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Coastal Inundation due to Sea Level Rise in the Pearl River Delta, China

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Abstract. This paper examines the increased potential risk of tidal inundations in the Pearl River delta, China, due to future rises in sea level. The research is based on tidal records of 54 tide gauges distributed across the delta plain, and employs mathematical calculations to predict potential rises of water level in different parts of the delta under a number of flood scenarios. After assessing a 72-year tidal record of Hong Kong and factors such as estuarine backwater effects and long-term geological subsidence, it suggests that a 30 cm rise in relative sea level at the mouth of the estuary is possible by 2030. Based on the prediction and five freshwater discharge scenarios, the potential impacts in water level across the delta plain are calculated. Three zones are identified as least affected, heavily affected and severely affected. The impacts are also translated into return periods of water level. It is suggested that in a large part of the delta plain, return periods will be shortened and hence will be increasingly vulnerable to tidal inundation. Finally, management implications are discussed along with assessment of adequacy of the existing tidal flood defences, as well as evaluation of the cost implications if they are to be improved.

Key words: sea-level rise, tidal inundation, flood defences, management implications, Pearl River delta

1. Introduction

According to the Inter-governmental Panel of Climate Change's (IPCC, 1996) IS92a emission scenario, assuming the 'best estimate' of climate sensitivity, global mean temperature increase by 2100 is about 2.4 °C. The associated global mean sea-level rise is projected as 49 cm. The IPCC's (2001a) recent report confirms that the 49 cm is the best estimate and the predicted range is between 20 cm and 86 cm. However, changes in future sea level will not occur uniformly around the globe. Regional responses could in fact differ substantially, owing to regional differences in heating and circulation changes. Tides, waves and storm surges could also be affected by regional climate changes. Nevertheless, such a rise in sea level will pose severe threats to, or will degrade, coastal infrastructure such as flood defence (IPCC, 2001b). The magnitude of sea-level rise may be reduced if some mitigation measures are implemented, but the effects of the mitigation may not be realised

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until 2030 (IPCC, 2001c). Therefore, coastal societies have to face the threats of sea-level rise for at least the next few decades.

Impacts of future sea-level rise on the socio-economic development of major coastal cities in China have been a main focus of recent research. Han *et al.* (1995) provided a brief national assessment of the impacts for China. Wang *et al.* (1995), and Chen and Zong (1999) examined the implications of sea-level rise on socio-economic development and agriculture for Shanghai, whilst Yim (1995) assessed the likely impacts on land reclamation projects in Hong Kong. During the 1990s, in the Pearl River delta, a number of research projects were carried out to identify the possible impacts of future sea-level rises. These research projects focused on socio-economic development (e.g., Li *et al.*, 1993) and the environment, the latter including saline water intrusion (e.g., Fan, 1994), inter-tidal environment (e.g., Huang, 2000), as well as flood hazards.

In order to quantify the socio-economic impacts of future sea-level rises, researches need to project the potential physical consequences rising sea level may result in. Impacts of sea-level rise on a coastal lowland are usually multiple. This includes an increase in the frequency of coastal inundation. In turn, potentially affected areas may be extended due to estuarine backwater effects, or certain areas may become hazardous due to rising water levels. Ultimately, human lives and livelihoods will increasingly rely on the protection offered by sea/flood defences. Although the risk of an area being inundated by the sea is determined by a combination of many factors, including tidal waves and typhoon storm surges, this paper will focus on the prediction of water level across the deltaic plain based on the estimated sea-level rise and effects of estuarine backwater. This paper will also assess management implications such as the effectiveness of the current sea/flood defences.

2. The Pearl River Delta

The Pearl River is the collective name of three rivers: the East River, the North River and the West River. These three rivers drain the southern part of China and converge together in the Pearl River delta (Figure 1). The delta plain started to emerge some 2000 years ago (Li and Qiao, 1982) and has expanded rapidly over the last few centuries. The unique feature of the Pearl River delta is its complex tributary network, with a density of 0.68 km/km^2 to 1.10 km/km^2 at different parts of the delta plain.

At present, the Pearl River delta covers 9750 km^2, and is the third largest delta in China. Within the northern fringe of the delta plain (Figure 2), the ground level is generally over 2.4 m above mean sea level (MSL), with numerous localised depressions ranging from 0.2 m to −0.1 m relative to MSL. The ground altitude of the northern and central parts of the delta is between 0.4 m to 2.4 m above MSL. The ground level of the southern part of the delta is slightly lower, ranging from 0.4 m to −0.3 m relative to MSL. Average tidal range within the estuary ranges

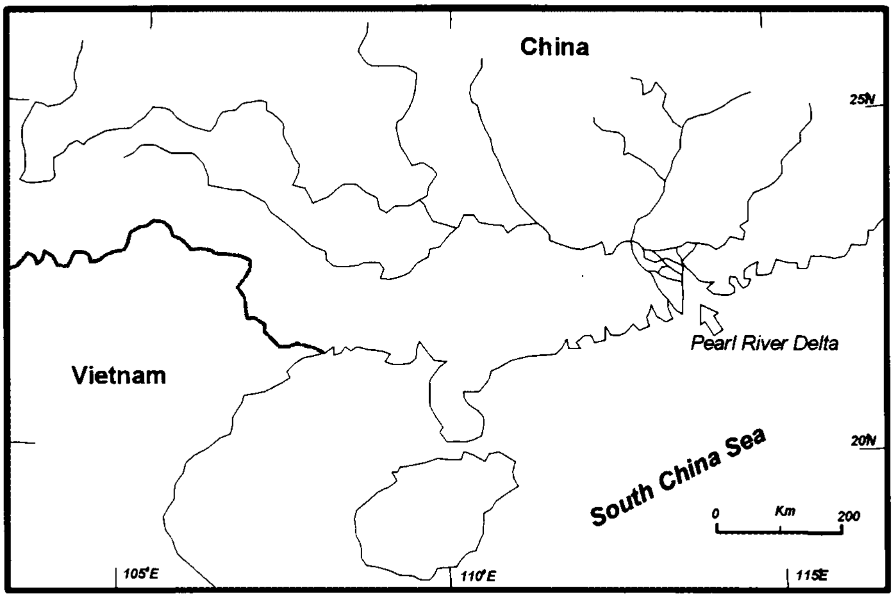

Figure 1. Location of the Pearl River Delta.

from 0.86 m at the mouth to 1.57 m at the head of the estuary, but increases to between 2.29 m and 3.36 m during astronomical tides.

