RESEARCH REPORT

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Adaptation To Sea Level Rise In The Vietnamese Mekong River Delta: Should A Sea Dike Be Built?

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Vietnam is one of the five countries in the world that will be most seriously affected by sea level rises as a result of global climate change. Now a new EEPSEA study has looked at how the country should protect itself from this steadily developing challenge. To do this, the study assessed five different concrete dyke options for the development of Vietnam's sea dyke protection system.

The study is the work of Vo Thanh Danh from the School of Economic and Business Administration, Can Tho University, Can Tho City, Vietnam. It finds that, although a concrete sea dyke system would be more expensive than the existing sea dyke program, such a system would bring significant economic benefits and protect large areas of agricultural land from storms, flooding and salinity. The study makes specific recommendations for the size of dykes that should be built and outlines how the existing national sea dyke upgrading program should be revised.

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All the opinions, findings, conclusions, and recommendations expressed in this report are those of the author and do not necessarily reflect the views of EEPSEA. The author alone is responsible for any errors in this paper.

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B/C	Benefit-Cost Ratio
CBA	Cost-Benefit Analysis
CCFSC	Central Committee for Flood and Storm Control
DCA	Damage Cost Avoided
ENPV	Expected Net Present Value
GIS	Geography Information System
IRR	Internal Rate of Return
MARD	Ministry of Agriculture and Rural Development
MONRE	Ministry of Natural Resources and Environment
NCHMF	National Center for Hydrometeorological Forecasting
SLR	Sea Level Rise
SIWRP	Southern Institute of Water Resources Planning
VMD	Vietnamese Mekong Delta

ADAPTATION TO SEA LEVEL RISE IN THE VIETNAMESE MEKONG RIVER DELTA: SHOULD A SEA DIKE BE BUILT?

Vo Thanh Danh

EXECUTIVE SUMMARY

Vietnam is one of five countries in the world most likely to be seriously affected by the impact of global climate change and any consequent rises in sea level (SLR). The boundaries of the Vietnamese Mekong Delta (VMD) are marked by the sea and so this area faces a risk of SLR due to global climate change. The necessity of investing in creating a concrete sea dike system in the VMD is still the subject of debate. This study was conducted in Tra Vinh province, which borders the South East Asia Sea and so represents an area of the VMD that would be typically affected by an increase in SLR. The purpose of this study is to conduct an economic valuation of creating a concrete sea dike system as an adaptation measure to counter the impacts of a rise in sea level. A risk cost-benefit analysis (CBA) framework was used. It uses an ex-ante approach with risk considerations for storms, floods, and salinity by specifying probability distribution functions in a simulation process, in order to incorporate these risk factors into the analysis. The study developed five dike options associated with three hypotheses of the scale of different sea dike systems: option 1 represented a dike that could withstand the severity of a storm that occurs once every 20 years, option 2 and option 3 represented a dike that could withstand the severity of a storm that occurs once every 50 years, and option 4 and option 5 represented a dike that could withstand the severity of a storm that occurs once every hundred years. The results showed that the benefits of storms and floods avoided dominated the dike options. The benefit of salinity avoided was also valuable, with annual rice and aquaculture productivity losses avoided of USD 331.25 per ha and USD 915 per ha, respectively. Based on the NPV decision rule, the results indicated that dike options should be recommended as an appropriate adaptation measure for the VMD's particular geographic situation. The larger in scale the dike system options were, the higher the ENPVs were. Of the dike alternatives applicable to the VMD, initially small-scale dikes that can be subsequently heightened should be a priority choice if the impacts of a SLR focus mainly on storms, floods, and salinity factors. The sensitivity analyses showed that the ENPVs of dike options were very sensitive with changes in discount rate but were not sensitive with increases in salinized areas at all. The findings provide evidence to support the necessity of the construction of a concrete sea dike system in the Vietnamese Mekong Delta, given the context of global climate change.

ADAPTATION TO SEA LEVEL IN THE VIETNAMESE MEKONG RIVER DELTA: SHOULD A SEA DIKE BE BUILT?

Vo Thanh Danh

1.0 INTRODUCTION

1.1. Statement of Problem

Vietnam is one of five countries that may be the most seriously affected by global climate change and a consequent rise in sea level (SLR). If the sea level rises by between 0.2 and 0.6 meters, 100-200 thousand ha of Vietnamese plains will be submerged. A one-meter rise would result in 0.3 to 0.5 million ha of the Red River Delta being submerged and 90% of the Mekong Delta would be flooded. The SLR scenarios released by the Ministry of Natural Resources and Environment (MONRE) in 2009 were constructed with two levels of environmental emergency in mind – a high level and a medium level. The results showed that compared to 1980-1999, on average, the SLR would measure between 30 cm and 33 cm, and between 74 cm and 100 cm by the middle and at the end of this century, respectively. Table 1 presents SLR scenarios for Vietnam.

Table 1: Forecasted sea level rise in Vietnam, 2020-2100, compared to 1980-1999

Scenario	**Time**								
	2020	**2030**	**2040**	**2050**	**2060**	**2070**	**2080**	**2090**	**2100**
High	12	17	24	33 cm	44	57	71	86	100 cm
Medium	12	17	23	30 cm	37	46	54	64	74 cm

Source: MONRE (2009)

Mekong Delta provinces will be seriously affected if the sea level rises by one meter: Ben Tre would have 50.1% of its area flooded; Long An would suffer 49.4% flooding; Tra Vinh would experience 45.7% flooding; Soc Trang would lose 43.7% of its area to flooding; Ho Chi Minh City would suffer 43% flooding; Vinh Long would see flooding of 39.7%; Bac Lieu would lose 38.9% of its land to flooding; Tien Giang would lose 32.7%; Kien Giang would lose 28.2%; and Can Tho would lose 24.7% of its land area to flooding. If rivers rise by 0.5-1 meter, the waters will reach the height of the current dike system. According to the SLR scenarios, the SLR in the Vietnamese Mekong Delta (VMD) will reach levels of between 0.69 meter and 1 meter by 2100. During low tide, inundated areas would fall below water levels of 0.5 meter, 0.5-1 meter, and 1-1.5 meters: remaining above 1.5 meter would be 215,000 ha, 1,944,000 ha, 1,413,000 ha, and 288,000 ha of land respectively (see Appendix 1). According to MONRE's projected scenarios, depending on whether an area has, or does not have, the protection of the appropriate infrastructure, inundated areas would suffer from different water levels. Areas with no protective infrastructure would be inundated to a water level of 1-1.5 meters and in scenario 1 a water level of above 1.5 meters would inundate 2,196,000 ha and 1,666,000 ha of land respectively. The same water levels under scenario 2 would inundate 1,499,000 ha and 2,363,000 ha of land respectively. During high tide, the inundated areas would correspond to water levels of 1.5-2.5 meters and 2.5-≤3.0 meters, leaving an inundated area of 747,000 ha and 278,000 ha respectively (see Appendix 2). In the case of land without the benefit of protective infrastructure, areas corresponding to water levels of 1.5-2.5 meters and 2.5-≤3.0 meters (scenario 1), would leave 1,566,000 ha and 365,000 ha of land respectively inundated. Under scenario 2, 2,306,000 ha and 425,000 ha of land respectively would be inundated. Areas that benefit from protective infrastructure, inundated to the water levels outlined in scenario 1, would leave 1,684,000 ha and 365,000 ha respectively of inundated land. Under scenario 2, 2,472,000 ha and 425,000 ha respectively would be inundated. In addition, there is the possibility that the tidal peak under scenario 1 and scenario 2 could be 1.7-2.2 meters and 2-2.5 meters respectively. In this case, the VMD would be lower than the tidal peak by 0.2-0.7 meter (scenario 1) and by 0.5-1 meter (scenario 2). This means that coastal areas would be inundated by the SLR. Futhermore, during the flood season the situation could become more serious. The water level in flooded areas would increase by 0.2-0.5 meter (scenario 1) and by 0.3-0.7 meter (scenario 2). If a high tide were to be combined with flooding, the possible levels of inundation in both the SLR scenarios would be even greater.

According to the MONRE's forecast, due to the impact of a global rise in sea levels, 15,000-20,000 km^2 of the VMD's coastal areas would be inundated – nine of its 13 provinces would be completely below water. The current sea dike system in coastal areas cannot effectively protect people and the land when storms and high tides occur at the same time. The construction of a sea dike has to be considered as a potential solution to a rise in sea level .

The dike system in the VMD is 1,400 km long, with nearly 620 km of sea dikes. Most of these dikes were constructed many years ago. The height of the sea dikes in the VMD is about 3.5-4 meters in the east and 2.5-3 meters in the west. The sea dike system in the VMD has a unique characteristic – the sea dikes were created in conjunction with planting mangrove forests, to further protect the dike. Figure 1 shows the extent of the sea dike system in Vietnam. The current sea dike system in the VMD is made out of earth, set into earth. These dikes are not able to cope with the level-eight storms that come from the South East Sea during the flood season. Meanwhile, some VMD provinces have no sea dikes or not enough sea dikes to prevent seawater intrusion. For example, in Ca Mau province, along a coastline of 254 km there is only 93 km of earth-built sea dikes in the west and there are no sea dikes in the east. Every year sea dikes are destroyed by tides, floods, and storms. The repair and maintenance of sea dikes requires a great deal of money, which is supplied by the national dike management budget.

In May 2009 the government issued Decree No. 667/QĐ-TTg regarding sea dike maintenance and upgrading. The implementation program is divided into three periods: 2009-2012, 2013-2016, and 2017-2020. From 2009-2012 mangrove forests will be planted parallel to the sea dike system. From 2013-2016 the sea dike system will be upgraded and developed alongside the road network. From 2017-2020 a sluice system will be constructed so that the sea dike system can be operated for the purposes of both adapting to a SLR and for transportation. However, up to the year 2020 the sea dike system from the center of Vietnam to the south will still be an earth-built one. The main objective of the program is to establish the sea dike system in preparation for the impacts of a rise in sea level. The total budget for the program is 19.5 thousand billion VND (more than 1 billion USD).

In the next few decades the national transportation development plan will invest in a coastal road system parallel to the planned sea dike network. The coastal road system will incorporate current roads and build new ones as well. It will be connected to the sea dike network in order to facilitate emergency defenses against natural disasters and for national security. The project will be implemented in two phases. In the first phase, from 2010-2020, 892 km of coastal roads will be built or upgraded at a cost of 16 thousand billion VND (850 million USD). In the second phase, from 2021-2030, 1,058 km of new coastal roads will be built, at a cost of 12.11 thousand billion VND (640 million USD). In the first phase, coastal roads in key economic regions and 15 coastal economic zones will be built and upgraded.

The necessity of investing in a concrete sea dike system in the VMD is the subject of an ongoing policy debate in Vietnam. Some think that the government should not build a cement sea dike system for the VMD. The reason given for such a view is that a concrete sea dike system will need billions of USD of investment and will not be effective. An alternative solution is proposed, which combines policies of moving people in the affected areas during a natural disaster and adapting life in coastal areas (by increasing collective action and public awareness of the measures necessary for living with SLR). On the other hand, proponents of the sea dike system think that the VMD needs a large sea dike system, like the Netherlands, because the VMD is surrounded by sea and it faces a high risk of SLR due to global climate change. The national budget would not be sufficient for such a big investment. In summary, there are two different points of view: one is an adaptation policy, the other is a coping policy. The question of whether a sea dike system needs to exist or not needs to be answered. The VMD's agriculture-based economy would certainly be affected by a rise in sea level, and the region has to prepare for future changes. This study proposes an economic valuation of a concrete sea dike system as an adaptation to the impacts of a rise in sea level. The study uses a risk cost-benefit analysis (CBA) framework.

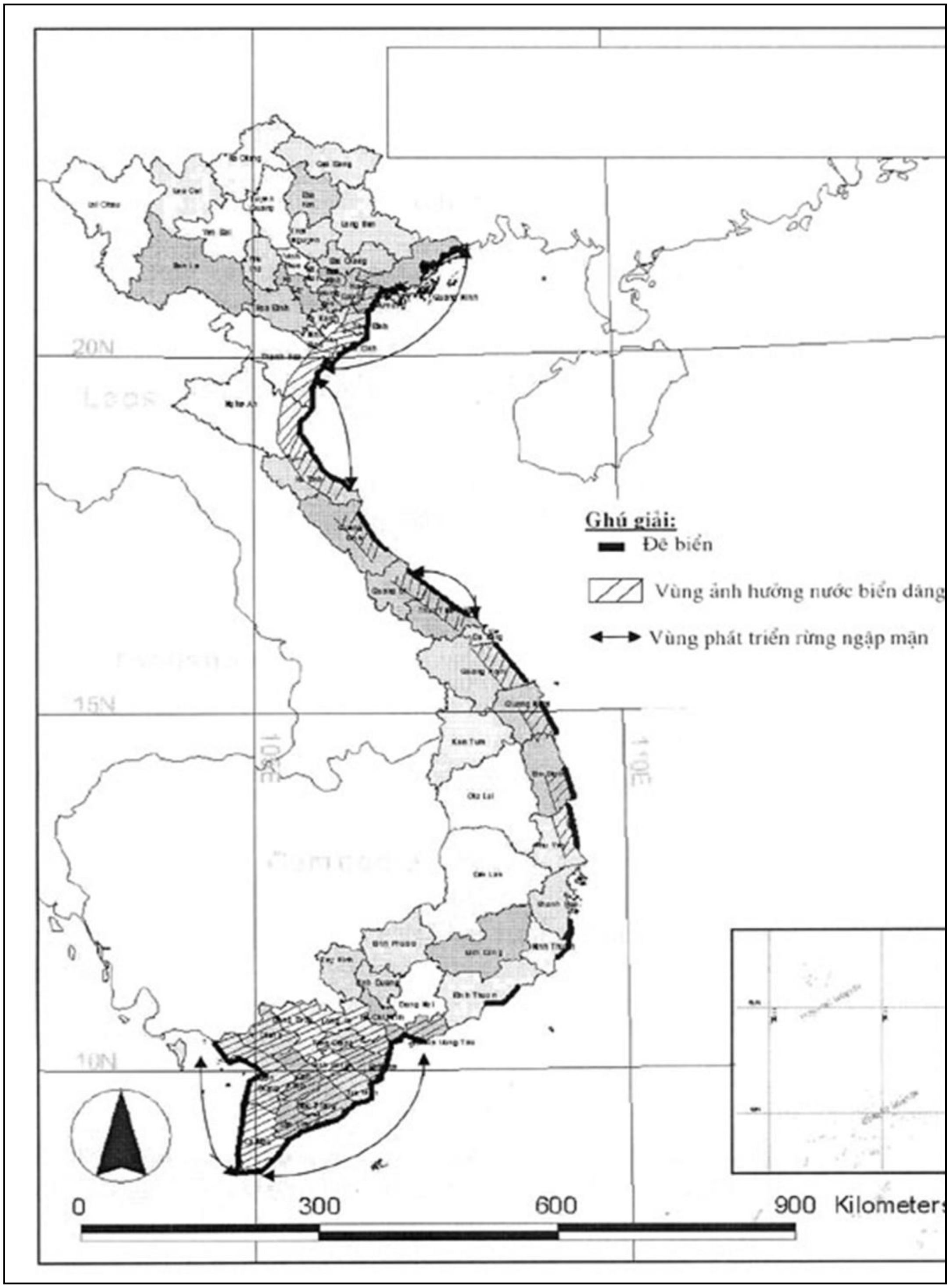


Figure 1: A map of the sea dike system in Vietnam

1.2 Research Questions

The following research questions were asked.

