THE 3D SIMULATION INFORMATION SYSTEM FOR ASSESSING THE FLOODING LOST IN KEELUNG RIVER BASIN

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ABSTRACT
Due to the factors of geographical location, climate and terrain, flooding resulting from typhoons was frequently caused the loss of life and property in Taiwan. Flood damage assessment and risk analysis are important issues in damage management and mitigation. The officials cannot deal with emergency management and disaster relief because of the lack of timely (real time) flood inundation information; meanwhile, the public also cannot quickly identify at-risk area and realize the potential threat. Therefore, it is very significant to develop an information system to predict, prepare and estimate the flood inundation to alleviate the flood disasters.
This study primarily makes use of Geographic Information System (GIS) as the operating platform and applies 3D simulation technique to develop the information system. This information system also utilizes hydrological and weather data to simulate flood inundation as flooding occurs. The study area for this demonstration is in Xi-Zhi area within the Keelung River Basin. The demonstration of this study generates Flood Frequency Map (FFM) to analyze the flood inundation probabilities. Furthermore, FFM can also apply in constructing a depth-damage curve with social-economic data, in assessing the damage of flood inundations with 3D Building Model and even in computing the flood insurance rate.

KEY WORDS: 3D Simulation, Assessing Benefits, Flood Alleviation, Geographic Information System

1. INTRODUCTION

Urbanization degree and population density are highly raised because of the rapidly growing economy. The threat from the potential disasters is more and more serious; moreover, these disasters usually cause major loss of infrastructure, life and property. Due to the drainage area is small and the river is short, enormous flood damage is frequently caused by typhoons or severe rainfall in Taiwan. For example, the annual material loss caused by flood is greater than 17 billion N.T. dollars. It is because the officials cannot certainly acquire flood information so that they cannot estimate the potential threat of flood, draw up disaster response plans and deal with emergency management. Therefore, how to develop an information system to integrate the related database, to estimate the potential impact and to support decision-making is an urgent research issue of flood management.

This study primarily makes use of GIS as the operating platform and applies 3D simulation technique to develop the information system. As a result of simulation involves the effective presentation of information to a varied audience, there are two types of simulation that will be developed in this study: 1) 3 D simulation of the terrain and buildings for a part of Keelung river basin, and 2) time series data sets showing time varying events such as flooding that occur over a period of time.

The principle objective of this study is to develop a GIS-based 3D flood simulation tool that can be applied quickly and economically throughout the Keelung River Basin. The expected contribution is as following:

(1) To integrate the needed spatial information and the related database.
(2) To establish 3D models of terrain and buildings to simulate a flood event
(3) To develop a 3D Flood Simulation Information System.
(4)To display 3D Flood Simulation, the distribution of flood inundations and estimate the flood damage in Xi-Zhi area.

2. METHODS / PROCEDURES

2.1 Methods

There are two parts of the 3D simulation information system for assessing the flooding lost. First of all, this study makes use of GIS as the operating platform to develop the information system, including: System Analysis, Database Management System and Basic Database Constructing. Secondly, this study will integrate the related module of flood simulation system to develop the 3D simulation information system. The research framework is shown in figure 1. Figure 2 shows the information system framework.