The northern fringe of the delta plain was reclaimed as early as the Tang Dynasty, c. 1400 years ago, and the speed of reclamation has gradually increased since then. During the past 50 years, reclaimed lands were merged into just over 100 enclosures (called *Wei* in Chinese). Each enclosure is protected by flood defences, and between enclosures are tributaries or tidal channels. In 1998, there were flood defences of 3057.6 km in total length in the delta plain.

Being the area of most rapid economic development in China, the delta has a population of over 12 million, and a population density of 1230 persons/km^2. There are 16 cities, including Guangzhou, the provincial capital. Up to 64% of the population are urban residents, and the area is highly industrialised. By the year 2000, the GDP of the delta accounts for c. 59% of the provincial total. However, the human lives and economic assets have always been under threats of natural hazards, including river flood, waterlog, wind storm (typhoon), tidal flood and saline water. These hazards will no doubt be intensified by the predicted rise in sea level. Current and future economic developments will also increase socio-economic exposure to such hazards. If the projected rise in sea level will increase the livelihood of the deltaic lowlands being inundated by the sea, there is then an urgent need to understand the potential extent of hazardous sea inundations, in order for adaptive measures be designed and implemented accordingly.

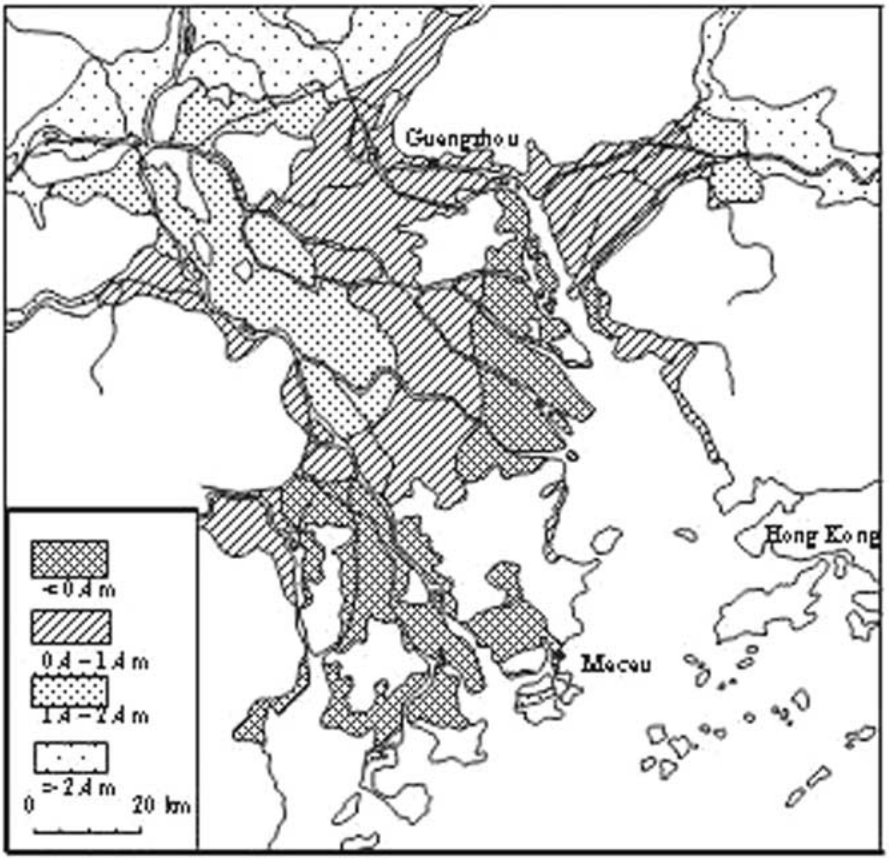

Figure 2. This map shows the Pearl River deltaic plain with ground altitudes above mean sea level.

3. Methodology

This paper follows the methodology similar to that suggested by Parry and Carter (1998). After the problems being defined as shown in previous section, it is to develop the scenarios of sea-level rise by examining the following factors. Firstly, tidal records from a number of tide gauges are used to calculate the secular trend of mean sea level which is then compared with the IPCC prediction. Secondly, the tidal records are used again to estimate the average magnitude of mean sea-level fluctuations, because inundations are more likely to happen during periods of higher mean sea level. Thirdly, as water levels within the delta are influenced by the freshwater discharges, the additional heights in water level induced by various freshwater discharges are calculated. Fourthly, long-term ground subsidence due to tectonic movement and sediment compaction is also estimated.

Based on the various sea-level scenarios, this paper assesses one of the likely impacts, i.e., the geographical extent of future floods. The definition of affected areas is based on the calculation of return periods for highest water level at a number of locations across the delta and ground altitudes shown on the 1:10,000 scale topographic maps which were surveyed and published after 1980 and depict ground altitudes accurate to 0.1 m. These areas are mapped and these maps then become the basis for the assessment of flood vulnerability of the deltaic plain. This leads to the next stage of study, evaluating management implications and adaptive responses. The benefit of sea/flood defences and the possible cost for any future enhancement are calculated according to the need and level of protection.

This research uses a large amount of tidal records from a total of 54 tide gauges (Figure 3), as well as socio-economic data from the Pearl River delta. A number of statistical methods (i.e., one-dimensional and two-dimensional hydraulic models for steady flows) are applied, and the calculations are based on the post-1980s topographic data at 1:10,000 scale. The tributary network is divided into 255 sections, and a total of 948 cross sections are used for the calculation.