- What is the most appropriate analytical framework of the CBA assessment of the sea dike system applicable to the VMD?
- What forms could the sea dikes take?
- What are the costs and benefits of a sea dike system in the VMD?
- What is the best sea dike option?

1.3 Research Objectives

The overall objective of the study was to assess the viability of sea dikes as a structural response to a rise in sea level caused by climate change, and also to investigate the acceptability of such a project in the Vietnamese Mekong Delta. The specific objectives were:

1. to develop a risk assessment and cost benefit analysis framework specific to SLR in the VMD;
2. to assess the viability of building sea dikes as an infrastructure response to the impacts of climate change; and
3. to identify the levels of risk, cost, and benefit associated with the sea dike option.

1.4 The Current Sea Dike System in the Mekong Delta

South Vietnam has 1,100 km of seashore, 750 km to the east and 350 km to the west. The sea dike system and salinity control dam system at the rivermouth acts as a fence to protect the land for agricultural activities such as rice planting, fruit growing, and aquaculture, etc. The main function of the sea dike system is to prevent seawater intrusion. The function of the salinity control dam system is to prevent the intrusion of salinity and to desalt the rice fields. The sea dike system is mostly constructed out of earth and, although they are constantly maintained and repaired, these dikes are very weak in the face of natural disasters such as storms and high tides. The annual cost of maintaining the VMD’s existing sea dike system requires a large central budget and a big share of local budgets. Table 2 shows sea dike maintenance costs for 2005-2009.

In recent years mainland seawater intrusion has occurred on a large scale in Ca Mau, Soc Trang, Ben Tre, and Tra Vinh provinces. During the 2010 dry season salinity intrusion in the VMD was very serious. Upgrading the sea dike system is considered an appropriate measure to cope with these natural disasters. Table 3 indicates the demand for sea dike systems in the provinces of the VMD. A total of 1,469 km of new dikes are needed, 438 km of sea dikes and 1,031 of rivermouth dikes. Provinces that need a significant number of new sea dikes are Kien Giang, Ca Mau, and Tra Vinh, which need 126 km, 96 km, and 65 km respectively. The total area protected by the dike system is 494,000 km^2, home to around 1.5 million people. A unique characteristic of the sea dike and rivermouth dike systems in the VMD is the existing mangrove forest that protects the dike systems – this is the difference between the VMD's sea dike system and others in Vietnam.

Table 2: Maintenance costs of the existing sea dike system in the Mekong Delta (2005-2009)

Province	Maintenance Costs (million VND)
Long An	54,433
Tien Giang	86,000
Ben Tre	396,790
Tra Vinh	310,000
Soc Trang	12,720
Bac Lieu	264,000
Ca Mau	434,000
Kien Giang	235,000
Total	1,792,943 (USD 100,000,000)

Source: Southern Institute of Water Resources Planning (SIWRP) (2009)

Table 3: Projected sea dike and rivermouth dike systems in the Mekong Delta

Item	Province								
	Unit	Total	Tien Giang	Ben Tre	Tra Vinh	Soc Trang	Bac Lieu	Ca Mau	Kien Giang
Total length	km	1469	21	160	147	618	81	278	164
In which: – Sea dike	km	438	21	30	65	50	50	96	126
– Rivermouth dike	km	1031	-	130	82	568	31	182	38
Natural area protected	10^3ha	494	23	64	29	152	53	124	49
Total population protected	10^3 persons	1482	186	175	85	480	152	298	106

Source: Hoi (1999)

Although natural disasters such as storms rarely attack the VMD, the consequences when storms do occur are severe. Storms usually create a high tide and salinity intrusion takes place. A high tide jeopardizes the VMD's sea dike system, particularly during the storm season from July to November when high tides can cause the seawater level to rise by between 0.2 and 0.4 meters. For example, in 1994 the high tide caused the seawater level to rise by 0.6 meters. Consequently, the sea dike system in Vinh Chau District, Soc Trang province, was destroyed and seawater intruded into hundreds of ha, leaving rice fields salinated for a long time. In January 2008, at Hiep Thanh commune, in the Duyen Hai district of Tra Vinh province, thanks to a combination of a high tide and the monsoon, a 120-meter-long earth-built sea dike with a width of between 4 and 5 meters succumbed to a landslide. As a consequence seawater encroached on an area of nearly 1,000 ha of agricultural land. In 2008, in order to protect the land and the lives of thousands of people, the local government spent 18.5 billion VND (more than 1 million USD) on repairing the 560-meter-long earth-built sea dike.

1.5. Master Plan for the Sea Dike System in the Mekong Delta

The sea dike system plays an important role in ensuring the sustainable development of coastal areas. Its main functions are to prevent seawater intrusion and to protect agricultural production systems such as rice fields and aquaculture. The sea dike system from the center of the country to the south (Quang Ngai to Kien Giang) has been established and developed over time with various advantages and disadvantages. The sea dikes and sluice dikes help to mitigate the impacts of salinity, help to protect the land, and help to maintain cropping systems. The routes of the sea dikes are also used jointly as a road network in coastal areas. However, the current sea dike system is not integrated. The technical standards of various sea dikes are very different and have not been regulated. Most of the sea dikes are built out of earth and their quality is low and longevity limited. The management of the sea dike system is usually organized by the local authorities and their maintenance budget is finite and cannot always meet the needs of annual maintenance services. In addition, many sea dikes and sluice dikes are of poor quality and cannot withstand high tides and aggressive storms. Finally, the sea dike system does not cover all of the coastal areas.

On 27 May 2009 the Vietnamese Prime Minister announced a national program to upgrade the current sea dike system from central Vietnam to the south (Quang Ngai to Kien Giang). The program is to be implemented up to 2020. From 2009-2012 the sea dike system will be extended to the whole of the VMD, mainly with lines of earth-built sea dikes. Mangrove forests will be planted to protect these dikes. From 2013-2016 the sea dike system will be permanently upgraded. From 2017-2020 bridges and sluices will be constructed and the main sea dikes will also be used as roads.

In 2009 the Southern Institute of Water Resources Planning (SIWRP) released a sea dike system master plan for the VMD. The goal of the program is to cope with the impacts of rises in sea level and to prepare for living with climate change in the long term. Specific objectives include: (1) upgrading the current lines of sea dikes and sluice dikes; (2) creating and constructing complementary infrastructure, such as planting mangrove forests to protect sea dikes, building new dikes etc.; and (3) developing the main lines of sea dikes into a national road system along the coast. According to the master plan, the VMD sea dike system is 1,359 km long, including 618 km of sea dikes and 741 km of river dikes. There are 21 dike lines in total and, at 129 km, Tra Vinh’s dike line is the longest. The average length of a river dike along a big river is 30 km. Small rivers have dikes around 10-15 km in length. Most of the western sea dike lines are situated 200-500 meters from the seashore, and the eastern ones are 500-2,000 meters from the seashore. The sea dike line in the area of Bay Hap-Ganh Hao, Ca Mau province, is inside the area of the mainland. The total budget for the upgrading program is about VND 2,310 billion (125 million USD), with VND 1,422 billion (77 million USD) earmarked for sea dike lines and VND 888 billion earmarked for river dikes.

The master plan includes 280 flood control dams of different scales and seven large bridges along the dike lines. The sea dike system will surround more than 1.24

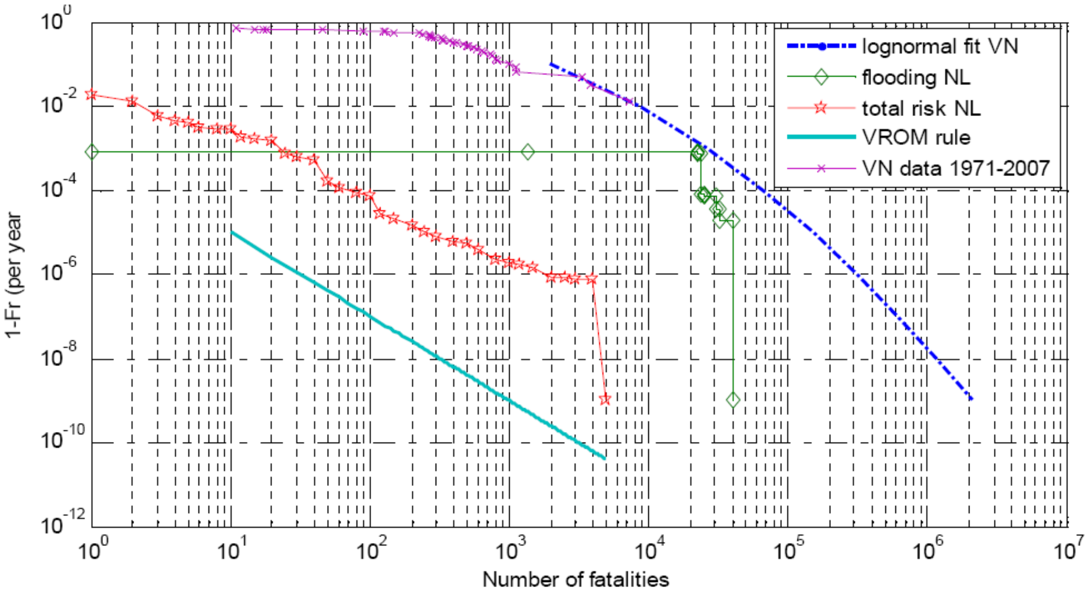
million ha of agricultural land and protect the 4.4 million inhabitants of the region. The principles of designing the system are that the sea dikes should be built alongside the existing lines and should be part of the socio-economic master plan of the VMD. The sea dike construction should be combined with the development of a new road system in the coastal region. Designing the sea dike lines will depend on the movement of the sea. Specifically, for areas where the level of the land has been raised thanks to soil filling, the new dike should be placed at least 200 meters away from the existing dike, (as per the Dike Law) to protect the body of the new dike. In areas where the sea has already invaded the land and soil erosion has taken place, a parallel sea dike system with an additional/complementary sea dike line should be designed. An additional system of stone embankments and mangrove forest should be built to protect the lines of sea dikes.

The technical requirements of the sea dike system are based on whether the projected SLR has been considered. In the short-term, not taking into account the impacts of SLR: in agricultural areas the sea dike system should be designed to cope with high tides (with a probability of 5%) and level-nine winds; in inhabited areas the sea dike system should be designed for high tides (with a probability of 5%) and to withstand level-12 winds; and in areas where sea dikes are combined with the road system, they should reach the technical standards of TCVN4054-2005, as issued by the Ministry of Transport. In the long-term, taking into consideration the impacts of SLR, the height of the sea dikes should be increased. Based on these technical requirements, the VMD's sea dike system should, according to the Master Plan, have the following characteristics:

- Sea dike line from Ba Ria Vung Tau to Ca Mau: height 3.5-4 meters, width 7.5 meters, in-land roof 2 meters, sea-house roof 3 meters, loading capacity of H13.
- Sea dike line from Ca Mau to Ha Tien: height 2-2.5 meters, width 7.5 meters, in-land roof 2 meters, sea-house roof 3 meters, loading capacity of H13.

1.6. Safety Assessment of Existing Sea Dikes in Vietnam

Most of the sea dike systems in Vietnam run in single lines, not in tandem. These dikes consist of a sand or clay body and have revetments on the seaward side. The dikes have relatively steep slopes with a height of between 3.5 and 4 meters. Cong et al. (2008) showed that the height of the sea dike system in Vietnam was unsafe. Most of these sea dikes were based on loads with a return period of 20 years or less (a 'return period' being an estimate of how often an event, such as a storm of particular force, will happen). These return periods are small compared to the standard return period in the Netherlands of 1,000 to 10,000 years (see Figure 2 for a comparison). Moreover, because most of these dikes were poorly constructed they fail more frequently. The current sea dike system in Nam Dinh province has been tested using different scenarios to evaluate its safety. Using the Monte Carlo simulation method, the failure probability of the whole sea dike system was analyzed. The results showed that the failure of the sea dike at Nam Dinh was mainly due to waves overtopping the dike. It was clear that the existing sea dike system was unsafe and the probability of failure was about 0.78 times every year – the dike was built and designed with the assumption that it would fail once every 20 years. In order to come up with the current existing safety standard of 1/20 years (probability of 5%), the sea dikes should be increased in height to about 6.8 meters.



Note: risk values in the Netherlands were stimulated in the model.
Source: Cong et al. (2008)
Figure 2: Comparison of sea dike system risks, Vietnam and the Netherlands

1.7 Study Location

Geographically, the VMD is a flat delta with an average height of between 0.7 and 1.2 meters, apart from the northern area of An Giang province. The VMD has a population of more than 18 million people. It has an area of more than 4 million ha, 2.7 million ha of which is agricultural land. Annually, flooding inundates 2 million ha and affects more than 11 million people. The terrain has limitations, including: (1) the inundation of between 1.4 and 1.9 million ha of land in upstream areas; (2) the salination of between 1.2 and 1.6 million ha of land along coastal areas; (3) the water flow upstream has been affected by climate change; (4) seasonal changes in temperature and precipitation; and (5) the impacts of SLR. Sea level rise is a serious threat to the VMD. Areas not usually permanently inundated by seawater have become so and are rendered unsuitable for agricultural production. Moreover, approximately 1.7 million ha of the region have become salinized. The five million people living in these areas cope with the salinity problem year after year. The salinized areas are in coastal provinces, including all of the following provinces: Ben Tre, Tra Vinh, Bac Lieu, and Ca Mau, a large part of Soc Trang and Kien Giang, half of Long An and Tien Giang, a small part of Hau Giang and Vinh Long, and a very small part of An Giang province. In recent years, the salinity problem has become more serious during the dry season.

The study area was Tra Vinh province (Figure 3). Tra Vinh province is located at the south-east end of the VMD, between Tien river (Co Chien river) and Hau river. The climate of the province is tropical monsoon. The eastern border of the province sits on the South China Sea. The province's natural area measures 223,000 ha and the seashore has a length of 65 km. The entire coastal area of Tra Vinh is affected by high tides and seawater intrusion. Salinity and seawater intrusion begins during the dry season, starting in December and continuing to April/June. In the dry season at Co Chien station, a distance of 35 km from the sea, salt measures 10% (the salt level of seawater is 30%).

More than 90% of the total agricultural land area of 90,000 ha suffers from seawater intrusion. Salinity usually begins in December at Hung My, at the Co Chien river and Tra Kha, on the Hau river. The salinity peaks in April and ends in June. Tra Vinh is split into areas of differing salinity (where salt levels are more than 4%).

- Salinized all year round: area occupies 17.7% of the total agricultural land along coastal areas such as Long Khanh, Long Vinh, Dong Hai, Dan Thanh, Truong Long Hoa communes in Duyen Hai district.
- Salinized bi-annually (January-June): area occupies 25.8% of total agricultural land and includes the other communes of Duyen Hai district, the communes of Cau Ngang district, Don Chau, Don Xuan, Dinh An, and Dai An communes of Tra Cu district, and Long Hoa and Hoa Minh communes of Chau Thanh district.
- Three-month salinization period (March-May): this affects 16.6% of the agricultural land at Cau Ngang and Chau Thanh, which are part of Tieu Can and Tra Cu districts respectively.
- Two-month salinization period (April-May): affects 1.8% of agricultural land in Cau Ngang, Tra Cu, and Tieu Can districts, a part of Chau Thanh and Cau Ke districts and Tra Vinh city.
- Abnormal two-month salinization period: this affects 15.1% of the total agricultural land in parts of Cang Long and Cau Ke districts.
- Year-round salinity-free areas: scattered through Cang Long and Cau Ke districts.

