SIMULATION OF RIVER HYDRAULIC MODEL FOR FLOOD FORECASTING THROUGH DIMENSIONAL APPROACH

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Abstract

Flooding is considered to be one of the worst natural catastrophes effecting million of people throughout the world. Flooding is referred to as potentially destructive abundance of water in a normally dry location. Flooding occurs when water inundate the areas adjacent to the river channel called as the floodplain, causing potential damage to the inhabitants of that area. Thus, a proper flood forecasting system including the development of flood zoning maps, the right of river bed and extent of inundation of floodplain are required for these areas. A composite river hydraulic model provide basis for the development of forecasting system providing timely management of future flood events. Several computer programs are used for the simulation of these models based on either one- or two-dimensional modelling approach. As there are variety of performance capabilities and access to the data required for the development of these hydraulic models, thus it is essential to choose the best software related to those models. A review of various well-known models developed on different software for flood forecasting has been presented in this paper that address the performance of software and the analysis techniques adopted to produce final results.

Keywords: Flooding, Flood Forecasting, Floodplain Zoning, Hydraulic Model, Dimensional Approach, HEC RAS, MIKE

I. Introduction

Flooding is a natural phenomenon causing tremendous loss to the human lives and infrastructure over millions of years. Floods are produced rapidly, resulting from heavy rainfall along with accumulation and release of runoff water from upstream to downstream. Changing climatic conditions and human interference like urbanization in the river watershed systems have also increased the flood risks and its catastrophes [1].
In 2010, nearly all of Pakistan was affected when enormous flooding caused by record breaking rains hit Khyber Pakhtunkhwa (KPK) and Punjab. Around 1985 people died and over 20 million people were affected by this flood. Overall damage caused by this flood was estimated at PKR 855 billion which is about 5.8 percent of 2009/10 GDP [II].

Flooding is thought to be an exceedingly manageable peril in the light of the fact that prior to flooding the flood risk can be identified leading to proper preparedness if there should be an occurrence of any crises alongside with the development of mitigation strategies [III]. Floods occur, following a regular seasonal rhythm, permitting predication of their area and cautioning of their event [IV]. Much can be identified about flooding and its outcomes ahead of its occurrence with the likelihood to figure out who will be affected and what issues they will confront. In view of this, the opportunity exists to work out early (i.e. to arrange for) how a flood can best be overseen in the interests of maximising public safety and minimising property and other damage. This allows the fruitful venture of money and effort in the management of flooding [IV].

To decrease the negative impacts of flooding, numerous measures have been contrived to help communities change in accordance with and live with the flood hazard. One of these measures incorporates development of early flood warning systems to help in the development of response and recuperation capacities, and empowering community in understanding of both the flood risk and the methods by which individual can oversee it [V].

A flood warning system contains particular timely information, based on a reliable forecast that a high stage is likely to occur at a specific location and time. It aims to ensure that emergency actions, such as fortifying spur dikes or evacuation of the vulnerable area can be undertaken. The movement of flood waters through the lands can be approximated through several different methods such as describing natural physical phenomena using numerical techniques which require making wide assumptions to create governing equations. While simple hydraulic modelling methods may be adequate for approximating propagation of flood peaks through river channels, more complex hydraulic analyses may be necessary to consolidate the impacts of infrastructure or complex overland flow [VI]

The hydraulic and hydrological models are mostly applied for simulating flood runoff in the low-lying flood-prone areas, to determine the probability of the occurrence of the flood event, its magnitude, location and depth of the inundation in order to provide flood risk assessment information for flood management [VII].

II. Floodplain Zoning

By proper management of the Floodplain, the damages due to flooding can be greatly reduced. Two types of management techniques, structural and non-structural can be adopted. Elimination of the destructive effect prior to the occurrence of the flood without construction of any physical structure comes under the definition of non-structural flood management approach while the structural flood management application involves construction of various hydraulic structures like dams, trenches, weirs for the diversion and mitigation of flood water. Proper Zoning of the floodplain
and delineation of the river cross section boundaries is the key to the non-structural measures for planning and development of the areas around the river in order to reduce flood damage [VIII].

Several computers based hydraulic models are developed for the production of floodplain zoning maps. Without the use of computer, models based on mathematical calculations and engineering judgments are more conservative and expensive. However, development of several computer models, will certainly lead to the most optimal model selection. Floodplain zoning simulation models have several advantages and disadvantages, so the selected model should meet all criteria defined, compared and evaluated through its efficiency, accuracy, speed and many more. [IX]

III. Hydraulic Models

One Dimensional Hydraulic Model

In one-dimensional hydraulic modelling, the core assumption is that all water flows in the longitudinal direction. One-dimensional models represent the terrain as a succession of cross-sections and simulate flow to approximate the average velocity and water depth at every cross-section. In numerous applications, waterways, streams or channels are modelled as one dimensional completely hydrodynamic system. Among the several 1-Dimensional hydrodynamic models available today extensively use models that are developed on HEC-RAS and Mike 11 [X].

