels can last between 3 and 6 months.

Severe flooding has occurred in the delta in 1961, 1966, 1978, 1991, 1994, 1996, 2000, 2001, 2002, and 2011. Such flooding usually occurs when very strong rain events coincide with high tides. The flood of 2000 is historically the worst of the last 75 years. In addition to the human cost (600 people have been reported dead) and the damage to agricultural land (up to 170,000 hectares of paddies and 94,000 hectares of fruit and industrial tree plantations were affected),

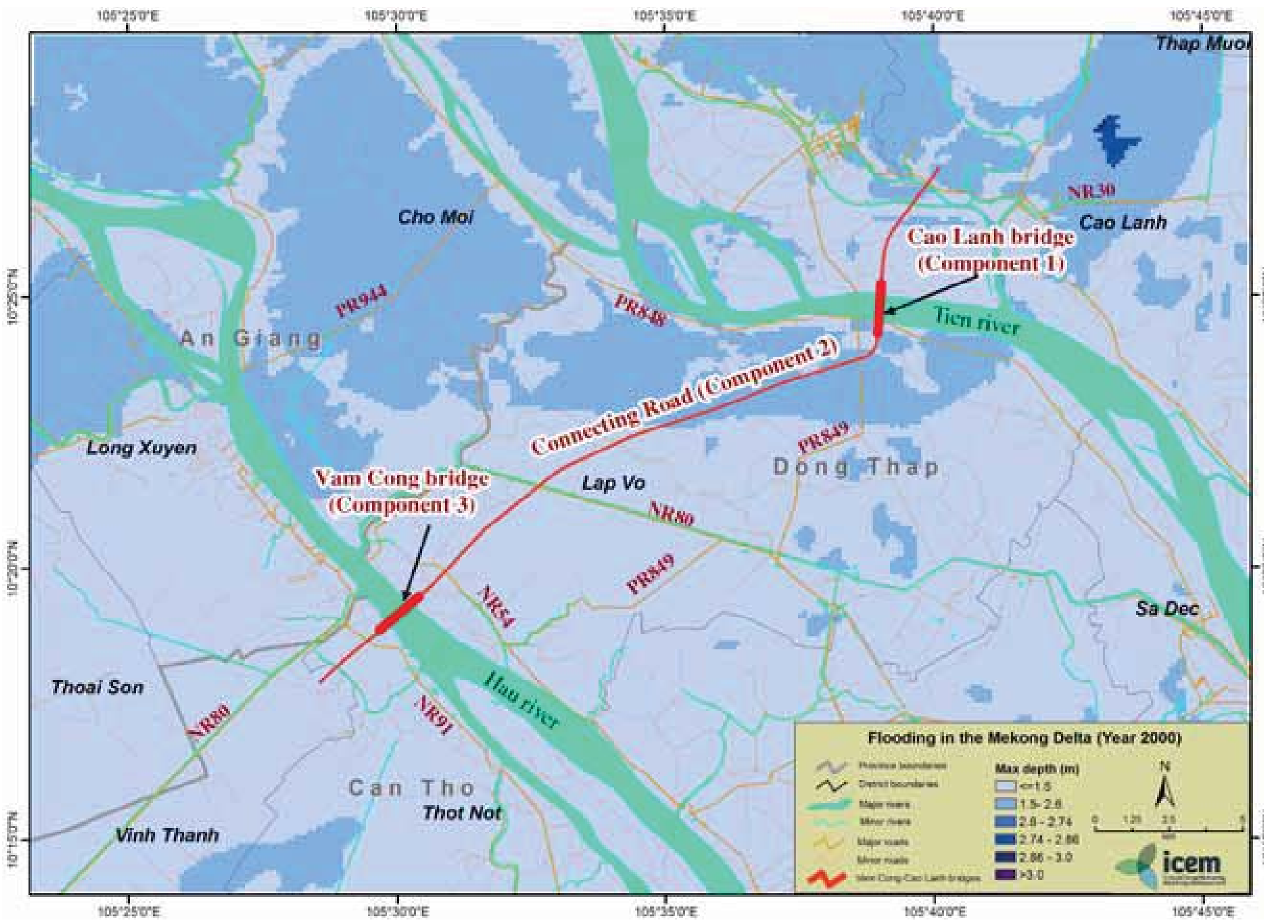
[1] The feasibility study of the Central Mekong Delta Region Connectivity Project mentions components other than the three components (two bridges [and their respective approaching roads] and one interconnecting road) examined in this rapid climate vulnerability assessment study.

[2] Other provinces of the Mekong Delta regularly experiencing flooding include Long An, An Giang, Kien Giang, Can Tho, Tien Giang, Hau Giang, and Vinh Long.

Figure 1: Infrastructure Components of the Central Mekong Delta Region Connectivity Project

Source: ADB. 2013. *Central Mekong Delta Region Connectivity Project. Report and Recommendation of the President to the Board of Directors*. Manila.

Figure 2: Simulated Flooding of Project Site for Year 2000 Flood Conditions



approximately 1,273 km of the national interprovincial road and 9,737 km of intercommune, intertown roads were submerged.

Simulation of floodwater levels corresponding to the 2000- year flood at the project site is shown in Figure 2 based on the MIKE 11 model.[3]

At the project site, floodplain water levels are highest at the right and left bank of the Tien River and lowest near the banks of the Hau River. This reflects the dominance of the Tien River in the conveyance of Mekong flow at this point, which accounts for two-thirds of river discharge traveling down the Tien River. In addition, the location of the project site at the

[3] MIKE 11 is a computer program developed by DHI. The program simulates flow and water level as well as sediment transport in rivers, floodplains, irrigation canals, reservoirs, and other inland water bodies.

transition from deep to medium inundation zone can clearly be seen, with the majority of upstream areas experiencing flooding of up to 2.6 m, while the area immediately downstream is restricted to flood depths of less than 1.5 m.

With the projected increase in precipitation and sea level rise as well as more frequent and stronger storm surges due to climate change, project stakeholders have raised concerns as to the impacts that climate change may have on the project bridges, approach roads, and interconnecting road. While the original project feasibility study prepared by Transport Engineering Design Incorporated (TEDI) used sea level rise projections developed by the Institute of Meteorology, Hydrology and Environment of the Ministry of Environment and Natural Resources, questions were raised as to the possible incremental combined impacts of the intensification of storm surges and changes in rainfall patterns in the Mekong River Basin. Furthermore, it has also been suggested that the projected large increase in hydropower capacity in the Mekong Basin may reduce water discharges in the Mekong River and Mekong Delta in the wet season (as reservoirs are being replenished) and thus reduce flooding in the Mekong Delta.

This study was thus commissioned to provide an additional assessment of the potential risks posed by climate change to the bridges and roads, and to suggest adaptation options that may be incorporated into the detailed designs.[4] Specifically, the study aimed to

(i) test a climate change threat and vulnerability assessment methodology for use in transport infrastructure projects;
(ii) improve understanding of climate change risks among key stakeholders, including the detailed design team and policy makers;
(iii) quantify climate change impacts on the infrastructure, performance, maintenance, and legal compliance of the bridges and roads; and
(iv) prioritize specific adaptation options that are technically sound, realistic, and economically viable.

This report summarizes the original study report produced by the International Centre for Environmental Management with project details and costs updates based on the project's report and recommendation of the President to the Board of Directors.[5] The report outlines key lessons and recommendations for further policy dialogue and consensus building around the complex issue of addressing climate change uncertainties.

Section II provides a brief description of the overall threat and vulnerability assessment methodology. The modeling of climate change threats is presented in Section III and Section IV presents a discussion of the vulnerability of the project's components to these threats, and of possible adaptation options. Section V presents a brief discussion of how the results of this climate risk vulnerability assessment were used by project stakeholders. Brief summary remarks are presented in Section VI.

[4] The study—formally known as Central Mekong Delta Region Connectivity Project: Rapid Climate Change Vulnerability and Adaptation Assessment—was funded through the ADB regional technical assistance project Promoting Climate Change Adaptation in Asia and the Pacific (TA-6420).

[5] The report is available at http://www.adb.org/sites/default/files/projdocs/2013/40255-033-vie-rrp.pdf

Methodology

Overview of Methodology

Figure 3 summarizes the approach used to conduct the vulnerability assessment. Threats are identified for the atmospheric and hydrological system at three different scales: regional (Mekong Basin), national (Mekong Delta), and local (project site). Sensitivity is assessed for specific components of the bridge and road design. Impact is a function of the threat and sensitivity and considered as changes to (i) the integrity of project assets (i.e., damage); (ii) performance or use of the bridge and road; (iii) maintenance requirements over the project life; and (iv) the project's compliance with design standards or regulations. The vulnerability of the bridge and road components is the combination of the impact and the adaptive capacity of the project, in terms of both the technical aspects of design and financial and the management capacity to define and respond to change.

The response to climate change impacts varies depending on the type of impact. For example, impacts that may prevent compliance with Viet Nam national law or design standards must be avoided regardless of cost. Some other impacts could potentially be absorbed with little change to design and/or operation; others may require adaptation at different phases throughout the design and maintenance life. Figure 4 identifies the key steps of the vulnerability assessment methodology.

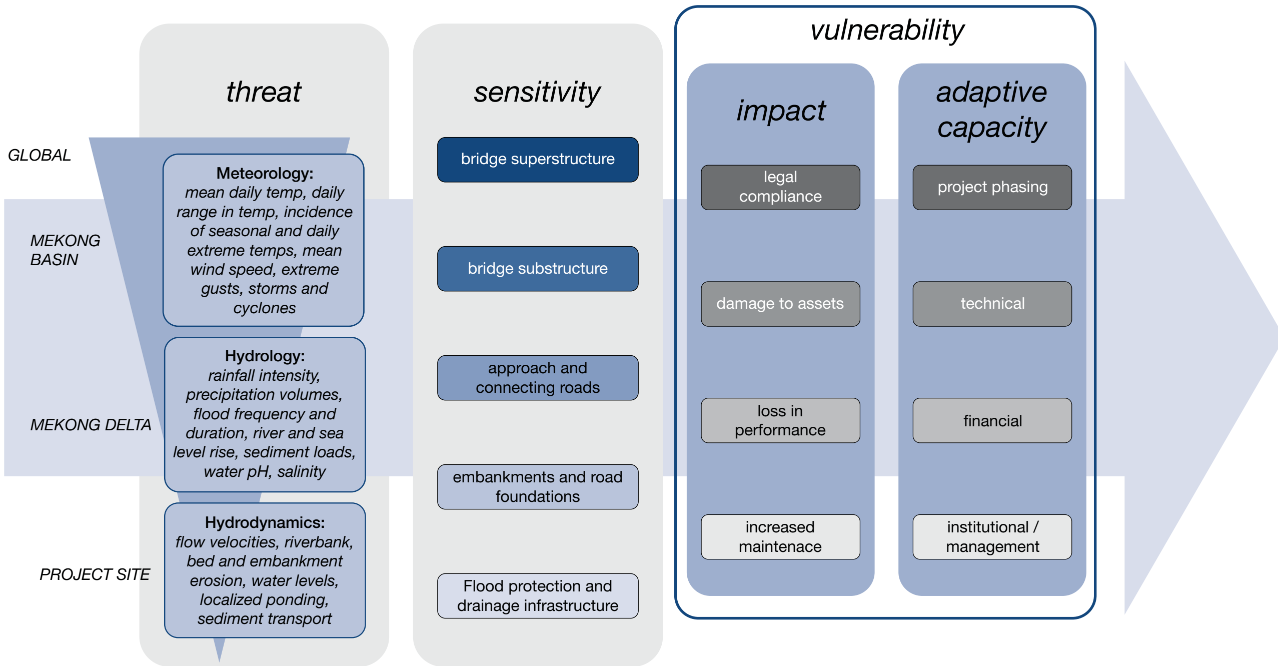
Overview of Climate Modeling

The hydrometeorological threat of climate change is modeled using a statistical downscaling technique and a combination of hydrological and hydrodynamic modeling at three different scales. A number of critical steps and decision points in developing the modeling methodology pertain to (i) the selection of appropriate climate scenarios from the Special Report on Emissions Scenarios (SRES) presented by the Intergovernmental Panel on Climate Change (IPCC); (ii) the selection and processing of general circulation models (GCM) data; (iii) the downscaling of GCM data to the Mekong Region; and (iv) the nature of hydrological and hydrodynamic modeling. These are described in greater detail below.

Selecting Emissions Scenarios

The threat modeling component starts with a selection of IPCC scenarios and appropriate GCMs that have performed well in the Mekong Basin.

Figure 3: Overview of the Vulnerability Assessment Approach

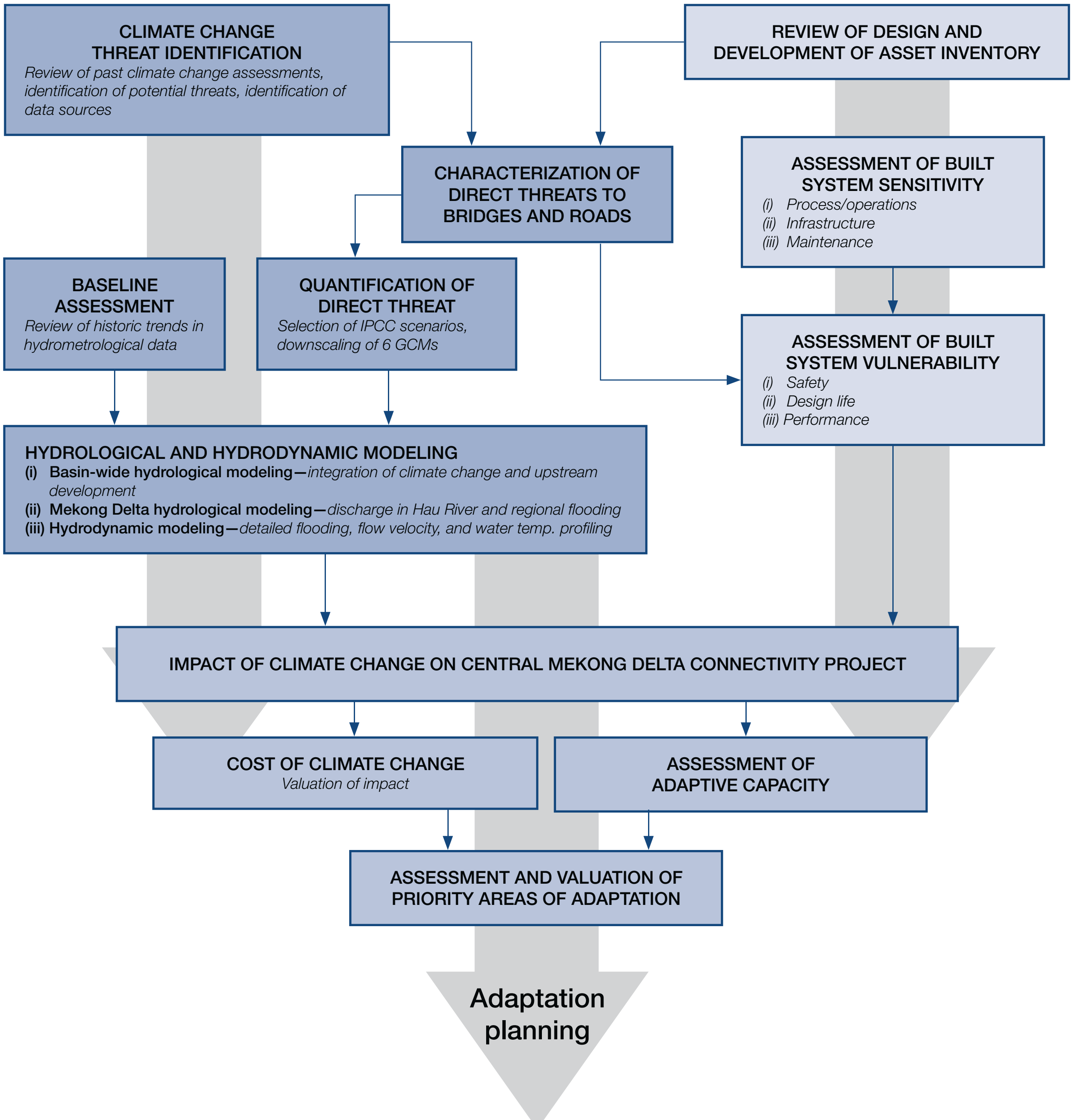


IPCC SRES scenario A1B was selected for use in the study because it falls within the range predicted by the official climate change scenarios of the Government of Viet Nam (A2 and B2), but is closer to the upper limit of the family of SRES scenarios. Recent studies have found that the original range of change expressed in the IPCC SRES scenarios, first developed in 2000, underestimates the likely impact of climate change, and that changes in atmospheric concentrations of greenhouse gases experienced in the last 12 years is comparable to or exceeds the upper limit of the SRES projections, thus limiting the applicability of the B1/B2 family of scenarios.

Selecting General Circulation Models

The IPCC utilizes 24 different GCMs in its Fourth Assessment Report (generally referred as AR4). GCMs include a full description of atmospheric and ocean physics that drive global circulation patterns. Because

Figure 4: Key Steps of the Vulnerability Assessment Methodology



of their complexity, GCMs operate at relatively coarse resolutions (200–400 km grid cells). In addition, the description of physical processes and parameters can vary depending on the GCM used, resulting in varying accuracy for any given GCM over the earth's surface. Some GCMs are therefore more accurate at predicting the future climate of the Mekong River Basin than others.

Studies at the global level have identified that GCMs have varying levels of accuracy for different regions in the world (Cai et al. 2009). Twelve GCMs have been considered in past studies for the Mekong Basin (Table 1), of which six are known to have performed well in terms of replicating historical records of the climate of the Mekong Basin region (Cai et al. 2009).

Outputs from the six selected GCMs provide daily future climate data for average, maximum, and minimum temperature and precipitation at the 100 weather monitoring stations found in the basin. The use of six GCMs allows the study team to explore the suitability of different GCMs to the Mekong region and the impact of model architecture on climate change results.

Downscaling General Circulation Model Data

GCMs operate at coarse resolution (200–400 km grid cells) essentially because of limits to computer processing power. This resolution is inappropriate for detailed spatial assessment at the national, basin, or provincial level. A necessary step of any vulnerability

Table 1: General Circulation Models Applied to the Mekong Basin and Selected in this Study

GCM Name	Institute of Origin	Selected in this Study
ncar_ccsm3_0	NCAR United States	√
miub_echo_g	MIUB Germany	
micro3_2_medres	CCSR Japan	
micro3_2_hires	CCSR Japan	√
inv_echam4	MPI Germany	√
giss_aom	GISS United States	√
csiro_mk3_0	CSIRO Australia	
cnrm_cm3	CNRM France	√
cccma_cgcm3_1_t63	CCCMA Canada	
cccma_cgcm3_1	CCCMA Canada	√
bccr_bcm2_0	BCCR Norway	
gfdl_cm2.1	GFDL United States	

NCAR = National Center for Atmospheric Research; MIUB = Meteorologisches Institut, University of Bonn; CCSR = Center for Climate System Research; MPI = Max-Planck-Institut für Meteorologie; GISS = Goddard Institute for Space Studies; CSIRO = Commonwealth Scientific and Industrial Research Organisation; CNRM = Centre National de Recherches Meteorologiques; CCCMA = Canadian Centre for Climate Modeling and Analysis; BCCR = Bjerknes Centre for Climate Research; GFDL = Geophysical Fluid Dynamics Laboratory.

assessment study is to downscale predicted climate change to grid sizes suitable for vulnerability assessment (see Box).

Several studies have compared results from statistical and regional downscaling approaches showing that the two downscaling techniques are usually quite similar for present-day climate, while differences in future climate projections are more frequent.

A key factor affecting accuracy of downscaling is the availability of existing climate information for the target region. Weather data is used for the calibration of the model and must be sufficiently long to ensure that interannual variability in climate patterns is captured by the model. The International Centre for Environmental Management has long time series historical data for more than 100 weather stations in the Mekong Basin covering the period 1980–2005. The number of weather stations is, however, limited by the need for long time series data. These data records have been collected from national government sources, regional bodies (such as the Mekong River Commission), and global sources including the Tropical Rainfall Measuring Mission, the US National Oceanic and Atmospheric Administration's National Centers for Environmental Predictions, and the US National Climatic Data Center.

This study draws on downscaled data from the six GCMs using both the statistical and dynamical downscaling techniques, providing an opportunity to compare downscaling results from two different techniques. This represents a first for the Mekong region and an opportunity to consolidate and assess some of the variability found in previous modeling efforts.

Hydrological and Hydrodynamic Modeling

The modeling strategy and approach involves a basin-wide model, a Mekong Delta model, and a project site model.

Basin-wide hydrological and hydrodynamic model. This model provides boundary values for the Mekong Delta model. The model includes erosion, sediment transport, and sediment trapping by reservoirs. Modeled future changes in sediment input to the delta are used directly in the local model.

The basin-wide model developed by the International Centre for Environmental Management with the Mekong River Commission is a gridded, raster-based watershed model, allowing for strong correspondence to GIS-based data representation. The model includes hydrology, water resources allocation and management, and hydrodynamics.[6]

The steps for the basin-wide modeling are as follows:

(i) Select period for the baseline that includes dry, average, and wet years (e.g., 1995–2005 or 1991–2001).
(ii) Select comparable periods in the future scenarios (e.g., 2041–2051 and 2091–2101).
(iii) Compute the scenarios (baseline and future climate change) with the basin-wide model for baseline, (2041–2051 and 2091–2101) using data from six different downscaled GCMs.
(iv) Develop daily time series for discharge at Kratie.

