FINAL REPORT:

Climate risk analysis and assessment report for Cai Lon - Cai Be sluice gate project based on the PIEVC protocol

Enhancing Climate Services for Infrastructure Investment (CSI)

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EXECUTIVE SUMMARY

Background

This report presents the results of the climate risk assessment conducted for the Cai Lon – Cai Be Sluice Gate project in the Mekong Delta, Vietnam, between August 2018 and May 2019. The assessment was conducted using the Public Infrastructure Engineering Vulnerability Committee (PIEVC) engineering protocol for infrastructure vulnerability assessments (the "Protocol"). The PIEVC is a step-by-step methodology developed by Engineers Canada for climate vulnerability assessments for infrastructure (www.pievc.ca). The observations, conclusions and recommendations derived from the application of the Protocol provide a framework to support effective decision-making about infrastructure design, operation, maintenance, planning and development as part of climate risk management. The study has considered the potential impacts of existing and future climate conditions and hydrological factors and their potential influences on project engineering and operations.

The assessment was conducted in the context of the global project "Enhancing Climate Services for Infrastructure Investment (CSI)". CSI is implemented by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH on behalf of the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) in the context of the International Climate Initiative (IKI, www.international-climate-initiative.com/en/). CSI supports its partners in making their infrastructure more resilient towards climate change via climate-risk-informed infrastructure planning and management using climate services. More on CSI can be found on the IKI webpage.

The Cai Lon – Cai Be Sluice Gate Project

The Cai Lon - Cai Be Sluice Gate project (the "Project"; presently in its first phase – the basic design stage) is situated in Vietnam's Mekong Delta (MKD), where significant climate change impacts are anticipated. Due to the areas vulnerability and its importance for water allocation and regulation for the Ca Mau Peninsula in the future, it was determined that the project should be carefully studied before construction.

The Cai Lon - Cai Be Sluice Gate project has multiple infrastructure features including land transportation (roads and bridge), water navigation (sluices and ship locks), water resources (sluice gates), recreation (parks), buildings, power and so on. The Project is considered to be representative of other infrastructures in the MKD generally and in the project area particularly. To limit the scope of the climate risk assessment, this being the first implemented by the Vietnamese assessment team, the focus of the assessment was limited to the Cai Lon and Cai Be sluice gates.

The Assessment Team

The assessment team consisted of a multidisciplinary group of experts from engineering, climate science and water resources planning. The Vietnamese team consisted of representatives of the Ministry of Agriculture and Rural Development (MARD) and the associated Water Resources Investment and Construction Board 10 (PMU-10) and the Southern Institute for Water Resources Planning (SIWRP) as well as of the Southern Regional Hydrometeorological Center (SRHMC). A team of Canadian Experts of Engineers Canada, Wood PLC and Risk Sciences International (RSI) guided the team from Vietnam in the assessment.

The Risk Assessment Methodology

The PIEVC engineering protocol for infrastructure vulnerability assessment and adaptation to a changing climate is a five (5) step process to assess the responses of infrastructure components to the impacts of a changing climate. In this study, the climate risk assessment for the Cai Lon - Cai Be Sluice Gate project applied Steps of 1, 2, 3 and 5 of the Protocol. Step 4, focusing on engineering analysis, was not within the scope of the assessment.

Risk or vulnerability, in the context of the PIEVC Protocol is based on an understanding of probability of occurrence and severity of impacts associated with individual climatic factors. For this, the interactions between climate events and the infrastructure are evaluated component-by-component in order to identify the most vulnerable components. For this, the risk score (ranging from 0 to 49) is calculated as product of the severity score (ranging from 0, negligible to 7, extreme/ loss of asset) and the probability score (ranging from 0, negligible to 7, highly probable). This helps in prioritising risk management measures based on risk categorisation into high risks ($R > 36$), which require immediate action; medium risks ($12 \le R \le 36$), which may require action or engineering analysis; and low risks ($R < 12$) needing no immediate action.

To evaluate risk even under circumstances of limited data availability, the PIEVC follows a bottom-up, participatory approach. The assessment involves a series of workshops with all relevant stakeholders involved in planning, managing and using the infrastructure as well as climatologists. This presents several advantages. Besides providing access to relevant knowledge to supplement the often-scarce information available on climate-impacts on infrastructure, it helps to create awareness and capacity in the involved stakeholders and ensures agreement and transparency on the process and decisions made throughout.

The Risk Assessment Results

As part of the assessment, the following climate and hydrological parameters have been identified as most relevant for the Cai Lon – Cai Be Sluice Gate system

- **Climatological factors:**
  - » high temperature,
  - » heat wave,
  - » heavy rain,
  - » 5-day total rainfall,
  - » tropical storms/depression,
  - » drought,
  - » high wind,
  - » tornado, and
  - » thunderstorms/lightning.
- Hydrological factors:
  - » water level, consisting of tides, storm surges, sea level rise and land subsidence
  - » salinity intrusion
- In addition, two **cumulative effects** were studied:
  - » salinity intrusion combined with high temperature and
  - » high water level combined with heavy rain.

Due to the limited data on hydro-geology, land subsidence, faults and earthquakes, the geological factors were not assessed individually, but were only considered in relation to other factors (such as climate, hydrology). Generally, the assessment focused on the impacts of climate-change related risks.

The risk assessment matrices obtained (see APPENDIX 9) show that there are no high-risk interactions for both existing and future conditions. The majority of interactions have a medium risk for future projections (76), while the number of low-risk interactions was 30. Compared to existing conditions, with 42 medium-risk interactions and 64 low-risk interactions, the analysis yielded that risks to the infrastructure are expected to increase under the influence of climate change.

The major infrastructure components including the staff, park, gates, water tight gasket, and the systems of electric power, monitoring, control and operation, and communication were mainly affected by tropical storms/depression, thunderstorms/lightning, high wind, water level, and salinity intrusion combined with high temperature. Particularly, salinity intrusion and salinity intrusion associated with high temperature affected the components made of metal and concrete at medium level (from 2 to 4) but had high probability scores (equal to 7).

Recommendations and Adaptation Options

Based on the completed risk assessment matrices, recommendations for managing risks were developed for the medium risks as well as for low risks where either severity or probability are high. The major recommendations for the stages of the detailed design, construction drawing design, and operation and maintenance of Cai Lon - Cai Be Sluice Gate are summarised in the table below.

Table: Summary of Main Recommendations

Components	Most relevant Climate Factors	Recommendations
Concrete components: Pillars Ship Locks	High temperature Heat waves Water level Salinity	Use of sulphate resistant cement, anti-corrosion additive mixture, or high concrete grade (M50) and coating method by Epoxy for these components.
Hydraulic Cylinders Gates	Salinity intrusion combined with high temperature	Study of mechanisms and causes of metal corrosion in the Mekong Delta to have the suitable prevention measure such as using a stainless steel together with coating method by Epoxy;
Electric System	Thunderstorms/Lightning, Tornado, Storm and Heavy Rainfall	Consideration of underground wiring designs for both of Cai Lon and Cai Be sluice gates and incorporation of lightning protection systems in the design for the whole infrastructure.
Operational Staff	High temperature Heat wave Tropical storm/depression Thunderstorm/lightning	Support through additional training courses on coping with tropical storms and tornados; self-protection skills from high temperature, heavy rain, high wind in case of working outdoors; using the automatic operation mode or choose the proper time for maintenance
Control and Automatic Monitoring System	Tropical storm/depression Tornado Thunderstorm/ lightning	Select sensors with high tolerance to climatic factors. **Project/Facility Management:** The monitoring system needs regular maintenance to ensure its continuous functionality.
General: Climate Services		It is necessary to develop a climate service program(s) to enhance data collection (e.g. tornados, sediment), sharing and to raise awareness about the need for climate services. This will make it easier to monitor and assess climate risks as a basis for effective climate risk management, not only for the Cai Lon – Cai Be project but also other infrastructures in the region.

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ACRONYMS AND ABBREVIATIONS

BMU	German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
CCHIP	Climate Change Hazards Information Portal
CS	Climate Services
CSI	Enhancing Climate Services for Infrastructure Investment
DARD	Department of Agriculture and Rural Development
GDP	Gross Domestic Product
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
HEC-2	Hydraulic and Construction Consultancy Join-stock Company No. 2
ICMP	Integrated Coastal Management Programme
IKI	International Climate Initiative
INDCs	Intended Nationally Determined Contributions
JMA	Japan Meteorological Agency
MARD	Ministry of Agricultural and Rural Development
MKD	The Mekong Delta
MONRE	Ministry of Natural Resources and Environment
PIEVC	Public Infrastructure Engineering Vulnerability Committee
PMU-10	Water Resources Investment and Construction Board 10
RSI	Risk Sciences International
SDG	Sustainable Development Goal
SIWRP	Southern Institute for Water Resources Planning
SRHMC	Southern Regional Hydrometeorological Center
The Protocol	PIEVC Engineering Protocol for infrastructure vulnerability assessment and adaptation to a changing climate
TOR	Terms of Reference
UN	United Nations
VAWR	Vietnam Academy for Water Resources
VDMA	Vietnam Disaster Management Authority

1. INTRODUCTION

1.1. Background

Developing and emerging countries invest billions of dollars into long-lived infrastructure. However, future climate conditions are seldom considered systematically in the planning of such infrastructure. This may lead to bad investment decisions and consequently these infrastructures have high risks for economic damage in the context of climate change. This is why the United Nations (UN) set Sustainable Development Goal (SDG) 9 [1] to "build resilient infrastructure, promote sustainable industrialization and foster innovation". Many countries, including Vietnam, have committed to achieving this goal and have identified this in the Intended Nationally Determined Contributions (INDCs). To address this objective, it is necessary to adapt existing planning procedures and requirements and to recognize the importance of Climate Services (CS) in the adaptation process.

However, many new infrastructure projects are implemented without knowledge of the vulnerability of the planned infrastructure. One reason for this is that information on the expected impacts of climate change is often unavailable, hard to access and tools are missing to translate the available data into information that is actionable for climate-risk-management decisions. What is missing are climate services, i.e. climate information tailor-made for the needs of decision-makers. In some cases, there is also a lack of awareness of decision makers about the need to change planning and management approaches. A solution is to involve all relevant stakeholders (suppliers of Climate Services, decision makers and engineers) throughout the planning process in order to identify the needs associated with Climate Services and the resultant offerings (i.e. understanding demand and supply). This ensures that users will receive the necessary Climate Services for climate-risk-informed infrastructure planning, while suppliers can develop user-friendly Climate Service products based on the users' needs.

The global project "Enhancing Climate Services for Infrastructure Investment (CSI)" supports its partners in enhancing Climate Services and creating enabling conditions for their use in infrastructure planning and management. Climate risk assessments that are conducted as part of CSI, in Vietnam for the Cai Lon – Cai Be sluice gate system, do not only help to develop capacities in the application of tools and processes for climate-proofing infrastructure. They also serve as test cases for the co-creation of Climate Services. The pilot assessment of the Cai Lon – Cai Be Sluice Gate project will, besides building capacities, inform the development of strategies and manuals on climate proofing for infrastructure investment.

The climate risk assessments conducted in the context of the CSI project use the PIEVC Engineering Protocol (the "Protocol") developed by Engineers Canada, a cooperation partner of CSI. The Protocol describes a step-by-step methodology of risk assessment for evaluating the impact of changing climate on infrastructure. The observations, conclusions and recommendations derived from the application of the Protocol provide a framework to support effective decision-making about infrastructure operation, maintenance, planning and development as part of climate risk management. Since 2008, the Protocol has been applied to assess climate risks and vulnerabilities across a wide range of infrastructure systems in Canada and internationally [2].

In Vietnam, the CSI project focuses on the water sector in the Mekong Delta because of its high vulnerability towards climate change, as well as its importance in relation to the total investment and potential losses that could result from climate change impacts. The Mekong Delta plays an important role for the economy of Vietnam, and it has been going through a period of rapid infrastructure development since the mid-1990s.

The Cai Lon - Cai Be Sluice Gate project, one of the biggest sluice gates in the Mekong Delta, was recently approved for the 1st phase by the Vietnamese Government with Decision 498/QD-TTg on 14 April 2017. This approval is aligned with the national program on climate change. The Cai Lon - Cai Be Sluice Gate project is expected to contribute to water allocation and regulation for the Ca Mau Peninsula in the future. Because of its importance for the region, it has been selected to be carefully studied, analysing the impact of climate change before it is constructed.

The Cai Lon - Cai Be Sluice Gate project was chosen for climate risk assessment for infrastructure using the Protocol through the assignment "Climate risk analysis and assessment report for Cai Lon - Cai Be Sluice Gate project based on PIEVC Protocol". This assessment has been managed by the GIZ/CSI team in Vietnam jointly with the Water Resources Investment and Construction Board 10 (PMU-10), and the Ministry of Agricultural and Rural Development (MARD). The Protocol based assessment has been completed over the period from 28th August 2018 to 31st May 2019. Facilitated through a learning-by-doing approach with many workshops and webinars, Engineers Canada guided the Vietnamese assessment team through the process of applying the Protocol with the objective of developing capacity within the Vietnamese institutions to understand and apply the Protocol not only to the Cai Lon - Cai Be Sluice Gate project but also to other projects in the future. The Vietnamese assessment team (Ref. Appendix 1) consists of experts in water resources, civil engineering and design, climate, hydrology and geology.

1.2. Report layout

This report is divided into six chapters. Chapter 1 introduces the general information about the project and an overview of the PIEVC Engineering Protocol. The next three chapters respectively correspond to Steps 1, 2, and 3 as outlined in the assessment process of the Protocol (Section 1.3). The main conclusions and recommendations (Step 5) are summarised in Chapter 5.

1.3. PIEVC Protocol

The PIEVC Engineering Protocol for infrastructure vulnerability assessment and adaptation to a changing climate (the Protocol) is a step-by-step process to assess the responses of infrastructure components to impacts of changing climate. The PIEVC protocol helps in identifying any gaps between additional duty loads that may be caused by climate change and the capacity of an infrastructure to adapt to this additional load that may not have been anticipated in its original design. Thus, it is able to facilitate decision-making on future design, operations, maintenance, planning, and development or potential upgrading or rehabilitation of the infrastructure. The process has five major steps, including: project definition (Step 1), data gathering and sufficiency (Step 2), risk assessment (Step 3), engineering analysis (Step 4), and recommendations (Step 5) (Figure 1-1). The detailed description of PIEVC Protocol is presented in the principles and guidelines [3]. Its main contents are summarised below.

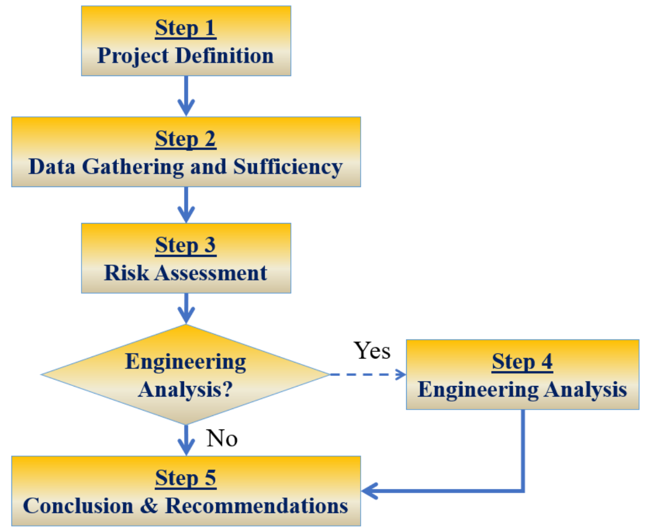

Figure 1-1. Five major steps of PIEVC (source: Engineers Canada (2016))

1.3.1. Step 1: Project definition

This step introduces general information about the infrastructure (e.g., location, main infrastructure components, design standard, legal basis, etc.) and data on climate, hydrology and geology required to support the risk assessment (including parameters, trends, and events which may impact on infrastructure vulnerability). Step 1 also seeks to identify major documents and information sources as well as preliminarily assess data sufficiency for the next steps. In this step, the boundary conditions for the assessment are defined.

1.3.2. Step 2: Data gathering and sufficiency

This step focuses on two main activities as follows:

1. Identification of the features of the infrastructure that will be assessed

This component of Step 2 identifies the main infrastructure systems and how they break down, including number of physical components, location, material of construction, design life of the infrastructure and its components, importance within the region, physical condition, operation and management of the infrastructure (i.e., specific regulations, standards, guidelines, and administrative processes). Establishing the design life of the infrastructure is important, as it informs the time horizon relevant for the assessment and applicable for the climate projections used.

The infrastructure threshold values are also identified. They refer to the "load" of a given climate event the infrastructure is designed and able to withstand without (significant) impact. These thresholds form the foundation of the analysis, as they are used to determine the severity of a given interaction between an infrastructure component and a climate event. Lastly, an assessment of data sufficiency is also carried out related to the information on the infrastructure.

2. Identification of the information on the applicable climate, hydrology and geology

Depending on the requirements of the project, as well as the features and the location of the infrastructure, the applicable climate, hydrology and geology factors to be considered in the assessment are identified. At this stage, the state of climate and hydrological variables under current conditions (baseline climate) are determined based on historical data. Based on the available information as well as further data analysis and modelling, assumptions are made about how the identified climate and hydrological variables will change under conditions of climate change. Though the risk scoring is done in Step 3, first ideas are already collected about how each infrastructure component may be impacted by individual or combined events to allow the assessment team to identify the most relevant events. Another key aspect is the definition of the time horizon based on the design life of the infrastructure, as this will determine the relevant timeframe for the climate-projections used. Based on the information collected about the climate and hydrological events, the probability scores (from 0, negligible, to 7, highly probable/ approaching certainty) are established for both the baseline climate and the future climate. They are later used to determine the risk scores (see explanation of Step 3).

At this stage, data sufficiency is again assessed by the assessment team. If required data and information are not available or of too low quality for the risk assessment, an additional survey may be required, or professional judgement may be employed to address the issue. Alternatively, aspects of the assessment requiring that data may be waived and recommendations made (in Step 5) for a new data collection program.

A component of this aspect of Step 2 is definition of scoring methods for climate variables and phenomena. The decision which method to use is made by the whole assessment team and is based, among other aspects, on the availability of information.

1.3.3. Step 3: Risk assessment

This is the core step in the Protocol as it embodies the risk assessment. The major goal of Step 3 is to identify the interactions between the infrastructure, the climate and other factors (e.g., hydrology and geology) and evaluate the resulting climate risk (whether existing or future risk, influenced by climate change). The risk evaluation for the interactions is presented in the risk matrix (see Appendix 9), containing the risk scores that are calculated from the climate probability scores (from 0, negligible, to 7, highly probable/ approaching certainty) and impact severity scores (from 0, negligible to 7, extreme/ loss of asset). In this step the impacts of cumulative climate effects (e.g., high water level combined with heavy rain.) on coastal and other infrastructure are also assessed.

Before the assessment team enters into the risk assessment, it needs to review the foundations established in Step 2, i.e. the infrastructure components, climate and other risk-driving factors parameter values and probability scores, minimum performance goals and thresholds. This is to make sure that the information and basis used for the subsequent steps is sufficient, complete and to avoid any errors. Using the information collected before, professional judgement is used (referring to the combined skills, training, expertise and experience of the entire team) to evaluate the severity and subsequently risks of the interactions. An essential element of this process is the risk assessment workshop, which besides regular working sessions is where the subsequently described tasks are implemented. It serves to consult with the owners, operations personnel and other relevant stakeholders that can provide their insights and professional judgement to the evaluation of risks. This workshop allows the assessment team to apply professional judgement in a transparent and consistent manner.

The risk scores are established in a step-by-step process. After the confirmation of the information collected in Step 2, a "Yes/No"-Analysis is conducted. At this stage, the analysis focuses on the question whether a specific infrastructure component interacts with a specific climate event. Basically, it asks the question of whether a specific element is exposed or not without yet going into the question of how severe the impact of a given event is. If the answer to this interaction is "Yes", then the component is included in the subsequent discussion on severity. If the answer to this interaction is "No", then no potential impact (i.e. no exposure) with regard to this climate-infrastructure interaction is foreseen and the assessment can continue to the next infrastructure-climate interaction. This qualitative assessment can also include the potential for the service of the overall project to be impacted, which would by extension entail losses to society, the economy and the environment.

For all components which have been identified as exposed to a climate event, subsequently the severity is assessed. Like for the probability, a scoring system is used for this based on the severity scoring table (see table 4-4). Based on professional judgement, stemming from knowledge from past impacts on similar infrastructure, research etc., the assessment team agrees on severity scores for the different interactions, reaching from 0 (not applicable/ negligible) to 7 (extreme/ loss of asset). Together, severity and probability scores are then used to establish the risk scores via multiplication, thus yielding an evaluation of the different risks (from 0 to 49). Beyond the impact a given event may have on a single component of the infrastructure, part of this analysis is also to assess how a given event may impact the service of the infrastructure as a whole.

Once all of the interactions between infrastructure components and climate variables have been assessed, the risk tolerance thresholds are established. They are based on what degree of risk the owner of the infrastructure is willing to accept. Based on the thresholds, the risks are categorized into a high, medium and low risk ranking (other categorizations can also be developed for a given assessment, if required). Typically, low risk rankings are not considered to be of immediate concern. Conversely, high risk rankings should lead to immediate action. Interactions with medium risk ranking may be considered for further engineering analysis (ref. Step 4).

Data sufficiency will also be evaluated at this stage. If data is deemed to be insufficient, the Protocol advises to revisit Step 2 to acquire and refine the data or add a recommendation for data collection in Step 5. As an alternative, professional judgement may also be used to make qualitative assessment wherever data is insufficient. If this is the case, it may be prudent to make recommendations for additional data gathering and/or analysis to inform future regular reviews of the risk assessment.

1.3.4. Step 4: Engineering analysis

Please note that Step 4 of the Protocol has not been within the scope of this assignment. The information presented below is provided for completeness of the Protocol description only.

This is an optional step in the Protocol. The engineering analysis is conducted on the interactions identified in Step 3, if further assessment is deemed to be required. The implementation of the Step 4 analysis also depends on available budget and project scheduling constraints.

In this step, the total load and capacity of the infrastructure components under both current and future conditions are calculated. This will be followed by the numerical analysis to evaluating to what extent an infrastructure component is vulnerable (i.e., total projected load exceeds total projected capacity) or whether sufficient adaptive capacity exists (i.e., total projected load is less than total projected capacity). The analysis allows to rank interactions based on their decree of vulnerability, i.e. the extent to which their future capacity is projected to be out-passed by future loads.

Similar to Step 3, a final assessment about data availability and quality is carried out in this step. The assessment team is advised to revisit Step 2 to acquire and refine the data to a sufficient level unless the data quality can support the robust engineering analysis. Generally, the extent of data and information as well as expertise required for Step 4 makes it a relatively resource-intensive and time-consuming step, leading to it often being skipped if not deemed of high importance.

1.3.5. Step 5: Recommendations

In Step 5, based on the results of the risk assessment, the assessment team identifies options for managing the risks identified in the assessment. The team then agrees on recommendations to give to the owner, operator, designer or planner of the infrastructure. Assumptions, limitations and recommendations from the assessment process are presented in the assessment report as guidance. The recommendations are generally categorised as follows:

- Remedial action to upgrade the infrastructure;
- Management action to account for changes in the infrastructure capacity;
- Additional study recommended;
- No further action required;
- Action to enhance availability or quality of data for further work.

To allow for the priorisation of the implementation of the recommendations, the recommendations also include, where possible, information on the associate cost, suggested time frame of implementation and the stakeholders who need to take action. In this manner, "low hanging fruit" can be highlighted for near term action while more expensive or complex recommendations can be integrated into longer-term planning and budgeting programs.

1.4. Objectives and scope of project

1.4.1. Objectives

The objective of the assignment is to assemble and coordinate the climate risk assessment team for the Cai Lon – Cai Be sluice gate system following the PIEVC Protocol approach and under the guidance of Engineers Canada. The results of the assessment are later to be used for the Sluice Gate design and construction in order to reduce the risks related to climate change. The goal is to make the finished sluice gate project more resilient towards climate change and hence more cost effective over the life of the infrastructure.

1.4.2. Scope of project

- As the Cai Lon - Cai Be Sluice Gate system has not as yet been constructed and is, at the time of this assessment, in the basic design stage, the version of the infrastructure design as of December 2018 was selected to conduct the risk assessment using PIEVC Protocol. Updated versions of design of this system (if any) have not been considered in the scope of this risk assessment.
- Only Steps 1, 2, 3 and 5 of PIEVC Protocol have been applied to assess the vulnerability of the Cai Lon - Cai Be Sluice Gate project as required in the Terms of Reference (TOR) for this assignment. Step 4 for engineering analysis has not been considered in the scope of the project.
- This study has the objective to address potential impacts of current and future climate for the planned life of the infrastructure.
- The work has also included the climate data purchasing package from the Southern Regional Hydrological and Meteorological Centre in Ho Chi Minh City which is to support the risk assessment process.

2. PROJECT DEFINITION

2.1. Overview of Cai Lon-Cai Be Sluice Gate Project

2.1.1. History of the project

The Cai Lon – Cai Be Sluice Gate project was approved by the Prime Minister in Decision No. 498/QD-TTg on April 17th 2017 and assigned to the Ministry of Agriculture and Rural Development (MARD) to consider the investment decision for the first phase. In the role of an investor, MARD assigned the Water Resources Investment and Construction Board 10 (PMU-10) to manage this project. This project is classified into Group A of new construction works with the total investment of 3,300 billion VND (approx. 142 million USD). It is also sorted into level 1 of the irrigation works for agriculture and rural development.

The Cai Lon and Cai Be sluice gate project was first proposed in 2006. Since then, the project has been studied further in regional master plans and related studies in 2009, 2012 and 2017 (ref. Figure 2.1).

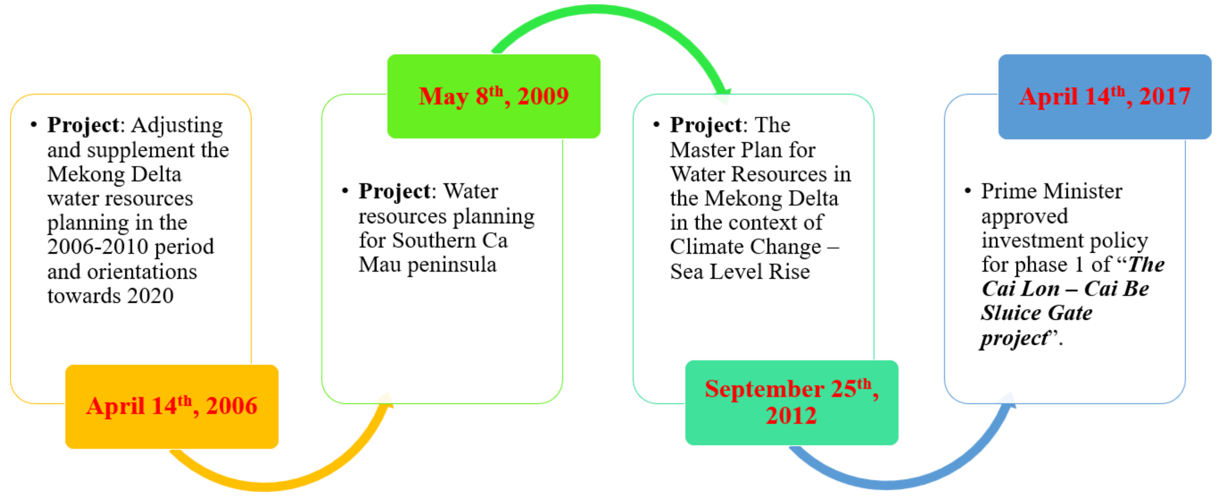

Figure 2-1. History of the Cai Lon – Cai Be Sluice Gate project

2.1.2. Overview of study area

a. Objectives

The general objectives of the Cai Lon – Cai Be Sluice Gate Project are as follows:

- To control salinity intrusion, resolving the conflicts between coastal aquaculture and agricultural production of Kien Giang, Hau Giang and Bac Lieu provinces in the Cai Lon - Cai Be river basin, and contribute to a stable fisheries development in coastal areas of Kien Giang province;
- To actively respond to climate change, especially sea level rise, to retain freshwater resource for the dry season, prevent forest fire in drought years, contribute to sustainable socio-economic development;
- To strengthen drainage and flood water management, and improve soil quality;
- To enhance land and water navigation systems.

b. Location

The study area is a part of Ca Mau Peninsula that is one of four major regions of the Mekong Delta (MKD). It borders the Cai San canal in the North – West, Quan Lo – Phung Hiep canal in the South – East, the Hau River (the Bassac River) in the North – East and the West Sea in the West (Figure 2.2). The project consists of three main components, namely: (i) Cai Lon sluice, (ii) Cai Be sluice, (iii) and the dike connecting the sluices to the National Highway 61 and the National Highway 63.

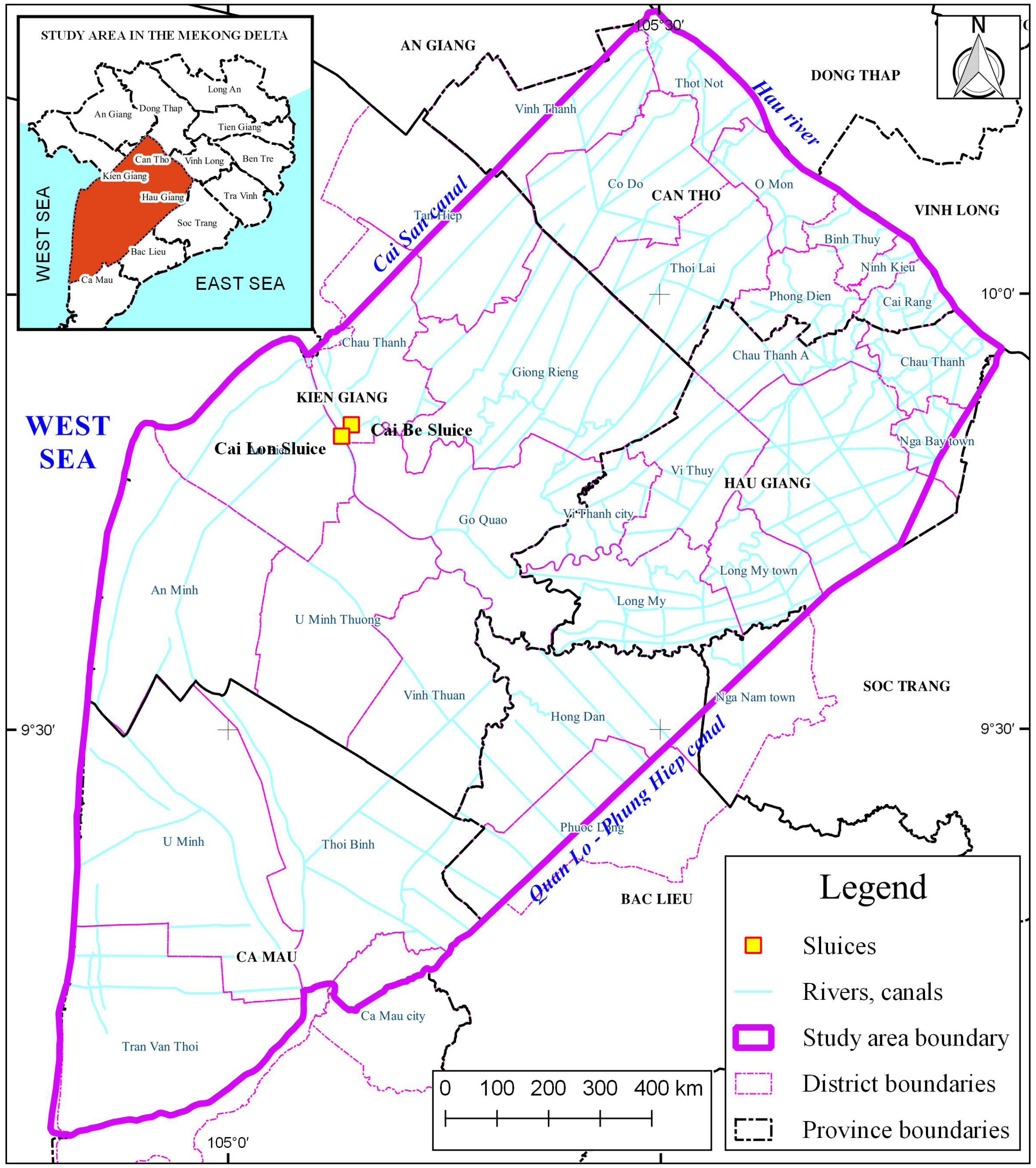

Figure 2-2. Location of the study area

c. Nature conditions

The study area is about 909,248 ha [4], spreading over 32 districts/cities of 6 provinces including: Bac Lieu, Ca Mau, Kien Giang, Hau Giang, Soc Trang and Can Tho City. This area has an approximately flat terrain (Figure 2-3). However, its elevation decreases from the boundary to the centre, creating a depression area like a bowl shape, making it difficult for drainage. According to the results of overlapping the coastline maps of the Mekong Delta over the period of 1903 – 2014, an analysis completed as a component of the Integrated Coastal Management Programme (ICMP) implemented by GIZ, the coastline in this area has extended, with an accretion rate about 20 – 40 m/year [5].

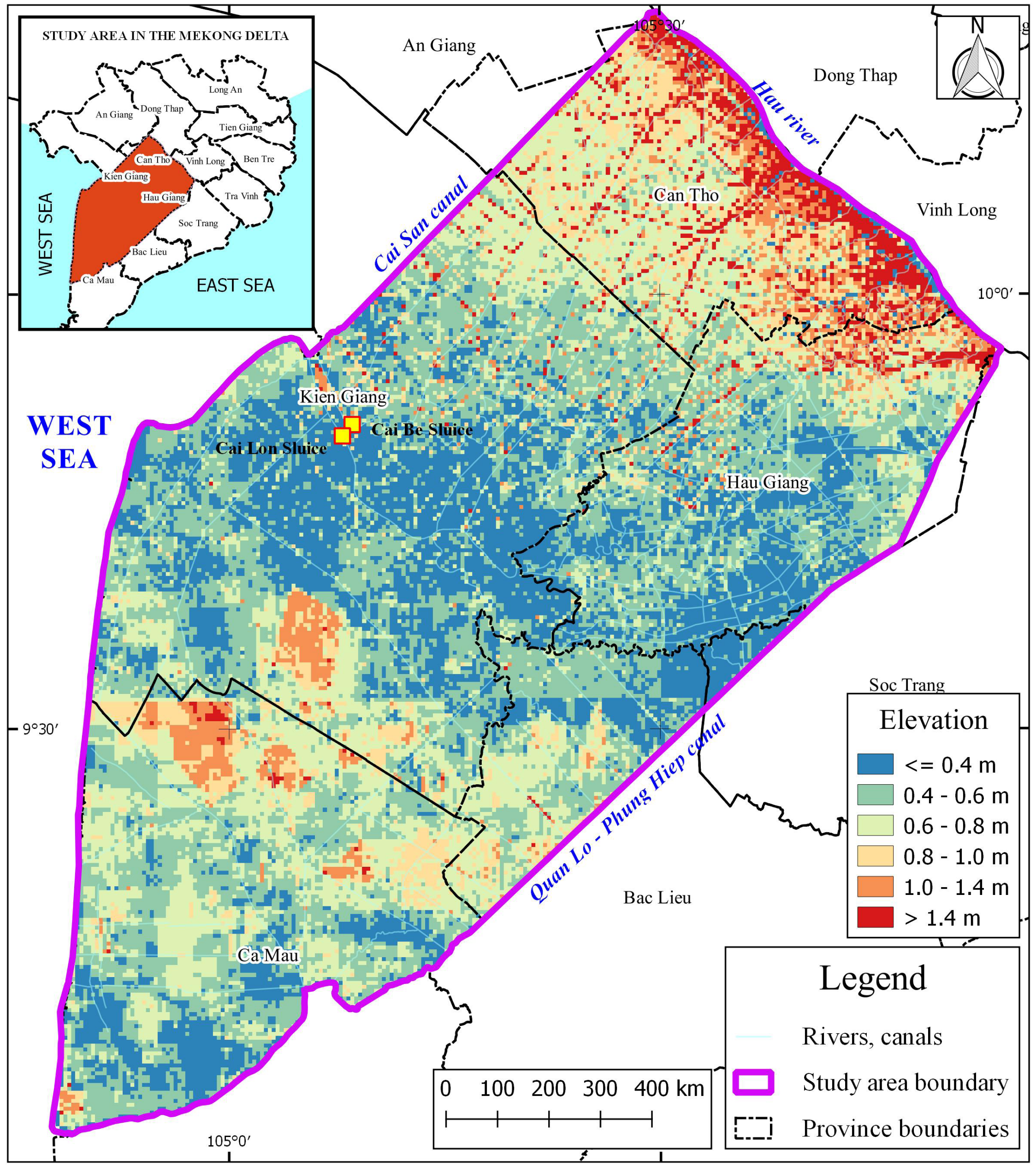

Figure 2-3. Topography of the study area

The study area has a dense canal system, in which the flow directions are generally from North to South and East to West. In addition to the natural rivers, there are also many man-made dug canals (mainly from the period of the French colony) which were constructed in order to divert freshwater from the Hau River.

d. Socio – economic conditions

According to statistical data in 2015, the study area has about 3,612 thousand inhabitants, accounting for 20.6% of the population of the MKD [4]. The average population density (about 397 persons/km²) in the study area is lower than that of the overall MKD. However, the population is not evenly distributed and is mainly concentrated in the urban areas (about 800 – 1,400 people/km²).

The work-skills of the local labour force are generally considered to be poor and occupations are mainly in three sectors: agriculture, forestry and aquaculture. Aquaculture activities contribute the highest percentage of income but this industry is also deemed to be a high-risk sector due to lack of high-quality water for aquaculture, disease, and uncertain market pricing. On the other hand, agriculture activities generate lower incomes but are deemed to be much more stable. The GDP per personof localities in the study area was 42.95 mil. VND/person/year in 2015 (1,837.89 USD (05/2019 exchange rate)). This is four times higher than in 2005 and it is also higher than the average GDP per person of the MKD generally (38.64 mil. VND/person (1,643.19 USD (05/2019 exchange rate)).

e. Challenges in the study area

Ca Mau Peninsula is faced with several serious problems which substantially impact people's livelihoods. These are:

- Annual flooding due to heavy rains and spring tides;
- Salinity intrusion from the West and East Seas through the major river systems such as the My Thanh River, Ganh Hao River, Ong Doc River and Cai Lon – Cai Be River;
- Freshwater shortages because the study area is far from the nearest freshwater source (i.e. the Hau River).

2.2. Cai Lon-Cai Be Sluice Gate System

The Cai Lon – Cai Be Sluice Gate project for the 1st phase includes the main infrastructure features, namely the Cai Lon sluice, Cai Be sluice, and the dike connecting the two sluices to the National Highway 61 and the National Highway 63 (known as the connecting dike) (Figure 2-4). In this study, however, only the Cai Lon and Cai Be sluices were selected, as these are major components of the planned project and are considered to be representative of other similar infrastructures in the MKD in general and in the study area in particular. In addition, the main components (e.g. sluice gates, bridges, roads, embankments and canals connecting the two embankments) of the Cai Lon and Cai Be sluices are similar to the components of the connecting dike. As such, the findings of this risk assessment are considered to be more broadly applicable to infrastructure engineering and design beyond the specific infrastructure assessed.

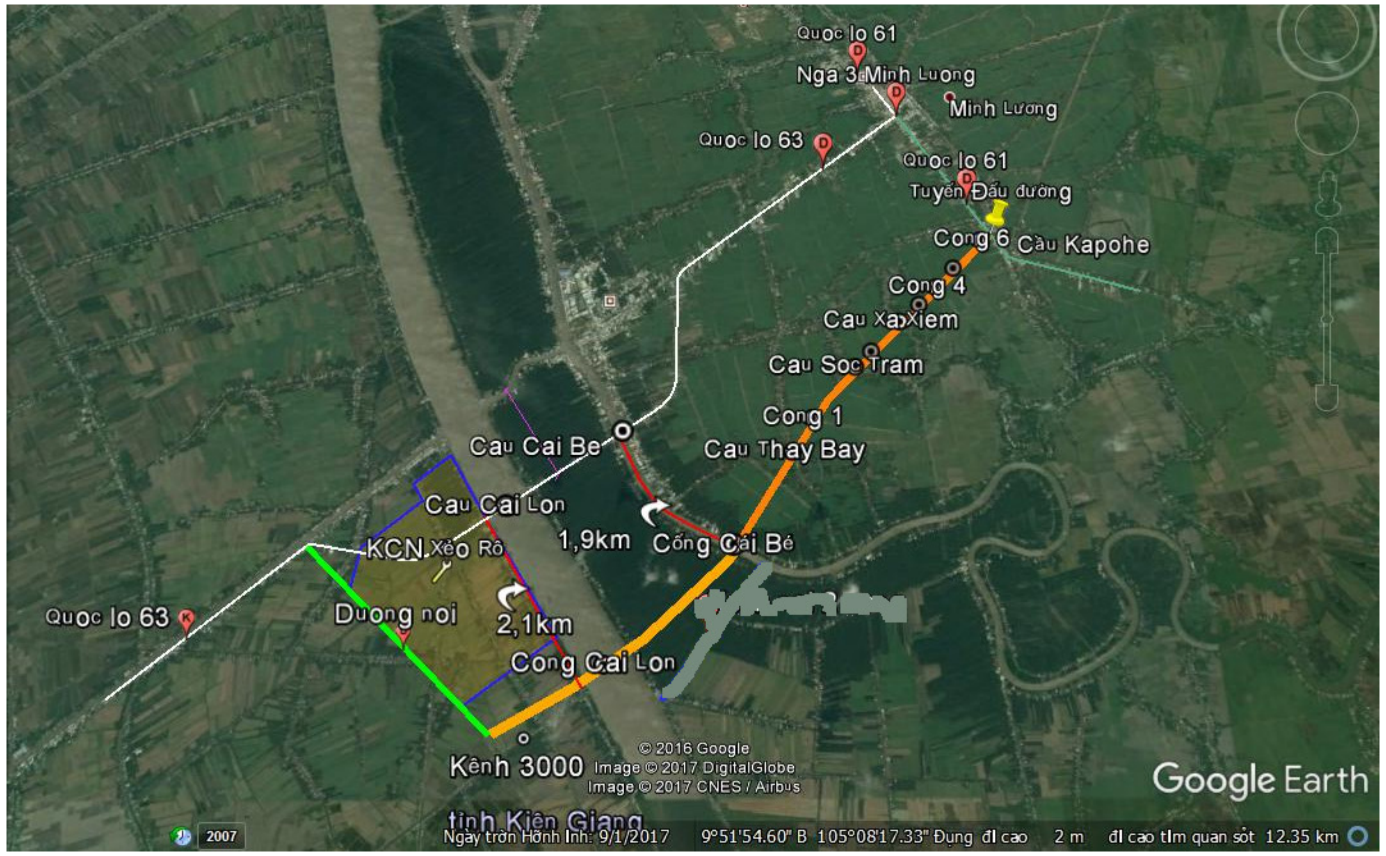

Figure 2-4. Overview of the infrastructures in the project

2.2.1. General description of the infrastructure

a. Cai Lon Sluice

Cai Lon sluice is located 2.1 km upstream from Cai Lon Bridge. The sluice is categorized as a Grade I hydraulic work (based on QCVN 04 - 05:2012/BNNPTNT), including the main components: sluice gate, ship lock, bridge, connecting road, downstream and upstream embankments, operation house, canal connecting the two embankments, landscape and lightninglightning system.

In terms of scale, the total width of the sluice works is 470 m, consisting of 11 sluice gates of 40.0 m width (elevation threshold of -3.5÷-6.0 m) and 2 ship locks of 15 m width and 100 m length (elevation threshold of -5.0 m). The sluice gate is designed with an altitude +2.5 m and is proposed to be constructed of steel. The gate is designed as a vertical lift system to be operated by a hydraulic cylinder system. The sluice is also designed with an integrated bridge designed to accommodate a traffic load of HL93[1] and having a width of 9.0 m. An artist's rendering of the overall perspective of Cai Lon sluice is shown in Figure 2-5.

[1] HL93 refers to Highway Load 1993. This is a hypothetical Live Load Model proposed by AASHTO for analysis of bridges.

Figure 2-5. Overall perspective of Cai Lon sluice [13]

b. Cai Be Sluice

The Cai Be sluice is located 1.9 km upstream from Cai Be Bridge. The main components of this sluice are similar to the Cai Lon sluice, but the Cai Be sluice has a smaller scale and is categorized as a Grade II hydraulic work (based on QCVN 04 - 05: 2012/BNNPTNT).

The total width of Cai Be sluice is 85 m, consisting of 2 sluice gates of 35 m width (elevation threshold of -5.0 m) and 1 ship locks of 15 m width and 100 m length (elevation threshold of -4.0 m). The sluice gate is designed with an altitude +2.5m and is planned to be made of steel. The gate is designed as a vertical lift system to be operated by a hydraulic cylinder system. The sluice also has an integrated bridge designed to accommodate a traffic load of HL93 and having a width of 9.0 m. An artist's rendering of the overall perspective of the sluice is shown in Figure 2-6.

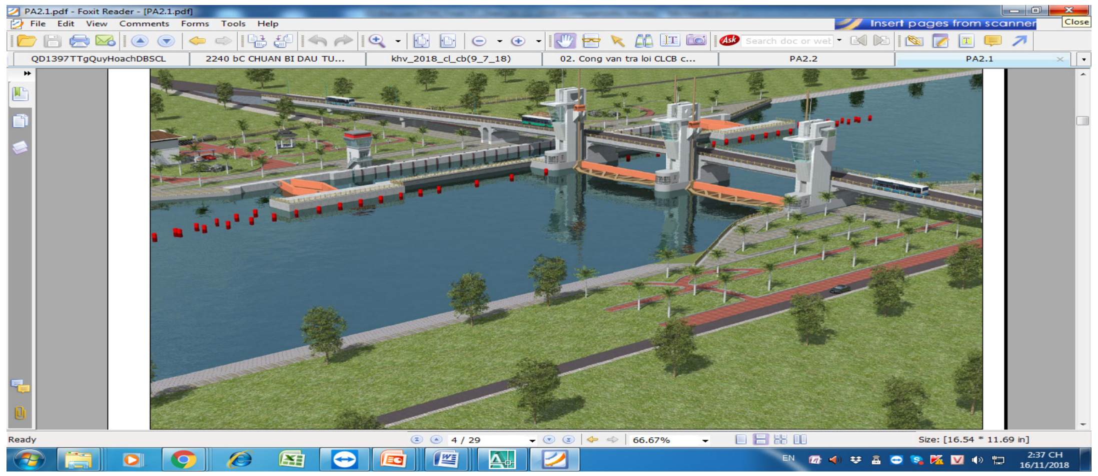

Figure 2-6. Overall perspective of Cai Be sluice [13]

2.2.2. Overview of the operation and management of the work

a. Preliminary plan of operation procedures

The operation procedures are sorted into two periods (low flow and flood) in order to control salinity, manage water resources, and support production and living of residents. During the low flow period (from January to June), the sluice is closed to control salinity (limit movement of saline water from downstream to upstream) and retain fresh water (in upstream reaches), except for one sluice gate which remains open for environmental flow. In a year, the sluice gates are expected to be operated with a total of about 24 to 26 days for the closing period.

2. Project Definition

The longest period to close the sluice is anticipated from February to May. In the flood period, most of the sluice gates are expected to be open and to only be closed for tidal control (when the tidal level is more than 0.5 m and the water level in the field is lower than that in the river). However, depending on the actual agricultural production activities and water demand of each year, operation procedures will be adjusted accordingly.

b. Management of the infrastructures

The management, operation and service of the infrastructures must strictly follow the operation procedures of the competent agencies (e.g., MARD). All the infrastructures in this project must be synchronously operated together to meet the objectives as required.

