# 8 Water Management for Agricultural Production in a Coastal Province of the Mekong River Delta Under Sea-level Rise

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**Abstract**

Bac Lieu province, a low-lying coastal province in the Ca Mau peninsula of the Mekong River Delta (MRD) of Vietnam, is recognized as an area strongly affected by sea-level rise (SLR) accompanying global climate change. SLR will aggravate inundation and salinity intrusion and hence exert a strong influence on agriculture and aquaculture production in the province. The study presented in this chapter aims to quantify the impacts of SLR on agriculture in this province and to propose adaptive options.

The 'Vietnam River Systems and Plains' (VRSAP) model was used for simulation of water level, flow and salinity in the canal network of the MRD for 3 years of low, average and high water volume from upstream of the MRD and different levels of SLR (12, 17, 30, 50 and 75 cm). Under present sea level conditions, the western part of the province faces the highest flooding risk in October during the rainy season. In the dry season, salinity is high in the western part where farmers grow brackish water shrimp, while it is low in the eastern part where rice is grown. The inundation depth increases with the level of the SLR. For SLR less than 30 cm, salinity is expected to decrease slightly due to more fresh water from the Bassac River. When SLR is higher than 30 cm, salinity in the eastern part will also increase because the saline water intrudes into freshwater intake canals along the Bassac River. In the near future, adjustment of the cropping calendar as well as the operations of existing water control structures will be required. In the distant future, additional structures will be needed to cope with aggravated inundation and salinity.

## 8.1 Introduction

Rice is the most important food source for half of the world's population and the most important crop in Vietnam. The MRD, with an annual rice production of 16 Mt, accounts for 50% of the national rice production. The MRD, with a total area of 4 Mha and a total population of 17.5 million in 2011, has been identified as a region that will be significantly affected by SLR associated with climate change (MONRE, 2012). The most

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important impact of SLR is the aggravation of inundation and salinity intrusion that strongly influences agriculture and aquaculture production in the MRD, especially in the coastal provinces (Dasgupta *et al*., 2007; IPCC, 2007).

An area of 770,000 ha of land (19% of the MRD) may suffer from frequent and severe submergence by the end of the century due to SLR (MONRE, 2012). In addition, SLR also enlarges the areas affected by salinity intrusion. With a 75 cm SLR by 2100 (MONRE, 2012), 17.5% of the population in the MRD will be directly affected. Developing adaptation strategies to SLR for the coastal provinces is crucial to Vietnam's economy, food security and livelihoods of people living in these provinces. It requires quantitative information on impacts of SLR on the salinity and submergence in the affected areas, in particular at the 'hot spots' where impacts are the most aggravated (Wassmann *et al*., 2004). Bac Lieu, a low-lying coastal province in the Ca Mau peninsula of the MRD, is a representative province for considering influences of SLR. It was estimated that with SLR of 1 m in 2100, 39% of the provincial area and 45% of its population will be affected (Carew-Reid, 2007).

The objectives of the study presented in this chapter are: (i) to evaluate the impacts of SLR on salinity intrusion and submergence in Bac Lieu province under different conditions of upstream flows; and (ii) to recommend the adaptation strategy for agriculture production in the province.

## 8.2 Methodology

### 8.2.1 The study area

The study area is Bac Lieu province at the southern extent of the MRD (Fig. 8.1). It is very flat (elevation from 0.2 m to 0.8 m above mean sea level) and has a dense canal network for navigation, irrigation and drainage. The network comprises the Quan Lo Phung Hiep (QLPH) main canal that connects the study area to the Bassac River, a main branch of the Mekong River in the MRD (Fig. 8.1), and a series of canals of different sizes with a total length of 715 km. Four primary canals, typically 30–50 m wide and 4–10 m deep with 10 m-wide embankments, are perpendicular to the QLPH canal at 4–5 km apart. Secondary canals, 10–15 m wide and 1.5–2.0 m deep with 7 m-wide embankments, connect to the primary canals at 1 km spacing. Tertiary canals, typically 5–8 m wide and 1–2 m deep with 5 m-wide embankments, are spaced at 500 m along the secondary canals. Rice and shrimp fields are usually connected to secondary and tertiary canals by tiny channels.

Twenty seven sluices along the national road No. 1 (NR1) and a series of seasonal dams (Fig. 8.1) are operated for controlling saline and freshwater flows in the study area. Among these sluices, the Ho Phong (HP) and Gia Rai (GR), the two largest three-gate sluices 3 × 8 m and 3 × 7.5 m wide, respectively, play an effective role in managing salinity and drainage. However, sluices at the West Sea side have not been built. Therefore the province is still intruded by saline water, although inflow from the West Sea is not as strong as from the East Sea due to smaller tidal amplitude and diurnal tide. Fresh water for rice and upland crops in the eastern part of the province is delivered from the Bassac River through the QLPH main canal. In general, the sluice system and temporary dams divide the province into three different areas (Fig. 8.1): (i) the freshwater area including zones I, V, VI and VII in the east; (ii) the brackish area including zones II, III, IV, VIII and IX in the west; and (iii) the saline area of zone X in the south.

There are two distinct seasons in the province: the rainy season from May to November, accounting for 86% of total annual rainfall, which averages 2300 mm year$^{-1}$, and the dry season from December to April. Land use in the province is associated closely with the distribution of brackish and fresh water. Farmers grow rice and upland crops on a total area of 72,542 ha (SNIAPP, 2008) in the eastern part comprising of zones I, V, VI and VII. Shrimp culture is mainly practised in the western part (zone IV, VIII and IX) and at the south of NR1 (zone X). In zones II and III, the buffer area