Data collection was conducted in Cau Ngang, Duyen Hai, Cang Long, and Cau Ke districts of Tra Vinh province. Cau Ngang and Duyen Hai districts are in coastal areas and Cang Long and Cau Ke are not. These districts were chosen to assess the impact of salinity and seawater intrusion. With the assumption that rice production in Tra Vinh has homogeneous characteristics, the production function with the salinity impact dummy variable as described in section 2.3.2 allows measurement of marginal productivity loss due to salinity. A sample of 115 rice farmers from Cau Ngang and Duyen Hai districts was taken. These areas are affected by salinity. A sample of 118 rice farmers was taken from parts of Cang Long and Cau Ke districts. These areas are not affected by salinity.

Figure 3: Map of study sites, Tra Vinh province, Mekong Delta

To prepare for the calculations of the CBA model, socio-economic data was collected. Table 4 shows forecasted indices for 2010-2020. Baseline calculations were implemented based on these values.

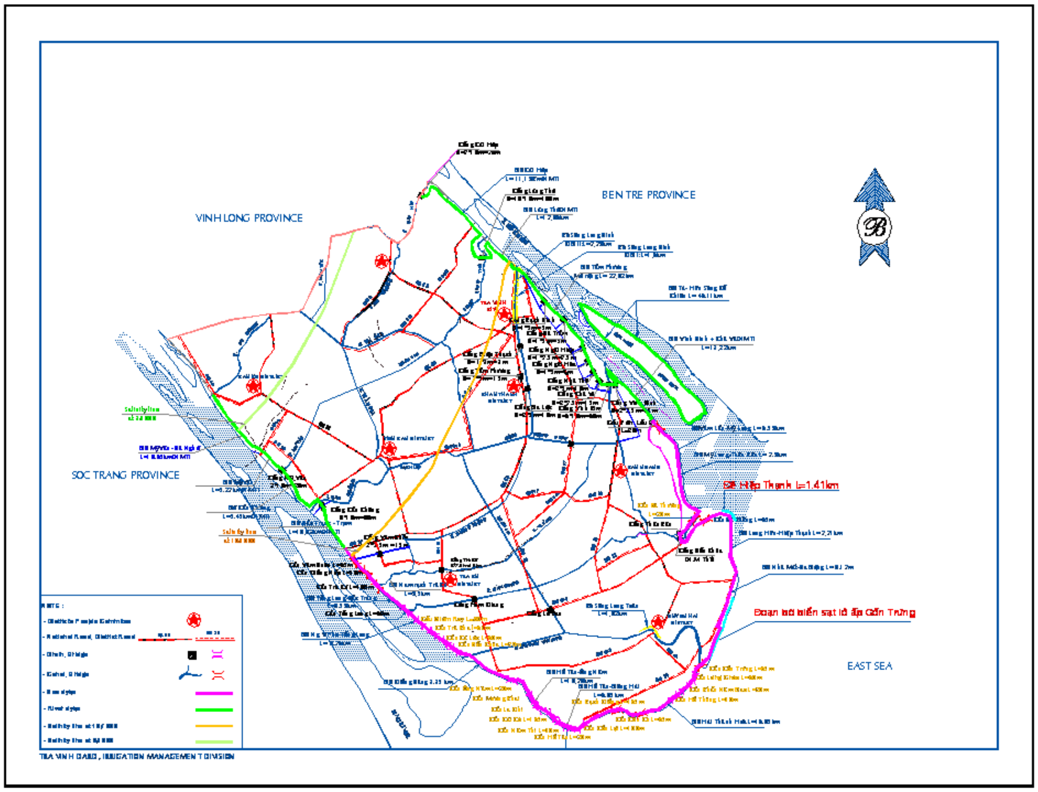
Table 4: Forecasted indices for Tra Vinh province, 2010-2020

Item	Unit	2010	2015	2020
1. Natural area	km^2	2,292.8	2,292.8	2,292.8
2. Population, in which:	1,000 persons	1,005	1,026	1,046
- Urban population	1,000 persons	150.8	266.6	314
3. GDP (1994), in which:	Bil. VND	8,211	14,470	30,430
- Industry/Construction	%	1,710.9	4,236.4	11,308.2
- Agriculture/Forestry/Aquaculture	%	3,629.7	4,467.0	5,617.8
- Services	%	2,870.4	6,426.6	13,504.0
4. Percentage of urbanization	%	15	26	30
5. GDP growth rate, in which:	%	11.64	13	15
- Industry/Construction	%	18.50	19.88	21.70
- Agriculture/Forestry/Aquaculture	%	4.66	4.24	4.69
- Services	%	20.87	17.49	16.01
6. GDP (2005)	Bil. VND	11,681	23,451	48,688
	Bil. USD	0.65	1.31	2.71
7. GDP percentage (2005)	%	100.0	100.0	100.0
- Industry/Construction	%	23.59	28	36
- Agriculture/Forestry/Aquaculture	%	43.85	40	30
- Services	%	32.56	32	34
8. GDP per capita (2005)	Mil. VND	11.6	22.8	46.5

Note: exchange rate – USD 1 = VND 18,000
Source: Tra Vinh province 2020 Socio-economic Master Plan

1.8. Development of the Dike System in Tra Vinh Province

Tra Vinh lies between two big rivers: the Co Chien and Hau rivers. Along the side of these two rivers there is a dike system consisting of sea dikes and river dikes. Figure 4 shows a map of the dike system in Tra Vinh province.



Source: Socio-economic Master Plan, Tra Vinh province, 2010-2020

Figure 4: Sea dike and river dike systems in Tra Vinh province

In the development strategy, the Socio-economic Master Plan stated that a combination of central government investment and investment from the provincial budget is needed in order to build a new sea dike line and to upgrade existing lines. Up to 2020 the following investments will be implemented.

- Upgrade and enlarge provincial road 914 (from Dai An commune, alongside national road 53, to Hiep Thanh commune, alongside the South East Sea).
- Build a new provincial road 915 (alongside the sea dike parallel with the Hau river). This investment (Decision No. 1457) was decided at the Tra Vinh People's Committee, 5 August, 2005.
- Build a new provincial road 915B (by upgrading along the sea dike line that runs next to Co Chien river and the South East Sea). The starting point of this road is at Hiep Thanh commune, Duyen Hai district, and it would cross the districts of Cau Ngang, Chau Thanh, and Cang Long. This road is of importance for developing the northern economic zone of Tra Vinh province.
- Build new sea dike lines in combination with road construction parallel to the South East Sea, for the purpose of socio-economic development.

2.0 METHODOLOGY

2.1. Theoretical Framework

The study uses a risk CBA framework that considers the likelihood of an extreme storm event and SLR. In a traditional CBA, all the variables in the model are non-random and they have single values. However, in the risk CBA framework critical variables relating to the probability of an extreme event (storm) are random. This allows consideration of both the range of values of the variables and the way of measuring the values of variables in the context of the likelihood of an extreme storm event. To do the risk analysis, one needs an assessment of probability with which changes in critical variables may occur. By assigning appropriate probability distributions to the critical variables, probability distributions for the economic indicators can be estimated. For the critical variables relating to the extreme event, a binomial distribution function is built. A simulation model is then used to obtain the expected/forecasted values for the risk CBA calculations.

This study applies the risk CBA framework using a six-step procedure.

1. Define the nature of the problem, including the alternative options to sea dikes and interested stakeholders.
2. Determine the direct cost of sea dike alternatives.
3. Determine the benefits of the sea dike system, calculate the difference between the losses with and without sea dikes.
4. Do a sensitivity analysis, formulate probability distribution functions for the extreme event-related critical variables in order to calculate the risk, and obtain expected/forecasted values.
5. Calculate the attractiveness of the alternatives to sea dikes using an Expected Net Present Value (ENPV) calculation.
6. Choose the best alternative sea dike option.

Following Boardman (2001) and introducing the risk analysis into the CBA study (Figure 5), a risk assessment and cost benefit analysis framework specific to the SLR sea dike options in the VMD is described as follows.

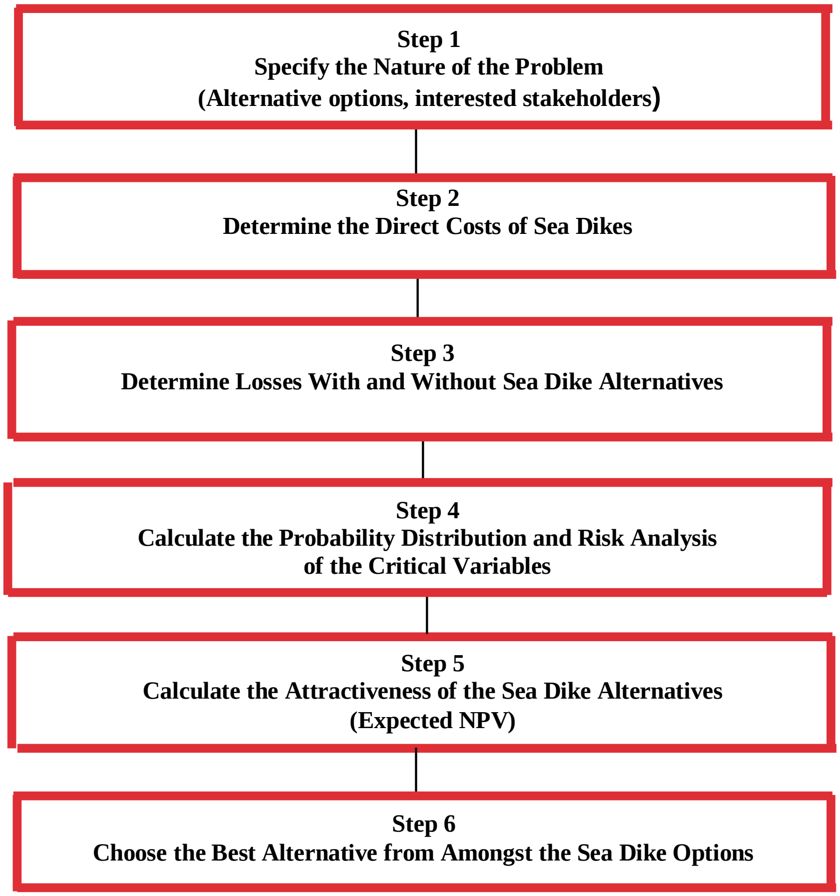


Figure 5: The risk CBA framework

2.2 Specify the Nature of the Problem

In this step the alternative options to concrete sea dikes need to be specified and the interested parties need to be identified. As previously mentioned, a permanent concrete sea dike system is a principal adaptation strategy for mitigating the impacts of SLR. This sea dike system runs along the coastal areas of the VMD (see Figure 4 for the dike systems in Tra Vinh province). At present, most of the existing sea dikes in Tra Vinh province are made of earth, except for one 615-meter concrete sea dike at Bao village, Hiep Thanh commune, Duyen Hai district[2]. In this CBA study the base scenario is the status-quo, which is no concrete sea dikes.

Identifying alternatives to sea dikes depends on timing, size, and construction materials. Firstly, the time factor chosen in this study is long term – a concrete sea dike

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[2] This sea dike opened on 30 June 2010. The construction costs of this dike were VND 18.5 billion (approximately one million USD) funded by the central budget. In 2011 the remaining 700 meters will be implemented at a cost of VND 24 billion (approximately 1.27 million USD).

system must survive for a very long time, for instance, 100 years. The proposed lifespan of a permanent concrete sea dike network for the VMD is 100 years. Secondly, the scale of the sea dike system depends on the SLR scenario that is selected, the probability of the occurrence of an extreme storm event, and which safety standards are specified. Thirdly, the construction costs vary depending on the different types of materials chosen for the dike. Three hypotheses regarding the scale of the sea dike system can be considered: a dike that can withstand a storm that occurs once every 20 years, one that can withstand a storm that occurs once every 50 years, and one that can withstand a storm that occurs once every 100 years. Three scales of sea dike system can be considered: the first is small in scale; the second is medium-scale; and the third is large-scale. In addition, the time frame given to the construction of the sea dike is important. Technically, the dike should be constructed in one go or in sequential periods. This study examines five different dike options (see below) associated with different scales, construction phases, and lifespans.

- Option 1: a small-scale dike 2 meters high, lasting 50 years.
- Option 2: a medium-scale dike 3 meters high that is constructed all in one go, with no plans for future upgrading. The lifespan of this dike is 100 years.
- Option 3: a medium-scale dike with a height of 3 meters that is constructed over two time periods, with the initial investment in a dike on as small a scale as option 1 (at a height of 2 meters) but with the body of the dike constructed on the medium scale; at the second phase of construction the dike would be upgraded to a height of 3 meters. The lifespan of this dike is 100 years.
- Option 4: a large-scale dike constructed all at once, with a height of 4 meters and no plans for upgrading in the future. The lifespan of this dike is 100 years.
- Option 5: a large-scale dike constructed in two phases, with the initial investment of an option-1 dike (height of 2 meters) but with the body of the dike constructed on a large scale; at the second phase additional investment would raise the dike to 4 meters. The lifespan of the dike is 100 years.

Using a base scenario of “no concrete sea dike system” allows us to compute the differentials between with and without alternative option values. These values are the costs and benefits used in the CBA calculations.

2.3 Determining the Costs and Benefits

2.3.1 Quantifying the costs

The cost of sea dikes depends on the safety standards that are adhered to and their scale. In Vietnam dike costs vary because of the differing prices of materials, land use, and revetments. The cost of labor is highly variable but constitutes a relatively small percentage of the total cost (Hillen et al. 2008, Mai et al. 2008). Because information about the cost of dikes was not available from the local dike management authority, the cost category in this study uses the dike cost calculations given by Mai et al. and by Hillen et al. for a typical sea dike in rural Vietnam. Mai et al. (2008) determined the cost of dike heightening with a comparable probabilistic approach to ascertain the safety standards of the sea dike system. The safety standards in Mai et al. are comparable to

Hillen et al. The costs of dike heightening in Mai et al. are also comparable with those found by Hillen et al. (Appendix 3). Mai et al. used both outer- and inner-slope protection and included the costs of maintenance in the dike costs category. Because dike costs data are estimated at different levels, in the risk CBA framework the probability distributions of the construction costs, maintenance costs, and dike heightening variables were assigned to have a uniform distribution with the minimum values of the Hillen et al. estimations and the maximum values of the Mai et al.estimations.

2.3.2 Quantifying the benefits

Using sea dikes as a coastal defense avoids damage to the VMD. In this study, two types of damage were avoided: (1) loss of life, homes, infrastructure (roads, electricity network, water connections, etc.) due to storms and flooding; and (2) loss in yields of rice and aquaculture due to salinity. The measurement of each type of benefit was calculated by the methods described in the following sections.

