GLOBAL BLUEPRINTS FOR CHANGE

First Edition--Prepared in conjunction with the Pre-World Congress on Disaster Reduction, August 19-22, 2001

The Global Blueprints for Change contain guidance for working together to improve the capability to identify indicators of physical, social, enterprise, and environmental vulnerabilities throughout the world and to select and implement realistic solutions to reduce them towards acceptable levels.

Theme B: Building to Withstand Natural and Environmental Disasters
Topic B.1: Improving Hazard-Characterization Models and Maps

"Development and Prospective Application of Inundation Potential Maps in Taiwan"

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DEVELOPMENT AND PROSPECTIVE APPLICATION OF INUNDATION POTENTIAL MAPS IN TAIWAN[1]

Abstract: Building to withstand natural and environmental disasters is one of the most important issues to be addressed in the Global Blueprints of Change to provide guidance for the improving professional practice of disaster reduction throughout the world. This Blueprint focuses on improving hazard-characterization models and maps, with experiences in Taiwan on flooding, to strengthen such capability. To effectively mitigate flood disasters, the structural measures, such as building levees or constructing flood diversion channels, should be supported with nonstructural measures, such as building emergency response and warning systems, which inundation potential maps can provide valuable information for planning and regulation.

Introduction

Taiwan is located at the intersection of the Euro-Area continent and the Pacific Ocean, heavy storms induced by typhoons or tropical cyclones often brings serious disasters during summer and fall. For example, Typhoons Zeb and Babs resulted in serious overbank flooding along the Keelung River in 1998. While structural measures were still working in progress, Typhoon Xangsane struck the area again and caused serious inundation in 2000. In order to have an integrated approach for natural hazards mitigation, the National Science Council (NSC) in Taiwan approved the operation of the National Science and Technology Program for Hazards Mitigation (NAPHM) in 1998. The objectives of the program are to combine the efforts of various government and private agencies, to promote the upstream and downstream research, to integrate the research results for practical applications, and to develop methodologies for hazard potential analysis, risk assessment, and disaster scenario simulation. Under this framework, inundation potential maps were generated for 23 counties and cities throughout the island within 3 years. On the other hand, the Taipei City Government has been cooperating with the NAPHM to cost-effectively pursue flood mitigation work to effectively reduce the impact of flooding to the city since 1999. Several research results and mitigation technologies were put to use for the city government through such cooperative work, which the generation and application of inundation potential maps for urban Taipei are the most valuable ongoing progress.

To improve the capability of communities to withstand flood disasters, inundation potential maps provide valuable information for precaution, regulation, management, and mitigation measures against such disasters. For example, regulation policy can be ruled to ban land development of areas with high vulnerability to hazards. Emergency warning systems and response measures can be constructed and planned with information characterized in hazard potential maps. Structural measures can be designed with better capacities to sustain disaster demolition by locating areas of having high disaster risks from hazard maps. Flood insurance rate-zone maps can be generated based on regional flood vulnerability from inundation potential maps. Therefore, information characterized in the hazard maps should be carefully reviewed and studied as well as what should be included to meet the cost-effective purpose.

Although the preliminary hazard information can be obtained based on past disaster record, this can only provide a regional disaster tendency. It may overestimate or underestimate the

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real impact when a bigger event never happened before does attack. To make comprehensive hazard maps, physical-based models should be employed and validated with regional characteristics, such as land development conditions. The more rigorous the model is, the more precise the hazard maps can be. Primary variables to be mapped should be carefully conceptualized in the models. Availability of database plays an important role on model performance and usability. Past disaster records are needed for model verifications and validations.

The following presentations are experiences learned from past work of flood mitigations conducted by researchers in Taiwan. Generated inundation potential maps were underwent rigorous reviewing and challenging processes by other researchers and government agents before going to publics. Continuing research on improving both accuracy and efficiency of models has never been stooped, as well as studies for maps usages. Researchers from fields of engineering and sociology were gathered together to build sustainable development of flood mitigation research in Taiwan.

Information to be mapped in inundation potential maps:

Inundation depths and regions are the basic information to be mapped in flood hazard maps. They can be obtained by solving governing equations of physical-based inundation models with inputs from either designed or real rainfall events. The designed rainfall events are included for the consideration of different degrees of storms, especially the worst case. Other information, such as buildings, streets, land developments, and populations, can also be included in the maps depending on the purposes of using hazard maps. For example, land development and populations are needed for performing risk assessment to estimate flood impact on social and economic phases. The determination of emergency shelter locations and evacuation routes may require detailed street layouts and building locations.

