Based on mitigation and adaptation viewpoint in water sensitive city- A case study in land subsidence area in Yunlin, Taiwan

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Abstract

Excessive urbanization, unbalanced water usage, and land use out of control result in serious planning failures. Urban development has changed land-use coverage directly which affects overall water cycling and eventually leads to flood disaster. A thorough consideration of water balance and spatial planning might become significant urban flood mitigation strategy. Owing to the geographic features and climate condition, we propose to apply water balance concept into a water sensitive city like Taiwan Yunlin, and further construct water safety (without flood), water satisfaction (reasonable ground water withdrawn), and water environment communities. A coupling model of urban water balance on land use change can analyze the relationship between land use development, anthropogenic activities and water cycling, and further simulate different scenarios to propose appropriate land use patterns while achieving water safety, water satisfaction, and water environment communities.

Keywords: water cycling, water balance, spatial planning

1. Introduction

Global climate changes has speed up and strengthen disasters frequencies and scale (Kleinen & Petschel-Held, 2007), such as tsunami in Southeast Asia in 2004 and Japan in 2011. A myriad of planning failures including excessive urbanization, unbalanced water usage, and land use out of control result in the increasing of surface run-off and the change of water cycle. In fact, urban development changes land-use coverage directly which affects overall water cycling and eventually leads to flood disaster (Beighley et al.,2003; Haase et al.,2009). Hence, international organizations, both European Union Framework Programme (EUFP) and World Meteorological Organization (WMP) started to integrate water adaptation approach, water cycle concept and water balance in land use plans. And cities came out various flood managements integrated into comprehensive land uses planning such as water sensitive cities in Australia, living with water and room for the river in Netherland, and making space for water in England.

Taiwan has confronted critical flood resulted from urbanization with a typical imbalanced land use and water environment planning in previous days. Under complicated relationship between land use change and water balance, the issues is required involving various professional fields such as hydraulic engineering, civil engineering urban planning etc. Risk management, of spatial planning, emphasized that restriction should be worked out in high risk zones such as flood plain area, river buffer zone, and flood tendency area (Coeur & Lang, 2008; Böhm et al., 2004). Hydraulic engineering stressed flood management by utilizing model simulations and facilities location analyses to appraise non-engineering flood mitigation measures (Water Resources Agency, Ministry of Economic Affairs, 2008). In fact, a thorough consideration of various professional fields while practicing water balance might become significant urban flood mitigation strategy (WMO, 2010).

The concept of water balance can be divided into three categories. The 1st category discusses the driving forces of land resource and land use change affected the imbalance on water cycling mechanism, such as precipitation, evapotranspiration, runoff, infiltration etc.(Emmerling and Udelhoven, 2002; Collin and Melloul, 2003; Deal and Schunk, 2004; Haase et al., 2007; 2009). The 2nd category emphasizes the importance of water management in various land uses, such as drinking water, rainwater, waste water (Pauleit et al., 2000, 2005). The 3rd category analyzes water and energy under different climate conditions (Grimmond, 1986; Mitchell, 2004, 2008).

There was various research integrated water balance into land use change simulation, such as Markov Chain Model, Cellular automatic Method, Logistic Regression, Artificial Neural Network (McColl and Aggett, 2007；Liu and Seto, 2008；Kamusoko et al., 2009；Shen et al., 2009). Sivapalan (1996) predicted impacts on hydrologic cycle of deforestation through water balance model in Australia basin. Guo (2002) discussed water sensitivity under global climate change. Bormann (2006) evaluated the effects of under different land use scenarios. A coupling model of urban water balance on land use change can analyze the relationship between land use development, anthropogenic activities and water cycling, and further simulate different scenarios to propose appropriate land use patterns while achieving a water balance land use planning to further knock down negative environmental impacts (Dwyer and Childs, 2004).

This study initially identifies the cause and the consequence of land subsidence and flood disasters in Taiwan Yunlin County, and then uses physiographic inundation-drainage model to forecast flood disaster under various return periods. We are testing flood disasters under diverse scenarios and trying to evaluate the benefit of considering both traditional flood prevention works and land use plan. Ultimately, the integration of water balance model into land use plan is looking forward to mitigate present natural disaster caused by civilization and further reach the equilibrium between urban development and natural environment.

