Available online www.ejaet.com

European Journal of Advances in Engineering and Technology, 2015, 2(7): 23-28

Research Article ISSN: 2394 - 658X

Modelling of Floodplain Using Recent Technology

Prafulla Kumar Panda

Department of Civil Engineering, Centurion University of Technology and Management, Odisha, India
prafullapanda@cutm.ac.in

ABSTRACT

Floodplains are land areas adjacent to rivers and streams that are subject to recurring inundation. Owing to their continually changing nature, floodplains and other flood-prone areas need to be examined in the light of how they might affect or be affected by development A Floodplain is the normally dry land area adjoining river or stream that is inundated during flood events. The most common reason for flooding could be overtopping of river or stream due to heavy downfall. The floodplain carries flow in excess of the river or stream capacity. Flood frequency and flood water-surface elevations are the crucial components for the evaluation of flood hazard. This Review paper presents the recent methodology that incorporates advanced technologies for hydrologic and hydraulic analyses that are needed to be carried out to predict the flood water-surface elevations for any ungagged watershed.

Key words: Floodplain, Flood Hazard, Hydraulic analysis, Sediment transport, GIS, HEC RAS

INTRODUCTION

Flooding is a natural and recurring event for a river or stream. Statistically, streams will equal or exceed the mean annual flood once every 2.33 years [Leopold et al., 1964]. Flooding is a result of heavy or continuous rainfall exceeding the absorptive capacity of soil and the flow capacity of rivers, streams, and coastal areas. This causes a watercourse to overflow its banks onto adjacent lands. Floodplains are, in general, those lands most subject to recurring floods, situated adjacent to rivers and streams. Floodplains are therefore 'flood-prone' and are hazardous to development activities if the vulnerability of those activities exceeds an acceptable level.

Flooding is considered as the world's most costly type of natural disaster in terms of both human causalities and property damage [Singh and Sharma, 2009]. The extreme flood events could cause severe damage to property, agricultural productivity, industrial production, communication networks and infrastructure, especially in the downstream parts of catchments. The annual disaster record reveals that flood occurrence has increased about 10 folds during the last 45 years, from 20 events in the year 1960, to 190 events in the year 2005 [Scheuren et al., 2007]. As a result, extreme floods are posing a great concern and challenge to design engineers, reinsurance industries, policy makers and to the government.

Floodplains can be looked at from several different perspectives: 'To define a floodplain depends somewhat on the goals in mind. As a topographic category it is quite flat and lies adjacent to a stream; geomorphologically, it is a landform composed primarily of unconsolidated depositional material derived from sediments being transported by the related stream; hydrologically, it is best defined as a landform subject to periodic flooding by a parent stream. A combination of these [characteristics] perhaps comprises the essential criteria for defining the floodplain' [Schmudde, 1968]. Most simply, a flood-plain is defined as 'a strip of relatively smooth land bordering a stream and overflowed [sic] at a time of high water' [Leopold et al, 1964].

With increase in constructions along river courses and concentration of population around floodplain areas, the flood-induced damages are continuously increasing. Activities like land clearing for urbanisation or agriculture, development of infrastructures such as highway and bridges in the floodplain are further aggravating the flood magnitude. Owing to their continually changing nature, floodplains and flood-prone areas need to be carefully analysed in the light of how they might affect or be affected by development. The complete flood protection by provision of great flood control structures like flood dams are practically impossible due to its high cost. Also, the behaviour of flood due to flood mitigation project such as river widening and straightening should be thoroughly analysed, as this kind of mitigation works may transfer the flood problem from upstream to downstream part of the river. The literature review manifest that the best way to analyse the flood behaviour is generating the flood-prone or flood hazard map. Flood-prone area maps show areas likely to be flooded by virtue of their proximity to a river, stream, or other watercourse, from readily available information. Flood hazard maps show the extent of inundation, determined from a study of flooding at the given location. The extent and severity of flood damage are usually defined by water depth. Such an analysis can be effectively and efficiently carried out with numerical modelling tools on a GIS platform. This also provides a framework for decision-support system and facilitates evaluation of alternatives for flood management.

Current Status

India is one of the worst flood-affected countries, being second in the world after Bangladesh and accounts for one fifth of global death count due to floods. About 40 million hectares is flood-prone, which is about 12% of the total geographical area (328 million ha) of the country [Singh and Sharma, 2009]. The 1986 flood on the Godavari River, with a peak discharge of about 99,300 m 3 /s [Nageswara Rao, 2001], is the largest flood on record in the entire Indian subcontinent till date [Kale, 2007]. The total area affected by floods has also increased during these years. The flooding occurs typically during the monsoon season (July - September), caused by the formation of heavy tropical storms, ever decreasing channel capacity due to encroachments on river beds, and sometime due to tidal backwater effects from the sea. Thus, it is of prime importance to minimise the property damage, reduce infrastructure disturbances, and identify zones and building structures having greater flood hazard and flood risk.

