

# SEA LEVEL RISE AFFECTING THE VIETNAMESE MEKONG DELTA: WATER ELEVATION IN THE FLOOD SEASON AND IMPLICATIONS FOR RICE PRODUCTION

REINER WASSMANN<sup>1,5</sup>, NGUYEN XUAN HIEN<sup>2</sup>, CHU THAI HOANH<sup>3,5</sup> and  
TO PHUC TUONG<sup>4</sup>

<sup>1</sup>*Institute for Meteorology and Climate Research (IMK-IFU), Forschungszentrum Karlsruhe,  
Kreuzackbahnstr. 19, 82467 Garmisch-Partenkirchen, Germany*

*E-mail: reiner.wassmann@imk.fzk.de*

<sup>2</sup>*Sub-Institute for Water Resources Planning (SIWRP), Ho Chi Minh City, Vietnam*

<sup>3</sup>*International Water Management Institute (IWMI), Colombo, Sri Lanka*

<sup>4</sup>*International Rice Research Institute (IRRI), Los Baños, Philippines*

<sup>5</sup>*Formerly at IRRI.*

**Abstract.** In this study, we assessed the impact of sea level rise, one of the most ascertained consequences of global climate change, for water levels in the Vietnamese Mekong Delta (VMD). We used a hydraulic model to compute water levels from August to November – when flooding is presently critical – under sea level rise scenarios of 20 cm (=  $\Delta 20$ ) and 45 cm (=  $\Delta 45$ ), respectively. The outputs show that the contour lines of water levels will be shifted up to 25 km ( $\Delta 20$ ) and 50 km ( $\Delta 45$ ) towards the sea due to higher sea levels. At the onset of the flood season (August), the average increment in water levels in the Delta is 14.1 cm ( $\Delta 20$ ) and 32.2 cm ( $\Delta 45$ ), respectively. At the peak of the flood season (October), high discharge from upstream attenuates the increment in water level, but average water level rise of 11.9 cm ( $\Delta 20$ ) and 27.4 cm ( $\Delta 45$ ), respectively, still imply a substantial aggravation of flooding problems in the VMD. GIS techniques were used to delineate areas with different levels of vulnerability, i.e., area with high (2.3 mio ha = 60% of the VMD), medium (0.6 mio ha = 15%) and low (1 mio ha = 25%) vulnerability due to sea level rise. Rice production will be affected through excessive flooding in the tidally inundated areas and longer flooding periods in the central part of the VMD. These adverse impacts could affect all three cropping seasons, Mua (main rainfed crop), Dong Xuan (Winter–Spring) and He Thu (Summer–Autumn) in the VMD unless preventive measures are taken.

## 1. Introduction

Over the last three decades, the Vietnamese Mekong Delta (VMD) has undergone drastic changes in hydrology to improve agricultural production, namely, growing rice (Duong and Cho, 1994; Xuan and Matsui, 1998; Hashimoto, 2001; Minh and Kawaguchi, 2002). New canals and sluices resulted in a complex web of interconnected water bodies (see Figure 1) that will further be expanded to improve living condition of approximately 16 million inhabitants. The Vietnamese part of the Mekong Delta covers an area of 3.9 mio ha (of about 6 mio ha of the total Mekong Delta, including the Cambodian part) of which 2.9 mio ha are currently



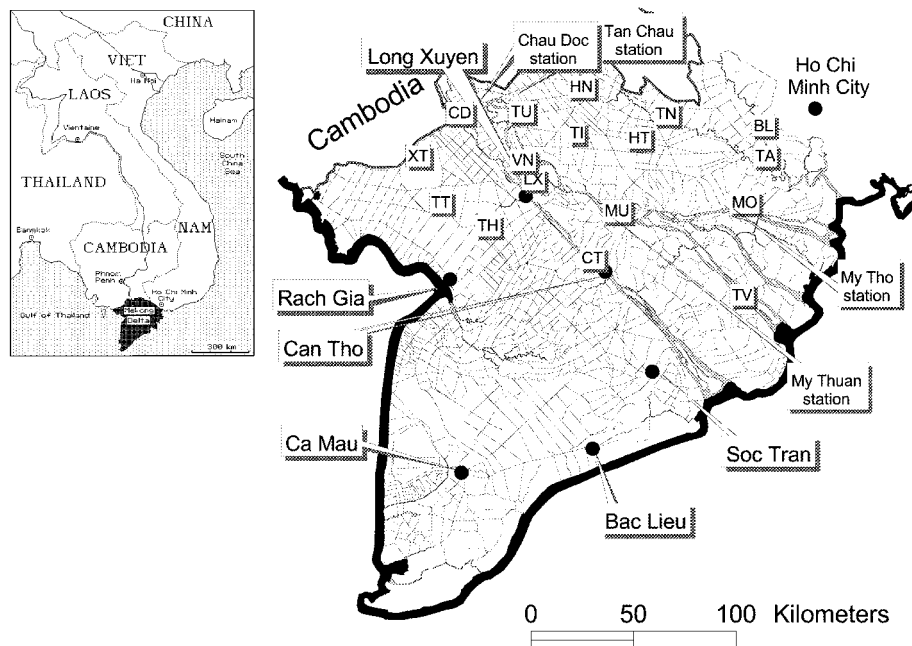


Figure 1. Geographic setting and detailed map of the Vietnamese Mekong Delta depicting canal/river system, provincial centers, and hydrological stations used for model calibration (see Table I for acronyms).

used for agriculture, 0.6 mio ha for settlements and infrastructures and the remainder being mangrove and melaleuca forests. In 2000, rice production constituted 78% of the land use in the VMD. Although 60% of the soils in the VMD are acid sulfate and saline soils, rice production has markedly increased in recent years allowing Vietnam to become the third largest rice exporter of the world (Sanh et al., 1998).