2. Issues identification in study area

Our study area is located in the middle of Taiwan (see Figure 1), and the topography stretches across coast and plain. A general elevation is below 10 m along the west coast area, and an elevation is below sea level in some specific area in the west-south coast. In the case of champaign, flat terrain results in flood disasters during torrential rain.

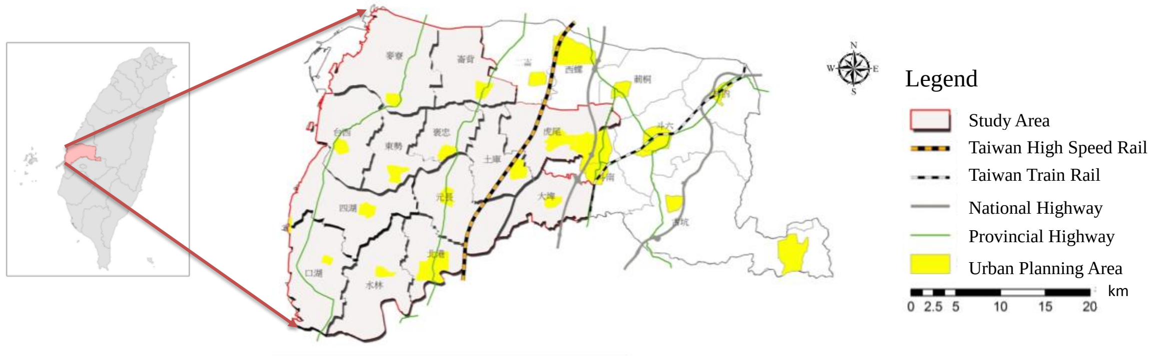

Figure 1: Study area

In addition, the encouragement of rice plantation with inappropriate irrigation systems results in the excess ground water withdrawn. There are over a hundred thousand wells and are mostly used for irrigation. The physical condition and excess ground water withdrawn led serious land subsidence problem. There were two states of land subsidence happened, along coast area and inland area (see Figure 2). In the period of 1992 to 1999, serious land subsidence happened along the west coast. Started from the year of 1996, land subsidence moved into inland area which might affect the operation of Taiwan high speed rail (Taiwan HSR) (see Figure 3).

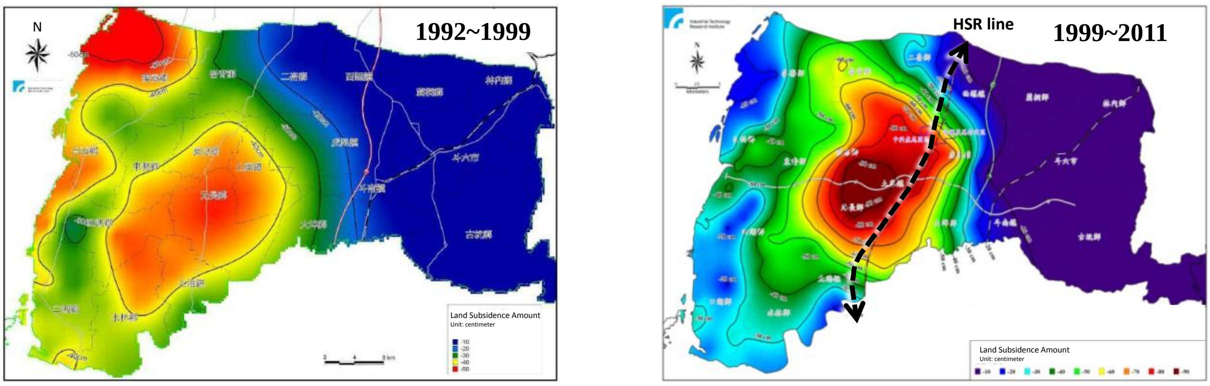

Figure 2: Land subsidence rate comparison between different time period

Figure 3: Land subsidence affected area

The flood investigation results (Council for Economic Planning and Development, 1996) identified various flood risks in our study area, including latent flood area, constantly inundated area, flood sensitive area and so on (see Figure 4). It is likely serious land subsidence with sea level rising under global climate change might result in much serious flood disasters (see Figure 5).

