FLOOD CONTROL MEASURES IN THE LOWER DONG NAI - SAI GON RIVER BASIN

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ABSTRACT

The lower Dong Nai - Sai Gon river basin plays a significant role in Vietnam's economic development. In the basin, Ho Chi Minh (HCM) City is known as the biggest center with a fast growing economy and increasing population. However, this area is undergoing inundation problems caused by upstream floods, heavy rains and changes in sea levels. Flooding control in this area has been subject to many studies and thus a number of measures was proposed, such as the hydraulic construction system (1547/QĐ-TTg), sea dike from Vung Tau to Go Cong, sea dike from Can Gio to Go Cong and so on. However, the effectiveness of such measures have not been analyzed and compared. This study applies one large scale 1-D hydrodynamic model and GIS techniques to clarify and assess the ability of flood control measures. Three sea level rise scenarios for Vietnam are also taken into account. The computed results with sea level rise show that the current hydraulic construction system (1547/QĐ-TTg) can control floods but in the future, an integrated measure with the Can Gio - Go Cong sea dike is the most effective one in controling flood in this area.

Keywords: *Sai Gon - Dong Nai river, flood control, inundation, sea level rise (SLR)*

1. INTRODUCTION

The lower Dong Nai - Sai Gon river (LDSR) basin (Fig. 1) spreads over a wide area, including Ho Chi Minh City (HCMC) and six provinces of Binh Duong, Dong Nai, Tay Ninh, Long An, Dong Thap, Tien Giang, with a total area of 1,080,520 hectares. It is a lowland, adjacent to the East Sea of Vietnam. This lowland is strongly influenced by river flows and tides . In recent years, many large reservoirs have been constructed in the upstream. Salt water intrusion and lack of fresh water are also the problems of this area. Being affected by climate change and sea level rise, salinity intrusion, inundation and flooding in the LDSR have became more serious. Extreme rainfall on the Dong Nai - Sai Gon River Basin in HCMC area, combining the high tides - rising sea levels will progressively put pressure on the drainage system and increased flooding to HCMC in the near future.

A number of flood control measures was proposed as summarized below. One of those measures introduced the construction of a hydraulic system along the Sai Gon River and main canals. This solution was approved by Vietnamese Goverment (under decision 1547/QĐ-TTg) and focuses only on protecting the downtown area of HCM city. Thus, it does not fully solve the flooding problems in the whole area downstream of the Dong Nai - Sai Gon River. In efforts to find a more comprehensive solution, the idea of the sea dike from Vung Tau to Go Cong was proposed. This sea dike can control flooding and prevent the sea level rise, but it can cause potential problem of environment;

sedimentation; and the eco-system of the Can Gio mangrove forest. Along with the sea dike from Vung Tau to Go Cong, a new sea dike from Can Gio to Go Cong was also suggested. The sea dike Can Gio – Go Cong is shorter than the sea dike Vung Tau – Go Cong, and it does not cover the mangrove forest in Can Gio. This solution allows the exchange of water between the inside and outside of the sea dikes to easily occur, while minimizing environment effect. However, the ability to control flooding of this solution is less effective than that of the sea dike Vung Tau – Go Cong.