Preliminary inundation maps generated in Taiwan focused on mapping buildings and streets together with inundation depths and regions. The inundation potential maps of downtown Taipei with a 100-yr 24-hr rainfall was shown in Figure 1 with streets layouts. Figure 2 presented the maximum inundation depth for the Muchia region, which was circled with dashed lines in the bottom of Figure 1, under a 100-yr 24-hr rainfall with regional storm sewer system. Different degrees of inundation zones were also delimited based on different designed rainfall events from hydrological analyses. Propagation time of peak flood wave at different flooding zones in the maps can be used to initiate the corresponding degrees of emergency warning systems and response measures.

Models employed to generate inundation potential maps in Taiwan

Several physical-based models were developed or combined for generating inundation potential maps with the GIS technology by researchers in Taiwan.

Hydrological models

In order to describe regional rainfall-runoff characteristics, past rainfall and runoff records should be gathered for frequency analysis. The maximum rainfall depths of different return periods and durations were evaluated by using the log-Pearson Type III distribution. Regional rainfall intensity-duration-frequency characteristic was described with the Horner equation.

Each rainfall event considered in current practices was assumed to be homogeneous in space for a 24-hr duration. The total precipitation was unevenly distributed in time by using the

Alternating Block Method (Chow et al, 1988). Although the rainfall distribution was assumed to be spatially uniform, the runoff hydrograph was evaluated by the idea of Semi-distributed Parallel-type Linear Reservoir developed by Hsieh and Wang (1999) to represent the regional runoff characteristics. The computed rainfall and runoff hydrographs were applied as input conditions for dynamic river routing models and 2-D overland flow routing models.

Dynamic river routing models

Dynamic river routing is needed when there is any river flowing through or around the boundary of the domain of interest in conjunction with the possibility of overbank flooding. The flood flow in a channel is described by the one-dimensional unsteady gradually varied flow equation, the St. Venant equation, which can be found elsewhere (Yen, 1973).

Diffusive overland flow models

Extensive studies of developing a series of numerical modeling for two-dimensional inundation simulations has been conducted by Hsu et al. (1990-2000) in Taiwan. It was concluded that a 2-D diffusion wave model could accurately simulate the overland-flow characteristics of floodplains in a watershed due to its slow regional flow dynamics. Based on the assumption that accelerations of water flow on the land surface are small compared to gravity and friction, the inertial terms in the St. Venant equation are neglected. The continuity equation and depth-averaged shallow water equations on land surface can be written as:

$$\frac{\partial d}{\partial t}+\frac{\partial (ud)}{\partial x}+\frac{\partial (vd)}{\partial y}=q \tag{1}$$

$$-\frac{\partial h}{\partial x}=u\left[\frac{n^2\,|u|}{d^{4/3}}+\frac{q}{dg}\right] \tag{2}$$

$$-\frac{\partial h}{\partial y}=v\left[\frac{n^2\,|v|}{d^{4/3}}+\frac{q}{dg}\right] \tag{3}$$

where d = water depth; u, v = velocity component in x- and y-direction respectively; h = water stage; q = excess rainfall intensity; n = Manning's roughness of floodplains. In the above equations, d, u, and v are the dependent variables to be solved. It should be noted that Manning's roughness of floodplain is the only parameter to be verified. Equations 1 to 3 were solved with a two-step Alternating Direction Explicit scheme and finite difference discritization as presented in Hsu et al. (2000) and Chang et al. (2000).