4. The Magnitude of Sea-level Rise by 2030

The magnitude of mean sea-level rise in the Pearl River delta between 1990 and 2030 has been predicted as 20 cm to 25 cm (Ren, 1993), 25 cm to 30 cm (Li *et al.*, 1993), or 30 cm to 40 cm (Chinese Academy of Science, 1994). These predictions were mostly crude estimates based on some tide-gauge records. The current study examines three factors that all play a part in future sea-level rise in the Pearl River delta.

Within the Pearl River delta area there are two tide gauges at Hong Kong and Macau respectively, both started from 1925 and are the longest serving tide gauges in southern China. However, there are gaps in tidal records from both gauges. There is no record for 1930–1949 at Hong Kong, whilst the Macau station moved three times during 1963–1981. This study, therefore, takes the year 1959 as the connection point to combine the two data sets. As a result, the monthly mean sea-level records from Macau are added to the Hong Kong data set and form a 72-year series (1925–1958 from Macau and 1959–1996 from Hong Kong, Figure 4).

After the data being filtered by a series of low passes, a single-order linear regression is applied to produce an average annual rate of sea-level movement. The result indicates that the rate of sea level rise at the mouth of the Pearl River estuary is 1.8 ± 0.1 mm/a between 1925 and 1996. This rate is close to the estimate of between 1 mm/a and 2 mm/a for China by Ren (1993) and for the global average (Gornitz, 1995). Given the fact that the geology of the sites of the two tide gauges is relatively stable (Yim, 1995), this value (1.8 mm/a) can be used as a conservative estimate of sea level rise for the period up to 2030.

By applying a multiple-order non-linear regression to the data set, the following equation has been formulated:

$$Z(t) = 40.85 + 6.19 \times 10^{-12} t^4. \qquad (1)$$

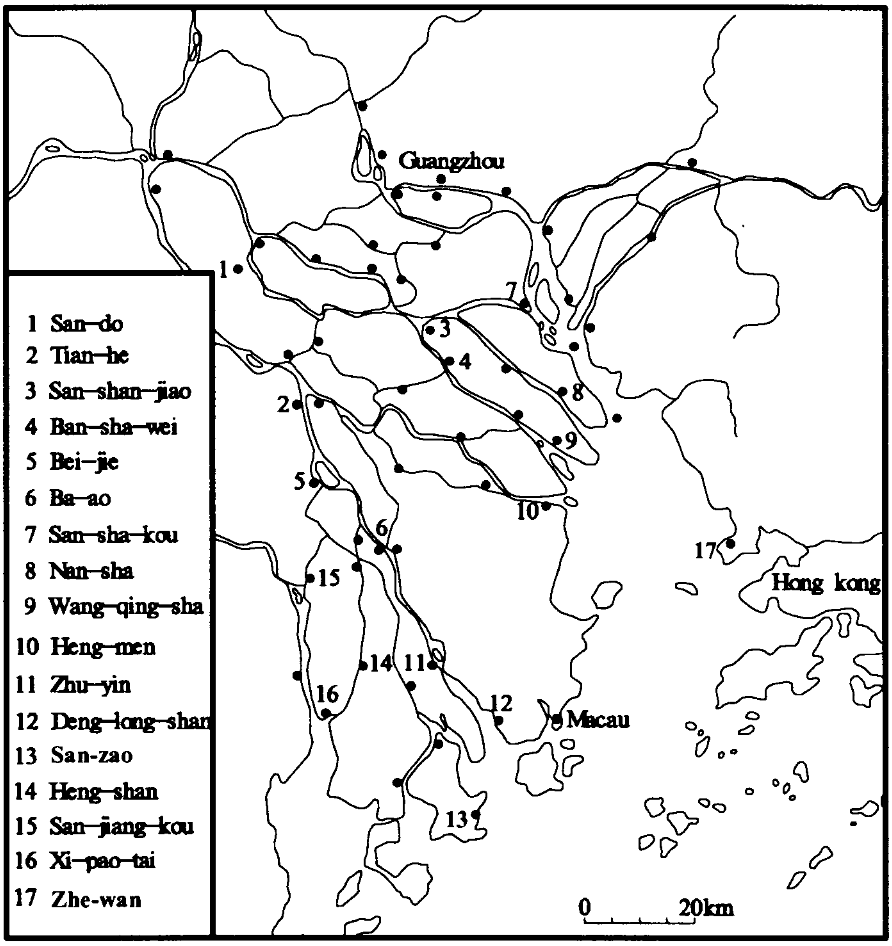

Figure 3. Locations of the 54 tide gauges with records of 40 years. Names for 17 of the tide gauges are listed.

Here, Z is the magnitude of sea-level rise, and t is time. This formula implies that sea level has been rising exponentially. From this formula, the rates of sea-level rise for the early part of the record are 1.7 mm/a, and 2.0 mm/a for the 1990s. This trend therefore fits the global trend (e.g., IPCC, 2001a). In order words, sea level in the Pearl River delta may have risen by 8 cm to 12 cm by the year 2030 (i.e., the IPCC prediction).

The second factor to be considered is the magnitude of sea level variations from the mean for areas within the estuary, because the rise in sea level within the estuary may not be the same as the eustatic rise of sea level at the mouth of the estuary. The calculation is based on the equation,