To improve the effectiveness of the infrastructures, monitoring systems have been set up in the project, including: controlling and automatic monitoring system (SCADA) for water quality monitoring; land subsidence monitoring system; movement monitoring system; automatic warning system for operation (for example, as the concentration of salt water is higher than the allowable value, the system will warn in order for the gates to be closed); and a sluice gate operation monitoring system.

In addition, the management of the infrastructures must also strictly comply with the regulations related to the environment, water resources, health and labour safety, and other relevant regulations.

2.3. Overview about climate, meteorological and hydrological data

There are more than 30 meteorological stations in the Ca Mau Peninsula. In this study, 16 stations (6 for climate factors and 10 for hydrological factors) have been selected for use based on the station location and the available data. In regard to climate data, there are 8 parameters included in the assessment: (i) daily rainfall (16 stations), (ii) sub-daily rainfall (6 stations), (iii) daily temperatures (maximum, minimum and average values) (6 stations), (iv) storm/depression data, (v) wind data (6 stations), (vi) thunderstorm data (6 stations), (vii) evaporation data, and (viii) humidity data (6 stations).

In the Ca Mau Peninsula, there are 10 permanent hydrological stations under the management of the Southern Regional Hydrometeorological Center (SRHMC). In addition, there are the local stations managed by the Department of Agriculture and Rural Development (DARD), and some temporary stations which were set up for the water resources management projects in this region. According to observed parameter classifications, these stations are divided into four groups, consisting of: (i) water level and salinity measurement (8 stations), (ii) water salinity measurement (3 stations), (iii) water level measurement (3 stations), and (iv) water level and flow measurement (1 station).

The water level dataset period of record is almost 30 years from 1988 to 2017, except for the Song Doc station which has only data for 22 years. The data is collected on an hourly basis. The salinity data span almost 22 years from 1996 to 2017, measured every 2 hours (12 measurements/day) and 5 - 7 days/month at the high tide period during the dry season. The time series of the hourly flow data at Can Tho station is 1995 – 2017 (23 years).

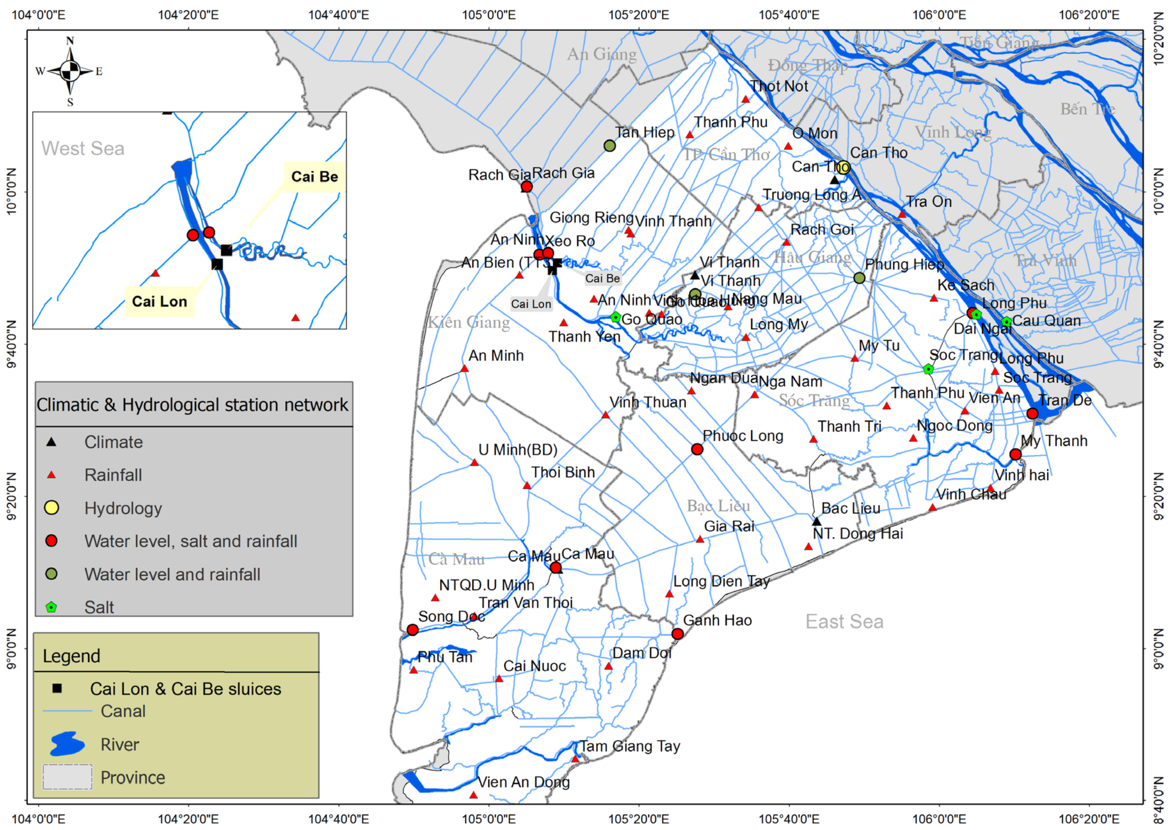

Figure 2-7. Climatic and hydrological station network in Ca Mau Peninsular

2.3.1. Meteorological and climate parameters

Located in Southern Vietnam, the study area of the Cai Lon – Cai Be sluice gate project has the characteristics of a tropical climate. Generally, the minimum temperature is not less than 16ºC and the maximum temperature is not more than 38ºC. In the area, there are two distinct seasons, the rainy season (from May to October) and the dry season (from November to April). The rainy season is featured by the Northeast monsoon, while the dry one is featured by the Southwest monsoon. Tropical storms and depressions usually appear from October to March of the next year.

In this study, the climate factors to be considered in the assessment were selected based on the geographic features of the study area. They include,:

- high temperature,
- heat wave,
- heavy rain,
- 5-day total rainfall,
- thunderstorms/lightning,
- tropical storms/depression,
- high wind,
- tornado,
- drought,
- humidity and
- evaporation.

2. Project Definition

Generally, the climate change - sea level rise scenarios for Vietnam show that many climate factors are expected to significantly change. For example, increases in heavy rain intensity, total annual rainfall, and extreme temperature events in the Mekong Delta are projected by 2100 ([7], [8]). Therefore, the analysis of these climate factors plays an important role for climate risk assessments of the infrastructures in this area.

2.3.2. Hydrological parameters

In the Mekong Delta, there are two seasons: flood season (from July to November) and low flow season (from January to June). The flood peak frequently appears in October while the lowest river flows generally occur in April.

The Ca Mau Peninsula is influenced by the tidal regime of both the East Sea and West Sea. The East Sea tide is semi-diurnal while the West Sea tide is diurnal[2]. The highest tide appears in the last months of the year (from October to December). Due to the geographical characteristics, salinity intrusion in the Cai Lon- Cai Be region is from the West Sea through Cai Lon – Cai Be Rivers.

In 2014 (updated 2016), the Ministry of Natural Resources and Environment (MONRE) published a report on storm risk and storm surges for the coastal region of Vietnam. The maximum recorded storm surge has attained 120 cm along the coastal area of Ca Mau - Kien Giang and it is predicted to increase to 210 cm in the future [8].

Based on the hydrological characteristics described above, the following hydrological parameters have been considered in the climate risk assessment on the Cai Lon – Cai Be sluice gate:

- Water level, tide;
- Flow (Flood and low flow);
- Salinity intrusion;
- Hydrological drought;
- Storm surge;
- Tsunami;
- Some of environmental factors, such as water temperature, pH…
- Sedimentation.

According to the analysis based on climate change and sea level rise scenarios for Vietnam in 2016 for the dataset from 1993 to 2014, the mean sea level in most of the coastal region of Vietnam increases at about 3.34 mm/year.

In recent years, the amount of sediment in the Mekong Basin and in the Mekong Delta has been drastically reduced due to the development of upstream hydropower plants, which have retained a part of the sediment [9]. The hydropower development in the upstream area is also expected to affect the flow regime in the Mekong Delta. Some hydrological trends which may have an impact on the Cai Lon – Cai Be sluice gate are:

- Sea level rise;
- Decreased sediment load;
- The increase of salinity intrusion in terms of both volume and durability;
- Decreasing low flow and increasing flood flow in combination with uncertain changes due to the upstream development;
- The effects of climate change on storm surges; and
- Coastal and river bank erosion.

[2] An area has a diurnal tidal cycle if it experiences one high and one low tide every lunar day. An area has a semidiurnal tidal cycle if it experiences two high and two low tides of approximately equal size every lunar day. *[Source: https://oceanservice.noaa.gov/education/kits/tides/media/supp_tide07a.html]*

2.3.3. The effect combination of climate and hydrological factors

Combined effects of climatic and hydrological events may also have implications for infrastructure vulnerability. In this study, some combinations of events are considered as follows:

- High water level (including tides, sea level rise and storm surges) combined with heavy rain;
- Salinity intrusion combined with meteorological drought;
- The decreased sediment load combined with erosion and flood flow or storm surges.

2.4. Overview about geology

a. Geomorphology – hydrogeology

The Cai Lon and Cai Be sites are located on the edge of the south-west area of the Cenozoic Era depression and formed above the bedrock between the Late Palaeozoic and Early Mesozoic Eras. The stratigraphy in the project area is mainly the sediment of the Quaternary Period created at the early stages of the Pleistocene Epoch, consisting of three layers:

- The organic clay layer (Layer 1) belongs to the Late (Upper) Holocene Epoch originating from river sediments.
- The yellowish brown, white pink, white grey, red-brown layer (Layer 2) belongs to Middle Holocene Epoch of the Hau Giang geology system, originating from marine sediments.
- The light brown, bluish grey, yellowish grey mixed sand layer (Layer 3a) belongs to Late (Upper) Pleistocene Epoch of the Moc Hoa geology system.

In terms of hydrogeology, due to the low elevation, the water table is located within the shallow layer and its top elevation varies through the seasons. Therefore, this shallow water table is affected by saline water intrusion and so groundwater in this area is mainly brackish water. In the dry season, salt concentrations increase considerably.

b. Effects of geological factors on the project area

According to the project documents implemented by the joint venture of Vietnam Academy for Water Resources (VAWR), HEC-2, and Southern Institute for Water Resources Planning (SIWRP), the Cai Lon-Cai Be Sluice Gates might be affected by the following geographical factors:

- Soil texture (the linkage between different soil particles)
- Soil consolidation (soils change its volume in response to a change in pressure): For most transportation infrastructures and waterworks, the soil consolidation rate must be higher than 90%.
- Ground intensity: load capacity of soil
- Water table

c. Geological trends and phenomena

Based on previous studies and the reports of the Cai Lon-Cai Be Sluice Gate project, some main geological phenomena have been summarized below:

- Subsidence

The subsidence rate is about 15 – 45 mm/year and the cumulative subsidence varies from 20 to 50 cm [10]. This cumulative subsidence is predicted to continue happening and will reach to 1.0 m in the next decades, and 40% of which occurs at the depth higher than 100 m. The causes of subsidence are depositional landform, loading by structures, and overexploitation of groundwater, in which the last one is claimed as a major cause ([10], [11], [12]). If these predictions become reality, they have the potential to affect the stability and engineering structure of Cai Lon and Cai Be.

- Landslide/Bank erosion

Riverbank erosion refers to the removal of soil and other material, such as rock and vegetation, from the riverbank [22]. Riverbank erosion is a naturally occurring process, but the rate at which it occurs is often increased by anthropogenic or human activities such as urbanization and agriculture. Changes in land use can cause riverbanks to erode at rates much faster than those seen in natural, undisturbed systems.

Bank sloughing is a movement of a mass of soil down a river bank into the channel, similar to a landslide and also referred to as slumping [23].

- Faulting/Cracking

Faulting in the project area has occurred in three directions: the north-east to the south-west, the north-west to the south-east, and the meridian. However, these faults are fissured terrain lying beneath the thick landform layers so that they are not expected to impact ground surface infrastructures [13].

- Earthquake

According to the Vietnamese Building Standards TCXDVN 375:2006 Design of Structures for Earthquake Resistance, the Cai Lon – Cai Be Sluice Gates are located in the Chau Thanh district, Kien Giang Province where the peak ground acceleration is 0.0092 corresponding to earthquake level 5 on the MSK-64 scale. This issue has also been considered in the basic design.

d. Cumulative Impacts

The geographical phenomena above are experienced now and are expected to continue in the future. If these phenomena occur simultaneously with adverse hydro-meteorological events, the infrastructures are expected to be highly vulnerable. As such, some cumulative impacts have been considered:

- Land subsidence coupled with sea level rise
- Weak-structure soil combined with flooding

2.5. Identify the Time Horizon

The design life of the planned infrastructure is 100 years [13]. With regard to climate change scenario planning, the latest version of the climate change scenarios for Vietnam was revised in 2016. The predicted periods of climate change include 2016- 2035; 2046-2065 and 2080-2099. The time milestone for sea level rise projections is every 10 years from 2030 to 2100. In this study, the climate change scenario at the end of 2080-2099 was used, as it is consistent with the lifespan of the infrastructure.

2.6. Jurisdictional Considerations

- Decision No. 84/2006/QD-TTg on April 19th 2006 of Prime Minister for approving "*Adjusting and implementing Water Resources Planning for the Mekong Delta in the period of 2006 – 2010 and orientation to 2020"*;
- Decision No. 1336/QD-BNN-KH on May 8th 2009 of MARD for approving "*Water Resources Planning for Southern Ca Mau Peninsula*";
- Decision No. 1397/QD-TTg on September 25th 2012 of Prime Minister for approving "*Master plan for water resources in the Mekong Delta in context of climate change and sea level rise*";
- Decision No. 3113/QD-BNN-KH on October 10th 2009 of MARD's Minister about the agreement of investment and investor assignment on "*The Cai Lon – Cai Be sluice gate project (1st phase)*";
- Decision No. 498/QD-TTg on April 17th 2017 of Prime Minister for approving investment policy of *"The Cai Lon – Cai Be sluice gate project (1st phase)";*

- Decision No. 3805/QD-BTNMT on December 18th 2018 of the Ministry of Natural Resources and Environment approving the report on environmental impact assessment of *The Cai Lon – Cai Be sluice gate project (1st phase).*
- Decision No. 5078/QD-BNN-XD on December 25th 2018 of the Ministry of Agriculture and Rural Development approving the investment of *The Cai Lon – Cai Be sluice gate project (1st phase).*

2.7. Data sufficiency

- For infrastructure data

The information and data about the infrastructures used in this study are reliable because they are sourced from the reports of the Cai Lon – Cai Be sluice gate project (1st phase), with the latest version from December 2018. This data is generally deemed to be sufficient to support this PIEVC climate risk assessment.

- For the hydro-meteorological data

Most of the selected parameters collected are available with a 30-year dataset, except for the salinity data (22 years). Some parameters are irregularly measured such as storm surges, waves, and water temperature. Tsunamis have not been monitored in this area in the past. The data of the sediment transport is only recorded at the gauges along the main branches of Mekong River and is not measured in the study area. Generally, the hydro-meteorological data is deemed to be sufficient to support this PIEVC climate risk assessment.

- Hydro-geological data

- Based on review of the collected geomorphology and hydrogeology data (mainly groundwater data) and the requirements of the PIEVC Protocol, it can be concluded that the available geological data is inadequate to conduct the risk assessment for Cai Lon and Cai Be Sluice Gate. Therefore, the effect of hydrogeology will be left out in this study.
- Regarding land subsidence data, most of the previous studies only focused on Can Tho City and Ca Mau City ([10], [14]). Recently, some subsidence rate measurements have been conducted for the whole Ca Mau Peninsula ([10], [11], [12]), including the Cai Lon and Cai Be area. However, these measurements only started recording in 2014, so data coverage is short and deemed to be inadequate for the current assessment. As such, the assessment team decided not to include subsidence for further evaluation.
- Data on faulting/cracking and earthquakes is limited; hence the assessment team decided not to include this data in this study.

3. DATA GATHERING AND SUFFICIENCY

3.1. A breakdown of Cai Lon and Cai Be Sluice Gate

Pillar dam type designs have been proposed for both the Cai Lon and Cai Be sluice gates. Basically, technical requirements in the design of their components are determined following the Vietnamese Technical Standard TCVN 10400:2015 (Hydraulic Structures –Pillar Dam – Technical requirements for Design). Their main components are illustrated in Figure 3-1.

(1) Pile foundation	(4) Pillar	(7) Bottom beam
(2) Waterproof piles	(5) Gate tower	(8) Gate
(3) Pillar footing	(6) Bridge	(9) Reinforcement

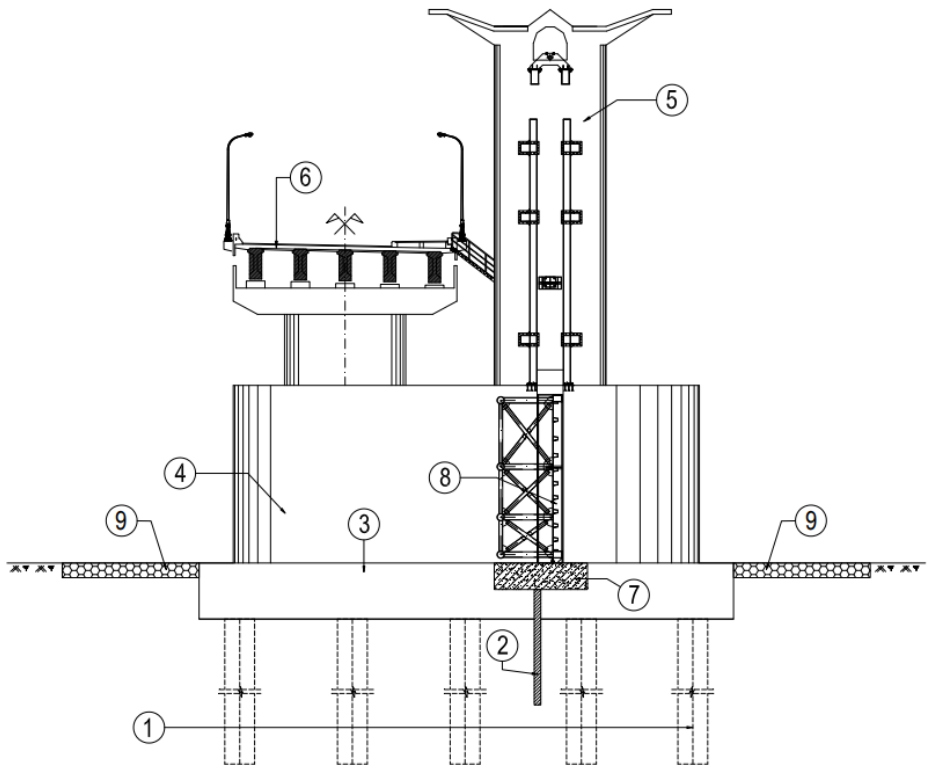

Figure 3-1. Main components of a pillar dam

The main components of the Cai Lon and Cai Be sluice gates are similar (Table 3.1 and Figure 3-2). In this report, these sluice gates will be described in an integrated manner, based on the design reports of the Cai Lon and Cai Be sluice gates from the Vietnam Academy for Water Resources (VAWR) and Hydraulic and Construction Consultancy Join-stock Company No. 2 (HEC-2).

Table 3-1. Main systems and components of Cai Lon and Cai Be sluice gates

No.	Main system	Components
1	**Operation and maintenance**	
1.1		Regular maintenance staff
1.2		Maintenance equipment
1.3		Maintenance records
2	**Sluice gate structure**	
2.1		Pile foundation
2.2		Waterproof pile foundation
2.3		Pillar footing
2.4		Bottom beam
2.5		Pillar
2.6		Gate tower (gate hanger)
3	**Ship lock**	
3.1		Lock chamber
3.2		Lock head
3.3		Filling and discharge culverts
3.4		Leading jetty
4	**Gates**	
4.1		Sluice gates
4.2		Water tight gasket
4.3		Bolts
5	**Bridge**	
5.1		Pile foundation
5.2		Bridge pier
5.3		Bridge beam
5.4		Bridge surface
5.5		Bridge hand rail
5.6		Bridge slope/ramps
5.7		Expansion joints
5.8		LightningLightning system
5.9		Traffic signals/guide posts
5.10		Drainage system/scupper
6	**Retaining walls and connected embankment**	
6.1		Retaining walls
6.2		Connected embankment
6.3		Overflow preventing walls
6.4		Base of retaining walls
6.5		Hand rail
6.6		Rip-rap of connected embankments
6.7		River bed gabion
6.8		River banks (after connected embankments)
7	**Operation houses**	
7.1		House structure (front steps, windows…)
7.2		Equipment and facilities (computers, bulbs…)
8	**Park**	
8.1		Protective fences
8.2		Trees, flowers and grass cover
9	**Power supply**	
9.1		Transmission lines
9.2		Voltage transmission
9.3		Standby generators
9.4		Lightning protection system
10	**Operation and control system**	
10.1		Hydraulic cylinder
10.2		Oil tank (hydraulic power source)
10.3		Control station
10.4		Operational bells and lights…
11	**Monitoring system**	
11.1		SCADA
11.2		Movement monitoring system
11.3		Seepage monitoring system
11.4		Prestressed monitoring system
12	**Fire extinguishing system**	Fire warning system, extinguisher…
13	**Communication system**	Computers, phones, fax machines…

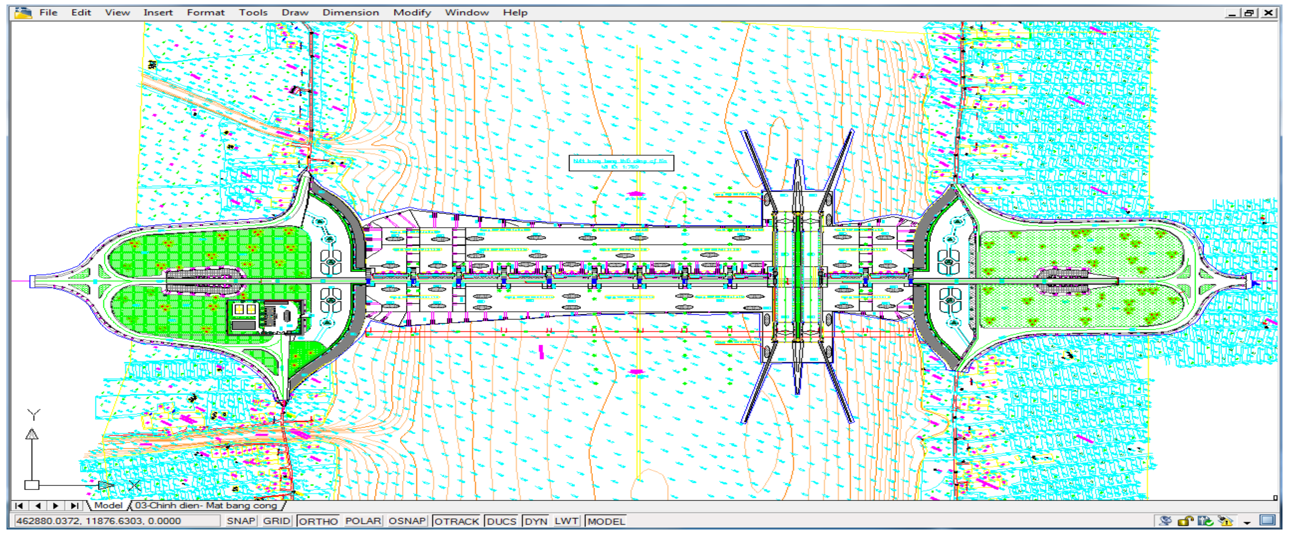

Figure 3-2. A plan of Cai Lon sluice gate

3.1.1. Operation and Maintenance

The operation and maintenance system has three main components including regular maintenance staff, maintenance equipment and maintenance records.

a. *Regular maintenance staff*

Regular maintenance staff work at the operation house that is located nearby the sluice gates' sites. Their duties are to regularly monitor the operation and management of the gates through the control system in the operation houses. In case of emergencies, staff may need to reach the sluice gates in order to deal with these cases immediately. In addition, the staff has to conduct the maintenance works at the end of the dry season and the beginning of the flood season.

b. *Maintenance equipment*

The equipment for the maintenance and operational activities includes cars, canoes, barges (with the capacity of 300 tons) and painting tools. These items are placed in store houses and covered areas and are only used when needed.

c. *Maintenance records*

Maintenance records consist of all documents (hard and soft copies) related to the maintenance and operational activities such as operational procedures. These documents are kept in the operation houses.

3.1.2. Sluice gate structure

The sluice gate structure is responsible for water level control and is the place where the valve gates are installed. The components of the sluice gates are pile foundation, waterproof pile foundation, pillar footing, bottom beam, pillar and valve tower (ref. Figure 3-3 and 3-4). Most of both of Cai Lon and Cai Be sluice gates will be made of reinforced concrete of M400; particularly waterproof pile foundations will be made of Larsen IV steel piles (the length will be 9 m for Cai Lon and 12 m for Cai Be).

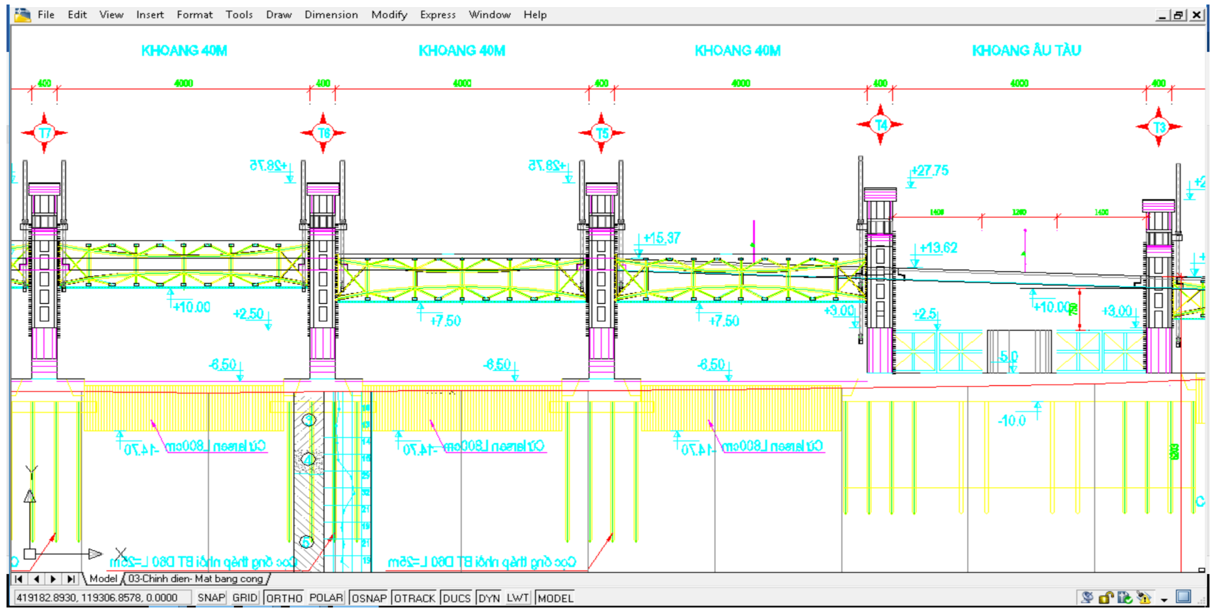

Figure 3-3. Cross-section of Cai Lon sluice gate

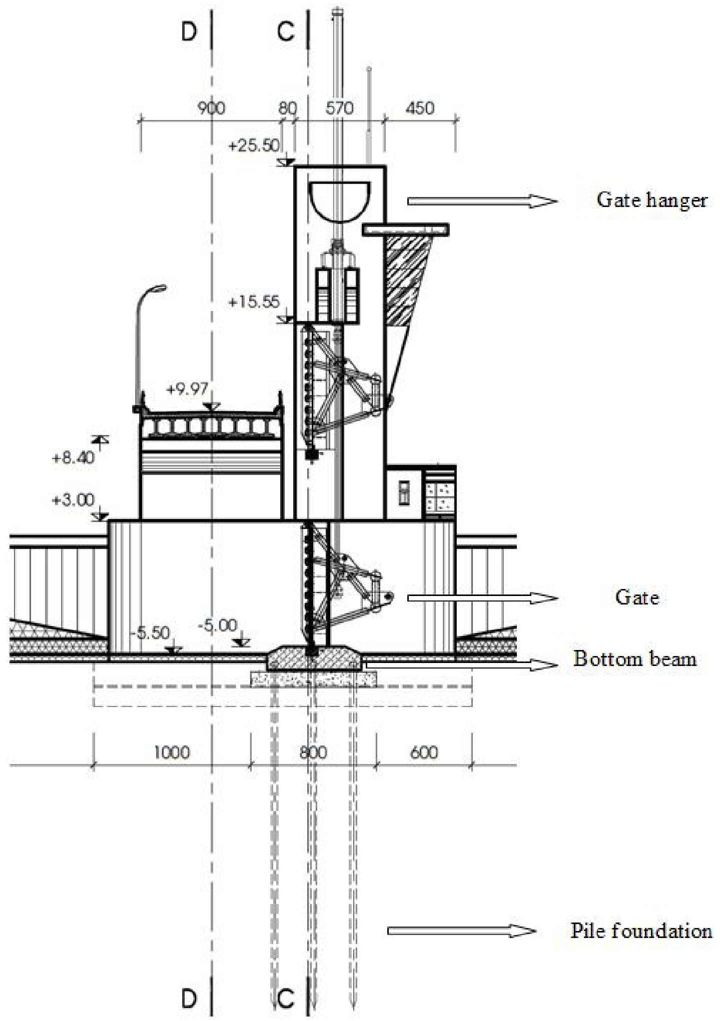

Figure 3-4. Longitudinal section of one pillar of Cai Be sluice gate

3.1.3. Ship lock of Cai Lon – Cai Be Sluice Gate

The main components of the Cai Lon ship lock have been identified as follows: lock chamber, lock head, filling and discharge culverts (Figure 3-5). These components are planned to be constructed of reinforced concrete of M300 and M400. The ship lock of Cai Lon sluice gate consists of two locks with dimensions of 15 m width and 130 m length, and sill levels of -5 m (ref. Figure 3-6). The ship lock of Cai Be sluice gate has only a lock with dimensions of 15 m width and 100 m length, and sill levels of -4 m. The pile foundation is made from reinforced concrete. The function of the ship lock is to enable ships to move through the structure while the sluice gates are closing or in a closed position.

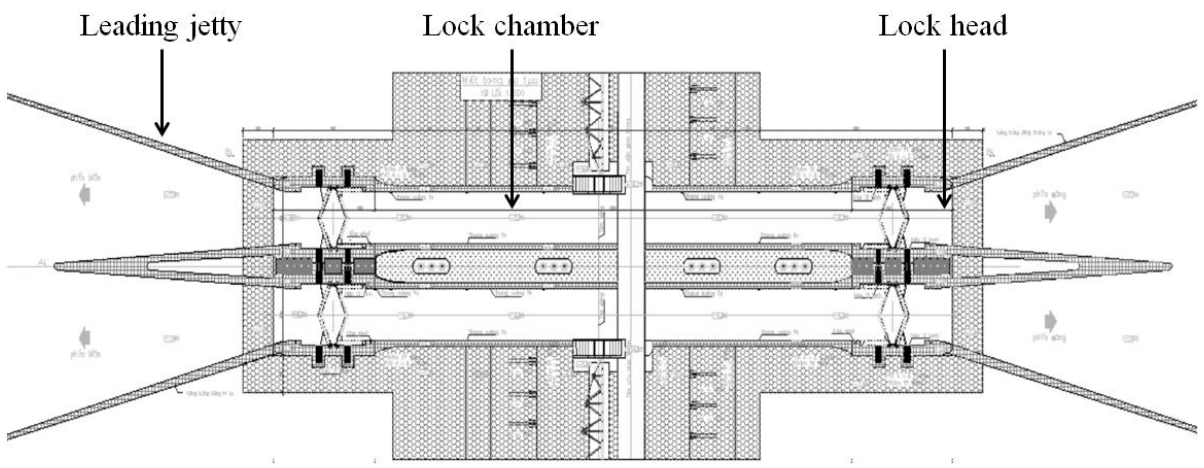

Figure 3-5. Plan of the ship lock at Cai Lon sluice gate

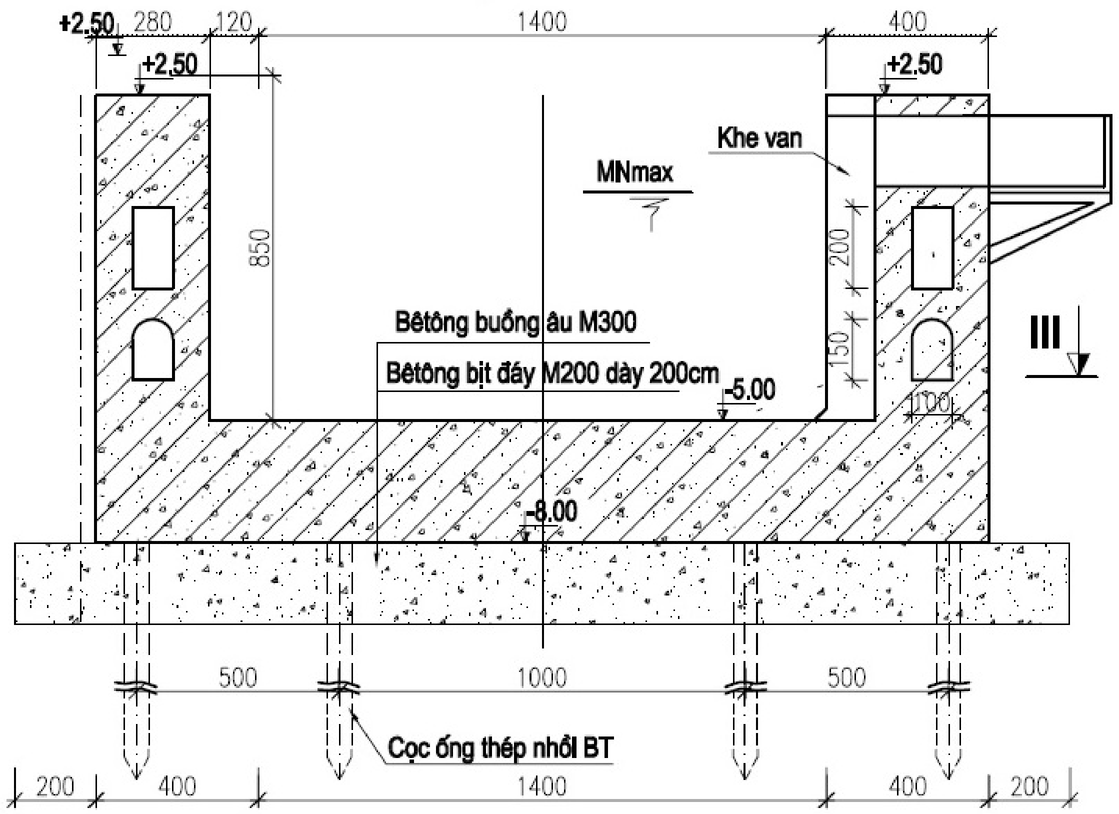

Figure 3-6. Cross-section of the ship lock at Cai Lon sluice gate

3. Data Gathering and Sufficiency

3.1.4. Sluice and ship lock gates

- Sluice gates

The lift gate type is recommended for both of the Cai Lon and Cai Be sluice gates (Figure 3-7 and 3-8). The primary duty of this infrastructure component is to control salinity intrusion. The sluice gate will be installed on the sluice gate structure and the gate(s) move up and down vertically along hydraulic cylinders. The three main components of the sluice gate are the gates, watertight gaskets and bolts.

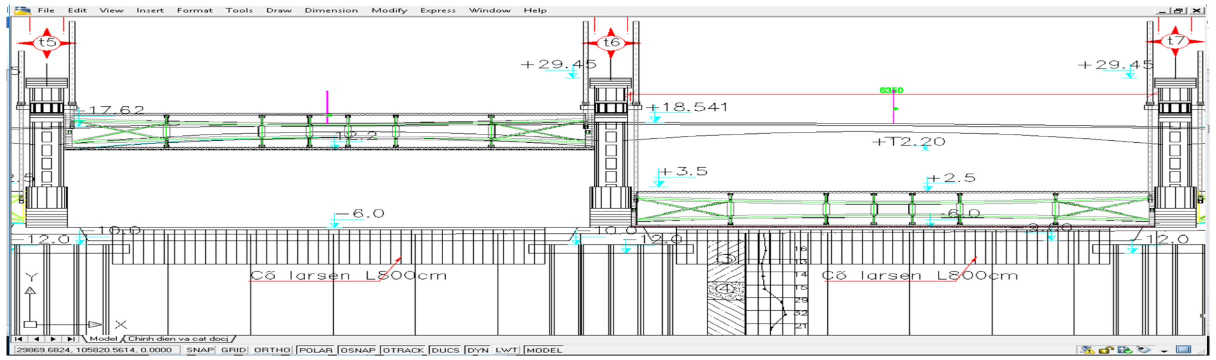

Figure 3-7. The gate design of Cai Lon sluice gate

Figure 3-8. The gate of Bao Chau sluice gate (the width of 31.6 m) in Ca Mau

As mentioned in the basic design reports, both the Cai Lon and Cai Be gates are recommended to be constructed of Q345 steel with coating, which has high durability and anticorrosion capability. The rubber watertight gaskets are to prevent water leakage through the gate when closed. The bolts are made of high-intensity steel and painted for high durability.

- Ship lock gates

Similar to the sluice gates, the gates of the ship locks will be made of high-intensity steel (ref. Figure 3-9) and are designed with two layers of "X-shaped" and alintel level of +2.50 m. The ship lock gates are plain gates and will be opened and closed by the hydraulic cylinders.

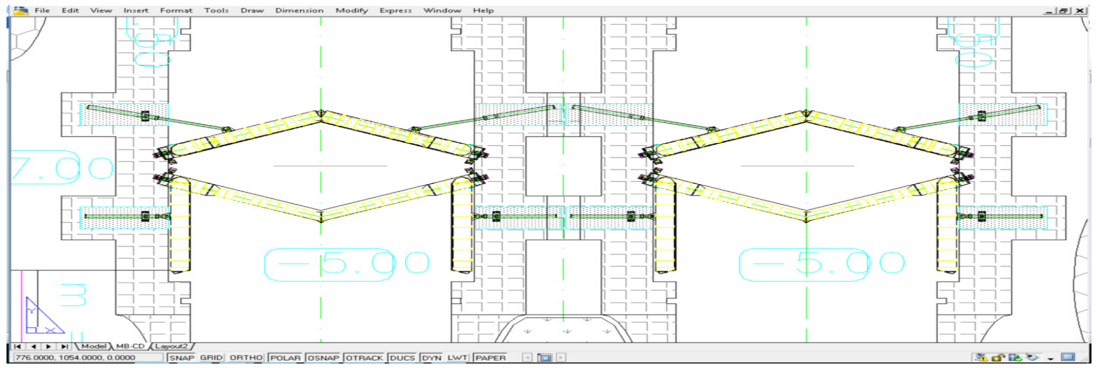

Figure 3-9. The ship lock gate of Cai Lon sluice gate

3.1.5. Bridge

Both the Cai Lon and Cai Be sluice gates are integrated with a bridge with a design load of HL93 made from reinforced concrete of M300. The bridge is designed with the width of 9.0 m (Figure 3-10). The main components of the bridge are pile foundations, bridge pier, bridge beams, bridge surface, bridge slope, expansion joints, handrails and lightninglightning system (ref. Figure 3-11), traffic signals and drainage system. Pile foundations are made from reinforced concrete and located in the ground. Other parts such as bridge piers and bridge beams are also made from reinforced concrete, but they are located on the land surface. The bridge surface will be paved with asphalt.

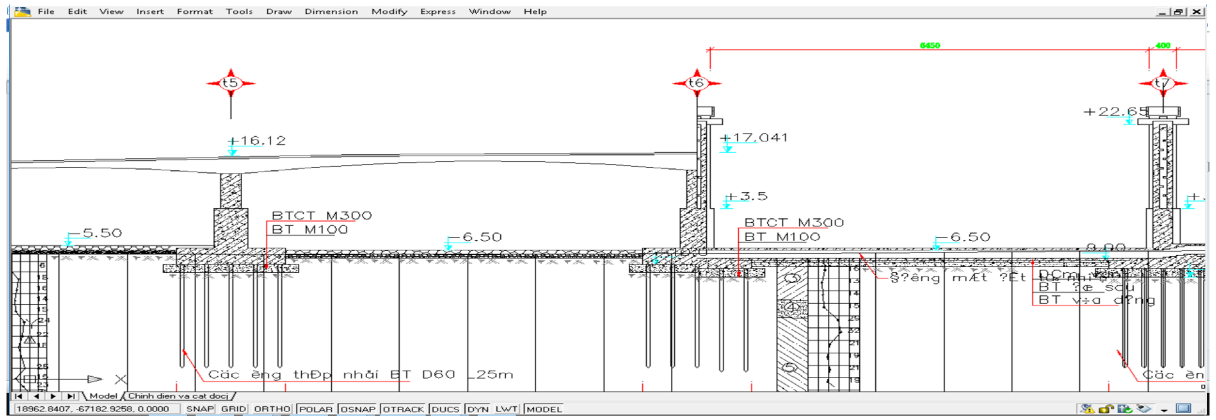

Figure 3-10. A longitudinal section of the bridge on Cai Lon sluice gate

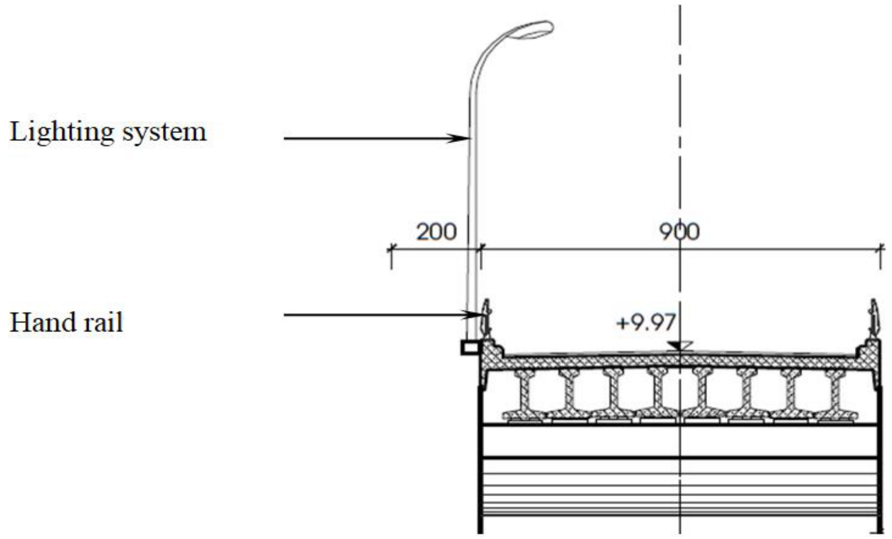

Figure 3-11. A cross-section of the bridge on Cai Be sluice gate

3.1.6. Retaining walls and connected embankment

The retaining walls are the parts that connect the sluice gate structures and river banks (ref. Figure 3-12 and 3-13). The connecting section between the retaining walls and river banks is an earthen embankment. Similarly, stilling basins located before and after the sluice gates have the main role of anticorrosion due to the increase in velocity of stream flow at the locations of the sluice gates.

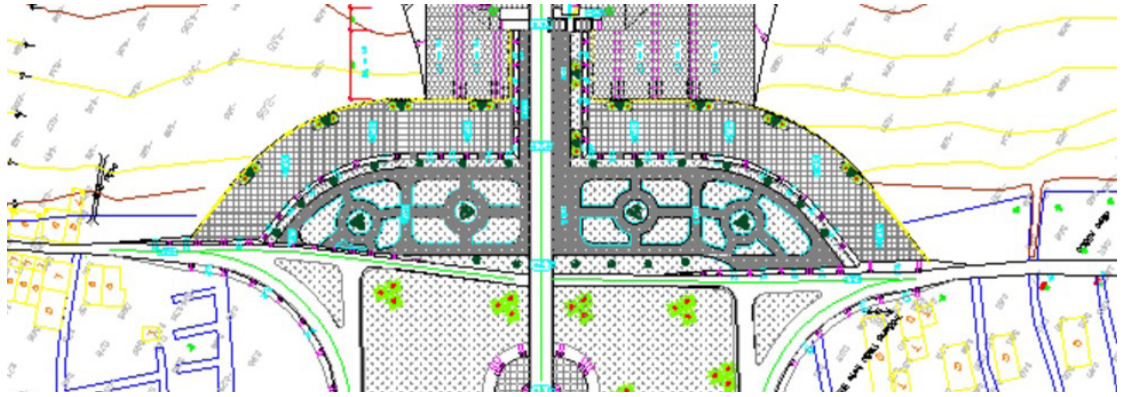

Figure 3-12. Retaining walls and connected embankment of Cai Lon sluice gate

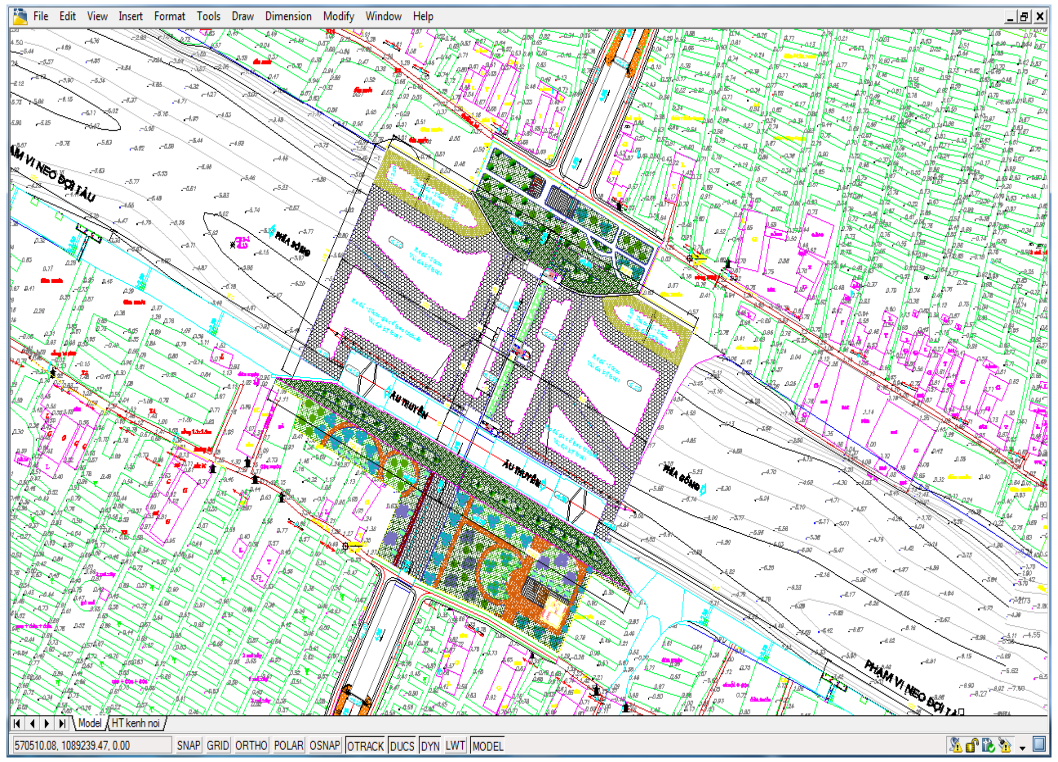

Figure 3-13. Retaining walls and connected embankment of Cai Be sluice gate

The retaining walls will be constructed with precast concrete piles backfilled earth (mechanically stabilized earth) connecting the sluice gates and river banks. The connected part of the retaining walls and river banks for the Cai Lon sluice gate will be made of precast concrete piles. The next sections are river banks which are constructed slopes and protected by growing grasses. Similarly, stilling basins in the river bed areas are reinforced by gabions with a thickness from 0.3 to 0.5 m.

