



WATER MANAGEMENT IN THE UPPER MEKONG DELTA

Pre-feasibility study for the An Giang / Kien Giang floodway project

Implemented by

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LIST OF ABBREVIATIONS

AFD	French Development Agency
BMZ	German Federal Ministry for Economic Cooperation and Development
ESMF	Environmental and Social Management Framework
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
HOAI	VN: fee structure for architects and engineers
ICMP	GIZ Integrated Coastal Management Programme
IRR	Internal Rate of Return
KfW	Kreditanstalt für Wiederaufbau – German Development Bank
LXQ	Long Xuyen Quadrangle
MARD	Ministry of Agriculture and Rural Development
MONRE	Ministry of Natural Resources and Environment
NPV	Net Present Value
PPC	Provincial People's Committee
SIWRP	Southern Institute for Water Resources Planning
SIWRR	Southern Institute of Water Resources Research
Sub-FIPI	Sub Forest Inventory and Planning Institute

1 EXECUTIVE SUMMARY

The GIZ study “Water Management in the Upper Mekong Delta” provides a pre-feasibility assessment of the World Bank subproject 1 “Improving the Ability of Flood Drainage and Climate Change Adaptation for the Long Xuyen Quadrangle”. The basic approach agreed with the Vietnamese Government and the World Bank is that this assessment serves as the basis for national consultants to conduct the full feasibility assessment later in 2016.

The study commenced in December 2015. Inception Report and Mid-Term Report were submitted in January and April 2015 respectively. Two missions have been conducted as part of this assignment, including a mission by the team leader in December 2015 and a full feasibility mission in April 2016. The latter mission included national consultants from SIWRR, SIWRP, and Sub-FIPI. As part of the mission the consultants also participated in an inter-provincial meeting with An Giang and Kien Giang Provinces organized by GIZ to discuss the basic subproject idea. The assessment was conducted based on a consultative process, which included – in addition to the above mentioned Ho Chi Minh City based institutes – the Ministry of Agriculture and Rural Development (MARD), various Departments of Agriculture and Rural Development (DARDs), the Ministry of Natural Resources and Environment (MONRE), the Provincial People’s Committees (PPCs) in An Giang and Kien Giang, and the World Bank.

The report is structured as follows. After the main activities conducted as part of the assignment have been summarized, the approach applied for this assessment will be introduced. Chapter 4 presents the preliminary concept of subproject 1 as it has been introduced to the consultant team, including proposed measures and investments. This preliminary concept was used as the basis for this pre-feasibility study, which analyzes the suitability of the proposed investments to reach the envisaged project objectives. Chapter 5 analyzes the general biophysical conditions the subproject is facing, including flooding, saline intrusion and climate change impacts. Further, based on a “hydrological sketch” the prevailing flood regime in Long Xuyen Quadrangle is discussed. Chapter 6 provides the technical and financial assessment of the measures initially proposed for subproject 1 to cope with flood events of recurrence intervals of 50 years. It starts with a detailed analysis of the hydraulics of the floodway based on a basic hydrostatic model using ArcGis and a digital elevation model. Further, the proposed measures are technically assessed, including structural measures for flood and water management and forestry-related measures. An economic and financial analysis is conducted to assess the profitability of subproject 1. The economic analysis also includes proposed alternative livelihood models. The chapter closes with recommendations on essential steps to be conducted as part of the full feasibility ensuring a sound technical design of the proposed floodway. The conclusions briefly summarize the critical findings and focus on the proposed way forward concerning the preparation of subproject 1.

With respect to the findings, it should be noted that subproject 1 is at a rather early conceptual stage. The basic idea of a floodway, which serves as a retention area to reduce flood risks for surrounding areas while adapting land use within (and outside) the floodway accordingly, is innovative and is generally appropriate from a technical perspective. However, a better understanding of the basic hydraulics in the project

area is a prerequisite for defining an appropriate design of the floodway. The current concept does not ensure that water from the surrounding flood-prone areas is discharged into floodway. Additional structural measures, such as a further extension of the floodway into the North-East, extension and upgrade of the canal system, and sluice gates, are required to allow the floodway to fulfill its role as a retention area. Only with an additional arm of the floodway in the Northeast significant reduction of flooding in the rural areas and Long Xuyen and Can Tho Cities can be achieved. Further, due to the low gradients within the floodway, it cannot be assumed that the water will flow automatically, i.e. without any additional structural measures, in north-south direction and discharge into the West Sea. According to the preliminary assessment this water flow will not be ensured by the current concept even during extreme flood events, i.e. the water would accumulate within the floodway.

The benefits for Kien Giang Province, both in terms of flood management and secondary benefits (such as water storage) are less apparent and should be further explored as part of the full feasibility study. Concerning flood management the most obvious benefit will be due to the reduction of water levels in Vinh Te Canal. However, effects can be assumed to be rather small given the fact that the flooding of the canal is not posing a significant risk to the province. Since it is expected that only extreme events would lead to significant arrival of fresh water at Kien Giang, investments into water storage does not seem to be profitable at this point. These preliminary findings lead also to the conclusion that the project objective should focus on flood management and supporting the transformation of peoples livelihoods to enable them "living with floods" rather than focusing too much on other benefits, such as water storage.

Another critical issue, which should influence the final approval of the subproject, is the rubber dam at Vinh Te Canal. Since this dam currently constitutes the only controlled inflow into the floodway, its impacts need to be taken into account when designing the project, even if it is not financed by the World Bank. A dam upgrade to increase water volumes discharged into the floodway is considered key to effectively reduce flooding in the areas west of the floodway. If the upgrade is delayed or even rejected, the basic concept of the subproject would need to be revised. The economic analysis indicates that it cannot be automatically assumed that the project would be attractive from an economic perspective. Scale, location, and design of structural measures for flood and water management need to be defined carefully to ensure a promising cost-benefit ratio.

Nevertheless, given the soundness of the basic idea and the potential of significantly reducing damages and losses in the surrounding areas, it is highly recommended that the concept and design of the floodway is further assessed. The activities recommended for conducting the full feasibility are outlined in section 6.3 and summarized in the conclusions.

2 MAIN ACTIVITIES

The assignment was initiated in December 2015. A kick-off call was conducted with the GIZ ICMP Team to receive guidance on the technical proposal and clarify expectations and next steps. Based on this feedback by the GIZ ICMP Team, internal consultations were held to mobilize the consultant team, fine tune the work plan and further specify the roles and responsibilities of each expert. As part of the assignment two missions have been conducted.

Team Leader Mission December 2015

The Team Leader Dr. Johannes Wölcke conducted a mission to Vietnam from November 30 - December 11, 2015, to fine tune the work plan with GIZ, introduce the study to other partners (e.g. MARD/DARD, SIWRR/SIWRP and the World Bank) and explore linkages with relevant investment operations in the pipeline, including the World Bank "Mekong Delta Integrated Climate Resilience and Sustainable Livelihoods Program". As part of the mission, he was also asked to make recommendations concerning the directions of the other two GIZ feasibility studies "Integrated Coastal Protection Feasibility" (see relevant Final Report) and the "Climate Smart Agriculture Feasibility".

The Team Leader participated in the pre-appraisal mission of the World Bank supported program. The major objective of the World Bank mission was to: (i) review the progress on preparation activities, especially on the status of the Feasibility Studies of selected sub-projects and required safeguards documents; (ii) conduct field visit to the sites of the proposed sub-projects for the first year, for technical, environmental and social assessments; and (iii) agree on the next steps and update timeline for project preparation including approvals from the Government of Vietnam and project negotiations.

The World Bank Mission started with a Kick-Off Meeting with MARD and MONRE in Hanoi. Further, discussions were held with the World Bank Team (Task Team Leader: Anjali Archaya) to start exploring how the GIZ feasibility studies (including coastal protection, water management, agriculture) could be linked to the World Bank Program. In Ho Chi Minh City a workshop was conducted by MARD (plus SIWRR/SIWRP) and the World Bank to discuss the status of the four subprojects of the first round. The Consultant Team Leader also participated in field visits to sites of potential subprojects in Kien Giang and An Giang. In Can Tho, Mr. Wölcke participated in the World Bank-internal wrap-up meeting of the mission.

As a conclusion concerning the mission the following general points should be highlighted:

- **Feedback to the MARD feasibility studies of World Bank subprojects:** During the mission the results of the feasibility studies of the first four subprojects were presented and discussed in Ho Chi Minh City and during the field visits. In general the following aspects can be highlighted: (i) there is a need for more explicitly considering integrated approaches to coastal protection instead of focusing mainly on "hard infrastructure investments" (e.g. concrete dykes, sluice gates); (ii) impacts of proposed investments on livelihoods should be considered more explicitly;

(iii) more emphasis should be placed on economic and financial analyses; (iv) subprojects were promoting increased rice production (or continuation with three rice crops) in some cases.

- **Focus of the “Water Management Feasibility Study”:** The first option discussed during the mission was to support the feasibility study of a specific subproject to be implemented as part of the overall World Bank Program. The World Bank Team expressed interest for support of the feasibility of subproject 1 in An Giang/Kien Giang (Long Xuyen Quadrangle), since it is considered as being very complex, both technically and politically. Technical aspects (flood management/flood retention in the Upper Delta) and the geographic location are in line with ICMP priorities and experiences. Another option discussed was to support the feasibility of subproject 3 in Dong Thap. Here as well the technical area is flood management and flood retention. However, the location is not in line with ICMP area. Both subprojects are considered to be part of the second round of subprojects. Currently, the timeline envisages that the MARD feasibility studies would be conducted during the second half of 2016. The option to focus the feasibility study – as originally planned – on irrigation information systems was also considered, but not agreed upon eventually given the changes of priorities by stakeholders, partners and the ICMP Team. After the mission, ICMP held consultations with MARD and the World Bank, and it was decided that the GIZ feasibility study will be considered as a pre-feasibility study focusing on subproject 1 for the reasons mentioned above.

Full Feasibility Mission April 2016

The full feasibility mission was conducted from March 30 to April 14, 2016. The mission focused on both feasibilities, the “Integrated Coastal Protection Feasibility” and the “Water Management Feasibility”. The major objectives of the mission were to: (i) understand the status of preparation of the selected World Bank subprojects; (ii) identify particular challenges for preparation of the selected subprojects (incl. those related to conducting the (pre) feasibility studies); (iii) collect available data and information; (iv) conduct field visits to all sites covered by the study; and (v) define the way forward up to completion of the study in close collaboration with the GIZ ICMP Team. The consultant team consisted of: Dr. Johannes Wölcke (Team Leader), Dr. Thorsten Albers (Coastal and River Engineer Expert), Dr. Ho Dac Thai Hoang (Mangrove Expert), Max Roth (Mangrove Expert), Dr. Miriam Vorlaufer (Economist), Dr. Nguyen Nghia Hung (Director of Research Center for Rural Engineering and Infrastructure Development, SIWRR), Project Management Specialist), Dr. Lam Dang Thanh (Vice Director SIWRP, Water Resource Engineer), Dr. Thinh Pham Trong (Director, Sub-FIPI, Forestry Expert), and Dr. San Dinh Cong (Vice Director SIWRR, Water Resource Engineer).

The mission started in Hanoi with a kick-off meeting at the GIZ ICMP Office. During that meeting, the revised approach was discussed and mission logistics fine-tuned. A meeting was held with MARD and the World Bank to further clarify the role of the ICMP feasibility study with respect to the preparation of the relevant subprojects. The mission continued with a meeting with the ICMP staff in Ho Chi Minh City. Further, meetings with the national consultants were organized (who are staff of the Ho Chi Minh City Institutes SIWRR, SIWRP, and Sub-FIPI) to clarify the status of preparation of the respective subprojects and prepare the field visits. Field visits were conducted to

An Giang and Kien Giang (subproject 1), and other areas of relevance to the “Integrated Coastal Protection Feasibility”, in particular Soc Trang/Cu Lao Dung Island (subproject 7) and Ca Mau (subproject 8 plus potential KfW and AFD sites). As part of the field visit, the consultants also participated in an inter-provincial meeting with An Giang and Kien Giang Provinces organized by GLZ to discuss the basic subproject idea. Throughout the field visits the international consultants were accompanied by national consultants plus respective ICMP staff based in the provinces. Back in Ho Chi Minh City, additional meetings were organized with the national consultants to discuss remaining issues and the way forward. The wrap-up was conducted on April 14 (with a skype connection to the ICMP Office in Hanoi).

Inception Report and Mid-Term Report

The Inception Report and the Mid-Term Report were submitted in due time in January and April 2016 respectively. The Inception Report presented the major findings of the mission conducted by the team leader, provided an updated work plan and defined next steps (including the full feasibility mission, the mid-term report and other important milestones). The Mid-Term Report summarized the findings of the full feasibility mission and defined the revised conceptual approach (see chapter 3). Further, it provided some preliminary findings concerning the World Bank Subprojects 1. Finally, the results of this feasibility study are scheduled to be presented at a workshop with all major stakeholders in Can Tho in early July 2016.

3 APPROACH

This GIZ Feasibility Study provides a comprehensive pre-feasibility assessment of subproject 1 of the World Bank “Mekong Delta Integrated Climate Resilience and Sustainable Livelihoods Program”. The subproject was chosen, since it is considered as being particularly complex from a technical perspective and politically sensitive. This assessment will serve as an input to the full feasibility study, which will be carried out by national MARD consultants. This chapter describes the revised strategic approach and the methodology applied for this assessment.

3.1 Revised approach

As mentioned briefly in chapter 2, originally and as per the TOR the assignment was supposed to focus on irrigation information systems in the upper Mekong Delta. However, during the mission of the team leader in December 2015 it was decided that the assignment should rather focus on subproject 1 of the World Bank. After the submission of the Inception Report end of February 2016, the GIZ ICMP Team indicated that priorities concerning the focus of the ICMP feasibility studies had been further fine-tuned. While these changes were more significant for the coastal protection feasibility study, it also affected the water management feasibility study. During early stages of the assignment it became apparent that subproject 1 (i) is technically very complex, (ii) very little preparatory work had been conducted and (iii) the subproject is politically quite sensitive since it encompasses two provinces. Acknowledging the change of scope of the coastal protection feasibility study and the complexity of subproject 1 (and its very preliminary status of preparation), it was agreed that the water feasibility study – as the coastal protection feasibility study – should focus on technical and economic/financial aspects (elements 1-3 of the 7 elements outlined in the technical offer and the inception report), while the other elements 4-7 (e.g. environmental and social safeguards, socio-economic impacts, capacity development, and institutional implementation arrangements) should not be addressed explicitly any more (see Figure 1).

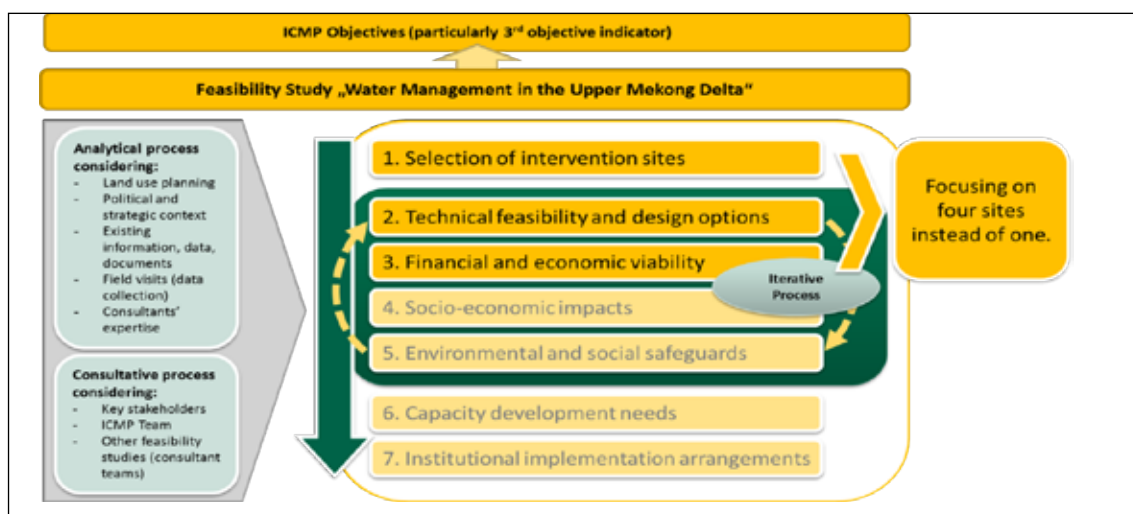


Figure 1: Revised Strategy Diagram

To further clarify the elements covered by the final deliverable of the water management feasibility, the consultants provide an illustration of the work phases in accordance with the “fee structure for architects and engineers” (HOAI) and the typical investment project cycle (see Figure 2). This work phases do not only apply for infrastructural investments, but in principle also for other investment types, such as mangrove rehabilitation. As indicated in Figure 2, the water management feasibility assessment will focus on the first two work phases “basic assessment” and “preliminary planning and design” (incl. cost-benefit analyses), which are usually conducted as part of investment project preparation and appraisal. The other phases 3-9 include steps covering the award procedures and the construction phase, which are typically conducted as part of investment project implementation and will not be addressed by this feasibility assessment.



Figure 2: Clarification of final deliverable – HOAI Work Phases

Further, Figure 3 illustrates in more detail what elements are included in the first two phases “basic assessment” and “preliminary planning and design”, which are covered by the ICMP feasibility study. The former includes for example clarification of project objectives, analysis of development challenges, determination of boundary conditions, and development of concept of proposed measures. The latter includes for example identification of possible solutions (taking into account practicality, cost effectiveness, environmental and social sustainability), development of planning concept (incl. alternative options, graphics and evaluation, rough design), and cost-benefit estimates. Figure 3: HOAI Work Phases “Basic Assessment” and “Preliminary Planning and Design” indicates the location of the 9 World Bank subprojects planned so far as part of the “Mekong Delta Integrated Climate Resilience and Sustainable Livelihoods Program”. The circle in Figure 4 marks the location of subproject 1 in An Giang and Kien Giang Provinces.