$$\pm \Sigma A = |Z'(t) - Z(t)|/n. \tag{2}$$

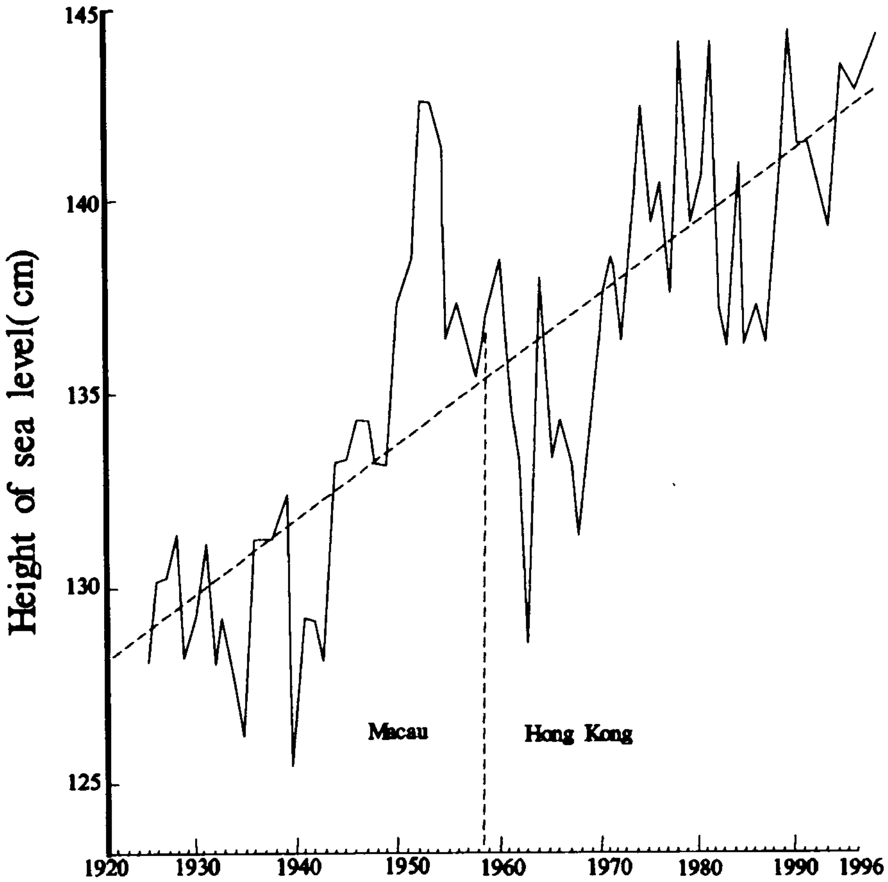

Figure 4. The mean sea level observed from Macau and Hong Kong indicates a secular trend of 1.8 ± 0.1 mm/a for the period between 1925 and 1996.

Here, A is the variation of mean sea level; $Z'(t)$, the observed tide gauge record for the given year; $Z(t)$, the calculated tidal value for the corresponding year using Equation (1); and n, the number of years. Tidal data for 1955–1994 from 7 gauges of the estuary (3 from the mouth of the estuary and 4 from within the estuary) are analysed. The results show that the average magnitude of annual mean sea-level variations from the long-term mean is around 6.4 cm at the mouth of the estuary, and the magnitude increases to 12.1 cm inside the estuary (Table 1). The higher magnitude inside the estuary may reflect changes of geometry in the estuary or tidal amplification within the estuary. The present-day maximum tidal range increases up-estuary from 2.34 m near Hong Kong, to 3.31 m at Zhe-wan, and to 3.35 m at Nan-sha (see Figure 3 for locations).

The third factor is the amount of ground movement due to geological subsidence and sediment compaction. According to the repeated survey from 1951 to 1989, ground surface of the delta plain has subsided at a rate of 1.5 to 2.0 mm/a during

Table I. The magnitude of annual mean sea-level variations in the Pearl River delta (1955–1994)

	Tide gauge*	Magnitude (cm)	Average (cm)
Inside estuary	San-sha-kou	10.8	12.1
	Nan-sha	11.9	
	Wan-qing-sha	15.0	
	Heng-me	10.5	
Estuary mouth	Deng-long-sha	8.4	6.4
	San-zao	5.6	
	Che-wan	5.1	

* See Figure 3 for locations.

Table II. Potential rises in sea level in the Pearl River delta between 1990 and 2030

Factor	Maximum (cm)	Minimum (cm)	Average (cm)
Eustatic rise	12.0	8.0	10.0 ± 2.0
Variations of mean sea level	12.1	6.4	9.3 ± 2.9
Ground subsidence	12.0	8.0	10.0 ± 2.0
Total		29.3 ± 2.3	

the 40 years of survey (Figure 5). Therefore, a total of 6 cm to 8 cm subsidence may be expected by the year 2030.

Putting all the three factors together, the potential rise in sea level in the Pearl River delta is 29.3 ± 2.3 cm by the year 2030 as shown in Table 2. Therefore, we assume a 30 cm rise in sea level for the subsequent analysis.

5. The Interaction between Sea-level Rise and Freshwater Discharge

In order to assess the impacts of sea-level rise during flood seasons (excluding typhoon storm conditions), this study simulates the interaction between a 30 cm rise in sea level and a number of flood conditions. Due to the estuarine backwater effects, there will be an increase of water level within the delta area, and the increase may vary spatially across the delta plain. Therefore, the assessment is performed for the 54 tide gauge locations across the delta plain, based on the assumption of a 30 cm rise in mean sea level at San-zao and under five different flood scenarios (Table 3), using Equations (3) and (4). The additional increases of water level due to the estuarine backwater effects are calculated by subtracting the observed water level from the projected water level, as shown in Figure 4. The area associated with an additional increase of 5 cm or less in water level is viewed as less affected. The area related to an additional increase of 25 cm or higher in