3.1.7. Operation houses

The operation houses will be made of concrete and bricks and include house structures (e.g., columns, beams, front steps, windows, roofs) and equipment (e.g., control system, operational and management tools, tables, computers, lights, etc.). Figure 3-14 illustrates the overall perspective of the operation house of the Cai Lon sluice gate. Particularly, the operation house will be a three-story house in case of the Cai Lon sluice gate and a single-story house for the Cai Be sluice gate.

Figure 3-14. Plan and perspective of the operation house in Cai Lon sluice gate

3.1.8. Park

In order to create a good view, the park will feature iron fences, trees, flowerpots, the grass and lightninglightning systems (ref. Figure 3-15).

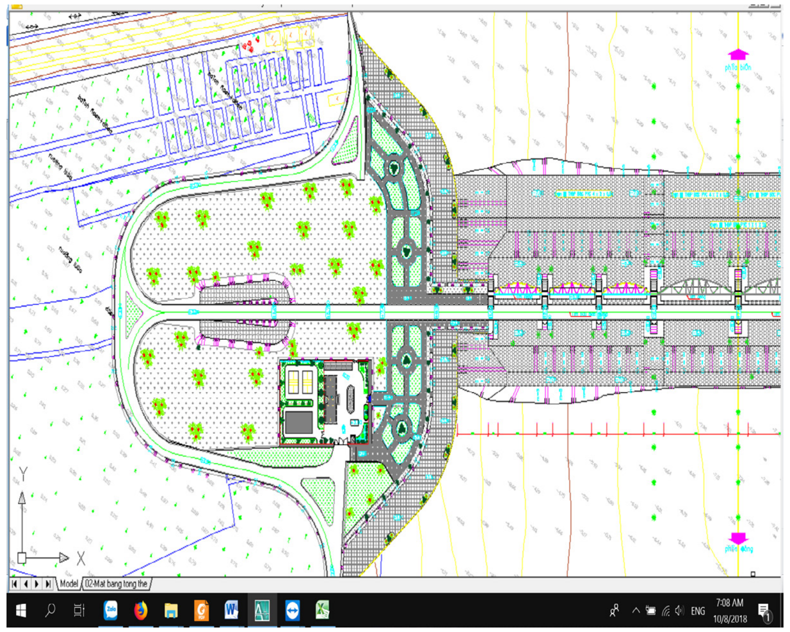

Figure 3-15. Plan of park

3.1.9. Electric system

The electric systems for both the Cai Lon and Cai Be sluice gates will include three main components namely grid supply, backup generators and lightning protection system. These components are illustrated in Figure 3-16.

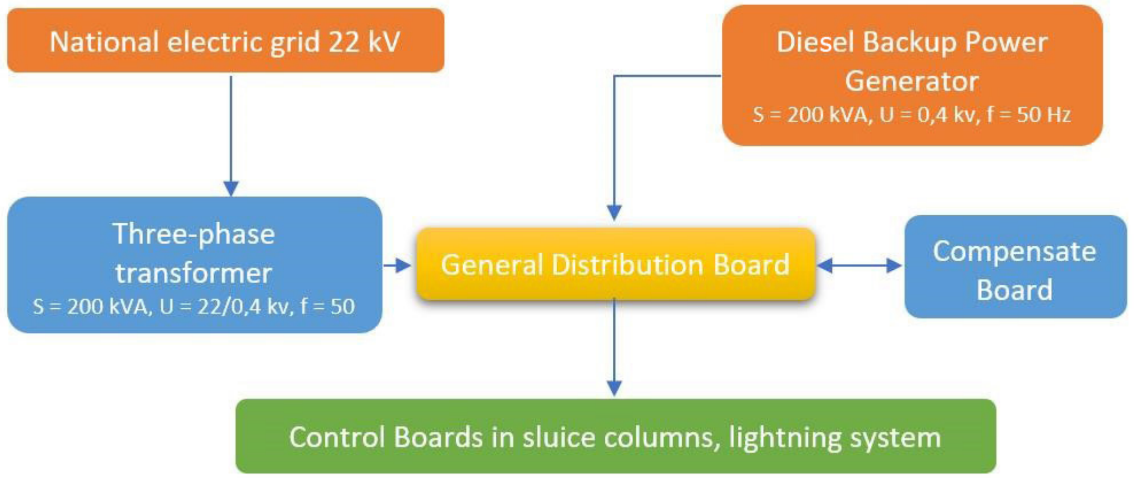

Figure 3-16. The electric system in the sluice gates

a. *Electric line system*

The electric line system for the Cai Lon and Cai Be sluice gates will use the national grid power of 22 KV via the transformers/substations of S = 1,500 kVA, U = 22/0.4 kV, f = 50 Hz. These transformers are located in the operation houses to supply the electric power of 0.4 kV for loads, including the sluice gates operation system; the gates control system; and indoor and outdoor lightninglightning facilities.

Cable lines are made of copper wires that are covered and protected by polyvinyl chloride-PVC (Cu/XLPE/DSTA/PVC-0.6/1 kV) and Cross-linked Polyethylene (XLPE).

b. Backup generator

The diesel backup generator has capacity of S = 1,500 kVA, U = 0.4 kV, f = 50 Hz. It will be started manually when the grid power is disrupted. Normally, it will be placed near the transformer/substation in the operation house. The maximum site design load of a diesel backup generator depends on the capacity of storage tanks.

c. Lightning protection system

The lightning protection systems are designed in the Cai Lon and Cai Be sluice gates to protect staff and the electric system from damages caused by lightninglightning. The Ioniflash Mach 45 system is part of the designin this case and it is to be placed on the 14 m high lightning poles.

3.1.10. Operation and control system

The operation and control system consist of two main components: operation system and control system. The operation system is located near sluice gates to open and close the gates. The control system has monitoring components placed at the sluice gates and control stations installed in the operation houses.

a. Operation system

The operation system is installed to control the sluice gates and ship lock gates. It includes three main components: hydraulic cylinders, the fluid supply system and electrical panels.

- Two hydraulic cylinders are installed vertically along the pillars. The barrel/cover and rod mount/head of the cyclinders are made of corrosion resistant steel.
- The fluid supply system consists of fluid tanks, fluid supply tubes made of corrosion resistance SUS304 steel, and two electrical pumps and one manual pump. The function of this system is to supply fluid for the two hydraulic cylinders associated with each gate.
- The electrical panels are placed next to the fluid tanks.

Figure 3-17 shows the operating system in Lang The sluice gate in Tra Vinh Province

Figure 3-17. Hydraulic cylinders at Lang The sluice in Tra Vinh Province (Taken by the Vietnamese Assessment Team on 23/09/2018)

3. Data Gathering and Sufficiency

b. Control system

The main components of the control system are measuring panels, a control station and control monitors. The data related to water level, the process of opening and closing gates, and hydraulic cylinders will be recorded by the measuring panels. This data then will be transmitted to the control station where they will be treated and displayed on the control monitors. Staff will execute their commands based on control monitors that allow them to open or close the gates.

3.1.11. Monitoring system

The monitoring system of the Cai Lon and Cai Be sluice gates includes the movement monitoring system, the environmental monitoring system, and cameras.

- **The movement monitoring system** is used to monitor any error and failure occurring in the operation process of the sluice gates. The main part of this system is elevation benchmarks placed on the pillars at upstream, downstream and river bank locations. Any data related to vertical or horizontal transposition, seepages and pressure will be detected.
- **The environmental monitoring system** includes the sensors to record water level, salt concentration, BOD and COD at the 10 selected points in the region surrounding the Cai Lon and Cai Be sluice gates. This data will be used to change the operation procedure of the Cai Lon and Cai Be system appropriately.
- **Cameras** are set up upstream and downstream of the sluice gates. These cameras are used to monitor boats and support operational staff to give warnings when opening and closing the sluice gates.

3.1.12. Fire extinguishing system

The fire extinguishing system of the Cai Lon and Cai Be sluice gate project was designed based on the Vietnamese standards TCVN 5738-2001 and NFPA72. This system has alarm bells, warning signs, fire and smoke detectors, and extinguishers. Particularly, the Cai Lon sluice gate has antique fire hydrants. Systematically, fire and smoke detectors detect the fire and warning the fire location to staff by alarm bells. This system is critical in terms of safety, so it will be maintained regularly under relevant regulations and standards such as Circular No. 52/2014/TT-CA.

3.1.13. Communication system

The communication system includes sending and receiving devices such as telephones, telephone lines, fibre optic cables, wireless devices, and cellular phones.

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3.2. Time Horizon for the Assessment

The Cai Lon and Cai Be sluice gates are designed with a lifespan of 70 to 100 years for the physical structures made of cast-in-situ reinforced concrete. The lifespan of other components varies depending on their materials. Table 3-2 shows designed lifespans for the main components.

Table 3-2. Time horizon for the Cai Lon-Cai Be assessment

System	Design life (year)	Material	Source
Physical structures (cast-in-situ concrete composition)	70-100	Reinforced concrete of M300-400, Larsen IV	- Project documents; - Similar infrastructures
Mechanical system (gates, hydraulic cylinders)	30-50	Steel of Q345 or SUS304	
Rip-rap sections	25-40	Precast concrete pile, gabions	
Electric power supply	15-20	PVC, copper wires	
Control and monitoring systems	10	Sensors and cables	
Communication system	15-20	PVC, cables	
Watertight gasket	5-10	rubber	

3.3. Specific jurisdictional considerations

The standards and regulations that were used to design for the Cai Lon and Cai Be sluice gates are listed as follows:

a. *Sluice gate structure, ship lock and bridge design standards*

- QCVN 04-05-2012/BNNPTNT: National technical regulation on hydraulic structures - The basic stipulation for design;
- QCVN 07-2012/BKHCN: National technical regulation on steel for the reinforcement of concrete;
- TCVN 10400-2016: Hydraulic structures - Pillar dam - Technical requirements for design;
- TCVN 9144:2012: Hydraulic structures – Requirement for ship lock design.
- TCVN 5664-2009: Technical decentralization of inland waterways;
- TCVN 8422-2010: Hydraulic structure – Design of adverse filter;
- TCVN 9152-2012: Hydraulic structures - Designing process for retaining walls;
- TCVN 9139-2012: Hydraulic structures - Concrete and reinforced concrete structures in coastal areas - Technical specifications;
- TCVN 4116-1985: Hydraulic concrete and reinforced concrete structures;
- TCVN 9902-2013: Hydraulic structures - Requirements for river dyke design;
- TCVN 4253-2012: Hydraulic structures - Foundation of hydraulic projects - Design standard;
- TCVN 8421-2010: Hydraulic Structures – Loads and actions of wind-induced and Ship-induced waves on structures;
- TCVN 10304-2014: Pile foundation – Design standard;
- TCVN 5575-2012: Steel structures - Design standard;
- 22TCN 272-05: Specification for bridge design;
- TCVN 4054-2005: Highway – Specifications for design;

b. *Gate design standards*

- TCVN 8298-2009: Hydraulics structures - Technical requirements for manufacturing and installing mechanical equipment, steel structures;
- TCVN 8299-2009: Hydraulics structures –Technical requirements for steel gate and groove design;
- TCVN 8640-2011: Hydraulic structures - Operating cable mechanism - Technical requirements for designing, manufacturing, installation and inspection;
- TCVN 8646-2011: Hydraulic structures - Zinc covered surface of steel structure and mechanical equipment - Technical requirements;

c. *Embankment design standard*

- TCVN 8419-2010: Hydraulic structure - Design of river bank flood protection structures;
- 22TCN 219-94: Design standards for river port facilities.

d. *Electric power system design standard*

- TCVN 9163-2012: Hydraulic structures - Electro-mechanic drawing - Content requirements;

e. *Operational and management procedure standards*

- TCVN 8412-2010: Hydraulic structure - Guideline for setting operation procedure;
- TCVN 8418-2010: Hydraulic structure - Process for management, operation and maintenance of sluice;

f. *Relevant standards and circulars*

- TCVN 9345:2012: Concrete and reinforced concrete structures - Guide on technical measures for prevention of cracks occurring under hot humid climate;
- TCVN 8828:2011: Concrete - Requirements for natural moist curing;
- TCVN 12041:2017: Concrete and reinforced concrete structures – General requirements for design durability and service life in corrosive environments;
- QCVN 02:2017/BTC: National technical regulations on generators for national reserve;
- Circular No. 70/2015/TT-BTNMT: issued on 23 December 12, 2015 about "Automatic hydro-meteorological gauges - Technical requirements for designing, installing and operating".

3.4. Identify relevant hydro-meteorological parameters

Based on the basic design reports and hydro-meteorological data of the study area, the interactions between infrastructure components and hydro-meteorological variables are summarized in Table 3-3.

Table 3-3. Interactions between infrastructure components and hydro-meteorological variables

	Components	Hydro-meteorological parameters	Mechanism of impact
1	**Operation**		
1.1	Regular maintenance staff	Storm; **Lightning**; Heavy rainfall; High wind.	• Lightning and storms may cause injury to the staff; • Heavy rainfall and high wind create operational difficulties.
2	**Sluice gate structure**		
2.5	Pillar	High temperature; **Water level**; Salinity intrusion; Velocity; *Storm;* *Storm surge;* *Tides;* *Heavy rainfall;* *High wind;* *Sea level rise.*	• The increase in water level may lead to overtopping affecting the functionality of pillars; • Storm, tides, heavy rainfall, hind wind, storm surge and sea level rise will generate cumulative impacts leading to water level rise; • High temperature and velocity may cause cracking, erosion and increase the corrosion; • Salinity may corrode reinforced concrete structure, particularly at the positions where the water level often changes, thereby reducing the lifespan of the infrastructure.
3	**Ship lock**		
3.1	Lock chamber	**Velocity;** Salinity intrusion; Water level; *Storm;* *Storm surge;* *Heavy rainfall;* *High wind;* *Tides;* *Sea level rise.*	• The increase in velocity of streamflow may cause accidents for boats • Changing water level may affect the operation of the lock chamber; • Other factors contribute to the increase in water level. • The impacts of salinity are similar to those on the pillars.
4	**Sluice – ship lock gates**		
4.1	Gates	**Water level;** Salinity intrusion; Velocity; *Storm;* *Storm surge;* *Heavy rainfall;* *High wind;* *Tides;* *Sea level rise;* Lightning.	• Water level affects the stability, functionality and operation of gates; • Salinity may corrode gates, especially the positions scratched or peeled; • The increase in velocity may cause accidents for boats when they are passing gates; • Storms will affect the gate when it is hanging; • Gates are vulnerable to lightning; • Other factors contribute to the increase in water level.
4.2	Watertight gasket	**Water temperature;** Air temperature; Salinity intrusion; Heat wave.	• Watertight gasket is vulnerable to high air temperature and heat waves; • Salinity intrusion may reduce the lifespan of the watertight gasket. • Salt water combined with heat wave may reduce the lifespan of the watertight gasket when the gates are closed or opened.
5	**Bridge**		
5.4	Bridge surface/slope	**Heavy rainfall;** Storm; Heat wave.	• Heavy rainfall is a major factor causing damage to the bridge surface/slope; • Storms and heat waves may exacerbate this damage.
5.5 5.8 5.9	Handrail Lightning system Traffic signals	**Storm**; Heavy rainfall; High wind; **Lightning.**	• Storms and lightning have a strong impact on these components; • Wind and rainfall also have impacts but less.
6	**Retaining walls and connected embankment**		

	Components	Hydro-meteorological parameters	Mechanism of impact
6.1 6.2 6.6 6.8	Retaining walls Connected embankment Rip-rap sections of connected embankments Riverbanks	Water level; **Heavy rainfall;** *Storm surge;* *Tides;* *High wind;* *Sea level rise;* Drought; Heat wave.	• Heavy rainfall and changes in water level may increase the instability risk of slope and embankment; • Drought and heat waves damage the soil structure and lead to erosion of riverbanks; • Others contribute to the increase in water level.
6.7	Riverbed gabion	Discharge; **Velocity.**	• The increase in velocity and discharge will cause erosion for this component.
7	**Operation houses**		
7.1 8.1 8.2	House structure Protection fences Trees, flowers and the grass	**Storm;** Heavy rainfall; High wind.	• Storms and heavy rainfall may damage front steps and windows; • High wind may cause some damage to trees and flowers.
9	**Power supply**		
		Storm; Heavy rainfall; **Lightning;** High wind.	• The electric power supply is the most vulnerable to lightning; • Other factors may affect it but less.
10	**Operation and control system**		
10.1 10.2	Operation system Control system	Lightning **Storm** Heat wave High wind	• Hydraulic cylinders may be damaged due to lightning; • Salt water may affect metal cylinders and structures; • Various sensors and data transfer parts may be damaged due to storms; • The components of the system may be affected by heatwaves.
13	**Communication system**		
		Storm High wind Lightning	• Lightning may disrupt the communication. • Storm and high wind are similar threats, but to a lesser degree.

Noted:

Symbol	**Bold**	Underline	Normal	*Italic*
Magnitude of impact	**High**	Moderate	Low	*The cumulative impact*

3.5. Identify Infrastructure Threshold Values

3.5.1. Threshold values based on basic design reports

In general, the forces exerted on a certain hydraulic infrastructure component include vertical forces (self-weight, uplift load), horizontal forces (water load, silt load, wave load, wind load), and special loads such as earthquakes. For a sluice gate, the water load is the main force generated by the difference of water levels at the sea and in the field (i.e. upstream and downstream of the gates). In case of the Cai Lon and Cai Be sluice gates, because these sluice gates are in the design stage, the values used in calculating and testing the stability for adverse cases are considered as thresholds of the design. According to the 22TCN 272-05 and TCVN 10400:2015 standards, the gates and pillars of the Cai Lon sluice gate were calculated and tested with a load combination including the self-weight load, earth and silt load, earthquake load, transportation load, wind load, storm surge load and sea level rise load. The following explanation will clarify threshold values from these calculations (evaluating procedures).

a. *The stability analysis of sluice gates and ship lock gates of Cai Lon*

The stability analysis of sluice gates and ship lock gates of Cai Lon was conducted based on the difference of water level in front of the gates (at the sea) and water level behind the gates (in the field). Particularly, the adverse case is tested when water level at the seaside is +2.5 m (an equivalent to a combination of the maximum tide level with the probability of 5%, sea level rise in the scenario of 2050 and storm surge of Level 9) and water level of +0.0 m in the field (corresponding to minimum water level in the field with the probability of 99%)

b. *Crest of sluice gates and ship lock gates of Cai Lon*

The design crest level of sluice gates and ship lock gates of Cai Lon were +2.5 m (including maximum water level with the probability of 5%, sea level rise in the scenario of 2050, storm surge of Level 9 and a safety height increment). If the water level is higher than this value, the functionality of the gates will be affected.

c. *Sluice gate structures of Cai Lon*

Regarding to the sluice gate structures of Cai Lon, the stability analysis was tested for the case of the wind load of 25.0 m/s and two cases of water level difference: (1) the water level on the sea side is 2.64 m (including the maximum water level with the probability of 0.2%, storm surge of Level 9 and sea level rise in the scenario of 2100) and the water level in the field is 0.2 m (the minimum water level in the field with the probability of 99%); (2) the water level on the sea side is -0.77 m (corresponding to the minimum water level with the probability of 0.99%) and the water level in the field is +1.2 m (an equivalent to the maximum water level in the field with the probability of 0.2%). In addition, the velocity of streamflow should be lower than 1.5 m/s to ensure safe conditions of navigation when boats are passing the sluice gate structures.

d. *Crest of Cai Be sluice gates*

Design crest levels of sluice gates of Cai Be were selected at +2.5 m (an equivalent to a combination of the maximum water level at the sea with the probability of 0.2%, storm surge of Level 9 and sea level rise in the scenario of 2100).

e. *Crest of embankments and pillars of Cai Lon and Cai Be*

Design crest levels of embankments and pillars of both Cai Lon and Cai Be were selected at +3.0 m. They must be higher than the crest levels of the sluice gates.

f. *Ship lock*

Design water level was +1.12 m (corresponding to the maximum hourly water level with the probability of 5%). If the hourly water level is higher than this value, the movement of boats with the loading capacity of more than 1,000 tons for Cai Lon ship lock and 400 tons for Cai Be ship lock will be affected. In addition, the velocity of streamflow through ship locks should be lower than 1.5 m/s in terms of navigational safety.

g. Stilling basin

The velocity of streamflow in front of and behind the sluice gates must not exceed 1 m/s in order to prevent the erosion at bottom of sluice gate structures.

h. Watertight gasket

The degree of volume expansion of watertight gaskets must not exceed 2% in the water environment with the temperature of 70°C.

3.5.2. Threshold values based on additional standards, regulations and studies

In addition to threshold values above, each infrastructure component has some standards, regulations and studies guiding and analysing the impact of climatic variables on the component, depending on its material. In fact, the combination of hydro-meteorological variables may affect a certain infrastructure component more severely. Moreover, due to the project being in the basic design stage, the materials for all components may not have been mentioned and/or stated firmly. In order to contribute to the material assessment and selection for next steps of the project, this report documents the interactions between the constructional material and climatic variable based on additional documents as follows

a. Components made of cast-in-situ reinforced concrete

The interactions of components made of cast-in-situ reinforced concrete and climatic variables were documented in the standard of TCVN 9345:2012. Specifically, the standard of TCVN 8828:2011 also documented that the high temperature and sunshine can make the temperature of reinforced concrete increase to 50-55°C in the curing time for concrete. In the next stages, the high temperature will increase the physical and chemical process that causes corrosion. Moreover, the corrosion of reinforced concrete has a variety of causes such as Cl^-, SO_4^{-2} (chemical process); wave, rainfall, streamflow (physical process); marine animals such as *Austromegabalanus psittacus* (biological process) and/or the maintenance (operation and management process). Nevertheless, most of documents mention that high temperature will increase the degree of corrosion on reinforced concrete structures. ([15]; [16]; TCVN 12041:2017). In fact, in the MKD, corrosion has been recorded at some sluice gates (ref. Figure 3-18).

Figure 3-18. Corrosion recorded at Ho Phong sluice gate

b. Bridge surface

3. Data Gathering and Sufficiency

According to TCVN 11823-9:2017, the material for the bridge surface/slope should accommodate a temperature range of -30ºC to 50ºC, excluding the load factor.

c. Components made of steel (gates, hydraulic cylinders)

Some studies documented and examined the causes of steel corrosion, mainly in steel bridges. The main causes highlighted are the high salt concentration in the air moisture (for example Japanese standard is 0.05 mdd: mg.NaCl/dm²/day); the distance from structures to the sea; and the duration of high humidity condition [17]. The assessment team recorded corrosive effects on the hydraulic cylinders at some sluice gates in the MKD. These effects have occurred frequently after 2-3 years of the operation (ref. Figure 3-19).

Figure 3-19. Corrosion recorded at Lang Tram gates (on the left) and hydraulic cylinders at Can Chong sluice gate (on the right)

d. Power supply and backup generators

According to technical requirements for design, the materials used for transmission lines and their covers should accommodate high temperatures of 120 to 180oC. The backup generators have to be protected from heat (below 35oC) and moisture (not exceeding 85%) (QCVN 02:2017/BTC).

e. Automatic measuring devices

Automatic measuring devices will be selected depending on the scale and purposes of stations. However, the devices have to work properly in the environment with the air temperature from -10oC to 60oC (Circular No. 70/2015/TT-BTNMT).

3.6. Climate and hydrological analysis and projections

3.6.1. Introduction

3.6.1.1 Objectives

This section will determine the PIEVC probability of occurrence scores for each hydro-meteorological element in the study area for both the baseline and future climate. In order to achieve this objective, it is necessary to analyse the historical data, evaluate the trends, and project the future changes for these factors. In addition, the assessment team has also considered the cumulative effects of two or more climatic and hydrological factors occurring at the same time.

3.6.1.2 Time frame used for analysis

The time frame for historical data analysis is as follows:

- 30-year data (1988-2017) at the Rach Gia meteorological station for climatic factors, such as rainfall, temperature, evaporation, wind, and thunderstorm days;
- 30-year data (1988-2017) at 5 local rain gauges in Kien Giang province;
- 30-year data (1988-2017) for tropical storms/depression;

- 10-year statistical data (2005-2015) of damages caused by natural disasters such as lightning and tornado;
- 30-year data (1988-2017) at 8 hydrological stations (except for the data at Song Doc station which exists for 22 years) for water level;
- 22-year data (1996-2017) at 3 hydrological stations for salinity;
- 22-year data (1996-2017) at Can Tho hydrological stations for flow.

Projections have been taken into account for each of the selected climate - hydrological factors up to the year 2100. Probability scores have been determined in both historical trends and future projections based on the high emission scenario RCP8.5. RCP8.5 was selected as appropriate for long-lived infrastructures like Cai Lon – Cai Be Sluice Gates, following the recommendation in the report of MONRE (2016). Furthermore, the RCP4.5 scenario was also considered to check the trend of projections.

3.6.1.3 Probability scores in the PIEVC Protocol

The probability scores in the PIEVC Protocol reflect the probability of occurrence of each climate and hydrological phenomenon which is expected to have an impact on the infrastructure. In this project, the assessment team selected Method A of the Protocol's probability score factors to estimate the frequencies for both the historical data and projections. It was selected because it is appropriate for the scoring process involving professional judgement under circumstances of limited data availability. Scores are assigned between 0 and 7 as described in Table 3-4.

Table 3-4. Probability scores in the PIEVC Protocol

Score	Method A
0	Negligible Not Applicable
1	Highly Unlikely Improbable
2	Remotely Possible
3	Possible Occasional
4	Somewhat Likely Normal
5	Likely Frequent
6	Probable Very Frequent
7	Highly Probable Approaching Certainty

3.6.1.4 Methods used for data analysis

In support of the analysis of climate and hydrological data, the assessment team used the traditional statistical methods as well as the Climate Change Hazards Information Portal (CCHIP) (https://go.cchip.ca/) provided by Engineers Canada and Risk Sciences International (RSI). As a user-driven data retrieval tool, CCHIP allows to arrive at projections for climate and hydrological factors. The outputs from CCHIP for the study area in this project are provided using up to 40 climate models in an ensemble average.

3.6.2. Climate analysis and projections

This section analyses historical data, trends and projections of the following climatic factors, which may affect the infrastructure, as well as assign the probability scores for these factors.

- High temperature
- Heat wave
- Heavy rain
- Heavy 5-day total rainfall
- Tropical storm/depression
- Drought
- High wind
- Tornado
- Thunderstorm/lightning

Other factors such as low temperature, daily temperature amplitude, fog, hail, etc., are expected to have no influence or insignificant impacts on the Cai Lon – Cai Be Sluice Gates. Thus, these factors are not considered in this assessment.

In order to support the risk assessment in this study, the climate factors considered were defined in the next sections. In these definitions, the critical climate thresholds were identified based on Decision No. 46/2014/QD-TTg of the Prime Minister on providing for natural disaster forecasting, warning and communication and Decision No. 44/2014/QD-TTg of the Prime Minister on clarifying the levels of natural disasters.

3.6.2.1 High temperature

a. Historical data analysis

In this assignment, the value of high temperature has been defined as the average number of days in a year with a maximum temperature greater than 35°C. According to Decision No. 46/2014/QD-TTg of the Prime Minister on providing for natural disaster forecasting, warning and communication, 35°C is considered as an extreme threshold of temperature. The analysis of 30-year temperature data (1988 - 2017) indicated that the highest temperature recorded at the Rach Gia station was 37.2°C on 22nd April 1990. Furthermore, this analysis also indicated that there has been an average of 7.5 days with maximum temperature ≥ 35°C per year. Thus, the historical probability score for high temperature has been estimated to be "6".

The trend analysis of high temperature in Figure 3-20 indicated high temperature decreases at the Kien Giang station, especially from 2006 to present. This is also consistent with the results documented in the report of "climate change and sea level rise" by the MONRE (2016), which documented the number of days over 35°C at the Rach Gia station had a decreasing trend.

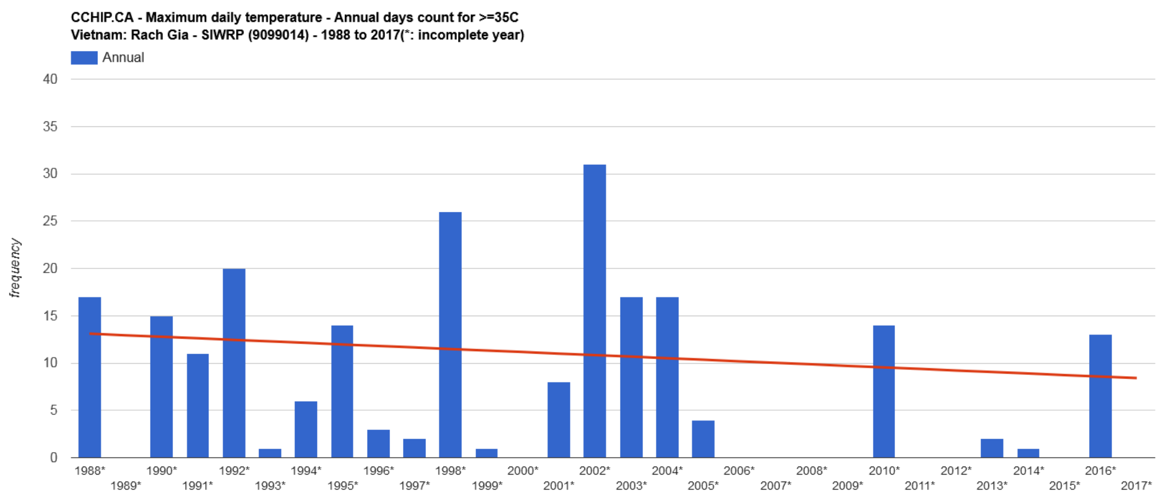

Figure 3-20. The number of days with the temperature ≥ 35oC (1988-2017)

b. Projections

The high temperature projection done by the MONRE (2016), and from the CCHIP tool, at the Rach Gia station are similar. In the report of MONRE (2016), the number of days with the high temperature in Vietnam tend to increase in the 21st century, especially at the end of the century. With the high emission scenario, this value is over 100 days.

On the other hand, the results from the CCHIP tool for the RCP 8.5 scenario in Kien Giang province indicated that the number of days with the high temperature increases to 13.7 days per year at the beginning of the century (to 2040), 36.3 days per year at the mid-century (1941 - 2070) and 88 days per year at the end of the century. These results also showed that the average increases of the high temperature are from 0.6 to 0.7°C, 1.7°C, and 3.0°C, respectively at the beginning, mid and end of the century.

In short, there is an increasing trend associated with high temperature in the future in the study area. Thus, the PIEVC probability score of the high temperature in the future has been estimated to increase to "7".

3.6.2.2 Heat wave

a. Historical data analysis

In addition to the high temperature, heat wave was also considered for the assessment of the vulnerability of the Cai Lon – Cai Be Sluice Gate project. In this report, heat wave has been defined as a period of 8 or more consecutive days in which the maximum temperature is greater than or equal to 35°C. According to the statistical data for the period from 1988 to 2017, at the Rach Gia station, there are four heat waves in total (two in 1988 and two in 2002) resulting in an annual frequency of 0.13. Thus, the PIEVC probability score related to heat wave for the historic period has been estimated to be "3".

For the trend of heat wave, Figure 3-20 illustrates that the temperature over 35°C hardly occurred in the period from 2006 to 2015 at the Rach Gia station. This figure also presented a sharp decrease of heat wave during the last 30 years in this area.

b. Projections

Although "heat wave" has had a decreasing trend over the past 30 years (1988-2017), the projections of MONRE (2016) and the CCHIP tool have indicated that the trend in the high temperature will increase in the 21st century (Section 3.6.2.1), especially at the end of the century (over 100 days per year for MONRE (2016) and 88 days per year for the CCHIP tool). With this forecast, "heat wave" would also tend to increase significantly at the end of the century. Thus, the future probability score of heat wave has been estimated to be "4".

3. Data Gathering and Sufficiency

3.6.2.3 Heavy rain

a. Historical data analysis

Heavy rain, for the purposes of this assessment, has been defined as the average number of days, in a given year, that had a total rainfall greater than or equal to 100 mm within a 24-hour period (corresponding to a "very heavy" rain event as stated in Decision No. 46/2014/QD-TTg). The 30-year (1988-2017) rainfall data showed that the highest daily rainfall recorded in An Minh, Kien Giang was 267.8 mm occurring on July 11, 2009. The frequency of the heavy rain events and the highest rainfall at the rain-gauging stations in Kien Giang are presented in Table 3-5. Thus, the historical probability score of the heavy rain in this case has been estimated to be "4".

Table 3-5. Heavy rain in the past 30 years (1988 - 2017)

No.	Station	day/year	Maximum daily rainfall (mm)
1	Vinh Hoa Hung	0.53	188
2	Rach Gia	0.67	220.3
3	Xeo Ro	0.77	194
4	Go Quao	0.53	167
5	Vinh Thuan	0.23	131
6	An Minh	0.67	267.8
	Mean	**0.57**	

For the trend of the heavy rain, the historical data showed that annual average rainfall in most stations in Kien Giang tends to change insignificantly; in particular, Rach Gia reduced by about 27 mm/year. The average number of rainy days per year at the stations ranges from 133 to 158 days and has a minor change. However, the average number of heavy rain days tends to decrease (ref. Figure 3-21).

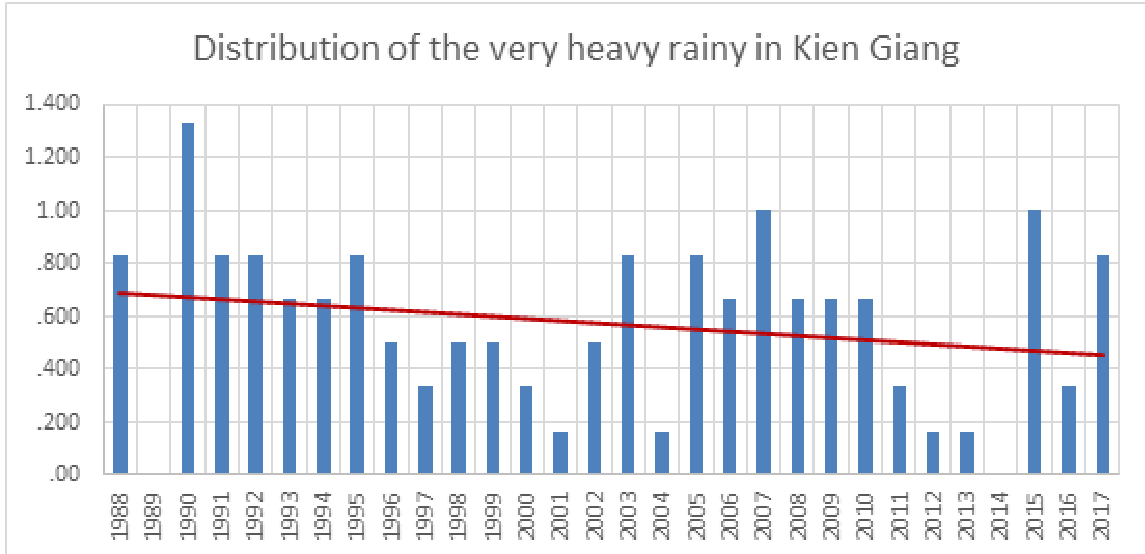

Figure 3-21. Distribution of the heavy rain in the period of 1988-2017

b. Projections

According to the results of MONRE (2016), the occurrence of heavy rain events demonstrates an increasing trend in Kien Giang. Under the RCP8.5 scenario, this increase is from 50% to 70% at the middle and end of the century. This forecast is also consistent with the forecast from the CCHIP tool (ref. Figure 3-22). The results of the CCHIP tool for the projection of heavy rain at the meteorological stations in Kien Giang province under the RCP8.5 scenario showed that there is an increase in heavy rain events (ref. Table 3-6). Therefore, the PIEVC probability score for this factor in the future has been estimated to increase to "5".

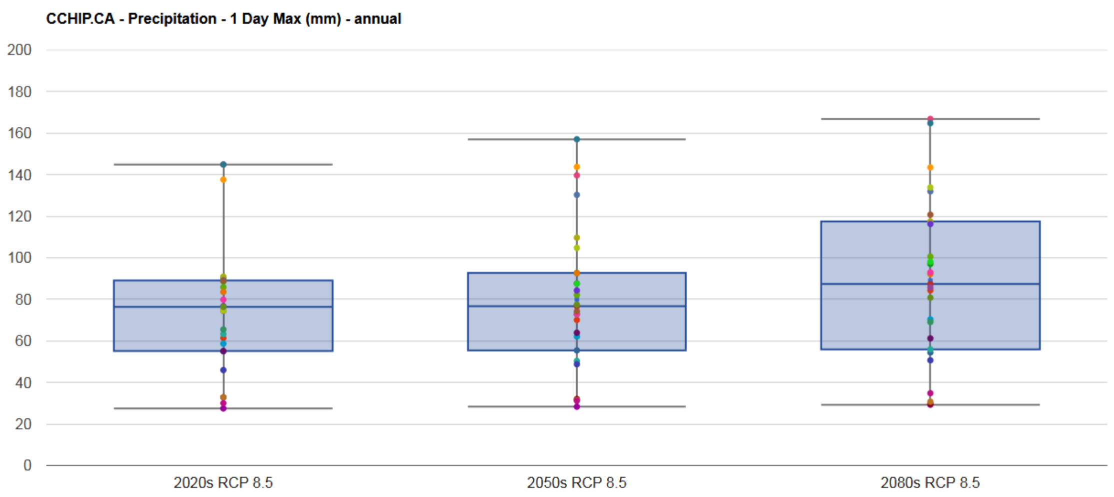

Figure 3-22. Daily maximum rainfall at the Rach Gia station for the RCP8.5 scenario

Table 3-6. The average number of heavy rain days for the RCP8.5 scenario

No.	Station	Day/year		
		1988 - 2017	2041 - 2070	2071 - 2100
1	Vinh Hoa Hung	0.53	0.7	0.73
2	Rach Gia	0.87	0.97	1.1
3	Xeo Ro	0.77	0.9	1.03
4	Go Quao	0.57	0.6	0.5
5	Vinh Thuan	0.23	0.33	0.43
6	An Minh	0.67	0.8	1.03
	Mean	0.6		0.8

3.6.2.4 Heavy 5-day total rainfall

a. *Historical data analysis*

In order to consider the impacts of the heavy rains on the infrastructure, this report also considered the number of the heavy 5-day total rainfall occurrences in a given year, where the heavy 5-day total rainfall was defined as a period of 5 consecutive days with a total rainfall being more than or equal to 250 mm. The historical data at the meteorological stations in Kien Giang for the 5-day heavy rainfall occurrences in a year is summarised in Table 3-7. The data outlined in the table indicates that the 5-day heavy rains occurred "normal", i.e., the historical probability score of this climate factor has been estimated to be "4".

3. Data Gathering and Sufficiency

Table 3-7. The heavy 5-day total rainfall in the period of 1988-2017

No.	Station	Event/year	Maximum total rainfall (mm)
1	Vinh Hoa Hung	0.23	316.4
2	Rach Gia	0.53	410.2
3	Xeo Ro	1.1	371
4	Go Quao	0.13	288.3
5	Vinh Thuan	0.33	298.7
6	An Minh	1.20	420
	Mean	0.59	

The results of rainfall data analysis for the period from 1988 to 2017 showed that the trend of the total 5-day rainfall has not changed, particularly the heavy 5-day rains tended to decrease. However, the number of the heavy 5-day rains had a slightly increasing trend at most of the meteorological stations in Kien Giang (ref. Figure 3-23).

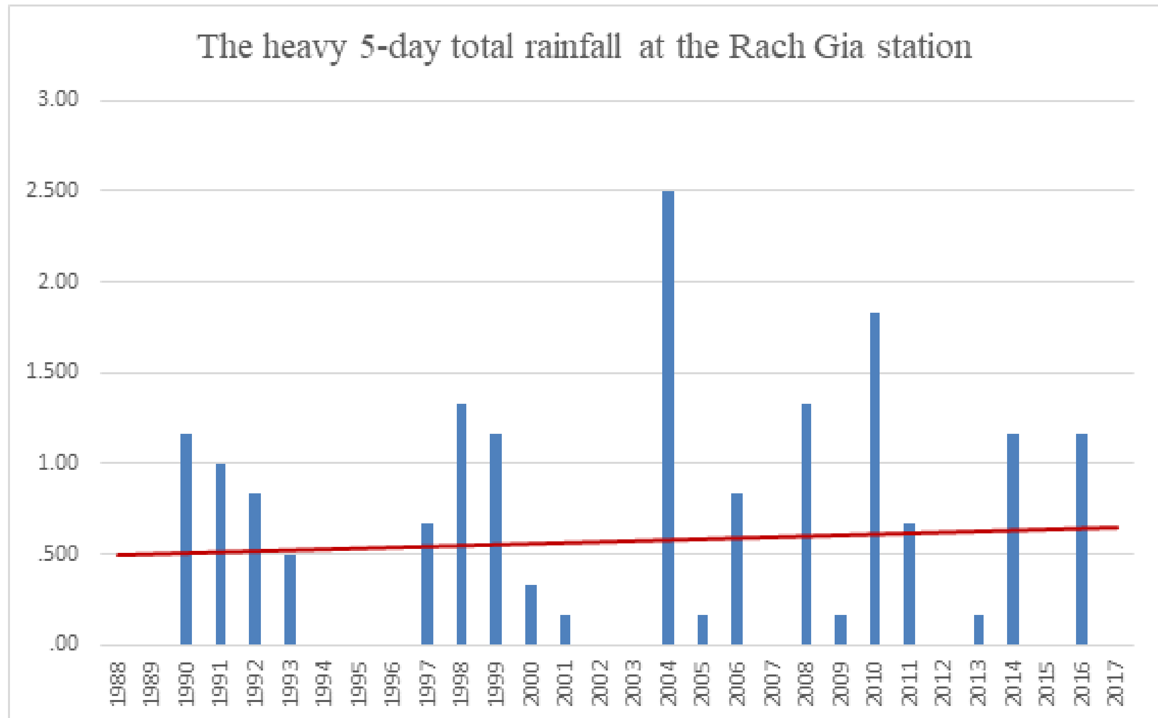

Figure 3-23. The heavy 5-day total rainfall at the Rach Gia station (1988-2017)

b. *Projections*

According to the climate change scenarios of MONRE (2016), Kien Giang is predicted to be one of the provinces which will experience a remarkable increase in the maximum 5-day total rainfall at the middle and end of the century. Both for the low and high emission scenarios increases of 40-70% are projected. However, the MONRE report did not mention a change in the number of the 5-day heavy rain occurrences. Also, the results from the CCHIP tool only indicated the change in the average 5-day rainfall. Therefore, it cannot be stated that the number of the 5-day heavy total rains will increase, decrease, or no change in the future. Thus, the future probability score of the number of the 5-day heavy rain occurrences has been estimated to remain at "4".

3.6.2.5 Tropical storm/depression

a. Historical data analysis

A storm event, for the purposes of this assessment, is defined to be a tropical cyclone in which the strongest wind is from level 8 (equivalent to a wind speed of 62 - 74km/h) or more, and may appear as wind gusts. In this study, the concept of tropical storms/hurricanes was understood as the number of storms directly affecting the study area in a year. Table 3-8 summarizes the number of tropical storms and depressions in the Southern Vietnam area for the period from 1988 to 2017. This data showes that in the past a storm landed in the study area about every six years. Thus, the historical probability score of the tropical storms has been estimated to be "3".

Table 3-8. Storms in the Southern Vietnam (1988 - 2017) Source: [18]

No	Name	Start	End	Storm level	Wind (kt)	Place entered
1	TESS	03/11/1988	06/11/1988	11	60	Binh Thuan
2	**ANGELA**	**15/10/1992**	**29/10/1992**	**12**	**65**	**Kien Giang**
3	TERESA	16/10/1994	26/10/1994	13	80	Binh Thuan
4	**ERNIE**	**7/11/1996**	**16/11/1996**	**8**	**40**	**Soc Trang, Bac Lieu**
5	**LINDA**	**31/10/1997**	**4/11/1997**	**10**	**50**	**Ca Mau**
6	ATNĐ04	22/10/1999	25/10/1999	7	30	Soc Trang, Tra Vinh
7	**MUIFA**	**13/11/2004**	**25/11/2004**	**13**	**80**	**Ca Mau, Kien Giang**
8	DURIAN	25/11/2006	6/12/2006	16	105	Vung Tau-Binh Thuan
9	PEIPAH	1/11/2007	10/11/2007	12	70	Binh Thuan –Ba Ria Vung Tau
10	PAKHAR	26/03/2012	2/04/2012	8	40	Binh Thuan –Ba Ria Vung Tau
11	ATNĐ 14	4/11/2013	7/11/2013	7		South of Vietnam
12	**TEMBIN**	**20/12/2017**	**26/12/2017**	**12**	**70**	**Ca Mau**

Note: **Bold lines** are the storms directly affecting the study area.

According to the statistical data (1988 – 2017) from Vietnam and Japan Meteorological Agency (JMA), the number of tropical storms and depressions in the East Sea was 259, of which 178 storms directly landed in Vietnam, 12 storms in Southern Vietnam, and 5 storms and one depression directly in the study area. This data showed that the frequency of storms directly affecting the study area was very low, compared to Vietnam as a whole. Most storms in the study area occurred from October to December. In recent years, the occurrence of strong storms (level 12 and above) has tended to increase, and the storm season is ending later [8].

Of the five storms that hit the study area, tropical storm Linda in November 1997 was the strongest and most damaging for the past 100 years (ref. Figure 3-24). As this storm swept through the study area, the highest wind speed observed in Ca Mau province was 28.0 m/s.

Figure 3-24. The path of tropical storm Linda (November 1997)

b. Projections

With regard to estimation of trends associated with tropical storms and depressions in the 21st century, the IPCC's most recent assessment showed that it is not possible to identify with confidence the trend of storm frequency on a global scale (including the North-western Pacific Ocean). Under the impact of climate change, the storm intensity is likely to increase 2-11%, and the rainfall in the radius of 100 km from the storm eye is likely to increase by about 20% [18].

According to the RCP8.5 scenario of MONRE (2016), tropical storms and depressions affecting Vietnam are likely to decrease in terms of frequency at the end of the century. The number of storms has an increasing trend at the end of the storm season, especially in the RCP8.5 scenario. Thus, the tropical storms and depressions tend to move towards the end of the storm season, when they mainly appear in the south. In terms of the storm levels, the number of weak and medium storms tends to decrease while the number of strong and very strong storms tends to increase considerably. With regard to storm intensity, the emergence of tropical storms, which are stronger than tropical storm Linda, directly affecting the study area is projected to have a higher frequency in the future.

Thus, the frequency of storm occurrences in the Southern Vietnam is expected to increase, compared to the historical data. The probability score for tropical storms and depressions in the future has been estimated to be "4", meaning that they are expected to occur at a "*normal*" level.

3.6.2.6 Drought

a. Historical data analysis

Drought is a complex term that can be defined in a variety of ways, such as meteorological drought, hydrological drought and agricultural drought. In the MKD, droughts can occur in the both, the dry and the rainy season of the year. However, in this report, the assessment team only considers droughts that occur during the dry season, as this is a prominent feature in the Mekong Delta.