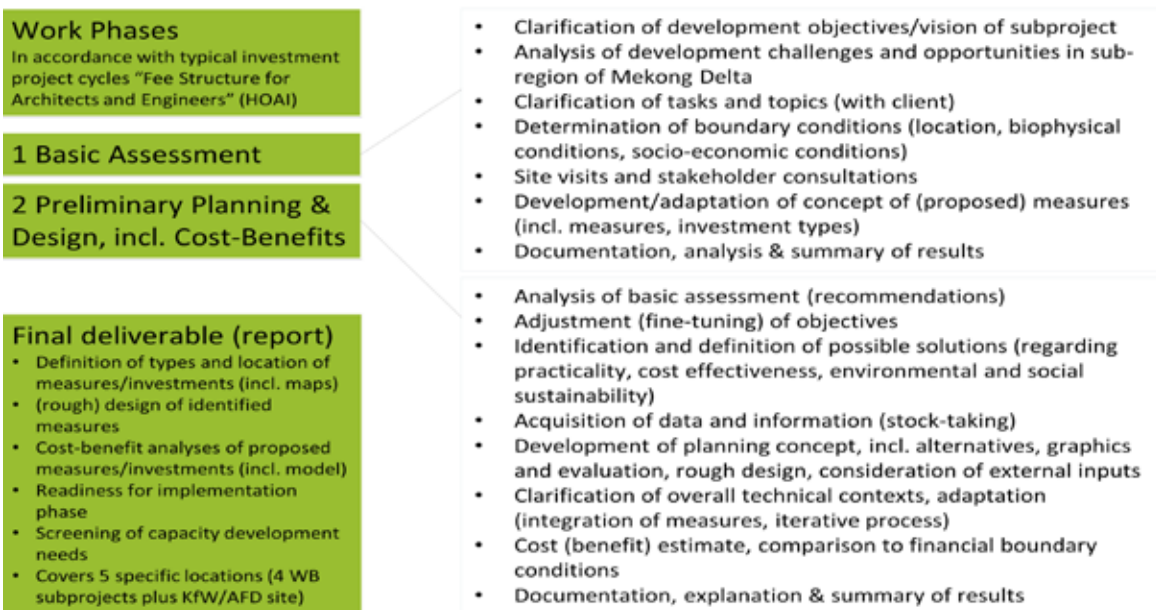


Figure 3: HOAI Work Phases "Basic Assessment" and "Preliminary Planning and Design"

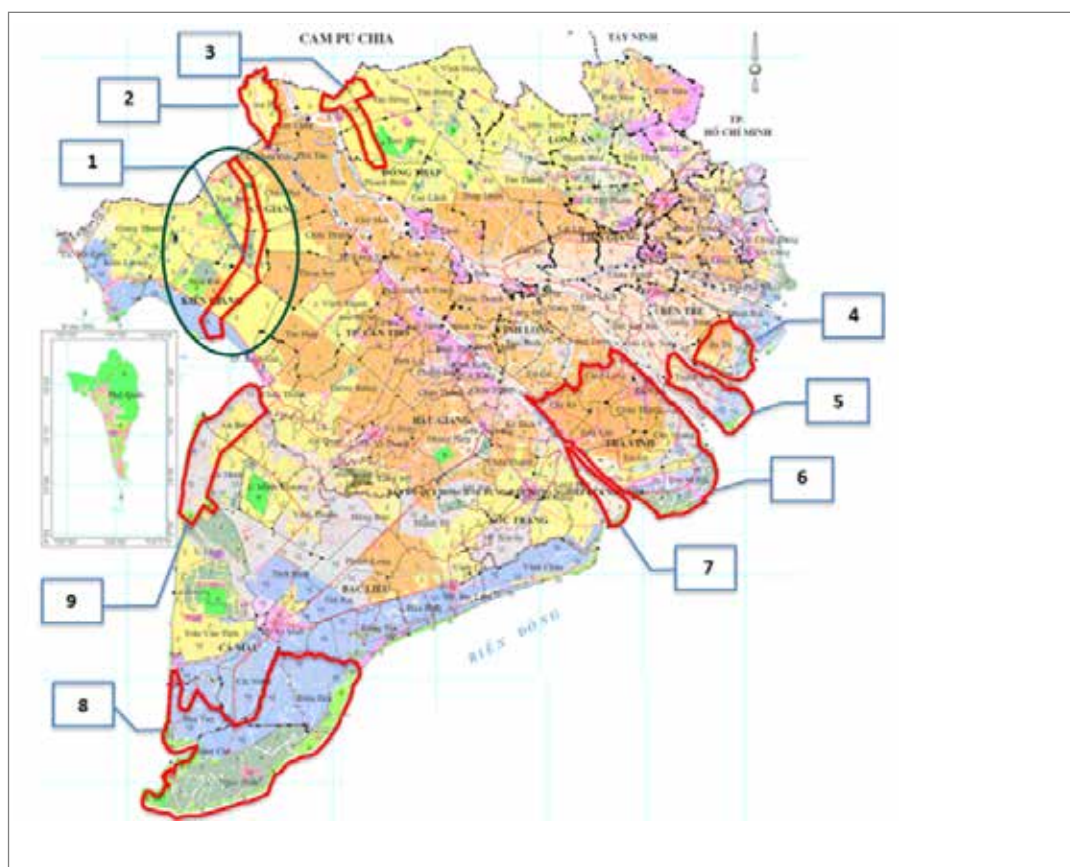


Figure 4: Location of World Bank Subproject 1

4 DESCRIPTION OF WORLD BANK SUBPROJECT 1

According to the Environmental and Social Management Framework (ESMF) of the World Bank, the current name of subproject 1 is “Improving the Ability of Flood Drainage and Climate Change Adaptation for the Long Xuyen Quadrangle”. Subproject 1 is part of the second round of subprojects for which the full feasibility studies are supposed to be completed by the end of 2016.

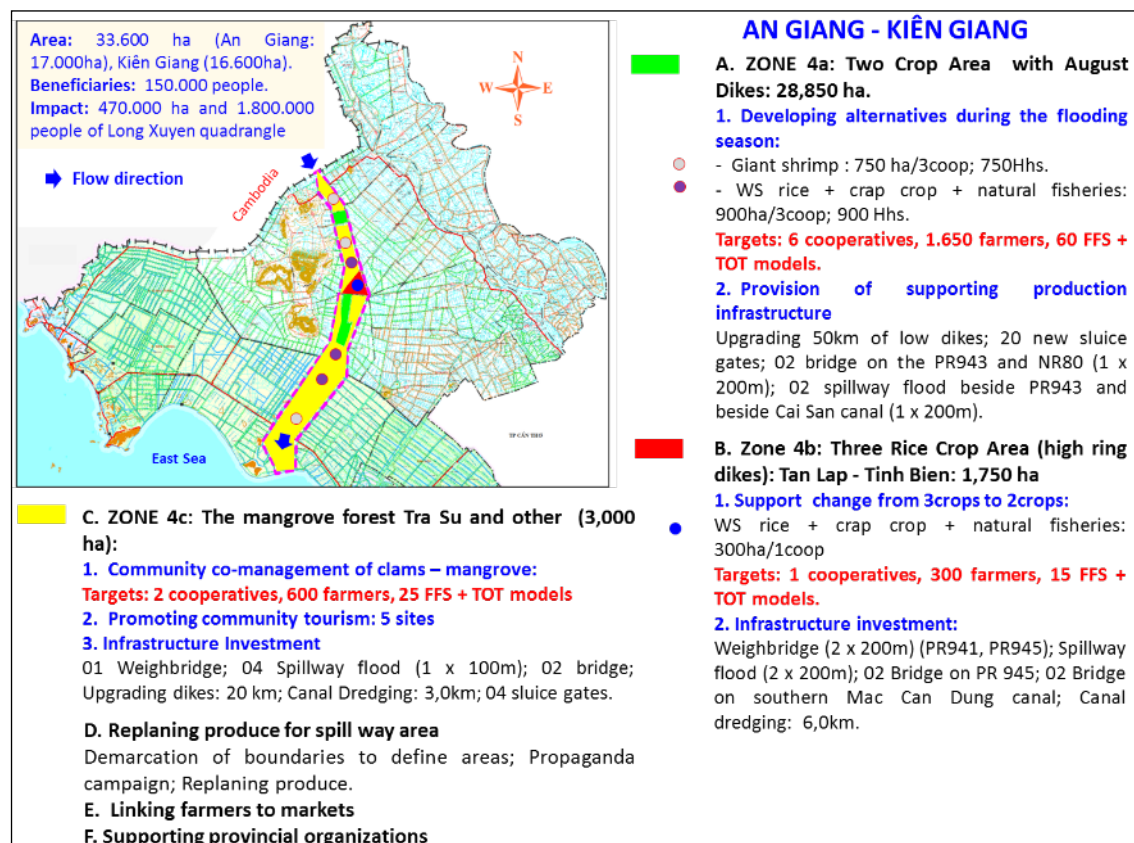


Figure 5: World Bank Subproject 1 An Giang / Kien Giang

Figure 5 illustrates the project area and the investment types initially proposed by the MARD consultants tasked with developing the first concept idea. This initial proposal was used as the basis for this pre-feasibility assessment. While the subproject objectives have not been completely defined yet, it became apparent during the mission that it aims at flood protection based on a spillway system combined with improved water management for sustainable livelihoods (“actively living with floods”)¹. It was also discussed with stakeholders during the mission whether the objectives should be broadened even further and should explicitly capture potential benefits of water management, such as water storage and soil fertility management. Another point of debate was the extent to which Kien Giang would benefit from the subproject. The

¹ “Living with floods” means adaptation of livelihood systems as a reaction to changing frequency and intensity of flooding. This could for example mean the adoption of alternative livelihoods away from 3 rice crops. “Living with floods” does not mean complete avoidance of flooding.

analysis conducted in the following chapters are informing these debates.

The proposed project area constitutes a potential floodway, covers 33,600 ha and spreads across An Giang (17,000 ha) and Kien Giang Provinces (16,000 ha). 150,000 people are considered as direct project beneficiaries (while the broader impact is assumed to cover 470,000 ha and 1.8 million people of the Long Xuyen Quadrangle). The proposed floodway is supposed to cope with extreme flood events with a recurrence interval of 50 years. Obviously this implies that the floodway should also be able to cope with more frequent and “weaker” flood events. The MARD consultants have divided the spillway area into three zones. The first and largest zone is characterized by a two rice crops system and spreads basically across the entire spillway. With respect to livelihood systems pilots for developing alternatives during the flooding season are proposed, including giant shrimp production and a combination of rice, cash crop and natural fisheries. To enable this transition the establishment of six cooperatives, six demonstration sites, and training of 1,650 farm households are envisaged. Concerning the infrastructure, an upgrade of 50-60 km of low dikes, 20 new sluice gates (while the exact locations for these investments are not specified), two bridges and flood spillways are proposed.



Figure 6: Two crop rice area in the center of the floodway at the southeast corner of the southern melaleuca forest

The second zone constitutes a triangle of 1,750 ha where currently a three rice crop system is dominant. In this zone, support for transitioning to two rice crops (e.g. rice, grasses/livestock, natural fisheries) is proposed. Here the establishment of one cooperative, one demonstration site, and training of 300 farm households are foreseen. With respect to infrastructure, three bridges, sluice gates and dredging of canals are

proposed. The following four figures are directly taken from a PowerPoint presentation of the MARD consultants, who initially proposed some investment types for the three rice crop area. These figures serve only as a first illustration to give an impression of what the preliminary thinking of the MARD consultants are concerning types of investments. The actual assessment of these proposals will be provided in chapter 6 of the report.

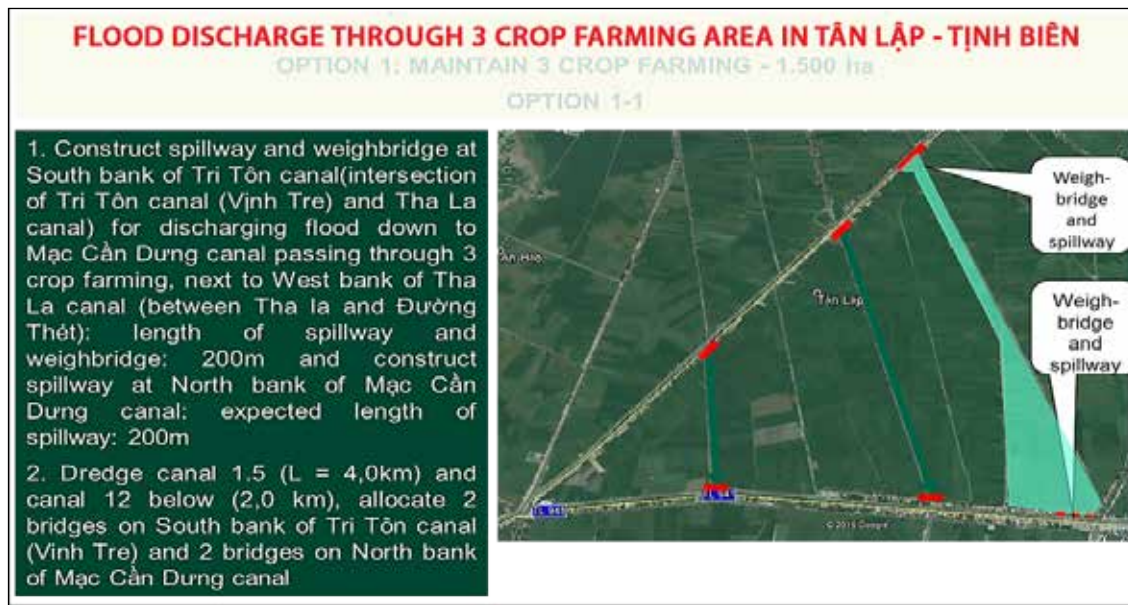


Figure 7: Option 1 for structural measures for 3 Crop Rice Area in the middle of floodway

As proposed by MARD consultants

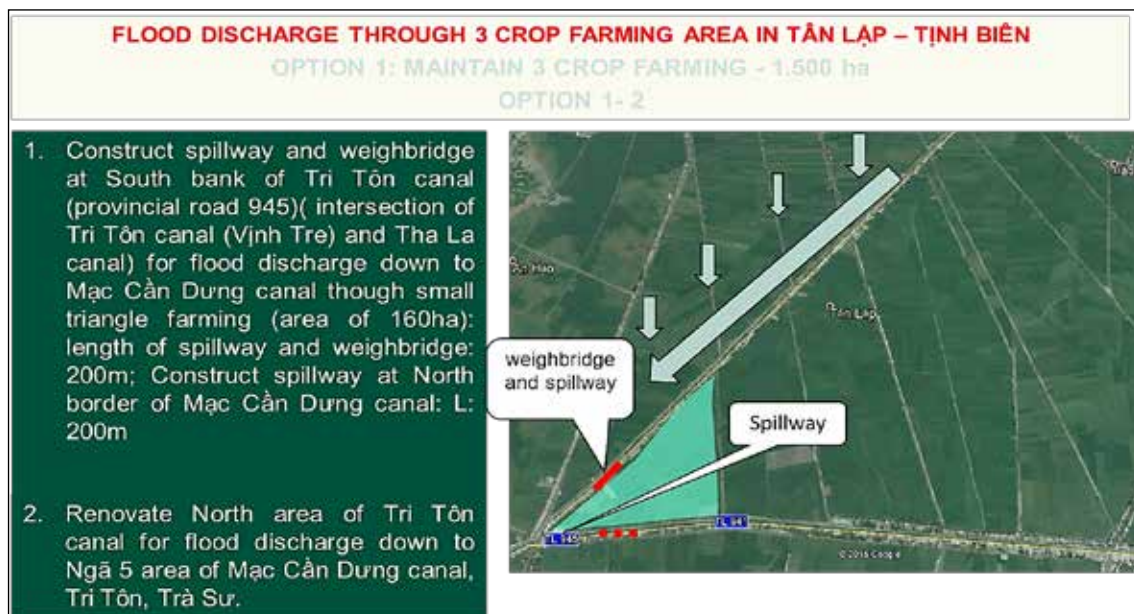


Figure 8: Option 2 for structural measures for 3 Crop Rice Area in the middle of floodway

As proposed by MARD consultants

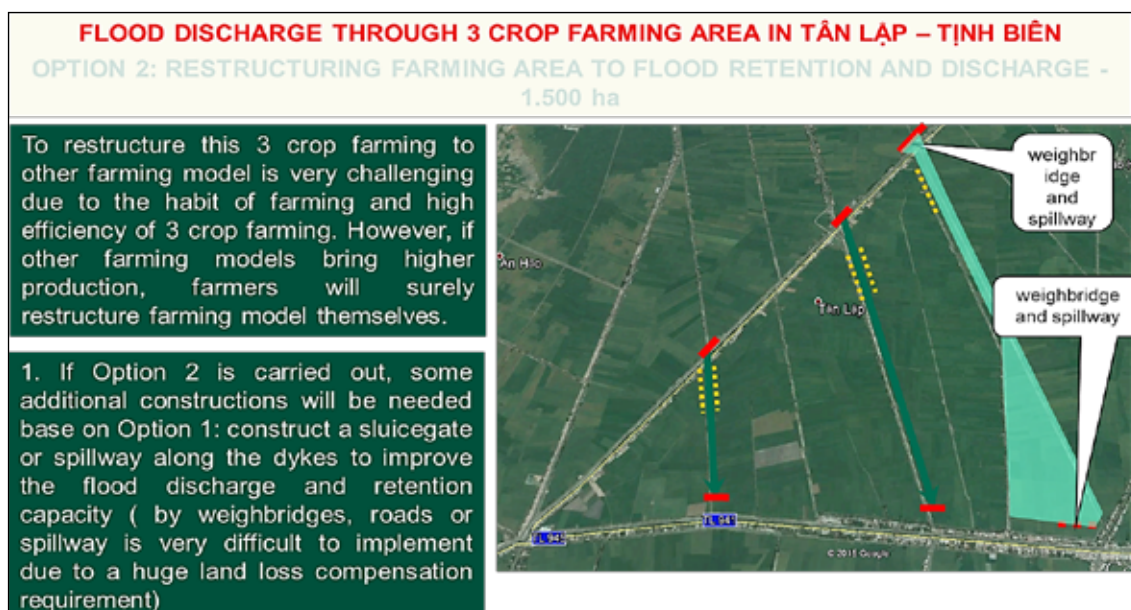


Figure 9: Option 3 for structural measures for 3 Crop Rice Area in the middle of floodway

As proposed by MARD consultants

Zone 3 consists of the mangrove forests in Tra Su and the middle part of the spillway south of the three rice crop triangle which together cover approximately 3,000 ha. Here initial investment proposals include community co-management of clams, again based on establishment of two cooperatives and training of 600 farm households. Further promotion of ecotourism plus various infrastructure investments, such as four sluice gates, two bridges, upgrading of dykes and dredging of canals are envisaged (see Figure 10).

