Vietnam: PIEVC Climate Risk Assessment PIEVC Up-Date and Follow-Up Check of the Cai Lon Cai Be Sluice Gate System

An extended and upscaled climate risk assess[1]ment for sluice gates system in Kien Giang Prov[1]ince, supplemented by an economic analysis

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On behalf of:

Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection

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In cooperation with:

CLIMATE RISK INSTITUTE

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WATER RESOURCES PLANNING

Table of Contents

List of figures

List of tables

Acronyms and Abbreviations

CL-CB	Cai Lon – Cai Be
CRA	Climate risk assessment
CS	Climate service
CSI	Enhancing Climate Services for Infrastructure Investment
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
MARD	Ministry of Agricultural and Rural Development
MCRP	Mekong Delta Climate Resilience Programme
MPI	Ministry of Planning and Investment
PIEVC	Public Infrastructure Engineering Vulnerability Committee
SDG	Sustainable Development Goal
The Protocol	PIEVC Engineering Protocol for infrastructure vulnerability assessment and adaptation to a changing climate
UN	United Nations

1 INTRODUCTION

1.1 Background

Developing and emerging countries invest billions of euros into long-lived infrastructure. However, future climate conditions are seldom considered systematically in the planning of such infrastructure. This leads to bad investment decisions and consequently to high risks for economic damage in the face of emerging climate change. This is why enhancing the resilience of infrastructure enters as goal 9 in the United Nation's (UN) Sustainable Development Goals (SDG). To achieve this, it is necessary to adapt existing planning procedures and requirements in order to incorporate the climate risk assessment with enhanced utilisation of climate services (CS).

In the Mekong Delta of Vietnam where existential threats by climate change is leading to rising sea levels, and according to studies, up to 60% of the Mekong Delta could be underwater by the year 2100, water infrastructures such as sluice gates, dyke, dams, etc. in one hand have a strong role for climate resilience and prevention for the coastal zone, in other hand are facing the increasing risk of climate change and related hazards.

With objective to support the Vietnamese authorities on their path for a sustainable development of the Mekong Delta through the climate-resilient management of coastal area, the Mekong Delta Climate Resilience Programme (MCRP) (2019-2021) and the Vietnam component of global project Enhancing Climate Services for Infrastructure Investments (CSI) (2017 - 2022) are being implemented by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) and funded by the governments of Viet Nam and Germany, with the case study in the Mekong Delta.

MCRP focuses on three working areas:

(1) Governance support for national level and 13 Mekong Delta provinces: Support the establishment of an institutional frame for regional coordination in the Mekong Delta

(2) Investment policy for national level and 13 Mekong Delta provinces: Support the improvement of investment planning and coordination for a climate-resilient and gender-sensitive land and water use management incl. coastal protection for the Mekong Delta

(3) Technology and Solutions for seven coastal provinces and An Giang province of the Mekong Delta to intensify the use of innovative and climate-adapted technologies and solutions.

And CSI focuses on support decision makers increasingly use CS and consider climate risk in planning of infrastructure investments.

In order to support the infrastructure project owners to make climate-risk-informed decisions, since 2017, a case study of climate risk assessment was conducted for the project of Cai Lon - Cai Be Sluice Gates System in the Mekong Delta, based on PIEVC Protocol (Public Infrastructure and Engineering Vulnerability Committee), owned by Canada institutions. This is a step-by-step methodology of risk assessment and optional engineering analysis for evaluating the impact of changing climate on infrastructures. In the first phase of the CSI project, the climate risk assessment (CRA) was conducted for the planning phase of the sluices, after completion of the feasibility study and basic design, through the approval of this investment project, until the completion of the detail design. The obtained results, including observations, conclusions and recommendations derived from the application of this Protocol, provided a framework to support effective decision-making about infrastructure's detail design, operation, maintenance, planning and development as part of climate risk management. This is an important foundation for future perspectives in climate proofing infrastructure investment plans. The comprehensive approach, tools and practical experience of climate risk assessment, once supplemented by cost-benefit analysis, have the potential to give basic advice on investment costs and design of infrastructure, with regard to different climate change scenarios in Vietnam.

In the upcoming time of the MCRP program and the CSI project, with an aim to support in extensive application of climate risk assessment for infrastructures throughout Vietnam and supplement with an economic lens of cost-benefit analysis, an extended and upscaled CRA for sluice gates system in Kien Giang province, supplemented by an economic analysis will be conducted, including three work packages. The main contents of the first work package (WP1) are follow-up check and update the results of the existing climate risk assessment developed for the Cai Lon - Cai Be (CL-CB) sluice system, focus on the period comprised from after the detail design until construction completion.

1.2 Objectives of the report

The objective of the report is to develop a complete, comprehensive climate risk assessment case for the infrastructure of sluice gate systems. The conducted case study of CRA in the period of after feasibility study until detail design has provided useful recommendations for decision makers and management board of CL-CB system's construction on detail design and materials for the infrastructure. And this follow-up check and update of CRA in the period comprised from after the detail design until construction completion is expected to revisit the case study and provide applicable and suitable recommendations for the management board of CL-CB system's construction, particularly on the structural operation and maintenance, before handing over to the authority in charge.

1.3 Methodology

In a climate risk assessment, a climate service is created with the joint efforts, expertise and resources from a variety of stakeholders along the CS value chain. These can be aggregated into 3 groups of key actors:

a. National Hydrometeorological Services in the role of climate information/service provider;

b. Infrastructure Engineers in the role of intermediate who: requests and receives climate data from the provider; requests and receives the technical details and demand from the user; develops the complete service of climate risk assessment for infrastructure;

and provides climate risk assessment results and recommendations to make the infrastructure resilient to climate change;

c. Infrastructure Project owner in the role of climate service user.

In WP1, a CRA team including the experts from these key actors will be established to accomplish all the required tasks. The CRA team consists of an expert on water infrastructure engineering and planning, an expert on water infrastructure engineering, an expert on sluice gate operation and management, an expert on water infrastructure construction engineering, and an expert on hydrometeorology, climate change and climate services. These experts take advantages of doing this because they were the key members of the Vietnamese assessment team for the pilot case of climate risk assessment for the project of CL-CB Sluice Gates. Also, they attended many trainings of climate risk assessment on infrastructures.

Based on the main tasks above, the methodology for WP1 is established, consisting of four major parts (Figure 1-1).

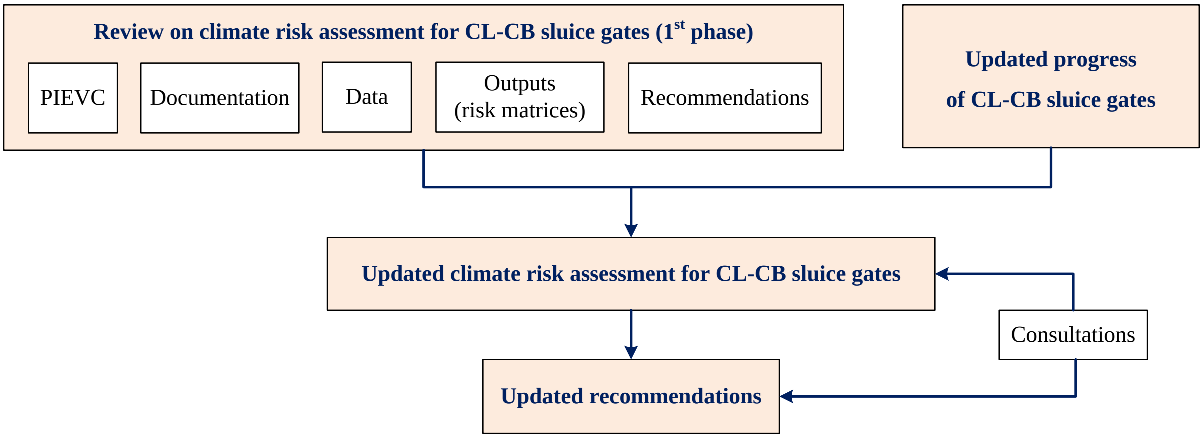


Figure 1-1. Methodology for WP1

❖ *Part 1: A desk review on the CRA for CL-CB sluice gates (1st phase)*

In order to accomplish this part, the documentation of the PIEVC climate risk assessment for CL-CB sluice gates (1st phase) and other involving materials will be collected, synthesized and analysed systematically. The document review process will get useful information from the existing documents and relevant stakeholders (including members of the assessment team of the climate risk assessment). The outputs of the desk review will provide a systematic overview of the CRA for CL-CB sluice gates at the stage of feasibility study and will be a basis to update the CRA at the period comprised from after the detail design until construction completion (Part 3).

The main contents reviewed in this part include:

- The implementation steps of the PIEVC Protocol;
- The technical report of CL-CB sluice gates (1st phase);
- Climate and hydrological data analysis;
- Results of CRA for CL-CB sluice gates (1st phase);

- Recommendations.

❖ Part *2: Updated progress of Cai Lon – Cai Be sluice gates*

In this part, the current status of CL-CB sluice gates will be updated in order to prepare the inputs for the CRA for these sluice gates at the period comprised from after the detail design until construction completion. Two main contents in this part include:

- To collect and analyse technical reports on the current design of CL-CB sluice gates.
- To have a field trip for CL-CB sluice gates to update the construction progress.

❖ *Part 3: Updated CRA for Cai Lon – Cai Be sluice gates*

This part will carry out an updated PIEVC CRA for CL-CB sluice gates based on the information and documentation obtained from Part 1 and 2. This CRA will focus on the vulnerable infrastructure components of CL-CB sluice gates in an interaction with climate and hydrological factors. The outputs of this CRA will be the risk matrices at both current condition and future projection as well as applicable and suitable recommendations for the management board of CL-CB system's construction, particularly on the structural operation and maintenance.

The main contents in this part include:

- Identification of vulnerable infrastructure components
- Updated climate and hydrological analysis and projections for CRA
    - Updated climate and hydrological data
    - Updated climate and hydrological analysis
- Updated CRA of CL-CB sluice gates
    - Determine Probability Scale Factors (Sc) (present/ future)
    - Determine Severity Scale Factors (Sr) (present/ future)
    - Determine the risk tolerance thresholds
    - Identification of risk values for infrastructure-climate interaction
- Updated recommendations for CL-CB sluice gates

❖ *Part 4: Consultations*

During the CRA process, each member of the working team needs to cooperate with other members to integrate technical inputs for the final report. All the obtained results are consulted and refined in an iterative process among the consultants of the working team, focal points at MARD, MPI and GIZ/CSI team until the final draft of the report on the assignment become ready to be submitted.

1.4 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 process is established to support decision makers in characterising any gaps between additional duty loads (as potentially exerted by climate change) and the capacity of infrastructure to adapt to that challenge outside the 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, data gathering and sufficiency, risk assessment, engineering analysis, and recommendations (Figure 1-2). The detailed description of PIEVC Protocol is presented in the principles and guidelines (Engineers Canada, 2016). Its main contents are summarised below.

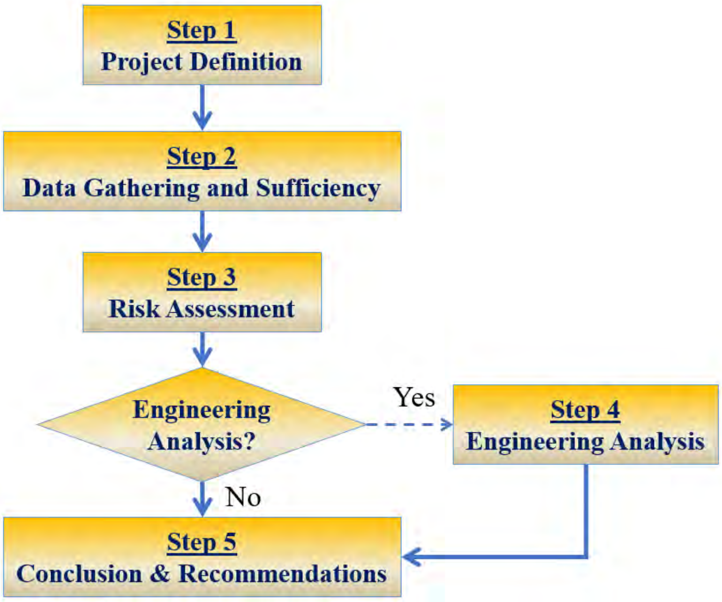


Figure 1-2. Five major steps of PIEVC

1.4.1 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.

1.4.2 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, locations, material of construction, design life of the infrastructure, 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. An assessment of data sufficiency will be carried out for this activity.

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

Depending on the requirement of the project, as well as the features and the location of the infrastructure, the applicable climate, hydrology and geology to be considered in the assessment are identified. One of the key aspects of Step 2 with regard to climate variables and phenomena is to state the baseline climate and formulate assumptions about climate change as well as first ideas about potential impacts on each infrastructure component individually and for cumulative effects of combined 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.

At this stage, data sufficiency is also assessed by an 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 engineering judgment 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 new a data collection program.

A component of this aspect of Step 2 is definition of scoring methods for climate variables and phenomena.

1.4.3 Step 3: Risk assessment

This is the core step in the Protocol as it embodies the risk assessment of the infrastructure's vulnerability to changing climate. 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 and impact severity scores. In this step, it is also possible to assess the impacts of cumulative climate effects (e.g., increased sea level or intense rainfall) on coastal and other infrastructure.

To achieve this, the assessment team needs to confirm the infrastructure components, climate and other risk-driving factors parameter values and probability scores, minimum performance goals and thresholds established in Step 2. 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 judgment 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 sub-sequent 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, based on 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.

Once all of the infrastructure component and climate variable/phenomena interactions 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 specific assessment, if required). Typically, low risk rankings are not considered to be of immediate concern. Conversely, high risk rankings should be an immediate concern. 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, engineering judgment may also be used to address a data issue. If this is the case, it may be prudent to make recommendations for additional data gathering and/or analysis to inform a future periodic review of the risk assessment.

1.4.4 Step 4: Engineering analysis

Step 4 of the Protocol is an optional step. The engineering analysis of Step 4 is conducted based 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 assessment team calculates the total load on the infrastructure and its total capacity for both current and future conditions. This will be followed by the numerical analysis to identify whether to be a vulnerability (i.e., total projected load exceeds total projected capacity) or adaptive capacity (i.e., total projected load is less than total projected capacity).

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.

1.4.5 Step 5: Recommendations

This step will present assumptions, limitations and recommendations from the assessment process. 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.

Aspects of the cost associated with the recommendation, time frame for completion and who are the primary stakeholders to be involved can also be advanced through recommendations. 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.

2 REVIEW ON CLIMATE RISK ASSESSMENT FOR CAI LON-CAI BE SLUICE GATES AT THE PERIOD OF FEASIBILITY STUDY

2.1 Overview about Cai Lon – Cai Be sluice gate system

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 2-1). The study area is about 909,248 ha, including Hau Giang (160.245 ha), Kien Giang (330.803 ha), Ca Mau (204.351 ha), Soc Trang (6.175 ha), Bac Lieu (63.779 ha) and Can Tho City (143.895 ha).

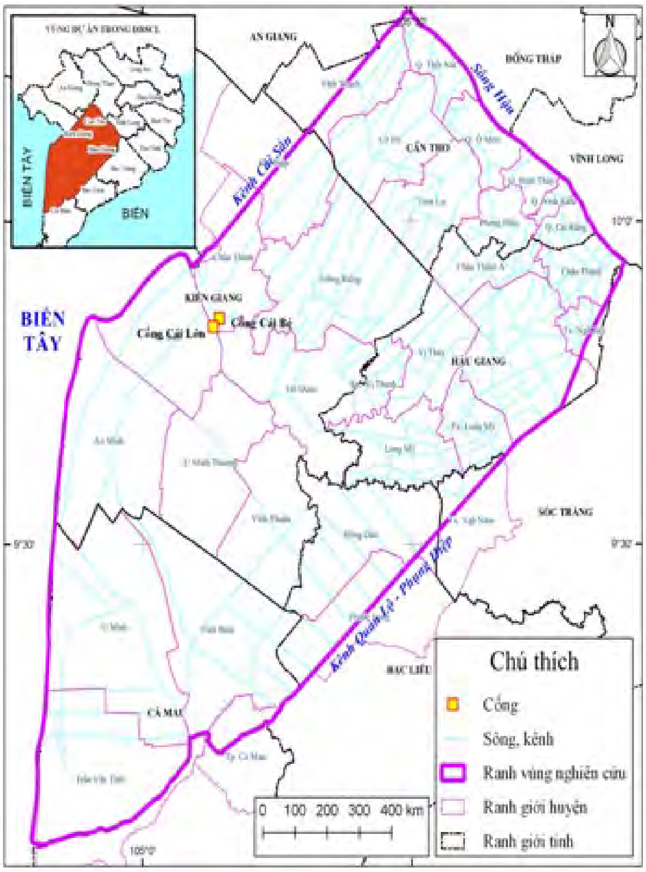


Figure 2-1. Location of the study area for the CL-CB sluice gate project

The main tasks of the CL – CB sluice gate project (1st phase) include:

- To control water resources (i.e., saltwater, brackish, and freshwater), create stable and sustainable production environment suitable to the natural ecosystem (freshwater, saltwater - brackish, freshwater - brackish alternately) for the beneficiary area of 384,120 ha, of which the land for agricultural and fishery production is 346,241 ha;

- To combine with the West Sea dykes for proactively responding to climate change - sea level rise, preventing and combating natural disasters, reducing inundation due to land subsidence; Mitigating damages caused by natural disasters such as drought and salinity intrusion in the dry season;

- To supply freshwater to production areas of mixing saltwater and freshwater in An Minh and An Bien districts for years with little rain; as well as draining for the beneficiary areas in the context of climate change - sea level rise;
- To develop of transport infrastructures, promoting socio-economic development in the project area.

The construction investment phase of the CL-CB sluice gate project includes 3 components: (i) construction, (ii) livelihood and non-structural activities in Kien Giang province, and (iii) livelihood and non-construction activities in Hau Giang province.

❖ ***Construction component***

Cai Lon sluice is built in the riverbed of Cai Lon river, with a total width of 470m, 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). Cai Be sluice is built in the riverbed of Cai Be river, with a total width of 85m, 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 dyke connecting the two sluices to the National Highway 61 has a total length of 5.843 km, where the part from Cai Lon sluice to Cai Be sluice is 1.031 km long and the part from Cai Be sluice to Highway 61 is 4.812 km long. The dyke surface has a width of 9.0 m, and the elevation of + 2.0m.

The main infrastructures invested in the CL – CB Sluice Gate project for the 1st phase include: 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).

[Source: Google Earth]

Figure 2-2 Overview of the infrastructures in the project

❖ ***Component of livelihood and non-structural activities in Kien Giang province***

- Name of assignment: Development of livelihood models in Kien Giang Province that adapt to climate change and water resources controlled after constructing Cai Lon and Cai Be sluices.

- Objective of assignment: To support the development and application of sustainable livelihood models towards biosafety production, suitable to practical conditions for local residents in districts of An Bien, Chau Thanh, Giong Rieng, U Minh Thuong.

- The tasks of assignment include: (1) trainning and enhancing the capacity of local residents in the project area to apply new science and technology for climate change adaptation; (2) Piloting the livelihood models; (3) Replication of livelihood models.

❖ ***Component of livelihood and non-structural activities in Hau Giang province***

- Name of assignment: Development of livelihood models in Hau Giang Province that adapt to climate change and water resources controlled after constructing Cai Lon and Cai Be sluices.

- Objective of assignment: (1) Building the rice - fishery model (organic rice and tiger shrimp; organic rice and giant freshwater shrimp) - Soursop - Vegetables in Luong Nghia commune, Long My district; (2) Building the pineapple - fishery model (pineapple and featherbacks; pineapple and brackish water fish or fresh water fish) in Hoa Tien commune, Vi Thanh district.

- The tasks of assignment include: (1) Construction of irrigation infrastructure such as electric pump stations, improving irrigation systems, and leveling the ground; (2) Developing models of sightseeing, training and transferring science and technology; (3) Replication of livelihood models.

2.2 Summary of characteristics, scale, structures of CL - CB sluice gates

2.2.1 General information

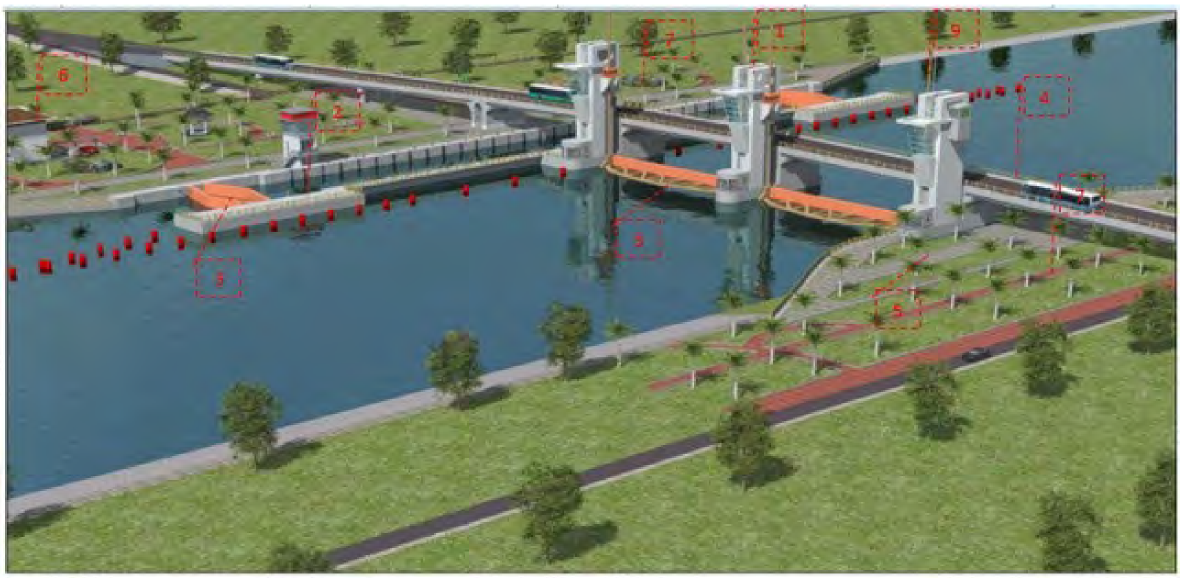
Cai Lon sluice is located 2.1 km upstream from Cai Lon Bridge. The sluice is categorized as a Grade I hydraulic work (based on QCVN 04 - 05:2012/BNNPTNT), including the main components: sluice gate, ship lock, bridge, connecting road, downstream and upstream embankments, operation house, canal connecting the two embankments, landscape and lighting 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 and having a width of 9.0 m. An artist’s rendering of the overall perspective of Cai Lon sluice is shown in Figure 2-3.

(Source: SIWRP, VAWR, and HEC-2, 2018)

Note: (1) – Sluice gate structure; (2) – Ship lock; (3) - Gates; (4) - Bridge; (5) - Retaining walls and connected embankment; (6) – Operation house; (7) - Parks; (8) - Electric system; (9) - Operation and control system; (10) - Monitoring system; (11) - Fire extinguishing system; (12) - Communication system.

Figure 2-3. Overall perspective of Cai Lon sluice at the period of feasibility study



(Source: SIWRP, VAWR, and HEC-2, 2018)

Note: (1) – Sluice gate structure; (2) – Ship lock; (3) - Gates; (4) - Bridge; (5) - Retaining walls and connected embankment; (6) – Operation house; (7) - Parks; (8) - Electric system; (9) - Operation and control system; (10) - Monitoring system; (11) - Fire extinguishing system; (12) - Communication system.