Storm water management model

For urbanized areas, surface overland flow process is altered by anthropogenic factors such as land use and storm drainage systems. The surface runoff rate and volume are increased due to more impervious areas like rooftops, squares, and roads. Overland flow direction is also changed by man-made facilities such as drainage systems, roads, and buildings. Urban surface runoff smaller than the design capacity of the storm drainage system, including storm sewers and pumping stations, is drained into underground sewers. Surface inundation does not occur. The Storm Water Management Model (SWMM) developed by U.S. EPA (Huber and Dickinson, 1988) is adequate to simulate the water flow in drainage sewer systems. When surface runoff exceeds the design capacity of the storm drainage system, water overflows from storm sewers through manholes or outlet pumping stations onto land surface and hence inundation occurs. SWMM can only provide hydrographs at surcharged manhole

In Taiwan, the SWMM was applied for quality and quantity processes of runoff in urbanized area. SWMM contains several blocks for analysis of different process. Two of them are used in this study, the RUNOFF and EXTRAN blocks (Huber et al., 1984, 1988). The RUNOFF block performs hydrologic simulation and its outputs are taken as input to the EXTRAN block, which routes the conduit flow in a storm sewer system using an explicit numerical solution of the Saint-Venant equations. SWMM can give hydrographs for each surcharged manhole, however, it cannot deal with detailed information such as inundation zones and depths caused by surcharged water. The distribution of surcharged water can be treated as described in the previous section by using the 2-D diffusive overland-flow model.

Databases needed to generate inundation potential maps in Taiwan

Database needed to generate inundation potential maps depends on models applied to produce these maps and purposes of using these maps.

Past inundation record

Past inundation record, including inundation depths and areas, provides regional inundation history, which can be used for model verifications and validations when the corresponding rainfall record inducing such flooding is available.

Hydrologic data

Hydrologic data, including rainfall and flood stages history, is needed for performing hydrological analyses and river routings. Flood stages of rivers can be used for verifying and validating dynamic river routing models.

Digital maps

Several digital maps are needed for generating inundation potential maps. Digital surface elevation maps are the most essential database for performing overland flow routings. Other maps, such as locations of buildings, streets, and hydraulic facilities, population distributions, and land development and allocations of urban sewerage system, are needed for different application purposes of inundation potential maps.

Training needed for using inundation potential maps

Training and education are necessary for both developing and using hazard-characterization models and maps. To understand information presented in inundation potential maps, basic knowledge of hydrology and hydraulics is needed. Proper interpolations and explanations by trained researchers may ease the gap to people without such training. This is often important when presenting these maps to policy makers. Further trainings and educations focused on fields of hydrology, hydraulics, and GIS technique are essential to the generation and interpretation of inundation potential maps. Personnel with engineering degrees related to water resources can easily fitted in development work after necessary training. Others from sociology related fields might participate in studies of planning emergency response measures, improving the applicability of inundation maps, and promoting what hazard maps can do for flood mitigations.

Applications of inundation potential maps

In the following, the author proposed several aspects on applying inundation potential maps for pursuing flood mitigation work in Taiwan.

Risk assessment

Risk assessments can be performed with information of inundation potential maps. Based on various designed rainfall events, several inundation zones can be delimited for assessing regional flood risks. Different degrees of flood impacts on both economic and social phases can be estimated by incorporating information of land development and populations of impact areas.

Emergency response measure

Inundation potential maps can be used for the planning of emergency response measures on the determinations of emergency shelters and evacuation routes. Propagation time of peak flood wave at different inundation zones delimited in the maps can be used to estimate emergency response time for different locations. Government agents should be trained to be capable of using basic information contained in maps for regulations and planning.

Land development

Future land development on areas with high vulnerability to floods should be avoided. With inundation potential maps, the determination of land development locations can be more cost-effective. In additions, areas with high flood risks and have been developed can be improved by imposing engineering measures. Before constructions of possible measures, performance assessments should be conducted to generate inundation potential maps for evaluations.

Public policy

Areas with high vulnerability to floods should be banned for future development through policy ruling. Inundation potential maps should be provided for government agents and policy makers for regulating related public policies. Constrained order should be imposed on areas with high disaster risks. Hazard-characterization maps certainly provide valuable quantitative information to assist regulation and ruling of public policy.

Flood insurance

Flood insurance provides financial protection to people and properties suffered flooding destructions. Flood insurance rates can be determined based on different degrees of flood vulnerability obtained from inundation potential maps. Areas easy to be flooded should have a higher flood insurance rate than areas with lower flood vulnerability. With information of rate calculations, flood insurance rate maps can be generated.

Disaster mitigation education

Inundation potential maps can be used to promote educations of flood mitigation to general publics. The idea of nonstructural measures should be publicized in addition to the constructions of structural measures. On the other hand, practices of emergence response actions can be performed with regional inundation potential maps to evaluate successfulness of such measures.