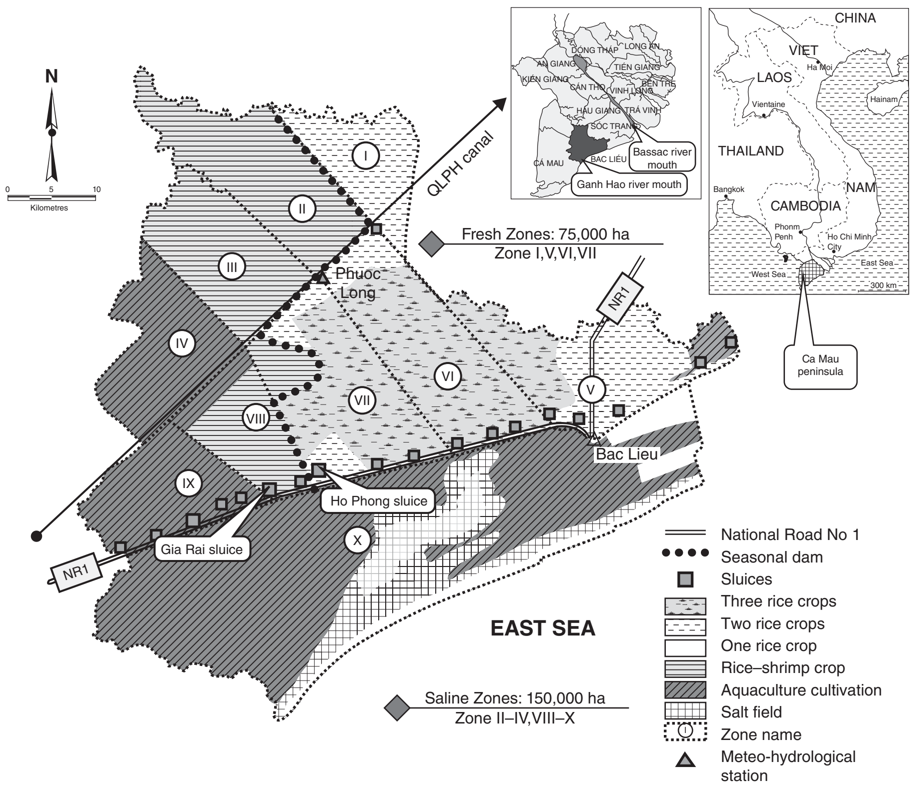


**Fig. 8.1.** Land use in Bac Lieu province in 2008 (from SNIAPP, 2008).

between fresh and brackish water north of the QLPH canal, shrimp–rice combination is practised with shrimp raised during February–July while rice cropping starts in August–September and is harvested in December–January.

Three rice crops are grown in the province: (i) He Thu (summer–autumn) is often sown in the middle of April and harvested in late July. Summer–autumn rice is mainly rainfed with supplementary irrigation when drought occurs and may suffer from salinity if rainfall in April–May is low; (ii) Thu Dong (autumn–winter) is usually grown from the end of July to early August. Autumn–winter rice is completely rainfed and often suffers from submergence in late September and October; and (iii) Dong Xuan (winter–spring) is sown after the harvest of the autumn–winter crop at the end of November–December. Winter–spring rice is fully irrigated, therefore it can be grown only in areas where salinity intrusion is completely controlled. In some years this crop suffers from shortage of irrigation water, therefore some farmers have replaced it with upland crops.

### 8.2.2 Setting the Vietnam River Systems and Plains model

The 'Vietnam River Systems and Plains' (VRSAP) model is a hydraulic and water quality model to simulate water flow, salinity and acidity in a complex canal network in the coastal zone influenced by tide (Phong *et al.*, 2007). In this study, VRSAP was used to simulate water level, flow and salinity in the canal and river systems in MRD, bounded by the Mekong river system from the delta boundary at Kratie in Cambodia to the East Sea and the West Sea in the Vietnamese

Mekong Delta. The model scheme includes 5066 segments (canal and river reaches and hydraulic structures), 3457 nodes (junction of two or more segments) and 2882 fields (space bounded by three or more segments). Boundary conditions were set using water level and salinity observations at 11 stations along the East and West Seas, and flow at Kratie station. Daily rainfall at 24 meteorological stations in MRD was also used as input data. Topographical data of mainstream rivers and canals were updated with surveyed data from 1999 to 2006. Topographical data of secondary and tertiary canals in Bac Lieu province were provided by the local authority in 2008. Elevation of ground surface in the MRD was derived from the elevation map provided by MONRE (2010) at the scale of 1:2000. Water demand for all land uses in the study area was calculated from evapotranspiration data for every 10-day interval.

Water level, discharge and salinity estimates from the VRSAP model were calibrated and validated with observed data in 1996 in the study area (Wassmann *et al*., 2004). The year of 2008 is the most recent year having sufficient hydrological data and sluice operation information for modelling and is used as the 'baseline' year. In that year two main sluices along NR1, the Ho Phong and Gia Rai, were opened a few days in each month of the dry season (November–May) for intake of saline water into zones VIII, IX, IV, III and II for shrimp cultivation, and opened permanently in the wet season from June to October for drainage. The model results showed a comparison between simulated and observed water levels and salinity in 2008 at several locations in the Ca Mau peninsula such as Phuoc Long and Bac Lieu (Fig. 8.2).

### 8.2.3 Sea-level rise scenarios

Water levels at boundary stations along the East and West Seas were assumed to rise

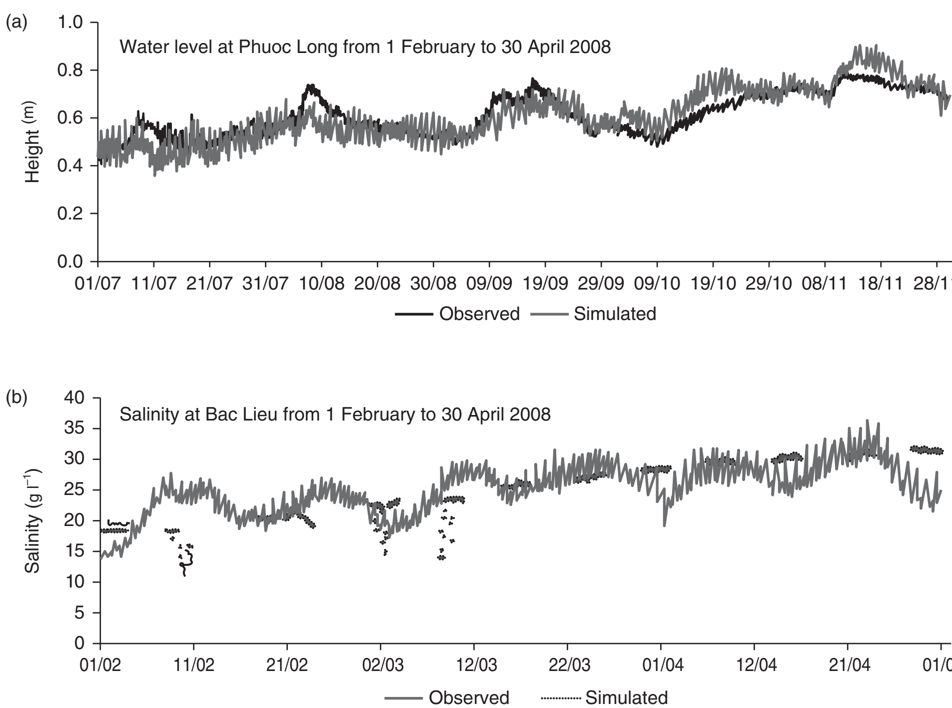


**Fig. 8.2.** Comparison of observed and simulated water level at Phuoc Long in the wet season and salinity at Bac Lieu in the dry season.

