THE ASSESSMENT OF FLOOD ALLEVIATION BENEFIT OF LAND USE MANAGEMENT

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ABSTRACT: Affected by rapid urbanization and the global warming, the features of flood have been and will be changed significantly in China. Land use risk management is an important measure to restrain the growing flood risk. Taking Taihu Basin as an example, a flood management benefit assessment model has been established. The future flood risk, the benefit of land use risk management and the integrated flood management measures are evaluated. The results reveal that by 2050 the flood risk of Taihu Basin will increase by 4~15 times under different climate change and socioeconomic scenario. The land use management will decrease the future flood risk by 39~50%, while the integrated measures may decrease the future flood risk by 70~74%. Based on the results, some suggestions are made for adjusting the strategic planning of flood management in the Taihu Basin.

Key Words: Flood management, Risk analysis, Land use, Benefit assessment

1. INTRODUCTION

Flood management, based on the recognition that flood couldn’t be eliminated thoroughly, has been widely accepted in the world. It advocates reducing the disaster impact by regularizing flood protection behaviors and improving human being adaptions to flood. It stresses the integration of natural and human systems as well as land and water management (Colin et al. 2004). Land use management, taking adaptive land development mode according to the flood risk, is considered as one of the most important flood management measures especially in the high densities countries. As the developing country China has large population but relatively less land. Moreover, with the rapid urbanization, many high flood risk areas have been developed and being continuously developed in China. Therefore, the flood risk condition would be further aggravated in turn for the over-development. It is necessary to implement land use management in China to restrain the growing flood risk.

In this context the research has sought to quantify the scale of possible future flood risk, the flood alleviation benefit of land use management and the integrated flood management measures, so as to be aware of the future flood threat and the effect of land management and better to prepare for the increasing flood risks that will undoubtedly occur in the future.

Taihu Basin is one of the fastest economic developed areas in China, population is migrating there, including to Shanghai as one of the largest coastal cities now on the globe. This appears to be a virtually unstoppable process, adding substantially to risk. Understanding the extent of this enhanced and enhancing risk is vital to planning a sustainable future for this region and for China as a whole. We thus here take Taihu basin as an example, assessing the upward trajectory of Taihu flood risk, using both a scenario approach and modeling risk using a combination of flood damage and flood probability assessments, and mainly evaluating benefit of land management under different scenario. This paper describes the frameworks of the flood risk analysis and the main outcomes of the impacts of rapid urbanization and land use management on the changes of flood risk in the Taihu Basin.

2. FEATURES OF TAIHU BASIN

The Taihu Basin covers an area of 36,895 km2 within the Yangtze delta region, spanning the administrative districts of Shanghai, Jiangsu, Anhui and Zhejiang, which represents an important and rapidly growing urban and economic center（Figure 1）. Although this area only takes 0.4 % of the nation’s territory, it contributes about 10.3% to the total GDP in 2011. The GDP per capita in this area is over 2.3 times the national average. The high-speed socioeconomic development has made this region sensitive to environmental hazards. Flood is one of the most frequent and threatening hazards.