The bulk of the land in the VMD is only slightly ( $<2$  m) above mean sea level. Approximately 1 mio ha are affected by tidal flooding and 1.7 mio ha by salt water intrusion. The Mekong Delta has experienced devastating floods by water from the Mekong river, e.g., in September/October 2000, leading to huge economic losses in the agricultural sector. These losses could substantially exacerbate under sea level rise (SLR). Given the dimension of coastal plains in Asia, SLR is likely to become a major challenge to many Asian countries, with Bangladesh being probably the most drastic example on national scale (Warrick and Ahmad, 1996; Ali, 1996).

The rationale for this study is primarily given by the economic significance of rice production in the VMD that has accounted for 50% of the Vietnamese rice production since 1997. The study focuses on the months from August to November, the flooding period in the Mekong Delta, when a further increment in water levels is especially critical. No other crop than rice can be grown under these adverse conditions of unstable flooding and – in many locations – moderate salinity in

Table I  
Hydrological stations and observed data used for model calibration

| Station        | Acronym | Location <sup>a</sup> | Calibration |             |
|----------------|---------|-----------------------|-------------|-------------|
|                |         |                       | Discharge   | Water level |
| 1. Ben Luc     | BL      | Central               |             | X           |
| 2. Can Tho     | CT      | Central               |             | X           |
| 3. Chau Doc    | CD      | North                 | X           | X           |
| 4. Hong Ngu    | HN      | Central               |             | X           |
| 5. Hung Thanh  | HT      | Central               |             | X           |
| 6. Long Xuyen  | LX      | Central               |             | X           |
| 7. My Thuan    | MU      | Central               |             | X           |
| 8. My Tho      | MO      | Coastal               |             | X           |
| 9. Tan An      | TA      | Central               |             | X           |
| 10. Tan Chau   | TU      | North                 | X           | X           |
| 11. Tan Hiep   | TH      | Central               |             | X           |
| 12. Tra Vinh   | TV      | Coastal               |             | X           |
| 13. Tram Chim  | TI      | Central               |             | X           |
| 14. Tri Ton    | TT      | Central               |             | X           |
| 15. Tuyen Nhon | TN      | Central               |             | X           |
| 16. Vam Nao    | VN      | Central               |             | X           |
| 17. Xuan To    | XT      | North                 |             | X           |

<sup>a</sup> Vietnamese Mekong Delta separated into North, Coastal and Central region.

the dry season. Most farmers in flood-prone rice areas are very poor, with limited options to divert to other sources of income.

Reliable assessment of possible changes has to be based on profound knowledge of the hydrological conditions in delta areas. Tide and river discharge variations over time are creating very complex and highly dynamic flow systems. In this study, we used a hydraulic model, the 'Vietnam River Systems and Plains' (VRSAP) model (Khue, 1986, 1991; NEDECO, 1991a,b, 1992, 1993; ESSA et al., 1992; KOICA and KARICO, 2000), to assess future changes in the Mekong Delta. This model is capable of computing water levels at any given point of the VMD and has widely been used to plan and design the water control system for achieving high rice production. The model uses the sea water level in the South China Sea and the Gulf of Thailand as boundary conditions, hence the model could be run under virtual conditions of higher sea level.

Rice production is affected by global climate change through various pathways. Increasing concentrations of carbon dioxide stimulate photosynthesis, while concomitant global warming may result in heat stress for rice grown in tropical/sub-tropical climates (Moya et al., 1998). The productivity of rice systems may also

be altered by hydrological changes, deriving either from changing precipitation patterns or – as investigated in this regional case study – from higher sea level. On the other hand, rice production itself is a source of greenhouse gases, mainly methane (Wassmann et al., 2000). This study was initiated within the framework of IRRI's (International Rice Research Institute) research on the interactive relationship between rice production and global climate change and was continued as part of an EU-funded project comprising a risk assessment for rice production in the Mekong delta.

## **2. Sea Level Rise in the Regional Context**

Irrespective of the ongoing debate on the human impact on global temperature and the possible mitigation of greenhouse gas emissions, rising sea level can already be observed along many shore lines including Southeast Asia. Tuong (2001) recorded increments in sea level varying from 1.75 to 2.56 mm/year at 4 Vietnamese stations. Mean sea level in the Eastern section of the South China Sea (Manila Bay, Philippines) climbed by 20 cm over the 1960s to the 1990s (Perez et al., 1996). Although geological processes may contribute to this acceleration, the anticipated global warming will further lift sea levels and thus, adversely affect land use in coastal areas (IPCC, 2001).

Previous impact assessments on the effect of SLR in the VMD were largely based on topography and coarse extrapolation of tidal effects. A report commissioned by Asian Development Bank (ADB, 1994) concluded that 1.5 to 2 mio ha in the VMD would be at higher risk of tidal threat, but this estimate is neither methodologically explained nor spatially explicit. A GIS-based study on integrated coastal management estimated that 4 mio ha will be flooded annually in the entire Vietnam when the sea level rises by 1 m (Zeidler, 1997). This study accounted for economic losses in the range of U.S.\$ 17 billion for the entire Vietnam stemming from annual flooding, which is about 80% of the national GDP. It also estimated that in the VMD region alone, approximately 14 million people will live in flood-prone areas if no additional protection measures are taken (Zeidler, 1997).

## **3. Modeling the Water Regime in the Delta**

The water level in the Mekong Delta is influenced by water discharge of the Mekong River as well as the tidal variations in the South China Sea and the Gulf of Thailand (Sanh et al., 1998). The rainy season in the Mekong Delta starts in May and lasts until November. Water level rapidly increases from July to October and starts to decrease in November. September and October are the months prone to large flooding due to high upstream discharge and heavy rainfall. Highest tidal levels are recorded in January.

In the flood season, the VMD can be divided into a deeply flooded area in the upper part and a shallow flooded area in the lower part. The deeply flooded area is strongly affected by seasonality of river discharge while the shallow-flooded area, including the Ca Mau peninsula (Figure 1), is primarily affected by tide. About 30% of the VMD is flooded at depths of 0.5–4.0 m. Inundation periods can last from 2 to 6 months per year depending on topography and climate variability.