Figure 2-4. Overall perspective of Cai Lon sluice at the period of feasibility study

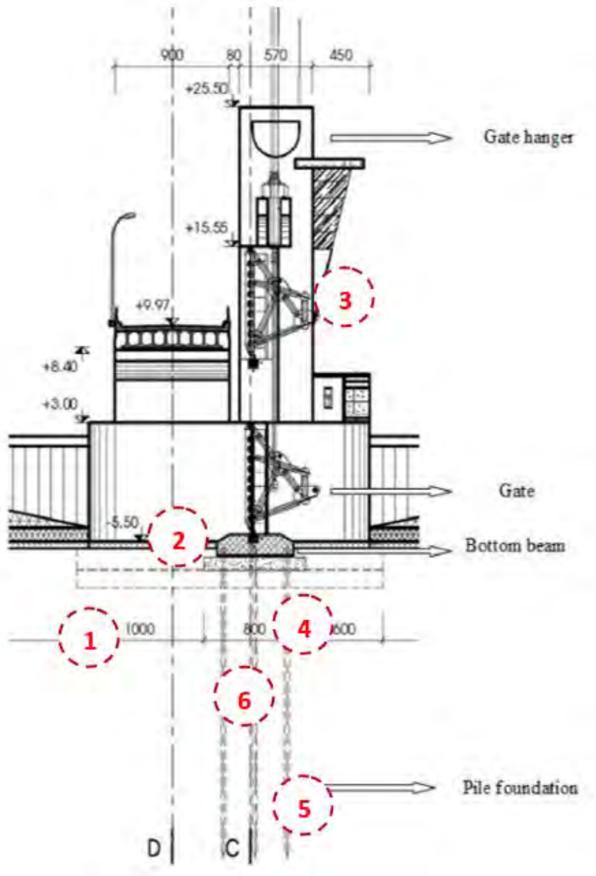
The Cai Be sluice is located 1.9 km upstream from Cai Be Bridge. The main components of this sluice are similar to the Cai Lon sluice, but the Cai Be sluice has a smaller scale and is categorized as a Grade II hydraulic work (based on QCVN 04 - 05: 2012/BNNPTNT).

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 2-4.

2.2.2 Main structural components of Cai Lon and Cai Be Sluice Gate

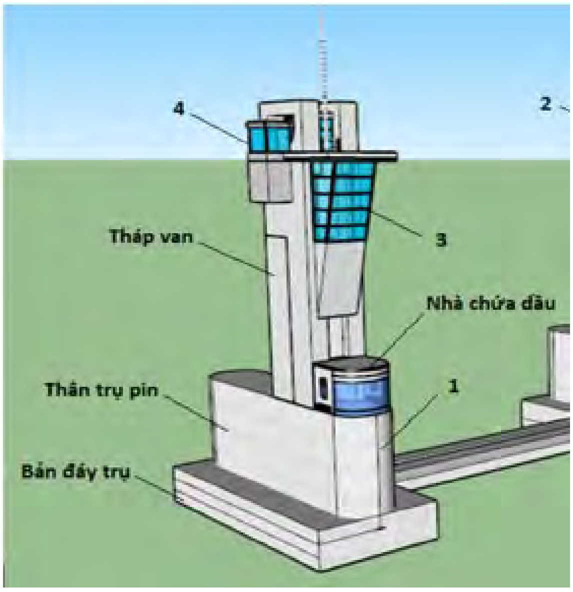
2.2.2.1 Sluice gate structure

The CL-CB sluice gates are designed in the form of a pillar dam, including the main components such as foundation piles, waterproof piles, pillar footing, bottom beam, pillar and valve tower (Figure 2-5).

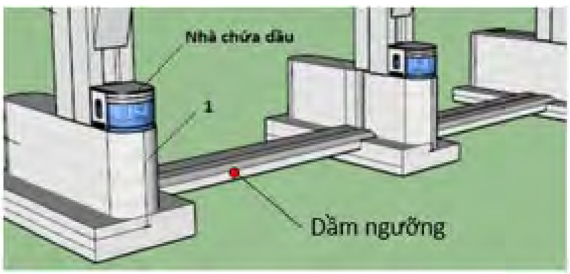


Structure of pillar

(1)- Bottom beam; (2)- Body; (3)- Valve tower; (4)- Threshold beams; (5)- Pile foundation; (6)- Waterproof piles



Overall perspective of a pillar



Overall perspective of threshold beams

Figure 2-5. Pillars of CL-CB sluice gates

- Pillar is made of reinforced concrete M400 (poured on the spot) with the average height of 35 ÷ 40m, and composed of the bottom beam, body and valve tower.

- Threshold beams are made of reinforced concrete (poured on the spot), linked to the pillars by PVC soft joints. The number of threshold beams for Cai Lon sluice are 12, with the length of 33m (corresponding to the bottom width of the pillar: 40m - 2x 3.5m = 33.0m); The number of threshold beams for Cai Be sluice is 3, with the length of 29.20m (corresponding to the bottom width of the pillar).

- Foundation piles is poured by prefabricated reinforced concrete M400. The average number of piles for each pillar of Cai Lon sluice are 128 with the pile length of 17.0 ÷ 25.0m. The average number of piles for each pillar of Cai Be sluice are 98 with the pile length of 14.0 ÷ 17.0m.

Waterproof piles for the CL-CB sluices are made of Larsen SP-IV steel, with the length of 6.0m. These piles are built in a row from left bank to right bank under the pillar bottom and threshold beam.

2.2.2.2 Ship locks

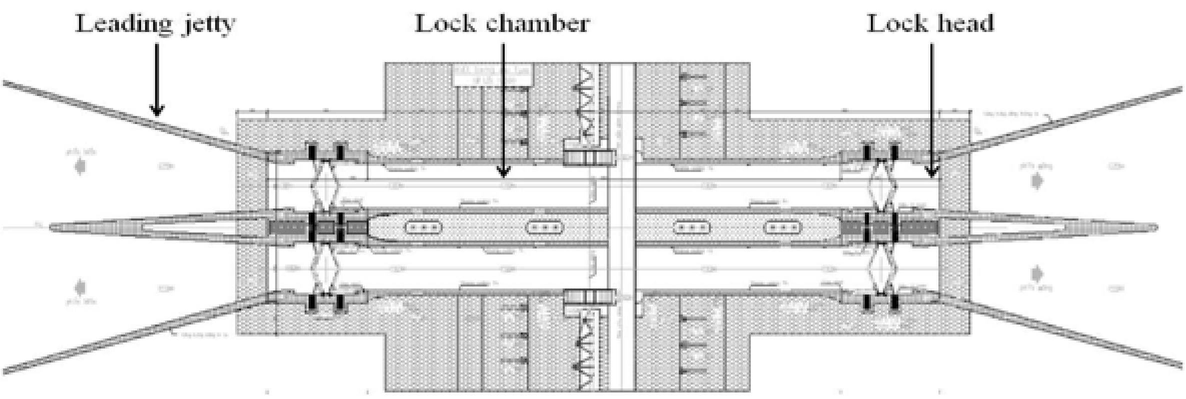
The ship locks of CL-CB sluice gates are designed at Level II according to the technical standard of ship lock. The main components of the ship locks include lock chamber, lock head, leading jetty (passageway combined with ship anchoring), filling and discharge system (Figure 2-6).

- Lock chamber has the U-shaped structure and made of reinforced concrete M400. The dimensions of each lock chamber are 15 m width and 100 m length. The number of ship locks for Cai Lon and Cai Be sluices are 2 and 1, respectively. The wall of the lock chamber has a rubber layer for anti-collision purpose.

- Lock head has the U-shaped structure and made of reinforced concrete M400. The dimensions of each lock head are 15 m width and 28 m length. There are two lock heads for each ship lock, including one in sea side and one in field side. Furthermore, each lock head is designed with auxiliary items such as main valve gate, filling and discharge valve gate, operation system of valve, traffic warning system, etc.

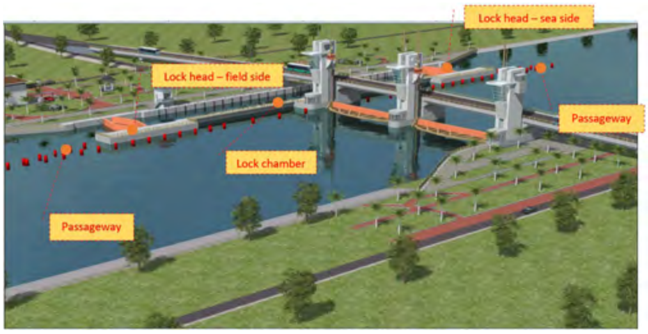
- Leading jetty is mainly structured M400 reinforced concrete girder. The main task of the leading jetty is to guide boats in and out of the lock and anchor boats when the lock is in operation..

The filling and discharge system is designed with the stainless steel gates on the lock head to balance water in the lock.



Layout of Cai Lon ship lock

Ship lock of Cai Lon sluice

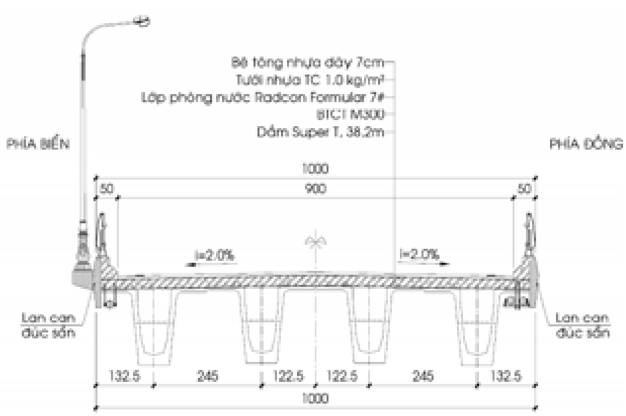


Ship lock of Cai Be sluice

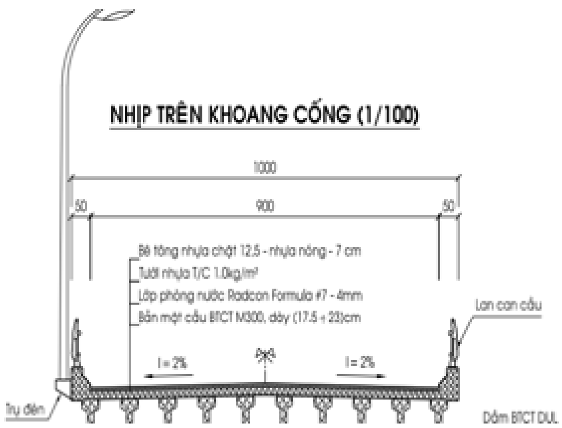
Figure 2-6. Ship locks at CL-CB sluice gates

2.2.2.3 Bridges

The traffic bridges of CL-CB sluice gates are designed with the width of 10.0 m and a design load of HL93 according to the current technical regulations of Vietnam. The bridges are structured by prefabricated beams combined with the M300 reinforced concrete surface. The main components of the bridges are bridge beams, bridge deck, bridge pier, expansion joints, piles foundation, bridge abutment, handrails and lighting system, drainage system, and traffic signs.



Cai Lon Sluice



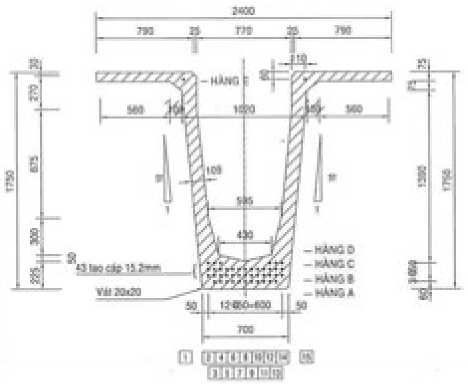
Cai Be Sluice

Figure 2-7. Structure of the bridge deck

- The bridge deck includes: (i) Load bearing layer which is made of M300 reinforced concrete and is 18-23cm thick; (ii) Water defense layer; (iii) Adhesive asphalt layer of 1.0 kg/m2; and (iv) Plastic concrete layer with an average thickness of 7cm.

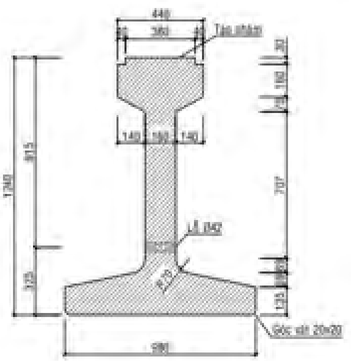
- The bridge beams are made of the M500 pre-stressed reinforced concrete, in which the main characteristics are shown in Figure 2-8.

Number of beams on a bridge cross section: 04;
Type of beam: Super T, L = 38.20m.



A cross section of bridge beam
for Cai Lon sluice

Number of beams on a bridge cross section: 10;
Type of beam: Super T, L = 33.00m.



A cross section of bridge beam
for Cai Be sluice

Figure 2-8. Structure of the bridge beam

- The bridge abutment are made of the M300 reinforced concrete block, and placed on the top of square reinforced concrete pile foundation.

- The bridge bearing is structured by rubber combined with the 78mm thick steel plate, specialized for the super T beams. Each head of the beam is designed with such rubber bearing (Figure 2-9).

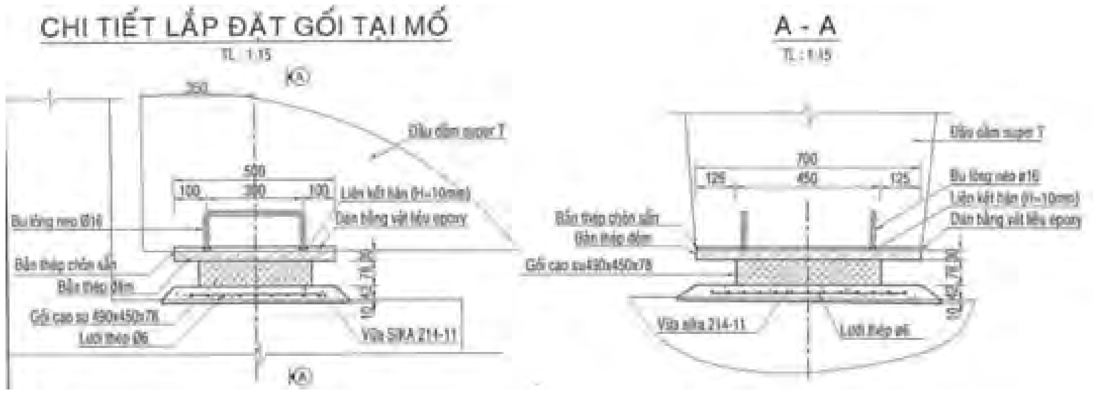


Figure 2-9. Structure of the bridge bearing for CL-CB sluice gates

- The expansion joints use the common type of steel rail for traffic bridges.

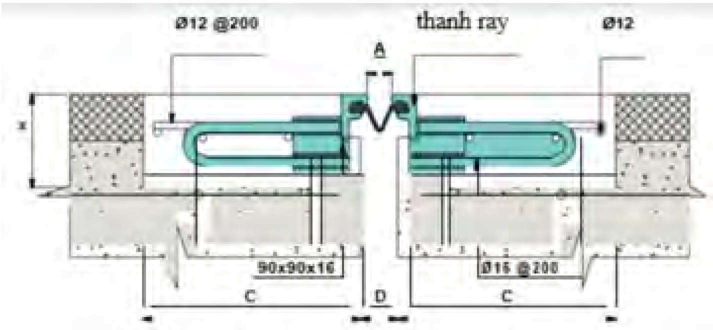


Figure 2-10. Structure of the expansion joints for CL-CB sluice gates

- The bridge handrail is prefabricated in modules, and linked by bulone to the prefilled concrete railing beam on the bridge deck. The handrail is made of CT3 steel covered by anti-rust paints (Figure 2-11).

- The drainage system of bridge deck includes water inlets, trash grating, and the conduction and drainage system of uPVC pipes (Figure 2-12).

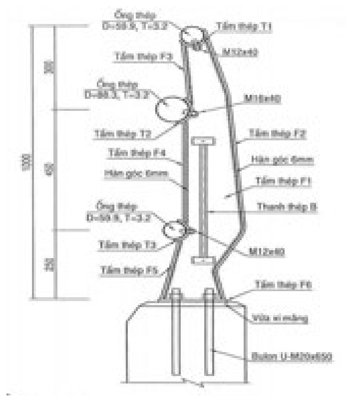


Figure 2-11. Structure of the bridge handrail for CL-CB sluice gates

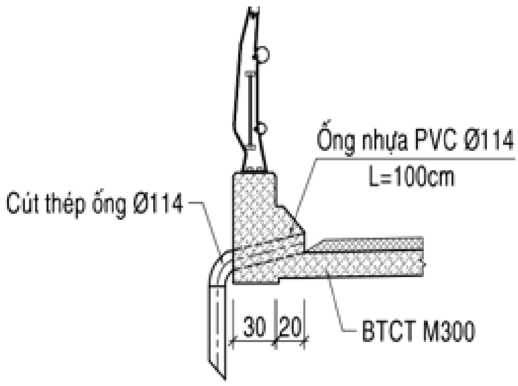


Figure 2-12. Structure of the drainage system for CL-CB sluice gates

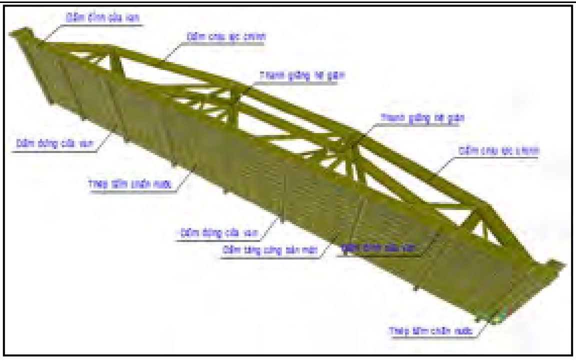
- Piles foundation: The bridge pillars and piers are protected by the M400 reinforced concrete piles. The number of piles for Cai Lon sluice are 24 and the length of piles is 17.0 ÷ 25.0m. The number of piles for Cai Be sluice are 21 and the length of piles is 22.0 ÷ 25.0m.

- The traffic signs are designed according to the current regulations for traffic infrastructures. The signs are made of CT3 steel covered by anti-rust paints.

2.2.2.4 Sluice and ship lock gates

The primary duty of the gates is to control salinity intrusion. The gates are structured by the steel frame, watertight rubber gaskets and bolts.

- The gates of the CL-CB sluices are the lift gate type, i.e., they can move up and down vertically along hydraulic cylinders (Figure 2-13). The gates are made of high-strength alloy steel with the code number of S355JR. Cai Lon sluice has 11 gates with the average dimension of 40.0 wide and 7.5m high, while Cai Be sluice has 2 gates with the average dimension of 35.0 wide and 7.5m high.

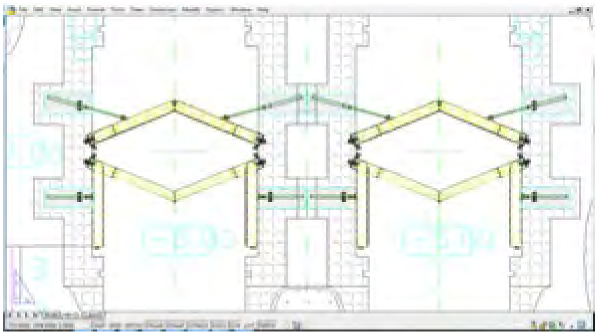


The structure of the lift gate type

Vertical operation of the gate

Figure 2-13. Structure of the lift gates for the CL-CB sluices

- The ship lock gates are operated by hydraulic cylinder and include the main gates and filling and discharge gates (Figure 2-14). The main gates in the 1st phase have a "X-shaped" structure (also known as the Miter gate). Each lock head has two layers of gates, with the dimension of 15.0m wide and high 7.0m. The filling and discharge gates uses the form of a vertical-pull flat structure, with the dimension of 2.0m wide and 1.6m high. These two types of gates are made of stainless steel with the code number of Sus-304.



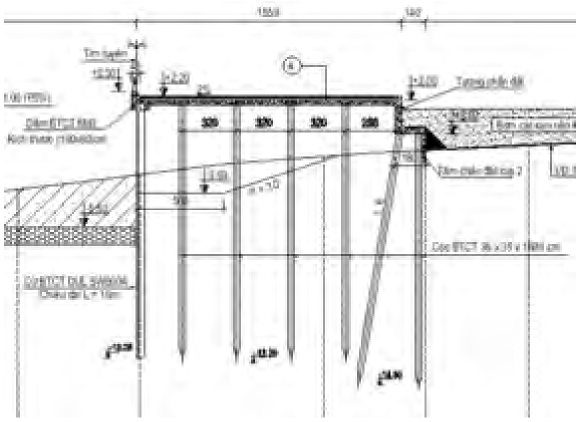
"X-shaped" structure of ship lock gates

Operation of ship lock gates (being opened to prevent water flow)

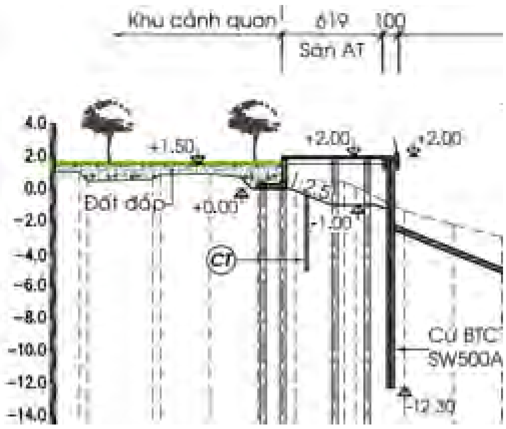
Figure 2-14. Structure of ship lock gates for the CL-CB sluices

2.2.2.5 Retaining walls and connected embankment

The retaining walls are the parts that connect the sluice gate structures and river banks, while the connected embankment is designed to prevent bank erosion due to the impacts of flows and climate conditions. These two components consist of the pre-stressed reinforced concrete walls with the code numbers of from SW-500A to SW-500B, the reinforced concrete foundation and piles to stabilize the wall (Figure 2-15). The embankment behind the wall is filled with sand up to the design elevation.



Cai Lon sluice



Cai Be sluice

Figure 2-15. Structure of retaining walls and connected embankment for the CL-CB sluices

2.2.2.6 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.). The operation house of the Cai Lon sluice is designed with three floors and the construction area of 216m^2. The operation house of the Cai Be sluice is smaller with two floors and the construction area of 114m^2.

Operation house of the Cai Lon sluice

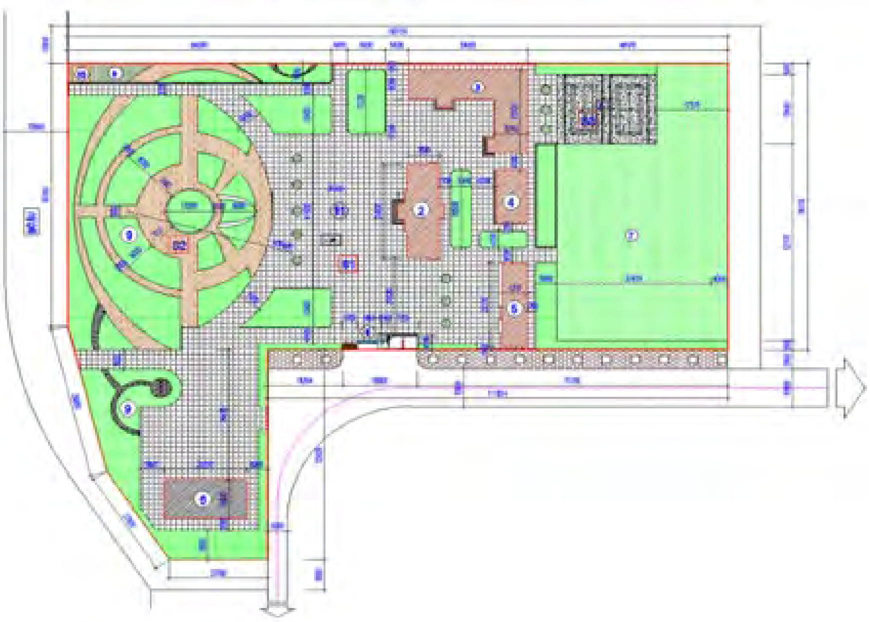
Operation house of the Cai Be sluice

Figure 2-16. Overal perspective of the operation houses for the CL-CB sluices

2.2.2.7 Park

The parks of the CL-CB sluice gates include the following components::

- The drainage system of the parks for the CL-CB sluice gates is designed, including: (a) Water collection holes, (b) Drainage pipes; (c) Drainage gates connected to the embankment. The whole drainage system is made of reinforced concrete which is equivalent to M250 to M300.
- The construction protection fence is made of steel.
- The park also includes trees, flower pots, and lawns.