Mekong Delta hydrodynamic model. The Delta model utilizes the MIKE 11[7] platform developed for the Mekong Delta by the Southern Institute of

[6] Elements of the model include (i) gridded hydrology and kinematic routing (VMod); (ii) 1D hydrodynamics (RNet); (iii) watershed erosion, sediment transport, and sediment trapping; (iv) water quality (VMod) including nutrients and salinity; (v) flooding; (vi) groundwater; (vi) crops and irrigation; (vii) water diversions from rivers, lakes, reservoirs, and groundwater; and (viii) hydropower operations and reservoirs database.

[7] MIKE 11 is a patented 1D hydraulic model software developed by the Danish Hydraulic Institute (DHI).

Box: Approaches to Downscaling General Circulation Model Climate Information

A number of approaches are used to downscale general circulation models (GCMs).

Spatial redistribution/pattern downscaling. In regions where climate data is both spatially distributed and extensive, a relatively simple downscaling technique can use this fine-resolution observation data to spatially differentiate the GCM results for a given grid cell into more detailed future climate outputs. This method cannot correct for statistical bias and so can only be used to assess relative changes or explore relative trends—it is not successful in predicting future absolute climate values.

In the Mekong Basin, a variation of this approach has been applied by Australia's Commonwealth Scientific and Industrial Research Organisation, which divided the Mekong Basin into 18 lumped sub-catchments and assumed linearity in future climate trends. This assumption was then used to scale the results from 11 GCMs to each sub-catchment using global interpolated data (Eastham et al. 2008).

Statistical/empirical downscaling. This approach relies on the premise that local climate is conditioned by large-scale (global) climate and by local physiographical features such as topography, distance from the ocean, and vegetation, such that at any specific location there is a link between large-scale and local climatic conditions. Determining the nature of these links in terms of physical processes can often be difficult, but by fitting long time series data with a statistical distribution, empirical links can be identified between the large-scale patterns of climate elements (predictors) and local climate conditions (predicted). To do this, GCM output is compared with observed information for a reference period to calculate period factors, which are then used on the rest of the GCM time series in order to adjust biases. These factors can be annual means (resulting in a single correction factor) or monthly means (resulting in 12 correction factors). In addition, it is possible to correct data in such a way that not only the mean, but also the variance, are corrected on the basis of the data observed in the reference time series. Statistical downscaling can be done for points (i.e., individual stations), but can also be spatially explicit (i.e., maps). Because of the use of correction factors, statistical techniques have been shown to be less accurate in arid climates where future climate trends can be masked by the correction factor, though results have been better for tropical zones. Standard interpolation techniques are then used to provide area-based climate information between stations and covering the entire basin.

Regional climate model/dynamical downscaling. The most sophisticated way to downscale GCM data is to use a physically based regional climate model. Such models are forced at the boundaries by GCMs and calculate the flows of energy, gases, etc., at a higher resolution for a specific area. These can also be "nested" in a GCM itself. Creating such a regional climate model requires a lot of expertise and labor to set it up and calibrate it properly, and it is also computationally very expensive.

To date in the Mekong Basin, there has been one attempt at dynamical downscaling using PRECIS. The PRECIS dynamic downscaling model was developed by the Met Office Hadley Centre for Climate Prediction and Research in the UK and was used by consortium partner SEA START for IPCC Special Report on Emissions scenarios A2 and B2.

Water Resource Research. The model's hydraulic schematization starts from Kratie and covers the floodplain in Cambodia, including the Tonle Sap system and the whole Mekong Delta of Viet Nam. Discharges from outside the model boundary in the Mekong River (upstream of Kratie) and the Saigon and Dong Nai river basins (upstream of Tri An hydropower station) together with tidal data at the Mekong River mouth and the Gulf of Thailand were selected as boundary conditions for the model.

The model setup includes more than 3,900 rivers and canals and more than 5,000 hydraulic works representing irrigation and drainage sluices as well as overland flood flow to the floodplain via low-lying road segments. The model divides the delta into 120 zones and utilizes more than 25,900 water levels and 18,500 flow points to calculate small-area water balances.

The steps for the Mekong Delta modeling are as follows:

(i) Define model boundary conditions using the daily discharge data at Kratie and rainfall and temperature data for Mekong monitoring stations within the delta.
(ii) Compute the three scenarios using the six GCM data sets combined with predicted sea level rise of 0.5 m (2041–2051) and 1.0 m (for 2091–2101).
(iii) Analyze the spectrum of changes focusing on average changes and extremes (extreme dry and wet episodes).
(iv) Simulate the highest flood period with maximum storm surge added.
(v) Simulate the impact of the highest estimated sea level rise for the period 2091–2101 (2–3 meters).

3D project site modeling. 3D modeling is required for simulation of the river flow, sediment transport, and erosion. 3D modeling takes into account both horizontal and vertical flow and suspended sediment distribution, as flow dynamics and sediment concentration vary greatly in both horizontal and vertical directions.

The objectives of the 3D hydrodynamic modeling of the climate change impacts are to (i) integrate floodplain, infrastructure, and river channel impacts on flow and water levels; (ii) integrate complex interaction of river, floodplain, and wind-induced flows; (iii) provide quantitative information on how climate change impacts road failure factors as well as bridge design parameters; and (iv) provide a basis for assessing mitigation measures.

The steps for the project site modeling are as follows:

(i) Use the discharges and water levels obtained from the Mekong Delta model and sediment results from the basin-wide model on the local model boundaries.
(ii) Calculate flow, water levels, waves, sedimentation, and erosion in the river channels on the bridge sites.
(iii) Calculate flow, water levels, waves, sedimentation, and erosion during flood situations on the floodplains surrounding the planned roads.
(iv) Provide detailed and quantified data on climate change threats related to sediments, water quality, flooding, and flow dynamics as an input into the threat and vulnerability assessment process.

Climate Change Threat Assessment

The objective of the threat analysis is to develop robust causal linkages between changes in global, meso, and local hydrometeorology to specific parameters and attributes of the bridge and road design. This is done through review of design parameters and calculations to identify critical hydroclimate variables that have shaped the current design process.

The following threats have been identified as being of direct relevance to the Central Mekong Delta Region Connectivity Project: ambient air temperature, rainfall, upstream (Mekong River) discharge, sea level rise, and flooding.

The quantification of the threats posed by temperature and rainfall changes relies on the statistically downscaled data from six GCMs. The 1D hydrological model was used to interpolate the spatial distribution of these parameters between monitoring stations. In order to ensure the climate change modeling accommodates quasi-periodic and interannual climate patterns, the study employs a 25-year baseline period of daily data as the basis for the climate change downscaling. At the basin scale, there are some 100 stations with suitable time series data for inclusion in the model. However, at the project site level there are relatively few stations in the Mekong Delta with sufficiently long time series for inclusion in the model and none in direct proximity to the project site. Consequently, spatial interpolation is used to estimate the 25-year daily temperature and rainfall time series for each grid cell between monitoring stations, using the built-in module of the IWRM 1D hydrological model at a resolution of 5 km x 5 km. This data is used to define the long-term relative trends in climate change for precipitation and temperature.

Relative trends of change in rainfall and temperature parameters within these grid cells are superimposed on monitoring data provided by provincial authorities of Dong Thap, Can Tho, and An Giang provinces to couple long-term climate change trends with short-term observation data.

Statistical analysis is then used on this time series data to identify changes in the frequency, magnitude, and duration of rainfall events, hot days, daily minimums and maximums, and droughts.

Assessment of the threat of climate change utilized daily temperature and rainfall data from the six GCMs under IPCC SRES scenarios A1b and B2 to develop a continuous daily time series for 1980–2100. These GCM time series were downscaled using a statistical technique for 151 precipitation and 61 temperature stations in the Mekong Basin. Downscaled data for each GCM was then compared with the historical baseline at the monitoring station, and the VMod distributed hydrological model—custom built for the Mekong Basin—was then used to spatially interpolate for temperature and rainfall throughout the catchment at a resolution of 5 km x 5 km.[7] Model simulations were then undertaken for approximately 25 years centered on two future time periods (2050 and 2100) to determine the changes in Mekong River hydrology and floodplain dynamics.

Simulations also included scenarios for hydropower development in the Mekong Basin, including 126 hydropower projects in the Mekong Basin with a combined active storage of 107.8 million cubic meters, which represents the full exploitation of all hydropower currently being considered by the five countries in the Mekong basin: Cambodia, the People's Republic of China, the Lao People's Democratic Republic (Lao PDR), Thailand, and Viet Nam. Based on the IPCC SRES scenarios, GCMs, and hydropower development, a total of 24 future scenarios were simulated for each time slice.

Air Temperature

Temperature variability in the Lower Mekong Basin is driven by two key factors: latitude and elevation (MRC 2011, ICEM 2013b). As shown in Figure 5, historic maximum daily temperatures in the Lower Mekong Basin average between 17 and 35 degrees Celsius (°C). The hottest temperatures are experienced in the low-elevation regions of the Cambodian floodplain, Khorat Plateau, and Mekong Delta, with decreasing temperatures in mid-elevation and high-elevation regions—in particular the higher-elevation areas of the Annamite mountain ranges and northeastern Lao PDR along the eastern catchment divide.

At the project site on the Cambodia–Viet Nam border, average maximum daily temperatures vary between 29.8°C and 34.7°C with an average of 31.8°C (Figure 6). Temperatures peak at the end of the dry season (March–June), dropping to a minimum at the end of the calendar year. Interannual variability of baseline temperatures is greatest during the dry season.

There is considerable variability between changes in temperature throughout the Lower Mekong Basin. Climate threat modeling predicted that across the basin the annual average maximum temperature by 2050 will increase by 2°C–3°C. Greater increases are projected for the southern and eastern regions of the basin with the largest change in temperature occurring in the Sesan, Srepok, and Sekong catchments. The area of the Mekong Delta is predicted to have an increase in average annual temperature of around 2.75°C. Within the Mekong Delta, the Northwestern region near the Cambodian border is projected to have a higher increase in maximum daily temperatures, while the Southeastern region will have an increase of up to 2.5°C.

Figure 7 presents the projections for future daily maximum temperature near the project site, averaged between six GCM results and a 25-year time slice. More than 80% of all simulated data indicates a clear increase in the maximum daily temperatures. Year-round maximum daily temperature is projected to increase by an average of 2.3°C (1.5°C–3.0°C). The largest increases are projected for the months of May–August, exacerbating hot weather at the start of the wet season. The greatest agreement between model results occurred for the end of the dry season and the transition season—with consistent trends from all GCMs.

Figure 5: Annual Average Maximum Daily Temperature (1980–2004)

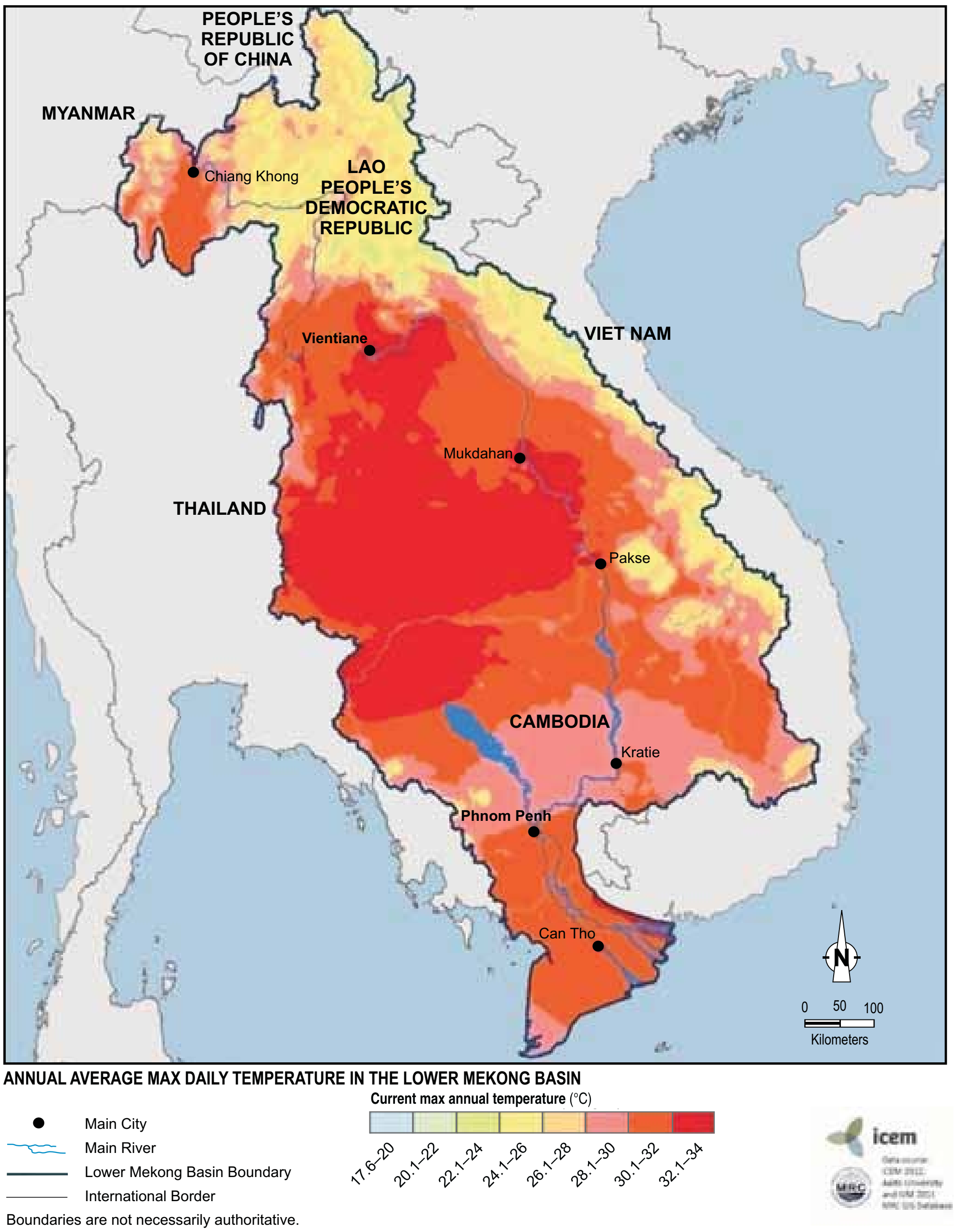


Figure 6: Statistical Variability in Baseline Maximum Daily Temperatures in Dong Thap Province (1980–2004)

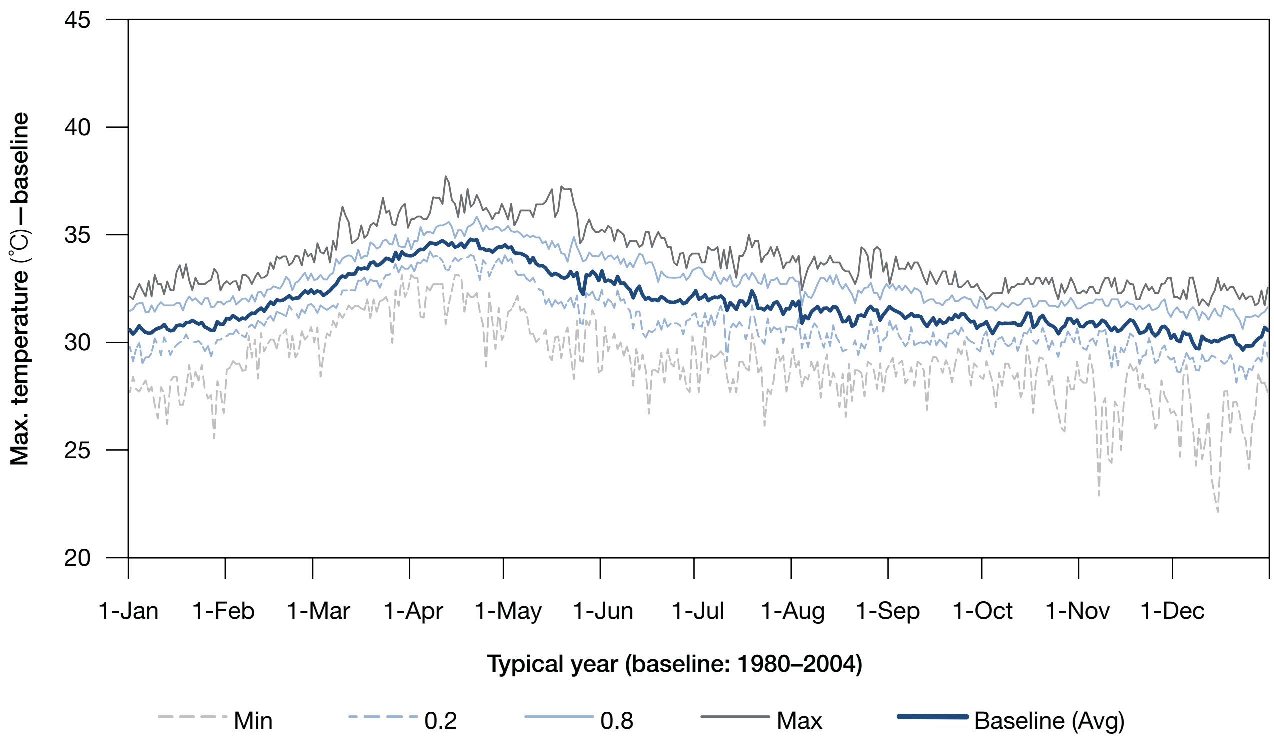


Figure 8 presents the projections for variation in percentage exceedance curves for daily maximum temperatures. It quantifies the proportion of a typical year that is exceeded by a given temperature. The shaded blue area represents the variability in results across all climate models. Under typical baseline conditions, maximum daily temperatures do not exceed 35°C. With climate change between 15%–45% of the year will see temperatures exceed 35°C, reflecting a 1.0°C–4.5°C increase in the highest temperature expected to be experienced in a typical year.

Rainfall

The Mekong Basin is one of the few regions of the world under the influence of different monsoon systems. The result is a marked contrast between wet and dry season rainfall that divides the hydrologic year (MRC 2011). The Southwest monsoon is the result of a strong seasonal temperature gradient between the Indian Ocean and the Asian landmass, which forces moisture-laden air over the Mekong catchment and is the dominant driver for wet season rainfall (June–July), while the Mekong Basin is largely in the rain

Figure 7: Statistical Variability in Projected Future Maximum Daily Temperatures in Dong Thap Province with Climate Change (2045–2069)

