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HYDROLOGIC/HYDRAULIC MODELLING AND FLOOD RISK ANALYSIS FOR THE WEST TIAOXI CATCHMENT, TAIHU LAKE REGION, CHINA

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ABSTRACT: Located in the headwater upstream of the Taihu Lake region, which is a densely populated and economically developed area in China, the West Tiaoxi River catchment is a frequently flood-hit area due to its nature and climatic characteristics. During the last several decades, more than ten catastrophic floods happened in this area, causing huge economic losses. Since 1990, due to the increasing property vulnerability to flood hazard, the disasters were even more serious than before, and economic losses increased year by year. Thus, there have great importance to study flood behaviors, flood risks and their consequences. In this paper the hydrologic/hydraulic modelling is presented firstly. It is the method to study the relationship between rainfall and runoff and the flood propagation process. Secondly, the author gives the summary of the current study methods for flood risk assessment. The West Tiaoxi River catchment has a long history of the construction of polders and hydraulic engineering. Most farmlands have been protected against floods. So the combination method has been used to obtain the real risk area. The results have been obtained by using this method, which, the authors think, will be used in disaster preparedness, property insurance etc.

KEY WORDS: West Tiaoxi River catchment; flood and waterlogging disasters; hydrologic/hydraulic modelling; flood risk assessment

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1 INTRODUCTION

The West Tiaoxi River, starting at the northern part of the Tianmu Mountains, northwest of the Zhejiang Province, geographically runs across the Huzhou Prefecture from southwest to northeast where it discharges into the Taihu Lake, the third biggest freshwater lake in China. It is the largest inflow river of the Taihu Lake and has a length of 150km in its maximum course. Its catchment covers an area of 3654km^2 of which 65% is mountain region.

There are four county level regions in this catchment. Except the one which only has 132km^2 in area belonging to the Xuancheng Prefecture of Anhui

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Province, the other three belong to the Huzhou Prefecture of Zhejiang Province, which are Anji, Changxing counties and Huzhou urban and rural district, respectively. Anji County, mainly located in the upstream mountain area, has a total area of $1806km^2$ of which only 4% are river valley plain area. The Changxing County, which has an area of $1432km^2$, occupies $1060km^2$ of the plain area.

Huzhou City, which has a population of more than 200 000 in its urban area, is located at the right bank of the downstream West Tiaoxi River. Since 1960 when the artificial channel of the East Tiaoxi River joined to the West Tiaoxi River in the southwest of the city, the flood risk of the city increased although many flood-reduction projects were constructed. In the past few years, Huzhou City developed very fast. Some township enterprises or factories were newly established in the low-lying area without flood-protection, so the flood losses increased year by year. For example, in the summer of 1996, a 5-year reoccurrence flood passed Huzhou City but caused more than 60 enterprises stop running for several days, resulting in US$ 1. 1 million of direct losses. If this condition continues for a long time, the economic losses will be huge, when a heavy flood happens.

This paper aims to study the formation processes of flood disasters and to assess the flood risk in the river network plain area of the downstream West Tiaoxi River catchment.

The hydrologic and hydraulic models were developed by the authors during the last several years (JIANG *et al.*, 1997). They have the accuracy for flood risk assessment. Because the content of hydrologic/hydraulic modelling has been published in related papers, this paper just gives simple introduction. The result of flood risk assessment is our new achievement. This paper will give detailed introduction. The raw data such as the river cross-section data, meteorological and hydrologic data, polder information, disaster data etc. either are provided by the Huzhou Water Resources Bureau or come from hydrologic yearbooks.

2 HYDROLOGIC AND HYDRAULIC MODELLING

2. 1 Hydrologic Model for Rainfall-Runoff Computation

2. 1. 1 Rainfall-runoff yield modules

Different ground conditions have different laws in rainfall-runoff yields. The land-surface in this region can be sub-divided in several types: water-surface, paddy field and dry-land/non-cultivated land. Thus, different simulation methods of rainfall-runoff yield have been used in this study. The water budget equations are very easy to be established on water surface and paddy field, and the runoff depth can be obtained from the calculation of these equations (LIANG, 1994). On dry-land or non-cultivated land, the saturated-storage rainfall-runoff yield model (ZHAO, 1982) was used in the calculation of runoff production. Then, for a catchment, the integrated runoff yield process is:

$$R(t) = C_1 R_1(t) + C_2 R_2(t) + C_3 R_3(t)$$

Where, R_1, R_2, R_3 are the runoff depths on water surface, paddy field and dry land respectively; C_1, C_2, C_3 are the weights of the three landuse types; $R(t)$ is the runoff depth of a catchment.