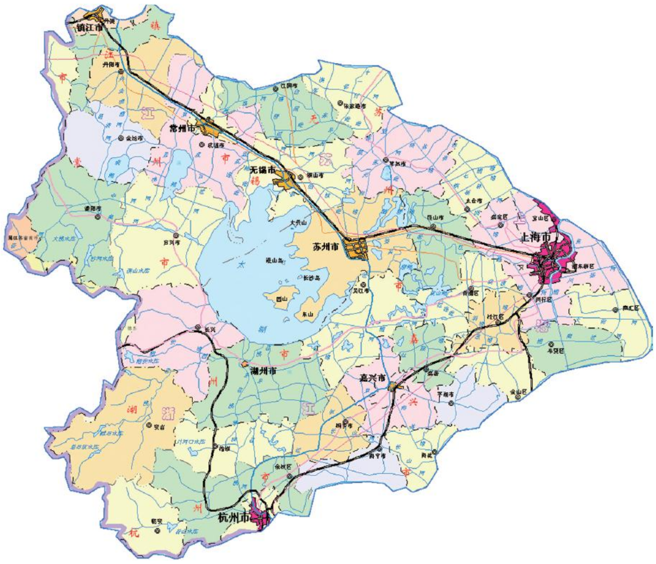


Figure 1: The Administrative Map of Taihu Basin

The Taihu Basin lies in the sub-torrid zone and is influenced by the monsoon climate with the average annual precipitation of 1177mm. Plain areas take about 80% of the basin with elevation between 3-4 m,. Since it is so flat with flow speed too slowly and its drainage system blocked by the high tide, it is a flood prone area suffered by river flooding, storm surge, and internal floods caused by local heavy rainfall.

During the big flood of 1991 in Taihu Basin, the highest water stage of the Taihu Lake reached 4.79m, 0.14 m higher than the historical record in the 1954 flood and caused heavy damages of live and property. The rate of 1991 flood damage to GDP was about 6.7%. A big flood event occurred again in the Taihu Basin in 1999. The monsoon- raining lasted for 43 days and the total average rainfall reached 670mm, and this catastrophic flood had brought a loss of 14.3 billion yuan RMB (Zong and Chen, 1999).

3. ASSESSMENT METHODOLOGIES OF FLOOD RISK AND FLOOD ALLEVIATION BENEFIT

Flood risk is defined as probability multiplied by consequences, including: properties damage, casualties, environmental and culture damage. Flood risk is also called as the expected value of the economic damage (EAD). A simple expression for flood risk is:

$$EAD = f(P, D) = \int_0^1 D(P)dp \approx \sum_{i=1}^{n} \frac{D_{i-1} + D_i}{2} \times (P_i - P_{i-1}) \qquad [1]$$

Where, P is the flooding probability; D is the consequences corresponding to the flooding and n is discrete number of probability.

In this paper 8 flooding events (probabilities being 0.5, 0.1, 0.05, 0.02, 0.01, 0.005, 0.002, 0.001) and the corresponding damages were taken to calculate the flood risk of Taihu Basin.

The object of flood management is to mitigate flood risk. The differences between the flood risk with and without flood management are considered as the expected economic benefit due to the safety increasing. It can be expressed as:

$$EAB = EAD_P - EAD_{\mathrm{a}} \qquad [2]$$

Where, EAB is the Benefit of flood management; EAD_P is the flood risk with flood management and EAD_{a} is the flood risk without flood management.

4. MODELS

The assessment of flood management benefit should be based on the calculations of flood risk. Whereas, the future flood risk will be changed due to the change of climate, socioeconomic, environment policy options and other elements even the present flood-defense system remaining unchanged. Scenarios are defined to express these elements besides the flood management condition. In this paper the flood risk under different scenarios is evaluated firstly, and then the land use management benefit is evaluated by calculating the flood risk reduction due to the safety increasing. The research is organized into 'work packages' to assess the flood risk of Taihu Basin under different scenarios (see Figure 2). Two specific scenarios are considered under the background of A2/A2 and B2/NP climate/socio economic combinations. Quantitative modeling the interactions of the various driver elements in the flooding processes is an essential approach. It requires building hydrology model, hydraulic model and flood damage assessment model to simulate dynamic runoffs and flood distributions, and evaluating the potential damages of socioeconomic assets.