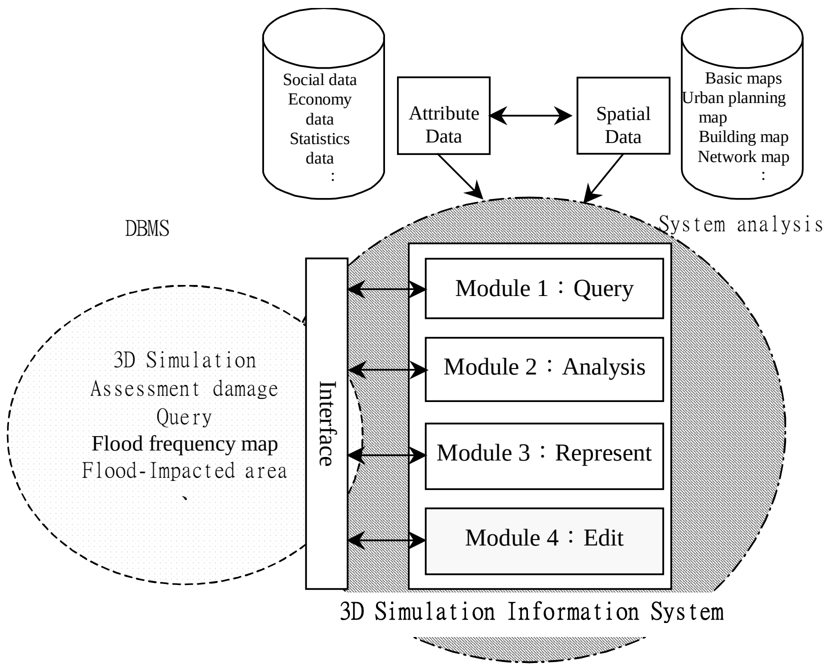

Figure 1: Research framework

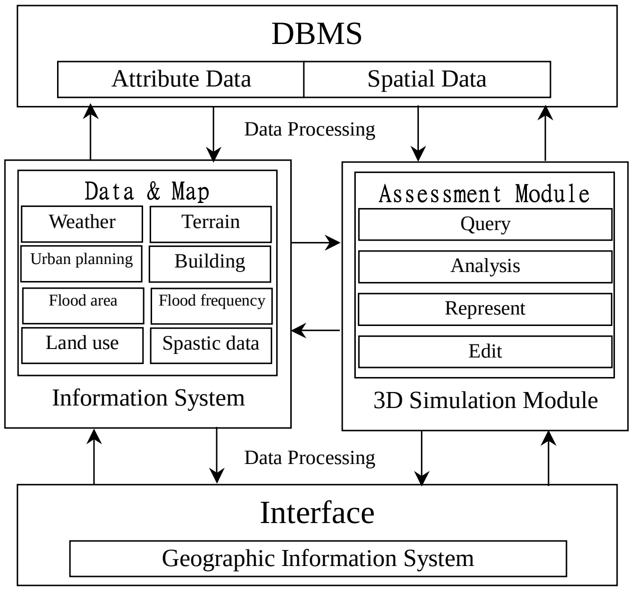

Figure 2: Information System framework

2.2 Procedures

This study reviews the related references and research projects to develop the framework of 3D simulation information system and the method of system analysis. Owing to the flood events possess geographical and spatial features; this study makes use of GIS as the operating platform to construct the related flood database, the simulated model and the interface of Inputs and Outputs.

The research steps of this study are as following:

(1) Gather and Construct Basic data

In addition to gather the present references, this study also gathers the digital maps and the related attribute data of the KeeLung river basin to construct the basic GIS database and provide spatial information. The digital maps include terrain maps, urban planning maps, Flood Frequency Map (FFM), building maps and so on.

(2) Data link and construct, develop the prototype

The work of this step is to integrate the related GIS database, including: hydrologic, hydraulic and social-economic model…etc. After that, this study will link all database to construct the system framework prototype. Data link transforms attribute data into GIS format and integrates attribute data with spatial data to proceed 3D flood simulation analysis.

(3) Test and amend case

This step will input the actual case to the 3D flood simulation prototype to analyze the outcome and to amend the prototype.

(4) Application and demonstration of the 3D flood simulation information system

This step will integrate the research achievements to develop the 3D flood simulation information system in order to provide needed information for assessing the flooding lost.

3. Construct the 3D Flood Simulation Information System

3.1 Inputs and Outputs

The system requires a number of inputs, including basic maps (for example: digital terrain map, urban planning map, traffic network map and building map…etc.), FFM (for example: T=6 years, T=20years…etc.) and related statistic or social-economic data (for example: flooding area, damage statistics…etc.). The system will provide information with different themes after system analysis (see figure 3 and table 1). For example, the function for 3D flood simulation utilizes basic maps, FFM and statistical data to output the 3D flood simulation maps.

