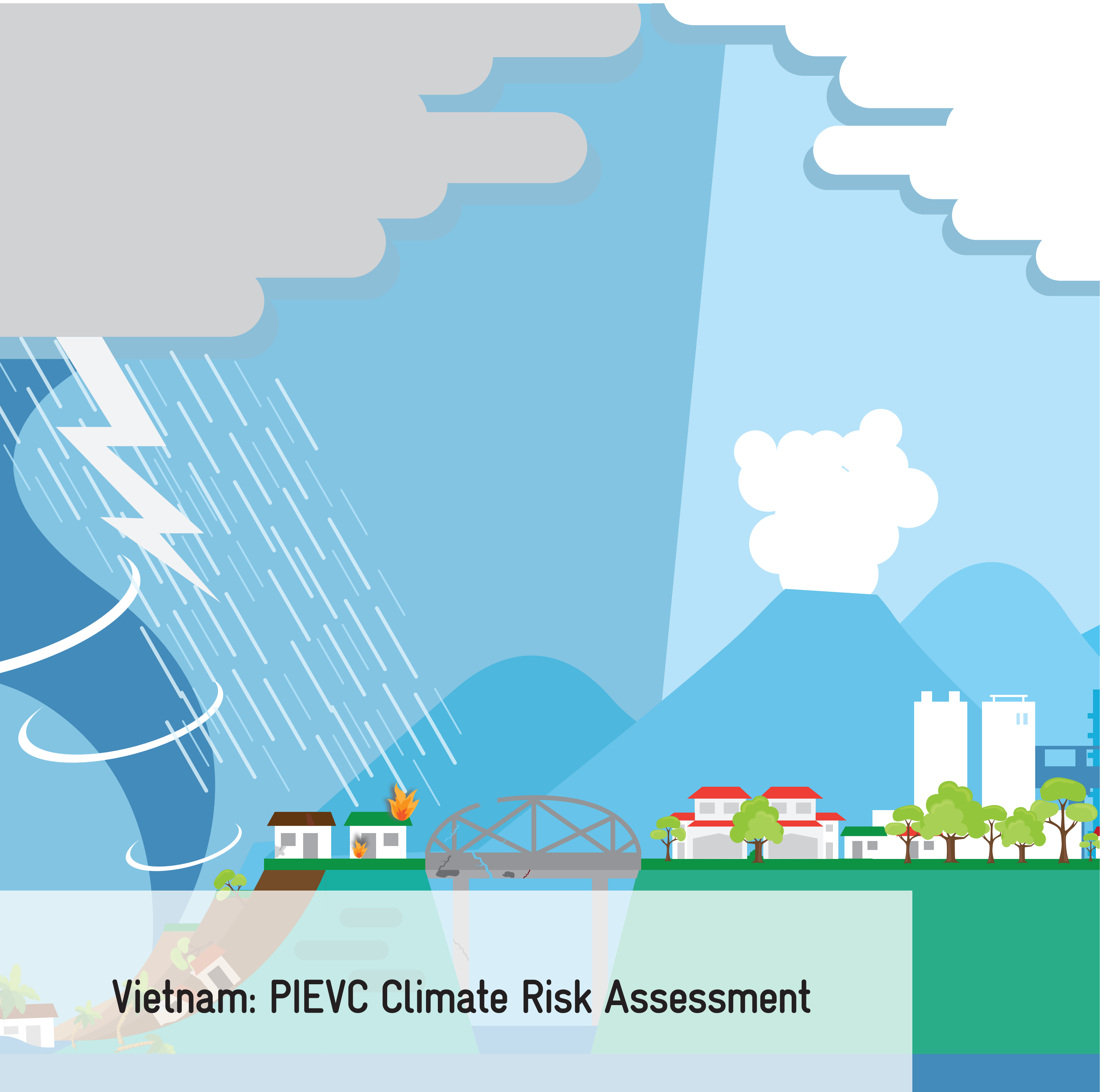

Vietnam: PIEVC Climate Risk Assessment

PIEVC Portfolio-Screening of 83 Sluice Gates in Kien Giang Province Final Report 2021

giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) Gm

On behalf of:

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

of the Federal Republic of Germany

In cooperation with:

CLIMATE RISK INSTITUTE

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On behalf of:
Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection of the Federal Republic of Germany

Eschborn/Bonn 2022

In cooperation with

IMPLEMENTED BY VIETNAM CLIMATE RISK ASSESSMENT TEAM

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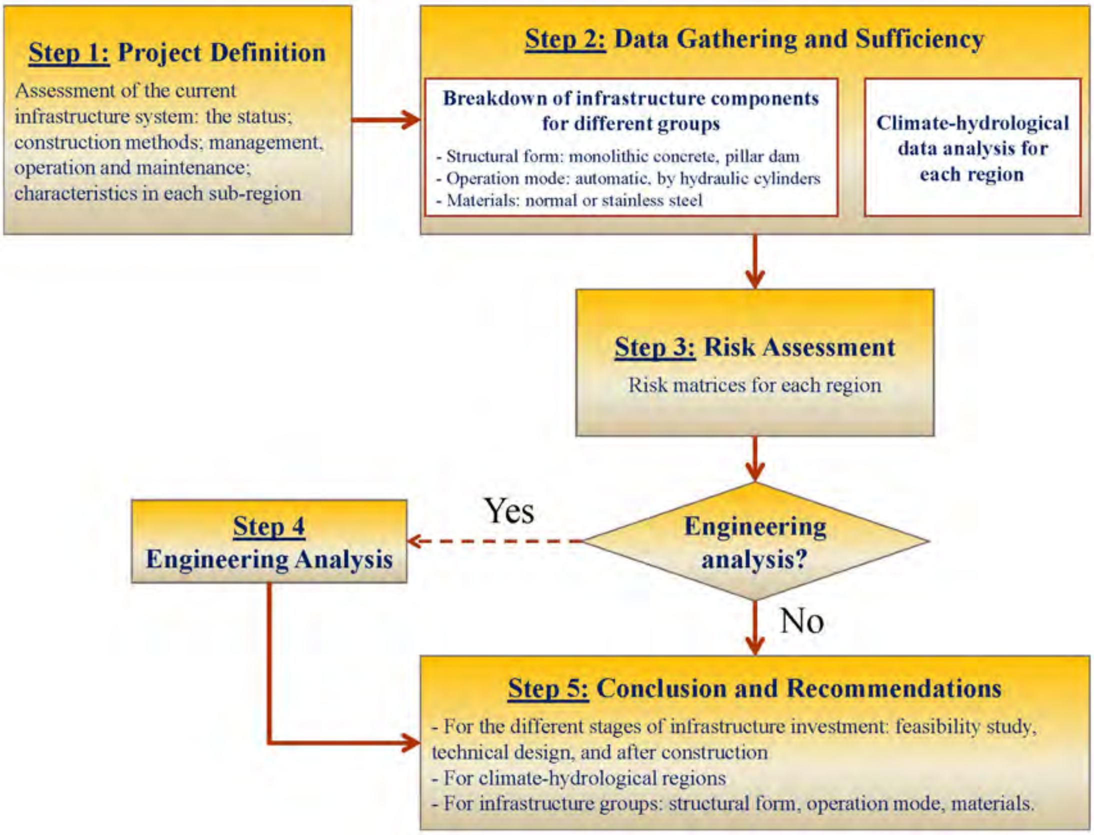
EXECUTIVE SUMMARY

The global project on Enhancing Climate Services for Infrastructure Investments (CSI) (2017 - 2022) by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) focuses on support decision makers increasingly use climate service (CS) and consider climate risk in planning of infrastructure investments. In the Vietnam component, the aim of CSI is to conduct climate risk assessment (CRA) for infrastructures based on the PIEVC Protocol (Public Infrastructure and Engineering Vulnerability Committee), owned by Engineers Canada. This is a step-by-step methodology of risk assessment and optional engineering analysis for evaluating the impact of changing climate on infrastructures. The obtained results, including observations, conclusions and recommendations derived from the application of PIEVC, are expected to provide a framework to support effective decision-making about infrastructure's detail design, operation, maintenance, planning and development as part of climate risk management.

With the 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 CSI in the cooperation with the Mekong Delta Climate Resilience Programme (MCRP) (2019-2021) by GIZ have funded a climate risk assessment (CRA) for the coastal sluice gate system in Kien Giang. The objective of this work package is to develop a set of standard but up-scalable criteria for the CRA of other cases of sluice gate system in Mekong Delta in general and Kien Giang province in particular. As sluice gate itself is adaptive infrastructural component of the entire sluice gates system in every locality, with function to regulate salt-fresh water in the context of climate change, the assessment results and recommendations of this work package are expected to provide inputs and solutions for a harmonised operation and maintenance for the current sluice gates and design for future sluice gates.

To achieve the above objectives, this report has developed a rapid CRA method (namely PIEVC Scanner) for the coastal sluice gate system in Kien Giang province based on a similar process to the PIEVC Protocol, including five major steps of project definition, data gathering and sufficiency, risk assessment, engineering analysis, and recommendations. An advantage of PIEVC Scanner is the ability to assess the responses of infrastructure components for each infrastructure group (e.g., monolithic concrete or pillar dam) under the impacts of climate and hydrological factors in different geographical regions (Step 2). As a result, the PIEVC Scanner will provide the corresponding risk matrices for different climate and hydrological regions (Step 3). In the PIEVC Scanner, Step 4 (engineering analysis) should be applied since the detailed design stage. Based on the risk matrices combined with the engineering analysis, the risk assessment team will provide the recommendations for infrastructure groups of different structural forms, operation modes, and materials in each climate and

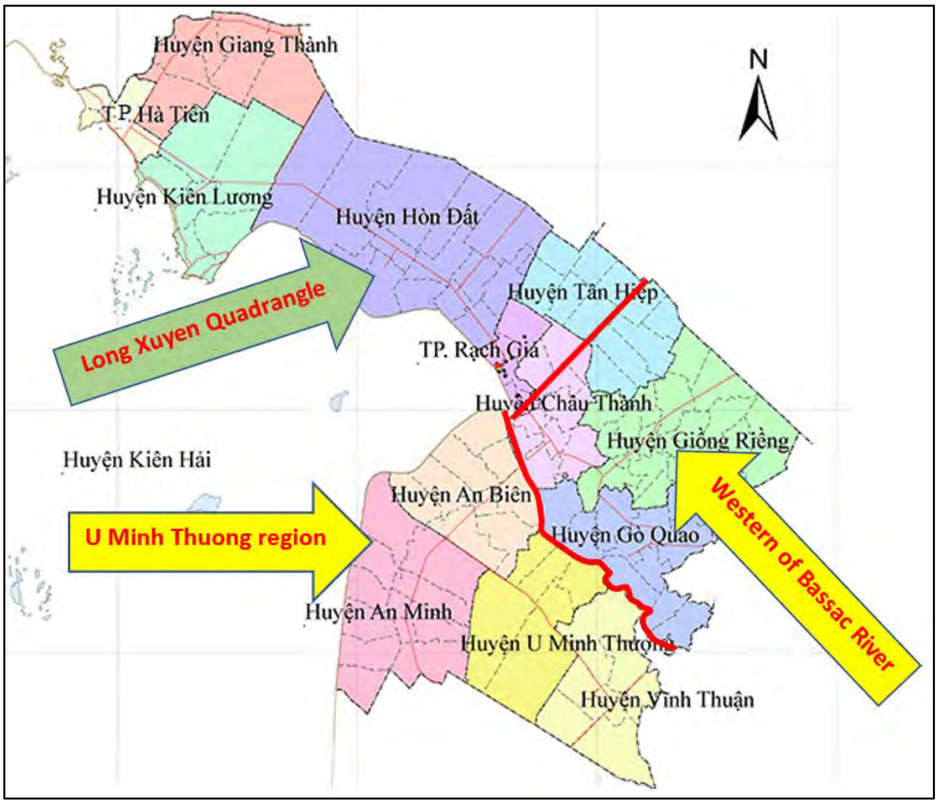
hydrological region in the different stages of infrastructure investment (i.e., feasibility study, technical design, and after construction). Thus, it is able to facilitate decision-making on future design, operations, maintenance, planning, and development or potential upgrading / rehabilitation of the infrastructure in the future.



Five major steps of PIEVC Scanner

Kien Giang has a relatively flat mainland topography and a coastline of 212 km. The province is located in the sub-equatorial tropical monsoon climate with the rainy season from May to November and the dry season from December to April. The hydrological regime in Kien Giang is strongly affected by the tidal regime of West Sea, the hydrological regime of Bassac River, the in-field rainfall. With such climatic and hydrological characteristics, Kien Giang was divided into three sub-regions, consisting of Long Xuyen Quadrangle region, Western region of Bassac River, and U Minh Thuong region.

The coastal sluice gate system in Kien Giang is responsible for flood drainage, salinity control, and water regulation for agricultural production and domestic use. This system (excluding Cai Lon and Cai Be sluice gates) has currently had 83 sluice gates in total, in which 56 are completed and operated, 11 are under construction, and 16 are at feasibility study stage. The main types of the sluice gates include: (i) Sluices with the automatically operated gates based on tide regime; (ii) Sluices with the automatically operated gates based on tide regime, combined with a flat gate vertically operated by hydraulic cylinder; (iii) Sluices with the form of pillar dam and bottom shutter gates operated by hydraulic cylinder; (iv) Sluices with the form of pillar dam and bottom shutter gates operated by winch; and (v) Sluices with the form of pillar dam and and flat gates vertically operated by hydraulic cylinder. The main components of these sluice gate types are similar, including operation and maintenance, sluice gate structure, ship lock, gates, bridge, retaining walls and connecting embankment, operation houses, park, power supply, operation and control system, monitoring system, fire extinguishing system, and communication system.



Climate - hydrological zones in Kien Giang province

Based on the geographic features of Kien Giang and referring to the CRA for Cai Lon-Cai Be sluice gates, the climate and hydrological factors for the CRA for the coastal sluice gate system in Kien Giang include high temperature, heat wave, heavy rain, 5-day total rainfall, tropical storms/depression, drought, high wind, tornado, and thunderstorms/lightning, water level (consisting of tides, storm surges, sea level rise and land subsidence) and salinity intrusion. In addition, this CRA also considered two cumulative effects, namely, salinity intrusion combined with high temperature and high water level combined with heavy rain.

The risk matrices for the LXQ, WBR and UMT regions were determined based on an understanding of probability of occurrence and severity of impacts associated with individual climate and hydrological factors. These matrices showed that of the 150 interactions to score the severity of the infrastructure components, there were 10 high-risk interactions due to thunderstorms/lightning for both future conditions in LXQ and

UMT regions, while there were no high-risk interactions in the WBR. The LXQ had the maximum number of medium risks for existing conditions (73 interactions) and for future projections (119 interactions). The WBR region had the maximum number of low risks for existing conditions (93 interactions), while the UMT region had the maximum number of low risks for future projections (35 interactions). In the medium-risk interactions for both existing and future conditions, the major infrastructure components including the staff, park, gates, water tight gasket, and the systems of electric power, monitoring, control and operation, and communication were mainly affected by tropical storms/depression, thunderstorms/lightning, and salinity intrusion combined with high temperature.

In this report, the engineering analysis was performed for the interactions between the infrastructure components (including sluice gate structure, gates, and hydraulic cylinder) and climate and hydrological factors (including tropical storms, water level, and salinity intrusion combined with high temperature). This analysis quantified the corrosion of reinforcement concrete due to carbonation and chlorine ion intrusion. In addition, the loads and bearing capacity of the infrastructure components under the impacts of climate-hydrological factors have also been calculated. The results of the engineering analysis showed that under the impact of salinity intrusion combined with high temperature by 2050, both sluice gate structures (monolithic concrete and pillar dam), types of gates, and hydraulic cylinders are likely to be vulnerable and reduce the lifespan of the infrastructure.

The main recommendations of the CRA for the coastal sluice gate system in Kien Giang province are summarized in the following table:

Infrastructure component	**The stage of technical design and before construction**	**The stage of after construction**
Operational staff		- To be trained on coping with tropical storms and tornado and improving self-protection skills in working outdoors; - To use the automatic operation mode or choose the time of proper maintenance.
The components made of reinforced concrete	- To use sulphate resistant cement, anti-corrosion additive mixture, or high concrete grade.	- To survey 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. - To carry out studies to assess carbonate and chlorine ion intrusion phenomena for reinforced concrete structures in the coastal area of Kien Giang province to increase the reliability of forecasting the lifespan of infrastructures. - To monitor the displacement (horizontal and vertical) of the infrastructure to control the eccentricity caused by horizontal loads, and

Infrastructure component	The stage of technical design and before construction	The stage of after construction
		control the displacement between the pillars. This will help the safe operation of the gates (i.e., no gate jam or damage). - To minimize the wind shield area of the pillars (e.g., do not hang the gates and only open the gates if absolutely necessary) during tropical storms/depression. - To check and monitor the stability and displacement of the pillars after storms or floods to handle (if necessary) and ensure stability and safety for the infrastructure. - Regularly inspect and repair to minimize damage to the protective concrete layer and reinforcement due to carbonation and chloride-ion intrusion.
The components made of metals	- To select the type of flat gates operated vertically by hydraulic cylinders for coastal sluice gates in Kien Giang to be invested. - To select materials with high corrosion resistance (stain-less steel Sus-304) and effective measures to protect metal corrosion such as Epoxy painting method - To study on mechanisms and causes of metal corrosion in Kien Giang to have suitable prevention measures. - To properly treat and coat joint welding positions to against rust - To cover the inside edges of boreholes with anti-rust paint	- To regularly check, periodically maintain, and promptly repair the damage of the gate (if any) in order to ensure the bearing capacity of the infrastructure and not to let rust spread to other positions. - If the gate is damaged and no longer safe during operation, it should be promptly replaced with a new one - For the sluice gates > 15m: The required operating force, especially the 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 make the load beyond the design limit; (ii) Controling boats to avoid colliding with structures; and (iii) Regularly checking the operating range of the gate to make sure it is not stuck.
Automatic gates		- In UMT region: As the sluice gates in this region operate automatically based on the tidal regime of West Sea, they are often filled with mud. Thus, it is recommended to replace from automatic gates to vertically lifted gates (operated by hydraulic cylinder. - In LXQ region: The sluice gates in this region have been constructed mainly for flood regulation. However, due to the automatic operation based on the difference of water levels, these sluice gates can not actively open and close the gates to regulate water sources, causing local inundation. Thus, it is recommended to replace an automatic gate

Infrastructure component	The stage of technical design and before construction	The stage of after construction
		(among existing gates) to a vertically lifted gate (operated by hydraulic cylinders).
Vertically lifted gates		- When tropical storms/depression occur, do not open the gates (hang the gates) in order to minimize the wind shield area.
Bottom shutter gates		- The coastal sluice gates in Kien Giang are currently facing many difficulties in operation (cannot be fully opened) due to sedimentation, potentially dangerous for waterway traffic. Therefore, it is necessary to regularly check and conduct dredging of sediment in the sluice gate area, as well as periodically operate the sluice gate to circulate the flow and limit sedimentation.
Gates made of CT3 or CT5 steel combined with an anti-rust epoxy coating		- Regularly check, periodically maintenance, and promptly repair the damage of the gate (if any) or replace the new gate (if necessary).
Gates made of stainless steel (SUS-304)		- This type of gates has a high price, but is usually less affected by climate and hydrological factors. Thus, this is an option that should be considered when damaged normal steel gates needs to be replaced.
Hydraulic cylinder		- To pay attention to checking and monitoring the working process of the hydraulic cylinders to ensure that they operate evenly.
Water tight gasket		- To regularly check, repair and replace the gaskets in time to ensure watertightness and limit the load due to friction during operation.
Systems of electric power, monitoring, control and operation, and communication	- To consider underground wiring designs to ensure safety for thunderstorms/ lightning, tornado or in the rainy season - To design the lightning protection system for the whole infrastructure - To select sensors with high tolerance to climatic factors	- Regularly inspect and maintain the systems of electric power, monitoring, control and operation, and communication. - To check and repair lightning protection system (if damaged) at the sluice gates to ensure the safety of the infrastructures in the case of thunderstorms and lightning.
The secondary components	- To select designs of operation houses to reduce the effects by storms and tornado, (e.g., reducing the height of houses) - To select appropriate plants for parks to be able to withstand extreme climate events (drought and heat wave)	- Check after storms to see whether it withstand the impact, and repair/maintain if necessary.

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Acronyms and Abbreviations

CL-CB	Cai Lon – Cai Be
CRA	Climate risk assessment
CS	Climate service
CSI	Enhancing Climate Services for Infrastructure Investment
DARD	Department of Agricultural and Rural Development
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
LXQ	Long Xuyen Quadrangle
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
UMT	U Minh Thuong
WBR	Western of Bassac River
WP2	Work package 2

1 INTRODUCTION

1.1 Background

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 climate services (CS) and consider climate risk in planning of infrastructure investments.

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 2nd work package (WP2) are to identify the most sensitive and vulnerable components of the completed Cai Lon – Cai Be case of sluice gate system and assess the potential climate risk that these components pose on the same type of infrastructure in the Kien Giang province.

1.1 Objectives and scope of project

1.1.1 Objectives

The objective of this report (WP2) is to develop a set of standard but up-scalable criteria for the climate risk assessment of other cases of sluice gate system in Mekong Delta in general and Kien Giang province in particular. As sluice gate itself is adaptive infrastructural component of the entire sluice gates system in every locality, with function to regulate salt-fresh water in the context of climate change, the assessment results and recommendations of this work package are expected to provide inputs and solutions for a harmonised operation and maintenance for the current sluice gates and design for future sluice gates.

1.1.2 Scope of project

There are currently hundreds of sluice gates of all kinds in Kien Giang province, including the Cai Lon - Cai Be sluice gate system, the sluice gate system along West Sea, the O Mon - Xa No sluice gate system, and the in-field irrigation sluices. However, in this report, the CRA was only applied to the coastal sluice gate system along West Sea. It is because these sluice gates are frequently damaged and require regular maintenance to ensure the lifespan of the infrastructures.

Cai Lon - Cai Be sluice gate system was categorized as level 1 of Agriculture and Rural Development works, in which Cai Lon sluice gate is a Grade I hydraulic work and Cai Be sluice gate is Grade II hydraulic work (based on QCVN 04 - 05:2012/BNNPTNT). The CRA for this sluice gate system was implemented at the feasibility stage (Phase 1) and in the period comprised from after the detail design until construction completion (the first work package – Phase 2), thus it was not included in this report. Furthermore, the CRA for other Grade I hydraulic works in the future (if any) in Kien Giang in particular and in the Mekong Delta in general can refer to the results of the CRA for this sluice gate system.

The O Mon - Xa No sluice gate system and other in-field irrigation sluices in the province are mainly small sized sluice gates (B < 10 m) or round sluices (Φ 100; Φ 200). As noted by the management unit, these sluice gates are less affected by climate and hydrological factors such as salinity, so they are less damaged than the coastal sluice gates, ensuring the lifespan of the infrastructures. Therefore, they were considered in this report. The CRA for these sluice gates (if necessary) can refer to the CRA for the coastal sluice gate system but ignore the salinity effect.

In addition, although Kien Giang has more than 140 large and small islands, the largest of which is Phu Quoc with an area of 567 km², this report mainly focused on the mainland part of Kien Giang province due to the CRA only for the coastal sluice gate system along West Sea.

1.2 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 WP2, 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 task because they were the key members of the Vietnamese assessment team for the pilot case of CRA for Cai Lon - Cai Be sluice gates. Also, they attended many trainings of CRA on infrastructures. Furthermore, they have experienced on management and operation of the sluice gate systems in Kien Giang Province.

To achieve the project objectives, the methodology for WP2 was established as shown in Figure 1-1.

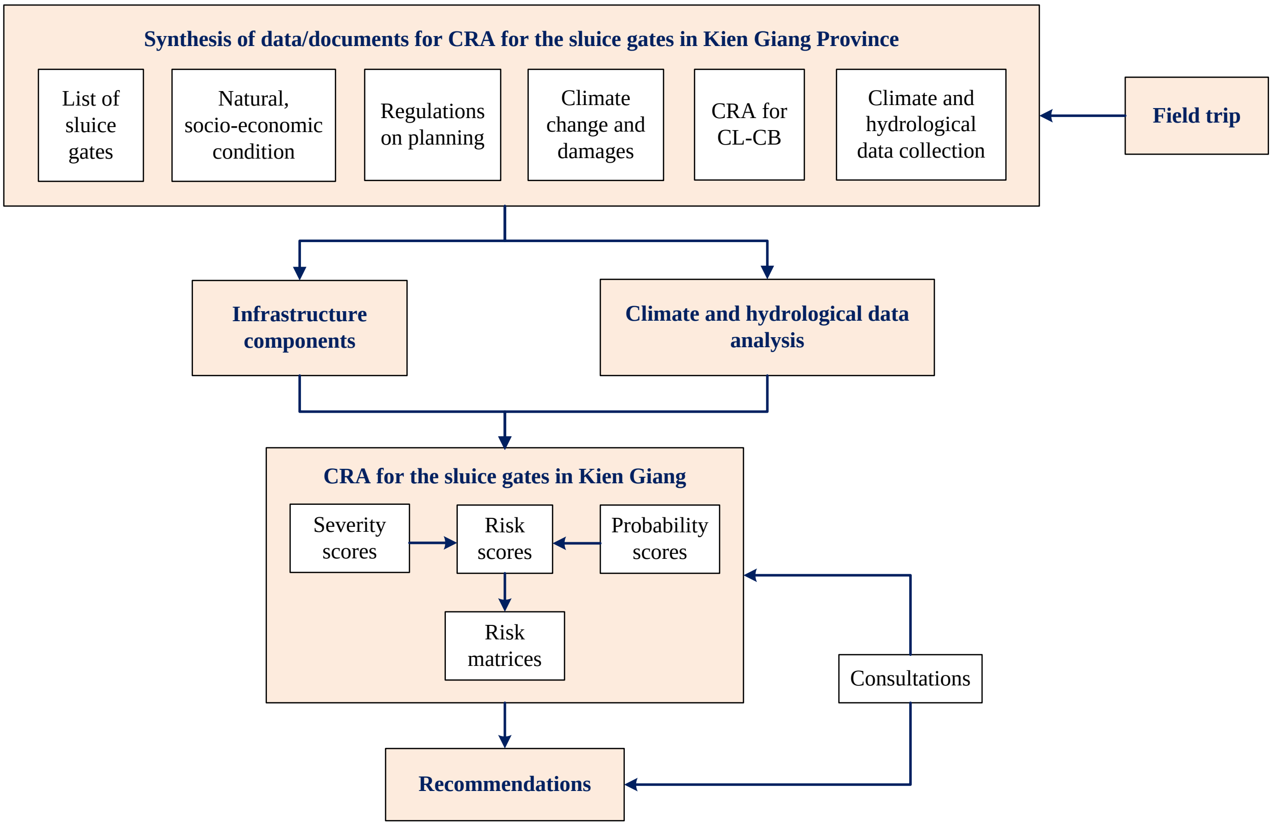


Figure 1-1. Methodology for WP2

❖ *Part 1: Review on sluice gate system in Kien Giang province*

In order to accomplish this part, the natural and socio-economic documentation, technical reports (including design, management, maintenance and operation), financial documents and other involving materials regarding with the sluice gates in Kien Giang

Province were collected, synthesized and analysed systematically. A field trip was ogranised to provide a systematic overview of the sluice gates in Kien Giang Province. Furthermore, the results of CRA for Cai Lon – Cai Be sluice gates were reviewed to identify vulnerable infrastructure components. This part also covered data sufficiency to support CRA for sluice gates system in Kien Giang province. The main contents in this part include:

- Natural and socio-economic condition in Kien Giang province;
- Climate change and the losses and damages due to disasters and climate change in Kien Giang province;
- Sluice gates system in Kien Giang province (including list of sluice gates/ descriptions on functions and design, typology, technical properties, status, operation and maintenance status, demand/significance of CRA);
- Related regulations on planning, constructing, operating and maintaining the sluice gates in Kien Giang province;
- Review on results and progress of the CRA for CL-CB sluice gates;
- Data sufficiency of sluice gates system in Kien Giang province.

❖ *Part 2: Climate and hydrological data analysis and projection*

Based on the review of CRA for CL-CB sluice gates in Part 1, this part re-identified the climate and hydrological parameters such as rain, temperature, salinity, storm, wind, tornado, water level, evaporation, humidity and flow. Next, all climate and hydrological data for CRA were collected to 2020 and then analysed the historical trends and the future forecasts to determine the Probability Scale Factors (Sc) for both present and future condition. This part also identified the different climate-hydrological regions in Kien Giang.

The main contents in this part include:

- Identification of climate and hydrological parameters (rain, temperature, salinity, storm, wind, tornado, water level, evaporation, humidity and flow)
- Climate data analysis and projection: trend analysis, projection and determining Probability Scale Factors (Sc) (present/ future);
- Hydrological data analysis and projection: trend analysis, projection, and determining Probability Scale Factors (Sc) (present/ future).

❖ *Part 3: CRA for the sluice gates in Kien Giang Province*

In this part, CRA for the sluice gates in Kien Giang Province was carried out using the PIEVC Scanner. The PIEVC Scanner could identify the potential climate risk (risk scores) for each group of sluice gates (different sizes and structural forms) and each different climate-hydrological region. Based on the risk matrices obtained, the recommendations for sluice gates in Kien Giang were proposed for the different stages of infrastructure investment (i.e., feasibility study, technical design, and after construction).

❖ *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 were 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 report become ready to be submitted.

1.3 PIEVC Scanner

Similar to the PIEVC Protocol, PIEVC Scanner is also a step-by-step process for infrastructure vulnerability assessment and adaptation to a changing climate, but it can assess the responses of infrastructure components for each infrastructure group (e.g., the monolithic concrete or the pillar dam) under the impacts of climate and hydrological factors in different geographical regions. 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.

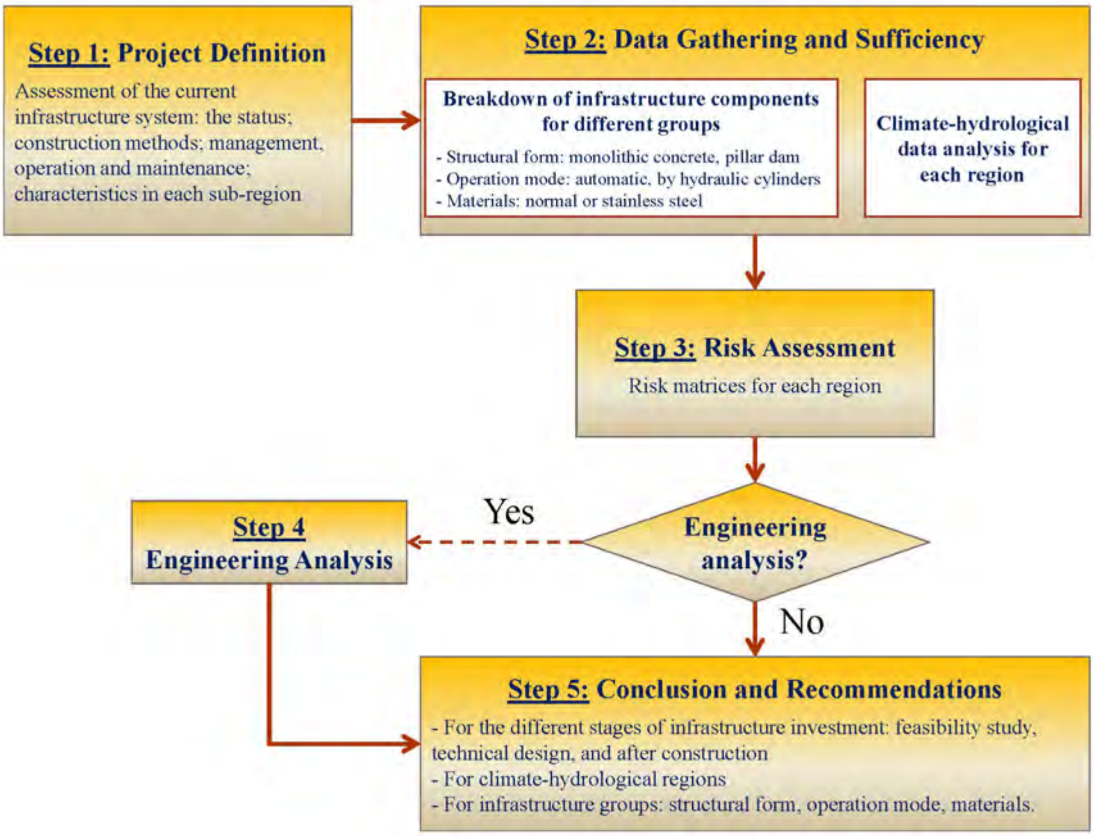


Figure 1-2. Five major steps of PIEVC Scanner

The process of PIEVC Scanner has five major steps, including: project definition, data gathering and sufficiency, risk assessment, engineering analysis, and recommendations (Figure 1-2). The main contents of PIEVC Scanner are summarised below. The detailed description of the PIEVC Protocol is presented in the principles and guidelines (Engineers Canada, 2016).

1.3.1 Step 1: Project definition

This step introduces general information about the infrastructure (e.g., location, main infrastructure components, design standard, legal basis, etc.) and data on climate and hydrology 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. In this step, the PIEVC Scanner will also assess the current infrastructure system, including the status of the infrastructures (operating, under construction, or at the stage of feasiblity study); the construction methods; the management, operation and maintenance of the system; and the georaphical characteristics of sub-regions in the study area.

1.3.2 Step 2: Data gathering and sufficiency

This step focuses on two main activities as follows:

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

This component of Step 2 identifies the main infrastructure systems and how they break down, including number of physical components, 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). Compared with the PIEVC Protocol, PIEVC Scanner also divides infrastructure groups based on different characteristics of structure (such as monolithic concrete or pillar dam), operation (automatically or forced by hydraulic cylinders), materials (normal steel or stainless steel), etc. 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 and hydrology

Depending on the requirement of the project, as well as the features and the location of the infrastructure, the applicable climate and hydrology to be considered in the assessment are identified. In the PIEVC Scanner, the study area will be also divided into the climate - hydrological zones based on the geographical location and climate and hydrological regimes.

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.

This component of Step 2 will also calculate the probability scores (P) of the climate and hydrological factors and their combined effects for the different climate - hydrological zones.

1.3.3 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 infrastructures and the climate and hydrological factors, 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 matrices for climate - hydrological zones (see Appendices from 2 to 7), 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 infrastructures.

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. 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. In the PIEVC Scanner, risk matrices will be built for each sub-region in both current conditions and future projections.

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.

1.3.4 Step 4: Engineering analysis

Similar to PIEVC, Step 4 of the PIEVC Scanner is also 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 engineering analysis depends on available budget and project scheduling constraints. In the PIEVC Scanner, Step 4 is also recommended to be applied since the detailed design stage.

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.

1.3.5 Step 5: Recommendations

This step will present assumptions, limitations and recommendations from the assessment process for the different stages of infrastructure investment (i.e., feasibility study, technical design, and after construction) in each climate, hydrological sub-region for infrastructure groups of different structural forms, operation modes, and materials. 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 OVERVIEW ABOUT KIEN GIANG PROVINCE

2.1 Geographical location

Kien Giang is a province of the Mekong Delta, with the geographical coordinates of from $103^0$30' (from Tho Chu island) to $105^0$32' East longitude and from $9^0$23 'to $10^0$32' North latitude. In terms of the administrative boundaries, Kien Giang borders on:

- An Giang, Hau Giang provinces, and Can Tho City in the NorthEast;
- Ca Mau and Bac Lieu provinces in the South;
- The West Sea in the SouthWest;
- Cambodia in the North.