Note: (1) - Gate, guard house; (2) - Operation house; (3) - Rest house for staff; (4) - Kitchen and dining room; (5) - Garage; (6) - Warehouse; (7) - Ground for sports and physical training; (8) - Badminton club; (9) - Area of aquariums, flower pots; (10) - Transformer stations; (11) - The yard of operation house.

Figure 2-17. The park and the operation house of Cai Lon sluice

2.2.2.8 Electric system

The electric systems for both the Cai Lon and Cai Be sluice gates include three main components namely grid supply, backup generators and lightning protection system, as illustrated in Figure 2-18.

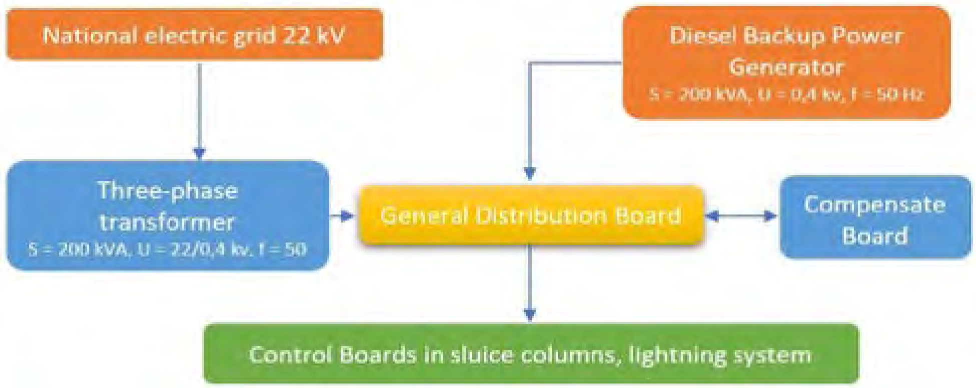


Figure 2-18. The electric system in the sluice gates

- ***Electric line system***

The electric line system for the Cai Lon and Cai Be sluice gates 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 lighting 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).

- ***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.

- ***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 lighting. The Ioniflash Mach 45 system is designed in this case and it is to be placed on the 14 m high lightning poles.

2.2.2.9 Operation and control system

The operation and control system consist of two main components: operation system and control 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. For a certain hydraulic cylinder, the barrel/cover and rod mount/head 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.

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.

2.2.2.10 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, seepage 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 at the 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.

2.2.2.11 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.

2.2.2.12 Communication system

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

2.3 Review on climate and hydrological data analysis

There are more than 30 meteorological stations in the Ca Mau Peninsula, distributed to six provinces including Kien Giang, Ca Mau, Bac Lieu, Soc Trang, An Giang, Hau Giang, and Can Tho City. However, in Phase 1, only the stations close to the location of the study area were selected to analyse the climate and hydrological factors, consisting of the Rach Gia meteorological station (daily rainfall, sub-daily rainfall, daily maximum temperatures, wind, thunderstorm, evaporation data, and humidity data), 5 local rainfall stations (An Minh, Vinh Hoa Hung, Vinh Thuan, Xeo Ro, Go Quao), 4 water level and salinity stations (An Ninh, Go Quao, Rach Gia, and Song Doc (measuring water level only)), and the Can Tho flow measurement station (Table 2-1). The data on tropical storms and depressions in the East Sea was collected from Vietnam and Japan Meteorological Agency (JMA). The data on tornadoes was recorded by the Provincial Committee for Flood and Storm Control, and Search and Rescue of Kien Giang.

At Phase 1, the climate and hydrological factors and their cumulative effects which may affect the infrastructure include:

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

- High wind
- Tornado
- Thunderstorm/lightning
- Water level (tide, sea level rise and storm surge)
- Salinity
- Salinity intrusion combined with high temperature
- High water level combined with heavy rain.

The probability score of each climate and hydrological factor as well as the cumulative effects was calculated based on the PIEVC probability scores of Method A (Table 2-1).

Table 2-1. 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

To determine the PIEVC probability scores, it is necessary to analyse historical data, trends and projections of the climate and hydrological factors. The methods used for this task included 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 enables the projections for climate and hydrological factors. The outputs from the CCHIP for the study area in this project tool are provided using up to 40 climate models in an ensemble average.

The time frame for historical data analysis is as follows:

- The 30-year data (1988-2017) at the Rach Gia meteorological station for climatic factors, such as rainfall, temperature, evaporation, wind, and thunderstorm days;

- The 30-year data (1988-2017) at 5 local rain gauges in Kien Giang province;
- The 30-year data (1988-2017) for tropical storms/depression;
- The 10-year statistical data (2005-2015) of damages caused by natural disasters such as lightning and tornado;
- The 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;
- The 22-year data (1996-2017) at 3 hydrological stations for salinity;
- The 22-year data (1996-2017) at Can Tho hydrological station for flow.

The projections have been taken into account for each of the selected climate - hydrological factors up to the year 2100.

2.4 Probability scores of climate and hydrological factors for CRA for CL-CB sluice gates (1st phase)

At Phase 1, the climate and hydrological factors were analyzed and evaluated with data series up to 2017 to determine the PIEVC probability scores. The historical and future probability scores of each factor are summarised in Table 2-2.

Table 2-2. The PIEVC probability scores for the CL-CB sluice gates (1st phase)

Parameters	Threshold	Unit	Historical probability score	Future probability score
Climate				
High temperature	≥ 35^{0}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	≥ 100mm in a day	Days/year	4	5
Heavy 5-day total rainfall	≥250mm	Events/year	4	4
Tropical storms/depression	From level 8 (equivalent to the windy speed of 62 - 74km/h) or more	Events/year	3	4
Drought	K ≥ 4 in dry season	Drought events/30 years	5	6
High wind	≥ 20m/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 (design probability 5%)	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 ≥ 35^0C	Events/year	4	5
High water level + heavy rain	Water level ≥ 0.9m and heavy rain ≥ 100mm/day	Events/year	2	4

The severity scores (S) at Phase 1 were determined through expert consultation at the risk assessment workshop, including the civil engineers, climate and hydrological experts, and water resources experts, under the guidance of the Canadian consultants. Based on the characteristics of Cai Lon - Cai Be sluice gates, all the workshop participants agreed to select Method E (see Table 2-3 for the severity scale) to determine the severity of impacts of each infrastructure component.

Table 2-3. 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

The severity scores for both historical and future conditions is presented in Table 2-4.

Table 2-4. Summary of severity scores for CL-CB Sluice Gate at Phase 1

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 wave 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.
		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 wave, drought 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/ lighting	7	7	Similar to storms and tornado, thunderstorm/lighting 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
Sluice gate structure	Pillar	Heat wave	2	3	Heat waves may increase the cracking and the 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 the 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

Components	Breakdown	Climate/ hydrological factors	Historical S	Future S	Comments
	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 the 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 the 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 the 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 the 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 the salinity
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 the instability, especially when the drain is open.

Components	Breakdown	Climate/ hydrological factors	Historical S	Future S	Comments
		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.
Bridge	Bridge surface/slope	Heat wave	3	4	Heat wave 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	Tornado 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 wave could change the soil texture, increasing the likelihood of erosion.
		Drought	3	4	Similar to heat wave, but the greater impact.
		Salinity	1	2	Similar to the pillar
		Salinity intrusion + high temperature	2	3	Similar to the effects of the salinity
	Rip-rap	Heat wave	1	2	Similar to the connected embankment

Components	Breakdown	Climate/ hydrological factors	Historical S	Future S	Comments
		Salinity	1	2	Salinity may damage the rip-rap and geotextile compositions.
		Salinity intrusion + high temperature	2	3	Similar to the effects of the salinity
Operation houses		Heat wave	1	2	Heat wave may cause cracking and damages of 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/ lighting	1	1	Thunderstorm/lightning inconsiderably affect the operation house.
Park		Heat wave	2	3	Heat wave 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, lighting systems, and protective fences.
		Drought	3	4	Similar to heat wave, droughts can also affect 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/ lighting	7	7	Thunderstorm/lighting can damage lighting 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/ lighting	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/ lighting	7	7	Lightning can completely destroy the system.

Components	Breakdown	Climate/ hydrological factors	Historical S	Future S	Comments
	Standby generators	Tornado	2	3	Similar to the voltage transformers.
		Thunderstorm/ lighting	7	7	Similar to the voltage transformers.
Operation and control system	Control system	Tropical storm/depression	7	7	Storms can completely damage the receiver and the signal transmission.
		Thunderstorm/ lighting	7	7	Thunderstorm/lighting 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/ lighting	7	7	Similar to the control system.
Monitoring system		Heavy rain	1	2	Heavy rain can cause the errors for the sensors, but 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/ lighting	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 could 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/ lighting	7	7	Destroy the communication system, affecting the communicating ability

At Phase 1, the risk tolerance thresholds for the CRA for CL-CB sluice gate at the extended phase were referenced in Table 2-5. In this table, high risks (R > 36) require a considerable response in the detailed design phase, while a low risk level (R < 12) needs no immediate actions. Medium risks (12 ≤ R ≤ 36) should also be taken into account during the detailed design phase.

Table 2-5. 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

Some special cases have the low-risk scores, but still need to be recommended to mitigate the damages, for example, tornado or storms (with the very low probability and the very high severity); or salinity intrusion (with the very high probability and the very low severity) which may cause physical abrasion and corrosion for concrete or metal in the long-term period.

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

$$R = P \times S \quad (1)$$

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 at Phase 1. The number of the low, medium and high risks for both existing and future conditions is summarised in Table 2-6.

Table 2-6. 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

2.5 Summary of recommendations for CL-CB sluice gates at Phase 1

The recommendations for the stages of the detailed design, construction drawing design, and operation and maintenance of the infrastructure associated with the Cai Lon - Cai Be Sluice Gates Project have been presented based on the results of the risk. Based on 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 the extreme events, then they need to support through additional training courses on coping with tropical storms and tornado; self-protection skills from high temperature, heavy rain, high wind in case of working outdoors; using the automatic operation mode or choose the time of proper maintenance.

- Primary Infrastructure Components

The concrete components as pillars and ship locks are expected to impact by high temperature and heat wave, and increase 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 coating method by Epoxy for these components.

The hydraulic cylinders and gates are likely to be corroded by high salt concentration in water and moisture, especially a combination with high temperature. Thus, it is necessary to study on 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.

- Operations Systems

Due to the technical characteristic of sensors of the SCADA system, they exposure 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, tornado, storm and heavy rainfall, the recommendations are to consider underground wiring designs for both of Cai Lon and Cai Be sluice gates and to design lightning protection systems for the whole infrastructure.

- Project/Facility Management

It needs regular maintenance of monitoring system to ensure continuous functionality.

- Climate Services

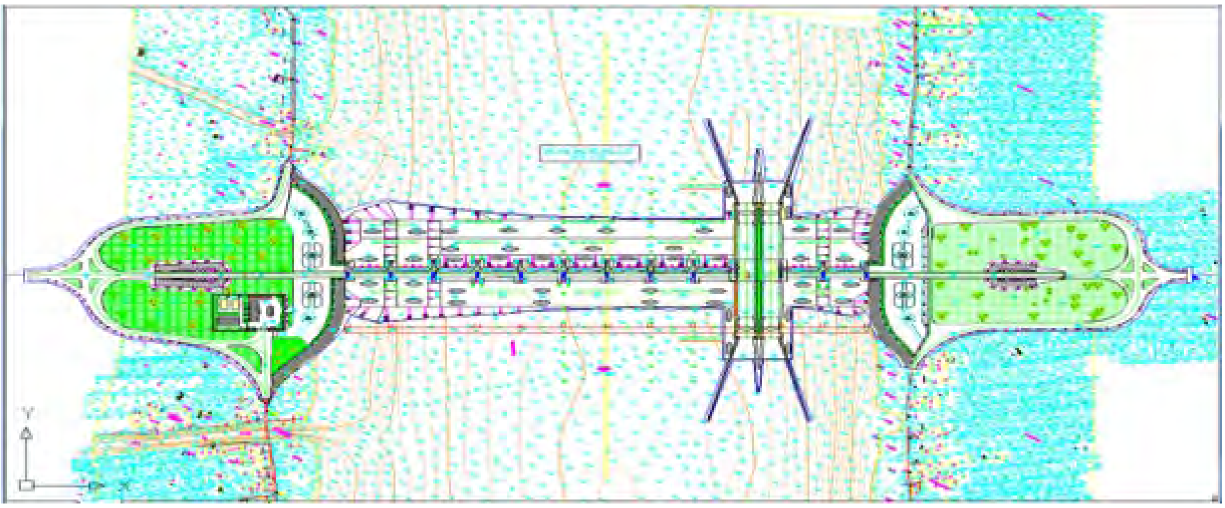
It is necessary to develop climate services program(s) to collect data (e.g. tornado, sediment), sharing data and raise awareness on climate services.

3 UPDATED CLIMATE RISK ASSESSMENT FOR CL-CB SLUICE GATES

3.1 Changes of the current design of the CL-CB sluice gates compared to that of feasibility study period (1st phase)

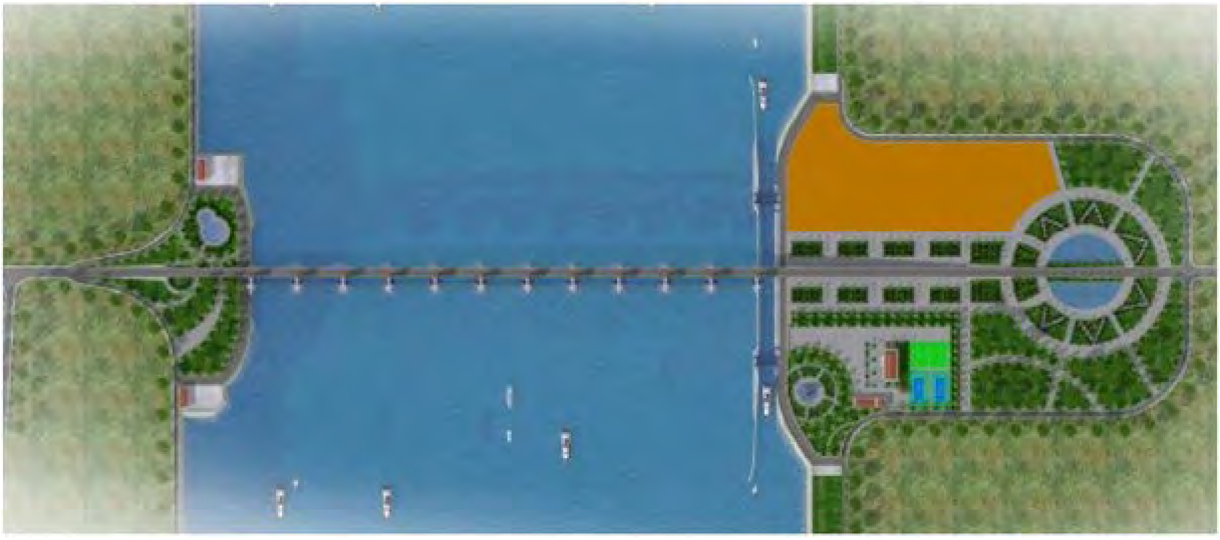
The Cai Lon – Cai Be sluice gate project was approved by Minister of Agriculture and Rural Development for investment policy in Decision No. 5078/QD-BNN-XD dated December 25, 2018 and for adjustment of basic design in Decision No. 3100/QD-BNN-XD dated August 9, 2019. The changes of the current design of the CL-CB sluice gates compared to that of feasibility study period (1st phase) include: (a) the size of the sluice gates; (b) the number and layout of the ship locks; and (c) the form of the door of the ship locks. The details are described as follows:

- In terms of the overall layout of the infrastructures, the Cai Lon ship lock is moved close to the bank embankment (Figures 3-1 and 3-2).



(Source: SIWRP, VAWR, and HEC-2, 2018)

Figure 3-1. Overall layout of Cai Lon sluice at the first phase (stage of feasibility study)



(Source: SIWRP, VAWR, and HEC-2, 2018)

Figure 3-2. Overall layout of Cai Lon sluice at the stage of construction

- The middle pillars of the Cai Lon sluice at the current design are higher than those at the feasibility study period. This will further improve the architecture and landscape for the project.

(Source: SIWRP, VAWR, and HEC-2, 2018)

Figure 3-3. Overall perspective of Cai Lon sluice (stage of feasibility study)

(Source: SIWRP, VAWR, and HEC-2, 2019)

Figure 3-4. Overall perspective of Cai Lon sluice (stage of construction)

- For the structure of the ship locks, the number of ship locks are reduced from 2 to 1 to accommodate the number of ships passing on the construction route of Cai Lon river. In addition, the form of the gate of the ship lock are changed from “X-shaped” (Miter gate – Width = 2 x 7.5 m) to “I-shaped” (Width = 15 m).

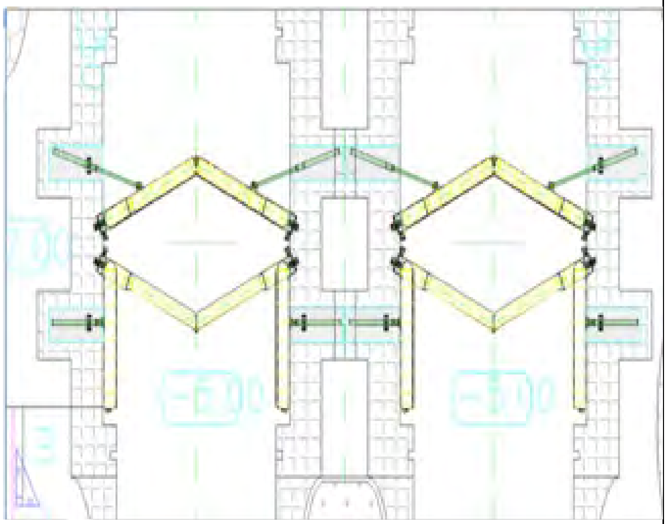


Figure 3-5. Ship lock gate with two layers of the “X-shaped”- stage of feasibility study

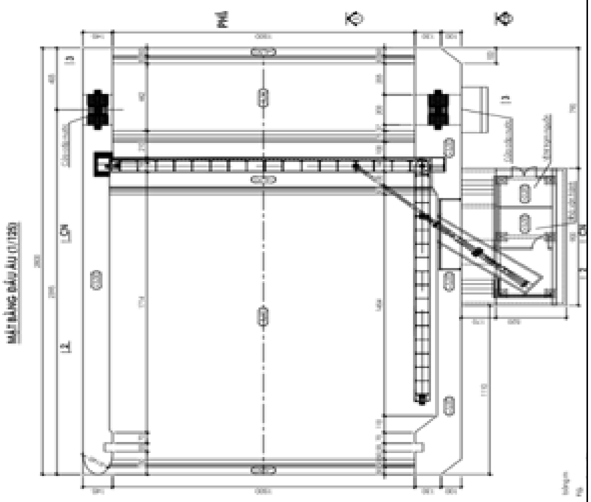


Figure 3-6. Ship lock gate with two layers of the “I-shaped”- stage of construction

3.2 Updated climate – hydrological data analysis

3.2.1 Updated climate – hydrological data

At the extended phase (Phase 2), the climate and hydrological data was updated to 2019 for the stations managed by Southern Regional Hydro-meteorological Center. For local rainfall stations, due to the transition from manual measurement to automatic measurement, there was lack of data from January to May in 2018. However, based on regional climatic characteristics, the data has been still included in the climate data analysis in Phase 2. The time frame for updated historical data analysis is shown in Table 3-1.

Table 3-1. Updated historical climate – hydrological data

No.	**Climate/ hydrological factors**	**Number of stations**	**Length of data (years)**	
			Phase 1	Phase 2
1	Daily rain	11	30 (1988 - 2017)	32 (1988 - 2019)
2	Sub-daily rainfall	6	30 (1988 - 2017)	32 (1988 - 2019)
3	Daily temperature	5	30 (1988 - 2017)	32 (1988 - 2019)
4	Daily wind	5	30 (1988 - 2017)	32 (1988 - 2019)
5	Daily evaporation	5	30 (1988 - 2017)	32 (1988 - 2019)
6	Daily humidity	5	30 (1988 - 2017)	32 (1988 - 2019)

No.	Climate/ hydrological factors	Number of stations	Length of data (years)	
7	Water level	10	30 (1988 - 2017)	32 (1988 - 2019)
8	Hourly flow	1	23 (1995 - 2017)	25 (1995 - 2019)
9	Salinity	8	22 (1996 - 2017)	24 (1996 - 2019)
10	Monthly thunderstorm/Lightning	5	30 (1988 - 2017)	32 (1988 - 2019)
11	Storms		30 (1988 - 2017)	32 (1988 - 2019)
12	Tornado		10 (2005 - 2015)	10 (2005 - 2015)

In a similar way of Phase 1, future projections in Phase 2 were considered up to 2100 for the selected climate and hydrological factors. The results of the future projections are calculated from the 2016 climate change and sea level rise scenario of MONRE and the CCHIP tool.

3.2.2 Changes in climate - hydrological data analysis at Phase 2

Similar to Phase 1, the PIEVC probability scores at Phase 2 were determined by analysing historical data, trends and projections of the climate and hydrological factors. The comparison of the probability scores between two phases showed no change in climate and hydrological factors, except for the thunderstorms/lightning, and salinity intrusion combined with high temperature. While the future probability score for the thunderstorms/lightning increased by one (5 to 6), the probability scores for salinity intrusion combined with high temperature increased by one (4 to 5) and two (5 to 7) for historical and future probability scores, respectively.

3.2.2.1 High temperature

In Phase 1 (1988-2017), the value of high temperature calculated was 7.5 days/year. However, the corresponding value in Phase 2 (1988-2019) decreased slightly, only reaching about 7.1 days/year. On the other hand, the historical data analysis showed that high temperature continues to tend to decrease at the study area.

For projections, the RCP8.5 scenario in the Kien Giang province indicated that the number of days with temperature ≥35^{o}C has an average increase of 13.7 days per year at the early century (up to 2040), 36.3 days per year in the mid-century (2041 - 2070) and 88 days per year at the end of the century. The CCHIP tool also resulted that the average maximum temperature increase is 0.6 - 0.7^{o}C at the early century, 1.7^{o}C at the mid-century, and 3.0^{o}C the end of the century.