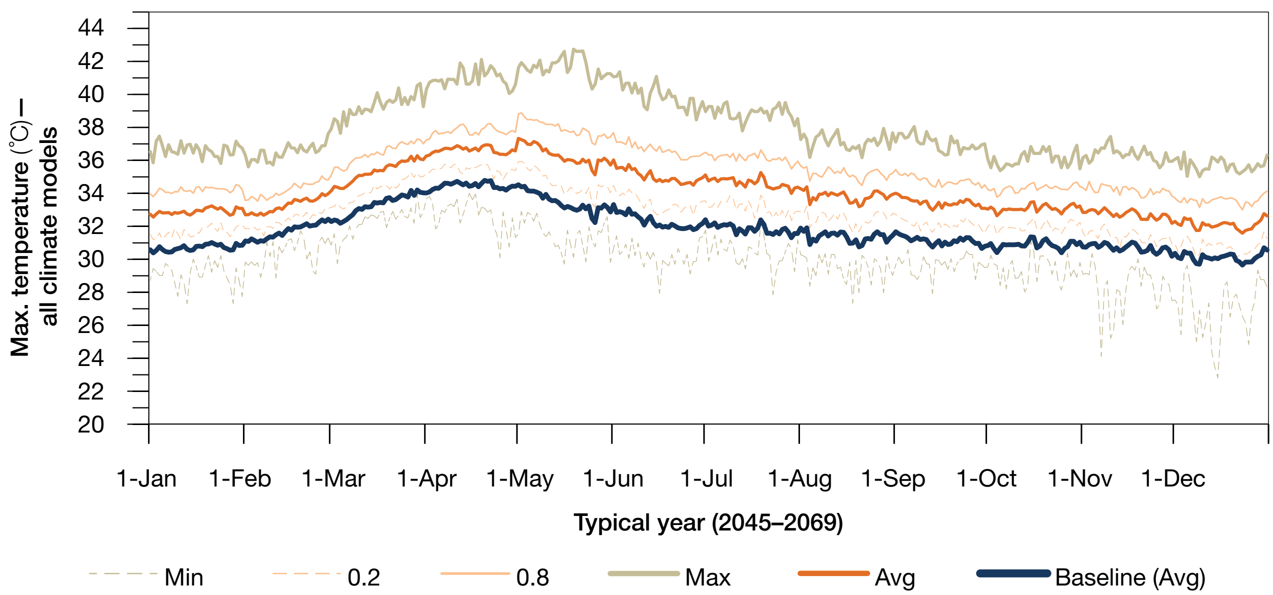
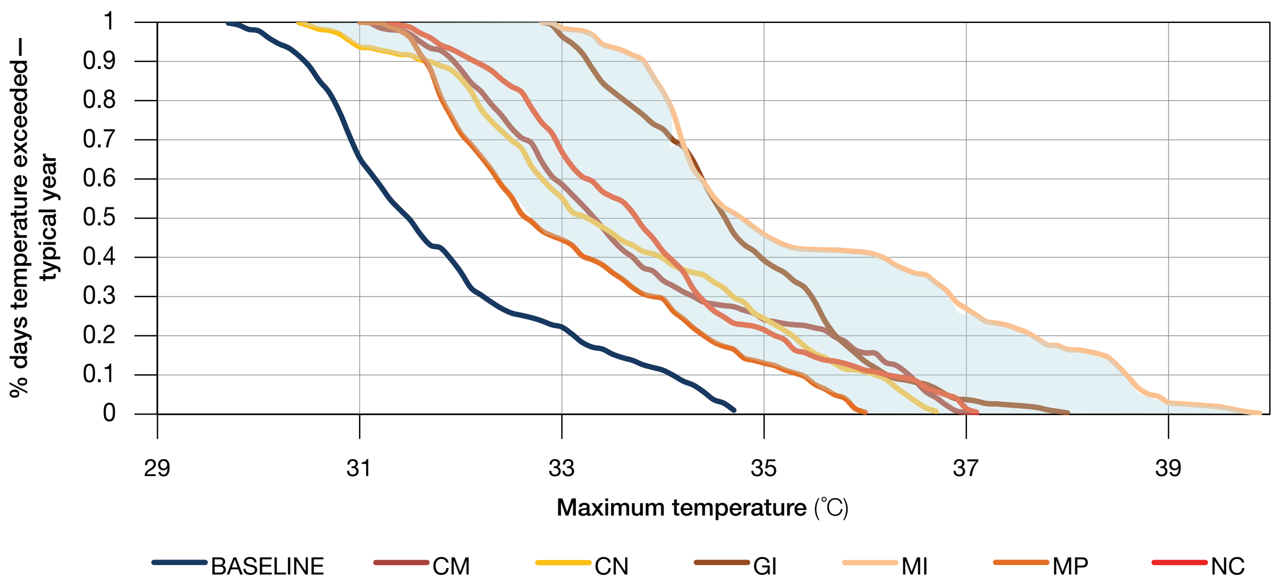
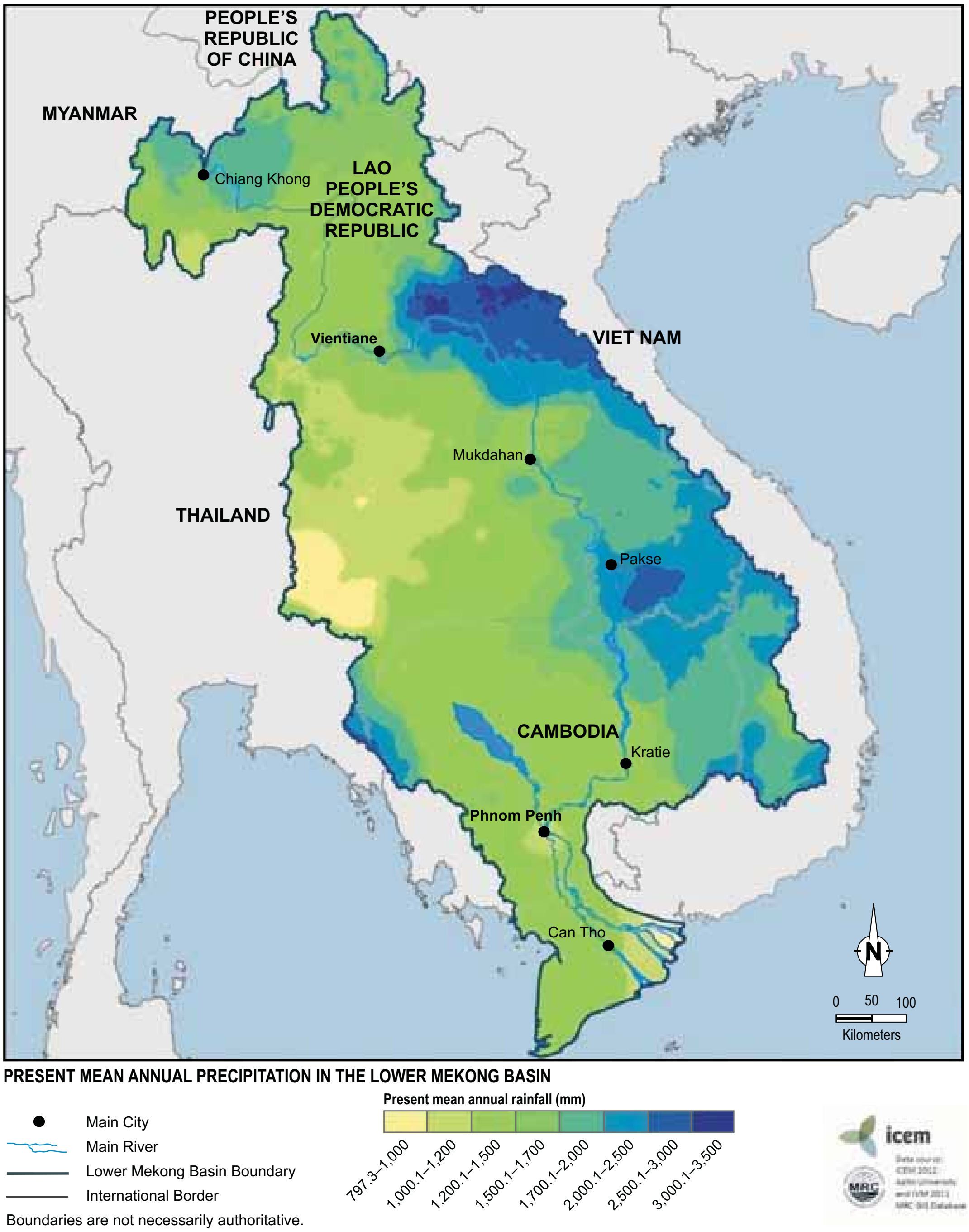


Figure 8: Daily Maximum Temperature Percentage Exceedance Curves



CM = CCCMA, CN = CNRM, GI = GISS, MI = CCSR, MP = MPI, NC = NCAR.

Figure 9: Historical Mean Annual Precipitation in the Lower Mekong Basin (1980–2004)



shadow of the Northeast monsoon—except for the Vietnamese area of the basin, including the delta.

Distribution of rainfall is highly variable throughout the basin. The highest rainfall occurs on the western slopes of the Annamites of the Lao PDR and Viet Nam, where mean annual rainfall can exceed 2,500 millimeters (mm) per year, while the majority of northeast Thailand and the northeastern coastal region of the delta experience less than 1,200 mm/year (Figure 9). Rainfall at the project site displays two peaks: a leading peak in May corresponding to the start of the Southwest monsoon and the main peak in October corresponding to the start of the Northwest monsoon. Average peak rainfall is 273 mm/month.

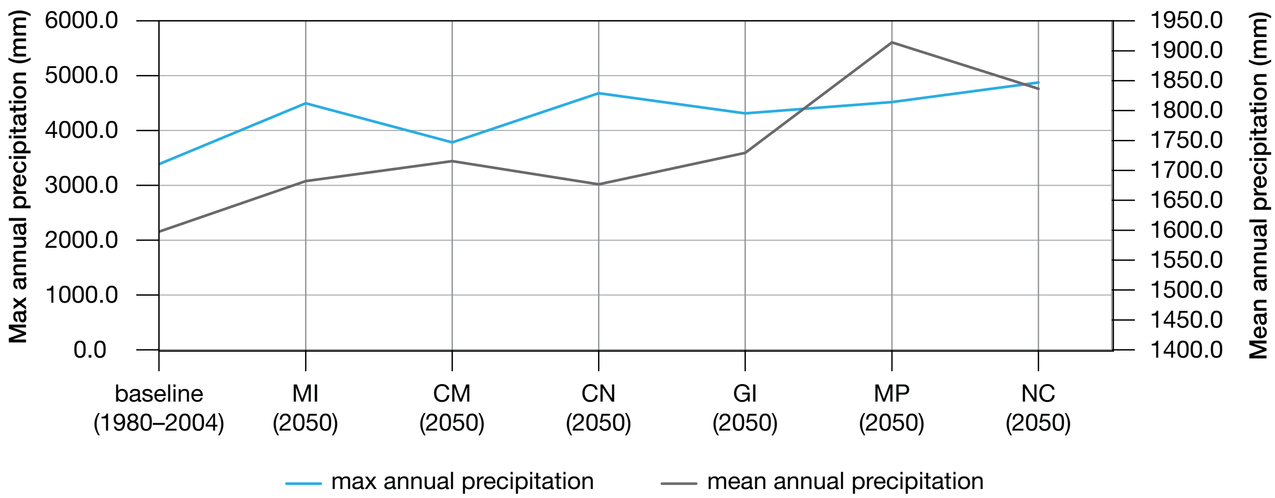
Warmer atmospheric temperatures will affect rainfall patterns and the strength of the hydrological cycle and of rainfall patterns. The capacity for the atmosphere to hold water is exponentially proportional to the air temperature. As temperatures continue to rise in the 21st century, the mass of water vapor held in the atmosphere will also increase, which will in turn increase the magnitude of rainfall events. In addition, one of the key drivers of storms is the release of latent energy from water vapor as it condenses to form clouds. In a wetter atmosphere the energy available to power storms will increase proportionate to the increase in atmospheric water vapor content, resulting in more intense storms.

Climate change analysis predicts that total annual precipitation will increase in the Lower Mekong Basin by an average of 162 mm by 2050, while maximum annual precipitation is expected to increase by 933 mm (Figure 10). The vast majority of the increase in rainfall will occur during the wet season, affecting the hydrology of the Mekong River and ultimately the water levels in the Mekong floodplain during the flood season. Spatially, the highest increases are predicted for areas with historically high rainfall, including (i) the central and northern Annamites (more than 500 mm increase per annum) and (ii) to the east of the basin (increase of more than 300 mm per annum). In the mid-elevation areas of northern Thailand and the Lao PDR near the borders with the People's Republic of China and Myanmar, precipitation will experience a moderate increase (200–300 mm increase per annum). Lower increases in precipitation will occur in the Khorat Plateau of Thailand, the Cambodia floodplain, and the delta of Viet Nam (less than 200 mm increase per annum).

The impact of changes in precipitation manifest as two issues: (i) changes in rainfall–runoff regime and hence changes in upstream discharge arriving at the delta and (ii) changes in direct precipitation at the project site. The Mekong Delta is projected to experience smaller increases in precipitation compared with the rest of the basin. At the project site, the largest increases in rainfall are expected for the wet season, including an average 8% increase in peak rainfall during October. Variability in peak October rainfall is large, ranging between –8% to +50% across the six GCMs (Figure 11).

Cumulative rainfall is expected to increase from an average of 1,300 mm/year to 1,400 mm/year with all GCM simulations predicting an annual increase (Figure 12). During the wet season, average historic wet season rainfall varied between 600 and 1,400 mm. With climate change, wet season rainfall is expected to become 50% more variable, ranging from 600 to 1,800 mm. In addition, there is not likely to be a significant increase in the number of rainy days during the wet season, indicating the increased intensity of individual rainfall events.

Figure 10: Basin-Wide Average Changes in Mean and Maximum Precipitation



CM = CCCMA, CN = CNRM, GI = GISS, MI = CCSR, MP = MPI, NC = NCAR

Figure 11: Changes in Average Monthly Rainfall in Dong Thap Province

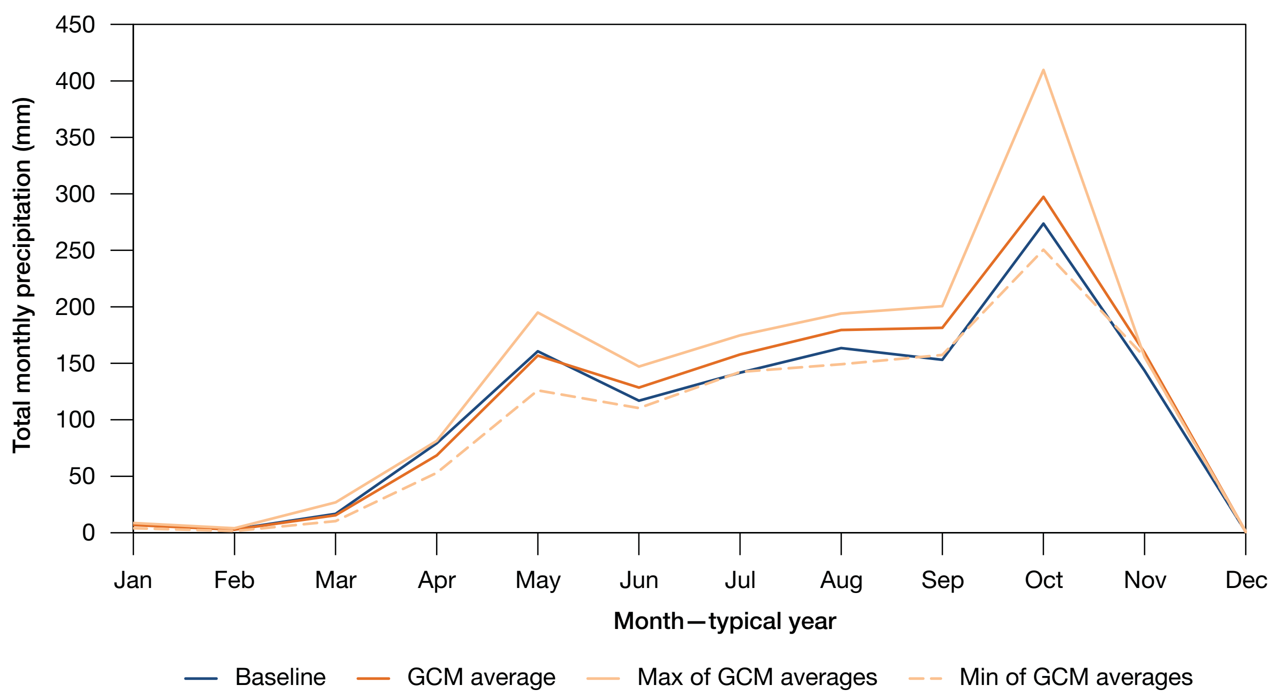
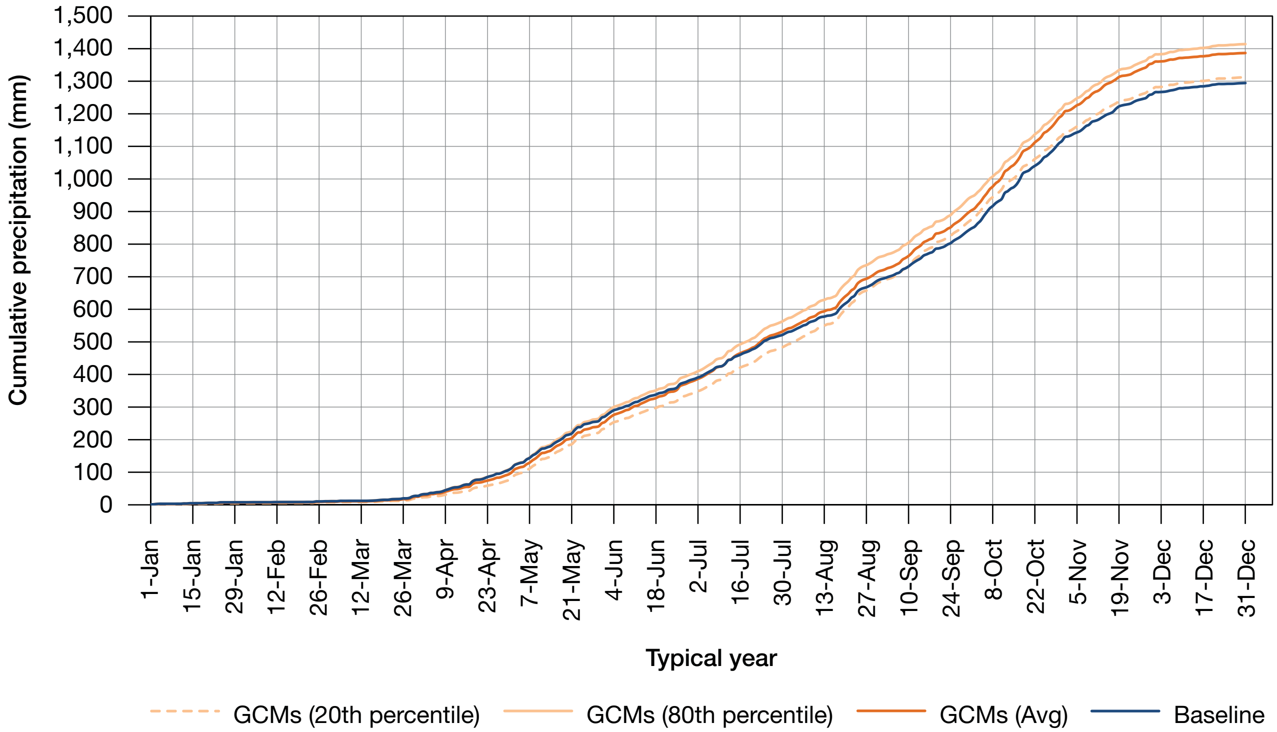


Figure 12: Changes in Cumulative Rainfall Totals at Project Site



Mekong River Flow

Typical Events

The Mekong River is 4,880 km long with a total fall of 4,583 m, covers an area of 795,000 square kilometers (km^2), and has an average annual flow of 505 cubic kilometers (km^3) (MRC 2005). The unifying hydrological feature of the system is the river's flood pulse, which sees the individual rainfall–runoff events throughout the catchment coalesce into a stable and predictable hydrograph with distinct hydrological seasons.

The annual hydrograph for the Mekong River has three important features that are critical for the functioning of the current hydrological regime:

(i) the response of the hydrograph to the monsoon exhibits a single amplitude peak complemented by a highly predictable phase (MRC 2009),
(ii) the onset of the flood season occurs within a consistent and small time window with a standard deviation of approximately 2 weeks (MRC 2005), and
(iii) there is a long period of low flows, which eases the seasonal transition from aquatic to terrestrial environments.

This predictability of the river hydrology has resulted in a good understanding of the dynamic natural equilibrium that is manifest throughout the 90 years of sampling data (ICEM 2010).

Hydrology of the Mekong basin was simulated using the a 1D model that was custom built by ICEM for the Mekong Basin with a grid resolution of 5 km x 5 km. The model was calibrated for discharge at two monitoring stations on the Mekong mainstream: Chiang Saen and Kratie. Output data was generated for Kratie station and then compared with observational data from the station with a correlation coefficient (R^2) exceeding 0.9. Kratie station was selected because it represents the most downstream station on the Mekong River before the river enters the Cambodian floodplain. The model showed good capability to model the timing and duration of the Mekong flood pulse, and the magnitude of the flood event.

Changes in catchment rainfall will increase seasonal discharge in the Mekong River. At the same time, storage hydropower in the Mekong basin will, under average conditions, store wet season flows for release during the dry season—moderating the increases in discharge induced by climate change. Using the VMod model, the study inputted daily climate data from six GCMs for two 25-year time periods centered on 2050 and 2100. This analysis produced some 500 future hydrological years for analysis.

Analysis of daily data for historical and future climate data at six mainstream stations indicates that the nature of change is consistent along the course of the Mekong River and can be summarized by four key changes:

(i) *Increase in flood magnitude and volume:* The dominant feature of the Mekong flood pulse is a single flood peak during August and September. Across all stations, climate change will increase the flow during the flood season and the size of the flood peak (Figure 13).

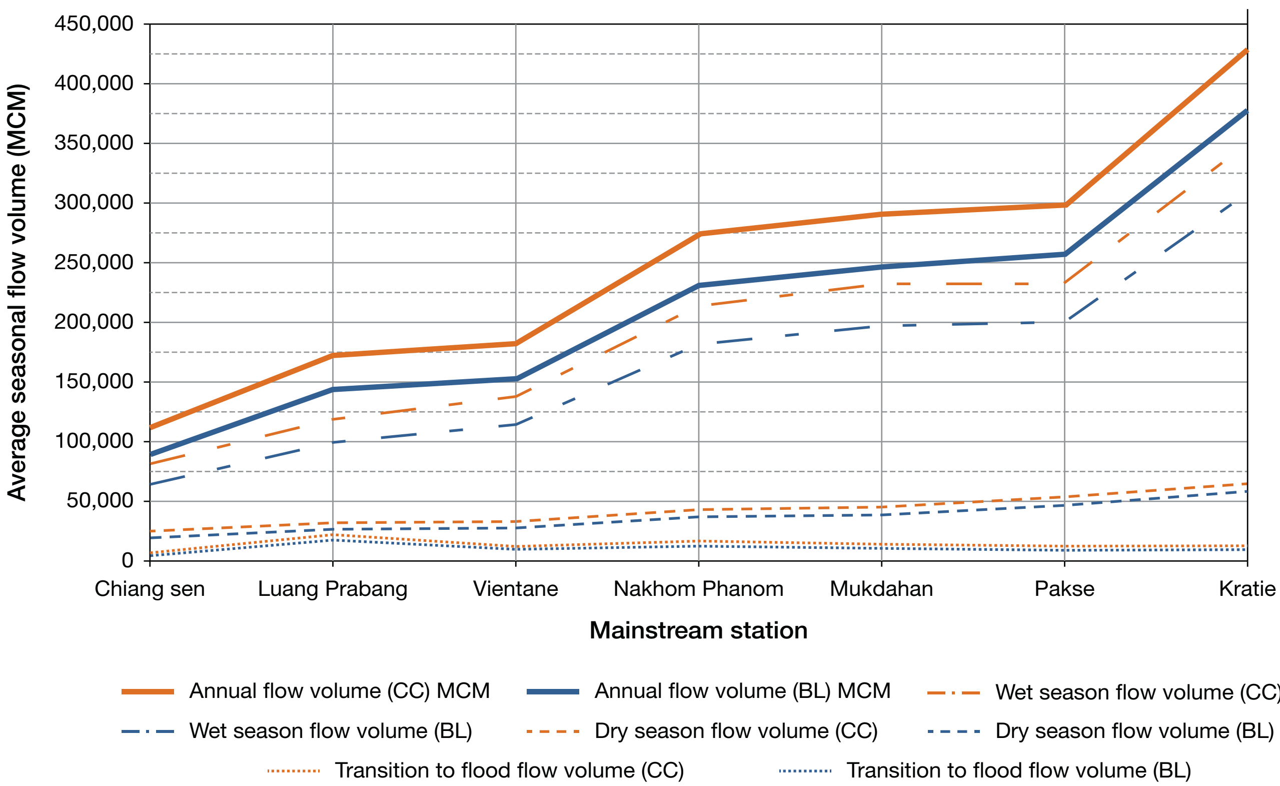
In terms of the average annual total flow volume, the increase in flow will be more pronounced in the lower reaches, increasing by up to 51,000 million cubic meters at Kratie (Figure 13). In terms of the percentage change in volume, the increase will be greatest for the upper reaches including an over 25% increase in flow at Chiang Saen, approximately 20% for the middle reaches of the Mekong (Vientiane to Pakse), and 15% in the lower riverine reaches (Pakse to Kratie).