HEC RAS

HEC-RAS software developed by the U.S. Army Crop of Engineers is used for the simulation of various phenomena of the river and the associated crossover structures. One Dimensional Hydraulic can be developed using HECRAS [XI]. The hydraulic data (River morphology and bed Roughness coefficients), topographic data (longitudinal profiles, river cross section and flood plain) and hydrological data (flood inflow hydrograph and discharge stage curve) required for floodplain zoningsimulation can be modelled using HEC-RAS [XII]. Floodplain zone simulation is done through HEC-GeoRAS tool which act as a bridge between GIS and hydraulic model developed in HEC-RAS software. Standard numerical methods (energy equation) are incorporated to calculate the surface flood level between the two sections needed for simulation [XIII].

Hydraulic models developed using HEC-RAS has following limitation:
1. The flow is one-dimensional because of the assumption that energy head is same for all points along the rivercross sections.
2. The slope of the river is lower than the actual river bed slope because the pressurehead gradients in the energy equation represent the depth of the water (Maximum 1:10) [XIV].

MIKE11

MIKE 11 developed by Danish Hydraulic Institute (DHI) that is used for one dimensional river flow simulation, water canals, irrigation systems, water canals and other hydrological fields. The flow simulation is performed by solving St. Venant
equations and modulus of continuity equations in all networking points at a specified time. MIKE 11 was used for the development of hydrodynamic models for flood management through calculation of water surface profiles which produced acceptable results, but the methodology was very complicated for the users [XV].

MIKE 11 can generate hydraulic models several roughness coefficients. The detailed floodplain image, watershed and coastal processes could be clearly determined by integrating the proposed river and the floodplain modelling. MIKE 11 can also suggest the groundwater codes links, and its application in complex structure operation and other proposed forecasting projects [XV].

Comparison of Hydraulic Models Developed By HEC-RAS & MIKE 11

Water surface profiles developed for the same flood event in HEC-RAS model are slightly higher than the MIKE 11 models because the highest sensitivity of water surface profiles in HEC-RAS mainly depends on the roughness coefficient without in cooperating any other factors such as opening and narrowing of the energy gradient coefficient. This difference results in a non-steady flow, showing that MIKE11 model is more consistent than the HEC-RAS model. Moreover, HEC-RAS software can be easily accessed and is free to use and has the ability to run in a windows environment. It has graphical chart displaying the input and output. The HEC RAS models are easy to use and have simple features whereas MIKE 11 is complicated and is not freely available. The models generated through MIKE11 are expensive and are much difficult to be developed [XIV].

Two-Dimensional Hydraulic Modelling

In two-dimensional models, water is permitted to move both in the longitudinal and lateral directions, while velocity is supposed to be insignificant in the vertical direction. Unlike one-dimensional models, two-dimensional models signify the terrain as a continuous surface through a finite element mesh. All input and output hydrological and hydraulic parameters are said to be uniform throughout the cell. The benefit of such models over the equivalent one-dimensional models is their capacity to illustrate direction as well as magnitude in both river channel and flood plains. Some of 2D models which are frequently applied to rivers and floodplain are MIKE21, Info Works 2D [IX].

MIKE 21

MIKE 21 developed by DHI produces hydrodynamic two-dimensional hydraulic models. It consists of analyzing size mesh design with hydrodynamic and morphological technology. At proposed location, identification of bank lines to the hydrodynamic behaviour and bed topography of the river can be done from the dynamic response through operating the model components at the same time. Through MIKE 21 models flow and sediment transport pattern in river channel and on the flood, plain can also be identified [XVI].
InfoWorks 2D

InfoWorks RS developed by Wallingford Software is a combination of GIS function, advance ISIS Flow simulation and database storage which is used for a unique hydrology and hydraulic 2D modelling. InfoWorks 2D can perform detailed surface flooding analysis for overland flows, floodplains and hydraulic structures, and it is more stable than HEC-RAS on unsteady solution and data management. The model can simulate the rainfall-runoff and fully dynamic flood mapping [XVII]. Online help system can provide fast, free and fully documented error checking and warning of the InfoWorks RS software. This software is used for complex modelling and forecasting flood situations in Europe and the US [XVIII].