### 3.1. INTRODUCTION TO THE VRSAP MODEL

The ‘Vietnam River Systems and Plains’ (VRSAP) model was developed by the Sub-Institute for Water Resources Planning (SIWRP), Ministry of Agriculture and Rural Development, Vietnam and is a numerical model using Saint-Venant equations for solving complex flow and mass transport problems in a complex network of interconnecting open channels of rivers, canals, and sewers (Khue, 1986; Delft Hydraulics, 1989; Dong, 2000). The model simulates the overland flow by assuming a quasi-two-dimensional scheme using virtual constructions to direct the flow to different directions in the large flooded plains. The VRSAP model has been used in a number of local and nation-wide water control studies in Vietnam such as salt intrusion studies, master plan for the VMD, eco-development planning, flood prevention etc. (NEDECO, 1991b, 1993; ESSA et al., 1992; KOICA and KARICO, 2000).

The continuity and the momentum equations for each segment of the channel network are as follows:

$$\frac{\partial Q}{\partial x} + B_c \frac{\partial z}{\partial t} = q \quad (1)$$

$$\frac{\partial z}{\partial x} + \frac{\alpha_0}{g} \frac{\partial(Q/A)}{\partial t} + \frac{\alpha}{g} \frac{Q}{A} \frac{\partial(Q/A)}{\partial x} = \frac{-Q/Q}{K^2} \quad (2)$$

in which:

$$K = AC\sqrt{R} \quad C = \frac{1}{n} R^{1/6},$$

where  $Q$  is the discharge,  $x$  is the distance along the segment,  $B_c$  is the canal width, including storage area, averaged over the segment,  $z$  is the water level,  $t$  is time,  $q$  is the lateral flow per unit length into the segment,  $\alpha_0$  and  $\alpha$  are adjustment coefficients, varying from 1.0 to 1.1,  $g$  is the gravity acceleration,  $A$  is the cross-section area,  $C$  is the Chezy coefficient for bottom roughness,  $R$  is the hydraulic radius,  $n$  is the Manning’s coefficient.

A segment can be a reach of a river or canal, or a hydraulic structure such as a sluice, connected to another segment at a node. Water interchange between segments and the land area is simulated within VRSAP by defining parcels of land (fields) bounded by specified channel segments, and by indicating the nature of water exchange (uncontrolled or controlled by structures) between them. The

model assumes that when there is no standing water in the field, evapo-transpiration continues, thus causing soil drying, until a 'sub-surface' storage is depleted. Conversely, at the onset of the rainy season, the sub-surface storage has to be filled before water accumulates above the soil surface.

Using the implicit finite difference scheme (Delft Hydraulics, 1989), VRSAP computes water level at each node and in each field, and discharge in each segment. Two sets of input data are required for the model: (i) the configuration and dimensions of the river and canal network, including sluices and operation schedule; and (ii) hydrological data (water level and discharge) at boundaries and initial conditions of segments, nodes and fields.

For spatial data management, visualization and analysis, the topographical and hydrological input data as well as the model outputs are transferred to a GIS data base. The river and canal network are represented in a scheme of inter-connected line segments, and the simulated hydrological variables are assigned to the other components of the scheme, for example, water level to nodes (waterway junctions) and polygons (fields), and discharge to line segments (canals and rivers). The spatial interpolation tools of the GIS are used to generate contour lines of water levels from the point-based model results.

Due to vastly different flow patterns between flood and dry seasons, the model encompasses two different schemes with distinct coverage areas in the flood and dry seasons, respectively. The flood season scheme goes beyond the Vietnamese part of the Delta and covers an area starting from Kratie in Cambodia (ca. 250 km upstream of the Vietnamese border) including the Cambodian Mekong tributaries and flood plains as well as the Great Lake/ Tonle Sap river. The flood scheme comprises of 2,111 segments, 1,505 nodes and 555 storage plains.

### 3.2. BOUNDARY CONDITIONS

The main factors determining the hydraulic regime in the Mekong Delta are used as boundary conditions in the VRSAP model:

- Water level and discharge at upstream boundaries of the Delta.
- Tidal water level in the South China Sea and the Gulf of Thailand (these boundary conditions were then altered to simulate the SLR scenarios).
- Rainfall and evaporation at 25 stations in the Mekong Delta.
- In the VMD, the scheme was based on the most recent topographic and hydrographic maps available. For the Cambodian part, topographic data were extracted from the SOGREAH model developed in the early sixties (SOGREAH, 1963), but the canal system was updated from the most recent surveys.

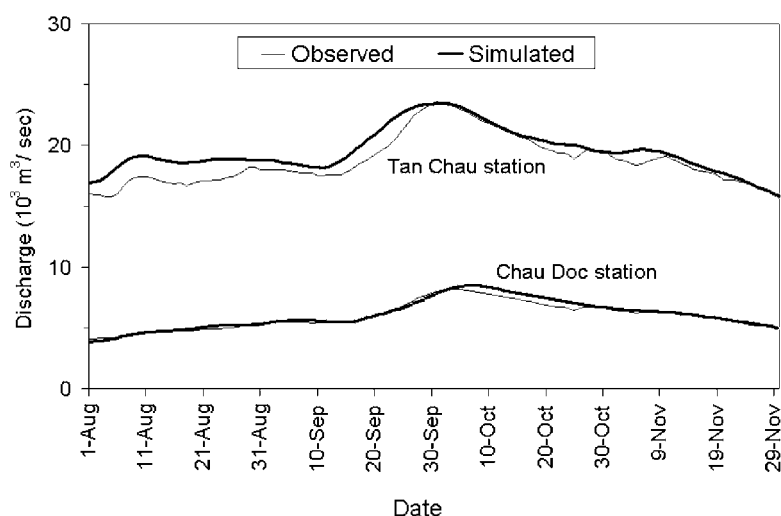


Figure 2. Comparison of observed and simulated values of river discharge at Chau Doc and Tan Chau station during in flood season 1996.