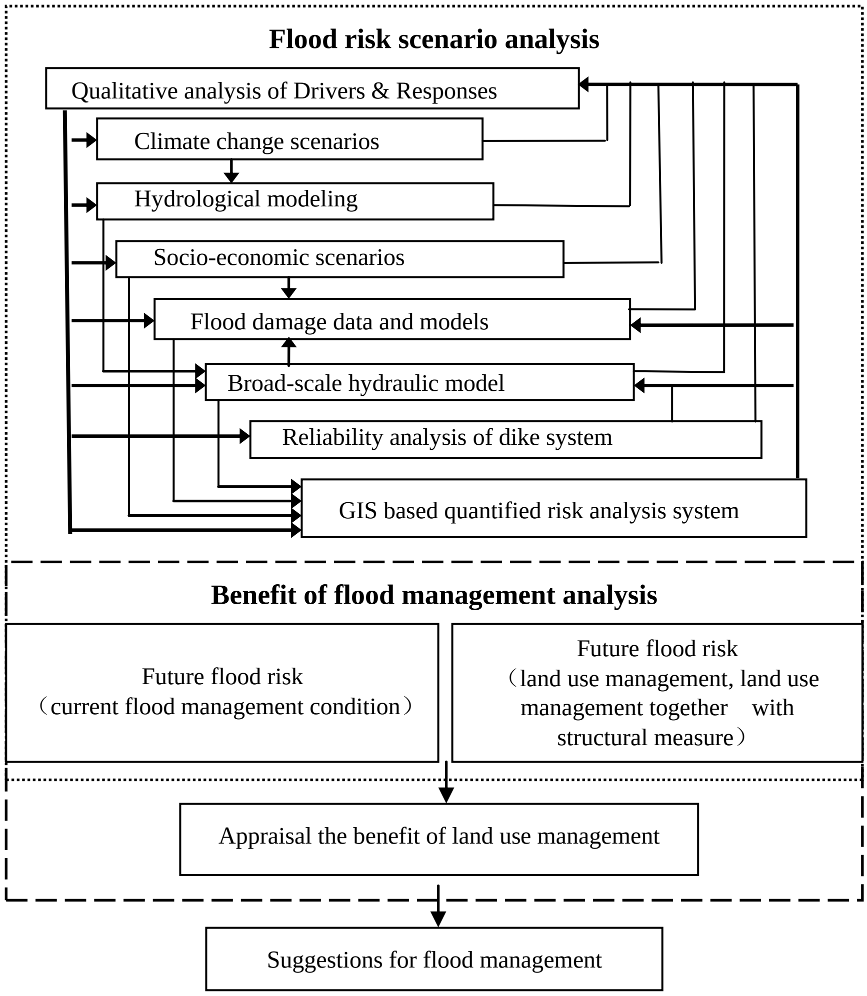


Figure 2: The Framework of Models

4.1 Define scenarios

In accordance with the objectives of the research (assessing potential future flood risks), based on scenarios provided by SRES (Carter et al.1994) and China's economic development features, three scenarios: A2, B2 and NP (China's National Plan programme), are explored. The year 2005 is taken as the baseline year, and the year 2050 being the study period of future. The economic characteristics of different scenarios in 2050 are summarized in Table 1.

Table1 GDP and Urbanization Rate (UR) Prediction of Taihu Basin under Different Scenarios in 2050 (Billion RMB, %)

	Shanghai		Hangzhou		Jiaxing		Huzhou		Suzhou		Wuxi		Changzhou		Zhenjiang	
	GDP	UR	GDP	UR	GDP	UR	GDP	UR	GDP	UR	GDP	UR	GDP	UR	GDP	UR
A2	4472	93	1406	65	546	60	321	60	1695	68	1259	80	6965	75	417	65
B2	7768	90	2442	55	948	45	558	45	2945	60	2187	74	1210	68	724	55
NP	6948	91	2542	60	1032	52	581	52	3206	62	2694	76	1317	70	843	58

4.2 Flood inundation analysis

A broad scale hydraulic model is developed on the base of ISIS to meet the needs of flood risk analysis in the Taihu Basin. The model has been validated by the observed data of the 1999 flood. The outputs of the hydraulic modeling include dynamic the water levels and flow volumes for each river section, and a volume of floodwater for each flood cell during a flood event. We constructed 198 flood cells to represent the plain area. These flood cells are linked with their surrounding river sections in hydraulic modeling for representing water exchange between the river and land. The spatial distribution of the floodwater within a flood cell is mainly affected by its total volume, the elevation of terrain surface, and the protected areas by polders. We consider that the floodwater is mostly caused by overtopping from the surrounding river channels and local direct rainfalls. The defense system and the DEM data are combined to model the flood distribution process within a flood cell.