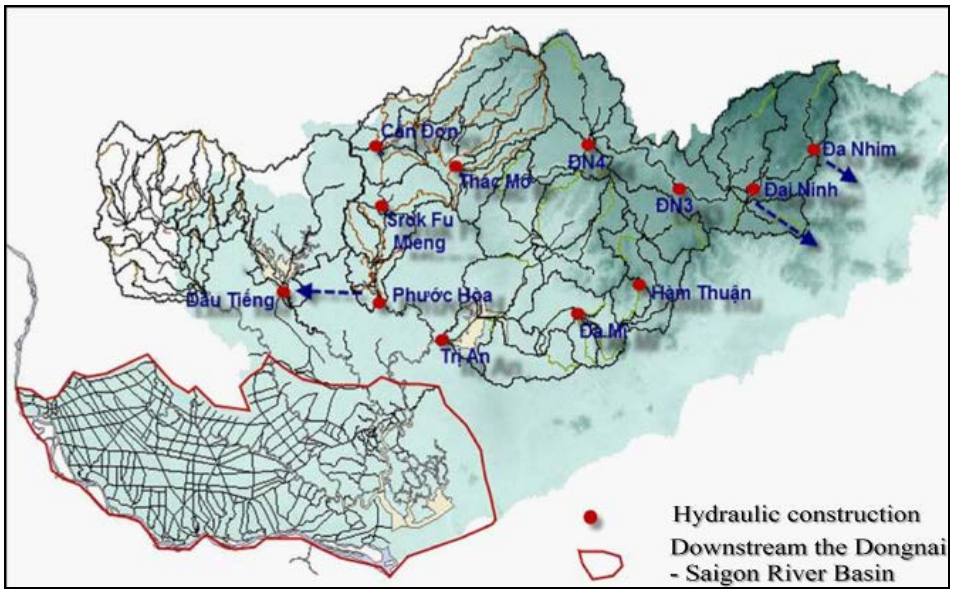

Figure 1. *Upstream reservoir and the LSDR*

1.1. Hydraulic construction system (decision 1547/QĐ-TTg)

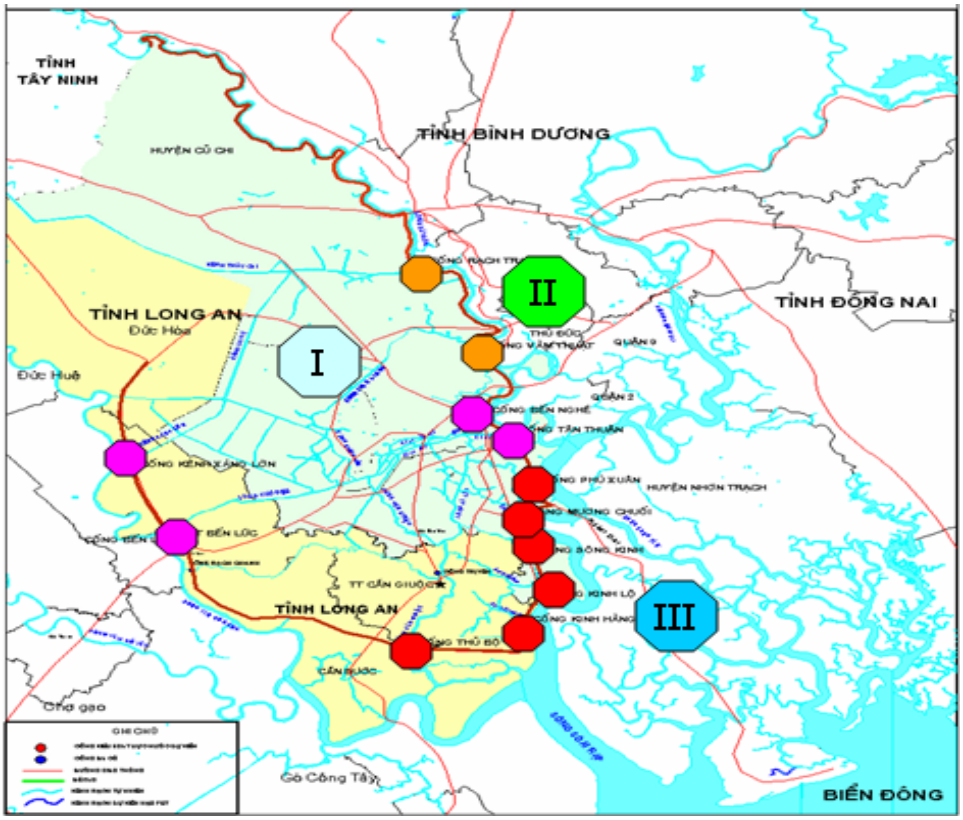

Figure 2. *Hydraulic construction system (decision 1547/QĐ-TTg)*

Due to the geographical characteristics, study area always copes with a great amount of flooding from the Dong Nai, Sai Gon and Mekong River. Moreover, HCM city completely in the tide affected areas. About 60% of study area is low-lying land and it often is flooded and heavy rain. Therefore, Vietnamese Government approved the plan of hydraulic construction system (decision 1547/QD-TTg, Otc, 2008) to prevent flooding in HCM city. The project's area is HCM city and a part of Long An provinces. This project includes one dike system to control flooding and 12 large sluices to support drainage. This project divided study area into three part, and the highest protect area is the downtown of HCM city (Figure 2).

1.2. The sea dike Vung Tau - Go Cong

In order to find the more comprehensive solution to control flooding for whole downstream area of the Dong Nai – Sai Gon River, the idea about super sea dike from Vung Tau to Go Cong was suggested.

The length of super sea dike is 33 km, and the average water depth is about 6.5 meter. In this sea dike, there are one large sluices to control tidal water and large locks (water transport) for drainage and navigation (see Figure 3).

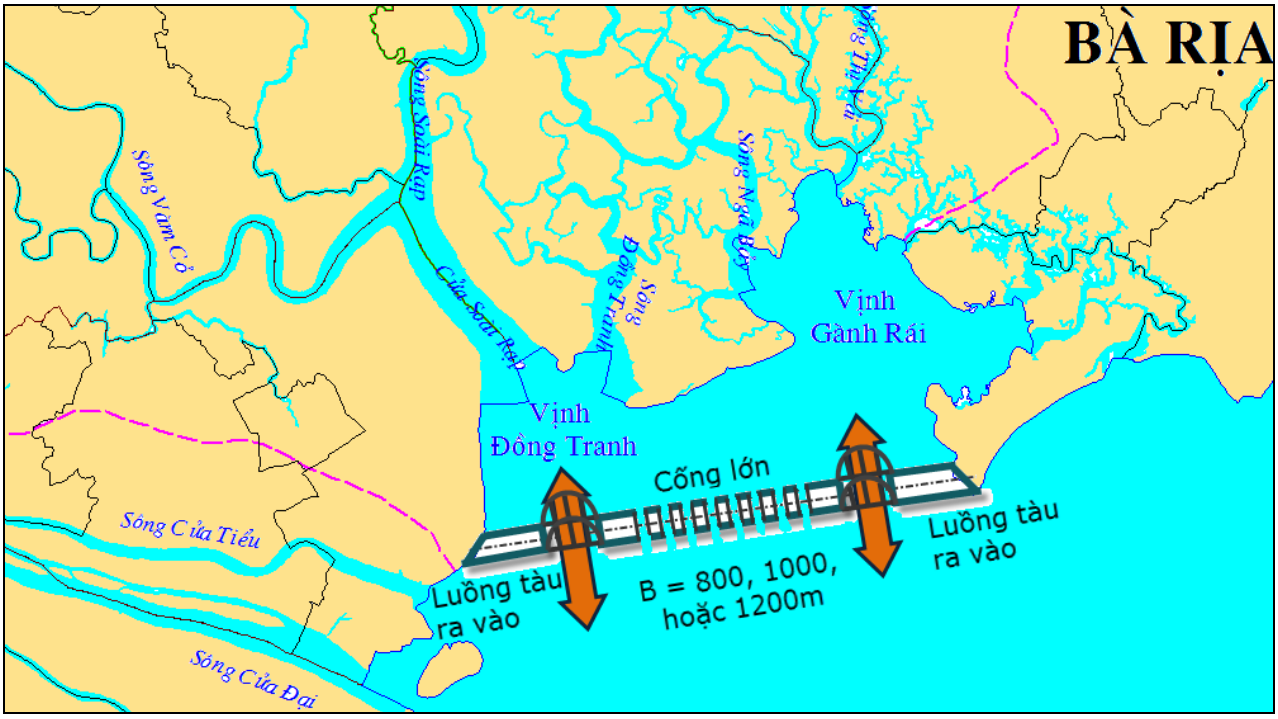

Figure 3. *The sea dike Vung Tau - Go Cong*

1.3. The sea dike Can Gio – Go Cong

The sea dike is from Go Cong to near Vung Tau (5km from Vung Tau) this sea dike is followed by a sub dike to Can Gio so Ganh Rai Bay is not covered (see Figure 4). The length of this sea dike shorter than sea dike Vung Tau - Go Cong about 5 km, but it has same the average water depth (6.5 meter).

This sea dike has also one large sluice to control tidal water and large locks (water transport) for drainage and navigation. The sub sea dike is about 13 km and the mean water depth is 4.5 meter.

In the Long Tau River, a large sluice, with 200m width, is built to control tidal water and drainage. The elevation of the Long Tau River's sluice is - 10m. Besides, one navigable lock is also built in the Long Tau River.

In order to find the most comprehensive solution to control flooding of the Dong Nai - Sai Gon River's downstream area, this study

simulates and analyzes the inundation processes using the MIKE11 model combined with GIS techniques. Three sea level rise (SLR) scenarios are also considered. The computed results will clarify and assess the ability to control flooding of those solutions above.