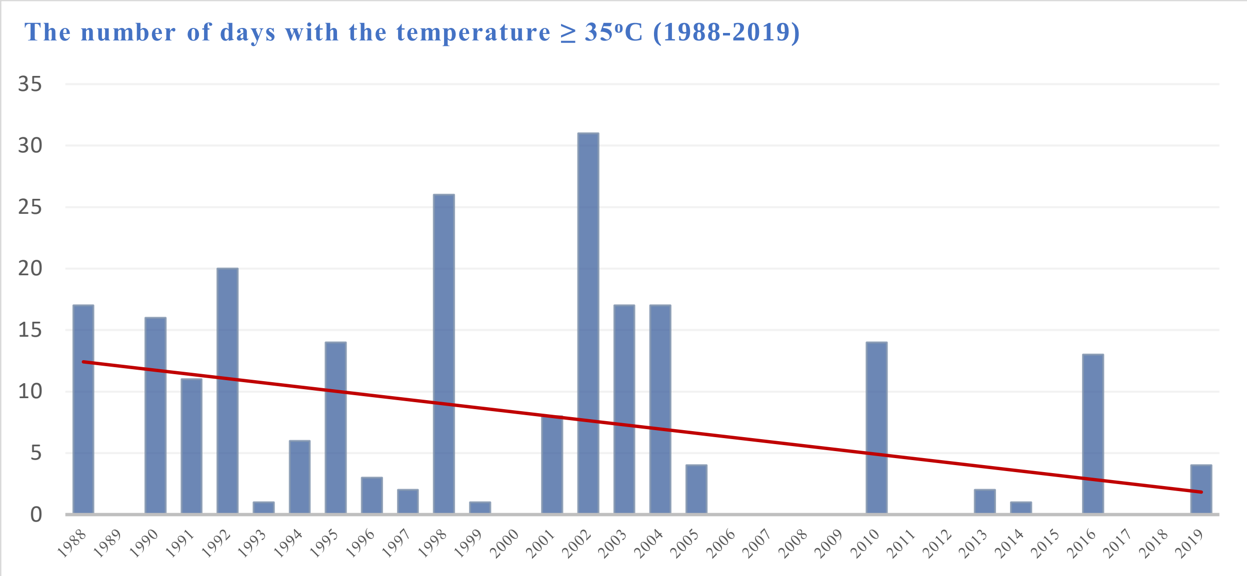


Figure 3-7. The number of days with the temperature ≥ 35°C (1988-2019)

3.2.2.2 Heat wave

According to the statistical data at the Rach Gia station for the period from 1988 to 2019, the number of heat waves in total are the same as that in phase 1 (two in 1988 and two in 2002). However, the average number of heat waves in a year at phase 2 reduced significantly compared to that at phase 1 (0.125 compared to 0.13).

The historical data analysis resulted a sharp decrease of the heat waves in the past 32 years (1988-2019) in the Rach Gia station. However, the projections of this factor from Vietnam's climate change scenarios (MONRE, 2016) and the CCHIP tool showed that the maximum temperature will increase again in the 21st century, and even increase sharply at the end of the century. The number of days with the maximum temperature will be 100 and 88 days for Vietnam's climate change scenarios and results of the CCHIP tool, respectively. As a result, the heat waves more than 8 days will be forecasted to increase again in the 21st century.

3.2.2.3 Heavy rain

The average frequency of heavy rainfall for the meteorological stations in Kien Giang in the period of 1988-2019 was 0.57 (no change compared with the result in phase 1). However, the number of days with heavy rainy in the stations of Xeo Ro, Rach Gia, and Vinh Hoa Hung increased slightly, while in the stations of Go Quao, Vinh Thuan, An Minh there was a slight decrease (Table 3-3).

Table 3-2. Heavy rain in the past 32 years (1988 - 2019)

No.	Station	Day/year (1988-2019)	Day/year (1988-2017)	Maximum daily rainfall (mm)
1	Vinh Hoa Hung	0.52	0.53	188.0
2	Rach Gia	0.66	0.67	220.3
3	Xeo Ro	0.72	0.77	194.0

4	Go Quao	0.56	0.53	167.0
5	Vinh Thuan	0.28	0.23	131.0
6	An Minh	0.69	0.67	267.8
Mean		**0.57**	**0.57**	

The analysis of updated rainfall data (1988-2019) showed that the annual average rainfall at Rach Gia station has increased. The average shortage increased from -27mm/year to 0.0mm/year. The average number of rainy days per year at the stations ranges from 135 to 159 days and has little change in comparison with the corresponding values in phase 1.

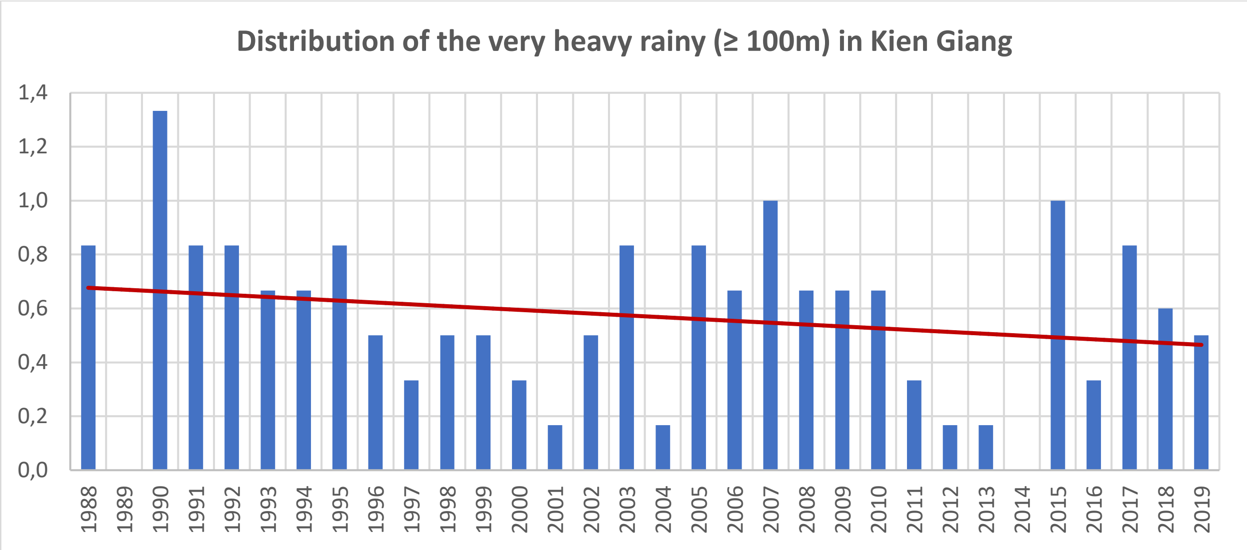


Figure 3-8. Distribution of heavy rainy (≥ 100m) in Kien Giang in the period of 1988-2019

In general, Kien Giang is forecasted in the region with high growth rates across the country. In the RCP8.5 scenario, this increase will range from 50-70% at the middle and end of the century. These also matched the results from the CCHIP tool.

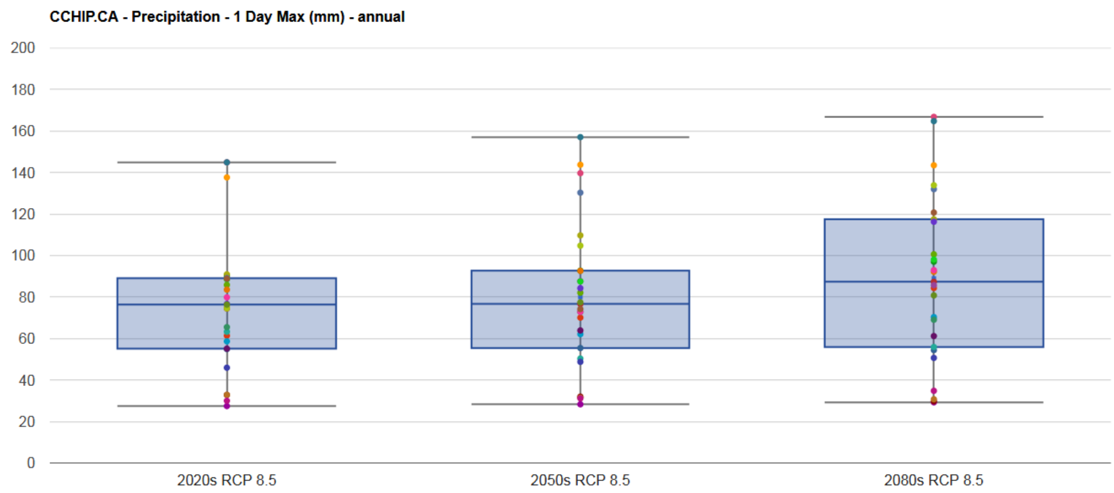


Figure 3-9. Daily maximum rainfall at the Rach Gia station for the RCP8.5 scenario

3.2.2.4 Heavy 5-day total rainfall

The analysis of the rainfall data in the period of 1988-2019 (Table 3-4) showed that the number of heavy 5-day total rainfall occurrences in the period of 1988-2019 has decreased but not significantly compared to that in 1988-2017 (0.55 event/year compared to 0.59 event/year). Thus, the probability score of heavy 5-day total rainfall was unchanged, i.e. the value was kept as phase 1.

Table 3-3. The heavy 5-day total rainfall in the period of 1988-2019

No.	Station	Event/year	Maximum total rainfall (mm)
1	Vinh Hoa Hung	0.23	316.4
2	Rach Gia	0.56	410.2
3	Xeo Ro	1.0	371.0
4	Go Quao	0.13	288.3
5	Vinh Thuan	0.32	298.7
6	An Minh	1.06	420.0
Mean		**0.55**	

According to the climate change scenarios of MONRE (2016), Kien Giang is predicted to be one of the provinces which will experience a remarkably increase in the maximum 5-day total rainfall at the middle and end of the century. Both low and high emission scenarios showed the increase of 40-70%. However, the MONRE report did not mention the 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, in a similar way in phase 1, it could not be stated that the number of the 5-day heavy total rains will increase, decrease, or no change in the future.

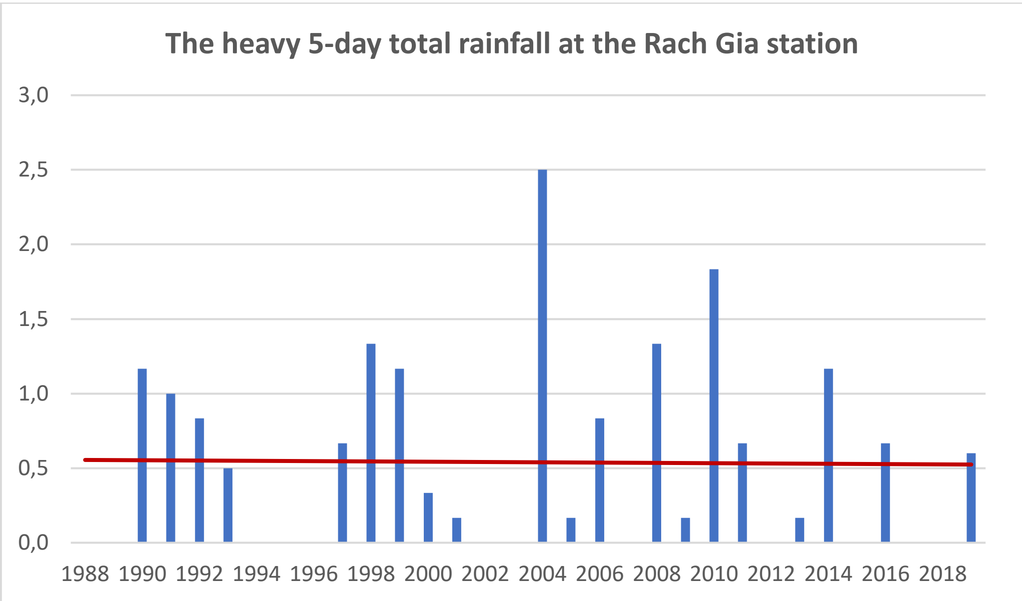


Figure 3-10. The heavy 5-day total rainfall at the Rach Gia station (1988-2019)

3.2.2.5 Tropical storm/depression

The collected data showed that a storm landed into the study area about every 6.4 years (Table 3-5). According to the statistical data (2018 – 2019) from Vietnam and Japan Meteorological Agency (JMA), there was 19 tropical storms and depressions in the East Sea, of which 10 storms directly landed in Vietnam, 1 storm in Southern Vietnam. As a result, the number of tropical storms and depressions in the East Sea in the period of 1988 – 2019 was 278, of which 188 storms directly landed in Vietnam, 13 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 small, 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 (MONRE, 2016).

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 completely identify 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 about 20%.

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 forecasted to have a higher frequency in the future.

Table 3-4. Storms in the Southern Vietnam (1988 – 2019)

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**
13	USAGI	13/11/2018	26/11/2018	11	60	Ho Chi Minh City

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

(Source: Vietnam Center of Hydro-meteorological data, Storm Surveys in Vietnam)

3.2.2.6 Drought

In phase 2, drought was also defined by the number of years that the water balance factor K in the dry season is greater than 4. The analysis of updated climate data from 1988 to 2019 showed that the number of drought events occurring at the Rach Gia Station was still 13, but the corresponding frequency reduced slightly to 40.6%, instead of 43% as in phase 1.

However, the trend line showed that the dry season has been getting more intense. This is being shown clearly in recent years in the Mekong Delta in general, Kien Giang in particular. For instance, the dry season of 2015-2016 is considered the most severe in the past 100 years. Recently, in the dry season of 2019-2020, the drought situation in the Mekong Delta and Kien Giang was even more severe.

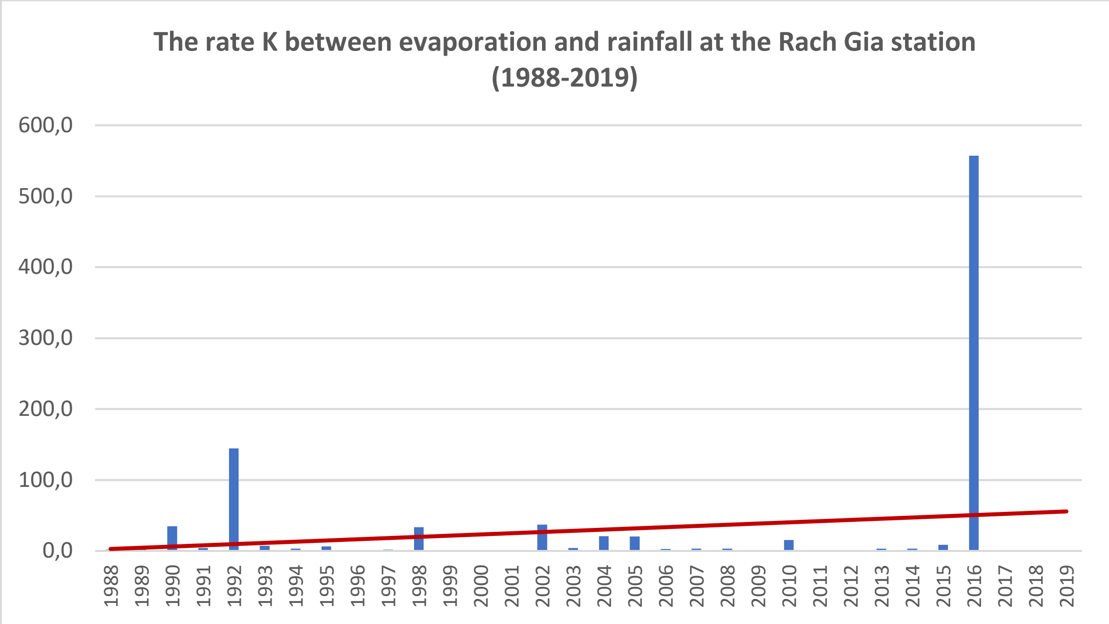


Figure 3-11. The rate K between evaporation and rainfall at the Rach Gia station from December to April

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. The analysis from the CCHIP tool showed that rainfall in the dry season (from December to March) is almost unchanged, while for April and May it tends to decrease (ref. Figure 3-6). The evaporation capacity will increase throughout the year (ref. Figure 3-7). The water balance K for the RCP8.5 scenario also shows that the rainfall is much smaller than the evaporation in the dry season (ref. Figure 3-8). In short, drought events are anticipated to become more severe in the future in Kien Giang.

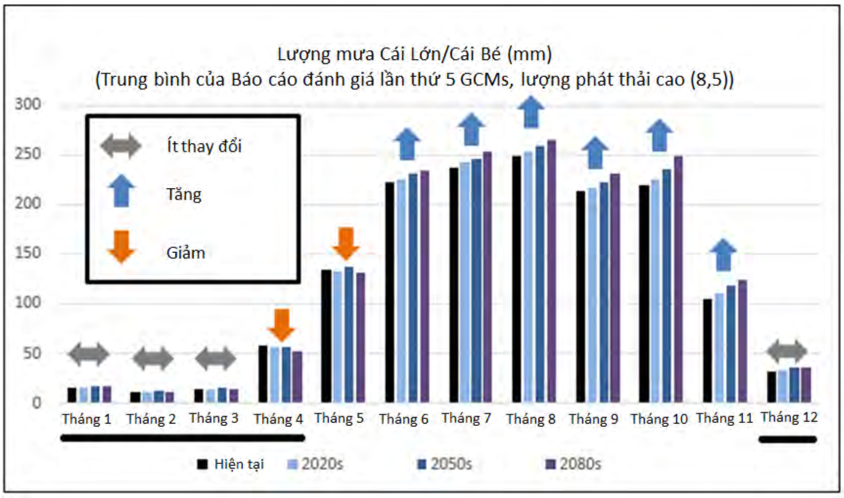


Figure 3-12. Forecast of rainfall (mm) for the RCP8.5 scenario

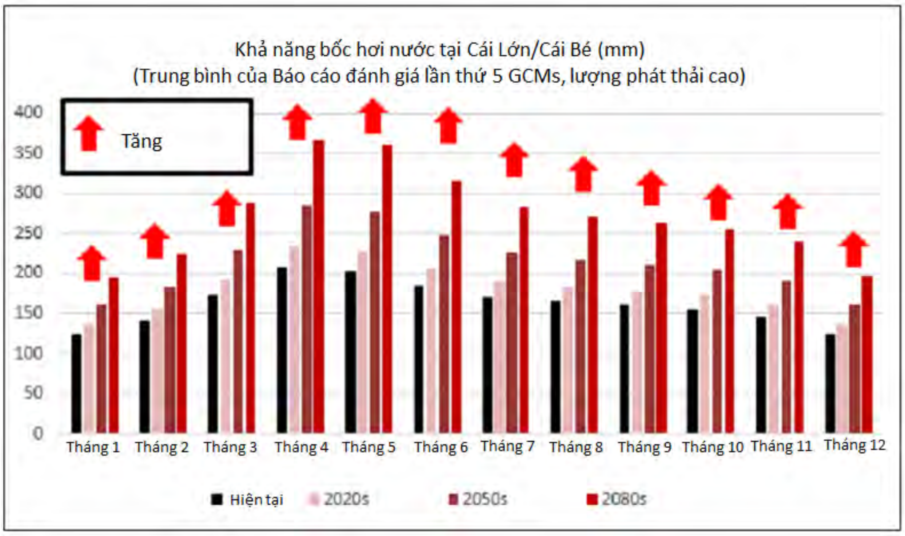


Figure 3-13. Forecast of evaporation (mm) for the RCP8.5 scenario

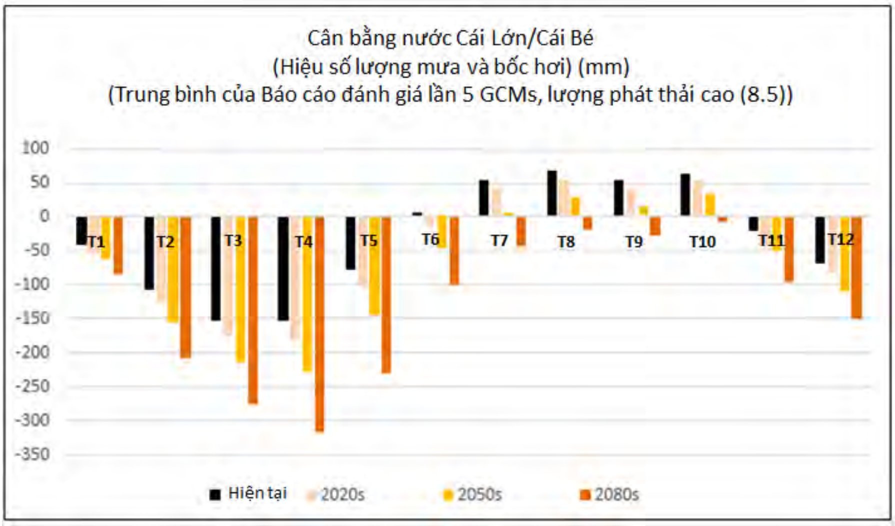


Figure 3-14. Forecast of the difference between rainfall and evaporation (mm) for the RCP8.5 scenario

3.2.2.7 High wind

There was a total of 12 days (approximately 0.4 days/year) with the high wind at the Rach Gia station for the period of 1988-2017. During 2018-2019, there was no day with high wind more than 20 m/s in this area. As a result, the number of days with the high wind in the period of 1988-2019 slightly decreased to 0.375 days/year.

The distribution of days with the high wind at the Rach Gia station was mainly concentrated in the period of 1995-2006 (ref. Figure 3-9). The number of days with the high wind tended to decrease in this area. However, the statistical data showed that the number of days with gusts (≥ 20m/s) in Rach Gia in recent years tends to increase. According to the report of MONRE (2016), there is no forecast for the frequency of high winds in the future in the study area.

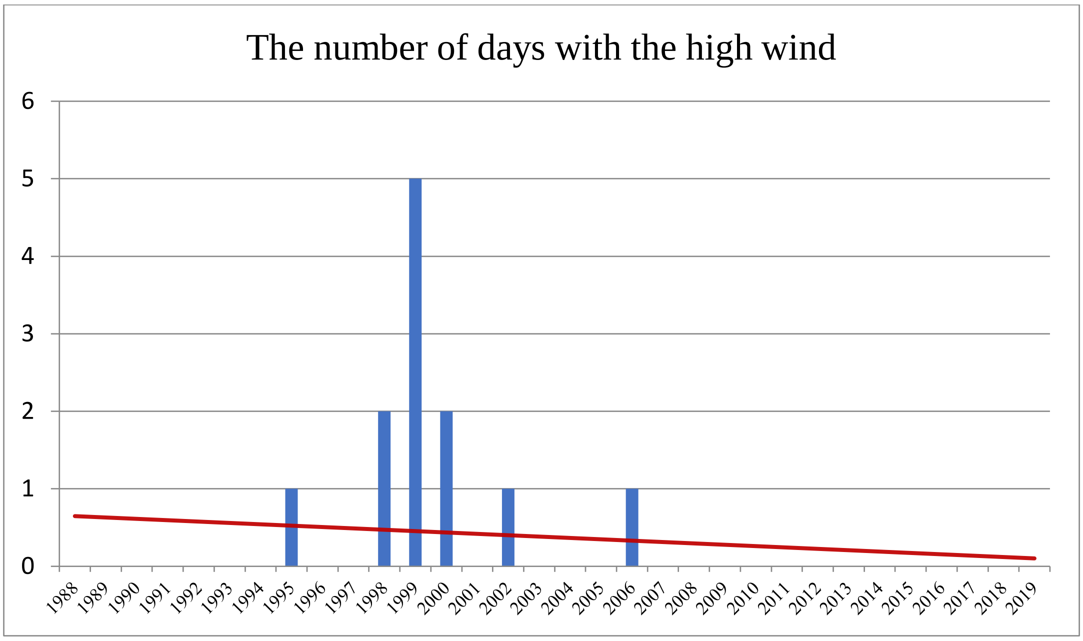


Figure 3-15. The number of days with the high wind at the Rach Gia station in the period of 1988-2019

3.2.2.8 Tornado

In this phase, the average number of tornadoes in a given year is based on the recorded damages from the tornadoes in the report of the Provincial Committee for Flood and Storm Control, and Search and Rescue of Kien Giang. According to the statistical data on the damages caused by tornadoes in the period of 2005 - 2015, tornadoes occurred almost every year in Kien Giang, at least 1-2 tornadoes recorded in a year.

As the data of tornadoes have been collected too little, it is difficult to assess the trend of this phenomenon in the past. According to the report of MONRE (2016), there is no consideration on the future trend of tornadoes. However, under the impacts of climate change, the intensity of the tornadoes is expected to be stronger.