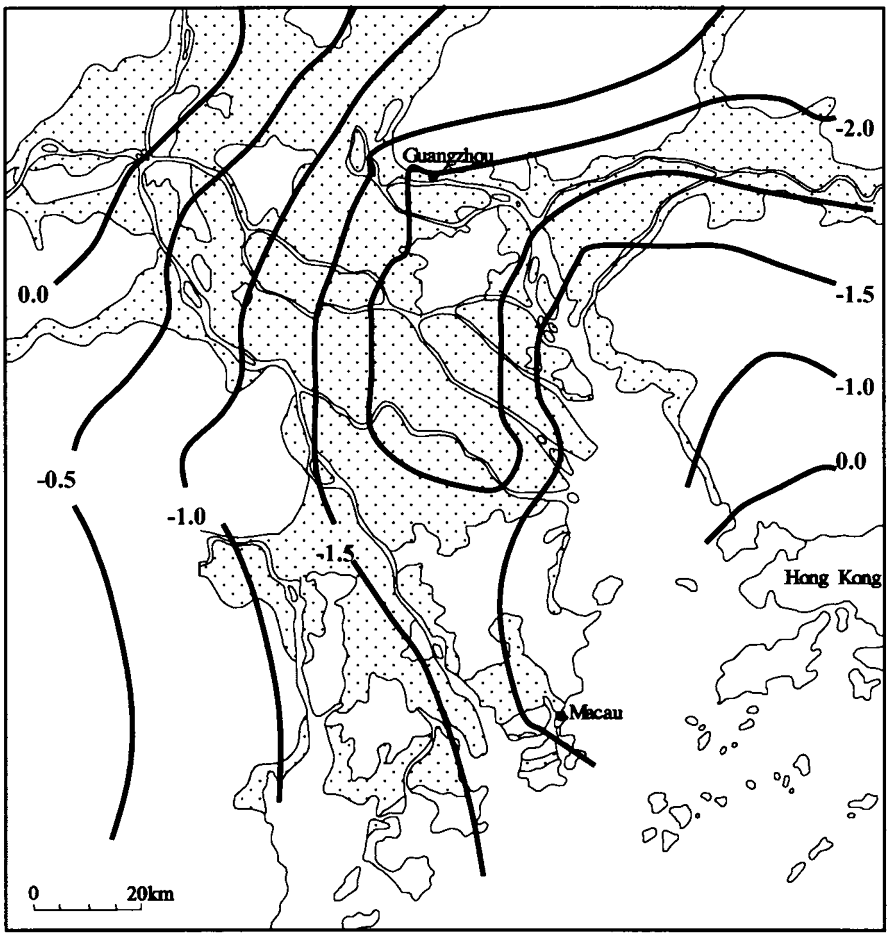

Figure 5. Rates (mm/a) of land subsidence across the deltaic plain based on repeated levelling during the 40 year (1951–1989).

water level is considered as severely affected. The area between these two values is heavily affected.

The estuarine backwater effects are first estimated under the lowest freshwater discharge scenario (dry-season freshwater discharge, 2000 m^3/s) to provide a baseline estimate of the impacts. This calculation uses the following equation,

$$Z_I = C_1 Z_1 + \beta Q + \alpha Z_1 Q + C_2. \quad (3)$$

Here, Z_i is the high tide level at each station; Z_1, the high tide level at San-zao Station; Q, the freshwater discharge at Ma-kou Station situated at the northwest apex of the delta plain; α and β, slope; C_1 and C_2, constants. Given the rise in sea

Table III. The five floodwater (or freshwater discharge) scenarios

Type	Discharge (m^3/s)	Storm conditions	Observed in	Equivalent to return period
Dry year	2,000	Moderate		Lowest discharge
Small flood	11,800	Severe	Sept. 1993	
Medium flood	33,110	Moderate	July 1974	1/5 years (33,043 m^3/s)
Large flood	40,200	Strong	?	1/20 years (40,203 m^3/s)
Severe flood	46,300	Moderate	June 1994	1/100 years (46,736 m^3/s)

level as ΔZ_1, the impacts for stations near the tributary outlets can be obtained from Equation (3) as,

$$Z_I = (\alpha Q + C_1) + \Delta Z_1. \tag{4}$$

The impacts are calculated, based on a scenario of a 30 cm rise in sea level at the mouth of the estuary. The results show that the additional increase in water level due to the 30 cm rise in sea level appears to be 30 cm to 35 cm at the outlets of the delta and 25 cm to 30 cm in a large part of the delta plain (Figure 6). The magnitude of additional water level decreases towards the northwest apex of the delta.

Under the small floodwater scenario as observed in September 1993, the severely affected area is confined to the areas around the head of the estuary and the southern part of the delta plain (Figure 7-I). The area around the northwest apex is less affected because of the increased river gradient. The medium flood scenario represents the flood conditions equivalent to a 1-in-5 year event. Under this scenario, the low-lying areas along the shoreline are severely affected (Figure 7-II), with large parts of the delta plain heavily or less affected. If the floodwater discharge increases as equivalent to a 1-in-20 year event, the less affected area expands significantly southwards (Figure 7-III). Finally, under the severe flood scenario as observed in June 1994, equivalent to a 1-in-100 year event, only the narrow strip along the shoreline is affected severely (Figure 7-IV). In order words, during severe flood seasons, the delta plain is heavily influenced by floodwater discharges. During dry seasons, the projected rise in sea level will have much greater impact on the delta plain.

According to the above simulations, the delta plain can be divided into three zones, namely A (less affected), B (heavily affected) and C (severely affected) (Figure 8). The average maximum net increases in water level are summarised in Table 4. It is noted that the 30 cm rise in sea level will have very little impact in zone A. Therefore, the threat to zone A mainly comes from river floods. The impacts of future sea-level rises in zones B and C are significant. As zone C is