2. 1. 2 Flow concentration modules

The West Tiaoxi River catchment has a complicated topography. It has been affected by human activities for a long time. Based on the topography and the distribution of the polders, the catchment was divided into 45 sub-catchments or sub-regions. Several simulation methods for runoff concentration calculation were used in our research. The main methods are:

(1) Instantaneous Unit Hydrograph Method

This method was used in the data-lacking mountain sub-catchments. It is a linear method and produces approximate results.

(2) Xinanjiang Model

It is a concept, deterministic or distributed model (ZHAO, 1982). The structure of the model is somewhat like the Stanford and Sacramento Models. This method was used in the upstream sub-catchments of the West Tiaoxi River catchment.

2.2 Hydraulic Model for Flood Propagation Computation in the River Network of the Plain Area

2.2.1 Model selection

Most plain areas of the downstream this catchment are protected by polder dikes. Consequently, only the 1-D unsteady flow model can be selected for the computation of the flood propagated in the river channels.

2.2.2 Computation method for model

The mathematical equations of 1-D unsteady flow can only be solved by numerical methods. In this research the finite difference method (FDM) was adopted. The Pressimann 4-points implicit difference scheme was used for this computation. The detailed solution methods see related reference papers (LIANG, 1994; XU, 1994).

2.2.3 Simplification of the river network

It was difficult to get detailed topographic information about some small rivers. And it was not necessary to consider all rivers in this hydraulic computation. So these small rivers were schematized. Some nearby parallel small rivers were combined into a virtual big river. The hydraulic factors of this virtual big river were calculated from the invested data of these small rivers. After river network simplification, 23 cross nodes of rivers were obtained. These cross-nodes divided all rivers (including virtual rivers) into 13 exterior river parts and 32 interior parts. There were 103 computed difference river sectors for the exterior rivers and 204 for the interior rivers (JIANG *et al.*, 1997).

2.2.4 Model calibration

The model was developed by the authors from the year 1993. During the last several years, it has been carefully tested for many times. The calibration results of the model shown that it had the accuracy for flood risk assessment (JIANG *et al.*, 1997).

3 SUMMARY OF FLOOD RISK ASSESSMENT AND MAPPING

3.1 Definition of Disaster Risk Assessment and Its Contents

Risk assessment of disasters aims to evaluate the potential disaster types, occurrence frequencies (or probability or return period) and their consequences in a specific region. As of the importance of frequency in the risk assessment, it can then also be called the probabilistic assessment and probabilistic safety assessment. Thus, risk is the mathematical expectancy value of all consequences at different disaster frequencies (MEI, 1993):

$$R = \sum_i F_i \sum_j E_{ij} V_{ij}$$

where, R is the total risk of all kinds of disasters; F_i is the occurrence frequency of disaster i; E_{ij} is the threatened environment factor j in the condition of F_i; V_{ij} is the relative vulnerability.

Then, four aspects must be included in the risk assessment of disasters as: disaster types such as flood, drought and earthquake etc.; frequency or return period of a disaster such as a 50-year flood or a 20-year waterlogging; environmental factors threatened by a disaster such as population, farmland etc., and at last the vulnerability of all impacted factors.

3.2 Methods for Flood Risk Assessment and Mapping

As one of the important parts in analyzing the disaster risks, flood risk assessment mainly focuses on the evaluation and mapping of the floods on a specific research region. In large area of the Eastern China, earthquakes may not happen in several decades although it is the most vulnerable disaster, but flood disasters occur almost every year. In some parts of the low-lying depression area (near the lakes or marshes), the total risk can be fully represented by flood risk. The following four methods for flood risk assessment and mapping have been concluded from many reference papers or reports:

3.2.1 Flood frequency analysis and mapping for inundation area

Flood distribution and flood characteristics at different frequencies can be obtained from hydrological probability analysis based on the data sets of precipitation, water stages and flood peaks of the historical floods. This method was developed during the 1950s and the 1960s and was widely used in the USA and European countries. It's recommended by UNISCO as a standard method for flood risk assessment. For example, this first kind of map — the 1951 flood of the Kansas River — was compiled by the Geological Surveying Bureau of the USA (GSBU) in 1959. In 1961, the inundation regions for the floods of 25, 50 and 100 return periods were marked for the first time by GSBU in the map "Inundation Map of the 1961 Flood in the Bored Region of the Colorado River Valley". During the next 20 years after this map came out, the GSBU compiled about 13 thousand sheets of the flood inundation maps in 16 000 flood-prone regions of the USA. During the past several years, several provincial insurance companies in China have compiled many city inundation maps at different flood frequencies with co-operation of water resources or city construction organizations based on this method (LIU, 1991). This method is suitable to be used in the higher plains and river valley plains where no or less flood-prevention projects are constructed.

3.2.2 Geomorphologic classification mapping showing flood inundated conditions

This classification is based on the differences of the causes, patterns, storage and drainage conditions and water-saturation time of different kinds of geomorphologic types. Japanese scientists do a lot of research work on the topic (National Research Centre for Disaster Prevention[①], Japan, 1986, 1989. YOSHIKI *et al.*, 1988). They use satellite images of different periods before, during and after disasters to study the relationship of the flooding area and the geomorphologic types in the years of very big, big or normal flood frequencies. This method can be used not only in the mountain watersheds but also in plain areas as long as the satellite images are available.

3.2.3 Hydraulic computation and the simulation of flood propagation

Today, high-speed computers make this method more available. For a specific event (flood or broken dam), the flood propagation process can be simulated by a set of hydraulic computations (TAMATSU *et al.*, 1987, 1990; CHENG *et al.*, 1995). For example, TAMATSU *et al.* studied the flood damage risk of the wood houses after the break of levees, and used this method to assess the evacuation system for water and mud floods. CHENG *et al.* applied this method to flood risk mapping and zoning in the diversion and detention area of the floodplain of China. This method has a high accuracy for a small enclosed region which has a simple boundary.

3.2.4 GIS and risk ranking methods

This method is a regional comprehensive method. Firstly, the risk-ranking model can be established by analyzing the influence degrees of the geological, geomorphologic, topographic and landuse factors to flood and waterlogging disasters. Secondly, the risk degree and distributed scope can be determined by using the overlay analysis in GIS. ZIZAM-UR-ROHMAN *et al.* compiled a flood risk map in Bangladesh. Some scholars in China, such as ZHONG *et al.*, YU *et al.*[②] and ZHOU also did some researches on the applications of GIS in flood disaster management.

4 FLOOD RISK ASSESSMENT FOR THE STUDY AREA

4.1 Preparation

Except the geomorphologic classification method, the other three methods were combined in this study. The method of the frequency analysis was used to obtain the spatial distribution of precipitation. The hydrologic and hydraulic models were used to obtain the water stages and discharges at different rainfall frequencies. Based on these results the disaster risks were assessed for the plain area. The GIS method was used for risk mapping.

4.2 The GIS Data Needs

In this study two different GIS (ATLAS-GIS and

① National Research Centre for Disaster Prevention, 1989. A Geomorphologic Survey Map of the Central Plain of Thailand Showing Classification of Flood Inundated Areas; 1:25000 Flood Area Map of Tsukuba from Landsat/TM Data, 1986.

② YU Xiu-bo, ZHAO Hong, 1992. Report on Training Program on Remote Sensing and GIS for Regional Flood Disaster Management. United Nations Centre for Regional Development, Nogoya, Japan.

TNTmips) were used to take advantage of the specific tools and utilities available in each of them, and to enhance the quality of the processes involved. As a preliminary task, the existing cartography was digitized. Information came from the raw topographical maps, the administrative maps or the other maps. Some maps such as the polder maps were firstly scanned to the computer with raster format, then digitized directly on the screen. The ATLAS-GIS was mainly used for raw map digitization. The digitized vector files were very easy to be transferred from the ATLAS format files to the TNTmips project files. The scanned raster maps were also digitized through the Object Edit function of the TNTmips. The satellite TM image of Aug. 24, 1984 were used as one GIS layer in this research.