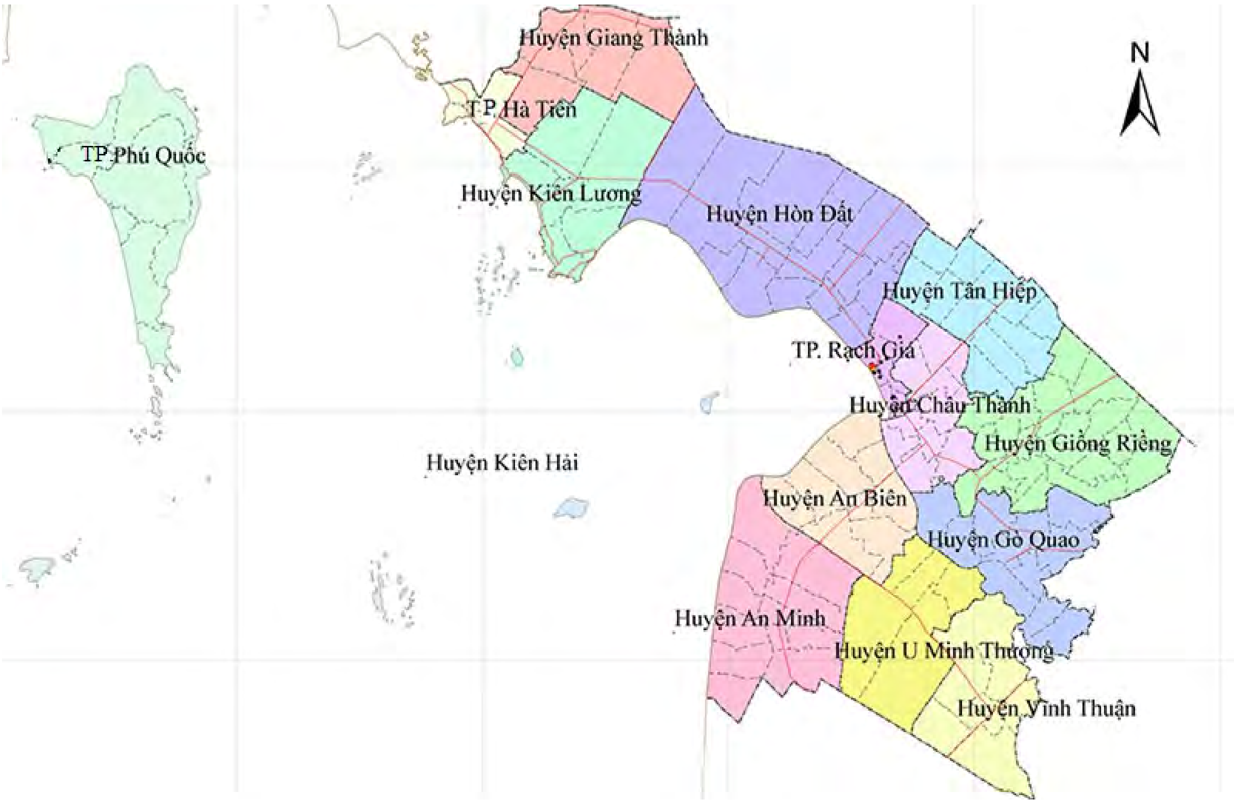


Figure 2-1. Administrative map of Kien Giang province

Kien Giang has 15 administrative units at district level, including Rach Gia city, Ha Tien city, Phu Quoc City and 12 districts (including Kien Hai island district) with a total of 145 communes, wards and towns. The total natural area of Kien Giang is 634,852.67 ha.

2.2 Natural and socio-economic characteristics of Kien Giang province

The mainland topography of Kien Giang province is relatively flat, with a gradually lower direction from the Northeast (average elevation from 0.8 to 1.2 m) to the Southwest (average elevation from 0.2 to 0.4m) above sea level. Kien Giang has a dense network of rivers and canals, taking advantage of agricultural development, flood drainage, and water traffic. In addition to the main rivers such as Cai Lon, Cai Be and Giang Thanh rivers, the canal system is distributed across the province with a total length of about 2,054 km. The hydrological characteristics of these rivers together with the tidal regime of the West Sea dominate the ability of water drainage in the rainy season and prevent salinity in the dry season.

Kien Giang has a coastline of 212 km, along with the coastal sluice gate system which is responsible for flood drainage, salinity control, and water regulation for agricultural production and domestic use. The investment of the coastal infrastructures has contributed to promoting the efficiency of agricultural restructuring, adding value to agricultural products, stabilizing people's lives, contributing to socio-economic development and capacity building in disaster prevention and control in the province. In the period of 2016 - 2020, the growth rate of economy in Kien Giang was 7.22% per year (compared to 2010). By 2020, the proportion of agriculture, industry and service was 31.54%, 20.06% and 48.4%, respectively. Per capita (at current prices) was estimated at 58 million VND (equivalent to 2,458 USD), 1.66 times higher than that in 2015.

2.3 Climate and hydrological characteristics of Kien Giang province

2.3.1 Climate characteristics

Kien Giang province is located in the sub-equatorial tropical monsoon climate. The climate is divided into two distinct seasons, including: the rainy season from May to November and the dry season from December to April.

- The temperature moderate throughout the year, the average temperature in the period of 1988-2020 in Rach Gia is 27.1ºC. The temperature ranges from 17.0ºC to 37.2ºC, in which the average highest and lowest temperatures are about 31.0ºC and 24.9ºC, respectively. The hottest months in a year are April, May and June, while the coolest months are December, January and February.
- Kien Giang is one of the provinces with the most rainfall in the Mekong Delta. The average annual rainfall in the period of 1988-2020 was about 1,800-2,400 mm, in which the highest value is at An Minh (2,418.4 mm) and the lowest is at Tan Hiep (1,795 mm). The rainfall in the rainy season accounts for 90% of the total annual rainfall.
- The annual average relative humidity in Kien Giang is 81%, with the difference of 77-85% among months. The annual average lowest humidity is 68%. The difference in humidity between the dry season and the rainy season is not much, about 8,10%.
- There are two main seasons in the year, namely northeast monsoon (December - April) and southwest monsoon (May - October). The northeast monsoon blows from the continent so it is dry and cold. The average speed of the northeast monsoon in Rach Gia is 1.6 - 3.6 m/s. In constrast, the southwest monsoon blows from the sea with a lot of water vapor causing rain.

- Storms in Kien Giang are less frequent and often come late (mainly in November and December) and do not cause heavy rainfall like in the Central or Northern regions of Vietnam.

2.3.2 Hydrological characteristics

The hydrological regime in Kien Giang province is strongly affected by three main factors: the tidal regime of West Sea, the hydrological regime of Bassac River, the in-field rainfall.

The West Sea tide has an irregular diurnal form, with a sharp peak and a lower 2nd peak, and the elongated tidal base. The amplitude of oscillation is low, in which the tidal peak fluctuates around 0.7 m and the tidal base is between 0.8 and 1.0 m. The half-month and full-year fluctuations of the West Sea tide are also much weaker than those in the East Sea. The West Sea tide directly affects Kien Giang and Ca Mau through the propagation of tides into rivers and canals along the coast, most notably Cai Lon, Cai Be and a number of main canals flowing into Rach Gia Bay.

The basic feature of the Bassac river flow is strongly impacted by the water flow upstream. From July to December, there is almost no backflow from the sea. However, as the upstream flow into the Mekong Delta gradually decreases at the end of November and early December, the reverse flow started on the Bassac River due to the impacts of the semi-diurnal tide in the East Sea. The largest tide at Chau Doc in October is 16 cm, November is 8 cm, and gradually increasing to 101 cm in January and reaching 126 cm in May.

The rainfall in Kien Giang is fairly large, but not enough to determine flow trends in in-field canals. It only affects to instantaneous flow trends, increasing the water level on the canals in the rainy season, combined with flood and high tide. In addition, because the rainfall is mainly distributed in the flood season (from July to December), the in-field rain regime has a significant impact on the flood flow.

In the flood season, the flow is influenced by all the upstream flood, hydrological regime of Bassac River and in-field rainfall. The water level in the canals in Kien Giang increased rapidly due to the trans-boundary flows into Vinh Te canal and flood from Bassac River through the flood drainage canals to the West Sea. The discharge of floods through Cai Lon and Cai Be rivers is about 700-850 m^3/s in 2000 and 400-600 m^3/s in 2011.

In the dry season, particularly in February, the West Sea tide is stronger, while the flow to supply freshwater reduces. This increases the length of salinity intrusion. However, as the average water level on Bassac River is higher than the average coastal water level, the flow direction is still from Bassac River to the West Sea through the main channels. Currently, due to the dredging of main canals, the volume of fresh water supplying to the area increases significantly in the dry season.

2.4 Climatic - hydrological zones in Kien Giang province

Kien Giang is a coastal delta province with the sub-equatorial climate, so the meteorological factors such as temperature, evaporation, humidity, sunshine, wind, and thunderstorms do not have a clear differentiation among the regions in the province, except for the uneven rainfall distribution. However, the hydrological regime of the different regions is different. In order to facilitate the sluice gate system management in Kien Giang, Kien Giang province was divided into three sub-regions, consisting of Long Xuyen Quadrangle region (Rach Gia City, Ha Tien City, and Giang Thanh, Kien Luong, Hon Dat districts, and the part of Tan Hiep and Chau Thanh districts), Western region of Bassac River (Giong Rieng, Go Quao districts, and the part of Tan Hiep and Chau Thanh districts), and U Minh Thuong region (An Bien, An Minh, U Minh Thuong, and Vinh Thuan districts). These sub-regions were used for CRA for the coastal sluice gate system in Kien Giang (Figure 2-2).

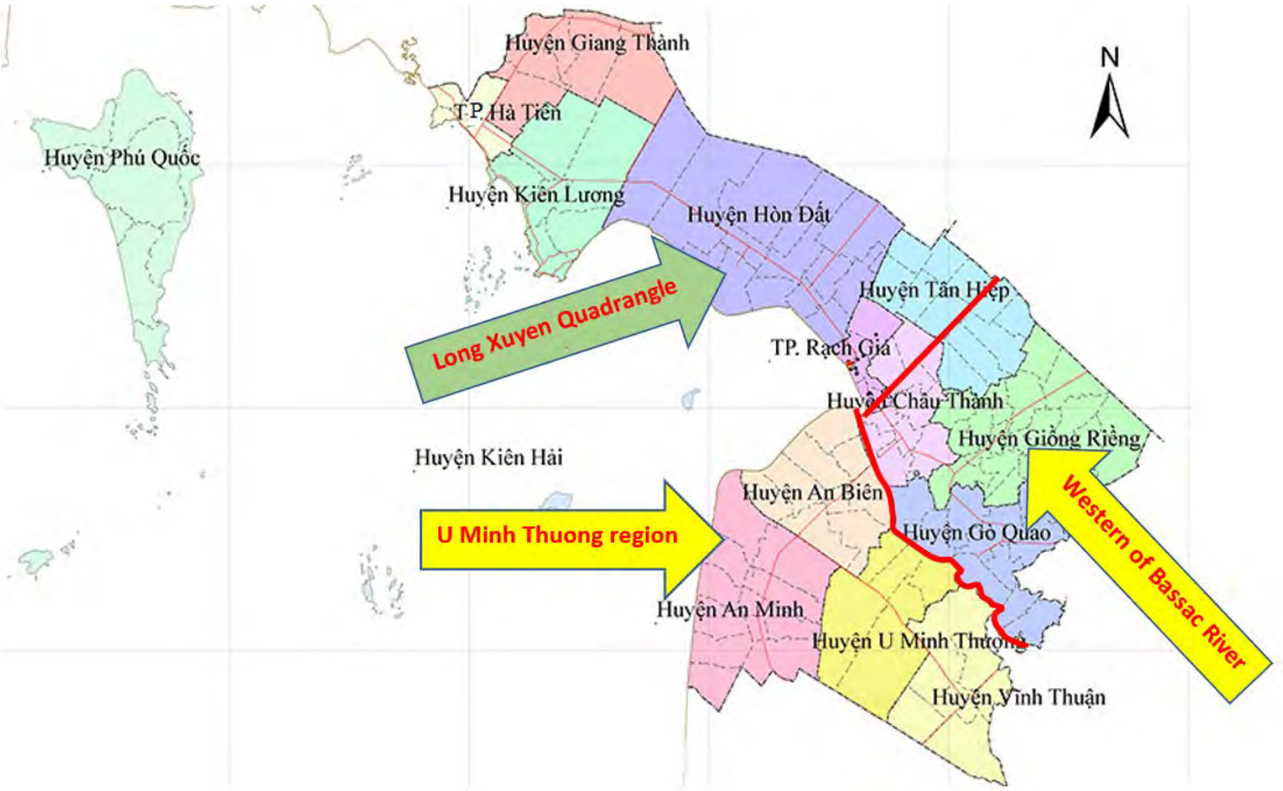


Figure 2-2. Climate - hydrological zones in Kien Giang province

2.4.1 Long Xuyen Quadrangle region

The topography of Long Xuyen Quadrangle region (LXQ) is lower from the Northwest to the Southeast with the elevation of from 0.2 to 1.2 m. The average annual rainfall in the region ranges from 1,952mm to 2,356mm. In the flood season, the water level in the canals in the region increased rapidly due to the trans-boundary flows and in-field rainfall. In the dry season, the water level is strongly affected by the West Sea tide.

2.4.2 Western region of Bassac River

The topography of Western region of Bassac river (WBR) is lower from Northeast to Southwest, with the elevation of 0.1 to 0.9 m. The highest area (from 0.7 to 0.9 m) is in Tan Hiep district and the lowest area (from 0.1 to 0.2m) is along Cai Be river. With the average annual rainfall of from 1679.5mm to 2058mm, the region has the least total annual rainfall in

Kien Giang province. The maximum flood water level in this region usually occurs from late September to the end of November.

2.4.3 U Minh Thuong region

U Minh Thuong region (UMT) has a low topography, with many inundated, low-lying areas in the rainy season. The elevation in the region ranges from - 0.1 to 1.1m. The highest area (from 0.8 to 1.2 m) is in Ho Rung and the lowest area (from -0.1 to -0.4m) is along Cai Lon river. The average annual rainfall in the region (from 2014mm 2367mm). In terms of the hydrological regime, Cai Lon and Cai Be Rivers are the water outlet from the region to the West Sea.

3 COASTAL SLUICE GATE SYSTEM IN KIEN GIANG PROVINCE

3.1 Current status of coastal sluice gate system in Kien Giang

In Kien Giang, there are currently hundreds of sluice gates of all kinds, of which 130 key sluice gates are managed by Kien Giang Irrigation Sub-Department. The coastal sluice gate system (excluding Cai Lon and Cai Be sluice gates) has 83 sluice gates in total, in which 56 sluice gates are completed and operated, 11 sluice gates are under construction, and 16 sluice gates are at feasibility study stage (Table 3-1). The sluice gates under construction and at the stage of feasibility study have been mainly located in the UMT region and designed in the form of pillar dam and flat gates vertically operated by hydraulic cylinders.

Table 3-1. The number of coastal sluice gates by climate-hydrological zones in Kien Giang

No.	Type of sluice gates	LXQ		WBR		UMT	
		No. of sluice gates	Status	No. of sluice gates	Status	No. of sluice gates	Status
1	Sluices with the automatically operated gates based on tide regime (excluding the sluice gates in Item 2) (Figure 3-1)	40	Operating	0	Operating	7	Operating
2	Sluices with the automatically operated gates based on tide regime, combined with a flat gate vertically operated by hydraulic cylinder (Figure 3-2)	3	Operating	0	Operating	0	Operating
3	Sluices with the form of pillar dam and bottom shutter gates operated by hydraulic cylinder (Figure 3-3)	1	Operating	0	Operating	0	Operating
4	Sluices with the form of pillar dam and bottom shutter gates operated by winch (Figure 3-4)	0	Operating	1	Operating	0	Operating
5	Sluices with the form of pillar dam and and flat gates vertically operated by hydraulic cylinder (Figures 3-5 and 3-6)	1	Operating	3	Operating	0	Operating
		0	Under construc-tion	1	Under construc-tion	10	Under construc-tion
		0	Feasibilit y study	0	Feasibilit y study	16	Feasibilit y study

(Source: Kien Giang Irrigation Sub-Department, 2021)

Figure 3-1. Kien River sluice gate (Rach Gia City)

Figure 3-2. Vam Ray sluice gate (Hon Dat district)

Figure 3-3. Kenh Cut sluice (Rach Gia City)

Figure 3-4. Soc Tram sluice gate (Chau Thanh – Kien Giang)

Figure 3-5. Ca Lang sluice gate (Chau Thanh – Kien Giang)

Figure 3-6. Thu Nam sluice gate (An Bien district)

3.2 Operation and maintenance of the coastal sluice gate system in Kien Giang

The management of the design, construction, operation and maintenance for the coastal sluice gate system in Kien Giang province is summarized based on the field trips, and the information and documents collected from Kien Giang Irrigation Sub-Department.

3.2.1 Construction methods for the coastal sluice gate system

- Traditional method (i.e., the use of a rotating dyke and dry foundation pit): Wide ground clearance, long construction time, limited use of equipment for construction, large investment costs ...

- Contruction method using the barge technology or the pillar dam technology: This method allows construction at the sluice site, and thus requires little ground clearance. However, this method is limited in quality control, and the investment cost is not much reduced compared to the traditional method. In addition, it requires higher technique knowledge and management skills in construction.

- Construction method with the walls of steel sheet piles: This method is able to be active, flexible in construction, speed up the progress, and does not depend much on the weather. The walls of steel sheet piles can prevent water to keep the construction site dry, so it is convenient in quality control, less costs for site clearance, and appropiate investment costs.

3.2.2 Advantages and disadvantages in the operation form of the coastal sluice gate system

3.2.2.1 Automatic operation based on tidal regime

a. Advantages

- This type of operation is simply, and does not need a lot of manpower to open and close as well as a staff of highly qualified and skilled.

- The automatic operation of the coastal sluice gate system is effective and convenient for flood drainage and water regulation in the LXQ region. Thus, it is recommended to continue using these sluice gates for this region to drain floods into the West Sea, but there should be solutions to overcome the following shortcomings.

b. Disadvantages

- As the flow velocity through the sluice gates is small, the upstream and downstream canals as well as the location of the gates will be sedimented quickly and seriously (the sediment layer may be from 1m to more than 2m thick). Thus, dredging is usually required prior to operation. The sluice gates for flood drainage in the Long Xuyen Quarangle region has less sedimentation but still faces difficulties in operation.

- The valve gates are always under water and covered with mud for a long time, leading to easy damage and rust.

- For the sluice gates for flood drainage and waterlogging (automatic one-way valve gates): When the gates are closed, if heavy rain cause local inundation and the higher upstream water level, the gates cannot be operated to drain water into the sea in time. At that time, the gates will be only opened if the downstream water level rises to the required level by the tide. This is the biggest disadvantage of this type of gate for flood drainage, particular in the Long Xuyen Quadrangle region.

- For automatic 2-way valve gates, during the process of taking salt water for shrimp farming, if there is high tide, it is impossible to actively close the sluice gate. Therefore the risk of salinity intrusion into the interior fields is very high, causing damage to agricultural production.

3.2.2.2 Bottom shutter gates operated by hydraulic cylinder or winch

a. Advantages

- These sluice gates can be proactively and promptly operated to drain water as required. However, for the operation by winch, the difference between upstream and downstream water levels should to be within the permissible limit.

- The valve gate can be large in size. As the valve gates are fully under water, they are affected much by high wind or storms.

b. Disadvantages

- Cable breakage and/or electrical motor overload may occur during closing the sluice gates if the load of the gates is increased due to sediment.

- The valve gates can not be fully opened if stuck with sediment at the bottom. As a result, it may obstruct water traffic and mitigate the capacity of the water drainage as designed. For the sluice gates operated by winch, it is difficult to determine whether the valve gates is fully opening or not.

- It requires operation staff with qualified knowledge and skills to ensure the safety of the infrastructure and water traffic through the sluice gates.

- It is difficult for maintenance and repair because the valve gates are fully under water and there is lack of equipment to lift the gates. Up to now, this type of sluice gate has not been repaired yet.

- The production, installation, and construction of the gates require high technology. In addition, this type of valve gate is limited to apply for the gates with large height.

3.2.2.3 Vertically lifted sluice gates operated by hydraulic cylinder, screw mechanism or winch

a. Advantages

- In general, the vertically lifted sluice gates have simple design and is easy to operate and maintain.

- The opening and closing operation is active and timely, and has high stability because of less depending on the difference between upstream and downstream water levels.

- The valve gates can be large due to the hydraulic cylinder operation. The structure of the valve gates is simple, easy to make and easy to arrange the watertight gasket. As the valve gates can be removed easily, so it is convenient to check, maintain, and repair the gates.

- In the opening state, the valve gates are lifted above the water surface, so it is less corrosive than other valve gates, leading to longer periodic maintenance and repair times.

b. Disadvantages

- It requires a group of operation staff with qualified knowledge and skills.

- For the sluice gates operated by hydraulic cylinder, 3-phase electricity or large-capacity generators are required. This will increase the investment cost. In addition, the inspection and repair of electrical control system must be performed by highly qualified personnel.

- For the sluice gates operated by screw mechanism, it is necessary to carefully check the stroke of the screws to avoid the damage.
- For the sluice gates operated by winch, the gates can be imbalance due to uneven lifting and lowering.
- The hanging valve gates are easily unstable due to the impacts of high wind or storms.
- The clearance height for water traffic is low.

3.2.3 Operation management of the coastal sluice gate system

3.2.3.1 Long Xuyen Quadrangle region (LXQ)

The sluice gate system in the LXQ region is operated according to the "Operation regulation of irrigation system in the LXQ region" issued by the MARD under Decision No. 5313/QD-BNN-TCTL dated December 20, 2017. The Department of Agriculture and Rural Development of Kien Giang has commanded the Irrigation Sub-Department to regularly inspect and monitor the situation of the water sources as well as to operate the sluice gates in accordance with the regulations.

Figure 3-7. The coastal sluice gate system in the LXQ region

The operation management of the sluice gate system in the LXQ region has brought good results in regulating water sources for production, living and flood drainage for the LXQ region. Therefore, the farmers can be proactive in production with suitable seasonal calendars. Particularly during the period of drought and saline intrusion in 2019-2020, the Kien Giang Irrigation Sub-Department operated efficiently and flexibly the coastal sluice gates in the LXQ region to mitigate the impacts in the province.

3.2.3.2 U Minh Thuong region

The sluice gate system in UMT region has been operated for the agricultural production and daily life of local residents. The coastal sluice gates in An Minh and An Bien districts, that are automatically operated by the tide, are often sedimented, making it difficult for the operation. In addition, as this system has not been constructed completely, the operation of the existing sluice gates is not synchronized. Thus, it is necessary to use the temporary dams to prevent salinity intrusion in the canals without sluice gates in order to improve the effectiveness of the system operation.

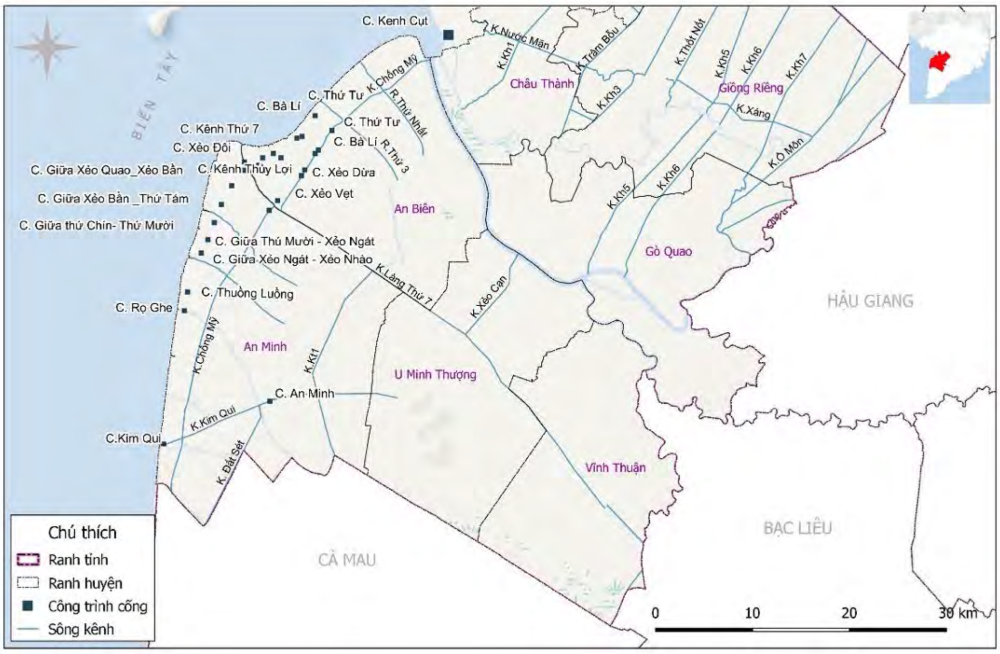


Figure 3-8. The coastal sluice gate system in the UMT region

3.2.3.3 The Western of Bassac River region

The coastal sluice gates in the WBR region are mainly concentrated in Chau Thanh district. They have been operated uniformly according to "Operation Procedures of Cai Lon – Cai Be Irrigation System" (under preparation for approval). These sluice gates combined with other sluice gates along the West Sea coast are responsible for controlling salinity and regulating water sources for the agricultural production and daily life of local residents. Most of these gates have been vertically operated by hydraulic cylinders, except for Soc Tram sluice gate (bottom shutter gates operated by winch). Therefore, the gates can be actively opened and closed.

3.2.4 Maintenance of the sluice gate system in Kien Giang

- The sluice gate system managed and operated by Kien Giang Irrigation Sub-Department is maintained periodically.

- To ensure the lifespan of infrastructures, the sluice gate system is regularly inspected to promptly detect and repair unexpected problems during operation.

4 INFRASTRUCTURE COMPONENTS OF THE COASTAL SLUICE GATE SYSTEM IN KIEN GIANG

4.1 Documents and data of sluice gate system in Kien Giang

❖ ***Documents of infrastructure design***

- Technical documents related to the design and construction of sluice gates along the West Sea dyke in Kien Giang province.

❖ ***Regulations on management and operation of sluice gate system in Kien Giang***

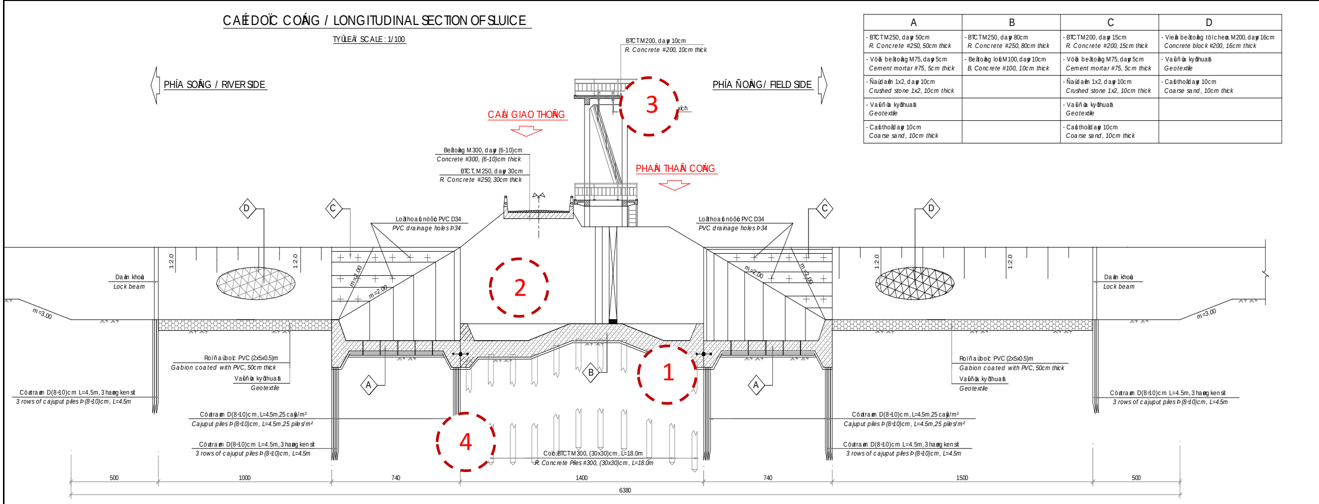
- Vietnam Law on Irrigation dated June 19, 2017.
- Decree No. 67/2018 / ND-CP dated May 14, 2018 of the Government on detailing a number of articles of the Law on Irrigation.
- Circular 05/2018/TT-BNNPTNT dated May 15, 2018 of the Ministry of Agriculture and Rural Development (MARD) on detailing a number of articles of the Law on Irrigation.
- "Operation regulation of irrigation system in the Long Xuyen Quadrangle region" issued by the MARD under Decision No. 5313/QD-BNN-TCTL dated December 20, 2017.
- "Operation regulation of O Mon - Xa No Irrigation System" under Decision No. 217/QD-BNN-XD dated January 23, 2017 of the MARD.
- Decision No. 20/2020/QD-UBND dated November 20, 2020 of the Kien Giang Provincial People's Committee on the promulgation of the regulation on decentralization of management, exploitation and protection of irrigation works in Kien Giang province.

4.2 A breakdown of the coastal sluice gate sytem in Kien Giang

The main infrastructure components of the sluice gate system in Kien Giang include: (1) Sluice gate structure; (2) Gates; (3) Bridge; (4) Retaining walls and connected embankment; (5) Operation house; (6) Parks; (7) Electric system; (8) Operation and control system; (9) Monitoring system; (10) Fire extinguishing system; (11) Communication system.

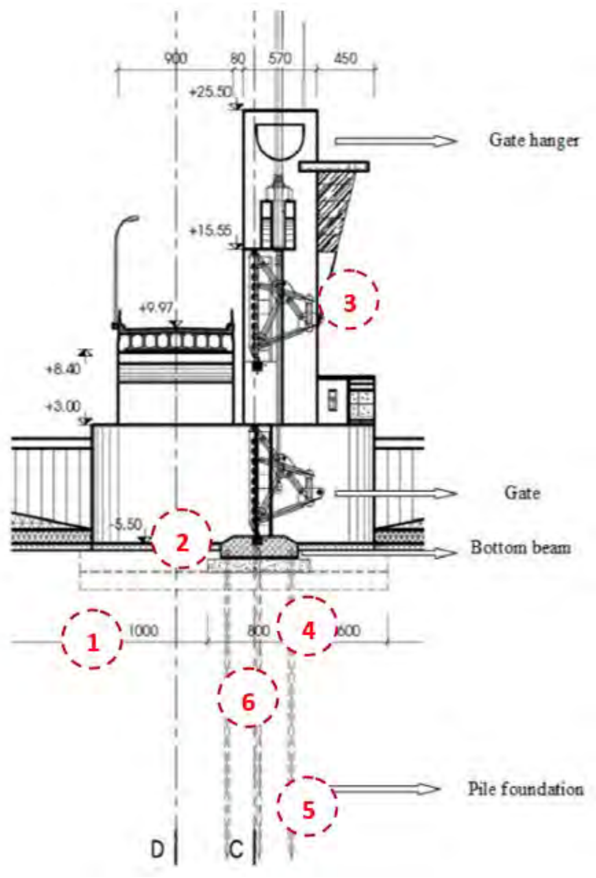
4.2.1 Sluice gate structure

The sluice gate structure is the component to arrange other components such as valve gates, gate lift system, and traffic bridges. The sluice gate structure in Kien Giang is clarified into two main types: (i) Type 1 - applicable to the gate size of less than 15m, including vertical concrete wall and concrete foundation (or monolithic concrete); (ii) Type 2 – being the form of a pillar dam, applicable to the gate size of more than 15m.



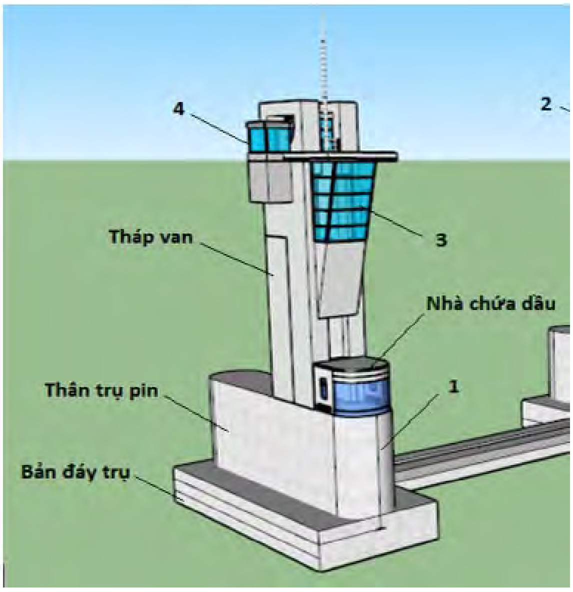
(1)- Foundation; (2)- Retaining walls; (3)- Gate lift system; (4)-Piles

Figure 4-1. Type 1 - Sluice gate structure of monolithic concrete

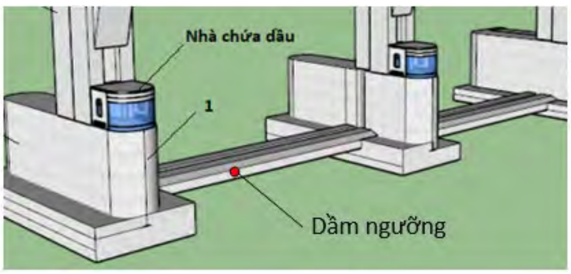


Structure of pillar

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



Overall perspective of a pillar



Overall perspective of beams

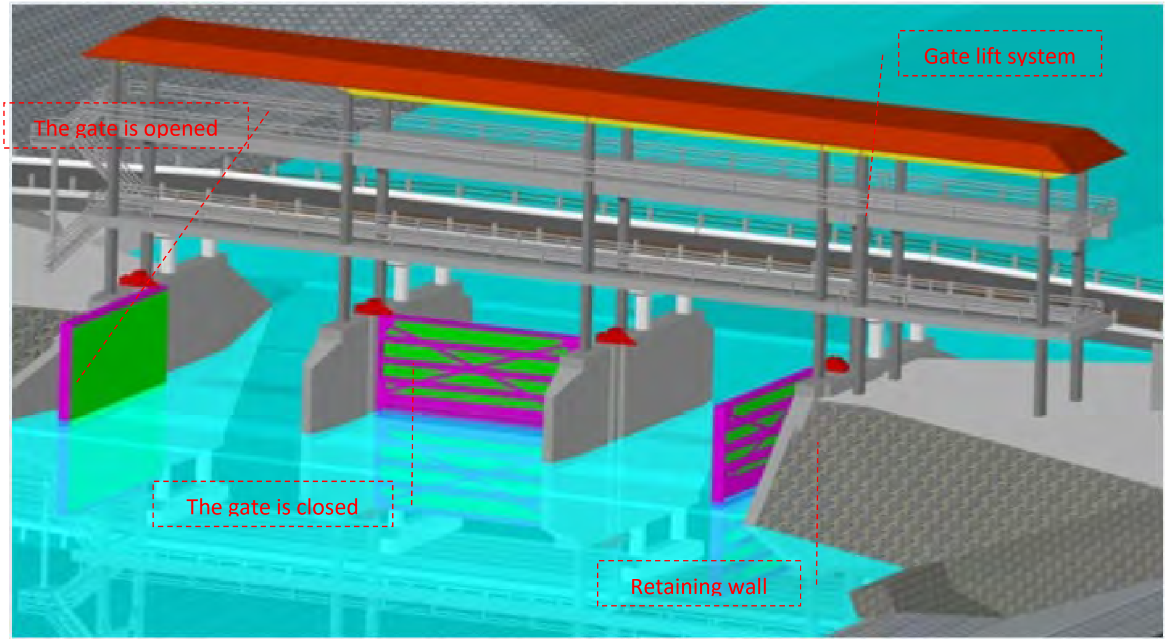
Figure 4-2. Type 2 - Sluice gate structure of pillar dam

4.2.2 *Gates*

The primary duty of a gate is to prevent and control water flowing through it. A gate is structured by the steel frame, watertight rubber gaskets and bolts. In Kien Giang, there are three types of gates as follows:

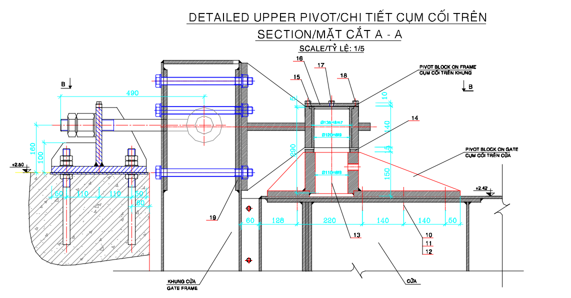
i. Automatic gates

- Mode of operation: The automatic gates are operated by rotating horizontally around one vertical axis (the axis of the upper and lower mortar). The gates are automatically closed and opened by the water column pressure on the back of the gate.



As the gate is opened for water drainage, it close to the pillar.