4.3 Flood damage assessment

4.3.1 Spatial analysis of socio-economic data

The flood damage model is developed on the GIS platform. To evaluate the flood damage, the socio-economic statistical data should be spatially distributed on the land use map. We allocated the economic values for each category to specific locations in a raster land use dataset, with a 500m spatial resolution. We considered only 3 land use types: cropland, urban and rural housing. Within a county, we assume that the grid cells with the same type of land use will have the same value in each economic category (see Figure 3).

To calculate the benefit of land use management of flood risk mitigation, two conditions in 2050, with and without land use management, are considered respectively. The land use condition without management is simulated by the buffer method according to the predicted built –up area data of different scenarios. The buffered built-up area equals to the increment built-up area due to urbanization (see Figure 4 (a)).

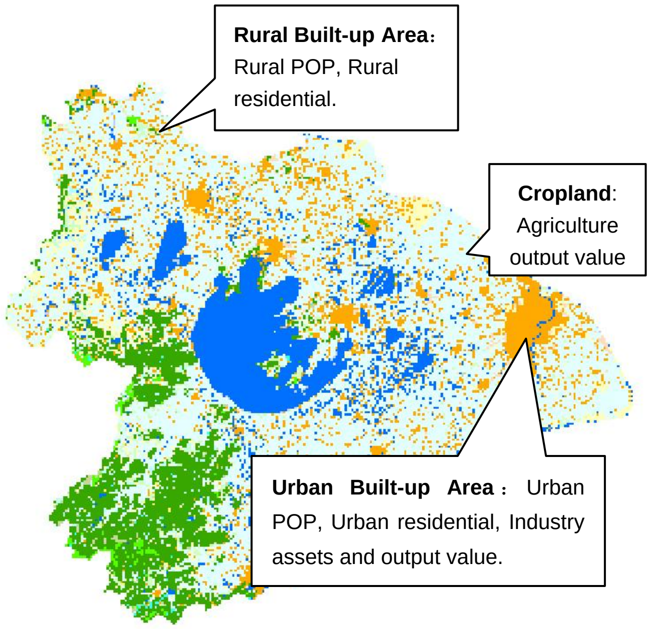
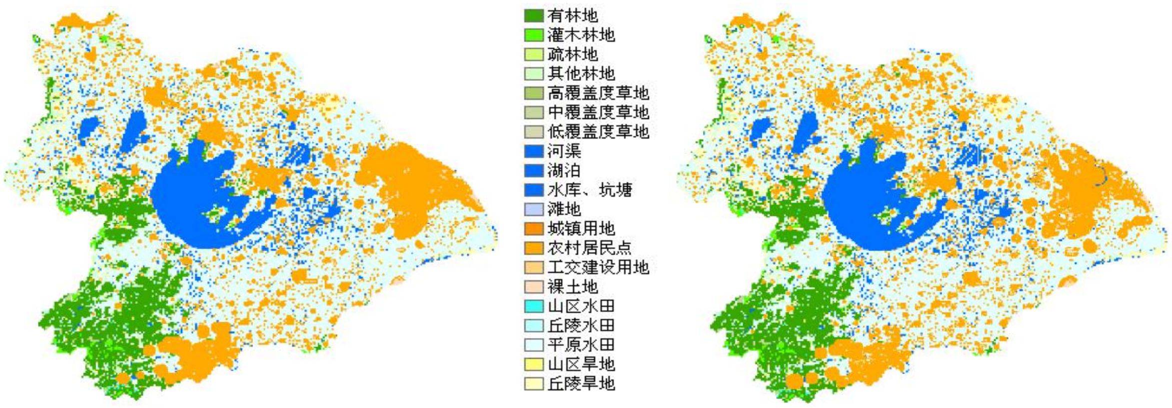


Figure 3:The assumptions of spatial distribution of socioeconomic data in Taihu Basin