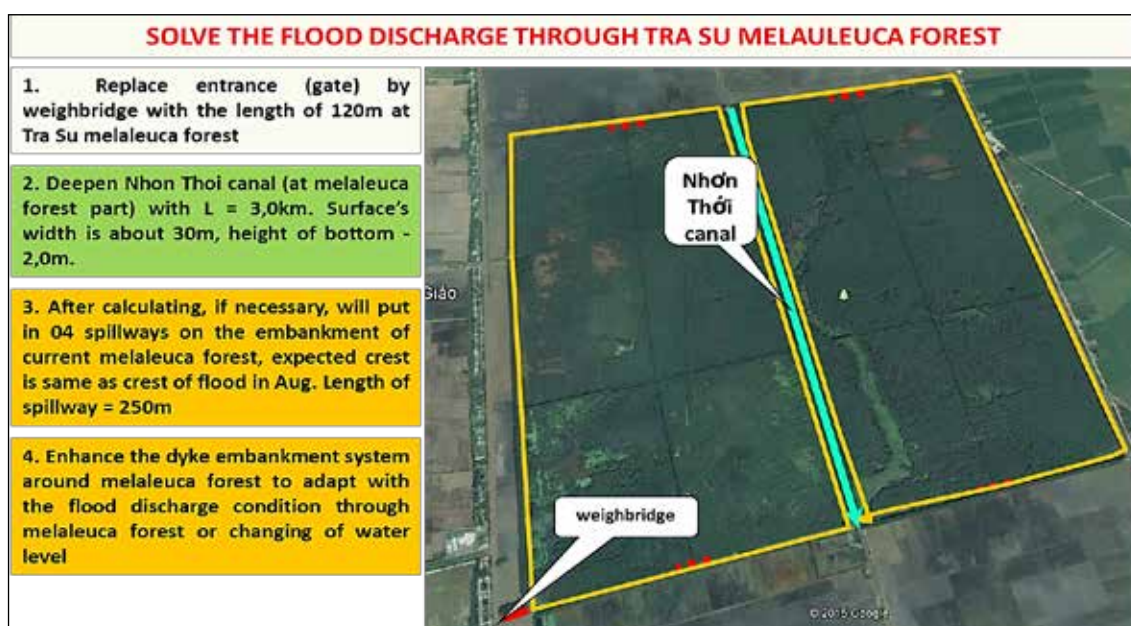


Figure 10: Proposed investments for Tra Su Melaleuca Forest

In the following chapter the general biophysical site conditions relevant to subproject 1 will be discussed.

5 BIOPHYSICAL SITE CONDITIONS

5.1 General hydrological boundary conditions

The Mekong River is one of the twelve largest river systems in the world with a length of 4,200 km. The origin of the river is in the Tay Tang Mountains of Tibet and it flows into the Vietnamese East Sea in South Vietnam. Overall the Mekong River has a catchment area of 795,000 km². In Vietnam, it covers an area of round about 40,500 km² (Dinh et al. 2012). The Mekong Delta begins at Phnom Penh in Cambodia. This is the place where the river is divided into Tien River and Hau (Figure 11). The Hau River is one of the main arms of the Mekong River and flows through the Vietnamese provinces of An Giang, Can Tho, Vinh Long, Tra Vinh and Soc Trang. Its total catchment area is about 490 km² (Thu 2006). The elevation in Vietnam's Mekong Delta is not higher than five meters above sea level in most places.

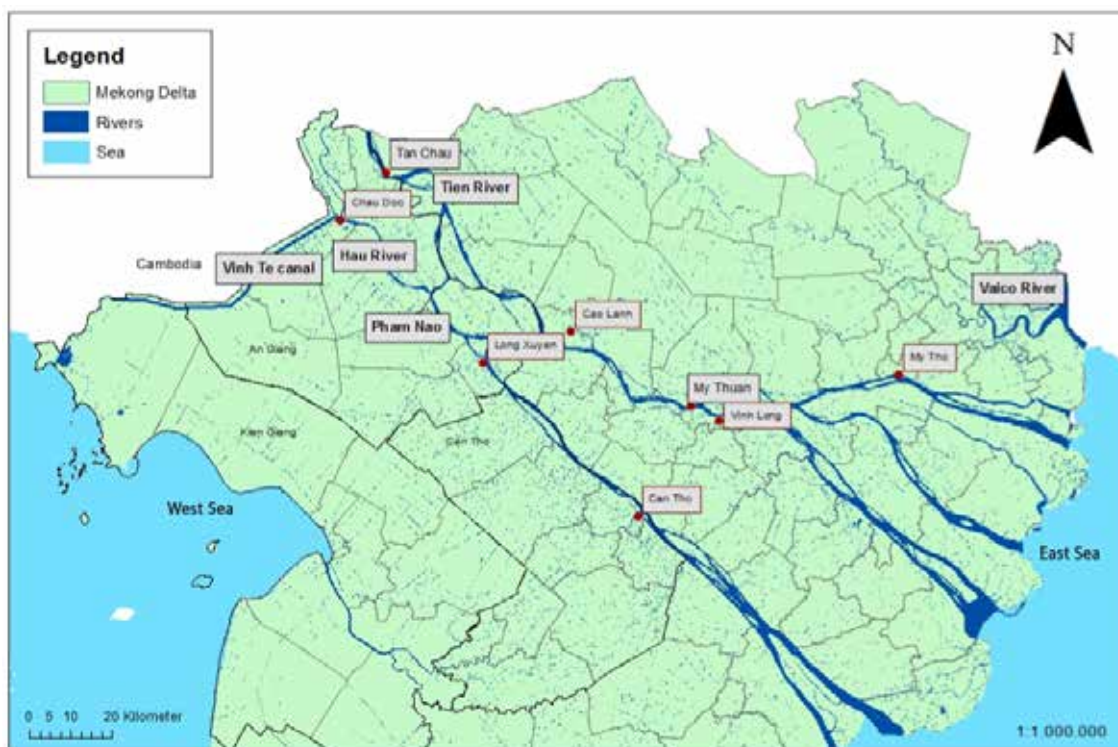


Figure 11: General map of the Mekong River in Vietnam

The Mekong Delta is located in a monsoon region with mean temperatures of 25 degrees Celsius. Due to the monsoons, there is a seasonal distribution of dry and wet months. The rainy season is from May to October. The average annual rainfall in the Mekong River Basin is 1,400 mm per year, mainly distributed over the few months of the rainy season. This means that a large volume of water needs to be drained in short time, which is considered as one main cause of flooding in the Mekong Delta. In the months March, April and May the highest evaporation is achieved reaching levels between 180-220 mm. When the rainy season begins, the evaporation decreases to 100-150 mm. During the dry season, a north-eastern wind predominates. In the rainy season between May and October, wind changes its direction and becomes a

south-western wind. During storms the wind velocity is between 15-18 m/s (Vietnam-Netherlands Delta Masterplan Project 2011).

The total average flow of the Tien River and the Hau River observed at Tan Chau and Chau Doc is about 387 billion m³ annually. The flow is distributed unevenly throughout the year. It is very high during the flood season, particularly during September and October, where the flow rate can reach up to 25,500 m³/s (Tri, 2012). The total flow in these two months accounts for about 17% of the annual flow. During the dry season the flow rate decreases significantly and reaches a minimum of 2,340 m³/s in April.

At the border between Vietnam and Cambodia, the flow of the Tien River is significantly larger than the flow of the Hau River. The discharge at Tan Chau (Tien River) and Chau Doc (Hau River) stations account for about 80% and 20% of the total annual flow respectively. However, due to the Vam Nao tributary which links the two rivers, the flow rate further south at Can Tho (Hau River) and My Thuan (Tien River) is almost equal. Hence, the Vam Nao River plays an important role in re-distributing the flow of these two rivers.

Month	Q Tan Chau (m ³ /s)	Q Chau Doc (m ³ /s)	Q total (m ³ /s)
1	6,220	1,360	7,580
2	3,720	700	4,420
3	2,600	420	3,020
4	2,010	330	2,340
5	2,640	460	3,100
6	7,180	1,450	8,630
7	11,270	2,390	13,660
8	16,390	3,970	20,360
9	20,140	5,290	25,430
10	20,340	5,480	25,820
11	15,260	4,700	19,960
12	10,180	2,710	12,890
Average	9,830	2,440	12,270
Total discharge (billion m ³)	310	77	387
% total discharge	80%	20%	100%

Table 1: Average monthly discharge at Tan Chau and Chau Doc (period 1977–1999)

Source: MRC, flood control planning for developing the Mekong Delta (MRC, 2005)

In the context of the hydrological boundary conditions, it should be noted that eleven hydropower projects are proposed for the Mekong Delta in Thailand, Lao PDR, and Cambodia. A study conducted by DHI and HDR (2015) concludes that construction of any or all proposed dams could potentially have substantial socio-economic and environmental impacts, particularly in the downstream floodplains of Cambodia and Vietnam. Impacts could include: (i) highly fluctuating flows and water levels; (ii) decreasing sediment and nutrient deposition; and (iii) increased salinity intrusion. These scenarios should be considered while designing and implementing this proposed subproject.

The bed morphology of a river is engraved by heterogeneously located pits with riffles,

benches and variable shapes. Within the years, river bed morphology is changing. For example, in 1998 the Hau River near Can Tho City was “corresponded to a riffle, bench and channel bar sector and was surrounded by two pools” (Brunier et al. 2014). Ten years later, the bench along the city disappeared because of erosion processes. Another problem of the Hau River is the permanent loss of bed material. In comparison to the Tien River, the Hau River experienced a loss about 110 million m³ over a period of ten years.

Groundwater in the Mekong Delta is quite abundant and it is used for several purposes: for agricultural production, domestic use and industrial use. However, unsustainable exploitation leads to sinking groundwater levels, especially in the dry season in certain areas (e.g. Cu Lao Dung Island). For example, wells were installed as part of a development project for people living in Mekong Delta area. As a result the quality of groundwater decreased significantly. Acid sulfate soils and pollution as well as salt intrusions were observed during the dry season (An et al. 2014). Groundwater in the Mekong River Basin can be found in aquifers. They have an artesian basin structure. Between the two rivers Tien and Hau, there is the deepest part of one of the seven aquifers. Over one hundred years, groundwater was the only source for fresh water. In most places the quality of groundwater is still good, however, pollution is observed at various locations. Sources for pollution include contamination by agriculture, surface pollutants, arsenic pollution or salinity (Vo & Huynh 2015).

5.2 Flooding

The climate in the Mekong River basin is influenced by climate variables such as El Niño Southern Oscillation (ENSO). El Niño is responsible for oceanic associations, while the Southern Oscillation refers to atmospheric associations. The results of this phenomenon are droughts, floods and typhoons. The flood events in the Mekong Delta depend on numerous factors, including the extent of upstream floods, the regulation by the Tonle Sap (the inundated area of Cambodia), the East Sea - West Sea tidal regime, the interior field rainfall regime, geomorphologic conditions of the inundated areas and anthropologic impacts across the whole basin.

Between the years 1991 and 2002 several severe floods and erosion have caused significant losses with thousands of victims and significant damages (Table 2). In the year 2000, a major flood event in the Mekong Delta, which was the highest flood since 1930, caused severe socio-economic damages. During this flood event the average discharge in September was 29,624 m³/s. More than 95,000 houses were damaged, more than 50,000 families were evacuated and 448 people were killed in this extreme event. Decreased rice productivity was reported on more than 110,000 hectares. The estimated total damage was more than 4,500 billion VND. The high losses were not only due to the high peak water level and discharge rates, but also due to the early arrival of the flood approximately six weeks before the actual wet season. This flood is considered as one of the highest floods in this region (Table 3). The total water volume of the flood was 420 million m³, approximately 17% flew into Hau River and 83% into the Tien River. Unique was also the course of the flood with a very wide peak of the water level (Figure 12). The peak was registered on 29th of September with a water level of 4.7 m followed by a saddle point four weeks later with a water level of 4.2 m.

	1991	1994	1995	1996	2000	2001	2002
Dead people	158	407	199	217	448	412	170
Damaged houses	19,747	50,590	28,240	78,859	95,283	17,108	5,209
Evacuated families	7	6	11,431	38,735	50,956	27,826	6,670
Decreased rice productivity [ha]	88,837	202,189	62,399	107,707	111,907	33,036	15,777
Total damage [billion VND]	2,217	2,228	700	2,181	4,597	1,456	457

Table 2: Damages and flow rates of floods in the Mekong River basin

Source: NGUYEN 2006

	Year			
	1978	1996	2000	2011
Flood water levels [m.a.D]	4.44	4.54	4.70	4.18

Table 3: Maximum historical flood water levels in the Hau River

Data source: SIWRR

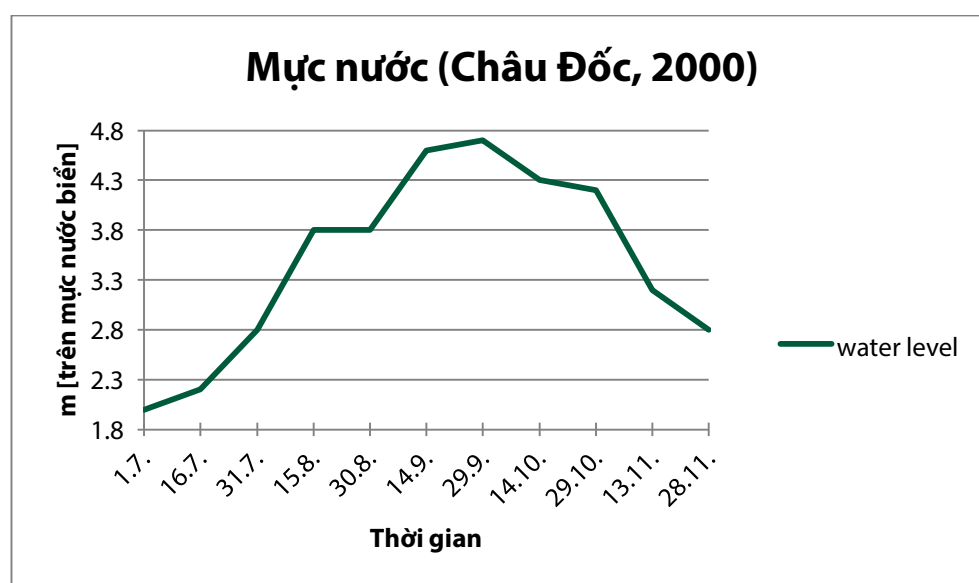


Figure 12: Water level at Chau Doc gauging station

Data source: SIWRR

These numbers above indicate that the catchment area of the Hau River is very much affected by major flood events. As a consequence, Vietnam worked on a national strategy for natural disaster prevention. Existing canals in the Mekong Delta have been deepened and widened for flood control purposes. Usually the main function of those canals is to divert water from the Hau River for agricultural production. In the

Long Xuyen Quadrangle (LXQ) canals with northwestern and south-eastern direction parallel to the Hau River were built.

However, the floods of the Mekong Delta also have positive aspects. First, a large volume of alluvium soils, mainly from the upstream basin, are deposited in the Mekong Delta. The ongoing deposition extends the Mekong Delta continuously towards the East Sea, improves the fertility of fields, provides a well-stocked fishery and creates very favorable conditions for aquaculture. The flood flow also improves the water quality, particularly by flushing acid sulfate soils and agricultural pests. In addition, this freshwater source is important for agriculture, aquaculture, and livelihoods, and provides a vast freshwater ecosystem for the plain.

5.3 Climate change

An increasing frequency and intensity of flood events is most likely at least partly related to global climate change. Hence, these events are expected to further increase in the future. At the same time, drought events are likely to increase in terms of frequency and severity. As one of the most likely impacts of global warming, sea level rise (SLR) will have severe consequences for Vietnam with a hotspot being the low-lying Mekong Delta. The most imminent impact of SLR on the Mekong Delta will be the increased risk of inundation. Various reports, such as the IPCC AR5, provide a range of future SLR scenarios. As a consequence of SLR it is almost certain that flooding in the Mekong Delta is likely to increase in duration and frequency. Flooding will not be limited to the immediate coastal zone, but will also affect the major estuaries upstream due to hindered discharge and wider penetration of the tidal wave land inwards. For example, the water levels at Can Tho will most likely show a trend similar as the SLR. The direct influence of SLR will decrease towards Long Xuyen City. However, there will be indirect impacts of SLR, such as hindered discharge that will most likely increase the frequency and intensity of flooding.

However, focusing on SLR and the tidal regime, might lead to an underestimation of actual future water levels, if other climate change-related effects, such as morphology changes of the river bed and significant changes of precipitation, are neglected. Scenarios with intensified dry seasons and increasing rainfall in the rainy season must consider these factors, which should be subject to future research.

Assuming two scenarios of a median value of SLR of 25 cm in the middle of the twenty-first century (actual projections lie in the range of 24-29 cm) and 60 cm at the end of the century (actual projections lie in the range of 43-73 cm), the probability of an inundation of downtown Can Tho will increase. For example, the areas near the riverbank will be inundated for a total of about 3 months per year under an SLR of 60 cm according to recent studies (THAO et al. 2014).

Thus, a sustainable flood protection and management will be a key issue in future decades, and strategies and proposed measures need to consider medium to long-term developments. Besides an increasing frequency of hydro-climatological events, such as floods or typhoons, the frequency and intensity of droughts will increase as well. Severe droughts have already repeatedly occurred in the recent past in the dry season – especially if they were intensified by the El-Nino phenomenon as in the year

2016. Droughts cause low water levels and thus decrease the water quality through salinization and acidification of soils, resulting in significant losses in agriculture and aquaculture. Lower water availability has the potential to sharpen the conflicts between different water users on a provincial, but also on an international level.

5.4 Saline intrusion

The Mekong Delta is currently facing the strongest salinity intrusion of the country affecting approximately 1.77 million ha. Salt water usually affects about 45% of the delta in the dry season. Especially in March and April when the upstream flow is lower and constant easterly winds lead to increased tidal water levels, salinity penetrates inland. Salinity intrusion itself is determined by the interplay of the discharge of the river and the tidal regime from the sea.

In the dry season from December to June, the average discharge of the Mekong River is about 6,000 m³/s. From March to April it is at its lowest level with approximately 2,500 m³/s. As a consequence salinity intrusion reaches far inland during this period. In this period of the dry season, the tide is the main factor affecting water levels and water flow in the Mekong Delta. The tide regime of the East Sea is of an unsteady semi-diurnal type with two peaks and two lows as well as two flood tides and two low tides in the month. When the upstream flow decreases, the tide can have an effect up to 60–70 km land inward from the estuaries of the Mekong River. The tide of the West Sea is an unsteady diurnal type with one peak and one low. The amplitude is about 0.8–1.0 m, which has a marginal impact on the Mekong Delta. It mainly affects the small canals and the Ong Doc River and Cai Lon River systems.