There are many different indicators to determine droughts. In terms of meteorology, a drought is defined by the rate between evaporation and rainfall, namely the water balance factor K. In this study, drought was defined by the number of years that the water balance factor K in the dry season is greater than 4. The data analysis from 1988 to 2017 showed that there were 13 drought events occurring at the Rach Gia Station, corresponding to the frequency of 43%. Thus, the historical probability score for the drought in this case has been estimated to be "5".

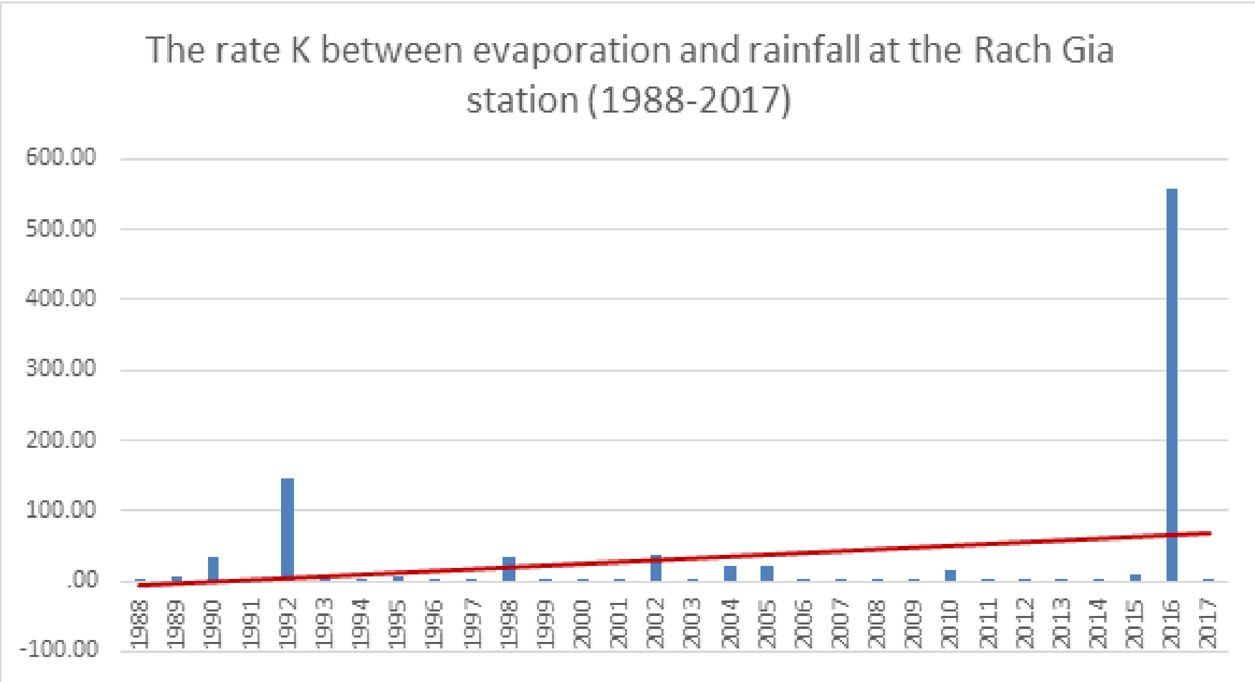

Figure 3-25. The rate K between evaporation and rainfall at the Rach Gia station from December to April

The K value (556.9) in the dry season of 2016 was significantly higher than other years in the historical data series (ref. Figure 3-25). This year is also recorded as the most severe drought event in the Mekong Delta in the past 100 years, with 5 consecutive months without rain.

In addition, drought was also considered through the Standardized Precipitation Index[3] (SPI) for the dry season (from January to April) using the CCHIP tool. The values of SPI in the dry season at the Rach Gia station are less than -2. The CCHIP tool also calculated the monthly average amount of evaporation, rainfall, deficit water and excess water in a year (ref. Figure 3-26). In summary, drought events mainly occurred from December to May, where the months from February to April had the highest shortage of rainfall.

[3] The Standardized Precipitation Index (SPI) is a probability (i.e.: statistical) index that gives a representation of abnormal wetness and dryness. Source: https://www.ncl.ucar.edu/Applications/spi.shtml

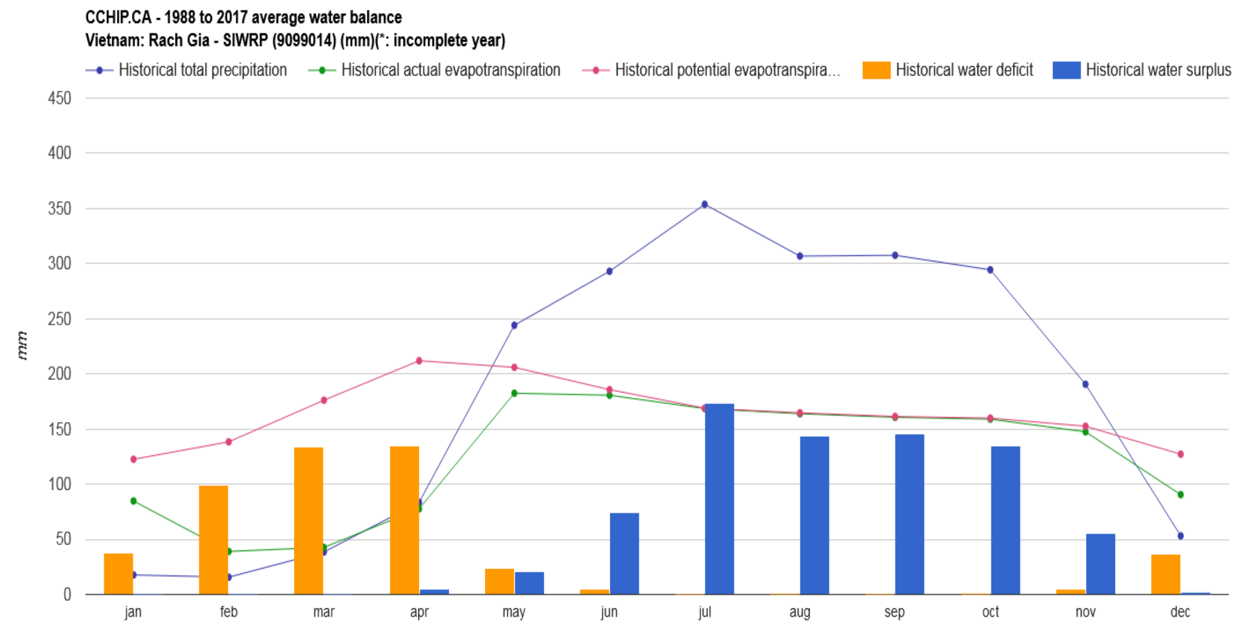

Figure 3-26. Monthly average amount of deficit water and excess water at the Rach Gia station in the period of 1988-2017

b. Projections

According to MONRE (2016), temperature is predicted to have an increasing trend in the 21st century. The number of days with high temperature strongly increases at the end of the century, and the dry season in Kien Giang is also expected to be more severe. According to the analysis from the CCHIP tool, rainfall in the dry season (from December to March) is almost unchanged, while for April and May it tends to decrease (ref. Figure 3-27). The evaporation capacity will increase throughout the year (ref. Figure 3-28). The water balance K for the RCP8.5 scenario also shows that the rainfall is much less than the evaporation in the dry season (ref. Figure 3-29). In short, drought events are anticipated to become more severe in the future. Thus, the future probability score for drought has been estimated to be "6".

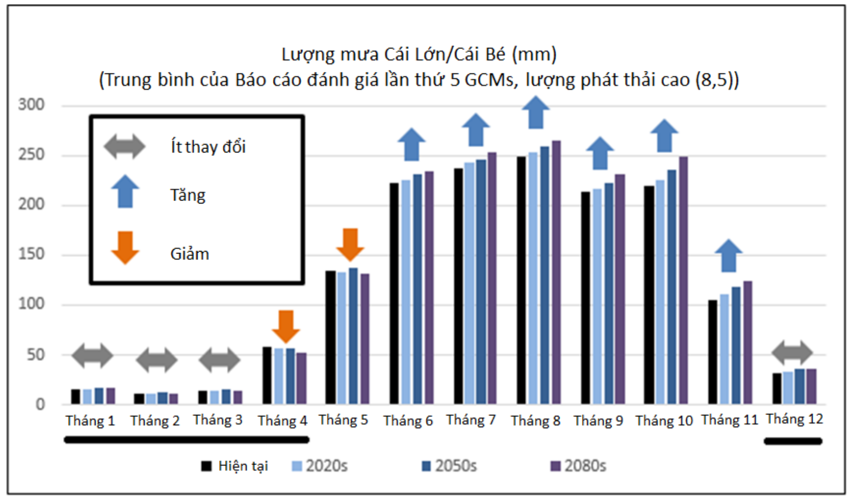

Figure 3-27. Forecast of rainfall (mm) for the RCP8.5 scenario

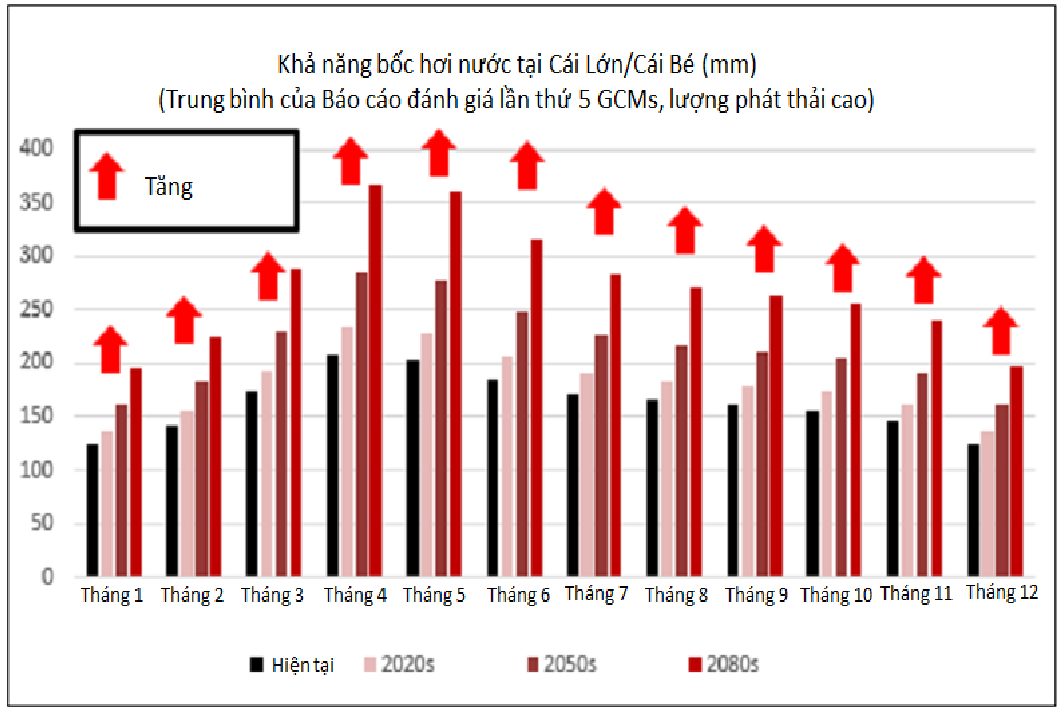

Figure 3-28. Forecast of evaporation (mm) for the RCP8.5 scenario

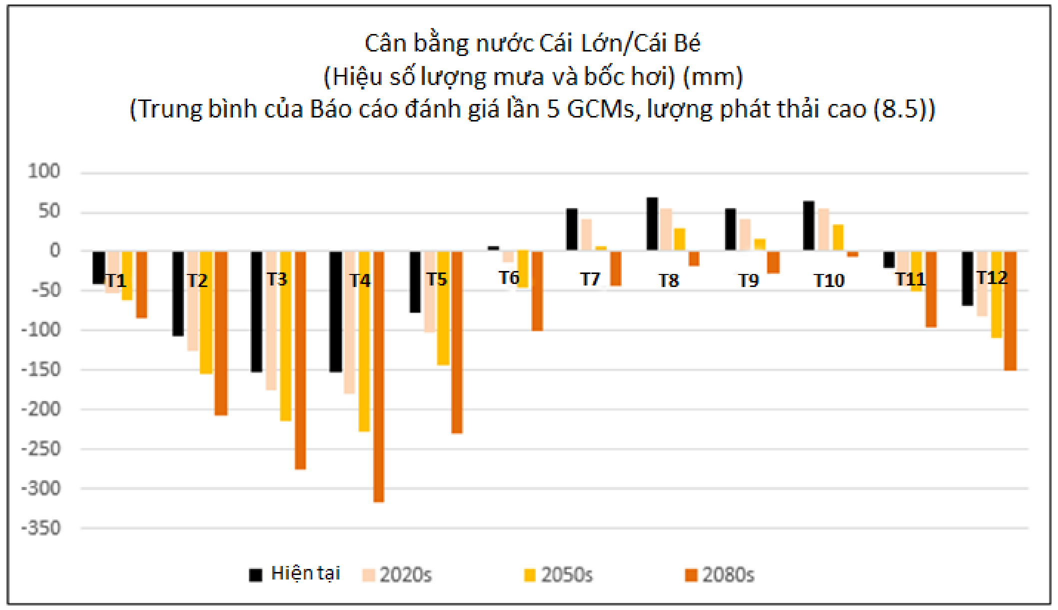

Figure 3-29. Forecast of the difference between rainfall and evaporation (mm) for the RCP8.5 scenario

3.6.2.7 High wind

a. *Historical data analysis*

Wind is the horizontal movement of air in the earth's surface [19]. In this study, high wind was defined as the average number of days in which the wind speed is more than 20 m/s (equivalent to the end of level 12 of the Beaufort scale). The historical data (1988-2017) shows that the highest wind speed recorded at the Rach Gia station was 27 m/s on 25th May 1999. In addition, there were a total of 12 days with the high wind at this station, or approximately 0.67 days/year. Therefore, the PIEVC probability score of the high wind in the past has been estimated to be "4".

The distribution of days with the high wind at the Rach Gia station was mainly concentrated in the period of 1995-2006 (ref. Figure 3-30). The number of days with the high wind tended to decrease in this area.

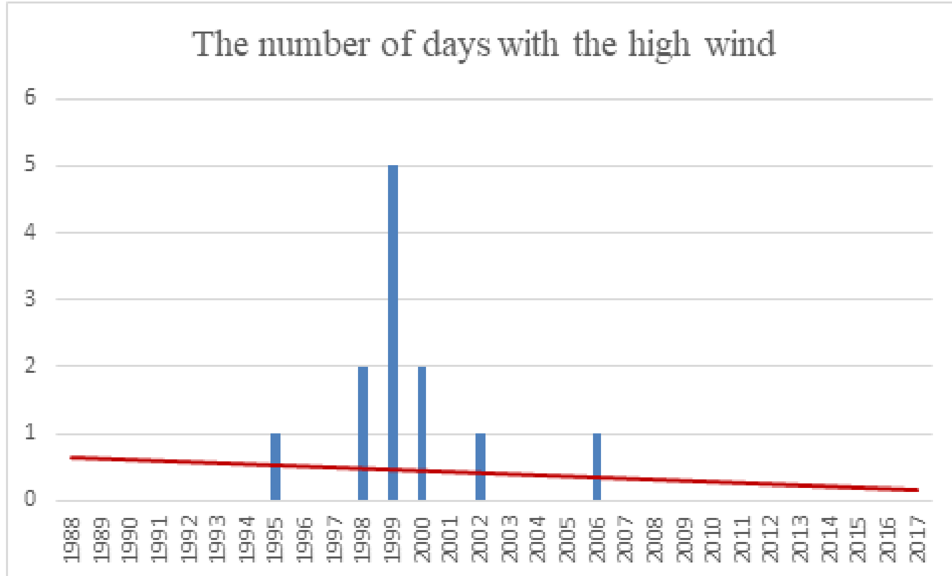

Figure 3-30. The number of days with the high wind at the Rach Gia station in the period of 1988-2017

b. *Projections*

According to the report of MONRE (2016), there are no projections for the frequency of high winds in the future. Therefore, the future probability score of the high wind has been estimated to remain unchanged at "4".

3.6.2.8 Tornado

a. *Historical data analysis*

According to Decision No. 46/2014/QD-TTg, tornados are the swirling winds with the same speed as the wind speed of storms, but they form and disappear in a short time with the narrow range of activity, from several square kilometres to several dozen square kilometres. In the study area, there is no measurement or research on this weather phenomenon. In this report, the concept of tornado was determined by the average number of tornados recorded in a given year. According to the report of the Provincial Committee for Flood and Storm Control, and Search and Rescue of Kien Giang, there are at least 1-2 tornados recorded in a year. Thus, the historical probability score of tornados in this case has been estimated to be "1".

According to the statistical data on the damages caused by tornados in the period of 2005 - 2015, tornados occurred almost every year in Kien Giang. However, this data only recorded the damages from tornados, but not the actual number of tornados occurring. Therefore, it is difficult to assess the trend of this phenomenon in the past.

b. *Projections*

According to the report of MONRE (2016), there is no consideration on the future trend of tornados. However, under the impacts of climate change, the intensity of the tornados is expected to be stronger. Thus, the probability score of tornados in the future has been estimated to be "2".

3.6.2.9 Thunderstorm/lightning

a. *Historical data analysis*

According to the Decision No. 46/2014/QD-TTg, lightning is the phenomenon of sudden electrical discharge from or within a cloud. Lightning usually occurs in a thunderstorm. In this study, lightning has been defined as the number of lightning events the damages of which are recorded in a year. According to the report of the Provincial Committee for

Flood and Storm Control, and Search and Rescue of Kien Giang, there were about from 1 to 3 lightning events which strike people every year in the province. Therefore, the historical probability score of lightning has been estimated to be "5", meaning that they occur at a "*frequent*" level.

Thunderstorm/lightning mainly occurred in the rainy season and in the period of transition between the seasons. In the period from 1988 – 2017, there were about 96 days with thunderstorms per year in Kien Giang. The number of thunderstorm days has had a slightly increasing trend over the past 30 years (ref. Figure 3-31).

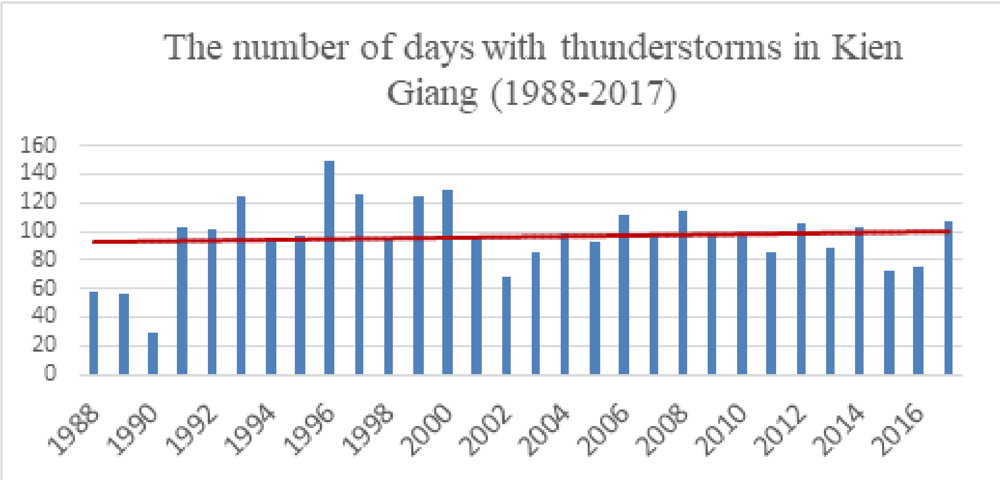

Figure 3-31. The number of days with thunderstorms in Kien Giang (1988-2017)

b. *Projections*

At present, there have been no forecasts for the trend of thunderstorm/lightning in the future. Thus, the future probability score of lightning has been estimated to remain unchanged as "5".

3.6.3. Hydrological analysis and projections

This section will analyse the historical data, trend and projections for the hydrological events that affect the Cai Lon – Cai Be Sluice Gate project, including: water level (tide, sea level rise and storm surge), flow, and salinity.

3.6.3.1 Water level

a. *Historical data analysis*

The hydrological stations in the West Sea are Rach Gia, Xeo Ro, and Song Doc, of which Xeo Ro station is the closest to the Cai Lon - Cai Be Sluice Gate project site and has the P5% maximum water level of 0.9 m. The highest variation in water level measured in Rach Gia was 1.2 m, and the average value has ranged from -0.01 m to 0.05 m (ref. Table 3-9). The lowest water level was about -0.70 m, while the tide in a year changed from 1.0 to 1.9 m. Every year the tidal water level was high in the last months of the year (from September to December) and was the lowest from April to July (ref. Figure 3-32).

According to Decision No. 2901/QD-BTNMT of MONRE dated 16/12/2016 on storm zones, the risk of storms, storm surges and wind zones from Ho Chi Minh City to Ca Mau, the highest recorded storm surge was 200 cm.

Table 3-9. Statistical characteristics of hourly water levels from 1988 to 2017 (Unit: m)

Station	Minimum	Lower quartile	Median	Upper quartile	Maximum	Mean	Standard deviation
Rach Gia	-0.72	-0.14	0.04	0.22	1.20	0.04	0.25
Song Doc	-0.70	-0.13	0.04	0.22	1.02	0.05	0.25
Xeo Ro	-0.71	-0.19	-0.03	0.17	0.99	-0.01	0.25
Can Tho	-1.60	-0.02	0.48	0.85	2.15	0.40	0.62

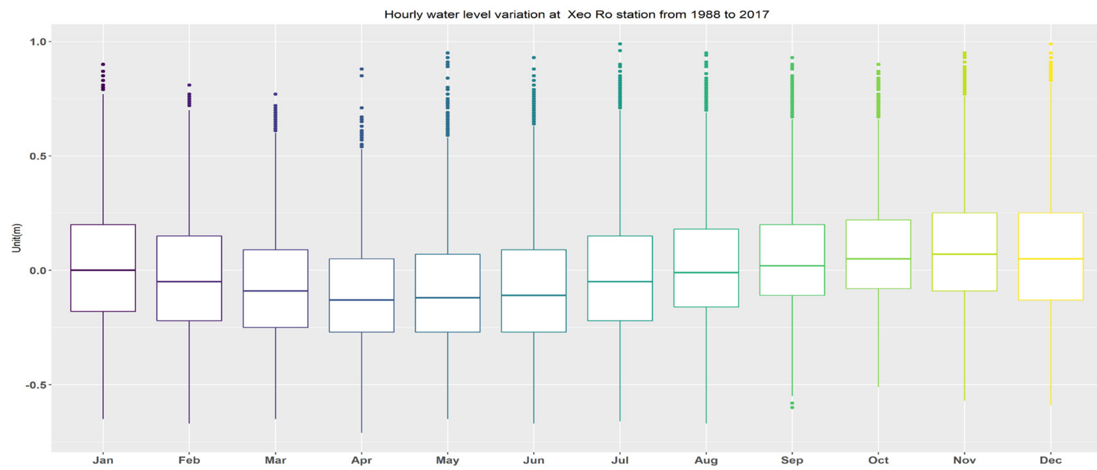

Figure 3-32. Hourly water levels at Xeo Ro station from 1988 to 2017

The trend analysis at the stations in the study area showed that the water levels at most of the stations increased in the period from 1988 to 2017. This trend has been clearly presented in Figure 3-33. This is consistent with the results of the tide assessment for the 2016 climate change scenarios for the period from 1993 to 2014, in which the average sea level at the ocean stations increases, about 3.34 mm/yr. Based on the water level analysis and the hydrological impacts outlined in Section 3.5, the historical probability score of the water level has been estimated to be "7".

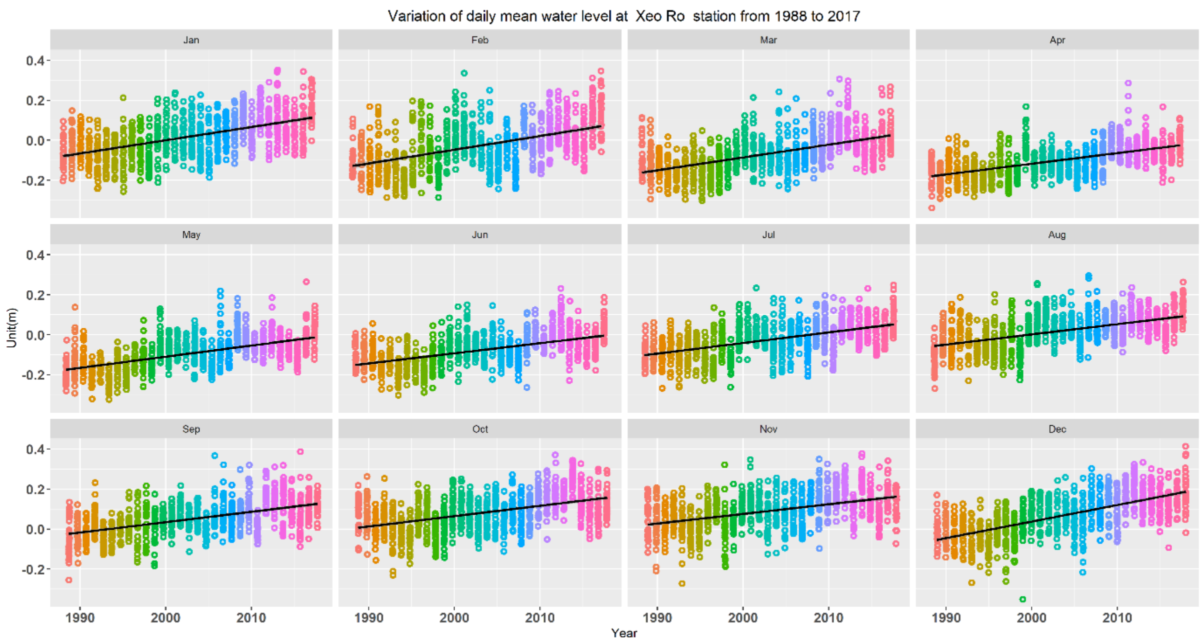

Figure 3-33. Daily average water level trends at Xeo Ro station from 1988 to 2017

b. *Projections*

According to the IPCC projections [16], sea level in the Rach Gia region is expected to increase at the end of the century for both RCP8.5 and RCP4.5 scenarios. In the RCP8.5 scenario, the average sea level rise by 2100 is 0.75 m, and the 95th percentile is 1.1 m. The corresponding values of the RCP4.5 scenario are 0.55 m and 0.82 m.

The results from the IPCC projection are in line with the projection of MONRE in 2016 [8], meaning that increases are expected. However, the difference between the forecasted values from the IPCC report and MONRE is not large because the IPCC projection is applied to the specific location (the Rach Gia station) in this study (ref. Figure 3-34). According to the MONRE projections, the average sea level rise is 0.75 m by 2100 and the 95th percentile is 1.06 m for the RCP8.5 scenario. Meanwhile, the values in the RCP4.5 scenario are 0.55 m and 0.78 m, respectively.

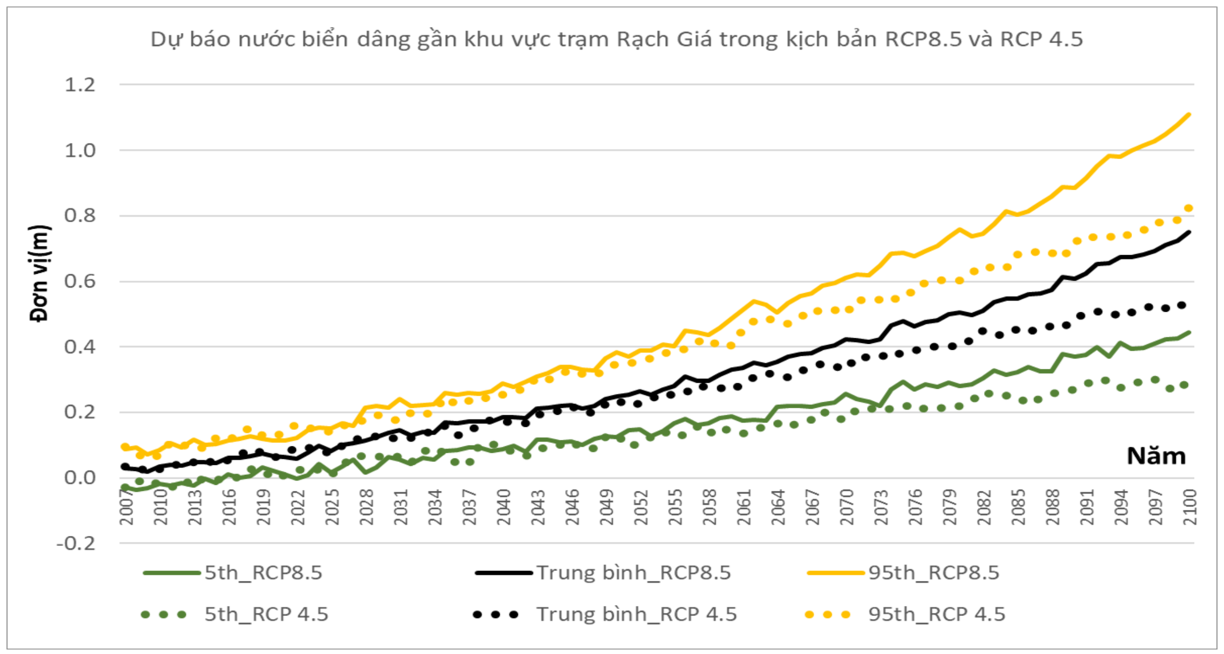

Figure 3-34. Projection of sea level rise in the Rach Gia region for both RCP 8.5 and RCP 4.5 scenarios

3. Data Gathering and Sufficiency

For the projections of storm surge: According to Decision No. 2901/QD-BTNMT of the MONRE, maximum storm surge in the future is expected to increase to 270 cm. The corresponding values in Ca Mau and Kien Giang are 120 cm and 210 cm.

According to the Southern Institute of Water Resources Research (SIWRR) [17], the highest storm surges for the storm levels of 13, 12, 11, and 10 with the assumed trajectory of QD2 are 1.7 m, 1.45 m, 1.2 m, and 1.15 m, respectively. The Cai Lon sluice gate (at P4) will reach to 0.8 - 1.0 m under the storm levels from 9 to 11 (ref. Figure 3-35).

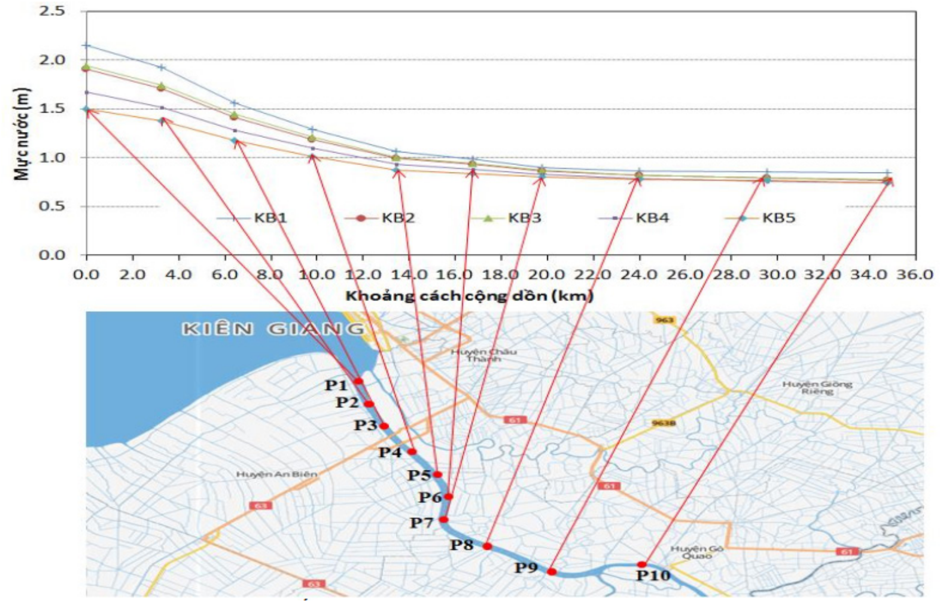

Figure 3-35. Storm surges along Cai Lon river with the assumed trajectory of QD 2

3.6.3.2 Flows

a. *Historical data analysis*

With regards to the flow regime of the Hau River at the Can Tho station in a given year, April had the smallest flow (around 2,000 m³/s), while the highest flow (about 20,000 m³/s) occurred in October. The median and average flows were 4,638 m³/s and 6,118 m³/s, respectively (ref. Figure 3-36). The analysis of flow data was used to assess the effect combination in Section 3.6.4.

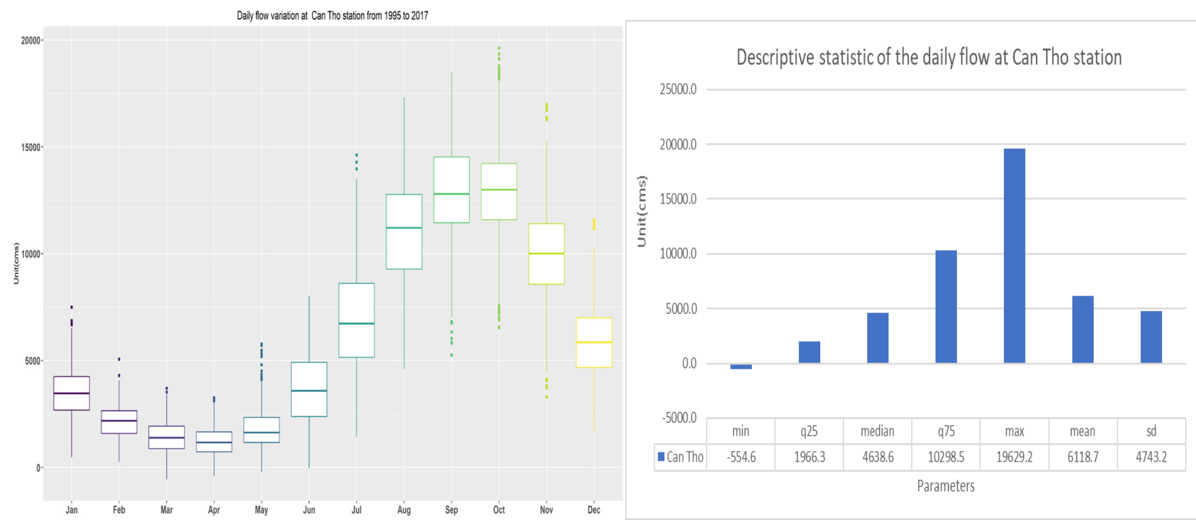

Figure 3-36. Statistical characteristics of the daily flow at Can Tho station in the period of 1995-2017

b. Trend of flows

The analysis of the daily flow data at the Can Tho station showed that the monthly flow had a decreasing trend, except for April and May (the low flow season) and October (the flood season) (ref. Figure 3-37). Flow decreases in the low flow season, especially from December to February, could exacerbate salinity intrusion and support an earlier occurrence. On the contrary, the high flows in the flood season could increase flood risk.

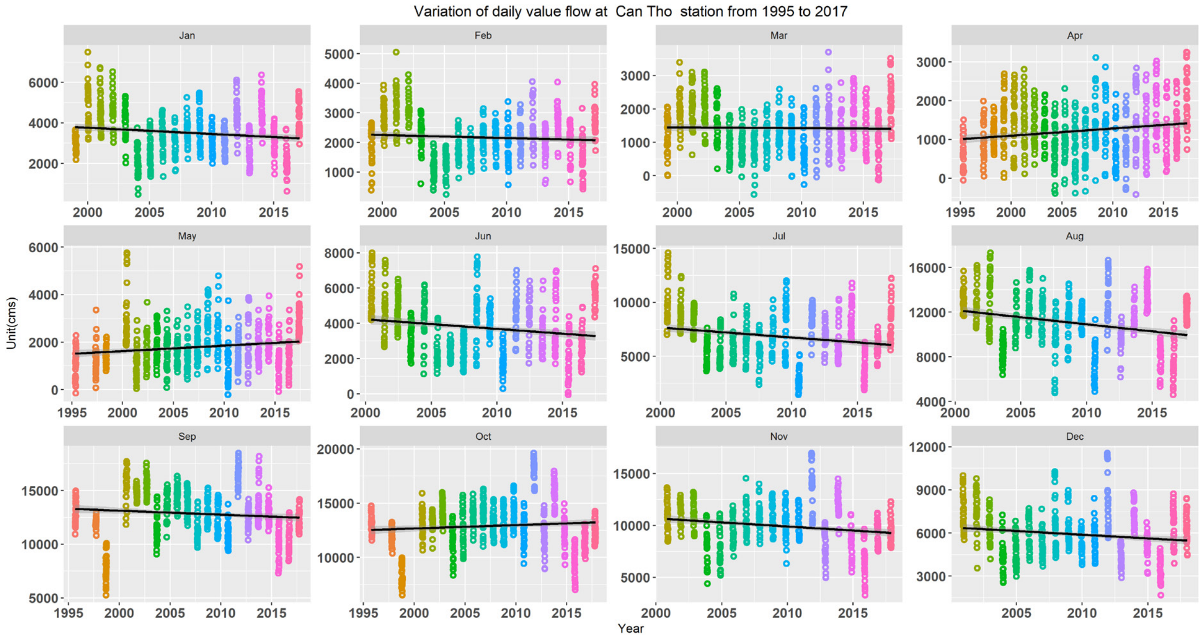

Figure 3-37. Trend of average flow at the Can Tho station in 1995-2017

3.6.3.3 Saline intrusion

a. Historical data analysis

The largest salinity concentration at the Xeo Ro station (close to the Cai Lon - Cai Be sluice gate) was 30 g/l, while the average value was around 8 g/l (ref. Table 3-10). The median value of salinity was highest in April, while the salinity concentration higher than 4 g/l (which corresponds to the salinity threshold of rice cultivation) also occurred in January, February, March, and May (ref. Figure 3-38). When the rainy season begins (in June and July), the salinity concentration tends to decrease.

Table 3-10. Statistical characteristics of hourly salinity concentration ≥ 1 g/l (Unit: g/l)

Station	Lower quartile	Median	Upper quartile	Maximum	Mean	Standard deviation
An Ninh	2.2	3.9	7.3	30.1	5.6	4.9
Rach Gia	3.6	6.5	11.0	30.0	7.8	5.5
Song Doc	21.9	27.8	30.1	40.8	24.9	8.1
Xeo Ro	3.9	7.8	12.6	31.0	8.8	5.9

3. Data Gathering and Sufficiency

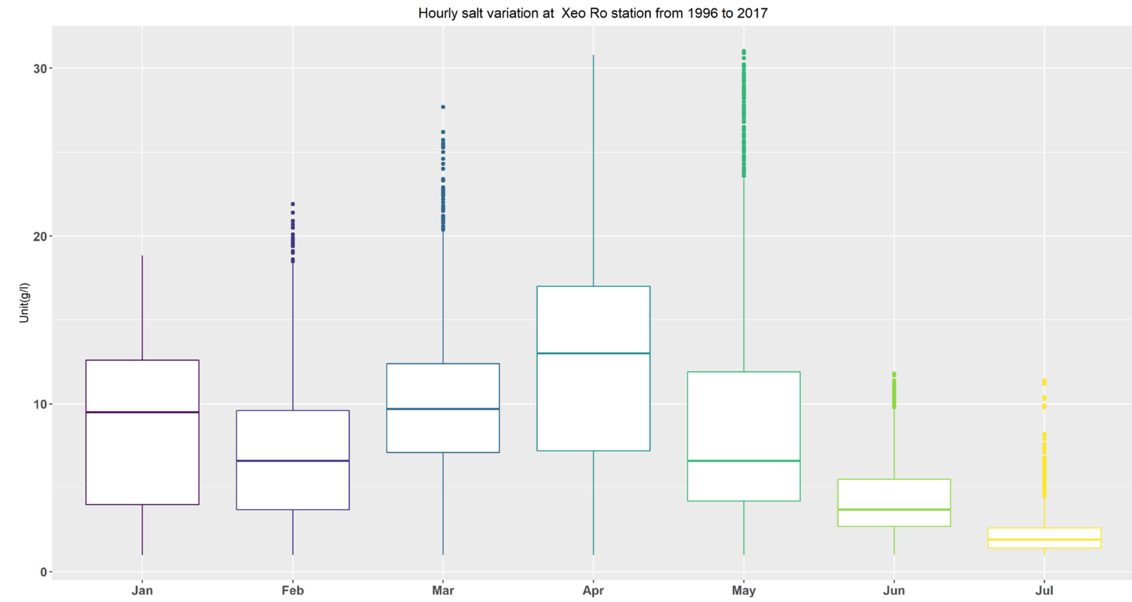

Figure 3-38. Hourly salinity concentration ≥ 1 g/l at the Xeo Ro station (1996-2017)

According to TCVN 9139: 2012 about "Concrete and reinforced concrete Structures in coastal areas", the threshold of salinity concentration defined for the use in this report is 3 g/l. The historical data analysis showed that the occurrence frequency of salinity > 3 g/l was high, so the PIEVC probability score has been estimated to be "7".

b. Trend of salinity intrusion

Figure 3-39 illustrates that the highest daily salinity at the coastal and inland stations is likely to increase, especially in the dry months (February to April). This trend is in line with the water level trend in the coastal stations.

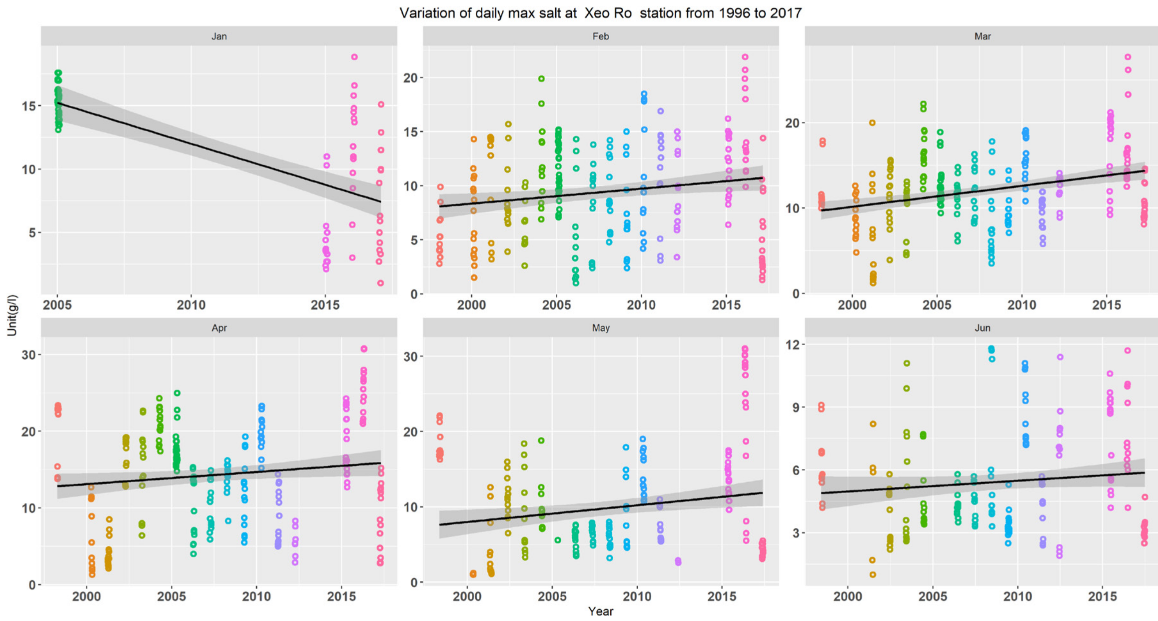

Figure 3-39. Trend of the highest daily salinity concentration at the Xeo Ro station in the period of 1996-2017

c. Projections

According to the feasibility report of the Cai Lon – Cai Be Sluice Gate project, under the impact of sea level rise and the decrease of the upstream flow, salinity intrusion will become more extreme in the future (i.e., the higher values and the longer durations) (ref. Figure 3-40). According to the climate change – sea level rise scenarios of MONRE (2016), the sea level is also projected to rise in the future. Therefore, the future probability score of salinity intrusion has been estimated to remain unchanged as "7".

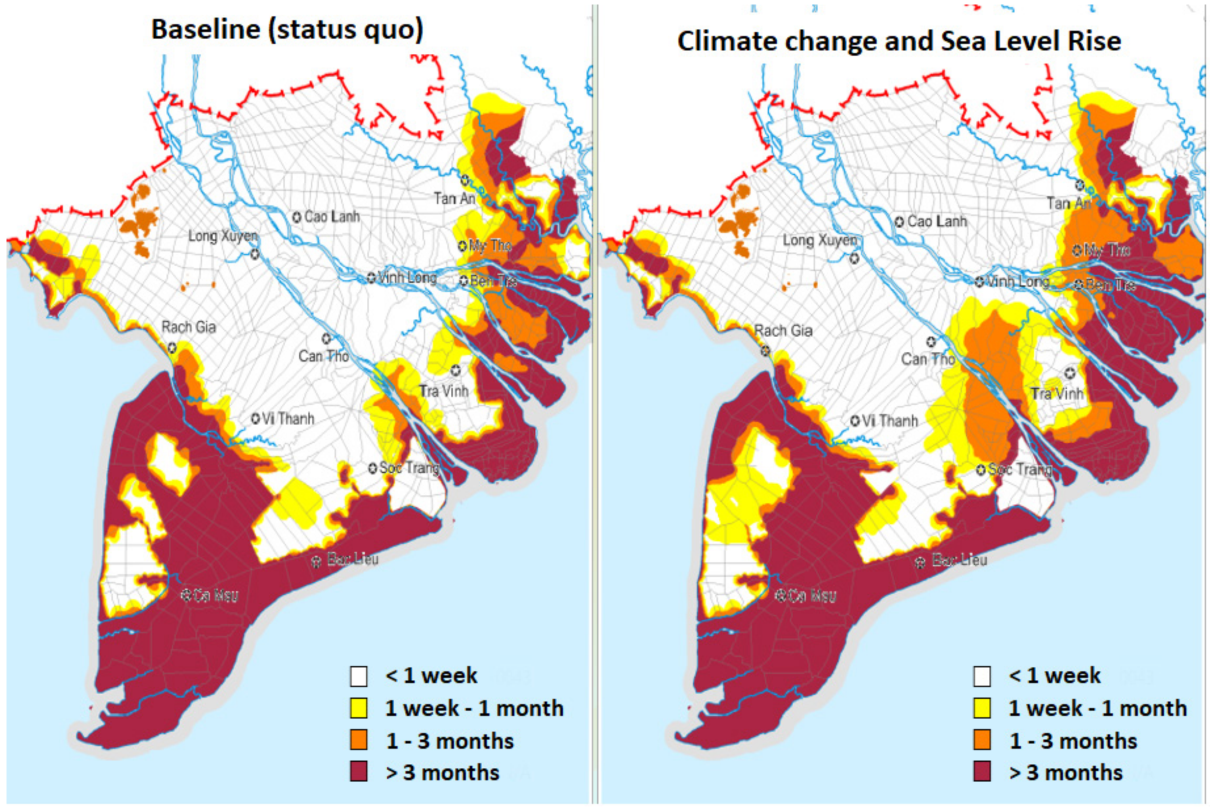

Figure 3-40. Comparison of salinity intrusion between the current condition and sea level rise

3.6.4. Potential cumulative effects

In the first step of the PIEVC Protocol, the effect combinations of climate and hydrological elements on the Cai Lon – Cai Be Sluice Gate project were identified. However, due to the limited data on sediment transport, only two combinations have been assessed in this study, including salinity intrusion combined with high temperature and high water level combined with heavy rain. These combinations are in line with the experience of the senior operation staff of sluices and the natural characteristics of the Mekong Delta. Particularly, the corrosion of reinforced concrete and metal of the infrastructure components was mainly impacted by high temperature, high rainfall, salinity and water level change (by tides, storm surges, sea level rise and land subsidence).