With a GIS it is possible to produce new information by taking advantage of existing algorithms. The production of the new maps, such as slope or elevation maps, must be preceded by using a digital terrain model (DTM). This process was undertaken for the whole catchment.

4.3 Frequency Analysis for Precipitation

Except the northern part of the Changxing Plain, which is affected by the Taihu Lake high water, the other area of the downstream plain is mainly affected by the flash flood from the mountain area. The statistical results show that the yearly highest water stages at the Hengtang station and the Fanjiacun station have high correlation with the yearly maximum rainfalls in 1, 3 and 7 days. The 1963, 1984, 1961, 1962 and 1983 floods rank the first five most serious floods since 1950. The maximum 3-day precipitation of these years also rank from 1 to 5 for the whole West Tiaoxi River catchment. So the yearly maximum 1, 3, 7-day precipitation were chosen for frequency analysis.

Precipitation frequency analysis is a basic work for flood risk assessment. First, the possible precipitation for different frequencies in each station can be obtained based on the data series. After analyzing precipitation frequency curves of all stations in a catchment, the spatial distribution maps for different frequencies are given.

4.3.1 Precipitation intensity data sets

There are 39 gauging stations distributed on the whole West Tiaoxi River catchment. Each station controls about $90km^2$ in area. The arithmetic mean method was used to calculate areal precipitation for the West Tiaoxi River catchment or sub-catchments because of the dense gauges. Some gauges have long data series, and the longest time series lasts for 75 years from 1922 to 1996. But most stations only have data length of 31 years. So the 31-year series of maximum 1, 3 and 7-day precipitation were chosen for analysis. Eleven sub-catchments or sub-regions were divided based on their topographic features and station distributions. Each subcatchment or subregion had at least two stations.

4.3.2 Analysis methods

The design precipitation of a certain probability (or return period) can be obtained from frequency analysis (or probability analysis). There are many probability distribution curves used for the analysis of the hydrologic extreme event. In USA, the Log-normal and Extremal-1 curves are broadly used. In China, the Person-Ⅲ distribution curve is recommended by many hydrologists. In this research the standard errors were estimated for six curves (Truncated Normal, 2-Para. Lognormal, 3-Para. Lognormal, Type-I Extremal, Person-III, and L-Pearson-III) by using the FREQ program (KITE, 1991). Except the Truncated Normal distribution curve, the other five had the same order of errors. The Person-Ⅲ distribution curve was chosen in our analysis based on our experiences.

The parameter estimate is the most important aspect in frequency analysis. The moment's method is a biased estimate. It is not used in practice. The maximum likelihood method is an unbiased estimate method, but sometimes no solution is obtained for this method because of the strict solution condition. At last, the graphical method was used for the estimates of the parameters of Person-Ⅲ distribution curve.

4.3.3 Temporal and spatial distribution of maximum 1, 3, 7-day precipitation

The design precipitation for the whole catchment and each sub-catchment can be calculated according to the frequency curves of each station. In this research, the outputs were the 1, 3, 7-day precipitation at frequencies of 0.1%, 0.2%, 1%, 2%, and 5%. Using GIS method the spatial distributions of precipitation intensities were mapped out.

4.4 Computational Results of the Hydrologic and Hydraulic Models for Different Precipitation Frequencies

In order to have an approximate knowledge of the discharge values in a particular cross-section of a river, a hydrologic model is used. This model relates precipitation to discharge, considering parameters that characterize both the relevant meteorological event and the river catchment basin, such as rainfall distribution, soil properties, soil cover and other human-related activities including land use.

The relationship between river flow discharges and water depths is then characterized by hydraulic modelling. In this case the river characterization is a main factor. Mathematical modelling of hydraulic phenomena is labor intensive in terms of both human effort and computer power. Nowadays, the GIS provides a good basis for implementing hydrologic and hydraulic models, taking advantage of all data directly available in the system and providing scenarios of flood hazards for different flood alleviation measures.

The objective of hydrologic and hydraulic computations is to define the flood-affected areas, using relevant input data such as precipitation and landuse. The application of a rainfall-runoff model is necessary to determine flood hydrographs, and maximum floods used in the hydraulic model were necessary to define the flood-prone areas.