The average intrusion of salt water into the Mekong Delta in April is shown in Figure 13. At the immediate coastline, salinity levels reach more than 16 g/l on an area of 210,000 ha. The area adjacent to the immediate coastline, constitutes the largest zone (1,195,680 ha) and has a salinity level of 4–16 g/l.

The western coastal zone covers the two provinces of Kien Giang and Ca Mau which are characterized by a low topography (0.2–0.6 m above sea level). The water salinity values at the measurement stations fluctuate greatly, both monthly and yearly. Salinity intrusion is affected by the tide of the West Sea. The salinity of the water gradually increases from March to April. The area is also supplied with fresh water from the Hau River. The extent of salinity intrusion at most river mouths reaches up to 60 km inland and has its strongest impact on the estuary zones in March and April. Figure 14 shows the distribution of salinity concentration land inwards starting from the Hau River mouth at the East Sea in Soc Trang.

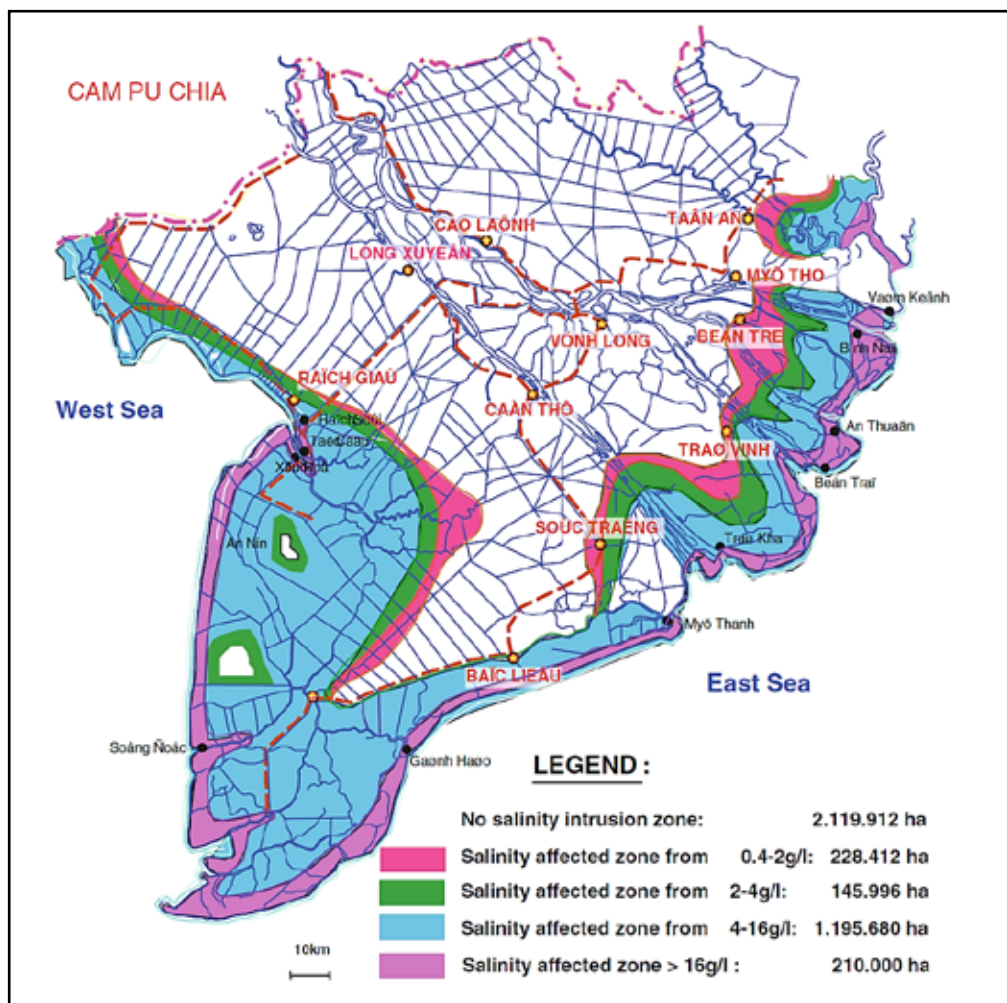


Figure 13: Areas affected by salinity in April in the Mekong Delta

Source: SIWRR 2010

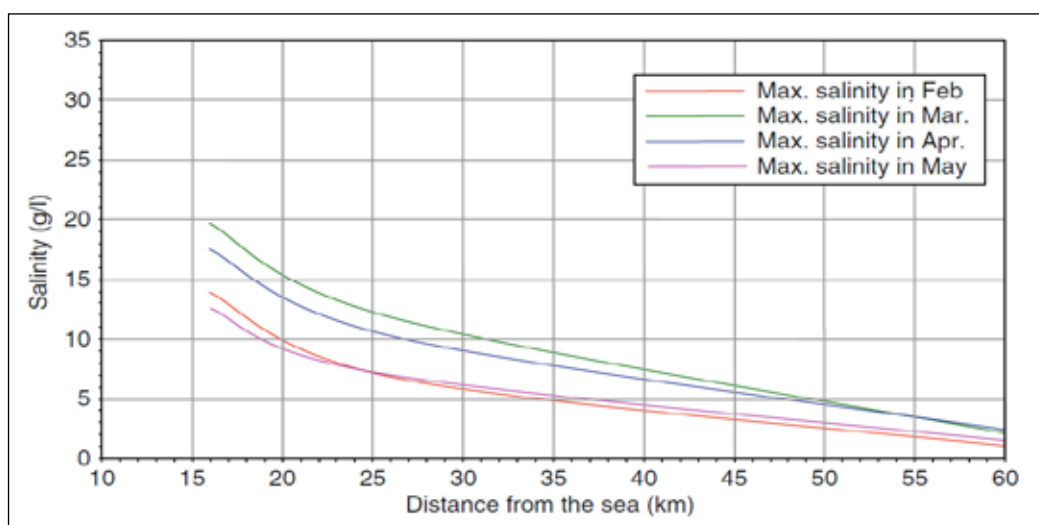


Figure 14: The distribution of salinity concentration in the Hau River mouth

Tri et al. 2006

5.5 Flood regime in the Long Xuyen Quadrangle (LXQ)

The travel time of a flood wave from Phnom Penh to Tan Chau (Tien River) and Chau Doc (Hau River) respectively is about 2-3 days. The velocity of the flood wave decreases gradually after the Mekong River is divided into the Tien River and the Hau River. The increase of the water level is usually not higher than 10 cm/day during the main seasonal floods in both rivers. In case of flood events, the Tien River and the Hau River discharge 92.6% of the total upstream water volume into the East Sea (out of which 82-86% are drained by the Tien River and 14-18% by the Hau River). 4.6% of the total water volume are drained to the West Sea, and 2.8% is drained through the Vam Co River in the northeast of the delta (Lanh et al., 2005).

Figure 15 provides a simplified hydrological sketch for the LXQ. It illustrates the water flow along Hau River and Tien River once entering the Vietnamese border. Water flow in Tien River entering Vietnam accounts for about 85% of the total water volume and water flow in Hau River accounts for 15% accordingly. As indicated in Figure 15, a minor part of the flood water will flow into the Vinh Te Canal, which runs along the Cambodian border in southwest direction and passes An Giang and Kien Giang Provinces. In addition, the canal is filled by its catchment areas on both sides of the canal. Currently, the water volume in the Vinh Te Canal can be reduced by a maximum of 800 m³/s by lowering the rubber dam. However, areas in the west of Kien Giang and An Giang are still flooded through the Vinh Te Canal (Area A). In addition, during high water levels, water flows from the Hau River into the LXQ and induces inundation of large areas (Area B). Furthermore, Long Xuyen City and Can Tho City experience major flooding during these flood events. The volume of water that flows into Area B significantly influences the flood level in Long Xuyen City and Can Tho City. Increased dike heights along the Hau River and an accordingly decreased discharge to area B would increase the flood levels in both cities.

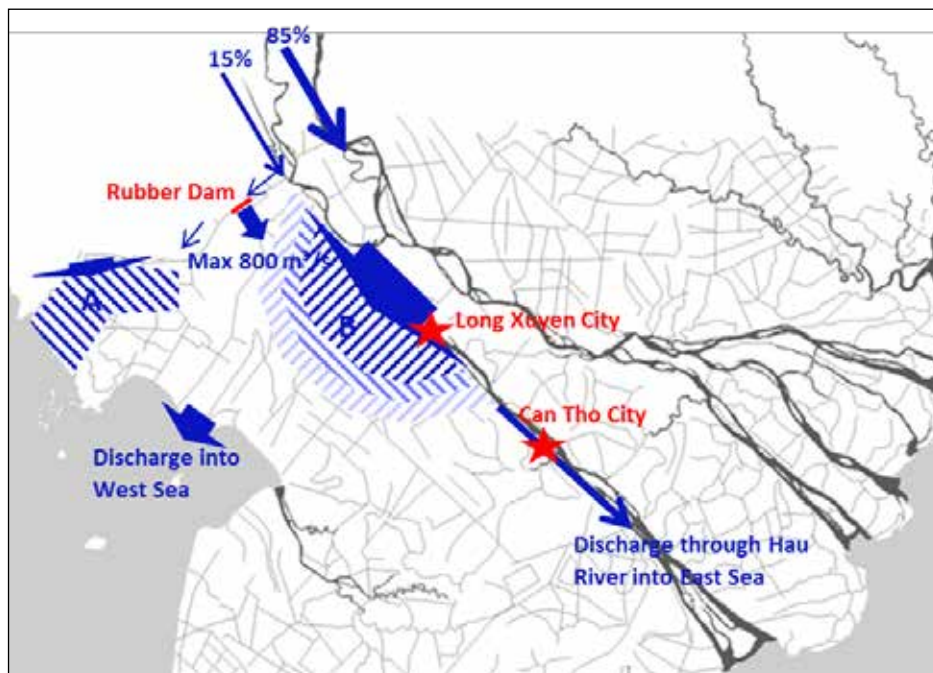


Figure 15: Simplified hydrological sketch for the LXQ

In the following the water flow distribution in the Plain of Reeds and the LXQ will be discussed in more detail, while the focus will be on the latter, since the area is of immediate relevance to subproject 1. Figure 16 shows the estimated maximum discharge during the flood event in the year 2000. The floods inundating the Plain of Reeds are mainly caused by water flow coming from the border to Cambodia through the Tien River. The flood water in the Plain of Reeds is drained back into the Tien River again and the Vam Co River.

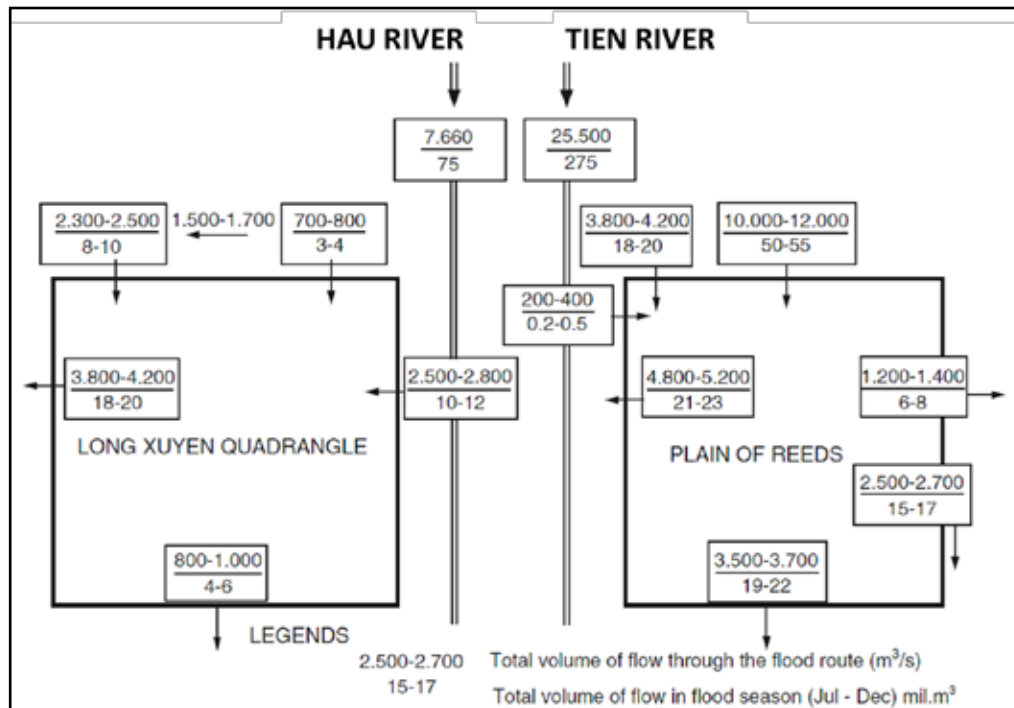


Figure 16: Estimated maximum discharge and total volume in the year 2000

Lanh et al., 2005

The situation in LXQ is discussed in more detail. The LXQ has a total area of approximately 490,000 ha distributed over An Giang with an area of 239,813 ha (48.92%), Kiên Giang 235,054 ha (47.97%) and Can Tho 15,183 ha (3.11%). The LXQ borders to Cambodia in the northwest, to the Hau River in the northeast, to the Cai San canal in the southeast and to the Gulf of Thailand in the southwest. It is strongly affected by floods from upstream that cause inundation, including severe damages and losses of life (see Figure 17). Furthermore, LXQ is constantly facing the challenges of soil acidification and saline intrusion, and lack of fresh water in some areas during the dry season.



Figure 17: Inundation in the LXQ

Source: SIWRP

The inundation of the Long Xuyen Quadrangle is mainly caused by the flood in the Mekong River, which passes through the inundated areas of Cambodia and the Vinh Te Canal from the north, and through the Hau River (see Figure 18). Water from the inundated areas of Cambodia and the Vinh Te Canal accounts for 42% of the total flood water and water from the Hau River accounts for 58%. In addition, rainfall within the area contributes partly to the floods. 78% of the flood water is discharged to the West Sea and 22% to the Ca Mau Peninsula.

In general, the tidal effect in the river is limited during major flood events. However, it causes hindered discharge and a substantial delay in terms of drainage to the sea, particularly during days of high tide. Water flow can be stagnant during days of high tides. As a result, the water levels in the rivers and the inland area increase up to Tan Chau and Chau Doc. This stagnation of water flow causes instant sedimentation in some river reaches.

In recent years different flood control measures have been planned and realized in LXQ, such as the construction of dikes, bridges, dams and weirs. Main purposes were flood control, input of alluvium material to inland areas, improvement of the alkaline soil, increasing the productivity of agriculture and aquaculture, infrastructure and socio-economic development and disaster management. Sluice gates have been constructed for salinity control. Some existing issues of the flood protection management are:

- The projected and existing flood control system needs to be finished, upgraded and maintained
- The two dams Tha La and Tra Su need to be completed and operational guidelines need to be developed

- Along the Hau River a flood control system is missing
- Operational regulations of sluice gates for management of salinity intrusion are missing.

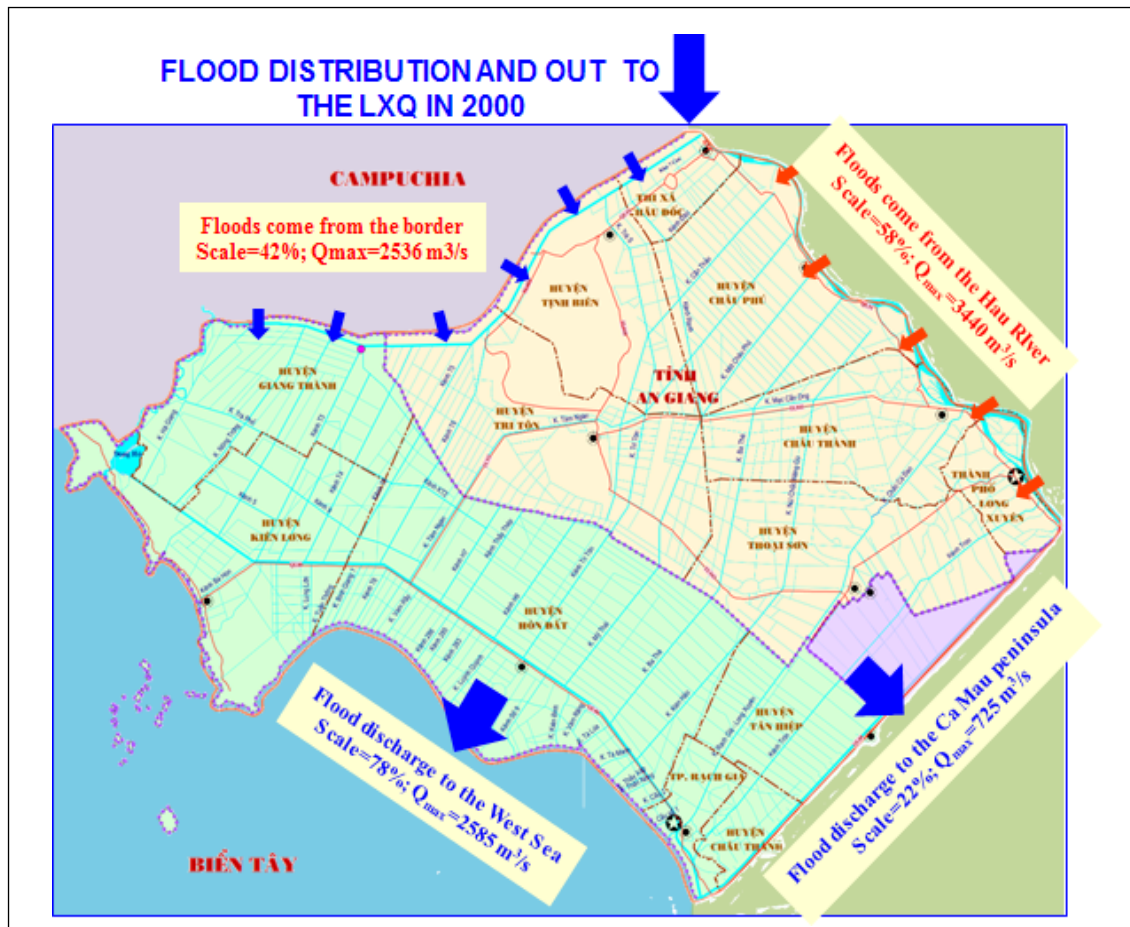


Figure 18: Distribution of flow in the LXQ (Source: SIWRP)

At many locations secondary impacts of flood events cause further damages such as riverbank erosion (see Figure 19) and the release of pollutants due to flooding.