Figure 4. *The sea dike Can Gio - Go Cong*

2. NUMERICAL MODELING

2.1. Model setting

The hydrodynamic MIKE 11 model (1-D) is built for the entire Mekong River Basin and the study area. The rivers network is established with 1415 rivers and 6890 cross sections (Fig. 5). All terrain data are collected from survey data of the Mekong River Commission (1998); Southern institute for water resources planning, institute for water and environment research – Water Resources University (2010), and Southern institute for water resources research (2009). Besides, the DEM map of the Mekong River Commission (2003) and DEM map of the downstream Dong Nai-Sai Gon River Basin of the MONRE is used in this hydrodynamic model.

The discharges are collected from 6 hydrological stations: Kratie, Tonlesap, Vam Co Dong, Dau Tieng, Phuochoa and Tri An. Whereas, the measure water level data of hydrological stations, located on mouth of main rivers such as Vung Tau (Soai Rap and Long Tau River),Vamkenh (Tieu River), Binhdai (Dai River), Anthuan (Hamluong River); Bentrai (Cochien – Cunghau River); Mythanh (Dịnhan – Trande River), Ganh, Ongdoc, Xeoro, Rachgia.

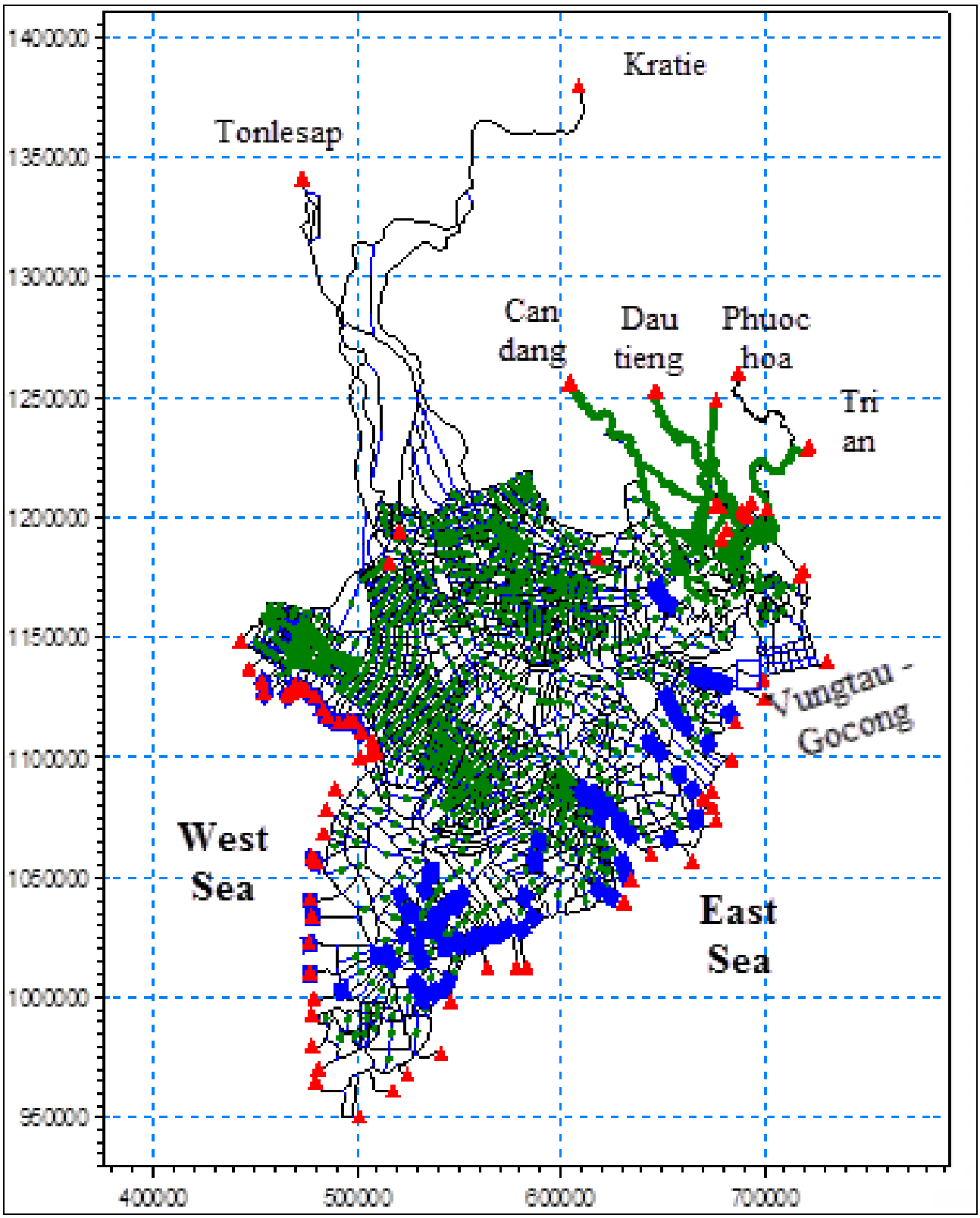

Figure 5. *Network of the Dong Nai – Sai Gon and the Mekong River*

2.2. Model calibration and validation

The calibration was done for data from July to November 2000 (Figure 6, Figure 7) and model validation was made for data in 2005 (Figure 8). It can b seen that model result has a good agreement with measured data. Computed water level is in accordance with measured data in values, amplitude, and phase of the tide. The difference between measured data and computed results is only from 5 to 7 cm.