Conclusions: To strengthen capability of communities to withstand natural and environmental disasters, hazard-characterization maps provide nonstructural approaches other than constructions of engineering prevention measures. Physical-based models presented herein are reliable for generating inundation potential maps. With comprehensive databases, object-oriented hazard maps can be developed for users with different purposes, such flood insurance rate maps. However, the applications of these maps may require people with necessary training to avoid misuses. Although the above presentations were focused on inundation potential maps for flood mitigation in Taiwan, similar procedures and guidelines can be followed for other natural or environmental disasters with certain modifications. The key point is to identify the primary variables to be mapped in hazard maps. For example, contaminant sources and forms should be identified for generating pollution-characterization maps. Capability and adaptability of models should be carefully studied and reviewed. Accuracy of database also plays an important role on performance of models. The purpose of object-oriented maps may determine how much subsequent information should be included for developments.

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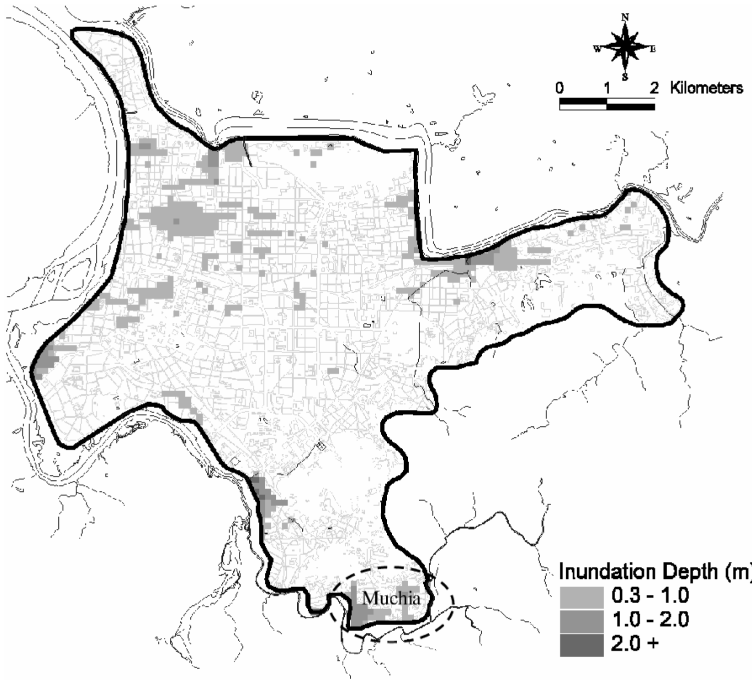

Figure 1. Inundation Potential Maps of Downtown Taipei with a 100-yr 24-hr Rainfall

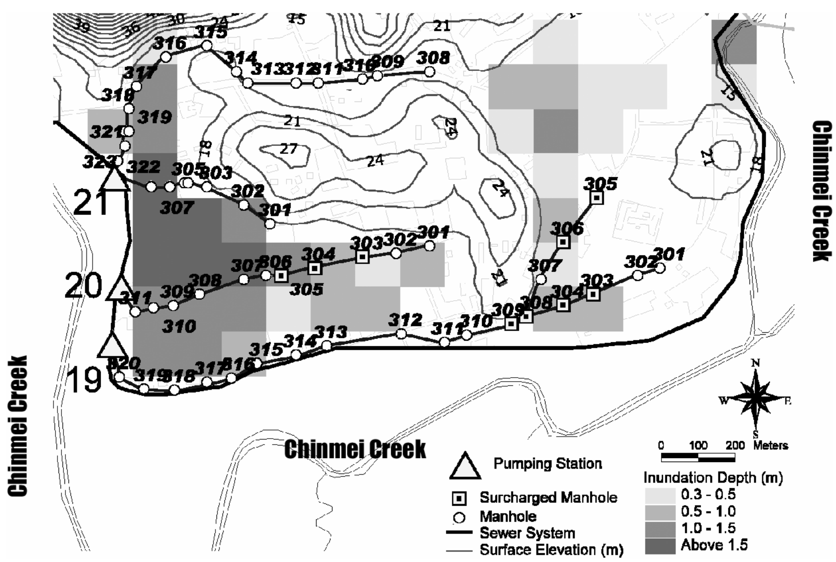

Figure 2. Maximum Inundation Depth for the Muchia Region with a 100-yr 24-hr Rainfall