Figure 19: Erosion in Long Xuyen City in 2012

Riverbank erosion along No.91 highway, Binh My commune, Chau Phu district (Source: SIWRP)

Many kilometers of dikes were constructed especially between 2003 and 2013 in the LXQ and protect larger rural areas from flooding. This lost retention area caused increased inundation in downstream urban areas, such as Long Xuyen City and Can Tho City (Figure 20). The flood wave mainly streams through narrow canals. During events with higher water levels embankments and dikes are overflowed resulting in damage and failure of dike sections and thus inundation of larger areas. At the border between Vietnam and Cambodia, the dike system along the Vinh Te Canal was reinforced, including a road and several bridges. These measures led to increasing water levels and inundation on the Cambodian side of the border in recent years.



Figure 20: Inundation in Long Xuyen City (left) and Can Tho City (right)

Source: SIWRP

Considering those recent developments and different scenarios of climate change, a holistic and sustainable flood risk management is required for the LXQ. Lost retention areas must be reclaimed to reduce inundation of downstream urban areas and effective drainage of inundated rural areas must be established. The projected floodway in the LXQ is supposed to contribute to this objective. Thus, the main purpose of the floodway is flood management by (i) creation of retention areas to reduce inundation in downstream urban areas; and (ii) drainage of the flood wave into the West Sea instead LXQ.

For the realization of the floodway several structural and non-structural measures are required. Aspects such as freshwater storage, back filling of groundwater through infiltration or enhanced management of saline intrusion may be positive secondary effects, but are considered as being secondary benefits.

6 TECHNICAL AND FINANCIAL ASSESSMENT OF PROPOSED MEASURES

After the general biophysical and hydrological boundary conditions of the broader project area have been discussed above, the measures initially proposed for subproject 1 will be assessed. As a first step, the hydrological conditions affecting the functioning of the floodway will be analyzed. In the following sections, the measures initially proposed by MARD consultants will be assessed, including structural measures for flood and water management and forestry-related measures. This technical assessment is followed by an economic analysis of subproject 1. The chapter concludes with recommendations on which activities/steps should be conducted as part of the full feasibility study to be carried out by the national consultants.

Figure 21 and Figure 22 again illustrate the proposed position of the floodway within LXQ and the three major zones within the floodway (see also chapter 4). The proposed floodway covers a total area of 33,600 ha and leads through existing canals. The borders on both sides of the floodway are formed by existing dikes. In general within the floodway a two-field crop rotation exists (Zone 1, see Figure 23: Longitudinal section of the floodway). Key element of the planning is the Melaleuca forest in the north (Zone 3) that interrupts the floodway on its complete width. Here a hydraulic permeability must be ensured here. Another key element is the red triangle with a three-field crop rotation (Zone 2). The creation of a hydraulic permeable system must be accompanied by a change in the land use.



Figure 21: General map of Mekong Delta incl. floodway in Long Xuyen Quadrangle (LXQ)



Figure 22: Different zones in the floodway

6.1 Basic Hydraulics of the Floodway

During the field visits along the course of the projected floodway in Kien Giang and An Giang several basic issues concerning the general hydraulics arose. These were discussed during the field trips and in subsequent meetings. At the current planning status some main issues are not yet clarified:

- Potential upgrade of rubber dam:** Currently the only controlled inflow into the floodway is the rubber dam at the Vinh Te Canal at the border to Cambodia. The dam is not in a good condition and requires maintenance. The dam's maximum capacity is 800 m³/s. The maximum discharge through the Vinh Te Canal, which is leading along the border to Cambodia and is flowing into the West Sea, was approximately 3,900 m³/s in the year 2000. Thus it is possible to lead only 20% of the discharge of the Vinh Te Canal into the floodway. Since there occurred significant flooding, even after construction of the rubber dam along the border, the maximum volume of the dam must be increased to release additional water volumes out of Vinh Te Canal and thereby improve the flood management along the border. The dam is not included in the proposed World Bank subproject.
- Potential second water inflow:** A second water inflow is proposed as part of the subproject north of the triangle (see Figure 22) at the eastern side of the floodway. The proposal is to lower the crest of the respective dike section and let the water flow from the inundated areas northeast into the floodway. However, it is not clear whether the natural gradient is sufficient to facilitate a steady water flow or if additional infrastructure is required. This second inflow is essential for the evaluation of the floodway, since it directly influences the reduction of the flood risk in the rural areas northeast of the floodway.
- Implications for Long Xuyen and Can Tho Cities:** In addition, the second inflow is crucial for management of the flood risk in Long Xuyen City and Can Tho City, since the rubber dam at the Vinh Te Canal does not influence the water levels at these cities significantly. Thus the second inflow into the floodway is crucial for the

assessment of the investments.

- **Definition of design flood event:** Currently it is not specified for which recurrence interval of flood events (or severity of floods) the floodway is being designed. Questions about volumes and water levels in the floodway remained unclear.
- **Duration of inundation of floodway:** Since the water flow within the floodway has not been assessed, the durations of inundation cannot be assessed as well.
- **Water levels in Kien Giang Province:** As a consequence it is also not clear which water volume will enter Kien Giang Province through the floodway.

All these questions need to be considered and answered in the full feasibility study (see section 6.3). They directly influence the design and position of structural measures and thus the investment costs. Sufficient results must be available before types of measures, and their design and position can be assessed. Also secondary effects can only be evaluated in depth after there is a better understanding of the above issues. To provide a rapid assessment of the investments proposed as part of subproject 1 and derive recommendations for the full feasibility study, simplified modeling has been executed as a first step.

An approximate hydrostatic modeling of flood scenarios using ArcGIS has been carried out to gain a preliminary understanding of water levels and thereby assess the general effectiveness of the floodway. A digital elevation model forms the background data set. Figure 23 shows the terrain elevations along the longitudinal section of the floodway. The location of the two melaleuca forests and the triangle are marked. The longitudinal section is interrupted by several cross-sectional elements, such as embankments, dikes or roads. In general, the gradient in the northern part of the floodway in An Giang is very small or nearly zero. In the center part there is a slight gradient, and in the coastal area of Kien Giang the gradient is near zero again. As a result of the modeling work, no clear flow directions could be computed for the entire area of the floodway due to the low gradient. If the water flows through the existing canals, there is a very slow but steady flow from north to south during normal conditions. Even if large volumes are led into the floodway the velocity will not increase significantly. As a result, it is most likely that the duration of flooding will be substantial in the floodway.

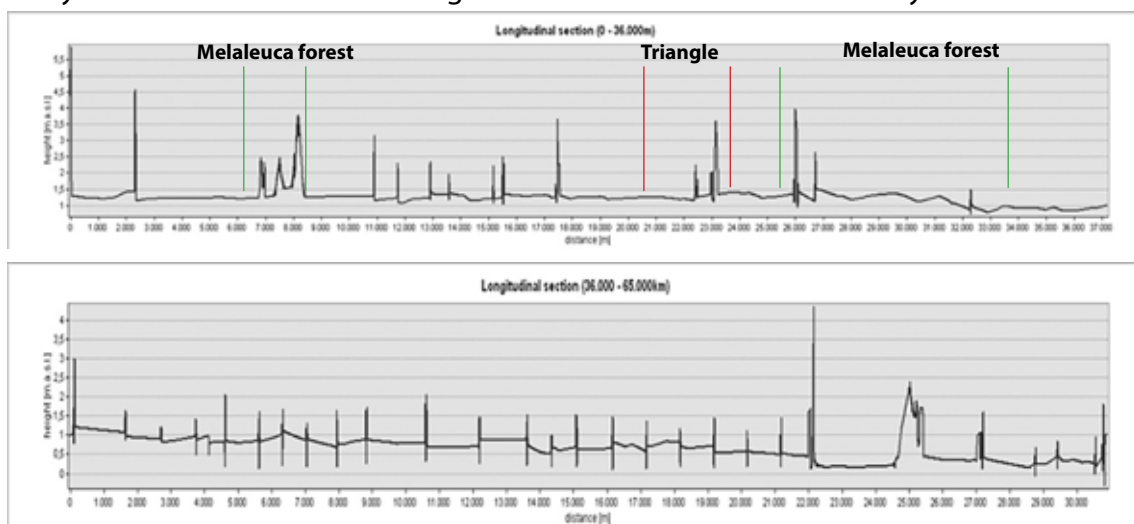


Figure 23: Longitudinal section of the floodway

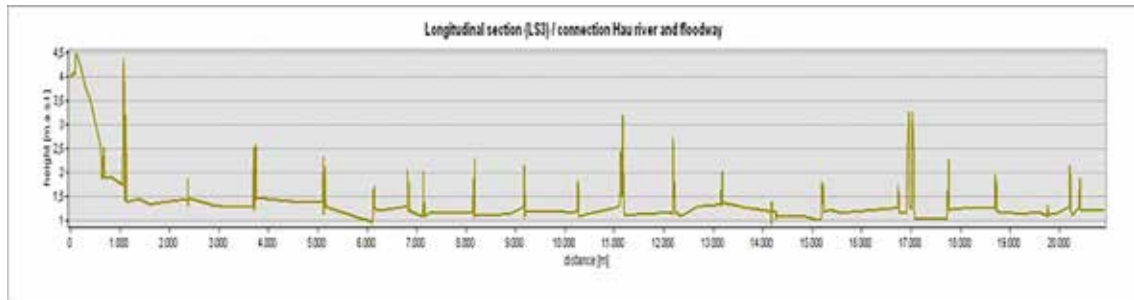


Figure 24: Longitudinal section northeast of the floodway

Figure 23: Longitudinal section of the floodway shows the terrain elevations along the longitudinal section northeast of the floodway between Hau River and the floodway at the proposed second inflow. Throughout this distance, the natural gradient is very low. In case of flooding inflow into the floodway will occur only at the immediate adjacent area. However, water from areas further remote from the floodway (i.e. 20-25 km) will not flow into the floodway without any additional structural measures. As a summary, it should be noted that the characteristics of the elevation within the floodway and of the surrounding areas are not favorable to the idea of the spillway. Additional infrastructure, such as sluice gates and canal upgrades/extension, would be required.

Based on the available digital elevation model different volumes of retention provided by the floodway and their respective water levels in the floodway have been computed. The results are illustrated in Table 4, whereas “floodway 1” refers to the current proposed course of the floodway and “floodway 2” refers to a proposed additional branch of the floodway in north-east direction connecting with Hau River (this second option will be discussed further below in this section). Assuming a maximum volume of $800 \text{ m}^3/\text{s}$ passing the rubber dam, a total volume of $69.1 \cdot 10^6 \text{ m}^3$ per day will flow into the floodway. According to Table 4 this results in a corresponding water level of 0.25 m if the water was equally distributed over the entire floodway. Obviously it stays in the northeast of the floodway (ca. 19% of the entire area) and water levels will be accordingly higher there (about 1.05 m). This also implies that under this scenario (current dam capacity), the water levels in the floodway in Kien Giang would be very low.

To reduce the flood risk along the Vinh Te Canal it is necessary to increase the capacity of the dam. If larger water volumes flow into the floodway at this location significant inundation within the floodway will occur (see Table 4. “Floodway 1” in Table 4 means the original main arm of the floodway, while “Floodway 2” means the additional arm in the Northeast). Assuming the total volume which flows into the floodway would increase by 100% to the scenario above, the corresponding water level would be 0.5 m if the water would be distributed equally over the entire floodway. Again, the majority of the water would stay in the northeast of the floodway.

However, the inflow from the Vinh Te Canal into the floodway will not decrease the water levels in the Hau River significantly and thus does not influence the flood risk in Long Xuyen City, Can Tho City and rural areas northeast of the floodway.

	Floodway 1	Floodway 2	Floodway 1 + 2
Water level in floodway (m)	Water volume [m ³]	ΣV [m ³]	ΣV [m ³]
0.25	$69.46 \cdot 10^6$	$24.89 \cdot 10^6$	$94.35 \cdot 10^6$
0.50	$138.93 \cdot 10^6$	$49.78 \cdot 10^6$	$188.71 \cdot 10^6$
1.00	$277.86 \cdot 10^6$	$99.56 \cdot 10^6$	$377.42 \cdot 10^6$
1.20	$333.43 \cdot 10^6$	$119.47 \cdot 10^6$	$452.90 \cdot 10^6$
1.50	$416.79 \cdot 10^6$	$149.34 \cdot 10^6$	$566.13 \cdot 10^6$
1.87	$519.60 \cdot 10^6$	$186.18 \cdot 10^6$	$705.78 \cdot 10^6$
2.00	$555.72 \cdot 10^6$	$199.12 \cdot 10^6$	$754.84 \cdot 10^6$
2.30	$639.08 \cdot 10^6$	$228.99 \cdot 10^6$	$868.07 \cdot 10^6$
2.50	$694.65 \cdot 10^6$	$248.90 \cdot 10^6$	$943.56 \cdot 10^6$
3.00	$833.58 \cdot 10^6$	$298.68 \cdot 10^6$	$1,132.27 \cdot 10^6$
3.10	$861.37 \cdot 10^6$	$308.64 \cdot 10^6$	$1,170.01 \cdot 10^6$
3.20	$889.15 \cdot 10^6$	$318.60 \cdot 10^6$	$1,207.75 \cdot 10^6$
3.30	$916.94 \cdot 10^6$	$328.55 \cdot 10^6$	$1,245.50 \cdot 10^6$
3.50	$972.51 \cdot 10^6$	$348.46 \cdot 10^6$	$1,320.98 \cdot 10^6$
4.96	$1,378.19 \cdot 10^6$	$493.83 \cdot 10^6$	$1,872.02 \cdot 10^6$

Table 4: Water levels and maximum volumes within the floodway

There are no reliable time series on the water volume that would need to be discharged from the area northeast of the floodway into the floodway in time of floods to significantly reduce water levels in these areas. It is assumed that in average 2,600 m³/s enter the LXQ from the Hau River and must be led through the floodway. This is equivalent to $224 \cdot 10^6$ m³ per day which will induce a water level of nearly 1 m if the water was equally distributed over the entire floodway (see Table 4). If concentrated in the northern part of the floodway (ca. 45% of the entire area), water levels will be accordingly higher there (ca. 1.45 m).

If it is assumed that the water level at Long Xuyen City and Can Tho City is to be reduced significantly, it is assumed that a water volume of 4,000 m³/s must be led into the floodway in a controlled way. This is equivalent to $346 \cdot 10^6$ m³ per day which will induce a water level of ca. 1.30 m if the water was equally distributed over the entire floodway. Combining the inflow of $138.93 \cdot 10^6$ m³ per day from northwest of the floodway (through Vinh Te Canal due to an upgraded rubber dam) with the inflow of $346 \cdot 10^6$ m³ per day from the northeast of the floodway, the total inflow would amount to $484.93 \cdot 10^6$ m³ per day. Under this scenario the water level would be about 1.7 m if the water was equally distributed over the entire floodway. Such a scenario would be comparable to the flood event in the year 2000, which is assumed to be a flood event which occurs statistically every 50 years.

However, as indicated above, in reality the water will not be distributed equally throughout the floodway. Figure 25 illustrates the distribution of the water in the An Giang part of the floodway assuming various water levels based on a static model.

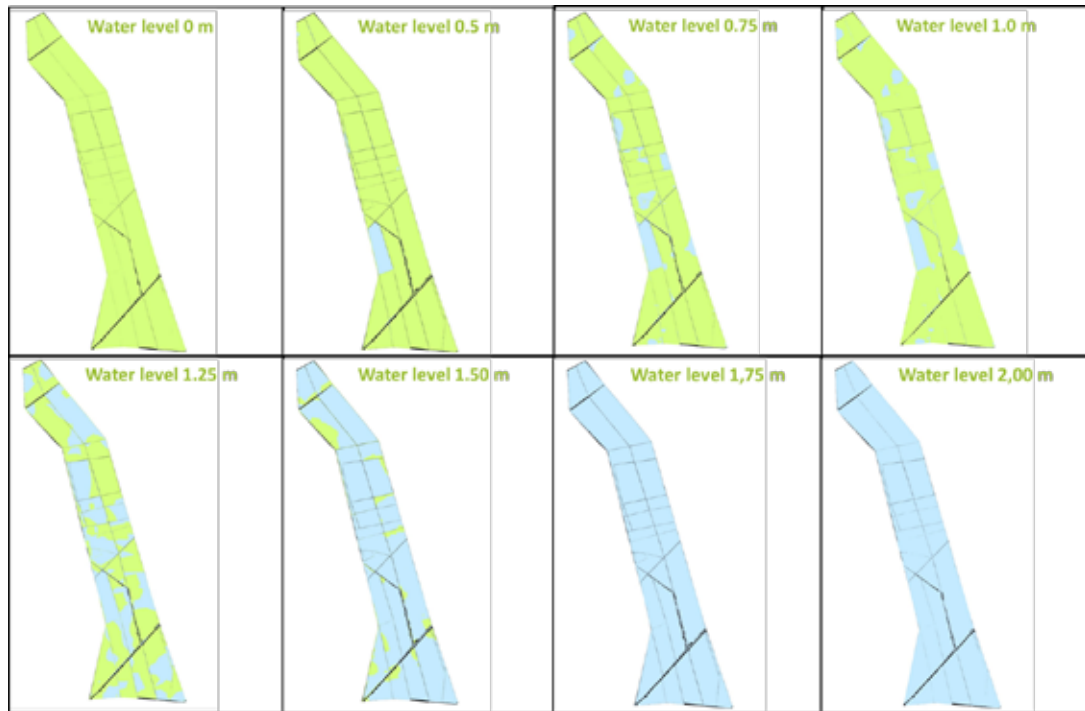


Figure 25: Animation of Water Levels in AG Floodway

Currently the area northeast of the floodway is flooded in an uncontrolled way. The water from this area should be drained into the floodway. However, the natural gradient does not allow the drainage without any further structural measures that have not been included in the proposal so far. Furthermore, the effect of the uncontrolled flooding of the rural areas on the water level in the Hau River is limited. The goal should be a holistic planning that also lowers the water levels at Long Xuyen City and Can Tho City during extreme events. Thus, alternative courses of the floodway should be assessed. One option would be to provide a direct connection of the floodway to the Hau River (named “floodway 2” in Table 4). Such an additional arm was proposed by MARD at an earlier planning stage, but was dismissed later on (mainly due to concerns regarding potentially high compensation payments to farmers).

Figure 26 illustrates the potential course of the proposed additional arm. From a hydrological point of view it is an option worthwhile to consider. Its length is 27.0 km and its width 4.0 km. The retention volume would be increased by approximately one third of the proposed floodway.