First, the hydrologic model was used. In this model, the estimation of rainfall-runoff relations in ungauged watersheds was made by using instantaneous unit hydrograph method. Computer program (XTXRR) for hydrologic model can generate a flood hydrograph for a given rainfall event in a catchment or sub-catchment, and to use this model it was necessary to consider various types of data such as basin data (watershed limit, area, slope and length of the principal watercourse) and rainfall data, based on historic records or design values. Other data necessary to run the hydrologic model were selected and entered by the user, for example the time step for flood hydrograph computation.

The second step in defining the flood-affected areas is to run a hydraulic model (XTXFP) whose output is the calculation of water surface profiles. The model allows the calculation of water stages and discharges at different river cross-sections for unsteady flow conditions. The lateral flow should be provided by hydrological model. To run this program (XTXFP) we must input the river cross-sections used for calculations, the Manning coefficients of overbanks and channels.

For the output of the hydraulic model various scenarios can be considered with flood-affected areas defined by the use of appropriate data sets. These scenarios can be based upon different return periods, different land uses and, eventually, different structural measures to control floods. Implementing an existing model in the framework of a GIS allows the integration of information from different sources and of different types and adds significantly to the quality of the resulting output. Without considering the polders, probable maximum inundation depths for 100-year precipitation in three days is shown in Fig. 1.

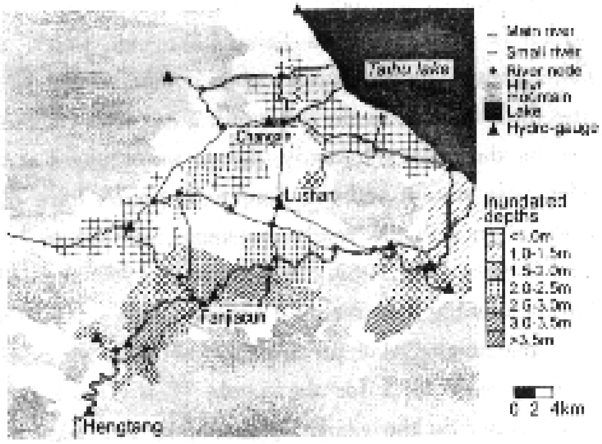

Fig. 1 Probable maximum inundation depths for 100-year precipitation in three days without considering the polders

4.5 Risk Analysis for Polders

4.5.1 The polder systems

A polder can be defined as the low-lying field surrounded with dikes. In the flood season, the river water stages outside the polder are always higher than farmland surface. Polder construction shows that the local people have accustomed themselves to living with the risk of floods, that means they have developed strategies on rising water stages.

The polder construction in the West Tiaoxi River catchment has taken for a long history. Nobody knows when and where the first polder was formed in the West Tiaoxi River catchment. Early in the Spring and Autumn Period (770 B. C. –476 B. C.) of the Zhou Dynasty, some polders existed in this region already according to an ancient chronicle book. And until the late Tang Dynasty (A. D. 618 – A. D. 917), the polder systems were gradually formed. During 1127 – 1949, the system became disordered. After 1949, the governments mobilized the local people to reconstruct the systems. At present, the systems have the capability against normal floods (less than 5 return years). But for the serious floods, for example a 50-year flood, most polders have not enough pumping power to drain the floodwater to the outside rivers, and some may be inundated because of the polder dike broken.

Generally speaking, flood and waterlogging are two different concepts. For the West Tiaoxi River catchment the rare frequency rainstorms always simultaneously happen in upstream and downstream and cause the flood and waterlogging hazard at the same time. The river water stages are 2. 0m higher than the average elevation of the landsurface. If no polder dikes protect the farmlands, which now are often waterlogged due to the low drainage capacity, these areas could be flooded. So the two concepts are considered as the same in this paper. The analysis for water logging risk in polders constitutes one important part in flood risk assessment.

There exist two kinds of polders in the West Tiaoxi River catchment. The first one, the hilly polder, mainly distributes on both riversides of the Middle West Tiaoxi River or its tributaries, of which only three sides are protected by dikes and the other side is on the hill in the backward. The other one, the plain polder, distributes on the downstream river network plain, which has an enclosed dike surrounding it. There are four factors to feature a polder: dike, farmland elevation, installation of pumps and sluice gates. And there are also four factors to determine whether a polder is inundated or water-logged or not: dike height, drainage capacity, relative elevation compared with the water level outside, and at last the percentage of the water surface in this polder.