### 3.3. MODEL CALIBRATION

The model has been calibrated as part of this project with hydrological data available in 1996, a high flood year with frequency about 1 per 20 years. The calibration process consists of adjusting the initial water level at nodes and in the plains, the Manning coefficient of segments and topographic data in rivers, canals and plains to derive at the best fit between the simulated and measured discharges/water levels. Calibration of the flood season model is hampered by the scarcity of updated topographic, hydrological and precipitation data available for Cambodian part. Therefore, water discharge at two northern stations is used to calibrate the hydrological and topographic conditions in Cambodia as shown in Figure 2 (see location in Figure 1). After calibration, the values of the input parameters for the best fit are used for scenarios analysis.

In the coastal and central part of the delta, the hydrologic regime is largely affected by tides. Figures 3a,b depicts observed and computed data in October at My Tho (45 km from coastline; see location in Figure 1) and My Thuan station (90 km from the coastline). At the peak of the flood season, the tidal amplitude in water levels is approximately 2 m at My Tho and still ranges at 0.7 m at My Thuan. The model showed accurate results in simulating both, seasonal as well as significant semi-diurnal variability with two high waters and two low waters in a day, and an alternate sequence of two spring tides and two ebb tides in a month.

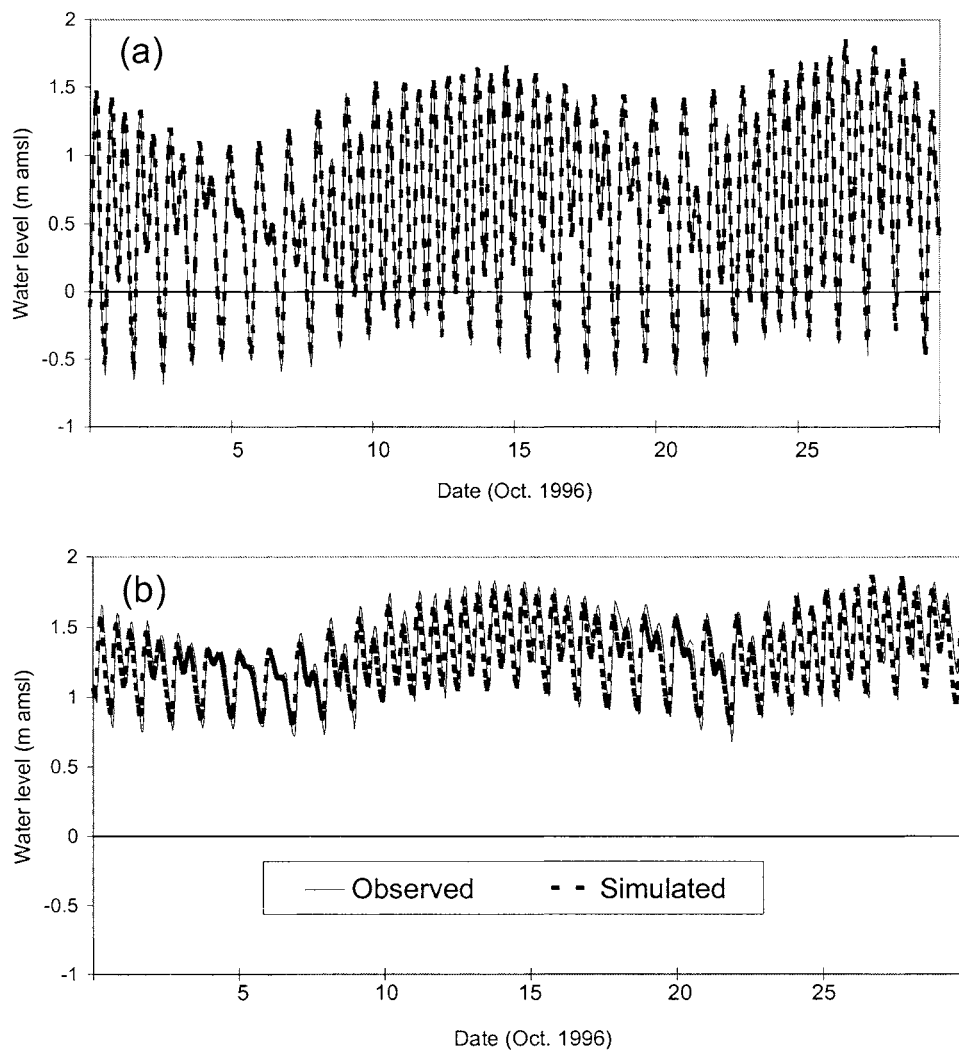


Figure 3. Comparison of observed and simulated values of water level (m above mean sea level) at (a) My Tho and (b) My Thuan station in October 1996.

### 3.4. SLR SCENARIOS

The first assessment of the Intergovernmental Panel on Climate Change (IPCC, 1990) included a Business-as-Usual Scenario for SLR that was specified by a medium-term ( $\Delta 8\text{--}29$  cm in 2030) and a long-term projection ( $\Delta 21\text{--}71$  cm in 2070). In the meantime, SLR scenarios by IPCC and others have been ramified in various ways, mainly as a result of more detailed emission/global warming scenarios (IPCC, 2001). Insofar, it is understood that the selection of a SLR scenario is inherently subjective. Within the scope of our study, we opted for the



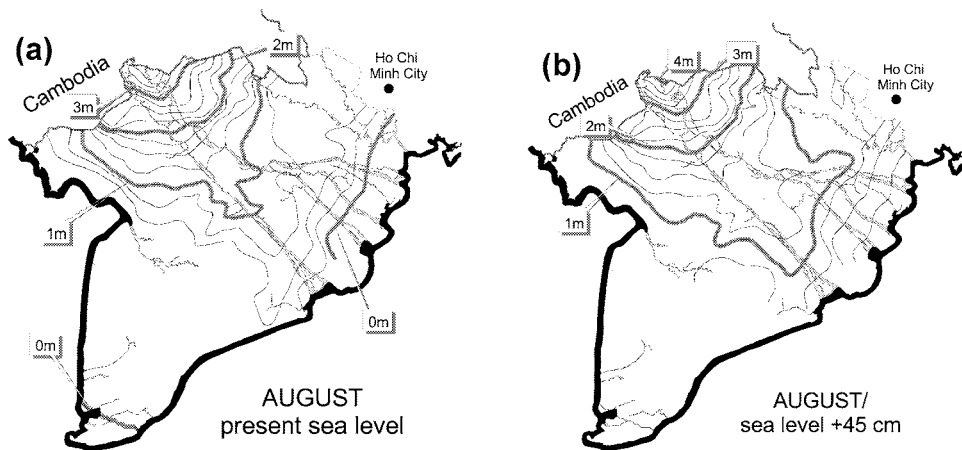


Figure 4. Water level contours (m above mean sea level) on August 15th under (a) present sea level and (b)  $\Delta 45$  SLR scenario.