Studies are continually going on for mapping the flood-prone areas in India. Several agencies, such as the Central Water Commission - CWC (Flood Atlas of India), the Building Materials and Technology Promotion Council - BMTPC (Vulnerability Atlas of India), and the National Atlas and Thematic Mapping Organization – NATMO (Natural Hazard Map of India), have been involved in the flood-hazard mapping. Outcomes form various studies indicate that the areas that are frequently vulnerable to flooding in the country are:

- Sub-Himalayan region and the Gangetic plains
- Brahmaputra Valley
- Punjab plains
- Mahanadi-Godavari-Krishna-Cauvery Delta plains
- Lower Narmada-Tapti-Mahi Valleys

FLOODPLAIN MODELLING

Hydrologic and Hydraulic Analysis

Hydrologic and hydraulic analyses of floods are required for the planning, design, and management of many types of facilities, including hydro-systems within a floodplain or watershed. These analyses are needed for determining potential flood elevations and depths, area of inundation, sizing of channels, levee heights, right of way limits, design of highway crossings and culverts, and many others. The typical requirements include [Hoggan, 1997]:

- Floodplain information studies: Development of information on specific flood events such as 10, 100, and 500-year frequency events.
- Evaluation of future land-use alternatives: Analysis of a range of flood events (with different frequencies) for existing and future land uses to determine flood-hazard potential, flood damage, and environmental impact.
- Evaluation of flood-loss reduction measures: Analysis of a range of flood events (with different frequencies) to determine flood damage reduction associated with specific design flows.
- Design studies: Analysis of specific flood events for sizing facilities to assure their safety against failure.
- Operation studies: Evaluation of a system to determine if the demands placed upon it by specific flood events can be met.

The methods used in hydrologic and hydraulic analysis are determined by the purpose and scope of the project and the data availability.

Hydrological modelling plays a vital role in effective water management. This technique is used to simulate rainfall-runoff, enabling to assess flood risk, improve decision-making about protection measures and mitigate the damage caused by flooding. Hydrologic analysis for floodplains entails either a rainfall-runoff analysis or a flood-flow frequency analysis. If information from an adequate number of historical annual instantaneous peak discharges is available, the flood-flow frequency analysis can be performed to determine peak discharge for various return periods. Otherwise a rainfall-runoff analysis must be performed using a historical storm or design storm for a particular return period to develop a storm runoff hydrograph. Thus, hydrologic analysis will finally result in a selection of hydrographs, which can be further processed in the hydraulic analysis. In general, the approach of gathering information for hydrologic analysis involves:

- On-site inspections
- Study of maps and technical documents
- Analysis of hydrologic records
- Documentation of historic events
- Modelling and plausibility checks

Hydraulic analysis deals with the dynamics of flow in a river or channel and in overbank areas. Hydraulic analysers predict water-surface elevations and flow velocities in time and space using the boundary conditions such as the results of hydrologic models and recorded flood data [CRC, 2006]. For a detailed and rigorous comprehensive analysis, an unsteady-flow analysis based upon a hydraulic-routing model and storm runoff hydrograph can be used to define more accurately maximum water-surface elevation. The unsteady-flow analysis could provide more detailed information such as the routed-discharge hydrographs at various locations throughout a river reach.

Tools for Modelling

Planning, execution, monitoring and assessment of flood mitigation projects based on the holistic and integrated approach of Integrated Flood Management (IFM) require knowledge of the entire river basin to ensure a more effective output and outcome. Advances in geospatial technologies (Global Positioning System (GPS), Remote Sensing (RS) and Geographic Information System (GIS) have enabled the acquisition of data and analysis of the river basin for urban flood hazard mapping in a faster and more accurate manner. GIS facilitates integration of spatial and non-spatial geographical data such as rainfall and stream flows, river cross-sections and profiles and river basin characteristics. Other information such as flood maps, infrastructures, land-use and socio-economic information can be inventoried for future use. Flood maps prepared using satellite images of real flood events and information from the ground are useful for flood damage assessment, future flood mitigation planning and validation of hydrologic and hydraulic analysis.