3.2.2.9 Thunderstorm/lightning

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. Thunderstorm/lightning mainly occurred in the rainy season and in the period of transition between the seasons. In the period from 1988 – 2019, there were about 98.5 days with thunderstorms per year in Kien Giang, increasing 2.5 days compared with the corresponding value in Phase 1 (96 days).

In 2018, 162 days of thunderstorm were recorded as the highest in a 32-year analysis data series. The number of thunderstorm days has had a slightly increasing trend over the past 32 years (ref. Figure 3-10).

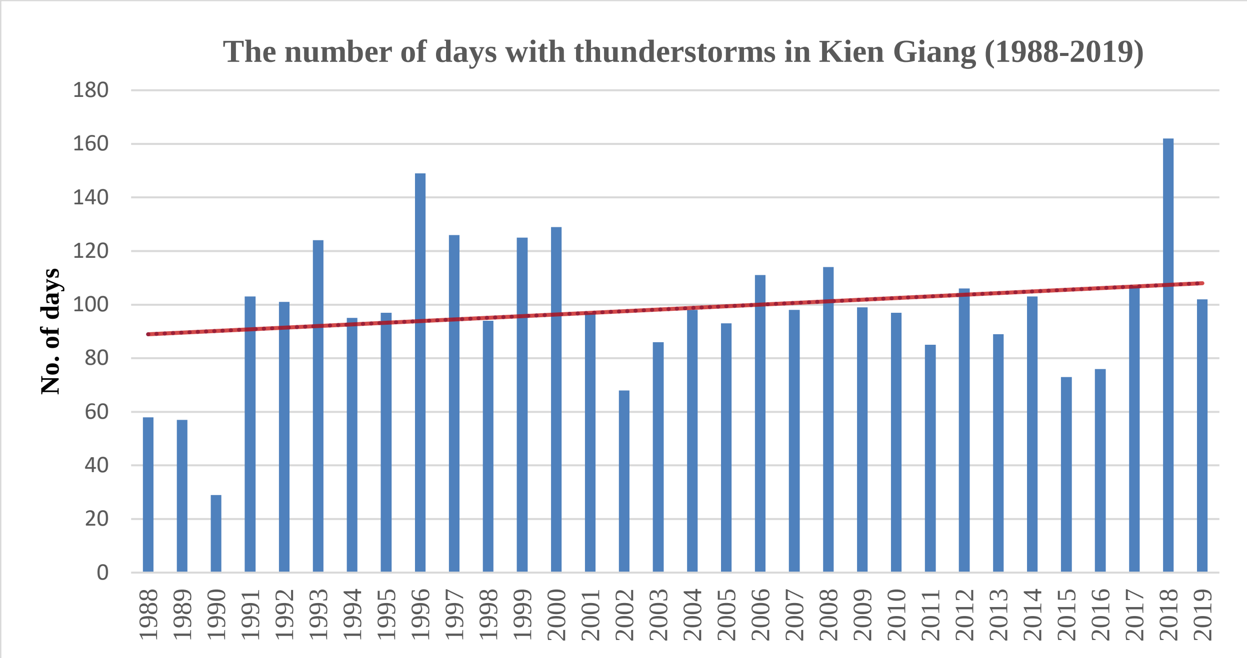


Figure 3-16. The number of days with thunderstorms in Kien Giang (1988-2019)

In the context of increasingly unpredictable climate change, the trend of extreme weather events is forecasted to occur more frequently. In addition, the historical data analysis showed that the number of days with thunderstorms tends to increase in Kien Giang. Thus, the future probability score of lightning has been estimated to be "6", increasing by 1 compared to the corresponding values in Phase 1.

3.2.2.10 Water level

In the hydrological data analysis in Phase 1, Xeo Ro is the closest hydrological station to the Cai Lon - Cai Be Sluice Gate project site. In the period of 1988-2019, the maximum water level at this station was 1.05m appeared on July 13, 2018, and the average water level is 0.00m. The corresponding values in Phase 1 were 0.99m and -0.01m, respectively.

However, every year the tidal water level was highest in the last months of the year (from September to December) and was the lowest from April to July (ref. Figure 3-11).

Table 3-5. Statistical characteristics of hourly water levels from 1988 to 2019 (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	0.07	0.26
Xeo Ro	-0.71	-0.19	-0.03	0.17	0.99	0.00	0.25

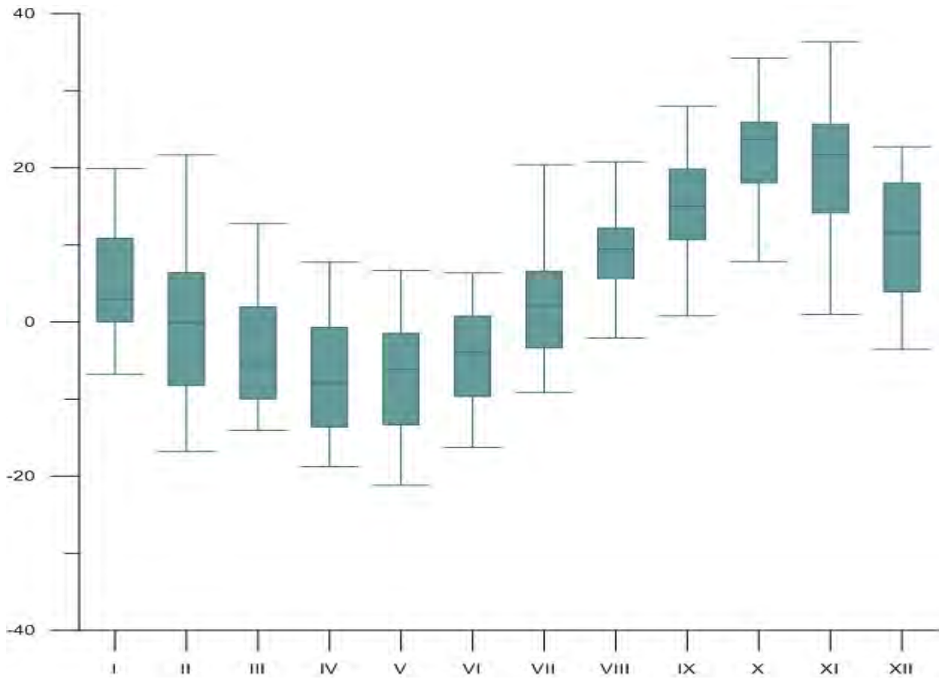


Figure 3-17. Hourly average water levels at Xeo Ro station from 1988 to 2019

The trend analysis at the Xeo Ro station showed that the highest water levels tended to increase in the period from 1988 to 2019. In 2018 and 2019, the recorded highest water levels both exceeded the results calculated in Phase 1 for the period of 1988-2017.

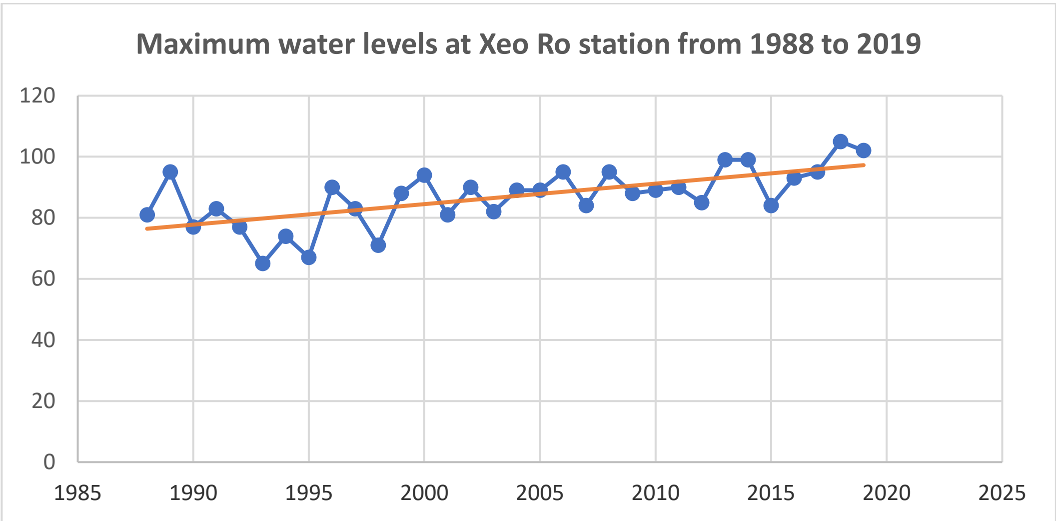


Figure 3-18. Maximum water levels at Xeo Ro station from 1988 to 2019

For the future projections, the changes of water level at the stations in Rach Gia region will continue to use the results of the climate change and sea level rise scenarios for Vietnam (MONRE, 2016) under 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 projection of storm surge is still under Decision No. 2901/QD-BTNMT of the MONRE, in which the maximum storm surge is forecasted to increase to 210 cm for Ca Mau and Kien Giang. Furthermore, 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 3-13).

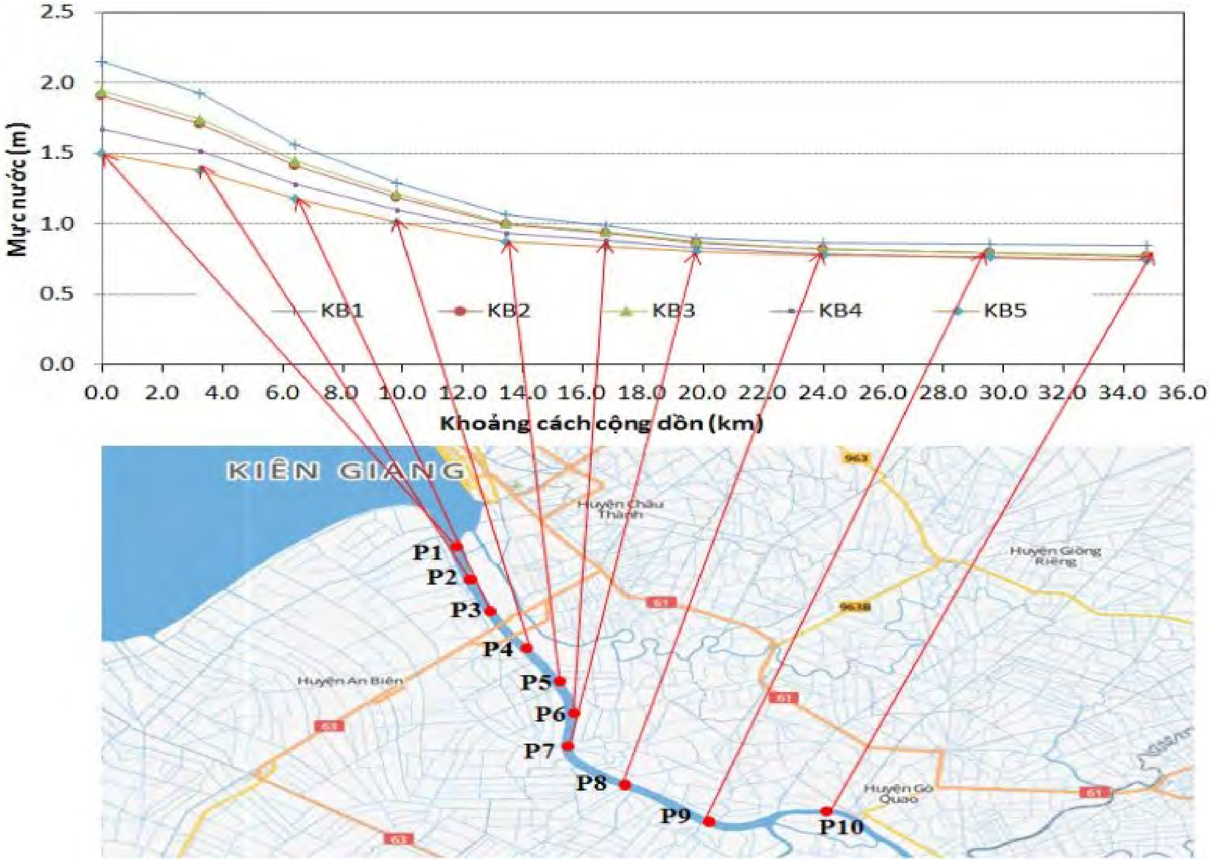


Figure 3-19. Storm surges along Cai Lon river with the assumed trajectory of QD 2

3.2.2.11 Saline intrusion

The analysis of updated saline data in the period of 1996-2019 showed that the maximum salinity value in Xeo Ro station was 31.0g/l, appeared on May 8, 2016, while the average salinity value was about 7.0g/l. In addition, the salinity values did not change much compared with the results of analysis of 1996-2017 saline data in Phase 1. The maximum salinity value was common in April, followed by February and March, and tended to decrease gradually in rainy season.

Table 3-6. Statistical characteristics of hourly salinity concentration ≥ 1 g/l

Station	Lower quartile	Median	Upper quartile	Maximum	Mean	Standard deviation
Xeo Ro	2.7	5.5	10.1	31.0	7.0	5.5

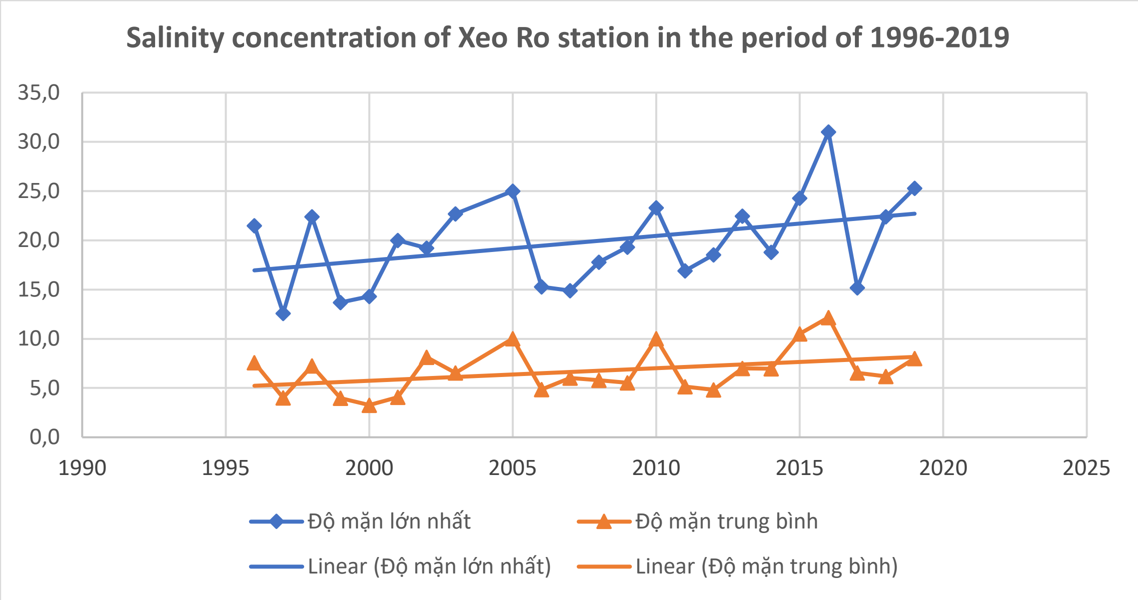


Figure 3-20. Maximum and average annual salinity concentration of Xeo Ro station in the period of 1996-2019

The number of days with salinity ≥ 3g/l, the maximum salinity, and the average salinity all increased in the period of 1996-2019 (Figures 3-14 and 3-15). In general, the trend of salinity intrusion in the dry season is becoming more severe. Thus, the updated PIEVC probability score has been estimated to be "7".

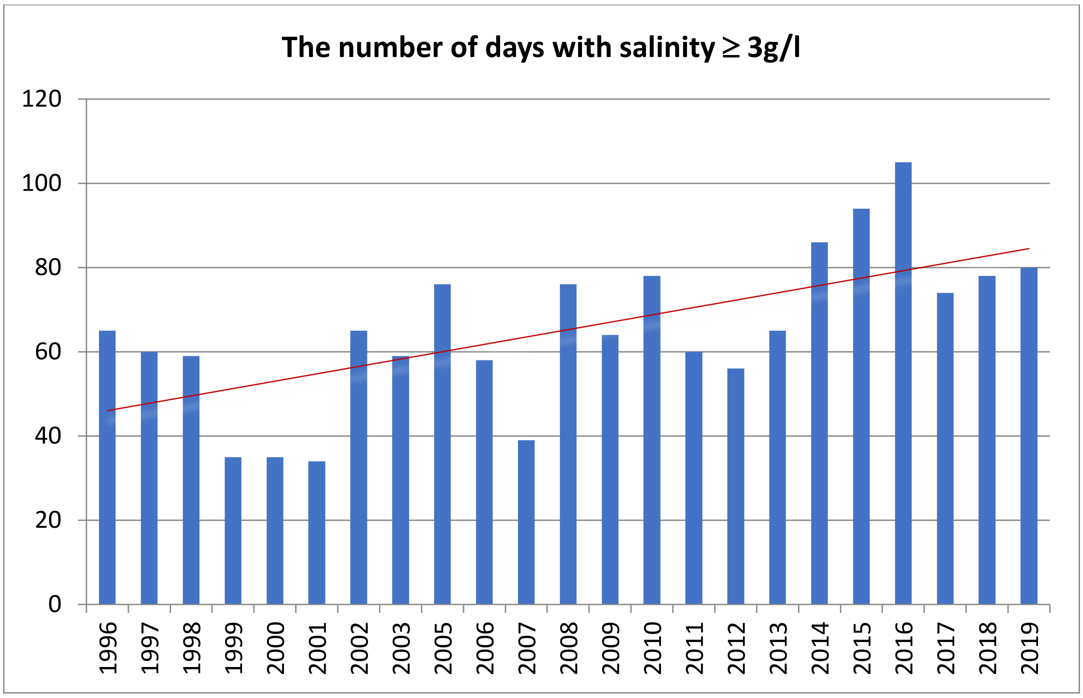


Figure 3-21. The number of days with salinity ≥ 3g/l in the period of 1996-2019

Do đó, điểm tần suất cho mặn hầu như không có sự thay đổi so với giai đoạn 1 là P = 7 (hình 3-28)

Regarding with the projections of salinity intrusion, under the impact of sea level rise combined with the decrease of the upstream flow, salinity intrusion is becoming more extreme in the future (i.e., the higher values and the longer durations), especially in the dry season (ref. Figure 3-16). Therefore, the future probability score of salinity intrusion has been estimated to remain unchanged as “7” as in Phase 1.

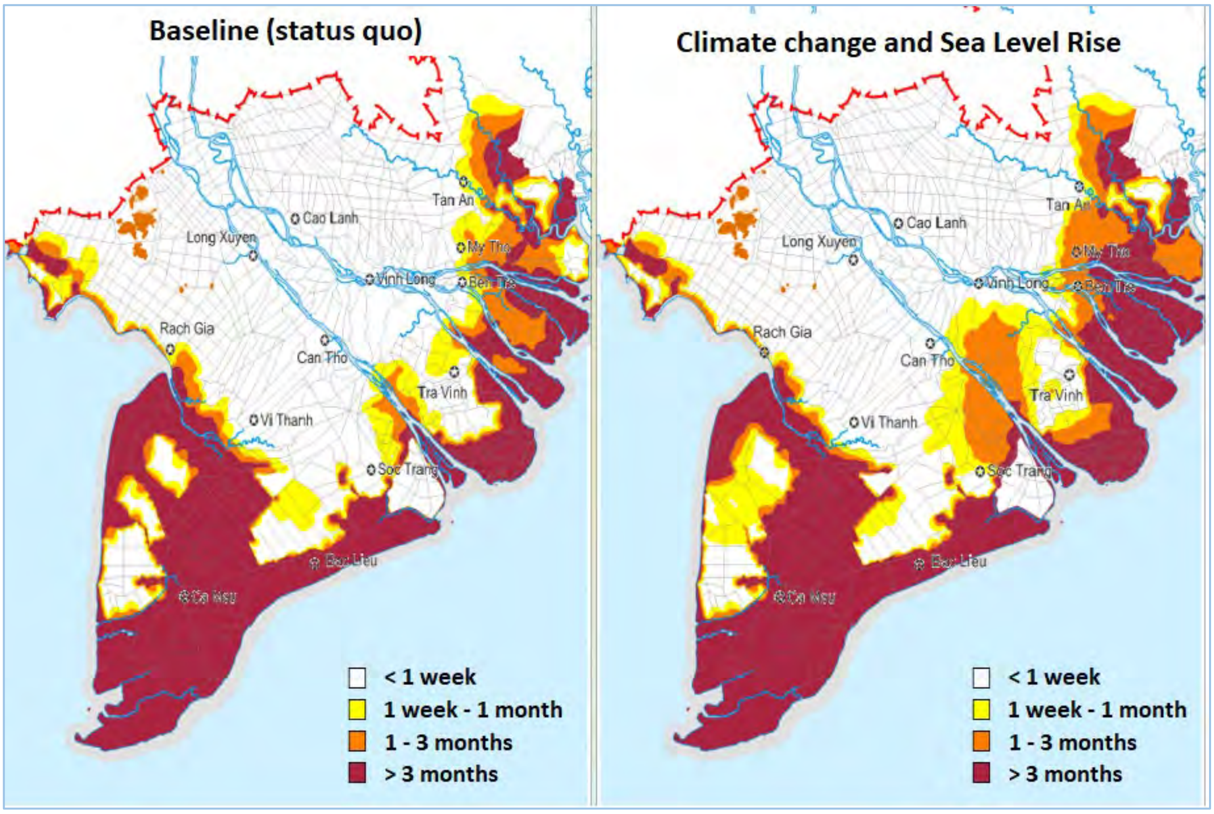


Figure 3-22.Comparison of salinity intrusion between the current condition and sea level rise

3.3 Updated potential cumulative effects

The effect combinations of climate and hydrological elements on the CL-CB sluice gate project proposed in Phase 1 continued to be used in the CRA in Phase 2, 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).

3.3.1 Salinity intrusion combined with high temperature

The 24-year (1996-2019) data analysis showed that the months where both high temperature and the maximum salinity intrusion appeared in a year were from March to May. In this study, salinity intrusion combined with high temperature were determined if these two factors occurred at the same time, in which the high temperature were over 35°C and the salinity concentration was more than 3.0 g/l.

The number of days with average high temperature in the period of 1996-2019 was 7.1 days per year, while the salinity of 3 g/l occurred during the dry season. As a result, the combination of these two factors occurred 2.46 times per year. Thus, the historical probability score in this case has been estimated to be "5".

It is predicted that in the future, the high temperature events will increase in Kien Giang, especially in the late 21st century, and the salinity intrusion will have the increase trend due to sea level rise. 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 in this case has been estimated to be "7", increasing by 2 compared to the results of Phase 1.

3.3.2 High water level combined with heavy rain

High water-level and heavy rain is defined as two occurences of the water level greater than 0.9m and the heavy rain events more than 100mm/day occurred at the same time. The analysis of updated data (1988-2019) showed that the combination between high water level and heavy rain only occurred only once time in August 2006. Therefore, the historical probability score of this combination has been still estimated to be "2" as the results of Phase 1.

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. 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 3.6.3. As such, the frequency of high water-level 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" as the results of Phase 1.

3.4 Updated results of climate risk assessment for CL-CB sluice gates

3.4.1 Probability scores of climate and hydrological factors at Phase 2

The historical and future PIEVC probability scores of each climate and hydrological parameter for the CRA for the CL-CB sluice gate system at Phase 2 are summarised in Table 3-1.