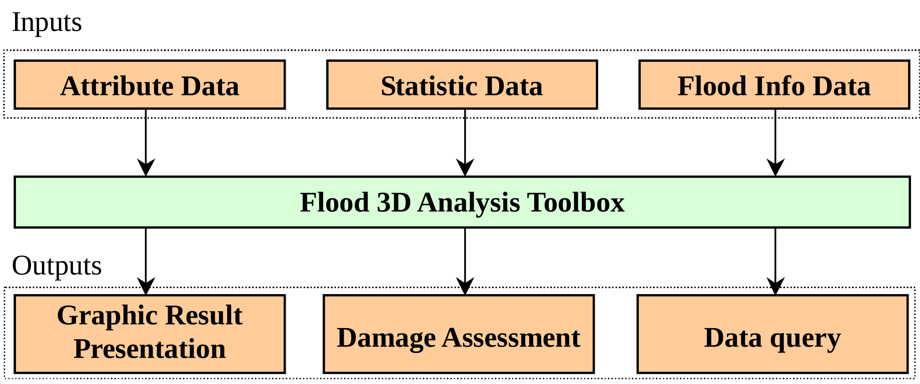

Figure 3: Inputs and Outputs

Table 1: Inputs and Outputs

Basic map / Inputs → Outputs	Basic map												Engineering map					Probability				Statistic data				
	North planning map																									
	Water	District map	Road map	Land use map	Building map	Taipei city urban planning map	Taipei county urban planning map	Digital terrain map (Tin)	Digital elevation map (Grid)	River basin map	Xi-Zhi area digital map	Neighborhood map	Pumping station	Embank map	Construction map	Flood control works map	Flood control region map	T= 1.1 years	T= 2 years	T= 6years	T= 20years	Neighborhood Area	Population	Household	Damage	Building area
Point													●													
Line	●	●	●	●	●					●	●	●		●	●	●	●	●	●	●	●					
Polygon	●	●		●	●	●	●	●	●		●	●	●	●	●	●	●	●	●	●	●					
Keelung river basin map	◎	◎	◎							◎		◎														
Flood Frequency Map	◎		◎									◎						◎	◎	◎	◎					
Flood probability	◎		◎									◎						◎	◎	◎	◎	◎				
Household (neighborhood)	◎	◎	◎									◎												◎		
Average population	◎	◎	◎									◎										◎		◎		

	Population (neighborhood)	◎	◎	◎									◎											◎			
	Flood area map			◎					◎			◎							◎	◎	◎	◎					
	Building damage map	◎		◎					◎			◎							◎	◎	◎	◎			◎	◎	◎
	Block damage map	◎		◎				◎	◎										◎	◎	◎	◎				◎	
	Neighborhood damage map	◎		◎					◎				◎						◎	◎	◎	◎				◎	
	Time series map	◎		◎					◎			◎							◎	◎	◎	◎					
	3D simulation map	◎		◎					◎			◎							◎	◎	◎	◎					
	Depth-damage map	◎		◎					◎			◎							◎	◎	◎	◎				◎	
	Range-damage map	◎		◎					◎			◎							◎	◎	◎	◎				◎	

3.2 Construct database

Before constructing database, it needs to perform requirement analysis according to function demands. Due to different application uses different data sorts and data precision, it must analyze data after understanding data demands (for example: source, precision and format…etc.) in order to construct database. This study makes use of GIS as the operating platform to construct the 3D flood simulation information system and therefore, it has to transform attribute and spatial data into GIS format to allow the system utilizing.

(1) Attribute data

Attribute data makes use of basic features (point, line and polygon) to display. Each spatial data has an individual code and corresponding attribute, for example: floors, land use zoning, area and so on (see figure 4). Attribute data stores in Attribute data table. When the record is selected, the attached polygon is selected, too.

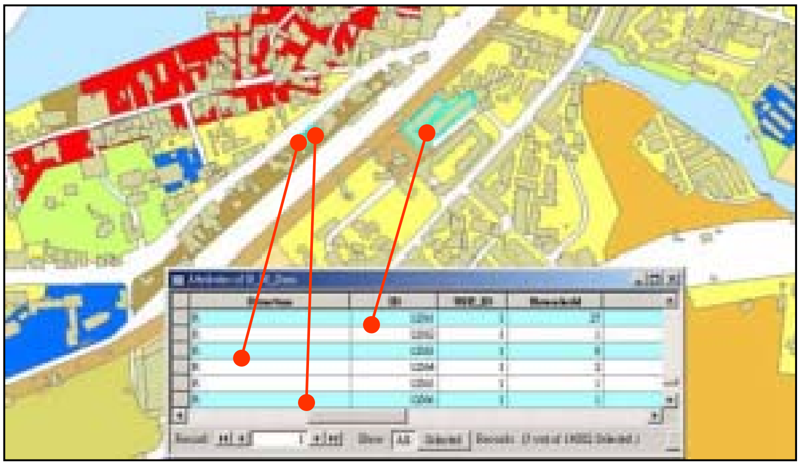

Figure 4: Property polygons and attached attributes

To draw basic maps is mainly to establish the spatial data for analyzing the 3D flood simulation, including: digital terrain map, neighborhood map, urban planning map and building map.