The gate is closed to prevent saline intrusion by the rotate along the vertical axis



Upper mortar (rotary of the gate)

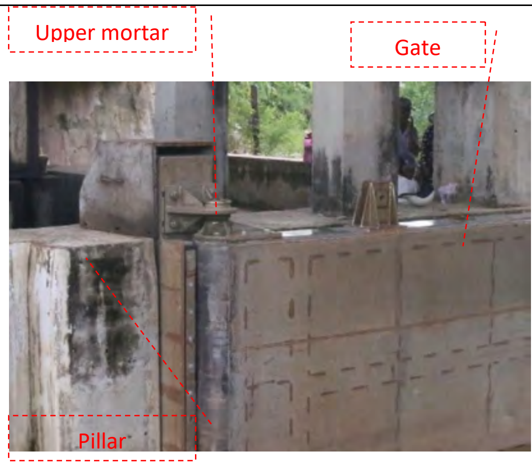


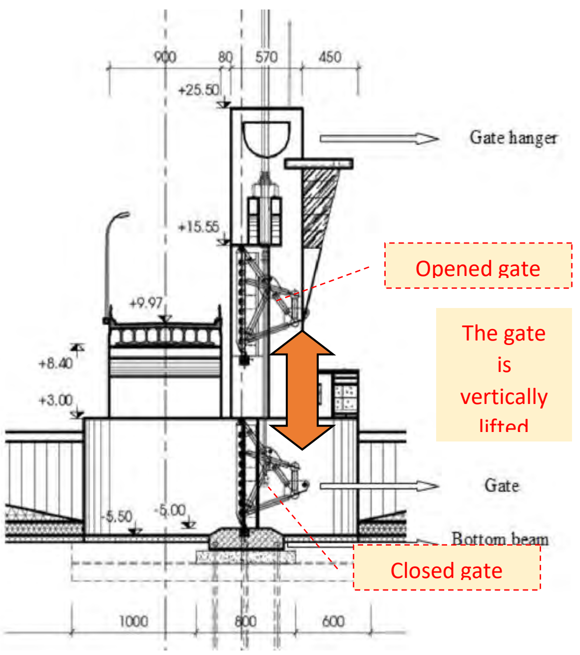
Photo of an upper mortar

Figure 4-3. Some pictures of automatic valve gate operation

- Materials of gates: The gates are commonly designed by two types of materials, including (i) CT3 or CT5 steel combined with an anti-rust epoxy coating; and (ii) Stainless steel (Sus-304). The watertight gaskets are made of rubber with P-shaped or leaf form.

ii. Vertically lifted gates

- Mode of operation: The gates are operated by hydraulic cylinder to slide vertically in the slot.



Longitudinal section of a sluice gate

Ca Lang sluice gate in Chau Thanh district, Kien Giang since 2018; the size of gate is B = 20.0m; type of flat gate; vertically lifted by hydraulic cylinder

Figure 4-4. A type of vertically lifted flat gate - Ca Lang sluice gate

- Materials of gates: The gates are mainly made of stainless steel (sus 304). The watertight gaskets are made of high-strength synthetic resin with P-shaped or leaf form.

iii. Bottom shutter gates

- Mode of operation: The gates are operated by hydraulic cylinder to rotate vertically around one axis horizontally at the bottom of the gate (lower mortar clusters).

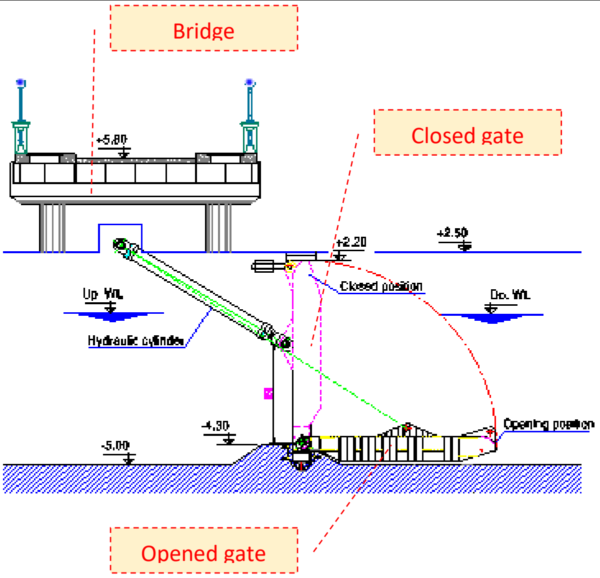
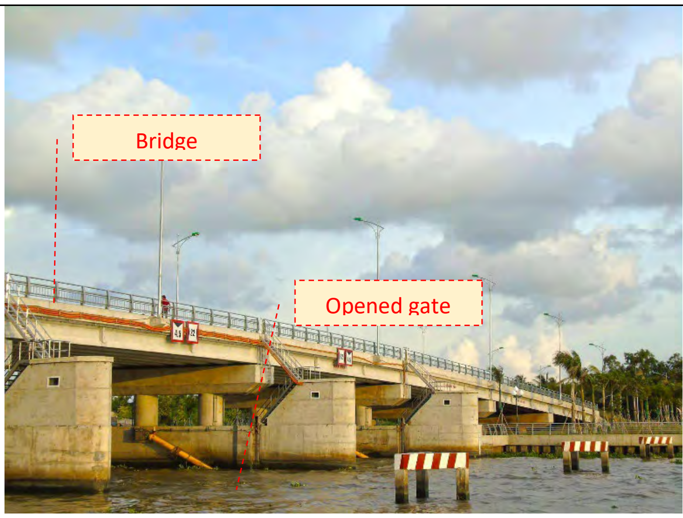


Illustration of gate arrangement and operation



Kenh Cut sluice gate in Rach Gia, Kien Giang since 2017; the size of gate is B = 22.0m; type of bottom shutter gate; operated by hydraulic cylinder

Figure 4-5. A type of bottom shutter gate - Kenh Cut sluice gate

- Materials of gates: In a similar way to automatic gates, the bottom shutter gates are commonly designed by two types of materials, including (i) CT3 or CT5 steel combined with an anti-rust epoxy coating; and (ii) Stainless steel (Sus-304). The watertight gaskets are made of rubber with P-shaped or leaf form.

4.2.3 Traffic bridge

Traffic bridges are designed with the bridge deck width and load based on the level of road or the dyke connecting to the sluice gate. Usually, the width of bridge deck is from 4.50m to 10.0m, and the average design load is from 0.65 x HL93 to 1.0 x HL93. 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.

- The bridge deck includes: (i) Load bearing layer which is made of M300 reinforced concrete and is 18-25cm thick; (ii) Water defense layer; and (iii) Plastic concrete layer with an average thickness of 6-10cm.

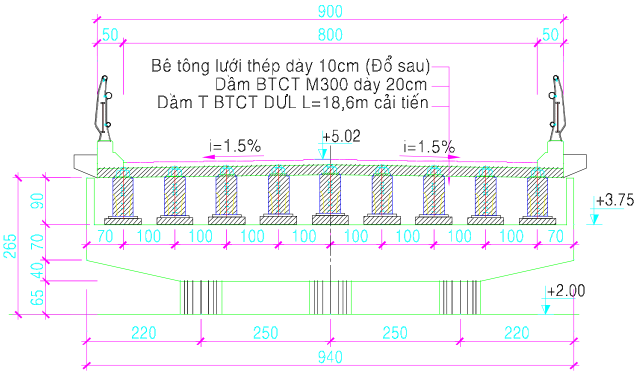


Illustration of the general layout of a bridge

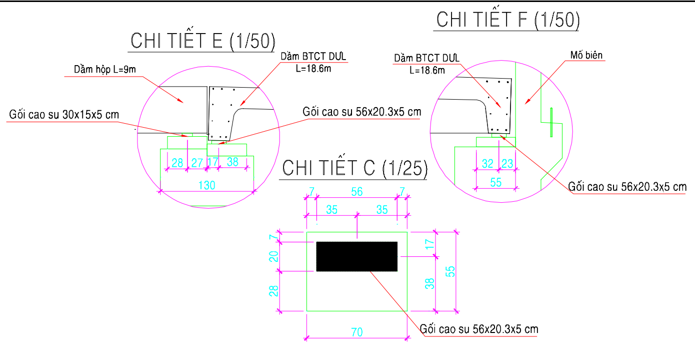
Traffic bridge of a sluice gate

Figure 4-6. General layout of traffic bridge

- The bridge beams are made of the M500 pre-stressed reinforced concrete for the large sluice gates with the gate size of more than 10 m. For the small sluice gates, the beams are made of reinforced concrete (poured on the spot).

- 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 reinforced rubber (Figure 4-7).



Rubber bearings for traffic bridges

Photo of traffic bridge bearings

Figure 4-7. Bearings of traffic bridges

- 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 reinforced concrete or CT3 steel covered by anti-rust paints.

- The drainage system of bridge deck includes water inlets, trash grating, and the conduction and drainage system of uPVC pipes.

- Piles foundation: The bridge pillars and piers are protected by the M300 reinforced concrete piles.

- 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.

4.2.4 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. The retaining walls and connected embankment for the sluice gate system in Kien Giang are mainly designed by the form of inclined roofs and made of reinforced concrete (Figure 4-8). The embankment behind the wall is filled with sand up to the design elevation.

Figure 4-8. Retaining walls and connected embankment for the sluice gates in Kien Giang

4.2.5 Operation house

The operation houses will be made of concrete and bricks and include house structures (e.g., columns, beams, front steps, windows, roofs). These houses are structured as level IV houses, with the building area of from 60-100m^2 (Figure 4-9).

Operation house –
Kenh Cut sluice gate, Rach Gia, Kien Giang

Operation house –
Ca Lang sluice gate, Chau Thanh, Kien Giang

Operation house –
Sluice gate No. 1, Rach Gia, Kien Giang

Operation house –
Kien River sluice gate, Rach Gia, Kien Giang

Figure 4-9. Photos of operation houses for the sluice gate system in Kien Giang

4.2.6 Parks

In the sluice gate system in Kien Giang, the parks on both sides of the sluice gates are mainly paved with reinforced concrete panels. However, in the central area of Rach Gia City, the parks of some sluice gates are planted trees to create a landscape.

4.2.7 Electric system

The electricity for the sluice gate system in Kien Giang is used from two main sources, including the common grid system and backup generator (Figure 4-10). For the sluice gates operated by hydraulic cylinders, the electrical system is relatively complete according to the general layout of the gates. Other sluice gates mainly use the electric systems for lighting and living in the management area. The electricity used to operate the cranes is almost inactive.

Figure 4-10. Low voltage stations, backup generators, main electrical cabinets

Regarding with lightning protection system, most sluice gates in Kien Giang have been equipped with air-termination needle on the top of the valve pull-out system. The grounding system is designed to prevent lightning on the infrastructures.

4.2.8 Operation and control system

The operation and control system for the sluice gate system in Kien Giang includes hydraulic cylinders, hydraulic and electrical systems at the operation house (Figure 4-11).


Power station for hydraulic cylinder operation


Operated by winch


Hydraulic piping system


Camera to check and operate sluice gate

Figure 4-11. Photos of operation and control system

4.2.9 Monitoring system

In the monitoring system for the sluice gate system in Kien Giang, the main component is the movement monitoring system, including the bronze landmarks placed on the sluice gates and the landmarks in the operation houses in order to check, measure, and evaluate the displacement of the infrastructures.

4.2.10 Fire extinguishing system

The fire extinguishing system is mostly only the mini CO_2 cylinders stored in the operation house and mainly used for local fire treatment (if any).

4.2.11 Communication system

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

5 ANALYSIS OF CLIMATE - HYDROLOGICAL DATA IN KIEN GIANG

5.1 Overview about climate, meteorological and hydrological data in Kien Giang

Since 2012, Kien Giang has been established many rain-gauging stations through the projects funded by World Bank, Vrain, and Korea. Currently, Kien Giang has a meteorological station (Rach Gia station) and 48 rain-gauging stations (27 World Bank measuring stations, 8 VRAIN stations, 10 local rain gauging stations, 1 Korean measuring station). The main meteorological characteristics include daily rainfall, sub-daily rainfall, daily temperatures (maximum, minimum and average values), storm, wind, thunderstorm, evaporation and humidity.

The current network of hydrological stations in Kien Giang province includes 15 water level stations (2 stations at level I and 13 stations at level III) and 6 salinity stations. In particular, the Southern Regional Hydro-meteorological Center is managing 3 water level stations and 3 salinity stations. The local stations are managed by the Department of Agricultural and Rural Development (DARD). In addition, there are some temporary measuring stations set up from the involved projects. In this study, the data for CRA was mainly from the main stations, the local stations and the temporary measuring stations. Based on the factors of measurement, the main stations are classified into 4 groups, including: water level and salinity stations; salinity stations (3 stations); water level stations; and water level and discharge stations (1 station) (Figures 5-1 and 5-2).

The water level dataset is almost 33 years from 1988 to 2020. The salinity data are almost 24 years from 1996 to 2020, measured every 2 hours (12 measurements/day) and 5 - 7 days/month at the high tide period during the dry season.

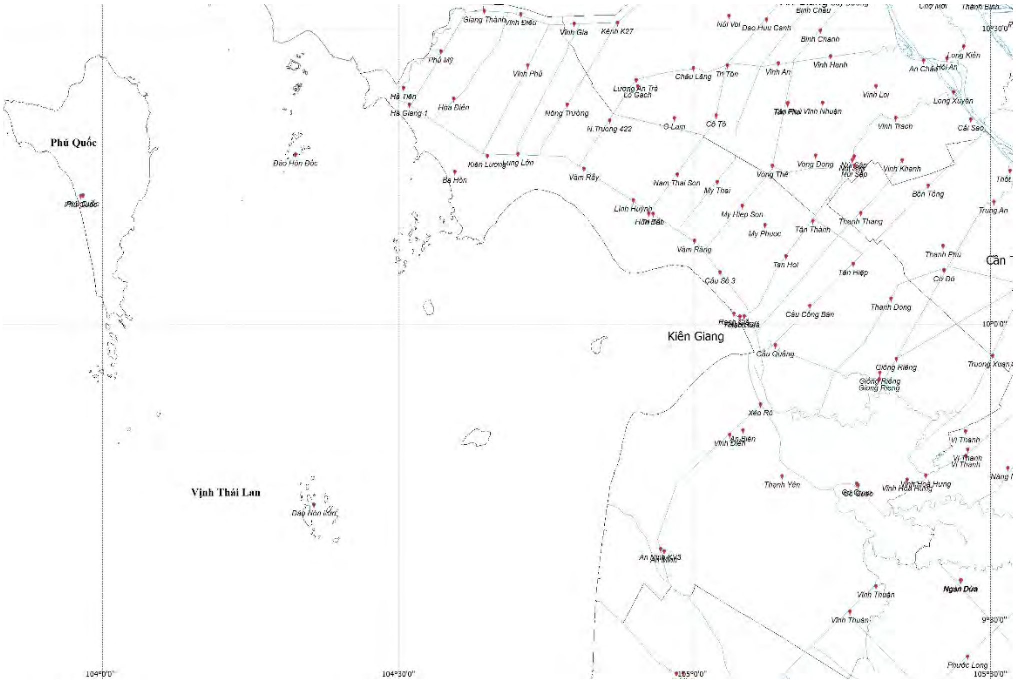


Figure 5-1. Rain-gauging station network in Kien Giang

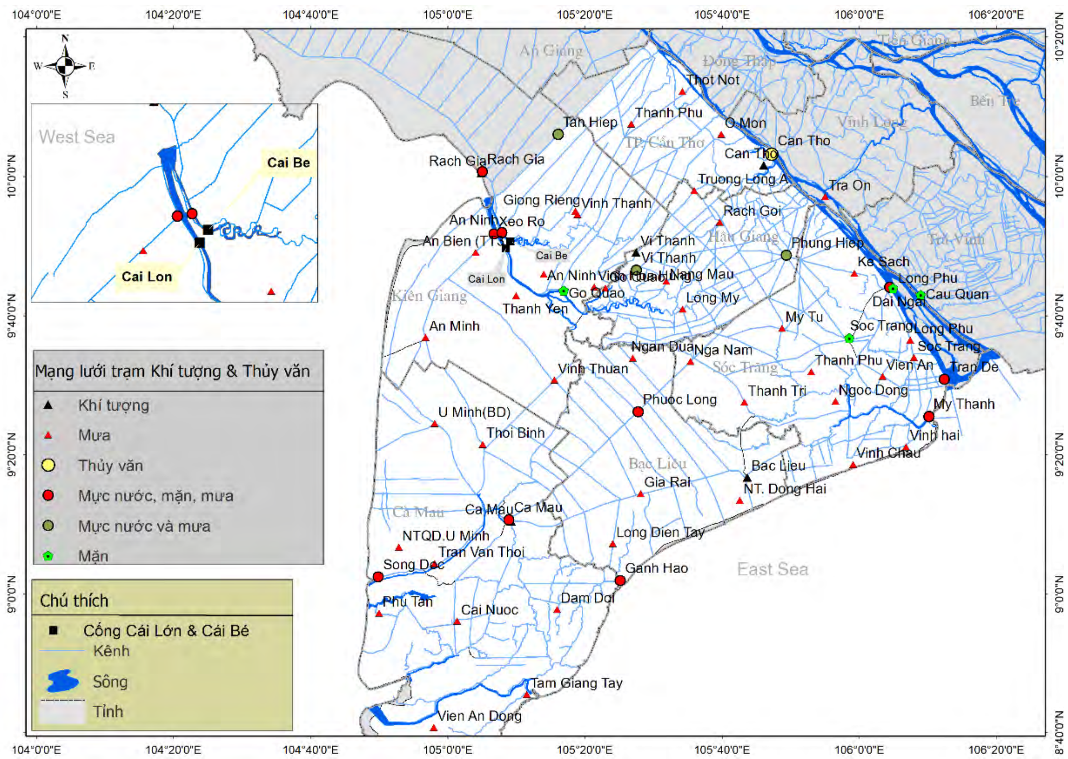


Figure 5-2. Climate and hydrological station network in Ca Mau Peninsular

5.2 Climate and hydrological analysis and projections

The climate and hydrological factors which may affect the coastal sluice gate system in Kien Giang 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; High water level combined with heavy rain; Salinity intrusion combined with high temperature.

Climate and hydrological data for CRA are analysed by the traditional statistical methods and the Climate Change Hazards Information Portal (CCHIP) tool (https://go.cchip.ca/) provided by Engineers Canada and Risk Sciences International (RSI). The probability scores are assigned between 0 and 7 as described in Table 5-1.

The time frame for historical data analysis is as follows:

- The 33-year data (1988-2020) at the Rach Gia meteorological station for climatic factors, such as rainfall, temperature, evaporation, wind, and thunderstorm days;
- The 32-year data (1988-2017 and 2019-2020) at 10 local rain gauges in Kien Giang province (particularly, the data in 2018 was recorded from June to December);
- The 33-year data (1988-2020) for tropical storms/depression;
- The 10-year statistical data (2005-2015) of damages caused by natural disasters such as lightning and tornado;
- The 33-year data (1988-2020) at 3 hydrological stations for water level;

- The 24-year data (1996-2020) at 3 hydrological stations for salinity, except for 2004 with only one month of data (so will not be used in the analysis).

The projections have been taken into account for each of the selected climate - hydrological factors up to the year 2100. Probability scores have been determined for both historical condition and future forecast under the low to high emission scenarios (i.e. RCP4.5 and RCP8.5) in the report of MONRE (2016) on "climate change and sea level rise" scenarios.

Table 5-1. Probability scores in the PIEVC

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

5.2.1 Heavy rain

5.2.1.1 Historical data analysis

Heavy rain has been defined as the average number of days in a given year, that had a total rainfall greater than or equal to 100 mm within a 24-hour period, with a data series length of 33 years (1988-2020) of 12 rain gauging stations in Kien Giang province. These stations are divided by the climate zoning of Kien Giang in Table 5-2.

Table 5-2. Rain gauging stations by the Climate-hydrological zones in Kien Giang

Climate-hydrological zones	Rain gauging stations
Long Xuyen Quadrangle region	Ha Tien, Hon Dat, Rach Gia, Kien Luong
Western region of Bassac River	Go Quao, Vinh Hoa Hung, Giong Rieng, Tan Hiep
U Minh Thuong region	An Minh, Vinh Dien, Xeo Ro, Vinh Thuan

The 33-year (1988-2020) rainfall data showed that the total annual average rainfall in UMT region is largest, followed by LXQ region and the WBR. The average number of rainy days in U Minh Thuong region (141.4 days) is also higher than other regions (126.5 and 136.1 days for LXQ region and the WBR, respectively). However, the number of days with heavy rain in the LXQ region dominates, almost twice as high as that of the WBR. The daily average frequency of heavy rain in the LXQ region, the WBR and the UMT region are 0.86, 0.44 and

0.61, respectively (Table 5-3). As a result, the PIEVC probability score for heavy rain in the LXQ region has been estimated to be “5”, while the corresponding value for the WBR and the UMT region is “4”.

Table 5-3. Heavy rain in the period of 1988-2020

No.	Station	The number of rainy days per year (1988-2020)	Maximum 1-day rainfall (mm)
Long Xuyen Quadrangle region			
1	Ha Tien	0.62	182.5
2	Rach Gia	0.73	220.3
3	Kien Luong	1.03	189.1
4	Hon Dat	1.06	189.9
Average value		0.86	
Probability score		5	
Western region of Bassac River			
1	Go Quao	0.61	167.0
2	Vinh Hoa Hung	0.53	188.0
3	Giong Rieng	0.38	148.1
4	Tan Hiep	0.25	211.5
Average value		0.44	
Probability score		4	
U Minh Thuong region			
1	An Minh	0.76	267.8
2	Vinh Dien	0.63	216.3
3	Vinh Thuan	0.33	131.0
4	Xeo Ro	0.72	194.0
Average value		0.61	
Probability score		4	

In 2020, the number of days with the heavy rain ≥ 100m in Kien Giang is higher than the years in the 33-year data series (Figure 5-3). The historical data showed that the average number of days with heavy rainy in 3 regions of LXQ, UMT and WBR tend to increase.

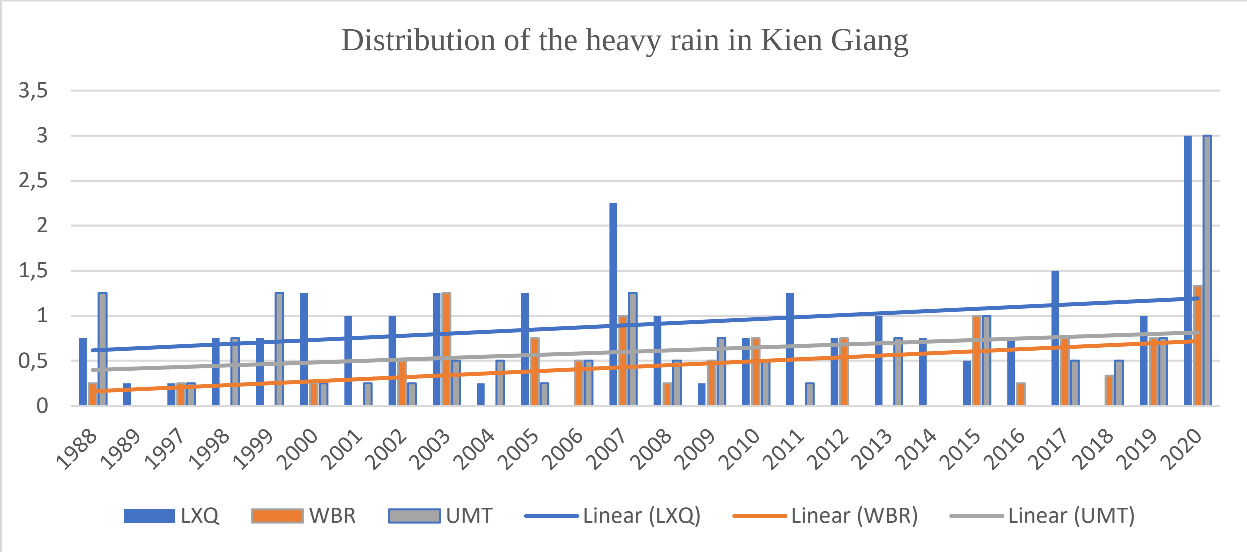


Figure 5-3. Distribution of the heavy rain in the period of 1988-2020

5.2.1.2 *Projections*

The daily maximum total rainfall is forecasted based on the climate change-sea level rise scenarios in Vietnam (MONRE, 2016) and the CCHIP tool. The results showed that the daily maximum total rainfall in Kien Giang has the high increasing rate across the country. Under the RCP8.5 scenario, this increase is from 50% to 70% at the middle and end of the century. This forecast is also consistent with the forecast from the CCHIP tool (Figure 5-4). For the RCP8.5 scenario, the WBR has the highest increasing rate of the daily maximum total rainfall, while the LXQ region has the highest increasing rate for the RCP4.5 (Figure 5-5).

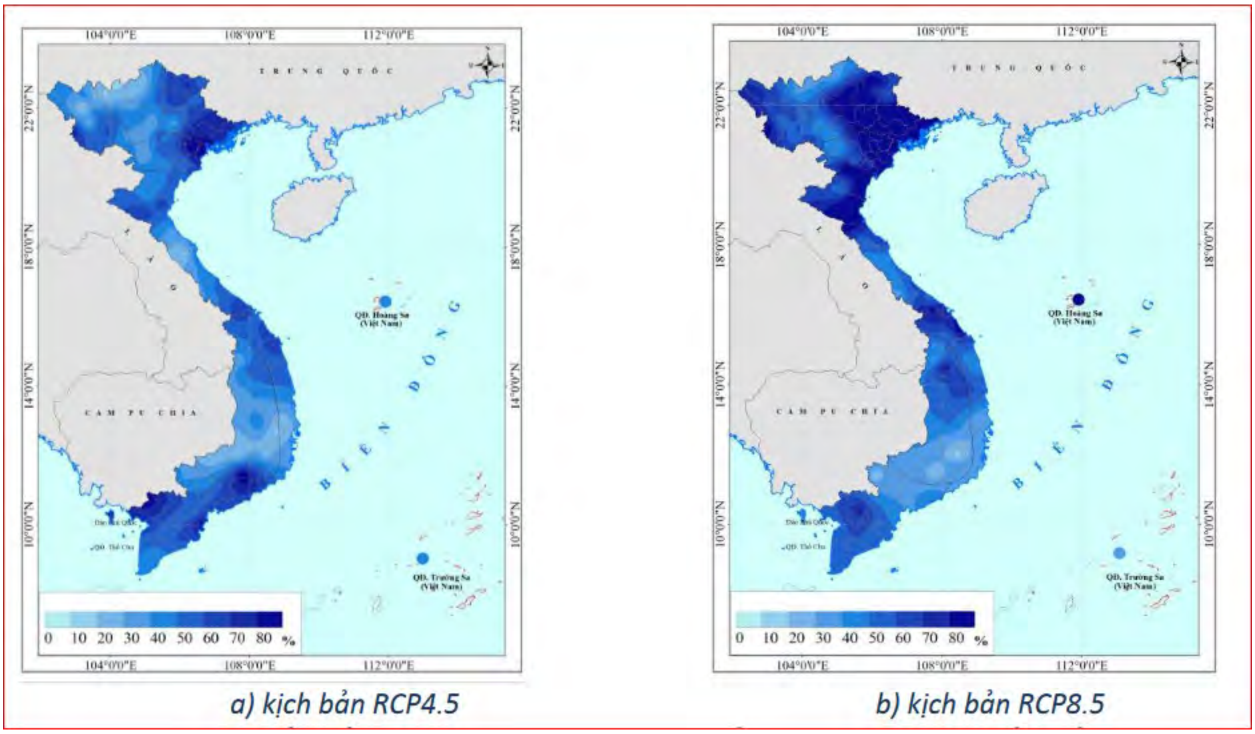


Figure 5-4. Daily maximum total rainfall in Vietnam for the RCP4.5 and RCP8.5 scenarios

The results of the CCHIP tool for the projection of heavy rain at the meteorological stations in Kien Giang province under the RCP8.5 scenario showed that there is an increase of the heavy rain events (ref. Table 5-4). Therefore, the PIEVC probability score for this factor in the future has been estimated to increase to "6" for the LXQ region, and “5” for the WBR and UMT region.

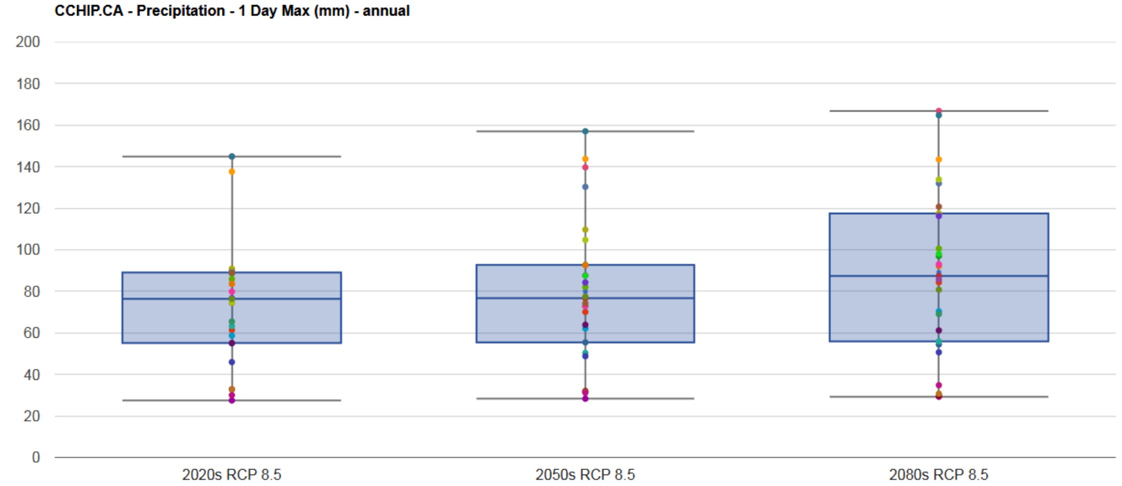


Figure 5-5. Daily maximum total rainfall at the Rach Gia station for the RCP8.5 scenario

Table 5-4. The average number of heavy rain days for the RCP8.5 scenario

No.	Station	Day/year		
		1988 – 2020	2041 - 2070	2071 - 2100
Long Xuyen Quadrangle region				
1	Rach Gia	0.73	0.97	1.1
Western region of Bassac River				
1	Go Quao	0.61	0.6	0.5
2	Vinh Hoa Hung	0.53	0.7	0.73
	Average value	0.54	0.65	0.62
U Minh Thuong region				
1	Xeo Ro	0.72	0.9	1.03
2	Vinh Thuan	0.33	0.33	0.43
3	An Minh	0.76	0.8	1.03
Average value		0.60	0.68	0.83

5.2.2 Heavy 5-day total rainfall

5.2.2.1 Historical data analysis

In order to consider the impacts of the heavy rains on the infrastructure, this report also considered the number of the heavy 5-day total rainfall occurrences in a given year, where the heavy 5-day total rainfall was defined as a period of 5 consecutive days with a total rainfall being more than or equal to 250 mm. The historical data at the meteorological stations in Kien Giang for the 5-day heavy rainfall occurrences in a year is summarised in Table 5-5.

In addition, the average number of days with heavy rain in U Minh Thuong region is higher than the LXQ region and the WBR. Most of districts in the UMT region has a least one heavy rain every year. In particular, Vinh Thuan has two 5-day heavy rains every year. For the LXQ region, the number of days with 5-day heavy rains every year in Kien Luong Districts is highest (1.14 days/year). In short, the historical probability scores of this climate factor has been estimated to be "5" for the UMT region, “4” for the LXQ region, and “3” for the WBR.

Table 5-5. The heavy 5-day total rainfall in the period of 1988-2020

No.	Station	The number of rainy days per year (1988-2020)	Maximum 1-day rainfall (mm)
Long Xuyen Quadrangle region			
1	Ha Tien	0.55	314.2
2	Rach Gia	0.58	410.2
3	Kien Luong	1.14	408.7
4	Hon Dat	0.69	410.7
Average value		0.73	
Probability score		**5**	
Western region of Bassac River			
1	Go Quao	0.15	283.3
2	Vinh Hoa Hung	0.24	316.4
3	Giong Rieng	0.13	310.5
4	Tan Hiep	0.34	377.4
Average value		0.20	
Probability score		**4**	
U Minh Thuong region			
1	An Minh	1.3	420.0
2	Vinh Dien	2.06	421.2
3	Vinh Thuan	0.31	298.7
4	Xeo Ro	1.00	371.5
Average value		1,17	
Probability score		**4**	

For the 1-day heavy rain ≥ 100, the LXQ and TSH regions increase, while the UMT region tends to decrease. The number of 5-day heavy rains has an increasing trend in the LXQ and UMT regions, but there is little change in the WBR (Figure 5-6).

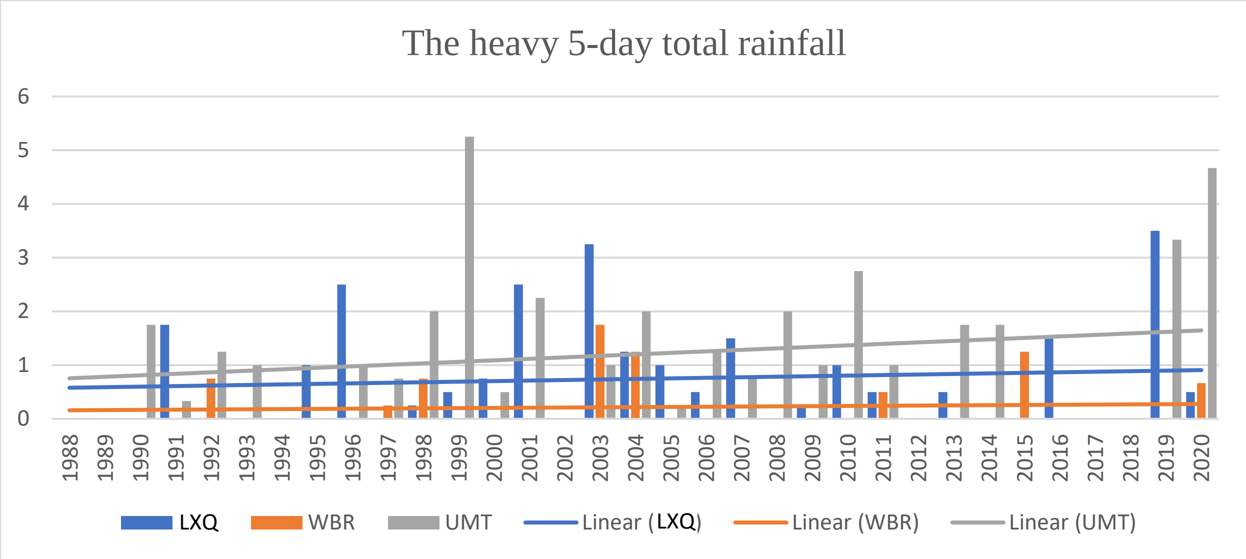


Figure 5-6. The heavy 5-day total rainfall in the period of 1988-2020

5.2.2.2 Projections

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.

In the context of increasingly unpredictable climate change, the daily extreme heavy rainfall and the average 5-day maximum rainfall tend to increase, so the number of 5-day heavy rains is forecasted to increase in the future, especially in the WBR and LXQ region. Thus, the future probability score of the number of the 5-day heavy rain occurrences has been estimated to remain as "5" for the UMT region, and increase to “5” and “4” for the LXQ region and the WBR, respectively.

5.2.3 High temperature

5.2.3.1 Historical data analysis

In this report, the value of high temperature has been defined as the average number of days in a year when the maximum temperature is greater than 35°C. To analyse historical data of high temperature, the representative meteorological stations for the LXQ region were Rach Gia, for the WBR region were Rach Gia and Can Tho, and for the UMT region were Rach Gia and Ca Mau. The high temperatures for these regions were shown in Table 5-6. In detail, the UMT region had the highest high temperature (9.1 days/year), which was followed by the WBR and LXQ region (8.4 and 7.2 days/year, respectively). The maximum temperature in the past 33 years had the small difference between Ca Mau and Rach Gia stations (37.4ºC and 37.2ºC).

Table 5-6. The maximum, average and high temperature (1988-2020)

Station/region	Maximum temperature	Average temperature	High temperature
Rach Gia station	37.2	31.0	7.2
LXQ region			**7.2**
Rach Gia station	37.2	31.0	7.2
Can Tho station	36.7	31.7	9.7
WBR region			**8.4**
Ca Mau station	37.4	32.6	11.1
Rach Gia station	37.2	31.0	7.2
UMT region			**9.1**

The high temperature tended to decrease in the LXQ and UMT regions, but increase in the WBR. This was also consistent with the 2016 report of MONRE on the climate change and sea level rise scenarios. As a result, the probability score of high temperature for all 3 regions of LXQ, UMT and WBR was "6".