The scenario that was considered above (combination of water inflow due to upgraded rubber dam ($138.93 \cdot 10^6 \text{ m}^3$ per day) and the amount required to significantly reduce water levels in both cities ($346 \cdot 10^6 \text{ m}^3$ per day)) would result in a total inflow of $484.93 \cdot 10^6 \text{ m}^3$ per day. The additional capacity of the north-east arm would result in a water level of about 1.2 m if the water was equally distributed over the entire floodway. Since the scenario with floodway 1 only resulted in a water level of about 1.7 m, the additional arm would lower the water level in by 0.5 m.

The main benefits, however, would be the effective reduction of water levels in the flood-prone areas due to the direct connection with Hau River. The installation of different flood controlling elements such as embankments or spillways in the area east of the floodway would be required anyway to enable flow from the plains into the floodway, even if the arm is included. The creation of the second arm of the floodway would be an extension of those elements.

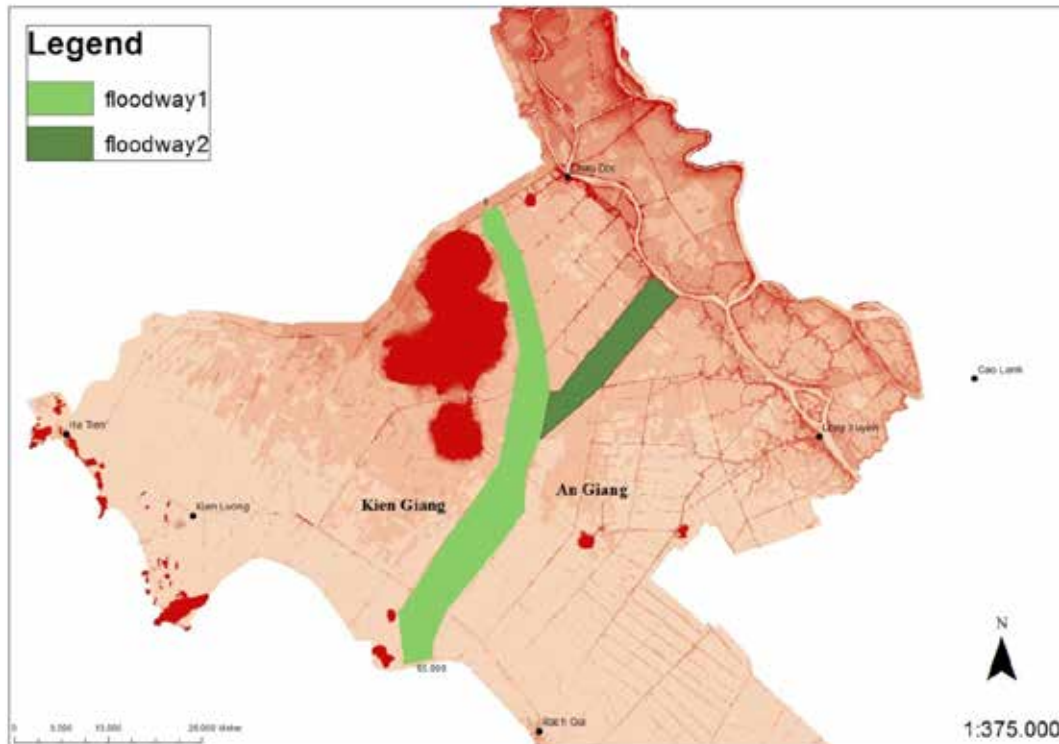


Figure 26: Course of the floodway with a second arm connection to Hau River

Table 5 summarizes the suitability of the three options for floodway design in the Northeast discussed as part of this pre-feasibility study. If the floodway would be designed in the way initially proposed, discharge into the floodway would not be sufficient to reduce flooding in the surrounding areas and there would be uncontrolled flooding in the North-East. If there would be additional measures implemented in the Northeast, such as embankments, canals, dredging of canals, discharge might be improved. However, there would still be uncontrolled flooding in the Northeast. An extension of the floodway in form of an arm combined with additional measures would not only contribute to enhanced discharge, but also improved flood management (reduced uncontrolled flooding).

Options	Characteristics	Suitability
Option 1: According to initial proposal	- As initially proposed - No additional measures	- Discharge into floodway not sufficient - Uncontrolled flooding in Northeast
Option 2: Additional measures in Northeast	Various additional measures in Northeast (e.g. dredging, canals, embankments)	- Enhanced discharge into floodway - Uncontrolled flooding in Northeast
Option 3: Second arm (incl. additional measures)	- Various additional measures in Northeast (e.g. dredging, canals, embankments) - Connection to Hau River	- Enhanced discharge into floodway - Improved flood management (reduced uncontrolled flooding)

Table 5: Options for Floodway Design in Northeast

The simplified calculations above show that potentially the proposed floodway could play an important role for flood management in the LXQ. However, it should be noted not nearly sufficient water would flow automatically into this retention area, i.e. without additional structural measures.² In addition to an additional arm, an upgrade of the rubber dam, additional inflows, and an upgrade of the canal systems and sluice gates are required. Currently it seems that the benefits for Kien Giang with respect to flood management would be limited to the Vinh Te Canal. Further, due to the fact that significant volume of water would only enter larger areas of the floodway in Kien Giang in case of extreme events with recurrence intervals of 50 years, investments to realize secondary benefits (e.g. in water storage) seem to be unlikely to be economically and financially attractive. This aspect should be further analyzed as part of the full feasibility study.

Further, the calculations indicate that potential water inflows could be substantial and therefore the floodway should be designed for extreme events. The described events used for the calculation have a recurrence interval of approximately once in fifty years (HQ50). Thus, major investments are required, such as significant upgrades of dykes.

² Given various definitions, it should be noted that as part of this report „flood retention“ means an area (in the case of this project the floodway) in which water can flow/drain into in order to reduce flooding in surrounding areas. „Water storage“ means that water is collected/stored for usage during dry periods for which additional structures are required.

The proposed measures do not have an influence on regular water management, i.e. average monthly and yearly flood discharge is not affected. The secondary effects, such as freshwater storage or groundwater infiltration will not be feasible during regular events. If the floodway should be used during flood events with a lower recurrence interval a second controlled inflow at the northeast side of the floodway with a lowered sill and weir crest is essential.

6.2 Assessment of proposed measures

This section provides a technical assessment of the measures initially proposed for subproject 1. The measures can be divided into structural measures for flood and water management, forestry-related measures and livelihood measures (see Figure 5). While the first two measures are addressed in extra sections, livelihood measures are addressed as part of the economic analysis. The economic analysis assesses the profitability of the proposed subproject 1. It should be emphasized that the assessment of the proposed measures can only be preliminary and focus on the appropriateness of the purpose of the specific measures. A more detailed assessment, including concerning scale, location and design, is only possible after the understanding of the hydrology is further advanced (see also section 6.3).

6.2.1 Assessment of structural measures for flood and water management

The proposed structural measures for flood and water management are listed in Table 5 for each zone, including the results of the technical assessments. The scale, location and design for almost all proposed measures must be specified based on the hydrological modeling mentioned below in section 6.3.

In particular in Zone 1 (two rice crops), the realization of the floodway requires the construction of numerous regulative structural elements, since it covers almost the entire area of the floodway (with the exception of the melaleuca forest and the 3 rice crop triangle). It is necessary to maintain and improve the dike system in and along the floodway and adapt it to the hydrodynamic loads resulting from the design event that is chosen for the floodway. At this point it is too early to assess whether the proposed 50 km of dike and embankment upgrading is reasonable and to make further recommendations concerning the location/design.

The realization of the floodway implies also adaptation of the irrigation and drainage system, and thus the construction or adaptations of sluice gates. Again, at this point no recommendations can be given whether the proposed number of 20 sluice gates is recommendable and where the exact location should be. Two main roads (TL943 and QL80) constitute cross-sectional barriers in the longitudinal course of the floodway. Therefore, bridges need to be constructed to create the longitudinal hydraulic permeability of the floodway. The construction of the bridge at TL943 is essential, since it crosses the center part of the floodway. The construction of the bridge at QL80 needs to be verified after the final layout of the floodway due to its location at the southern end of the floodway. At the canals along TL943 and Cái Sắn two spillways are proposed to ensure hydraulic permeability, which is generally recommendable.

Zone 2, which is the three rice crop area, has been identified as one key element of

the floodway. Here, the two roads TL941 and TL945 are cross-sectional barriers in the longitudinal course of the floodway. In order to ensure permeability the construction of two viaducts and 4 bridges is recommendable. The recommended lengths of 200 m of the viaducts seem reasonable. The proposed dredging of canals (6 km) is also generally recommendable, since the drainage effectiveness would be increased.

The Trà Sư melaleuca forest is another key element of the floodway. Several constructional elements such as bridges, spillways and dikes must be constructed to ensure the hydraulic permeability. Viaducts and bridges need to be constructed to create the longitudinal hydraulic permeability of the floodway. Dredging of canals is required to increase the drainage potential. The overall planning must be holistic and consider the construction and location of the viaducts and bridges. Additional sluice gates and dredging of canals are required to adapt the area to the changes hydrological boundary conditions during flood events.



Figure 27: Canal and protected embankment at the northeast end of the floodway

Proposed investments	Technical Assessment
Zone 1: Two rice crops	
Upgrading 50 km embankments and dikes	Recommendable. It is necessary to maintain and improve the dike system in the floodway and adapt it to the hydrodynamic loads resulting from the design event that is chosen for the floodway. Scale, design and locations must be informed by the results of the hydrological modelling.

Construction of 20 new sluice gates for irrigation and drainage	Generally recommendable. The final number and locations must be determined after the final layout of the floodway has been decided on based on the numerical modelling. This final layout also defines the required dimensions of the sluice gates.
Construction of 2 bridges at roads TL943 and QL80 (1 x 200m)	The two roads are cross-sectional barriers in the longitudinal course of the floodway. Bridges need to be constructed to create the longitudinal hydraulic permeability of the floodway. The proposed length is unclear. Generally the construction of the 2 bridges is recommendable. The construction of the bridge at TL943 is essential, since it crosses the center part of the floodway. The construction of the bridge at QL80 needs to be verified after the final layout of the floodway due to its location at the southern end of the floodway.
Construction of 2 spillways at the canals along TL943 and Cái Sắn (1 x 200m)	Generally recommendable. The final dimensions must be determined after the final layout of the floodway.
Zone 2: Three rice crops	
Construction of 2 viaducts (2 x 200m) at roads TL941 and TL945	The two roads are cross-sectional barriers in the longitudinal course of the floodway. Viaducts need to be constructed to create the longitudinal hydraulic permeability of the floodway. The proposed length is appropriate. The construction of the 2 viaducts is recommendable.
Construction of 2 spillways (2 x 200m)	Generally recommendable. The final dimensions must be determined after the final layout of the floodway.
Construction of 2 bridges at road TL945	The road is a cross-sectional barrier in the longitudinal course of the floodway. Bridges need to be constructed to create the longitudinal hydraulic permeability of the floodway. The proposed location and the according length are unclear. Generally the construction of the bridge is recommendable, but needs to be verified after the final layout of the floodway. The planning must be holistic and consider the construction and location of the viaducts.
Construction of 2 bridges at the southern bank of Mac Can Dung canal	Recommendable to keep the accessibility.
6.0 km dredging of canals	Dredging is generally recommendable to create the required discharge effectiveness. Length and especially depths must be determined after final design of the floodway.
Zone 3: Trà Sư melaleuca forest	
Construction of 1 viaduct	Generally recommendable to create the hydraulic permeability.

Construction of 4 spillways (1 x 100 m)	Generally recommendable to enable the discharge. Dimensions are unclear and must be determined after the final layout.
Construction of 2 bridges	Recommendable to keep the accessibility and create to hydraulic permeability.
20 km upgrading of dikes	Recommendable. It is necessary to upgrade the dike system in the forest to create the general function the floodway.
3.0 km dredging of canals	Dredging is generally recommendable to create the required discharge efficiency. Length and especially depths must be determined after final design of the floodway. Lowering of groundwater must be avoided.
Construction of 4 new sluice gates	Recommendable. The sluice gates are required to manage the discharge through the forest. The final dimensions must be determined after the final layout of the floodway.

Table 6: Summary of technical assessment of measures proposed for subproject 1

6.2.2 Assessment of forest-related measures

The floodway proposed by World Bank subproject 1 includes 2,800 ha of *Melaleuca* forest which was planted in 1978. It is divided into two areas of 860 ha in the northern part (Tra Su Forest) and 1,940 ha in the middle part of the floodway. Both forests are located in An Giang Province. *Melaleuca* forests grew naturally throughout An Giang Province. In recent decades large parts were converted into paddy rice cultivation. Its main tree species is *Melaleuca cajuputi*, which covers between 70-90% of Tra Su forest at a density of 6,100 – 7,000 trees/ha.

Project activities are only envisaged for Tra Su Forest. For the area of 1,940 ha, no activities are proposed assuming that this is due to ownership issues (the area is under the ownership of the army). The Tra Su *Melaleuca* Forest is located in Van Giau Commune, Tinh Bien District, and is managed by the Forest Protection Management Board under the authority of the provincial Sub-Department for Forest Protection. The area is separated in two plots of 448 ha and 426 ha. Both plots are separated by a flood canal and surrounded by dykes (see also Figure 10). Currently there are three main canals transporting water from north of the forest to the south: one canal on each the western and eastern side of the forest, and a third which passes through the middle.



Figure 28: Mangroves in the Tra Su Melaleuca Forest

The major role of the Tra Su *Melaleuca* Forest as part of subproject 1 is considered to be its potential to regulate the water flow from north to south along the floodway. In order to fulfill this role various measures are being proposed. Before these measures are being assessed, additional benefits, including ecosystem services, biodiversity, water regulation and usage, and carbon sequestration will be discussed briefly.

Ecosystem Services

From a global perspective wetlands are one of the most productive and valuable ecosystems. They play an important role in both local and global water cycles and are functioning as a connection between water, food, and energy. Wetlands are providing important and diverse benefits, which can be divided into provisioning, regulating, cultural and supporting ecosystem services (see Table 7). For instance, the economic value of inland wetland ecosystem services was estimated to amount up to US\$ 44,000 per hectare per year as a global average (TEEB, 2013). Preservation and protection of Tra Su Forest would contribute to maintaining these important services.

Ecosystem Service	Description	Relative magnitude
Provisioning		
Food	Production of fish, fruits, grain, honey, etc.	High
Fresh water	Storage and retention of water, provision of water for irrigation	Medium

Regulating		
Climate regulation	Regulation of greenhouse gases, temperature, precipitation and other climatic processes	Medium
Hydrological regimes	Groundwater recharge & discharge, water storage	Medium
Natural hazards	Flood control, storm protection	Medium
Cultural		
Recreational/Aesthetic	Tourism, appreciation of natural features	Medium
Supporting		
Biodiversity	Habitat for species	Medium
Nutrient cycling	Storage, recycling, processing of nutrients	High
Soil formation	Sediment retention and accumulation of organic matter	Medium

Table 7: Overview on Ecosystem services of wetlands

Source: TEEB, 2013

Biodiversity

Tra Su *Melaleuca* Forest is of high conservation value, since it is home to an abundance of birds, Amphibia and freshwater fish. The main tree species of Tra Su *Melaleuca* forest is *Melaleuca Cajuputi* with a density of 6,100 – 7,000 trees/ha. Its mean height is estimated to be 8 m and the forest cover is at about 67% of the overall area of Tra Su, which also includes waterways and grasslands. Grass species such as *Eleocharis dulcis*, *Myrmophoides indica*, *Ludwigia adscendens*, *Ipomea aquatic*, and *Cyperus iria* were observed in the wetland areas, whereas *Sesbania cannabina*, *Panicum repens* and *Phragmites vallatoria* are growing in dryer spots. All of those are indicating a diverse and balanced wetland ecosystem (Roberts et al, 2000). Tra Su is considered a bird sanctuary and is home to numerous bird species, such as *Mycteria leucocephala*, *Anhinga melanogaster*, *Ploceus hypoxanthus*, *Ardea purpurea*, *Nycticorax nycticorax* and *Phalacrocorax niger*, *Streptopelia tranquebarica* and *Stutnus malabaricus*. According to local officials, the population of some of those species consist only of a few individuals and are considered as being endangered.

Due to its biodiversity value, this area is used as an ecotourism site which is set up in a way that benefits local communities. Of the surrounding 400 households, around 100 households benefit from the 80000 annual visitors through employment in tourism.

Water usage and regulation

Regulation of water flow is considered to be the main function of the Tra Su Forest as an element of the floodway system. Wetlands continuously receive or lose water via exchange with the atmosphere, streams, and ground water. Therefore a favorable geologic location as well as an adequate and persistent water supply are important to ensure the existence of wetlands (Carter, 1998). Drainage and excessive use of ground water shortens the annual period during which wetlands are able to store water. As a

result dry conditions within the wetland ecosystem may prevail leading to an increase of wildfires. The fire can pose a threat to the whole ecosystem, even though melaleuca combines fire-tolerance and adaptation to seasonally low ground water levels (Wade et al, 1980).

Due to the current dry season, local authorities have to pump water into Tra Su Forest (approximately 800,000m³/month). Maintaining high water levels aims at preventing droughts and thus prevent forest fires. Yet the additional pumping further decreases the downstream flow which is necessary for agricultural production, in particular rice cultivation. When compared with similar cases and the average water needs of Melaleuca wetland ecosystems this seems to be a realistic number. It is important to note that pumping of water into the forest might not be necessary on an annual basis, as this strongly depends on weather conditions. Hence, if the dry season is not as severe as in 2016, then no external water might be needed.

Carbon Storage

Wetlands have a high potential for carbon sequestration and storage both above and below ground (see Figure 29). While the aboveground biomass is lower than those of tropical forests, wetlands accumulate layers of carbon-rich peat over the years (Erwing, 2009). Figure 29 visualizes a simplified carbon cycle in which carbon wetland trees sequester carbon from the atmosphere, most of which is then stored in biomass and partly reemitted via plant-respiration.