Avoidance of storm damage

Storm damage can incur loss of life, homes, infrastructure (roads, electricity network, public facilities, etc.), and the destruction of rice and aquaculture production. According to the National Centre for Hydrometeorological Forecasting (NCHMF), MONRE, from 1961 to 2010, 258 storms hit Vietnam, 17 of which were in the south of the country (Appendix 4). While many strong storms (level 11, and above, >103 km/h) have visited other parts of Vietnam, the VMD has rarely been a victim of this type of natural disaster. During this period, 43 level 11 (and above) storms hit Vietnam (or 16.7% of the total) and nine storms (or 3.5% of the total) reached level 13 and above (>133km/h). From 1961-2010 only 17 storms, or 6.6% of the total number of storms across Vietnam, hit the MRD and only one of these storms reached level 11, with an additional one attaining level 13. The frequency of storms in the VMD follows a pattern: once every four years there is a level-6 storm (39-49 km/h); once every 10 years there is a level 8-10 storm (62-102 km/h); once every 20 years there is a level-11 storm (103-117 km/h); and once every 50 years there is a level-13 storm (>133 km/h). However, for a project as huge as the sea dike system the probability distribution of storms (and floods) needs to simulate beyond the 1961-2010 time frame. An alternative is the World Bank's (2010) simulation of the economic losses caused by storm and flood events with different return period assumptions. The World Bank assessed economic losses caused by storms that take place once every 10 years (0.013% of national GDP), once every 50 years (0.023% of national GDP), and once every 100 years (0/03% of national GDP). The estimated economic losses caused by storms in the VMD, based on the Vietnam Central Committee for Flood and Storm Control (CCFSC) storm cost report, were consistent with the World Bank's estimates. For example, with the scenario of a "once every 40 years storm", the percentage of economic loss of the VMD's GDP was 0.016%, compared to 0.023% for the "once every 50 years storm" scenario of the World Bank's projection. The benefit due to the avoidance of losses due to storms was estimated as follows.

$$\text{Storm loss avoided} = \sum_{i=1}^{100}\sum_{k=1}^{5}\text{\% storm loss in } GDP_{RPk} \times GDP_i \quad \text{(Equation 1)}$$

Where rp_k: return period k (k=1-5)

GDP_i: GDP at time i (i=1-100, i.e. 2010-2110)

Avoidance of flood damage

The VMD is an area familiar with flooding. Flooding occurs frequently and brings much damage to the region. According to a CCFSC report, from 1991 to 2005 the VMD suffered eight floods and each one brought significant economic losses. Similar to the storm loss estimations, the flood scenarios used in this study were based on a combination of World Bank simulations (2010) and calculations by the CCFSC. There are four flood scenarios for the VMD: flooding once every two years; flooding once every 10 years; flooding once every 50 years; and flooding once every 100 years. The benefit due to the avoidance of losses due to flooding was estimated as follows.

Flood loss avoided = $\sum^{100}_{i=1}\sum^{4}_{k=1}$ % flood loss in GDP_{RPk} x GDP_i (Equation 2)

Where rp_k: return period k (k=1-4)

GDP_i: GDP at time i (i=1-100, i.e. 2010-2110)

Reduction of damage from seawater intrusion

Sea and river dike systems help to protect the land from seawater intrusion and salinity, which decrease yields of the rice and cash crops that are the main agricultural products of coastal areas. The benefit gained from avoiding salinity is at least the cost of building the sea dike system. In order to measure the value of losses in agriculture and aquaculture production due to salinity, a damage function was designed. Damage was defined as a loss of productivity due to salinity. Hypothetically, as the degree of salinity increases, the productivity of rice farming and fishing decreases. Figure 6 shows the relationship between salinity and loss of productivity per unit.

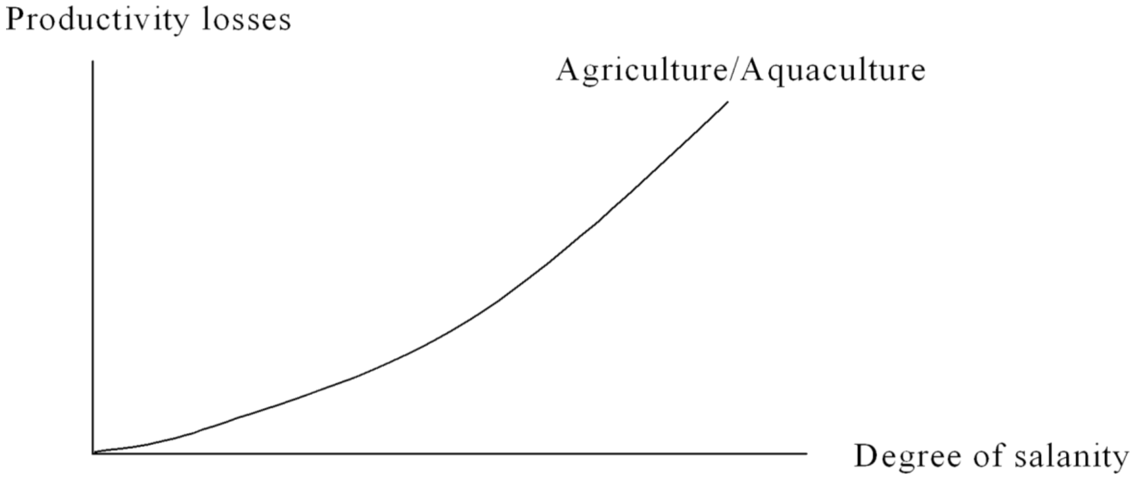

Figure 6: The damage salinity causes to agriculture and aquaculture

The total losses are the product of the marginal loss of productivity (per ha) and the area affected.

To estimate the impacts of salinity on farming yields in the affected areas, a simple production function was specified.

$Q_i = a_0 + a_1L_i + a_2K_i + a_3S_i + u_i$ (Equation 3)

Where Q_i: yield of product i (rice (tonne/ha), and *macrobrachium rosenbergii* (tonne/ha));

L: labor (kg/ha);

K: capital (fertilizer) (kg/ha);

S: dummy variable (1 for salinity; otherwise 0)

a_i: regression's coefficients

Equation 3 includes two types of explanatory variables: yield-increased variables (labor and capital) and yield-decreased variables (salinity and distance).

A decomposition analysis was used to measure the impact of salinity on productivity. Production function decomposition analysis allows decomposition of the difference in the change in farming productivity between land affected by salinity and land unaffected by salinity. That is, the changes are decomposed into two components: changes due to the effects of salinity, and input reallocation. A production function in a log-linear form is shown below.

No salinity:

$LnQ_n = LnA_n + a_1LnL_n + a_2LnK_n$ (Equation 4)

With salinity:

$LnQ_s = LnA_s + b_1LnL_s + b_2LnK_s + b_3LnS$ (Equation 5)

Taking the difference between Equation 5 and Equation 4 and rearranging terms results in the following:

$Ln(Qs/Qn) = Ln(As/An) + (b_1-a_1)Ln(L_s/L_n)) + (b_2-a_2)Ln(K_s/K_n) + b_3LnS$

(Equation 6)

The coefficient b_3 in Equation 6 implies the marginal loss of productivity due to salinity impact separately while other coefficients, (b_1-a_1) and (b_2-a_2), show the impact of differences in labor and capital respectively. It is expected that the sign of coefficient b_3 will be negative in the estimation.

The benefit of avoiding the negative impact of salinity, thanks to a dike system, is measured as follows:

Salinity loss avoided = marginal productivity loss x total areas affected

(Equation 7)

2.4 Probability Distribution and Risk Analysis of the Critical Variables

The risk analysis in Step 4 is central to the risk CBA framework. Methodologically, a risk CBA not only considers the range of values of the variables but also attaches to these values a measure of the likelihood of their occurrence. Two uncertainty variables need to be taken into account in the sea dike projection: storms and flooding. Estimation of these critical values must be implemented via the risk analysis framework. In this study, a simulation analysis is applied to obtain the expected values of these uncertainty variables.

In the VMD storms are not an annual weather phenomenon – they occur rarely in the region. However, when storms do happen, losses are usually large. Global climate change would suggest that in the future storms will be stronger and will move further to the south (MONRE 2010). As storms are a discrete variable, a certain probability distribution function is specified in order that, based on the type of probability distribution function, a simulation model can be run to estimate the expected value of the critical variable. Storm records for 1961-2010 were used to predict the form of probability distribution. As described in section 2.2, five return periods were specified with a binomial probability distribution function for the storm variable: once every four years, once every 10 years, once every 20 years, once every 50 years, and once every 100 years. The value of economic damage associated with each storm frequency was estimated by simulation analysis using Crystal Ball® software.

In contrast, flooding in the VMD is usually riverine in nature, rather than flash flooding, as in other parts of Vietnam. Flooding in the VMD causes significant economic damage. As shown in section 2.2, four flood scenarios were selected: once every two years, once every 10 years, once every 50 years, and once every 100 years. In order to estimate the expected values of this critical variable, a binomial probability distribution function was used. Similarly, the values of economic damage associated with each flood frequency were estimated by simulation analysis using Crystal Ball® software.

The exact costs of dike construction and dike heightening are unknown (Appendix 5). Some studies (Hillen et al. 2008; Mai et al. 2008) have estimated the typical costs for a typical sea dike in Vietnam (see section 2.2) but differences in technical specifications, location, region, etc., make accurate costings of dike construction and heightening problematic. In order to overcome these estimation difficulties, expected values have been calculated using Crystal Ball® software based on the assumption of a uniform probability distribution function, with maximum and minimum values given.

Finally, the area of agricultural land affected by salinity cannot be accurately measured. At Tra Vinh more than 90% of the total agricultural land area is affected by salinity[3] but the salinity status of other salinity-affected regions differs. Therefore, estimating the area affected by salinity needs to be done with the uncertainty condition. In this study, a uniform probability distribution form is assigned for this variable using

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[3] 2020 Socio-economic Master Plan, Tra Vinh province

Crystal Ball® software to predict the percentage of agricultural land area affected by salinity.

2.5 Baseline Alternatives

The main purpose of the sea dike system is to protect the region from the impacts of a rise in sea level – impacts that are being felt now, as well as impacts that may occur in the future. Therefore, predictions or projections about what will happen in the next 10, 20, or 30 years, are extremely important to this study. In order to construct the baseline for the risk CBA assessment, the study uses secondary data from Tra Vinh's Master Plan for 2010-2020 and also the 2025 Vision. Based on the projections in the Master Plan, further calculations for 2030 will be done in order to construct a baseline for 2010-2030. It is proposed that a simple regression model be used for calculating forecasted indicators. The most important parameter that needs to be forecast is the GDP values of the areas bounded by the dike system. It is plausible that the whole of Tra Vinh province could be protected by the river dike and sea dike systems (see Figure 4). The value of flood and storm losses avoided are based on the proportion of losses per GDP value (see Equations 1 and 2). Based on the development indices shown in the Tra Vinh Master Plan, the following situation is forecast for 2010-2110.

Table 5: Forecasts of GDP values and rice and aquaculture areas in period of 2010-2110

Forecasted value	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100	2110
GDP (billion US$)	0.65	2.02	5.24	13.58	26.72	52.56	103.39	203.38	301.05	445.6	659.6
Annual increase in GDP (%)	12	12	10	10	7	7	7	7	4	4	4
Rice area (ha)	90,000	89,000	89,000	89,000	89,000	87,000	87,000	87,000	87,000	85,000	85,000
Aquaculture area (ha)	55,000	55,000	55,000	55,000	55,000	55,000	55,000	55,000	55,000	55,000	55,000
In which:											
Fresh-water areas	10,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000

Note: Forecasts for 2010-2020 are from Tra Vinh province's 2020 Socio-economic Master Plan

2.6 Calculating the Attractiveness of the Sea Dike Alternatives

In this step all positive and negative impacts are calculated in monetary terms. A social discount rate of 3% is assigned to calculate the ENPV for all benefits and costs at different times.

2.7 The Best Sea Dike Alternative

Based on the project evaluation criteria, the best sea dike alternative from the options will be proposed. Before the final recommendations are made to policy makers a further sensitivity analysis will be conducted.

3. 0 FINDINGS AND DISCUSSION

3.1 Characteristics of the Sample

Two hundred and thirty-three rice farmers and 79 aquaculture farmers were interviewed in the survey. Questionnaires were designed to collect appropriate data such as production area, yield, input uses (labor, fertilizer use, chemicals, food, etc.), and investment, in order to estimate lost productivity due to the effects of salinity.

In order to ascertain the impact of salinity on rice yield, the sample was split into two sub-samples – one sample of 115 rice farmers at Duyen Hai (62 farmers) and Cau Ngang (53 farmers) and another sample of 118 rice farmers at Cang Long (56 farmers) and Cau Ke (62 farmers). Rice production at Cang Long and Cau Ke is mostly unaffected by salinity but other parts of Tra Vinh province, such as Duyen Hai and Cau Ngang, have to cope with salinity and seawater intrusion. Table 6 shows a summary of statistical variables used in the rice production model such as yield, labor, and seed and fertilizer uses. On average, rice farmers had a high yield of 7.77 tonnes per hectare and in a few cases an even higher yield of 11.5 tonnes per hectare was achieved. However, rice yield from the areas affected by salinity was lower than that of areas not affected by salinity. Farmers' inputs, except for fertilizer, at the areas affected by salinity were higher, with more seed and labor inputs. Statistically, all the variables did not have standard distribution, with the values of the statistical summary of skewness not equal to zero, so statistical references in regression analyses should be made carefully.

Table 6: Summary of statistical variables in the rice production model

Item	Mean	Median	Max	Min	Std. Deviation	Skewness	Kurtosis
Whole sample (n=233)							
Area (ha)	2.03	1.20	26.00	0.10	2.69	5.25	37.95
Yield (tonne/ha)	7,768.54	7,716.00	11,500.00	4,630.00	1,022.76	0.28	1.04
Seed (kg/ha)	157.79	150.00	620.00	17.00	62.65	1.99	12.42
Labor (day/ha)	30.60	27.70	94.90	3.00	13.04	1.44	3.38
Fertilizer (kg/ha)	453.06	425.00	3,129.00	31.00	235.01	6.82	73.17
Salinized sample (n=115)							
Area (ha)	1.79	1.04	10.00	0.26	1.79	2.18	5.03
Yield (tonne/ha)	7,088.20	7,200.00	9,105.00	4,630.00	718.52	-0.66	1.44
Seed (kg/ha)	163.26	150.00	620.00	17.00	67.81	2.82	17.22
Labor (day/ha)	32.38	30.00	79.28	13.33	12.29	1.24	2.38
Fertilizer (kg/ha)	430.02	420.00	1,040.00	31.00	161.34	0.94	2.74
Unsalinized sample (n=118)							
Area (ha)	2.26	1.30	26.00	0.10	3.33	5.04	30.29
Yield (tonne/ha)	8,431.58	8,253.85	11,500.00	6,639.20	820.27	0.98	1.32
Seed (kg/ha)	152.45	150.00	370.00	18.25	56.96	0.54	1.49
Labor (day/ha)	28.87	25.65	94.90	3.00	13.56	1.74	4.74
Fertilizer (kg/ha)	475.52	436.50	3,129.00	175.00	288.30	7.07	62.52

In the aquaculture survey 79 aquaculture farmers were interviewed. These farmers culture *macrobrachium rosenbergii*. As with the rice survey, two independent survey areas were selected. Forty-two aquaculture farmers in Cang Long district (the salinity-free area) and 37 aquaculture farmers in Duyen Hai district (the salinity-affected area) were interviewed regarding production activities such as cultivation area, yield, inputs (seed, fish food, chemicals, labor), and investment. Questions were asked about the estimated numbers of male shrimps at harvest time[4] and average density per m^2 at culturing time; these variables play a significantly role in the yield of *macrobrachium rosenbergii*. Table 7 shows a summary of statistical variables relating to *macrobrachium rosenbergii* production.

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[4] The rate of male shrimp will decide the yield.