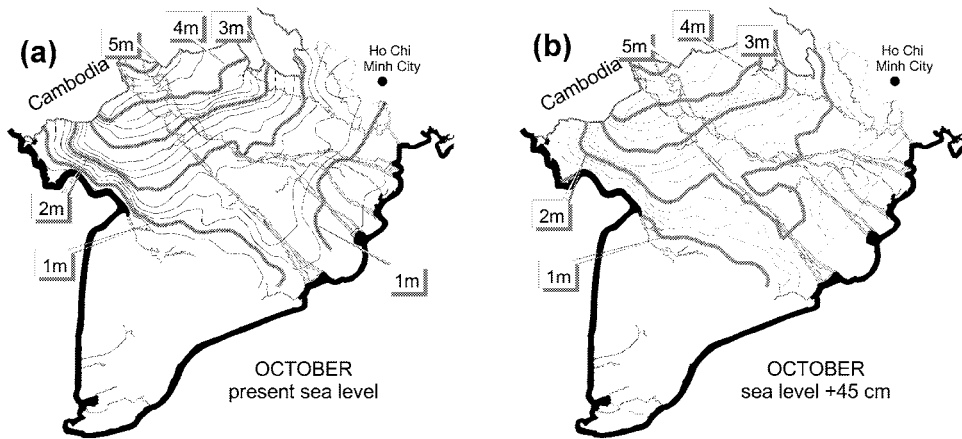


Figure 5. Water level contours (m above mean sea level) on October 15th under (a) present sea level and (b)  $\Delta 45$  SLR scenario.

Business-as-Usual Scenario of the initial IPCC study. The ‘best estimates’ for the by medium-term ( $\Delta 18$  cm) and long-term projections ( $\Delta 44$  cm) were rounded up to  $\Delta 20$  cm and  $\Delta 45$  cm, respectively, because this study was originally conceived as an initial stage of a broader assessment of SLR impacts in discrete steps of 5 cm (not included in this paper).

## 4. Results and Discussion

### 4.1. SPATIAL EFFECTS OF SLR ON WATER LEVELS DURING FLOOD SEASON

Simulated data on water levels were transferred into a GIS data base to display the spatial effects of SLR within the course of the flood season. Thus, we have produced a series of 20 maps of which we selected 8 maps for this presentation. As reference, the daily average water level contours under present conditions are shown in Figures 4a and 5a for the 15th of August and October, respectively. In August 1996, water level is below 1 m amsl (above mean sea level) along the downstream part of the main rivers and the Ca Mau peninsular. Only the upper part of the VMD has a distinct gradient in water level with approximately 3 m amsl at the Vietnamese-Cambodian border (Figure 4a). At the peak of the flood season in October 1996, water level reaches up to 5 m amsl at the Vietnamese-Cambodian border whereas only the coastal sections and the Ca Mau peninsula have water level below 1 m amsl (Figure 5a).

At the onset of the flood season in August, the 1 m amsl contour cuts the main river channels at approximately 70 km distance from the sea (Figure 4a). In the  $\Delta 45$  SLR scenario, this 1 m amsl contour is shifted in the main river channels by 40–50 km towards the sea (Figure 4b), reflecting a significant increase in water level in the coastal and central part of the VMD. The 2 m and 3 m contours are also shifted by 10 km and 5 km, respectively, indicating a lower, but still discernable impact of SLR in the northern part in August. In the  $\Delta 20$  SLR, which is not shown here to limit space needed for figures, the August contour lines of 1 m and 2 m amsl were shifted by 15–25 km and 5 km, respectively, while there was only a minor effect on the 3 m amsl contour line.

At the peak of the flood season in October, the shifts in contour lines are generally smaller and the northern part of the Delta appears largely buffered from SLR impacts (Figures 5a,b).

The contours in Figures 4a,b (August) and 5a,b (October) are depicted by 0.25 m steps to cover the slope from 0 to 5 m amsl water levels. This scale, however, is too coarse to highlight the incremental difference in water depth of 0–45 cm. Therefore, we produced a series of ‘water level rise’ (WLR) maps showing the differences ( $\Delta_i$ ) in water level of respective scenario and present sea level. The months of September (Figures 6a,b) and October (Figures 7a,b) were chosen for this presentation because they correspond to the critical periods, i.e., harvesting and planting, of rice crops during the flood season. The WLR maps clearly show that virtually the entire VMD will be affected by SLR in September and November, although the WLR gradually decreases towards upstream. Even at the Vietnamese-Cambodian border, water levels are elevated by 4 cm ( $\Delta 20$ ) and 8 cm ( $\Delta 45$ ), respectively.