Digital Terrain Map (DTM) uses GIS theory as the basis. It digitises the elevation data to display the undulate terrain. The data formats for GIS presentation are composed of Raster Data and Vector Data in general. There are three types of presentation for digital elevation model (DEM): Triangulated irregular network (TIN), Digital contour and Regular grid. DTM of Xi-Zhi area is modelled by TIN (see figure 5).

Figure 5: Digital terrain map of Xi-Zhi area

The attribute data of Neighborhood map is including: neighborhood area, population, population density and so on. It is mainly to analyze the flood damage of each neighborhood in Xi-Zhi area. Figure 6 is the neighborhood map of Xi-Zhi area.

Figure 6: Neighborhood map of Xi-Zhi area

This study transforms AutoCAD file, which is produced by Taipei County Government, into GIS format to construct urban planning map. After transforming AutoCAD file, this study will create attribute data, including: block area, land use zoning, block ID and so on. It is mainly to analyze the flood damage of each block in Xi-Zhi area. The Xi-Zhi urban planning map is shown in figure 7.

This study uses digital raster graphic files to construct the building map of Xi-Zhi area. The attached attribute data includes floor, structure type, code, area and so on. It is mainly to simulate the 3D flood and analyze the flood damage of each building. Figure 8 is the building map of Xi-Zhi area.

Figure 7: Urban planning map of Xi-Zhi area

Figure 8: Building map of Xi-Zhi area

(2) Statistical data

It has to establish the related statistical data in order to estimate the flood damage, for example: buildings, households, prices and so on. The relationship between the depth and the damage is very close. We can draw the depth-damage curve to analyze the impact of the flood damage through the analysis of statistical data and water depth.

(3) Flood frequency data

This study analyzes flood events with different probabilities, terrain features and rainfall to generate flood frequency map. It provides information for flood simulation and flood damage assessment. There are four probabilities (T=1.1 years, T=2 years, T=6 years and T=20 years) of flood frequency map in figure 9.

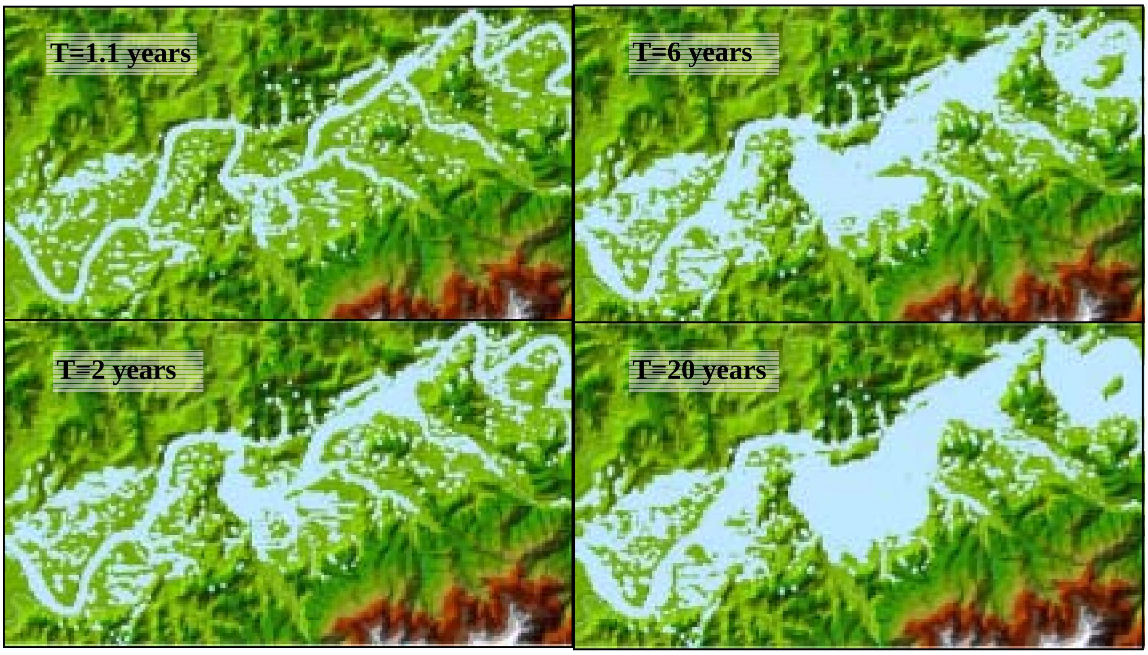

Figure 9: Flood frequency map of Xi-Zhi area

3.3 Simulation Concept

This study uses DTM, building maps and flood frequency maps to simulate the flood-impacted area and building. It also applies 3D simulation to understand the relationship between water depth and building. Besides, it analyzes the flood impacts to assess the damage of each building, and furthermore it will assess the damage of each neighborhood and block.