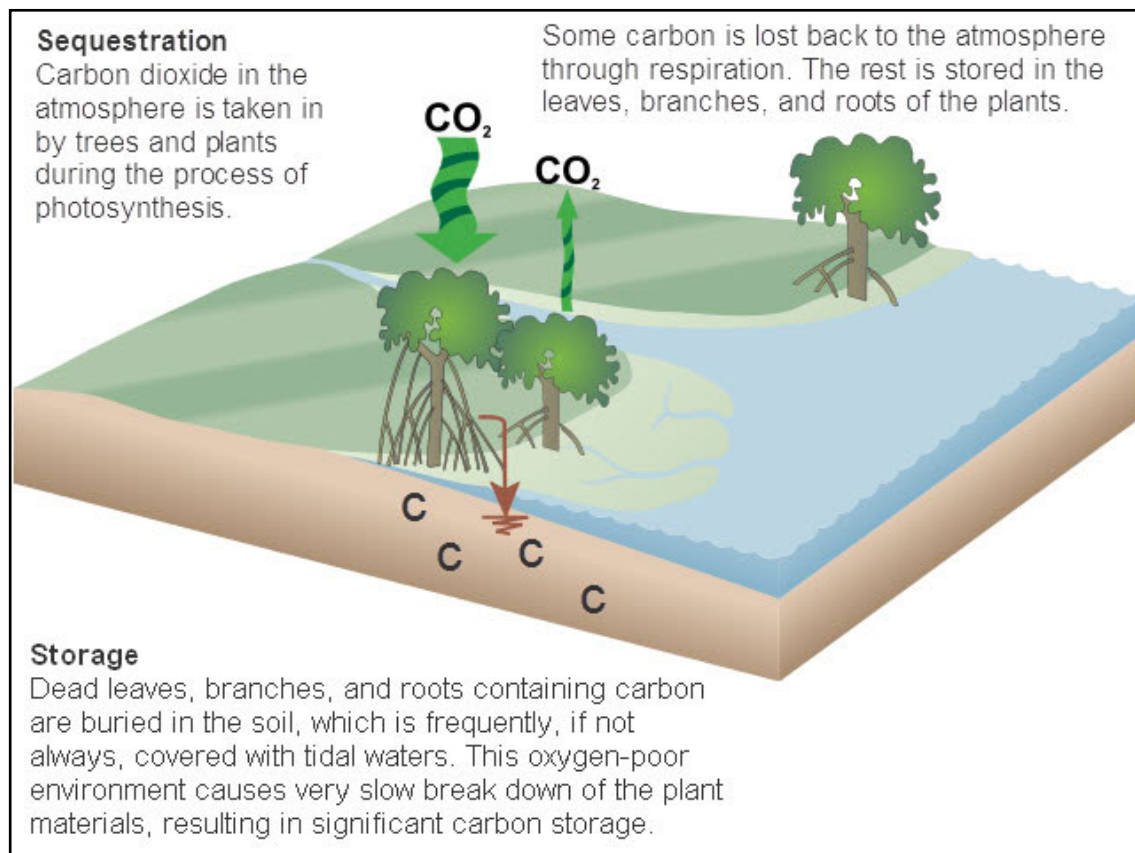


Figure 29: Simplified carbon cycle

Source: NOAA, 2014

Peat soils of wetlands are mostly anaerobic. As a result they have very low decomposition rates. Hence wetlands such as the Tra Su Melaleuca forest do both, they store carbon and contribute to additional carbon sequestration. However, under anaerobic conditions, there is a certain potential that wetlands emit greenhouse gases, such as methane, nitrous oxide and carbon-dioxide. This factor is of specific importance when considering the high water usage during the dry season. Therefore the benefits of pumping additional water into Tra Su Melaleuca forest are twofold: (i) forest fire prevention, and (ii) ensure greenhouse gas storage.

In the case of the Melaleuca forests within World Bank subproject 1 there are no available data on potential carbon storage. Based on extensive research on Ca Mau's Melaleuca forests, which consist of a similar species composition, it can be assumed that the carbon stored above- and below ground ranges between 300 - 800 tCO₂e/ha (Tran et al, 2015). Considering that the Melaleuca forests were planted in 1978, the peat layer is assumingly thin and thus the carbon storage potential is assumed to amount at a maximum of 500 tCO₂e/ha.

After having discussed the general benefits provided by the Tra Su *Melaleuca* Forest, the forestry-related measures proposed by subproject 1 are assessed below.

Activity 1: Bridge at entrance of *Ecotourism Site*

The bridge which allows access to Tra Su is proposed to be upgraded. Currently only motorbikes are able to cross the bridge and an upgraded bridge would also allow cars and buses to directly go to the entrance of the ecotourism site. As the entry point of the ecotourism site is at the border of the forest area, disturbance of biodiversity would be very limited. This intervention is considered to be reasonable without any currently foreseeable negative impacts. A replacement of the current bridge should have no negative impacts on the hydraulic permeability.



Figure 30: Current bridge at the entrance to of the Tra Su Melaleuca Forest

Activity 2: Deepening of Nhon Thoi Canal (3 km)

To cope with the issue of water blockage from North to South, the project proposes the dredging of the main canal separating the two Melaleuca forest plots vertically. Such dredging would increase the water flow through the Melaleuca forest and thereby potentially increase water discharge to the south. Additional discharge would be beneficial during flood events and for agricultural production, especially during the dry season. However, at the same time this measure might also result in a limited amount of water in the forest during the dry season which would increase the risk of fire.

Dredging is generally recommendable to create the required discharge efficiency. Length and especially depths must be determined after final design of the floodway has been determined. Lowering of groundwater must be avoided. During dry season sufficient water levels in the forest can be achieved in combination with the other proposed measures.

Activity 3: Installation of four additional sluiceways

As another intervention, the installation of four additional sluice gates is proposed to better regulate water storage and flow through the *Melaleuca* forest. The idea behind this intervention is to better manage water discharge during “normal” years, but in particular during flood events. This intervention is regarded as recommendable since it facilitates improved water management within Tra Su Forest and better management

of extreme flooding events. The final dimensions must be determined after the final layout of the floodway. In addition to Activity 2 and 3 it is recommended to include the water management in and around Tra Su Melaleuca Forest into the subproject to be able to better manage water storage and discharge.

Activity 4: Enhancement of dyke embankment system (20 km)

Further, upgrading of the dykes surrounding the forest area is proposed as an additional activity. Currently the dykes are only overtopped during extreme flood events. High water levels might have negative impacts on biodiversity and tree survival which might lead to loss of habitat for both flora and fauna (i.e. specific crane species only feed on very shallow waters, which would not be possible if the *Melaleuca* forest is severely flooded over long time).

In principle, this investment seems recommendable. It is necessary to upgrade the dyke system in the forest to create the general function the floodway. However, a better understanding of the water regime is required to provide a more informed assessment.

Activity 5: Improvement of community-based ecotourism

Soft measures of the subproject are expected to further improve ecotourism and community based tourism. Specific measures and activities have not been specified yet. However, in general it is recommendable that ecotourism should be further strengthened to enhance the benefits of the surrounding communities on a sustainable basis.

Community-based ecotourism could be improved in a number of different ways: (i) capacity building for communities working in the service sector; (ii) increased production of locally sourced products (i.e. honey); (iii) development of new or improved services to offer in and around Tra Su *Melaleuca* forest; and (iv) development of outreach/promotion material to create more visibility for the Tra Su ecotourism site. It has been reported that approximately 80,000 visitors come to the ecotourism site per year. A significant increase of this number might be unrealistic. However, further intensification of the services provided could be explored.

Activity 6: Mangrove-clams co-management

The initial project idea also included the establishment of two farmer cooperatives and the training of households for mangrove-clams co-management. However, during the field visits and the discussions with the national consultants, this idea did not feature prominently any more. Eco-tourism directly involving the communities is considered as the favorable solution.

One additional option which was discussed is community-based fire prevention. The linkage of fire prevention with some type of economic incentive would apply to communities which have social or economic benefits from fire prevention. This mostly relies on options for economic utilization of park resources (such as tourism under Activity 5 or other Non-Timber Forest Products). This can be implemented through distribution of benefits based on successful fire prevention or generation of

access to small loans which eligibility requirements could be linked to fire prevention performance.

Main aspects under such a scheme would be:

- Maintenance of high water levels in specified areas of the park.
- Prescribed burning to establish fuelbreaks around threatened *Melaleuca* stands.
- Education to the surrounding communities.
- Establishment of fire brigades
- As another benefit the involvement of communities in improved fire prevention might decrease the amount of water which is currently pumped in to prevent forest fires. Hence increase the amount of water available for rice cultivation further Southward of Tra Su

6.2.3 Economic and financial analysis

The economic viability of structural flood management and forest-related measures identified in the technical assessment is analyzed as part of the pre-feasibility assessment of subproject 1. Further, livelihood-related measures, which were proposed by the MARD consultants, were considered. The overall profitability of the proposed subproject is indicated by the Net Present Value (NPV) and the Internal Rate of Return (IRR). The analysis is based on a dynamic “with and without project” comparison. Further, a time period of 30 years and a discount rate of 10% were assumed. Based on the quantitative description of the hydrological site conditions, the effect of the proposed floodway on the intensity and frequency of 5-year flood events was assessed.

The main economic benefits generated by the subproject would include:

- Avoided losses both in terms of private and public infrastructure and agricultural production due to 5-year flood events (including in An Giang and Can Tho City).
- Increased and sustainable agricultural production derived from the adoption of flood-based livelihood systems.
- Enhanced resilience of natural ecosystems and livelihood systems through enhanced water and soil quality and biodiversity.
- Improved social stability and overall well-being through reduced risk to natural hazards.

The direct benefits of the latter two (soil quality and biodiversity, and social stability and well-being) have not been quantified as part of the economic analysis.

Concerning flood management all measures listed above have been included in the analysis. Due to technical and construction capacity constraints, up-scaling was assumed to be distributed over the entire project length of 6 years. The construction unit costs are based on costs norms, provided by national consultants from MARD at 2015 prices. Annual maintenance costs of 3 percent of the total construction costs were assumed. To quantify the damages due to flooding, data provided by SIWRP on

the flood event in the year 2000 are used. Based on the hydrological sketch, a reduction of damages of 20% due to the proposed investments are assumed.

Concerning forestry-related measures all investments discussed have been considered. As proposed by the MARD consultants, investments into forest co-management comprise the establishment of farmer cooperatives and the training of farmers. As for the flood management measures implementation over a period of 6 years is assumed. The cost for the establishment of farmer cooperatives and the training of farmers were based on costs norms, provided by MARD consultants at 2015 prices. In the “without project” scenario information on the marketed honey volume, farm gate price and profit margin provided by the Forest Protection Management Board were used. The *Melaleuca* forest provides intact ecosystem functions, suggesting that the anthropogenic pressure is of minor significance in this area. Hence, it is reasonable to assume that the expected future honey production is likely to be stable in the “without” project scenario. The proposed investments into co-management induce an increase in both the production/extraction of forest honey and farm gate price. Considering the limited market potential, conservative assumptions, based on the consultants’ and Forest Protection Management Board’s experience, are made.

In the “without project” scenario information on the number of visitors, entrance fee and profit margin, made available by the Forest Protection Management Board are used. It is assumed that the promotion of ecotourism induces an increase in the number of visitors. In consultation with forest protection management board conservative estimates on the number of visitors are made. Non-quantified benefits include: i) benefits through more systematic involvement of neighboring local communities. This would result in increased environmental awareness, higher ownership and potentially less illegal activities (mostly poaching) impacting on Tra Su; and ii) increased biodiversity and forest fire protection through joint management and protection activities (community based forest fire prevention).

While flood management and forest-related measures, proposed by MARD consultants have been already technically assessed and adapted, livelihood-related measures considered in the economic analysis are solely based on recommendations made by MARD consultants. Aimed at triggering the transformation from intensive rice production towards flood-based livelihood systems, the following livelihood models were proposed: (i) promotion of winter-spring (WS)-rice plus freshwater prawn; (ii) the promotion of WS-rice plus upland crop; (iii) the promotion of two crop rice plus upland crop. Further, the promotion of floating rice and an upland crop have been added in the economic analysis. As recent data show, floating rice rotated with upland crops may generate higher economic benefits compared to high-yielding varieties (mainly due to low production costs of floating rice cultivation). Hence, it is increasingly discussed as an alternative flood-based livelihood systems (Nguyen, 2015). However, it should be noted that the production of floating rice is also facing certain challenges (see ICMP, 2015).

In An Giang, upland crops such as cassava, chili, pumpkin, eggplant, leek, cucumber, maize or taro are rotated with rice crops (Nguyen, 2015). Due to a lack of access of smallholders to financing, only upland crops with relatively low up-front investments were considered. As cassava requires less financial investment and is suitable for acid

sulfate soil, results of the economic analysis are presented for cassava. The consideration of additional adoption barriers, in particular the high volatility of market prices, lack of access to high value markets and weak bargaining power due to limited storage capacities goes beyond the scope of the pre-feasibility study.

As proposed by MARD consultants, the adoption of the alternative livelihood models is fostered by the same four key activities: (i) implementation of clusters/cooperatives; (ii) establishment of demonstration sites; (iii) establishment/strengthening of extension system; (iv) implementation of irrigation and water/soil quality monitoring facilities; (iv) promotion of contract farming. These activities are in line with the “large field” (*canh dong mau lon*) program of the Vietnamese Government, encouraging farmers to organize as cooperatives and to establish long-term relationships with companies through contracts. These contracts would cover the supply of inputs, provision of extension advice by company agents, and the purchase of farmers’ produce at agreed prices. The program aims at facilitating productivity increases and reduce transaction costs, particularly for smallholders (Smith, 2013).

For the livelihood- related measures one-ha cash flow models were developed. Again, an implementation period of the activities and investments of 6 years is assumed. Average yields and farm-gate selling prices were available. All data refer to 2014 prices. Data on production costs and benefits are provide by DARD.

The incremental production of freshwater prawns was assumed to be absorbed by the Vietnamese market, and to a lesser extent by export markets, without affecting prices. The domestic demand for fisheries products, which contribute more than 30% of animal protein in the daily diet, is expected to increase by more than 6% per year as a result of population growth and increased living standards. A substantial share of current aquaculture production is being exported, and export demand is expected to remain strong. However, it would be crucial to understand these market risks better before any investment decision is made.

Non-quantified benefits derived from the transformation towards flood-based livelihood systems include further supporting ecosystem services, such as water cycling and provision of habitat and cultural services, such as recreation, aesthetic values, spiritual benefits and in-situ conservation of traditional rice practices.

Assuming the proposed interventions would reduce damages by 20 %, the project would yield an Internal Rate of Return of (IRR) of 2 % and a negative Net Present Value (NPV) of US\$ 28.910 million (at a 10 % discount rate). The project would therefore be unprofitable from an economic perspective. The key performance indicators are summarized in Table 8.

Cost/benefit item	Value
Total project costs (US\$) (6 years)	81.583 million
Total project benefits (US\$) (6 years)	24.519 million
Net financial benefits (US\$) (6 years)	-57.063 million
NPV (10%) (US\$) (30 years)	-28.910 million
IRR (%) (30 years)	2

Table 8: Results of the economic analysis

However, sensitivity analyses indicate that the IRR reacts significantly on changes in the effectiveness of the proposed interventions. Assuming the proposed interventions would lead to a reduction of damages by 50 and 60 percent, the project would yield an IRR of 13 and 17 percent respectively (see Figure 31).

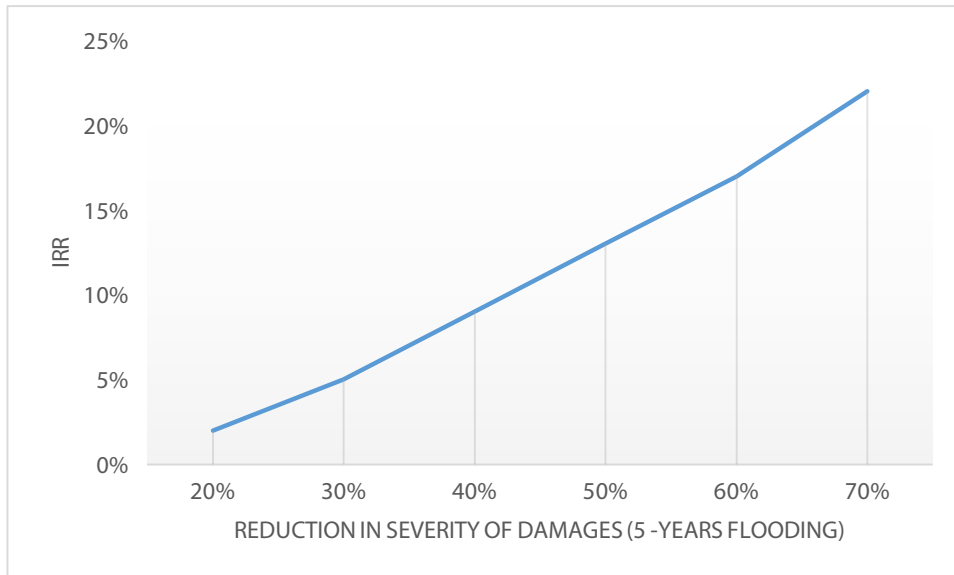


Figure 31: Sensitivity of IRR on changes in the effectiveness of the proposed investments.

Another aspect which was considered in the economic analysis is the impact of climate change, specifically sea level rise. The IRR is reacting quite sensitive to significant SLR. Assuming a SLR of 0.25, the IRR would increase to 6%. A SLR of 0.5m would lead to an IRR of 30%.

The results of the economic analysis reveal that the economic profitability of subproject is questionable at this point. Only under quite optimistic assumptions concerning the interventions effectiveness in reducing flood damages, reasonable IRR can be achieved. Therefore the economics of the project should be carefully considered as part of the further preparation process. The results indicate already that the selection of the type of measures, including their scale and locations will be key if profitability of the interventions is one objective.

6.3 Recommendations for full feasibility

Generally the planning of the floodway, and therefore the overall subproject 1, is at a rather early conceptual stage. However, the basic idea is innovative and follows the approach of holistic and sustainable flood risk management through the creation of retention areas. The retention areas and its structures could be managed in a way which would allow optimized land use and would enable an optimized discharge during flood events. Thus, the creation of the floodway and the respective investments are generally recommendable from a technical point of view. However, in the frame of the pre-feasibility study several major questions arose and need to be clarified within the full feasibility study. These issues are mainly related to the hydraulics of the floodway. These hydraulics determine the scale, location and design of almost all measures to be

implemented as part of the subproject.

In the following activities which would need to be conducted as part of the full feasibility study are specified.