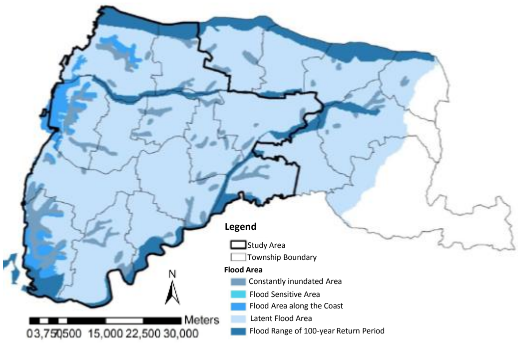

Figure 4: Latent flood area

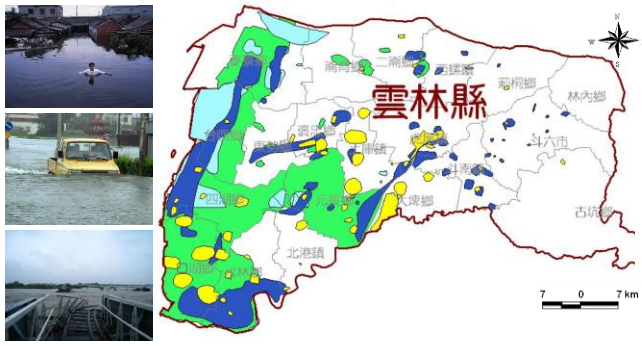

Figure 5: Flood disaster affected area

To radically resolve land subsidence issue in water sensitive city like Taiwan Yunlin, there have been cooperation across sectors in both central and local governments while focusing on distinct professional fields such as spatial planning, regulations, industrial developments, coordination, water engineering and public participation. In fact, not only cross sectional cooperation but the practice in land use management is more momentous. The idea of this paper is to testify the importance of land use plan on flood disasters and further get to the equilibrium of civilization and disasters.

3. Planning concepts in water sensitive area

Our overall framework starts with flood risk simulations and gets forward to proposing land use strategies based on flood simulation results. There are three scenarios (see Figure 6) in our flood simulation process, type A is under similar climate tendency (with land subsidence, sea level rising, wave and rainfall change) without any flood prevention works, type B is under traditional flood prevention works and type C is land use plan with water balance concepts such as fallow farmland and wetland as reservoirs and multi-purpose floodwater facility.

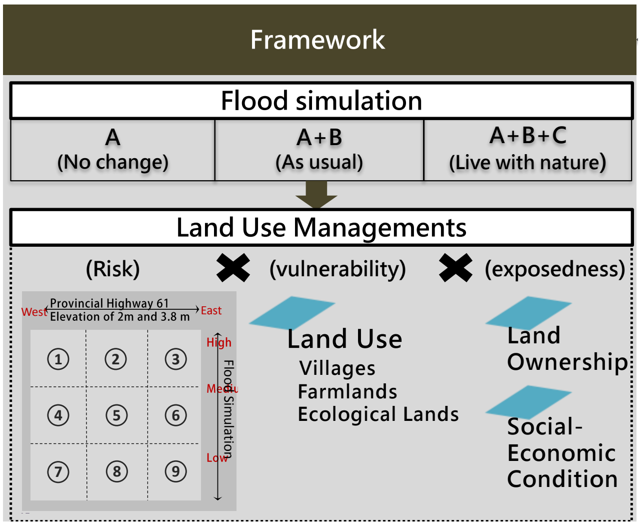

Figure 6: Research framework

3.1 Flood simulation framework

We apply physiographic inundation-drainage model to simulate flood disasters based on irregular grids (grids are divided according to roads and river). Digital elevation model, soil map, land use map, river basin and road system maps are inputs in our flood model, together with future climate change impacts on sea level and rainfall (see Figure 7).