(ii) *Increase in flood duration:* Historically, the flood season of the Mekong River is defined as the period of the year in which the flow exceeds the mean annual flow and typically starts in June and ends in November (depending on the station). Across all stations, climate change will increase the duration of the flood season.

(iii) *Shortening of transition seasons and onset of flooding:* Situated between the wet season and dry season are two important transition seasons: transition to flood (May/June) and transition to dry (November/December). These transition seasons are typically short but are important in triggering a number of biological processes and in controlling the rate of transition of floodplain environments from terrestrial to aquatic and vice-versa. Climate change will shorten the transition seasons at all stations and increase the rate of increase of discharge. This will accelerate the rate of transition from dry to flood and vice-versa.

(iv) *Increase in dry season water levels:* Climate change will increase dry season flows in response to increases in dry season rainfall for most areas of the Mekong catchment. The middle reaches of the Mekong (Vientiane to Pakse) will experience the largest proportional increases in dry season water levels (20%–30%) due to changes in dry season rainfall in the highly productive left-bank tributaries draining the Annamite mountain

Figure 13: Changes in Annual and Seasonal Flow Volumes for the Mekong River



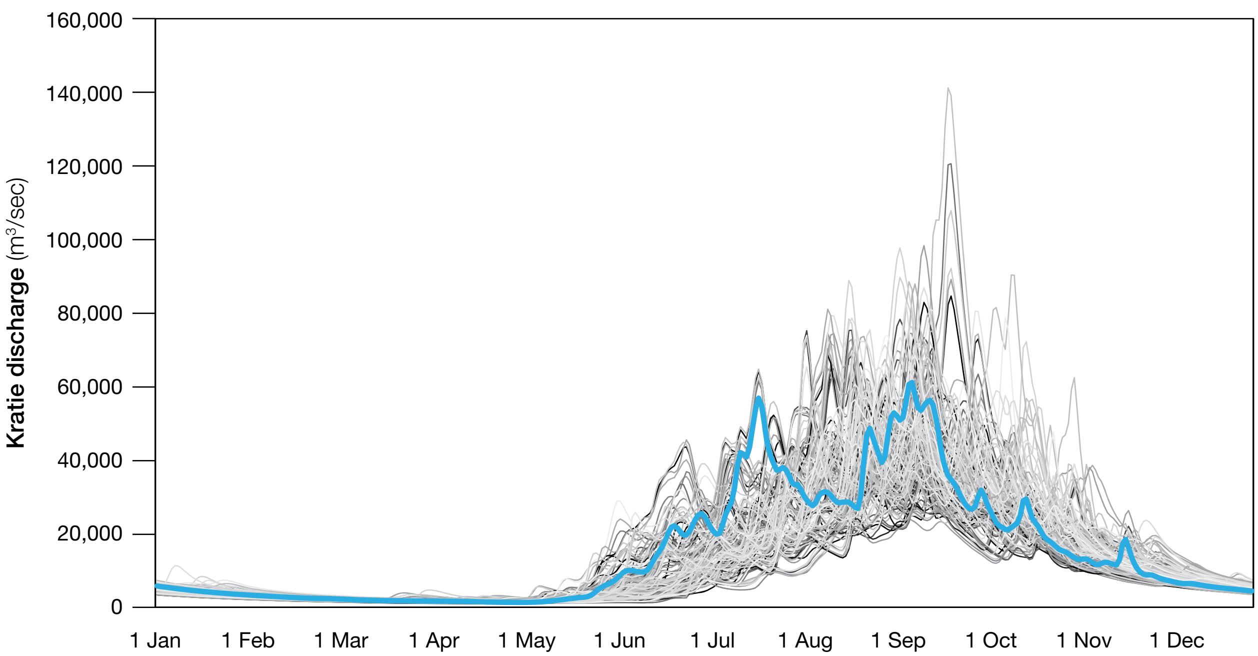
BL = baseline, CC = climate change, MCM = million cubic meters

ranges. These tributaries account for some 30% of the total flow in the Mekong River (MRC 2010).

Stations further upstream (Chiang Saen and Luang Prabang) will experience smaller proportionate increases in dry season water levels of 10%–20% due to the dominance of the Upper Mekong Basin to dry season hydrology, where snowmelt, not changes in rainfall, is the dominant driver. Stations in the lower reaches (Pakse to Kratie) will also experience proportionately smaller increases in dry season water levels (5%–20%), predominantly due to significant widening and braiding of the channel increasing cross-sectional flow areas.

Figure 14 compares the 2000 flood event (blue) to some 150 hydrological years with climate change (gray) and illustrates that there is a considerable range in the response of the river hydrograph to changes in climate and hydropower exploitation. Under baseline conditions, the year 2000 flood is considered an extreme event; however, comparison with the full set of climate change projections shows that the likelihood of more extreme discharges at Kratie is

Figure 14: Daily Discharge at Kratie under Baseline and Climate Change Scenarios



increasing. The greatest variability in prediction occurs during the flood peak in September, where projected future flood peaks ranged between 20,000 cubic meters per second (m^3/sec) and 140,000 m^3/sec.

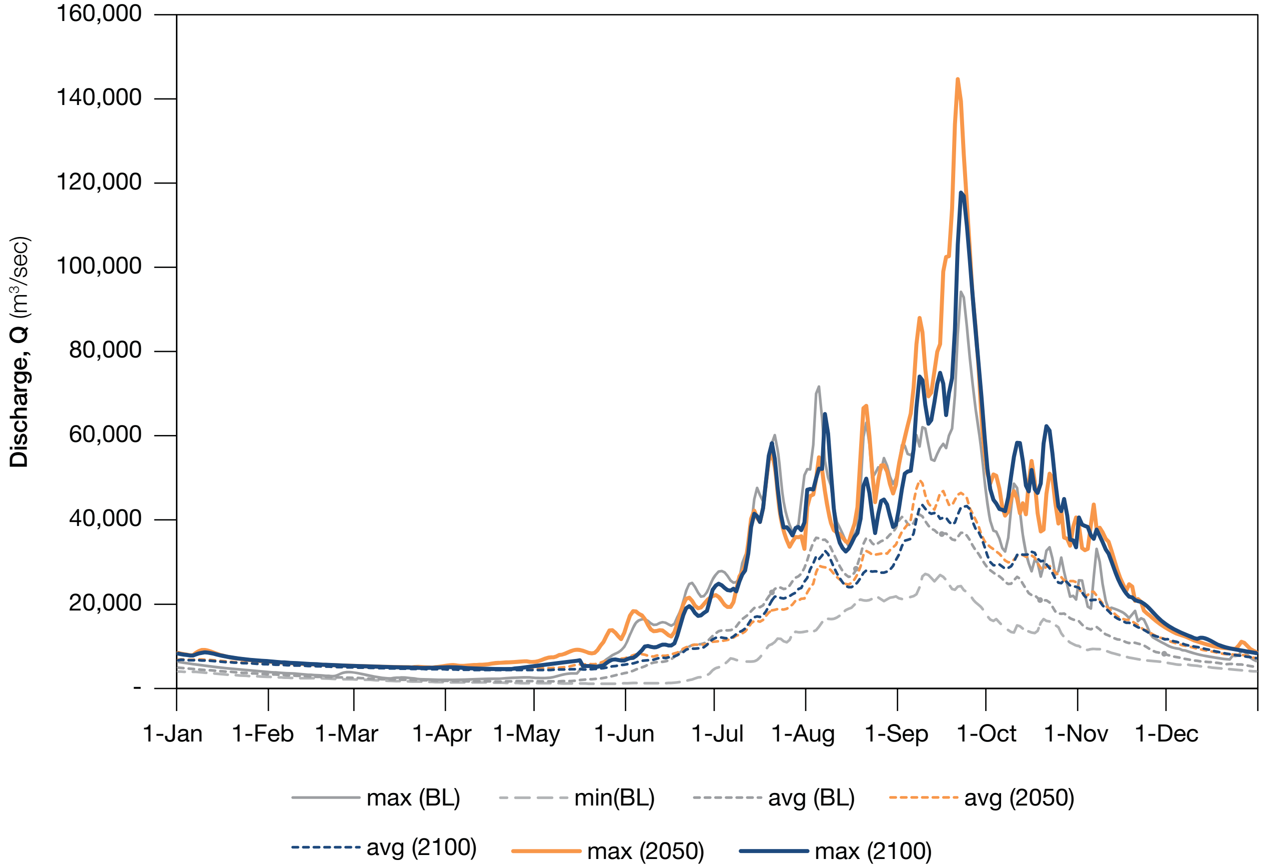
As a result of increases in rainfall, flow in the Mekong River will increase in both the dry and wet seasons. While the increase is observed in mean flow conditions, the peak flow events of the flood season are expected to be significantly impacted, resulting in greater variability of the flood event and higher flood peaks. Figure 15 presents a statistical summary of the minimum, average, and maximum hydrograph at Kratie under (i) baseline, (ii) 2050, and (iii) 2100 conditions. Findings include the following:

(i) The largest impact of climate change will be on the peak flood events. About 60% of all simulated peak daily flows increased by a factor of 1.08–1.93 (average of 1.21) compared with simulated baseline flows.

(ii) The most extreme peak events (greater than the 80th percentile) see peak simulated floods 1.25–1.50 times the baseline simulated floods. While the smallest flood events see simulated peak floods increase 2.25–2.50 times the simulated baseline flows.

(iii) Peak flows are greater for the period centered on 2050 (i.e., 2045–2069) than on 2100 because of the nature of the Special Report on Emissions scenario A1b, which sees a stabilization in global

Figure 15: Climate Change Influence on the Kratie Hydrograph



BL = baseline.

population and shift to a global economy with more renewable technology and greater efficiency in the last quarter of the century.

(iv) Changes in mean annual flow experienced similar changes at 2050 and 2100, with increases in flow during the dry season and flood season and a decrease during the transition to flood.

Extreme Events

This section assesses how the likelihood of extreme events may change in response to climate change.

Frequency analysis uses probabilities to express the likelihood of an event based on fitting statistical distributions to time series data. Return periods express the likelihood that a certain value will be exceeded—for example, the P1% (or 1-in-100 year) flood indicates that there is annually a 1% chance of a flood exceeding or equal to that flood. The selection of the appropriate return period is then determined by the significance of exceedance. For example, the P5% is selected for navigation clearance because the implications of exceeding this limit, though inconvenient for navigation and economic activity, do not represent a risk to the structural integrity of the infrastructure, while the P1% is selected for embankment design because overtopping during flood events can wash out the structure causing damage and safety risks. If extreme events are predicted to become more frequent (i.e., the return period diminishes), then the risk associated with the design will increase.

Central to statistical methods used in frequency analysis is the assumption that the time series can be approximated as stationary—that is, key statistical parameters (mean, variance) are approximately constant over very long periods (Chow et al. 1988). In the context of climate change, it is clear that time series for hydrometeorological phenomena are nonstationary—that is, the values for the mean, variance, and mode are dynamic over time. This presents a challenge for the use of extreme event analysis. Climate change assessments have one of two options:

Option 1: *Assume stationarity* of the long-term time series and combine historic and future time series into one record and conduct frequency analysis over the entire data set.

Option 2: *Acknowledge nonstationarity* by disaggregating future time series data from past time series data and undertake frequency analysis on each data set separately. This means that the future hydrometeorological regime is seen to have undergone a fundamental shift from the historic regime to a new regime. Frequency analysis is then applied to the future climate change time series independent of the past time series.

In choosing how to approach frequency analysis with climate change, neither option is technically wrong, but each comes with a set of assumptions and implications for the structures risk profile. From a risk management point of view, Option 2 is more cautious as the changes in magnitude and frequency of extreme events will be greater when decoupled from historic data, while Option 1 is more conservative. This study undertook the frequency analysis assuming stationarity (Option 1), which produces a lower level of risk. For completeness, the study also undertook a rapid sensitivity analysis to the findings by comparing the range of risk estimated with this method to the range of risk estimated using Option 2.

Analysis was undertaken to determine the return periods for the Kratie station under baseline conditions. A historic annual maxima series for daily peak flows was developed for 86 years of gauging station data available for the Mekong River Commission (1924–2009). The data was then fitted to an extreme value distribution and return periods were calculated using the methodology outlined by Chow et al. (1988) for peak flows at Kratie. The calculated extreme event frequency distribution was then compared with that calculated by the Mekong River Commission for the same station (Kratie) and parameter (peak discharge) and using a baseline period of 1924 to 2006 (Table 2).

Estimates from this study produced marginally higher estimates for high-frequency events (return periods of less than 5 years) and lower estimates for infrequent events with return periods greater than 5 years, compared with the Mekong River Commission estimates.

The future daily flow was calculated for Kratie over the period 2045–2069 using six GCMs, providing a total of 168 hydrological years of daily data. For each

Table 2: Calculation of Return Periods for Extreme Flows at Kratie Station

Return Period	Annual Exceedance Probability (%)	Mekong River Commission (MRC) (1924–2006)	This Study (1924–2009)	% Variability from MRC Estimate
2 year	50	52,000	52,745	1.4
5 year	20	58,000	58,309	0.5
10 year	10	63,000	61,992	(1.6)
20 year	5	68,000	65,526	(3.6)
100 year	1	78,500	73,527	(6.3)

GCM, the 25-year future data set was coupled with the 86-year historical baseline and then fitted with the extreme value distribution to calculate magnitudes and return periods.

Results are presented in Figure 16. Based on this analysis, peak flows are projected to increase in magnitude. For example, the P1% flood at Kratie will increase in magnitude from 77,597 m^3/sec to between 82,862 m^3/sec and 102,586 m^3/sec (Table 3).

With climate change, flood events are likely to be more frequent. For example, a peak flow of 77,597 m^3/s (historic P1%) is likely to occur with a return period of once every 15–40 years, whereas an historic 1-in-20 year event will occur with a return period of 1-in-5 to 1-in-10 (Figure 16). If the historic 1-in-100 year event becomes a 1-in-40 year event (as predicted by all of the GCMs), the risk of experiencing this event at least once over the design life rises from 63.4% to 92.0%.

Sea Level Rise

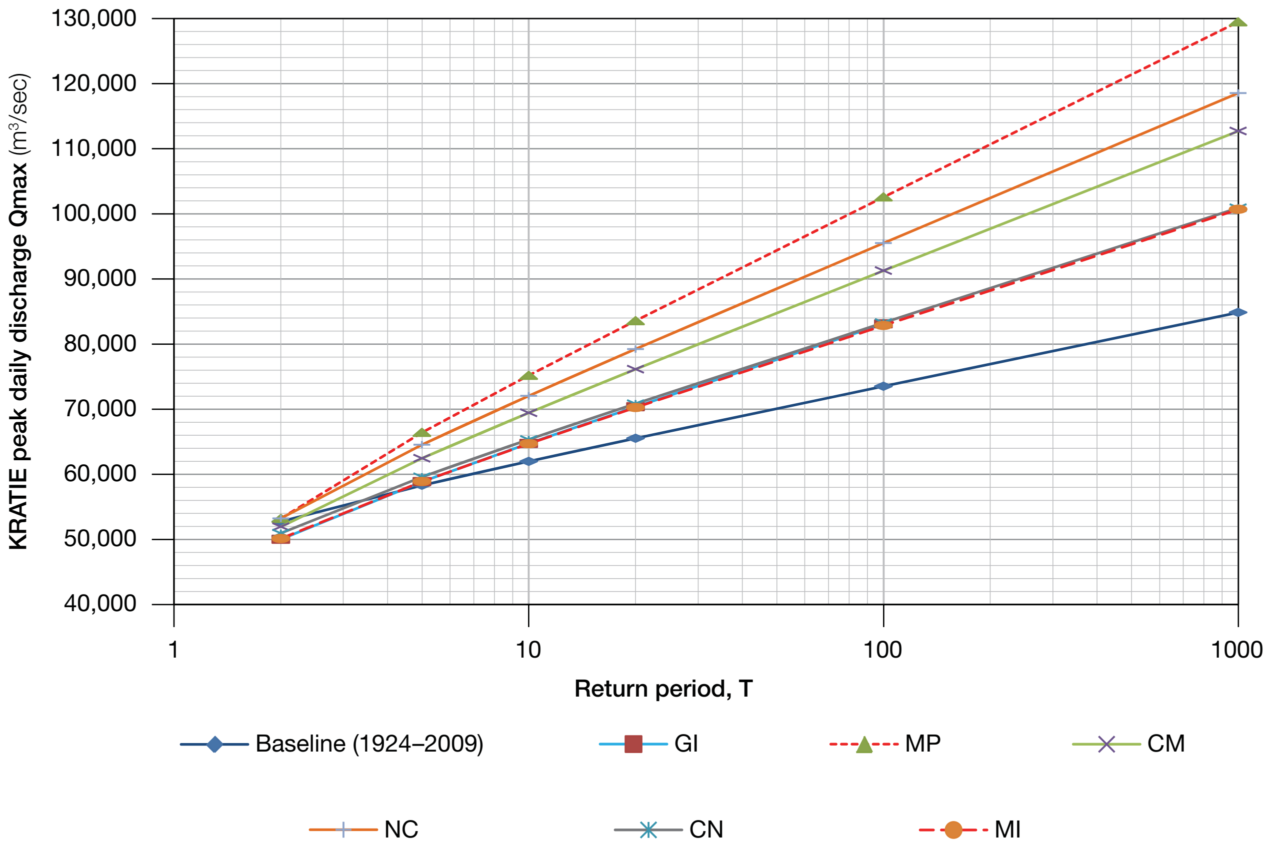
Sea level rise due to climate change will exacerbate flooding issues at the project site by reducing the delta's drainage efficiency, prolonging both the depth and duration of flooding.

The rate of global sea level rise has tripled in the past 100 years, with long-term rates for the 20th century ranging between 1.9 and 3.4 mm/yr (Rahmstorf 2007, Cazenave and Llovel 2010, and IPCC 2007). Analysis of historic rates of sea level rise indicate that they are nonlinear, as they are an expression of a complex interaction of processes, including glacial, sheet ice, and polar melt as well as thermal expansion of the oceans due to increasing temperatures. The increase in sea level has accelerated in recent decades, reaching 3.1mm/yr (1993–2006), more than double the average rate of rise for the 20th century, while the rate of rise in the 20th century was an order of magnitude larger than the 2 preceding millennia (Cazenave and Llovel 2010).

Actual rates of sea level rise along the coastlines of the earth's continents are highly dependent on meso and regional scale dynamics of the ocean system with large variability within and between oceans. In the western coastlines of the Pacific Ocean, Viet Nam is considered to be highly exposed. Analysis of the hourly fluctuation of sea levels at Vung Tau gauging station in southern Viet Nam indicates that sea levels have risen on average 3.0 mm/yr between 1979 and 2006, compared with average annual sea level rise of 1.8 mm/yr in Shanghai and 2.0 mm/yr in Hong Kong, China (Yu et al. 2002 and Ding et al. 2002).

Figure 17 presents the range in sea level rise expected for the 21st century in comparison with the averaged 1980–1999 reference level. The estimates were produced by the Institute of Meteorology, Hydrology and Environment using three IPCC SRES scenarios (B1, B2, and A1F1), representing a range of future emissions scenarios from low (B1 and B2) to high (A1F1) as well as the official scenarios for sea

Figure 16: Changes in Extreme Events at Kratie Station (extreme value distribution)

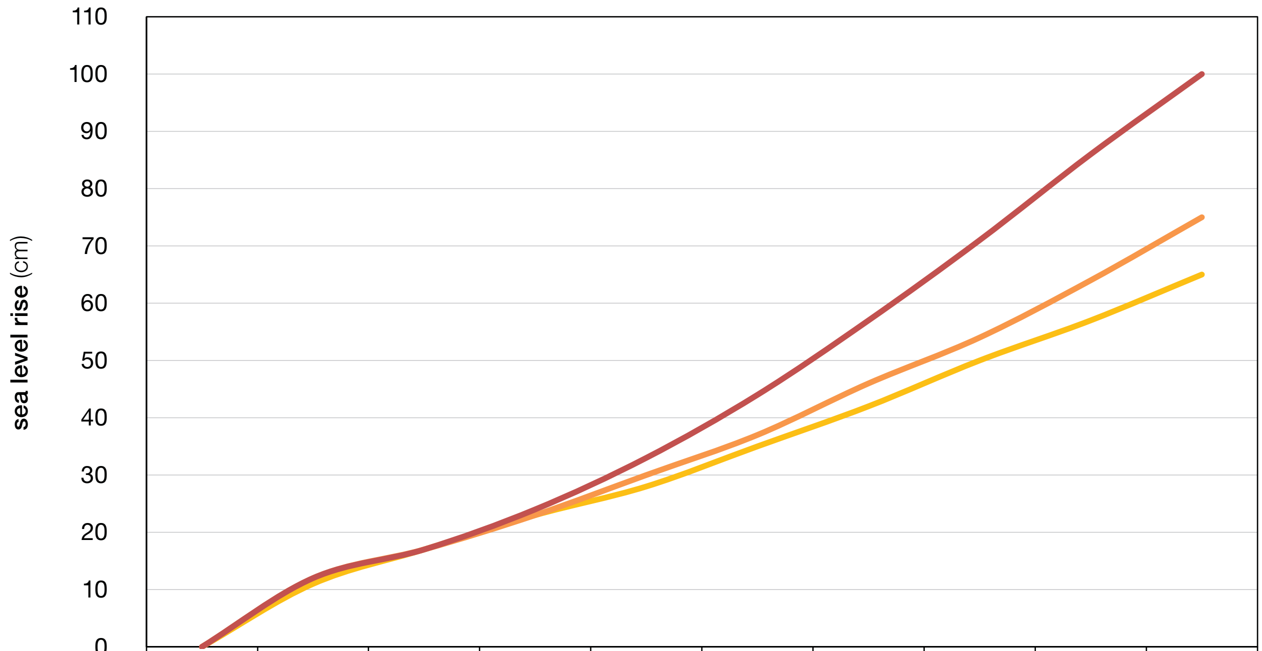


CM = CCCMA, CN = CNRM, GI = GISS, MI = CCSR, MP = MPI, NC = NCAR.