(1) Simulation Technology

As a result of simulation involves the effective presentation of information to a varied audience, there are two types of simulation that will be developed in this study: 1) 3 D simulation of the terrain and buildings, and 2) time series simulation.

3D simulation provides an easily understandable geographic base for the presentation and analysis of GIS data. The planned simulation will be a direct aid in the understanding of flood events as typhoons occur. People relate well to simulation that show the location of their subdivision relative to features that they recognize, such as a school or a shopping mall. 3D simulation is effective technique to convey information to the general population. Furthermore, it can represent the dynamic changes of the water and indicate the flood-impacted area (see figure 10).

Time series simulation can dynamically show the water rising in 3D GIS for different probabilities in a period of time and show what area could be inundated and during what time frame the flood would occur. Damage assessments could be determined based on GIS combined with the time series flood data. Time series simulation would be an extremely effective tool conveying information to the population affected by flooding during a flood event. Effective presentation of the time series simulation could help train the officials for an unexpected flood event in the future.

Figure 10: 3D simulation map of Xi-Zhi area

(2) Assess flood damage

The flood damage is related to land use zoning. The flood damage is more serious in the developed area. This study analyzes building area and social-economic data in residential and business district to assess the flood damage.

Assess building damage

According to the statistics data of “Report on the Housing Status Survey In Taiwan Area, 1993”, the average area is 108.59 square meter per house. Therefore, this study supposes each house area is 108.59 square meter to estimate the household of the building. The damage calculation makes use of the depth-damage table (see table 2) of “Flood-Damage Assessment and Related Database Implementation for KeeLung River Basin” to assess the equipment damage with different water depth. Furthermore, it adds the damage of facilities (see table 3) and the equipment damage to calculate the total damage of each building. The following formula shows how to calculate the building flood damage:

$$L_D = (H_D + P_D) * A/108.59 \qquad \text{Formula 1}$$

Where:

L_D：building flood damage (NT $)
H_D：equipment flood damage (NT $)
P_D：facilities flood damage (NT $)
A：building area (m^2)

Assess block damage

This study uses the building flood damage, which calculated in formula 1, to calculate the total damage of each block. It also utilizes urban planning map to show the flood damage in block. The following formula shows how to calculate the block flood damage:

$$B_D = \sum_{k-1}^{n} L_{D\,k} = L_{D\,1} + L_{D\,2} +、、+ L_{D\,K} \qquad \text{Formula 2}$$

Where:

B_D ：block flood damage (NT $)

L_D ：building flood damage (NT $)

Assess neighborhood damage

This study uses the building flood damage, which calculated in formula 1, to calculate the total damage of each neighborhood. It also utilizes neighborhood map to show the flood damage in neighborhood. The following formula shows how to calculate the neighborhood flood damage:

$$C_D=\sum_{k-1}^{n} L_{D\,k} = L_{D\,1} + L_{D\,2} + 、、+ L_{D\,K} \qquad \text{Formula 3}$$

Where:

C_D ：neighborhood flood damage (NT $)

L_D ：building flood damage (NT $)

Table 3: Facilities Damage

Types	Public facilities (Ten thousand NT dollars)	Average damage per household (Ten thousand NT dollars)
1-5 Floors	0	0
6-11 Floors	60	1.2
12 Floors	75	2.1
> 13 Floors	150	2.65

4. Current Research Result

The result of this study is composed of visual simulation and damage assessment. The study area for this demonstration is in Xi-Zhi area within the KeeLung River Basin. This area was selected because of the water basin flows into a heavily developed district. This study constructs attribute and spatial data to simulate and assess flood events.

4.1 Flood Simulation

(1) 2D simulation

2D simulation represents the flood areas and the flood-impacted building. It also analyzes the flood-impacted situation with different rainfall. Figure 11 shows the flood area and the flood building with different probabilities. The green buildings are safe and the flood impacts the red buildings.