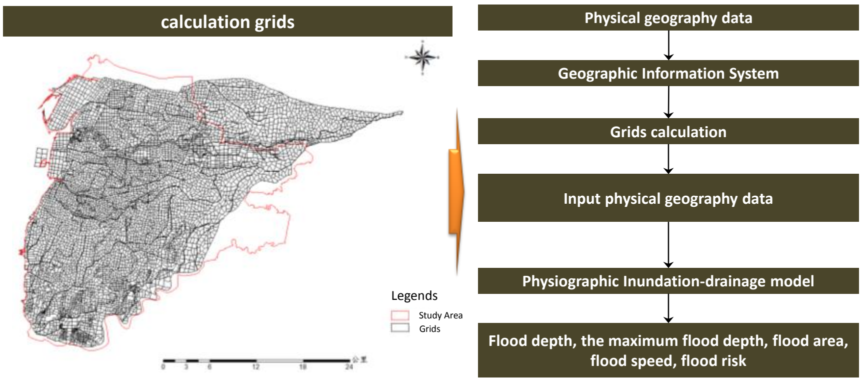

Figure 7: Calculation procedure

In the 1st scenario, we forecast climate change impacts based on historical records of land subsidence, rainfall and sea level in the beginning. We then simulate flood risks according to land subsidence amount in 2038 (see Figure 8), rainfall forecast (see Figure 9) and sea water level forecast (see Figure 10).

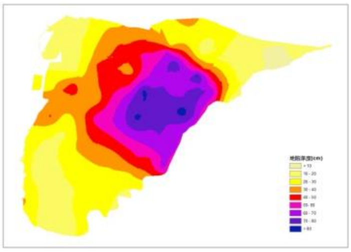

Figure 8: 2038 land subsidence amount

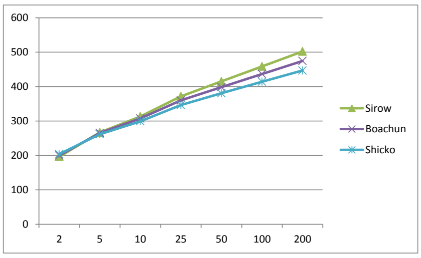

Figure 9: Rainfall forecast in various reture period

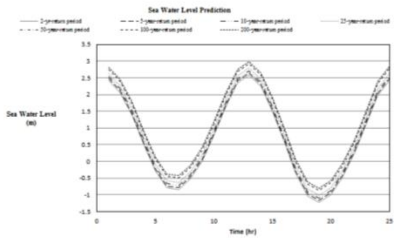

Figure 10: Sea water level prediction

In the 2nd scenario, traditional engineering flood prevention works (see Figure 11) such as drainage, dikes, pumping stations and detentions under various status (operation, under construction or planning) have been included.

In the 3rd scenario, we designate fallow farmlands and wetlands as multipurpose reservoirs (see Figure 12). Since the depth of fallow farmlands and wetlands is different from traditional reservoirs, so we here assume the capacity of fallow farmlands and wetlands are 70% off for flood water storing.

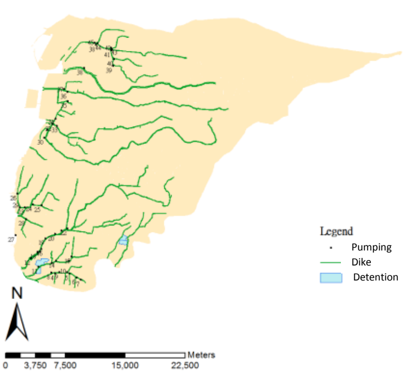

Figure 11: Traditional flood prevention works

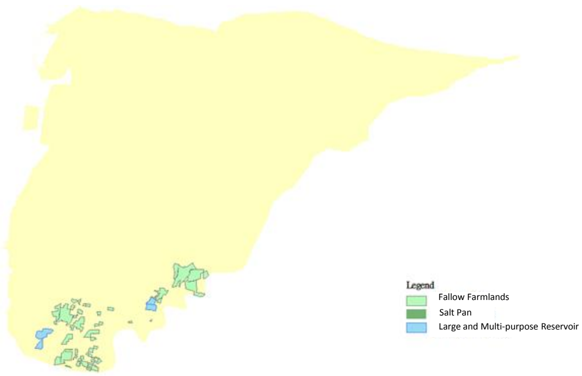

Figure 12: Land use plan with water balance concepts

3.2 Land use adjustments

We then base on elevation of 2m, provincial highway 61 (average height is 3 or 4 m) and 3.8m (the boundaries have been defined by central government based on land subsidence rate and sea level, and have been referred to other research projects in Taiwan), and flood simulation results (the results can be divided into 3 categories, high risk, medium risk and low risk) to propose land use adjustment strategies (See Figure 13).