Table 7: Summary of statistical variables in the aquaculture model

Item	**Mean**	**Median**	**Maximum**	**Minimum**	**Std. Dev.**	**Skewness**	**Kurtosis**
Whole sample (n=79)							
Area (ha)	1.33	1.00	13.00	0.30	1.62	5.29	35.18
Yield (kg/ha)	1,153.85	990	3,500	300	517.73	1.50	4.15
Numbers of male shrimp (%)	53.61	52	90	27	14.94	0.41	-0.59
Average density per m^2 (shirmp)	14.34	15	25	7	4.96	0.27	-0.77
Industry food (tonne/ha)	3.22	2.97	7.40	0.79	1.49	0.70	0.15
Costs:	71,575.78						
Dam cost per ha (thousand VND)	9,792.48	6,862	45,346	589	8,367	2.10	4.77
Seed cost per ha (thousand VND)	17,131.58	17,400	34,365	1,715	8,357	0.28	-0.48
Food cost per ha (thousand VND)	34,746.96	29,430	77,871	737	23,478	0.22	-1.27
Chemical cost per ha (thousand VND)	4,844.41	4,544	9,212	498	2,693	-0.02	-1.18
Labor cost per ha (thousand VND)	5,060.35	5,373	9,657	232	5,373	-0.04	-1.17
Salinized area (n=37)							
Salinized area (n=37)							
Area (ha)	1.32	1.00	5.50	0.30	1.02	2.55	2.55
Yield (kg/ha)	1,046.35	970	2,300	300	427.82	0.92	0.92
Rate of male shrimp (%)	52.41	50	90	31	16.02	0.55	-0.48
Average density per m^2 (shirmp)	15.84	16	25	7	5.01	-0.06	-0.58
Fish food (kg/ha)	3.45	3.50	7.40	0.79	1.47	0.34	0.00
Costs:	77,786.73						
Dam cost per ha (thousand VND)	10,269.49	6,781	45,346	1,104	9,152	2.24	5.51
Seed cost per ha (thousand VND)	19,317.70	18,864	33,692	1,715	8,437	-0.04	-0.64
Food cost per ha (thousand VND)	38,372.03	39,739	77,871	737	24,452	-0.09	-1.34
Chemical cost per ha (thousand VND)	4,913.76	4,675	9,212	246	2,871	-0.07	-1.36
Labor cost per ha (thousand VND)	4,913.76	4,675	9,571	232	2,841	-0.21	-1.11
Fresh area (n=42)							
Area (ha)	1.33	0.80	13.00	0.30	2.02	5.01	28.36
Yield (kg/ha)	1,248.55	1,138	3,500	490	574.12	1.58	4.28
Rate of male shrimp (%)	54.67	53	85	7	14.03	0.31	-0.59
Average density per m^2 (shirmp)	13.02	12	25	7	4.57	0.55	-0.54
Fish food (kg/ha)	3.021667	2.55	7.4	0.99	1.49	1.09	3.63
Costs:	66,119.71						
Dam cost per ha (thousand VND)	9372.262	7,813	34,125	589	7,699	1.89	3.63
Seed cost per ha (thousand VND)	15205.71	15,654	34,365	2,855	7,889	0.58	0.31
Food cost per ha (thousand VND)	31553.45	25,397	75,332	1,031	22,390	0.52	-0.97
Chemical cost per ha (thousand VND)	4994.143	4,329	9,207	498	2,559	0.01	0.99
Labor cost per ha (thousand VND)	4994.143	5,084	9,657	322	2,757	0.12	1.19

The average yield of *macrobrachium rosenbergii* was 1,153 kg per hectare. Average yield in the area affected by salinity was 1,046 kg per hectare, compared to a yield of 1,249 kg per hectare in the area unaffected by salinity. The average density of baby shrimp was not largely different between the two areas so the different yields in the two areas were not due to density of shrimp. However, there was a difference in the production cost pattern between the two areas: the total production costs (per ha) were 77.8 million VND and 66.1 million VND in the salinity-affected and non-salinity-affected areas respectively. This shows the disadvantage of culturing *macrobrachium rosenbergii* in salinity-affected areas compared to non-salinity-affected areas – farmers in the salinity-affected areas incurred greater production costs but earned less yield.

Table 8 shows comparative analyses of revenues, production costs, and profits of these production models. Aquaculture farmers received more revenue than rice farmers – more than 3.27 times – but they had to spend up to five times more on production costs than rice farmers. Generally, aquaculture farmers earned 2.25 times more profit than rice farmers, but the profit ratio was lower than 20.38%.

Table 8: Comparative analyses of revenues, production costs and profits, rice and aquaculture production

Item	**Rice production**	***Macrobrachium rosenbergii*** **production**
Revenue per ha (thousand VND)	38,843	126,923
Cost per ha (thousand VND)	14,282	71,576
Profit per ha (thousand VND)	24,560	55,348
Profit per ha (USD)	1,228	2,767
Profit ratio (%)	63.23	43.61

To assess the impact of salinity on the efficient use of inputs, a regression analysis taking into account interaction effects between dummy salinity variables and input variables was applied. Table 9 and Table 10 show the OLS estimations of the rice model's regression and the aquaculture model's regression respectively. The rice production model result showed that labor use was statistically significantly affected by salinity while other input uses did not show statistical evidence of salinity impact on yield. The analysis of the interaction effect with the negative "labor*labor" variable implied that the increased rate of rice yield was less than the increased rate of labor use. Moreover, in salinized areas rice farmers used less labor than in non-salinized areas. In the aquaculture production model variables of area, shrimp density, and food statistically significantly affected the yield of *macrobrachium rosenbergii*. The experience of farmers also played an important role in ontaining a high yield. Analysis of the interaction effect showed that the level of salinity was the main factor affecting *macrobrachium rosenbergii* production.

Table 9: OLS estimation of rice production function with salinity impact, dependent variable: yield (kg/ha)

Variable	Without interaction effect	With interaction effect
Constant	8466.04*	7765.0988*
Seed (kg/ha)	0.806	1.4860
Labor (day/ha)	-6.651***	29.79169**
Fertilizer (kg/ha)	0.073	-0.1539
Salinity (Dummy)#	-1325.49*	
Salinity*Seed		-1.7762
Salinity*Labor		-15.1224***
Salinity*Fertilizer		0.1230
Seed*Seed		0.0004
Labor*Labor		-0.37265**
Fertilizer*Fertilizer		0.0001
R Square	0.443	0.4657
F-test	45.2938*	19.3416*

Note: # 1 if salinized; otherwise 0
*, **, *** significant at 1%, 5%, 10% respectively

Table 10: OLS estimation of aquaculture production function with salinity impact, dependent variable: yield (kg/ha)

Variable	Without interaction effect	With interaction effect
Constant	939.545***	1282.741*
Area (ha)	-16.829**	-24.246**
Male rate (%)	4.077	-5.921
Density (shrimp per m^2)	-13.044**	9.043**
Food (tonne)	12.588**	51.130
Dam cost (thousand VND per ha)	-0.009	
Seed cost (thousand VND per ha)	0.006	
Food cost (thousand VND per ha)	0.002**	
Chemical cost (thousand VND per ha)	0.026	
Labor cost (thousand VND per ha)	0.007	
Salinity (dummy)#	-183.643**	
Experience (year)	43.351**	27.969
Education (year)	-15.884	-24.377
Total cost (thousand VND per ha)		0.002
Salinity*male rate		13.004**
Salinity* density		-37.029***
Salinity* food		-85.33**
Salinity* total cost		-0.001**
R Square	0.150	0.195
F-test	45.9707*	47.4721*

Note: # 1 if salinized; otherwise 0

*, **, *** significant at 1%, 5%, 10% respectively

3.2 Marginal Productivity Losses Due to Salinity

To estimate the marginal productivity losses in Equation 7, changes in rice yield and *macrobrachium rosenbergii* yield due to salinity were derived from a salinity dummy-introduced production function. The OLS estimations in the without-interaction-effect columns in Table 8 and Table 9 show the values of marginal productivity losses due to salinity. These values imply that if salinity is present the rice yield and *macrobrachium rosenbergii* yield decrease at 1.33 tonnes per hectare and 183.64 kg per hectare respectively.

3.3 Cost and Benefit Measurement

3.3.1 Cost measurement

Dike construction costs

Five dike options were considered in this risk CBA study. Construction costs and maintenance costs were projected across all the options but the costs of dike heightening were only applied to options 3 and 5. The estimations of dyke costs were based on the dike cost projections in Hillen[5] et al. (2008) and Mai et al. (2008)'s. According to Hillen and Mai, construction costs include the cost of creating the body of the dike, land use, berm, outer protection and inter protection or revetments. These construction costs vary because of the differing costs of materials and land use, and the application of inner and outer protection or revetments. Although labor costs are important, they were relatively small in the overall scheme of dike construction costs. Please note that in these two studies dike construction costs were projected for the dike system in rural areas.

Dike maintenance costs

The annual dike maintenance cost comprises a small amount of total dike capital budgeting. Based on the dike department and ministry budgets, Hillen et al. (2008) estimated the yearly dike maintenance cost for 1 kilometer of dike as USD 27,000. Table 11 shows the construction costs and maintenance costs of dikes at the heights estimated by Hillen et al. (2008) and Mai et al. (2008).

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[5] Hillen et al. (2008) determined the costs of dike construction using data from local dike departments, from the cost data of stretches of newly constructed sea dikes, and from interviews with dike departments, ministries and academic staff of the Hanoi Water Resources University.

Table 11: Decomposition of dike construction and maintenance costs (per km) in rural Vietnam

Cost category	**Height at 2 meters**			**Height at 3 meters**			**Height at 4 meters**		
	Hillen		**Mai**	**Hillen**		**Mai**	**Hillen**		**Mai**
	(M€)	(M$)	(M$)	(M€)	(M$)	(M$)	(M€)	(M$)	(M$)
Dike body	0.286	0.386	0.92	0.471	0.636	1.38	0.729	0.984	2.00
Land use	0.071	0.096	0.31	0.229	0.309	0.72	0.400	0.540	1.00
Berm	0.014	0.019	-	0.014	0.019	-	0.014	0.019	-
Revetment	0.486	0.656	-	0.714	0.964	-	0.929	1.254	-
Outer/inter protection	-	-	0.57	-	-	0.58	-	-	0.71
Maintenance	-	-	0.02	-	-	0.02	-	-	0.04
Total cost	0.857	1.157	1.82	1.429	1.929	2.70	2.071	2.796	3.75

Source: Hillen et al. (2008)

Dike heightening costs

In order to calculate the dike heightening costs at the second phase for option 3 and option 5, the unit cost price standards given by IPCC CZMS (1990), cited by Hillen et al. (2008), are applied in this study. Table 12 shows the unit cost prices of coastal defenses with the assumption of "all-in" costs for dike construction. Since most of the sea dikes in the VMD, and in Tra Vinh province in particular, are in rural areas, the dike heightening costs chosen for calculations in this study were in the range of USD 0.702-1.404 million per kilometer.

Table 12: Unit cost prices of dike heightening (USD/km)

Type of coastal defense measure	Unit cost IPCC CZMS (1990) (2009 price level, USD)
New 1-m-high sea dike	0.55
New 1-m-high sea dike with regular maintenance	0.84
Raising low sea dike by 1 m in rural areas	0.70
Raising high sea dike by 1 m in rural areas	1.40
Raising sea dike by 1 m in urban areas	14.03

Source: Hillen et al. (2008)

3.3.2 Cost simulations

One of the problems of estimating the cost of building sea dikes is a lack of reliable data – some adjustments in calculations need to be made to compensate for this. Cost estimations by Hillen et al. (2008) and Mai et al. (2008) were dependent on various assumptions regarding safety standards and the frequency of natural disasters such as storms and floods. These assumptions vary under different uncertainty conditions. The cost estimations by Hillen et al. (2008) were lower than those of Mai et al. (2008). Based on this, the probability distributions of construction costs, maintenance costs, and the costs of dike heightening were assigned uniform distributions with minimum values and maximum values. Table 13 shows the simulation values of the cost variables used in the CBA calculations. The results showed that all simulation values followed standard distributions (skewness value = 0) (Appendix 6, Appendix 7, Appendix 8, Appendix 9, Appendix 10).

Table 13: Simulation results, dike costs, CBA analysis

Cost component	**Distribution**	**Minimum value**	**Maximum value**	**Simulated value**	**Skewness**
Construction cost					
2-m high dike	Uniform	1.16	1.82	1.49	0
3-m high dike	Uniform	1.93	2.7	2.31	0
4-m-high dike	Uniform	2.8	3.75	3.27	0
Maintenance cost	Uniform	0.027	0.04	0.3	0
Heightening cost					
By 1 m	Uniform	0.702	1.404	1.05	0
By 2 m	Uniform	1.41	2.81	2.11	0

Note: Corresponding minimum/maximum values are drawn from appendices 5 to 11

Some assumptions regarding the longevity of the dikes were made for each option: option 1 assumed a life of 50 years and all the other dikes were assumed to have a life of 100 years. In the case of dike heightening, after a period of 20 years the dikes in options 3 and 5 were heightened to the level of the dikes in options 2 and 4, respectively. The total length of the dikes in Tra Vinh province is 147 km[6]. Table 14 shows the total costs of the proposed dike options.

Having been simulated, these dike cost values were used to calculate the present values of dike options. Table 15 shows a summary of results of present values of dike costs with a discount rate at 3% and a timeline of 100 years. Results showed that option 4 had the highest cost, at USD 666.492 million, and option 1 had the lowest cost, at USD 361.893 million. Generally, the dike options that included the flexibility to heighten the dikes at a later date incurred higher costs (Appendix 12).

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[6] See Table 3.

Table 14: Costs of dike options (million USD)

Cost category by option	**2010**	**2020**	**2030**	**2040**	**2050**	**2060**	**2110**
Option 1	221.97	2.94	2.94	2.94	2.94	221.97	2.94
Construction cost	219.03	0	0	0	0	219.03	0
Maintenance cost	2.94	2.94	2.94	2.94	2.94	2.94	2.94
Heightening cost	0	0	0	0	0	0	0
Option 2	5.25	2.94	2.94	2.94	2.94	2.94	2.94
Construction cost	2.31	0	0	0	0	0	0
Maintenance cost	2.94	2.94	2.94	2.94	2.94	2.94	2.94
Heightening cost	0	0	0	0	0	0	0
Option 3	221.97	2.94	157.29	2.94	2.94	2.94	2.94
Construction cost	219.03	0	0	0	0	0	0
Maintenance cost	2.94	2.94	2.94	2.94	2.94	2.94	2.94
Heightening cost	0	0	154.35	0	0	0	0
Option 4	486.57	5.88	5.88	5.88	5.88	5.88	5.88
Construction cost	480.69	0	0	0	0	0	0
Maintenance cost	5.88	5.88	5.88	5.88	5.88	5.88	5.88
Heightening cost	0	0	0	0	0	0	0
Option 5	221.97	2.94	313.11	5.88	5.88	5.88	5.88
Construction cost	219.03	0	0	0	0	0	0
Maintenance cost	2.94	2.94	2.94	5.88	5.88	5.88	5.88
Heightening cost	0	0	310.17	0	0	0	0

Note: Maintenance cost is yearly annuity cash flow

Table 15: Costs of dike options (discount rate = 3%, unit: million USD)

Dike option	**Construction cost**	**Maintenance cost**	**Heightening cost**	**Total cost**
Option 1	268.99	92.901	-	361.893
Option 2	339.57	92.901	-	432.471
Option 3	219.03	92.901	85.460	397.391
Option 4	480.69	185.802	-	666.492
Option 5	219.03	142.062	171.734	532.825

3.3.3 Benefit measurement

Storm damage that has been avoided, flood damage that has been avoided, and productivity losses that have been avoided, are benefit categories in the CBA calculations. Table 16 and Table 17 show the economic losses for corresponding return periods for Vietnam and the VMD respectively. First, in order to estimate the benefit of storm losses avoided, the study assigned five return periods for storms: once every four years, once every 10 years, once every 20 years, once every 50 years, and once every 100 years. The first three scenarios were used in Table 17 and the last two scenarios were used in Table 16. Second, in order to estimate the benefit of flood losses avoided, the study assigned four flood scenarios in the VMD: once every two years, once every 10 years, once every 50 years, and once every 100 years. The first two scenarios were used in Table 17 and the last two scenarios were used in Table 16. Third, productivity losses avoided were derived from Table 9 and Table 10 for rice and aquaculture respectively. In order to forecast the values of productivity losses avoided, a uniform distribution form was assigned for the salinity-affected area variable, as described in Appendix 11. Using the probabilities of disaster events and their corresponding damage, the values of the economic loss per event were measured. Results showed that the benefits of avoiding storm losses for corresponding return periods measured via percentage per GDP were 0.000004%, 0.013%, 0.005%, 0.023% and 0.027%, respectively. By the same method, the benefits of floods avoided for corresponding return periods were 0.006%, 0.037%, 0.026%, 0.033% respectively.