3.6.4.1 Salinity intrusion combined with high temperature

In the dry season, the Cai Lon - Cai Be Sluice Gate area is often affected by salinity intrusion, along with the effects of high temperatures. In this study, salinity intrusion combined with high temperature were defined as events of these two factors occurring at the same time. Specifically, with a number of days with high temperature over 7.5 days and a salinity concentration of more than 3.0 g/l. The analysis of the 30-year (1988-2017) data showed that the months in which high temperature and maximum salinity intrusion tend to coincide are from March to May. The historical data also shows that there were 12 years with over 7.5 days of high temperatures. Furthermore, the salinity of 3 g/l occurred during the dry season. As a result, the combination of these two factors occurred 0.4 times per year. Thus, the historical probability score in this case has been estimated to be "4".

It is projected that in the future, the high temperature events will increase in Kien Giang, especially in the late 21st century (Section 3.6.2.1), along with an increasing trend in salinity intrusion due to sea level rise (Section 3.6.3.3). This means that the combination of high temperature and salinity intrusion is expected to occur more frequently. Therefore, the PIEVC future probability score of this combination has been estimated to be "5".

3.6.4.2 High water level combined with heavy rain

To determine the occurrence of this combination, it is necessary to analyse the changes of high water level and heavy rain over a long period of time. The analysis of 30-year water level data at the Xeo Ro station showed that a water level greater than 0.9m occurred 26 times and heavy rain events of more than 100mm/day w23 times. However, in the historical data, the combination between high water level and heavy rain only occurred once in August 2006. Therefore, the historical probability score of this combination has been estimated to be "2".

According to the MONRE projections in 2016, the average sea level rise is 0.75m and the 95th percentile is 1.06m for the RCP 8.5 scenario to 2100 (see Section 3.6.3.1). This indicates that the water levels greater than 0.9m will appear more frequently, especially at the end of the century. In addition, the intensity of rainfall and the number of days with heavy rain are also expected to increase in the future as mentioned in Section 3.6.2.3. As such, the frequency of high water levels combined with heavy rain is predicted to be higher in the past. Thus, the future probability score of this combination has been estimated to be "4".

3.7. Geological data

The field-measured geological data and the laboratory analysis [13] indicate that the stratigraphy at the site of the Cai Lon - Cai Be sluices is composed of many layers as shown in Tables 3.1 and 3.3. The mechanical properties of each layer are shown in Tables 3.2 and 3.4. In fact, this geological data was used in the preliminary design of the Cai Lon - Cai Be sluices.

Table 3-11. Geological data at the site of Cai Lon Sluice

Layer	Symbol	Characteristics
1	OH	Organic clay, dark grey – bluish grey; quasi-liquid soil.
2	CL	Light sandy clay loam, bluish grey – brown; soft-plastic soil.
3	CL	Light sandy clay loam, yellowish brown – white grey – pinkish brown –bluish grey; semi-hard soil.
4	SC - SM	Dust clay sand, yellowish brown –pinkish brown – reddish brown.
5	CL	Light sandy clay loam, yellowish brown – bluish grey – white grey; semi-hard soil
5a	SC - SM	Dust clay sand, bluish grey.
6	SC - SM	Dust clay sand, bluish grey – white.
6a	CL	Light sandy clay loam, bluish grey – dark grey – brownish grey; semi-hard soil

Table 3-12. Mechanical properties of soil layers at the site of Cai Lon Sluice

Properties	Soil layers							
	1	2	3	4	5	5a	6	6a
Grain composition (%)								
+ Gravel	0	0	0	0	0	0	0	0
+ Sand	3.6	12	9.7	71.9	13.8	68.5	72.6	11
+ Dust	53.3	60	52.8	23.2	53.7	27	22.9	60.8
+ Clay	43.1	28	37.6	4.9	32.5	4.5	4.5	28.2
Atterberg limits (%)								

Properties	Soil layers							
	1	2	3	4	5	5a	6	6a
Liquid limit (W_L)	70.1	44.6	46.8	-	42.2	-	-	45.9
Plastic limit (W_p)	38.2	25.6	25.2	-	23.2	-	-	27.1
Plastic index (I_p)	31.9	19	21.6	-	19.1	-	-	18.9
Viscosity (B)	1.26	0.56	0.08	-	0.07	-	-	0.07
Natural Moisture (W%)	78.38	36.24	26.93	23.66	24.43	17.21	21.89	28.48
Wet density (g_w g/cm^3)	1.46	1.84	1.92	1.92	1.94	1.98	1.93	1.88
Dry density (g_k g/cm^3)	0.82	1.35	1.51	1.56	1.56	1.69	1.58	1.46
Floating density (g_{dn})	0.5	0.86	0.96	0.98	0.98	1.06	0.99	0.92
Density Δ	2.6	2.74	2.72	2.67	2.71	2.67	2.67	2.7
Pore diameter n (%)	68	51	45	42	42	37	41	46
Void ratio ε	2.168	1.026	0.803	0.709	0.739	0.577	0.688	0.852
Saturation G (%)	94	97	91	89	90	79	85	90
Cohesive force (C kG/cm^2)	0.038	0.176	0.349	0.083	0.334	0.092	0.083	0.331
Angle of interior friction φ (degree)	03°47'	10°05'	14°44'	24°45'	14°47'	25°33'	25°05'	14°28'
Standard Penetration Test (SPT)	0-2	4	9-33	15-36	11-48	14-17	27-50	21-33

Table 3-13. Geological data at the site of Cai Be Sluice

Layer	Characteristics
1a	Clay, brownish grey – dark grey; Soft-plastic soil; Discontinuous distribution, 0.5 m thick.
1	Organic clay, dark brownish grey; quasi-liquid or liquid soil.
2'	Clay, yellowish brown – light yellow – white grey – reddish brown – purplish yellowish brown; Semi-hard and hard-plastic soil.
2	Clay, yellowish brown – light yellow – white grey – reddish brown – purplish yellowish brown; hard and semi-hard soil.
2a	Heavy clay mixed with little gravel and fine sand, white grey – reddish brown – yellowish brown; hard plastic soil.
2b	Clay (heavy or medium) mixed with fine sand and little gravel, purplish bluish grey – yellowish brown – white grey; hard plastic soil.
2c	Light clay, pinkish and purplish yellow – white grey.
2	Clay, yellowish brown – light yellow – white grey – reddish brown – purplish yellowish brown; hard and semi-hard soil.
3a	Light clay – heavy clay, white grey – yellowish brown – bluish grey.

Table 3-14. Mechanical properties of soil layers at the site of Cai Lon Sluice

Properties	Soil layers						
	1	2'	2	2a	2b	2c	3a
Grain composition (%)							
- Clay	48	46	42	24	22	12	12
- Dust	19	19	17	14	14	10	6
- Sand	33	35	40	61	63	78	82
- Gravel			1	1	1		
Atterberg limits (%)							
- Liquid limit W_{ch}	68	50	45	34	35		
- Plastic limit W_d	36	27	24	21	21		
- Plastic index I_p	32	23	21	13	14		
Viscosity B	1.15	0.11	-0.07	0.35	0.30		
Natural Moisture W (%)	72.6	29.4	22.1	25.4	24.9	24.5	20.3
Wet density γ_W (T/m^3)	1.53	1.92	2.02	1.92	1.95	1.93	2.02
Dry density γ_c (T/m^3)	0.89	1.48	1.66	1.54	1.56	1.55	1.68
Density Δ	2.66	2.71	2.71	2.68	2.69	2.66	2.66
Pore diameter n (%)	66.5	45.2	38.9	42.8	41.8	41.7	37.0
Void ratio ε	1.989	0.824	0.636	0.748	0.719	0.716	0.587
Saturation G (%)	96.9	96.5	94.2	91.0	92.9	91.0	92.0
Cohesive force C (KG/cm^2)	0.06	0.30	0.32	0.21	0.21	0.14	0.13
Angle of interior friction φ (degree)	2°58'	16°7'	16°42'	16°57'	16°58'	24°10'	22°57'
Permeability coefficient K (cm/s)	3.9×10^{-6}	9.7×10^{-7}	3.7×10^{-6}	5.1×10^{-5}	3.5×10^{-5}		7.8×10^{-4}

Generally, the site of the Cai Lon - Cai Be sluice has a relatively good geology compared to other areas in the Mekong Delta. However, irrigation works and other infrastructures have mainly been built on the Holocene layer with a soft, weak structure. Technically, this layer has a high clay content mixed with many organic materials and is often saturated, resulting in its poor load bearing capacity. Thus, it is required to retreat the foundation for the infrastructures (e.g., bridges, sluices, and dams) in this region before construction.

According to the recommendations from the units of geological survey and foundation design for the Cai Lon - Cai Be sluice gate project, additional experiments using the cone penetration test (CPT) should be carried out to evaluate the mechanical properties of the soil layers in the detailed design phase [13]. In addition, the individual impact of the geological factors is unclear and should be investigated further at a later stage.

3.8. Assess data sufficiency

- Geographical data

Based on the collected data and the recommendations from the units of geological survey and foundation design (see Section 3.7), the existing geological data does not meet the data sufficiency requirements of the PIEVC Protocol for the climate risk assessment on the Cai Lon - Cai Be sluice gate, especially for the individual impacts. Therefore, within this assignment, the geological features were only considered in relation to other factors (such as climate, hydrology) to evaluate the vulnerability of the infrastructure. Particularly, land subsidence was combined into the cumulative effect between the water level and high rain as described in Section 2.3.3.

4. RISK ASSESSMENT

This section presents the methods and results (matrices) of the risk assessment using the PIEVC Protocol (corresponding to Step 3) under the impacts of climatic and hydrological parameters for both historical and future conditions using historical data and future projections. To achieve this goal, a risk assessment workshop was held for the consultation of experts and relevant stakeholders.

4.1. Risk assessment workshop

4.1.1. Introduction

The workshop on "*Climate risk assessment for infrastructures in the Mekong Delta*" was held for 3 days (16-18 October 2018) in Ho Chi Minh City. This followed the workshop on the introduction of the PIEVC protocol in April 2018 in Can Tho City.

The objectives of the PIEVC Workshop #2 were (i) to train the assessment team on the next steps of the PIEVC Protocol and improve the capacity of the Vietnamese technical experts for climate risk assessments for infrastructure development; and (ii) to apply the PIEVC Protocol to assess climate risks for the Cai Lon - Cai Be Sluice Gate Project. The agenda and workshop minutes are provided in *Appendixes 3 and 4*.

The participants of the PIEVC workshop #2 included (*see Appendix 5 for details*):

- Representatives of GIZ;
- Canadian consultants on the PIEVC Protocol;
- Representatives of Vietnam Disaster Management Authority;
- Representatives of the Water Resources Investment and Construction Board 10 (the investor);
- Representative of Kien Giang Department of Water Resource;
- Representatives of Kien Giang hydro-meteorological station;
- Climate and hydrological experts of the Southern Regional Hydro-meteorological Center;
- Water resources experts of the Southern Institute of Water Resources Planning (SIWRP).

4.1.2. Main contents at the PIEVC Workshop # 2

The PIEVC Workshop # 2 conducted three main tasks as follows:

a. *Part 1 (day 1)*

On the first day, the assessment team presented the intermediate results of the climate risk assessment for the Cai Lon - Cai Be Sluice Gate project using the PIEVC Protocol (mainly Steps 1 and 2). In detail, the team summarized: (i) the objectives, scope of project and results of Step 1 of the PIEVC Protocol (see *Appendix 6*); (ii) introduction of the Cai Lon - Cai Be Sluice Gate Project and its key components (see *Appendix 7*); and (iii) historical data analysis and projections of climate and hydrological parameters which are likely to affect the Cai Lon - Cai Be Sluice Gate Project (see *Appendix 8*), as well as the historical and future PIEVC probability of occurrence scores. This information provided an overview to the workshop participants to understand the study work completed-to-date.

Next, under the guidance of the Canadian experts, the workshop participants reviewed the list of climate and hydrological parameters and their probability scores. To accomplish this task, they were divided into three groups as illustrated in Table 4-1. After the group discussion, the group leaders presented the results of each group for a general discussion. The result of Day 1 was a table of the probability scores for the associated climate and hydrological parameters (*see Section 4.2 for details*). Some photos of Day 1 at the workshop are shown in Figure 4-1.

Table 4-1. List of members in group in Day 1

No.	Group 1	Group 2	Group 3	Role
1	Le Viet Minh	Nguyen Duc Cong Hiep	Nguyen Thi Lien	Moderator
2	Tran Minh Dien	Pham Ho Quoc Tuan	Doan Ngoc Anh Vu	Recorder
3	Tran Binh Phuong	Le Quang Tuan	Helen Uyen Nguyen	
4	Ngo Thanh Toan	Le Xuan Hien	Tran Quang Dai	
5	Nguyen Thi Minh Ngoc	Ma Thi Lan Huong	Ron Flugel	
6		Trang Tien Dai		

Figure 4-1. Risk assessment workshop photos in Day 1

b. Part 2 (day 2)

The main goals of Day 2 were to introduce Step 3 of the PIEVC Protocol and complete the risk assessment for the Cai Lon - Cai Be Sluice Gate Project. Firstly, Canadian consultants trained participants on the key contents of Protocol Step 3, especially the method to score the severity of impacts for each infrastructure component under the impact of each climate and hydrological parameter determined in Step 2. Next, the workshop participants were divided into two groups to conduct the severity of impacts scoring (Table 4-2).

Similarly to Day 1, the two team leaders presented the severity scores of each group for general discussion. The result of Day 2 were two risk assessment matrices (see *Appendix 9*) for the components of the Cai Lon - Cai Be

Sluice Gate Project in terms of climate and hydrological features (see *Sections 4.3 and 4.4* for details). One matrix shows the assessment results for current, the other for future climate conditions. Some photos of Day 2 at the workshop are shown in Figure 4-2.

Table 4-2. List of members in group for severity scoring (Day 2)

No.	Group 1	Group 2	Role
1	Le Viet Minh	Nguyen Duc Cong Hiep	Moderator
2	Le Van Quyen	Nguyen Thi Lien	Recorder
3	Tran Binh Phuong	Helen Uyen Nguyen	
4	Ngo Thanh Toan	Le Xuan Hien	
5	Nguyen Thi Minh Ngoc	Ma Thi Lan Huong	
6	Pham Ho Quoc Tuan	Tran Quang Dai	
7	Trang Tien Dai	Ron Flugel	
8	Tran Minh Dien	Doan Ngoc Anh Vu	

Figure 4-2. Risk assessment workshop photos in Day 2

c. Part 3 (day 3)

On the last day of the workshop, the Canadian experts trained the assessment team on the key contents of Step 5 in the PIEVC Protocol. Based on the analysis of the risk matrix in Step 3, the process to develop recommendations for the next phase (the detailed design) of the Cai Lon - Cai Be Sluice Gate project was initiated by the workshop participants (Figure 4-3). All of these recommendations were summarised in Chapter 5.

Figure 4-3. Risk assessment workshop photos in Day 3

4.2. Review on probability scores of climatic and hydrological parameters

In Step 2 (Section 3.6), the assessment team identified climate and hydrological parameters affecting the infrastructure, analysed their historical data and projections, and assigned their PIEVC probability scores. The thresholds for each of these parameters were also determined by the assessment team. The identification of these PIEVC probability scores was discussed during the online meetings between the assessment team, the Canadian consultants and GIZ before being reviewed at the PIEVC workshop #2. The values of the historical and future probability scores are summarised in Table 4-3.

Table 4-3. Summary of the PIEVC probability scores for Cai Lon – Cai Be sluice gate

Parameters	Threshold	Unit	Historical probability score	Future probability score
Climate				
High temperature	≥ $35^{o}C$	Days/year	6	7
Heat wave	≥ 8 or more consecutive days with the maximum temperature ≥ $35^{o}C$	Events/year	3	4
Heavy rain	≥ 100 mm in a day	Days/year	4	5
Heavy 5-day total rainfall	≥ 250 mm	Events/year	4	4
Tropical storms/ depression	From level 8 (equivalent to the wind speed of 62 - 74 km/h) or more	Events/year	3	4
Drought	K ≥ 4 in dry season	Drought events/30 years	5	6
High wind	≥ 20 m/s	Days/year	4	4
Tornado	Fujita wind scale Based on the statistical data on the damages	Events/year	1	2
Thunderstorm/ Lightning	Based on the statistical data on the damages	Events/year	5	5
Hydrology				
Water level	0.9 m (P5% maximum water level at Xeo Ro station)	Exceeding value/year	7	7
Salinity	3g/l	Exceeding value/year	7	7
Cumulative effects				
Salinity intrusion + high temperature	Salinity = 3g/l and high temperature ≥ $35^{o}C$	Events/year	4	5
High water level + heavy rain	Water level ≥ 0.9m and heavy rain ≥ 100mm/day	Events/year	2	4

4.3. Determination of severity scores

As described in Section 4.1.2, the severity scores (S) were determined through expert consultation at the PIEVC workshop #2. Basis for the professional judgement was the collected expertise of a group of experts representing different disciplines and institutions. Participants included civil engineers, climate and hydrological experts, and water resources experts. Canadian consultants provided guidance throughout the process of arriving at and agreeing about joined judgements. The main steps to identify the severity scores include:

- To select the method for severity scoring (see *Section 4.3.1*);
- To set up a matrix of interaction severity, the rows of which are infrastructure components and the columns of which are climate and hydrology parameters, as well as the effect combinations of these elements;
- To do a YES/NO analysis to consider the interaction between the columns (the infrastructure components) and rows (climate and hydrological parameters, and effect combinations) (see *Section 4.3.2*);
- To determine the severity scores (S) for each infrastructure component under the impacts of each climate and hydrological factor, in both the past and future cases (see *Section 4.3.3*). This step is only conducted for those component-parameter interaction for which the YES/NO analysis yielded a "YES".

4.3.1. Selection of severity scoring method

According to the PIEVC guidelines, there are two methods (D and E) to express severity scores (S). At the PIEVC workshop #2, all the participants agreed to select Method E (see Table 4-4 for the severity scale) to determine the severity of impacts of each infrastructure component. It was accepted as appropriate for the scoring process involving professional judgement under circumstances of limited availability of data.

Table 4-4. Severity scale factors

Score	Severity of Consequences and Effects
0	Negligible Not Applicable
1	Very Low Some Measurable Change
2	Low Slight Loss of Serviceability
3	Moderate Loss of Serviceability
4	Major Loss of Serviceability Some Loss of Capacity
5	Loss of Capacity Some Loss of Function
6	Major Loss of Function
7	Extreme Loss of Asset

4.3.2. YES/NO analysis

A YES/NO analysis is to determine whether a climate, hydrological element interacts with a given infrastructure component or not. At this stage, the question is only whether component and event interact, not yet what the impact of said interaction is. This process helps remove the infrastructure components that are not affected by climate and/or hydrological parameters.

In this study, the YES/NO analysis was conducted for 52 components of Cai Lon - Cai Be Sluice Gate Project (see Section 3.1) and 11 climate and hydrological elements (see Section 4.2). The results of this analysis showed that only 26 infrastructure components are expected to be affected by climate and hydrological parameters (see *Appendix 9*). These components were the focus of determining severity scores in the next section.

Details of the YES/NO analysis are presented as follows:

a. Operation and maintenance

The results of the analysis indicated that the staff could be influenced by the climate and hydrological factors during their work. Other components, such as the maintenance equipment and the procedure, are often stored in the operation house, so they are little affected by the climate and hydrological factors. In addition, at the PIEVC workshop #2, the transportation of supplies in the operation and maintenance process was suggested to be added to the risk assessment.

b. Sluice gate structure

The components of the sluice gate structure (e.g., pile foundation, waterproof pile foundation, pillar footing and bottom beams) are under the ground, so they are not considerably affected by climate or hydrological factors. Pillar, gate tower and other poured-concrete components could be impacted by heat waves, salinity intrusion and erosion due to water level changes.

c. Ship lock

The ship locks are mainly made of reinforced concrete, so in the similar way to the sluice gate structure, they may be impacted by such climate and hydrological factors as heat waves, salinity intrusion and water level changes.

d. Gates

As the gates are closed (i.e., they are under water), they may be affected by water pressure (due to water level differences), flow velocity (obstructing the operation), sediment and salinity intrusion (increasing the corrosion). On the other hand, when opened (the gates are hanging), they are likely to be affected by high wind, heavy rain, storms and lightning.

Water tight gaskets are often influenced by air temperature (for the components above water level), water temperature and salinity (for the components under water level). In addition, the bolts are less susceptible to the changes of climate and hydrological factors.

e. Bridge

The pile foundation is pushed into the ground, so the climate and hydrological factors cannot significantly impact it. The bridge pier and beam are affected by climate and hydrological factors in the similar way to the pillar (see *Sluice gate structure section*).

The impacts on the lightning system and traffic signals, and the park are similar, so they have been mentioned in the park section. The bridge hand rail could be affected by climate factors such as tropical storms, high wind, heavy rain and thunderstorms, while high temperature and heavy rain are likely to have an impact on the bridge surface/slope.

f. Retaining walls and connected embankment

Drought, heat waves, and fluctuations of the water level could change the soil structure, resulting in the erosion of the river bank. This occurrence was also investigated by the assessment team at the Ba Lai Sluice (Ben Tre). Furthermore, salinity intrusion may cause chemical corrosion of the reinforced concrete components as mentioned above. In short, retaining walls, connected embankment and rip-rap may be affected by heat waves, drought and salinity intrusion.

g. Operation houses

The operation houses are likely to be affected by tropical storms, tornados, high wind, heavy rain, thunderstorms and heat waves.

h. Park

The park is impacted by most of the climate factors such as tropical storms, tornados, high wind, heavy rain, thunderstorms, heat waves and drought.

i. Electric power system

Most of the electrical components are at risk of being damaged/destroyed by thunderstorms/lightning, and tornado. Furthermore, transmission lines and voltage transformers are also affected by tropical storms, high wind and heavy rain.

j. Operation and control system

The operation systems of the sluice gates and ship lock are set up outdoors, so they could be affected by heavy rain, tropical storms, and thunderstorms/lightning. In addition, the senior staff in operation and management of sluices has experienced that the control system may be malfunctioning under a thunderstorm or storm.

k. Monitoring system

As the monitoring system is set up outdoors, it is at high risk of being affected by climatic factors such as rain, storms, tornados and thunderstorms.

l. Fire extinguishing system

The components of the fire extinguishing system are mainly kept in the house and are regularly maintained; thus, they should not be impacted by the climate and hydrological factors.

m. Communication system

Similar to the electric power and monitoring systems, the communication system could also be strongly affected by climatic factors such as rain, storms, tornados and thunderstorms/lightning.

4.3.3. Severity determination

Following the PIEVC guidelines, the severity scores for the interaction between the components of Cai Lon - Cai Be Sluice Gate and the identified climate and hydrological factors were determined based on:

- Design standards and regulations for the Cai Lon - Cai Be Sluice Gate Project;
- Characteristics of the Cai Lon - Cai Be Sluice Gates;
- Historical data, trends and projections of the climate-hydrological factors;
- Consultations with the administration and operation staff for the similar infrastructures such as the Ba Lai Sluice (Ben Tre), Lang The Sluice (Tra Vinh);
- The information on administration and operation of the similar infrastructures such as the Ho Phong Sluice, Lang Tram Sluice (Bac Lieu) and Can Chong Sluice (Tra Vinh);
- Professional judgement of the experts from the different sectors (i.e., construction, climate, hydrology and water resources) at the PIEVC workshop #2 on risk assessment of the Cai Lon - Cai Be Sluice Gate.

The severity scores for both historical and future conditions are presented in Table 4-5.

Table 4-5. Summary of severity scores for Cai Lon - Cai Be Sluice Gate

Components	Breakdown	Climate/ hydrological factors	Historical S	Future S	Comments
Operation and maintenance	Staff	High temperature	3	3	High temperature may cause fatigue and affect the performance of the staff.
		Heat wave	5	6	Heat waves could considerably affect the staff when they have to work outdoors.
		Heavy rain	3	4	Heavy rain may make the surfaces slippery.
		Heavy 5-day total rainfall	2	3	Heavy 5-day total rainfall can influence the working ability of the staff, similarly to heavy rain.
		Tropical storm/ depression	7	7	Storms can endanger the lives of the operators during their work.
		Drought	2	3	Similar to high temperature and heat waves, droughts may also affect the staff during their work.
		High wind	3	4	High wind can obstruct to the working ability of the staff if it is necessary to operate or inspect the sluice.
		Tornado	6	7	Similar to storms, tornados can endanger the lives of operators during work.
		Thunderstorm/ lightning	7	7	Similar to storms and tornados, thunderstorm/lightning could be dangerous to the lives of the operators when they are working in the field.
					TCVN 988-1:2013
	Transportation	Heavy rain	1	2	Heavy rain can impede transportation.
		Heavy 5-day total rainfall	1	1	Similar to heavy rain
		Tropical storm/ depression	6	7	Storms may cause interruption, even danger to transportation
		Tornado	6	7	Similar to storms

Components	Breakdown	Climate/ hydrological factors	Historical S	Future S	Comments
Sluice gate structure	Pillar	Heat wave	2	3	Heat waves may increase the cracking and corrosion of concrete.
		Water level	1	2	The rise of water levels could increase physical abrasion and corrosion for concrete as recorded in some sluices in the Mekong Delta.
		Salinity	1	2	Salinity may increase the chemical corrosion, resulting in cracked concrete.
		Salinity intrusion + high temperature	3	4	Similar to the effects of salinity
		High water level + heavy rain	2	2	Similar to the effects of the water level
	Gate tower	Heat wave	2	3	Similar to the pillar
	Poured concrete components	Heat wave	2	3	Similar to the pillar
		Salinity	1	2	Similar to the pillar
		Salinity intrusion + high temperature	2	3	Similar to the effects of salinity
Ship lock	Lock chamber	Heat wave	1	2	Similar to the pillar, but the lower, indirect impact
		Water level	3	4	High water level may affect the function of the ship locks (e.g. boat traffic).
		Salinity	1	2	Similar to the pillar
		Salinity intrusion + high temperature	3	4	Similar to the effects of salinity
		High water level + heavy rain	4	5	Similar to the effects of the water level
	Lock head	Heat wave	1	2	Similar to the lock chamber
		Water level	3	4	Similar to the lock chamber
		Salinity	1	2	Similar to the lock chamber
		Salinity intrusion + high temperature	3	4	Similar to the effects of salinity
		High water level + heavy rain	4	5	Similar to the effects of the water level
	Filling and discharge culverts	Heat wave	1	2	Similar to the lock chamber
		Salinity	1	2	Similar to the lock chamber
		Salinity intrusion + high temperature	2	3	Similar to the effects of salinity
	Leading jetty	Heat wave	1	2	Similar to the lock chamber
		Salinity	1	2	Similar to the lock chamber
		Salinity intrusion + high temperature	3	4	Similar to the effects of salinity

Components	Breakdown	Climate/ hydrological factors	Historical S	Future S	Comments
Gates	Hydraulic Cylinder	Salinity	2	3	High salinity concentration of saltwater and vapour can lead to faster erosion of the cylinder.
		Salinity intrusion + high temperature	3	4	Similar to the effects of the salinity
	Sluice gate	Tropical storm/ depression	5	6	Storms raise the water level, increasing the risk of overflowing the sluice and thus causing instability, especially when the drain is open.
		High wind	4	5	Similar to storms but with lower impact.
		Tornado	3	4	Similar to storms but with lower impact due to the shorter duration of tornados.
		Water level	3	4	Water level affects the function of the sluice if overflowing, and its stability if the water level difference between front and behind of the sluice is large. In addition, water level also indirectly causes physical and chemical corrosion.
		Salinity	2	3	High salinity concentration of saltwater and vapour can lead to faster erosion of the gate.
		Salinity intrusion + high temperature	3	4	Similar to the effects of the salinity
		High water level + heavy rain	3	4	Similar to the effects of the water level
	Water tight gasket	High temperature	3	3	High temperature may reduce the lifespan and affect the function of the water tight gasket.
		Heat wave	5	6	Similar to high temperature, but with the higher impact.
		Salinity	1	2	Salinity contributes to reducing the lifespan of the water tight gasket.
		Salinity intrusion + high temperature	3	4	In the working environment between salt water (as the gates are closed) and high temperature (as the gates are opened), the water tight gasket is easily damaged.

Components	Breakdown	Climate/ hydrological factors	Historical S	Future S	Comments
Bridge	Bridge surface/ slope	Heat wave	3	4	Heat waves can damage to the asphalt bridge surface/slope.
		Heavy rain	1	2	Heavy rain may damage to the bridge surface/slope.
		Tornado	2	2	Tornados may cause the peeling of the bridge surface.
	Bridge hand rail	Tornado	2	2	Tornados may damage the bridge hand rail.
Retaining walls and connected embankment	Retaining walls	Heat wave	2	2	Similar to the pillar
		Salinity	1	2	Similar to the pillar
		Salinity intrusion + high temperature	2	3	Similar to the effects of the salinity
	Connected embankment	Heat wave	1	2	Heat waves could change the soil texture, increasing the likelihood of erosion.
		Drought	3	4	Similar to heat waves, but with a greater impact.
		Salinity	1	2	Similar to the pillar
		Salinity intrusion + high temperature	2	3	Similar to the effects of salinity
	Rip-rap	Heat wave	1	2	Similar to the connected embankment
		Salinity	1	2	Salinity may damage the rip-rap and geotextile compositions.
		Salinity intrusion + high temperature	2	3	Similar to the effects of salinity
Operation houses		Heat wave	1	2	Heat waves may cause cracking and damages to the front steps, floor tiles, etc.
		Heavy rain	2	2	Heavy rain could damage some minor components such as the front steps.
		Tropical storm/ depression	2	3	Storms can damage the house.
		High wind	1	2	Similar to tropical storms, but with lower impact.
		Tornado	5	6	Similar to storms, but with greater impact.
		Thunderstorm/ lightning	1	1	Thunderstorm/ lightning inconsiderably affect the operation house.

Components	Breakdown	Climate/ hydrological factors	Historical S	Future S	Comments
Park		Heat wave	2	3	Heat waves can affect the trees and grass cover in the park.
		Heavy rain	2	2	Heavy rain may affect the grass cover and garden walk.
		Tropical storm/ depression	6	7	Storms can damage trees, lightning systems, and protective fences.
		Drought	3	4	Similar to heat waves, droughts can also affect the grass cover and trees, but with greater impact.
		High wind	3	4	Similar to storms, but with lower impact
		Tornado	6	7	Similar to tropical storms
		Thunderstorm/ lightning	7	7	Thunderstorm/lightning can damage lightning systems and protective fences.
Power supply	Transmission lines	Heavy rain	1	2	Heavy rain can cause electric shock.
		Tropical storm/ depression	4	5	Storms can break the wires, interrupting the transmission.
		High wind	3	4	Similar to tropical storms
		Tornado	6	7	Similar to storms but with greater impact
		Thunderstorm/ lightning	7	7	Lightning can completely destroy the system (TCVN 988-1:2013).
	Voltage transformers	Heavy rain	1	2	Heavy rain can cause electric shock.
		Tropical storm/ depression	2	3	Storms can indirectly disrupt the system.
		Tornado	2	3	Similar to tropical storms
		Thunderstorm/ lightning	7	7	Lightning can completely destroy the system.
	Standby generators	Tornado	2	3	Similar to the voltage transformers.
		Thunderstorm/ lightning	7	7	Similar to the voltage transformers.
Operation and control system	Control system	Tropical storm/ depression	7	7	Storms can completely destroy the receiver and the signal transmission.
		Thunderstorm/ lightning	7	7	Thunderstorm/lightning can damage the whole system.
	Operation system	Heavy rain	1	2	Heavy rain can impact on the electrical cabinet of the operation system.
		Heavy 5-day total rainfall	1	1	Similar to heavy rain
		Tropical storm/ depression	4	5	Storms can impact on the electrical cabinet, interrupting the operation.
		Thunderstorm/ lightning	7	7	Similar to the control system.

Components	Breakdown	Climate/ hydrological factors	Historical S	Future S	Comments
Monitoring system		Heavy rain	1	2	Heavy rain can cause errors for the sensors, but with negligible impact
		Heavy 5-day total rainfall	1	1	Similar to heavy rain
		Tropical storm/ depression	7	7	Storm can damage the sensors.
		Tornado	6	7	Similar to tropical storms
		Thunderstorm/ lightning	7	7	Similar to tropical storms
Communication system		Heavy rain	1	2	Heavy rain can affect transmission lines, causing difficulties in communication
		Heavy 5-day total rainfall	1	1	Similar to heavy rain
		Tropical storm/ depression	6	7	Storm can damage transmission lines and columns.
		High wind	3	4	Similar to tropical storms, but with lower impact
		Tornado	6	7	Similar to tropical storms
		Thunderstorm/ lightning	7	7	Thunderstorm/ lightning can destroy the communication system, affecting the communication ability

4.4. Risk assessment matrix

4.4.1. Risk tolerance threshold

In order to support the risk assessment of infrastructure components under the impacts of climate and hydrological factors, risk tolerance thresholds were established based on the PIEVC Protocol guidelines (Table 4-6). High risks ($R > 36$) require a considerable response in the detailed design phase. In contrast, a low risk level ($R < 12$) does imply that there is no need for immediate action. Medium risks ($12 \leq R \leq 36$) should also be taken into account during the detailed design phase.

Table 4-6. Risk tolerance thresholds

Risk range (R)	Threshold	Response
< 12	Low risk	- No immediate action necessary
12 – 36	Medium risk	- Action may be required - Engineering analysis may be required
> 36	High risk	- Immediate action required

However, in some special cases, infrastructure components with the low risk scores still need to be considered, including: those with very high severity and the very low probability and vice versa (i.e., the very low severity and the very high probability). For example, although tornados have a very low probability, they are expected to have a very high severity, thus it is necessary for them to be considered to mitigate the potential damages. In contrast, water level or salinity intrusion usually have a very low severity for the pillars or lock head in a short-term period. However, due to the very high probability, they may cause physical abrasion and corrosion for concrete or metal in the long-term, resulting in damages of these components. Therefore, these interactions also need to be considered.

4.4.2. Risk scores

The risk scores (R) in the PIEVC guidelines are calculated by the following formula:

$$\mathbf{R = P \times S} \qquad \mathbf{(1)}$$

In which:

- P: probability score of climate and hydrological factors

- S: severity scores of infrastructure components under the impacts of climate and hydrological factors

- R: risk scores

Equation (1) was used to calculate the risk scores for the whole risk matrix of the Cai Lon - Cai Be Sluice Gate (*Appendix 9*). This matrix is also the output of the risk assessment developed at the PIEVC workshop #2. The number of the low, medium and high risks for both existing and future conditions is summarised in Table 4-7.

Table 4-7. Summary of low, medium and high risks for both existing and future conditions

Main components	Breakdown	Historical Risk			Future Risk		
		Low	Medium	High	Low	Medium	High
1 - Administration	Personnel	3	6	0	0	9	0
	Transportation	3	1	0	2	2	0
2 - Sluice Gate Structure	Pillar	4	1	0	1	4	0
	Gate tower / Gate hanger	1	0	0	1	0	0
	Cast-in-situ concrete	3	0	0	0	3	0
3 - Ship Lock	Lock chamber	3	2	0	1	4	0
	Lock head	3	2	0	1	4	0
	Filling and discharge culverts	3	0	0	1	2	0
	Leading jetty	2	1	0	1	2	0
4 - Gates	Hydraulic Cylinder	0	2	0	0	2	0
	Gates (large and small)	2	5	0	1	6	0
	Water tight gasket	1	3	0	0	4	0
5 - Bridge	Bridge surface/slope	3	0	0	2	1	0
	Hand rail	1	0	0	1	0	0
6 - Retaining walls & connected embankments	Retaining walls	3	0	0	1	2	0
	Connected embankments	3	1	0	1	3	0
	Rip-rap embankments	3	0	0	1	2	0
7 - Operation house		6	0	0	4	2	0
8 - Park		3	4	0	1	6	0
9 - Electric Power	Transmission Lines	2	3	0	1	4	0
	Power Supply	3	1	0	2	2	0
	Standby Generators	1	1	0	1	1	0
10 - Control and operation system	Control Systems	0	2	0	0	2	0
	Operation systems	2	2	0	2	2	0
11 - Monitoring systems		3	2	0	2	3	0
13 - Communication system		3	3	0	2	4	0
Total (for 106 interactions)		64	42	0	30	76	0

The main findings of the risk matrix are as follows:

- Of the 468 interactions entering the YES/NO analysis, only for 106 interactions the answer was "YES" and they were consequently scored in terms of severity (see *Appendix 9*).
- Of the above 106 interactions, there are no high-risk interactions for both existing and future conditions.
- The majority of interactions have a medium risk for future projections (76), while there are only 42 medium-risk ones for existing conditions (baseline climate). This indicates that the risk overall is expected to increase under future climate conditions.

- The number of low-risk interactions for existing and future conditions is 64 (existing conditions) and 30 (future conditions), respectively. This is due to the fact that some of the low risks under existing conditions are expected to become medium risks in the future.
- The medium-risk interactions for existing conditions are mainly due to tropical storms/depression, thunderstorms/lightning, high wind, water level, and salinity intrusion combined with high temperature. The corresponding variables for future projections are tropical storms/depression, thunderstorms/lightning, tornados and salinity intrusion combined with high temperature.
- The major infrastructure components affected are the staff, park, gates, water tight gasket, and the systems of electric power, monitoring, control and operation, and communication for both existing and future conditions. In addition, the pillar, ship lock, and connected embankment are expected to become more affected under the future conditions.
- There are 91 interactions where the risk scores increase in a comparison between current and future conditions.
- Some climate factors, such as tropical storms/depression and thunderstorms/lightning, have average probability scores (from 3 to 5), but have a significant impact (i.e., the severity scores were mainly from 5 to 7) and an increasing trend in the future.
- Salinity intrusion and salinity intrusion associated with high temperature affect the components made of metal and concrete at medium level (from 2 to 4) but have high probability scores (equal to 7).

5. CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

This study has completed a climate risk assessment for the Cai Lon - Cai Be Sluice Gate project (1st phase) using the PIEVC Protocol. This assessment has identified historic and projected representations of climatic variables and phenomena and their interactions with infrastructure and operations associated with the Cai Lon - Cai Be Sluice Gates Project. The identified interactions form the basis for quantification of probability of occurrence and severity of impact estimates which have led to the identification of vulnerabilities affected by climate change and the quantification of risk. Steps 1, 2, 3 and 5 have been included in this assessment. Although Step 4 has not been included in the assessment, the risk matrices obtained from the assessment process present a picture of the potential risks for the Cai Lon - Cai Be Sluice Gates under the impacts of climate and hydrological factors for both historical conditions and future projections. The study has also provided recommendations to support the next stages of Cai Lon - Cai Be Sluice Gate project (i.e., the detailed design, construction drawing design, and operation and maintenance).

As noted earlier in this report, 106 climate / infrastructure interactions have undergone detailed assessment. While no interactions were identified as being in the high risk category, there is a clear trend for increasing potential for climate change to impact the infrastructure as presently designed, noting an increase in medium risk interactions from 29 to 70, in the historic context to the future context, respectively. There are 91 climate/infrastructure interactions where the risk scores increase from existing to future conditions.

The primary climate parameters/phenomena driving the identified increasing trend are:

- tropical storms/depressions;
- thunderstorms and lightning;
- tornados; and,
- salinity intrusion combined with high temperature.

Due to the limited or insufficient data available for some geological, climate and hydrological factors (e.g., hydro-geology, land subsidence, faults and earthquakes, storm surges, waves, water temperature and sediment transport), this study could not complete the risk assessment related to the potential impacts of these factors. Thus, additional work in terms of data collection for these specific parameters should be considered in the next steps.

The major infrastructure components experiencing increased vulnerability for both existing and future conditions are:

- staff;
- park;
- gates;
- water tight gasket;
- pillar;
- ship lock;
- connected embankment; and the
- systems of electric power, monitoring, control and operation, and communication.

Recommendations (ref. next section) following directly from the assessment of vulnerability have been developed to inform the continued development of the design of the Cai Lon - Cai Be Sluice Gate project, its construction and operations and maintenance.

The overall achievement demonstrated by this assessment confirms that the PIEVC Protocol can be applied for risk assessment of infrastructures in the Mekong Delta, in particular, and Vietnam in general. This has been a major goal of the CSI global project.

5.2. Recommendations

Where vulnerability has been identified, options to mitigate vulnerability have been assessed including possible reductions in load effects, changes in the performance criteria or additional capacity building. As a general rule, systems with high adaptive capacity are better able to deal with climate change impacts. Step 5 details infrastructure-specific recommendations on adaptive measures, such that the desired performance criteria are met in those circumstances where Step 3 has indicated insufficient adaptive capacity.

The recommendation categories, based on the PIEVC protocol, are as follows:

- *Remedial engineering or operations action required*
- *Management action required*
- *Additional study or data required*
- *No further action required.*

In fact, what generates the greatest need (and opportunity) to take action in terms of climate change adaptation now is the stage at which the Cai Lon – Cai Be is in its development. Though climate risks are expected to increase in the future, the Government of Vietnam is in an ideal position to proactively mitigate and adapt to these challenges through existing programs with its infrastructure development partners.

The recommendations given for the stages of the detailed design, construction drawing design, and operation and maintenance of the infrastructures associated with the Cai Lon - Cai Be Sluice Gates Project are based on the results of the risk assessment. Following the function and characteristics of the main components of the Cai Lon – Cai Be Sluice Gate Project, the recommendations generally consider six (6) primary groups as follows:

- Staff

The operational staff are affected by most climatic factors, especially extreme events. They need support through additional training courses on coping with tropical storms and tornados, as well as enhanced self-protection skills for high temperature, heavy rain and high wind (in case of working outdoors). The use of the automatic operation mode as well as choosing the appropriate time of proper maintenance are other risk mitigation options.

- Primary Infrastructure Components

The concrete components as pillars and ship locks are expected to be impacted by high temperature and heat waves, and increases the in water level and salinity, causing cracking and concrete corrosion. Therefore, it is recommended to use sulphate resistant cement, anti-corrosion additive mixture, or high concrete grade (M50) and the coating method by Epoxy for these components.

The hydraulic cylinders and gates are likely to be corroded by high a salt concentration in the water and moisture, especially in combination with high temperature. Thus, it is necessary to further study the mechanisms and causes of metal corrosion in the Mekong Delta to identify suitable prevention measures such as using a stainless steel together with the coating method by Epoxy.

- Operations Systems

Due to the technical characteristic of sensors of the SCADA system, they are exposed to climatic factors and it is necessary to select sensors with high tolerance to climatic factors.

- Ancillary Infrastructure Components

As the electric system is highly vulnerable to thunderstorms/lightning, tornados, storms and heavy rainfall, it is recommended to consider underground wiring designs for both of Cai Lon and Cai Be sluice gates and to include lightning protection systems in the design for the whole infrastructure.

- Project/Facility Management

The monitoring system needs regular maintenance to ensure its continuous functionality.

- Climate Services

It is necessary to develop climate service program(s) to enhance data collection (e.g. tornados, sediment), sharing and to raise awareness about the need for climate services. This will make it easier to monitor and assess climate risks as a basis for effective climate risk management, not only for the Cai Lon – Cai Be project but also other infrastructures in the region.

Table 5-1 details the following elements:

- Infrastructure components and climate variable interactions taken directly from the risk assessment workshop matrices where a significant interaction has been identified (focusing on the medium risk scores). An additional "General" grouping of recommendations has been added for recommendations that are applicable beyond specific component-climate factor interactions.
- The recommendation categories are consistent with the PIEVC classification.
- Comments on the recommendations provide additional details with regard to the respective recommendation and its basis.

This information provides a gauge with which the recommendations can be grouped for planning and budgeting purposes.

- *"Cost Range"* provides a suggested range of costs that can reasonably be associated with the implementation of the recommendation as outlined below. The range was estimated based on the design report and costs for similar infrastructures.

$	< 2 bil. VND
$$	2 bil. VND to 10 bil. VND
$$$	10 bil. VND +

- *"Time Frame"* provides a similar suggested implementation target for recommendations as "ASAP" – as soon as possible meaning these initiatives are immediately relevant. A "Short" time frame suggests initiation of a recommendation with 5 years. A "Medium" time frame suggests initiation of a recommendation with 10 years and is particularly relevant to climate phenomena that are expected to impact the subject infrastructure in the medium to long term.
- *"Action by"* provides a suggestion as to which agency / organization should lead the advancement of recommendations.

Declare Assumptions Regarding Available Information, Data Sources, Uncertainties and Relevant Limitations

The uncertainty in the assessment of the likelihood and magnitude of climate - infrastructure interactions is a limitation of this study. As outlined in Step 3, judgement of likelihood and magnitude were unique to the individuals who took part in the risk assessment workshop. The probability and risk values documented from the workshop are consensus views of likelihood and magnitude. Nonetheless, a range of limiting factors contribute to uncertainty about some of the risks. More specifically:

- The data of some climate and hydrological factors such as storm surges, waves, water temperatures are not regularly measured. The data on sediment transport is available only on the Mekong mainstream stations and is not measured in the study area.
- The data/information of hydro-geology, land subsidence, faults and earthquakes are at a basic level (i.e., short/limited data coverage). Therefore, these factors were not assessed individually, but were only considered in cumulative effects, for example, the land subsidence combined into the water level element.
- The information related to the climate risks of the similar projects was limited (about 15 years) because the other large sluice gates in the Mekong Delta, such as Lang The sluice (Tra Vinh) and Ba Lai sluice (Ben Tre), have only been in operation since 2004.

Overall, though, the results of this study are based on professional judgement based on the most recent information available. The process followed was well-documented within the scope of the PIEVC Protocol. Therefore, the results of the assessment can be used as a guide for future action to inform the detailed design of the Cai Lon - Cai Be Sluice Gates Project.