Coupling One/Two Dimensional Hydraulic Models

In one-dimensional hydraulic models there is limitation of resolving complex floodplain flow fields as they require post-processing for the production of realistic flood extents. Whereas two-dimensional hydraulic models are unable to produce structural elements that may create super-critical or pressurized flow conditions [XIX]. It has been observed by [XIX] & [XX] that in order to avoid these limitations recent urban flood models are focused on dynamically coupling one- and two-dimensional models. More accuracy and computational efficiency in hydraulic model can be achieved through complementation of one-dimensional hydraulic model of river channel by two-dimensional model of flood plain [XX]. Numerous hydraulic models have effectively been coupled or are available in commercial packages: [XXI] coupled ISIS and DIVAST, Delft-FLS, LISFLOOD-FP, SOBEK 1D2D and MIKE FLOOD.

IV. Sources of Error

Flood inundation maps are the most useful outputs derived from the flood simulations but considerable errors introduced throughout the development process making these outputs unreliable for the generation of floodplain zoning maps [XXI]. It was identified by [XXII] that these errors in the results are typically left unsolved when flood inundation maps are released. Since these errors have cumulative effect as they are introduced in each phase from data collection to model development including post-processing and theoretical assumptions, rendering the final result inaccurate and ultimately misleading [XXII].

In predicting inundation extent one of the most important factors are model roughness parameters and geometry. In most of the modelling practice, parameterization of the roughness coefficients is done to calibrate it with the observed measurements. This results in minimizing error between the observation and prediction. The basic assumption in this approach is that only set of parameters are considered to minimize this error however, the non-linearity of flood models possibly indicates the existence of several optimum parameter sets which are yet to be identified [XXIII]. To determine these optimum parameter sets [XXIII] & [XXIV] suggested performing Monte-Carlo simulations while utilizing the generalized likelihood uncertainty estimation (GLUE) procedure.
The other data source required for the development of flood inundation models is topography. It was found by [XXV] that Light Detection and Ranging (LiDAR) derived topographic data is currently the highest resolution data available having a horizontal resolution of 1 m and vertical accuracy of ±15 cm. These datasets have a considerable improvement over the dataset provided by USGS National Elevation Dataset (DEMs), which have a horizontal resolution of approximately 10 m and vertical accuracy of ±7 m [XXVI]. To determine the effect of DEM grid size on flood inundation mapping [XXVII] performed 1D hydraulic simulation of 50- and 200-year return period on a study reach.

The methodology involved creating DEMs with resolutions of 2.5, 5, 10, and 25 meters, and then comparing inundated area obtained through simulation at each depth for the test reach. It was found that when DEM resolution increased from 2.5 m to 5 m during the 50-year event, the inundation area increased to 10% and for 200-year event it increased to 26% when DEM resolution increased from 5 m to 25. It was also concluded that the results of similar investigations would vary by river reach. For example, in a channelized reach would less grid sensitivity will be demonstrated than one with a wide floodplain [XXVII].

Another assumption made for the flood inundation mapping is that these maps are typically created with a steady gradually varied flow. This assumption results in over prediction of the inundation area at higher discharges as greater time is required to reach a steady condition [XXII]. This time usually exceeds the duration and total volume of the peak discharge presented in flood hydrograph [XXII] and would result in more inundation than a flash flood hydrograph. [XXII] Devised an alternative to the steady flow assumption by incorporating the effect of hysteresis in the delineation of flood extent in order to utilize real-time forecasting to estimate inundation. However, the significant challenge in developing this framework is constructing hydraulic models having a capability of running faster than a 1:1 ratio of simulation time to real time.

The disclosure of these uncertainties along with inundation boundaries in mapping products would more clearly communicate flood risk. [XXVIII] Developed a technique for the development, evaluation and presentation of these floodplain uncertainty maps. Hydrologic, hydraulic, and flood plain delineation model were run to create these maps. These models were run repetitively using stochastic probability distribution function values as input parameters, producing a series of flood boundaries. These boundaries were then used to create a continuous inundation map showing uncertainties from 0 to 100 percent for a 100-year event [XXVIII].

V. Conclusion

The most essential tool to prevent the risks of the flooding and the optimization of the damages incurred to the surrounding lands by these events is to determine their boundaries and also the riverbeds. The hydraulic modelling done for the development of river zoning maps are certainly one of the most basic, and important information required in carrying out feasibility of civil projects, and proper consideration is needed before investing or operating any development project. It is
vital to provide these maps prior to beginning of any project as it gives valuable information such as the depth and area of flood prevention in flood zones.

An important component for the development of these maps is the software used for hydraulic analysis. There are a number of software packages available, both for commercial or non-commercial use. Selecting an appropriate modelling package depends on the degree of detail desired and software limitations.

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