The polders in the West Tiaoxi River catchment are distributed on the plain area below the town of Ancheng. The statistical results show that the polders along the main river course have a total area of 672. 4km^2. The paddy fields occupies 70% of the total polder area, and drylands 19. 8%, mulberry orchards 2. 6%, fishponds 4. 5%, water surface 3. 1%. Total dike length for flood-protection is 1012. 2km. The average elevation of the paddy fields is about 4. 8m. The dangerous dike length is 212. 8km, that means, these dikes cannot protect from 3 – 5 years reoccurrence floods.

4. 5. 2 The analysis method

The two kinds of polders were classified mainly based on the topographic features. There are 63 mountain/hilly polders and 138 plain polders in the downstream along the West Tiaoxi River. Each kind was reclassified based on cluster analysis method. For the mountain polders there are two subclasses (M-1, M-2) and three for the plain polders (P-1, P-2, P-3). The variables used for this method are: watersurface percentage W ($W = A_w / A$, A_w is water surface area, A is the polder area); dranaige modulus M ($M = Q / A$, Q is the drainage discharge in m^3/s of each polder, A is polder area in km^2); difference H_d of landsurface elevation and average water stage of the rivers inside the polder ($H_d = H - Z$, H is landsurface elevation, Z is the average water stage).

These variables decide the storage and drainage capacity. The larger the water surface W and the bigger the difference H_d are, the more the runoff can be stored inside the polder. The drainage modulus defines the amount of logged water to be drained off. The results were calculated by using cluster analysis program after inputting and normalizing the data sets of these variables.

The cluster analysis classes the polders with similarities. Different subclasses have different risks. For example, the M-1 polder has a higher risk than the M-2 polder. Because of the difference between each polder, perhaps the polders in the same subclasses are not all easily waterlogged at a given frequency precipitation. And the risk difference between M type and P type is unknown. This only can be done by hydrologic computation.

Each polder can be seen as a small catchment. The runoff production can be easily calculated by using the hydrologic model mentioned above. The precipitation intensities for each polder at different frequencies can be obtained by overlaying the precipitation map and polder map.

A classification indicator has been applied in assessing the polder risk. It integrates the polder feature and runoff production characteristics:

$$N = \frac{\triangle H}{M \cdot T \cdot t \cdot 3600}$$

$$\triangle H = R - k \cdot H_d \cdot W$$

where, N is the classification indicator of risk degrees; R is the runoff depth inside the polders; M, W and H_d have the same meanings mentioned above; T is drainage days, here $T = 4$ days; t is operation hours of pumping stations in each day, here $t = 22$ hours; k is defined as an empirical coefficient, here $k = 1/3$ for hilly polders, and $k = 2/3$ for plain polders.

4.5.3 Risk ranking results

The cultivated lands in this study region are mainly rice fields. If the water cannot be drained off the polders in the following day after a heavy 3-day-rainfall, the rice production will be reduced. So the variable T is chosen as four days. The indicator N is seen as the risk coefficient. $N = 1$ means that a polder has the drainage capacity to fully drain the logged water off right after the fourth day. If $N > 1$, the water depth of the rice field is higher than the flood-enduring depth after four days drainage. Fig. 2 is obtained through the calculation of classification indicator N. The authors give N the meaning of risk because it represents the dangerous degree of a polder. For risk 1, N is greater than 3, and $3 \geqslant N > 2$ for risk 2, $2 \geqslant N > 1$ for risk 3, $N = 1$ for risk 4, $N < 1$ for risk 5.

The polders of risk 4 and 5 may also be waterlogged because of the low efficiency of the drainage machines. Some machines in some polders only have 30% of efficiency according to the investigation information. The given classes only show the risk degrees of each polder. Whether a polder is safe or not depends on the efficiency of pumping machines and other factors.