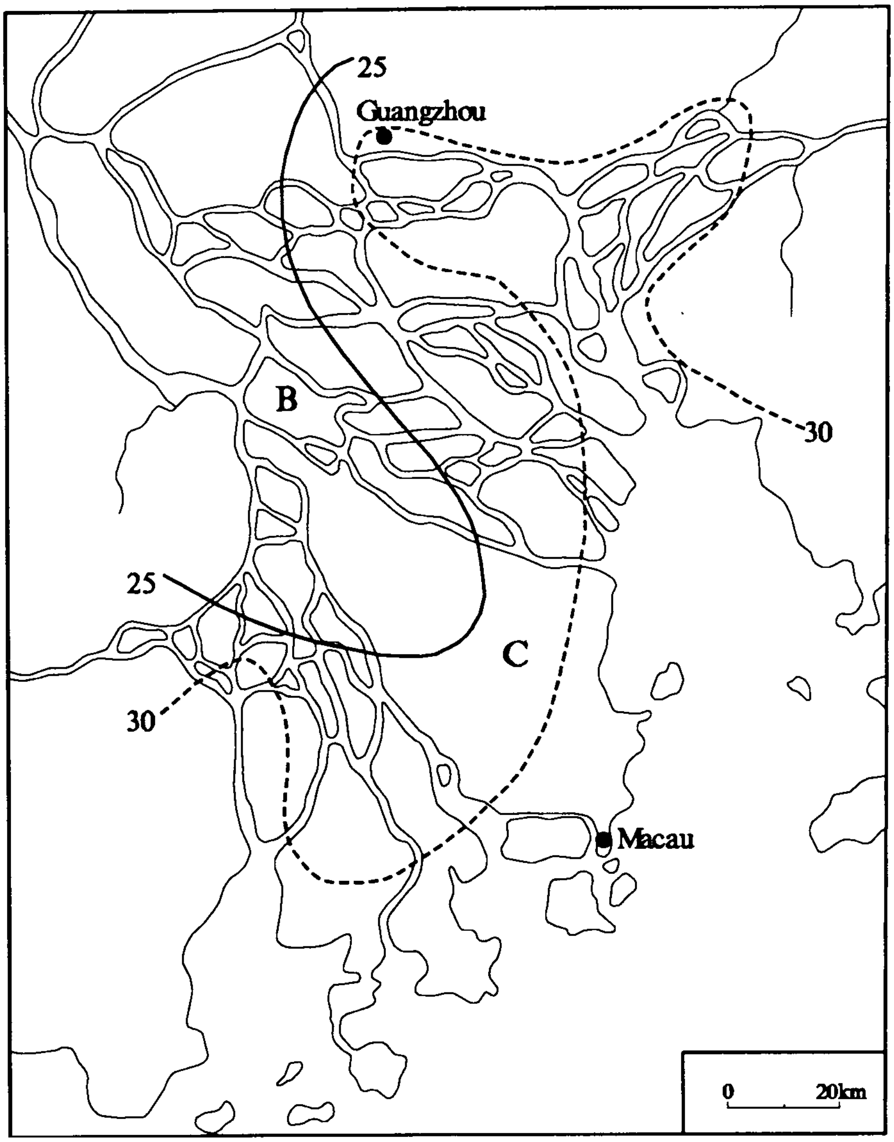

Figure 6. According to the lowest freshwater discharge scenario (2000 m^2/s from the Pearl River, the simulated results show the impact of the projected 30 cm rise in sea level on the deltaic plain. The NW part of the plain will be affected heavily (up to 25 cm rise in water level in zone B), whilst the majority of the plain will be affected severely (over 25 cm rise in water level in zone C).

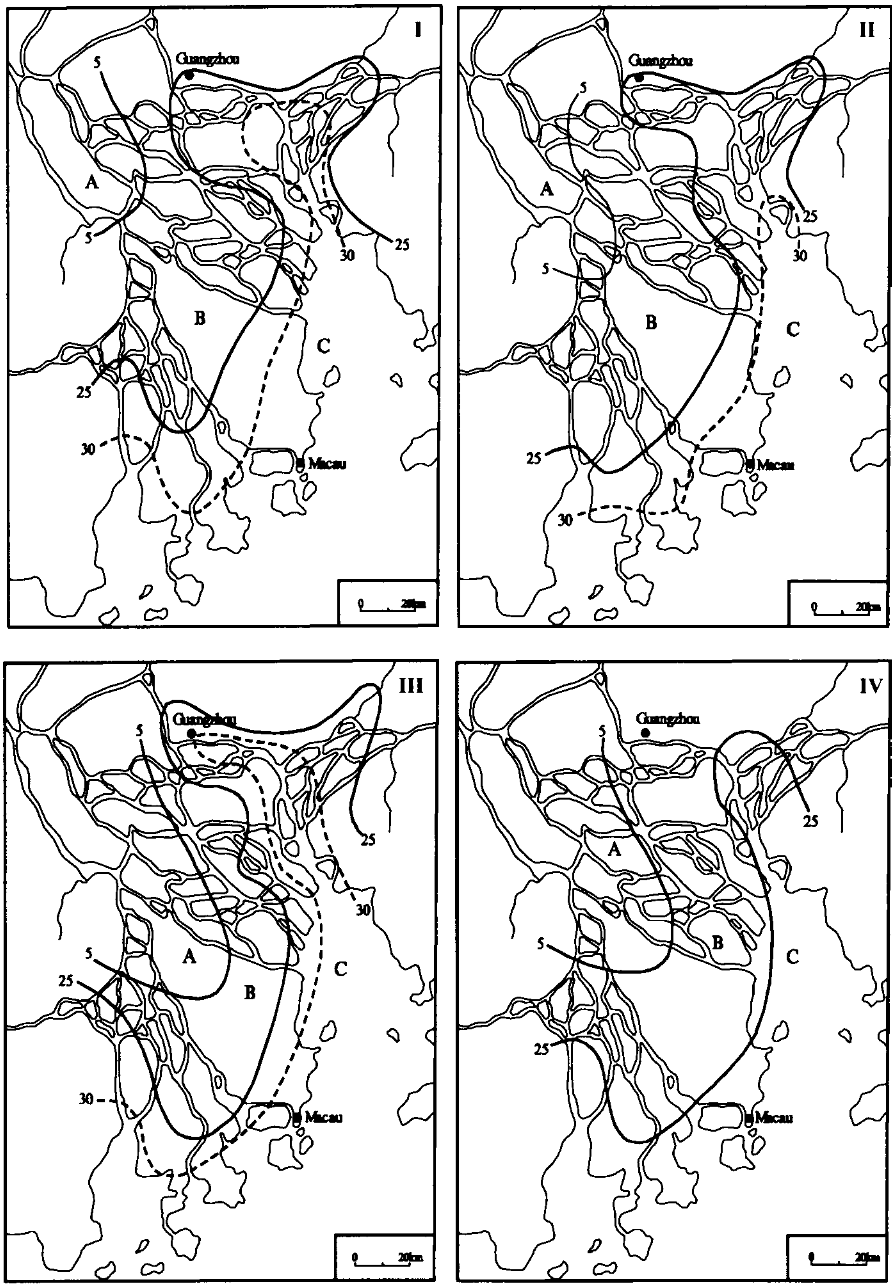

Figure 7. The impacts of the projected 30 cm rise in sea level are simulated according to various scenarios of freshwater discharge (map I, small flood with 11,800 m^3/s; map II, medium flood with 33,110 m^3/s; map III, large flood with 40,200 m^3/s and map IV, severe flood with 46,300 m^3/s).