Table 3: Variation in the P1% and P5% Peak Flows for Kratie

Return Period	Historic Flow at Kratie (m³/sec)	Range of Predicted Flow at Kratie with Climate Change (m³/sec)	Predicted Flow at Kratie with Climate Change (m³/sec)
P5%	66,928	70,262–83,581	74,889
P1%	77,597	82,862–102,586	89,290

Figure 17: Revised Viet Nam National Scenarios for Climate-Change-Induced Sea Level Rise



	1980–1999	2020	2030	2040	2050	2060	2070	2080	2090	2100
B1	0	11	17	23	28	35	42	50	57	65
B2	0	12	17	23	30	37	46	54	64	75
A1F1	0	12	17	24	33	44	57	71	86	100

level rise from the Government of Viet Nam. Under these official projections, sea level in 2050 will be 0.28–0.33 m higher than 1980–1999 levels, while by the end of the century, levels will be 0.65–1.00 m above baseline levels. Given that the design life of the Cao Lanh and Vam Cong bridges is 100 years, it would appear that the design should take into account a realistic projection of sea level rise during this time horizon. This study assesses sea level rise using the highest official estimate at the 2100 time slice.

As the Central Mekong Delta Region Connectivity Project is located more than 120 km from the coastline, specific changes in channel water levels are dependent on hydraulics of the river channel including bed slope, channel width, height, upstream flow inputs, tidal influence, and distance from the coastline. Using the MIKE 11 model, the study assessed the sensitivity of in-channel water levels for five monitoring stations on the Tien River and three on the Hau River over a distance of approximately 100 km (Tan Chau to Can Tho). The assessment inputted 0.50 m, 0.75 m, and 1.00 m sea level rise forcings onto hourly flow simulations for the year 2000 flood and then assessed how peak water levels at the monitoring stations responded to this forcing. Stations closest to the coast registered the largest increases in water levels, with increases at My Thuan and Can Tho ranging between 78% and 93% of the sea level rise increment, while upstream stations (Tan Chau and Chau Doc), experienced increases in water levels equivalent to 10%–15% of the sea level rise increment.

At project sites (Cao Lanh and Long Xuyen), water level increases correspond to approximately 55% of the sea level rise increment (for example, an increase in sea level rise of 0.5 m results in an increase of water level at Cao Lanh of 0.24m).

Based on sea level rise alone, Cao Lanh will experience increases in maximum water levels during peak flood events (Table 4).

Table 4: Relationship between Sea Level Rise and Increase in River Water Levels at Cao Lanh Monitoring Station

Sea Level Rise (meters)	Estimated Year	Rise in Tien River Water Level (meters)
0.30	2050	0.15
1.00	2100	0.55

In addition, the sea level rise impacts may be aggravated by increased storm, cyclone, and typhoon intensity. To date conclusive modeling of future extreme events has not been undertaken; however, based on current understanding of atmospheric processes, storms and cyclones are not expected to become more frequent but will become more intense and for Viet Nam track further southward. Historic observations at Vung Tau station indicate that spring tides can increase sea levels by as much as 0.03 m between consecutive years.

Flooding

Figure 18 outlines the causal relationships through which climate change will impact water levels of the Hau and Tien Rivers and the interchannel floodplain and hence impact the design of the bridge and embankment structures. Each of the key threats identified above are brought together and assessed for their cumulative impact on water levels and flow velocities for both floodplain and channel environments.

Summarizing from previous sections, the key assumptions in developing projections of future flood dynamics at the project site include the following:

(i) Increase in sea level rise has been set at 1.0 m as this represents the upper limit of the official Government of Viet Nam scenarios.
(ii) Increase in catchment rainfall is based on a future time slice of 2045–2099, based on an assessment that increases are among the largest within this bracket.
(iii) Increase in hydropower storage takes into account all hydropower under some form of consideration; however, its impact affects average flows, not extreme flows.

Typical Flood Years

Figure 19 compares average flooding at the project site under baseline and climate change conditions. Average flooding conditions are summarized in Table 5 and calculated using 25 years of observation data (baseline) and 150 years of simulated data compiled

Figure 18: Causal Relationship between Climate Change Threats and Water Levels at the Project Site

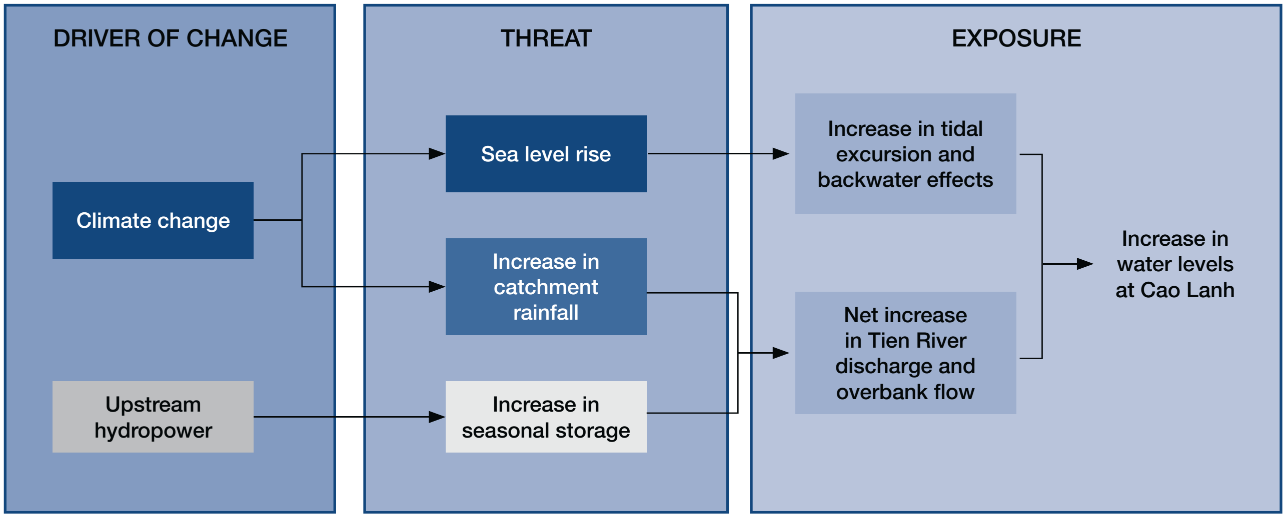


Table 5: Overview of Average Kratie Flood Characteristics under Baseline and Climate Change Scenarios

Parameter	Baseline	Climate Change
mean annual flow (m^3/sec)	11,983	13,585
peak flow (m^3/sec)	39,810	46,007
flood season volume (MCM)	297,680	340,577
flood duration (days)	134	137
flood start	1 Jul	28 Jun
flood end	12 Nov	12 Nov
annual flow volume (MCM)	377,908	428,418

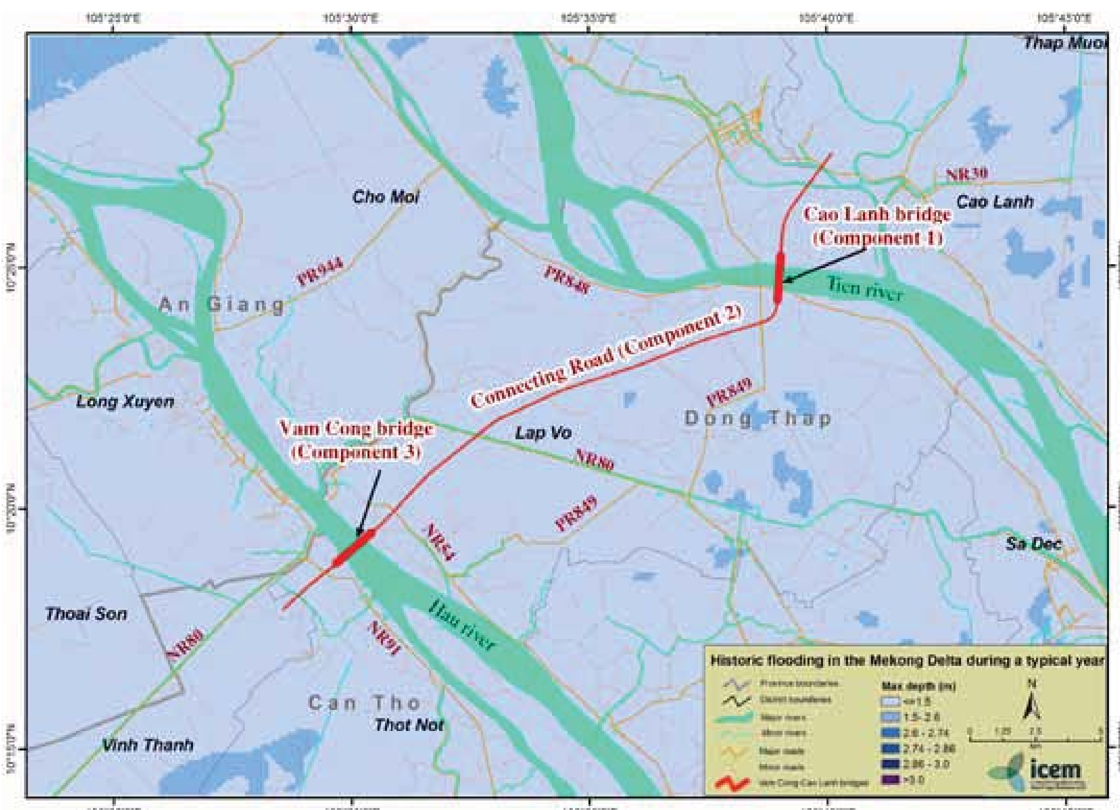
m^3/sec = cubic meters per second, MCM = million cubic meters.

from six GCMs. There is an approximate 15% increase in both mean annual and peak flows due to climate change, while the timing and duration of the flood season, together with the proportion of annual flow arriving during the flood season, remains at approximately 80%.

Under baseline conditions, flooding at the project site remains uniformly below 1.5 meters above sea level (masl). Location of the connecting road is marginally higher than the surrounding floodplain and there is a natural southward gradient that orients drainage from the Tien River and surrounding floodplains to the Hau River channel. With climate change, floodplain dynamics are not expected to change significantly but there will be an increase in the floodwater levels. Most of the connecting road will be exposed to water levels of 1.5–2.6 masl.

The two bridges are located at sites where water levels remain relatively stable under interannual fluctuations in flooding. Analysis of historic water levels indicate that even between low flood and above-average floods, water levels at Cao Lanh and Vam Cong vary by less than one meter.

Figure 19: Comparison of Average Flood Conditions in Project Vicinity under Baseline and Climate Change Conditions



Extreme Flood Years

In pulsing tropical rivers like the Mekong, flooding is an annual occurrence. Extreme flood events are those that differ substantially from typical conditions expected on a year-in-year-out basis—though definitions of "substantial" can vary. One option for defining "substantial difference" is assess the long-term historic distribution of annual flood volume and fit this data to a statistical distribution. This has been undertaken for the Kratie station by the Mekong River Commission (2011) with results presented in Figure 20.

Based on this definition, significant events are those with a return period greater than 1 in 10 years (P10%), and extreme floods are those with a return period greater than 1 in 20 (P5%).

In order to link these events to flood dynamics at the project site, this study assessed peak water levels at the two gauging stations closest to the bridge sites: Cao Lanh and Long Xuyen. Based on this analysis the P1% and P5% water levels at Cao Lanh and Long Xuyen were identified (Table 6).

Figure 20: Statistical Definition of Extreme Floods for the Mekong Based on Flow Volume at Kratie (1924–2006)

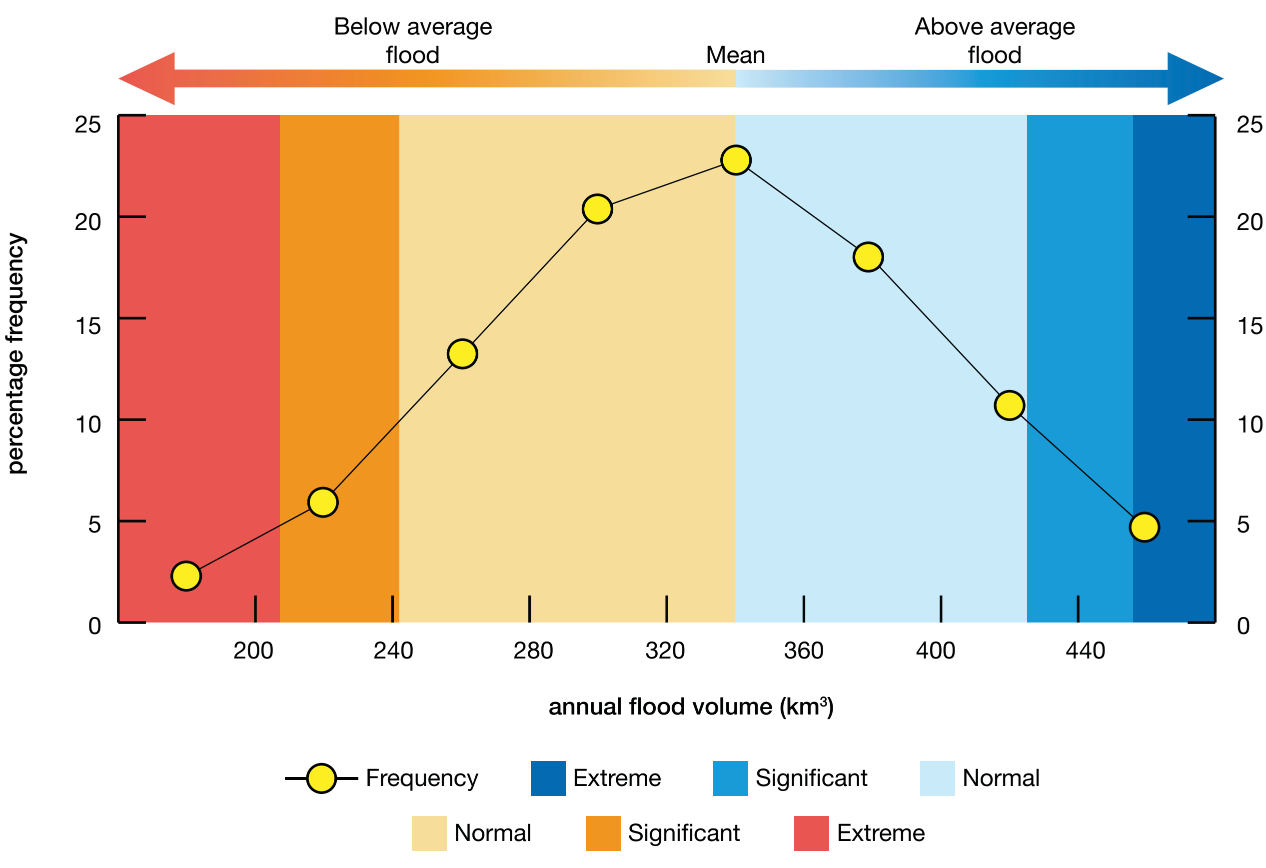


Table 6: Historic Extreme Water Levels at Cao Lanh and Long Xuyen

Station	Annual Exceedance Probability	Maximum Water Level (meters)
Long Xuyen	P1%	2.76
	P5%	2.59
Cao Lanh	P1%	2.84
	P5%	2.53

The methodology for calculating the return period used an annual maxima series derived from the peak daily discharge event in each flood season. It should be noted that this works well for discharge frequency analysis where flow is predominantly confined to channel systems. However, linking these return periods to levels in a floodplain environment can show poor correlation. For the Mekong, where downstream of Kratie flows spill in and out of the river channel into the surrounding floodplain including the reversal and natural storage of flows in the Tonle Sap, other assessments have used the 1-month flow volume during the peak flood month.

For example, comparison of recent large floods has shown that the 1961 flood was smaller than the 2000 flood in terms of both flood volume and flood peak; however, the maximum water levels in the Mekong Delta were higher than the 2000 flood. This reflects the dynamic nature of the floodplain environment, especially in relation to the distribution of floodwaters between the channels and floodplain. It is likely that in 1961 floodwaters were more confined to the Mekong channels than in 2000, when overland flow accounted for 20%–30% of total volume.

Changes in River Water Levels under the P1% Event

Figure 21 compares Cao Lanh water levels under baseline and climate change conditions. Comparison of river water levels at the Cao Lanh bridge site indicates that the design embankment height of 2.86 masl is sufficient to accommodate for the historic P1% flood (2.70 masl) and some 0.22 m above the year 2000 flood level. With climate change, water levels at the site will increase, resulting in a peak water level of 3.44 masl. This is 0.58 m above the current design embankment height.

Under future P1% conditions in the Tien River channel with climate change, water levels will exceed the embankment height for approximately 1 month, spread out between late August and mid-November.

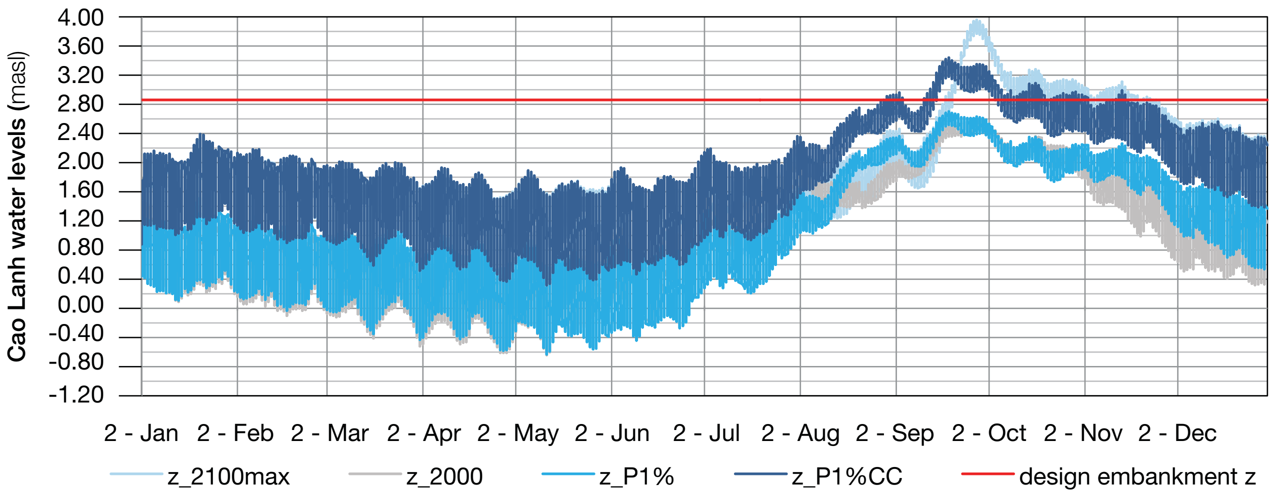
Comparison of the results shows good agreement between the 1D and 3D models at the Cao Lanh site. Figure 22 shows that during the peak flood period, water levels at Cao Lanh will reach 3.40 masl. This is 0.54 m above the current design embankment height.

A summary of the changes in water levels at the bridge site is presented in Table 7.

Table 7: Variation in P1% Cao Lanh Water Levels with Climate Change
(meters above sea level)

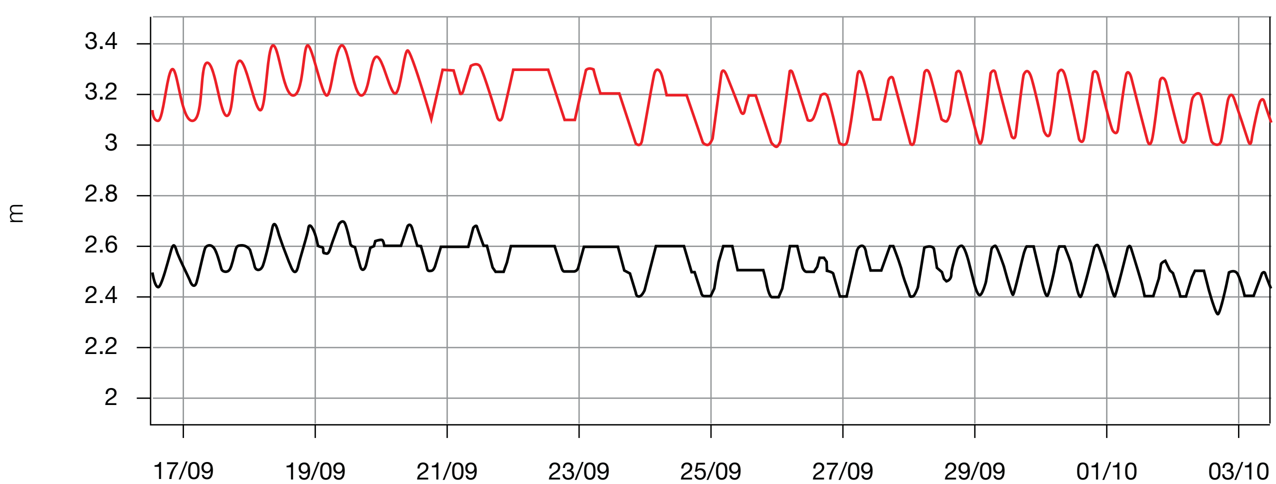
Baseline	Climate Change (1D Model)	Climate Change (3D Model)
2.7	3.44	3.4

Figure 21: P1% Hourly Water Levels at Cao Lanh



Note: Design embankment elevation is shown at 2.86 meters above sea level (red line); z_P1% = historic P1% flood level; z_P1%CC = future P1% flood levels with climate change; z_2100max = largest annual flood event produced by 500 years of simulated data from six general circulation models; and z_2000 = water level during the year 2000 flood.