with sea level by 12, 17, 30, 50 and 75 cm SLR in 2030, 2040, 2050, 2075 and 2100, respectively (MONRE, 2012). The impacts of SLR were considered for different upstream flows. From time series data of daily upstream discharge at Kratie from 1985 to 2008 (MRC, 2008), low, average and high water conditions in 1998, 2004 and 2000, with the total annual volumes of 240 $Mm^3$, 362 $Mm^3$ and 507 $Mm^3$, respectively, were selected to compare with the baseline year 2008 with a total annual volume of 404 $Mm^3$. Impacts of climate change and future upstream hydropower and irrigation development are not included. The sluice operation in 2008 is applied for all cases.

Daily water level and salinity at nodes in the canal network estimated by VRSAP model were used to assess the impacts of SLR. Submergence and drainage capacities in each zone of the province are evaluated by comparing maximum and minimum water level in canals with average ground surface elevation. Salinity levels exceeding a threshold of 4 $g l^{-1}$ are considered deleterious for rice production. From these assessments, adaptation strategies in agriculture production are recommended, for example, application of new rice varieties with enhanced submergence or salinity tolerance.

## 8.3 Results and Discussions

### 8.3.1 Submergence and salinity in Bac Lieu province under present sea level

Daily water level is particularly high if heavy rain coincides with high tide and increased flow into the province from the Bassac River, as indicated by the variation of water level at Ganh Hao river mouth (Fig. 8.3, location in inset map of Fig. 8.1). The effects of tide and local rainfall in the province are stronger than upstream flow as reflected by higher water level in the baseline year 2008 than in all other years (Fig. 8.3), although water volume from upstream in 2008 is only slightly higher than in the normal water year 2004 and lower than in the high water year 2000.

Similarly, Fig. 8.4 also shows that maximum inundation depth, which usually occurs in zones II, III and IV during October–November, is rather high in the baseline 2008 compared to other years. These maps reaffirm that for a province close to the coast such as Bac Lieu, the effect of total volume from the Mekong upstream on inundation depth is not as important as the simultaneous occurrence of high tide, local rainfall and high daily upstream flow.

The tide from the East Sea is a dominant influencing factor on salinity intrusion in

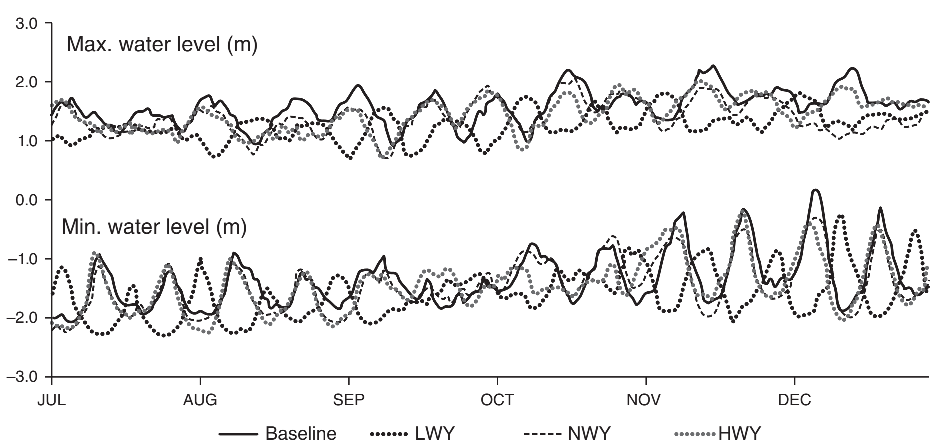


**Fig. 8.3.** Daily maximum and minimum water levels at Ganh Hao river mouth in low water (LWY, 1998), normal water (NWY, 2004) and high water (HWY, 2000) years compared with baseline (2008).

the eastern zones (Fig. 8.5). Salinity in the unprotected zone X and in the well-protected zones I, V, VI and VII does not vary much year by year. On the other hand, variations of salinity in different hydrological years are clearer in the western zones II, III, IV, VIII and IX with lower salinity and shorter duration in the high water year. In the low water year, the salinity peak in zone IX occurs in April (32 g $l^{-1}$) and extends until May.

### 8.3.2 Impacts of sea-level rise on inundation

For all SLR scenarios analysed using inland water conditions of the baseline year 2008, both maximum and minimum daily water levels in the canals in the study area will increase. Under the present sea level the drainage capacity in the province, represented by the difference between the daily minimum water level and ground elevation