(2) 3D simulation

3D simulation represents the relationship between water depth and building. It can display the dynamic rising water in a period of time and show the impacted floors. The flood-impacted building map is shown in figure 12. The red buildings are risky and the yellow ones are safe.

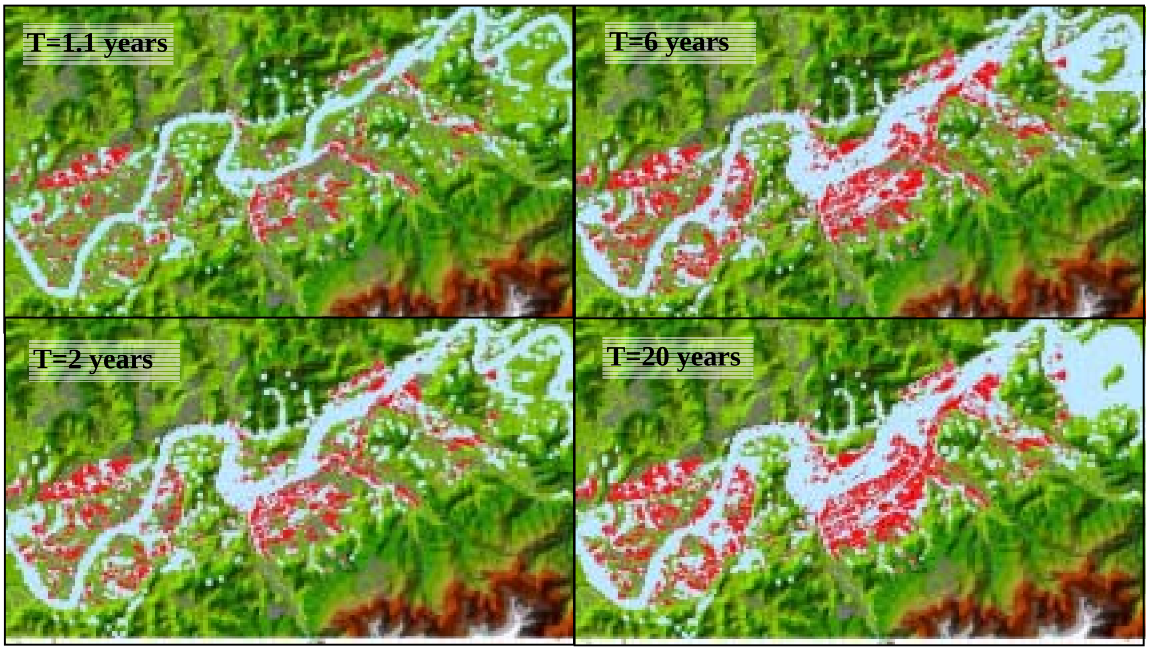

Figure 11: Flood inundation map

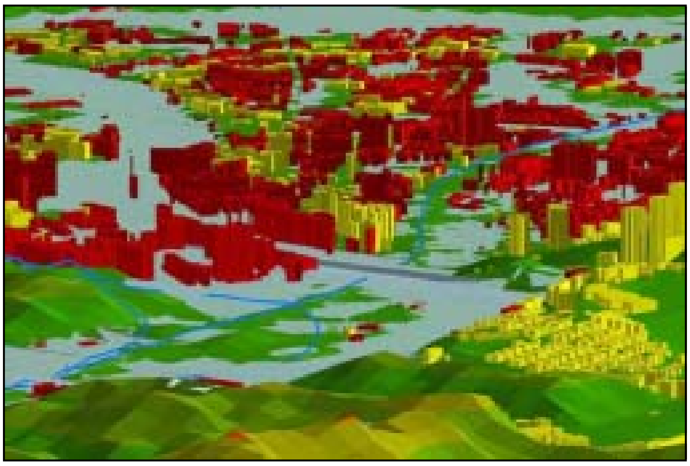

Figure 12: 3D Flood building map

(3) Time series simulation

Time series simulation represents the dynamic changes in a period of time and shows the flood spreading and rising. It divides the twenty-four hours into four periods to represent the dynamic changes. Figure 13 shows the flood spreading map and the flood rising map is shown in figure 14.

4.2 Flood Assessment

This study makes use of the 5% (T=20 years) annual probability flood data to estimate the flood damage. It calculates the flood damage according to different flood depth, including 0.1, 1.1, 2.1, 3.1, 4.1 and 5.1 meters.