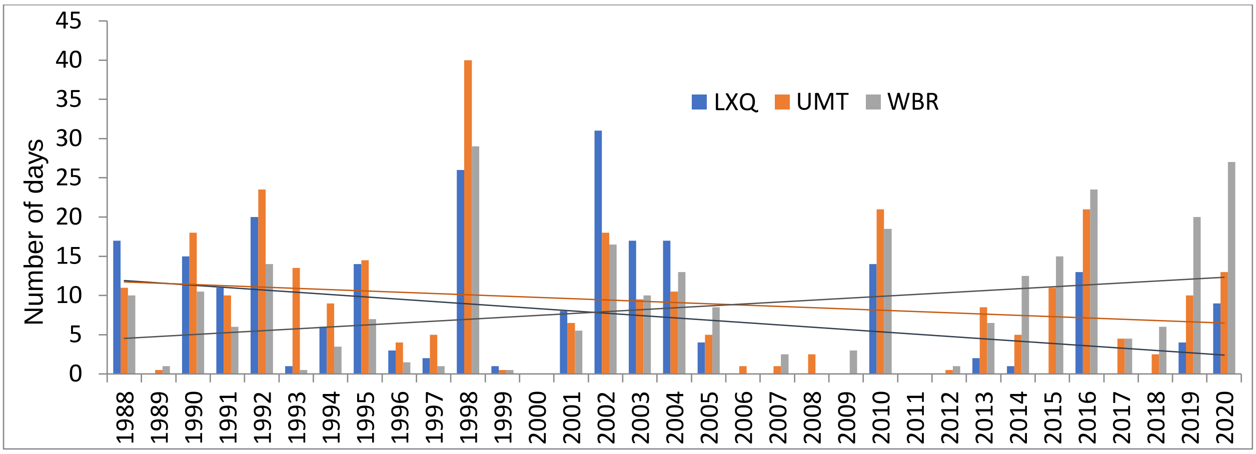


Figure 5-7. The distribution of high temperature in the period of 1988-2020

5.2.3.2 Projections

According to the RCP8.5 scenario of MONRE (2016), the number of days with high temperature at the mid-century in Ca Mau, Kien Giang and Can Tho increase compared to the whole country. This increase is 31-40 days for Kien Giang and 41-60 days for Ca Mau and Can Tho. At the end of the century, the corresponding increase are 81-90 days for Kien Giang and over 100 days for Ca Mau and Can Tho.

In Phase 1, the results from the CCHIP tool for the RCP 8.5 scenario in Kien Giang province indicated that the number of days with the high temperature increases to 13.7 days per year at the beginning of the century (to 2040), 36.3 days per year at the mid-century (1941 - 2070) and 88 days per year at the end of the century. These results are also consistent with the report of MONRE (2016). Thus, the future projections under the RCP8.5 scenario for the

WBR, UMT and LXQ regions will increase 91-100 days, over 100 days, and 70-90 days at the end of the century.

In addition, the CCHIP tool also gave an average maximum temperature increase of 0.6 - 0.7°C at the beginning of the century, 1.7°C in the mid-century, and 3.0°C at the end of the century. Meanwhile, the report of MONRE (2016) showed that the average annual maximum temperature increases from 1.6÷2.4°C in the mid-century, and 3.0÷4.2°C at the end of the century. As a result, the future probability scores of the high temperature for all three regions of LXQ, WBR, and UMT has been estimated to increase to "7".

5.2.4 Heat wave

5.2.4.1 Historical data analysis

In this CRA, heat wave has been defined as a period of 8 or more consecutive days in which the maximum temperature is greater than or equal to 35°C. According to the termperature data in the period of 1988 to 2020, the number of heat waves in Rach Gia, Ca Mau and Can Tho are 4, 5 and 9 respectively. As a result, the average number of heat waves for the LXQ, UMT and WBR are 0.125, 0.141, and 0.172 respectively. Thus, the probability score of heat wave for the historic period has been estimated to be "3" for LXQ and UMT regions, and "4" for the WBR region.

Table 5-7. The average number of heat wave (1988-2020)

Station/Region	The number of heat wave in the period of 1988-2020	The average number of heat wave
Rach Gia station	4	0.121
Can Tho station	9	0.273
Ca Mau station	5	0.152
LXQ region	4	0.121
WBR region	6.5	0.197
UMT region	4.5	0.136

For the trend of heat wave, Figure 5-7 illustrates that the number of days with the temperature over 35°C has slightly increased in the period of from 2013 to 2020. However, the heat wave tends to decrease in the Rach Gia.

In general, the number of heat waves in Kien Giang were concentrated in the first half of the period 1988-2020. Since 2003 until now, there has been no large-scale heat wave in Kien Giang. Meanwhile, since 2010, the frequency of occurrence of heat waves in Can Tho and Ca Mau tends to increase. In Figure 5-8, the trend of heat wave in the LXQ and UMT regions are decreasing, while the WBR region is increasing.

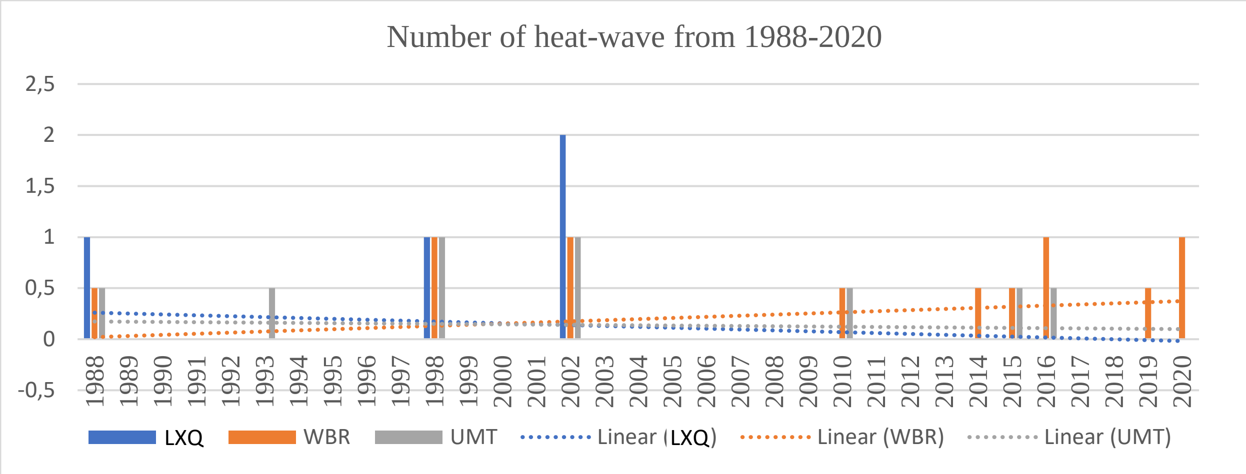


Figure 5-8. Distribution of heat wave in the period of 1988-2020

5.2.4.2 Projections

The projections of MONRE (2016) and the CCHIP tool have indicated that the number of days with high temperature will increase in the Mekong Delta, especially in the WBR and UMT regions the end of the century. The corresponding values for WBR, UMT and LXQ regions will be 91-100 days, over 100 days, and 70-90 days, respectively. The 1988-2020 data analysis also showed that the number of days with high temperature will increase in the WBR region. As a result, the trend of heat wave to the end of the century will increase in all three regions. Thus, the future probability scores of heat wave for the LXQ, UMT and WBR regions have been estimated to be “4”, “5”, and “6” respectively.

5.2.5 Tropical storms/depression

5.2.5.1 Historical data analysis

A storm event, for the purposes of this assessment, is defined to be a tropical cyclone in which the strongest wind is from level 8 (equivalent to the windy speed of 62 - 74km/h) or more, and may appear as wind gusts. In this study, the concept of tropical storms/hurricanes was understood as the number of storms directly affecting the study area in a year. Table 5-8 summarized the number of the tropical storms and depressions in the Southern Vietnam area for the period from 1988 to 2019. This data showed that a storm landed into the study area about every 6.6 years. Thus, the historical probability score of the tropical storms for three regions has been estimated to be "3".

According to the statistical data (1988 – 2020), the number of tropical storms and depressions in the East Sea was 292, of which 194 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). Of the five storms that hit the study area, tropical storm Linda in November 1997 was the strongest and most damaging of the past 100 years (Figure 5-9). As this storm swept through the study area, the highest wind speed observed in Ca Mau province was 28.0 m/s.

Table 5-8. 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** refer to the storms that directly affect the study area. Source: Hydro-meteorological Data Center

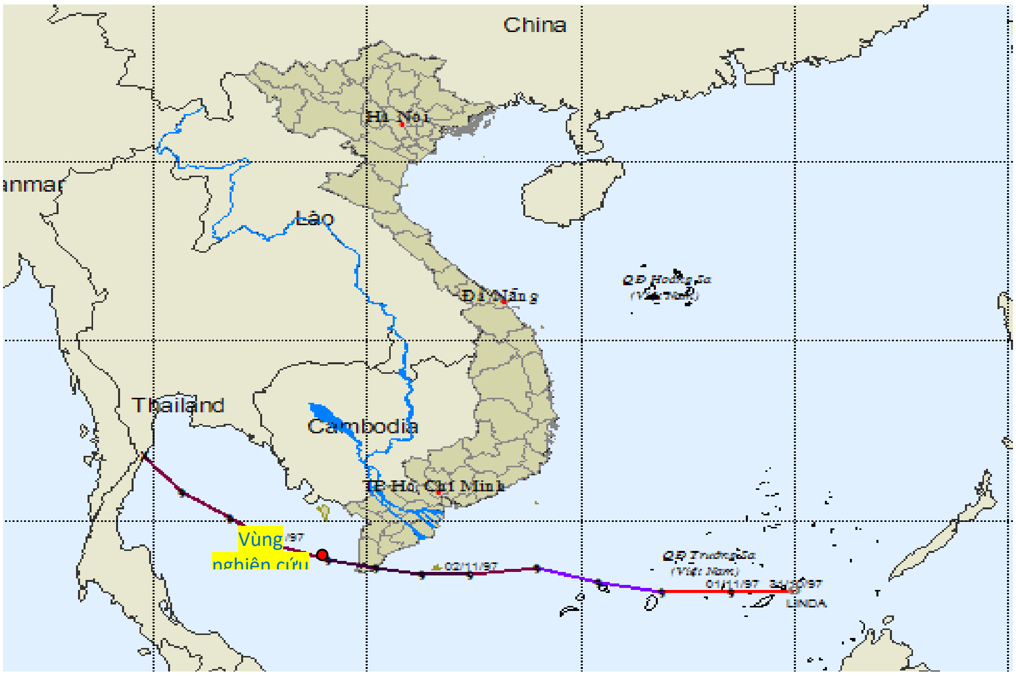


Figure 5-9. The path of tropical storm Linda (November 1997)

5.2.5.2 Projections

With regard to estimation of trends associated with tropical storms and depressions in the 21st century, the IPCC's most recent assessment showed that it is not possible to 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 tends 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.

Thus, the frequency of storm occurrences in the Southern Vietnam is expected to increase, compared to the historical data. The probability score for tropical storms and depressions in the future for three regions has been estimated to be "4".

5.2.6 High wind

5.2.6.1 Historical data analysis

In this CRA, high wind was defined as the average number of days in which the wind speed is more than 20 m/s (equivalent to the end of level 12 of the Beaufort scale). The historical data (1988-2020) showed that the number of high wind for the LXQ was 0.91 days/year, while the corresponding value for the WBR and UMT regions was 0.58 days/year. Therefore, the probability score of the high wind in the past has been estimated to be “4” for the region and “3” for the WBR and UMT regions.

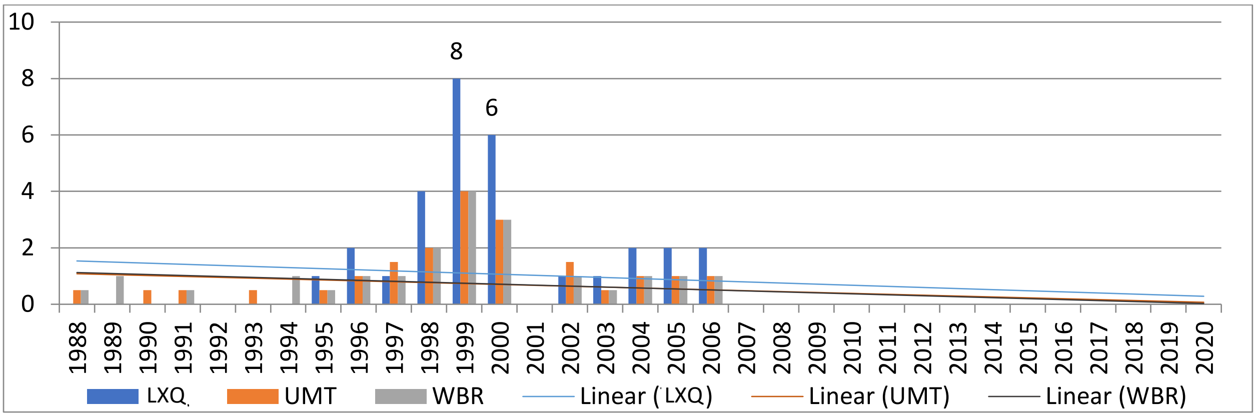


Figure 5-10. Distribution of high wind in Kien Giang (1988-2020)

The distribution of high wind in Kien Giang was mainly concentrated in the period of 1995-2006 (ref. Figure 5-10). The trend of the high wind tended to decrease in three regions.

5.2.6.2 Projections

According to the report of MONRE (2016), there is no forecast for the frequency of high winds in the future. Therefore, the future probability score of the high wind has been estimated to remain unchanged at “4” for the region and “3” for the WBR and UMT regions.

5.2.7 Tornado

5.2.7.1 Historical data analysis

According to Decision No. 46/2014/QD-TTg, tornadoes are the swirling winds with the same speed as the wind speed of storms, but they are formed and disappear in a short time with the narrow range of activity, from several square kilometres to several dozen square kilometres. In the study area, there is no measurement or research on this weather phenomenon. In this report, the concept of tornado was determined by the average number of tornadoes recorded in a given year. According to the report of the Provincial Committee for Flood and Storm Control, and Search and Rescue of Kien Giang, there are at least 1-2 tornadoes recorded in a year. As a result, in the CRA for Cai Lon-Cai Be sluice gates, the historical probability score of tornadoes at the location of these sluice gates was “1”. However, the historical probability score of tornadoes in the CRA for the coastal sluice gate system in Kien Giang is higher due to the larger impact range. In detail, historical probability score of tornadoes for the LXQ, WBR and UMT regions has been estimated to be “3”.

According to the statistical data on the damages caused by tornadoes in the period of 2005 - 2020, tornadoes almost occurred every year in Kien Giang. However, this data only recorded the damages from tornadoes, but has not assessed the actual number of tornadoes occurred. Therefore, it is difficult to assess the trend of this phenomenon in the past.

5.2.7.2 Projections

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. Thus, the probability score of tornadoes in the future has been estimated to be "4".

5.2.8 Thunderstorm/lightning

5.2.8.1 Historical data analysis

According to the Decision No. 46/2014/QD-TTg, lightning is the phenomenon of suddenly electrical discharge from or within a cloud. In this study, lightning has been defined as the number of lightnings whose damages are recorded in a year. According to the report of the Provincial Committee for Flood and Storm Control, and Search and Rescue of Kien Giang, there were about from 1 to 3 lightning events which strike people every year in the province.

Thunderstorms/lightning mainly occur in the beginning period of each season and in the rainy season. The 1988 – 2020 data analysis showed that the number of days with thunderstorms/lightning in the LXQ, UMT and WBR regions were 98.0, 96.5 and 85.7 respectively. In general, the difference in the number of days of thunderstorm occurrence in the regions is not much.

The number of days with thunderstorms/lightning tend to increase in all three regions (Figure 5-11). In the 33-year period, the number of days of thunderstorms was usually concentrated in the first half in Ca Mau, in the middle in Can Tho, and at the early stage and in recent years in Rach Gia. Therefore, the historical probability score of thunderstorm/lightning has been estimated to be "5" for the LXQ and UMT regions, and "4" for the WBR region.

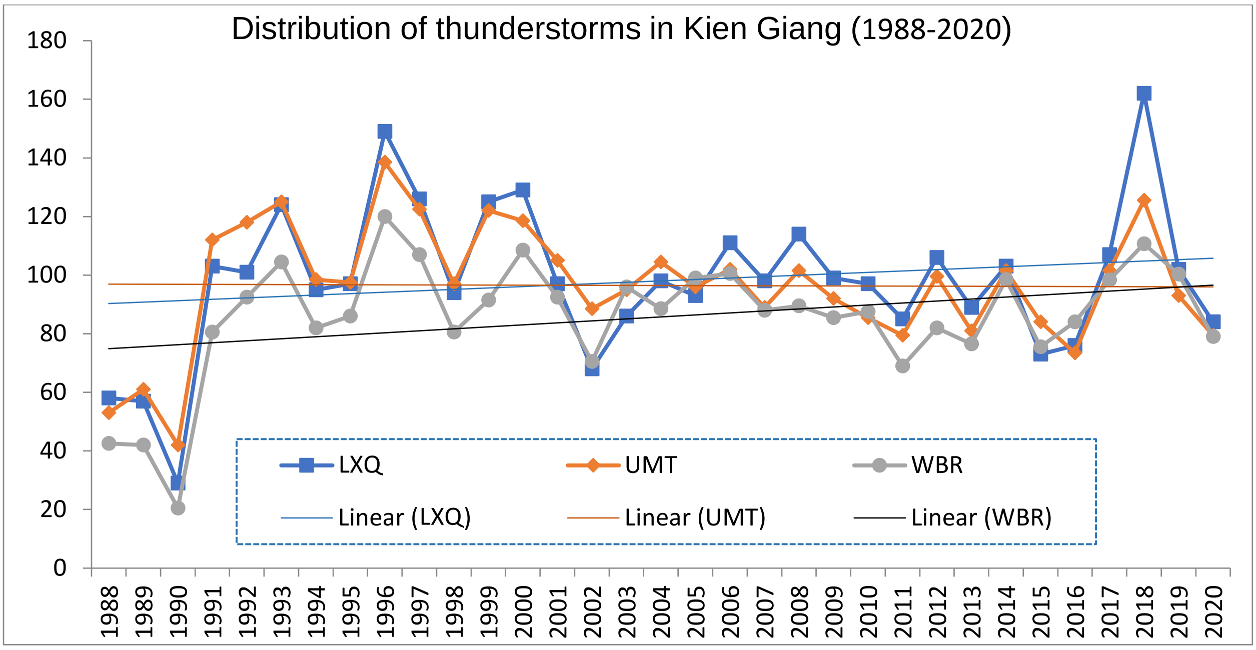


Figure 5-11. Distribution of thunderstorms in Kien Giang (1988-2020)

5.2.8.2 Projections

At present, there have been no forecasts for the trend of thunderstorm/lightning in the future. However, in the context of increasingly unpredictable climate change, the trend of extreme weather events will occur with more frequency. Meanwhile, the historical calculation results also showed an increasing trend of thunderstorm/lightning in Kien Giang. Thus, the future probability score of thunderstorm/lightning has been estimated to be "6" for the LXQ and UMT regions, and "5" for the WBR region.

5.2.9 Drought

5.2.9.1 Historical data analysis

In this study, drought was defined by the number of years that the water balance factor K in the dry season is greater than 4. The data analysis from 1988 to 2020 at the Rach Gia, Can Tho and Ca Mau stations showed that there were 19 drought events in the WBR region (corresponding to the frequency of 57.6%), and 14 drought events in the LXQ and UMT regions (corresponding to the frequency of 42.4%). Thus, the historical probability score for the drought for all three regions has been estimated to be “5”.

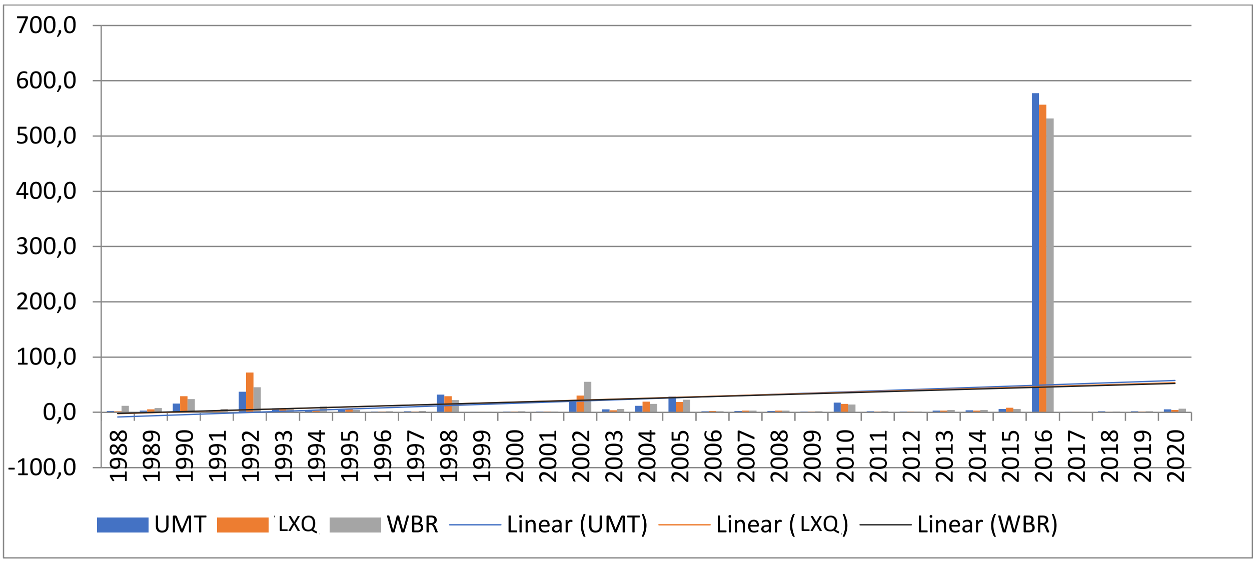


Figure 5-12. The rate K between evaporation and rainfall from December to April

The K value (556.9) in the dry season of 2016 was significantly higher than other years in the historical data series (ref. Figure 5-12). This year is also recorded as the most severe drought event in the Mekong Delta in the past 100 years. At the time, Kien Giang had the consecutive 5 months without rain. The corresponding values in Ca Mau and Can Tho were 3 and 4 months. In summary, drought events mainly occurred from December to May, where the months from February to April had the highest shortage of rainfall.

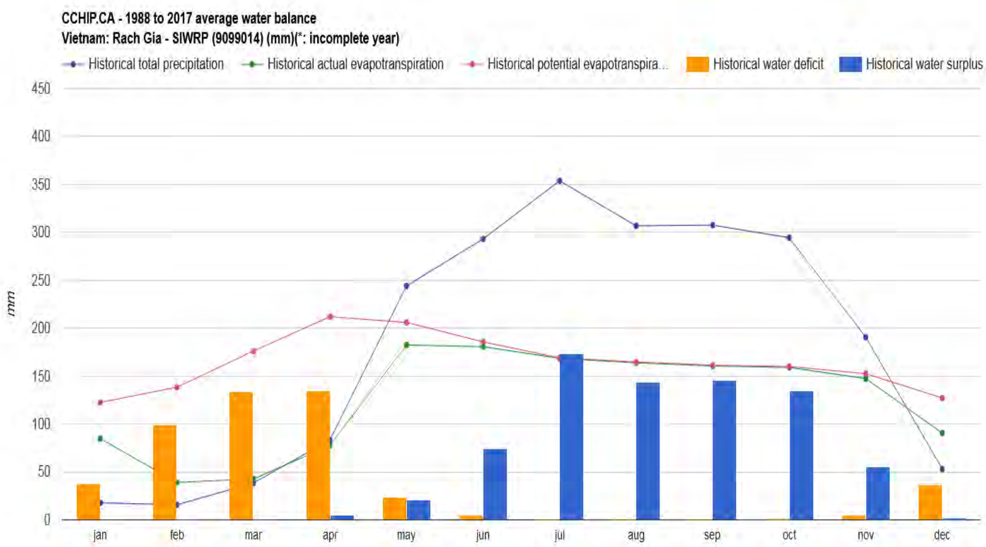


Figure 5-13. Monthly average amount of deficit water and excess water at the Rach Gia station in the period of 1988-2017

5.2.9.2 Projections

According to MONRE (2016), temperature is predicted to have an increasing trend in the 21st century. The number of days with high temperature strongly increases at the end of the century, and the dry season in Kien Giang is also expected to be more severe. For the RCP8.5 scenario, the rainfall in March and April in the LXQ and WBR regions and the rainfall from March to May in the UMT region have little change in the future, while the remaining months will increase (Figures 5-14, 5-15 and 5-16).

Also, the average temperature in the winter and spring months (December to May) in Ca Mau, Kien Giang, Can Tho will increase. The RCP8.5 scenario has an increase of 0.8-0.9°C at the beginning of the century, 1.8-1.9°C in the mid-century, and 3.2-3.4°C at the end of the century. The number of hot days and the evaporation are also increasing. The water balance K also showed that the rainfall is much smaller than the evaporation in the dry season. In short, drought events are anticipated to become more severe in the future. Thus, the future probability score of drought for three regions has been estimated to be "6".

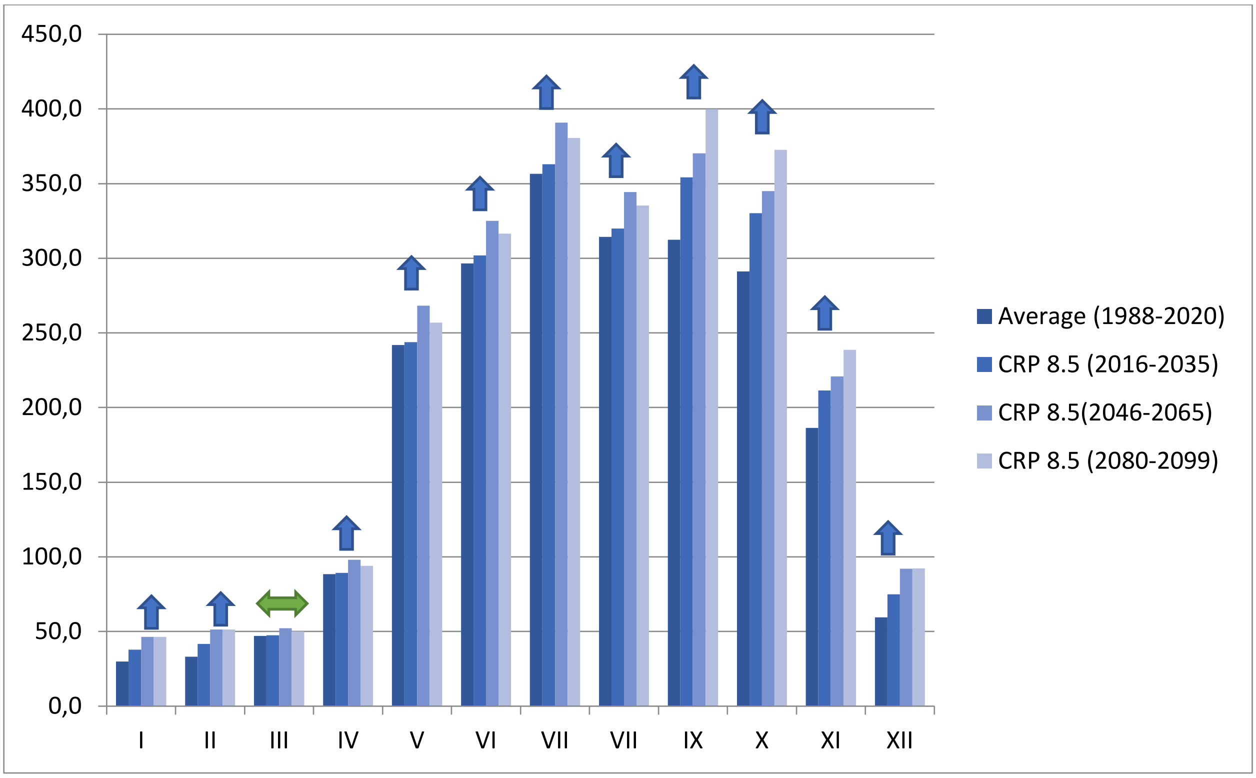


Figure 5-14. Scenario RCP8.5 for monthly average precipitation for the LXQ region

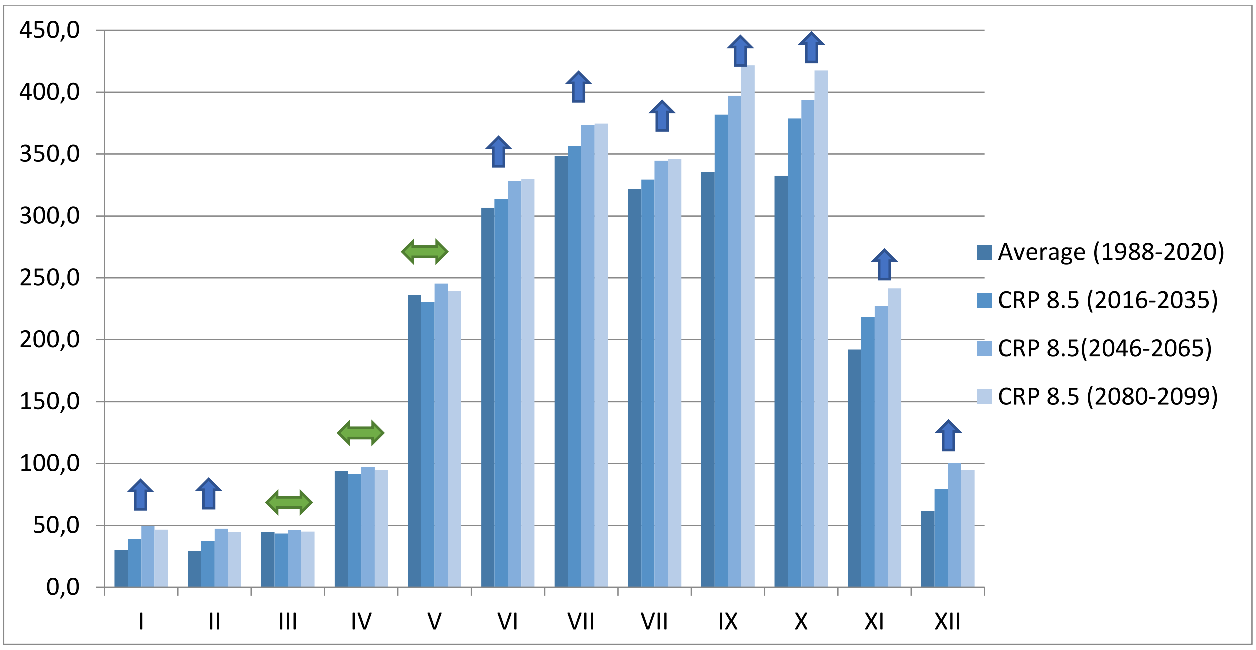


Figure 5-15. Scenario RCP8.5 for monthly average precipitation for the UMT region

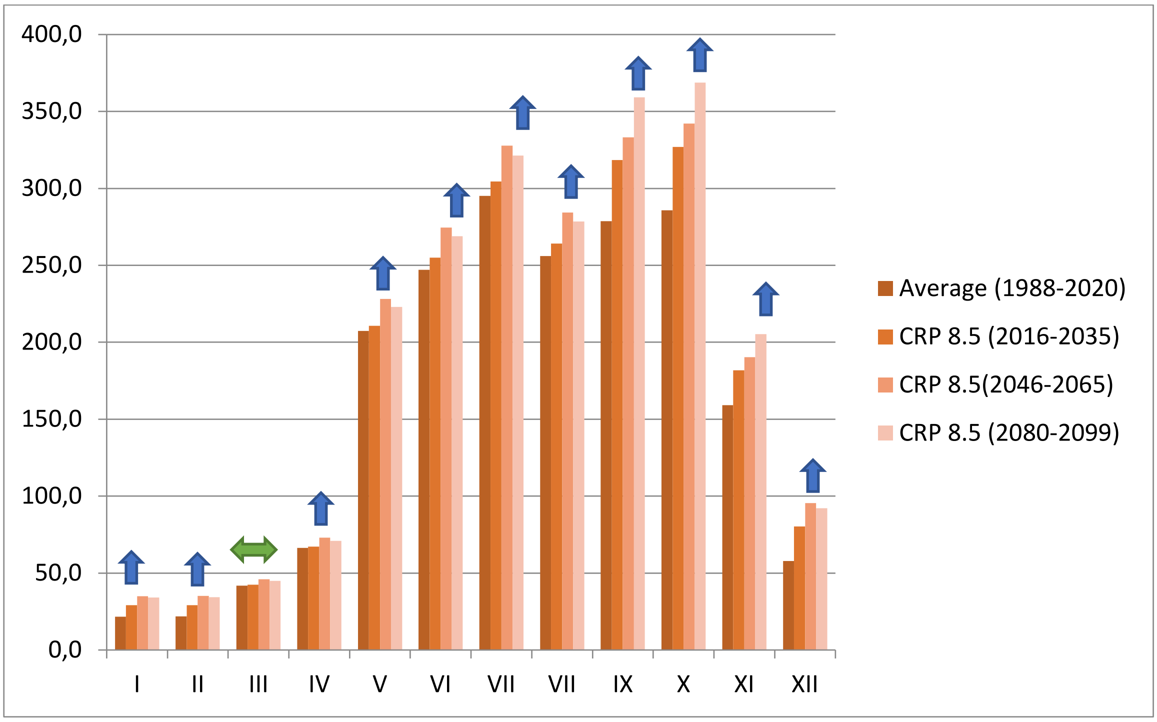


Figure 5-16. Scenario RCP8.5 for monthly average precipitation for the WBR region

5.2.10 Water level

5.2.10.1 Historical data analysis

Kien Giang has three water level stations, including Tan Hiep, Rach Gia and Xeo Ro. In addition, in Ca Mau Peninsula, there are two water level stations, Vi Thanh and Song Doc. In this report, the representative stations for the LXQ region was Rach Gia station, for the WBR were Tan Hiep and Vi Thanh, and for the UMT region were Song Doc and Xeo Ro. The statistical characteristics of hourly water levels are shown in Table 5-9.

Table 5-9. Statistical characteristics of hourly water levels from 1988 to 2020 (Unit: m)

Station	Minimum	Lower quartile	Median	Upper quartile	Maximum	Mean	Standard deviation
Long Xuyen Quadrangle region							
Rach Gia	-0.72	-0.13	0.05	0.22	1.20	0.05	0.25
U Minh Thuong region							
Xeo Ro	-0.71	-0.19	-0.02	0.17	1.22	-0.01	0.26
Song Doc	-0.70	-0,11	0.07	0.26	1.18	0.08	0.26
Western region of Bassac River							
Vi Thanh	-0.56	0.12	0.25	0.40	0.91	0.25	0.20
Tan Hiep	-0,55	0,18	0,38	0,69	1.90	0.46	0.39

i. Long Xuyen Quadrangle region

The highest variation in water level measured in Rach Gia was 1.2 m, the average value was 0.05 m, and the lowest value was about -0.72 m. Every year the tidal water level was high in the last months of the year (from September to December) and was the lowest from April to July (Figure 5-17).

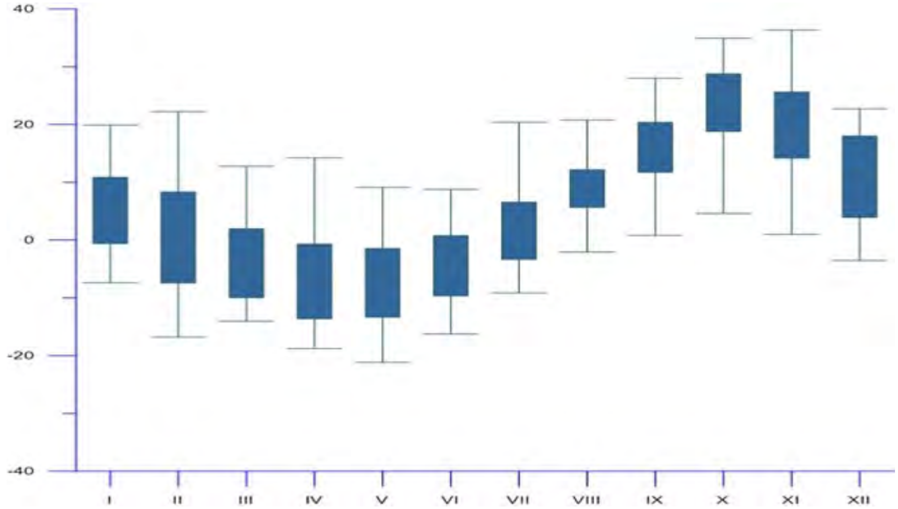


Figure 5-17. Daily average water level trend at Rach Gia station from 1988 to 2020

i. Western region of Bassac River

The water level in the WBR is affected by local rainfall and the flow of Bassac River. The data analysis for Tan Hiep and Vi Thanh stations showed that the highest water levels between two stations had a large difference. The corresponding values at Tan Hiep and Vi Thanh were 1.9 m and 0.91 m, respectively. The average water level was 0,26÷0,46 m, while the lowest water level was -0.55m. Every year the tidal water level was high in the last months of the year (from September to December) and was the lowest from March to July (Figures 5-18 and 5-19).