5 RESULTS AND DISSCUSSIONS

(1) The research region is affected by flash flood from the upstream mountain. The maximum water levels and discharges are the main risk factors to threaten the life of local people and their properties. Thus, the flood-prevention standard should be enhanced to guarantee important cities or towns away from flooding. The dikes along the shoreline of Lake Taihu and the riversides of River Tiaoxi should be reinforced and raised in the future to resist the 50-year reoccurrence floods. Other projects, such as reservoir construction and river channel shortening, smoothening, and dredging and widening etc., should be considered and planned in the future.

(2) Polders can protect the farmlands not to be flooded. But if a polder doesn't have enough drainage power, the land will be waterlogged as a result of a large amount of water produced during the heavy precipitation period. In some circumstances, no big flood peak comes from upstream, but some polders are submerged because the small rivers inside the polders are blocked up by dikes. This is the negative effect of the construction of polders. This phenomenon can be called man-made waterlogged hazard. Therefore, the polder re-construction should be carefully planned in the future. The pumping power should be designed based on the runoff yield method this paper provided.

(3) The construction of polders decreases the water surface area outside the polders, that means, it decreases the flood storage volume. During the last several decades, the water stages increase year by year. For example, the 1-day 100-mm precipitation at the Lushan station caused 0.35m increase in water level in

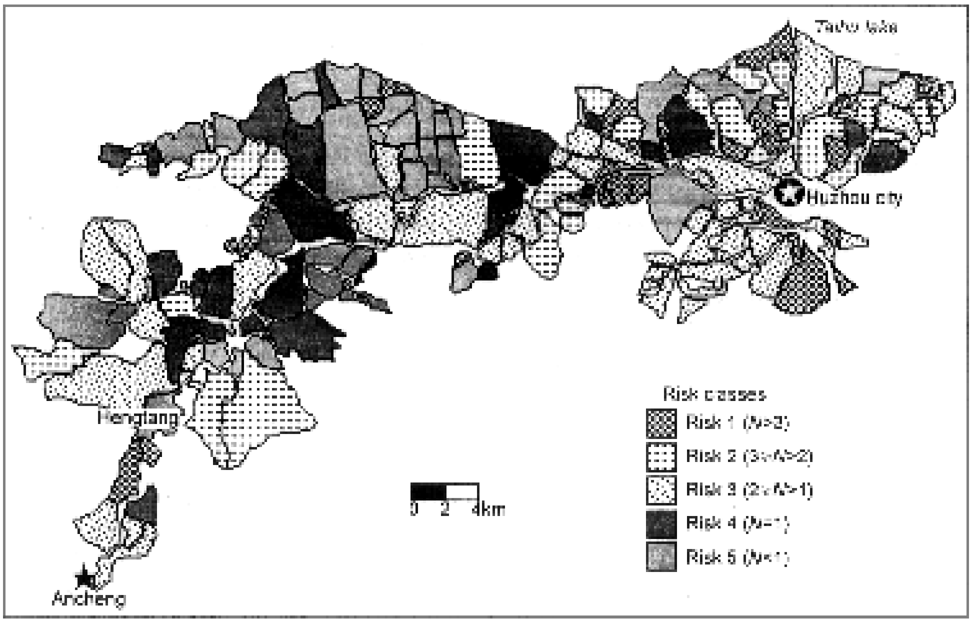

Fig. 2 Risk classification for the polders on the downstream West Tiaoxi River watershed for 100-year precipitation in three days

1957, but 0.58m in 1963, 0.62m in 1973, 0.7m in 1983, and 0.82m in 1991. In the future, if planned projects of polder re-construction are proposed and finished, the water levels will hence become higher and higher under the condition of unchangeable river channels. Some polders that now are safe will be at risk. The flood risk in the plain area will change and need to be assessed again.

(4) Besides the structural projects, many non-structural measures should be taken into account before, during and after flood events to maximally minimize the intangible and non-intangible impacts of the disasters. The headquarters of flood prevention of the local municipal or county governments have the responsibility for reporting or disseminating the flood information. Floods monitoring, forecasting and warning should be used in the disaster reduction activities. According to the real-time water stages, the risk areas can be obtained in a very short time by using the assessment method this paper provided. Real-time risk information can be received by every township governments either directly from the headquarters or the telephone information system of telecommunication, via TV and radio. The affected populations receive the information via TV and radio or from the cable broadcast system connecting the township government.

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