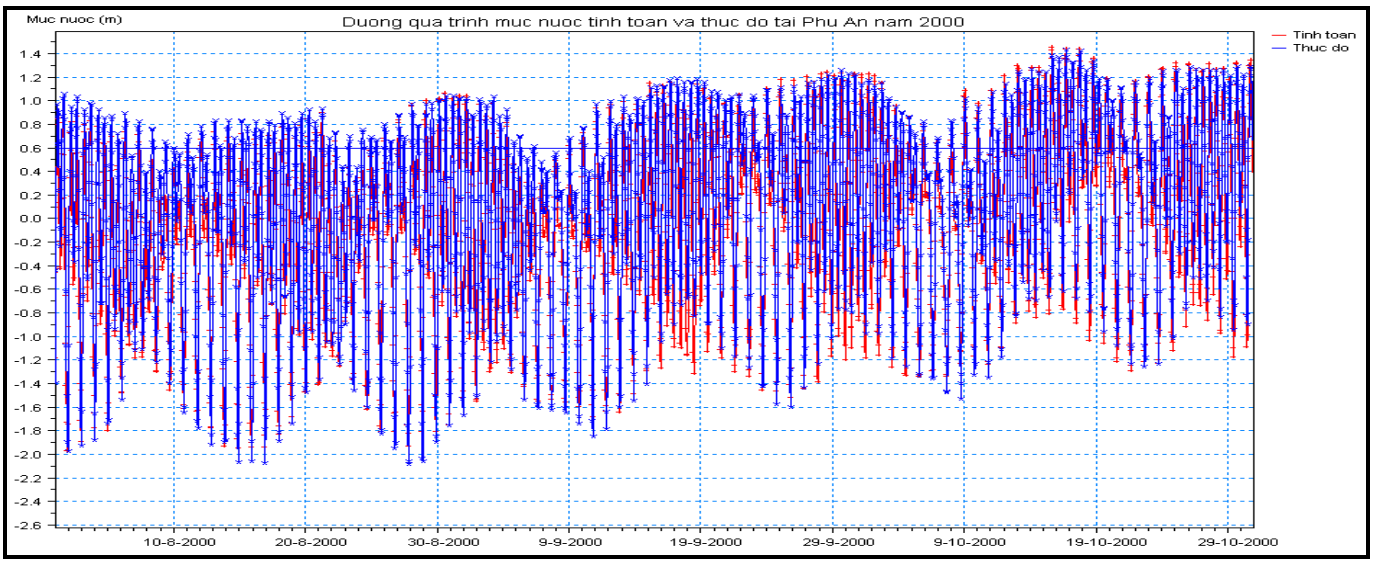

Figure 6. *Measured data and model verification result at Phu An station in 2000*

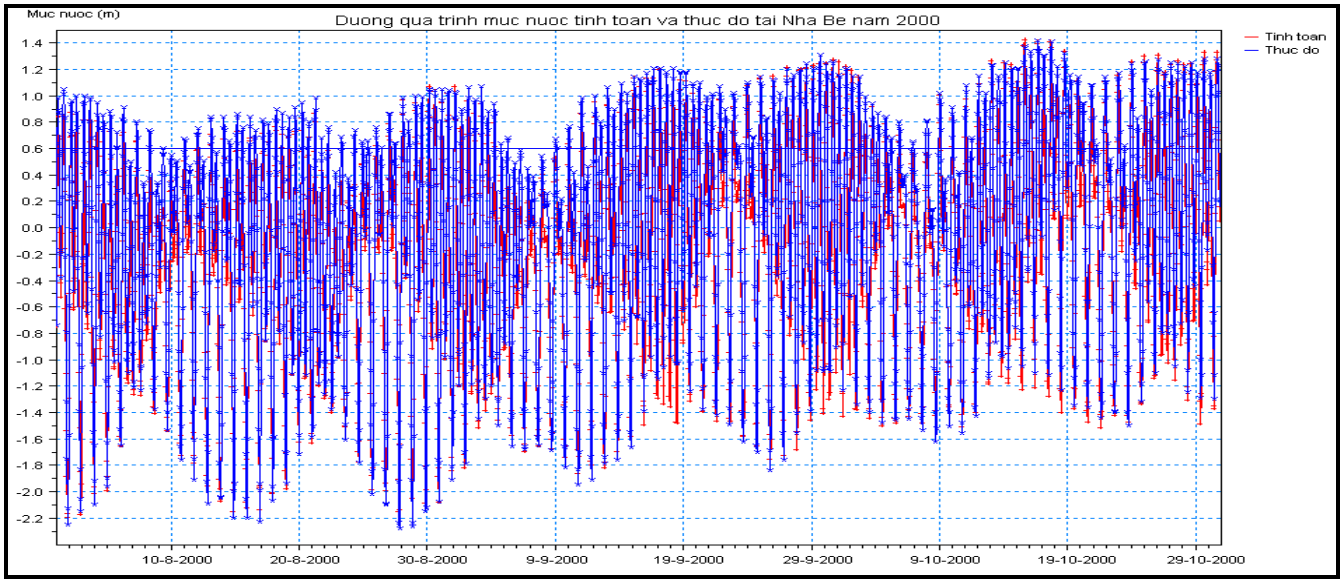

Figure 7. *Measured data and model verification result at Nha Be station, calibration in 2000*

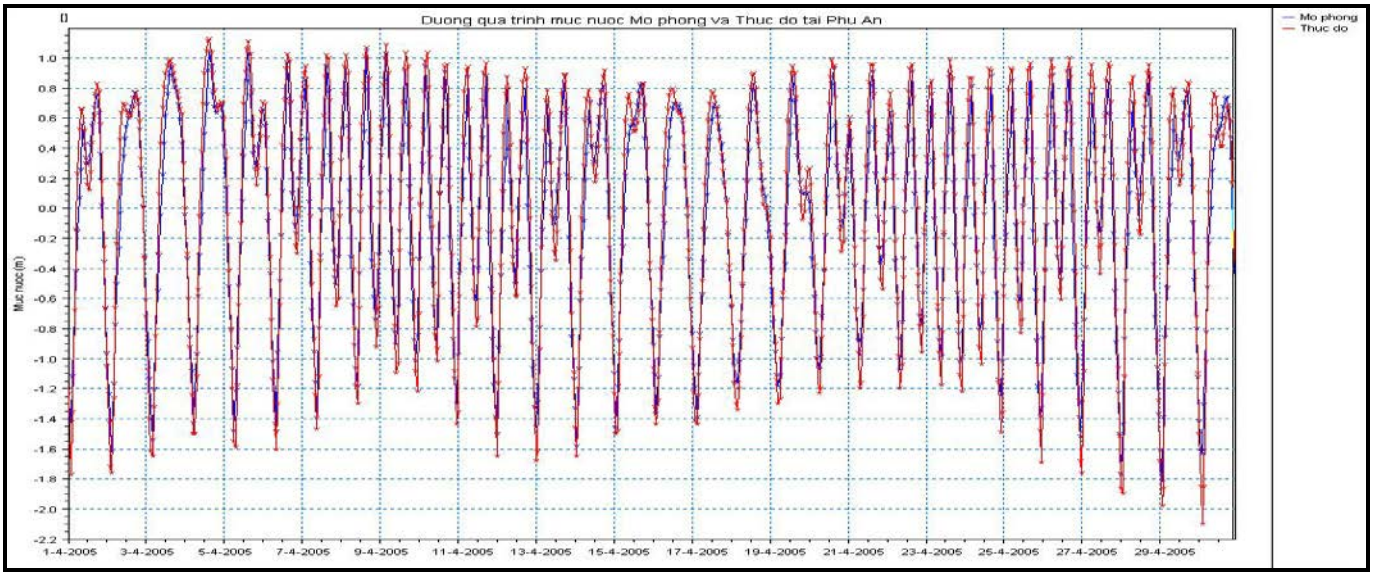

Figure 8. *Measured water level and model result at Phu An station, verification in Apr, 2005*

The computed discharge result is not as good as the water level simulation. However, it still ensures phase and the deviation between the measured data and computed result is in the range of 6 and 11%. Thus, it is acceptable. In addition, it should be noted that the measured discharge data has a relative accuracy. Therefore, the model is a reasonable simulation of the actual hydrodynamic characteristics in the downstream of the Dong Nai – Sai Gon River.