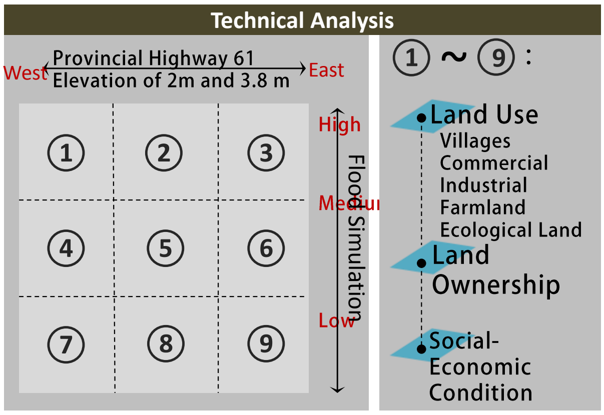

Figure 13: Land use adjustment framework

4. Result

4.1 Flood Simulation Results

Comparing to the 1st scenario (see Figure 14) and the 2nd scenario (see Figure 15), traditional flood prevention works are able to mitigate flood slightly under flood range of 5-, 10-, 25-year return periods for those engineering works came out mostly based on flood range of 50-, 100-, 200-year return periods. Therefore, our study area in southern west part has the most obvious mitigation benefit by constructing dikes, pumping stations and other traditional flood preventions works.