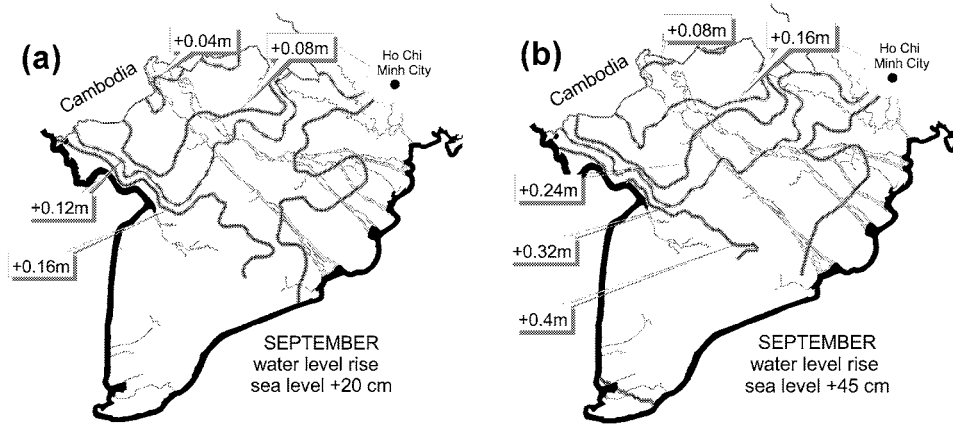


Figure 6. Water level rise on September 15th under (a)  $\Delta 20$  and (b)  $\Delta 45$  SLR scenario; depicted values refer to difference in water level of respective scenarios and present sea level scenario.

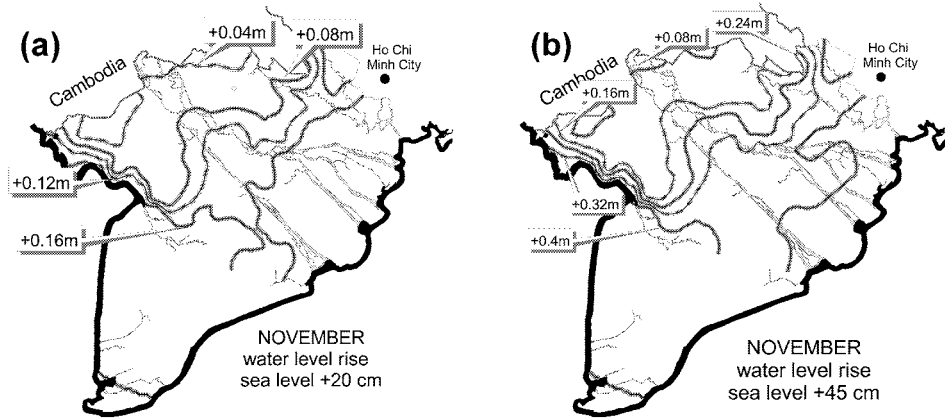


Figure 7. Water level rise on November 15th under (a)  $\Delta 20$  and (b)  $\Delta 45$  SLR scenario; depicted values refer to difference in water level of respective scenarios and present sea level scenario.

#### 4.2. DELTA-WIDE INDICES DESCRIBING IMPACT OF SLR

To substantiate the wide-ranging impact on water level, we have computed delta-wide indices based on the actual water level rise ( $\Delta_i$ ) at any given point in the delta (Table II). The delta-wide averages of  $\Delta_i$  vary from 11.9 to 14.1 cm ( $\Delta 20$ ) and from 27.4 to 32.2 cm ( $\Delta 45$ ). As for the shift in contour lines (see 4.1), these average values reveal an attenuation of SLR effects by high background water level and river discharge at the peak of the flood season (October). For either SLR scenario,  $\Delta_i$  values in October are ca. 18% lower than the respective value at the onset of the flood season in August.

In the next step, we have assessed the percentage area affected by SLR in the VMD by assuming a threshold of  $\Delta_i = 8$  cm between negligible and discernable

Table II

Water level rise ( $\Delta_i$ ), percent area affected and WLR/SLR ratio  $\omega$ ; all values computed for the 15th of each month during the flood season

| Date                                  | $\Delta 20$ |       |       |       | $\Delta 45$ |       |       |       |
|---------------------------------------|-------------|-------|-------|-------|-------------|-------|-------|-------|
|                                       | Aug.        | Sept. | Oct.  | Nov.  | Aug.        | Sept. | Oct.  | Nov.  |
| Average $\Delta_i$ (cm)               | 14.1        | 13.2  | 11.9  | 12.4  | 32.2        | 30.7  | 27.4  | 28.6  |
| Area affected<br>( $\Delta_i > 8$ cm) | 91.4%       | 81%   | 68.7% | 71.5% | 99.8%       | 99.3% | 86.4% | 97.6% |
| Average $\omega$                      | 0.70        | 0.66  | 0.59  | 0.62  | 0.72        | 0.68  | 0.61  | 0.63  |

impacts of SLR. The area affected by SLR in the flood season varies from 68.7 to 91.4% under  $\Delta 20$  SLR and from 86.2 to almost 100% under  $\Delta 45$  SLR (Table II). In line with the average value, the area affected by SLR is smallest in October when the background water levels and river discharge are highest.

The WLR/SLR ratio ' $\omega$ ' is computed as  $\omega = \Delta_i / \Delta S$  to gauge the relative impact triggered by the SLR scenario ( $\Delta S = 20$  cm or 45 cm). In the flood season, the delta-wide averages of  $\omega$  vary from 0.59 to 0.70 in the  $\Delta 20$  scenario and 0.61 to 0.72 in the  $\Delta 45$  scenario.

#### 4.3. VULNERABILITY ASSESSMENT FOR THE FLOOD SEASON

The results of spatial effects and delta-wide indices were combined to a vulnerability assessment for the VMD (Figure 8). We used the WLR/SLR ratio in October to define three vulnerability classes, i.e., areas with high ( $\omega > 0.66$ ), medium ( $0.66 > \omega > 0.33$ ) and low ( $\omega < 0.33$ ) vulnerability. Admittedly, the number of vulnerability classes is inherently subjective, but a coarse classification into three classes at highest water level appeared a reasonable approach for a first impact assessment. It should be reiterated that this vulnerability does not include typhoon-induced flood disasters that will also aggravate the flooding condition under SLR. Thus, approximately 2.3 mio ha (=60% of the VMD) can be classified as highly vulnerable to SLR. This area comprises the entire coastal zone and the Ca Mau peninsular. The transitional area with moderate vulnerability is relatively small (approximately 0.6 mio ha =15% of the VMD) located in a central belt in the VMD. The northern part of the VMD with a belt of approximately 30–50 km at both sides of the Mekong rivers appears relatively shielded from SLR impacts; the area classified with low vulnerability comprises approximately 1 mio ha (=15% of the VMD).