Table 3-7. The PIEVC probability scores for the CL-CB sluice gates at Phase 2

Parameters	Threshold	Unit	Historical probability score	Future probability score
Climate				
High temperature	≥ 35°C	Days/year	6	7

Heat wave	≥ 8 or more consecutive days with the maximum temperature ≥ 35°C	Events/year	3	4
Heavy rain	≥ 100mm in a day	Days/year	4	5
Heavy 5-day total rainfall	≥250mm	Events/year	4	4
Tropical storms/depression	From level 8 (equivalent to the windy speed of 62 - 74km/h) or more	Events/year	3	4
Drought	K ≥ 4 in dry season	Drought events/32 years	5	6
High wind	≥ 20m/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	6
Hydrology				
Water level	0.9 m (design probability 5%)	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°C	Events/year	5	7
High water level + heavy rain	Water level ≥ 0.9m and heavy rain ≥ 100mm/day	Events/year	2	4

3.4.2 Determination of severity scores

The severity scores (S) at the extended phase were determined based on the results of the climate risk assessment at Phase 1 and through expert consultation in different fields (including civil engineering, climate, hydrology, and water resources). Similar to Phase 1, Method E in the PIEVC guidelines is selected to calculate S with the severity scale in Table 2-3.

3.4.2.1 YES/NO analysis

Similar to Phase 1, the YES/NO analysis at the extended phase considered 52 components of Cai Lon - Cai Be Sluice Gate Project, in which 26 infrastructure components need to be determined severity scores due to the effects by climate and hydrological parameters. A summary of the YES/NO analysis is presented as follows:

❖ *Operation and maintenance*

The climate and hydrological factors affect the working process of the operation management staff and the transportation of supplies in the operation and maintenance process

❖ *Sluice gate structure*

Pillar, gate tower and other poured concrete components could be impacted by heat wave, salinity intrusion and erosion due to water level change. The pillar in the technical and construction drawing design is higher than that in the basic design, particularly the T7 pillar increased from 39.0 m to 62.0 m. Hence, it is more vulnerable under the impacts of the climate factors.

❖ *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 wave, salinity intrusion and water level. In the technical and construction drawing design, the number of ship locks of Cai Lon sluice are reduced from 2 to 1. In addition, the Cai Lon ship lock is moved close to the bank embankment, so the lock is more stable, as well as safer for the ships to anchor and go back and forth when heavy rain or storms occur.

❖ *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.

In addition, the form of the gate of the ship lock are changed from “X-shaped” in the basic design to “I-shaped” in the technical and construction drawing design. This change can be convenient for the infrastructure operation by hydraulic cylinder system.

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.

❖ *Bridge*

The bridge pier and beam are affected by climate and hydrological factors in the similar way to the pillar. The impacts on the lighting 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 impact on the bridge surface/slope.

❖ *Retaining walls and connected embankment*

Retaining walls, connected embankment and rip-rap may be eroded or damaged (directly or indirectly) due to heat wave, drought and fluctuation of water level. Furthermore, salinity intrusion may cause chemical corrosion of the reinforced concrete components.

❖ *Operation houses*

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

❖ *Park*

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

❖ *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.

❖ *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.

❖ *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, tornado, thunderstorms, and salinity intrusion.

❖ *Communication system*

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

3.4.2.2 Severity determination

Under the PIEVC guidelines, the rules for determining the severity scores of the components of CL-CB Sluice Gate at the extended phase under the impacts of climate and hydrological factors include:

- Design standards and regulations for the CL-CB Sluice Gate Project at the extended phase (i.e., the stage of technical design and construction drawings);
- The severity scores from the CRA for CL-CB Sluice Gate at Phase 1;
- Characteristics of the CL-CB Sluice Gates at the extended phase;
- Historical data, trends and projections of the climate-hydrological factors;
- Professional judgement of the experts from the different sectors (i.e., civil, climate, hydrology and water resources).

The severity scores for both historical and future conditions is presented in Table 3-8.

Table 3-8. Summary of severity scores for CL-CB Sluice Gate at the extended phase

Components	Breakdown	Climate/ hydrological factors	Historical S	Future S
Operation and maintenance	Staff	High temperature	3	3
		Heat wave	5	6
		Heavy rain	3	4
		Heavy 5-day total rainfall	2	3
		Tropical storm/depression	7	7
		Drought	2	3
		High wind	3	4
		Tornado	6	7
		Thunderstorm/lighting	7	7
	Transportation	Heavy rain	1	2
		Heavy 5-day total rainfall	1	1
		Tropical storm/depression	6	7
		Tornado	6	7
Sluice gate structure	Pillar	Heat wave	2	3
		Water level	1	2
		Salinity	1	2
		Salinity intrusion + high temperature	3	4
		High water level + heavy rain	2	2
	Gate tower	Heat wave	2	3
	Poured concrete components	Heat wave	2	3
		Salinity	1	2
		Salinity intrusion + high temperature	2	3
Ship lock	Lock chamber	Heat wave	1	2
		Water level	3	4
		Salinity	1	2
		Salinity intrusion + high temperature	3	4
		High water level + heavy rain	4	5
	Lock head	Heat wave	1	2
		Water level	3	4
		Salinity	1	2
		Salinity intrusion + high temperature	3	4
		High water level + heavy rain	4	5
	Filling and discharge culverts	Heat wave	1	2
		Salinity	1	2
		Salinity intrusion + high temperature	2	3
	Leading jetty	Heat wave	1	2
		Salinity	1	2
		Salinity intrusion + high temperature	3	4
Gates	Hydraulic Cylinder	Salinity	2	3
		Salinity intrusion + high temperature	3	4
	Sluice gate	Tropical storm/depression	5	6
		High wind	4	5

Components	Breakdown	Climate/ hydrological factors	Historical S	Future S
		Tornado	3	4
		Water level	3	4
		Salinity	2	3
		Salinity intrusion + high temperature	3	4
		High water level + heavy rain	3	4
	Water tight gasket	High temperature	3	3
		Heat wave	5	6
		Salinity	1	2
		Salinity intrusion + high temperature	3	4
Bridge	Bridge surface/slope	Heat wave	3	4
		Heavy rain	1	2
		Tornado	2	2
	Bridge hand rail	Tornado	2	2
Retaining walls and connected embankment	Retaining walls	Heat wave	2	2
		Salinity	1	2
		Salinity intrusion + high temperature	2	3
	Connected embankment	Heat wave	1	2
		Drought	3	4
		Salinity	1	2
		Salinity intrusion + high temperature	2	3
	Rip-rap	Heat wave	1	2
		Salinity	1	2
		Salinity intrusion + high temperature	2	3
Operation houses		Heat wave	1	2
		Heavy rain	2	2
		Tropical storm/depression	2	3
		High wind	1	2
		Tornado	5	6
		Thunderstorm/lighting	1	1
Park		Heat wave	2	3
		Heavy rain	2	2
		Tropical storm/depression	6	7
		Drought	3	4
		High wind	3	4
		Tornado	6	7
		Thunderstorm/lighting	7	7
Power supply	Transmission lines	Heavy rain	1	2
		Tropical storm/depression	4	5
		High wind	3	4
		Tornado	6	7
		Thunderstorm/lighting	7	7
	Voltage transformers	Heavy rain	1	2
		Tropical storm/depression	2	3

Components	Breakdown	Climate/ hydrological factors	Historical S	Future S
		Tornado	2	3
		Thunderstorm/lighting	7	7
	Standby generators	Tornado	2	3
		Thunderstorm/lighting	7	7
Operation and control system	Control system	Tropical storm/depression	7	7
		Thunderstorm/lighting	7	7
	Operation system	Heavy rain	1	2
		Heavy 5-day total rainfall	1	1
		Tropical storm/depression	4	5
		Thunderstorm/lighting	7	7
Monitoring system		Heavy rain	1	2
		Heavy 5-day total rainfall	1	1
		Tropical storm/depression	7	7
		Tornado	6	7
		Thunderstorm/lighting	7	7
Communication system		Heavy rain	1	2
		Heavy 5-day total rainfall	1	1
		Tropical storm/depression	6	7
		High wind	3	4
		Tornado	6	7
		Thunderstorm/lighting	7	7

3.4.3 Risk assessment matrix for CL-CB sluice gate at the extended phase

Silimar to Phase 1, the risk tolerance thresholds for the CRA for CL-CB sluice gate at the extended phase were referenced in Table 2-5. The risk scores for the whole risk matrix of the Cai Lon - Cai Be Sluice Gate at the extended phase was also calculated by Equation (1) (*Appendix 1*). The number of the low, medium and high risks for both existing and future conditions is summarised in Table 3-9.

Table 3-9. 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	8	1
	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	5	1
9-Electric Power	Transmission Lines	2	3	0	1	3	1
	Power Supply	3	1	0	2	1	1
	Standby Generators	1	1	0	1	0	1
10-Control and operation system	Control Systems	0	2	0	0	1	1
	Operation systems	2	2	0	2	1	1
11-Monitoring systems		3	2	0	2	2	1
13-Communication system		3	3	0	2	3	1
Total (for 106 interactions)		64	42	0	30	67	9

The main findings of the risk matrix are as follows:

- Of the 468 interactions that need YES/NO analysis, only 106 interactions were answered "YES" to score the severity of the infrastructure components (see *Appendix 1*).
- Of the above 106 interactions, there were 9 high-risk interactions for future conditions.
- The majority of interactions had a medium risk for future projections (76), while there were only 42 ones for existing conditions (baseline climate).
- The number of low-risk interactions for existing and future conditions were 64 and 30, respectively.
- The medium-risk interactions for existing conditions were mainly affected by tropical storms/depression, thunderstorms/lightning, high wind, water level, and salinity intrusion combined with high temperature. The corresponding variables for future projections were tropical storms/depression, thunderstorms/lightning, tornado and salinity intrusion combined with high temperature.
- The major infrastructure components affected were 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 were also affected under the future conditions.

- There are 91 interactions where the risk scores increase in a comparison of existing and future conditions.
- Some climate factors, such as tropical storms/depression and thunderstorms/lightning, had the average probability scores (from 3 to 5), but had a significant impact (i.e., the severity scores were mainly from 5 to 7) and the increase trend in the future.
- 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).

3.5 Engineering analysis of vulnerable components of CL-CB sluice gates

3.5.1 Determination of infrastructure components of CL-CB sluice gates for engineering analysis

3.5.1.1 Selection criteria

The infrastructure components of CL-CB sluice gates for engineering analysis are selected based on the following criteria:

i. The results of the CRA for Cai Lon - Cai Be sluice gates in Section 2.

ii. The infrastructure components with the medium risk scores [12; 36] as regulated in Table 2-5.

iii. The selected infrastructure components play an important role in the main functions and operation of the CL-CB sluice gate system. If they are damaged, the infrastructures will reduce the functions and even can not continue operating, affecting the lives of people around the project area.

iv. The infrastructure components selected for engineering analysis have been calculated in detail in the documents of construction drawing design.

v. The infrastructure components are made of the materials that are susceptible to climatic conditions.

vi. The selection of the infrastructure components for engineering analysis also bases on the specific characteristics of the CL-CB sluice gate system in terms of the size, structure, and construction method.

The list of infrastructure components of CL-CB sluice gates for engineering analysis is shown in Table 3-10.

Table 3-10. Infrastructure components of CL-CB sluice gates for engineering analysis

No.	Main components	Breakdown	Climate and hydrological factors	Risk scores	
				Current	Future
1	Sluice gate structure	Pillar	Water level (0.9m)	7	14
			Salinity intrusion + high temperature	15	21
2	Ship lock	Lock head	Water level (0.9m)	21	28
			Salinity intrusion + high temperature	15	21
		Filling and discharge culverts	Salinity intrusion + high temperature	10	21
		Leading jetty	Salinity intrusion + high temperature	15	21
3	Gates	Sluice gate – ship lock gate	Water level (0.9m)	21	28
			Salinity intrusion + high temperature	15	21
4	Bridge	Bridge surface/slope	Heat wave	9	16

3.5.1.2 Technical standards and regulations for designing hydraulic structures in Vietnam

Currently, the design of hydraulic structures in Vietnam is basically in accordance with QCVN 04-05: 2012/BNNPTNT, National Technical Regulation on hydraulic structures - the basic stipulation for design. Under this regulation, some main technical criteria related to the CL-CB irrigation project include:

- Classification of hydraulic structures: Based on irrigated area or natural drainage area;
- Design criteria for guaranteed service level of hydraulic structures;
- Main design criteria for flow;
- Main design indicators on climate;
- Rules on the applied load on structures;
- Rules on load combination to be applied to structures;
- Rules on safety factor in design;

Other regulations for designing hydraulic structures in Vietnam are listed as follows:

- Law No. 08/2017/QH14 on irrigation passed by the 14th National Assembly of Vietnam at the 3rd meeting session on 19th June 2017;
- Decree No. 46/2015/ND-CP dated 12 May 2015 of the Government on quality control and maintenance of construction works;

- National Technical Regulation QCVN 03: 2012/BXD on Rules of Classifications and Grading of Civil and Industrial Buildings and Urban Infrastructures;
- National Technical Regulation QCVN 02-2009/BXD on data of natural conditions used in construction;
- National Technical Standard TCVN 10400-2015: Hydraulic structures - Pillar dam - Technical requirements for design;
- TCVN 10304-2014: Pile Foundation - Design Standard;
- TCVN 9346-2012: Structure of concrete and reinforced concrete - Requirements of protection against corrosion in the marine environment;
- TCVN 9139-2012: Hydraulic structures - Concrete and reinforced concrete structures in coastal areas - Technical specifications.

3.5.2 Pillar

3.5.2.1 Impacts of storms

Since 1988, many storms (up to level 13) have occurred in the study area, such as Typhoon Muifa on November 13, 2004. However, the pillar in the design document was calculated with a Level 9 storm (see Appendix 2 for details). Therefore, it is necessary to pay attention when operating during storm, particularly for the high pillars with the peak elevation up to + 63.50m. In addition, the ratio of wind pressure between level 12 and level 9 is 1.51 (times), causing a relatively large eccentricity of the foundation stress.

The horizontal forces such as wind, water pressure, and wave can affect the construction stability (displacement, deviation, instability, etc.). In case of the water level rise of 75cm (by 2100) due to climate change, the horizontal force is estimated to increase by about 985.09 / 689.36 = 1.42 (times), while the vertical load to the infrastructures has no significant change.

3.5.2.2 Impacts of water level

The water level used in the current design is from 1988 to 2017. The highest water level over the years is + 0.99m, which appeared in 2014. However, according to actual measured data, water levels in recent years often appear higher, at + 1.05m, + 1.02m and + 1.20m in 2018, 2019 and 2020 respectively.

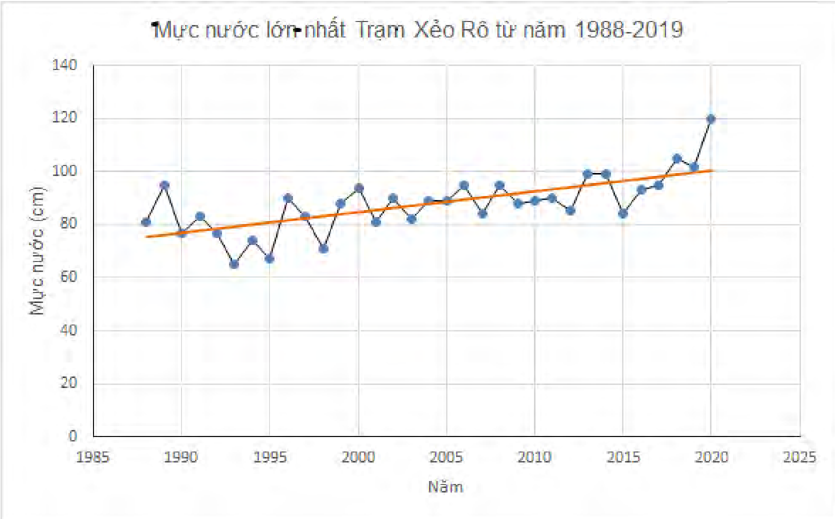


Figure 3-23. Maximum water level at Xeo Ro station from 1988 to 2020

The frequency of the maximum water level is 0.2% based on the data series of from 1988 to 2020. The corresponding maximum water level Hmax is 131.19cm, which is higher 13.19cm than the maximum designed water level.

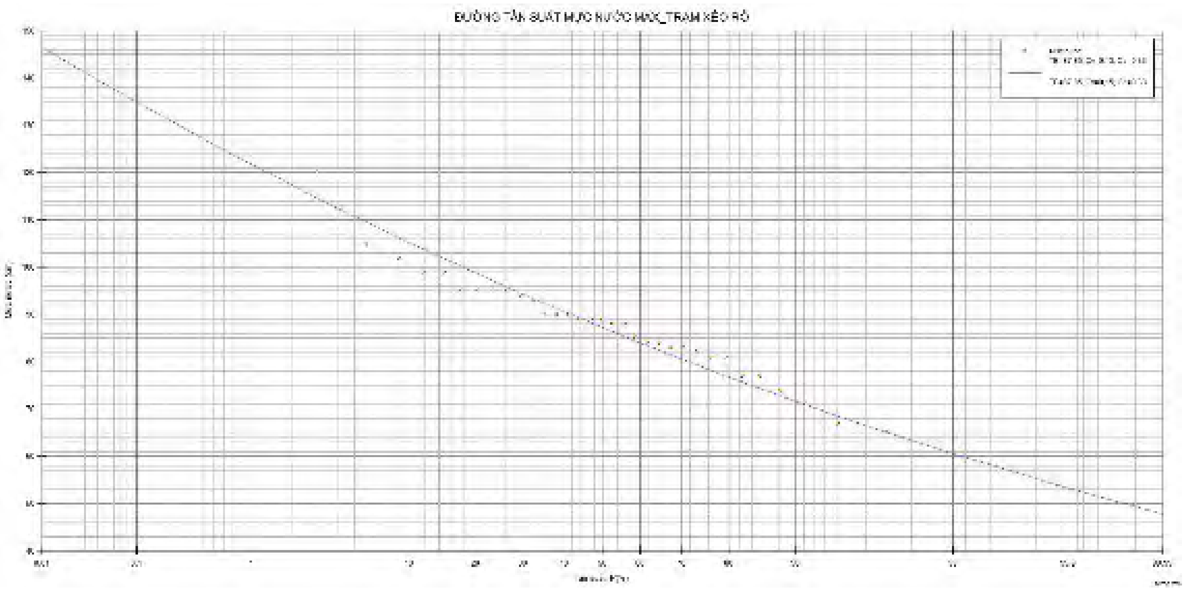


Figure 3-24. Frequency line of water level at Xeo Ro station from 1988 to 2020

3.5.2.3 Combined effects of high temperature and saline intrusion

The design lifespan of the pillar of Cai Lon - Cai Be sluices is 70-100 years. The pillar is mainly made of reinforced concrete M400 (compressive strength of the cube of 150x150x150 mm after 28 days is 40Mpa), the bearing reinforcement layer h is 100 mm.

The lifespan of the infrastructure gradually decreases over time due to the influence of erosion and corrosion on the reinforced concrete. According to Nguyen et al. (2018), two main causes of reinforcement corrosion in concrete include carbonation and chlorine ion intrusion. Carbonation phenomenon is the reaction between atmospheric CO2 and the alkaline components of the concrete, resulting in reducing the amount of OH-ions in the pore solution of concrete, and so the pH of this solution closes to neutralization level. Chlorine ion intrusion phenomenon occurs mainly for reinforced concrete structures in marine environment. When the concentration of chloride ion penetrating into the concrete reaches the corrosive concentration threshold, it will break down the oxide layer and cause corrosion of the reinforcement. In short, the lifespan of the infrastructure (end of corrosion propagation) due to carbonation is calculated by the following formula:

$$t_{sd} = \frac{(h-10)^2}{K_{Ca}^2} + 6\ (years)$$

In which:

t_{sd}: lifespan (end of corrosion propagation).

h: thickness of the concrete layer to protect the reinforcement.

K_{ca}^2: Carbonation coefficient of the environment.

6 years: propagation time of corrosion.

Using the above formula for M400 concrete with a protective layer thickness of 70mm ÷ 100mm, the lifespan of the infrastructure is about 90 ÷ 100 years for working conditions in seawater environment (Table 3-2).

Table 3-11. Projected lifespan of the infrastructures based on the carbonation coefficient of concrete (30-40Mpa, thickness of protection layer from 50mm ÷ 100mm)

Type of concrete	$R_{compressive}$ (Mpa)	K_{ca} (mm/ year$^{0.5}$)	t_{sd} - lifespan (year)		
			h =50mm	h =70mm	h =100mm
M400	40	6.53	43	90	195

The study of Nguyen et al. (2018), showed that the lifespan of infrastructure based on chlorine ion intrusion is calculated by the following formula:

$$t_{bđ} = \left[\frac{(h-\Delta h)^2}{4.D_{28}.k_c.k_e.t_{28}^m\left(erf^{-1}.\left(1-\frac{C_{CR}}{C_S}\right)\right)}\right]^{\frac{1}{1-m}}$$

In which:

C_{CR} - Critical chlorine concentration for corrosion.

C_S - Chlorine concentration of the concrete surface.

t_{28} = 28 days= 0.0767 year.

k_e - coefficient considers the exposure environment (marine environment k_e = 0.68).

k_c - coefficient considers the curing condition of the concrete, k_c = 0.79 – 1.00,

h - protective layer thickness of concrete.

Δh - tolerance of protective layer thickness of concrete.

Erf^{-1} - Inverse function of error function.

m = 0.23, coefficient for ordinary cement concrete.

The research results show that the lifespan of concrete with strength from 25Mpa to 30Mpa and thickness from 50mm to 120mm is from 35 to 70 years (Figure 3-1).

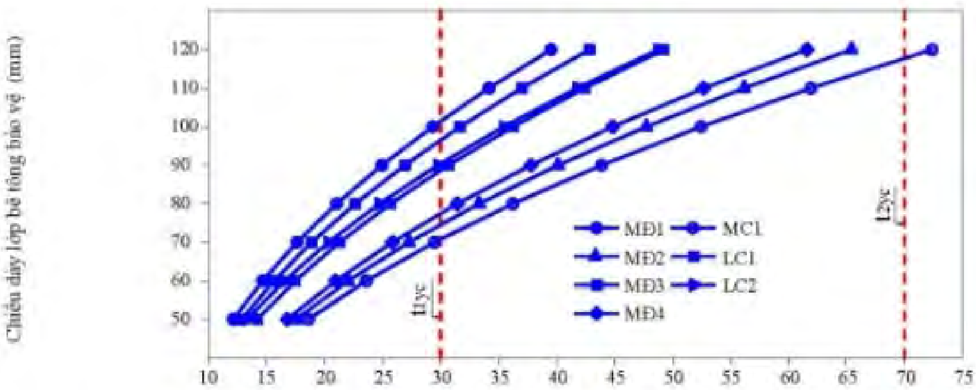


Figure 3-25. The relationship between the lifespan and the concrete protective layer thickness for the coastal reinforced concrete structures due to ion intrusion

In general, as it is designed with B30 (M400) concrete, the concrete protective layer thickness of 100 mm, and sulfated durable cement, the pillar of CL-CB sluice gates is able to mitigate erosion phenomenon (carnonation and chlorine ion intrusion), and thus ensuring the lifespan of the infrastructure is 70 to 100 years.

3.5.3 Ship lock

3.5.3.1 Combined effects of high temperature and saline intrusion

Similar to the pillar, the main components of the ship lock (such as lock head and lock chamber) are made of reinforced concrete M400 with a protective layer thickness of 100 mm. Therefore, the design of the ship lock is suitable for the lifespan of 70-100 years as it can minimize erosion phenomenon (carnonation and chlorine ion intrusion) under combined effects of high temperature and saline intrusion. However, the lock chamber is influenced by waterway traffic, while the lock head is affected by flow and water pressure during the operation of the gates.

3.5.4 Sluice and ship lock gates

The gates of the CL-CB sluices are the lift gate type, i.e., they can move up and down vertically along hydraulic cylinders. They are made of high-strength low-alloy steel (code S355JR) and coated by electrostatic paint to prevent rust for the structure.

The gate structure has a large width, so it cannot be fully manufactured at the factory. Instead, the gates consist of separated components which are assembled at the construction site. As a result, the gates may be affected by a corrosive environment during assembly.