5. Conclusion and Recommendations

Table 5-1. Recommendations for interactions between infrastructure components and climate/hydrological factors

Components	Breakdown	Climate/ hydrological factors	Risk Baseline	Risk Future (2080)	Climate/Infrastructure Interaction Comments	Recommendation Category	Recommendation	Cost Range	Implementation Time Frame	Recommended Action By
Operation and maintenance	Staff	High temperature (≥35ºC)	18	21	Outside work in high temperatures expected to cause increased fatigue and negatively impact the performance of the staff.	Operations action required	Define an operational procedure to use the automatic operation mode or choose the time of proper maintenance in the condition of heat wave, for example, in the afternoon when the temperature is lower.	Not applicable	After construction	Management Company
							Limit exposure or require use of protective equipment and clothing when working outdoors	Not applicable	After construction	Management Company
		Heat wave (≥ 8 consecutive days with temperature ≥35ºC)	15	24	Outside work during heat waves is expected to cause increased fatigue and negatively impact the performance of the staff.	Operations action required	Same as for high temperature	Not applicable	After construction	Management Company
		Heavy rain (≥100mm in a day)	12	20	Heavy rain may make surfaces slippery, resulting in increased falling hazards for outside workers	Operations action required	Limit exposure or require use of protective equipment and clothing when working outdoors	Not applicable	After construction	Management Company
		Heavy 5-day total rainfall (≥250mm)	8	12	Outside work during multi-day rainfall events expected to negatively impact the performance of the staff.	Operations action required	Same as Heavy Rain	Not applicable	After construction	Management Company
		Tropical storm/depression (the wind speed of 62-74km/h)	21	28	Storms can endanger the lives of the operators during their work.	Operations action required	Limit working outdoors	Not applicable	After construction	Management Company
		Drought (K≥4 in the dry season)	10	18	Similar to high temperature and heat wave	Operations action required	Same as for High temperature	Not applicable	After construction	Management Company
		High wind (≥ 20m/s)	12	16	Outside operations during periods of high winds represents a danger to staff and is expected to negatively impact the performance of outside workers.	Operations action required	Same as Tropical storm/depression	Not applicable	After construction	Management Company
		Tornado (Fujita wind scale)	6	14	Similar to storms, tornados can endanger the lives of operators during work.	Operations action required	Same as Tropical storm/depression	Not applicable	After construction	Management Company
		Thunderstorm/lightning (statistical data)	35	35	Similar to storms and tornados, Thunderstorm/lightning could be dangerous to the lives of the operators when they are working in the field.	Operations action required	Same as Tropical storm/depression	Not applicable	After construction	Management Company
	Transportation	Tropical storm/ depression	18	28	Storms are expected to cause interruption, even danger to transportation	Operations action required	Limit working outdoors	Not applicable	After construction	Management Company
		Tornado	6	14	Similar to storms	Operations action required	Same as Tropical storm/depression	Not applicable	After construction	Management Company

5. Conclusion and Recommendations

Components	Breakdown	Climate/ hydrological factors	Risk Baseline	Risk Future (2080)	Climate/Infrastructure Interaction Comments	Recommendation Category	Recommendation	Cost Range	Implementation Time Frame	Recommended Action By
Operation and maintenance	General	Heavy rain			Sluice gates operations	Training	Training about the climate and hydrological risks for the infrastructure, as well as the main factors affecting the Cai Lon - Cai Be sluice gates;	Not applicable	After construction	MARD/VDMA
		Extreme Weather			Sluice gates operations	Training	Develop training on the skills needed to cope with extreme events with low probability such as tropical storms and tornado	Not applicable	After construction	MARD/VDMA
		All			Sluice gates operations	Training	Develop learning via field trips on management and operation from the similar projects in Vietnam and abroad	Not applicable	After construction	MARD/VDMA
					Staff performance	Health	Regular health check for staff	Not applicable	After construction	Management Company
					Staff performance	Operations action required	Develop Regulation for staff working procedures/ SOP/ incorporate recommendations for staff component	Not applicable	After construction	Management Company
					Staff performance	Training	Training for staff for dealing with extreme events	Not applicable	After construction	MARD/VDMA
Sluice gate structure	Pillar	Heat wave	6	12	Heat waves are expected to increase the cracking and the corrosion of concrete.	Structural Material	Use high quality cement (at least M40)	$$	ASAP	PMU-10
		Water level (0.9m)	7	14	The rise of water levels could increase physical abrasion and corrosion for concrete as recorded in some sluices in the Mekong Delta.	Structural Material	Use high quality concrete (at least M40); Use coating (EPOXY)	$$	ASAP	PMU-10
		Salinity (3g/l)	7	14	Salinity is expected to increase the chemical corrosion, resulting in cracked concrete.	Structural Material	Use high quality concrete (at least M40); Use coating (EPOXY)	$$	ASAP	PMU-10/ (options by design company)
		Salinity intrusion + high temperature	12	20	Similar to the effects of salinity	Structural Material	Same as salinity	$$	ASAP	PMU-10
						Further study	Conduct in-depth study on interaction between salinity, high-temperature and the infrastructure	Not applicable	ASAP	PMU-10
	Poured concrete components	Heat wave	6	12	Similar to the pillar	Structural	Same as the pillar	$	ASAP	PMU-10
		Salinity	7	14	Similar to the pillar	Structural	Same as the pillar	$	ASAP	PMU-10
		Salinity intrusion + high temperature	8	15	Similar to the effects of salinity	Structural	Same as the pillar	$	ASAP	PMU-10

5. Conclusion and Recommendations

Components	Breakdown	Climate/ hydrological factors	Risk Baseline	Risk Future (2080)	Climate/Infrastructure Interaction Comments	Recommendation Category	Recommendation	Cost Range	Implementation Time Frame	Recommended Action By
Ship lock	Lock chamber	Water level	21	28	High water level is expected to affect the function of the ship locks (e.g. boat traffic).	Operations	Set up traffic guiding signs specifically for Early Warning: Guidance during high water level	$	ASAP	Management Company
						Structural	Protective „column" before pillar	$	ASAP	PMU-10
						Operations	Set up monitoring network and Early Warning System	$	ASAP	Management Company
		Salinity	7	14	Similar to the pillar	Structural	Same as the pillar	$	ASAP	PMU-10
		Salinity intrusion + high temperature	12	20	Similar to the effects of salinity	Structural	Same as the pillar	$	ASAP	PMU-10
		High water level + heavy rain	8	20	Similar to the effects of the water level	Structural	Same as Water level	$	ASAP	PMU-10
	Lock head	Water level	21	28	Similar to the lock chamber	Structural	Same as the lock head	$	ASAP	PMU-10
		Salinity	7	14	Similar to the lock chamber	Structural	Same as the lock head	$	ASAP	PMU-10
		Salinity intrusion + high temperature	12	20	Similar to the effects of the salinity	Structural	Same as the lock head	$	ASAP	PMU-10
		High water level + heavy rain	8	20	Similar to the effects of the water level	Structural	Same as the lock head	$	ASAP	PMU-10
	Filling and discharge culverts	Salinity	7	14	Similar to the lock chamber	Structural	Same as the lock chamber	$	ASAP	PMU-10
		Salinity intrusion + high temperature	8	15	Similar to the effects of salinity	Structural	Same as the lock chamber	$	ASAP	PMU-10
	Leading jetty	Salinity	7	14	Similar to the lock chamber	Structural	Same as the lock chamber	$	ASAP	PMU-10
		Salinity intrusion + high temperature	12	15	Similar to the effects of salinity	Structural	Same as the lock chamber	$	ASAP	PMU-10

5. Conclusion and Recommendations

Components	Breakdown	Climate/ hydrological factors	Risk Baseline	Risk Future (2080)	Climate/Infrastructure Interaction Comments	Recommendation Category	Recommendation	Cost Range	Implementation Time Frame	Recommended Action By
Gates	Hydraulic Cylinder	Salinity	14	21	High salinity concentration of saltwater and vapor is expected to lead to faster erosion of the cylinder.	Structural Material Protection	Use coating (EPOXY)	$	ASAP	PMU-10
		Salinity intrusion + high temperature	12	20	Similar to the effects of salinity	Structural Material Protection	Same as Salinity	$	ASAP	PMU-10
	Sluice gate	Tropical storm/depression	15	24	Storms raise the water level, increasing the risk of overflowing of the sluice, and they cause instability of the gates, especially when the drain is open.	Operations action required	Close the gates (no operations)	Not applicable	After construction	Management Company
		High wind	16	20	Similar to storms but with lower impact.	Operations action required	Same as Tropical storm/depression	Not applicable	After construction	Management Company
		Water level	21	28	Water level affects the function of the sluice if overflowing, and its stability if the water level difference between front and back of the sluice is large. In addition, water level also indirectly causes physical and chemical corrosion.	Structural Material	Use materials with high corrosion resistance (such as stainless steel or SUS304); Use coating (EPOXY)	$$	ASAP	PMU-10
		Salinity	14	21	High salinity concentration of saltwater and vapor is expected to lead to faster erosion of the gate.	Structural Material	Use materials with high corrosion resistance (such as stainless steel or SUS304); Use coating (EPOXY)	$$	ASAP	PMU-10
		Salinity intrusion + high temperature	12	20	Similar to the effects of salinity	Structural Material	Same as salinity	$$	ASAP	PMU-10
		High water level + heavy rain	6	16	Similar to the effects of the water level	Structural Material	Same as Water level	$$	ASAP	PMU-10
	Water tight gasket	High temperature	18	21	High temperature is expected to reduce the lifespan and affect the functionality of the water tight gasket.	Function	Consider using more durable/resistant material (different type of rubber)	$	ASAP/ short term	PMU-10 (at construction), after: Management Company
						Maintenance	Regular maintenance (every 6 month) to replace when necessary	$	After construction	Management Company
		Heat wave	15	24	Heat wave significantly contributes to making the water tight gasket get damaged faster, as recorded by the senior operation staff.	Maintenance	Check after every heat wave to see whether it withstood the impact, replace if necessary	$	After construction	Management Company
		Salinity	7	14	Salinity partly contributes to reducing the lifespan of the water tight gasket.	Maintenance	Same as high temperature	$	After construction	Management Company
		Salinity intrusion + high temperature	12	20	Similar to the effects of salinity	Maintenance	Same as salinity	$	After construction	Management Company

5. Conclusion and Recommendations

Components	Breakdown	Climate/ hydrological factors	Risk Baseline	Risk Future (2080)	Climate/Infrastructure Interaction Comments	Recommendation Category	Recommendation	Cost Range	Implementation Time Frame	Recommended Action By
Bridge	Bridge surface/ slope	Heat wave	9	16	Heat wave can damage the asphalt bridge surface/slope.	Maintenance	Check after every heat wave to see whether it withstood the impact, repair if necessary	$	After construction	Management Company
Retaining walls and connected embankment	Retaining walls	Salinity	7	14	Similar to the pillar	Structural	Same as the pillar	$	ASAP	PMU-10
		Salinity intrusion + high temperature	8	15	Similar to the effects of salinity	Structural	Same as the pillar	$	ASAP	PMU-10
	Connected embankment	Drought	15	24	Drought could change the soil texture, increasing the likelihood of erosion	Maintenance	Check after drought to see whether it withstood the impact, repair/maintain if necessary	$	After construction	Management Company
		Salinity	7	14	Similar to the pillar	Structural	Same as the pillar	$	ASAP	PMU-10
		Salinity intrusion + high temperature	8	15	Similar to the effects of salinity	Structural	Same as the pillar	$	ASAP	PMU-10
	Rip-rap	Salinity	7	14	Salinity is expected to damage the rip-rap and geotextile compositions.	Maintenance	Regular maintenance annually to maintain/ repair when necessary	$	After construction	Management Company
		Salinity intrusion + high temperature	8	15	Similar to the effects of salinity	Maintenance	Same as salinity	$	After construction	Management Company
Operation houses		Tropical storm/depression	6	12	Storms can damage the house.	Maintenance	Check after storms to see whether it withstood the impact, repair/maintain if necessary	$	After construction	Management Company
		Tornado	5	12	Similar to storms, but with greater impact.	Maintenance	Same as tropical storm/depression	$	After construction	Management Company
Park		Heat wave	6	12	Heat waves are expected to affect the trees and grass cover in the park.	Operations	Irrigate the trees in the appropriate time such as early morning and late afternoon	Not applicable	After construction	Management Company
		Tropical storm/depression	18	28	Storm can damage trees, lightning systems, and protective fences.	Maintenance	Check after storms to see whether it withstood the impact, repair/maintain if necessary	$	After construction	Management Company
		Drought	15	24	Similar to heat wave, droughts are expected to also affect the grass cover and trees, but with a greater impact.	Operations	Same as heat waves	Not applicable	After construction	Management Company
		High wind	12	16	Similar to storms, but with a lower impact	Maintenance	Same as tropical storm/depression	$	After construction	Management Company
		Tornado	6	14	Similar to tropical storms	Maintenance	Same as tropical storm/depression	$	After construction	Management Company
		Thunderstorm/ lightning	35	35	Thunderstorm/lightning can damage lightning systems and protective fences.	Function	Consider underground wiring designs and no splices/cable junctions at risk (i.e. wet) areas;	$$	ASAP	PMU-10

5. Conclusion and Recommendations

Components	Breakdown	Climate/ hydrological factors	Risk Baseline	Risk Future (2080)	Climate/Infrastructure Interaction Comments	Recommendation Category	Recommendation	Cost Range	Implementation Time Frame	Recommended Action By
Power supply	Transmission lines	Tropical storm/depression	12	20	Storms can break the wires, interrupting the transmission.	Maintenance	Check after storms to see whether it withstood the impact, repair/maintain if necessary	$	After construction	Management Company
		High wind	12	16	Similar to tropical storms	Maintenance	Same as tropical storm/depression	$	After construction	Management Company
		Tornado	6	14	Similar to storms but with a greater impact	Maintenance	Same as tropical storm/depression	$	After construction	Management Company
		Thunderstorm/ lightning	35	35	Lightning can completely destroy the system (TCVN 988-1:2013).	Function	Consider underground wiring design	$$	ASAP	PMU-10
							Lightning protection system suitable for big infrastructures (e.g. like Rach Chanh ship lock)	$$$	ASAP	PMU-10
	Voltage transformers	Tropical storm/depression	6	20	Storms can indirectly disrupt the system.	Maintenance	Check after storms to see whether it withstood the impact, repair/maintain if necessary	$	After construction	Management Company
		Thunderstorm/ lightning	35	35	Lightning can completely destroy the system.	Maintenance	Check after thunderstorms to see whether it withstood the impact, repair/maintain if necessary	$	After construction	Management Company
	Standby generators	Thunderstorm/ lightning	35	35	Similar to the voltage transformers.	Maintenance	Same as the voltage transformers	$	After construction	Management Company
Operation and control system	Control system	Tropical storm/depression	21	28	Storms can completely damage the receiver and the signal transmission.	Maintenance	Check after storms to see whether it withstood the impact, repair/maintain if necessary	$	After construction	Management company
		Thunderstorm/ lightning	35	35	Thunderstorm/lightning can damage the whole system.	Maintenance	Check after thunderstorms to see whether it withstood the impact, repair/maintain if necessary	$	After construction	Management company
	Operation system	Tropical storm/depression	12	20	Storms can impact the electrical cabinet, interrupting the operation.	Maintenance	Check after storms to see whether it withstood the impact, repair/maintain if necessary	$	After construction	Management company
		Thunderstorm/ lightning	35	35	Similar to the control system	Maintenance	Same as the control system	$	After construction	Management company
Monitoring system		Tropical storm/depression	21	28	Storm can damage the sensors.	Functional	Conduct check of sensors after each tropical storm and take remedial action of necessary (replacement)	$	After construction	Management company
		Tornado	6	14	Similar to tropical storms	Functional	Same as tropical storm/depression	$	After construction	Management company
		Thunderstorm/ lightning	35	35	Similar to tropical storms	Functional	Same as tropical storm/depression	$	After construction	Management company
		General				Maintenance	Allocate additional maintenance budget reserve for monitoring system	$	After construction	Management company
						Maintenance	Regular maintenance of monitoring system to ensure continuous functionality	$	After construction	Management company

5. Conclusion and Recommendations

Components	Breakdown	Climate/ hydrological factors	Risk Baseline	Risk Future (2080)	Climate/Infrastructure Interaction Comments	Recommendation Category	Recommendation	Cost Range	Implementation Time Frame	Recommended Action By
Communication system		Tropical storm/depression	18	28	Storm could damage transmission lines and columns.	Maintenance	Check after storms to see whether it withstood the impact, repair/maintain if necessary	$	After construction	Management company
		High wind	12	16	Similar to tropical storms, but with a lower impact	Maintenance	Same as tropical storm/depression	$	After construction	Management company
		Tornado	6	14	Similar to tropical storms	Maintenance	Same as tropical storm/depression	$	After construction	Management company
		Thunderstorm/ lightning	35	35	Destroy the communication system, affecting the communication ability	Maintenance	Same as tropical storm/depression	$	After construction	Management company
Climate Services	Data Availability	Hydro-geology			Limited or insufficient data available to support completion of the risk assessment	Additional study or data required	Develop climate services program(s) to collect data	$$$	Long-Term	MONRE
		Land subsidence				Additional study or data required				
		Faults and earthquakes				Additional study or data required				
		Storm surges				Additional study or data required				
		Waves				Additional study or data required				
		Water temperatures				Additional study or data required				
		Sediment transport				Additional study or data required				

Note: (*) ASAP means that the action needs to be considered / implemented in the detailed design.

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APPENDIX 1. Project team members

No.	Name	Organisation	Role in team
1	Do Duc Dung	Southern Institute for Water Resources Planning (SIWRP)	Project Coordinator - Water resource expert
2	Nguyen Duc Cong Hiep	SIWRP	Technical secretary - Water resources expert
3	Pham Van Manh	SIWRP	Geology expert
4	Le Viet Minh	SIWRP	Water resources expert
5	Nguyen Trung Nam	SIWRP	Hydrology expert
6	Tran Minh Dien	Water Resources Investment and Construction Board 10, Can Tho	Civil expert
7	Nguyen Thi Lien	Southern Regional Hydro-meteorological Center	Climate expert

APPENDIX 2. Standards and regulations for sluice gate design

- QCVN 04-01-2010/BNNPTNT: National technical regulation On Work and Content Requirements for establishing Investment Report, Investment Project and Economic - Technical Report of Water Resources Development Projects;
- QCVN 04-05-2012/BNNPTNT: National technical regulation on hydraulic structures – The basic stipulation for design;
- QCVN 07-2012/BKHCN: National technical regulation on steel for the reinforcement of concrete;
- QCVN 41-2012/BGTVT: National Technical Regulation on Road Signs and Signals;
- TCVN 8478-2010: Hydraulic work – Demand for element and volume of the topographic survey in design stages.
- TCVN 8477-2010: Hydraulic work - Demand for element and volume of the geological survey in design stages
- 14TCN 4-2003: Hydraulic work - Demand for element and volume of the Hydrological works and survey in design stages;
- TCVN 5664-2009: Rules for Technical Classification of Inland Waterways;
- TCVN 9160-2012: Hydraulic structures - Technical requirements for design of diversion channel in construction;
- TCVN 9162-2012: Hydraulic structures - Construction roads - Technical requirements for design;
- TCVN 10400-2015: Hydraulic structures - Pillar dam - Technical requirements for design;
- TCVN 8419-2010: Hydraulic structure - Design of river bank flood protection structures;
- TCVN 8422-2010: Hydraulic structure – Design of adverse filter;
- TCVN 9152-2012: Hydraulic structures - Designing Process for Retaining Walls;
- TCVN 9139-2012: Hydraulic Structures - Concrete and reinforced concrete Structures in coastal areas - Technical Specifications;
- TCVN 9143-2012: Hydraulic structures - Calculate Permeable borders of Dam on unrock Foundation;
- TCVN 8412-2010: Hydraulic structure - Guideline for setting operation procedure;
- TCVN 8418-2010: Hydraulic structure - Process for management, operation and maintenance of sluice;
- TCVN 9902-2013: Hydraulic structures - Requirements for river dike design;
- TCVN 4118-2012: Irrigation system - Irrigation canal design standard;
- TCVN 8305-2009: Hydraulics structures - Earth canal - Technical requirements for construction and acceptance;
- TCVN 8304-2009: Hydrological works in irrigation system;
- TCVN 9845-2013: Calculation of flood flow characteristics;
- TCVN 4253-2012: Hydraulic structures - Foundation of hydraulic projects - Design standard;
- TCVN 9379-2012: Building structures and foundations - Basic rules for calculations;
- TCVN 8421-2010: Hydraulic Structures – Loads and actions of wind-induced and Ship-induced waves on structures;
- TCVN 10304-2014: Pile Foundation - Design Standard;
- TCVN 9394-2012: Pile driving and static jacking works- Construction, check and acceptance;
- TCVN 9395-2012: Bored pile - Construction, check and acceptance;
- TCVN 4055-2012: Organization of construction activities;
- TCVN 5574-2012: Concrete and reinforced concrete structures - Design standard;

- TCVN 5575-2012: Steel structures - Design standard;
- TCVN 4054-2005: Highway - Specifications for design;
- TCVN 9138-2012: Geotextile - Test method for determination of joint tensile strength;
- TCVN 9844-2013: Requirements of design, construction and acceptance of geotextiles in embankment construction on soft ground;
- TCVN 9163-2012: Hydraulic structures - Electro-mechanic drawing - Content requirements;
- TCVN 8298-2009: Hydraulics Structures - Technical requirements for manufacturing and installing mechanical equipment, steel structures;
- TCVN 8299-2009: Hydraulics Structures – Technical Requirements for Steel Gate and Groove Design;
- TCVN 8640-2011: Hydraulic structures - Operating cable mechanism - Technical requirements for designing, manufacturing, installation and inspection;
- TCVN 8646-2011: Hydraulic structures - Zinc covered surface of steel structure and mechanical equipment - Technical requirements;
- 22TCN 272-05: Specification for bridge design;

APPENDIX 3. The agenda of the PIEVC workshop # 2 – Risk assessment

GIZ Enhancing Climate Services for Infrastructure Investments (CSI) Project
PIEVC Protocol Capacity Building Support Services: Vietnam

Capacity Development Workshop for Engineers, Planners and other Staff on Integrating Climate Risk into Infrastructure Development

PIEVC WORKSHOP #2 AGENDA - RISK ASSESSMENT

Day 1 – PIEVC End-to-End Training Tuesday October 16, 2018		
08:00	Registration	All
08:30	Welcome and Opening Remarks	Mr. Le Quang Tuan, Deputy Director of Science Technology and International Cooperation Department of VNDMA under MARD Mr. Benjamin Hodick, CSI project lead
08:50	Workshop Participants Introductions	All
09:20	Overview of the Cai Lon-Cai Be Project (updated for the project)	Mr. Do Duc Dung and Mr. Tran Minh Dien
10:00	Refreshments and Networking	
10:15	Overview of PIEVC Protocol Step 1	Canadian advisors
	PIEVC Protocol Step 1 – Application to the Cai Lon-Cai Be Project	Vietnam Assessment Team/Canadian advisors
11:00	Discussion	Facilitated by Canada Coaching Team & GIZ Germany
11:30	Lunch	
13:00	Overview of PIEVC Protocol Step 2	Canadian advisors
13:15	Climate Data Overview	Vietnam Assessment Team (+Hydromet) Part 1 - Canadian advisors (Neil) &
13:45	Breakdown of Cai Lon-Cai Be infrastructure	Vietnam Assessment Team (Dien and Minh)
14:15	Discussion	Facilitated by Canadian advisors & GIZ Germany
15:00	Refreshments and Networking	

15:15	(Y/N Exercise 1 on worksheets) PIEVC Protocol Step 2 – Application to the Cai Lon-Cai Be Project (before break)	Vietnam Assessment Team
16:15	Discussion	Facilitated by Canadian advisors & GIZ Germany
16:45	Day 1 Recap and Day 2 Overview	Canadian advisors & GIZ
	Lead workshop facilitator will review the outcomes of Day 1 and provide a preview of Day 2. There will be time for discussion and questions	
17:00 17:30	Day 1 Adjourned Dinner together at Sai Gon Grill-Rooftop, at 91 Pasteur street	

APPENDIX 4. The minute of the PIEVC workshop # 2 – Risk assessment

Day 1 (16/10/2018)

The workshop was held at Bong Sen Hotel, started at 8:30 a.m, 16 October 2018.

Participants: 23

- Engineers Canada, GIZ
- Vietnam: SIWRP; VDMA; Southern HydroMet; PMU10

MC. Ngo Chuong welcomed the participants and introduced the agenda.

Welcome speech by Mr. Le Quang Tuan (VDMA) emphasized the spirit of Resolution 120 on linking the Mekong Delta to climate change, together with the action plans. In this context, infrastructure works must have solutions to reduce risks, resilient and adapt to climate change. The results of the project will support local and regional managers in planning, which will be applied across the region and at the scale of the delta alliance, resulting in sustainable development.

The speech by Mr. Benjamin Hodick welcomed the participants to the second PIEVC Workshop, following the success of the first Workshop in Can Tho. GIZ is very pleased to cooperate with VDMA and MPI through the risk assessment. The goal is to make planning for infrastructure investment more sustainable, prudent and relevant to climate change. The lessons about coastal and urban infrastructures in the America and Europe will be consulted for the selective use in Vietnam. Through cooperation among VDMA, SIWRP, HydroMet, MPI,... we will look back on the historical climate change to predict the future climate and assess the level of risk on the infrastructure, determine the progress of this support and the time frame for implementation, further training activities... to bring the best value for Cai Lon - Cai Be sluice gate project, on both design and operation aspects.

Participants introduction: Canadian Consultants (Peter, Neil, Helen), GIZ (Ben, Vu, Chuong, Ngoc, Dai), HydroMet (Lien, Huong, Tuan, Phuong), Kien Giang Department of Water Resource (Toan), Southern Institute for Water Resources Planning (SIWRP) (Dung, Ron, Hiep, Minh), PMU10 (Dien), Department of Construction Management (Tien), Kien Giang HydroMet Station (Hien).

Dien (PMU10) presented about an overview of the investment planning process and the approval progress of Cai Lon - Cai Be sluice gate. The planning process was involved and reviewed by several relevant experts in different sectors throughout workshops and consultative meeting (the most recent was the September meeting in Kien Giang). It is necessary to invest the Cai Lon - Cai Be project due to the natural challenges (valley, lack of fresh water), natural disasters, climate change and development. Construction of the works will help to be proactive for water resource for production, natural disaster prevention and response to climate change. Economic efficiency and cost benefit calculations were also presented, while the environmental impact assessment was finalized and submitted to the Ministry of Environment and Natural Resources for the final approval.

Discussion:

- Q: Mr. Peter (Canada) asked questions about the planning process, after approval, how long it will take to complete the technical and construction design.
- **A:** Mr. Dien (PMU10): It is expected to be approved in October, followed by 6 months to select the design contractor, design in 6-12 months, then 1-2 months select the contractor. So the earliest construction will be started in 10/2019.
- Q: Mr. Toan (Kien Giang Department of Water Resources) questioned whether it is necessary to reconsider the operation of sluice gates (closing and opening time of sluice gates).
- **A:** Mr. Dung (SIWRP) responded that the purpose of project is that to irrigate actively (not suitable for automatic irrigation), improve the precarious production situation in Kien Giang, within this workshop, we need to focus on climate risk assessment for the infrastructure.

Ms. Helen presented Overview of PIEVC Protocol Step 1.

Mr. Hiep (SIWRP) presented the results of Step 1 by the Vietnam Assessment Team, focusing on assessing the two sluices. The impacts of hydro-meteorological factors are not only considered individually, but also in terms of the effect combination (such as sea level rise caused by storm surges, associated with subsidence, soil texture combined with flood flow ...). The data sufficiency assessment indicated that the data is sufficient except for cyclones, thunderstorms... Geological and hydrography data is limited. The data gaps will be addressed in Step 5 - Recommendations.

Discussion:

- Mr. Peter commented that it should be updated, monitored and adjusted during the assessment process to achieve the best results.
- Q: Mr. Tuan (VDMA) asked which standards will be applied in the design, and whether this standard has been approved by MARD?
- **A:** The answer (Mr Dien - PMU10) is that, after approval, there will be a set of design standards, while the climate risk assessment process is an additional technical tool to provide advice, recommendations for reference and application if possible. Mr. Dung added that if the assessment tool shows the good results, it should be replicated and upgraded to standards in infrastructure design and planning. Mr. Peter and Mr. Ben also explained that the tool is not standardized and that it is legally enforceable, but is widely applied in many countries around the world, especially in the CSI project that will be applied to the infrastructure at large scale.
- Q: The question of data deficiency (groundwater, subsidence), should have additional collection when there are agencies, research works, published officially by other agencies.
- **A:** Mr. Tuan (HydroMet) proposed that HydroMet will try their best to support in meteorological information in hydrography, data on groundwater. To get the hydrology and geology data, we should contact with the federation of water resources and management in order to collect the necessary data. Mr. Dai (FPP) shared that GIZ is coordinating with the Mapping Department to detail the subsidence data for the entire Mekong Delta. In the next step, the SIWRP should contact relevant government agencies to collect data.

Mr. Peter introduced generally step 2 of the PIEVC protocol.

On behalf of the Vietnam Assessment Team, Ms. Lien (HydroMet) presented the role of climate and hydrological factors in PIEVC.

Next, Mr. Neil (Canada) presented the CCHIP tool, which is applied to the climate database in the Mekong Delta. In which there was no sudden increase in climatic parameters in the future, scoring will determine the parameters in recently and even the forecast in the future, thereby assessing the risk in the future for the works.

Mr. Dien (PMU 10) presented the detail components of the Cai Lon - Cai Be infrastructure, which is expected to last approximately 100 years, but some details have lower life expectancy, 15-20 years (communication), 30-70 years (gabion...). Then, Mr. Minh (SIWRP) presented the relationship between the structure and the meteorological and hydrological elements. This relationship will be used for further discussion.

Q&A:

- Q: Ben asked about sluice gate corrosion characteristics & consultant design selection plan.
- **A:** Mr. Dien (PMU10) explained the bidding process and plan, selection plan of design consultant submitted, will be implemented within 6 months after approval. The works has metal parts which are sensitive to be corroded in saltwater, although the material may have reached international standards.
- Q: Mr. Peter asked in history whether any works have been struck by lightning or not? And the road at Lang The sluice gate (Tra Vinh) is similar to Cai Lon - Cai Be or not?
- **A:** Mr. Dien answered that any irrigation works have a basic design of the same principle, so the two works have in common. Lightning strikes have occurred in the MKD, but are rather rare for irrigation works, where the winch is quite sensitive to the risk.
- Mr. Tuan (HydroMet) noted the cumulative effect of salinity and temperature on the work components (piston, hydraulic valve), after assessment is implemented that can be considered to recommend the contractor to increase the warranty period, consider the use of materials, ...
- Mr. Hiep (SIWRP) explained in Step 2 of the protocol this only refers to probability, but the impacts will be presented and analyzed in detail on Step 3 through severity assessment.

Exercise: Subgroup discussion is divided into 3 groups, each consisting of delegates with different expertise and tasks.

- Group 1: Minh (SIWRP) - Moderator, Toan (Department of Water Resources, Kien Giang), Dien (PMU10), Phuong (HydroMet), Ngoc (GIZ);
- Group 2: Hiep (SIWRP) - Moderator, Tuan (VDMA), Hien (HydroMet Kien Giang), Huong (HydroMet), Dai (GIZ), Tuan (HydroMet);
- Group 3: Lien (HydroMet) - Moderator, Helen (Canada), Ron (SIWRP), Vu (GIZ), Dai (VDMA).

Groups work on the matrix, review of climate-meteorological and hydro-meteorological variables to determine "YES or NO" for their impact on the infrastructure components. Some variables are detailed to understand the risk. The PIEVC probability scores implemented by the Vietnam assessment team was reviewed under the supervision of Canadian Consultants.

Day 2 (17/10/2018)

After agreeing on how to scoring, the workshop is divided into two discussion groups which scoring the probability and severity of meteorological and hydrological factors affecting the components of the infrastructure.

- Group 1: Minh (SIWRP) - Moderator, Quyen (SIWRP), Toan (Department of Water Resources, Kien Giang), Dien (PMU10), Phuong, Tuan (HydroMet), Dai, Ngoc (GIZ);
- Group 2: Hiep (SIWRP) - Moderator, Lien, Huong (HydroMet), Hien (HydroMet Kien Giang), Helen (Canada), Ron (SIWRP), Dai (VDMA), Vu (GIZ);

Mr. Neil introduced the CCHIP tool and instructed how to use it for the assessment.

Discussion:

- The expectations of both SIWRP and HydroMet for CCHIP tool for future work, particularly in the field of climate risk assessment.
- Ms. Lien (HydroMet) emphasized the advantages of CCHIP tool that shortening time for calculating climatic and hydro-meteorological parameters. CCHIP has 40 different sub-models (more than MONRE) for some higher levels of accuracy and similarity to other calculations. To adjust CCHIP to suit Vietnam, grant the right to use or develop another CCHIP tool, in Vietnamese language.
- Two groups presented the results and match each other.
- For the impact of temperature on the operator and the details of the infrastructure, the two groups discussed and agreed on the parameters of the nearest meteorological station instead of the average station in the area. We need to make sure that the equipment and measurement data of the nearest station is good enough. The two groups also discussed whether to use the most recent or cumulative impact. Recommendations for design adjustment may be considered for inclusion in TOR of the design consultant selection.
- For the impacts of temperatures above 35°C to operators, consideration may be given to recommendations on operating time as well as solutions for the protection of worker's health.
- For the impact lacking of groundwater, the value of the SPI normally does not exceed -2.5. This impact mainly affect

the park and its operators, which may also impact the ground structure and water level decrease, leading to erosion. In 2016 and 1998, the damage is the most severe, which can be used for reference.

- The impact of tornado (20 km/s) is different from the effect of horizontal wind (80-90 km/h). What level is usually in Vietnam? Annually, tornados have been reported to cause falling houses and trees, but not calculated yet. If there is a clear data on the trend and speed (2-3 level estimation in the future), it is possible to evaluate more closely. Cyclones mainly occurred at sea and affected vessels at sea, and land-based cyclones that have been observed to affect the house (roof speed, etc.), are considered to have little effect to sluice gate. In 2018, there were three cyclones in Kien Luong Sea and near Phu Quoc Island.
- The impact of water level is considered that combined the enhancement of sea level rise, ... which damaged the embankments, piles (small) and gates, chamber and head lock (small - medium). The location and material of the sluice gate should be considered, and how much we should invest when the probability score for this effect is assessed equal to 3.
- The impact of salinity, along with the duration of impact or temperature increase. For this impact, the recommendations on the operation procedures which regulated the time of opening and closing sluice gates for salinity intrusion control. The operation procedures of the sluice gate are closely related to the drought (the original design is 22-23 days), especially the number of opening and closing days of the sluice gate can increase/decrease based on future projection results. In the baseline design, there are 10 different salinity gauges to serve the operation of the sluice gate, in the future when we are having ability to forecast variations in the risk of salinity, water level ... that need to adjust the operation procedures.
- The next question is whether the impact of climate factors on the operating process needs to be assessed. PMU10 and SIWRP indicated that the current operating procedure is not available and will only be developed after the detailed design is approved, so the impact will be assessed on what basis. Canada engineers & GIZ suggested that the evaluation of the operation procedure (if possible) could be focused on a number of key factors, such as the number of closing/opening days of the sluice gate (due to significant impacts due to salinity, water level fluctuations) in the present as well as in the future in context of the impact of climate change. These recommendations may be included in the TOR for the design of the sluice gate system.
- The impact of ground subsidence did not affect significantly to the sluice gate because the sluice gate foundation was constructed on piles connected to the foundation stone which not affected by compressed sediment layers. This effect can be considered as cumulative factor along with sea level rise.
- The impact of future forecasting factors should be based on the results of the projection analysis to accurately assess the rate of increase or decrease in the frequency of occurrence. Severity can be temporarily considered unchanged in the context of the future.

Day 3 (18/10/2018)

The workshop started at 8:30 am with the full participation of the delegates. Discussion groups continued to discuss the impacts of hydro-meteorological factors on infrastructure.

- For thunderstorms, even if the probability is not high, due to the severity of the impact on operators, outdoor monitoring systems or electrical systems, consideration may be given to install lightning rods at appropriate locations, and regulate working time to avoid outdoor work during storms.
- Drought in the dry season has a relatively high probability (but not severely) affected trees in the park, so it is important to note the irrigation.
- Storm surge combined with high tides is a very clear trend and will increase in the future, mainly affect to the functions of the infrastructure (level 2-3).
- In terms of salinity, concrete corrosion can be considered, especially as the intensification of temperature increases in the future, and also needs to be investigated. The risk of metal corrosion should also be taken into account in order to make recommendations on the use of stainless steel materials.
- Mr. Neil and Mr. Ben noted the effects of thunderstorms along with extreme weather events on the site, and investigated whether the probability of the storm had increased. As the old works, the likelihood of seriousness increases. At present, there is insufficient evidence of damage to the infrastructure due to the effects of thunderstorms, but this is an important factor to consider.
- PMU10 proposed to distinguish the impact on the components that could be replaced partly and the failure components which have to replace the whole. For the salinity factor, water is also salty, which may affect both metals and concrete (see photos for water barrier, concrete column, corroded battery cell, erosion due to salinity 20 years after building while design life is 50 years, in which battery pillar is hard to replace each section). At present, the salinity and temperature factors have not been evaluated yet, which is a shortcoming in the current record.
- HydroMet commented on the need to look closely at measurements of salinity by month. Mr. Neil proposed considering a waterproof concrete solution to avoid the concrete penetration into the reinforcement and to destroy the building.
- Q: Olaf (FPP) questioned the cause of concrete damage in the battery pillar, whether due to salinity or vibration caused by traffic or construction techniques.
- **A:** PMU10 answered the real reasons is being studied, however, the existing concrete (sulfate concretes) does not meet the quality requirements under current conditions. The pin at this location (located on & near the water surface) is the strongest concrete corrosion problem, more than submergence and higher elevation, and also very difficult to replace. The problem of suitable resistance material should also be considered carefully.
- Q: Peter questioned the basis for determining the design elevation
- **A:** The PMU10 responded that it based on standard altitude is Hon Dau (Hai Phong).
- Regarding to forecasting future impacts and risks, storms, heavy rain for 5 days ... also affect the construction and operation of the infrastructure, along with the deterioration of the construction (severity increase). Typhoons tended to shift and increased in the south.
- Drought also has an increase trend in the future. Beside the frequency of drought, if the intensity of drought increases, it will increase the severity.

Peter presented recommendation for example of a sewerage system in Canada, which provided advice on short/long term solutions, cost of repairs/replacements.

- Mr. Dien commented that it is necessary to clarify how this recommendation will apply to the project. Unlike Peter's example of an infrastructure that was built in Canada, the Cai Lon - Cai Be project has not yet been developed, so recommendations should be directed towards on the design as well as materials used for this infrastructure.
- Mr Dien gave an example of a stainless steel sluice gate for a 20-year lifespan, however, it has been eroded to such an extent that it is difficult to recognize after 18 years, failing to meet the requirements of environmental impact, and has to be replaced (9 gates x $ 50,000).
- Another example of a design pitch is not long enough, leading to a landslide. In order to calculate the size of the components of the construction (pitch,...), consideration should be given to select appropriate hydraulic calculations to calculate tides, canals and rivers (etc. MIKE 11). Depending on the impact to the infrastructure (serious, not serious) to consider the options proposed.
- Another example of an asphalt road (thin) after a period of time impacted by rainstorms, the asphalt road is damaged.

All delegates continued the discussion by dividing into two groups, filling in and sticking the cards on the tables to identify specific recommendations for each impact of climatic factors on each component of the infrastructure. Recommendations on the design, operation, components of maintenance, materials used, staff working hours, number of days required to open the sluice, necessary cost to implement alternative solutions. In detail, the recommendations include:

- Specifically, it is recommended to pay attention to the joints of the construction, lightning prevention (especially in the time of season, rainy season) to the works and electrical system, operating in the hot/rain;
- Training for staff on storm response skills;
- Institutional and legislative application of climate risk assessment processes in infrastructure investment planning process;
- Taking into account impacts on the structure which has been built for a long time and is amortized/depreciated (S may decrease over time in the future for some specific infrastructure components);
- The impact factors need to be considered in an integrated manner (salinity & drought);
- Reassessing the level of climate risk after the infrastructure is constructed and operated to have appropriate adjustments.
- In addition to the recommendations for high-risk impacts, it should be considered to give recommendations for special circumstances (such as very low frequency but very high risk, effect combinations, etc.).

Recommendations will be recorded and aggregated as a reference for the assessment team to be included in the report, to assist policy makers in the future. Design, maintenance, and operation recommendations may also be included in the TORs for the selection of design consultants and operational designers in case the project is in the planning stage such as Cai Lon - Cai Be project.

All delegates discussed the plan to deploy activities in the coming time.

- Participants will continue contributing comments to complete this report in the first week of December
- After approval, there will be 6-8 months to select and implement the design consultancy package, followed by the selection of the operational design contractor (on site). It's the best if the reporting of preliminary results with recommendations to be made in December 2018 or January 2019.
- We should organize a workshop on December to agree on the results.
- PMU 10 will be the agency that drafts the reference for the design contractor. In December, the contractor for consultancy will be completed. December 2018 to June 2019 will be detailed design (technical design and construction design), October 2019 -> start of the construction (18-24 months of competition for operation). In terms of operation, there is a component of the operational design and field testing that will be implemented at the end of the design phase, at the same time of contractor selection. Recommendations related to the operation of the sluice gate system may therefore be made a few months later than recommendations regarding the design of the infrastructure.
- 13/11: webinar
- 10/12: First draft report
- 18/12: webinar
- Reduce the amount of time for webinar and exchange information via email.
- The assessment team exchanged assessment results with some of relevant agencies (PMU10, VDMA, HydroMet, SIWRR, HEC 2), etc., to share the same understanding of methods and information sharing. CSI VN can also participate if needed. Assessment results for consultation for better design, see if recommendations are appropriate? A meeting should be held to consult the concerned agencies.

Feedback from the participants:

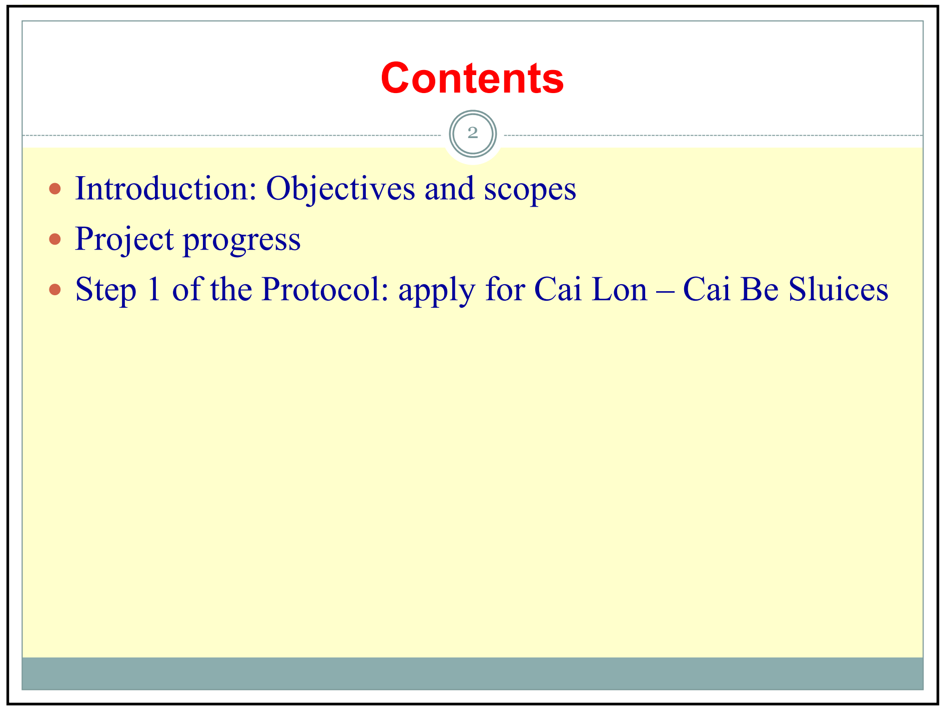
- Mr. Ben: Excited about the contents discussed in the workshop, this is a chance to gather experts from different fields (HydroMet, SIWRP,...), people cooperate to work seriously.
- Ms.Helen: All participants cooperated to achieve the best results, more motivation to contribute to the society of Vietnam.
- Mr. Tuan (HydroMet): Recognizing the need and significance of transferring assessment technology, in line with HydroMet's needs and desires, is putting climate information and data into the workplace building social development. HydroMet wished to continuecooperating to improve the level of adaptation and resilience of infrastructure in the MKD. This workshop has been well organized, focused, and much better than the first in terms of both content and form. Delegates as well as the consultant team understand clearly the work, serve in the assessment task, and identify the need to coordinate with other experts (design, management, meteorological industry) in other fields. To complete the report and provide realistic and useful recommendations and assessments to infrastructure managers.
- Mr. Hiep (SIWRP): Satisfied with the results of the workshop, thanks to the Canadian experts. This is a direct exchange opportunity that should clarify a lot of issues that the webinar does not meet. This kind of training-based learning allows the evaluator to have opportunity to see his/her own assessment results from different perspectives. The expected time of the draft report in December, which is reasonable and feasible.
- Mr. Dung (SIWRP): Thanks to GIZ for supporting the Institute, we believe that the assessment team understanded and had sufficient basis to perform the assessment task, rejoicing that all members have the opportunity to express their opinions. Individuals are confident in the method, and hope that this method is applied to Vietnam (legalization, procedures to help designers have more consideration and information for their decision and design), similar to MIKE 11. The desired results will be good in order topromote this method into legal procedures if possible.
- Mr. Peter (Canada) saw the good results of the workshop, from a variety of perspectives. Desire to return not only to this project but also to many more cooperation in the future.
- Mr. Neil (Canada): very happy to be back in Vietnam. The picture has become more evident than the first time when there are so many new options to choose from. Delegates seem to have a good grasp of the methodology and openness among engineers, climatologists and operators. Offer to stay in touch for assessment and cooperation.
- Ms. Lien (HydroMet) highly appreciated the opportunity to meet Canadian experts directly, helping to understand the problem.
- Mr. Chuong (CSI VN), recording feedbacks from delegates, hoping the next Workshop would be held in another place for participants to concentrate 100% to the Workshop.

Appendices

APPENDIX 5. List of participants at the PIEVC workshop # 2 – Risk assessment

No.	Full Name	Organization	
1	Ngo Tien Chuong	GIZ (CSI)	
2	Nguyen Thi Minh Ngoc		
3	Nguyen Hoang Xuan Anh		
4	Benjamin Hodick		
5	Ron Flugel	IF	
6	Peter Nimmrichter	Wood plc	Canadian experts supporting the project under contract to Engineers Canada
7	Helen Uyen Nguyen	Wood plc	
8	Neil Thomas Comer	RSI	
9	Le Quang Tuan	Vietnam Disaster Management Authority (VDMA)	
10	Tran Quang Dai		
11	Tran Minh Dien	Water Resources Investment and Construction Board 10	
12	Do Duc Dung	Southern Institute for Water Resources Planning (SIWRP)	
13	Le Viet Minh		
14	Le Van Quyen		
15	Nguyen Duc Cong Hiep		
16	Ma Thi Lan Huong	Southern Regional Hydro-meteorological Center	
17	Nguyen Thi Lien		
18	Pham Ho Quoc Tuan		
19	Tran Binh Phuong		
20	Le Xuan Hien	Kien Giang hydro-meteorological station	
21	Ngo Thanh Toan	Kien Giang Department of Water Resource	
22	Doan Ngoc Anh Vu	GIZ (ICMP)	
23	Olaf Neussner	GIZ (FPP)	
24	Trang Tien dai		

APPENDIX 6. Presentation on PIEVC Protocol Step 1 – Application to Cai Lon-Cai Be Sluices



Project objectives

3

- To conduct risk assessment for the Cai Lon – Cai Be sluice gate project using the PIEVC Protocol and under the guidance of Engineers Canada.
- To apply the assessment results for the Sluice Gate design and construction in order to reduce the risks related to climate change, thereby aiming at making the finished sluice gate more resilient towards climate change and hence more cost effective.

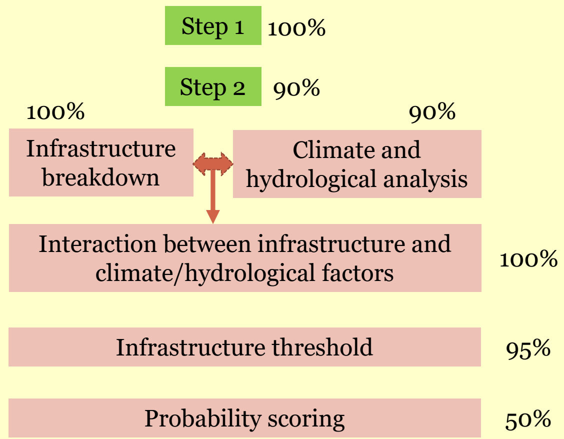
Project scopes

4

- Only focus on the updated version of infrastructure design in September 2018
- Do not implement Step 4 of the Protocol as required in the term of references (TOR)
- Address potential impacts of current climate and future climate for the planned life of the infrastructure.