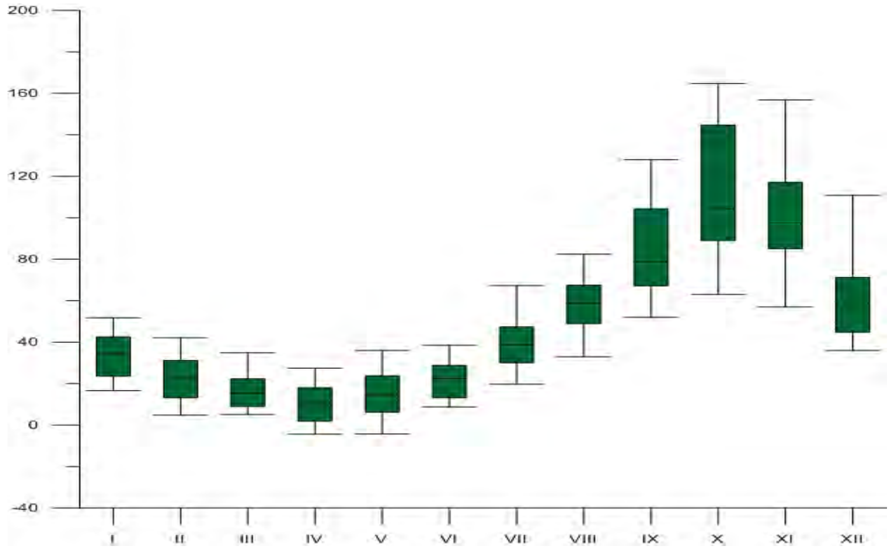


Figure 5-18. Daily average water level trend at Tan Hiep station from 1988 to 2020

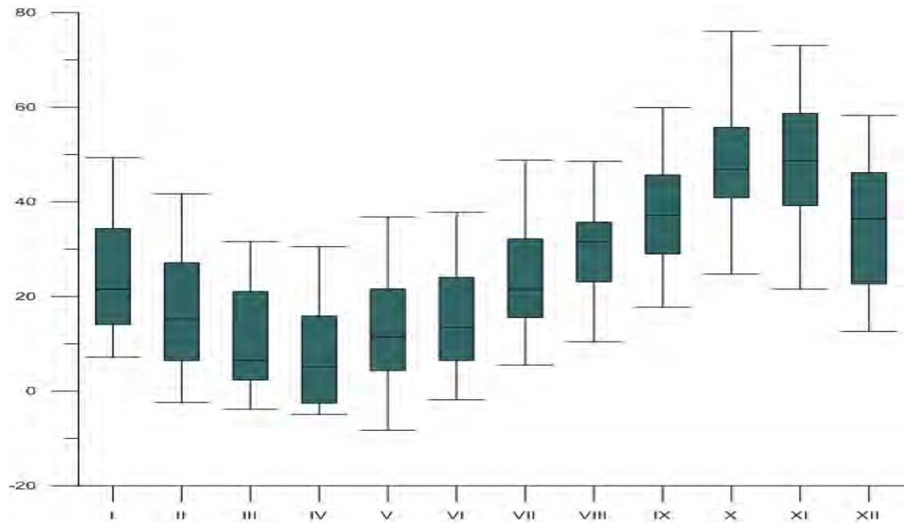


Figure 5-19. Daily average water level trend at Vi Thanh station from 1988 to 2020

ii. U Minh Thuong region

The water level characteristics in this area are similar. The highest water level for Xeo Ro and Song Doc stations were 1.22 m and 1.18 m. The annual average water level fluctuated from -0.01 to 0.08 m. The lowest recorded water level is only 0.01 m difference. The high tidal water levels occur in the last months of the year (from September to December) at Xeo

Ro, and from October to January at Song Doc station. The lowest water level at Xeo Ro is in April to July, while this is from May to August at Song Doc (Figures 5-20 and 5-21).

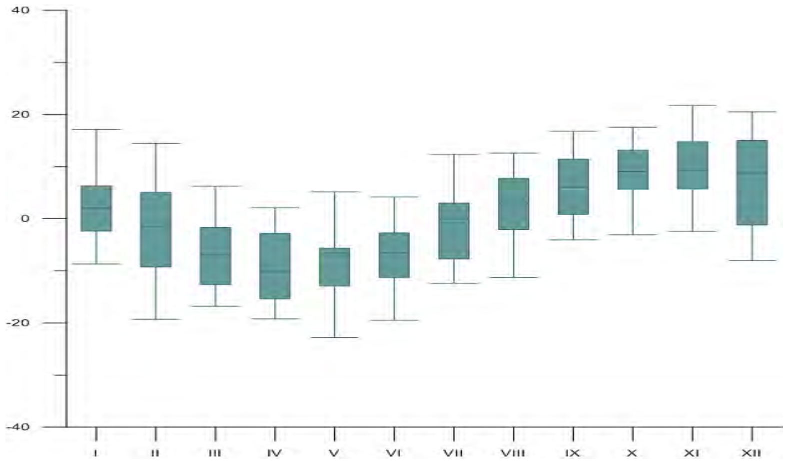


Figure 5-20. Daily average water level trend at Xeo Ro station from 1988 to 2020

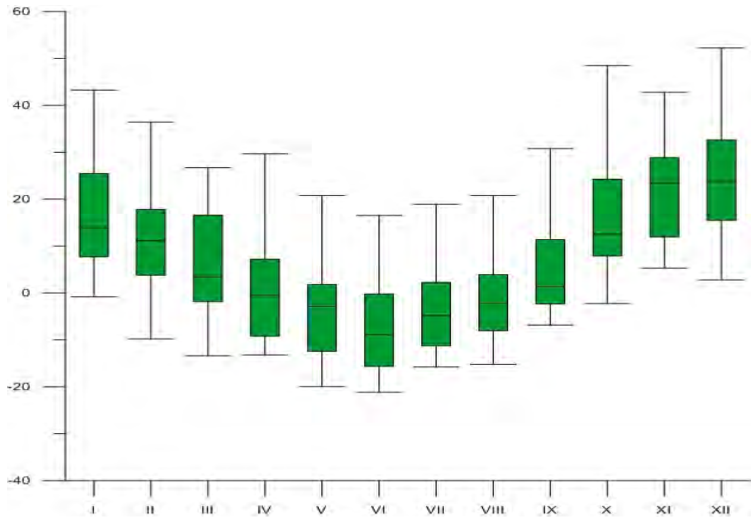


Figure 5-21. Hourly average water level trend at Song Doc station from 1996 to 2020

In general, the water levels at the inland stations of the WBR are higher than those of other regions. In addition, the water level at all the stations in Kien Giang tends to increase in the period of 1988-2020. This is consistent with the annual tide level in the climate change-sea level rise scenarios of MONRE in 2016, i.e., the average sea level at the ocean stations tended to increase (about 3.34. mm/year) during the period of 1993-2014. Based on the water level analysis and the hydrological impacts on infrastructures, the historical probability score of the water level has been estimated to be 7.

5.2.10.2 Projections

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

In the case of sea level rise under the RCP8.5 scenario, by the end of the 21st century, Kien Giang would have about 76.86% of the area at risk of flooding (Figure 5-22). At that time, only the northern part of the LXQ region is higher than the sea level.

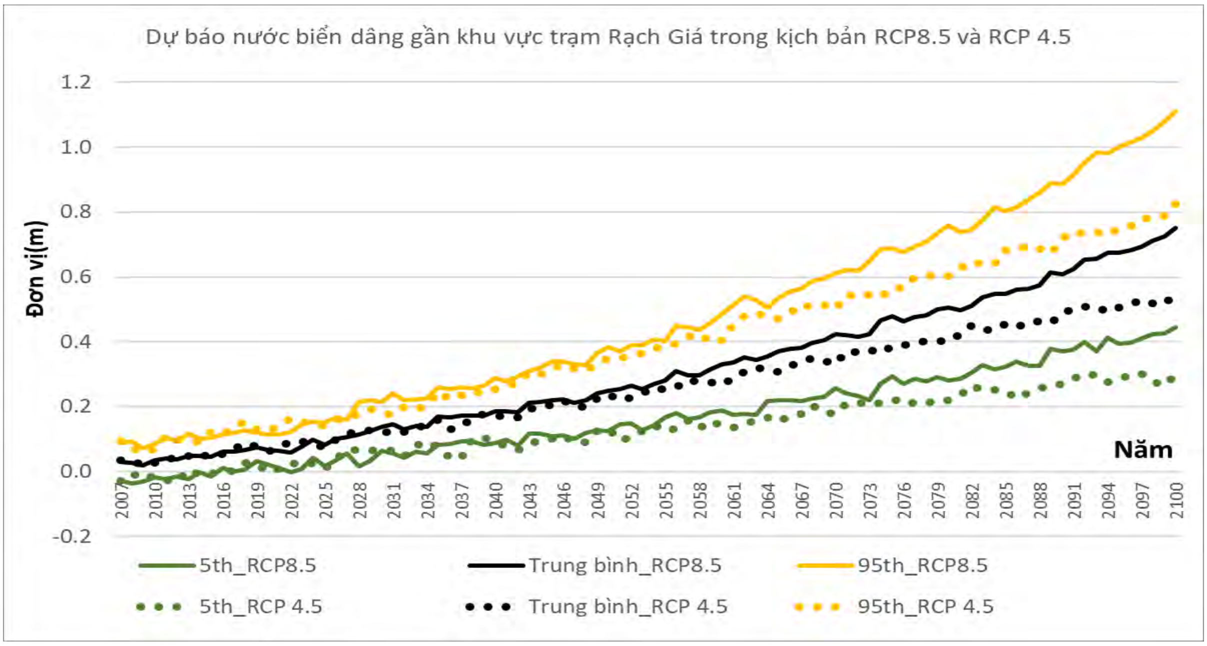


Figure 5-22. Projection of sea level rise in the Rach Gia region for both RCP 8.5 and RCP 4.5 scenarios

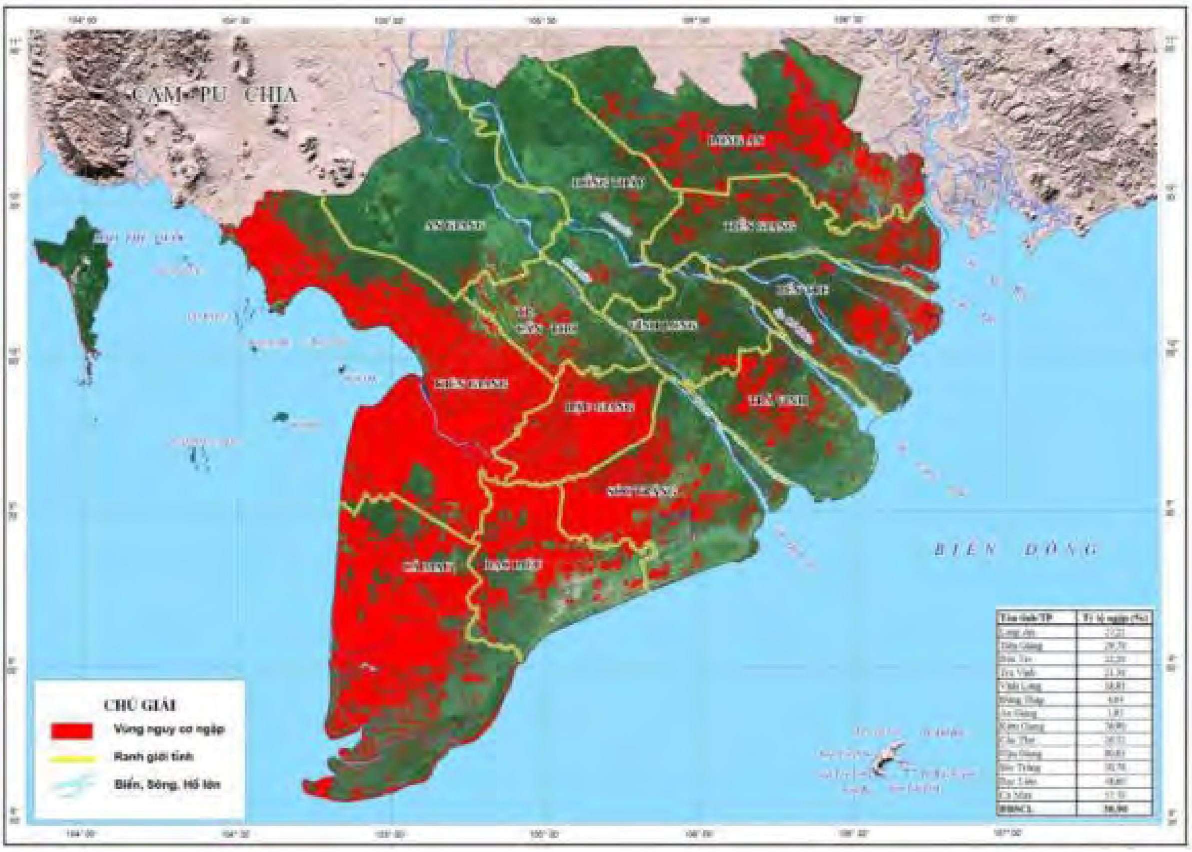


Figure 5-23. Inundation map of the Mekong Delta at 100 cm sea level rise scenario

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

According to the Southern Institute of Water Resources Research (SIWRR), 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 (Figure 5-24).

Thus, the water levels in rivers and canals in Kien Giang are forecasted to increase for the sea level rise scenarios in the future. The PIEVC probability score for all the regions has been estimated to be "7".

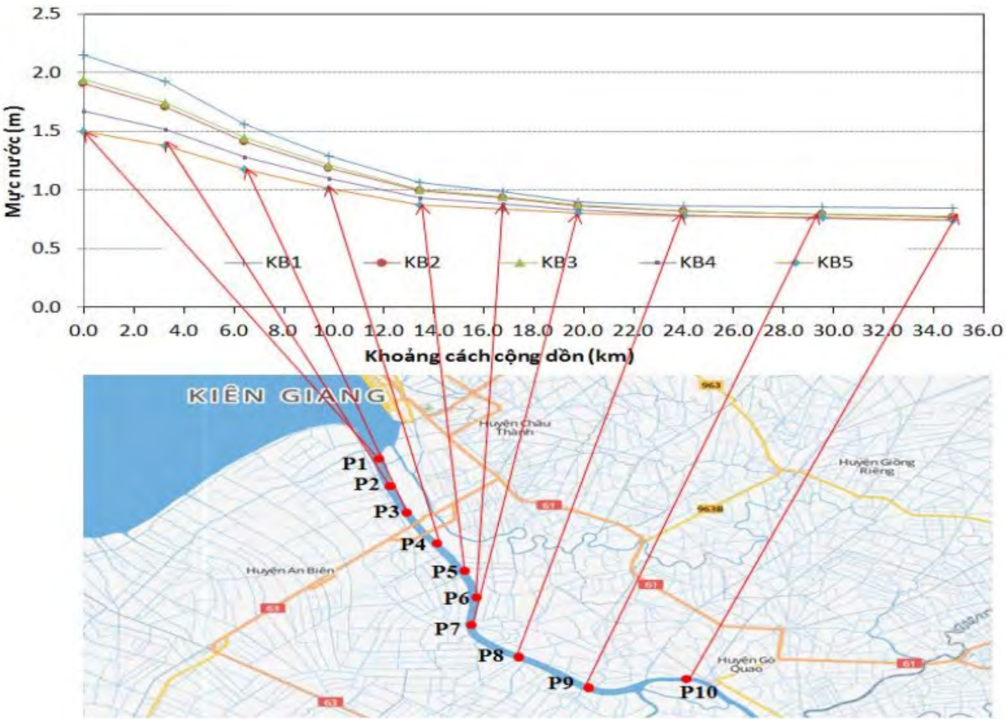


Figure 5-24. Storm surges along Cai Lon river with the assumed trajectory of QD 2

5.2.11 Salinity intrusion

5.2.11.1 Historical data analysis

Three salininity stations in Kien Giang are Rach Gia, Go Quao and An Ninh. Based on the location, Rach Gia is a representative station of the LXQ region, Go Quao is a representative station of the WBR, and An Ninh is a representative station of the UMT region. The distances of these stations (Rach Gia, Go Quao and An Ninh) to the estuary are 1km, 35km, and 8km, respectively.

It is noted that after Kien River sluice gate was completed in 2017, the salinity concentration measured at Rach Gia station no longer reflects the nature properly. Therefore, the Rach Gia station only uses the data of from 1988-2016.

Figure 5-25. Salinity stations in Kien Giang province

According to TCVN 9139: 2012 about "*Concrete and reinforced concrete Structures in coastal areas*", the threshold of salinity concentration defined for use in this report is 3 g/l. Usually, salinity measurement starts from January to July (about 6 months/year and calculated according to the lunar calendar). The number of days with salinity concentration ≥ 3 g/l are about 40-51 days/year (Table 5-10). The highest salinity values at Rach Gia and An Ninh stations are 30.0 g/l, while the average salinity ranges from 2.7 to 4.0 g/l. The maximum salinity value usually occurs in April, while the months of January, February, March and May also have salinity levels higher than 4 g/l (the salinity threshold to supply water for paddy. When the rainy season starts (around June and July), salinity tends to decrease.

Table 5-10. The number of days with salinity concentration ≥ 3 g/l

Station	Maximum	Mean	The number of days with salinity concentration ≥ 3 g/l
Rach Gia	30.0	4.0	50.6
An Ninh	30.1	3.4	44.0
Go Quao	22.7	2.7	40.1

Figure 5-26 shows that the highest daily salinity at the coastal and inland stations is likely to increase, especially in the dry months (February to April). While An Ninh station has an clearly increasing trend, Go Quao station has not much increase in salinity. In recent years, the salinity intrusion has occurred more intensely, especially the dry seasons of 2015-2016 and 2019-2020. The maximum salinity in the dry season of 2015-2016 was highest, while salinity intrusion occurred earlier in the dry season of 2019-2020. Thus, the historical probability score for salinty has been estimated to be “7”.

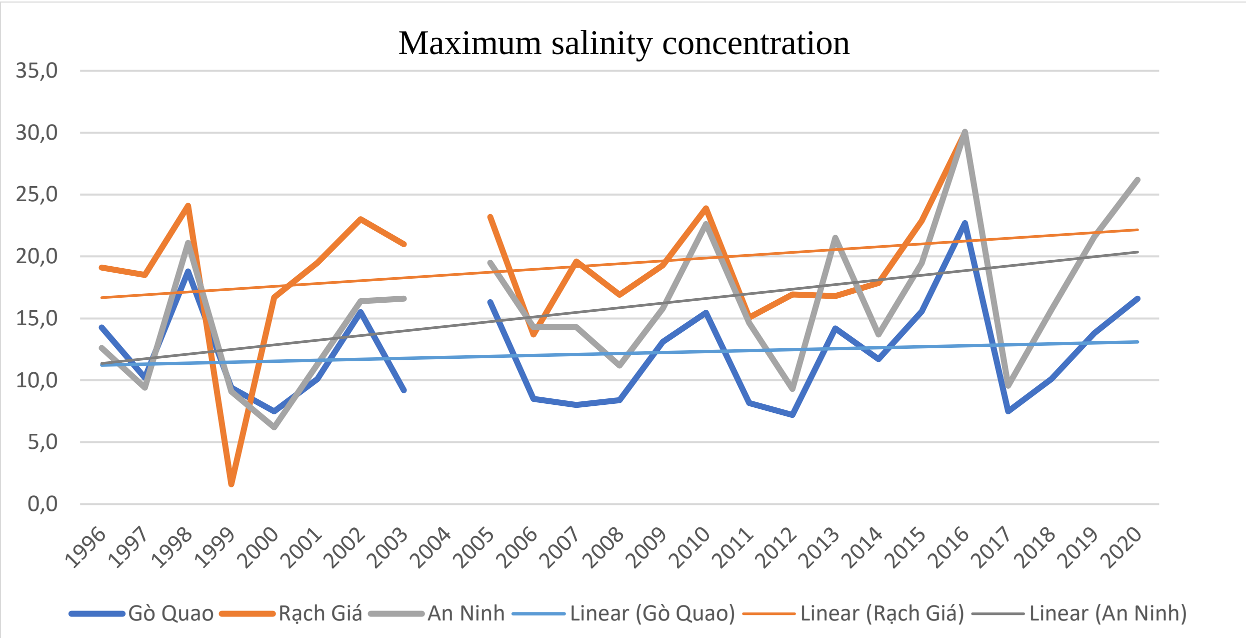


Figure 5-26. The maximum salinity concentration in the period of 1996-2020

5.2.11.2 Projections

Salinity intrusion is becoming more extreme in the future (i.e., the higher values and the longer durations) under the impact of sea level rise and the decrease of the upstream flow (Figure 5-27). According to the climate change – sea level rise scenarios of MONRE (2016), the sea level is also forecasted to rise in the future. Therefore, the future probability score of salinity intrusion has been estimated to remain unchanged as “7”.

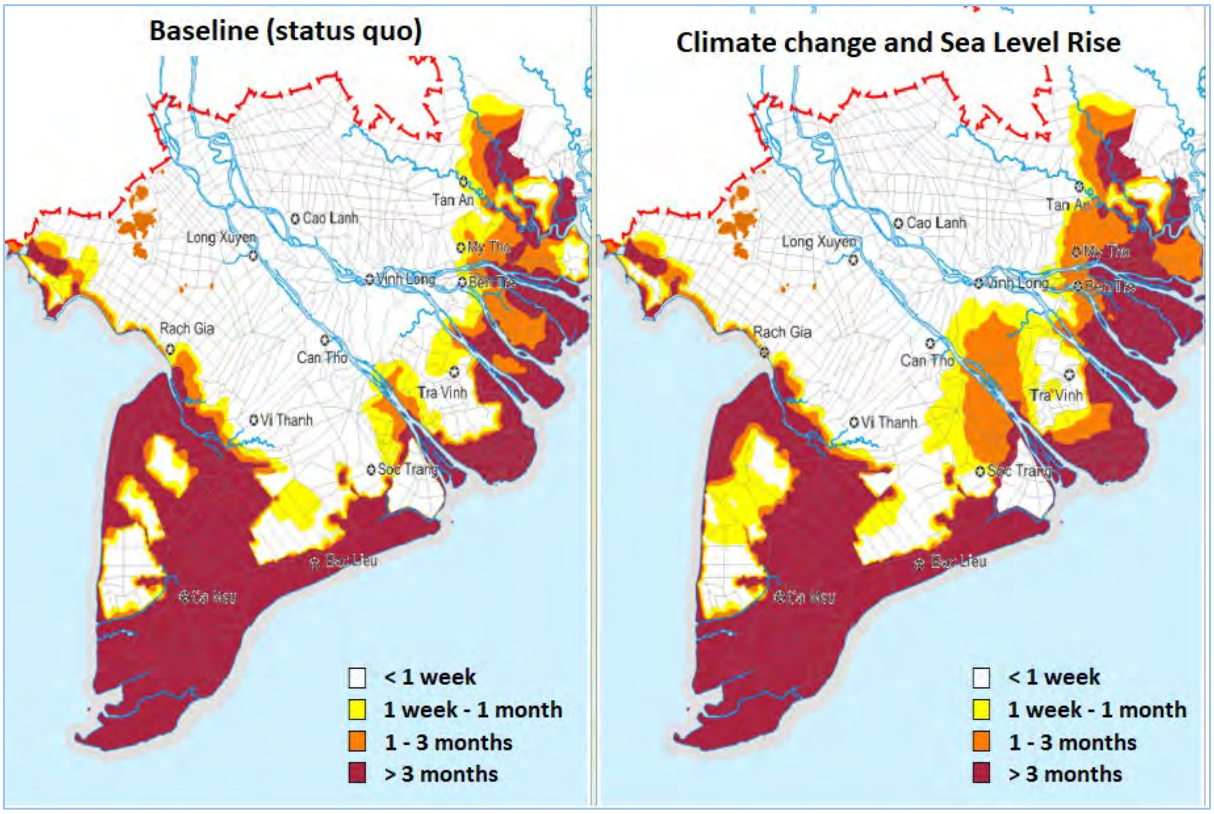


Figure 5-27. Comparison of salinity intrusion between the baseline and climate change-sea level rise

5.2.12 Salinity intrusion combined with high temperature

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 35ºC and the salinity concentration was more than 3.0 g/l. The 33-year (1988-2020) data analysis showed that salinity intrusion combined with high temperature appeared from March to May.

The high temperature in the period of 1988-2020 was 7.2 days per year for the LXQ region, 8.4 days per year for the WBR region, and 9.1 days per year for the UMT region. Meanwhile, the salinity of 3 g/l occurred during the dry season. As a result, salinity intrusion combined with high temperature occurred 5.5 times per year in the LXQ region, 4.6 times per year in the WBR region, and 5.1 times per year in the UMT region. Thus, the historical probability score in this case has been estimated to be "6" for the LXQ and UMT regions and “5” for the WBR region.

It is predicted that the high temperature events will increase in the late 21st century in Kien Giang, Ca Mau and Can Tho, and the salinity intrusion will be deeper and longer due to the impacts of 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 has been estimated to be "7" for all three regions.

5.2.13 High water level combined with heavy rain

High water level combined with heavy rain were determined if the water level greater than 0.9m and the heavy rain more than 100mm/day occurred at the same time. The analysis of 30-year data showed that this combination appeared once in the LXQ region (30/9/1991) and once in the WBR (17/9/2015), but not in the UMT region. Therefore, the historical probability score of this combination has been estimated to be "2" for the LXQ and WBR regions and “1” for the UMT region.

According to the MONRE projections in 2016, the average sea level rise to 2100 in Kien Giang is 0.75m and the 95th percentile is 1.1m for the RCP8.5 scenario. The corresponding values for the RCP4.5 scenario are 0.55m and 0.78m.

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.

Như vậy, với nước biển dâng cao, xu hướng số ngày xuất hiện mực nước lớn ≥ 0,9 m sẽ xảy ra thường xuyên hơn. Đối với cường độ mưa lớn và số ngày mưa lớn cũng được nhận định sẽ gia tăng trong tương lai (mục 3.6.2.3). Do đó, tần suất xảy ra mưa lớn trùng với thời điểm mực nước cao sẽ lớn hơn so với số liệu lịch sử. Điểm tần suất tương lai theo PIEVC cho tổ hợp này là “4”, UMT là “3”.

5.3 Probability scores of climate and hydrological factors in Kien Giang

The historical and future PIEVC probability scores of each climate and hydrological parameter in three climate-hydrological zones in Kien Giang are summarised in Table 5-11.

Table 5-11. The PIEVC probability scores for the sluice gate system in Kien Giang

Region	Historical probability score	Future probability score
High temperature		
LXQ	6	7
WBR	6	7
UMT	6	7
Heat wave		
LXQ	3	4
WBR	4	5
UMT	3	4
Heavy rain		

LXQ	5	6
WBR	4	5
UMT	4	5
Heavy 5-day total rainfall		
LXQ	4	5
WBR	3	4
UMT	5	5
Tropical storm/depression		
LXQ	3	4
WBR	3	4
UMT	3	4
Drought		
LXQ	5	6
WBR	5	6
UMT	5	6
High wind		
LXQ	4	4
WBR	3	3
UMT	3	3
Tornado		
LXQ	3	4
WBR	3	4
UMT	3	4
Thunderstorm/lightning		
LXQ	5	6
WBR	4	5
UMT	5	6
Water level 0.9 m (design probability 5%)		
LXQ	7	7
WBR	7	7
UMT	7	7
Salinity 3 g/l		
LXQ	7	7
WBR	7	7

UMT	7	7
Salinity intrusion combined with high temperature		
LXQ	6	7
WBR	5	7
UMT	6	7
High water level combined with heavy rain		
LXQ	2	4
WBR	2	4
UMT	1	3

6 CLIMATE RISK ASSESSMENT FOR THE COASTAL SLUICE GATE SYSTEM IN KIEN GIANG

6.1 Determination of severity scores

The severity scores (S) for CRA for the coastal sluice gate system in Kien Giang were determined based on expert consultation in different fields (including civil engineering, climate, hydrology, and water resources). In addition, Method E in the PIEVC guidelines was selected to calculate S with the severity scale in Table 6-1.

Table 6-1. 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

6.1.1 YES/NO analysis

A YES/NO analysis is to determine whether a climate, hydrological element interacts with a given infrastructure component or not. This process helps remove the infrastructure components that are not affected by climate and/or hydrological parameters.

In this study, the YES/NO analysis was conducted for 49 components of sluice gate system in Kien Giang and 11 climate and hydrological elements. The results of this analysis showed that 35 infrastructure components (particularly gates were divided into 5 different groups in terms of operating structure and materials) are expected to be affected by climate and hydrological parameters (Table 6-2). These components were the focus of determining severity scores in the next section. Details of the YES/NO analysis are presented below.

Table 6-2. YES/NO analysis for the interaction between climate - hydrological factors and infrastructure components

Infrastructure Components		Climate – hydrological factors										
		High temp.	Heat wave	Heavy rain	Heavy 5-day total rainfall	Tropical Storm/ Depre-ssion	Drought	High Wind	Tornado	Thunder-storm/ Light-ning	Water Level	Water Salinity
1. Administration												
1.1	Personnel	Y	Y	Y	Y	Y	Y	Y	Y	Y		
1.2	Transportation (Supplies Delivery)			Y	Y	Y			Y	Y		
2. Sluice Gate Structure												
2.1	Pile foundation											Y
2.2	Waterproof pile foundation											Y
2.3	Pillar footing											Y
2.4	Bottom beam											Y
2.5	Pillar		Y			Y					Y	Y
2.6	Gate tower / Gate hanger		Y			Y		Y	Y	Y		Y
2.7	Cast-in-situ concrete composition		Y									Y
2.8	Lifting system and gangway					Y		Y	Y	Y		Y
3. Gates												
3.1	Water tight gasket	Y	Y				Y					Y
3.2	Automatic gates										Y	
3.3	Vertically lifted gates			Y		Y		Y	Y	Y	Y	
3.4	Bottom shutter gates										Y	
3.5	Gates made of CT3 or CT5 steel combined with an anti-rust epoxy coating											Y
3.6	Gates made of stainless steel (SUS-304)											Y
3.7	Hydraulic Cylinder									Y		Y
4. Bridge												
4.1	Bridge Deck		Y	Y								Y
4.2	Bridge abutment		Y									Y
4.3	Bearing pad		Y									Y
4.4	Hand Rail					Y		Y	Y			Y
4.5	Lighting System					Y		Y	Y	Y		
4.6	Traffic Signs					Y		Y	Y			
5. Retaining walls and connected embankments												
5.1	Retaining walls		Y	Y	Y						Y	Y
5.2	Gabion										Y	Y
5.3	Connected embankments		Y	Y	Y		Y				Y	Y
5.4	Rip-rap embankments sections		Y	Y	Y		Y				Y	Y
5.5	Riverbank										Y	Y
5.6	Stilling basin										Y	Y
6. Operation house			Y	Y		Y		Y	Y	Y		
7. Park			Y	Y		Y	Y	Y	Y	Y		
8. Electric system												

Infrastructure Components		Climate – hydrological factors										
		High temp.	Heat wave	Heavy rain	Heavy 5-day total rainfall	Tropical Storm/ Depre-ssion	Drought	High Wind	Tornado	Thunder-storm/ Light-ning	Water Level	Water Salinity
8.1	Transmission Lines			Y		Y		Y	Y	Y		
8.2	Power Supply			Y		Y			Y	Y		
8.3	Standby Generators					Y			Y	Y		
9. Control and operation system												
9.1	Control Systems					Y				Y		
9.2	Operation systems			Y	Y	Y				Y		
10. Monitoring system				Y	Y	Y			Y	Y		
11. Fire extinguishing system												Y
12. Communication system				Y	Y	Y		Y	Y	Y		

❖ *Operation and maintenance*

The staff and the transportation of supplies in the operation and maintenance process could be influenced by the climate and hydrological factors such as high temperature, heat wave, heavy rain, heavy 5-day total rainfall, tropical storm/ depression, drought, high wind, tornado, and thunderstorm/lightning. Other components, such as the maintenance equipment and the procedure, are often stored in the operation house, so they are little affected by the climate and hydrological factors.

❖ *Sluice gate structure (sluice body)*

In general, both structural forms of the sluice body (i.e. monolithic concrete and pillar dam) are similarly impacted by climatic and hydrological factors. The components of the sluice body such as pile foundation, waterproof pile foundation, pillar footing and bottom beam are under the ground, so they are not considerably affected by climate-hydrological factors, except for salinity. Pillar and gate tower (made of reinforced concrete M25 ÷ M30), lifting system and gangway, and other poured concrete components could be impacted by heat wave, salinity and erosion due to water level change.

❖ *Gates*

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.

In terms of structure form, when the gates are under water, they may be affected by water pressure (due to water level differences), flow velocity (obstructing the operation), sediment and salinity (increasing the corrosion). Particularly, vertically lifted gates are likely to be affected by high wind, heavy rain, storms and lightning when opened (the gates are hanging).

In terms of materials, the gates which are made of CT3 or CT5 steel combined with an anti-rust epoxy coating can be affected by high temperatures and heat wave. Meanwhile, if the gates are made of stainless steel (SUS-304), they is almost not affected by climate-hydrological factors, except for the impact of salinity during the long period.

For vertically lifted gates and bottom shutter gates, hydraulic cylinder may be affected by high temperature and salinity.

- *Bridge*

Bridge abutment and bearing pad could be affected by heat wave and salinity. 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.

The impacts on the lighting system and traffic signals, and the park are similar, so they have been mentioned in the park section.

- *Retaining walls and connected embankment*

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

- *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. As the sluice gates are located along the coastal zone, the electrical system may be affected by the high salinity concentration of saltwater and vapour. 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 are set up outdoors, so they could be affected by heavy rain, tropical storms, and thunderstorms/lightning. 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 and thunderstorms.

❖ *Fire extinguishing system*

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

❖ *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.

6.1.2 Severity determination

Under the PIEVC guidelines, the rules for determining the severity scores of the components of sluice gate system in Kien Giang under the impacts of climate and hydrological factors include:

- Design standards and regulations of sluice gates in the stages of basic design, technical design and construction drawings;
- Characteristics of the sluice gates in Kien Giang;
- Historical data, trends and projections of the climate-hydrological factors in Kien Giang;
- Professional judgement of the experts from the different sectors.

The severity scores for both historical and future conditions is presented in Table 6-3.

Table 6-3. Summary of severity scores for sluice gate system in Kien Giang

Components	Breakdown	Climate/ hydrological factors	Historical S	Future S	Comments
Administration (Operation and maintenance)	Personel	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
		Thunderstorm/ lighting	1	1	Thunderstorm/lighting can impede transportation.
	Pile foundation	Salinity	1	2	Salinity may increase the chemical corrosion, resulting in cracked concrete.

Components	Breakdown	Climate/ hydrological factors	Historical S	Future S	Comments
Sluice gate structure (sluice body)		Salinity intrusion + high temperature	2	3	Similar to the effects of the salinity
	Waterproof pile foundation	Salinity	1	2	Similar to the pile foundation
		Salinity intrusion + high temperature	2	3	Similar to the effects of the salinity
	Pillar footing	Salinity	1	2	Similar to the pile foundation
		Salinity intrusion + high temperature	2	3	Similar to the effects of the salinity
	Bottom beam	Salinity	1	2	Similar to the pile foundation
		Salinity intrusion + high temperature	2	3	Similar to the effects of the salinity
	Pillar	Heat wave	2	3	Heat waves may increase the cracking and the corrosion of concrete.
		Tropical storm/depression	1	2	Similar to vertically lifted gates
		Water level	1	2	The rise of water levels could increase physical abrasion and corrosion for concrete as recorded in some sluice gates 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 / Gate hanger	Heat wave	2	3	Similar to the pillar
		Tropical storm/depression	1	2	Similar to vertically lifted gates
		High wind	2	3	Similar to vertically lifted gates
		Tornado	1	2	Similar to vertically lifted gates
		Thunderstorm/ lighting	1	1	Thunderstorm/lighting may damage the gate tower.
		Salinity	1	2	Similar to the pillar

Components	Breakdown	Climate/ hydrological factors	Historical S	Future S	Comments
		Salinity intrusion + high temperature	2	3	Similar to the effects of the salinity
	Cast-in-situ concrete composition	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
	Lifting system and gangway	Heat wave	2	3	Similar to gate tower / gate hange
		Tropical storm/depression	3	4	Similar to gate tower / gate hange
		High wind	2	3	Similar to gate tower / gate hange
		Tornado	1	2	Similar to gate tower / gate hange
		Thunderstorm/ lighting	1	1	Similar to gate tower / gate hange
		Salinity	1	2	Similar to the pillar
		Salinity intrusion + high temperature	2	3	Similar to the effects of the salinity
Gates	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.
	Automatic gates	Water level	3	4	Water level affects the function of the sluice gate if overflowing, and its stability if the water level difference between front and behind of the sluice gate is large. In addition, water level also indirectly causes physical and chemical corrosion.
		High water level + heavy rain	3	4	Similar to the effects of the water level
		Heavy rain	1	2	Similar to storms but with lower impact.