(1) Calculate building damage

According to the 5% annual probability flood data, this study calculates the flood damage with different flood depth (see figure 15 and figure16).

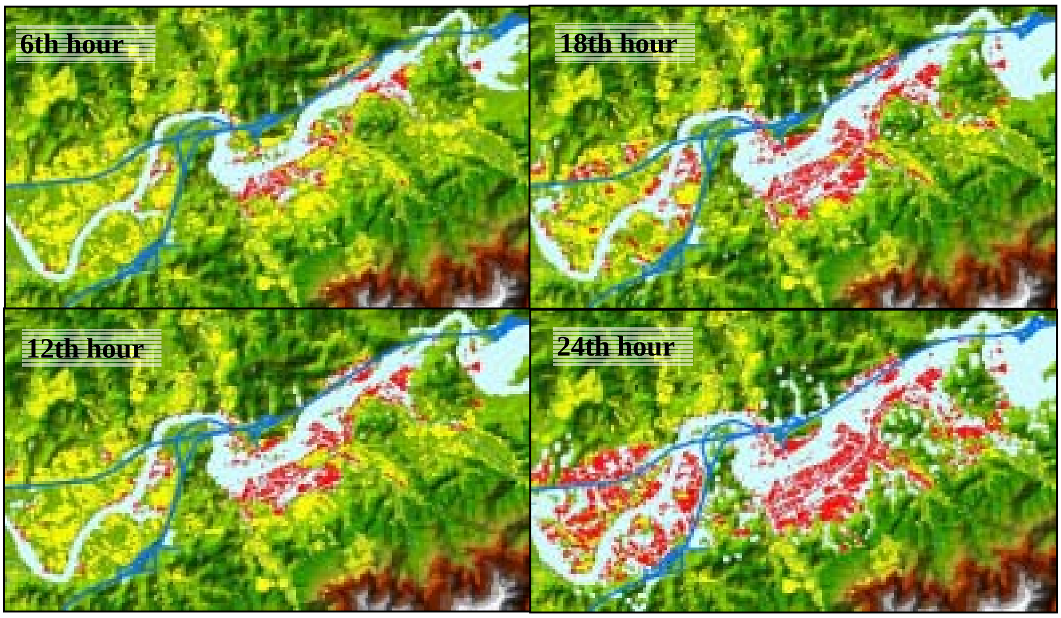

Figure 13: Flood spreading map

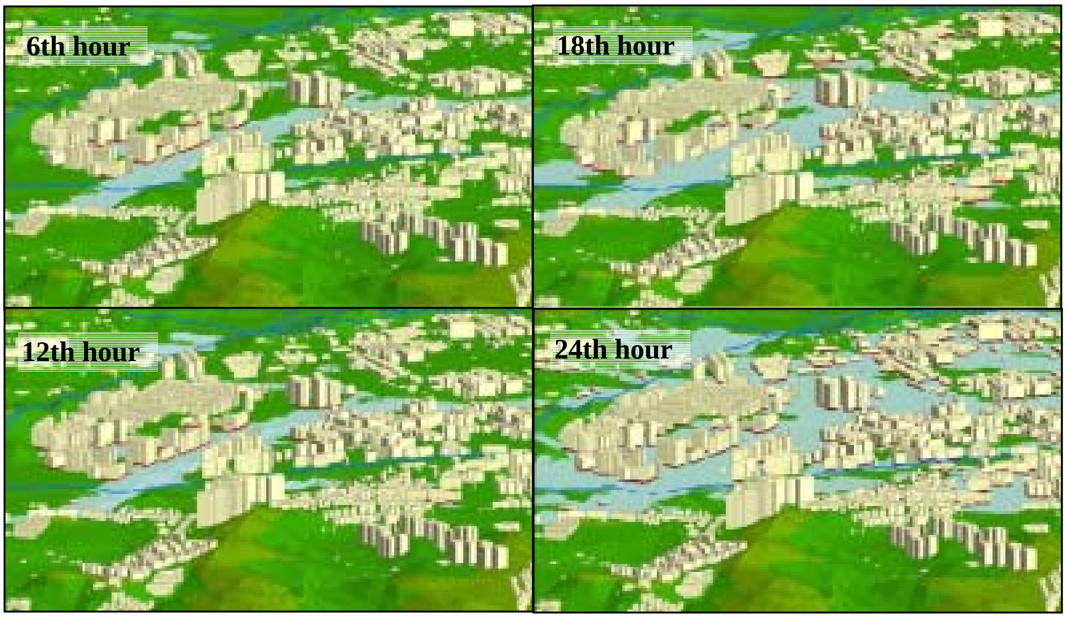

Figure 14: Flood rising map

Figure 15: 3.1 meters flood damage map

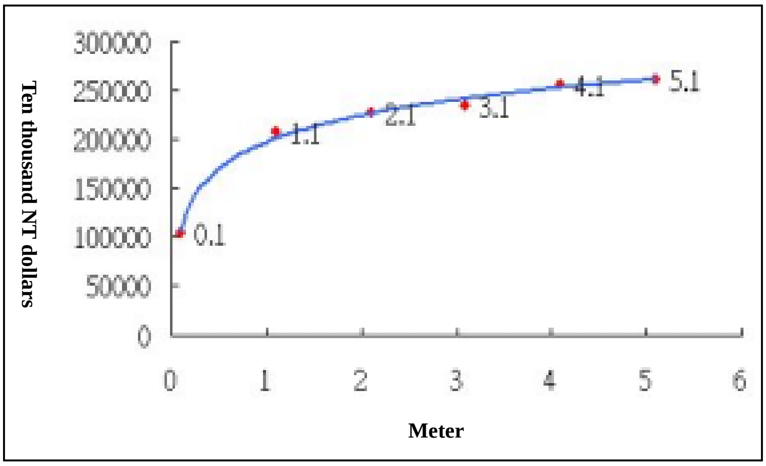

Figure 16: Depth-Damage curve map

(2) Calculate block damage

According to the flood damage data of the building, this study calculates the total loss of the buildings in each block. Figure 17 shows the flood damage in each block. It divides the damage into five levels. The darker block has greater loss.

Figure 17: 3.1 meters flood damage map (block)

(3) Calculate neighborhood damage

According to the flood damage data of the building, this study calculates the total loss of the buildings in each neighborhood. The flood damage in each neighborhood is shown in figure 18. If the neighborhood is near the river, it has greater loss.

4.3 A Brief Summary

The most convenient and user-friendly method to display and query the flood information is through the use of a GIS. Flood inundation maps and information created in this project will be provided in paper and digital form to the officials. The officials can use them to identify critical building and structures inside the flood zones. Such a system enables the officials to quickly identify at-risk structures, homes, and organizations. In addition, the system can be also used in selecting evacuation routes and buildings to be used as shelters.