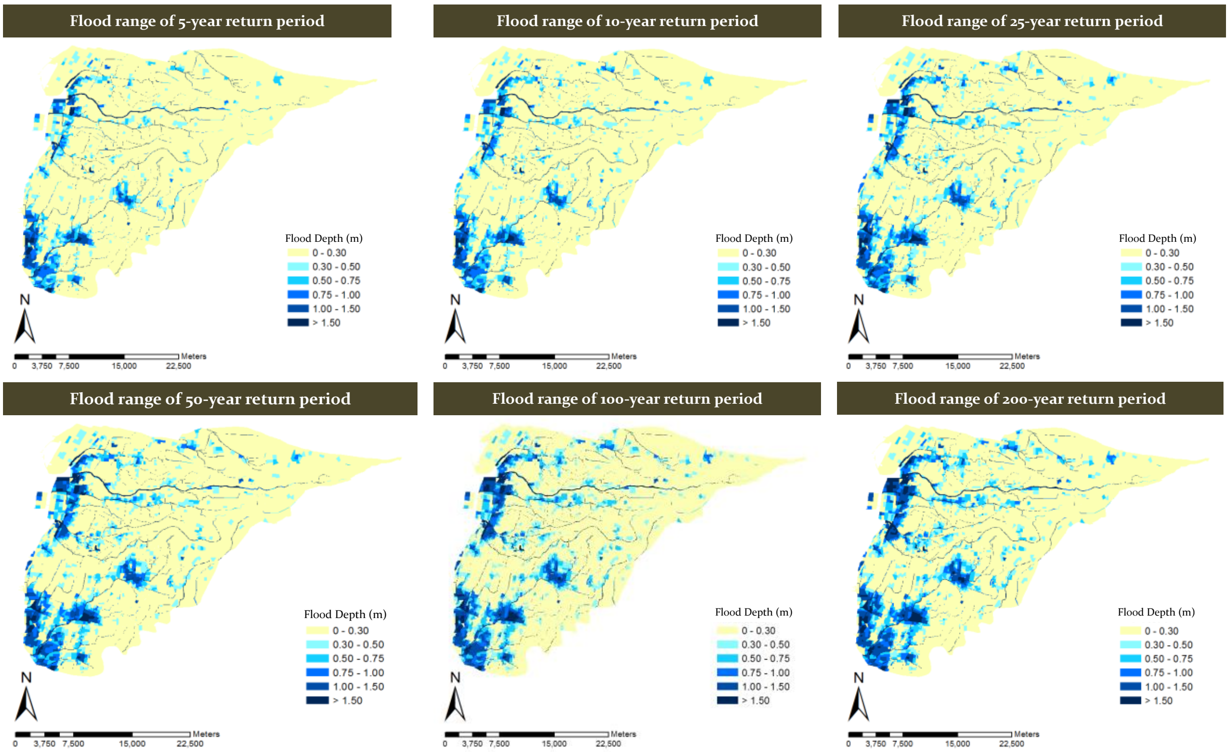

Figure 14: Flood range of various year return period under 1st scenario

Comparing to the 2nd scenario and the 3rd scenario (the integration of existing and planning traditional flood prevention works and other adaptive land use for detention) (see Figure 16), flood disasters have been improved conspicuously along the west coast under flood range of 5-, 10-, 25-year return periods for there are large amount wetlands. In addition, in inland area and upper stream region, we propose fallow farmlands as multipurpose reservoirs. Hence, flood disaster area is able to improve both along the coast and inland area under flood range of 50-, 100-, 200- return periods.