2.3. Setting the construction solution in model

The hydraulic construction system of three solutions above were setup in hydrodynamic model (Mike 11) in detai.

- The hydraulic construction system (according to decision No 1547/QĐ-TTg), the dike systems and 12 large sluices, are setup with design charateristics.

- The sea dike Vung Tau – Go Cong is from Vung Tau to Go Cong, with one large sluice to control tidal water and two navigable lock. The large sluice is calculated with the width in range from 600m to 3000m and the bottom elevation is – 10m. This sluice is one way when upstream flooding occurs (see Figure 9).

- The sea dike Can Gio – Go Cong starts at Go Cong, when it near Vung Tau 5km, it is followed by a long bridge so ships and tidal water can exchange through this place. Besides, one sub dike from Can Gio connect the main dike above. There are also one large sluice to control tidal water and navigable locks. The large sluice is calculated with the width in range from 600m to 3000m and the bottom elevation is – 10m. This sluice is one way when upstream flooding occurs. Morover, one more large sluice, with 200m width, is built to control tidal water and drainage in the Long Tau River. The bottom level of the Long Tau River's sluice is - 10m, and one navigable lock is also built in the Long Tau River (see Figure 10).

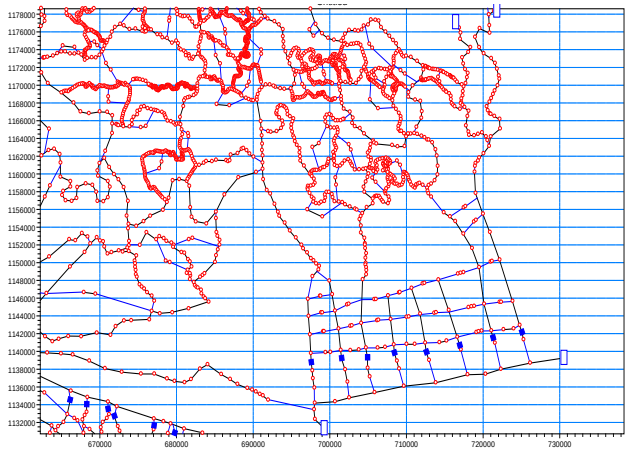

Figure 9. *Network of the sea dike Vung Tau – Go Cong*

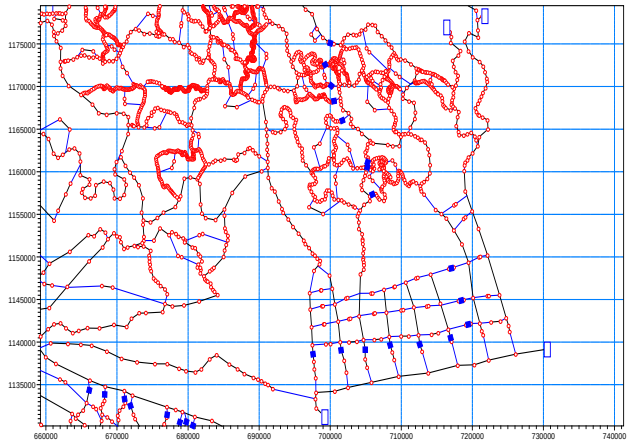

Figure 10. *Network of the sea dike Can Gio – Go Cong*

2.4. Model application

In order to investigate the effects of upstream flood on the study area, some simulation scenarios are proposed, based on the integration of the different flood frequency for upstream boundaries (Table 1). The first scenario, call name "TV1", is a special case, which combines of the great floods in the Train, Dau Tieng and Phuoc Hoa reservoirs. A particular great flood (P=0.5%) occurs in the Tri An reservoir and one other great flood (P = 1%) happens in the Dau Tieng Reservoir, whereas the Phuochoa reservoir copes with a strong flood (P=5%). The high floods also appear in the Vam Co Dong river and the Be River. While the upstream boundaries of the Mekong River (Kratie and Tonlesap) are collected

from the measured discharge data in 2000, which is one of the most flood years of the Mekong River in history. The other boundary condition, tidal water level is also set up with the highest tide, it is tide in 1994. Last but not least, the rain design frequency 5% is chosen for precipitation condition.

Table 1. Simulation scenarios

SCENARIO	TRI AN	DAU TIENG	PHUOCHOA	TIDE
TV1	Qmax = 4945	Qmax = 1194	Qmax = 1788	1994
TV1 + 12	Qmax = 4945	Qmax = 1194	Qmax = 1788	1994 + 12cm
TV1 + 30	Qmax = 4945	Qmax = 1194	Qmax = 1788	1994 + 30cm
TV1 + 75	Qmax = 4945	Qmax = 1194	Qmax = 1788	1994 + 75cm

After that, three scenarios of SLR, proposed by MONRE, are simulated to assess inundation in the study area. The first scenario is the low SLR, increasing 12 centimeters. The second scenario is medium SLR; sea water level significantly rises 30 centimeters. The last scenario, sea water level highly rises 75 centimeters. Three SLR scenarios have same baseline, which is tide in 1994 (Table **1**).

3. RESULTS AND DISCUSSION

Tables 2 to 5 are the computed water level results in the main rivers in three solutions. The results show the influences of extreme upstream flood and SLR on study area and the ability of three solutions to control flooding.

3.1. The hydraulic construction system (decision No 1547/QĐ-TTg)

Table 2. Water level result in the existing status and scenario with hydraulic construction system (decision No 1547/QĐ-TTg), in the Sai Gon River

Existing status (TV1)	1547/QĐ-TTg				Location
	TV1	TV1 + 12 cm	TV1 + 30cm	Tv1 + 75cm	
5.65	5.65	5.65	5.65	5.65	Dau Tieng
2.77	2.79	2.83	2.89	3.06	Ben Duoc
1.80	2.20	2.28	2.32	2.58	Thi Tinh River mouth
1.69	2.14	2.22	2.25	2.51	Thu Dau Mot
1.66	2.11	2.19	2.21	2.51	Rach Tra
1.62	2.02	2.11	2.14	2.48	Vam Thuat
1.61	1.86	1.96	2.01	2.36	Phu An
1.65	1.80	1.90	1.95	2.32	Den Do cape
1.62	1.76	1.86	1.91	2.33	Nha Be
1.52	1.61	1.70	1.78	2.21	Lo Canal mouth
1.52	1.61	1.70	1.82	2.21	Vam Co River mouth
1.51	1.51	1.62	1.79	2.23	Soai Rap Estuary
1.47	1.47	1.59	1.76	2.21	Sea

Under the effects of those two factors, extreme upstream flood and high sea level, the water level is strongly increased in main river such as the Sai Gon River. Under the effects of those two factors, extreme upstream flood and high sea level, the water level is strongly increased in main river such as the Sai Gon River. The hydraulic construction system (decision No 1547/QĐ-TTg), with one dike system along main rivers and 12 sluices, covers the downtown area of HCM city. Hence, it significantly prevents flood from sea water and upstream flooding. However, due to upstream flood and tidal water are trapped in the main rivers so the water level along those main rivers are all risen and higher than existing status.