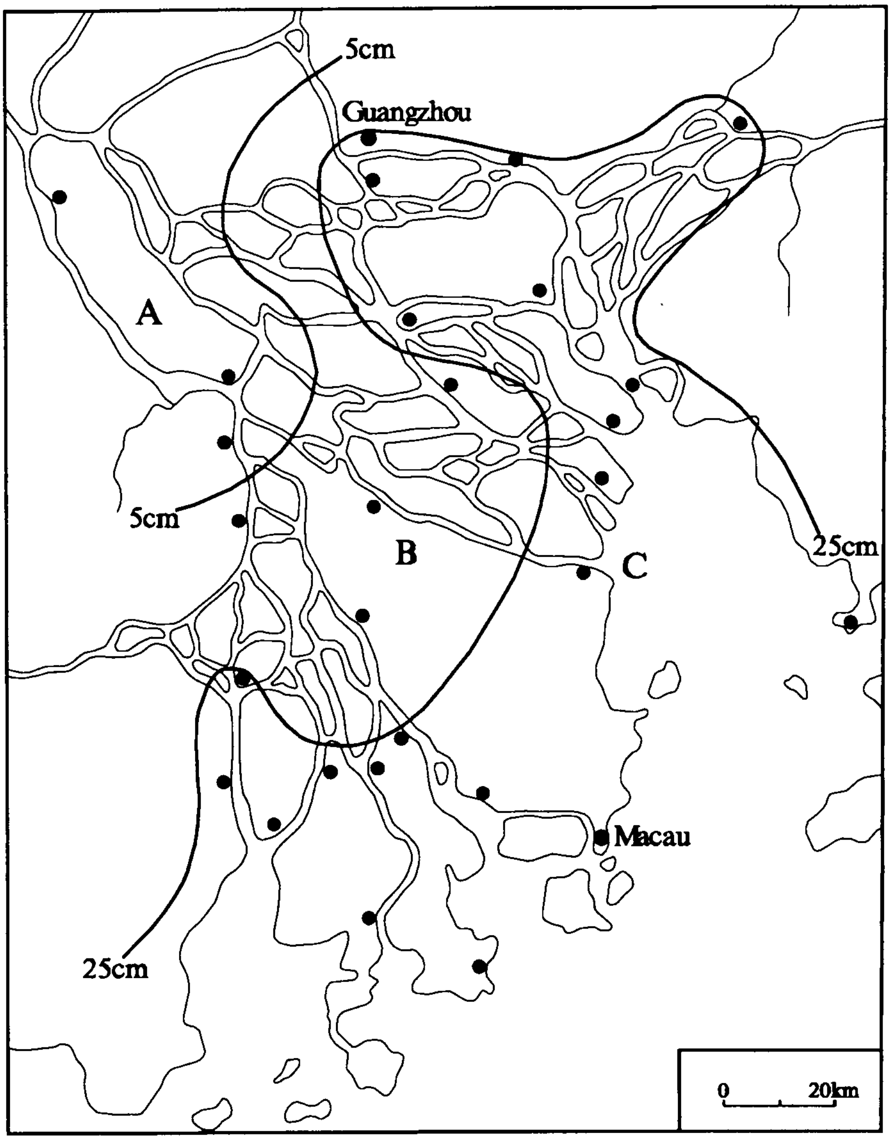

Figure 8. This map summarises the impacts of the projected 30 cm rise in sea level across the deltaic plain. The impacts are least in zone A, heavy in zone B and severe in zone C.

under threat from tidal floods, zone B appears to be vulnerable to a combination of river and tidal floods.

6. Management Implications

Over the last 40 years, there have been 190 flood events recorded at 39 tide gauges. Based on these records, four different return periods are calculated for a selected 17

Table IV. The net increase in water level (cm) due to the interaction between sea-level rise and floodwater

	Small flood (9/93)			Medium flood (7/74)			Severe flood (6/94)		
	A	B	C	A	B	C	A	B	C
Av.	1.3	18.2	29.2	1.1	18.7	27.9	1.3	14.5	27.8
Max.	4.0	25.0	31.0	3.0	24.0	31.0	3.0	23.0	30.0

Table V. Water levels of various return periods in the delta plain at present (left) and the projected increase by 2030 (right)

		Flood level at present (m)				Increase in flood level by 2030 (m)			
Zone	Location	1/100	1/50	1/20	1/10	1/100	1/50	1/20	1/10
A	1	7.81	7.40	6.80	6.32				
	2	6.68	6.38	5.94	5.56				
	3	5.34	5.08	4.71	4.39	0.000	0.000	0.000	0.009
B	4	3.76	3.54	3.24	3.00	0.063	0.078	0.093	0.111
	5	3.70	3.53	3.29	3.08	0.039	0.054	0.072	0.087
	6	3.23	3.08	2.88	2.72	0.096	0.111	0.126	0.141
	7	2.68	2.56	2.38	2.24	0.093	00.10	0.120	0.135
C	8	2.70	2.56	2.38	2.24	0.306	0.303	0.303	0.300
	9	2.68	2.53	2.32	2.16	0.345	0.342	0.339	0.336
	10	2.65	2.53	2.36	2.23	0.261	0.264	0.267	0.267
	11	2.62	2.48	2.31	2.17	0.231	0.234	0.240	0.243
	12	2.57	2.48	2.34	2.23	0.210	0.219	0.225	0.234
	13	2.49	2.39	2.26	2.15	0.312	0.309	0.303	0.300
	14	2.49	2.35	2.15	2.00	0.231	0.237	0.240	0.249
	15	2.48	2.37	2.21	2.09	0.336	0.336	0.333	0.330
	16	2.44	2.31	2.13	1.99	0.300	0.300	0.300	0.300
	17	2.44	2.35	2.22	2.11	0.357	0.354	0.351	0.348

locations (Table 5). Using Equation (4), the amount of increase in water level due to a 30 cm rise in sea level is also calculated for the 17 locations (Table 5). It is clear that there will be almost no impact on the return periods for locations within zone A. The increase in flood level in zone B may only shorten the return periods a little. However, there are significant changes for zone C. Consequently, the rise in water level will no doubt shorten the return periods significantly in zone C (Table 6). In turn, this will pose a serious challenge to flood defence management.