Similarly, the land use condition with management in 2050 is enlarged base on the present land use map. Two rules are adopted to get the land use spatial distribution: (1) the new enlarged built-up area should keep space continuity with the original built-up area. (2) The new enlarged built-up area should not be located in the high flood risk area and can only be developed in low risk area. We define high flood risk area as regions where the flood inundation depth of 1% frequency flood (A2 scenario) is larger than 30cm, and low flood risk area being the region where the flood inundation depth of the same flood smaller than 30cm. The land use distribution with management (see Figure 4 (b)) is obtained by the GIS spatial tools



(a) **(b)**

Figure 4: Land Use in Taihu Basin

(a) Land use in 2050(without considering the flood risk)

(b)Land use in 2050(implement land use management according to the flood risk distribution)

4.3.2 Flood damage assessment model

The paper mainly assesses the direct flood damage of Taihu Basin, including flood damage to residential, non-residential, agriculture, and transportation and so on. To match the character of the broad scale flood simulation model and to meet the requirement of flood risk analysis of the basin, the county level was chosen as the analysis unit. The flood damage of 47 counties in Taihu Basin was evaluated in all. The approach assessing the flood damage as a percentage of the pre-flood property value at varying flood depths (the ‘flood loss rate’) was adopted to assess the flood direct damage of Taihu Basin.

we used as the basic data existing ‘flood loss rate’ data and its associated flood damage data from the pre-existing Shanghai urban flood model (Wang et al., 2001), collected largely from past floods in Shanghai city (before 2000). Some modifications to that data were made according to the historical flood damage records of the Taihu Basin and from related studies (Wang et al., 2001; Johnson C, et al., 2001). The flood stage–loss rate relationships were established by asset categories and flood depth stage (see Table 4). Our calculated damage in the 1999 flood is 11.97 billion Yuan, by utilizing the 1999 economic data, the 2000 land use data, and the damage ratios in Table 4. Compared with the recorded damage 14.13 billion Yuan in 1999 flood, the calculated damage value is slightly different. This is because our indicators for damage assessment are not exactly the same as that used by the Taihu Basin Authority. Nevertheless, we believe that the calculation result is reasonable at the macro-level of the Taihu Basin as a whole.

Table2: Flood Depth-loss Rate Data of Taihu Basin (%)

Category (land use)		Flood depth (m)						
		<0.5	0.5-1.0	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	>3.0
Residential (urban, rural)	Housing	2	5	8	12	16	19	22
	Housing goods	3	8	16	23	27	31	41
Agriculture		12	25	60	80	100	100	100
Industry	Fixed Assets	2	6	9	13	17	21	25

(urban)	Stock	4	10	16	24	27	31	33
Business	Fixed Assets	2	6	9	12	15	18	21
(urban)	Stock	4	10	18	26	30	34	38
Infrastructure (urban-other)		3	7	12	17	22	27	30

5. RESULTS

5.1 The future flood risk

According to the scenario frame, using the methods and models mentioned above, we evaluate the future flood risk of 7 typical scenarios. The characteristics of each scenario and the flood risk assessment results are summarized in Table3.

Table 3: Description of Scenario Characteristics and the Assessment Results of Future Flood Risk

Scenario	Base line	2050 changes socioeconomic only		2050 changes climate (rainfall) only		2050 changes combined	
Case N0.	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7
Socioeconomic	2005	A2	NP	2005	2005	A2	NP
Land use	2000	A2	NP	2005	2005	A2	NP
Rainfall	1999 type	1999 type	1999 type	A2	B2	A2	Current rainfall increase by 5%
Sea level	Current	Current	Current	Current	Current	Current	Increase by 34 cm
Flood control SYS				Current Condition			
Flood risk (billion RMB/a)	1.24	4.77	6.70	5.36	7.14	19.04	13.23
Ratio EAD to baseline EAD (Case 1)	1	3.85	5.40	4.32	5.76	15.35	10.67