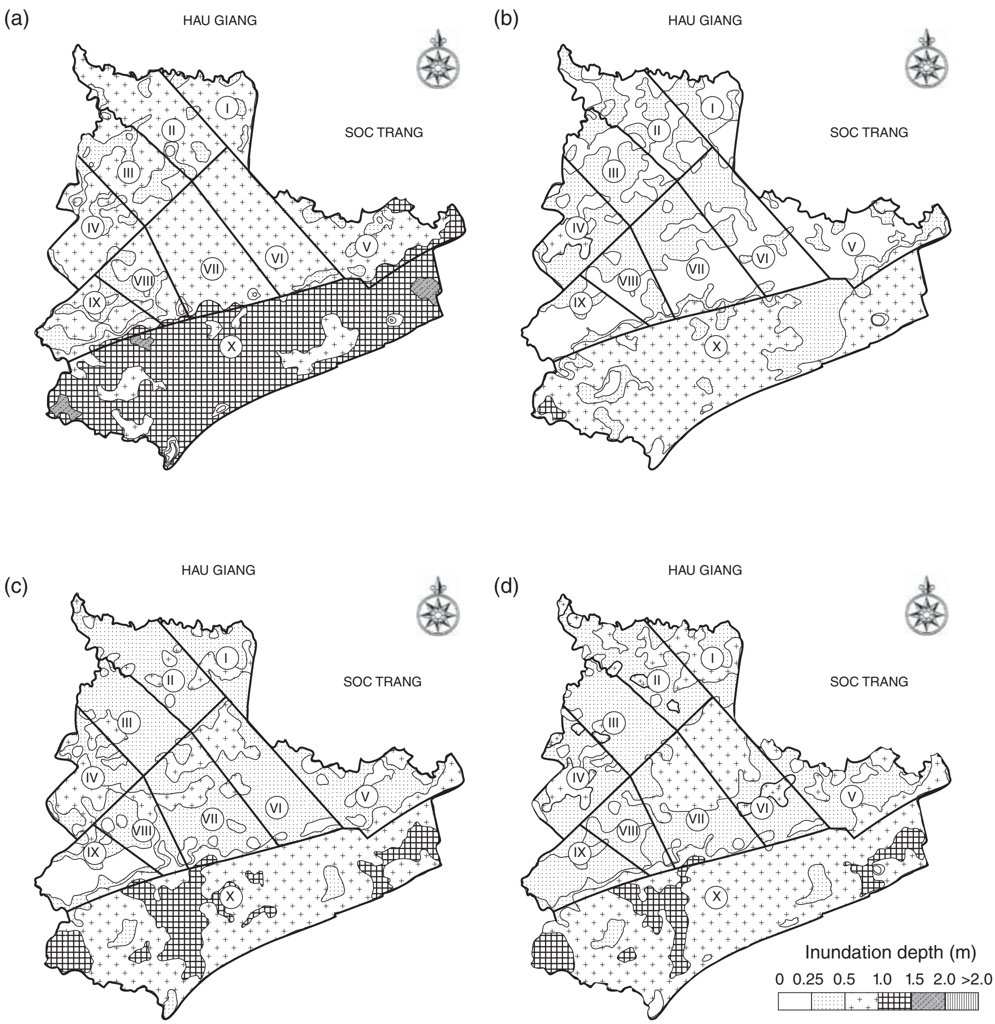


**Fig. 8.4.** Maximum inundation depth in rainy season for (a) baseline year 2008, (b) low water year 1998, (c) normal water year 2004 and (d) high water year 2000.

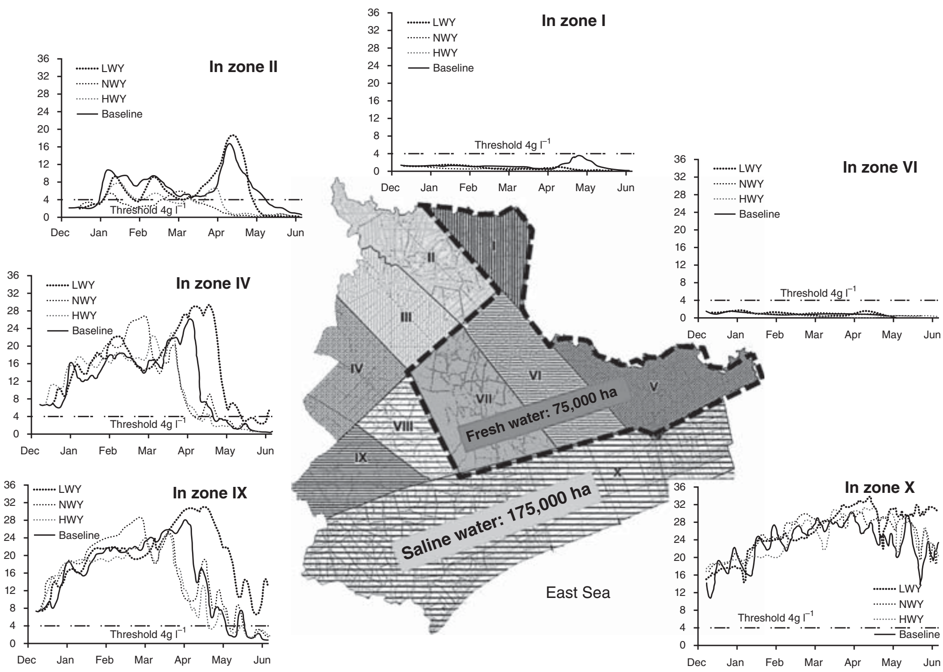


**Fig. 8.5.** Maximum salinity (g $l^{-1}$) in dry season in baseline 2008, low water year (LWY, 1998), normal water year (NWY, 2004) and high water year (HWY, 2000).

in Fig. 8.6, is hindered by the high water level at both high and low tides. Water in zones VIII and IX at the south-west of QLPH canal, and in zone X at the south of NR1 can be easily drained out during low tide because the minimum water level in canals is generally lower than the ground elevation. Drainage in the western zones of QLPH canal (zones I, II, III, IV) is poor in the rainy season, therefore inundation will be more serious with SLR.

With a 17 cm or 30 cm SLR, drainage capacity could be maintained in the eastern part of QLPH canal (such as zone V) where sluices are operated for drainage during low tides from July to October. With SLR up to 30 cm, the area with inundation depth of above 0 to 1 m and above 1 m will be 50% and 35% of the total province area, respectively (Fig. 8.7d, e, f).

For SLR higher than 30 cm, inundation will be severe if the water control systems (sluice, dyke and canal) are not improved (Figs 8.6, 8.7e, f). Under a 75 cm SLR scenario, the area with inundation depths of less than 1 m and above 1 m will cover 10% and 90% of the total province area, respectively (Fig. 8.7f).

The effects of a 75 cm SLR on maximum inundation depth in the low and high water years are shown in Fig. 8.8. Compared with the situation in these years under present SLR (Figs 8.4b, d), a larger area will be submerged deeper than 1 m. However, due to a worse combination of high tide, local rainfall and daily upstream flow, the maximum inundation in 2008 (Fig. 8.7f) was as severe as in the high water year 2000 (Fig. 8.8b) as discussed above.