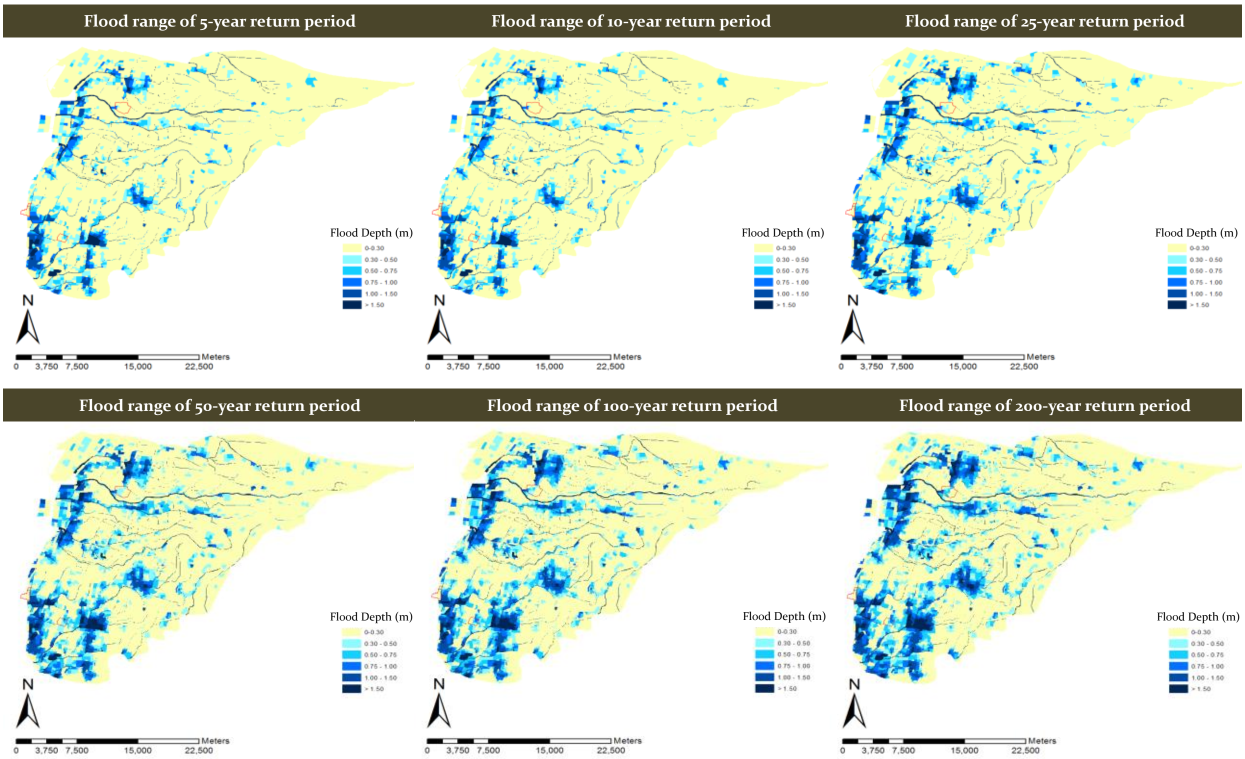

Figure 15: Flood range of various year return period under the 2nd scenario

Although areas along west coast have serious flood disasters under different scenarios, land use plan with water balance concepts indeed improve flood risks. Multipurpose reservoirs at fallow farmlands and wetlands are preliminary variables for now. We will then consider other potential land use types as flood detention purpose in later stages.

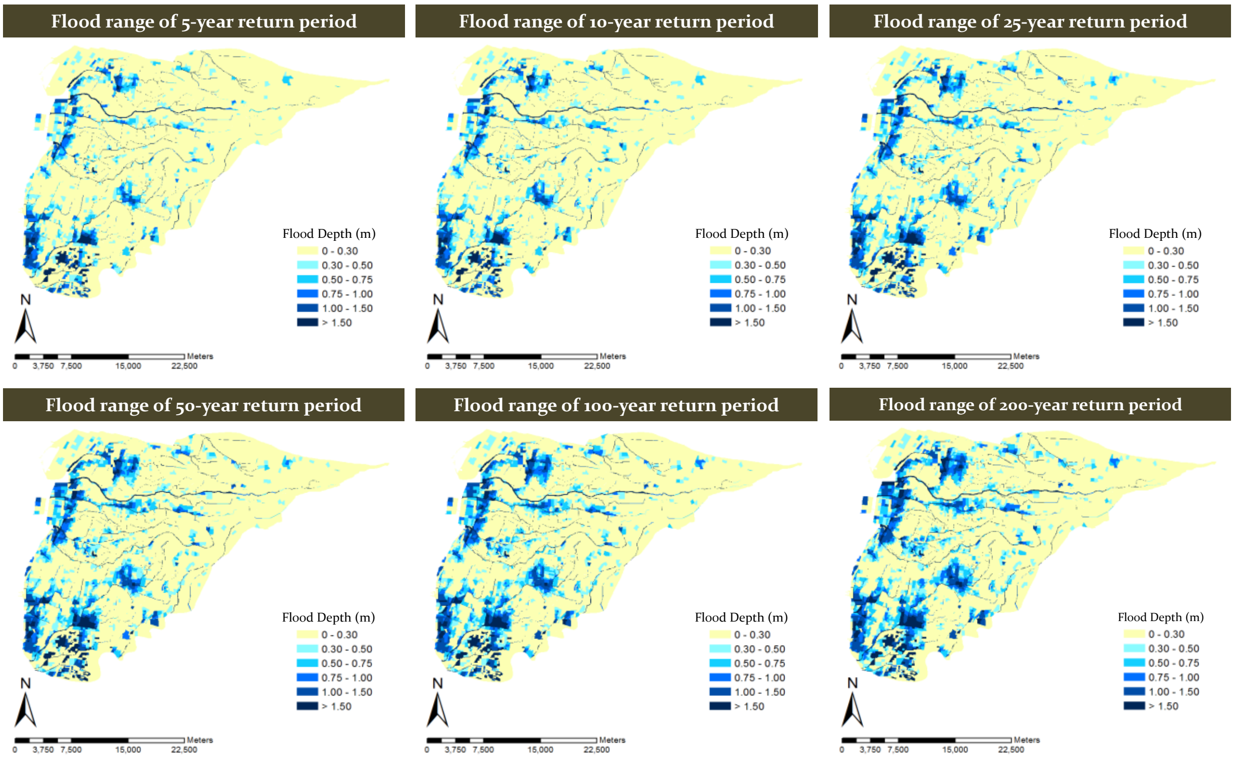

Figure 16: Flood range of various year return period under the 3rd scenario

4.2 Land use adjustment

In figure 17, we have separate buffer zones according to the elevations, including zone Ⅰ, zoneⅡ and zoneⅢ. Zone Ⅰ is the west of Provincial Highway 61 and elevation of 2m. The west boundaries of zone Ⅱ are Provincial Highway 61 and elevation of 2m, and the east boundary of zone Ⅱ is elevation of 3.8m. Zone Ⅲ is the east of elevation of 3.8m.