Table 3. Water level result in the existing status and scenario with hydraulic construction system (decision No 1547/QĐ-TTg), in urban area of HCM city

Existing status	1547/QĐ-TTg				Location
(TV1)	TV1	Tv1+12 cm	TV1+30cm	Tv1+75cm	
1.64	1.98	2.07	2.20	2.50	Ben Luc
1.52	1.10	1.17	1.25	1.37	Nuoc Len Canal – HCM Center
1.48	1.02	1.07	1.11	1.20	Tan Hoa Canal - HCM Center
1.53	0.91	0.95	1.00	1.14	Bridge “Y” - HCM Center
1.62	1.86	1.96	2.01	2.36	Bennghe River

3.2. The sea dike Vung Tau – Go Cong

The computed results shows that the sea dike Vung Tau - Go Cong effectively reduces water levels in the major rivers as well as in urban areas in study area. Table 4 points out that due to sea level rise effect, the maximum water level in main rivers also rise. An increase of water level depends on the degree of impact of rising sea levels. Into mainland and upstream area, the sea level rise effect is weaker.

Nevertheless, if compared with computed results with sea level rise and no construction, the sea dike Vung Tau - Go Cong makes water level be lower many times. In scenario TV1 (no sea level rise) the ability to control the water level of sea dikes VT-GC is very high. Even when the sea level rises 75cm and the great floods occur in the upstream, the maximum water level at Phu An (hydrological station in the Sai Gon River) is 1.24m and this value is still lower than the proposed inundation level of JICA (1.32m).

Table 4. Water level result in the existing status and scenario with sea dike Vung Tau - Go Cong, in the Sai Gon River

Existing status (TV1)	Sea dike Vung Tau – Go Cong				Location
	TV1	TV1 + 12 cm	TV1 + 30cm	Tv1 + 75cm	
5.65	5.65	5.65	5.65	5.65	Dau Tieng
1.80	1.34	1.39	1.48	1.63	Thi Tinh River mouth
1.69	1.06	1.12	1.22	1.37	Thu Dau Mot
1.66	0.99	1.06	1.15	1.30	Rach Tra
1.62	0.89	0.97	1.06	1.25	Vam Thuat

Existing status (TV1)	Sea dike Vung Tau – Go Cong				Location
	TV1	TV1 + 12 cm	TV1 + 30cm	Tv1 + 75cm	
1.61	0.82	0.90	1.01	1.24	Phu An
1.65	0.80	0.88	0.97	1.23	Den Do cape
1.62	0.70	0.79	0.90	1.21	Nha Be
1.52	0.68	0.76	0.88	1.19	Lo Canal mouth
1.52	0.66	0.75	0.88	1.20	Vam Co River mouth
1.51	0.63	0.71	0.86	1.20	Soai Rap Estuary
1.47	0.63	0.71	0.84	2.23	Sea

The sea dikes VT-GC not only reduces the water level, but also makes the fluctuations of the water level in study area become smaller. The water level amplitude is about 0.8 m to 1.2 m, the difference between the high tide and low tide in one day is not as large as existing status.

3.3. The sea dike Can Gio - Go Cong

When upstream floods and high tides occur in study area, the big culverts in sea dike Can Gio - Go Cong operates one-way so the maximum water level in main rivers are significantly lower. It can be noticed that the sea dike Can Gio - Go Cong is not significantly different from the sea dike Vung Tau - Go Cong. However, in order to increase water exchange and ensuring environmental factors in Can Gio mangrove forest area, sea dike Can Gio - Go Cong does not cover Ganh Rai Bay. Therefore hydraulic regime of the two solutions can not differ much.

Table 5. Water level result in the existing status and scenario with sea dike Can Gio - Go Cong, in the Sai Gon River

Existing status (TV1)	Sea dike Vung Tau – Go Cong				Location
	TV1	TV1 + 12 cm	TV1 + 30cm	Tv1 + 75cm	
5.65	5.65	5.65	5.65	5.65	Dau Tieng
1.80	1.28	1.33	1.43	1.61	Thi Tinh River mouth
1.69	1.00	1.05	1.17	1.40	Thu Dau Mot
1.66	0.94	0.99	1.10	1.35	Rach Tra
1.62	0.83	0.91	1.03	1.29	Vam Thuat
1.61	0.78	0.89	0.99	1.26	Phu An
1.65	0.77	0.88	0.99	1.25	Den Do cape
1.62	0.72	0.83	0.96	1.20	Nha Be
1.52	0.69	0.80	0.93	1.18	Lo Canal mouth
1.52	0.67	0.78	0.91	1.18	Vam Co River mouth
1.51	0.61	0.71	0.85	1.17	Soai Rap Estuary
1.47	0.58	0.69	0.82	1.15	Sea

The computed results of sea level rise scenarios show that the impact of climate change and sea level rise on hydrodynamic characteristics of study area is limited by sea dike Can Gio - Go Cong. At Phu An (hydrological station in the Sai Gon River), if sea level rises 75 cm and maximum water level result is 1.26m. This value is higher than the result of sea dike Vung Tau - Go Cong, but the disparity between two values is very small, only 2 cm. And that value (1.26m) of maximum water level at Phu An is still lower than proposal water level of JICA at Phu An (1.32m).

It can be noticed the sea dike Can Gio - Go Cong has high ability to control flooding. Moreover, this sea dike also ensures to exchange of water, restrict the pollution environment, maintain Can Gio mangrove forest, and etc. through Ganh Rai Bay.