Components	Breakdown	Climate/ hydrological factors	Historical S	Future S	Comments
	Vertically lifted gates	Tropical storm/depression	4	5	When the gates are closed, storms raise the water level, increasing the risk of overflowing the gates. When the gates are opensed, storms cause the instability of the gates.
		High wind	3	4	Similar to storms but with lower impact.
		Tornado	2	3	Similar to storms but with lower impact due to the shorter duration of tornados.
		Thunderstorm/ lighting	1	1	Thunderstorm/lighting has negligible impact on the gates, even when the gate is open
		Water level	3	4	Similar to automatic gates
		High water level + heavy rain	3	4	Similar to the effects of the water level
	Bottom shutter gates	Water level	3	4	Similar to automatic gates
		High water level + heavy rain	3	4	Similar to the effects of the water level
	Gates made of CT3 or CT5 steel combined with an anti-rust epoxy coating	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
	Gates made of stainless steel (SUS-304)	Salinity	1	1	Similar to the gates made of CT3 or CT5 steel combined with an anti-rust epoxy coating but with lower impact.
		Salinity intrusion + high temperature	1	2	Similar to the effects of the salinity
	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
Bridge	Bridge deck/surface	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.
		Salinity	2	3	The salinity may cause the peeling of the bridge surface
		Salinity intrusion + high temperature	3	4	Similar to the effects of the salinity
	Bridge abutment	Heat wave	3	4	Similar to bridge surface

Components	Breakdown	Climate/ hydrological factors	Historical S	Future S	Comments
		Salinity	2	3	Similar to bridge surface
		Salinity intrusion + high temperature	3	4	Similar to the effects of the salinity
	Bearing pad	Heat wave	3	4	Similar to bridge surface
		Salinity	2	3	Similar to bridge surface
		Salinity intrusion + high temperature	3	4	Similar to the effects of the salinity
	Hand rail	Tropical storm/depression	5	6	Tornado may damage the bridge hand rail.
		High wind	4	5	Similar to storms
		Tornado	3	4	Similar to storms
	Lighting system	Tropical storm/depression	5	6	Similar to hand rail
		High wind	4	5	Similar to hand rail
		Tornado	3	4	Similar to hand rail
		Thunderstorm/ lighting	7	7	Lightning can destroy the system
	Traffic signs	Tropical storm/depression	5	6	Similar to hand rail
		High wind	4	5	Similar to hand rail
		Tornado	3	4	Similar to hand rail
Retaining walls and connected embankments	Retaining walls	Heat wave	2	2	Similar to pillar
		Heavy rain	1	2	Heavy may damage the retaining walls
		Heavy 5-day total rainfall	1	1	Similar to heavy rain
		Salinity	1	2	Similar to pillar
		Salinity intrusion + high temperature	2	3	Similar to the effects of the salinity
	Gabion	Water level	1	2	Water levels indirectly cause physical and chemical corrosion of the gabions

Components	Breakdown	Climate/ hydrological factors	Historical S	Future S	Comments
		High water level + heavy rain	2	3	Similar to the effects of water level
		Salinity	1	2	Salinity can corrode gabion structures.
		Salinity intrusion + high temperature	2	3	Similar to the effects of the salinity
	Connected embankments	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 embankments sections	Heat wave	1	2	Similar to the connected embankment
		Salinity	1	2	Salinity may damage the rip-rap and geotextile compositions.
		Salinity intrusion + high temperature	2	3	Similar to the effects of the salinity
	Riverbank	Salinity	1	2	Salinity can corrode concrete.
		Salinity intrusion + high temperature	2	3	Similar to the effects of the salinity
	Stilling basin	Salinity	1	2	Similar to the riverbank.
		Salinity intrusion + high temperature	2	3	Similar to the effects of the salinity
Operation house		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.

Components	Breakdown	Climate/ hydrological factors	Historical S	Future S	Comments
		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.
Electric system	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).
	Power supply	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.
	Standby generators	Tropical storm/depression	2	3	Similar to the voltage transformers
		Tornado	2	3	Similar to the voltage transformers.
		Thunderstorm/ lighting	7	7	Similar to the voltage transformers.
Control and operation 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.

Components	Breakdown	Climate/ hydrological factors	Historical S	Future S	Comments
	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
Fire extinguishing system		Salinity	1	2	Salinity can rust and damage the fire extinguishing system
		Salinity intrusion + high temperature	2	3	Similar to the effects of the salinity
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

6.2 Risk assessment matrix for sluice gate system in Kien Giang

Risk tolerance thresholds in the CRA for sluice gate system in Kien Giang were established based on the PIEVC Protocol guidelines (Table 6-4). In this table, high risks (R > 36) require a considerable response in the detailed design phase. In contrast, a low risk level (R < 12) needs not immediate actions. Medium risks (12 ≤ R ≤ 36) should also be taken into account during the detailed design phase.

Table 6-4. 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

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

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 matrices of the sluice gate system in Kien Giang (*Appendices 1-6*). The number of the low, medium and high risks for both existing and future conditions is summarised in Table 6-5.

Table 6-5. Summary of low, medium and high risks for both existing and future conditions for 3 climatic zones in Kien Giang

Infrastructure Components	TGLX						TSH						UMT					
	Historical Risk			Future Risk			Historical Risk			Future Risk			Historical Risk			Future Risk		
	L	M	H	L	M	H	L	M	H	L	M	H	L	M	H	L	M	H
1-Administration																		
Personnel	2	7	0	0	8	1	3	6	0	0	9	0	3	6	0	0	8	1
Transportation (Supplies Delivery)	3	2	0	2	3	0	3	2	0	3	2	0	3	2	0	3	2	0
2-Sluice Gate Structure																		
Pile foundation	1	1	0	0	2	0	2	0	0	0	2	0	1	1	0	0	2	0
Waterproof pile foundation	1	1	0	0	2	0	2	0	0	0	2	0	1	1	0	0	2	0
Pillar footing	1	1	0	0	2	0	2	0	0	0	2	0	1	1	0	0	2	0
Bottom beam	1	1	0	0	2	0	2	0	0	0	2	0	1	1	0	0	2	0
Pillar	5	1	0	2	4	0	5	1	0	2	4	0	5	1	0	2	4	0
Gate tower / Gate hanger	6	1	0	3	4	0	7	0	0	4	3	0	6	1	0	4	3	0
Cast-in-situ concrete composition	2	1	0	0	3	0	3	0	0	0	3	0	2	1	0	0	3	0
Lifting system and gangway	6	1	0	2	5	0	7	0	0	3	4	0	6	1	0	3	4	0
3-Gates																		
Water tight gasket	1	3	0	0	4	0	1	3	0	0	4	0	1	3	0	0	4	0
Automatic gates	1	1	0	0	2	0	1	1	0	0	2	0	1	1	0	0	2	0
Vertically lifted gates	4	3	0	1	6	0	5	2	0	2	5	0	5	2	0	2	5	0
Bottom shutter gates	1	1	0	0	2	0	1	1	0	0	2	0	1	1	0	0	2	0
Gates made of CT3 or CT5 steel combined with an anti-rust epoxy coating	0	2	0	0	2	0	0	2	0	0	2	0	0	2	0	0	2	0
Gates made of stainless steel (Sus-304)	2	0	0	1	1	0	2	0	0	1	1	0	2	0	0	1	1	0
Hydraulic Cylinder	0	2	0	0	2	0	0	2	0	0	2	0	0	2	0	0	2	0
4-Bridge																		
Bridge Deck	2	2	0	0	4	0	1	3	0	1	3	0	2	2	0	1	3	0
Bridge abutment	1	2	0	0	3	0	0	3	0	0	3	0	1	2	0	0	3	0
Bearing pad	1	2	0	0	3	0	0	3	0	0	3	0	1	2	0	0	3	0
Hand Rail	1	2	0	0	3	0	1	2	0	0	3	0	1	2	0	0	3	0

Infrastructure Components	TGLX						TSH						UMT					
	Historical Risk			Future Risk			Historical Risk			Future Risk			Historical Risk			Future Risk		
	L	**M**	**H**	**L**	**M**	**H**	**L**	**M**	**H**	**L**	**M**	**H**	**L**	**M**	**H**	**L**	**M**	**H**
Lighting System	1	3	0	0	3	1	1	3	0	0	4	0	1	3	0	0	3	1
Traffic Signs	1	2	0	0	3	0	1	2	0	0	3	0	1	2	0	0	3	0
5-Retaining walls and connected embankments																		
Retaining walls	4	1	0	2	3	0	5	0	0	3	2	0	4	1	0	3	2	0
Gabion	3	1	0	0	4	0	4	0	0	0	4	0	3	1	0	1	3	0
Connected embankments	2	2	0	1	3	0	3	1	0	1	3	0	2	2	0	1	3	0
Rip-rap embankments sections	2	1	0	1	2	0	3	0	0	1	2	0	2	1	0	1	2	0
Riverbank	1	1	0	0	2	0	2	0	0	0	2	0	1	1	0	0	2	0
Stilling basin	1	1	0	0	2	0	2	0	0	0	2	0	1	1	0	0	2	0
6-Operation house	5	1	0	3	3	0	5	1	0	4	2	0	5	1	0	4	2	0
7-Park	2	5	0	0	6	1	3	4	0	1	6	0	3	4	0	1	5	1
8-Electric system																		
Transmission Lines	1	4	0	0	4	1	2	3	0	1	4	0	2	3	0	1	3	1
Power Supply	3	1	0	0	3	1	3	1	0	1	3	0	3	1	0	1	2	1
Standby Generators	2	1	0	0	2	1	2	1	0	0	3	0	2	1	0	0	2	1
9-Control and operation system																		
Control Systems	0	2	0	0	1	1	0	2	0	0	2	0	0	2	0	0	1	1
Operation systems	2	2	0	1	2	1	2	2	0	2	2	0	2	2	0	2	1	1
10-Monitoring systems	2	3	0	1	3	1	2	3	0	2	3	0	2	3	0	2	2	1
11-Fire extinguishing systems	1	1	0	0	2	0	2	0	0	0	2	0	1	1	0	0	2	0
12-Communication system	2	4	0	1	4	1	3	3	0	2	4	0	3	3	0	2	3	1
Total (for 149 interactions)	77	73	0	21	119	10	93	57	0	34	116	0	82	68	0	35	105	10

Note: L: low risk; M: medium risk; H: high risk.

The main findings of the risk matrix are as follows:

- Of the 507 interactions that need YES/NO analysis, only 150 interactions were answered "YES" to score the severity of the infrastructure components.
- Of the above 150 interactions, there were 10 high-risk interactions due to thunderstorms/lightning for both future conditions in LXQ and UMT regions, while there were no high-risk interactions in the WBR.
- The LXQ had the maximum number of medium risks for existing conditions (73 interactions) and for future projections (119 interactions).
- The WBR region had the maximum number of low risks for existing conditions (93 interactions), while the UMT region had the maximum number of low risks for future projections (35 interactions).
- The medium-risk interactions for existing conditions were mainly affected by tropical storms/depression, thunderstorms/lightning, and salinity intrusion combined with high temperature. The corresponding variables for future projections were tropical storms/depression, high wind, tornado, water level 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.
- 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).

7 ENGINEERING ANALYSIS OF VULNERABLE COMPONENTS

The engineering analysis for the infrastructure components was only applied to 54 coastal sluice gates that have been completed and put into operation in Kien Giang province.

7.1 Determination of infrastructure components for engineering analysis

The infrastructure components of the coastal sluice gate system in Kien Giang were selected for engineering analysis based on the following criteria:

i. The results of the CRA for the coastal sluice gate system in Kien Giang.

ii. The infrastructure components with the medium risk scores [12; 36] as regulated in PIEVC.

iii. The selected infrastructure components play an important role in the main functions and operation. 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 were calculated in detail in the documents of technical design and construction drawing design.

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

vi. The selection of the infrastructure components based on the specific characteristics of the sluice gate system in terms of the size, structure, and construction method.

vii. The records of management, operation, and maintenance of the coastal sluice gate system in Kien Giang.

The list of infrastructure components for engineering analysis is shown in Table 7-1.

Table 7-1. Infrastructure components of the coastal sluice gate system in Kien Giang for engineering analysis

No.	Infrastructure components	Climate and hydrological factors	LXQ		WBR		UMT	
			Current risk	Future risk	Current risk	Future risk	Current risk	Future risk
1	Sluice body (Pillar and gate tower)	Water level (0,9m)	7	14	7	14	7	14
		Tropical storm/depresion	3	8	3	8	3	8
		Salinity intrusion + High temperature	12	15	12	15	12	15
2	Automatic gates	Water level	21	28	21	28	21	28
	Vertically lifted gates	Water level	21	28	21	28	21	28
	Bottom shutter gates	Water level	21	28	21	28	21	28

No.	Infrastructure components	Climate and hydrological factors	LXQ		WBR		UMT	
			Current risk	Future risk	Current risk	Future risk	Current risk	Future risk
	Gates made of CT3 or CT5 steel combined with an anti-rust epoxy coating	Salinity intrusion + High temperature	12	20	12	20	12	20
	Hydraulic Cylinder	Salinity intrusion + High temperature	12	20	12	20	12	20
3	Bridge	Salinity intrusion + High temperature	12	20	12	20	12	20

7.2 Vietnam technical standards and regulations for designing hydraulic structures

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 coastal sluice gate system in Kien Giang province 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:

- 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.

7.3 Engineering analysis

7.3.1 Sluice gate structure (sluice body)

The current coastal sluice gate system in Kien Giang province consists of two main structural forms: (i) vertical concrete wall and concrete foundation (or monolithic concrete) and (ii) pillar dam, with concrete grade of M300 and mainly normal cement (except for some infrastructures recently used sulphate resistant cement).

7.3.1.1 Impacts of storms

According to the statistical data (1988 - 2020) from Vietnam and Japan Meteorological Agency (JMA), there were 5 tropical storms directly in the study area, in which Linda in November 1997 at the 10th storm level was the strongest and most damaging of the past 100 years. However, the pillar in the design document was calculated with a Level 9 storm (see Appendix for details). Therefore, it is necessary to pay attention when operating during storm. 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 different structures of sluice body result in different bearing capacity, so their vulnerability ratio (V_R) is different (the larger the value of V_R, the higher the vulnerability). The engineering analysis showed that under the impact of a Level 9 storm at the design/construction stage (as of 2010) and a Level 12 storm at present and in the future (2020 ÷ 2050), the structural form of pillar dam is more vulnerable than the structural form of monolithic concrete (Table 7-2).

Table 7-2. Vulnerability ratio of two structural forms of monolithic concrete and pillar dam under the impact of tropical storms/depression

Year	Climate and hydrological factor	Vulnerability Ratio (V_R)		The most vulnerable components
		Monolithic concrete	Pillar dam	
2010	Tropical storms/ depression	0.181	0.264	Pillar dam
2020		0.275	0.401	Pillar dam
2050		0.275	0.401	Pillar dam

(see Appendix 8 for details)

7.3.1.2 Impacts of water level

The water level data (from 1988 to 2020) used in the current CRA were collectd from five stations, including Rach Gia station (LXQ region), Vi Thanh and Tan Hiep stations (WBR), Song Doc and Xeo Ro stations (UMT region). Most of the water levels at these stations tend to increase in the period of 1988-2020. Especially, in recent years (2018-2020), the high water levels continuously appeared and reached a record in 2020. For example, at Xeo Ro station which was used in the for Cai Lon - Cai Be sluice gates, the highest water levels in 2018, 2019, and 2020 (+1.05m, +1.02m, and +1.22m, respectively) were more than the highest water level in 2004 (+ 99cm).

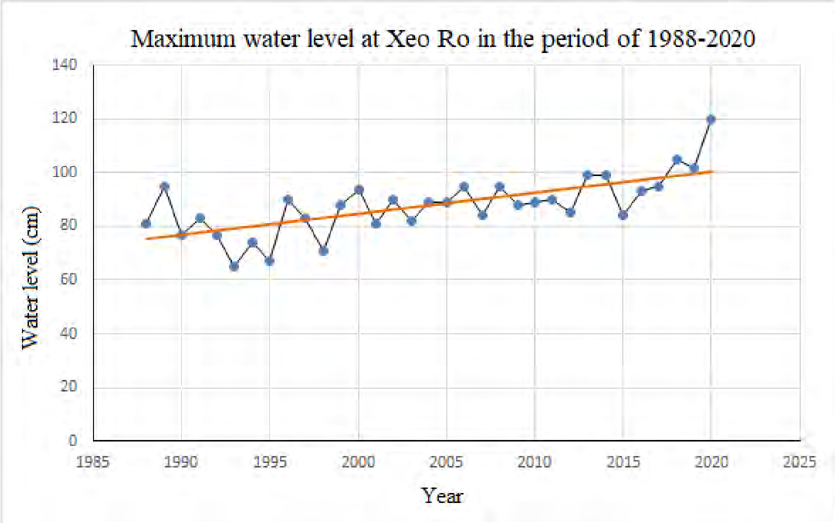


Figure 7-1. Maximum water level at Xeo Ro station in the period of 1988-2020

The frequency of the maximum water level is 1.5% based on the data series of from 1988 to 2020. The corresponding maximum water level Hmax is 119.18 cm, which is higher 20.18 cm than the maximum designed water level.

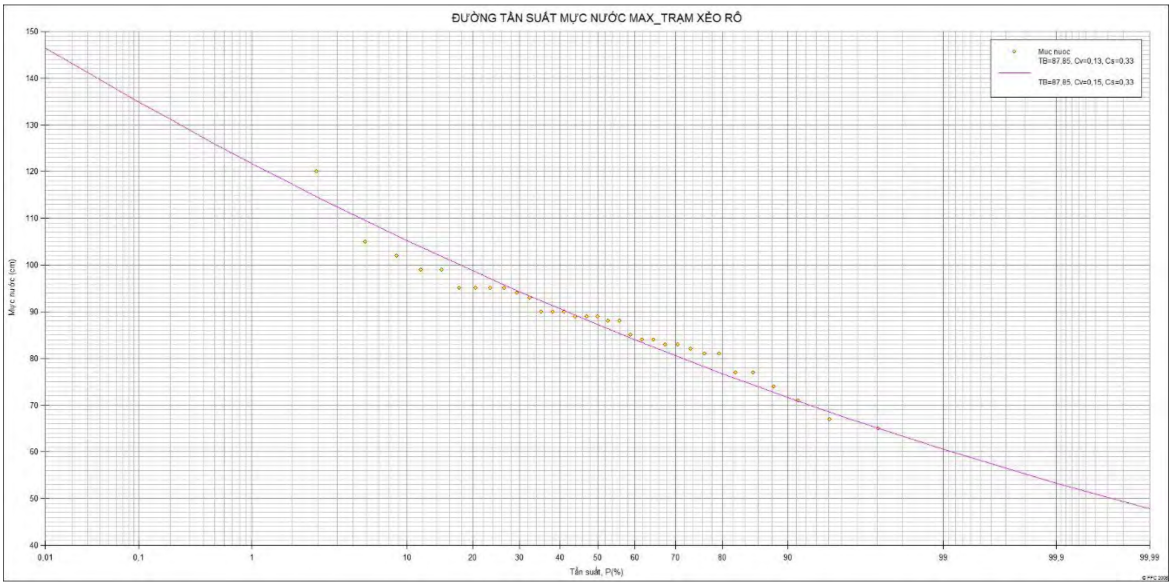


Figure 7-2. Frequency line of water level at Xeo Ro station from 1988 to 2020

Rising water level will affect the bearing capacity of the infrastructure component. The engineering analysis showed that the structural form of pillar dam is more vulnerable than the structural form of monolithic concrete under the impact of the water level at the design/construction stage (as of 2010), at present and in the future (2020 ÷ 2050) (Table 7-3).

Table 7-3. Vulnerability ratio of two structural forms of monolithic concrete and pillar dam under the impact of water level

Year	Climate and hydrological factor	Vulnerability Ratio (V_R)		The most vulnerable components
		Monolithic concrete	Pillar dam	
2010	Water level	0.258	0.358	Pillar dam
2020		0.286	0.397	Pillar dam
2050		0.384	0.533	Pillar dam

7.3.1.3 Combined effects of high temperature and saline intrusion

The design lifespan of the pillar for the coastal sluice gate system in Kien Giang is 20-50 years for the hydraulic works of Grade III - IV according to QCVN 04 - 05:2012/BNNPTNT. The pillar is mainly made of reinforced concrete M300-M350 (compressive strength of the cube of 150x150x150 mm after 28 days is 30-35 Mpa) with the bearing reinforcement layer (h) of 50-60 mm. Recently, some reinforced concrete pillars have been constructed with sulphate resistant cement.

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.

For M300-350 concrete with a protective layer thickness of 50mm ÷ 60mm, the lifespan of the infrastructure is over 43 years for working conditions in seawater environment (Table 7-4).

Table 7-4. Projected lifespan of the infrastructures based on the carbonation coefficient of concrete (30-40 Mpa, 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
M300 – M350	30	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 7-3).

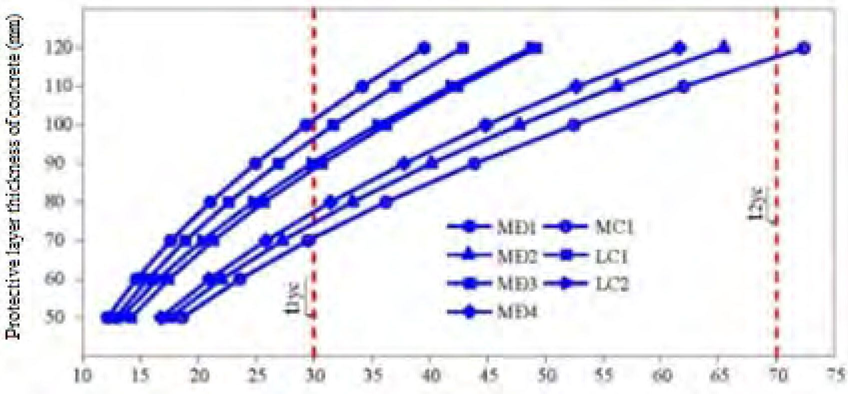


Figure 7-3. The relationship between the lifespan and the concrete protective layer thickness for the coastal reinforced concrete structures due to ion intrusion

In general, for ordinary cement concrete M300-M350 and the protective layer thickness of 100 mm, the engineering analysis of erosion phenomenon (carnonation and chlorine ion intrusion) showed that the lifespan of the infrastructures is about 43 years.

The increasing impact of high temperature combined with salinity intrusion will increasingly affect the bearing capacity of infrastructure. The engineering analysis showed that two structural forms of pillar dam and monolithic concrete are equally vulnerable due to the impact of high temperature combined with saline intrusion at the design/construction stage (as of 2010), at present and in future (2020 ÷ 2050) (Table 7-5).

Table 7-5. Vulnerability ratio of two structural forms of monolithic concrete and pillar dam under the impact of high temperature combined with saline intrusion

Year	Climate/hydrological factor	Vulnerability Ratio (V_R)		The most vulnerable components
		Monolithic concrete	Pillar dam	
2010	High temperature combined with saline intrusion	1.000	1.000	Equally
2020		1.000	1.000	Equally
2050		1.149	1.149	Equally

7.3.2 Gates

The coastal sluice gates in Kien Giang currently include 3 main types of gates including: vertically lifted gates, bottom shutter gates, and automatic gates.

- For vertically lifted gates: The gates are operated to slide vertically up and down by hydraulic cylinders (or winch). When opened, the gate is hang on the gate tower. These gates are mainly made of high-strength low-alloy steel (CT3) combined with powder coating (an anti-rust epoxy coating) to prevent rust (for the gates which were converted from automatic operation to vertical pull-down operation). Recently some new sluice gates have been made of stainless steel (Sus 304).

- For bottom shutter gates: The gates are operated by hydraulic cylinder (or winch) to rotate vertically around one horizontal axis. When opened, the gates are lowered to the bottom of the river. The gates are often in the water environment. These gates are mainly made of stainless steel (Sus-304).

- For automatic gates: These gates have been popularly used in Kien Giang, particularly for small sluice gates in Long Xuyen Quadrangle region. The gates are automatically closed and opened by the difference of the water column pressure between two sides of the gate. The automatic gates are operated by rotating horizontally around one vertical axis. They are mainly made of CT3 steel combined with an anti-rust epoxy coating or stainless steel (Sus-304).

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 sluice gates, 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.

Climatic-hydrological factors such as water level and salinity intrusion combined with high temperature have different impacts on the structure and the bearing capacity of the gates. The engineering analysis showed that automatic gates are most vulnerable to water level impacts at the design/construction stage (as of 2010), while the most vulnerable components at present and in the future (2020 ÷ 2050) are vertically lifted gates (Table 7-6). For the combined effects of salinity intrusion and high temperature, all three of the gates are equally vulnerable at the design/construction stage and at present, but bottom shutter gates and automatic gates are most vulnerable in the future.

Table 7-6. Vulnerability ratio of three different gate types under the impact of water level and high temperature combined with saline intrusion

TT	Year	Climate and hydrological factor	Vulnerability Ratio (V_R)			The most vulnerable components
			Vertically lifted gates	Bottom shutter gates	Automatic gates	
1	2010	Water level	0.264	0.309	0.355	Automatic gates
	2020		0.471	0.411	0.393	Vertically lifted gates
	2050		0.569	0.453	0.528	Vertically lifted gates
2	2010	High temperature combined with saline intrusion	1.000	1.000	1.000	Equally
	2020		1.000	1.000	1.000	Equally
	2050		1.200	1.667	1.667	Bottom shutter gates and automatic gates

7.3.3 Bridges

The bridges were mainly made of reinforced concrete M300 with a protective layer thickness of 50-60 mm. Similar to the pillar structure, the bridges were designed to ensure a lifespan of 43-50 years.

7.4 Calculation of loads and capacity

7.4.1 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 Tables 7-7 to 7-10.

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

+ Wave pressure: Ps = ki x ρ x g x h – Corresponding to the climate loads L_C in Tables 7-7 to 7-10.

- 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 Tables 7-7 to 7-10.

W = γ x Wo x K.x 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 Tables 7-7 to 7-10, based on the evaluation method of reinforcement corrosion above.

7.4.2 Load capacity

Under the impacts of climate and hydrological 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 5.50 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 7-7. Summary of loads and capacity for two main structural forms of monolithic concrete and pillar dam

No.	Structural forms	Materials of infrastructure components	Climate/ hydrological factors	Year	Total Load (L_T)	Total Capacity (C_T)	Vulnerability Ratio ($V_R = L_T / C_T$)	Adaptation Ratio ($A_R = C_T / L_T$)
1	Monolithic concrete	Reinforced concrete M300, protective layer thickness a = 5cm, normal cement	Water level	2010 (design/construction stage)	70.976	275.000	0.258	3.875
				2020 (present)	78.608	275.000	0.286	3.498
				2050 (future)	105.608	275.000	0.384	2.604
			Tropical storms/ depression	2010	49.780	275.000	0.181	5.524
				2020	75.570	275.000	0.275	3.639
				2050	75.570	275.000	0.275	3.639
			High temperature combined with salinity intrusion	2010	50.000	50.000	1.000	1.000
				2020	50.000	50.000	1.000	1.000
				2050	50.000	43.523	1.149	0.870
2	Pillar dam	Reinforced concrete M300, protective layer thickness a = 5cm, normal cement	Water level	2010	94.635	264.000	0.358	2.790
				2020	104.811	264.000	0.397	2.519
				2050	140.811	264.000	0.533	1.875
			Tropical storms/ depression	2010	69.692	264.000	0.264	3.788
				2020	105.798	264.000	0.401	2.495
				2050	105.798	264.000	0.401	2.495
			High temperature combined with salinity intrusion	2010	50.000	50.000	1.000	1.000
				2020	50.000	50.000	1.000	1.000
				2050	50.000	43.523	1.149	0.870

Table 7-8. Calculation of loads and capacity for two main structural forms of monolithic concrete and pillar dam

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 body with structural form of monolithic concrete	Water level (Hydrostatic pressure, wave pressure, change of water level due to climate change sea level rise)	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		2010	71	-	-	71	275	-	-	275	0.258	-	3.875	-
				Functionality		X	2020	71	8	-	79	275	-	-	275	0.286	-	3.498	-
				Operations and maintenance	X		2050	71	35	-	106	275	-	-	275	0.384	-	2.604	-
				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 = 1.5%; min water level with frequency P = 95%. Water levels were considered at the design/construction stage (as of 2010), at present (2020 - engineering analysis) and in the future (2050) 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															
				Public Health and Safety		X													
				Environmental Effects		X													
		Tropical storms/ Depression	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		2010	50	-	-	50	275	-	-	275	0.181	-	5.524	-
				Functionality		X	2020	50	26	-	76	275	-	-	275	0.275	-	3.639	-
				Operations and Maintenance	X		2050	50	26	-	76	275	-	-	275	0.275	-	3.639	-
				Emergency Response Risks		X	**Comments / Data sufficiency** 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													
		High temperature combined with salinity intrusion	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		2010	50	-	-	50	50	-	-	50	1.000	-	1.000	-
				Functionality		X	2020	50	-	-	50	50	-	-	50	1.000	-	1.000	-
				Operations and Maintenance	X		2050	50	-	-	50	44	-	-	44	1.149	-	0.870	6.5
				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													
2				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

No.	Main components	Climate/ hydrological factors	Risk scores	Performance response	Assessment basis		Horizon	Total Load (L_T)				Total Capacity (C_T)				Vulnerability Ratio	STEP 5	Adaptation 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	$A_R = C_T / L_T$	$C_D = L_T - C_T$
	Sluice body with structural form of pillar dam	Water level (Hydrostatic pressure, wave pressure, change of water level due to climate change sea level rise)	7 ÷ 18	Serviceability	X		2010	95	-	-	95	264	-	-	264	0.358	-	2.790	-
				Functionality		X	2020	95	10	-	105	264	-	-	264	0.397	-	2.519	-
				Operations and Maintenance	X		2050	95	46	-	141	264	-	-	264	0.533	-	1.875	-
				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 = 1.5%; min water level with frequency P = 95%. Water levels were considered at the design/construction stage (as of 2010), at present (2020 - engineering analysis) and in the future (2050) 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													
		Tropical storms/ Depression	7 ÷ 18	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		2010	70	-	-	70	264	-	-	264	0.264	-	3.788	-
				Functionality		X	2020	70	36	-	106	264	-	-	264	0.401	-	2.495	-
				Operations and Maintenance	X		2050	70	36	-	106	264	-	-	264	0.401	-	2.495	-
				Emergency Response Risks		X	**Comments / Data sufficiency** 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													
		High temperature combined with salinity intrusion	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		2010	50	-	-	50	50	-	-	50	1.000	-	1.000	-
				Functionality		X	2020	50	-	-	50	50	-	-	50	1.000	-	1.000	-
				Operations and Maintenance	X		2050	50	-	-	50	44	-	-	44	1.149	-	0.870	6.5
				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													

Table 7-9. Summary of loads and capacity for three gate types of automatic gates, vertically lifted gates, and bottom shutter gates

No.	Structural forms	Components	Materials of infrastructure components	Climate/ hydrological factors	Year	Total Load (L_T)	Total Capacity (C_T)	Vulnerability Ratio ($V_R = L_T / C_T$)	Adaptation Ratio ($A_R = C_T / L_T$)
1	Vertically lifted gates	Hydraulic Cylinder	CT3 or CT5 steel combined with an anti-rust epoxy coating	Water level	2010 (design/construction stage)	24.309	140.000	0.174	5.759
					2020 (present)	76.768	140.000	0.548	1.824
					2050 (future)	85.466	140.000	0.610	1.638
				High temperature combined with salinity intrusion	2010	30.000	30.000	1.000	1.000
					2020	30.000	30.000	1.000	1.000
					2050	30.000	25.000	1.200	0.833
		Gates	CT3 or CT5 steel combined with an anti-rust epoxy coating or stainless steel (SUS-304)	Water level	2010	70.976	200.000	0.355	2.818
					2020	78.608	200.000	0.393	2.544
					2050	105.608	200.000	0.528	1.894
				High temperature combined with salinity intrusion	2010	30.000	30.000	1.000	1.000
					2020	30.000	30.000	1.000	1.000
					2050	30.000	25.000	1.200	0.833
2	Bottom shutter gates	Hydraulic Cylinder	CT3 or CT5 steel combined with an anti-rust epoxy coating	Water level	2010	79.198	200.000	0.396	2.525
					2020	115.198	200.000	0.576	1.736
					2050	115.198	200.000	0.576	1.736
				High temperature combined with salinity intrusion	2010	30.000	30.000	1.000	1.000
					2020	30.000	30.000	1.000	1.000
					2050	30.000	18.000	1.667	0.600
		Gates	Stainless steel (SUS-304)	Water level	2010	70.976	320.000	0.222	4.509
					2020	78.608	320.000	0.246	4.071
					2050	105.608	320.000	0.330	3.030
				High temperature combined with salinity intrusion	2010	30.000	30.000	1.000	1.000
					2020	30.000	30.000	1.000	1.000
					2050	30.000	18.000	1.667	0.600
3	Automatic gates	Gates	CT3 or CT5 steel combined with an anti-rust epoxy coating or stainless steel (SUS-304)	Water level	2010	70.976	200.000	0.355	2.818
					2020	78.608	200.000	0.393	2.544
					2050	105.608	200.000	0.528	1.894
				High temperature combined with salinity intrusion	2010	30.000	30.000	1.000	1.000
					2020	30.000	30.000	1.000	1.000
					2050	30.000	18.000	1.667	0.600

Table 7-10. Calculation of loads and capacity for three gate types of automatic gates, vertically lifted gates, and bottom shutter gates

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	Adaptation 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	Vertically lifted gates																		
	Hydraulic cylinder	Water level (Hydrostatic pressure, wave pressure, change of water level due to climate change sea level rise)	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		2010	24	-	-	24	140	-	-	140	0.174	-	5.759	-
				Functionality		X	2020	24	52	-	77	140	-	-	140	0.548	-	1.824	-
				Operations and maintenance	X		2050	24	61	-	85	140	-	-	140	0.610	-	1.638	-
				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 = 1.5%; min water level with frequency P = 95%. Water levels were considered at the design/construction stage (as of 2010), at present (2020 - engineering analysis) and in the future (2050) under climate change -sea level rise scenarios of MONRE (2016). 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.											
				Insurance Considerations		X													
				Policies and Procedures		X													
				Economics	X														
				Public Health and Safety		X													
				Environmental Effects		X													
		High temperature combined with salinity intrusion	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		2010	30	-	-	30	30	-	-	30	1.000	-	1.000	-
				Functionality		X	2020	30	-	-	30	30	-	-	30	1.000	-	1.000	-
				Operations and maintenance	X		2050	30	-	-	30	25	-	-	25	1.200	-	0.833	5.0
				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. The cylinder shell (cover) is relatively durable because it is less exposed to the water environment.											
				Insurance Considerations		X													
				Policies and Procedures		X													
				Economics	X														
				Public Health and Safety		X													
				Environmental Effects		X													
	Gates	Water level (Hydrostatic pressure, wave pressure, change of water level due to climate change sea level rise)	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		2010	71	-	-	71	200	-	-	200	0.355	-	2.818	-
				Functionality		X	2020	71	8	-	79	200	-	-	200	0.393	-	2.544	-
				Operations and maintenance	X		2050	71	35	-	106	200	-	-	200	0.528	-	1.894	-
				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 = 1.5%; min water level with frequency P = 95%. Water levels were considered at the design/construction stage (as of 2010), at present (2020 - engineering analysis) and in the future (2050) 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													
		High temperature combined with salinity intrusion	12 ÷ 20	Structural Integrity	X		(năm)	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		2010	30	-	-	30	30	-	-	30	1.000	-	1.000	-
				Functionality		X	2020	30	-	-	30	30	-	-	30	1.000	-	1.000	-
				Operations and maintenance	X		2050	30	-	-	30	25	-	-	25	1.200	-	0.833	5.0
				Emergency Response Risks		X	**Comments / Data sufficiency** 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														

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	Adaptation 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	Bottom shutter gates																		
	Hydraulic cylinder	Water level (Hydrostatic pressure, wave pressure, change of water level due to climate change sea level rise)	21 ÷ 28	Structural Integrity	X		(năm)	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		2010	79	-	-	79	200	-	-	200	0.396	-	2.525	-
				Functionality		X	2020	79	36	-	115	200	-	-	200	0.576	-	1.736	-
				Operations and maintenance	X		2050	79	36	-	115	200	-	-	200	0.576	-	1.736	-
				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 = 1.5%; min water level with frequency P = 95%. Water levels were considered at the design/construction stage (as of 2010), at present (2020 - engineering analysis) and in the future (2050) under climate change -sea level rise scenarios of MONRE (2016). 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.												
				Insurance Considerations		X													
				Policies and Procedures		X													
				Economics	X														
				Public Health and Safety		X													
				Environmental Effects		X													
		High temperature combined with salinity intrusion	12 ÷ 20	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		2010	30	-	-	30	30	-	-	30	1.000	-	1.000	-
				Functionality		X	2020	30	-	-	30	30	-	-	30	1.000	-	1.000	-
				Operations and maintenance	X		2050	30	-	-	30	18	-	-	18	1.667	-	0.600	12.0
				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													
	Gates	Water level (Hydrostatic pressure, wave pressure, change of water level due to climate change sea level rise)	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		2010	71	-	-	71	320	-	-	320	0.222	-	4.509	-
				Functionality		X	2020	71	8	-	79	320	-	-	320	0.246	-	4.071	-
				Operations and maintenance	X		2050	71	35	-	106	320	-	-	320	0.330	-	3.030	-
				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 = 1.5%; min water level with frequency P = 95%. Water levels were considered at the design/construction stage (as of 2010), at present (2020 - engineering analysis) and in the future (2050) 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													
		High temperature combined with salinity intrusion	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		2010	30	-	-	30	30	-	-	30	1.000	-	1.000	-
				Functionality		X	2020	30	-	-	30	30	-	-	30	1.000	-	1.000	-
				Operations and maintenance	X		2050	30	-	-	30	18	-	-	18	1.667	-	0.600	12.0
				Emergency Response Risks		X	**Comments / Data sufficiency** 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														

No.	Main components	Climate/ hydrological factors	Risk scores	Performance response	Assessment basis: Numerical calculation	Assessment basis: Engineering judgement/ assumption	Horizon	Total Load (L_T): Existing Load L_E	Climate Load L_C	Other Load L_O	Total Load $L_T = L_E + L_C + L_O$	Total Capacity (C_T): Existing Capacity C_E	Maturing Capacity C_M	Additional Capacity C_A	Projected Total Capacity $C_T = C_E + C_M + C_A$	Vulner-ability Ratio $V_R = L_T/C_T$	STEP 5 Y/N	Adaptation Ratio A_R $A_R = C_T / L_T$	Capacity Deficit $C_D = L_T - C_T$
				Public Health and Safety		X													
				Environmental Effects		X													
3	Automatic gates																		
	Gates	Water level (Hydrostatic pressure, wave pressure, change of water level due to climate change sea level rise)	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		2010	71	-	-	71	200	-	-	200	0.355	-	2.818	-
				Functionality		X	2020	71	8	-	79	200	-	-	200	0.393	-	2.544	-
				Operations and maintenance	X		2050	71	35	-	106	200	-	-	200	0.528	-	1.894	-
				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 = 1.5%; min water level with frequency P = 95%. Water levels were considered at the design/construction stage (as of 2010), at present (2020 - engineering analysis) and in the future (2050) 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													
		High temperature combined with salinity intrusion	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		2010	30	-	-	30	30	-	-	30	1.000	-	1.000	-
				Functionality		X	2020	30	-	-	30	30	-	-	30	1.000	-	1.000	-
				Operations and maintenance	X		2050	30	-	-	30	18	-	-	18	1.667	-	0.600	12.0
				Emergency Response Risks		X	**Comments / Data sufficiency** 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													

8 RECOMMENDATIONS

The recommendations for the coastal sluice gate system in Kien Giang are summarized as follows:

8.1 The stage of technical design and before construction

8.1.1 Primary Infrastructure Components

8.1.1.1 For the components made of reinforced concrete

The concrete components such as pillars may be impacted 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.