Owing to various land use types in the study area, public properties are top priority for land adjustment strategy in this planning phase. Figure 18 indicates that the north and the south coast has relative higher flood risks, so public properties, fallow farmlands and wetlands have to become flood detentions. Other land use types such as residential, commercial and industrial have to integrate advanced construction techniques such as stilt houses and floating buildings.

Figure 19 indicates flood risks might happen in relative lower area especially in the south area in zone Ⅱ. Lower land area have similar land use adjustment strategies to zone Ⅰ by integrating advanced construction techniques. Other public properties have to be top priority for village move from zone Ⅰ.

Figure 20 indicates zone Ⅲ is relative low flood risk area comparing to zone Ⅰ and zone Ⅱ. However, public properties have to be top priority for flood retention in upstream region, and adequate flood water drainage system is necessary as well.

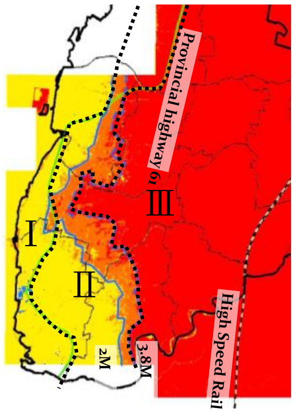

Figure 17: Buffer zones

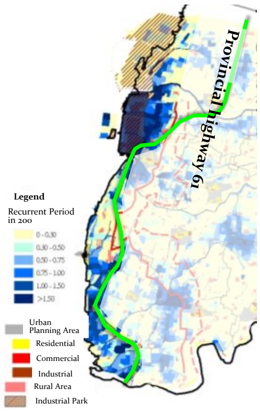

Figure 18: Zone Ⅰ

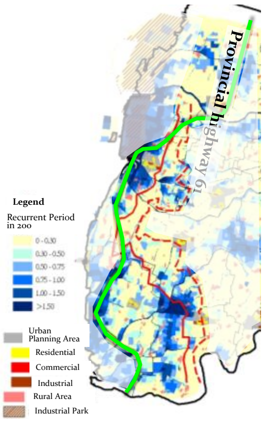

Figure 19: Zone Ⅱ

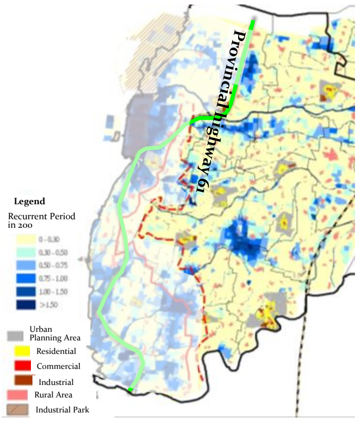

Figure 20: Zone Ⅲ

5. Conclusion

Coupling with serious land subsidence and flood disasters, we attempt to base on water balance concept and scenario simulation techniques to clarify the urgency and timeliness of various policies for overall land use adaption in such water sensitive city like Yunlin in Taiwan. The integration of land use planning strategies under proper sequence and dynamic land subsidence monitoring system will elaborate flood adaptation and mitigation benefits. Our findings in this stage are as followings:

A. Based on flood simulation results of applying physiographic inundation-drainage model, traditional flood prevention works are able to mitigate flood slightly under flood range of 5-, 10-, 25-year return periods.

B. The integration of existing and planning traditional flood prevention works and other adaptive land use for detention are able to improve flood disasters conspicuously along the west coast for there are large amount wetlands.

C. In the relative higher flood risks zone, public properties, fallow farmland and wetland are top priorities to become flood detentions. Land use adjustment strategies in relative lower area should integrate advanced construction techniques to mitigate property loss during flood disasters. Flood retention in upstream region and adequate flood water drainage system are necessary in the relative safer zone.

6. Acknowledgements

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