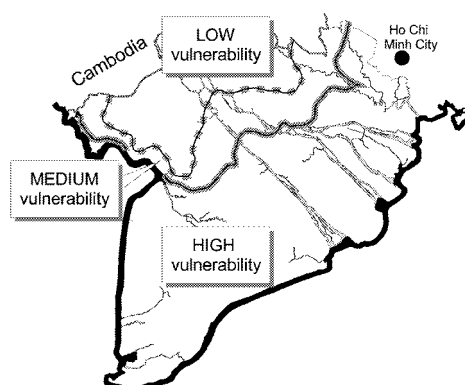


Figure 8. Spatial distribution of vulnerability to SLR; see text for classification criteria.

#### 4.4. PROJECTING SLR EFFECTS TO DRY SEASON

Although the model simulations only cover the flood season, the findings allow a general outlook on possible SLR impacts during the dry season. Apparently, high discharge from the river system and background water levels at the peak of the flood season (October) attenuate the WLR in the VMD. In turn, it can be assumed that the increments in water levels will be especially pronounced in the dry season, i.e., from December to May. In April, the discharge of the Mekong river branches at the Vietnamese-Cambodian is less than 10% of the discharge in October. For example, the two stations used for the flood season validation (Tan Chau and Chau Doc, Figure 2) had a combined discharge of less than 2000 m<sup>3</sup>/s in April (data not shown). Water levels in April are <1 m amsl throughout the VMD while they show a distinct upstream gradient from 0 to 5.25 m amsl in October (Figure 5a).

In addition to this temporal extrapolation of our model simulations, the impacts of SLR on the hydrological conditions during the dry season can also be deduced from the long-range propagation of tidal cycles in the river/canal system. As one example, Figure 9 displays water level fluctuations at Can Tho station at the center of the VMD, 80 km from the coastline (see Figure 1 for location). Tidal fluctuations in water levels are much higher in April (2 m amplitude) than in October (1 m amplitude). The tidal amplitude at Chau Doc station (190 km from coastline) is still as high as 1 m in April while there is no tidal effect in October.

Derived from this empirical data (on tidal fluctuations) and simulation results (i.e., higher WLR at lower discharge/background water levels), we project that the WLR/SLR ratio in the dry season will be substantially higher than in the flood season. In the dry season, even small increments in the sea level will affect large areas of the VMD. On the other hand, water cover in the dry season is basically restricted in the rivers/canals, hence higher water level will probably not cause significant impacts on rice production. In fact, a large part of the VMD is suffering from limited water availability during dry season which may be ameliorated by

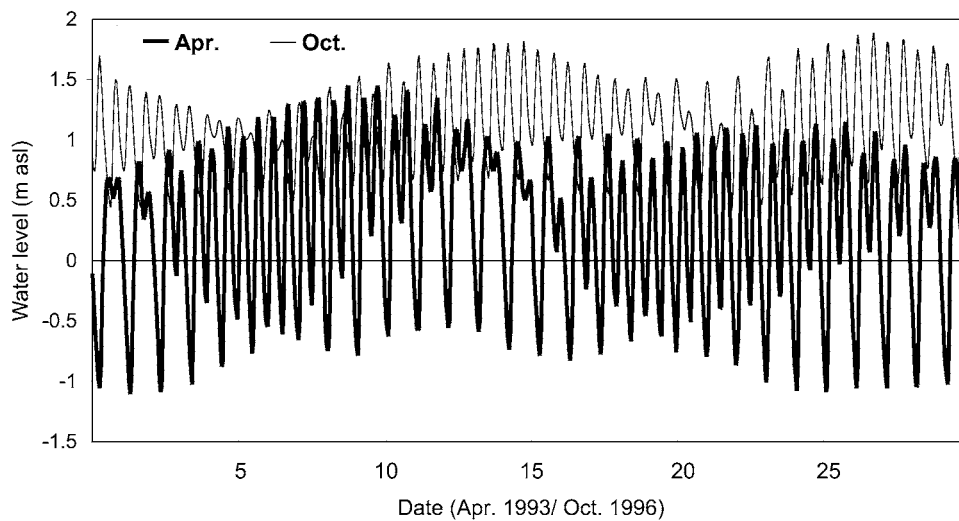


Figure 9. Comparison of observed water levels (m above sea level) in dry season (April) and flood season (October) at Can Tho; see Figure 1 for location.

higher water level as a consequence of SLR. However, this projection does not take any unforeseen environmental degradation such as deeper salinity intrusion into consideration, which was beyond the scope of this paper. In the dry season, the area affected by salinity intrusion, about 1.7 mio ha, comprises of a broad strip along the coastal area as well as the Ca Mau peninsular.

#### 4.5. POSSIBLE IMPLICATIONS OF SLR IN THE FLOOD SEASON ON RICE PRODUCTION

Rice can be grown in the VMD in three different crops (Table III), i.e., Dong Xuan (winter–spring crop), Mua (rainfed crop) and He Thu (summer–autumn crop). Farmers can also grow a spring–summer crop, but this is only applied in a limited area with good irrigation system and therefore not included in this assessment. The three main rice crops appear in different combinations in the VMD:

- as single crop: Mua
- as double crop: either Dong Xuan + He Thu or He Thu + Mua
- as triple crop: short duration varieties in Dong Xuan + He Thu + Mua

The seasonal impacts of SLR can be characterized as follows (Table III):

- Phase A: Excessively high water level.  
At the peak of the flood season, water level in the fields often reaches the physiological limits of the rice plant. Additional increase in the flooding depth