8.1.1.2 For the components made of metals

In order to meet the current requirements of coastal sluice gates in Kien Giang province (specifically, regulating water resources and preventing local inundation in the LXQ region; controlling salinity in the WBR region; and minimizing sedimentation around the gates in the UMT region), the type of flat gates operated vertically by hydraulic cylinders should be selected for infrastructures to be invested.

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 recommended to select materials with high corrosion resistance (such as stainless steel Sus-304) and effective measures to protect metal corrosion such as Epoxy painting method.

In addition, it is necessary to study on mechanisms and causes of metal corrosion in Kien Giang province (and the Mekong Delta in general) to have the suitable prevention measure.

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.

8.1.2 Systems of electric power, monitoring, control and operation, and communication

The systems supporting electric power, monitoring, control and operation, and communication were assessed to have low risk from heavy rain. The medium risks to these systems are mainly caused by climate factors such as tropical storms, high winds, tornado and thunderstorms/lightning. The main impacts on these systems are wire breakage, line disruption, and electric fire. The recommendations for these systems include:

- To consider underground wiring designs to ensure safety for thunderstorms/lightning, tornado or in the rainy season;

- To design the lightning protection system for the whole infrastructure;

- 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 in order to minimize damage and errors.

8.1.3 The secondary components

The secondary components such as the operation houses and park have been assessed to experience medium risks from tropical storms, droughts, high temperatures, heat waves, tornados and thunderstorms/lightning. Some recommendations for these components are as follows:

- To select designs of the operation houses to reduce the effects by storms and tornado, for example, reducing the height of houses;

- To select the appropriate plants for the park, in order to ensure the landscape and be able to withstand extreme climate events such as drought and heat wave.

8.2 For completed and operated sluice gates (the stage of after construction)

8.2.1 Operational staff

The operational staff are affected by most climatic factors, especially the extreme events. Thus they need to be supported through additional training courses on coping with tropical storms and tornado; improving self-protection skills from high temperature, heavy rain, high wind in case of working outdoors; and using the automatic operation mode or choose the time of proper maintenance.

8.2.2 Primary Infrastructure Components

8.2.2.1 For the components made of reinforced concrete

- To survey 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.

- To carry out studies to assess carbonate and chlorine ion intrusion phenomena for reinforced concrete structures in the coastal area of Kien Giang province to increase the reliability of forecasting the lifespan of infrastructures.

- 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).

- To minimize the wind shield area of the pillars (e.g., do not hang the gates and only open the gates if absolutely necessary) during tropical storms/depression.

- To check and monitor the stability and displacement of the pillars after storms or floods to handle (if necessary) and ensure stability and safety for the infrastructure.

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

8.2.2.2 For the components made of metals

- Regularly check, periodically maintain, and promptly repair the damage of the gate (if any) in order to ensure the bearing capacity of the infrastructure and not to let rust spread to other positions. If the gate is damaged and no longer safe during operation, it should be promptly replaced with a new one.

8.2.2.2.1 For mode of operation

- Automatic gates

+ For the sluice gates under sea dykes in UMT region: As the sluice gates in this region operate automatically based on the tidal regime of West Sea, they are often filled with mud. Thus, it is recommended to replace from automatic gates to vertically lifted gates (operated by hydraulic cylinder.

+ For the sluice gates in LXQ region: The sluice gates in this region have been constructed mainly for flood regulation. However, due to the automatic operation based on the difference of water levels, these sluice gates can not actively open and close the gates to regulate water sources, causing local inundation. Thus, it is recommended to replace an automatic gate (among existing gates) to a vertically lifted gate (operated by hydraulic cylinders).

- For vertically lifted gates: When tropical storms/depression occur, do not open the gates (hang the gates) in order to minimize the wind shield area.

- For bottom shutter gates: The coastal sluice gates in Kien Giang are currently facing many difficulties in operation (cannot be fully opened) due to sedimentation, potentially dangerous for waterway traffic. Therefore, it is necessary to regularly check and conduct dredging of sediment in the sluice gate area, as well as periodically operate the sluice gate to circulate the flow and limit sedimentation.

- For the sluice gates with the gate size of more than 15m: The required operating force, especially the 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 make the load beyond the design limit; (ii) Controling boats to avoid colliding with structures; and (iii) Regularly checking the operating range of the gate to make sure it is not stuck.

8.2.2.2.2 For materials used to making gates

- Gates made of CT3 or CT5 steel combined with an anti-rust epoxy coating: Regularly check, periodically maintenance, and promptly repair the damage of the gate (if any) or replace by a new gate (normally every 10 years).

- Gates made of stainless steel (SUS-304): This type of gates has a high price, but is usually less affected by climate and hydrological factors. Thus, this is an option that should be considered when damaged normal steel gates needs to be replaced.

8.2.2.3 Hydraulic cylinder

It is necessary to pay attention to checking and monitoring the working process of the hydraulic cylinders to ensure that they operate evenly, in order to avoid damage to the hydraulic cylinders, the gates, and other related mechanical components.

8.2.2.4 Water tight gasket

Watertight gaskets are made of rubber, so over time there will be rubber peeling. Therefore, it is necessary to regularly check, repair and replace the gaskets in time to ensure watertightness and limit the load due to friction during operation.

8.2.3 Systems of electric power, monitoring, control and operation, and communication

- Regularly inspect and maintain the systems of electric power, monitoring, control and operation, and communication.

- To check and repair lightning protection system (if damaged) at the sluice gates to ensure the safety of the infrastructures in the case of thunderstorms and lightning.

8.2.4 The secondary components

- Check after storms to see whether it withstand the impact, and repair/maintain if necessary.

9 CONCLUSION

This report has developed and successfully applied the rapid climate risk assessment method - PIEVC Scanner - for the coastal sluice gate system in Kien Giang province. An advantage of this method is the ability to assess the responses of infrastructure components for each infrastructure group (e.g., monolithic concrete or pillar dam) under the impacts of climate and hydrological factors in different geographical regions. As a result, the PIEVC Scanner provided the corresponding risk matrices for three regions of LXQ, WBR and UMT. Based on the risk matrices combined with the engineering analysis, the risk assessment team provided the recommendations for infrastructure groups of different structural forms (monolithic concrete and pillar dam), operation modes (automatic or by hydraulic cylinders) and materials (normal or stainless steel) in these regions in the different stages of infrastructure investment (i.e., feasibility study, technical design, and after construction). Thus, it is able to assist the sluice gate management units in Kien Giang in decision making regarding the design, operations, maintenance, planning, and development or upgrading / rehabilitation of the sluice gate system in the future. This also demonstrates that the PIEVC Scanner can be applied to assess climate risks for infrastructures in the Mekong Delta in particular and Vietnam in general.

The risk matrices for the LXQ, WBR and UMT regions were determined based on an understanding of probability of occurrence and severity of impacts associated with individual climate and hydrological factors. These matrices showed that of the 150 interactions to score the severity of the infrastructure components, there were 10 high-risk interactions due to thunderstorms/lightning for both future conditions in LXQ and UMT regions, while there were no high-risk interactions in the WBR. The LXQ had the maximum number of medium risks for existing conditions (73 interactions) and for future projections (119 interactions). The WBR region had the maximum number of low risks for existing conditions (93 interactions), while the UMT region had the maximum number of low risks for future projections (35 interactions). In the medium-risk interactions for both existing and future conditions, the major infrastructure components including the staff, park, gates, water tight gasket, and the systems of electric power, monitoring, control and operation, and communication were mainly affected by tropical storms/depression, thunderstorms/lightning, and salinity intrusion combined with high temperature.

The engineering analysis in the report was performed for the interactions between the infrastructure components (including sluice gate structure, gates, and hydraulic cylinder) and climate and hydrological factors (including tropical storms, water level, and salinity intrusion combined with high temperature). This analysis quantified the corrosion of reinforcement concrete due to carbonation and chlorine ion intrusion. In addition, the loads and bearing capacity of the infrastructure components under the impacts of climate-hydrological factors have also been calculated. The results of the engineering analysis showed that under the impact of salinity intrusion combined with high temperature by 2050, both sluice gate structures (monolithic concrete and pillar dam), types of gates, and hydraulic cylinders are likely to be vulnerable and reduce the lifespan of the infrastructure.

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Appendix 1. List of the coastal sluice gates in Kien Giang province

No.	Name	Location (District)	Year completed	Year started to use	Investor	Width of a gate (m)	Height of a gate (m)	No. of gates	Threshold elevation	Elevation of pillar	Type of sluice gates	Functions - Projects	Notes
I	**THE SLUICE GATES ARE COMPLETED AND OPERATED**												
1	**Ro Ghe**	An Minh	2013	2019	**Construction investment project management board (PMU) – Kien Giang DARD**	10.0	4.7	1	-2.5	3.0	2 ways	Investment project to restore and upgrade An Bien - An Minh sea dyke	
2	**Thuong Luong**	An Minh	2013	2018	**PMU – Kien Giang DARD**	7.5	5.5	1	-2.5	3.0	2 ways	Investment project to restore and upgrade An Bien - An Minh sea dyke	
3	**Xeo Quao**	An Bien	2013	2018	**PMU – Kien Giang DARD**	10.0	5.5	2	-2.5	3.0	2 ways	Investment project to restore and upgrade An Bien - An Minh sea dyke	
4	**Canal No. 7**	An Bien	2013	2018	**PMU – Kien Giang DARD**	7.5	5.5	1	-2.5	3.0	2 ways	Investment project to restore and upgrade An Bien - An Minh sea dyke	
5	**Xeo Doi (An Bien)**	An Bien	2013	2018	**PMU – Kien Giang DARD**	7.5	5.5	1	-2.5	3.0	2 ways	Investment project to restore and upgrade An Bien - An Minh sea dyke	

No.	Name	Location (District)	Year completed	Year started to use	Investor	Width of a gate (m)	Height of a gate (m)	No. of gates	Threshold elevation	Elevation of pillar	Type of sluice gates	Functions - Projects	Notes
6	**Xeo Nhao**	An Minh	2017	2019	**PMU – Kien Giang DARD**	10.0	5.5	2	-2.5	3.0	2 ways	Investment project to restore and upgrade An Bien - An Minh sea dyke	
7	**Soc Tram**	Chau Thanh	2016	2018	**PMU – Kien Giang DARD**	7.5	4.3	1	-2.5	2.5	Bottom shutter gates, operated by winch. Pillar dam.	Project on investment of Soc Tram sluice gate	
8	**Ca Lang**	Chau Thanh	2017	2018	**PMU – Kien Giang DARD**	20.0	4.5	1	-2.5	2.5	Vertically lifted flat gates, operated by hydraulic cylinder.	Project on investment of emergency infrastructures to overcome drought and salinity intrusion along Cai Be River.	
9	**Dap Da**	Chau Thanh	2017	2018	**PMU – Kien Giang DARD**	12.0	4.5	1	-2.5	2.5	Vertically lifted flat gates, operated by hydraulic cylinder.	Project on investment of emergency infrastructures to overcome drought and salinity intrusion along Cai Be River.	
10	**Kenh Cut**	Rach Gia City	2017	2018	**PMU – Kien Giang DARD**	22.0	6.0	3	-3.5	3.0	Bottom shutter gates, operated by hydraulic cylinder. Pillar dam.	Project on investment of Kenh Cut sluice gate – Rach Gia, Kien Giang	Inox gate
11	**Kien River**	Rach Gia City	2012	2016	**PMU – Kien Giang DARD**	10.0	6.5	5	-4.3	3.0	2 ways	Project on investment of Kien River sluice gate – Rach Gia, Kien Giang	Inox gate

No.	Name	Location (District)	Year completed	Year started to use	Investor	Width of a gate (m)	Height of a gate (m)	No. of gates	Threshold elevation	Elevation of pillar	Type of sluice gates	Functions - Projects	Notes
12	**Kim Quy**	An Minh	1998	2000	**PMU 419**	7.5	4.7	2	-2.7	2.5	2 ways	Prevent salinity intrusion, store freshwater, drain inundation, and improve acid sulfate soil - An Minh, Kien Giang	
13	**Canal No. 5**	Hon Dat	2009	2018	**PMU – Kien Giang DARD**	5.5	4.7	1	-2.7	2.0	2 ways	Vam Rang - Ba Hon aquaculture project	
14	**Canal No. 10**	Hon Dat	2010	2016	**PMU – Kien Giang DARD**	5.5	4.7	1	-2.7	2.0	2 ways	Vam Rang - Ba Hon aquaculture project	
15	**Kenh Hai**	Hon Dat	2011	2016	**PMU – Kien Giang DARD**	5.5	4.7	1	-2.7	2.0	2 ways	Vam Rang - Ba Hon aquaculture project	Inox frame. Steel gates
16	**Kenh Bon**	Hon Dat	2012	2014	**PMU – Kien Giang DARD**	5.4	4.5	1	-2.5	2.0	2 ways	Vam Rang - Ba Hon aquaculture project	
17	**Kenh Bay**	Hon Dat	2011	2013	**PMU – Kien Giang DARD**	5.4	4.7	1	-2.5	2.0	2 ways	Vam Rang - Ba Hon aquaculture project	
18	**Kenh 285**	Hon Dat	2009	2018	**PMU – Kien Giang DARD**	5.5	4.7	1	-2.7	2.0	2 ways	Vam Rang - Ba Hon aquaculture project	
19	**Kenh Tam**	Hon Dat	2009	2018	**PMU – Kien Giang DARD**	5.5	4.7	1	-2.7	2.0	2 ways	Vam Rang - Ba Hon aquaculture project	
20	**Kenh 287**	Hon Dat	2012	2014	**PMU – Kien Giang DARD**	5.4	4.3	1	-2.5	2.0	2 ways	Vam Rang - Ba Hon aquaculture project	
21	**Tam Nguyen**	Hon Dat	2011	2016	**PMU – Kien Giang DARD**	7.5	4.7	1	-2.7	2.0	2 ways	Vam Rang - Ba Hon aquaculture project	
22	**Kenh 500**	Kien Lương	2013	2015	**PMU – Kien Giang DARD**	3.0	4.3	1	-2.5	2.0	2 ways	Vam Rang - Ba Hon aquaculture project	

No.	Name	Location (District)	Year completed	Year started to use	Investor	Width of a gate (m)	Height of a gate (m)	No. of gates	Threshold elevation	Elevation of pillar	Type of sluice gates	Functions - Projects	Notes
23	**Kenh 282**	Hon Dat	2009	2012	**PMU – Kien Giang DARD**	5.5	4.2	1	-2.7	2.0	2 ways	Vam Rang - Ba Hon aquaculture project	
24	**Kenh 281**	Hon Dat	2011	2014	**PMU – Kien Giang DARD**	5.4	4.7	1	-2.5	2.0	2 ways	Vam Rang - Ba Hon aquaculture project	
25	**Kenh 284**	Hon Dat	2012	2014	**PMU – Kien Giang DARD**	5.4	4.7	1	-2.5	2.0	2 ways	Vam Rang - Ba Hon aquaculture project	
26	**Rach Phoc**	Hon Dat	2011	2013	**PMU – Kien Giang DARD**	7.8	4.3	1	-2.5	2.0	2 ways	Vam Rang - Ba Hon aquaculture project	
27	**Vam Rang 2**	Hon Dat	2012	2016	**PMU – Kien Giang DARD**	3.0	4.5	1	-2.7	2.0	2 ways	Vam Rang - Ba Hon aquaculture project	
28	**Hon Me 2**	Hon Dat	2009	2011	**PMU – Kien Giang DARD**	3.5	4.2	1	-2.5	2.0	2 ways	Vam Rang - Ba Hon aquaculture project	
29	**Ta Luc**	Hon Dat	2008	2012	**PMU – Kien Giang DARD**	8.0	4.2	1	-3.0	2.0	2 ways	Vam Rang - Ba Hon aquaculture project	
30	**Muong Kham**	Hon Dat	2012	2016	**PMU – Kien Giang DARD**	5.5	4.5	1	-2.5	2.0	2 ways	Vam Rang - Ba Hon aquaculture project	
31	**Lung Lon 2**	Kien Luong	2000	2002	**PMU 419**	7.5	4.8	1	-3.0	2.0	2 ways	Flood drainage into the West Sea	Concrete backup gates were replaced by steel ones in 2018
32	**Binh Giang 2**	Hon Dat	2002	2004	**PMU 419**	7.5	6.2	3	-4.0	2.0	2 ways	Flood drainage into the West Sea	

No.	Name	Location (District)	Year completed	Year started to use	Investor	Width of a gate (m)	Height of a gate (m)	No. of gates	Threshold elevation	Elevation of pillar	Type of sluice gates	Functions - Projects	Notes
33	**T6**	Hon Dat	1998	1999	**PMU 419**	7.5	5.0	2	-3.2	2.0	one way	Flood drainage into the West Sea	
34	**Binh Giang 1**	Hon Dat	2002	2004	**PMU 419**	7.5	6.2	3	-4.2	2.0	2 ways	Flood drainage into the West Sea	
35	**T5**	Hon Dat	1998	1999	**PMU 419**	7.5	4.8	3	-3.0	2.0	one way	Flood drainage into the West Sea	
36	**286**	Hon Dat	1998	1999	**PMU 419**	7.5	4.5	1	-2.5	2.0	one way	Flood drainage into the West Sea	
37	**Vam Ray**	Hon Dat	1999	2000	**PMU 419**	7.5	6.0	3	-4.2	2.0	one way	Flood drainage into the West Sea	To maintain a gate
38	**Lung Lon 1**	Kien Luong	1997	1999	**PMU 419**	7.5	4.8	3	-3.0	2.0	2 ways	Flood drainage into the West Sea	Concrete backup gates were replaced by steel ones in 2018
39	**Cai Tre**	Kien Luong	2002	2006	**PMU 419**	7.5	4.5	3	-3.0	2.0	2 ways	Flood drainage into the West Sea	
40	**Linh Huynh**	Hon Dat	1999	2004	**PMU 419**	7.5	5.5	3	-3.5	2.0	one way	Flood drainage into the West Sea	To maintain a gate
41	**283**	Hon Dat	1999	2000	**PMU 419**	7.5	4.5	1	-2.5	2.0	one way	Flood drainage into the West Sea	
42	**Canal No. 2**	Hon Dat	1999	2001	**PMU 419**	7.5	5.2	2	-3.2	2.0	one way	Flood drainage into the West Sea	

No.	Name	Location (District)	Year compl eted	Year started to use	Investor	Width of a gate (m)	Height of a gate (m)	No. of gates	Threshold elevation	Elevation of pillar	Type of sluice gates	Functions - Projects	Notes
43	**Than Nong**	Hon Dat	1997	1998	**PMU 419**	7.5	4.3	1	-2.5	2.0	one way	Flood drainage into the West Sea	
44	**Thay Xep**	Hon Dat	2000	2003	**PMU – Kien Giang DARD**	3.5	4.2	1	-2.2	2.0	one way	Flood drainage into the West Sea	Inox gate
45	**Canal No. 3**	Hon Dat	2000	2001	**PMU 419**	5.0	5.0	2	-3.0	2.0	one way	Flood drainage into the West Sea	
46	**Ta Manh**	Hon Dat	2000	2001	**PMU – Kien Giang DARD**	4.0	4.2	1	-2.5	2.0	one way	Flood drainage into the West Sea	Inox gate
47	**Ta Hem**	Hon Dat	1998	1999	**PMU 419**	7.5	4.3	1	-2.5	2.0	one way	Flood drainage into the West Sea	
48	**Ta Lua**	Hon Dat	1999	2001	**PMU 419**	5.0	5.0	2	-3.2	2.0	one way	Flood drainage into the West Sea	Concrete backup gates were replaced by steel ones in 2018
49	**Vam Rang**	Hon Dat	2010	2013	**PMU – Kien Giang DARD**	10.0	6.7	3	-5.0	2.0	2 ways	Flood drainage into the West Sea	
50	**Canal No. 7**	Hon Dat	2000	2001	**PMU 419**	5.5	5.0	2	-3.2	2.0	one way	Flood drainage into the West Sea	Concrete backup gates were replaced by steel ones in 2018

No.	Name	Location (District)	Year completed	Year started to use	Investor	Width of a gate (m)	Height of a gate (m)	No. of gates	Threshold elevation	Elevation of pillar	Type of sluice gates	Functions - Projects	Notes
51	**Canal No. 9**	Hon Dat	1999	2002	**PMU 419**	7.5	5.0	3	-3.0	2.0	one way	Flood drainage into the West Sea	A gate was replaced
52	**Hon Soc**	Hon Dat	2000	2001	**PMU 419**	5.0	4.5	1	-2.5	2.0	one way	Flood drainage into the West Sea	
53	**Ba Hon**	Kien Luong	1998	1999	**PMU 419**	7.5	6.0	3	-4.2	2.0	one way	Flood drainage into the West Sea	
54	**Canal No. 1**	Rach Gia City	2000	2004	**PMU – Kien Giang DARD**	5.0	4.5	1	-2.5	2.0	One way	Flood drainage into the West Sea	Inox gate
	Ta Nien	Chau Thanh		2021	**PMU – Kien Giang DARD**	15.0		1			Vertically lifted flat gates, operated by hydraulic cylinder.		Inox gate
	Kenh Nhanh	Rach Gia City		2021	**PMU – Kien Giang DARD**	20.0		2			Vertically lifted flat gates, operated by hydraulic cylinder.		Inox gate
II	**THE SLUICE GATES ARE COMPLETING**												
1	**Cai Be**	Chau Thanh			**PMU 10**								

No.	Name	Location (District)	Year completed	Year started to use	Investor	Width of a gate (m)	Height of a gate (m)	No. of gates	Threshold elevation	Elevation of pillar	Type of sluice gates	Functions - Projects	Notes
2	**Cai Lon**	Chau Thanh			**PMU 10**								
III	**THE SLUICE GATES ARE UNDER CONSTRUCTION**												
1	**Kenh Thu Nam**	An Bien			**PMU – Kien Giang DARD**	10.0		2			Vertically lifted flat gates, operated by hydraulic cylinder.	Project on Mekong delta integrated climate resilience and sustainable livelihoods (MD-ICRSL)	
2	**Kenh Thu Sau**	An Bien			**PMU – Kien Giang DARD**	15.0		2			Vertically lifted flat gates, operated by hydraulic cylinder.	MD-ICRSL	
3	**Kenh Thu Hai**	An Bien			**PMU – Kien Giang DARD**	8.0		1			Vertically lifted flat gates, operated by hydraulic cylinder.	MD-ICRSL	
4	**Kenh Thu Ba**	An Bien			**PMU – Kien Giang DARD**	15.0		2			Vertically lifted flat gates, operated by hydraulic cylinder.	MD-ICRSL	

No.	Name	Location (District)	Year completed	Year started to use	Investor	Width of a gate (m)	Height of a gate (m)	No. of gates	Threshold elevation	Elevation of pillar	Type of sluice gates	Functions - Projects	Notes
5	**Kenh Thu Nhat**	An Bien			**PMU – Kien Giang DARD**	10.0		1			Vertically lifted flat gates, operated by hydraulic cylinder.	MD-ICRSL	
6	**Xeo Ban**	An Minh			**PMU – Kien Giang DARD**	10.0		1			Vertically lifted flat gates, operated by hydraulic cylinder.	MD-ICRSL	
7	**Kenh Thu Tam**	An Minh			**PMU – Kien Giang DARD**	15.0		1			Vertically lifted flat gates, operated by hydraulic cylinder.	MD-ICRSL	
8	**Kenh Thu Chin**	An Minh			**PMU – Kien Giang DARD**	10.0		1			Vertically lifted flat gates, operated by hydraulic cylinder.	MD-ICRSL	
9	**Kenh Thu Muoi**	An Minh			**PMU – Kien Giang DARD**	10.0		1			Vertically lifted flat gates, operated by hydraulic cylinder.	MD-ICRSL	
10	**Vam Ba Lich**	Chau Thanh			**PMU – Kien Giang DARD**	22.5		2	-4.0				
11	**Xeo Ro**	An Bien			**PMU – Kien Giang DARD**	30+14			-4.0				

No.	Name	Location (District)	Year completed	Year started to use	Investor	Width of a gate (m)	Height of a gate (m)	No. of gates	Threshold elevation	Elevation of pillar	Type of sluice gates	Functions - Projects	Notes
V	**THE SLUICE GATES AT THE FEASIBILITY STUDY STAGE**												
1	**Xeo La**	An Minh			**PMU – Kien Giang DARD**	8.0		1	-2.5				
2	**Xeo Doi (An Minh)**	An Minh			**PMU – Kien Giang DARD**	8.0		1	-2.5				
3	**Xeo Ngat**	An Minh			**PMU – Kien Giang DARD**	8.0		1	-2.5				
4	**Kenh Dai**	An Bien			**PMU – Kien Giang DARD**	10.0		1	-2.5				
5	**Kenh 40**	An Bien			**PMU – Kien Giang DARD**	8.0		1	-2.5				
6	**Muong Chua**	An Bien			**PMU – Kien Giang DARD**	8.0		1	-2.5				
7	**Muong Quao**	An Bien			**PMU – Kien Giang DARD**	8.0		1	-2.5				
8	**Hai Sen**	An Bien			**PMU – Kien Giang DARD**	8.0		1	-2.5				
9	**Chong My**	An Bien			**PMU – Kien Giang DARD**	10.0		2	-2.5				
10	**Muong Dao**	An Minh			**PMU – Kien Giang DARD**	8.0		1	-2.5				
11	**Chu Vang**	An Minh			**PMU – Kien Giang DARD**	10.0		1	-2.5				
12	**Muoi Than**	An Minh			**PMU – Kien Giang DARD**	8.0		1	-2.5				

No.	Name	Location (District)	Year completed	Year started to use	Investor	Width of a gate (m)	Height of a gate (m)	No. of gates	Threshold elevation	Elevation of pillar	Type of sluice gates	Functions - Projects	Notes
13	**Cay Go**	An Minh			**PMU – Kien Giang DARD**	8.0		1	-2.5				
14	**Tieu Dua**	An Minh			**PMU – Kien Giang DARD**	15.0		1	-2.5				
15	**Nga Bat**	An Bien			**PMU – Kien Giang DARD**	8.0		1	-2.5				
16	**Xeo Vet**	An Bien			**PMU – Kien Giang DARD**	5		1					

Appendix 2. Matrix of historical climate risk assessment for the coastal sluice gate system in Long Xuyen Quadrangle region

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			
	A				B				C				D				E			
	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 (Operation and maintenance)																				
Personnel	Y	6	3	18	Y	3	5	15	Y	5	3	15	Y	4	2	8	Y	3	7	21
Transportation (Supplies Delivery)									Y	5	1	5	Y	4	1	4	Y	3	6	18
2-Sluice Gate Structure																				
Pile foundation																				
Waterproof pile foundation																				
Pillar footing																				
Bottom beam																				
Pillar					Y	3	2	6									Y	3	1	3
Gate tower / Gate hanger					Y	3	2	6									Y	3	1	3
Cast-in-situ concrete composition					Y	3	2	6												
Lifting system and gangway					Y	3	2	6									Y	3	3	9
3-Gates																				
Water tight gasket	Y	6	3	18	Y	3	5	15												
Automatic gates																				
Vertically lifted gates									Y	5	1	5					Y	3	4	12
Bottom shutter gates																				
Gates made of CT3 or CT5 steel combined with an anti-rust epoxy coating																				
Gates made of stainless steel (Sus-304)																				
Hydraulic Cylinder																				
4-Bridge																				
Bridge Deck					Y	3	3	9	Y	5	1	5								
Bridge abutment					Y	3	3	9												
Bearing pad					Y	3	3	9												
Hand Rail																	Y	3	5	15
Lighting System																	Y	3	5	15
Traffic Signs																	Y	3	5	15
5-Retaining walls and connected embankments (upstream and downstream of sluice gates)																				
Retaining walls					Y	3	2	6	Y	5	1	5	Y	4	1	4				
Gabion																				
Connected embankments					Y	3	1	3												
Rip-rap embankments sections					Y	3	1	3												
Riverbank																				
Stilling basin																				
6-Operation house					Y	3	1	3	Y	5	2	10					Y	3	2	6
7-Park					V	3	2	6	Y	5	2	10					Y	3	6	18
8-Electric system																				
Transmission Lines									Y	5	1	5					Y	3	4	12
Power Supply									Y	5	1	5					Y	3	2	6
Standby Generators																	Y	3	2	6
9-Control and operation system																				
Control Systems																	Y	3	7	21
Operation systems									Y	5	1	5	Y	4	1	4	Y	3	4	12
10-Monitoring systems									Y	5	1	5	Y	4	1	4	Y	3	7	21
11-Fire extinguishing systems																				
12-Communication system									Y	5	1	5	Y	4	1	4	Y	3	6	18

Time Period Current to 2020																
Infrastructure Components	Drought				High Wind >=20 m/s				Tornado				Thunderstorm/ Lightning			
	F				G				H				I			
	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R
1-Administration (Operation and maintenance)																
Personnel	Y	5	2	10	Y	4	3	12	Y	3	6	18	Y	5	7	35
Transportation (Supplies Delivery)									Y	3	6	18	Y	5	1	5
2-Sluice Gate Structure																
Pile foundation																
Waterproof pile foundation																
Pillar footing																
Bottom beam																
Pillar																
Gate tower / Gate hanger					Y	4	2	8	Y	3	1	3	Y	5	1	5
Cast-in-situ concrete composition																
Lifting system and gangway					Y	4	2	8	Y	3	1	3	Y	5	1	5
3-Gates																
Water tight gasket																
Automatic gates																
Vertically lifted gates					Y	4	3	12	Y	3	2	6	Y	5	1	5
Bottom shutter gates																
Gates made of CT3 or CT5 steel combined with an anti-rust epoxy coating																
Gates made of stainless steel (Sus-304)																
Hydraulic Cylinder																
4-Bridge																
Bridge Deck																
Bridge abutment																
Bearing pad																
Hand Rail					Y	4	4	16	Y	3	3	9				
Lighting System					Y	4	4	16	Y	3	3	9	Y	5	7	35
Traffic Signs					Y	4	4	16	Y	3	3	9				
5-Retaining walls and connected embankments (upstream and downstream of sluice gates)																
Retaining walls																
Gabion																
Connected embankments	Y	5	3	15												
Rip-rap embankments sections																
Riverbank																
Stilling basin																
6-Operation house					Y	4	1	4	Y	3	5	15	Y	5	1	5
7-Park	Y	5	3	15	Y	4	3	12	Y	3	6	18	Y	5	7	35
8-Electric system																
Transmission Lines					Y	4	3	12	Y	3	6	18	Y	5	7	35
Power Supply									Y	3	2	6	Y	5	7	35
Standby Generators									Y	3	2	6	Y	5	7	35
9-Control and operation system																
Control Systems													Y	5	7	35
Operation systems													Y	5	7	35
10-Monitoring systems									Y	3	6	18	Y	5	7	35
11-Fire extinguishing systems																
12-Communication system					Y	4	3	12	Y	3	6	18	Y	5	7	35

Time Period Current to 2020																
Infrastructure Components	Water Level				Water Salinity				Salinity intrusion combined with high temperature				High water level combined with heavy rain			
	K				L				L				L			
	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R
1-Administration (Operation and maintenance)																
Personnel																
Transportation (Supplies Delivery)																
2-Sluice Gate Structure																
Pile foundation					Y	7	1	7	Y	6	2	12				
Waterproof pile foundation					Y	7	1	7	Y	6	2	12				
Pillar footing					Y	7	1	7	Y	6	2	12				
Bottom beam					Y	7	1	7	Y	6	2	12				
Pillar	Y	7	1	7	Y	7	1	7	Y	6	3	18	Y	2	2	4
Gate tower / Gate hanger					Y	7	1	7	Y	6	2	12				
Cast-in-situ concrete composition					Y	7	1	7	Y	6	2	12				
Lifting system and gangway					Y	7	1	7	Y	6	2	12				
3-Gates																
Water tight gasket					Y	7	1	7	Y	6	3	18				
Automatic gates	Y	7	3	21									Y	2	3	6
Vertically lifted gates	Y	7	3	21									Y	2	3	6
Bottom shutter gates	Y	7	3	21									Y	2	3	6
Gates made of CT3 or CT5 steel combined with an anti-rust epoxy coating					Y	7	2	14	Y	6	3	18				
Gates made of stainless steel (Sus-304)					Y	7	1	7	Y	6	1	6				
Hydraulic Cylinder					Y	7	2	14	Y	6	3	18				
4-Bridge																
Bridge Deck					Y	7	2	14	Y	6	3	18				
Bridge abutment					Y	7	2	14	Y	6	3	18				
Bearing pad					Y	7	2	14	Y	6	3	18				
Hand Rail																
Lighting System																
Traffic Signs																
5-Retaining walls and connected embankments (upstream and downstream of sluice gates)																
Retaining walls					Y	7	1	7	Y	6	2	12				
Gabion	Y	7	1	7	Y	7	1	7	Y	6	2	12	Y	2	2	4
Connected embankments					Y	7	1	7	Y	6	2	12				
Rip-rap embankments sections					Y	7	1	7	Y	6	2	12				
Riverbank					Y	7	1	7	Y	6	2	12				
Stilling basin					Y	7	1	7	Y	6	2	12				
6-Operation house																
7-Park																
8-Electric system																
Transmission Lines																
Power Supply																
Standby Generators																
9-Control and operation system																
Control Systems																
Operation systems																
10-Monitoring systems																
11-Fire extinguishing systems					Y	7	1	7	Y	6	2	12				
12-Communication system																

Appendix 3. Matrix of future climate risk assessment for the coastal sluice gate system in Long Xuyen Quadrangle region