Figure 22: Simulated Water Levels—Cao Lanh Bridge Site under Baseline and Climate Change Scenarios



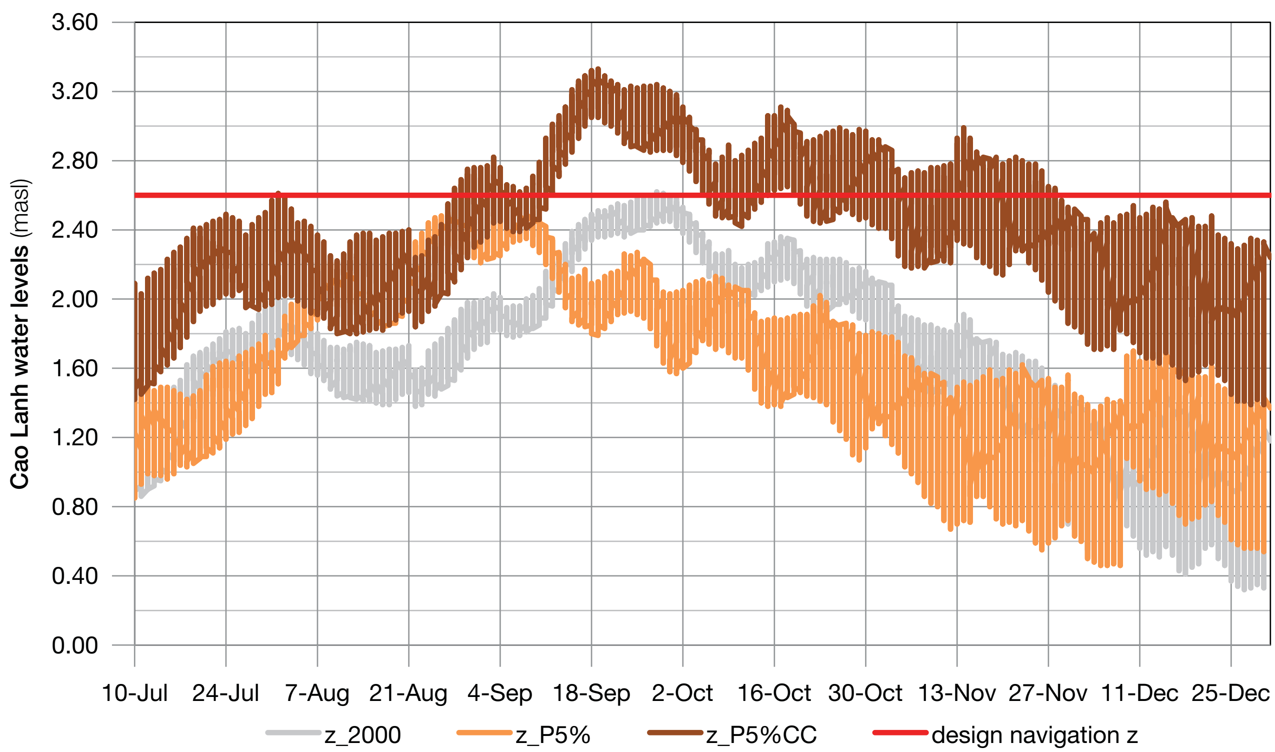
red = climate change; black = baseline.

Changes in River Water Levels under the P5% Event

Under the baseline scenario, the areas surrounding the left bank of the Hau River are subject to flooding of less than 1.5 masl, while the right bank of the Tien River will experience deeper flooding of up to 2.6 masl (Figure 23). With climate change, P5% floodplain water levels along the connecting road will reach up to 2.6 masl. Increases in flooding become more pronounced further upstream in the vicinity of Cho Moi and the Cambodian border.

Comparison of river water levels at the Cao Lanh bridge site indicates that the design navigation clearance of 2.60 masl is sufficient to accommodate for the historic P5% flood (2.58 masl) and approximately equivalent to the year 2000 flood level (Figure 24). With climate change, water levels at the site will increase, resulting in a peak water level of 3.33 masl. This is 0.73 m above the current design level. The P5% water level with climate change will exceed the design clearance for more than 2 months spread out between mid-August and late November.

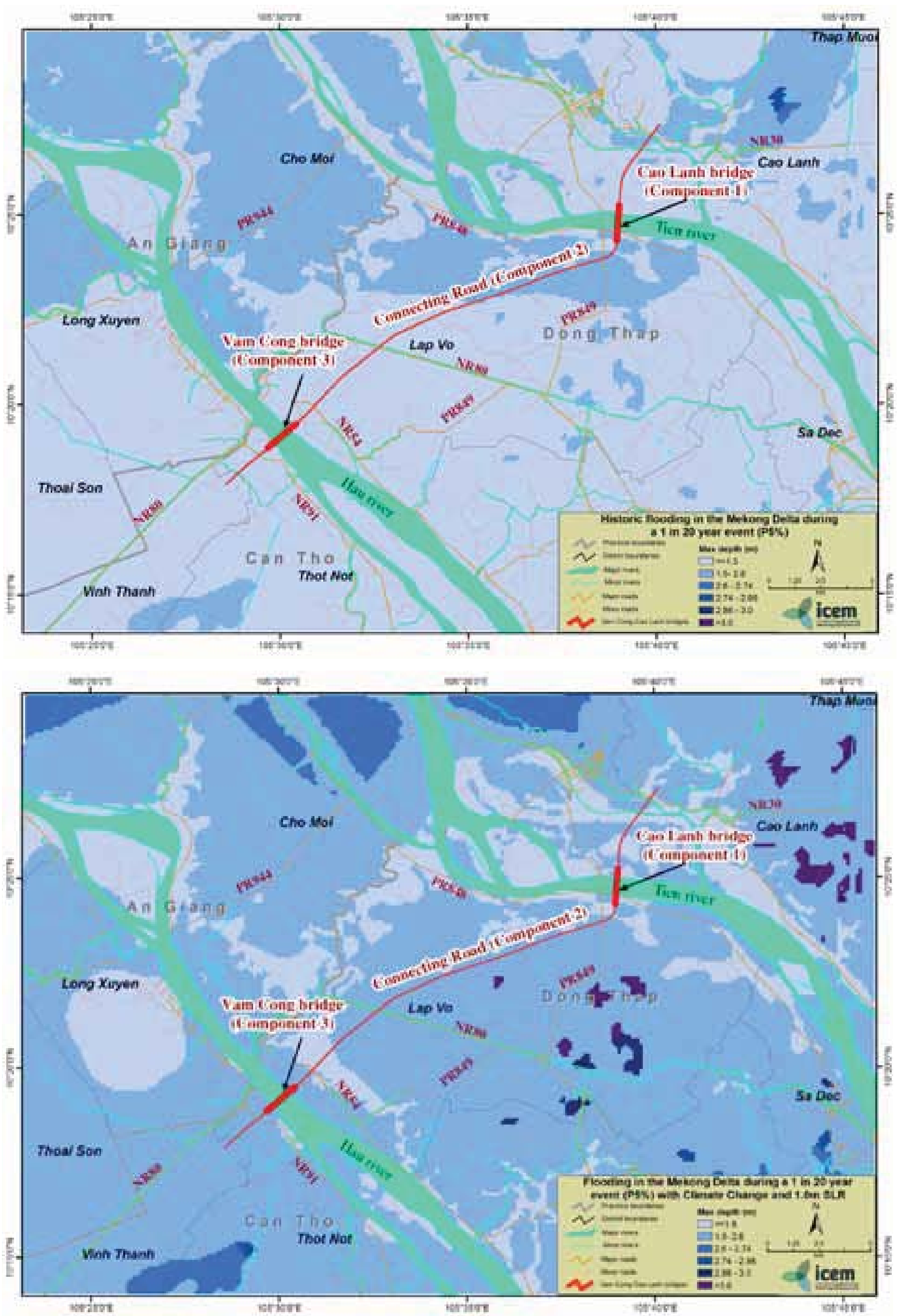
Figure 23: P5% Hourly Water Levels at Cao Lanh



z_P1% = historic P1% flood level; z_P1%CC = future P1% flood levels with climate change; z_2100max = largest annual flood event produced by 500 years of simulated data from six general circulation models; and z_2000 = water level during the year 2000 flood.

Note: Design navigation clearance is shown as 2.6 meters above sea level (red line).

Figure 24: Change in P5% Flooding of the Mekong Delta with Climate Change
(Top: baseline conditions; Bottom: with climate change)



Changes in Flow Velocities

An assessment was made of changes in flow speed at the bridge and road sites using the 3D hydrodynamic model. Results were outputted for midstream, surface, and bed velocities at the two bridge sites and for surface velocities along the road alignment.

Surface velocities peak near 5 m/s in the Tien River channel and nearly 6 m/s in the Vam Cong in the last half of September, while midstream velocities reach 4.8 m/s at Cao Lanh and 5.9 m/s at Vam Cong (Figure 25). With climate change the midstream flow velocities have increased by +0.2 m/s at Cao Lanh and +0.5 m/s at Vam Cong. The high water velocities, especially those near channel banks, may require riverbank protection.

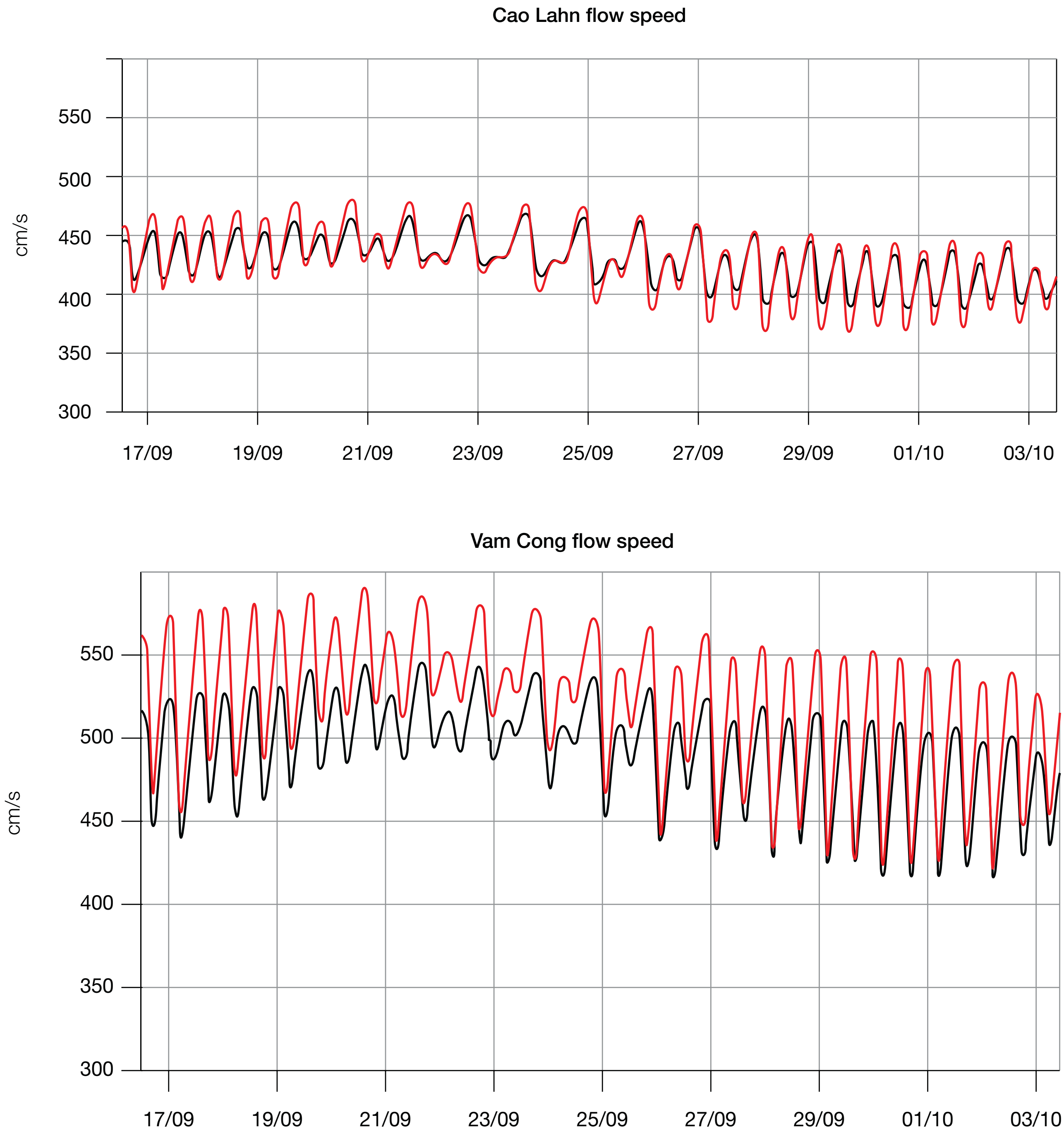
In the floodplain environment, the highest average flow speeds are over 0.7 m/s on the western and eastern ends of the connecting road. Speeds of 0.7 m/s can be critical velocity for onset of erosion. Assessments were also made to assess the sensitivity of floodplain flow speeds to wind conditions. It is evident that wind plays a minor role compared with the flood flow.

With climate change, flow speeds through road embankment openings are likely to increase by 0.5–0.8 m/s during a 1-in-100 year event.

Waves are a serious threat to floodplain roads as they increase water overtopping over the road and can cause major embankment erosion. Wave height depends mostly on fetch (length of open space for wave formation) and water depth. The highest waves are generated by northerly winds. Wave heights for a 15 m/s north wind can reach 33–42 centimeters on the northern side of the road embankment.

A rapid, simple model was also developed to assess flow through hydraulics for drainage culverts in the context of a future P1% event with climate change. Flow through the structures was capable of reaching speeds of 1.5–4.0 m/s.

Figure 25: Changes in Midstream Flow Velocities with Climate Change



red = climate change scenario, black = baseline.

Vulnerability and Adaptation Assessment

In the infrastructure design process, engineers utilize an understanding of hydrometeorological processes to quantify the occurrence and magnitude of forces experienced by infrastructure as a result of their surrounding environment (floods, storms, wind speeds, temperatures). This understanding is then used to establish design criteria that set the level of risk considered acceptable on an annual basis or over the design life. It is neither economical nor technically possible to design infrastructure that is immune to the surrounding environment, so the engineering design process is fundamentally one of managing physical and economic impacts to minimize risk to an acceptable level.

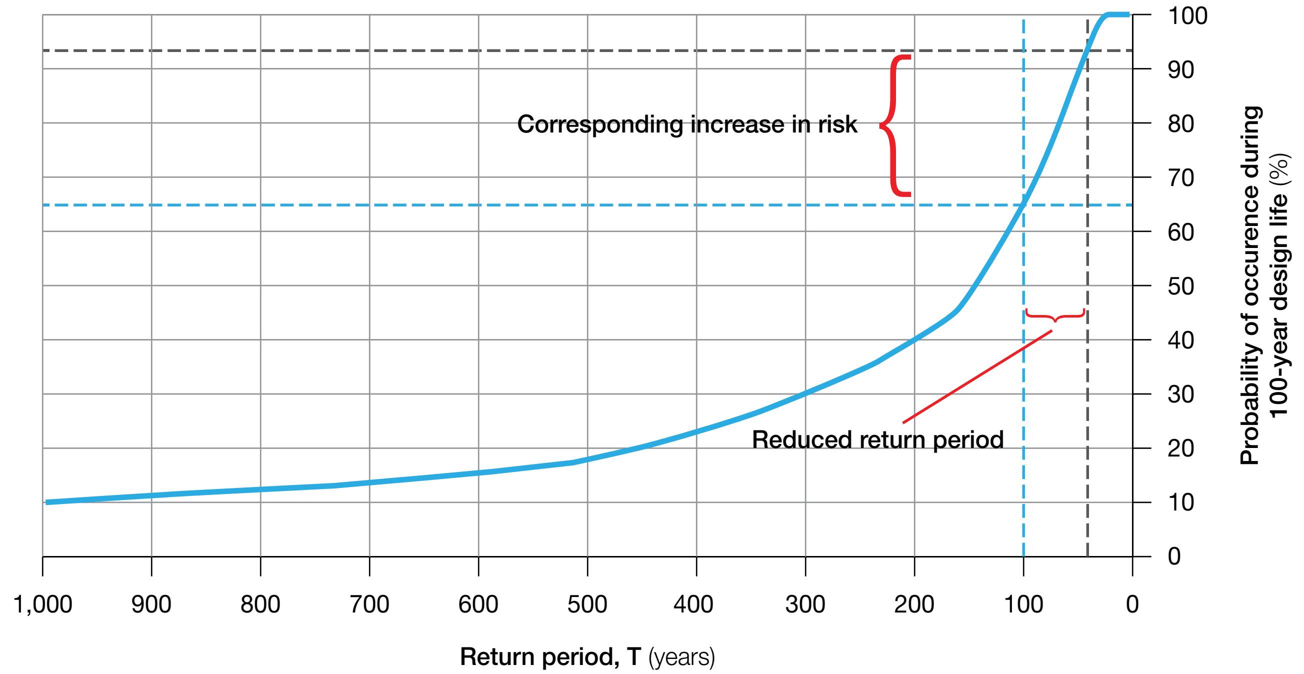
In the context of climate change, it is usually not economical or technically possible to climate proof infrastructure beyond all doubt. Engineers, together with climate scientists, need to establish a clear evidence base of how climate change is impacting the asset and surrounding environment and then assess what level of additional risk is acceptable. This determination of acceptable risk is as much a function of economic and political considerations as it is a technical one—especially given the novelty of climate change assessments and that to date there are no formal standards for infrastructure design with climate change within Viet Nam's legislative framework.

Engineering risk is the cumulative probability of occurrence for a particular extreme event over the structure's design life. For example, Figure 26 illustrates the probability that an extreme event will occur during the 100-year design life of the project. Under baseline conditions, the P5% has a 99.4% chance of occurring at least once during the design life, whereas the P1% flood has a 63.4% chance of occurring at least once during the design life. Changes to the global climate system will increase the risk (or likelihood) of a design threshold being breached during the design life of the project.

Central to the characterization of sensitivity has been an assessment of the specific design requirements of individual components as outlined in the Vietnamese design standards. Environmental loads are defined in the standards according to the philosophy of load and resistance factor design, which combines different limit states to establish the design specification for each component against published limiting force capacities. Each limit state is given equal importance to achieve the basic design objectives of constructability, safety, and serviceability.

(i) *Service limit state:* Controls long-term issues of usability and durability, and is typically based on established empirical relationships.

Figure 26: Extreme Event Risk for P1% Flood Over a 100-Year Design Life



(ii) *Fatigue and fracture limit state:* Exceeding fatigue limits can cause structural damage or lead to limitations for heavy traffic loadings.

(iii) *Strength limit state:* This is the main limit state for structural safety. Extensive distress and structural damage may occur under strength limit state, but overall structural integrity is expected to be maintained. Ductile behavior is favored because large displacements warn users.

(iv) *Extreme event limit state:* Sets loading to resist collapse. Extreme event limit states are considered to be unique occurrences whose return period may be significantly greater than the design life of the bridge.

Load and resistance factor design provides a framework for understanding sensitivity of individual components. Loadings presented in the standards represent extreme values to be expected in the design life of the structure. The extreme values are defined using existing data available with safety margins depending on the liability and coverage of the data. Design loads are also factored with safety factors. The overall safety margin varies depending on the accuracy of loads and the importance and sensitivity of the structural component under assessment. Larger safety margins are usually used in geotechnical design because of uncertainties in geotechnical parameters and soil conditions. When the extreme event limit state is applicable, the safety margins are lower and the structures may be subject to remarkable damage.

The design life and maintenance schedule are important considerations for setting the level of vulnerability and also prioritizing the phasing of adaptation response. Table 8 presents an overview of these characteristics for the main components of the Central Mekong Delta Region Connectivity Project. Maintenance scheduling has been divided by yearly, general (5–10 years), and special inspections (before major repair operations).

Bridge Substructure

Bridge infrastructure can be divided into two components, the substructure and the superstructure. The substructure consists of the foundational elements including the piling, foundation slabs, abutments, columns, pylons, and bearings. Those elements located above the bearings comprise the superstructure. The design life of bridge substructures is generally 100 years.