The results reveal that by 2050 the flood risk of Taihu Basin will increase obviously. With only socioeconomic change scenario, the flood risk in 2050 increases 3.9~5.4 times compared with 2005. Table3 also shows the climate change (precipitation) in 2050 will result in flood risk approximately 4.3~5.8 times of that in the baseline. The combinations of multiple drivers in different scenarios can result in sharp increase on flood risks. The combinations of climate change with the NP and A2 socioeconomic scenarios can generate 10.7~15.4 times of risks in comparison with the 2005 baseline risk. The maximum flood risk in 2050 can increase to 19 billion yuan/a. The results also reveal that in most scenarios the flood events which probability are less than 0.01 play a major rule in the total flood risk and the impact of great flood on the flood risk is relatively small. That is to say, increasing the capacity of the defense system can efficiently restrain flood risk, but unnecessarily only pursue the high structural standard to alleviate flood risk. The combination of non-structural responses, including introducing a system of land-use development control would be necessary.

5.2 The flood alleviation benefit of land use management

The flood alleviation benefit of land use management and the benefit of integrated measures(the combination land use management with structural measure) shown shown in Table 4.

Table 4: The Flood Alleviation Benefit of Land Use Management and Integrated Measures

Scenario	2050 changes Socioeconomic only	2050 changes climate (rainfall) only	2050 changes combined
Case NO.	Case3’	Case5’	Case7’
Socioeconomic	NP（2050）	2005	NP（2050）
Land use	2050 land use management according to the flood risk		
Rainfall	1999 type	B2（2050）	Current rainfall increase by 5%

Sea level		Current condition	Current condition	Increase by 34 cm
Flood control SYS		Current flood control system		
Flood risk（billion yuan/a）	With land use management	6.69	7.14	1.32
	Without land use management	3.94	3.64	8.01
Annual flood alleviation benefit of land use management（billion yuan/a）		2.74	3.50	5.23
Flood control SYS		flood control system when flood control planning (2025) is completed		
Flood risk（billion yuan/a）	No integrated measures	6.69	7.14	1.32
	With integrated measures	1.98	2.00	3.49
Annual flood alleviation benefit of integrated measures（billion yuan/a）		4.71	5.14	9.75

The results show the land use management will decrease the future flood risk greatly. The flood risk will be decreased by 39~50% when the land use control management are implemented. The annual benefit of land use management is about 2.74~5.23 billion yuan/a. For the risk in Taihu basin will increase sharply in the coming year, and the residual risk will still keep 3.0~6.5 times of the present level. Table 4 also shows that the integrated flood management measures may decrease the future flood risk more significantly and the flood risk will be decreased by 70%~74%. The annual benefit of integrated measures can reach to 4.71~9.75 billion yuan/a, and the residual flood risk could be 1.6~3.0 times of the present risk level.

6. CONCLUSIONS

(1)The flood risk of Taihu Basin will increase sharply in the future. These increases are much faster than the 9.13 times of GDP growth in the 2050 NP socioeconomic scenario. Considering the current fast socioeconomic development in the Taihu Basin and the ongoing global warming, such combined scenarios are highly possible. It means that, if there are no proactive measures to reduce flood threats, the future Taihu Basin are likely to be more risky than today’s situations.

(2)Land use management is demonstrated as an efficient approach to alleviate flood risk. It can mitigate the future flood risk by 39%~50%. The annual benefit of land use management would be 2.74~5.23 billion yuan/a. With the rapid urbanization of Taihu Basin, many areas will be developed continuously. The implementation of land use management according to the flood risk would be necessary and urgent.

(3)The quantitative analysis result also shows that integrated measures can decrease the future flood risk more significantly, which can decrease flood risk by 70%~74%. Combined with other non-structural responses, including improved forecasting, emergency response, and building standards control and so on, the integrated flood management could retrain the future flood risk to an accepted level. It should be the best choice for Taihu Basin.

(4)The models in the paper could evaluate the flood risk and flood management benefit of Taihu Basin. For the complex of calculation process and the shortage of the data sources, the study made a series of assumptions and simplifications in modeling floodwater distribution, spatial distribution of socioeconomic data and land use management mode and so on. And the impact of land use on the runoff-producing and flow concentration, indirect flood damage were neither considered in the study. Such assumptions and simplifications need further investigation.

7. ACKNOWLEDGEMENTS

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