Table III

Cropping calendar and hydrological characterization of major rice crops in the VMD (ir = irrigated; rf = rainfed); SLR impact phases denote excessively high water level (A), prolonged inundation period (B), and improved water supply (C)

| Month              | Apr.                  | May | June | July           | Aug.           | Sept.    | Oct.           | Nov. | Dec. | Jan.           | Febr. | March          |
|--------------------|-----------------------|-----|------|----------------|----------------|----------|----------------|------|------|----------------|-------|----------------|
| Summer-autumn crop |                       |     |      | HE THU (ir/rf) |                |          |                |      |      |                |       |                |
| Flood season crop  |                       |     |      |                |                | MUA (rf) |                |      |      |                |       |                |
| Winter-spring crop |                       |     |      |                |                |          |                |      |      | DONG XUAN (ir) |       |                |
| Water level        | Min. ....> Max. ....> |     |      |                |                |          |                |      |      |                |       |                |
| Rainy season       | =====                 |     |      |                |                |          |                |      |      |                |       |                |
| SLR impact phase   |                       |     |      |                |                |          | A              |      |      |                |       |                |
|                    | C <sub>1</sub>        |     |      |                | B <sub>1</sub> |          | B <sub>2</sub> |      |      |                |       | C <sub>2</sub> |

could severely hamper the performance of the MUA crop. This cropping pattern is mainly applied in the tidally-inundated areas to circumvent salinity effects during the dry season. The timing and the location makes this crop especially vulnerable to rising water level. It is typically planted with traditional rice cultivars with a long growing period that inevitably stretches over the peak of the flood season.

- Phase B: Prolonged inundation period.

Another effect of SLR is the prolonging of field inundation that may cause excessively moist conditions during the harvesting of the He Thu (Phase B<sub>1</sub>) and a delay in planting of the Dong Xuan crop (Phase B<sub>2</sub>). For both crops, a certain shift towards the dry season may technically be feasible, but would unavoidably lead to higher water demand during the dry months. It is not clear, if this increment could be compensated by improved water supply associated with higher sea level.

At the same time, potential yield of He Thu crop would decline when planting date is earlier. Crop simulation using the WOFOST model (van Diepen et al., 1989) and weather data (1983–1995) from the central part of the VMD indicated an 8% decrease in potential yield of the He Thu crop planted in mid-March (i.e., approximately one month earlier than the usual date). Early

planting increases yield risk of the He Thu crop since losses can be as high as 18%.

- Phase C: Improved water supply in the dry season.

In spite of the expected water level increment in the dry season (see 4.4) it is unlikely that this impact will result in flooding on the land because of low background water level in the river/canal system in this season. The water level rise may even become beneficial to farmers because water accessibility will generally be improved and less fuel will be required for pumping during the low water level period from March to May. Such positive impact may affect the early stage of He Thu (Phase C<sub>1</sub>) and late stage of Dong Xuan (Phase C<sub>2</sub>) crops. On the other hand, salinity intrusion is especially serious during the dry season, so rice crops in Phase C<sub>1</sub> as well as C<sub>2</sub> may encompass adverse impacts along the present margins of salinity intrusion.

## 5. Conclusion

The scenarios discussed in this paper correspond to the medium-term (for the year 2030) and long-term (for the year 2070) projections of the initial Business-as-Usual Scenario by the Intergovernmental Panel on Climate Change (IPCC, 1990). However, the assumption of 20 cm sea level rise could also be reconciled with the more recent emission scenarios (SRES) published in the special report of the IPCC (IPCC, 2000). Pending on the SRES scenario, a SLR of 20 cm can be expected at earliest in 2040 and at latest in 2100. The SRES projections end in 2100, so that an increment in sea level of 45 cm is only included in the two SRES scenarios assuming very strong SLR ( $\Delta 45$  cm to be expected in the years of 2075 and 2100, respectively). Changes in sea level will vary locally along different coastlines (Smith and Lazo, 2001), but at present it is not possible to give region-specific deviations from global trends that could be incorporated into an impact assessment.

The results of this study can only be considered as a first approximation of possible impacts. The scope of this impact assessment was confined to the general trend in water level rising and thus, left out other problems associated with SLR. For example, higher water level will make the VMD more vulnerable to extreme weather events, such as storm surges. Though not included in this assessment, it should be mentioned that natural habitats such as wetlands will also be affected by rising water level caused by sea level rise (Nicholls et al., 1999).

The effects of human activities such as construction of water control systems (e.g., hydro-dams in upstream areas) or increasing water withdrawal may further complicate the situation in the VMD when the sea level is rising. At upstream part (Lancang river) in China, some small reservoirs were built in the mainstream of the Mekong Basin, but this part only covers about 20% area of the whole basin. The effect of these reservoirs on hydrology in the Delta was insignificant due to the regulation of Great Lake in Cambodia and strong tide effect from the seas. As of now,



no large reservoir has been built in the mainstream in the Lower Mekong Basin (Lao PDR, Thailand, Cambodia and Vietnam) and new constructions – requiring approval by all four riparian countries – are not expected in the near future.

The economical consequences of SLR will vary from region to region due to deviating bio-physical and socio-economical settings (Smith and Lazo, 2001). While developed countries will likely invest in protective measures, most developing countries will have to cope with this problem under a very tight budget that can possibly be allotted to flood protection. Due to its prevalence in delta areas of the tropics, rice can be seen as a ‘frontier crop’ in the struggle to sustain agricultural production against gradually water level rise. Rice production in the other deltas such as Ganges-Brahmaputra, Irrawaddy and Chao Phraya will also severely suffer from the anticipated SLR – unless major efforts to avert hydrological changes are taken.

More information is needed to devise definite adaptation measures coping with SLR in the VMD. Adequate land management options require site-specific information on flooding patterns. Technical options of upgrading the existing water control system such as levees, dikes and sluices have to be substantiated by thorough cost/benefit analyses (Tol et al., 1998). Despite the huge investment involved, the task of minimizing adverse effects on rice production may not be beyond reach. Sea level will rise gradually over several decades, therefore the improvement of the water control system could be done step by step. This case study for the VMD provides an initial database for a regional risk analysis that may stimulate further in-depth research on ecological and economic consequences of SLR and – most of all – on possible flood prevention and adaptation measures.

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