### 8.3.3 Impacts of sea-level rise on salinity intrusion

In the baseline year 2008 sluices along NR1 and temporary dams were operated to manage satisfactorily saline water intake for shrimp production in western and southern parts of the Bac Lieu province and also to

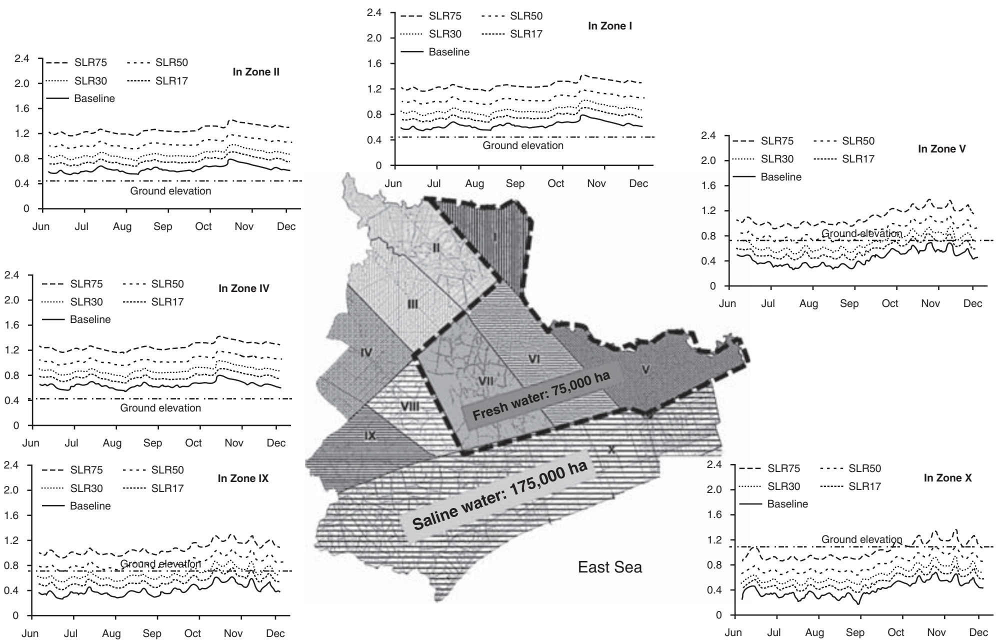


**Fig. 8.6.** Minimum daily water level (m) in the rainy season under 17, 30, 50 and 75 cm SLR with inland water conditions of the 2008 baseline year.


**Fig. 8.7.** Maximum inundation in the rainy season in (a) baseline year (2008) and with sea-level rise of (b) 12, (c) 17, (d) 30, (e) 50 and (f) 75 cm.

protect the rice production area in the eastern part from salinity intrusion.

SLR will cause higher water level in the Bassac River and consequently increase water level in the QLPH canal and other canals that connect this river to the Ca Mau peninsula. Figure 8.9 indicates the increase of water level at stations along the Bassac River and the up-river extent of the salinity boundary of 4g $l^{-1}$ (a threshold for rice production) for different SLR scenarios. For all SLR scenarios this salinity boundary will not go beyond 50 km from the mouth of the Bassac River. The maximum intrusion is 47.6 km, which is about 7 km further upstream compared with the situation at the present sea level. The projected increase in salinity intrusion up the Bassac River is not expected to affect intake of fresh water into the canal network of the QLPH area as the intake points are from Cai Con station, 60 km from the river mouth, and further upstream. On the other hand elevated water levels upstream of Cai Con station will increase freshwater volume flowing through the upper intake points into the QLPH area. This additional amount will reduce salinity, even in the dry season, at the northern and western parts of Bac Lieu province.

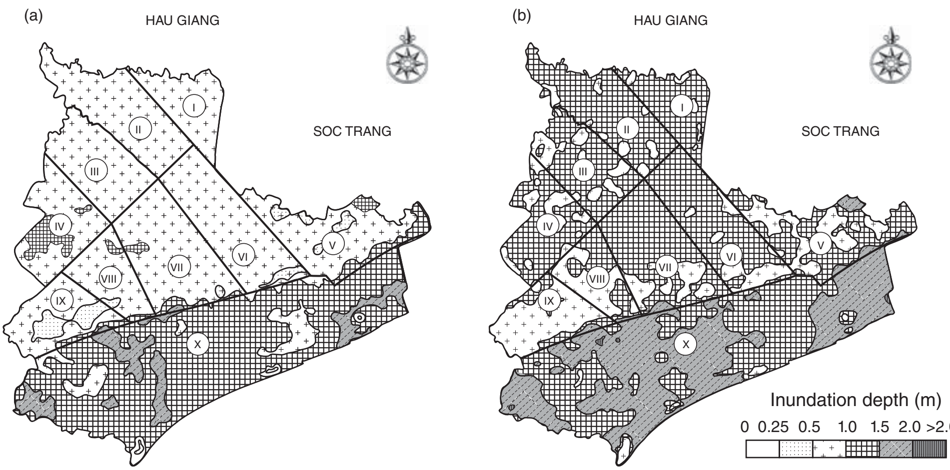


**Fig. 8.8.** Maximum inundation in the rainy season under 75 cm SLR in (a) low (1998) and (b) high (2000) water years.

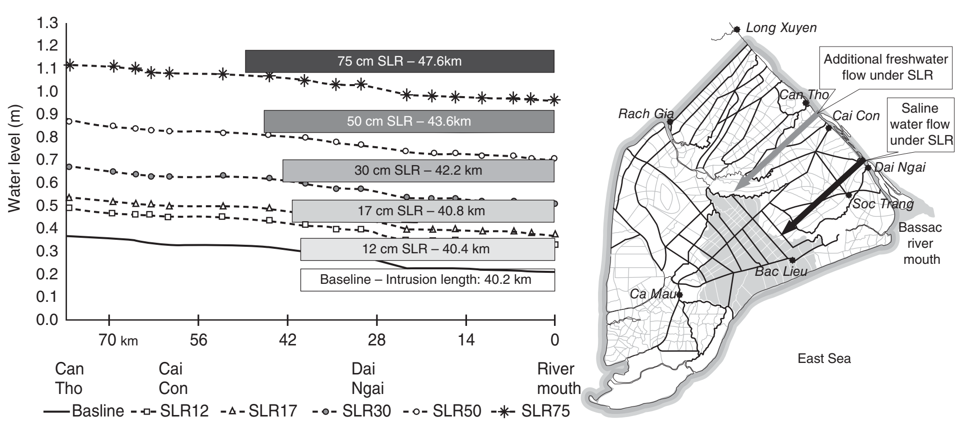


**Fig. 8.9.** The average water level along the Bassac River and maximum length of saline intrusion of 4 g $l^{-1}$ salinity in April under SLR.