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			
	A				B				C				D				E				F			
	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 (Operation and maintenance)																								
Personnel	Y	7	3	21	Y	4	6	24	Y	6	4	24	Y	5	3	15	Y	4	7	28	Y	6	3	18
Transportation (Supplies Delivery)									Y	6	2	12	Y	5	1	5	Y	4	7	28				
2-Sluice Gate Structure																								
Pile foundation																								
Waterproof pile foundation																								
Pillar footing																								
Bottom beam																								
Pillar					Y	4	3	12									Y	4	2	8				
Gate tower / Gate hanger					Y	4	3	12									Y	4	2	8				
Cast-in-situ concrete composition					Y	4	3	12																
Lifting system and gangway					Y	4	3	12									Y	4	4	16				
3-Gates																								
Water tight gasket	Y	7	3	21	Y	4	6	24																
Automatic gates																								
Vertically lifted gates									Y	6	2	12					Y	4	5	20				
Bottom shutter gates																								
Gates made of CT3 or CT5 steel combined with an anti-rust epoxy coating																								
Gates made of stainless steel (Sus-304)																								
Hydraulic Cylinder																								
4-Bridge																								
Bridge Deck					Y	4	4	16	Y	6	2	12												
Bridge abutment					Y	4	4	16																
Bearing pad					Y	4	4	16																
Hand Rail																	Y	4	6	24				
Lighting System																	Y	4	6	24				
Traffic Signs																	Y	4	6	24				
5-Retaining walls and connected embankments (upstream and downstream of sluice gates)																								
Retaining walls					Y	4	2	8	Y	6	2	12	Y	5	1	5								
Gabion																								
Connected embankments					Y	4	2	8													Y	6	4	24
Rip-rap embankments sections					Y	4	2	8																
Riverbank																								
Stilling basin																								
6-Operation house					Y	4	2	8	Y	6	2	12					Y	4	3	12				
7-Park					V	4	3	12	Y	6	2	12					Y	4	7	28	Y	6	4	24
8-Electric system																								
Transmission Lines									Y	6	2	12					Y	4	5	20				
Power Supply									Y	6	2	12					Y	4	3	12				
Standby Generators																	Y	4	3	12				
9-Control and operation system																								
Control Systems																	Y	4	7	28				
Operation systems									Y	6	2	12	Y	5	1	5	Y	4	5	20				
10-Monitoring systems									Y	6	2	12	Y	5	1	5	Y	4	7	28				
11-Fire extinguishing systems																								
12-Communication system									Y	6	2	12	Y	5	1	5	Y	4	7	28				

Time Period 2080 - 2099	Climate and Other Variables and Events																											
Infrastructure Components	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			
	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
1-Administration (Operation and maintenance)																												
Personnel	Y	4	4	16	Y	4	7	28	Y	6	7	42																
Transportation (Supplies Delivery)					Y	4	7	28	Y	6	1	6																
2-Sluice Gate Structure																												
Pile foundation																	Y	7	2	14	Y	7	3	21				
Waterproof pile foundation																	Y	7	2	14	Y	7	3	21				
Pillar footing																	Y	7	2	14	Y	7	3	21				
Bottom beam																	Y	7	2	14	Y	7	3	21				
Pillar													Y	7	2	14	Y	7	2	14	Y	7	3	21	Y	4	2	8
Gate tower / Gate hanger	Y	4	3	12	Y	4	2	8	Y	6	1	6					Y	7	2	14	Y	7	3	21				
Cast-in-situ concrete composition																	Y	7	2	14	Y	7	3	21				
Lifting system and gangway	Y	4	3	12	Y	4	2	8	Y	6	1	6					Y	7	2	14	Y	7	3	21				
3-Gates																												
Water tight gasket																	Y	7	2	14	Y	7	4	28				
Automatic gates													Y	7	4	28									Y	4	4	16
Vertically lifted gates	Y	4	4	16	Y	4	3	12	Y	6	1	6	Y	7	4	28									Y	4	4	16
Bottom shutter gates													Y	7	4	28									Y	4	4	16
Gates made of CT3 or CT5 steel combined with an anti-rust epoxy coating																	Y	7	3	21	Y	7	4	28				
Gates made of stainless steel (Sus-304)																	Y	7	1	7	Y	7	2	14				
Hydraulic Cylinder																	Y	7	3	21	Y	7	4	28				
4-Bridge																												
Bridge Deck																	Y	7	3	21	Y	7	4	28				
Bridge abutment																	Y	7	3	21	Y	7	4	28				
Bearing pad																	Y	7	3	21	Y	7	4	28				
Hand Rail	Y	4	5	20	Y	4	4	16																				
Lighting System	Y	4	5	20	Y	4	4	16	Y	6	7	42																
Traffic Signs	Y	4	5	20	Y	4	4	16																				
5-Retaining walls and connected embankments (upstream and downstream of sluice gates)																												
Retaining walls																	Y	7	2	14	Y	7	3	21				
Gabion													Y	7	2	14	Y	7	2	14	Y	7	3	21	Y	4	3	12
Connected embankments																	Y	7	2	14	Y	7	3	21				
Rip-rap embankments sections																	Y	7	2	14	Y	7	3	21				
Riverbank																	Y	7	2	14	Y	7	3	21				
Stilling basin																	Y	7	2	14	Y	7	3	21				
6-Operation house	Y	4	2	8	Y	4	6	24	Y	6	1	6																
7-Park	Y	4	4	16	Y	4	7	28	Y	6	7	42																
8-Electric system																												
Transmission Lines	Y	4	4	16	Y	4	7	28	Y	6	7	42																
Power Supply					Y	4	3	12	Y	6	7	42																
Standby Generators					Y	4	3	12	Y	6	7	42																
9-Control and operation system																												
Control Systems									Y	6	7	42																
Operation systems									Y	6	7	42																
10-Monitoring systems					Y	4	7	28	Y	6	7	42																
11-Fire extinguishing systems																	Y	7	2	14	Y	7	3	21				
12-Communication system	Y	4	4	16	Y	4	7	28	Y	6	7	42																

Appendix 4. Matrix of historical climate risk assessment for the coastal sluice gate system in Western region of Bassac River

Time Period: Current to 2020 / Infrastructure Components	High Temperature >=35oC (A)				Heat Wave (8 consecutive days >=35oC) (B)				Heavy Rain / >100mm/day (C)				5-day Total Rain / >=250mm (D)			
	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R
1-Administration (Operation and maintenance)																
Personnel	Y	6	3	18	Y	4	5	20	Y	4	3	12	Y	3	2	6
Transportation (Supplies Delivery)									Y	4	1	4	Y	3	1	3
2-Sluice Gate Structure																
Pile foundation																
Waterproof pile foundation																
Pillar footing																
Bottom beam																
Pillar					Y	4	2	8								
Gate tower / Gate hanger					Y	4	2	8								
Cast-in-situ concrete composition					Y	4	2	8								
Lifting system and gangway					Y	4	2	8								
3-Gates																
Water tight gasket	Y	6	3	18	Y	4	5	20								
Automatic gates																
Vertically lifted gates									Y	4	1	4				
Bottom shutter gates																
Gates made of CT3 or CT5 steel combined with an anti-rust epoxy coating																
Gates made of stainless steel (Sus-304)																
Hydraulic Cylinder																
4-Bridge																
Bridge Deck					Y	4	3	12	Y	4	1	4				
Bridge abutment					Y	4	3	12								
Bearing pad					Y	4	3	12								
Hand Rail																
Lighting System																
Traffic Signs																
5-Retaining walls and connected embankments (upstream and downstream of sluice gates)																
Retaining walls					Y	4	2	8	Y	4	1	4	Y	3	1	3
Gabion																
Connected embankments					Y	4	1	4								
Rip-rap embankments sections					Y	4	1	4								
Riverbank																
Stilling basin																
6-Operation house					Y	4	1	4	Y	4	2	8				
7-Park					V	4	2	8	Y	4	2	8				
8-Electric system																
Transmission Lines									Y	4	1	4				
Power Supply									Y	4	1	4				
Standby Generators																
9-Control and operation system																
Control Systems																
Operation systems									Y	4	1	4	Y	3	1	3
10-Monitoring systems									Y	4	1	4	Y	3	1	3
11-Fire extinguishing systems																
12-Communication system									Y	4	1	4	Y	3	1	3

Infrastructure Components	Tropical Storm/Depression (E)				Drought (F)				High Wind >=20 m/s (G)				Tornado (H)				Thunderstorm/ Lightning (I)			
	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 (Operation and maintenance)																				
Personnel	Y	3	7	21	Y	5	2	10	Y	3	3	9	Y	3	6	18	Y	4	7	28
Transportation (Supplies Delivery)	Y	3	6	18									Y	3	6	18	Y	4	1	4
2-Sluice Gate Structure																				
Pile foundation																				
Waterproof pile foundation																				
Pillar footing																				
Bottom beam																				
Pillar	Y	3	1	3																
Gate tower / Gate hanger	Y	3	1	3					Y	3	2	6	Y	3	1	3	Y	4	1	4
Cast-in-situ concrete composition																				
Lifting system and gangway	Y	3	3	9					Y	3	2	6	Y	3	1	3	Y	4	1	4
3-Gates																				
Water tight gasket																				
Automatic gates																				
Vertically lifted gates	Y	3	4	12					Y	3	3	9	Y	3	2	6	Y	4	1	4
Bottom shutter gates																				
Gates made of CT3 or CT5 steel combined with an anti-rust epoxy coating																				
Gates made of stainless steel (Sus-304)																				
Hydraulic Cylinder																				
4-Bridge																				
Bridge Deck																				
Bridge abutment																				
Bearing pad																				
Hand Rail	Y	3	5	15					Y	3	4	12	Y	3	3	9				
Lighting System	Y	3	5	15					Y	3	4	12	Y	3	3	9	Y	4	7	28
Traffic Signs	Y	3	5	15					Y	3	4	12	Y	3	3	9				
5-Retaining walls and connected embankments (upstream and downstream of sluice gates)																				
Retaining walls																				
Gabion																				
Connected embankments					Y	5	3	15												
Rip-rap embankments sections																				
Riverbank																				
Stilling basin																				
6-Operation house	Y	3	2	6					Y	3	1	3	Y	3	5	15	Y	4	1	4
7-Park	Y	3	6	18	Y	5	3	15	Y	3	3	9	Y	3	6	18	Y	4	7	28
8-Electric system																				
Transmission Lines	Y	3	4	12					Y	3	3	9	Y	3	6	18	Y	4	7	28
Power Supply	Y	3	2	6									Y	3	2	6	Y	4	7	28
Standby Generators	Y	3	2	6									Y	3	2	6	Y	4	7	28
9-Control and operation system																				
Control Systems	Y	3	7	21													Y	4	7	28
Operation systems	Y	3	4	12													Y	4	7	28
10-Monitoring systems	Y	3	7	21									Y	3	6	18	Y	4	7	28
11-Fire extinguishing systems																				
12-Communication system	Y	3	6	18					Y	3	3	9	Y	3	6	18	Y	4	7	28

Infrastructure Components	Water Level (K)				Water Salinity (L)				Salinity intrusion combined with high temperature (L)				High water level combined with heavy rain (L)			
	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R
1-Administration (Operation and maintenance)																
Personnel																
Transportation (Supplies Delivery)																
2-Sluice Gate Structure																
Pile foundation					Y	7	1	7	Y	5	2	10				
Waterproof pile foundation					Y	7	1	7	Y	5	2	10				
Pillar footing					Y	7	1	7	Y	5	2	10				
Bottom beam					Y	7	1	7	Y	5	2	10				
Pillar	Y	7	1	7	Y	7	1	7	Y	5	3	15	Y	2	2	4
Gate tower / Gate hanger					Y	7	1	7	Y	5	2	10				
Cast-in-situ concrete composition					Y	7	1	7	Y	5	2	10				
Lifting system and gangway					Y	7	1	7	Y	5	2	10				
3-Gates																
Water tight gasket					Y	7	1	7	Y	5	3	15				
Automatic gates	Y	7	3	21									Y	2	3	6
Vertically lifted gates	Y	7	3	21									Y	2	3	6
Bottom shutter gates	Y	7	3	21									Y	2	3	6
Gates made of CT3 or CT5 steel combined with an anti-rust epoxy coating					Y	7	2	14	Y	5	3	15				
Gates made of stainless steel (Sus-304)					Y	7	1	7	Y	5	1	5				
Hydraulic Cylinder					Y	7	2	14	Y	5	3	15				
4-Bridge																
Bridge Deck					Y	7	2	14	Y	5	3	15				
Bridge abutment					Y	7	2	14	Y	5	3	15				
Bearing pad					Y	7	2	14	Y	5	3	15				
Hand Rail																
Lighting System																
Traffic Signs																
5-Retaining walls and connected embankments (upstream and downstream of sluice gates)																
Retaining walls					Y	7	1	7	Y	5	2	10				
Gabion	Y	7	1	7	Y	7	1	7	Y	5	2	10	Y	2	2	4
Connected embankments					Y	7	1	7	Y	5	2	10				
Rip-rap embankments sections					Y	7	1	7	Y	5	2	10				
Riverbank					Y	7	1	7	Y	5	2	10				
Stilling basin					Y	7	1	7	Y	5	2	10				
6-Operation house																
7-Park																
8-Electric system																
Transmission Lines																
Power Supply																
Standby Generators																
9-Control and operation system																
Control Systems																
Operation systems																
10-Monitoring systems																
11-Fire extinguishing systems					Y	7	1	7	Y	5	2	10				
12-Communication system																

Appendix 5. Matrix of future climate risk assessment for the coastal sluice gate system in Western region of Bassac River

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			
	A				B				C				D				E				F			
	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 (Operation and maintenance)																								
Personnel	Y	7	3	21	Y	5	6	30	Y	5	4	20	Y	4	3	12	Y	4	7	28	Y	6	3	18
Transportation (Supplies Delivery)									Y	5	2	10	Y	4	1	4	Y	4	7	28				
2-Sluice Gate Structure																								
Pile foundation																								
Waterproof pile foundation																								
Pillar footing																								
Bottom beam																								
Pillar					Y	5	3	15									Y	4	2	8				
Gate tower / Gate hanger					Y	5	3	15									Y	4	2	8				
Cast-in-situ concrete composition					Y	5	3	15																
Lifting system and gangway					Y	5	3	15									Y	4	4	16				
3-Gates																								
Water tight gasket	Y	7	3	21	Y	5	6	30																
Automatic gates																								
Vertically lifted gates									Y	5	2	10					Y	4	5	20				
Bottom shutter gates																								
Gates made of CT3 or CT5 steel combined with an anti-rust epoxy coating																								
Gates made of stainless steel (Sus-304)																								
Hydraulic Cylinder																								
4-Bridge																								
Bridge Deck					Y	5	4	20	Y	5	2	10												
Bridge abutment					Y	5	4	20																
Bearing pad					Y	5	4	20																
Hand Rail																	Y	4	6	24				
Lighting System																	Y	4	6	24				
Traffic Signs																	Y	4	6	24				
5-Retaining walls and connected embankments (upstream and downstream of sluice gates)																								
Retaining walls					Y	5	2	10	Y	5	2	10	Y	4	1	4								
Gabion																								
Connected embankments					Y	5	2	10													Y	6	4	24
Rip-rap embankments sections					Y	5	2	10																
Riverbank																								
Stilling basin																								
6-Operation house					Y	5	2	10	Y	5	2	10					Y	4	3	12				
7-Park					V	5	3	15	Y	5	2	10					Y	4	7	28	Y	6	4	24
8-Electric system																								
Transmission Lines									Y	5	2	10					Y	4	5	20				
Power Supply									Y	5	2	10					Y	4	3	12				
Standby Generators																	Y	4	3	12				
9-Control and operation system																								
Control Systems																	Y	4	7	28				
Operation systems									Y	5	2	10	Y	4	1	4	Y	4	5	20				
10-Monitoring systems									Y	5	2	10	Y	4	1	4	Y	4	7	28				
11-Fire extinguishing systems																								
12-Communication system									Y	5	2	10	Y	4	1	4	Y	4	7	28				

Time Period 2080 - 2099	Climate and Other Variables and Events																											
Infrastructure Components	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			
	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
1-Administration (Operation and maintenance)																												
Personnel	Y	3	4	12	Y	4	7	28	Y	5	7	35																
Transportation (Supplies Delivery)					Y	4	7	28	Y	5	1	5																
2-Sluice Gate Structure																												
Pile foundation																	Y	7	2	14	Y	7	3	21				
Waterproof pile foundation																	Y	7	2	14	Y	7	3	21				
Pillar footing																	Y	7	2	14	Y	7	3	21				
Bottom beam																	Y	7	2	14	Y	7	3	21				
Pillar													Y	7	2	14	Y	7	2	14	Y	7	3	21	Y	4	2	8
Gate tower / Gate hanger	Y	3	3	9	Y	4	2	8	Y	5	1	5					Y	7	2	14	Y	7	3	21				
Cast-in-situ concrete composition																	Y	7	2	14	Y	7	3	21				
Lifting system and gangway	Y	3	3	9	Y	4	2	8	Y	5	1	5					Y	7	2	14	Y	7	3	21				
3-Gates																												
Water tight gasket																	Y	7	2	14	Y	7	4	28				
Automatic gates													Y	7	4	28									Y	4	4	16
Vertically lifted gates	Y	3	4	12	Y	4	3	12	Y	5	1	5	Y	7	4	28									Y	4	4	16
Bottom shutter gates													Y	7	4	28									Y	4	4	16
Gates made of CT3 or CT5 steel combined with an anti-rust epoxy coating																	Y	7	3	21	Y	7	4	28				
Gates made of stainless steel (Sus-304)																	Y	7	1	7	Y	7	2	14				
Hydraulic Cylinder																	Y	7	3	21	Y	7	4	28				
4-Bridge																												
Bridge Deck																	Y	7	3	21	Y	7	4	28				
Bridge abutment																	Y	7	3	21	Y	7	4	28				
Bearing pad																	Y	7	3	21	Y	7	4	28				
Hand Rail	Y	3	5	15	Y	4	4	16																				
Lighting System	Y	3	5	15	Y	4	4	16	Y	5	7	35																
Traffic Signs	Y	3	5	15	Y	4	4	16																				
5-Retaining walls and connected embankments (upstream and downstream of sluice gates)																												
Retaining walls																	Y	7	2	14	Y	7	3	21				
Gabion													Y	7	2	14	Y	7	2	14	Y	7	3	21	Y	4	3	12
Connected embankments																	Y	7	2	14	Y	7	3	21				
Rip-rap embankments sections																	Y	7	2	14	Y	7	3	21				
Riverbank																	Y	7	2	14	Y	7	3	21				
Stilling basin																	Y	7	2	14	Y	7	3	21				
6-Operation house	Y	3	2	6	Y	4	6	24	Y	5	1	5																
7-Park	Y	3	4	12	Y	4	7	28	Y	5	7	35																
8-Electric system																												
Transmission Lines	Y	3	4	12	Y	4	7	28	Y	5	7	35																
Power Supply					Y	4	3	12	Y	5	7	35																
Standby Generators					Y	4	3	12	Y	5	7	35																
9-Control and operation system																												
Control Systems									Y	5	7	35																
Operation systems									Y	5	7	35																
10-Monitoring systems					Y	4	7	28	Y	5	7	35																
11-Fire extinguishing systems																	Y	7	2	14	Y	7	3	21				
12-Communication system	Y	3	4	12	Y	4	7	28	Y	5	7	35																

Appendix 6. Matrix of historical climate risk assessment for the coastal sluice gate system in U Minh Thuong region

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 (Operation and maintenance)																																																				
Personnel	Y	6	3	18	Y	3	5	15	Y	4	3	12	Y	5	2	10	Y	3	7	21	Y	5	2	10	Y	3	3	9	Y	3	6	18	Y	5	7	35																
Transportation (Supplies Delivery)									Y	4	1	4	Y	5	1	5	Y	3	6	18									Y	3	6	18	Y	5	1	5																
2-Sluice Gate Structure																																																				
Pile foundation																																									Y	7	1	7	Y	6	2	12				
Waterproof pile foundation																																									Y	7	1	7	Y	6	2	12				
Pillar footing																																									Y	7	1	7	Y	6	2	12				
Bottom beam																																									Y	7	1	7	Y	6	2	12				
Pillar					Y	3	2	6									Y	3	1	3																	Y	7	1	7	Y	7	1	7	Y	6	3	18	Y	1	2	2
Gate tower / Gate hanger					Y	3	2	6									Y	3	1	3					Y	3	2	6	Y	3	1	3	Y	5	1	5					Y	7	1	7	Y	6	2	12				
Cast-in-situ concrete composition					Y	3	2	6																																	Y	7	1	7	Y	6	2	12				
Lifting system and gangway					Y	3	2	6									Y	3	3	9					Y	3	2	6	Y	3	1	3	Y	5	1	5					Y	7	1	7	Y	6	2	12				
3-Gates																																																				
Water tight gasket	Y	6	3	18	Y	3	5	15																																	Y	7	1	7	Y	6	3	18				
Automatic gates																																					Y	7	3	21									Y	1	3	3
Vertically lifted gates									Y	4	1	4					Y	3	4	12					Y	3	3	9	Y	3	2	6	Y	5	1	5	Y	7	3	21									Y	1	3	3
Bottom shutter gates																																					Y	7	3	21									Y	1	3	3
Gates made of CT3 or CT5 steel combined with an anti-rust epoxy coating																																									Y	7	2	14	Y	6	3	18				
Gates made of stainless steel (Sus-304)																																									Y	7	1	7	Y	6	1	6				
Hydraulic Cylinder																																									Y	7	2	14	Y	6	3	18				
4-Bridge																																																				
Bridge Deck					Y	3	3	9	Y	4	1	4																													Y	7	2	14	Y	6	3	18				
Bridge abutment					Y	3	3	9																																	Y	7	2	14	Y	6	3	18				
Bearing pad					Y	3	3	9																																	Y	7	2	14	Y	6	3	18				
Hand Rail																	Y	3	5	15					Y	3	4	12	Y	3	3	9																				
Lighting System																	Y	3	5	15					Y	3	4	12	Y	3	3	9	Y	5	7	35																
Traffic Signs																	Y	3	5	15					Y	3	4	12	Y	3	3	9																				
5-Retaining walls and connected embankments (upstream and downstream of sluice gates)																																																				
Retaining walls					Y	3	2	6	Y	4	1	4	Y	5	1	5																									Y	7	1	7	Y	6	2	12				
Gabion																																					Y	7	1	7	Y	7	1	7	Y	6	2	12	Y	1	2	2
Connected embankments					Y	3	1	3													Y	5	3	15																	Y	7	1	7	Y	6	2	12				
Rip-rap embankments sections					Y	3	1	3																																	Y	7	1	7	Y	6	2	12				
Riverbank																																									Y	7	1	7	Y	6	2	12				
Stilling basin																																									Y	7	1	7	Y	6	2	12				
6-Operation house					Y	3	1	3	Y	4	2	8					Y	3	2	6					Y	3	1	3	Y	3	5	15	Y	5	1	5																
7-Park					V	3	2	6	Y	4	2	8					Y	3	6	18	Y	5	3	15	Y	3	3	9	Y	3	6	18	Y	5	7	35																
8-Electric system																																																				
Transmission Lines									Y	4	1	4					Y	3	4	12					Y	3	3	9	Y	3	6	18	Y	5	7	35																
Power Supply									Y	4	1	4					Y	3	2	6									Y	3	2	6	Y	5	7	35																
Standby Generators																	Y	3	2	6									Y	3	2	6	Y	5	7	35																
9-Control and operation system																																																				
Control Systems																	Y	3	7	21													Y	5	7	35																
Operation systems									Y	4	1	4	Y	5	1	5	Y	3	4	12													Y	5	7	35																
10-Monitoring systems									Y	4	1	4	Y	5	1	5	Y	3	7	21									Y	3	6	18	Y	5	7	35																
11-Fire extinguishing systems																																									Y	7	1	7	Y	6	2	12				
12-Communication system									Y	4	1	4	Y	5	1	5	Y	3	6	18					Y	3	3	9	Y	3	6	18	Y	5	7	35																

Appendix 7. Matrix of future climate risk assessment for the coastal sluice gate system in U Minh Thuong region

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			
	A				B				C				D				E			
	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 (Operation and maintenance)																				
Personnel	Y	7	3	21	Y	4	6	24	Y	5	4	20	Y	5	3	15	Y	4	7	28
Transportation (Supplies Delivery)									Y	5	2	10	Y	5	1	5	Y	4	7	28
2-Sluice Gate Structure																				
Pile foundation																				
Waterproof pile foundation																				
Pillar footing																				
Bottom beam																				
Pillar					Y	4	3	12									Y	4	2	8
Gate tower / Gate hanger					Y	4	3	12									Y	4	2	8
Cast-in-situ concrete composition					Y	4	3	12												
Lifting system and gangway					Y	4	3	12									Y	4	4	16
3-Gates																				
Water tight gasket	Y	7	3	21	Y	4	6	24												
Automatic gates																				
Vertically lifted gates									Y	5	2	10					Y	4	5	20
Bottom shutter gates																				
Gates made of CT3 or CT5 steel combined with an anti-rust epoxy coating																				
Gates made of stainless steel (Sus-304)																				
Hydraulic Cylinder																				
4-Bridge																				
Bridge Deck					Y	4	4	16	Y	5	2	10								
Bridge abutment					Y	4	4	16												
Bearing pad					Y	4	4	16												
Hand Rail																	Y	4	6	24
Lighting System																	Y	4	6	24
Traffic Signs																	Y	4	6	24
5-Retaining walls and connected embankments (upstream and downstream of sluice gates)																				
Retaining walls					Y	4	2	8	Y	5	2	10	Y	5	1	5				
Gabion																				
Connected embankments					Y	4	2	8												
Rip-rap embankments sections					Y	4	2	8												
Riverbank																				
Stilling basin																				
6-Operation house					Y	4	2	8	Y	5	2	10					Y	4	3	12
7-Park					V	4	3	12	Y	5	2	10					Y	4	7	28
8-Electric system																				
Transmission Lines									Y	5	2	10					Y	4	5	20
Power Supply									Y	5	2	10					Y	4	3	12
Standby Generators																	Y	4	3	12
9-Control and operation system																				
Control Systems																	Y	4	7	28
Operation systems									Y	5	2	10	Y	5	1	5	Y	4	5	20
10-Monitoring systems									Y	5	2	10	Y	5	1	5	Y	4	7	28
11-Fire extinguishing systems																				
12-Communication system									Y	5	2	10	Y	5	1	5	Y	4	7	28

Infrastructure Components	Drought				High Wind >=20 m/s				Tornado				Thunderstorm/ Lightning			
	F				G				H				I			
	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R
1-Administration (Operation and maintenance)																
Personnel	Y	6	3	18	Y	3	4	12	Y	4	7	28	Y	6	7	42
Transportation (Supplies Delivery)									Y	4	7	28	Y	6	1	6
2-Sluice Gate Structure																
Pile foundation																
Waterproof pile foundation																
Pillar footing																
Bottom beam																
Pillar																
Gate tower / Gate hanger					Y	3	3	9	Y	4	2	8	Y	6	1	6
Cast-in-situ concrete composition																
Lifting system and gangway					Y	3	3	9	Y	4	2	8	Y	6	1	6
3-Gates																
Water tight gasket																
Automatic gates																
Vertically lifted gates					Y	3	4	12	Y	4	3	12	Y	6	1	6
Bottom shutter gates																
Gates made of CT3 or CT5 steel combined with an anti-rust epoxy coating																
Gates made of stainless steel (Sus-304)																
Hydraulic Cylinder																
4-Bridge																
Bridge Deck																
Bridge abutment																
Bearing pad																
Hand Rail					Y	3	5	15	Y	4	4	16				
Lighting System					Y	3	5	15	Y	4	4	16	Y	6	7	42
Traffic Signs					Y	3	5	15	Y	4	4	16				
5-Retaining walls and connected embankments (upstream and downstream of sluice gates)																
Retaining walls																
Gabion																
Connected embankments	Y	6	4	24												
Rip-rap embankments sections																
Riverbank																
Stilling basin																
6-Operation house					Y	3	2	6	Y	4	6	24	Y	6	1	6
7-Park	Y	6	4	24	Y	3	4	12	Y	4	7	28	Y	6	7	42
8-Electric system																
Transmission Lines					Y	3	4	12	Y	4	7	28	Y	6	7	42
Power Supply									Y	4	3	12	Y	6	7	42
Standby Generators									Y	4	3	12	Y	6	7	42
9-Control and operation system																
Control Systems													Y	6	7	42
Operation systems													Y	6	7	42
10-Monitoring systems									Y	4	7	28	Y	6	7	42
11-Fire extinguishing systems																
12-Communication system					Y	3	4	12	Y	4	7	28	Y	6	7	42

Infrastructure Components	Water Level				Water Salinity				Salinity intrusion combined with high temperature				High water level combined with heavy rain			
	K				L				L				L			
	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R
1-Administration (Operation and maintenance)																
Personnel																
Transportation (Supplies Delivery)																
2-Sluice Gate Structure																
Pile foundation					Y	7	2	14	Y	7	3	21				
Waterproof pile foundation					Y	7	2	14	Y	7	3	21				
Pillar footing					Y	7	2	14	Y	7	3	21				
Bottom beam					Y	7	2	14	Y	7	3	21				
Pillar	Y	7	2	14	Y	7	2	14	Y	7	3	21	Y	3	2	6
Gate tower / Gate hanger					Y	7	2	14	Y	7	3	21				
Cast-in-situ concrete composition					Y	7	2	14	Y	7	3	21				
Lifting system and gangway					Y	7	2	14	Y	7	3	21				
3-Gates																
Water tight gasket					Y	7	2	14	Y	7	4	28				
Automatic gates	Y	7	4	28									Y	3	4	12
Vertically lifted gates	Y	7	4	28									Y	3	4	12
Bottom shutter gates	Y	7	4	28									Y	3	4	12
Gates made of CT3 or CT5 steel combined with an anti-rust epoxy coating					Y	7	3	21	Y	7	4	28				
Gates made of stainless steel (Sus-304)					Y	7	1	7	Y	7	2	14				
Hydraulic Cylinder					Y	7	3	21	Y	7	4	28				
4-Bridge																
Bridge Deck					Y	7	3	21	Y	7	4	28				
Bridge abutment					Y	7	3	21	Y	7	4	28				
Bearing pad					Y	7	3	21	Y	7	4	28				
Hand Rail																
Lighting System																
Traffic Signs																
5-Retaining walls and connected embankments (upstream and downstream of sluice gates)																
Retaining walls					Y	7	2	14	Y	7	3	21				
Gabion	Y	7	2	14	Y	7	2	14	Y	7	3	21	Y	3	3	9
Connected embankments					Y	7	2	14	Y	7	3	21				
Rip-rap embankments sections					Y	7	2	14	Y	7	3	21				
Riverbank					Y	7	2	14	Y	7	3	21				
Stilling basin					Y	7	2	14	Y	7	3	21				
6-Operation house																
7-Park																
8-Electric system																
Transmission Lines																
Power Supply																
Standby Generators																
9-Control and operation system																
Control Systems																
Operation systems																
10-Monitoring systems																
11-Fire extinguishing systems					Y	7	2	14	Y	7	3	21				
12-Communication system																

Calculation of water pressure (due to the water level acting on the infrastructure)

Hydrostatic pressure	$H_{s.\ Field\ side}$	$H_s = (1/2) x H^2 x B x g_n$ $H_{.d}$ = 2.83 (m)
	$H_{s.\ Sea\ side}$	$H_{.b}$ = 4.30 (m) B = 15.00 (m)

Calculation of wave pressure (due to the water level acting on the structure)

Wave pressure ($Wa_{1/3}$)	$W_{a\ (1/3)}$	$P_s = k_i$ x ρ x g x h (TCVN 8421:2010)				
				(ki)	(Ps)	W_a (T/m)
		η_c =	0.35	0.00	0.00	
		0.00 x d	0.00	0.75	0.98	0.171
		0.25 x d	1.08	0.55	0.72	0.908
		0.50 x d	2.15	0.32	0.42	0.608
		1.00 x d	4.30	0.24	0.31	0.783

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

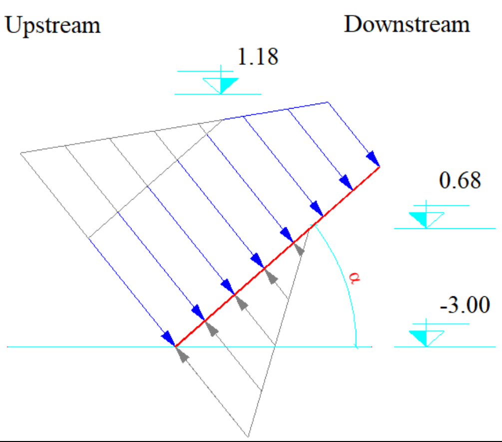
Symbol	9th-level storm	12th-level storm	Rate	Note
Wo	0.83	1.26		Standard wind pressure (kN/m^2)
γ	1.20	1.20		Correlation coefficient
k	1.19	1.19		Pressure coefficient 1.00 - 1.38
c	1.40	1.40		Aerodynamic coefficients including wind catcher + wind away surface
W	1.66	2.52		Calculated wind pressure (kN/m^2)
H1	2.50	2.50		Height of pillar under pressure (m)
B1	1.20	1.20		Width of pillar under pressure (m)
H2	1.80	1.80		
B2	15.00	15.00		
S	30.00	30.00		Area of pillar under pressure (m^2)
W_{TT}	49.78	75.57	151.8%	Load exerted by wind on the pillar (kN)
z_W	7.00	7.00		Distance from the force center to the foundation bottom (m)
M	34.85	52.90	151.8%	Moment caused by the wind at the foundation center (ton. M)

Calculation of the pull force on the hydraulic cylinder for bottom shutter gates:

When the door is closed:

Upstream water level:	1.18	(m)
Downstream water level:	0.68	(m)
Threshold elevation:	-3.00	(m)
Peak elevation of gates:	2.50	(m)
Gate height:	5.50	(m)
Distance from mortar - anchor cluster:	4.68	(m)
Gate weight:	51	(T)

Diagram of calculating hydrostatic pressure



Hydrostatic pressure value

Point	α (°)	P_{TL} (T)	P_{HL} (T)	SP (T)	$Z_{3mortar}$ (m)
1	41.68	244.81	162.39	82.42	3.350
2	49.74	231.11	162.33	68.79	3.183
3	57.79	217.43	162.26	55.17	3.016
4	65.84	203.75	162.19	41.56	2.849
5	73.89	190.09	162.12	27.97	2.682
6	81.95	176.44	162.05	14.39	2.515

Calculation of required moment and lift force of operating equipment:

$M_{yc} = (1.1*G*g + P*a + 1*2*R*f*r)$

$M_{tk} = T*\rho \geq M_{yc}$

Point	α (°)	Calculate the moment at the mortar									
		ΣP (T)	a_{mortar} (m)	L (m)	R_{mortar} (T)	R_{neo} (T)	G (T)	g (m)	f	r (m)	M (T.m)
1	41.68	82.42	3.35	4.68	23.36	59.06	38.09	3.0	0.3	0.05	402.21
2	49.74	68.79	3.18	4.68	21.95	46.83	32.96	3.0	0.3	0.05	328.12
3	57.79	55.17	3.02	4.68	19.58	35.59	27.19	3.0	0.3	0.05	256.45
4	65.84	41.56	2.85	4.68	16.24	25.33	20.87	3.0	0.3	0.05	187.58
5	73.89	27.97	2.68	4.68	11.93	16.04	14.15	3.0	0.3	0.05	121.91
6	81.95	14.39	2.51	4.68	6.65	7.74	7.14	3.0	0.3	0.05	59.87

Point	Calculation of designed lift force							
	ρ (m)	Lifting force P corresponding to angle β (°)						
		10	20	30	45	60	75	90
1	4.68	109.66	97.73	90.63	86.18	87.85	96.29	115.20
2	4.68	89.46	74.82	71.33	70.43	74.57	85.41	108.59
3	4.68	69.92	56.13	54.90	56.25	62.01	74.75	102.91
4	4.68	51.14	40.23	40.33	42.93	49.50	63.54	98.04
5	4.68	33.24	26.14	26.86	29.78	36.19	50.48	94.00
6	4.68	12.81	13.09	13.81	16.02	20.78	32.70	91.42
Max		109.66	97.73	90.63	86.18	87.85	96.29	115.20

** β: angle of the force to the horizontal*

Calculation to check the lifespan of concrete

The lifespan of the infrastructure due to carbonation is calculated by the following formula:

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

In which:

K_{ca} = 6.53 (mm/year$^{0.5}$);

Average carbonation coefficient of the environment 5.31 ÷ 6.53 mm/ year$^{0.5}$

Type of concrete	$R_{compressive}$ (Mpa)	K_{ca} (mm/year$^{0.5}$)	t_{sd} - lifespan (year)		
			h =50mm	h =70mm	h =100mm
M300	30	6.530	43.52	90.43	195.96

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