Table 16: Probability of flood and storm losses for the whole of Vietnam

Return period	Indicative annual aggregate probable maximum loss, 2008 GDP			
	Flood		Typhoon	
	Value[a)] (USD million)	Percentage per GDP[b)] (%)	Value[a)] (USD million)	Percentage per GDP[b)] (%)
10 years	1,093	0.013	1,095	0.013
50 years	2,225	0.026	1,913	0.023
100 years	2,781	0.033	2,290	0.027

Sources: a) World Bank (2010), b) author's calculation

Table 17: Probability of flood and storm losses for the Mekong Delta

Storm/Flood	**Storm (mil. VND)**	**Flood (mil. VND)**	**Frequency**
Linda storm 1997	7,179,615	-	1/50
Storm 1998	317,055	-	1/20
Tropical depression 1999	300	-	1/4
Flood 1996	-	2,571,223	1/10
Flood 1994	-	2,283,858	1/10
Flood 2001	-	1,535,910	1/10
Flood 1991	-	590,000	1/2
Flood 2002	-	456,831	1/2
Flood 1995	-	383,752	1/2
Flood 2000	-	302,069	1/2
Flood 1997	-	67,496	1/2
Average loss per year:	2,498,990	1,023,892	
in million USD	138.83	56.88	
% loss in regional GDP [a]	0.037	0.018	
% loss per event in regional GDP [a] :			
Storm once every four years	0.000004	-	
Storm once every 20 years	0.005	-	
Storm once every 40 years	0.106	-	
Flood once every two years	-	0.006	
Flood once every 10 years	-	0.037	

Note: [a] median 1998 GDP and 1997 GDP for storms and floods respectively
Source: CCFSC and author’s calculation

Table 18 shows the monetary benefits of the different dike options over different periods of time, classified by storms, floods, and salinity. To calculate the monetary values of storm losses avoided and flood losses avoided, the disaster losses in terms of percentage of GDP were multiplied by the corresponding GDP values projected in the baseline scenario (Table 5). To measure the monetary values of salinity damages avoided, the values of marginal productivity losses for rice and for aquaculture were multiplied by the salinized areas projected in the baseline scenario and the simulation value of 83% of areas invaded by salinity (Appendix 11). While the cash flow for storms and floods were assumed at the end of the period of the events, the cash low for salinity takes the form of annuities.

Table 18: Benefits of dike options (unit: million USD)

Benefit category by option	**2010**	**2020**	**2030**	**2040**	**2050**	**2060**	**2070**	**2080**	**2090**	**2100**	**2110**
Option 1	36.7	129.7	842.9	688.4	4,151.0	2,558.8	15,958.3	9,799.3	46,398.7	21,427.0	101,620.6
Storm	0.0	10.1	581.2	68.0	2,965.7	263.0	11,476.2	1,017.7	33,417.2	2,229.9	73,221.3
Flood	3.9	86.8	225.2	584.0	1,148.8	2,259.9	4,445.6	8,745.1	12,944.9	19,161.7	28,364.0
Salinity	32.8	32.8	36.5	36.5	36.5	35.9	36.5	36.5	36.5	35.4	35.4
Option 2	36.7	129.7	842.9	688.4	4,151.0	5,712.2	15,958.3	9,799.3	46,398.7	21,427.0	141,198.2
Storm	0.0	10.1	581.2	68.0	2,965.7	1,682.0	11,476.2	1,017.7	33,417.2	2,229.9	91,031.2
Flood	3.9	86.8	225.2	584.0	1,148.8	3,994.3	4,445.6	8,745.1	12,944.9	19,161.7	50,131.7
Salinity	32.8	32.8	36.5	36.5	36.5	35.9	36.5	36.5	36.5	35.4	35.4
Option 3	36.7	129.7	842.9	688.4	4,151.0	5,712.2	15,958.3	9,799.3	46,398.7	21,427.0	141,198.2
Storm	0.0	10.1	581.2	68.0	2,965.7	1,682.0	11,476.2	1,017.7	33,417.2	2,229.9	91,031.2
Flood	3.9	86.8	225.2	584.0	1,148.8	3,994.3	4,445.6	8,745.1	12,944.9	19,161.7	50,131.7
Salinity	32.8	32.8	36.5	36.5	36.5	35.9	36.5	36.5	36.5	35.4	35.4
Option 4	36.7	129.7	842.9	688.4	4,151.0	5,712.2	15,958.3	9,799.3	46,398.7	21,427.0	185,393.3
Storm	0.0	10.1	581.2	68.0	2,965.7	1,682.0	11,476.2	1,017.7	33,417.2	2,229.9	110,820.0
Flood	3.9	86.8	225.2	584.0	1,148.8	3,994.3	4,445.6	8,745.1	12,944.9	19,161.7	74,537.9
Salinity	32.8	32.8	36.5	36.5	36.5	35.9	36.5	36.5	36.5	35.4	35.4
Option 5	36.7	129.7	842.9	688.4	4,151.0	5,712.2	15,958.3	9,799.3	46,398.7	21,427.0	185,393.3
Storm	0.0	10.1	581.2	68.0	2,965.7	1,682.0	11,476.2	1,017.7	33,417.2	2,229.9	110,820.0
Flood	3.9	86.8	225.2	584.0	1,148.8	3,994.3	4,445.6	8,745.1	12,944.9	19,161.7	74,537.9
Salinity	32.8	32.8	36.5	36.5	36.5	35.9	36.5	36.5	36.5	35.4	35.4

Note: Losses due to salinity avoided is yearly annuity cash flow

Once they had been measured, the values of losses for each event (storms, floods, and salinity) were used to calculate the present values of benefits in the CBA calculation. Table 19 shows a summary of the results of the present values of the benefits of dikes, with a discount rate of 3% and a timeline of 100 years. The results showed that option 4 and option 5 had the highest benefits, of USD 23,875 million, and option 1 had the lowest benefit, of USD 18,797 million.

Table 19: Present values of the benefits of the different dike options (discount rate = 3%, units: million USD)

Dike options	Storm losses avoided	Flood losses avoided	Salinity losses avoided	Total benefit
Option 1	10,509.2	7,192.8	1,094.6	18,796.7
Option 2	11,759.6	8,721.1	1,094.6	21,575.3
Option 3	11,759.6	8,721.1	1,094.6	21,575.3
Option 4	12,789.3	9,991.0	1,094.6	23,874.9
Option 5	12,789.3	9,991.0	1,094.6	23,874.9

3.4 Cost-benefit Analysis

Cost estimations (Table 15) and benefit estimations (Table 19) under uncertainty conditions are jointly presented in Table 20. Based on the NPV decision rule, the results indicated that all the dike options could be recommended as appropriate dike adaptation measures. The larger in scale the dike systems were, the higher the ENPVs were. Among the dike alternatives applicable to the VMD, the initially small-scale dike options (option 3 and option 5) that have subsequent heightening as a built-in feature are the most appropriate choices if the impacts of rises in sea level are mainly storms, floods, and increased salinity.

Table 20: Cost-benefit analysis of sea dike options with uncertainty conditions (discount rate = 3%)

Category	Option 1	Option 2	Option 3	Option 4	Option 5
Benefit	18,796.7	21,575.3	21,575.3	23,874.9	23,874.9
Cost	361.9	432.5	397.4	666.5	532.8
ENPV	18,434.8	21,142.8	21,177.9	23,208.4	23,342.1

3.5 Sensitivity Analysis

Although estimations of costs and benefits were done under the uncertainty of storms, floods, and the state of salinity, changes that are not predictable in the impact levels of these factors could affect the CBA results. In order to ensure that the selected sea dike options were assessed at the appropriate levels, the sensitivity analyses of negative changes in discount rate and salinity were prepared in this section.

3.5.1 Change in discount rate

As the selected discount rate for a CBA calculation increases, the present values decrease. This causes changes in ENPV that provide benchmarks for selecting the best dike options. Tables 21, 22, and 23 show the CBA results in terms of present values of costs, present values of benefits, and ENPVs respectively if the discount rate is 6%. The results showed that the ENPVs of dike options were very sensitive to an increase in discount rate. The uncertainty of the socio-economic environment is a potential factor leading to changes in discount rate.

Table 21: Present values of costs of dike options (discount rate = 6%)

Dike options	Construction costs	Maintenance costs	Heightening costs	Total cost
Option 1	230.9	48.9	-	279.8
Option 2	339.6	48.9	-	388.4
Option 3	219.0	48.9	48.1	316.0
Option 4	480.7	97.7	-	578.4
Option 5	219.0	64.0	96.7	379.7

Table 22: Present values of benefits of dike options (discount rate = 6%)

Dike option	Storm losses avoided	Flood losses avoided	Salinity losses avoided	Total benefit
Option 1	1,409.9	1,048.5	593.9	3,052.3
Option 2	1,539.4	1,206.8	593.9	3,340.1
Option 3	1,539.4	1,206.8	593.9	3,340.1
Option 4	1,597.7	1,278.8	593.9	3,470.4
Option 5	1,597.7	1,278.8	593.9	3,470.4

Table 23: Cost-benefit analysis of sea dike options with uncertainty (discount rate = 6%)

Category	Option 1	Option 2	Option 3	Option 4	Option 5
Benefit	3,052.3	3,340.1	3,340.1	3,470.4	3,470.4
Cost	279.8	388.4	316.0	578.4	379.7
ENPV	2,772.5	2,951.7	3,024.1	2,892.0	3,090.7

3.5.2 Change in salinized areas

The CBA calculations showed that productivity losses avoided provided the highest proportion of total benefits. Values from salinity-affected areas were used to project values for all rice and aquaculture land. According to the Socio-economic Master Plan of Tra Vinh province, more than 90% of the total natural area of the province could become salinized. The natural area currently affected in six permanently-salinized regions (see section 1.7) is about 75%. It is reasonable to assume that these salinity-affected areas depend on the effectiveness of the river dike and sea dike systems. In order to assess the effect of this important variable on the ENPVs, a further analysis was conducted. Tables 24 and 25 show the present values of the benefits of ENPVs, assuming that 50% of the rice and aquaculture land is salinized. The sensitivity analysis showed that compared to the initial CBA assessment, the ENPVs were still robust.

Table 24: Sensitivity analysis of present values of benefits of different dike options (discount rate = 3%, salinized areas = 50%)

Dike options	**Storm losses avoided**	**Flood losses avoided**	**Salinity losses avoided**	**Total benefit**
Option 1	10,509.2	7,192.8	566.6	18,268.6
Option 2	11,759.6	8,721.1	566.6	21,047.2
Option 3	11,759.6	8,721.1	566.6	21,047.2
Option 4	12,789.3	9,991.0	566.6	23,346.8
Option 5	12,789.3	9,991.0	566.6	23,346.8

Table 25: Cost-benefit analysis of different dike options with sensitivity analysis (discount rate = 3%, salinized areas = 50%)

Category	**Option 1**	**Option 2**	**Option 3**	**Option 4**	**Option 5**
Benefit	18,268.6	21,047.2	21,047.2	23,346.8	23,346.8
Cost	361.9	432.5	397.4	666.5	532.8
ENPV	17,906.7	20,614.8	20,649.9	22,680.3	22,814.0

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

The impact on the Vietnamese Mekong Delta of a rise in sea level has been discussed in this report. Various sea dike options were proposed as appropriate adaptation measures. In the past, river dikes and sea dikes have helped to mitigate the impacts of salinity, protect the land, and maintain cropping systems. However, the existing sea dike system in the VMD is mainly made of earth and is not able to cope with large storms and high tides. The Government launched an ambitious sea dike upgrade program in 2009 that will run until 2020. This program has a total budget of VND 19.5 thousand billion (more than 1 billion USD) and its main objective is to establish a sea dike system that can adapt to the impacts of a future rise in sea level.

This study developed five dike options associated with three hypotheses regarding different scales of sea dike systems: option 1 would be suitable for a storm that occurs once every 20 years, option 2 and option 3 were suitable for a storm that occurs once every 50 years, and option 4 and option 5 were appropriate for a storm that occurs once every 100 years. Option 1 was a small, 2-meter-high dike; options 2 and 3 were medium in scale, at 3 meters high; and options 4 and 5 were large in scale, at 4 meters in height. Option 3 and option 5 were designed to be constructed in two phases: an initial investment would have to be made in a small-scale dike (the same as option 1, 2 meters in height) but the dike's main body would be constructed on a medium or large scale so that at a later stage the dike could be heightened and, therefore, upgraded. It was assumed that the lifespan of the dike in option 1 was 50 years. The lifespan of dike options 2, 3, 4 and 5 was set at 100 years.

The study used the risk CBA framework to assess the dike options proposed for the VMD. The baseline was derived from Tra Vinh province's Socio-economic Master Plan. To overcome the uncertainty in estimating the impacts of storms, floods, and salinity, a simulation analysis using Crystal Ball® was applied to these uncertainty variables. There were three cost components in the cost category: construction costs, maintenance costs, and dike heightening costs. To calculate the uniform probability distribution of dike costs, minimum values from Hillen et al. (2008) and maximum values from Mai et al. (2008)'s were used to estimate the simulated values of dike costs. The benefit category was defined as economic damage avoided in the VMD because of the protection offered by the dike system. There were two types of damage avoided: (1) losses from storms and floods sustained by houses, infrastructure such as roads, electricity supplies, water connections, crops destroyed, etc., and (2) the avoidance of productivity losses due to salinity. To estimate the economic losses caused by storms, the study proposed five scales of storms corresponding to different return periods: once every four years, once every 10 years, once every 20 years, once every 50 years, and once every 100 years. There were also four flood scenarios: once every two years, once every 10 years, once every 50 years, and once every 100 years. The economic damage due to each event was projected from the World Bank's projections (2010) and CCFSC's data. In order to estimate the rice yield loss due to salinity or seawater intrusion, a salinity dummy variable was introduced into the production function. The values of productivity losses were also calculated using the simulation procedure.

The risk CBA results showed that applying option 4 to the entire length of the dike system (147 km) incurred the highest present value (PV) of USD 666.5 million. Option 1 had the lowest PV costs, at USD 361.9 million. In general, dike options with built-in subsequent heightening incurred lower PV costs than alternative options that built to full height from the start. The results also showed that the benefits of losses avoided due to storms and floods were important. In the case of salinity, annual rice and aquaculture productivity losses avoided were USD 331.25 per hectare and USD 915 per hectare respectively. Based on the NPV decision rule, results indicated that all the dike options should be taken into account if dike adaptation measures were to be considered for the VMD. The larger in scale the dike systems were, the higher the ENPVs were. Of the dike alternatives applicable to the VMD, the small-scale dike options – option 1, option 3 and option 5 – should be chosen as the impacts of sea level rise focus on storms, floods, and salinity.

Following the CBA framework, sensitivity analyses of negative changes in discount rates and salinity impacts were conducted to assess the robustness of the projected dike options. First, the results showed that the ENPVs of dike options were very sensitive to changes in discount rate. Second, if the salinity-protected area is 50% of the total land area, the CBA results were not significantly altered.

It should be noted that the dike options in this study focused on economic valuations of storms, floods, and salinity. Other factors, such as the cost/value of loss of life, the cost/value of wetland protection, and the cost/value of planting mangrove forest to protect dikes, etc., were not calculated in the CBA analyses. Although arguments regarding the feasibility of a concrete sea dike system for coping with climate change impacts are still the subject of policy debates, the CBA results in this study have found initial evidence to support the construction of a concrete sea dike system for the VMD.