Within the delta plain, there are flood defences (or sea walls) of 3057.6 km in length, protecting 368,500 ha of agricultural land and 6.68 million people. How-

Table VI. The possible changes in return period for zone C

Zone	Location	Return period			
		1/100	1/50	1/20	1/10
C	8		1/100	1/50	1/20
	9		1/100	1/50	1/20
	10		1/100	1/50	1/20
	11		1/100	1/50	1/20
	12		1/100	1/50	1/20
	13			1/100	1/50
	14		1/100	1/50	1/20
	15			1/100	1/50
	16		1/100	1/50	1/20
	17			1/100	1/50

ever, not all of the flood defences are under threat from the 30 cm sea-level rise. As discussed in a previous section, the impacts to zone A are minimal. Consideration should therefore be taken for zones B and C where the total length of flood defence is 2608.6 km.

The criteria for flood defence design were set by the provincial government in 1955 for the first time. There were two significant revisions in 1963 and 1995. According to the 1995 design criteria, flood defence was divided into two categories: river flood defence and tidal flood defence, with tidal flood defence being further divided into five classes (Table 7).

At present, the majority of tidal flood defence in the delta plain is within class 4 and class 5. There are 116 class-4 defences in the delta plain, and 95 of them lie within zones B and C with a total length of 2608.6 km. About 43% of the defences in these two zones (c. 1126.1 km) are below standard even at present. In other words, improvements to these flood defences are needed urgently.

According to the projected rise in sea level (Table 5), this study has calculated the amount of engineering work needed to meet the design standard for each of the 95 defences. To raise the standard to meet the 30 cm rise in sea level, the total engineering work will amount to 17.5 million m^3 of soil and stone. Based on the 1998 price, the total investment will amount 2103 million Chinese Yuan (equivalent to 262.9 million USD). Although seemingly a huge investment, this amount is comparable with the direct economic loss of 2218 million Chinese Yuan inflicted by the 1994 flood in the Pearl River delta region.

Table VII. Design criteria and protection levels of tidal flood defence set by the provincial government of Guangdong in 1995

Class	Design			
	Return period (year)	Height above maximum flood level (m)		Width at the top of tidal flood defence (m)
1	>200	1.0		8
2	200 to 100	0.8		8 to 7
3	100 to 50	0.7		7 to 6
4	50 to 20	0.6		6 to 4
5	<20	0.5		4 to 3

Class	Protection				
	Agricultural land ($\times 10^3$ ha)	Rural population ($\times$1000)	City and town	Urban population ($\times$1000)	Industrial district
1	>200	>2500	Capital city	>1500	
2	200 to 66.7	2500 to 1000	Large city	1500 to 500	Very large
3	66.7 to 13.3	1000 to 200	City	500 to 200	Large
4	13.3 to 0.7	200 to 10	Small city	200 to 10	Medium
5	<0.7	<10	Town	<10	Small

7. Conclusion

The Pearl River delta is one of the areas in China where rapid economic growth is taking place. Recently, this area has attracted inward migration of population, making it one of the most densely populated areas in China. The potential rise in sea level during the 21st century will pose a severe threat to the communities in the deltaic area. In order for the current and future investments and communities to be protected from potential threat of marine inundation, preventive policies need to be formulated and implemented as soon as possible. For these policies to be formulated correctly, scientific research is needed to provide accurate estimates of the magnitude of additional increase in water level due to the rise in sea level.

This study considers global (eustatic) and local (estuarine effects and geological subsidence) factors, and calculates the rate of sea-level rise in the 72 years since 1920. These analyses predict that, by 2030, a rise in relative sea level will be possibly close to 30 cm at the mouth of the Pearl River estuary. This finding forms the basis for subsequent analyses.

Using the tidal records from the 54 tide gauges, return periods of water level across the delta plain are calculated against five known flood events raging from situations in dry seasons to a severe flood recorded in 1994. Further calculations are carried out to assess the impacts of a 30 cm rise in sea level. Results show that, due to estuarine backwater effects, the impacts lessen towards the apex of the delta plain, and the low-lying areas adjacent to the estuary are affected most. Summing up the possible impacts of a 30 cm rise in sea level under the five flood scenarios, three zones are identified, namely Zone A (least affected), Zone B (heavily affected) and Zone C (severely affected). The impacts are of rising water level which can be translated into the shortening of flood return periods.

According to the results, large areas will be affected *heavily* and *severely*. Adding to this is the fact that a large number of existing tidal flood defences are below the standard set by the provincial government. Thus, the projected 30 cm rise in sea level by 2030 will no doubt pose a serious challenge to the local authorities who are responsible for flood prevention and who provide protection for economic and industrial developments. Based on current construction prices, a large investment to improve the defences is needed urgently.

The current study focuses only on the potential threat of tidal inundation under the scenario of a 30 cm rise in sea level by 2030 and five known freshwater discharge scenarios raging dry seasons to severe floods. Coastal flood hazards due to wave actions and storm conditions have not been considered. Due to the micro-tide conditions in the Pearl River delta, typhoon storm induced water level rise and wave actions both require further investigation. Indeed, information on the impacts of water level changes due to both secular rise in sea level and short-term storm conditions are needed to help local governments correctly formulate their policies.

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