However, SLR above 30 cm will cause high salinity in the intake canals below Cai Con station such as the canal at Dai Ngai which is not sluice-protected. This will cause expansion of the salinity-affected area in the eastern part of Bac Lieu province. Figure 8.10 shows that for all SLR scenarios salinity in zone X (outside of the sluice and dam system) is almost the same as in the baseline. On the other hand, salinity in zone VI is higher than in the baseline, and increases with higher SLR. Variations in other zones (e.g. zones I, II, IV, IX) are complex, with higher salinity in certain months and lower in other months, depending on the tidal flows in the canal system and the operation of the sluice system. In this study the operation in each month is assumed for the same purpose of salinity control for shrimp and rice production as in 2008.

Figure 8.11 shows that for a 75 cm SLR scenario, maximum salinity in the western and southern parts in the dry season will be lower by 4–8 $g l^{-1}$ compared to the baseline while salinity in the eastern part will be higher by 4–8 $g l^{-1}$ (Fig. 8.11f). The mapped results suggest that under high SLR scenarios sluices and dykes are required to protect the rice area from salinity intrusion from the Bassac River into the eastern part of the province.

The effects of SLR on salinity in the low and high water years are shown in Fig. 8.12. Maximum salinities in the low and high water years under present sea level (Fig. 8.12a, c) are respectively higher and lower than in the baseline year 2008 (Fig. 8.11a), indicating that unlike inundation, salinity in the dry season in Bac Lieu province is strongly influenced by upstream flow. Under a 75 cm SLR scenario, salinity variations in these years are similar to the baseline year 2008 with a decrease in the western part and an increase in the eastern part, and salinity

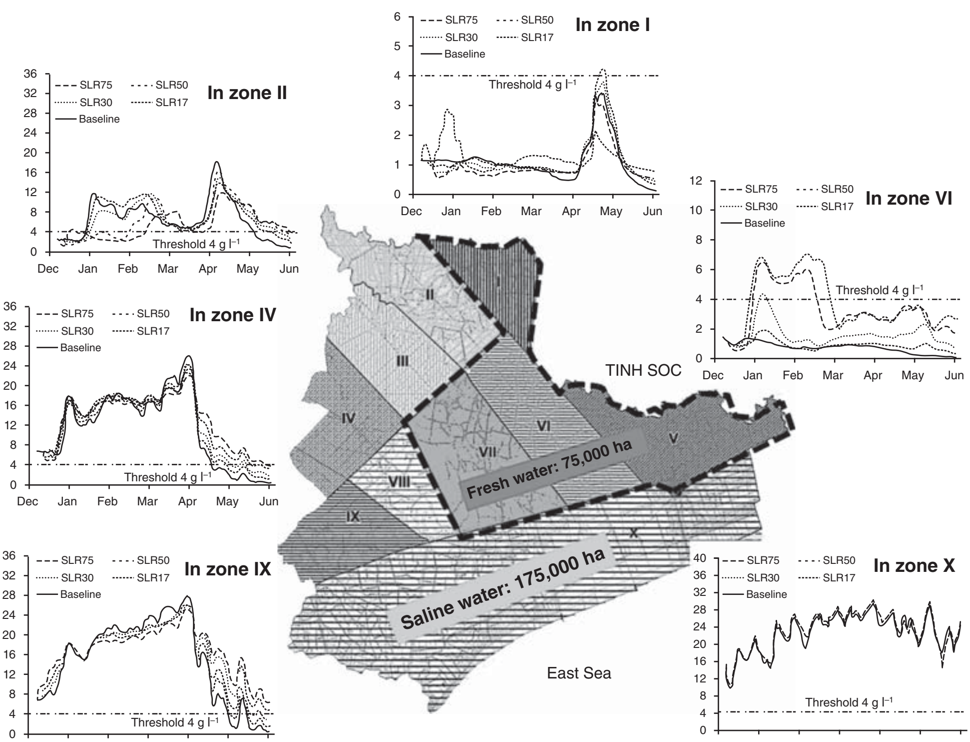


**Fig. 8.10.** Maximum daily salinity (g $l^{-1}$) in different zones of Bac Lieu province under SLRs of 17, 30, 50 and 75 cm.

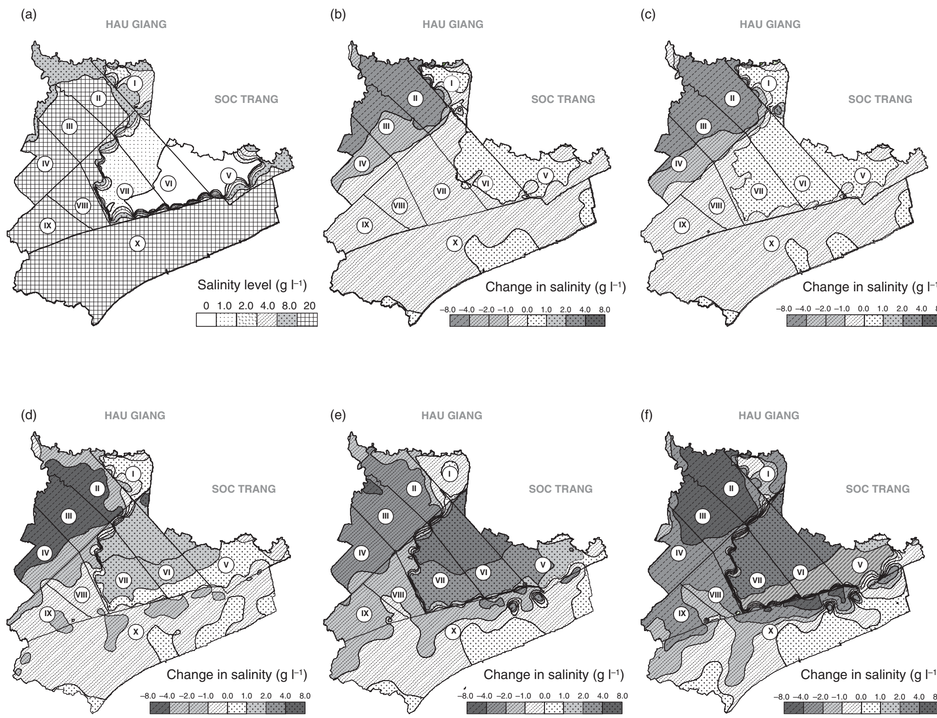


**Fig. 8.11.** Changes of maximum salinity in Bac Lieu province in the dry season compared with (a) the 2008 baseline under present sea level and under (b) 12, (c) 17, (d) 30, (e) 50 and (f) 75 cm sea-level rise.

in the high water year is consistently lower than in the low water year.