4.2 Recommendations

Based on the CBA analysis of projected sea dike options, the following recommendations can be given.

- First, the construction of sea dikes in the VMD as an adaptation measure to climate change is a suitable response.
- Second, because the effects of climate change are uncertain, climate change-related projects such as sea dike options should be appraised within a risk CBA framework. If a traditional CBA model is applied, the measurement of losses will not be appropriate.
- Third, if the proposed sea dike options in this report are taken into consideration, the existing national sea dike upgrading program would need to be revised as a concrete sea dike system with a century-long lifespan rather than a working life of 2020-2030. Although such a concrete sea dike system would be more expensive than the existing sea dike program, the benefits demonstrate that it deserves to be considered.
- Fourth, if the sea dike options in this report are to be seriously considered, then the establishment of initially small-scale dike systems would be the most appropriate option for the VMD.
- Fifth, in this study sea dike options were assessed mainly on the impacts of storms, floods, and salinity while other factors such as dike failure, lives lost, wetland protection, the benefits of mangrove forest protecting dikes, etc., were not measured. Therefore, in the next sea dike-related study, these important factors need to be considered in the calculations.

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APPENDICES

Appendix 1: Areas affected by sea level rises during low tide (unit: thousand hectares)

Water level (m)	**Status-quo**	**Without protective infrastructure**				**With protective infrastructure**			
		Scenario 1 (0.69 m)		**Scenario 2 (1.00 m)**		**Scenario 1 (0.69 m)**		**Scenario 2 (1.00 m)**	
	Area	Area	Com-pared to status-quo	Area	Com-pared to status-quo	Area	Com-pared to status-quo	Area	Com-pared to status-quo
0.0-0.5	215	0	-215	0	-215	0	-215	0	-215
0.5-1.0	1,944	0	-1,944	0	-1,944	88	-1,856	62	-1,883
1.0-1.5	1,413	2,196	782	1,499	86	2,128	714	1,287	-127
> 1.5	288	1,666	1,378	2,363	2,075	1,646	1,357	2,513	2,225
Total	3,862	3,862		3,862		3,862		3,862	

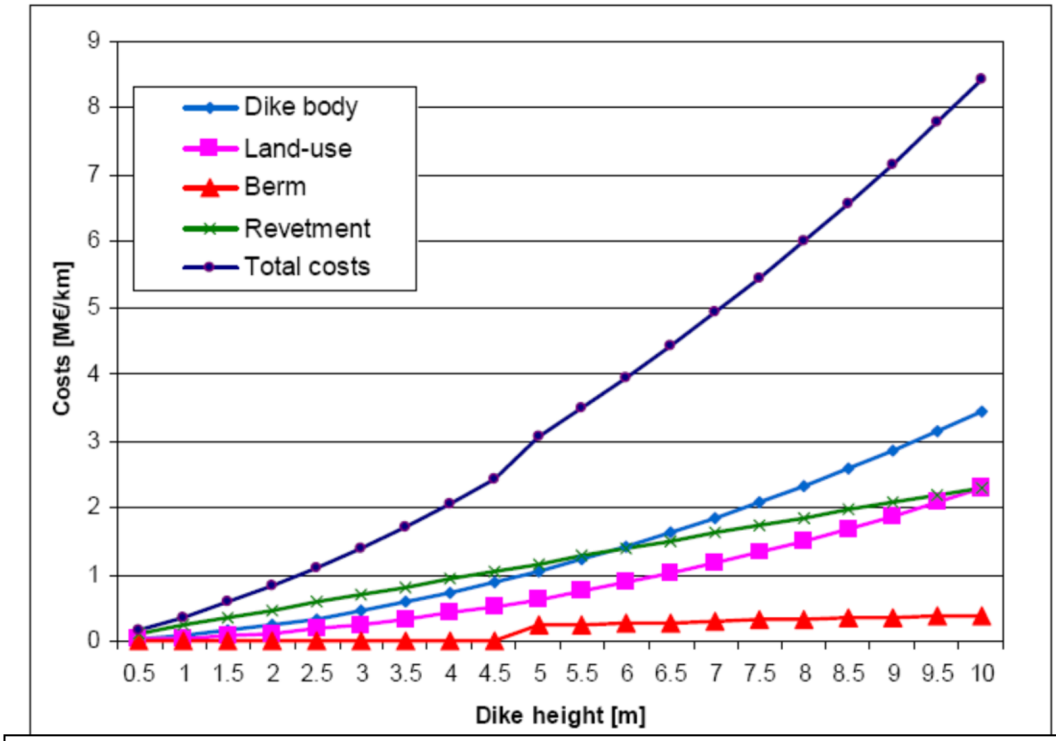
Source: Truong (2008)

Appendix 2: Areas affected by sea level rises during high tide (unit: thousand hectares)

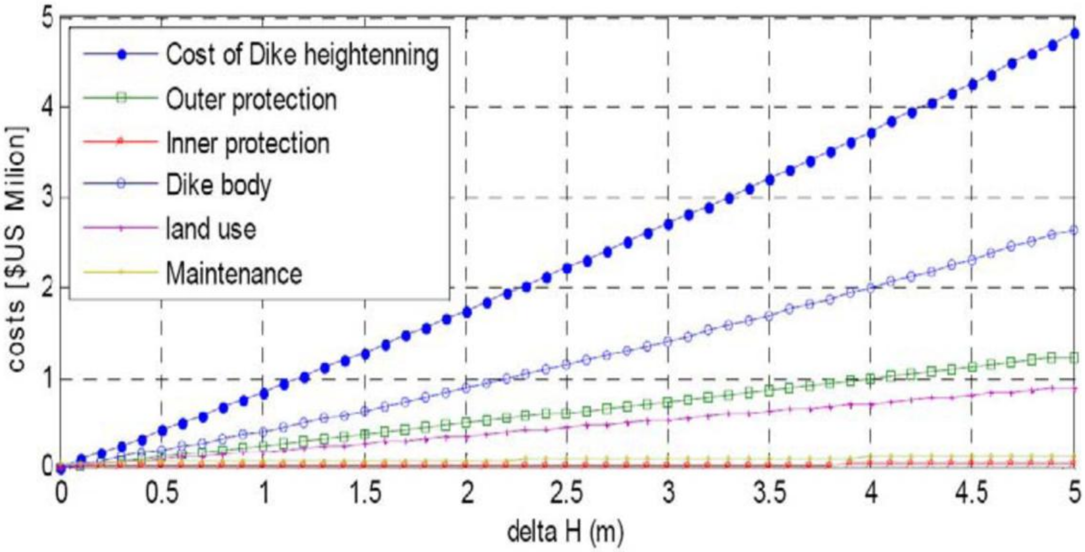
Water level (m)	Status -quo	Without protective infrastructure				With protective infrastructure			
		Scenario 1 (0.69 m)		Scenario 2 (1.00 m)		Scenario 1 (0.69 m)		Scenario 2 (1.00 m)	
	Area	Area	Compared to status -quo	Area	Compared to status-quo	Area	Compared to status-quo	Area	Compared to status-quo
H < 0.5	1,049	289	-761	51	-998	202	-848	47	-1,002
0.5<H≤1.0	1,063	645	-418	629	-435	604	-459	496	-567
1.0<H≤1.5	724	998	274	451	-273	1,007	284	421	-302
1.5<H≤2.0	459	1,156	697	1,738	1,279	1,270	811	1,880	1,421
2.0<H≤2.5	288	410	121	568	280	414	126	592	304
2.5<H≤3.0	212	281	69	323	111	281	69	323	111
H > 3.0	66	84	17	102	36	84	18	102	36

Source: Truong (2008)

Appendix 3: Comparison of costs of sea dikes between Hillen et al. (2008) and Mai et al. (2008)



Costs of dykes as a function of dyke height according to Hillen et al. (2008)



Costs of dykes as a function of dyke height according to Mai et al. (2008)

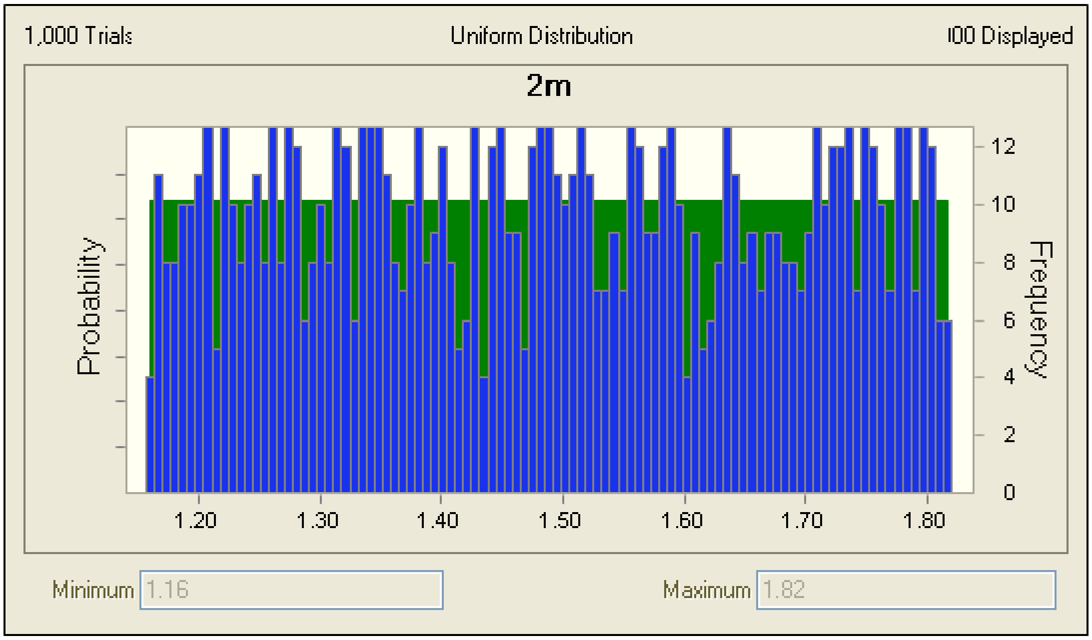
Appendix 4: Storms in the Mekong Delta, 1961-2010

Place	**Time**	**Name**	**Storm Level**	**Total**
Number of storm events in Vietnam				258
Number of storm events in South Vietnam, in which				17
Binh Thuan-Ca mau	18/01/2010	Tropical Storm	Level 6 (39-49 km/h)	
Binh Thuan-Ca mau	23/11/2009	Tropical Storm	Level 6 (39-49 km/h)	
Binh Thuan-Ca mau	22/01/2008	Tropical Storm	Level 6 (39-49 km/h)	
Binh Thuan-Ca mau	13/01/2008	Tropical Storm	Level 6 (39-49 km/h)	
Binh Thuan-Ca mau	4/11/2007	Peipah	Level 6 (39-49 km/h)	
Binh Thuan-Ca mau	2/11/2007	Tropical Storm	Level 6 (39-49 km/h)	
Binh Thuan-Ca mau	24/11/2006	Durian	Level 13 (>133 km/h)	
Binh Thuan-Ca mau	22/10/1999	Tropical Storm	Level 6 (39-49 km/h)	
Binh Thuan-Ca mau	11/11/1998	CHIP	Level 6 (39-49 km/h)	
Binh Thuan-Ca mau	31/10/1997	LINDA	Level 8 (62-74 km/h)	
Binh Thuan-Ca mau	7/11/1996	ERNIE	Level 6 (39-49 km/h)	
Binh Thuan-Ca mau	26/06/1994	Tropical Storm	Level 6 (39-49 km/h)	
Binh Thuan-Ca mau	3/11/1988	TESS	Level 11 (103-117 km/h)	
Binh Thuan-Ca mau	10/10/1985	Tropical Storm	Level 6 (39-49 km/h)	
Binh Thuan-Ca mau	14/11/1973	THELMA	Level 10 (89-102 km/h)	
Binh Thuan-Ca mau	18/10/1968	HESTER	Level 8 (62-74 km/h)	
Binh Thuan-Ca mau	28/11/1962	LUCY	Level 9 (75-88 km/h)	
Ratio of South: Vietnam (%)				6.56
Average of storms per year				0.3
Number of storms level 10 and above				3
Average number of storms level 10 and above per year				0.1

Source: NCHMF/MONRE, http://www.thoitietnguyhiem.net/BaoCao/BaoCaoBao.aspx

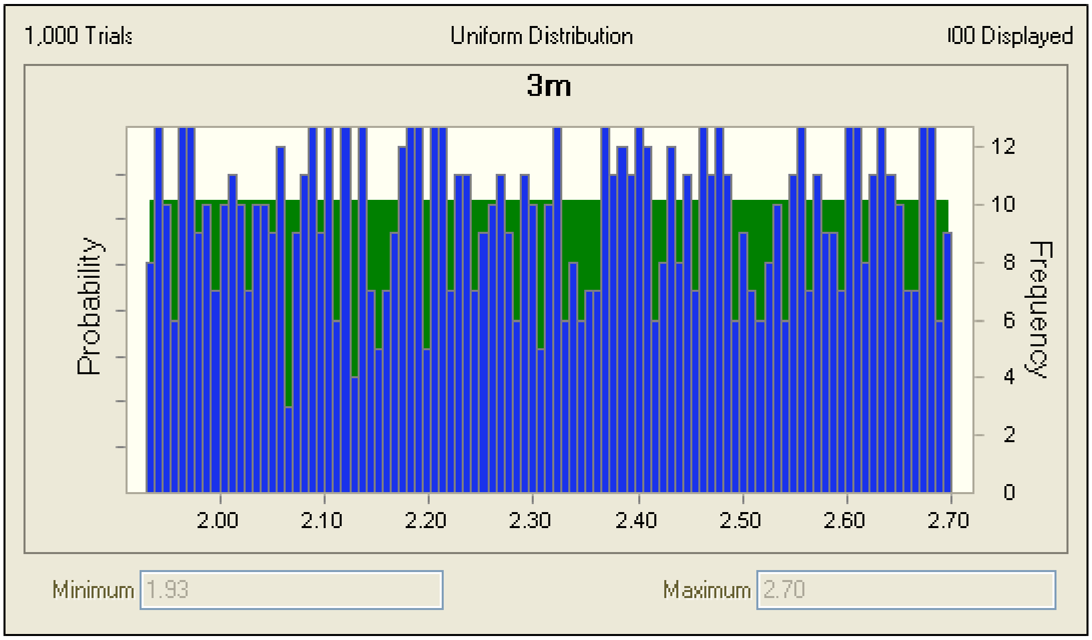
Appendix 5: Results of simulation of construction costs for a 2-meter-high dike

Statistic	Assumption values	Uniform distribution
Trials	1,000	'---
Mean	1.49	1.49
Median	1.49	1.49
Mode	'---	'---
Standard deviation	0.19	0.19
Variance	0.04	0.04
Skewness	0.0206	0
Kurtosis	1.77	1.8
Coeff. of variability	0.1282	0.1286
Minimum	1.16	1.16
Maximum	1.82	1.82
Mean std. error	0.01	'---



Appendix 6: Results of simulation of construction costs for a 3-meter-high dike

Statistic	Assumption values	Uniform distribution
Trials	1,000	'---
Mean	2.31	2.31
Median	2.32	2.31
Mode	'---	'---
Standard deviation	0.22	0.22
Variance	0.05	0.05
Skewness	-0.0035	0
Kurtosis	1.8	1.8
Coeff. of variability	0.0969	0.0962
Minimum	1.93	1.93
Maximum	2.7	2.7
Mean std. error	0.01	'---