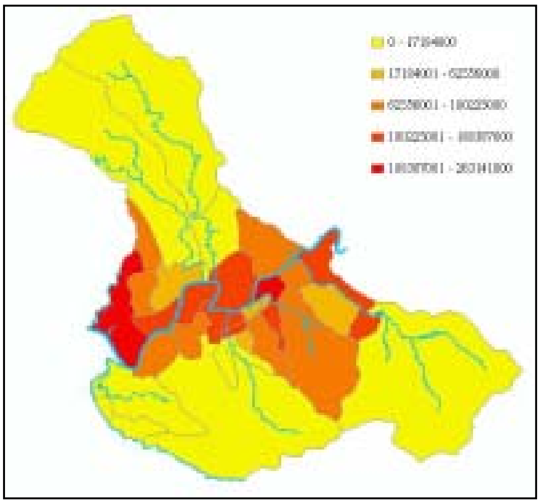

Figure 18: 3.1 meters flood damage map (neighborhood)

5 Conclusion

The 3D Simulation Information System makes use of GIS theory and technique as the system basis. It applies database, spatial analysis and 3D simulation with geographical concept to improve the quantity of the flood works. The system will provide information to the officials to deal with emergency management, plan responding projects and manage flood events. Besides, this system also provides a basis for predicting the area to be impacted and the water level.

The most effective method to analyze and assess the flood damage is through the use of GIS and spatial model. For the officials, it provides an easier way to understand and handle the flood. For the public, it provides the useful flood information. This system can provide information to support decision makers making policy. In addition, the 3D simulation information system, which constructed by this study, can be applied quickly and easily throughout the similar flood areas.

In the future, this system can become an integrated tool through the extending of database. It can also extend the analytic module to enhance the system function. Furthermore, this system can integrate with other disaster system tools to popularize its research and application.

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