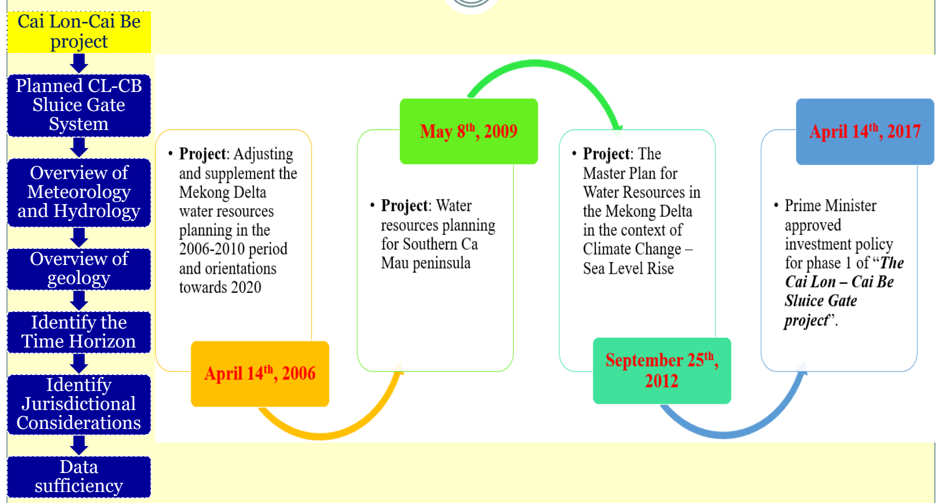
Project progress

5



History of the project

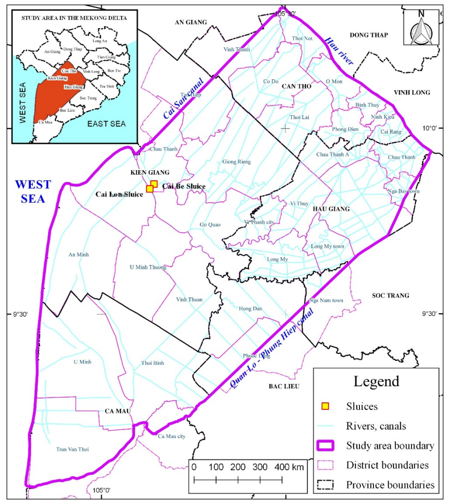
6



Overview of Cai Lon-Cai Be Sluice Gate Project

7

- Cai Lon-Cai Be project
- Planned CL-CB Sluice Gate System
- Overview of Meteorology and Hydrology
- Overview of geology
- Identify the Time Horizon
- Identify Jurisdictional Considerations
- Data sufficiency



Area: 909,248 ha
Population: 3,612,000

Main occupations: agriculture, forestry and aquaculture

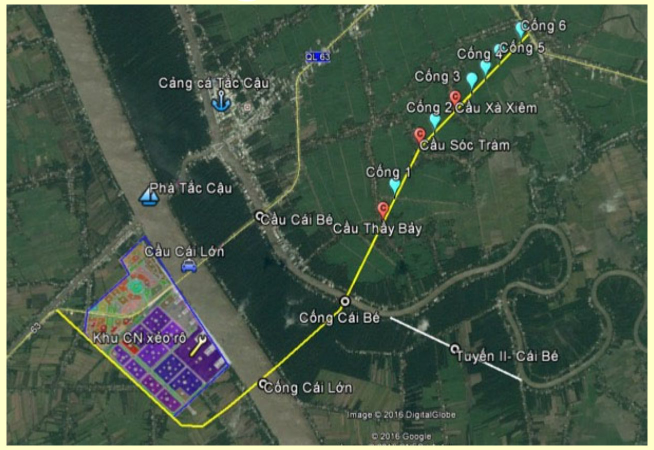
Challenges in the study area

- Annual flooding;
- Salinity intrusion;
- Freshwater shortage.
- Subsidence
- Climate change – sea level rise

Location of Cai Lon-Cai Be Sluice Gates

8

- Cai Lon-Cai Be project
- Planned CL-CB Sluice Gate System
- Overview of Meteorology and Hydrology
- Overview of geology
- Identify the Time Horizon
- Identify Jurisdictional Considerations
- Data sufficiency



Cai Lon Sluice Gate

9

- Cai Lon-Cai Be project
- Planned CL-CB Sluice Gate System
- Overview of Meteorology and Hydrology
- Overview of geology
- Identify the Time Horizon
- Identify Jurisdictional Considerations
- Data sufficiency

Total width: 395 m
-2 sluice gates of 63.5 m
- 6 sluice gates of 40 m
- 2 ship locks of 14 m
Bridge: traffic load of HL93 and the width of 9.0 m.

Cai Be Sluice Gate

10

- Cai Lon-Cai Be project
- Planned CL-CB Sluice Gate System
- Overview of Meteorology and Hydrology
- Overview of geology
- Identify the Time Horizon
- Identify Jurisdictional Considerations
- Data sufficiency

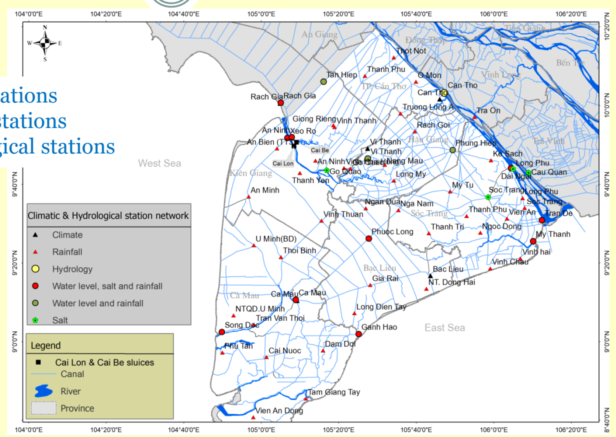
Total width: 90 m (3 sluice gates of 30 m)
Bridge: traffic load of HL93 and the width of 9.0 m.

Meteo-hydrological stations

11

- Cai Lon-Cai Be project
- Planned CL-CB Sluice Gate System
- Overview of Meteorology and Hydrology
- Overview of geology
- Identify the Time Horizon
- Identify Jurisdictional Considerations
- Data sufficiency

6 climate stations
10 rainfall stations
10 hydrological stations



Time series: mainly 30 years (1988 – 2017), except for salinity data 22 years (1996 – 2017)

Overview about climate data

12

- Cai Lon-Cai Be project
- Planned CL-CB Sluice Gate System
- Overview of Meteorology and Hydrology
- Overview of geology
- Identify the Time Horizon
- Identify Jurisdictional Considerations
- Data sufficiency

Climate factors:
- High temperature
- Heat wave
- Heavy rain, heavy 5-day rainfall
- Thunderstorm/Lightning
- Tropical storm/depression
- High wind
- Tornado
- Drought
- Humidity
- Evaporation

Climate trends/events:
- Increase of heavy rain intensity
- Increase of total annual rainfall
- Increase of extreme temperature events
- Increase of number of storms

Overview about hydrological data

13

- Cai Lon-Cai Be project
- Planned CL-CB Sluice Gate System
- Overview of Meteorology and Hydrology
- Overview of geology
- Identify the Time Horizon
- Identify Jurisdictional Considerations
- Data sufficiency

Hydrological factors:
- Water level, tide
- Flow (Flood and low flow)
- Salinity intrusion
- Hydrological drought
- Storm surge
- Tsunami
- Some of environmental factors, such as water temperature, pH
- Sedimentation

Hydrological trends/events:
- Sea level rise
- Decreased sediment load
- Increase of salinity intrusion (both volume and durability)
- Decreasing low flow and increasing flood flow combining with uncertain changes due to the upstream development
- Effects of climate change on storm surges
- Coastal and river bank erosion

Effect combination of meteo-hydrological factors

14

- Cai Lon-Cai Be project
- Planned CL-CB Sluice Gate System
- Overview of Meteorology and Hydrology
- Overview of geology
- Identify the Time Horizon
- Identify Jurisdictional Considerations
- Data sufficiency

- Upstream flooding combined with heavy rain and tides or storm surges
- Salinity intrusion combined with meteorological drought and upstream low flow
- The decreased sediment load combined with erosion and flood flow or storm surges

Overview of geology

15

Cai Lon-Cai Be project → Planned CL-CB Sluice Gate System → Overview of Meteorology and Hydrology → Overview of geology → Identify the Time Horizon → Identify Jurisdictional Considerations → Data sufficiency

Geological factors

- Soil texture
- Soil consolidation
- Water table

Geological trends and phenomena:

- Subsidence
- Landslide
- Faulting/Cracking
- Earthquake

Cumulative Impacts:

- Land subsidence coupled with sea level rise
- Weak-structure soil combined with flooding

Time Horizon

16

Cai Lon-Cai Be project → Planned CL-CB Sluice Gate System → Overview of Meteorology and Hydrology → Overview of geology → Identify the Time Horizon → Identify Jurisdictional Considerations → Data sufficiency

- Design life of infrastructure: 100 years
- Predicted periods of climate change: 2016 -2035; 2046-2065 and 2080 – 2099
- Time milestone of sea level rise prediction is 10 year per time from 2030 to 2100

Jurisdictional Considerations

17

Cai Lon-Cai Be project → Planned CL-CB Sluice Gate System → Overview of Meteorology and Hydrology → Overview of geology → Identify the Time Horizon → Identify Jurisdictional Considerations → Data sufficiency

- Decision No. 84/2006/QĐ-TTg on 19/04/2006 of Prime Minister;
- Decision No. 1336/QĐ-BNN-KH on 08/05/2009 of MARD;
- Decision No. 1397/QĐ-TTg on 25/09/2012 of Prime Minister;
- Decision No. 3113/QĐ-BNN-KH on 10/10/2009 of MARD;
- Decision No. 498/QĐ-TTg on 17/04/2017 of Prime Minister;
- National technical regulation QCVN 04-01: 2010/BNNPTNT;
- National technical regulation QCVN 04 - 05 : 2012/BNNPTNT;
- Other national technical regulations on designing hydraulic structures in Vietnam.

Data sufficiency

18

Cai Lon-Cai Be project → Planned CL-CB Sluice Gate System → Overview of Meteorology and Hydrology → Overview of geology → Identify the Time Horizon → Identify Jurisdictional Considerations → Data sufficiency

Infrastructure data

- Reliable
- Generally sufficient for risk assessment using PIEVC.

Hydro-meteorological data

- A 30-year dataset, except for salinity data (22 years)
- Tornado, tsunami: not measured / recorded
- Storm surge, waves, and water temperature: irregularly measured
- Sediment transport: only recorded at the gauges along the main branches of Mekong River and not measured in the study area

Data sufficiency

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Cai Lon-Cai Be project
Planned CL-CB Sluice Gate System
Overview of Meteorology and Hydrology
Overview of geology
Identify the Time Horizon
Identify Jurisdictional Considerations
Data sufficiency

Geographical data

- Groundwater data: inadequate
- Land subsidence: short and inadequate data, and only focused on urban area (Can Tho City and Ca Mau City)
- Faulting/cracking and earthquake: limited data

→ data gaps in Step 5

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THANK YOU

APPENDIX 7. Presentation on PIEVC Protocol Step 2 – Main components of Cai Lon – Cai Be Sluice Gates

Conduct the Climate Risk Analysis and Assessment for Cai Lon - Cai Be Sluice Gate Project based on PIEVC Protocol

Step 2
Main components of Cai Lon - Cai Be Sluice Gates

Vietnamese Assessment Team
16 – 10 – 2018

1

Contents

1) Components of Cai Lon and Cai Be Sluice Gates
2) State the Time Horizon for the Assessment
3) Interactions between Sluice Gates and Hydro-Meteorological Variables
4) Probability score
5) Infrastructure Response Considerations

2

1- Components of Cai Lon and Cai Be Sluice Gates

(Corresponding to Section 2.2 Protocol's Worksheet 2)

Sort	System	Cai Lon	Cai Be
1	Operation and Maintenance	x	x
2	Sluice gate structure	x	x
3	Ship lock	x	o
4	Gate	x	x
5	Bridge	x	x
6	Retaining walls and connected embankment	x	x
7	Operation house	x	x
8	Park	x	x
9	Power supply	x	x
10	Operation and control system	x	x
11	Monitoring system	x	x
12	Fire extinguishing system	x	x
13	Communication system	x	x

TCVN 10400:2015 (Hydraulic Structures –Pillar Dam – Technical requirements for Design)
Basic Design Reports (Vietnam Academy for Water Resources and HEC2, 2018)

3

1- Components of Cai Lon and Cai Be Sluice Gates

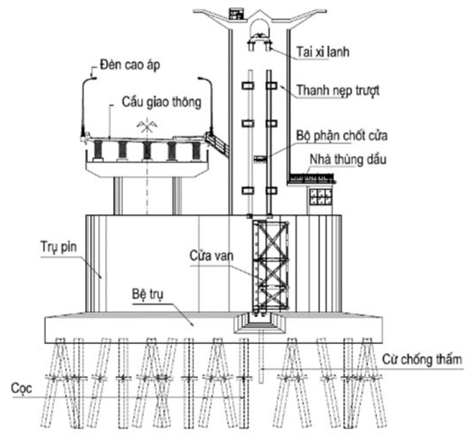
1-Operation and Maintenance	Components
	Regular maintenance staff
	Maintenance equipment
	Historical files of maintenance

4

1- Components of Cai Lon and Cai Be Sluice Gates

Pillar dam type was proposed for both Cai Lon and Cai Be sluice gates. Their main components can be listed as below:

- Pillar footing and Pillar
- Pile foundation;
- Bottom beam;
- Waterproof pile foundation;
- Gates.

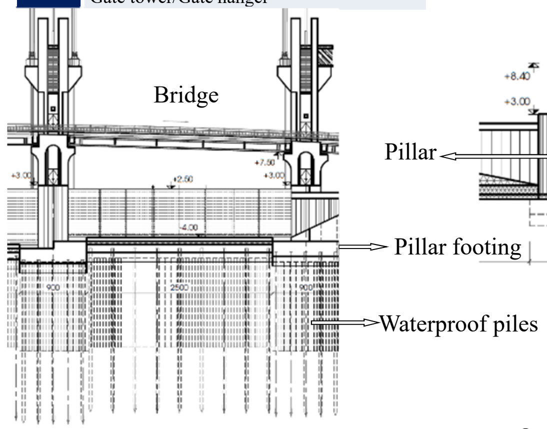


TCVN 10400:2015 (Hydraulic Structures –Pillar Dam – Technical requirements for Design)

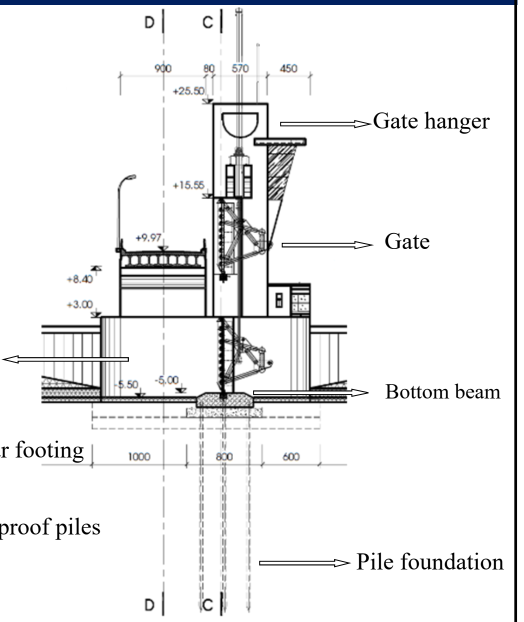
5

1- Components of Cai Lon and Cai Be Sluice Gates

2-Sluice gate structure	Components
	Pile foundation
	Waterproof pile foundation
	Pillar footing
	Bottom beam
	Pillar
	Gate tower/Gate hanger



Cross-section of Cai Be between Pillar 3 and 4

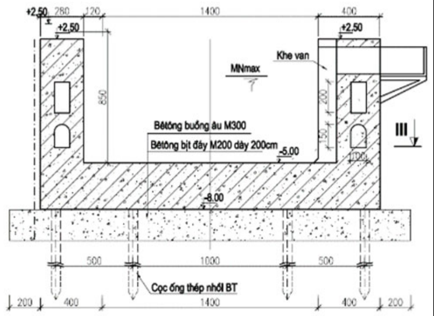


Longitudinal section of 1 pillar of Cai Be

6

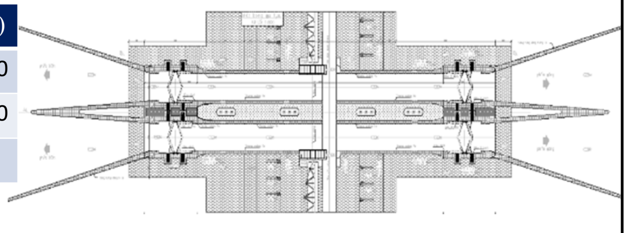
1- Components of Cai Lon and Cai Be Sluice Gates

	Components
3-Ship lock	Lock chamber
	Lock head
	Filling and discharge culverts
	Leading jetty



Cross-section of ship lock of Cai Lon

Dimension	L (m)	W (m)
Lock head	33.0	14.0
Lock chamber	150.0	14.0
Leading jetty	110.0	



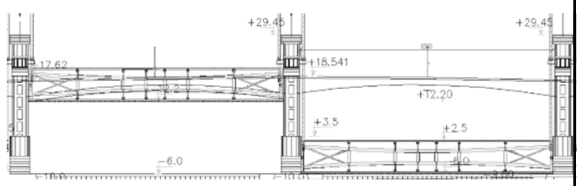
Plan of ship locks of Cai Lon

7

1- Components of Cai Lon and Cai Be Sluice Gates

	Components
4-Gates	Sluice gate
	Water tight gasket
	Bolts

Gates made by steel (Q345), 02 gates (63.5 x 8.5)m and 06 gates (40 x 7.5)m;
Vertical lift gates, operating by hydraulic cylinder

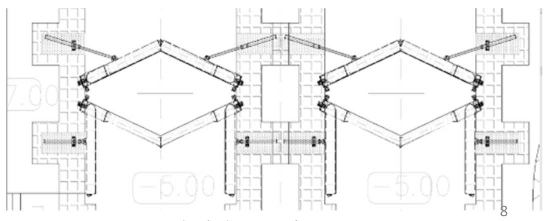


Gate of Cai Lon

Bao Chau Gate, Ca Mau (31.5 m)

Ship lock's gate made by (Q345), 04 gates (7x2x7.5)m,
Lift gates, operating by hydraulic cylinder

Illustration of Ship lock's gates



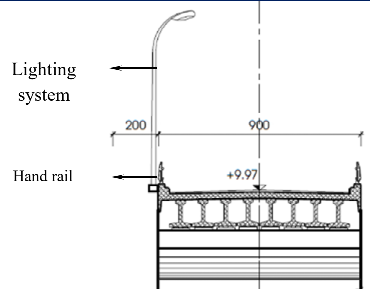
Ship lock's gates of Cai Lon

8

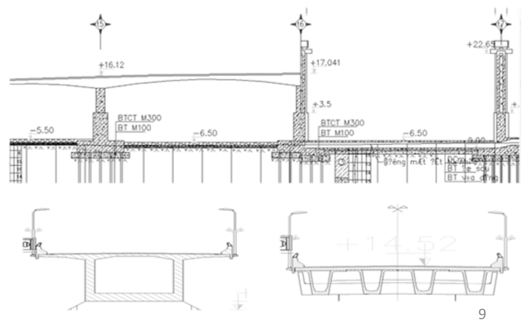
Appendices

1- Components of Cai Lon and Cai Be Sluice Gates

	Components
5-Bridge	Pile foundation
	Bridge pier
	Bridge beam
	Bridge surface
	Bridge hand rail
	Bridge slope/ramps
	Expansion joints
	Lighting system
	Traffic signals/Guide post
	Drainage system/scupper



Cross-section of the bridge on Cai Be



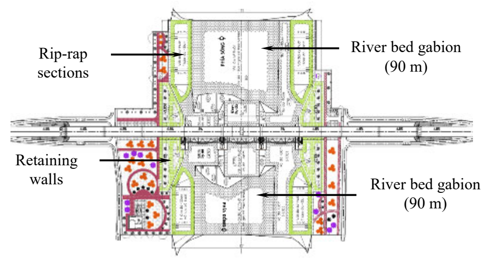
9

Drawings of the bridge on Cai Lon

1- Components of Cai Lon and Cai Be Sluice Gates

	Components
6-Retaining walls and connected embankment (up and down-stream)	Rip-rap section (retaining walls)
	Connected embankment
	Overflow preventing walls
	Base of retaining walls
	Hand rail
	Rip-rap section of connected embankments
	River bed gabion
	River banks after connected embankments

Plan of Retaining walls and connected embankment of Cai Lon

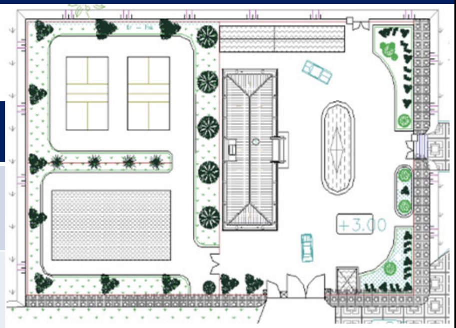


Plan of Cai Be

10

1- Components of Cai Lon and Cai Be Sluice Gates

	Components
7-Operation house	House structure (front steps, wall, windows...)
	Equipment and facilities (computers, bulbs)



Plan of operation house

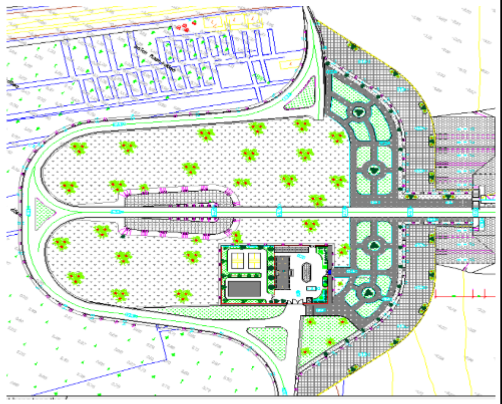
Rendering of operation house of Cai Lon

11

1- Components of Cai Lon and Cai Be Sluice Gates

	Components
8-Park	Protection fences
	Trees, flowers and grass

	Components
9-Power supply	Power generator
	Outdoor lighting system (lines and bulbs)
	Indoor lighting system (lines and bulbs)
	Backup power generator



Plan of park

12

1- Components of Cai Lon and Cai Be Sluice Gates

	Components
10-Operation and control system	Hydraulic cylinder
	Hydraulic power source
	Control station
	Lights, operational bells…

Hydraulic cylinder at Lang The, Tra Vinh (taken by Vietnamese Assessment Team in 23/09/2018)

13

1- Components of Cai Lon and Cai Be Sluice Gates

System	Components
11-Monitoring system	SCADA (water level and salinity measuring and data centre)
	Site transposition monitoring system
	Seepage monitoring system
	Prestressed monitoring system
12-Fire extinguishing system	(alarm bells, fire and smoke alarms, extinguishers)
13-Communication system	(FAX, computers, telephones…)

14

2-State the Time Horizon for the Assessment

(Corresponding to Section 2.3 Protocol Worksheet-2)

System	Design life (years)	Material	Sources
Physical structures (cast-in-situ concrete composition)	80-100	Reinforced concrete M300	Project's documents Similar structures in the surroundings Producer's documents
Mechanical Systems (sluice gates, hydraulic cylinder)	30-70	Steel Q345	
Embankments (Rip-rap section)	15	Reinforced concrete M200-300, gabion	
Electric Power Supply	15-20	PVC, copper	
Control and Monitoring System	10	Sensors, cables	
Communication System	15-20	PVC, Cables	
Water tight gasket	5-10	Rubber	

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3- Interactions between Sluice Gates and Hydro-Meteorological Variables

(Corresponding to Section 2.7 Protocol's Worksheet-2)

Sort	Infrastructure Components	Hydro-meteorological variables and loading	Mechanism of impact
1	Administration/Operation		
1.1	Personnel	High temperature; **Lightning**; Heavy rainfall; High wind.	- Lightning are danger to the staff. - Heavy rain and high wind make difficulties for operating.

Magnitude of impact:

Bold: High; Underline: Moderate; Normal: Low; *Italic: the cumulative impact*

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Appendices

3- Interactions between Sluice Gates and Hydro-Meteorological Variables

Sort	Infrastructure Components	Hydro-meteorological variables and loading	Mechanism of impact
2	Sluice Gate Structure		
2.5	Pillar	High temperature; **Water level**; Velocity; *Tropical storm;* *Storm surge;* *Tides;* *Heavy rainfall;* *High wind;* *Sea level rise.*	- Water level: Increased overtopping that affects to functionality of pillars. - *Storm, tides, heavy rainfall, high wind, storm surge and sea level rise will generate the cumulative impact on water level increase.* - High temperature may cause cracking - Velocity may cause erosion.

Magnitude of impact:

Bold: High; Underline: Moderate; Normal: Low; *Italic: the cumulative impact*

17

3- Interactions between Sluice Gates and Hydro-Meteorological Variables

Sort	Infrastructure Components	Hydro-meteorological variables and loading	Mechanism of impact
3	Ship Lock		
3.1	Lock chamber	**Velocity**; Water level; *Storm;* *Storm surge;* *Heavy rain;* *High wind;* *Tides;* *Sea level rise.*	- Velocity of flow may cause accidents for boats - Water level may constrain operation - Other factors contribute to the increase in water level.

Magnitude of impact:

Bold: High; Underline: Moderate; Normal: Low; *Italic: the cumulative impact*

18

3- Interactions between Sluice Gates and Hydro-Meteorological Variables

Sort	Components	Hydro-meteorological variables and loading	Comments
4	Sluice and ship lock gate		
4.1	Gate	**Water level**; Velocity; *Storm;* *Storm surge;* *Heavy rain;* *High wind;* *Tides;* *Sea level rise;* Lightning.	- Water level affects to stability, functionality and operation of gate. - Velocity may cause the accidents boats. - Other factors happening together will increase water level and velocity. - Storm will affect to the gate when it is hanging. - Gate is vulnerable to lightning
4.2	Water tight gasket	**Water temperature**; **Air temperature;** Salinity intrusion; *Heat wave.*	- Water tight gasket is vulnerable to high temperature and heat wave. - Salinity may take its life span be reduced.

Magnitude of impact:
Bold: High; Underline: Moderate; Normal: Low; *Italic: the cumulative impact*

3- Interactions between Sluice Gates and Hydro-Meteorological Variables

Sort	Infrastructure Components	Hydro-meteorological variables and loading	Comments
5	Bridge		
5.4	Bridge surface	**Heavy rainfall;** Storm; Heat wave.	- Heavy rainfall is the major factor to damage bridge surface. - Storm and heat wave may exacerbate this damage.
5.5 5.8 5.9	Hand rail Lighting system Traffic sign post	**Storm**; Heavy rainfall; High wind; **Thunderstorm/lighting**	- Storm and lightning have a strong impact on these components. - Other factors also have impacts but less.

Magnitude of impact:
Bold: High; Underline: Moderate; Normal: Low; *Italic: the cumulative impact*

3- Interactions between Sluice Gates and Hydro-Meteorological Variables

Sort	Infrastructure Components	Hydro-meteorological variables and loading	Comments
6	Retaining walls and stilling basin		
6.1 6.2 6.6 6.8	Rip-rap section Connected embankment Gabion River bank (earth-fill section)	Water level; **Heavy rainfall;** *Storm surge;* *Tides;* *High wind;* *Sea level rise.* Drought Heat wave	- Heavy rainfall and water level increase the risk of slope and embankment instability; - Drought and heat wave damage the soil structure and lead to erosion river banks. - Others contribute to the increase in water level
6.7	Stilling basin (*river beds protection*)	Discharge; **Velocity.**	The increase in velocity and discharge will cause erosion for this component.

Magnitude of impact:
Bold: High; Underline: Moderate; Normal: Low; *Italic: the cumulative impact*

3- Interactions between Sluice Gates and Hydro-Meteorological Variables

Sort	Infrastructure Components	Hydro-meteorological variables and loading	Comments
7-8	Operation house and park		
7.1 8.1 8.2	Front steps, windows Protection fences Trees, flowers and grass	**Storm;** Heavy rainfall; High wind.	- Storm and heavy rainfall may damage front steps and windows. - High wind may also cause some effects but not much.
9	Electric power		
		Storm; Heavy rainfall; **Lightning;** High wind.	- The electric power is the most vulnerable component by lighting. - Other factors may also affect but not much because electrical lines and cables are underground and protected by PVC covers.

Magnitude of impact:
Bold: High; Underline: Moderate; Normal: Low; *Italic: the cumulative impact*

3- Interactions between Sluice Gates and Hydro-Meteorological Variables

Sort	Infrastructure Components	Hydro-meteorological variables and loading	Comments
10	Control and Operation System		
10.1	Operation system	Lightning	Hydraulic cylinder may be damaged due to lighting.
10.2	Control system (similar to SCADA)	**Storm** <u>Heat wave</u> High wind	- Sensors and data transfer parts may be damaged due to storm. - Errors of the system may occur when it is affected by heatwave and high wind in the long period.
13	Communication system		
		<u>Storm</u> High wind **Lightning**	- Lightning disrupt the communication. - Storm and high wind are similar.

Magnitude of impact:
Bold: High; <u>Underline: Moderate</u>; Normal: Low; *Italic: the cumulative impact*

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Ba Lai Sluice Gate in Ben Tre (2002-)
(Taken by Vietnamese Assessment Team 23/09/2018)

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Appendices







Láng Thé, Chà Và Sluice Gates in Tra Vinh (2004-)
(Taken by Vietnamese Assessment Team 23/09/2018)

25

4-Probability Score

Hydro-meteorological variables	Infrastructure Indicator	Thresholds Triggered?	Magnitude of Event	Frequency of Event	Robustness of Forecast	Professional Judgment	Probability Score
		Y N	H M L	H M L	H M L	Comments	0-7
		☟	☟	☟	☟	P =ƒ (A,B,C,D, & E)	
		B	C	D	E	☞	P
Gates							
Water level (WL)						The differences between water level at river and field sides	
<u>Velocity flow</u>	1 m/s					Velocity higher than 1 m/s causing erosion, accidents	
Storm surge;	68 cm					These factors will generate the cumulative impact on WL	
Heavy rain;	5-day rainfall						
High wind;	25 m/s						
Tides;	+ 1.09 cm						
Sea level rise;	87 cm (2100)						
Field water level	+ 0.00 cm					It is too low may increase the difference in WL	
Lighting						Gate made by steel that is may be affected by lightning	

Magnitude of impact:
Bold: High; <u>Underline: Moderate</u>; Normal: Low; *Italic: the cumulative impact*

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5-Infrastructure Response Considerations

Infrastructure Components	Infrastructure Response Considerations					Hydro-meteorological variables				
	Structural Design	Functionality	Serviceability	Watershed, Surface Water & Groundwater	Operations, Maintenance & Materials Performance	Infrastructure Threshold Value				Rationale for Infrastructure Threshold (Provide reference to code or standard if relevant)
Gates	Mark Relevant Responses with ✓					Y/N	P	S	R	Rationale For Severity Score
Water level (WL)		✓	✓		✓					
Velocity flow	✓	✓	✓		✓					
Storm surge;		✓	✓		✓					
Heavy rain;		✓	✓	✓	✓					
High wind;		✓	✓		✓					
Tides;		✓	✓	✓	✓					
Sea level rise;		✓	✓		✓					
Field water level		✓	✓		✓					
Lighting					✓					

APPENDIX 8. Presentation on PIEVC Protocol Step 2 – Climate and hydrology analysis

Conduct the Climate Risk Analysis and Assessment for Cai Lon - Cai Be Sluice Gate Project based on PIEVC Protocol

CLIMATE & HYDROLOGY ANALYSIS

1

VIETNAMESE ASSESSMENT TEAM
Presenter: Nguyen Thi Lien
16 – 10 – 2018

OUTLINES

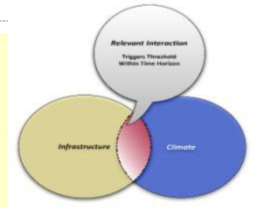
2

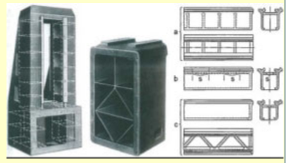
1. **Role of climate and hydrological parameters in the PIEVC Protocol**
2. **Climate:** selected parameters for assessment; historical data analysis; climate change projection
3. **Hydrology:** selected parameters for assessment; historical data analysis; climate change projection

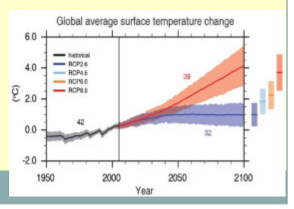
Role of climate and hydrological parameters in the PIEVC Protocol

3

1. **Be key factors for risk assessment of structural components (function and overall structure).**
2. **Focus on assessing the thresholds → give recommendations on the sustainability of the structure.**
3. **Assess infrastructure vulnerability under climate change and sea level rise.**







OVERVIEW OF DATA INPUT

4

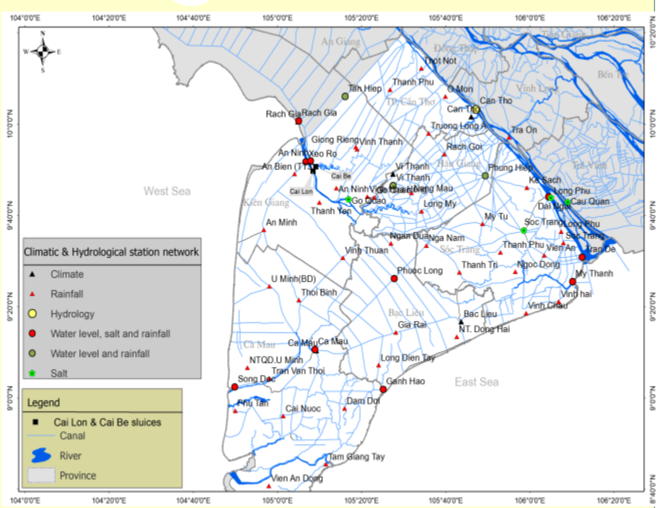
Dataset: 1988 - 2017

- Climate

+ Rainfall
+ Sub-daily rainfall
+ Temperature
+ Wind; typhoon
+ Thunderstorm

- Hydrology

+ Flow
+ Tide/Water level
+ Salinity (22 years)



Appendices

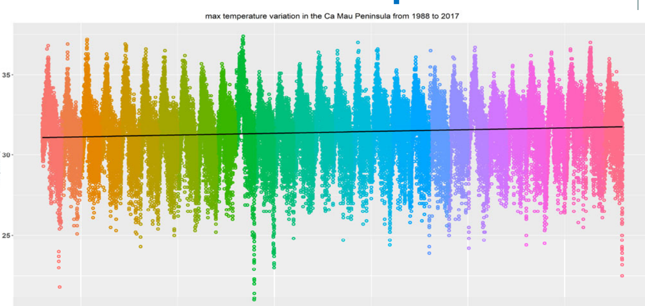
CLIMATE – Selected parameters

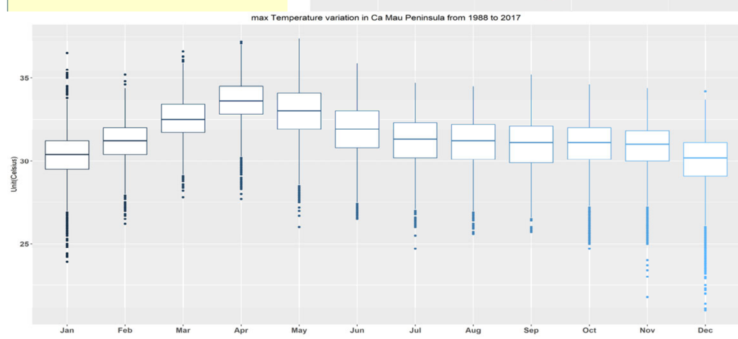
4

- **High temperature**
- **Heat wave**
- **High wind**
- **Thunderstorm/Lightning**
- **Tropical Storm**
- **Heavy Rain**
- **Total rainfall of 3 days, 5 days, 7 days**
- **Tornado**
- **Drought in dry season**

CLIMATE – Historical data - Temperature

Tmax = 37.4 C.
The hotest month is April. An increasing trend in 1988-2017





CLIMATE ANALYSIS - Historical data - Temperature

7

Location	Minimum	25th percentile	Mean	Standard deviation	Median	75th percentile	Maximum
Rach Gia	21	29.9	31	1.8	31	32	37.2
Can Tho	21.4	30.5	31.7	1.8	31.7	33	36.7
Soc Trang	22	30.5	31.6	1.8	31.7	32.7	37.2
Bac Lieu	21.1	30	31	1.7	31.1	32.1	36.7
Ca Mau	22.3	30.6	31.7	1.8	31.9	33	37.4

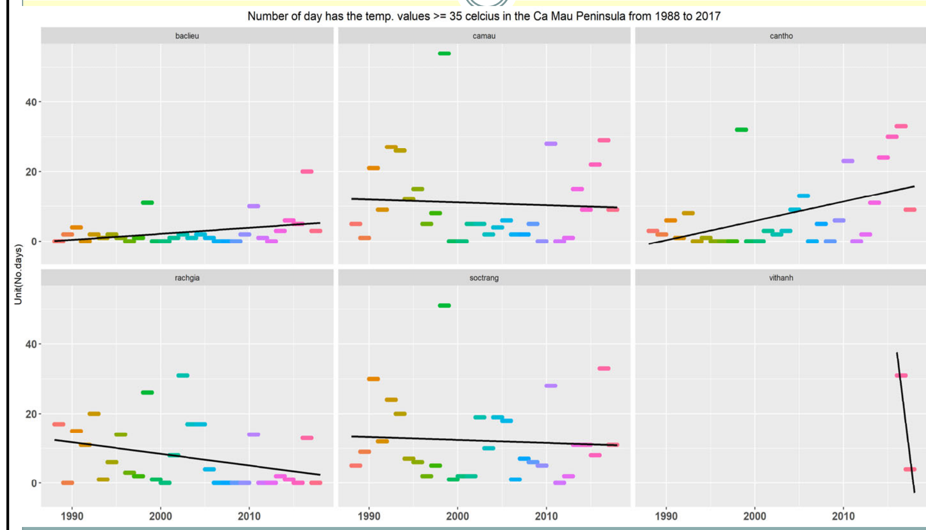
CLIMATE ANALYSIS - Historical data - Temperature

8

- High temperature is measured by the number of days over 35^0C.
- Dataset: 1988 – 2017
  - High temperature = 7.63 days/year
- Recently, high temperature has an upward trend at most stations in study area, except Rach Gia station.

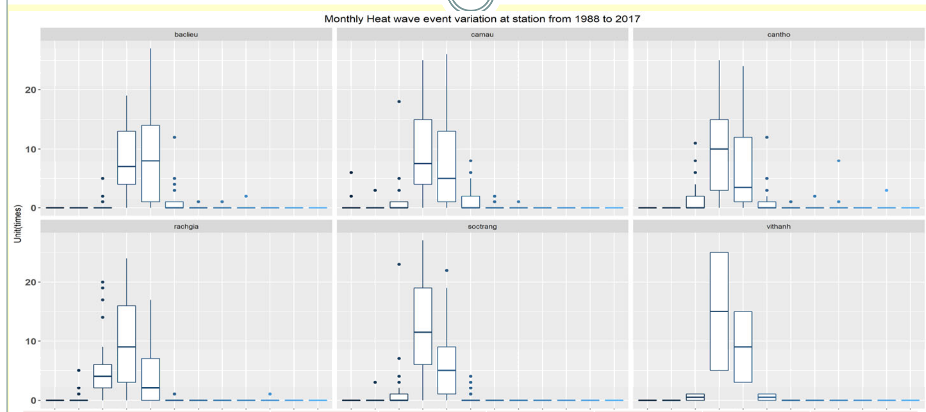
CLIMATE ANALYSIS - Historical data - Temperature

9



CLIMATE ANALYSIS - Historical data – Heat Wave

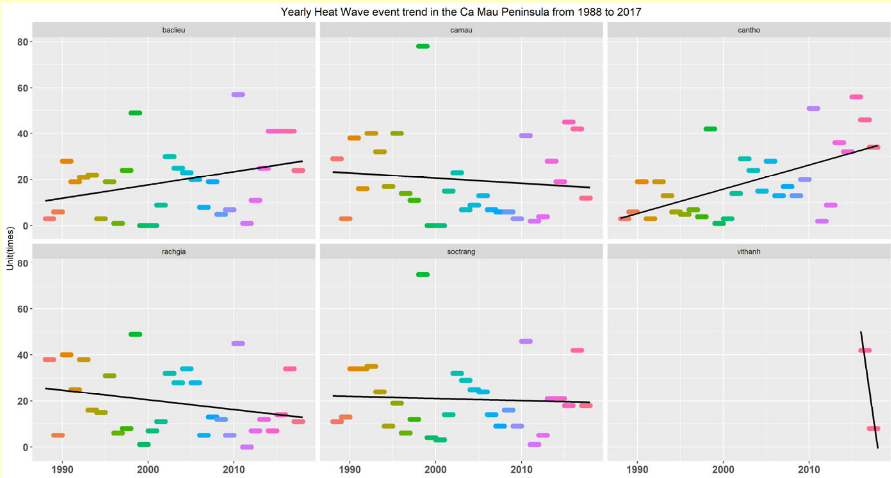
10



Station	Bac Lieu	Ca Mau	Can Tho	Rach Gia	Soc Trang	Vi Thanh
T(celcius)_Percentile 90	33.1	34	33.9	33.3	33.9	34.1

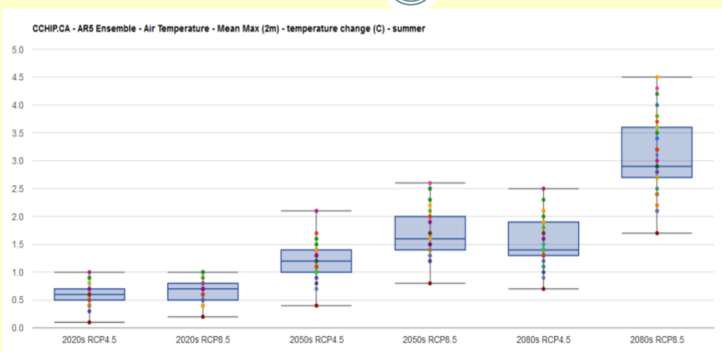
CLIMATE ANALYSIS - Historical data – Heat Wave

11



CLIMATE ANALYSIS - Projection - Temperature

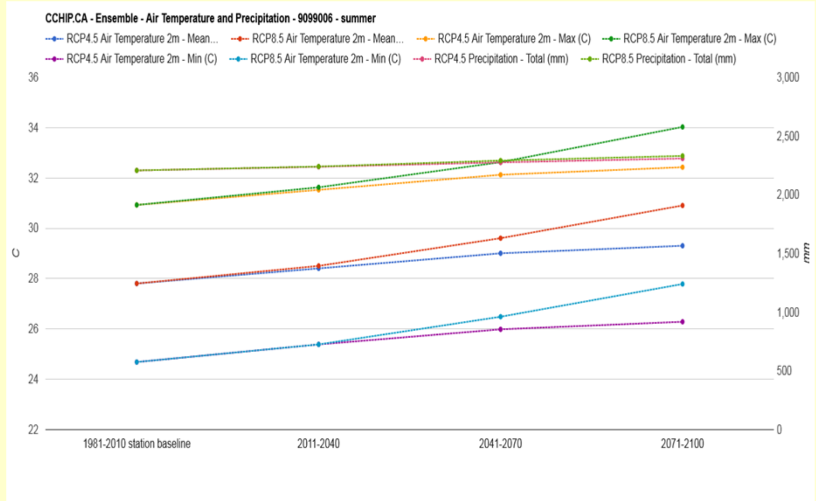
12



- High temperature has a upward trend
- Outputs of max temperatue change from CCHIP tool are quite similar with the Climate change scenarios for Vietnam
- In RCP8.5, number of days with a max temperature >=35 are increasing strongly in the end of the century 21th about over 100 days

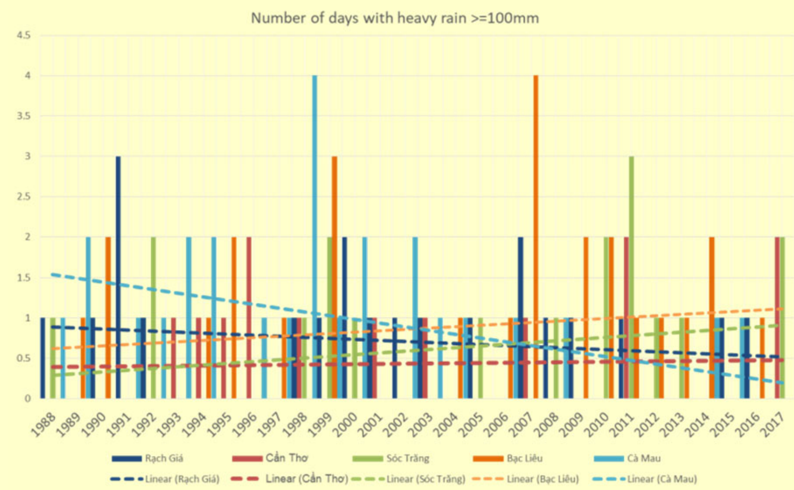
CLIMATE ANALYSIS - Projection - Temperature

13



CLIMATE ANALYSIS - Historical data - Heavy rain

14



CLIMATE ANALYSIS - Historical data - Heavy rain

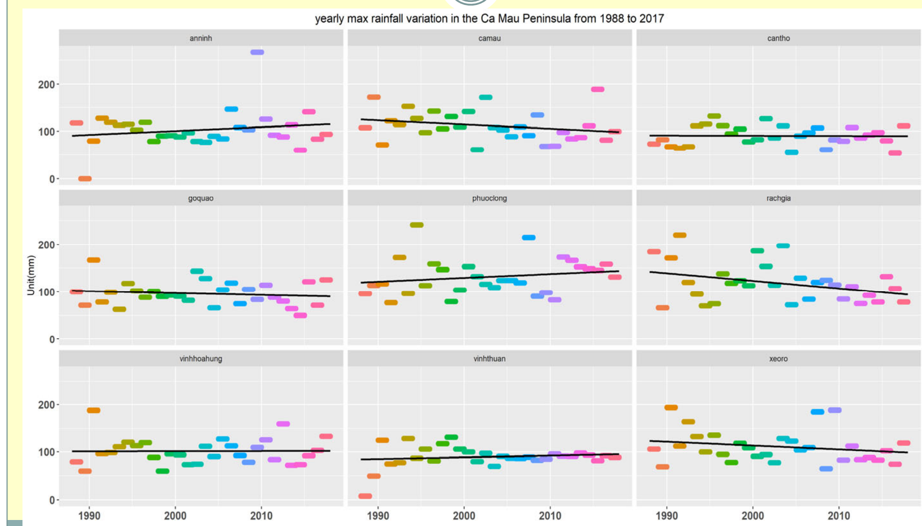
15

Description	Number of days with heavy rainfall >=100mm
	Days/year
Vinh Hoa Hung	0.53
Rach Gia	0.67
Xeo Ro	0.77
Go Quao	0.53
Vinh Thuan	0.23
An Minh	0.67
Can Tho	0.43
Phung Hiep	0.33
Vi Thanh	0.17
Soc Trang	0.53
My Thanh	0.47
Bac Lieu	0.87
Phuoc Long	1.70
Ganh Hao	0.73
Ca Mau	0.87
Song Doc	1.57
Average	0.63