3.4. Inundation

The computed results show the hydraulic constructions system (decision No 1547/QĐ-TTg) has significant ability to prevent flooding for downtown area of HCM city, whereas the sea dike Can Gio – Go Cong is more advantage than the sea dike Vuntau – Go Cong. These sea dike have same high ability to control flooding in study area when sea level rises. But , the sea dike Can Gio – Go Cong ensures to exchange of water, restrict the pollution environment, maintain Can Gio mangrove forest, and etc. through Ganh Rai Bay, while the sea dike Vung Tau – Go Cong covers whole area of study area. so water exchange is not easy. Hence, it causes environmental problems and negative impacts on Can Gio mangrove forest. Therefore, the hydraulic constructions system (decision No 1547/QĐ-TTg) and the sea dike Can Gio – Go Cong are chosen to appy techniques to analyze in detail.

Based on the Mike 11 results and terrain data of the study area, inundation maps are established, corresponding with five simulation scenarios above (see from Figure 11, Figure 12 to Figure 16). After that, the GIS technique is applied to find out the inundation area in detail.

Table 6. Simulating inundation area of 5 scenarios (km^2)

Location	Area (km^2)	Existing Status (TV1)	TV1		TV1 + 12		TV1 + 30		TV1 + 70	
			1547	CG-GC	1547	CG-GC	1547	CG-GC	1547	CG-GC
HCM Center	231.5	71.8	39.5	29.72	45.64	33.4	62.44	37.52	74.36	45.7
Ds 2, 9 &Thu Duc	209.4	121.2	126.6	44.72	133.52	49.45	140.36	54.91	145.72	63.52
Nha Be - Binh Chanh	171.1	160.8	43.0	20.28	51.6	24.44	67.8	30.35	104.88	37.24
Thu Dau Mot-Bien Hoa	384.4	43.1	53.4	50.36	88.2	52.18	92.24	54.4	98.6	58.07
Hoc Mon	342	207.1	77.4	134.24	134.92	138.52	148.16	143.62	172.16	154.02
Dong Nai – Vung Tau	1090	351.3	358.5	268.84	373.28	282.89	395.64	302.28	422.84	332.21
Cu Chi	435.3	110.5	78.3	87.32	101.16	88.97	102.16	91.19	107.32	95.5
Can Gio	615.6	512.7	517.2	243.56	526.96	256.98	536.28	282.66	595.24	348.3

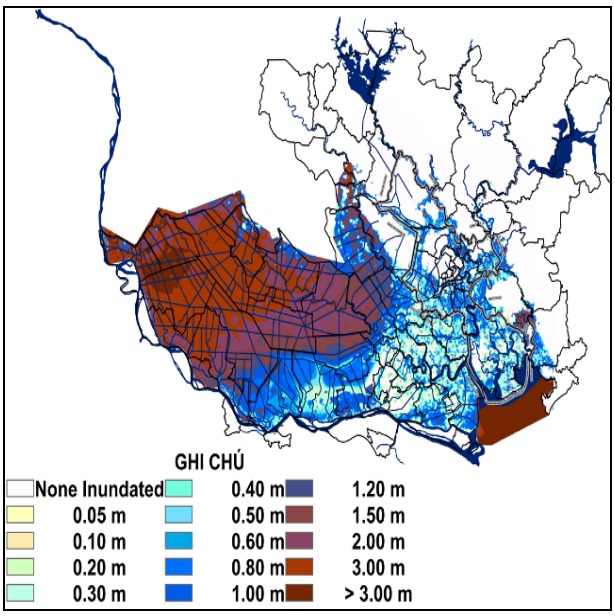

Figure 11. *Inundation map of the existing status scenario*

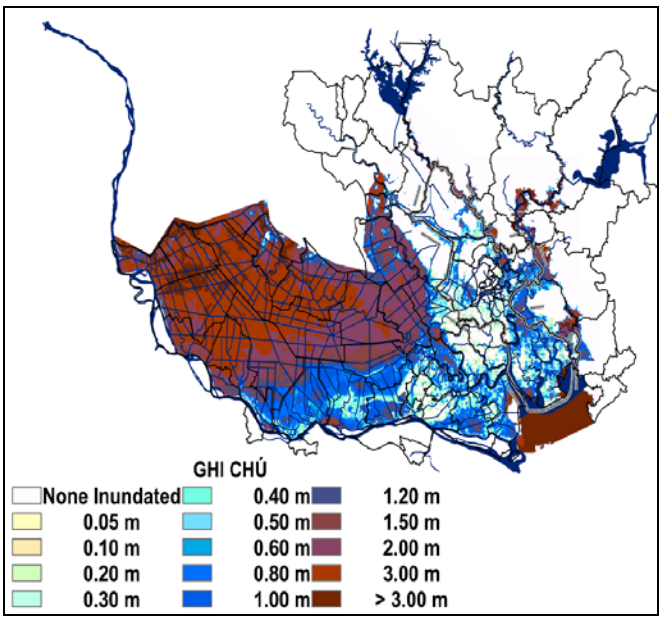

Figure 12. *Inundation map of hydraulic constructions system 1547, "TV1" scenario*

The inundation results in table 6 show that, as low-lying land, the flooding strongly happens because of sea level rise in Can Gio, district No 2, No 9, Thu Duc, Nha Be and Binh Chanh. The most inundation are is Can Gio with 85% area is under water level in TV1 scenario. Can Gio is not downtown area of HCM city so it is still strong inundation when hydraulic constructions system is built. The other ares, which is also hard inundation, is District No 2, No 9. This area is out of protect area by hydraulic constructiuons system (decision 1547/QD-TTg) so inundation area of this place is from 50% to 70% when sea level rises from 12cm to 75cm. Only center area of HCM city is protected by the hydraulic constuctions system, only 17% area is inundation when upstream flood and high tide occur and 30% area will be under water if sea level rises 75cm and upstream flood and high tide occur.