## 8.4 Adaptation Strategies to Sea-level Rise in Bac Lieu Province

Based on the changes in inundation depth and salinity in three representative zones (Fig. 8.13) where rice and shrimp cropping systems are predominant, the following adaptations to SLR are recommended.

SLR below 30 cm before 2050 will cause a maximum increase in inundation depth of less than 20 cm in all three zones and a slight decrease in salinity, 5 g $l^{-1}$ in zone IV and 1 g $l^{-1}$ in zones I and VII, respectively. In general, infrastructure measures can be applied to reduce the effects of these changes such as: (i) opening and closing all sluices at ebb tide and flood tide, respectively, for improving drainage in the wet season; (ii) elevating the field bunds by 20 cm to avoid over-bund flow into the rice fields; and (iii) opening the Ho Phong and Gia Rai sluices for more days during the dry season for intake of saline water into zone IV for shrimp cultivation. Major adaptation strategies to SLR in different zones are:

- In the freshwater zones I, V, VI and VII, more water flowing into the province under SLR will be favourable as a source for irrigation of the winter–spring rice from December to March. Maximum salinity in these zones will slightly increase but it is still not a major constraint to rice cultivation. On the other hand, new rice varieties with higher submergence tolerance will be required for the autumn–winter rice from August to November.
- In the brackish water zones II, III and IV where shrimp is raised in the dry season and rice is grown in the wet season, slightly lower salinity and longer duration of fresh water will provide more

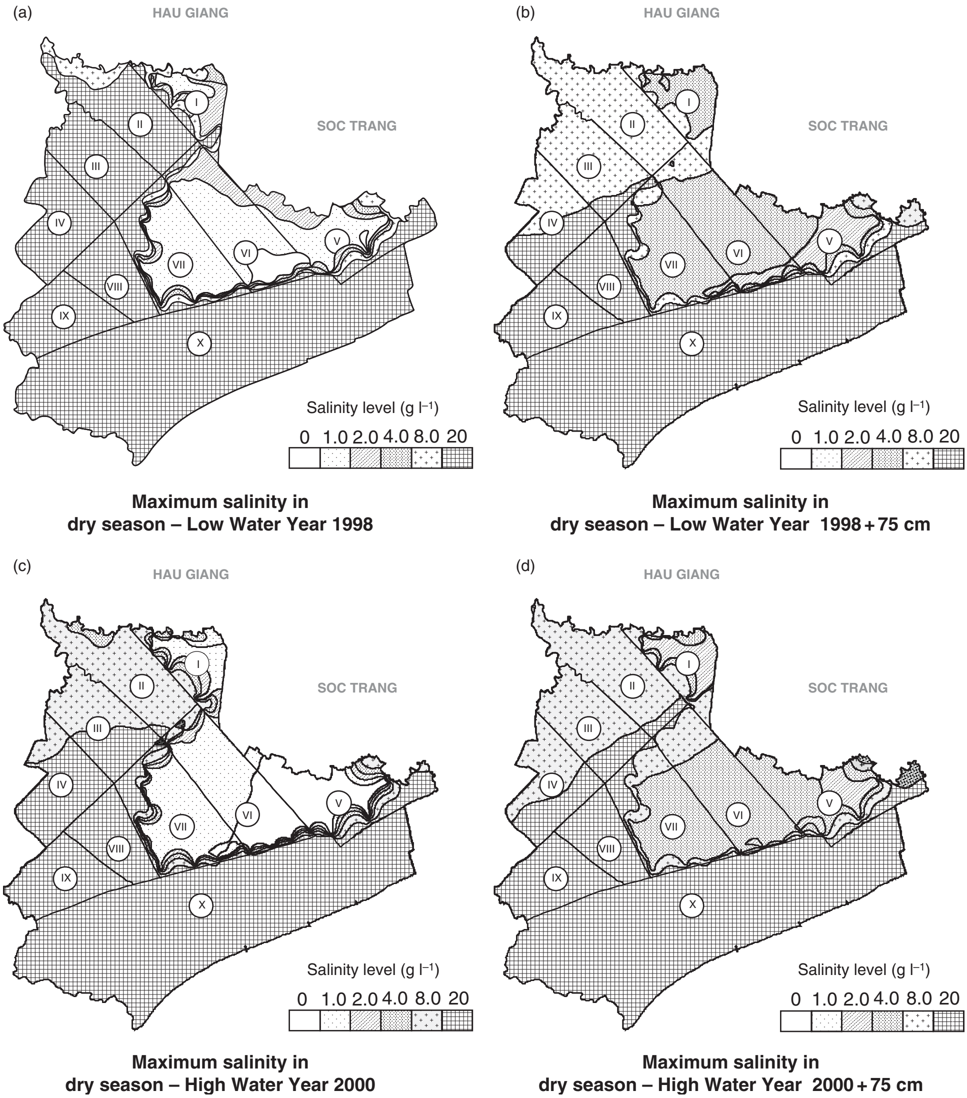


**Fig. 8.12.** Salinity in the low and high water years under present sea level and 75 cm SLR.

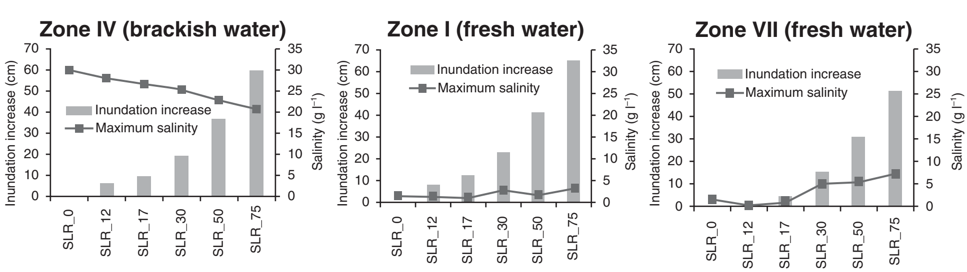


**Fig. 8.13.** Changes in inundation depth and salinity due to SLR in brackish water zone (IV) and fresh-water zones (I and VII)

favourable conditions for the rice crop, although new rice varieties with higher submergence tolerance are also required for the summer–autumn crop.