CLIMATE ANALYSIS - Historical data – Rainfall

yearly max rainfall event trend from 1988-2017

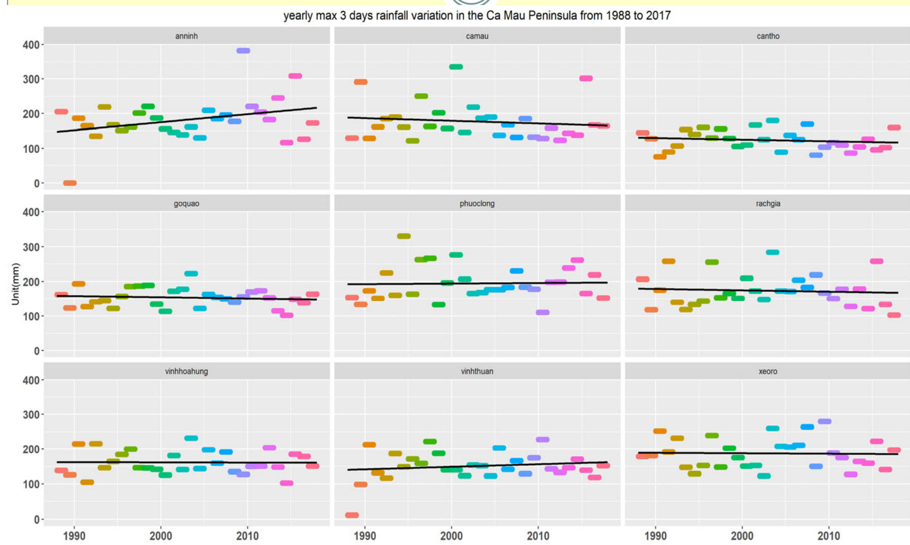
16



CLIMATE ANALYSIS - Historical data – Rainfall

yearly max 3 consecutive days rainfall event trend from 1988-2017

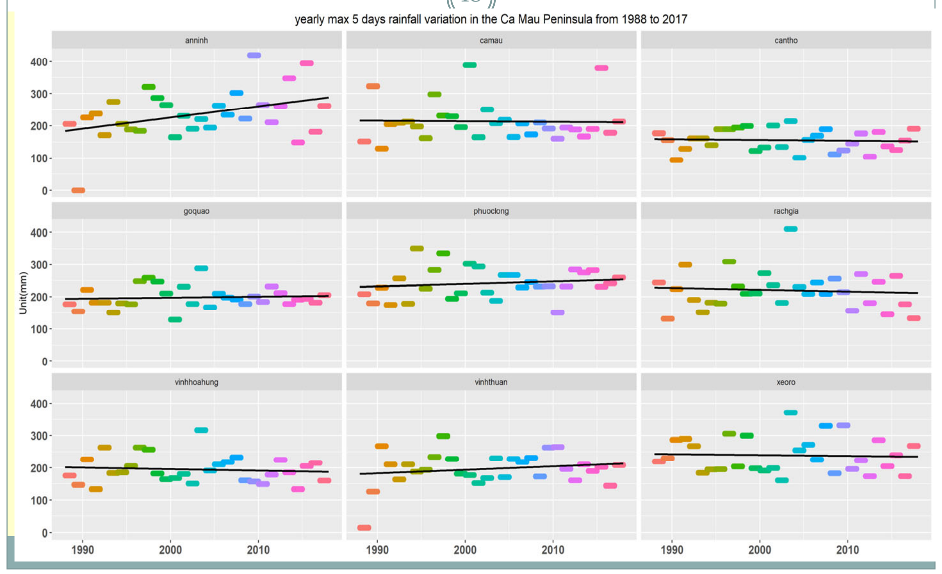
17



CLIMATE ANALYSIS - Historical data – Rainfall

yearly max 5 consecutive days rainfall event trend from 1988-2017

18



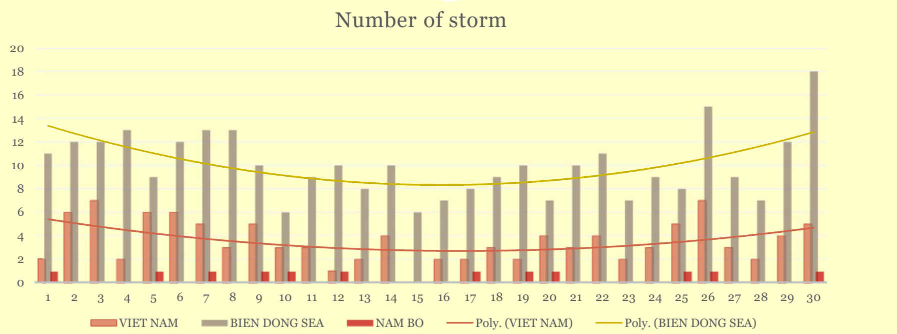
CLIMATE ANALYSIS - Projection - Heavy rain

19

- Upward trends of total rainfall 1day max and annual precipitation extremes in the future
- Outputs of CCHIP tool are quite similar to the Climate change Scenarios for Vietnam in rainfall

CLIMATE ANALYSIS - Historical data - Tropical storm

20



- Number of TS/TD within a give year have affected to the southern Vietnam is 0.4
- In recent years, the number of storms increases in East Sea (e.g, 2013: 19 times, 2017: 20 times)

Appendices

CLIMATE ANALYSIS - Historical data - Tropical storm

21

Name	Name (Vn)	Time bắt đầu	Time kết thúc	Cấp bão lớn nhất	Pmax (hPa)	Gió (kt)	Nơi độ bộ
TESS	10	03/11/1988	06/11/1988	11	975	60	Bình Thuận
ANGELA	6	15/10/1992	29/10/1992	12	970	65	Kiên Giang
TERESA		16/10/1994	26/10/1994	13	955	80	Bình Thuận
ERNIE	8	7/11/1996	16/11/1996	8	992	40	ST, BL
LINDA	5	31/10/1997	4/11/1997	10	985	50	Cà Mau
ATNĐ04		22/10/1999	25/10/1999	7	1000	30	ST, TV
MUIFA		13/11/2004	25/11/2004	13	950	80	CM, KG
DURIAN		25/11/2006	6/12/2006	16	915	105	VT-BT
PEIPAH		1/11/2007	10/11/2007	12	970	70	BT-BRVT
PAKHAR		26/03/2012	2/04/2012	8	998	40	BT-BRVT
ATNĐ 14		4/11/2013	7/11/2013	7	30		NB
TEMBIN		20/12/2017	26/12/2017	12	970	70	Cà Mau

Tropical storms have affected to Nam Bo from 1988-2017

CLIMATE ANALYSIS - Historical data - Tropical storm

22

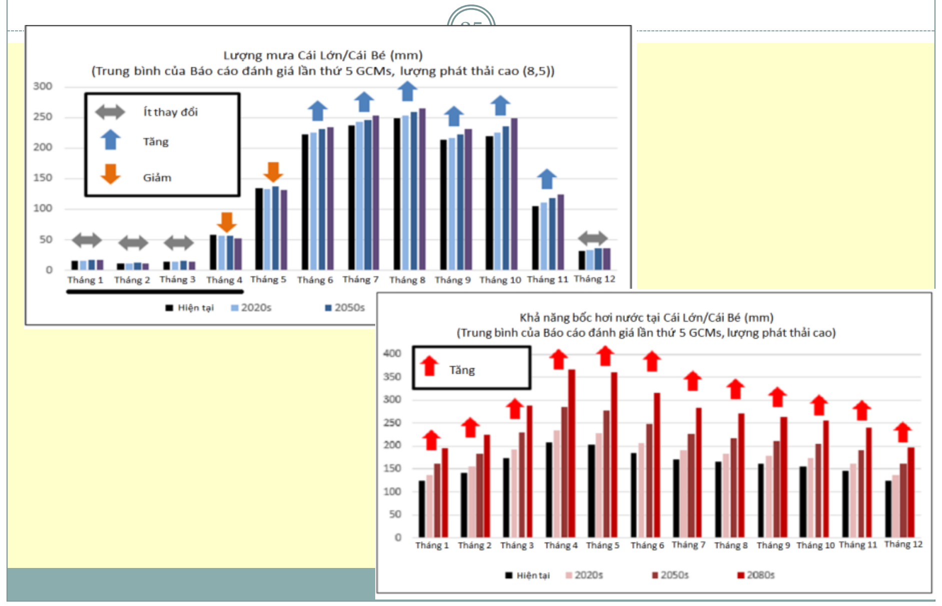
Appendices

CLIMATE ANALYSIS - Projection- Tropical storm

23

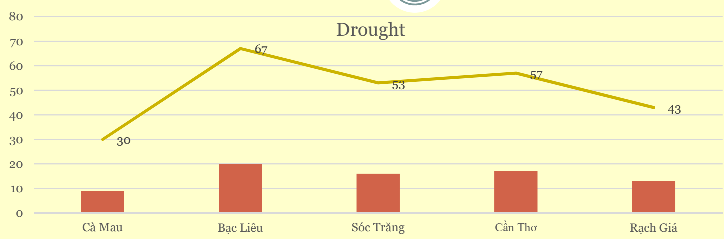
- Uncertainty in storm frequency change but intensity of storm has a upward trend in the future
- Upward trend in the number of storms will affect to the southern Vietnam

CLIMATE ANALYSIS - Historical data - drought in dry season



CLIMATE ANALYSIS - Historical data - drought in dry season

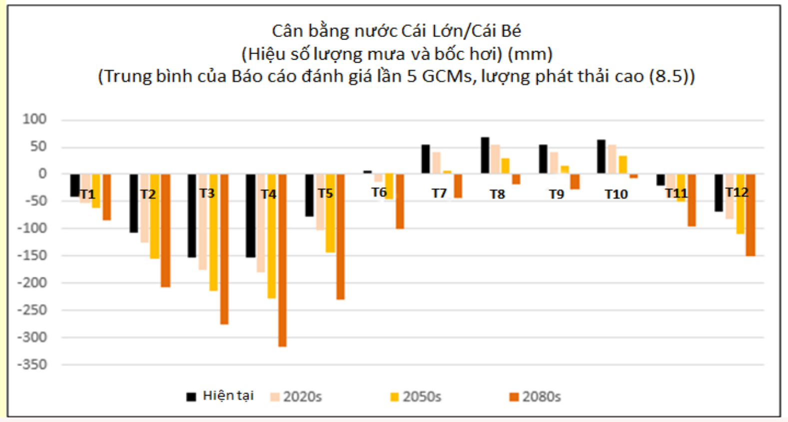
24



	1997-1998		2015-2016	
	Number of days > 35°C	Number of consecutive days without rain	Number of days > 35°C	Number of consecutive days without rain
Rach Gia	26	145	13	130
Can Tho	32	131	33	123
Soc Trang	51	194	33	126
Bac Lieu	11	144	20	130
Ca Mau	54	120	29	126

CLIMATE ANALYSIS - Projection- Drought in dry season

26



The drought will become more severe than in the dry season

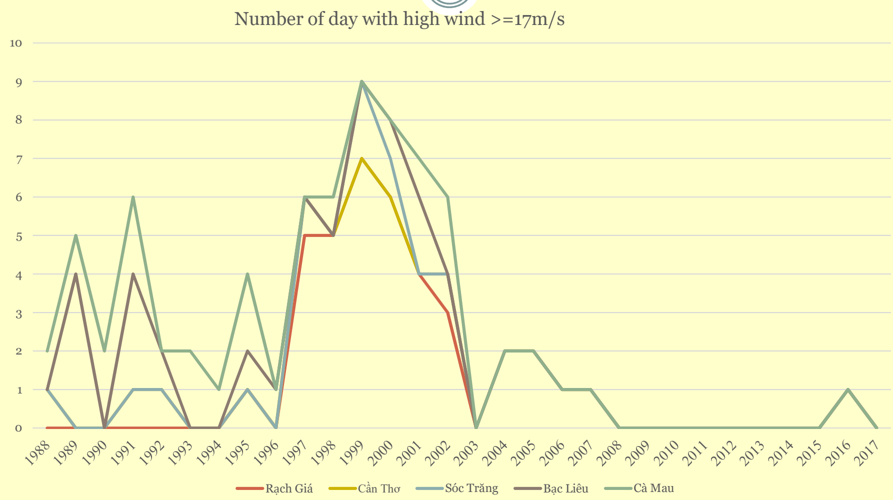
CLIMATE ANALYSIS - Historical data - High wind

27

- Wind-gust is measured by the average number of days having wind speed over 62 km/h (Beaufort scale : 8).
- Wind-gust data from 1988 – 2017 = 0.5 days/year
- Wind-gust for Rach Gia = 2.8 days/year

CLIMATE ANALYSIS - Historical data - High wind

28



Appendices

HYDROLOGY

30

The selected parameters

+ Water level, tide;
+ Flow (Flood and low flow);
+ Salinity intrusion;
+ Hydrological drought;
+ Storm surge;
+ Stunami;
+ Some of evinronmental factors: water temperature, pH.
+ Sedimentation.

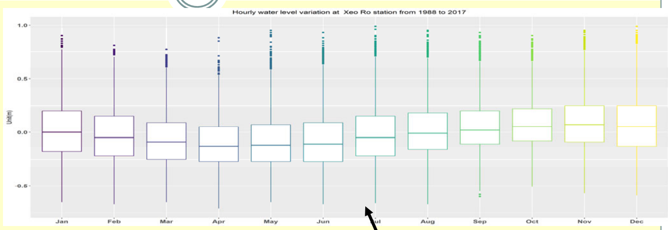
+ Sea level rise;
+ Decreased dediment load;
+ The increase of salinity intrusion at both value and durability
+ Decreasing low flow and increasing flood flow combining with unpredictable changes due to the upstream development.
+ The effects of climate change on storm surges;
+ Coastal and river bank erosion.

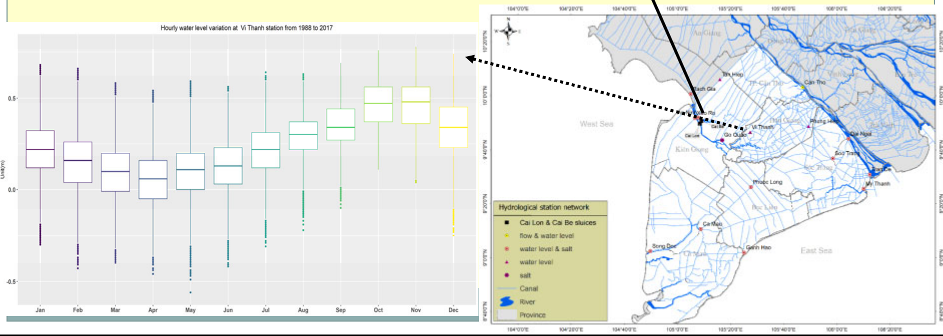
- Floods from upstream combined with heavy rain and tides or storm surges;
- Salinity intrusion combined with meteorological drought and upstream low flow.
- The decreased sediment load and associated with erosion and flood flow or storm surges.

HYDROLOGY ANALYSIS - Historical data - Hourly water level

31

Xẻo Rô
Max ~ 1m; Min ~-0.7 m. Triều cao: T9-T11; Triều thấp 6-9.





HYDROLOGY ANALYSIS - Historical data - Hourly water level

32

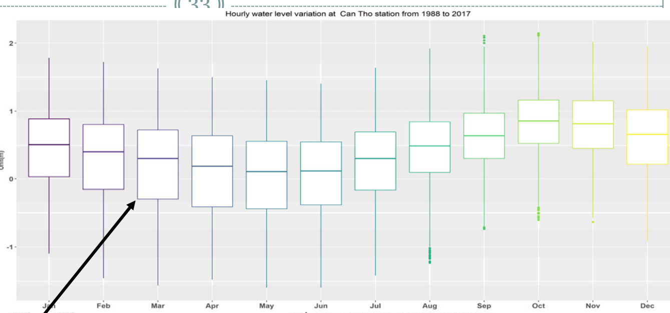
Location	name	q25	median	q75	max	mean	sd	Location	name
East Sea	Gành Hào	-2.45	-0.59	0.28	0.86	2.28	0.11	0.95	4.73
West sea	Mỹ Thành	-2.35	-0.61	0.18	0.78	2.39	0.07	0.91	4.74
West sea	Rạch Giá	-0.72	-0.14	0.04	0.22	1.20	0.04	0.25	1.92
West sea	Sông Đốc	-0.70	-0.13	0.04	0.22	1.02	0.05	0.25	1.72
West sea	Xẻo Rô	-0.71	-0.19	-0.03	0.17	0.99	-0.01	0.25	1.70
Inland	Cà Mau	-0.73	0.14	0.30	0.44	0.94	0.28	0.24	1.67
Inland	Phụng Hiệp	-1.46	0.12	0.47	0.72	1.58	0.39	0.45	3.04
Inland	Phước Long	-0.32	0.15	0.28	0.41	0.85	0.28	0.18	1.17
Inland	Vị Thanh	-0.56	0.11	0.24	0.37	0.78	0.24	0.20	1.34
East Sea	Cần Thơ	-1.60	-0.02	0.48	0.85	2.15	0.40	0.62	3.75

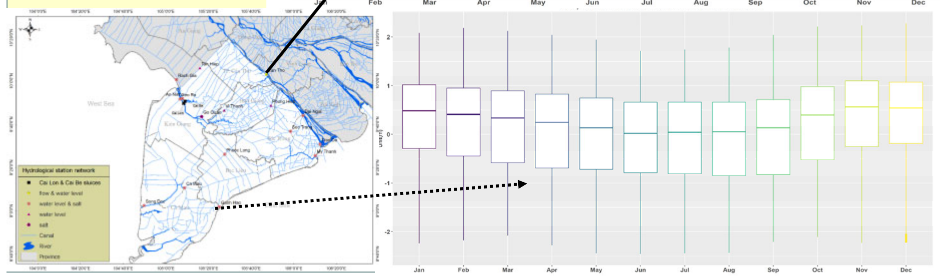
Appendices

HYDROLOGY ANALYSIS - Historical data - Hourly water level

33

Cần Thơ
Max ~ 2.15m; Min ~-1.6 m. Triều cao: T9-T11; Triều thấp 6-9.

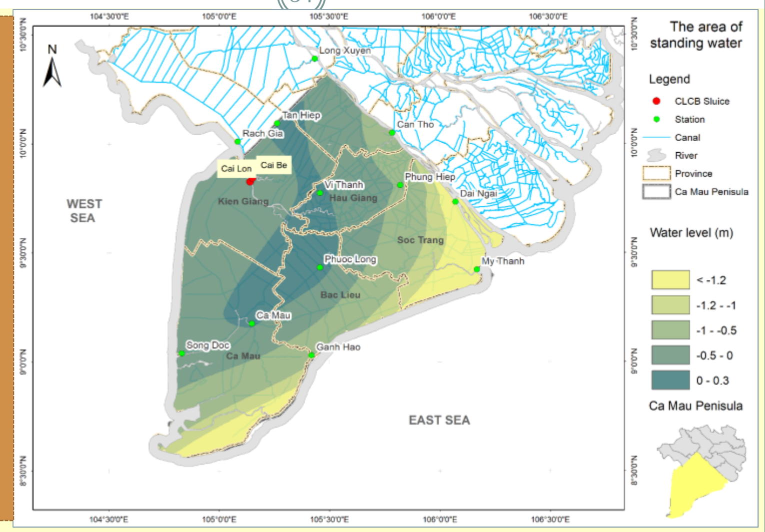


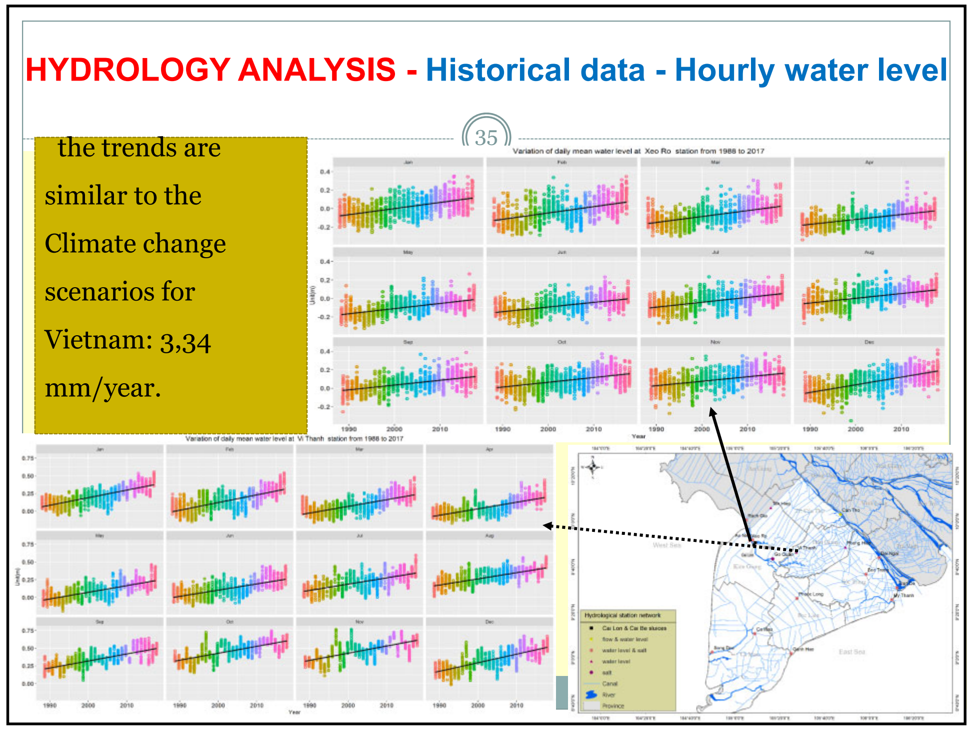


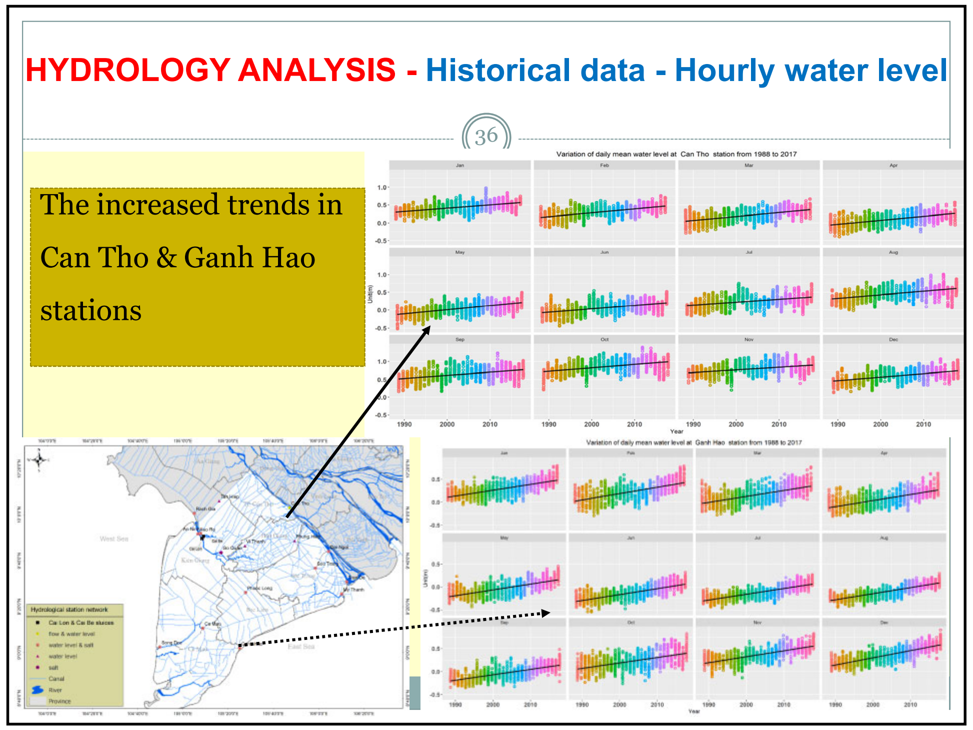
HYDROLOGY ANALYSIS - Historical data - Hourly water level

34

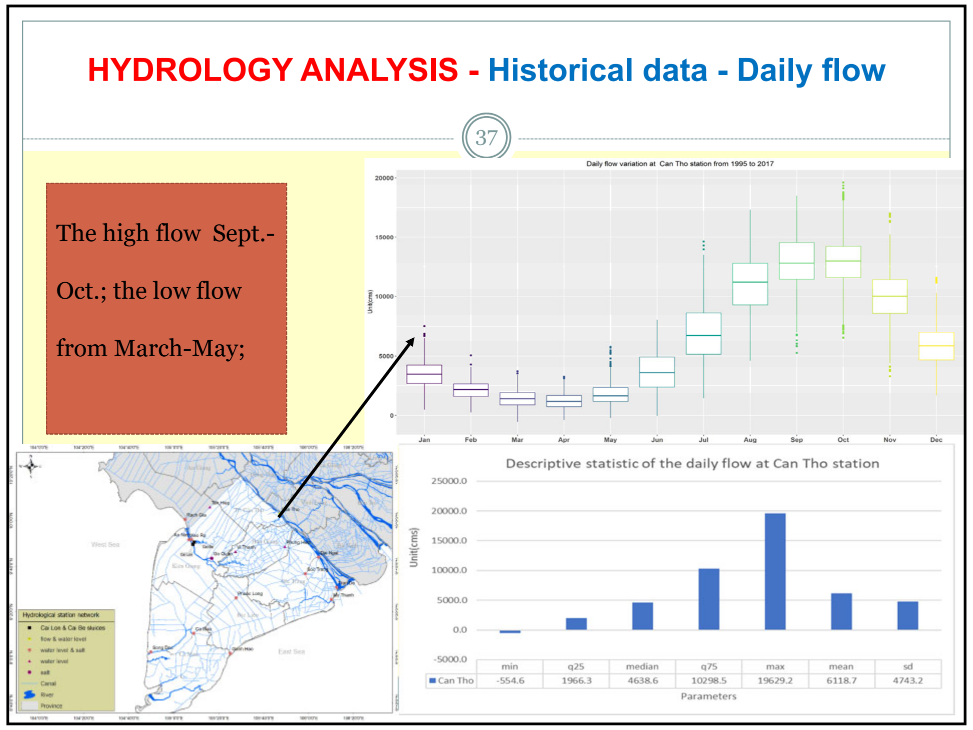
tidal interference + River flow => the standing water which might impact irrigation & drainage acitivies of sluice gate.

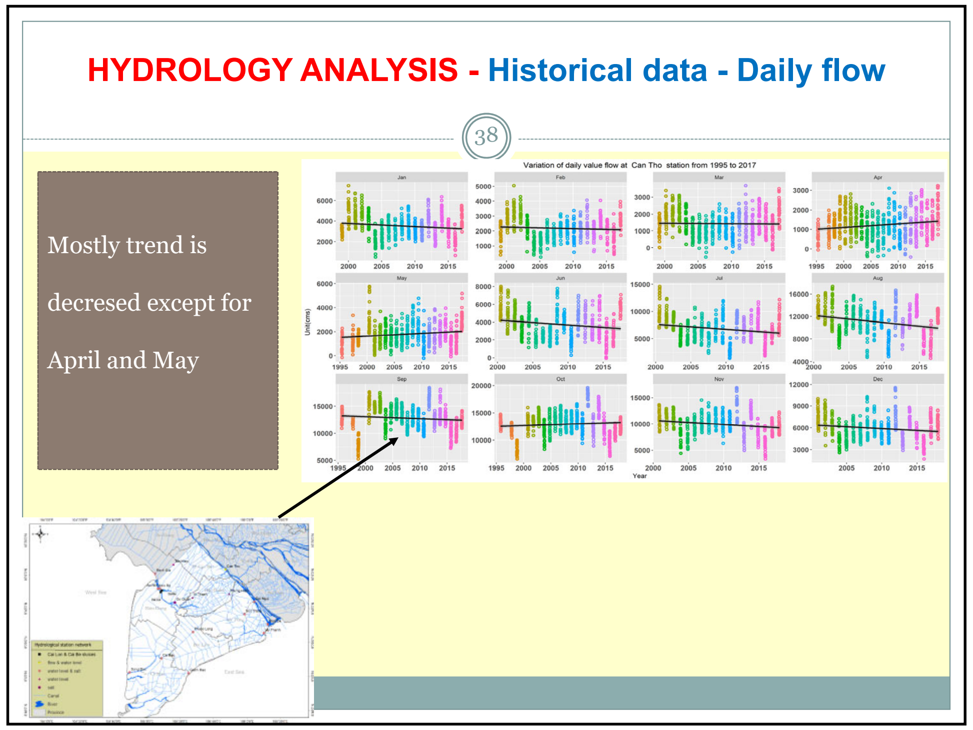



HYDROLOGY ANALYSIS - Historical data - Hourly water level
35
the trends are similar to the Climate change scenarios for Vietnam: 3,34 mm/year.


HYDROLOGY ANALYSIS - Historical data - Hourly water level
36
The increased trends in Can Tho & Ganh Hao stations

Appendices


HYDROLOGY ANALYSIS - Historical data - Daily flow
37
The high flow Sept.- Oct.; the low flow from March-May;
Descriptive statistic of the daily flow at Can Tho station

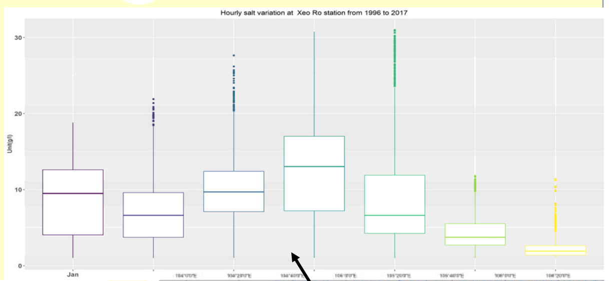

HYDROLOGY ANALYSIS - Historical data - Daily flow
38
Mostly trend is decreased except for April and May

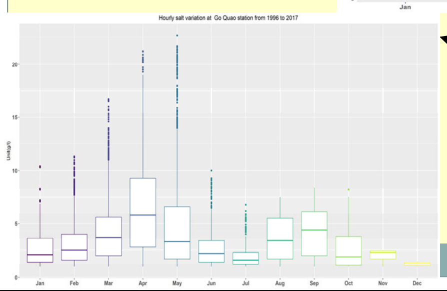
Appendices

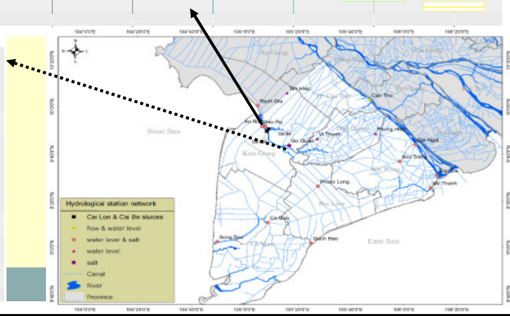
HYDROLOGY ANALYSIS - Historical data - Salinity

39

The highest value of salt is April. The salt value is decreased in the ending dry season.

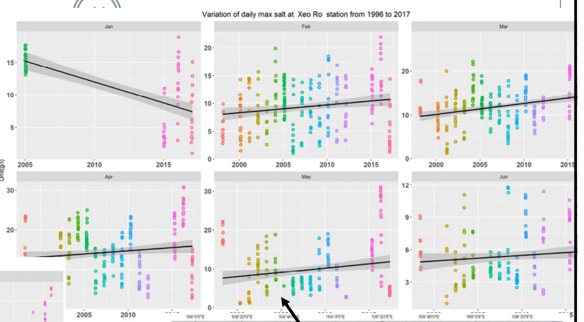


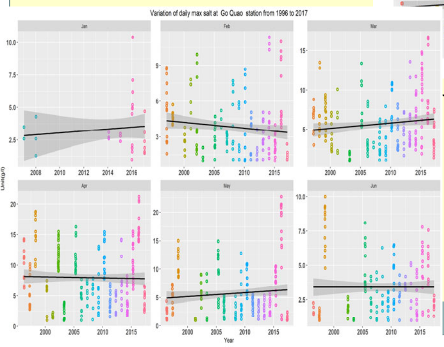


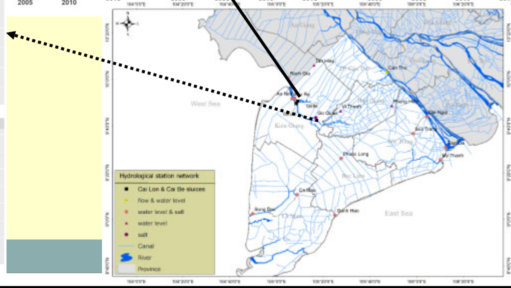


HYDROLOGY ANALYSIS - Historical data - Salinity

The increasing trend is in recent years.







HYDROLOGY ANALYSIS - Historical data - Salinity

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Location	name	q25	median	q75	max	mean	sd
East Sea	Mỹ Thanh	9.3	14.2	19.2	36.8	14.3	6.7
West sea	An Ninh	2.2	3.9	7.3	30.1	5.6	4.9
West sea	Rạch Giá	3.6	6.5	11.0	30.0	7.8	5.5
West sea	Sông Đốc	21.9	27.8	30.1	40.8	24.9	8.1
West sea	Xẻo Rô	3.9	7.8	12.6	31.0	8.8	5.9
Inland	Cà Mau	12.9	23.7	28.0	39.4	20.7	9.6
Inland	Gò Quao	1.9	3.2	6.1	22.7	4.6	3.7
Inland	Phước Long	11.0	20.9	26.0	37.8	18.4	9.5
Inland	Sóc Trăng	1.3	1.8	2.7	9.0	2.2	1.4

HYDROLOGY ANALYSIS - Comparison between design values and re-calculated design values

No	Design parameters	Technical standard	Design value	Re- calculation on the dataset 1988-2017
1	Hmax P = 0.2% ($Z_{maxo.2\%}$) ; To test the Sluice gate stablelization	QCVN 04-05:2012 /BNNPTNT	+1.09	+1.08
2	Hmax P = 0.5% ($Z_{maxo.2\%}$) ; To design the Sluice gate stablelization	QCVN 04-05:2012 /BNNPTNT	+1.06	+1.06
3	Hmax P = 5%; To calculate the gate level	QCVN 04-05:2012 /BNNPTNT	+0.95	+0.99
4	Hmin P=95%	QCVN 04-05:2012 /BNNPTNT	-0,76m	-0.72 m
5	Hmin P = 10% ; To estimate the gravity flow	QCVN 04-05:2012 /BNNPTNT	-0.54m	-0.52 m
6	Hmin P = 90 % ; To test the design requiments	QCVN 04-05:2012 /BNNPTNT	-0.73m	-0.69 m
7	Hmax to calculate the design height for navigation (Frequency = 5%).	TCVN 5664-2009	+1.12m	+ 0.43 m
8	Hmin to calculate the design depth for navigation (Frequency = p98%).	TCVN 5664-2009	-0.15	- 0.23 m

HYDROLOGY ANALYSIS - Historical data - Salinity

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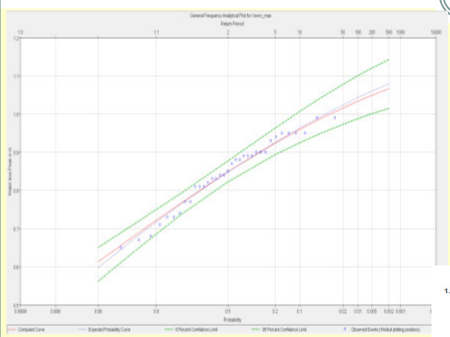
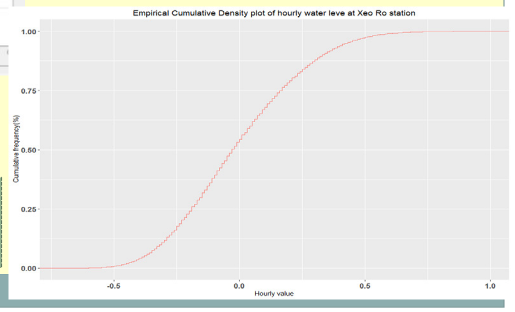


The Probability curve of the max water level at Xeo Ro station



The cumulative curve of the hourly water level at Xeo Ro station

Probability Scoring of PIEVC

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PIEVC Probability Score	Method A	Calculated number of occurences per Year (range)
0	Negligible or not applicable	0
1	Improbable/Highly unlikely	>0 or 0.05
2	Remote	0.05-0.1
3	Occasionnal	0.1-0.25
4	Moderate/possible	0.25-0.75
5	often	0.75-1.25
6	Probable	1.25-2.0
7	Certan/highly proble	>2.0

Appendices

Summary of Findings

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Climate Parameter	Current Probability Score	Future Probability Score
High tempeature	7	7
Heat wave		
Heavy Rain	4	
Heavy 3 days, 5 day, 7 days total Rainfall		
Tropical storm	4	5???
Lightning/Thunderstorm		
Drought in the dry season	4	
Wind-gust	4???	
Tornado		

Combination of Hydrology and climate parameters

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- Drought, high temperature and salinization in the dry season
- heavy rain + high wind + spring tide + flood
- Storm surge + flood + heavy rain

Appendices

APPENDIX 9. Matrix of climate risk assessment for Cai Lon - Cai Be Sluice Gates: Current and Future Conditions

Time Period / khoảng thời gian Current to 2020 / Hiện tại đến năm 2020		Climate and Other Variables and Events / Biến đổi khí hậu và các biến cố và sự kiện khác																																											
Infrastructure Components / Thành phần cơ sở hạ tầng (Sheet 1 of 1) (Trang 1/1)		High Temperature / Nhiệt độ cao>=35 oC (6)				Heat Wave (8 consecutive days >=35oC)/ Sóng nhiệt (3)				Heavy Rain / Mưa lớn>100mm/day (5)				5 day Total Rain / Tổng cộng 5 ngày mưa >=250mm (5)				Tropical Storm | Depression / Bão/ATNĐ (3)				Drought/ hạn hán (5)				High Wind (>=20 m/s) / Gió mạnh (4)				Tornado / Lốc xoáy (7)				Thunderstorm| Lightning / giông | Sét (7)				Water Level / Mực nước (7)				Water Salinity / Nước mặn (7)			
		A				B				C				D				E				F				G				H				I				K				L			
		Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R
1-Administration	Quản lý vận hành																																												
Personnel	Nhân viên	Y	6	3	18	Y	3	5	15	Y	5	3	15	Y	5	2	10	Y	3	7	21	Y	5	2	10	Y	4	3	12	Y	7	6	42	Y	4	7	28								
Transportation (Supplies Delivery)	Vận chuyển (cung cấp vật tư)									Y	5	1	5	Y	5	1	5	Y	3	6	18									Y	7	6	42												
2-Sluice Gate Structure	Thân cống																																												
Pile foundation	Móng cọc																																												
Waterproof pile foundation	Cừ chống thấm																																												
Pillar footing	Bản đáy trụ																																												
Bottom beam	Dầm cửa van																																												
Pillar	Trụ pin					Y	3	2	6																													Y	7	1	7	Y	7	1	7
Gate tower / Gate hanger	Tháp van (đóng/mở cống)					Y	3	2	6																																				
Cast-in-situ concrete composition	Thành phần bê tông đúc tại chỗ					Y	3	2	6																																	Y	7	1	7
3-Ship Lock	Âu thuyền																																												
Lock chamber	Buồng âu					Y	3	1	3																													Y	7	3	21	Y	7	1	7
Lock head	Đầu âu					Y	3	1	3																													Y	7	3	21	Y	7	1	7
Filling and discharge culverts	Cống và cống xả					Y	3	1	3																																	Y	7	1	7
Leading jetty	Hàng rào dẫn hướng					Y	3	1	3																																	Y	7	1	7
4-Gates (large and small)	Cửa van																																												
Hydraulic Cylinder	Xi lanh thủy lực																																									Y	7	2	14
Gates (large and small)	Cửa cống-âu (lớn và nhỏ)																	Y	3	5	15					Y	4	4	16	Y	7	3	21					Y	7	3	21	Y	7	2	14
Water tight gasket	Gioăng cao su	Y	6	3	18	Y	3	5	15																																	Y	7	1	7
5-Bridge	Cầu giao thông																																												
Bridge Surface	Cầu bề mặt					Y	3	3	9	Y	5	1	5																	Y	7	2	14												
Hand Rail	Lan can cầu																													Y	7	2	14												
Lighting System	Hệ thống chiếu sáng																																												
Traffic Sign Post	Hệ thống biển báo																																												
6-Retaining walls and connected em	Mang cống																																												
Retaining walls	Mang cống					Y	3	2	6																																	Y	7	1	7
Gabion	Rọ đá																																												
Connected embankments	Kè nối tiếp					Y	3	1	3													Y	5	3	15																	Y	7	1	7
Rip-rap embankments sections	Lát mái phần kè nối tiếp					Y	3	1	3																																	Y	7	1	7
Riverbank	Bờ sông nối tiếp sau kè																																												
Stilling basin	Sân tiêu năng																																												
7-Operation house	Nhà điều hành					Y	3	1	3	Y	5	2	10					Y	3	2	6					Y	4	1	4	Y	7	5	35	Y	4	1	4								
8-Park	công viên					V	3	2	6	Y	5	2	10					Y	3	6	18	Y	5	3	15	Y	4	3	12	Y	7	6	42	Y	4	7	28								
9-Electric Power	Hệ thống điện																																												
Transmission Lines	Dây điện, đường truyền									Y	5	1	5					Y	3	4	12					Y	4	3	12	Y	7	6	42	Y	4	7	28								
Power Supply	Trạm biến thế/biến áp									Y	5	1	5					Y	3	2	6									Y	7	2	14	Y	4	7	28								
Standby Generators	Máy phát điện dự phòng																													Y	7	2	14	Y	4	7	28								
10-Control and operation system	Hệ thống vận hành - điều khiển																																												
Control Systems	Hệ thống điều khiển																	Y	3	7	21													Y	4	7	28								
Operation systems	Hệ thống vận hành									Y	5	1	5	Y	5	1	5	Y	3	4	12													Y	4	7	28								
11-Monitoring systems	Hệ thống quan trắc									Y	5	1	5	Y	5	1	5	Y	3	7	21									Y	7	6	42	Y	4	7	28								
12-Fire extinguishing systems	Hệ thống chữa cháy																																												
13-Communication system	Hệ thống thông tin liên lạc									Y	5	1	5	Y	5	1	5	Y	3	6	18					Y	4	3	12	Y	7	6	42	Y	4	7	28								

Time Period / khoảng thời gian 2080 - 2099		Climate and Other Variables and Events / Biến đổi khí hậu và các biến cố và sự kiện khác																																											
Infrastructure Components / Thành phần cơ sở hạ tầng (Sheet 1 of 1) (Trang 1/1)		High Temperature / Nhiệt độ cao>=35 oC (6)				Heat Wave (8 consecutive days >=35oC)/ Sóng nhiệt (3)				Heavy Rain / Mưa lớn>100mm/day (5)				5 day Total Rain / Tổng cộng 5 ngày mưa >=250mm (5)				Tropical Storm | Depression / Bão/ATNĐ (3)				Drought/ hạn hán (5)				High Wind (>=20 m/s) / Gió mạnh (4)				Tornado / Lốc xoáy (7)				Thunderstorm| Lightning / giông | Sét (7)				Water Level / Mực nước (7)				Water Salinity / Nước mặn (7)			
		A				B				C				D				E				F				G				H				I				K				L			
		Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R
1-Administration	*Quản lý vận hành*																																												
Personnel	Nhân viên	Y	7	3	21	Y	4	6	24	Y	6	4	24	Y	5	3	15	Y	4	7	28	Y	7	3	21	Y	4	4	16	Y	7	7	49	Y	5	7	35								
Transportation (Supplies Delivery)	Vận chuyển (cung cấp vật tư)									Y	6	2	12	Y	5	1	5	Y	4	7	28									Y	7	7	49												
2-Sluice Gate Structure	*Thân cống*																																												
Pile foundation	Móng cọc																																												
Waterproof pile foundation	Cừ chống thấm																																												
Pillar footing	Bản đáy trụ																																												
Bottom beam	Dầm cửa van																																												
Pillar	Trụ pin					Y	4	3	12																													Y	7	2	14	Y	7	2	14
Gate tower / Gate hanger	Tháp van (đóng/mở cống)					Y	3	2	6																																				
Cast-in-situ concrete composition	Thành phần bê tông đúc tại chỗ					Y	4	3	12																																	Y	7	2	14
3-Ship Lock	*Âu thuyền*																																												
Lock chamber	Buồng âu					Y	4	2	8																													Y	7	4	28	Y	7	2	14
Lock head	Đầu âu					Y	4	2	8																													Y	7	4	28	Y	7	2	14
Filling and discharge culverts	Cống và cống xả					Y	4	2	8																																	Y	7	2	14
Leading jetty	Hàng rào dẫn hướng					Y	4	2	8																																	Y	7	2	14
4-Gates (large and small)	*Cửa van*																																												
Hydraulic Cylinder	Xi lanh thủy lực																																									Y	7	3	21
Gates (large and small)	Cửa cống-âu (lớn và nhỏ)																	Y	4	6	24					Y	4	5	20	Y	7	4	28					Y	7	4	28	Y	7	3	21
Water tight gasket	Gioăng cao su	Y	7	3	21	Y	4	6	24																																	Y	7	2	14
5-Bridge	*Cầu giao thông*																																												
Bridge Surface	Cầu bề mặt					Y	4	4	16	Y	6	2	12																	Y	7	2	14												
Hand Rail	Lan can cầu																													Y	7	2	14												
Lighting System	Hệ thống chiếu sáng																																												
Traffic Sign Post	Hệ thống biển báo																																												
6-Retaining walls and connected em	*Mang cống*																																												
Retaining walls	Mang cống					Y	4	2	8																																	Y	7	2	14
Gabion	Rọ đá																																												
Connected embankments	Kè nối tiếp					Y	4	2	8													Y	7	4	28																	Y	7	2	14
Rip-rap embankments sections	Lát mái phần kè nối tiếp					Y	4	2	8																																	Y	7	2	14
Riverbank	Bờ sông nối tiếp sau kè																																												
Stilling basin	Sân tiêu năng																																												
7-Operation house	*Nhà điều hành*					Y	4	2	8	Y	6	2	12					Y	4	3	12					Y	4	2	8	Y	7	6	42	Y	5	1	5								
8-Park	*công viên*					V	4	3	12	Y	6	2	12					Y	4	7	28	Y	7	4	28	Y	4	4	16	Y	7	7	49	Y	5	7	35								
9-Electric Power	*Hệ thống điện*																																												
Transmission Lines	Dây điện, đường truyền									Y	6	2	12					Y	4	5	20					Y	4	4	16	Y	7	7	49	Y	5	7	35								
Power Supply	Trạm biến thế/biến áp									Y	6	2	12					Y	4	3	12									Y	7	3	21	Y	5	7	35								
Standby Generators	Máy phát điện dự phòng																													Y	7	3	21	Y	5	7	35								
10-Control and operation system	*Hệ thống vận hành - điều khiển*																																												
Control Systems	Hệ thống điều khiển																	Y	4	7	28													Y	5	7	35								
Operation systems	Hệ thống vận hành									Y	6	2	12	Y	5	1	5	Y	4	5	20													Y	5	7	35								
11-Monitoring systems	*Hệ thống quan trắc*									Y	6	2	12	Y	5	1	5	Y	4	7	28									Y	7	7	49	Y	5	7	35								
12-Fire extinguishing systems	*Hệ thống chữa cháy*																																												
13-Communication system	*Hệ thống thông tin liên lạc*									Y	6	2	12	Y	5	1	5	Y	4	7	28					Y	4	4	16	Y	7	7	49	Y	5	7	35								