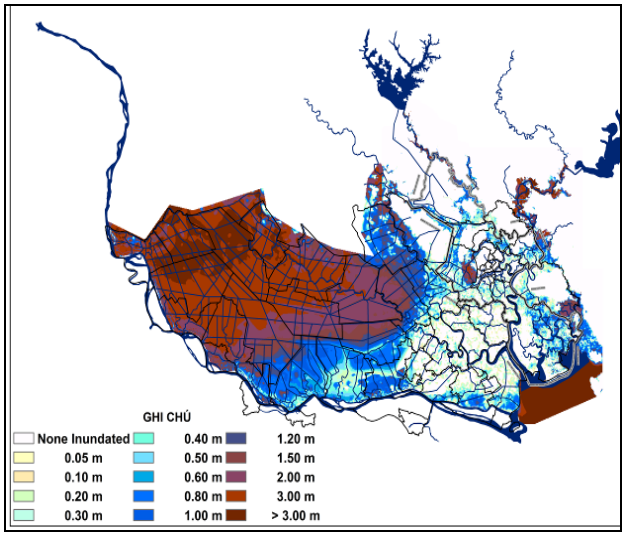

Figure 13. *Inundation map of sea dike Can Gio – Go Cong, "TV1" scenario*

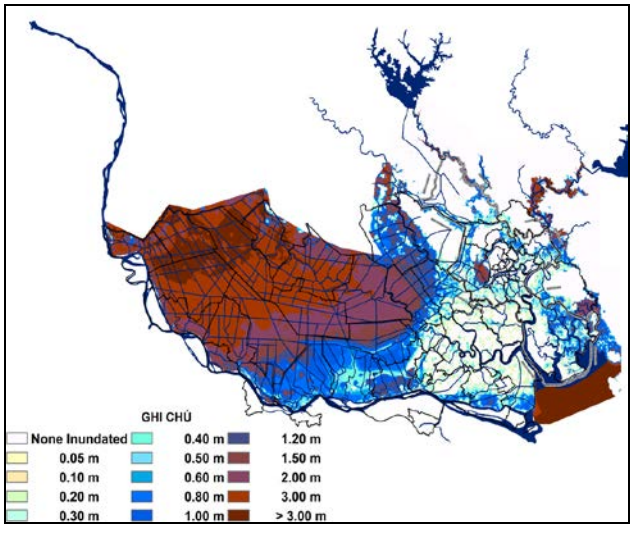

Figure 14. *Inundation map of sea dike Can Gio – Go Cong, "TV1+12cm" scenario*

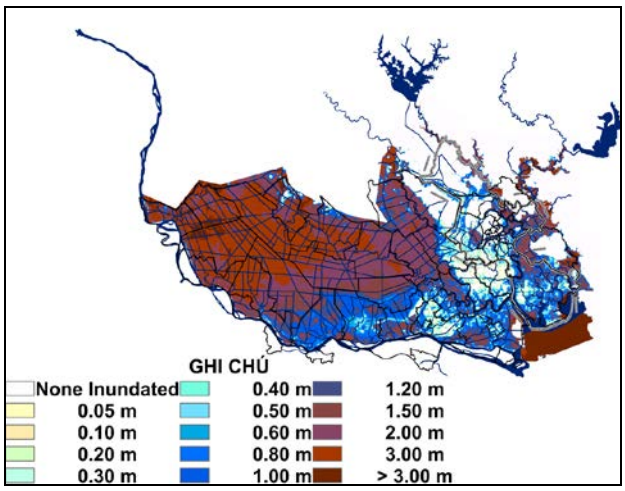

Figure 15. *Inundation map hydraulic constructions system 1547, "TV1+30" scenario*

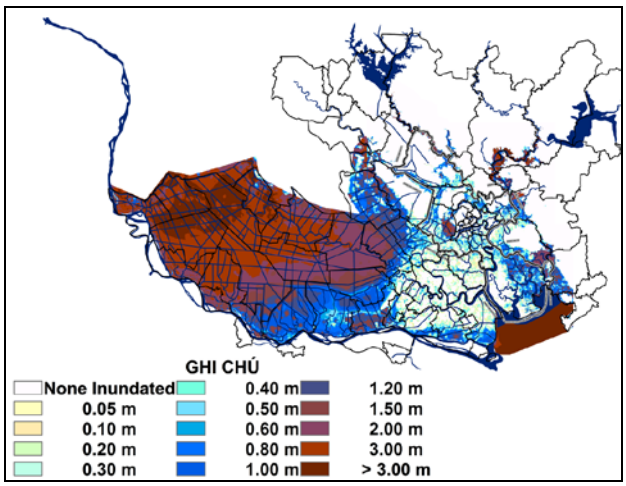

Figure 16. *Inundation map of sea dike Can Gio – Go Cong, "TV1+30" scenario*

Oposition with the result of hydraulic constructions system (decision No 1547/QĐ-TTg), the computed result of the sea dike Can Gio – Go Cong show the ability control flood is considerable in the whole study area. The inundation areas, in Can Gio, district No 2, No 9, Thu Duc, Nha Be and Binh Chanh, are about a half of those values of hydraulic constructions system results. The inundation area in Can Gio is only from 35% to 52% in TV1 scenario and TV1 + 75 cm. Those values in District No 2 and District No are 20% and 30% respectively.

4. CONCLUSIONS

The computed results of three solutions in this study concluded that the inundation problem is very serious in the downstream of the Dong Nai – Sai Gon River. That problem is mainly driven by the upstream flood and sea level rise. However, the impact of the upstream flood is different from sea level rise impact. The upstream flood governs the river dynamics in the proximal area behind of the Dau Tieng and Tri An reservoir, and makes the water surface elevation noticeably rise; but the impact of the upstream flood becomes weaker due to the larger river cross section and dense river canal system in downstream of the study area.

In three solutuons, the hydraulic constructions system (decision No 1547/QĐ-TTg) has high ability to control flood in the downtown area of HCM city, but this solution makes the inundation degree of the other places in study area become more serious. However, when in near future (sea level rises from 12 cm to 30cm) this solution still ensure drainage and control flooding of study area. But it will not afford the rising sea levels over 30cm.

The sea dike Vung Tau – Go Cong is more ability to control water level in the whole study area. Even if the rising of sea water level is 75cm, the maximum water level at Phu An is under the proposal water level of JICA. This result point that when upstream flood and high tide occur with sea level rise in far future, whole study area can endure with low inundation degree. Nevertheless, this solution not only causes environmental problems but also restrict exchange water. This solution can lead sedimentation in the Sai Gon River Estuary.

The sea dike Can Gio – Go Cong is more advantage than the sea dike Vung Tau – Go Cong. These sea dike has same high ability to control flooding in study area when sea level rises. But , the sea dike Can Gio – Go Cong ensures to exchange of water, restrict the pollution environment,

maintain Can Gio mangrove forest, and etc. through Ganh Rai Bay.

The impact of climate change and sea level rise on hydrodynamic characteristics of study area is limited by sea dike Can Gio - Go Cong. At Phu An (hydrological station in the Sai Gon River), if sea level rises 75 cm and maximum water level result is 1.26m. This value is higher than the result of sea dike Vung Tau - Go Cong, but the disparity between two values is very small, only 2 cm. And that value (1.26m) of maximum water level at Phu An is still lower than proposal water level of JICA at Phu An (1.32m). Base on results of hydrodynamic model Mike 11 and GIS application, this study can conclude that the current hydraulic construction system (1547/QĐ-TTg) can control flooding, but in future, the general solution with the super dike from Can Gio to Go Cong is the most effective to control flooding in study area.

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