- In the brackish and saline water zones VIII, IX and X where shrimp-based systems are predominant, adjustment in sluice operation will be needed to ensure suitable salinity for shrimp.

Beyond 2050 when SLR is higher than 30 cm, the daily maximum and minimum water levels in the canal network will increase with about 50–80% of the SLR. These increases will cause deeper inundation and hinder gravitational drainage in all zones. Besides the adjustment in production systems and operations of existing sluice systems, additional hydraulic structures will be needed to cope with these impacts. For example, embankments should be raised to a higher elevation than 20 cm, new sluices should be built in the canals upstream of Dai Ngai and pumping capacity should be improved. Major adaptation strategies to SLR in different zones are:

- In the freshwater zone I at the north of QLPH canal, SLR will cause higher submergence and restrict the drainage by gravity during the peak water level in September–November. The rice-cropping calendar must be adjusted to avoid this peak period. The autumn–winter rice crop will not be suitable unless pumps are deployed for drainage. Rice varieties with enhanced submergence tolerance will be needed for this cropping season, and also for the summer–autumn crop that is harvested in late July. On the other hand, the winter–spring crop in the dry season should be started earlier than under the present sea-level conditions to avoid increased salinity at the end of the crop season. Rice varieties with enhanced salinity tolerance are also needed.
- In the freshwater zones V, VI and VII to the south of QLPH canal, inundation depth will be lower than in zone I, but the increase in salinity will hamper the cultivation of the winter–spring rice crop in the dry season, although varieties with enhanced salinity tolerance (such as OM4900, OM6677, OM10252, etc.) have been applied. Unless new sluices are built upstream of Dai Ngai station to control salinity intrusion into these zones, this rice crop may be replaced by upland crops such as maize or vegetables with less water requirement and shorter crop duration. The summer–autumn and autumn–winter rice crops will also be hampered by increased submergence and reduced drainage capacity, but not as seriously as in zone I.
- In the buffer zones II and III between brackish and fresh water, rice varieties with enhanced submergence tolerance will be needed. With reduction in salinity, the time window for the winter–spring rice crop will be prolonged and the duration of shrimp cultivation at upper locations will be shorter. Even if the Ho Phong and Gia Rai sluices are opened for more days during the dry season, saline water from the East Sea would still not be able to reach these zones.
- In the brackish water zones IV, VIII and IX, lower salinity under SLR will provide more favourable conditions for expanding and extending the rice crop in the rainy season. A conflict in water requirement as in the past (Hoanh *et al*., 2012) will occur if sluices are opened for more days, for intake of brackish water to meet the demand of shrimp growers, while rice farmers need fresh water for their rice crop. Coordination between sluice operation at regional level and adjustment of cropping calendars at farm level should be strengthened to minimize such conflict.
- In the saline zone X, the slight change of salinity under SLR will not influence significantly the main production of shrimp and other aquaculture production such as crab and fish. However, because this zone is located along the seashore, the increased inundation depth will be close to the level of SLR and therefore embankments should be elevated.

## 8.5 Conclusions

In contrast with previous global studies (Zeidler, 1997; Nicholls *et al*., 1999; Dasgupta *et al*., 2007) whereby digital elevation models (DEM) of coastal zones were used directly to determine the impacts of SLR, this study analysed the hydrodynamics of unsteady flows in a complex canal and river network within a delta that is strongly affected by tide and SLR. The study showed that in a province close to the coast such as Bac Lieu, changes of inundation depth due to the variation in total annual water volume from upstream are not significant, but timing of the peak flow, tidal cycle and local rainfall are more relevant. The effects of SLR on salinity are more complex than on inundation depth. In the wet season SLR causes an increase of maximum and minimum water levels, but this increase gradually reduces inland, about 50%–80% of the increase of sea level. In the dry season, SLR will cause more fresh water from the mainstream flowing into the province at the northern and western parts, hence salinity in these parts will be lower. On the other hand salinity will be higher in the eastern part where saline water will reach the intake canals. Soft measures such as adjustment of cropping calendar or sluice operations are possible to adapt to low SLR. However, beyond 2050 when SLR is higher, hard measures such as new sluices, dykes and pumps will also be needed.

While the study is of a very specific case study area, it illustrates two important general points. The first is the importance of modelling to explore impacts that may not be intuitive (e.g. the decrease in salinity in some areas under SLR), but are significant in management terms. The second is that the study demonstrates very clearly that adaptation responses are not static, but must evolve as the severity of impacts increases; and that planning needs to reflect this strategy.

In this study impacts of climate change and development in the Mekong upstream as well as in the MRD were not taken into account when determining the impacts of SLR on production systems in Bac Lieu province. Nevertheless, if climate change is included, and given the current uncertainty in daily rainfall projection, we cannot expect more accurate results to develop suitable adaptation strategies. Another limitation of this study relates to the nature of SLR. Unlike sudden onset events such as a tsunami, SLR is a slow change amounting to an increase <1 cm year$^{-1}$. Therefore changes in siltation and streambed configuration of channels and in ecosystems are gradual, and adaptations by local people or heightening of canal embankments are likely to happen incrementally. These adaptations require other detailed investigations that were not considered in this study.

## Acknowledgements

The authors highly appreciate the project ‘Improving Rice Tolerance of Submergence and Salinity to cope with Climate Change in coastal area of Vietnamese Deltas’ funded by DANIDA and the project on Climate Change Affecting Land Use in the Mekong Delta: Adaptation of Rice-based Cropping Systems (CLUES) funded by ACIAR to support this study.

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