The valve gates are the main structural part of the sluices, and heavily impacted by climate factors such as water level, storm, salinity intrusion and high temperature. Therefore, they are exposed to the risks of climate conditions and the objective factors of materials, manufacture, and installation at present and future.

3.5.5 Bridge

The bridge pier is made of reinforced concrete M400 with a protective layer thickness of 100 mm. Similar to the pillar structure, the bridge pier is designed to ensure a lifespan of 70-100 years.

3.5.6 Calculation of loads and capacity

3.5.6.1 Loads

Loads (from climate and hydrological factors) on the infrastructure are calculated based on the current regulations on design.

1/. The water pressure on the structure:

+ Hydrostatic pressure: $Hs = (1/2) \times H^2 \times B \times \gamma_n$ – Corresponding to the existing loads L_E for water level in Table 3-3.

- H^2: Height under pressure.
- B: Width under pressure.
- γ_n: Specific gravity of water ($1.00 \div 1.05$ g/cm^3).

+ Wave pressure: $Ps = ki \times \rho \times g \times h$ – Corresponding to the climate loads L_C in Table 3-3.

- ki, ρ: Coefficient based on construction design regulations.
- g : Gravitational acceleration (9.81 m/s^2).
- h: Upstream water column height.

2/. The wind pressure on the structure: Corresponding to the existing loads L_E for storms in Table 3-3.

$$W = \gamma \times Wo \times K. \times c$$

- W: wind pressure.
- γ, K, c: Coefficients based on construction design regulations.
- Wo: The standard wind pressure depends on the construction site. Wo = 0.83 (kN/m^2) corresponds to wind pressure of a 9th-level storm, while Wo = 1.26 (kN/m^2) corresponds to wind pressure of a 12th-level storm.

3/. Projected lifespan of the infrastructure: Corresponding to the existing loads L_E for storms Table 3-3, based on the evaluation method of reinforcement corrosion in Section 3.3.

3.5.6.2 Load capacity

Under the impacts of climate factors such as water level and storms, load capacity of the infrastructure, particularly the piles, is mainly horizontal forces. The horizontal load capacity of a pile in the design is 8.50 tons.

The load capacity of the infrastructure under the impacts of salinity intrusion and high temperature depends on the lifespan of the design material.

Table 3-12. Summary of loads and capacity of the infrastructure components

No.	Main components	Climate/ hydrological factors	Risk scores	Performance response	Assessment basis		Horizon	Total Load (L_T)				Total Capacity (C_T)				Vulner-ability Ratio	STEP 5	Adapt-ation Ratio A_R	Capacity Deficit
					Numerical calculation	Engineering judgement / assumption		Existing Load L_E	Climate Load L_C	Other Load L_O	Total Load $L_T = L_E + L_C + L_O$	Existing Capacity C_E	Maturing Capacity C_M	Additional Capacity C_A	Projected Total Capacity $C_T = C_E + C_M + C_A$	$V_R = L_T/C_T$	Y/N	$A_R = C_T / L_T$	$C_D = L_T - C_T$
1	Sluice gate structure	**Water level**	7 ÷ 14	Structural Integrity	X		(m)	L_E	L_C	L_O	L_T	C_E	C_M	C_A	C_T	V_R	Y/N	A_R	C_D
				Serviceability	X		2017	649	-	-	649	1,785	-	-	1,785	0.364	-	2.749	-
				Functionality		X	2050	649	114	-	763	1,785	-	-	1,785	0.428	-	2.338	-
				Operations and Maintenance	X		2100	649	208	-	858	1,785	-	-	1,785	0.480	-	2.082	-
				Emergency Response Risks		X	**Comments / Data sufficiency <Calculated based on pillar T7 – the highest pillar of the infrastructure>** The water level data is calculated based on the Vietnam National technical regulations; max water level with frequency P = 0.2%; min Water level with frequency P = 97%. We consider three cases of water levels, 2017, and 2050 and 2100 under climate change -sea level rise scenarios of MONRE (2016). The sluice gate structure is made of reinforced concrete. However, it is not easy to inspect and maintain them because their working conditions is deep water environment, and high erosion environment. When the work structure has breakdown/damaged, it will impact on the general operation, resulting in the environment, socio-economy of surrounding area.												
				Insurance Considerations		X													
				Policies and Procedures		X													
				Economics	X														
				Public Health and Safety		X													
				Environmental Effects		X													
		Storms	7 ÷ 14	Structural Integrity	X		(km/h)	L_E	L_C	L_O	L_T	C_E	C_M	C_A	C_T	V_R	Y/N	A_R	C_D
				Serviceability	X		2017	229	-	-	229	1,785	-	-	1,785	0.128	-	7.787	-
				Functionality		X	2050	229	380	-	609	1,785	-	-	1,785	0.341	-	2.931	-
				Operations and Maintenance	X		2100	229	380	-	609	1,785	-	-	1,785	0.341	-	2.931	-
				Emergency Response Risks		X	**Comments / Data sufficiency <Calculated based on pillar T7 – the highest pillar of the infrastructure>** Wind calculated in the current design is equivalent to a 9th-level storm. In the future, the wind pressure level in the design will be changed to correspond to a 12th-level storm. The sluice gate structure is made of reinforced concrete. However, it is not easy to inspect and maintain them because their working conditions is deep water environment, and high erosion environment. When the work structure has breakdown/damaged, it will impact on the general operation, resulting in the environment, socio-economy of surrounding area.												
				Insurance Considerations		X													
				Policies and Procedures		X													
				Economics	X														
				Public Health and Safety		X													
				Environmental Effects		X													
		Salinity intrusion + high temperature	12 ÷ 20	Structural Integrity	X		(year)	L_E	L_C	L_O	L_T	C_E	C_M	C_A	C_T	V_R	Y/N	A_R	C_D
				Serviceability	X		2017	100	-	-	100	100	-	-	195	0.513	-	1.950	-
				Functionality		X	2050	100	-	-	100	100	-	-	100	1.000	-	1.000	-
				Operations and Maintenance	X		2100	100	-	-	100	75	-	-	75	1.333	-	0.750	25.0
				Emergency Response Risks		X	**Comments / Data sufficiency <Calculated based on pillar T7 – the highest pillar of the infrastructure>** The lifespan of the infrastructure gradually decreases over time due to the influence of corrosion on the reinforced concrete, in which two main causes include carbonation and chlorine ion intrusion.												
				Insurance Considerations		X													
				Policies and Procedures		X													
				Economics	X														

No.	Main components	Climate/ hydrological factors	Risk scores	Performance response	Assessment basis		Horizon	Total Load (L_T)				Total Capacity (C_T)				Vulner-ability Ratio	STEP 5	Adapt-ation Ratio A_R	Capacity Deficit
					Numerical calculation	Engineering judgement / assumption		Existing Load L_E	Climate Load L_C	Other Load L_O	Total Load L_T = L_E + L_C + L_O	Existing Capacity C_E	Maturing Capacity C_M	Additional Capacity C_A	Projected Total Capacity C_T = C_E + C_M + C_A	V_R = L_T/C_T	Y/N	A_R = C_T / L_T	C_D = L_T - C_T
				Public Health and Safety		X													
				Environmental Effects		X													
2	Ship lock																		
	Lock Head	Water level	21 ÷ 28	Structural Integrity	X		(m)	L_E	L_C	L_O	L_T	C_E	C_M	C_A	C_T	V_R	Y/N	A_R	C_D
				Serviceability	X		2017	288	-	-	288	748	-	-	748	0.385	-	2.594	-
				Functionality		X	2050	288	78	-	366	748	-	-	748	0.490	-	2.043	-
				Operations and Maintenance	X		2100	288	130	-	418	748	-	-	748	0.559	-	1.788	-
				Emergency Response Risks		X	**Comments / Data sufficiency** The water level data is calculated based on the Vietnam National technical regulations; max water level with frequency P = 0.2%; min Water level with frequency P = 97%. We consider three cases of water levels, 2017, and 2050 and 2100 under climate change -sea level rise scenarios of MONRE (2016). The lock head is made of reinforced concrete. However, it is not easy to inspect and maintain them because their working conditions is deep water environment, and high erosion environment. When the work structure has breakdown/damaged, it will impact on the general operation, resulting in the environment, socio-economy of surrounding area.												
				Insurance Considerations		X													
				Policies and Procedures		X													
				Economics	X														
				Public Health and Safety		X													
				Environmental Effects		X													
		Salinity intrusion + high temperature	12 ÷ 20	Structural Integrity	X		(year)	L_E	L_C	L_O	L_T	C_E	C_M	C_A	C_T	V_R	Y/N	A_R	C_D
				Serviceability	X		2017	100	-	-	100	100	-	-	195	0.513	-	1.950	-
				Functionality		X	2050	100	-	-	100	100	-	-	100	1.000	-	1.000	-
				Operations and Maintenance	X		2100	100	-	-	100	75	-	-	75	1.333	-	0.750	25.0
				Emergency Response Risks		X	**Comments / Data sufficiency** The lifespan of the infrastructure gradually decreases over time due to the influence of corrosion on the reinforced concrete, in which two main causes include carbonation and chlorine ion intrusion.												
				Insurance Considerations		X													
				Policies and Procedures		X													
				Economics	X														
				Public Health and Safety		X													
				Environmental Effects		X													
	Filling and discharge culverts	**Salinity intrusion + high temperature**	21 ÷ 28	Structural Integrity	X		(year)	L_E	L_C	L_O	L_T	C_E	C_M	C_A	C_T	V_R	Y/N	A_R	C_D
				Serviceability	X		2017	30	-	-	30	30	-	-	30	1.000	-	1.000	-
				Functionality		X	2050	30	-	-	30	30	-	-	30	1.000	-	1.000	-
				Operations and Maintenance	X		2100	30	-	-	30	20	-	-	20	1.500	-	0.667	10.0
				Emergency Response Risks		X	**Comments / Data sufficiency** The filling and discharge culverts work in aggressive environment (marine environment) combined with increased salinity and temperature, resulting in the increase of oxidation and rust, and so the decrease of infrastructure lifespan												
				Insurance Considerations		X													
				Policies and Procedures		X													
				Economics	X														

No.	Main components	Climate/ hydrological factors	Risk scores	Performance response	Assessment basis		Horizon	Total Load (L_T)				Total Capacity (C_T)				Vulner-ability Ratio	STEP 5	Adapt-ation Ratio A_R	Capacity Deficit
					Numerical calculation	Engineering judgement / assumption		Existing Load L_E	Climate Load L_C	Other Load L_O	Total Load L_T = L_E + L_C + L_O	Existing Capacity C_E	Maturing Capacity C_M	Additional Capacity C_A	Projected Total Capacity C_T = C_E + C_M + C_A	V_R = L_T/C_T	Y/N	A_R = C_T / L_T	C_D = L_T - C_T
				Public Health and Safety		X													
				Environmental Effects		X													
	Leading jetty	**Salinity intrusion + high temperature**	12 ÷ 20	Structural Integrity	X		(year)	L_E	L_C	L_O	L_T	C_E	C_M	C_A	C_T	V_R	Y/N	A_R	C_D
				Serviceability	X		2017	100	-	-	100	100	-	-	195	0.513	-	1.950	-
				Functionality		X	2050	100	-	-	100	100	-	-	100	1.000	-	1.000	-
				Operations and Maintenance	X		2100	100	-	-	100	75	-	-	75	1.333	-	0.750	25.0
				Emergency Response Risks		X	**Comments / Data sufficiency** The lifespan of the infrastructure gradually decreases over time due to the influence of corrosion on the reinforced concrete, in which two main causes include carbonation and chlorine ion intrusion.												
				Insurance Considerations		X													
				Policies and Procedures		X													
				Economics	X														
				Public Health and Safety		X													
				Environmental Effects		X													
3	Sluice and ship lock gates																		
	Hydraulic Cylinder	**Salinity intrusion + high temperature**	14 ÷ 21	Structural Integrity	X		(year)	L_E	L_C	L_O	L_T	C_E	C_M	C_A	C_T	V_R	Y/N	A_R	C_D
				Serviceability	X		2017	30	-	-	30	30	-	-	30	1.000	-	1.000	-
				Functionality		X	2050	30	-	-	30	30	-	-	30	1.000	-	1.000	-
				Operations and Maintenance	X		2100	30	-	-	30	20	-	-	20	1.500	-	0.667	10.0
				Emergency Response Risks		X	**Comments / Data sufficiency** The hydraulic cylinders work in aggressive environment (marine environment) combined with increased salinity and temperature, resulting in the increase of oxidation and rust, and so the decrease of infrastructure lifespan												
				Insurance Considerations		X													
				Policies and Procedures		X													
				Economics	X														
				Public Health and Safety		X													
				Environmental Effects		X													
		Water level	14 ÷ 21	Structural Integrity	X		(m)	L_E	L_C	L_O	L_T	C_E	C_M	C_A	C_T	V_R	Y/N	A_R	C_D
				Serviceability	X		2017	195	-	-	195	380	-	-	380	0.513	-	1.951	-
				Functionality		X	2050	195	120	-	315	380	-	-	380	0.828	-	1.208	-
				Operations and Maintenance	X		2100	195	134	-	329	380	-	-	380	0.865	-	1.156	-
				Emergency Response Risks		X	**Comments / Data sufficiency** The water level data is calculated based on the Vietnam National technical regulations; max water level with frequency P = 0.2%; min Water level with frequency P = 97%. We consider three cases of water levels, 2017, and 2050 and 2100 under climate change -sea level rise scenarios of MONRE (2016).												
				Insurance Considerations		X													
				Policies and Procedures		X													
				Economics	X														

No.	Main components	Climate/ hydrological factors	Risk scores	Performance response	Assessment basis		Horizon	Total Load (L_T)				Total Capacity (C_T)				Vulner-ability Ratio	STEP 5	Adapt-ation Ratio A_R	Capacity Deficit
					Numerical calculation	Engineering judgement / assumption		Existing Load L_E	Climate Load L_C	Other Load L_O	Total Load $L_T = L_E + L_C + L_O$	Existing Capacity C_E	Maturing Capacity C_M	Additional Capacity C_A	Projected Total Capacity $C_T = C_E + C_M + C_A$	$V_R = L_T/C_T$	Y/N	$A_R = C_T / L_T$	$C_D = L_T - C_T$
				Public Health and Safety		X	When the hydraulic cylinder is damaged, the infrastructure cannot be operated, greatly affecting the environment, socio-economy and the life of the people in the project area. In addition, it will also affect the safety and stability of the infrastructure because of the increased load.												
				Environmental Effects		X													
	Valve gates	**Water level**	21 ÷ 28	Structural Integrity	X		(m)	L_E	L_C	L_O	L_T	C_E	C_M	C_A	C_T	V_R	Y/N	A_R	C_D
				Serviceability	X		2017	617	-	-	617	800	-	-	800	0.771	-	1.297	-
				Functionality		X	2050	617	108	-	725	800	-	-	800	0.906	-	1.103	-
				Operations and Maintenance	X		2100	617	198	-	815	800	-	-	800	1.018	-	0.982	14.7
				Emergency Response Risks		X	**<u>Comments / Data sufficiency</u>** The water level data is calculated based on the Vietnam National technical regulations; max water level with frequency P = 0.2%; min Water level with frequency P = 97%. We consider three cases of water levels, 2017, and 2050 and 2100 under climate change -sea level rise scenarios of MONRE (2016).												
				Insurance Considerations		X													
				Policies and Procedures		X													
				Economics	X														
				Public Health and Safety		X													
				Environmental Effects		X													
		Salinity intrusion + high temperature	14 ÷ 21	Structural Integrity	X		(year)	L_E	L_C	L_O	L_T	C_E	C_M	C_A	C_T	V_R	Y/N	A_R	C_D
				Serviceability	X		2017	30	-	-	30	30	-	-	30	1.000	-	1.000	-
				Functionality		X	2050	30	-	-	30	30	-	-	30	1.000	-	1.000	-
				Operations and Maintenance	X		2100	30	-	-	30	20	-	-	20	1.500	-	0.667	10.0
				Emergency Response Risks		X	**<u>Comments / Data sufficiency</u>** The gates work in aggressive environment (marine environment) combined with increased salinity and temperature, resulting in the increase of oxidation and rust, and so the decrease of infrastructure lifespan.												
				Insurance Considerations		X													
				Policies and Procedures		X													
				Economics	X														
				Public Health and Safety		X													
				Environmental Effects		X													
4	Bridge																		
	Bridge surface/slope	**Salinity intrusion + high temperature**	12 ÷ 20	Structural Integrity	X		(year)	L_E	L_C	L_O	L_T	C_E	C_M	C_A	C_T	V_R	Y/N	A_R	C_D
				Serviceability	X		2017	100	-	-	100	100	-	-	195	0.513	-	1.950	-
				Functionality		X	2050	100	-	-	100	100	-	-	100	1.000	-	1.000	-
				Operations and Maintenance	X		2100	100	-	-	100	75	-	-	75	1.333	-	0.750	25.0
				Emergency Response Risks		X	**<u>Comments / Data sufficiency</u>** The lifespan of the infrastructure gradually decreases over time due to the influence of corrosion on the reinforced concrete, in which two main causes include carbonation and chlorine ion intrusion.												
				Insurance Considerations		X													
				Policies and Procedures		X													
				Economics	X														

No.	Main components	Climate/ hydrological factors	Risk scores	Performance response	Assessment basis		Horizon	Total Load (L_T)				Total Capacity (C_T)				Vulner-ability Ratio	STEP 5	Adapt-ation Ratio A_R	Capacity Deficit
					Numerical calculation	Engineering judgement / assumption		Existing Load L_E	Climate Load L_C	Other Load L_O	Total Load $L_T = L_E + L_C + L_O$	Existing Capacity C_E	Maturing Capacity C_M	Additional Capacity C_A	Projected Total Capacity $C_T = C_E + C_M + C_A$	$V_R = L_T/C_T$	Y/N	$A_R = C_T / L_T$	$C_D = L_T - C_T$
				Public Health and Safety		X													
				Environmental Effects		X													
		Storms	7 ÷ 14	Structural Integrity	X		(km/h)	L_E	L_C	L_O	L_T	C_E	C_M	C_A	C_T	V_R	Y/N	A_R	C_D
				Serviceability	X		2017	95	-	-	95	1,785	-	-	1,785	0.053	-	18.825	-
				Functionality		X	2050	95	157	-	252	1,785	-	-	1,785	0.141	-	7.086	-
				Operations and Maintenance	X		2100	95	157	-	252	1,785	-	-	1,785	0.141	-	7.086	-
				Emergency Response Risks		X	**<u>Comments / Data sufficiency</u>** Wind calculated in the current design is equivalent to a 9th-level storm. In the future, the wind pressure level in the design will be changed to correspond to a 12th-level storm.												
				Insurance Considerations		X													
				Policies and Procedures		X													
				Economics	X														
				Public Health and Safety		X													
				Environmental Effects		X													
	Bridge bearing (rubber + wire mesh)																		
		Salinity intrusion + high temperature	14 ÷ 21	Structural Integrity	X		(year)	L_E	L_C	L_O	L_T	C_E	C_M	C_A	C_T	V_R	Y/N	A_R	C_D
				Serviceability	X		2017	30	-	-	30	30	-	-	30	1.000	-	1.000	-
				Functionality		X	2050	30	-	-	30	30	-	-	30	1.000	-	1.000	-
				Operations and Maintenance	X		2100	30	-	-	30	20	-	-	20	1.500	-	0.667	10.0
				Emergency Response Risks		X	**<u>Comments / Data sufficiency</u>** The bridge bearing works in aggressive environment (marine environment) combined with increased salinity and temperature, resulting in the increase of oxidation and rust, and so the decrease of infrastructure lifespan.												
				Insurance Considerations		X													
				Policies and Procedures		X													
				Economics	X														
				Public Health and Safety		X													
				Environmental Effects		X													
		Storms	14 ÷ 28	Structural Integrity	X		(km/h)	L_E	L_C	L_O	L_T	C_E	C_M	C_A	C_T	V_R	Y/N	A_R	C_D
				Serviceability	X		2017	24	-	-	24	143	-	-	143	0.166	-	6.033	-
				Functionality		X	2050	24	39	-	63	143	-	-	143	0.440	-	2.271	-
				Operations aad Maintenance	X		2100	24	39	-	63	143	-	-	143	0.440	-	2.271	-
				Emergency Response Risks		X	**<u>Comments / Data sufficiency</u>** Wind calculated in the current design is equivalent to a 9th-level storm. In the future, the wind pressure level in the design will be changed to correspond to a 12th-level storm.												
				Insurance Considerations		X													
				Policies and Procedures		X													
				Economics	X														

No.	Main components	Climate/ hydrological factors	Risk scores	Performance response	Assessment basis		Horizon	Total Load (L_T)				Total Capacity (C_T)				Vulner-ability Ratio	STEP 5	Adapt-ation Ratio A_R	Capacity Deficit
					Numerical calculation	Engineering judgement / assumption		Existing Load L_E	Climate Load L_C	Other Load L_O	Total Load $L_T = L_E + L_C + L_O$	Existing Capacity C_E	Maturing Capacity C_M	Additional Capacity C_A	Projected Total Capacity $C_T = C_E + C_M + C_A$	$V_R = L_T/C_T$	Y/N	$A_R = C_T / L_T$	$C_D = L_T - C_T$
				Public Health and Safety		X	The bridge bearing is made of reinforced concrete. However, it is not easy to inspect and maintain them because their working conditions is wet and high erosion environment. When the work structure has breakdown/damaged, it will impact on the general operation, resulting in the environment, socio-economy of surrounding area.												
				Environmental Effects		X													

3.6 Recommendations

In addition to the recommendations proposed in phase 1, some additional recommendations for the extended phase are summarized below.

3.6.1 Gates

3.6.1.1 For materials used to making gates

The main material of the gates is high-strength low-alloy steel with code S355JR, coated with anti-rust paint. This is a relatively suitable solution to mitigate the reduction of gate lifespan. However, in the process of manufacture and installation of the gates, it is necessary to consider the following recommendations:

- As the gates consist of separated components and will be assembled at the construction site, joint welding positions need to be properly treated and coated to against rust;
- Boreholes for mounting bolts or associated with the operating equipment have small diameters, so their inside edges need to be covered with anti-rust paint;

The ship lock gate is made of steel which is relatively resistant to rust. This material is of good quality and has been tested with many infrastructures over the past 15 to 20 years (according to actual survey data on the sluice gate system along the West Sea in Kien Giang province). Therefore, it is a relatively suitable selection for the ship lock gates of CL-CB sluice gates to prolong the lifespan, especially when they frequently work in seawater environment.

3.6.1.2 For operation

- Closely inspect and control the waterway transports capable of impacting the gates (if any) during the gate operation to keep freshwater or prevent the salinity intrusion.

Due to the relatively large width of the gate (B = 14m ÷ 15m), the required thrust of the hydraulic cylinder (when closed) is quite large. Therefore, during operation, it is necessary to strictly comply with the following requirements: (i) The designed operating speed does not increase the load beyond the design limit; (ii) Control boats to avoid colliding with structures; iii /. Regularly check the operating range of the gate, make sure it is not stuck during operation.

3.6.1.3 For maintenance

Regularly check the gate, carry out periodic maintenance, promptly repair the damage of the gate (if any) in order not to reduce the bearing capacity of the structure and not to let rust spread to other positions.

3.6.1.4 For water tight gasket

The watertight gasket is made of rubber, so rubber peeling will occur for a long time. Therefore, it is necessary to regularly check, promptly repair and replace it to ensure watertight, and limit additional load due to friction during operation.

3.6.2 Pillar

- Regularly inspect and repair to minimize damage to the protective concrete layer and reinforcement, due to carbonation and chloride-ion intrusion.

- Carry out studies to assess carbonate and chlorine ion intrusion phenomena for reinforced concrete structures in the project area (i.e., coastal area of Kien Giang province) to propose the forecast of the lifespan of infrastructures such as CL-CB sluice gates.