Foundation Slabs, Pylons, and Abutments

Small and medium size bridges are founded on bored or driven concrete piles (D = 2.5 m). In the foundations for main bridges, large-diameter bored concrete piles are used. The foundation slabs are made of reinforced concrete cast in situ with dimensions 90 x 60 x 6 meters. The bottom level of foundation slabs for pylons is located below the low water level and the top level above the highest tide level. The abutments are of traditional shape and, like the two columns at each support, are made of reinforced concrete cast in situ. The pylons are also made of reinforced concrete cast in situ, with their height above the deck level set as ¼ of the main span length. For structural

Table 8: Overview of Design Life and Maintenance Requirements for Main Components of the Central Mekong Delta Region Connectivity Project

Design life	Maintenance
The design life for bridges is 100 years Essential structural parts and parts that are difficult to replace => 100 years Stay cables Substructure Superstructure Secondary parts or parts that can be easily replaced => 20–50 years Waterproofing => 20–25 years Railings => 25–50 years Roadway pavement => 10–25 years Expansion joints => 20–25 years Bearings => >50 years Drainage systems => >20 years	Monitoring Clean-up, small repairs => yearly Painting of steel parts => 15–20 years Renewal of waterproofing => 20–25 years Repair/renewal of railings => when needed (10–20 years) Renewal of roadway surfacing => when needed (5–7 years) Renewal/repair of expansion joints => when needed (10–20 years) Maintenance of bearings => 20–25 years Renewal of drainage systems => >20 years Renewal of cable stays => when needed (>25 years) Repair of structural concrete Structures exposed by running water => 20–30 years Structures subjected to mechanical wear, collision etc. => when needed Other structures => 30–50 years

concrete the need for repair is usually after 30–50 years, but only 20–30 years for surfaces subjected to running water.

Sensitivity

As the massive substructures (foundation, slabs, and abutments) are made of cast-in-situ concrete, they are usually not very sensitive to environmental changes. The threats caused by climate change include the following:

(i) Changes in stay cable forces result in changes in the division of support reactions.
(ii) The rise of high water level increases the uplift, which reduces stability and changes pile forces.
(iii) Increased water pressure against structures increases overturning moment and changes pile forces.
(iv) Increase in extreme wind speeds increases overturning moment and changes pile forces.
(v) There is increased risk of ship collision.
(vi) Changes in sedimentation and water flows may lead to increased scouring.
(vii) Changes in salinity and pH reduce the service life of structures exposed to river flow.

Exposure and impact

Changes in frequency and intensity of flood events and sea level rise: With climate change, the frequency and magnitude of extreme events will increase. Under typical flood events, the increase is by a factor of 1.08–1.93 times the baseline. Extreme flood events are also likely to become more frequent; for example, the historic 1-in-100 year event is likely to become a 1-in-20 or 1-in-30 year event under future climate. These changes will increase water pressure on foundational structures with the potential to cause uplift.

Changes in flow velocities, sediment load, and sediment composition: The threat assessment indicates that the bridge site is located in a geomorphologically stable section of the Tien River, which has undergone minimal lateral migration since 1966. The site is immediately downstream of a channel constriction and future projections without climate change suggest limited erosion in the future. For the bridge substructure, flow speed is used to calculate the water pressure acting on foundations and to estimate the scour depth. With climate change, in-channel midstream flow velocities in the Tien River will increase by 0.5 m/s, with surface velocities reaching close to 5 m/s during the P1% flood, and near bed velocities reaching 0.9 m/s. Bed velocities are greatest near the left bank of the Tien. Increases in velocity will increase the stream power and hence energy available for geomorphological work.

Potential impacts include the following:

(i) Scour to foundation of the bridge*:* Scouring is one of the most common causes of bridge failure. Changes in river hydraulics can enhance scouring efficiency at pylons, foundation slabs, and other components within waterways, reducing support, which can in turn compromise the superstructure and lead to possible failure. The study has not modeled scour directly; however, increases in velocity suggest that the near left-bank region of the channel cross-section will be most susceptible to scour.
(ii) Damage to support piles*:* There is the potential for increased erosion efficiency at the Tien left bank. Erosion can in the medium term lead to exposure of support piles, which are currently not designed to be in the river channel.
(iii) There is increased risk of ship collision with pylons and/or foundations due to change in location of the clearance relative to the structure.

Rainfall intensity: Projections of future rainfall with climate change indicate that the seasonal volume of rainfall is increasing by as much as 50% with no statistically significant variation in the number of rain-days. While this cannot be quantitatively linked to changes in hourly rainfall intensity, it is a clear indication that rainfall intensities are likely to increase. Comparison of peak daily rainfall also confirms that intensities are increasing—whereas under average baseline conditions less than 10 days experienced rainfall totals greater than 100 mm per day, with climate change more than 20 days exceeded 100 mm per day. For the bridge substructure, high-intensity, short-duration rainfall events can increase water pressure, uplift, and scour at foundations.

Mean wind speed: Wind speeds and alignment determine the horizontal and static wind loads. With climate change cyclones are likely to become more intense and there is a possibility that cyclone events will track further south, tracking more frequently over the Mekong Delta, which could lead to increased vibrational forcing from wind loading. At present, evidence is not available to confirm conclusively whether or not this will occur.

Changes in pH, salinity, sulfates, chlorine: Increases in river and floodplain salinity and pH can lead to (i) accelerated concrete erosion of pylons and bridge foundations, (ii) accelerated corrosion of metal reinforcements, (iii) reduced life of substructure components, and (iv) increased maintenance effort. The issue was not explored directly in this study; however, reductions in dry season flow levels as well as decreasing and more erratic direct rainfall during the dry season point to a drier and hotter dry season in contrast to a wetter rainy season. Greater variability between seasons will enhance the production of acidic waters in the floodplains of Dong Thap and An Giang through the seasonal exposure of acid sulphate soils. This will not affect the large bridge structures or the small bridges (soils are predominately alluvial in that region), but should be assessed for other future components of the Central Mekong Delta Region Connectivity Project closer to the Plain of Reeds and Long Xuyen Quadrangle areas.

The pylons are sensitive to following changes in climate:

(i) The increased static and dynamic wind effects cause larger stresses to pylons.
(ii) The 80 m long large diameter piles are not very sensitive to changes caused by short-term loading. They also provide a good counterweight against uplift.
(iii) The increased scouring is a serious risk that should be considered in detailed design.
(iv) The changes in pH and salinity should be considered in detailed design by choosing adequate concrete covers, suitable concrete mix, and/or noncorrosive reinforcement.
(v) The movement range of the bearings can be adjusted as a maintenance operation. In case of overloading the bearings have to be replaced by stronger bearings.
(vi) The increase in static wind load increases the moments in pylons and it should be considered in final design. The changes in stay cable forces due to temperature change are almost symmetrical to the pylon so the resulting moment to the pylon will stay in the safety margins.

Free-Sliding Bearings

Bridge bearings are devices for transferring loads and movements from the deck to the supporting foundations of the substructure. They are designed to allow for controlled relative movement between the bridge substructure and superstructure accounting for thermal expansion and wind and traffic vibration. The bearings are critical components that are relatively difficult to replace and are typically designed with a design life greater than 50 years, with maintenance required every 20–25 years.

In the Central Mekong Delta Region Connectivity Project, the bearings are pot bearings or elastomeric bearings. Pot bearings are used with higher loads and/or to resist horizontal loads or movements. In addition, dampers can be used to improve the behavior of bridge decks under dynamic load effects.

Sensitivity

The bearings are sensitive to the following changes:

(i) The change in division of support reactions due to changes in stay cable forces can lead to overloading and damage of bearings.
(ii) Increase in extreme wind speeds increases horizontal forces for fixed bearings.
(iii) Changes in temperature range and mean temperature cause asymmetric movement, which leads to extended wear and reduces the service life of bearings.

Exposure and impact

Change in mean daily temperature: With climate change, mean daily temperature will increase by an average of 2.3°C. There will also be a significant shift in maximum daily temperatures. Average maximum daily temperatures did not exceed 35°C under baseline conditions, but with climate change 35°C will be exceeded 15%–45% of the year. Bearings are sensitive to increases in temperature because they are designed to help bridge structures dissipate any potentially harmful loading associated with movement of the superstructure. One of the key factors in this is the difference in response time between steel and concrete components. So changes in temperature need to be considered in the dimensioning of the free-slide bearings. Increases in the average and range of temperatures could lead to (i) asymmetric movement with reduced range for expansion but increased range for compression and (ii) expansion of friction coefficient. The likely impact of this will be reduced design life and increased future replacement costs. These impacts could also lead to damage or failure.

Navigation Clearance

Sensitivity

Design water levels for the river channel and floodplain are set to provide vertical navigational clearance of 37.5 m to ensure operation of 10,000 deadweight tonnage vessels for the P5% flood. This clearance has been determined in consultation with the Mekong River Commission to allow future passage of 10,000 deadweight tonnage vessels upriver to Phnom Penh port. Bridge approach roads will have embankments set for the P1% event and supported by driven piles.

In addition to the two main bridges spanning the Tien and Hau rivers, there are 26 smaller bridge crossings that are required to traverse the dense network of channels and canals covering the delta. Vertical clearance for the smaller bridge crossings is based on the following:

(i) *Navigable channels and rivers:* Navigation clearance for the P5% event. This clearance varies between 1.2m and 3.5m, except for the Lap Vo River Bridge where the navigation clearance is set at 7 m due to the significance of the river channel.
(ii) *Non-navigable canals*: For small non-navigable waterways the bridge clearance level is set as P1% + 0.5 m freeboard.

Exposure and impact

Rainfall intensity, rainfall volume, changes in frequency and intensity of flood events, and sea and river level rise: Increases in frequency and duration of rainfall, sea level rise, and increasing river flow will result in elevation of river water levels. The impact of climate change on navigation clearance will be reduced usability through loss of clearance. For the main bridge design, 2.6 m river water level is taken as the design criteria for ship clearance. Vertical clearance is then set at 37.5 m above this water level, allowing passage of 10,000 deadweight tonnage vessels. Climate change will increase periods of the year when the full navigation clearance of 37.5 m is not available.

With climate change, water levels at the site will increase, resulting in a peak water level of 3.33 masl for the P5% event. This is 0.73 m above the current design level. The P5% water level with climate change will exceed the design clearance for more than 2 months (63 days) between mid-August and late November. Because the clearance is large, the expected future water level rise will not cause major problems for small and medium-sized vessels, but will impact the largest vessels predicted to use the river channel between the coast and Phnom Penh.

For the smaller bridges, water levels associated with the future P5% will see the majority of these bridges experience water levels of up to 2.60 masl; under historic conditions, only the road section adjacent to the Tien right bank experienced these levels. Current design—based on 2.60 masl—should not be significantly affected by this.

Mean wind speed: With climate change, there is a possibility that cyclone events will track further south, tracking more frequently over the Mekong Delta, which could lead to increased vibrational forcing from wind loading. However, little information is available on baseline wind speeds under non-cyclone conditions so no projection has been made on how this threat will change. Increases in wind speed will increase the difficulty in navigating ship passage under stronger wind conditions, with the potential to result in collisions with pylons or foundations.

Bridge Superstructure

The superstructure of the bridges consists of the deck, stay cables, expansion joints, and deck drainage and waterproofing systems.

Bridge Deck

Preliminary design indicates that the Cao Lanh bridge will have a prestressed concrete slab, while Vam Cong will have a composite steel-concrete deck (Figure 27). In small and medium-sized bridges of span lengths up to 24 m, prestressed concrete slab elements are used in deck structure. For larger spans, prestressed Super-T girder elements are used. The approach bridges are built using precast concrete elements with elastomeric bearings and expansion joints at supports.

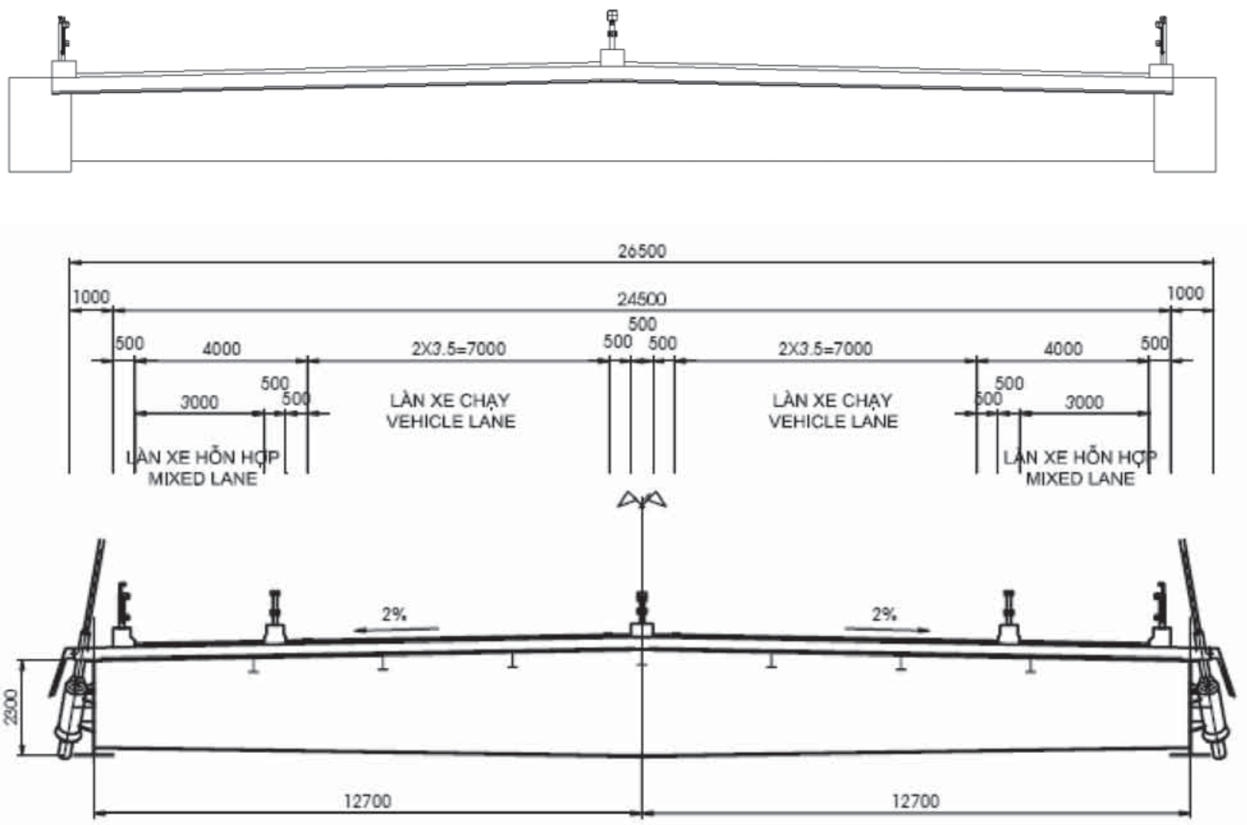
The design life of a bridge deck is typically 10–25 years for the road surfacing. The need for maintenance depends on structure. For steel deck, new painting is needed in 15 to 20 years. For concrete parts, the repair is needed after 30 to 50 years.

Sensitivity

The bridge deck has the following sensitivities:

(i) Changes in temperature variation and mean temperature can cause changes in stay cable forces and deck stresses, leading to reduced safety margins and design life. Increased deflection of the deck reduces clear navigation height and affects vertical road alignment.
(ii) Changes in wind and storm conditions can increase dynamic effects on stay cables and the deck.
(iii) The dynamic wind effects are verified using wind tunnel tests. They occur usually on low to moderate wind speeds so the environmental change should have negligible effect on them.

Figure 27: Bridge Deck Structures



Top: Cao Lanh Bridge prestressed concrete slab; Bottom: Vam Cong Bridge composite steel-concrete deck

(iv) Changes in deck form reduce the usability of the bridge and increases maintenance needed.

Exposure and impact

Change in mean daily temperature: Significant rises in mean temperature will induce different rates of elongation between stay cables and deck, causing changes in the cable loading and deflection of the bridge deck. In addition, ambient thermal conditions drive a temperature gradient within the deck structure. Temperatures at the surface can be significantly warmer than internal regions, causing internal stresses in the structure. Warming temperatures, in particular daily maximum temperatures, will increase the thermal forcing at the surface strengthening the gradient.

Impacts from variation in ambient temperatures include (i) damage due to deflection of the bridge deck, (ii) cracking of deck surface, and (iii) partial loss of navigation clearance.

Rainfall intensity: Increase in high-intensity, short-duration rainfall events will exacerbate short-term flooding and uncontrolled floodwater conveyance issues as well as lead to damage to deck and road surfaces and increased maintenance effort.

Extreme gusts, thunderstorms, and cyclones: With climate change, cyclones are likely to become more intense and there is a possibility that cyclone events will track further south, tracking more frequently over the Mekong Delta, which could lead to increased vibrational forcing from wind loading. At present, evidence is not available to confirm conclusively whether or not this will occur. Increase in frequency and magnitude of major gusts and storm events resulting in sustained loading at high wind speeds can cause vibration, oscillation, and vortex effects. In addition, wind- and rain-induced vibration of stay cables can combine with these other factors to induce dynamic effects such as galloping. The potential impacts include resonance-induced structural damage and fatigue of key supports in superstructure.

Stay Cables

Stay cables are made using either the prefabricated parallel wire cable or parallel strand cable system. Individual strands are encased in a corrosion inhibitor, galvanized, and then given a high-density polyethylene (HDPE) coating to form cables (Figure 28). There are approximately 30–100 strands (D = 15.7 mm) in each cable, requiring the stays to be assembled in two planes.

Although the design life of stay cables is 100 years, it is likely that a need for renewal may arise earlier, in 25–50 years. The structural system is usually designed to enable the replacement of stay cables one at a time.

Sensitivity

Key sensitivities of stay cables to environmental loadings include the following:

(i) Changes in temperature variation and mean temperature can cause changes in stay cable forces and deck stresses, leading to reduced safety margins and design life.
(ii) Increased deflection of the deck reduces clear navigation height and affects vertical road alignment.
(iii) Changes in wind and storm conditions can increase dynamic effects on stay cables and the deck.
(iv) Changes in stay cable forces will be within the limits of safety margins but the design life of cables may be reduced.

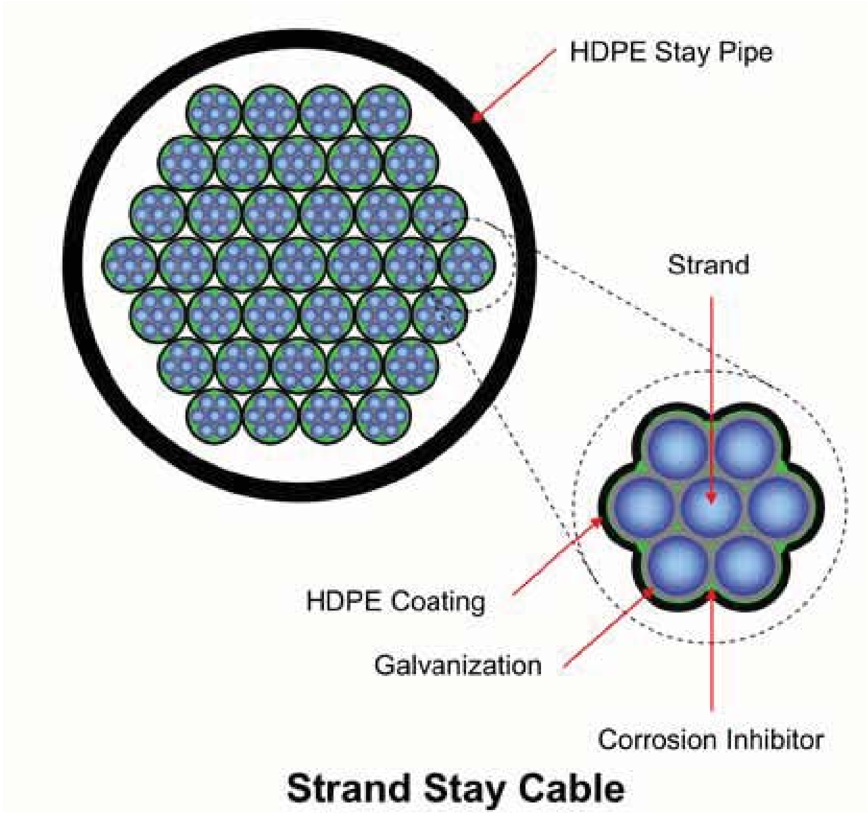
Exposure and impact

Extreme gusts, thunderstorms, and cyclones: Increase in frequency and magnitude of major gusts and storm events resulting in sustained loading at high wind speeds can cause vibration, oscillation, vortex effects, and galloping. Potential implications include resonance-induced structural damage and fatigue of key supports in superstructure.

Change in mean daily temperature: Significant rises in mean temperature will induce different rates of elongation between stay cables and deck, causing changes in the cable loading and deflection of the bridge deck. Potential impacts include (i) damage due to deflection of the bridge deck, (ii) cracking of deck surface, and (iii) partial loss of navigation clearance.

Rainfall intensity: Increases in high-intensity, short-duration rainfall events will exacerbate vibration

Figure 28: Components of Stay Cable



HDPE = high-density polyethylene.

of stay cable, resulting in increased fatigue to stay cables and reduced design life.

Deck Drainage

The bridge deck drainage system includes the bridge deck itself, bridge gutters, inlets, pipes, downspouts, and bridge end collectors. Bridge deck waterproofing is made using membranes, mastic, or liquid materials like polyurethane. The system is designed for major maintenance every 20+ years with regular monitoring and maintenance to ensure proper operations.

Sensitivity

The key sensitivity of the deck drainage system is to direct precipitation. An increase in rain intensity can exceed the capacity of the drainage system and result in flooding.

Exposure and impact

Rainfall intensity: High-intensity, short-duration rainfall events can exacerbate short-term flooding structures. The resulting impacts include (i) increased accidents on the road, (ii) increased downtime and reduced road usability, and (iii) increased maintenance effort.

Expansion Joints

Expansion joints are built into the end of side spans to accommodate expansion and contraction of bridge infrastructure in response to daily and seasonal temperature fluctuations. In small and medium-sized bridges and approach bridges of main bridges, sheet or strip seals or poured seals can be used. A modular bridge joint system is used in main bridge joints. All expansion joints should be watertight or waterproofed to avoid deterioration and to ensure they reach their design life of 20–25 years. Maintenance is also required every 10 years.