6.3.1 Recommendations for structural measures for flood and water management

Hydro-numerical modeling

Currently, besides the preliminary assessment of the hydraulics of the floodway presented in this study, there are no hydrological calculations available. To perform the final evaluation of the floodway and to determine scale, design and location of structural measures, detailed hydro-numerical modeling is required. This modelling work would also allow for assessing the interaction between various measures in this complex floodway system. Simplified 1D models, as presented above, are not sufficient to quantify projected water levels and discharges and the respective parameters required in the design process. The financial evaluation of the proposed floodway very much depends on the effects that it has on downstream urban areas and the benefits due to the reduction of water levels in the surrounding areas. Thus, the model of the floodway must be embedded in a comprehensive model of the Hau River. The model of the floodway must consider the horizontal structure of the floodway. Flow especially in case of extreme events is not concentrated on one major channel but is distributed over a large area with changing bed roughness.

For the above reasons a two-dimensional model needs to be set-up, calibrated and verified. The geometric basis of the model is informed by the digital terrain model. Breaklines such as canals, dikes and embankments need to be identified and considered in detail. As controlling input parameters at least water levels in the canals, inflow through the rubber dam, the projected lowered dike crest at the east side of the floodway, and outflow into the West Sea must be considered. Different proposed structural measures, such as sluice gates or bridges, should be considered and assessed by the numerical model. Optimization of design of key measures can be obtained based on various model runs. Different computed scenarios will lead to the final layout of the floodway.

The main steps of the numerical modeling are:

- Setup of the geometrical model (based on the digital terrain model)
- Definition of breaklines (e.g. canals, embankments, dikes)
- Consideration of existing flood controlling elements, such as sluice gates, bridges and spillways
- Definition of boundary conditions (water levels, inflow, outflow, bottom friction, friction of vegetation and infrastructure)
- Calibration and validation of the model (using available data sets and synthesized time series)
- Definition of various scenarios (e.g. flood events, additional structural elements such as sluice gates, spillways)

- Computation of various model runs considering different layouts of the floodway

Based on the results (e.g. required discharge through a sluice gate) the dimensions of the required structure can be determined.

The main benefits of the numerical model are:

- Detailed understanding of the hydrology of the floodway
 - Including water levels and discharges for different flood events
 - At status quo (without floodway)
 - After installation of the floodway
 - Including the consideration of various alternatives and scenarios
- Variation of the projected structural measures to optimize the overall layout
- Consideration of the interaction of various elements
- Detailed design of the proposed infrastructure adapted to the computed hydrological situation

Especially the model setup and calibration is time-consuming and challenging. Due to the large model area and the complex interaction of various elements (e.g. dikes, embankments, canals, sluice gates) with very different flow resistances (friction losses) a certain simplification is required. However, the model must simulate real conditions as far as possible, and thus the simplification must not be too strong. It is estimated that the entire modeling would take 6-10 months with 1-2 experienced numerical modelers (engineers).

Assessment of floodway design alternatives

As discussed above, the water does not follow automatically, i.e. without additional structural measures into the floodway. The basic hydrological calculations in Section 6.1 indicate that a further extension, e.g. an additional arm to the North-East, might be able (i) to prevent that water flows in an uncontrolled manner from the Hau River in the area east of the floodway; and (ii) to reduce the flood risks in Long Xuyen City and Can Tho City. Effects should be further explored and alternatives assessed as part of the full feasibility study. The numerical modeling can provide relevant insights on this issue as well.

Assessment of rubber dam upgrade

Currently, the only controlled inflow into the floodway is the rubber dam at the Vinh Te Canal.

Although the dam is not included in the subproject technical options to increase the capacity of the rubber dam (for example by lowering the dam crest or widening the dam) should be explored. Without an upgrade of the dam, the project will not be revised. The model should run different scenarios assuming an update of the dam with an increased maximum discharge capacity.

Assessment of second water inflow

A second water inflow is proposed in the northeast of the floodway. The full feasibility should explore technical options for the design and whether the measure would be appropriate from a hydrological perspective. This second inflow is essential for the evaluation of the floodway, since it directly influences the reduction of the flood risk in the rural areas northeast of the floodway and in Long Xuyen City and Can Tho City. The full feasibility study should assess the discharge of water through the second inflow into the floodway and the respective effects in these areas. Since rainfall is a significant source of water input, the model must be couple with a rainfall-runoff module.

Determination of recurrence intervals / design flood events

The full feasibility needs to determine for what recurrence intervals and severity of flood events the floodway should be designed. This significantly changes the flow regime, the inundation depths and the dimensions and number of the flood protection measures. Volumes and water levels for extreme events with different recurrence intervals should be assessed. Again, the model will provide key insights here.

Determination of water levels in Kien Giang Province

The basic modeling conducted as part of this pre-feasibility assessment indicated that the water levels within the floodway reaching Kien Giang Province are expected to be low. At this point it can be assumed that only during extreme events with a recurrence interval of 50 years result into significant water volumes in this area. However, this should be verified as part of the full feasibility study and included in the modeling work.

6.3.2 Recommendations for Forestry-related Measures

Hydrological assessment of Tra Su Melaleuca Forest

The Tra Su Forest plays an important regulatory role for the water flow within the floodway. The forest can theoretically do both store water and thereby reduce the downstream flow or release water in dry periods. At the same time, it needs to be ensured that there are adequate water levels within the forest for an intact ecosystem and fire prevention. The proposed structural measures, such as dredging the canals, sluice gates, and bridges affect this complex system. Therefore appropriate water management is required. As a consequence, the hydrological system needs to be further assessed as part of the full feasibility study.

Assessment of environmental impacts of structural measures

The proposed structural measures are likely to affect the ecosystem of the Melaleuca forest. The same is probably true for the proposed intensification of ecotourism. Both effects need to be assessed, risks identified and mitigation measures defined. However, it is assumed that the ESMF of the World Bank foresees Environmental Impact Assessments as part of project implementation.

Assessment of community-based fire prevention

Community-based forest prevention might be an option which should be further explored as part of the full feasibility assessment. It should be assessed which communities could benefit and in which manner. The institutional set-up, including roles and responsibilities of various stakeholders, need to be defined.

6.3.3 Other Recommendations

Alternative livelihood models

The further specification of livelihood measures should be on priority of the full feasibility study. Additional farming systems need to be identified in order to facilitate the transition of livelihoods which are better adapted to the changing environmental conditions, which are exacerbated by climate change. For example, 3 rice crops do not seem to be profitable and sustainable any more. It is important to note that the identification of alternative farming systems should not be limited to agronomic/technical issues, but should explicitly consider: (i) existence of appropriate policy and strategy frameworks; (ii) identification of adoption barriers (e.g. access to technologies, access to inputs, access to finance); (iii) improvements of research – extension – farmer linkages; (iv) capacity development of extension agents; (v) capacity development of farmer groups/cooperatives; and (vi) market access/integration into value chain.

Economic and financial analysis

The preliminary economic analysis conducted as part of this study indicates that profitability of subproject 1 is not automatically guaranteed. Therefore, it should be a central element of the full feasibility. Particularly in case of subproject 1, it is recommended that the economic analysis is not done ex-post, i.e. after the actual design of the project has been finalized, but rather as an element integrated into the preparation process. By doing so the economic analysis can inform the selection of appropriate measures and the specification of their location and design. It should also be noted that for this analysis, in particular since measures have not specified yet, rough figures have been assumed regarding the costs. A further specification of the design of the floodway will also allow to include more accurate costs and benefits in the analysis. The recommendations and activities defined above are summarized in Table 9 below.

Activity	Main purpose/objective
Hydrology and structural measures for flood and water management	
Hydro-numerical modeling	Basic requirement for informing adequate concept and design of floodway (due to limited current understanding of hydrology in the project area)
Assessment of floodway design alternatives	Ensure discharge from flood-prone areas (LXQ, Long Xuyen City and Can Tho City) into floodway
Assessment of rubber dam upgrade	Assess impacts of upgrade on water flow and levels within floodway (currently only controlled inflow into floodway)

Activity	Main purpose/objective
Assessment of second water inflow	Explore technical options for the design and whether the measure would be appropriate from a hydrological perspective (key element for flood-prone areas in North East)
Determination of recurrence intervals / design flood events	Assess for what design flood events (severity of floods) the floodway will be designed for
Determination of water levels in Kien Giang Province	Further assess benefits for Kien Giang Province (concerning both flood management and secondary effects)
Forestry-related measures	
Hydrological assessment of Tra Su Melaleuca Forest	Ensure appropriate regulatory function of the forest
Assessment of environmental impacts of structural measures	Reduce and mitigate environmental risks of proposed structural measures and ecotourism
Assessment of community-based forest prevention	Inform appropriate institutional set-up and benefit sharing
Others	
Livelihood measures	Assessment of: (i) existence of appropriate policy and strategy frameworks; (ii) identification of adoption barriers; (iii) improvements of research – extension – farmer linkages; (iv) capacity development of extension agents; (v) capacity development of farmer groups/cooperatives; and (vi) market access/ integration into value chain
Economic and financial analysis	Inform concept and design of proposed floodway and ensure adequate ratio of costs and benefits

Table 9: Activities for Full Feasibility Study

7 CONCLUSIONS

The World Bank subproject 1 “Improving the Ability of Flood Drainage and Climate Change Adaptation for the Long Xuyen Quadrangle” is at a rather early conceptual stage. The basic idea of a floodway which serves as a retention area to reduce flood risks for surrounding areas while adapting land use within (and outside) the floodway accordingly is innovative and is generally appropriate from a technical perspective.

However, a better understanding of the basic hydraulics in the project area is a prerequisite for defining an appropriate design of the floodway. The current concept does not ensure that water from the surrounding flood-prone areas is discharged into floodway. Additional structural measures, such as a further extension of the floodway into the North-East, extension and upgrade of the canal system, and sluice gates, are required to allow the floodway to fulfill its role as a retention area. Further, due to the low gradients within the floodway, it cannot be assumed that the water will flow automatically, i.e. without any additional structural measures, in north-south direction and discharge into the East Sea. According to the preliminary assessment this water flow will not be ensured even during flood events, i.e. the water would accumulate within the floodway.

The benefits for Kien Giang Province, both in terms of flood management and secondary benefits (such as water storage) are currently less visible. Concerning flood management the only obvious benefit at this point will be due to the reduction of water levels in Vinh Te Canal. However, effects can be assumed to be rather small given the fact that flooding of the canal is not posing a significant risk on the province. Since it is expected that only extreme events would lead to significant arrival of fresh water at Kien Giang, investments into water storage does not seem to be profitable. However, this aspect should be further analyzed as part of the full feasibility study. These preliminary findings lead also to the conclusion that the project objective should focus on flood management and supporting the transformation of peoples livelihoods to enable them “living with floods” rather than focusing too much on other benefits, such as water storage. Only with an additional arm of the floodway in the Northeast significant reduction of flooding in Long Xuyen and Can Tho Cities can be achieved.

Another critical issue, which should influence the final approval of the subproject, is the rubber dam at Vinh Te Canal. Since this dam currently constitutes the only controlled inflow into the floodway, its impacts, needs to be taken into account when designing the project, even if it is not financed by the World Bank. A dam upgrade to increase water volumes discharged into floodway is considered key to effectively reduce flooding in the areas west of the floodway. If the upgrade is delayed or even rejected, the basic concept of the subproject would need to be revised.

The economic analysis indicates that it cannot be automatically assumed that the project would be attractive from an economic perspective. Scale, location, and design of structural measures for flood and water management need to be defined carefully to ensure a promising cost-benefit ratio.

Nevertheless, given the soundness of the basic idea and the potential of significantly reducing damages and losses in the surrounding areas, it is highly recommended that

the concept and design of the floodway is further assessed. The full feasibility study should put particular emphasis on the following aspects: (i) numerical hydrological modeling to inform the basic concept and design of the floodway; (ii) assessment of floodway design alternatives, e.g. an additional branch to the North-East, to ensure sufficient discharge into the floodway; (iii) assessment of rubber dam upgrade (although it is not supposed to be financed by the World Bank), since as currently the only controlled inflow has significant impact on water levels; (iv) assessment of a second controlled water inflow to release surrounding areas in North East; (v) determination of recurrence intervals / design flood events for which the floodway will be designed; (vi) determination of water levels in Kien Giang (see above); (vii) hydrological assessment of Tra Su Melaleuca Forest to ensure its regulatory function; (viii) assessment of co-management arrangements for communities in Tra Su Forest (e.g. fire prevention); (ix) specification of support for transformation to alternative livelihoods; and (x) economic and financial analysis for informing adequate design and appropriate cost-benefit ratio. While the list of recommended activities to be conducted as part of the full feasibility it should be noted that most analyses and assessment can be conducted based on the proposed numerical hydrological model. The scope and timeframe to conduct these required steps seem to be adequate given the technical complexity and political sensitivity of the proposed subproject.

8 REFERENCES

- Ahmed, N., Bunting, S.W., Rahman, S., & Garforth, C.J. (2013). Community-based climate change adaptation strategies for integrated prawn-fish-rice farming in Bangladesh to promote social-ecological resilience, *Reviews in Aquaculture*, 6(1).
- AN, T.D., TSUJIMURA, M., PHU, V.L.; KAWACHI, A., HA, D.T. (2014): Chemical characteristics of surface water and groundwater in coastal watershed, Mekong Delta Vietnam: p. 731,716, Kyoto University.
- Beverley R. Clarkson, Anne-Gaelle E. Ausseil, Philippe Gerbeaux. 2015. WETLAND ECOSYSTEM SERVICES. Landcare Research, New Zealand.
- Brunier, G., Anthony, E. J., Goichot, M., Provansal, M., Dussouillez, P. (2014): Recent morphological changes in the Mekong and Bassac river channels, Mekong delta: The marked impact of river-bed mining and implications for delta destabilization: p. 178, 182ff, Marseille.
- Carter, V. 1998. Technical Aspects of Wetlands: Wetland Hydrology, Water Quality, and Associated Functions. National Water Summary on Wetland Resources. United States Geological Survey Water Supply Paper 2425.
- DHI and HDR (2015): Study on the Impacts of Mainstream Hydropower on the Mekong River. Final Report prepared for the Ministry of Natural Resources and Environment.
- Dinh et al. (2012): Climate change impact on flood hazard, vulnerability and risk of the Long Xuyen Quadrangle in the Mekong Delta in *International Journal of River Basin Management*: p. 103.
- Erwin K (2009) Wetlands and global climate change: the role of wetland restoration in a changing world. *Wetlands Ecol Manag* 17(1):71–84. doi:10.1007/s11273-008-9119-1
- GIZ, (2014). An Giang water management and adaptation to climate change: economic scoping study, available: http://daln.gov.vn/r/files//ICMP-CCCEP/tai_lieu/Document/An-Giang/Cost-benefit-analysis---Floating-Rice.pdf.
- ICMP (2015): Supporting Scaling Up of the Integrated Coastal Management Program (ICMP) in the Mekong Delta, Vietnam. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, June 2015.
- Irving AD, Connell SD, Russell BD (2011) Restoring coastal plants to improve global carbon storage: reaping what we sow. *PLoS One* 6(3):e18311.
- Joffre, O. & Bosma, R. (2009). Typology of shrimp farming in Bac Lieu Province, Mekong delta, using multivariate statistics, *Agriculture Ecosystems & Environment*, available: <https://www.researchgate.net/publication/222417908>.
- Lanh, D. T. et al (2005) Study on integrated water resources utility and environmental flow aims to protect the ecology and the sustainable development of the Mekong Delta (in Vietnamese). WRSI Danida project.
- MRC [Mekong River Commission] (2005) Overview of the hydrology of the Mekong Basin. Mekong River Commission, Vientiane, 73 pp.
- National Oceanic and Atmospheric Administration (NOAA), 2014. Carbon Sequestration 101

- Nguyen, K.V. (2015). Comparing the costs and benefits of floating rice-based and intensive rice-based farming systems in the Mekong delta, available: <https://www.researchgate.net/publication/283655293>.
- Nguyen, Q. M. (2000): Mekong delta floods in the past and present (online). Available: <http://info.mrcmekong.org/assets/midocs/0001642-environment-mekong-delta-floods-in-the-past-and-present.pdf> (20.4.2016).
- Nguyen, X. H. (2006): Report on flood management and mitigation in the Mekong Delta: p. 3, 5f, 7f, Ho Chi Minh City.
- Roberts, J., Young B and Marston F., 2000. 'Estimating the water requirements for plants of floodplain wetlands: a guide'. Occasional Paper 04/00.
- SIWRR (2010) The report on the monitoring of the Mekong Delta 2010. The program of the fundamental survey of 2010
- Smith, W. (2013). Agriculture in the central Mekong delta: Opportunities for donor business en-gagement, ODI report, available: <https://www.odi.org/sites/odi.org.uk/files/odi-assets/publications-opinion-files/9060.pdf>.
- TEEB 2013. The economics of ecosystems and biodiversity for water and wetlands. London and Brussels, Institute for European Environmental Policy (IEEP) & Ramsar Secretariat. 78 p.
- Thao, D. N. et al. (2014): Coastal Disasters and Climate Change in Vietnam. Elsevier. ISBN: 978-0-12-800007-6. Japan.
- Thu, P. M. (2006): Hau river estuary, Mekong River Delta (online). Available: <http://nest.su.se/mnode/Asia/Vietnam/hau/haubud.htm> (11.4.2016).
- Tonneijck, M., Van Halsema, G., Dirks, F., & Fiselier, J. (2016). Mekong Delta Integrated Climate Resilience and Sustainable Livelihoods Project
- Tran, D.B., Dargusch, P., Moss, P., Hoang, T.V., 2015, . An assessment of the carbon stocks and sodicity tolerance of disturbed Melaleuca forests in Southern Vietnam
- Tri V. K., Nghia, P. D., Kiem, L. V. (2006) Forecasting the influences of upstream flow on the threshold of salinity intrusion in the Mekong Delta, Vietnam. In: Proceedings of the second international symposium on sustainable development in the Mekong River Basin. Phnom Penh, 16–18 Sept 2006
- Tri, V. K. (2012): Hydrology and Hydraulic Infrastructure Systems in the Mekong Delta, Vietnam. In: Renaud, F.G., Kuenzer, C. (Eds.): The Mekong Delta System - Interdisciplinary Analyses of a River Delta. Springer.
- Vietnam-Netherlands Delta Masterplan Project (2011): Mekong Delta, water resources assessment studies: p. 8, 15 (online). Available: <http://nguyenthanhmy.com/courses/GOOD-Mekong-Water-Resource-2011.pdf> (11.4.2016).
- VO, T. D. & HUYNH, V. K. (2015): Household demand and supply for clean groundwater in the Mekong delta, Vietnam: p. 3ff, In: Renewables: Wind, water, solar.
- Wade, D., J. Ewel, and R. Hofstetter. 1980. Fire in south Florida ecosystems. USDA Forest Service, General Technical Report SE-17. Southeastern Forest Experiment Station, Asheville, NC. 125 p

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