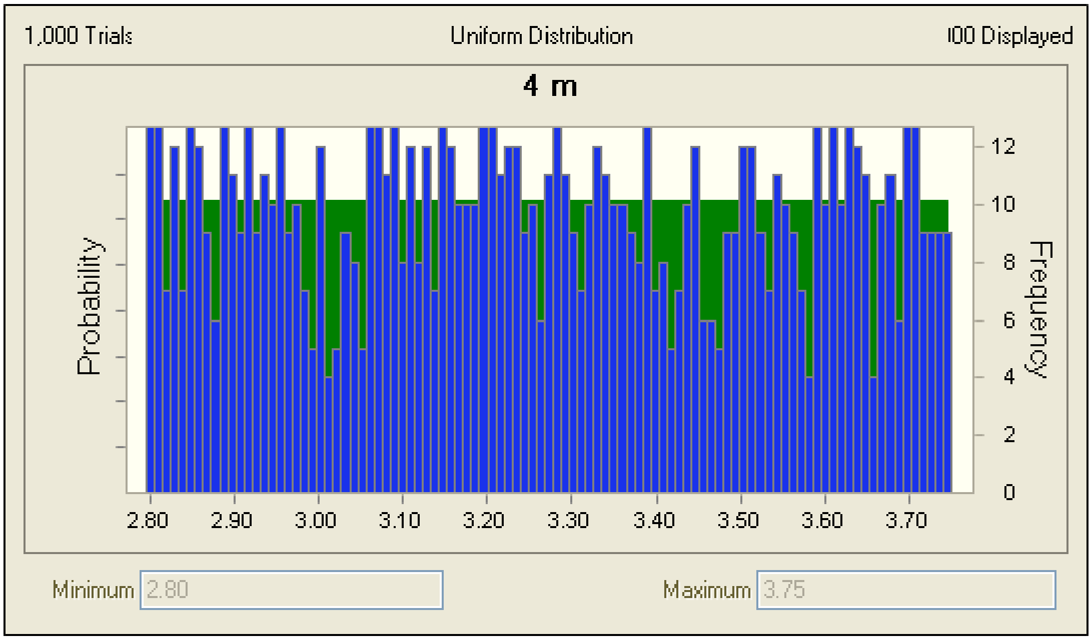


Minimum 1.93

Maximum 2.70

Appendix 7: Results of simulation of construction costs for a 4-meter-high dike

Statistic	Assumption values	Uniform distribution
Trials	1,000	'---
Mean	3.26	3.27
Median	3.25	3.27
Mode	'---	'---
Standard deviation	0.28	0.28
Variance	0.08	0.08
Skewness	0.0525	0
Kurtosis	1.8	1.8
Coeff. of variability	0.0855	0.0841
Minimum	2.8	2.8
Maximum	3.75	3.75
Mean std. error	0.01	'---

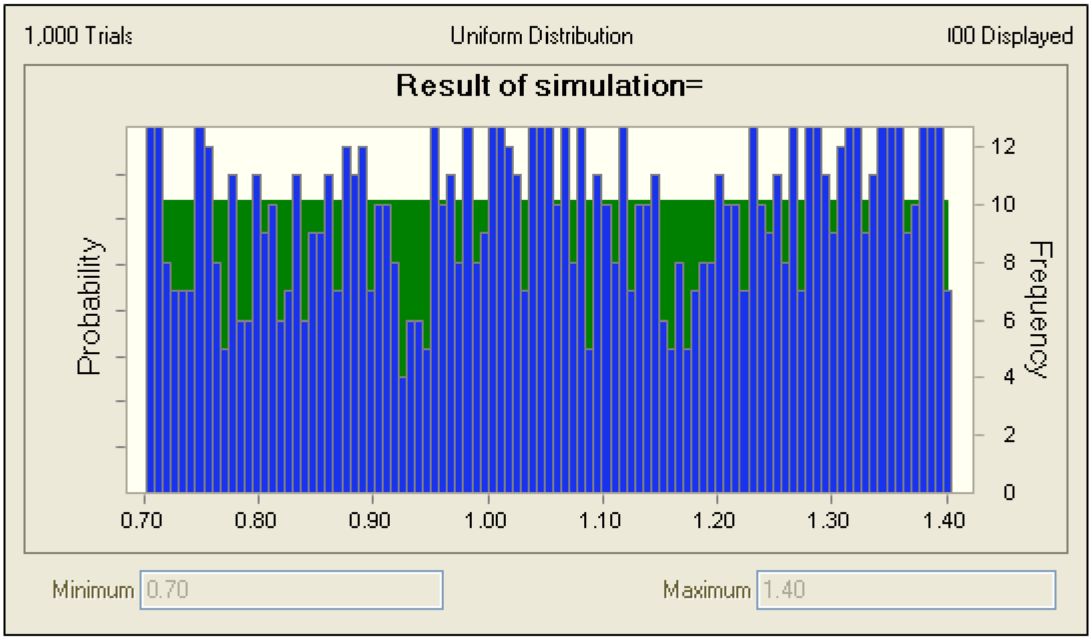


Minimum 2.80

Maximum 3.75

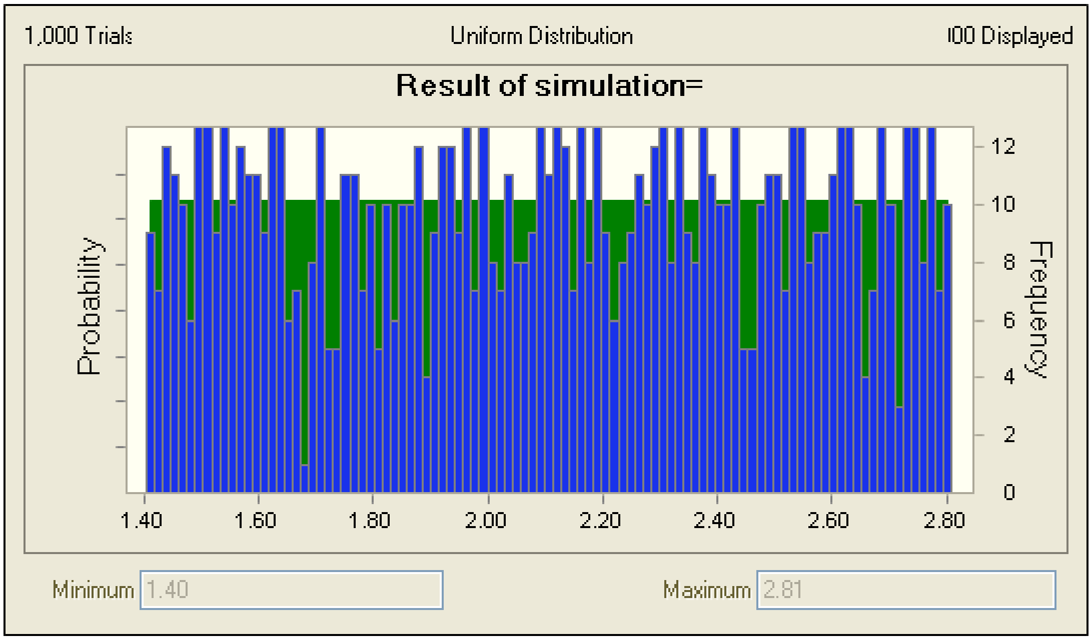
Appendix 8: Results of simulation of construction costs for variable heightening of dike (by 1 meter)

Assumption: **Result of simulation =**		
Statistic	**Assumption values**	**Uniform distribution**
Trials	1,000	'---
Mean	1.07	1.05
Median	1.06	1.05
Mode	'---	'---
Standard Deviation	0.21	0.2
Variance	0.04	0.04
Skewness	-0.088	0
Kurtosis	1.81	1.8
Coeff. of Variability	0.1926	0.1925
Minimum	0.7	0.7
Maximum	1.4	1.4
Mean Std. Error	0.01	'---



Appendix 9: Results of simulation of construction costs for variable heightening of dike (by 2 meters)

Assumption: **Result of simulation =**		
Statistic	**Assumption values**	**Uniform distribution**
Trials	1,000	'---
Mean	2.11	2.11
Median	2.12	2.11
Mode	'---	'---
Standard Deviation	0.41	0.41
Variance	0.17	0.16
Skewness	-0.0385	0
Kurtosis	1.79	1.8
Coeff. of Variability	0.1936	0.1925
Minimum	1.41	1.4
Maximum	2.81	2.81
Mean Std. Error	0.01	'---

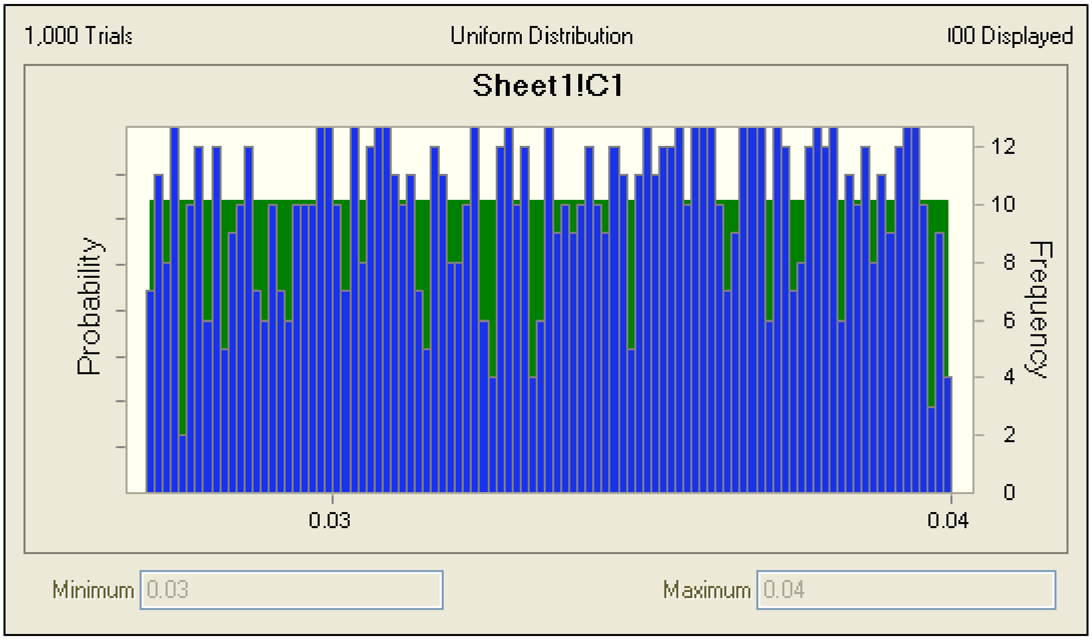


Minimum 1.40

Maximum 2.81

Appendix 10: Results of simulation of maintenance costs

Statistic	Assumption values	Uniform distribution
Trials	1,000	'---
Mean	0.03	0.03
Median	0.03	0.03
Mode	'---	'---
Standard deviation	0	0
Variance	0	0
Skewness	-0.0948	0
Kurtosis	1.81	1.8
Coeff. of variability	0.1093	0.112
Minimum	0.027	0.03
Maximum	0.04	0.04
Mean std. error	0	'---

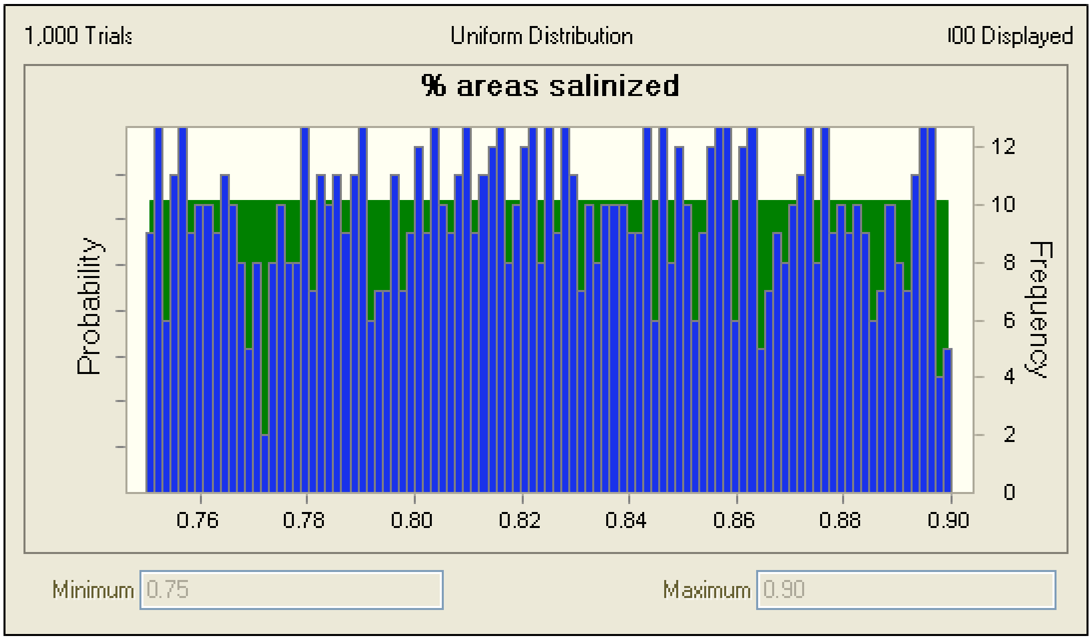


Minimum 0.03

Maximum 0.04

Appendix 11: Results of simulation of salinity-affected rice and aquaculture areas (%)

Statistic	Assumption values	Uniform distribution
Trials	1,000	'---
Mean	0.83	0.83
Median	0.83	0.83
Mode	'---	'---
Standard deviation	0.04	0.04
Variance	0	0
Skewness	-0.0297	0
Kurtosis	1.89	1.8
Coeff. of variability	0.0509	0.0525
Minimum	0.75	0.75
Maximum	0.9	0.9
Mean std. error	0	'---


1,000 Trials

Uniform Distribution

100 Displayed

Minimum 0.75

Maximum 0.90

Appendix 12: Costs of present values of dike options (discount rate = 10%, unit: million USD)

Dike option	Unit cost per km	2010	2015	2020	2030	2060
Option 1						
Construction cost	1.490	219.030	0.000	0.000		219.030
n		1				50
PV (construction cost)		220.896				1.866
Maintenance cost	0.020	2.940				
n		100				
PV (maintenance cost)		29.398				
Total cost PV		250.294				
Option 2						
Construction cost	2.310	339.570				
n		1				
PV (construction cost)		339.570				
Maintenance cost	0.020	2.940				
n		100				
PV (maintenance cost)		29.398				
Total cost PV		368.968				
Option 3						
Construction cost	1.490	219.030				
n		1				
PV (construction cost)		219.030				
Maintenance cost	0.020	2.940				
n		100				
PV (maintenance cost)		29.398				
Heightening cost	1.050				154.350	
n					20	
PV (heightening cost)		22.943			22.943	
Total cost PV		271.371				
Option 4						
Construction cost	3.270	480.690				
n		1				
PV (construction cost)		480.690				
Maintenance cost	0.040	5.880				
n		100				
PV (maintenance cost)		58.796				
Total cost PV		539.486				
Option 5						
Construction cost	1.490	219.030				
n		1				
PV (construction cost)		219.030				
Maintenance cost	0.02 - 0.04	2.940			5.880	
n		20			80	
PV (maintenance cost)		25.030			58.771	
Heightening cost	2.110				310.170	
					20	
PV (heightening cost)		46.105			46.105	
Total cost PV		290.165				

Note: Total length of dike projected as 147 km (see Table 3); lifespan of dike in option 1 is 50 years; lifespan of dike in options 2, 3, 4 and 5 is 100 years; after 20 years, the dikes in options 3 and 5 are heightened to the same level as the dikes in options 2 and 4 respectively.

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