- After being put into service for about 6-8 years, CL-CB sluice gates can occur corrosion propagation of reinforced concrete structures. Thus, it is necessary to carry out surveys and studies on the corrosion phenomenon (due to carbonation and chlorine ion intrusion) of the reinforced concrete structure, to recommend suitable solutions for increasing the lifespan of the infrastructure.

3.6.3 Ship lock

- Regularly check and promptly repair the damage (if any) to ensure safety, stability and lifespan of the ship lock as designed.

- The anti-collision cushion for the ship lock should be made of natural or synthetic rubber with added ingredients such as carbon black N330, to increase resistance to aging and corrosion in the marine environment. The bearing capacity of the material (tensile strength, elongation) after aging should not be less than 80% compared to the material without aging.

3.6.4 Operation of the infrastructure

- The load due to the wind on the infrastructure is relatively large due to the high pillars. Therefore, during storms, the sluice gates operate only if absolutely necessary. In addition, it is necessary to minimize the wind shield area of the pillar; for instance, do not open the gates (or hang the gates). After storms or floods, check and monitor the stability and displacement of the pillars to take measures to handle (if any), to ensure stability and safety for the infrastructure.

- The water level has been changing (an increase of about $\Delta H = 13.19$cm) during the construction of the infrastructure. This increase is currently within the design limit (an increase due to climate change is $\Delta H = 75$cm). However, changes in water level tend to be higher, and frequency of occurrence is increasing. Therefore, in the future (until 2100), when the sluice gates are put into operation, it is necessary to monitor and update hydrological data (water level). If the maximum water level exceeds the design limit, promptly take measures to handle to ensure the lifespan of the infrastructure (70 ÷ 100 years) as designed.

- The current climate (2020) has a more unfavorable trend compared to the period before 2017. Therefore, in the process of building the operation regulations, it is necessary to update climate factors such as rain and water level in the period of 2018 ÷ 2020.

- During operation, it is necessary to monitor the displacement (horizontal and vertical) of the infrastructure to control the eccentricity caused by horizontal loads, and control the displacement between the pillars. This will help the safe operation of the gates (i.e., no gate jam or damage).

4 CONCLUSION

Báo cáo này đã tiến hành cập nhật đánh giá rủi ro khí hậu cho hệ thống cống Cái Lớn - Cái Bé bằng phương pháp kỹ thuật PIEVC. Quá trình cập nhật bao gồm việc đánh giá các thay đổi trong thiết kế hiện tại (tức là thiết kế kỹ thuật và thiết kế bản vẽ thi công) so với thiết kế cơ sở, và cập nhật phân tích xu thế lịch sử và dự báo tương lai cho các yếu tố khí hậu. Từ đó, cập nhật ma trận rủi ro khí hậu thể hiện sự tương tác giữa các yếu tố khí hậu với các thành phần công trình cũng như sự vận hành của hệ thống cống Cái Lớn - Cái Bé.

Khác với giai đoạn 1, đánh giá ở giai đoạn mở rộng này đã thực hiện tất cả 5 bước trong phương pháp PIEVC, tức là bao gồm cả việc phân tích kỹ thuật ở Bước 4. Thực tế, các phân tích kỹ thuật đã giúp cho việc định lượng một số tương tác như quá trình ăn mòn cốt thép trong bê tông do hiện tượng cacbonat hóa và xâm nhập ion clo. Bên cạnh đó, các tải trọng và khả năng chịu lực của công trình đối với ảnh hưởng của các yếu tố khí hậu tác dụng lên công trình cũng đã được tính toán. Nhờ đó, một số rủi ro tiềm ẩn đối với cống Cái Lớn - Cái Bé đã được phân tích chi tiết để có các khuyến nghị cụ thể nhằm đảm bảo tuổi thọ công trình.

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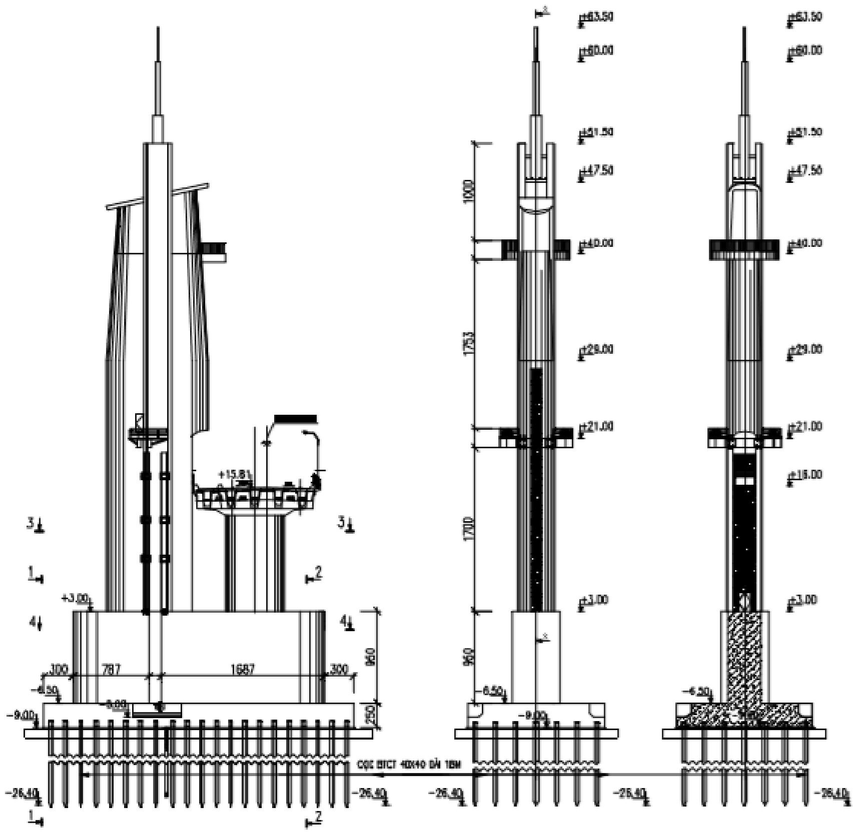
Appendix 1. Risk matrices

Time Period Current to 2020	Climate and Other Variables and Events																																																			
Infrastructure Components	High Temperature >=35oC				Heat Wave (8 consecutive days >=35oC				Heavy Rain / >100mm/day				5-day Total Rain / >=250mm				Tropical Storm/Depression				Drought				High Wind >=20 m/s				Tornado				Thunderstorm/ Lightning				Water Level				Water Salinity				Salinity intrusion combined with high temperature				High water level combined with heavy rain			
	A				B				C				D				E				F				G				H				I				K				L				L				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	Y/N	P	S	R	Y/N	P	S	R
1-Administration																																																				
Personnel	Y	6	3	18	Y	3	5	15	Y	4	3	12	Y	4	2	8	Y	3	7	21	Y	5	2	10	Y	4	3	12	Y	1	6	6	Y	5	7	35																
Transportation (Supplies Delivery)									Y	4	1	4	Y	4	1	4	Y	3	6	18									Y	1	6	6																				
2-Sluice Gate Structure																																																				
Pile foundation																																																				
Waterproof pile foundation																																																				
Pillar footing																																																				
Bottom beam																																																				
Pillar					Y	3	2	6																													Y	7	1	7	Y	7	1	7	Y	5	3	15	Y	2	1	2
Gate tower / Gate hanger					Y	3	2	6																																												
Cast-in-situ concrete composition					Y	3	2	6																																	Y	7	1	7	Y	5	2	10				
3-Ship Lock																																																				
Lock chamber					Y	3	1	3																													Y	7	3	21	Y	7	1	7	Y	5	3	15	Y	2	4	8
Lock head					Y	3	1	3																													Y	7	3	21	Y	7	1	7	Y	5	3	15	Y	2	4	8
Filling and discharge culverts					Y	3	1	3																																	Y	7	1	7	Y	5	2	10				
Leading jetty					Y	3	1	3																																	Y	7	1	7	Y	5	3	15				
4-Gates (large and small)																																																				
Hydraulic Cylinder																																									Y	7	2	14	Y	5	3	15				
Gates (large and small)																	Y	3	5	15					Y	4	4	16	Y	1	3	3					Y	7	3	21	Y	7	2	14	Y	5	3	15	Y	2	3	6
Water tight gasket	Y	6	3	18	Y	3	5	15																																	Y	7	1	7	Y	5	3	15				
5-Bridge																																																				
Bridge Surface					Y	3	3	9	Y	4	1	4																	Y	1	2	2																				
Hand Rail																													Y	1	2	2																				
Lighting System																																																				
Traffic Sign Post																																																				
6-Retaining walls and connected embankments (upstream and downstream of sluice gates)																																																				
Retaining walls					Y	3	2	6																																	Y	7	1	7	Y	5	2	10				
Gabion																																																				
Connected embankments					Y	3	1	3													Y	5	3	15																	Y	7	1	7	Y	5	2	10				
Rip-rap embankments sections					Y	3	1	3																																	Y	7	1	7	Y	5	2	10				
Riverbank																																																				
Stilling basin																																																				
7-Operation house					Y	3	1	3	Y	4	2	8					Y	3	2	6					Y	4	1	4	Y	1	5	5	Y	5	1	5																
8-Park					V	3	2	6	Y	4	2	8					Y	3	6	18	Y	5	3	15	Y	4	3	12	Y	1	6	6	Y	5	7	35																
9-Electric Power																																																				
Transmission Lines									Y	4	1	4					Y	3	4	12					Y	4	3	12	Y	1	6	6	Y	5	7	35																
Power Supply									Y	4	1	4					Y	3	2	6									Y	1	2	2	Y	5	7	35																
Standby Generators																													Y	1	2	2	Y	5	7	35																
10-Control and operation system																																																				
Control Systems																	Y	3	7	21													Y	5	7	35																
Operation systems									Y	4	1	4	Y	4	1	4	Y	3	4	12													Y	5	7	35																
11-Monitoring systems									Y	4	1	4	Y	4	1	4	Y	3	7	21									Y	1	6	6	Y	5	7	35																
12-Fire extinguishing systems																																																				
13-Communication system									Y	4	1	4	Y	4	1	4	Y	3	6	18					Y	4	3	12	Y	1	6	6	Y	5	7	35																

Time Period 2080 - 2099	Climate and Other Variables and Events																																																			
Infrastructure Components	High Temperature >=35oC				Heat Wave (8 consecutive days >=35oC				Heavy Rain / >100mm/day				5-day Total Rain / >=250mm				Tropical Storm/Depression				Drought				High Wind >=20 m/s				Tornado				Thunderstorm/ Lightning				Water Level				Water Salinity				Salinity intrusion combined with high temperature				High water level combined with heavy rain			
	A				B				C				D				E				F				G				H				I				K				L				L				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	Y/N	P	S	R	Y/N	P	S	R
1-Administration																																																				
Personnel	Y	7	3	21	Y	4	6	24	Y	5	4	20	Y	4	3	12	Y	4	7	28	Y	6	3	18	Y	4	4	16	Y	2	7	14	Y	6	7	42																
Transportation (Supplies Delivery)									Y	5	2	10	Y	4	1	4	Y	4	7	28									Y	2	7	14																				
2-Sluice Gate Structure																																																				
Pile foundation																																																				
Waterproof pile foundation																																																				
Pillar footing																																																					
Bottom beam																																																				
Pillar					Y	4	3	12																													Y	7	2	14	Y	7	2	14	Y	7	4	28	Y	4	2	8
Gate tower / Gate hanger					Y	4	2	8																																												
Cast-in-situ concrete composition					Y	4	3	12																																	Y	7	2	14	Y	7	3	21				
3-Ship Lock																																																				
Lock chamber					Y	4	2	8																													Y	7	4	28	Y	7	2	14	Y	7	4	28	Y	4	5	20
Lock head					Y	4	2	8																													Y	7	4	28	Y	7	2	14	Y	7	4	28	Y	4	5	20
Filling and discharge culverts					Y	4	2	8																																	Y	7	2	14	Y	7	3	21				
Leading jetty					Y	4	2	8																																	Y	7	2	14	Y	7	3	21				
4-Gates (large and small)																																																				
Hydraulic Cylinder																																									Y	7	3	21	Y	7	4	28				
Gates (large and small)																	Y	4	6	24					Y	4	5	20	Y	2	4	8					Y	7	4	28	Y	7	3	21	Y	7	4	28	Y	4	4	16
Water tight gasket	Y	7	3	21	Y	4	6	24																																	Y	7	2	14	Y	7	4	28				
5-Bridge																																																				
Bridge Surface					Y	4	4	16	Y	5	2	10																	Y	2	2	4																				
Hand Rail																													Y	2	2	4																				
Lighting System																																																				
Traffic Sign Post																																																				
6-Retaining walls and connected embankments (upstream and downstream of sluice gates)																																																				
Retaining walls					Y	4	2	8																																	Y	7	2	14	Y	7	3	21				
Gabion																																																				
Connected embankments					Y	4	2	8													Y	6	4	24																	Y	7	2	14	Y	7	3	21				
Rip-rap embankments sections					Y	4	2	8																																	Y	7	2	14	Y	7	3	21				
Riverbank																																																				
Stilling basin																																																				
7-Operation house					Y	4	2	8	Y	5	2	10					Y	4	3	12					Y	4	2	8	Y	2	6	12	Y	6	1	6																
8-Park					V	4	3	12	Y	5	2	10					Y	4	7	28	Y	6	4	24	Y	4	4	16	Y	2	7	14	Y	6	7	42																
9-Electric Power																																																				
Transmission Lines									Y	5	2	10					Y	4	5	20					Y	4	4	16	Y	2	7	14	Y	6	7	42																
Power Supply									Y	5	2	10					Y	4	3	12									Y	2	3	6	Y	6	7	42																
Standby Generators																													Y	2	3	6	Y	6	7	42																
10-Control and operation system																																																				
Control Systems																	Y	4	7	28													Y	6	7	42																
Operation systems									Y	5	2	10	Y	4	1	4	Y	4	5	20													Y	6	7	42																
11-Monitoring systems									Y	5	2	10	Y	4	1	4	Y	4	7	28									Y	2	7	14	Y	6	7	42																
12-Fire extinguishing systems																																																				
13-Communication system									Y	5	2	10	Y	4	1	4	Y	4	7	28					Y	4	4	16	Y	2	7	14	Y	6	7	42																

Appendix 2. Engineering analysis for the impacts of climatic factors on the infrastructure (Loads and load capacity of the infrastructure)

The highest pillar (T7) of the Cai Lon Sluice is selected for engineering analysis as shown below.



The typical vertical and horizontal sections of pillar T7 – Cai Lon Sluice

Engineering analysis will be applied for two cases, including (i) Case 1: The sluice gates are closed to prevent saline intrusion, corresponding to water level and climate conditions at the design time (as of 2018); and (ii) Case 2: The sluice gates is closed to prevent saline intrusion, corresponding to water level and climate conditions up to 2100 in the context of climate change and sea level rise. The results from the design documents are summarised in the following table.

No.	Cases	Load (Pillar T7)					Stress	
		N (T)	Qx (T)	Qy (T)	Mx (T.m)	My (T.m)	σ_{max} (T/m^2)	σ_{min} (T/m^2)
1	Case 1	-	-	-	-	-	23.94	14.63
2	Case 2	8640.25	180.61	528.72	4909.81	2714.86		
Pillar foundation: 210 square reinforced concrete piles, M400, cross section (40x40) cm, length of pile L = 23.0m.								

The outputs of engineering analysis are described below, including the comparison with the design and recommendations for the infrastructure.

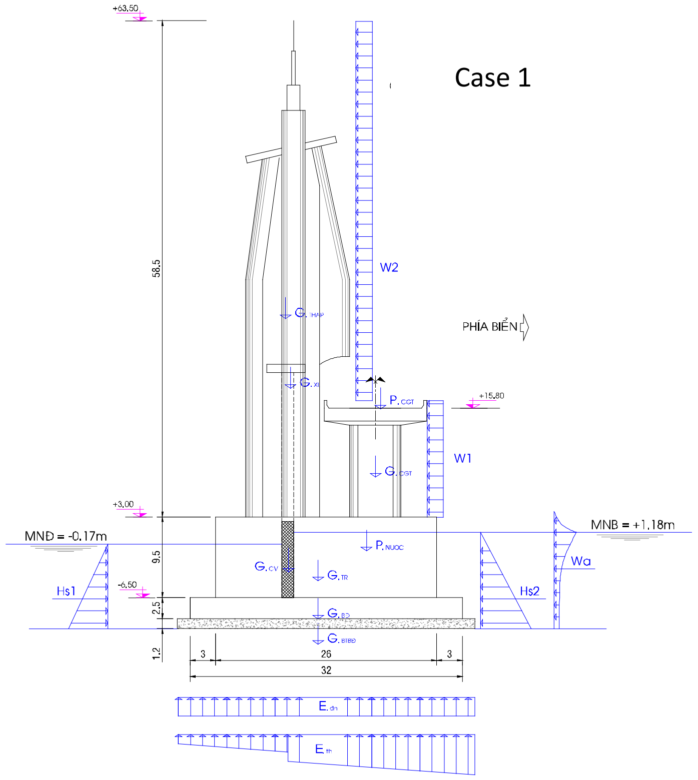


Diagram of loads on the pillar

Load on the infrastructure (ton)				
Direction / Load	Vertically		Horizontally	
	↓	↑	←	→
$G_{BTBĐ}$	1570.8			
$G_{BĐ}$	2800.0			
G_{TR}	2960.0			
G_{Thap}	862.5			
G_{XL}	20.0			
$G_{Mat\ cau}$	673.8			
G_{CGT}	99.2			
P_{CGT}	158.2			
W			40.1	
H_s			2590.0	2012.0
W_a			74.7	
P_{water}	223.2			
Eđn		2619.1		
Eth		302.4		
Gcv	43.9			
Total	6490.1		689.36	

Notes:

1. Weight of footing $G_{BTBĐ}$ = Volume x γ_{bt}
2. Weight of foundation bottom $G_{BĐ}$ = Volume x γ_{bt}
3. Weight of pillar G_{TR} = Volume x γ_{bt}
4. Weight of tower G_{thap} = Volume x γ_{bt}
5. Weight of the cylinder + equipment G_{XL} = 2 x 10 = 20 (ton).
6. Weight of bridge deck = 673.83 (ton)
7. Weight of columns + Bent Cap G_{CGT} = Volume x γ_{bt} = 39.7 x 2.5 = 99.25 (Ton).
8. Active load of bridge: total vertical load 158.2 (ton), moment = 161.5 (ton.m)
9. Wind pressure W = 28.1 (ton), corresponding to a 9^{th}-level storm.
10. Hydrostatic pressure H_s = ½ xΔH x B
11. Wave pressure P_s = ki x r x g x h
12. Water weight P_{water} = ΔH x b x L
13. Floating pressure E_{dn} = volume submerged in water x Δ_{water}
14. Absorption pressure E_{th} = length of permeable line x ΔH
15. Weight of gates + valve beam transmitted to the pillar (according to design calculations)

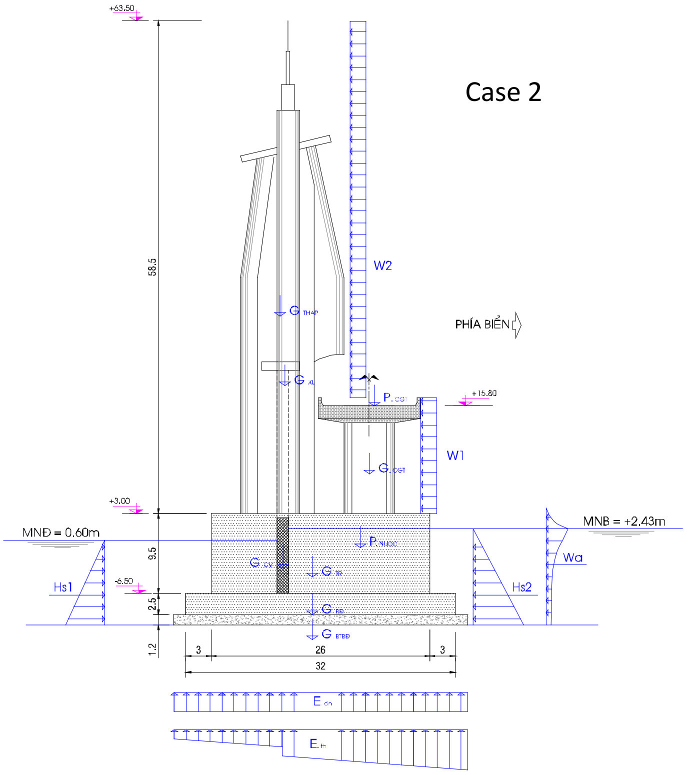


Diagram of loads on the pillar

Load on the infrastructure (ton)				
Direction / Load	Vertically		Horizontally	
	↓	↑	←	→
$G_{BTBĐ}$	1570.8			
$G_{BĐ}$	2800.0			
G_{TR}	2960.0			
G_{Thap}	862.5			
G_{XL}	20.0			
$G_{Mat\ cau}$	673.8			
G_{CGT}	99.2			
P_{CGT}	158.2			
W			40.1	
H_s			3190.3	2332.8
W_a			87.4	
P_{water}	302.6			
Eđn		2718.8		
Eth		409.9		
Gcv	43.9			
Total	6362.29		985.09	

Notes:

1. Weight of footing $G_{BTBĐ}$ = Volume x γ_{bt}
2. Weight of foundation bottom $G_{BĐ}$ = Volume x γ_{bt}
3. Weight of pillar G_{TR} = Volume x γ_{bt}
4. Weight of tower G_{thap} = Volume x γ_{bt}
5. Weight of the cylinder + equipment G_{XL} = 2 x 10 = 20 (ton).
6. Weight of bridge deck = 673.83 (ton)
7. Weight of columns + Bent Cap G_{CGT} = Volume x γ_{bt} = 39.7 x 2.5 = 99.25 (Ton).
8. Active load of bridge: total vertical load 158.2 (ton), moment = 161.5 (ton.m)
9. Wind pressure W = 28.1 (ton), corresponding to a 9th-level storm.
10. Hydrostatic pressure H_s = ½ xΔH x B
11. Wave pressure P_s = ki x r x g x h
12. Water weight P_{water} = ΔH x b x L
13. Floating pressure E_{dn} = volume submerged in water x Δ_{water}
14. Absorption pressure E_{th} = length of permeable line x ΔH
15. Weight of gates + valve beam transmitted to the pillar (according to design calculations)

Foundation bottom stress is tested with wind strength for 9th-level storm (standard wind pressure Wo = 0.83 kN/m^2) and 12th-level storm (standard wind pressure Wo = 1.26 kN/m^2). Wind pressure on the infrastructure is calculated based on the following formula:

$$W = \gamma \times W_o \times k \times c$$

In which:

W – Calculated wind pressure.

W_o – standard wind pressure.

γ – Correlation coefficient

K – Pressure coefficient

c- Aerodynamic coefficients

Symbol	9th-level storm	12th-level storm	Rate	Note
Wo	0.83	1.26		kN/m^2, standard wind pressure.
γ	1.20	1.20		Correlation coefficient
k	1.19	1.19		Pressure coefficient 1.00 - 1.38
c	1.40	1.40		Aerodynamic coefficients including wind catcher + wind away surface
W	1.66	2.52		kN/m^2, Calculated wind pressure
H1	48.50	48.50		(m). Height of pillar under pressure
B1	3.50	3.50		(m). Width of pillar under pressure
H2	1.80	1.80		
B2	40.00	40.00		
S	241.75	241.75		(m^2). Area of pillar under pressure
W_{TT}	401.14	608.97	151.8 %	(kN), Load exerted by wind on the pillar
z_W	37.45	37.45		(m), distance from the force center to the foundation bottom
M	1502.29	2280.58	151.8 %	(ton. M), moment caused by the wind at the foundation center

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