Sensitivity

Expansion joints are sensitive to changes in temperature variation and mean temperature, which cause asymmetric movement which leads to extended wear and reduces the service life of expansion joints.

Exposure and impact

Change in mean daily temperature: A shift in mean temperature could (i) accelerate aging through hardening and UV/solar deterioration; and (ii) cause asymmetric movement with reduced range for expansion but increased range for compression, increasing potential for damage, failure, or reduced design life and increased replacement cost.

Rainfall intensity and volumes: Changes in rainfall can lead to a number of impacts: (i) damage to expansion joint and knock-on weathering of bearing through increased exposure to rain and sand, (ii) structural damage to bridge and approach road, and (iii) reduced design life of components.

Connecting and Approach Roads

Aside from the bridge structures, the Central Mekong Delta Region Connectivity Project includes a number of key pieces of road infrastructure, primarily (i) approach road for Cao Lanh bridge with a total length of 5.7 km, (ii) approach road for Vam Cong bridge with a total length of 2.9 km, and (iii) connecting roads between the two major bridges with a total length of 15.7 km.

Road Embankments and Road Foundations

Roads are designed to accommodate six lanes of traffic in the future with a total cross-sectional width of 30.6 m and a design speed of 80 km/hr. Embankment side slopes are1V:2H. Discussion with the detailed design team indicated that road elevations can reach up to 4.75m for some areas. Design life for the road embankments is 20–30 years, while the road foundations have a longer design life of 50 years.

Sensitivity

The critical sensitivity of road embankments is the minimum design elevation of the road profile, which is established on

(i) P1% flood event,
(ii) 0.5 m freeboard to accommodate overflow and wave action from upstream floodplain, and
(iii) 0.3 m freeboard nominally set to account for sea level rise.

In addition, there is a 0.3 m crossfall from the road center line to the outer shoulder of the embankment. Changes in sea level rise and upstream rainfall and hydrology will lead to variation in water levels in the delta floodplain at the design 1-in-100 year event.

Exposure and impact

The design water level for CMDRC Project embankments corresponds to water surface levels of 2.74 masl in the floodplain areas and 2.7 masl at the Cao Lanh site.

Floodplains: With climate change water levels at the site will increase, resulting in a peak water level of 3.47 masl. This is 0.61 m above the current design embankment height. Under this event, water levels in the floodplain vary along the road alignment, dropping to 3.1masl near the Hau River right bank and increasing to 3.6 masl in the center of the floodplain near the Lap Vo crossing (north of route NR80). The inclusion of wind effects and wave propagation will see water levels rise a further 0.1 m.

With climate change, there will be substantial periods of the year during the P1% when water levels will exceed design expectations:

(i) late August to late November: 90-day period where water levels with climate change will exceed the historic P1% water levels (2.74 masl); and
(ii) late August to mid-November: 35 days during which water levels exceed the design embankment elevation of 2.86 masl.

Cao Lanh site: With climate change, water levels at the site will increase, resulting in a peak water level of 3.44 masl. This is 0.58 m above the current design embankment height.

With climate change, there will be substantial periods of the year during the P1% when water levels will exceed design expectations.

Under future P1% conditions in the Tien River channel with climate change, water levels will exceed the embankment height for 30 days spread out between late August and mid-November:

(i) mid-August to late November: 3.5-month period where water levels with climate change will exceed the historic P1% water levels (2.70 masl); and
(ii) late August to mid-November: 33 days during which water levels exceed the design embankment elevation of 2.86 masl.

The impact of climate change on road embankments is significant. Apart from compliance issues in relation to design standards, there are a number of key technical impacts: (i) erosion of road embankments, (ii) increased maintenance effort, (iii) scour of road foundations, (iv) pore-pressure-induced collapse and road subsidence, (v) waterlogging of road foundations, and (vi) reduced macrostability of infrastructure.

Drainage System and Road Culverts

Road structures will include two main design solutions for drainage:

(i) *Surface drainage:* Concrete curbs will be provided for embankments with elevations greater than 4 m. Discharge points will be every 25 m with rock riprap at the outlet to protect embankments.
(ii) *Flood conveyance:* 28 culverts are designed along the alignment of the connecting road ranging in size from 2 m x 2 m box culverts to 3 m x 3 m multicell culverts. The number and sizing of culverts has been set to provide sufficient openings for conveyance of the P1% event.

Typically drainage system components will have a design life of 20–25years.

Sensitivity

The approach and connecting roads of the Central Mekong Delta Region Connectivity Project bisect the freshwater floodplain of the Mekong Delta. Road embankments are therefore subjected to major forces from floodplain flow.

The drainage system plays an important role in maintaining the functioning and integrity of the road system by reducing buildup of floodwater on the upstream side, preventing overtopping of the road surface and minimizing downstream erosion through the control of outlet flow rates. The drainage systems described above are therefore sensitive to increases in floodwater levels.

In addition, surface drainage systems for the road itself are also sensitive to changes in rainfall intensities, which can affect the use of the road.

Exposure and impact

Rainfall intensity: Increase in high-intensity, short-duration rainfall events can exacerbate short-term flooding and reduce efficiency of drainage structures. Design rainfall intensity is 140 mm/hr. The implications would be (i) a greater risk of accidents to drivers using the road, (ii) increased downtime and reduced road usability, (iii) increased erosion, and (iv) increased maintenance effort.

Flood levels and volumes: Increase in wet season flooding due to increases in overbank flows and increased seasonal rainfall will put greater pressure on flood conveyance infrastructure. Current design is set to allow conveyance of the historic P1% event. With climate change, the P1% event will increase in magnitude, with peak water levels in the floodplain rising from 2.74 masl to 3.10–3.60 masl. The impact of reduced drainage efficiency includes (i) damage to road structures through wind and wave action against the upstream face, (ii) associated increased maintenance costs, (iii) reduced design life, and (iv) potential for downstream scour/damage to dyke and irrigation structures.

River Embankments and Riverbanks

In order to protect the approach road structure, embankments are designed within the immediate vicinity of the crossing. Driven piles are used to support the bridge approach embankment. The feasibility study due diligence report prepared by SMEC suggests three options for consideration during detailed design (SMEC 2011). Typically river embankments have a design life in the order of 10–25 years.

Sensitivity

The critical sensitivity of river embankments is to scour and erosion processes. If surface protection is poor then erosion can lead to bank collapse, exposure of the support piles, and eventually destabilization of the approach road itself. If surface protection has been considered (e.g., geotextile reinforced rock mattresses or riprap), scour impacts will concentrate at the footing of the embankment and weak points such as the grout between concrete slabs. Over time, the embankment material behind the casing will be slowly mobilized and eroded until the surface casing cracks, thereby exposing the supporting piles. The threat assessment indicates that the bridge site is located in a geomorphologically stable section of the Tien River, which has undergone minimal lateral migration since 1966. The site is immediately downstream of a channel constriction and future projections without climate change suggest limited erosion in the future.

Exposure and impact

Wind-induced wave energy: Increased wave action caused by (i) wider flood extent and river cross-sections contributing to increased wind fetch and larger waves, (ii) deeper water with less wave energy dissipation, and (iii) longer exposure due to prolonged flooding. Assessment of the influence of wind on wave energy was undertaken for the Tien River channel and was found to be small compared with flow-related effect.

Changes in frequency and intensity of flood events, and changes in sediment load and composition: Increased potential for erosion of riverbanks and embankments and instability of channel may result from a number of different factors, including the following:

(i) *Increases in river and flood return period:* With climate change, projected return periods for given events will decrease. This will affect typical flood flows like the 1-in-2 year event (often used to define the threshold of geomorphic effective flows) as well as extreme flows such as the historic 1-in-100 year event, which will become a 1-in-20 or 1-in-30 year event with climate change.

(ii) *Increases in flood flow velocities:* For river embankment stability, flow velocities can be used to give an indication of the erosion potential for channel flow. With climate change, in-channel midstream flow velocities in the Tien River will increase by +0.5 meters/second (m/s), with surface velocities reaching close to 5 m/s during the P1% flood, and near bed velocities reaching 0.9 m/s. Bed velocities are greatest near the left bank of the Tien. Increases in velocity will increase the stream power and hence energy available for geomorphological work. Velocities in the Hau River are much greater than the Tien, with near bed velocities reaching near 1.0 m/s across the channel cross-section.

(iii) *Greater seasonal variability in river water levels exacerbating erosion of sand lens in the riverbank:* Assessment of the hydrograph for Kratie under typical conditions demonstrates both an increase in wet season flows and a reduction in dry season flows. This will compound existing problems of bank instability where banks have been degraded or poorly protected.

(iv) *Reduced sediment load inputs combined with increased sediment transport capacity, and reduction in sediment grain size composition with resulting increase in channel material mobility*: The study did not look at changes to sediment dynamics directly. However, previous studies indicate that upstream hydropower development will have a dominating influence on sediment dynamics with 50%–75% of the current Mekong sediment load being trapped by the reservoirs proposed in Yunnan Province of the People's Republic of China; the Lower Mekong mainstream; and the tributary projects of Cambodia, the Lao PDR, and Viet Nam.

The implications of these changes are (i) increased riverbank erosion and scour at the foot of river embankments, (ii) collapse of riverbanks, and (iii) exposure of pylons.

Climate Proofing Measures: From Technical Assessment to Adoption

The Central Mekong Delta Region Connectivity Project was proposed and preparatory work begun at the time Viet Nam was formulating its current policies to respond to climate change threats. Its National Strategy on Climate Change, approved in 2011, calls for proactively coping with natural disasters and monitoring climate.[8] To realize the key priorities in the National Climate Change Strategy (and National Target Program to Respond to Climate Change), the Ministry of Transport adopted its own Action Plan to Respond to Climate Change, in which it stated its objective to "integrate/mainstream climate change considerations in transportation infrastructure development strategies, planning, plans, programs and projects, and refine and finalize the sector's system of technical standards and norms."[9]

To coordinate and facilitate key project decisions, the Project Coordination Committee (PCC) was set up in 2012 led by the Ministry of Transport. The first PCC meeting, held on 10 January 2012, highlighted that climate change considerations discussed in the ministry-approved basic designs in 2011 under the project's feasibility study would not be sufficient and additional adaptation measures may be required depending on the outcome of the ADB-funded vulnerability assessment, and that such measures would have to be incorporated into the detailed technical designs of the project. The methodology and vulnerability assessment results, as discussed in previous sections, were then presented at the subsequent PCC meetings, where questions were raised about the reliability of the assessment model and whether there were significant costs associated with the proposed adaptation measures.

Climate Change Assessments

The following climate change assessments were considered:

- The government's own assessment and recommendations based on the Ministry of Natural Resources and Environment (MONRE) *Climate Change, Sea Level Rise Scenarios for Viet Nam* (2009) and year 2000 flood levels suggested different design water levels under the P1% event contributed by sea level rise in the Mekong Delta.[10] Table 9 gives the sea level rise for the three emissions scenarios. It shows that (i) sea levels would rise gradually over the coming

[8] Decision 2139/QĐ-TTg dated 5 December 2011.
[9] Decision 199/QD-GTVT dated 29 January 2011.
[10] http://www.preventionweb.net/files/11348_ClimateChangeSeaLevelScenariosforVi.pdf

decades and (ii) the MONRE 2012 updated sea level rise values are similar to the 2009 report with the exception that the time line for sea level rise is delayed by few years—possibly half a decade. The medium emission scenario was recommended by MONRE for use as an initial basis in climate change and sea level rise impact assessments and in the development of action plans to respond to climate change. Sea level rise by the mid-21st century for the medium emission scenario would be about 30 cm, and by the end of the 21st century or soon afterward it would be about 75 cm compared with the period of 1980–1999.
- The due diligence report of the project feasibility study (SMEC 2011) looked at water levels for different flood frequencies with and without a sea level rise of 0.30 m (due to climate change).[11] However, it reported that Cao Lanh and Long Xuyen monitoring stations show the year 2000 flood level to be exceeded by 1-in-100 year flood levels, and therefore, the P1% flood level has been used to calculate the minimum elevation of road profiles without a climate change allowance. The bridge levels proposed in the feasibility study also do not consider a climate change allowance.
- This vulnerability assessment identified sea level rise and increase in catchment rainfall as climate-change-induced drivers of water level change of the Mekong River and its floodplain. Upstream hydrology is impacted by climate-change-induced increase in catchment rainfall, which contributes to a net increase in river discharge and overbank flow. The analysis suggested that a 0.3 m increase will be insufficient to negate the incremental risk of climate change on peak water levels and a minimum of 0.60 masl to 3.46 masl is required to ensure the project is prepared for climate change over its design life with no additional risk.

Differences in assessment results between Ministry of Transport estimates, the feasibility study, and the vulnerability assessment has provided a wealth of information and generated discussions between the ministry and project financiers as to whether all of these assessments had been sufficiently detailed and robust enough use as a foundation for critical and potentially costly decisions about climate change adaptation investments.

Climate Change Risks to Project Infrastructure

The Ministry of Transport and the project financiers agreed that there will be risks to the road as well as the bridges associated with water level rise due to climate change:

Road Embankments

- Some sections of the road embankment will be above the flood level as a result of the road profile required to provide adequate navigation and cross-road clearance at bridges. However, long stretches between bridges, which are lower, would be at risk due to higher water levels associated with climate change effects.
- Potential flooding of the road would result in major damage to the pavement and sublayers due to flow of water across the road surface and saturated conditions over extended periods.
- Making insufficient or no allowance for climate change effects increases these risks.

Bridges with Cross-Road or Navigation Clearance Requirements

- The critical factor for determining the elevations of the majority of the bridges is either the cross-road clearance (for the roads adjacent to the

[11] Project preparatory technical assistance, *Mekong Delta Connectivity Project Final Due Diligence Report* (2011).

Table 9: Different Sea Level Rise Projections (centimeters)

Ministry of Natural Resources and Environment Report, 2009									
	2020	2030	2040	2050	2060	2070	2080	2090	2100
Low emission scenario (B1)	11	17	23	28	35	42	50	57	65
Medium emission scenario (B2)	12	17	23	30	37	46	54	64	75
High emission scenario (A1F1)	12	17	24	33	44	57	71	86	100
Ministry of Natural Resources and Environment Report, 2012									
	2020	2030	2040	2050	2060	2070	2080	2090	2100
Low emission scenario (B1)	8–9	11–13	17–19	22–26	28–34	34–42	40–50	46–59	51–66
Medium emission scenario (B2)	8–9	12–14	17–20	23–27	30–35	37–44	44–54	51–64	59–75
High emission scenario (A1F1)	8–9	13–14	19–21	26–30	35–41	45–53	56–68	68–83	79–99

waterway) or navigation clearance, and not the hydraulic capacity. Further, the elevation at the abutment is determined by the project road profile requirements.

- As these considerations result in clearances that are much higher than the freeboard requirements and potential climate change water level rise, an additional allowance for climate change is not necessary.
- In the case of bridges where the controlling level is based on navigation clearance (three minor bridges), the full navigation clearance may not be available on some days during the flood season.

Bridges without Cross-Road or Navigation Clearance Requirements

- Where the bridge level is fixed on the basis of hydraulic capacity, those bridges (six minor bridges) would be at risk of damage from large floating matter due to insufficient freeboard, a reduced hydraulic capacity, and damage to bearings due to submergence.

Recommended Approach

While risks were clear, the consensus on the magnitude and scope of adaptation was only reached through continued dialogue and weighing response options and costs. Given the location, nature, scale, and investment needed, parties have agreed to the following phased adaptation approach:

Road Embankments

- A phased approach to climate change adaptation is adopted. During the first phase, a nominal increase of 0.30 m in finished road level for low-lying stretches of the road is adequate for the medium term to accommodate climate change.
- In the long term, say beyond a 30-year horizon, a second phase of adaptation should be considered as appropriate as part of further maintenance and road upgrades and expansion.

Cao Lanh and Vam Cong Bridge Navigation Clearances

- Two cable-stayed bridges will not require additional clearance underneath the bridge decks as navigation clearance, though impinged by larger magnitude P5% events, should be sufficient for most vessel passage.

Other Bridges with Navigation or Underpass Clearance

- There are 26 bridges other than the two main bridges; 19 of these waterways have navigation requirements.
- The levels of 17 of these bridges are based on underpass clearances (to cater to roads that cross the project road), which result in higher bridge levels.
- It is therefore not necessary to provide an additional climate change clearance for those bridges with navigation and/or underpass clearance requirements.

Bridges without Navigation or Underpass Clearance

- A nominal increase of 0.3 m climate change clearance for the six minor bridges without navigation or underpass clearance provides an acceptable level of risk mitigation, and is adequate.
- The level of these bridges is based on a 0.5 m freeboard to the underside of the bridge deck. This provides additional safety in terms of hydraulic capacity.
- A P1% flood event occurring toward the latter part of the bridge design life of 100 years may have the potential to affect the bridge bearings due to submergence. However, (i) bridge bearings need periodic replacement and this can be addressed as part of the component maintenance and replacement schedule and (ii) this is not a significant factor.

Culverts

- Increase in the P1% flood in the long term due to climate change effects is unlikely to have a significant impact on the culvert opening sizes. The numerous bridge crossings provide additional drainage capacity, which will likely compensate for such an event.

Scour and Bank Erosion

- Scour and bank erosion will be monitored during project implementation and operation to gain better understanding of overland flood flow dynamics, and adaptation measures will be designed flexibly.

The incremental cost due to (i) additional embankment volume, (ii) additional area of ground treatment due to increased width of embankment, (iii) additional length of culverts due to increased width of embankment, and (iv) additional height of abutments and piers of six bridges was estimated at $4.5 million (0.5% of project cost). Despite the nature and scale of the project, the project length is relatively short (some 35 km) and all incremental cost comes from increasing embankment height and height of the bridge piers and abutments, which will be constructed of relatively cheaper components and materials (i.e., granular materials and extra length of reinforced concrete for substructure and culverts).

Conclusions and Recommendations

The bridge and road structures of the Central Mekong Delta Region Connectivity Project are located in the floodplain of one of Southeast Asia's largest rivers—the Mekong River—and under the dual influence of fluvial and coastal processes. Soil structures are weak, riverbanks are mobile, and flooding is an annual phenomena. In addition, the Mekong Basin and Viet Nam have been identified among the most vulnerable areas in the world to climate change. Sea level rise, increases in catchment precipitation, and stronger cyclones, coupled with the shifts and interaction of two monsoon regimes, are changing the hydroclimatic conditions that have been used to design the bridge and road infrastructure.

The implications of climate change for the Central Mekong Delta Region Connectivity Project infrastructure are complex. However, the nature and trends in climate change threats are clear. The assessment process has used a multi-model ensemble of six GCMs, two IPCC scenarios, statistical downscaling techniques, and a suite of modeling tools developed for the Mekong over the past 15 years to build an evidence base of climate change vulnerability. Results between GCMs and scenarios vary and study findings have been developed to reflect these ranges and select conservative estimates of future change.

While differences emerged as to the projected impacts of climate change, consensus on the magnitude and scope of adaptation was reached through continued dialogue and weighing response options and costs. A key to the decision was that given the location, nature, scale, and investment needed, parties have agreed to a phased approach.

In addition to making specific technical recommendations, the study team also provided the following recommendations:

- An additional study is required to improve understanding of extreme events. A key limitation of this study is the correlation between peak discharges at Kratie and water levels at the project site. In this study, extreme event frequency analysis has been calculated based on the conventional approach of instantaneous peak discharge at Kratie station. Analysis has shown that the water levels at Cao Lanh show better correlation with the flow volume in the peak flow month than with the instantaneous peak discharge; however, even this correlation with 1-month flood volumes can be improved. The purpose of this additional work is to better understand the response of water levels to changing flows.

- An additional study is required to improve understanding of overland flood flow dynamics. Rapid expansion of agricultural and transport infrastructure in the delta is suspected to have changed the floodplain dynamics of the delta system. Current models do not have up-to-date representations of delta infrastructure, which is affecting their ability to accurately simulate the flow dynamics. The purpose of this additional work is also to better understand the response of water levels to changing flows.
- The climate change assessment of the Central Mekong Delta Region Connectivity Project should be expanded and integrated into the provincial context. During the inception mission the provincial government authorities requested that the technical assistance team support provincial road development by undertaking a climate change vulnerability assessment of the provincial transport master plans. Given the stated purpose of the project is to improve connectivity for local people to both banks of the Hau and Tien rivers, it is a concern that although the project has been safeguarded against climate-change-induced increases in flooding, the provincial feeder and access roads have not.

The study (i) provided a deeper understanding of climate change threats generally in the Mekong basin as well as how the infrastructure will be affected by extreme climate change events, (ii) offered a better appreciation of the need to incorporate climate change risk assessments and generate a body of knowledge over time, and (iii) served as a consensus-building tool for project financiers and the government of Viet Nam to adapt a better strategy for climate change response.

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Central Mekong Delta Region Connectivity Project
Rapid Climate Change Threat and Vulnerability Assessment

The Central Mekong Delta Region Connectivity Project aims to enhance connectivity across provinces of southern Viet Nam and Ho Chi Minh City. It includes two major bridges, a 15-kilometer road connecting the two bridges, and approach roads. Given the high exposure of the Mekong Delta to severe flooding, a climate risk and vulnerability assessment was conducted to assess the vulnerability of the project to climate change. The assessment report provides a better understanding of climate change threats to the project infrastructure. It also provides project stakeholders with information necessary for consensus building for the adoption of a robust approach to responding to climate change. The study illustrates that a constrained time frame and limited resources may not be significant impediments to the undertaking of climate risk vulnerability assessments, which can provide valuable information at the project design stage to increase the climate resilience of large investment projects.

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