Hydrologic analysis of floods can be carried out using HEC-HMS (developed by U.S Army Corps of Engineers) to derive the storm-runoff hydrograph for a particular return period. HEC-HMS is designed to simulate the rainfall-runoff processes of dendritic watershed systems and it is the successor to HEC-1. Hydrologic elements are arranged in a dendritic network, and computations are performed in an upstream-to-downstream sequence. The physical representation of a watershed is accomplished with a basin model. Basin model in HEC-HMS is set up for each sub-basin using two hydrologic elements: sub-basin and junction. Sub-basin element handles the infiltration loss and base-flow computations, and rainfall-runoff transformation process. Junction element handles the observed flow data and is mainly used for the comparison of the observed flow hydrographs with the simulated flow hydrographs. Meteorologic model in HEC-HMS is the major component that is responsible for the definition of the meteorologic boundary conditions for the sub-basins. It includes precipitation, Evapotranspiration and snowmelt methods to be used in simulations.

The time span of a simulation is controlled by control specifications and it include a starting date and time, ending date and time, and a time interval. A simulation run is created by combining a basin model, meteorologic model, and control specifications. Simulation results include information on peak flow and total volume. Analysis tools are also designed to work with simulation runs to provide additional information or processing. Model calibration need to be carried out to obtain optimal values of parameters of different methods used in sub-basin and junction elements. The calibrated model is then used for runoff generation for different frequency storms. The source of the frequency storms is the Intensity-Duration-Frequency curves which are prepared based on long records of precipitation data. Hydraulic analysis of floods can be carried out using HEC-RAS (developed by U.S Army Corps of Engineers) and it is a replacement for HEC-2 which was an earlier version. Initially, HEC-RAS could only be used for steady, gradually varied flow modelling. The capability of unsteady flow modelling was added in 2001. HEC-RAS model can perform water surface calculations for gradually varied steady flow for a river reach, or a full network of channels. This steady flow component is capable of modelling subcritical, supercritical and mixed flow regime water surface profiles. The steady flow component is based on the solution of the one dimensional energy equations. A peak discharge is applied at each cross section to determine the maximum water surface elevation. The unsteady flow component of HEC-RAS simulates one-dimensional unsteady flow through a full network of open channels and is primarily used for subcritical flow regime calculations but may also be applied for supercritical and rapidly varied flows. The unsteady flow module has some additional capabilities like it can model storage area and hydraulic connections between storage areas. The unsteady flow analysis is performed by applying the full equations of motion called St. Venant Equations at a cross-section with upstream and downstream boundary conditions and various other parameters.

The geometric data required to define in HEC-RAS includes:

- Cross-section data

- Reach lengths (measured between cross sections)
- Stream junction information (Reach lengths across junctions and tributary angles)

For an unsteady flow, hydraulic structures are modelled by taking into consideration the physical parameters of the structure in the appropriate standard structure format in the HEC-RAS data editor. The types of structures that can be modelled in HEC-RAS include bridges, culverts, inline and lateral weirs and gates, spillways and levees. Moreover the unsteady component can model storage areas, hydraulic connections between storage areas, hydraulic Connections between stream reaches, pumping stations, flap-gated culverts. Other features include floodplain encroachment analysis, channel modification analysis, scour analysis at bridges, groundwater interflow and contraction and expansion losses. Post processing capabilities include:

- Longitudinal profiles: It allows the user to view the water surface profiles along the length of the channel for each flow profile.
- Profile Plots: The user can view the profiles of various parameters such as velocity, flow and depth in the longitudinal direction.
- Rating curves: The user may view the computed rating curves at each cross-section.
- Perspective Plot: The user may view a 3D perspective view of the river system and the water surface profiles.
- Flow and stage hydrographs: The user may visualize flow and stage hydrographs at each cross section for unsteady flow simulation.
- Output tables: Detailed and summarized output tables of various parameters may be viewed and exported.

Floodplain Modelling

The evaluation of flood risk is generally based on a two-stage procedure: In the first stage, the statistical probabilities of stage-discharge characteristics of river sections are calculated; thereby the over-bank flow and the river sections at which the flow exceeds the carrying capacity of the river channel are determined.

In addition, measurements of critical channel sections are undertaken to assess the hydraulically determined characteristics of the sections of the river course. In the second stage, the inhabited areas falling in the greater or lesser flood risk zone are evaluated based on the relief map.

Research on flood hazard mapping [Miwa et al., 2003; Singh et al., 2005] reveals that three elements: maximum water level, the velocity of water flow, and the amount of time flood remains in a given land area, are essential to evaluate possible damage. The described requirements are considered to be essential for preparation of urban flood management and risk plans.

Fig. 1 presents the detailed schematic representation of the different steps involved in floodplain modelling. Rainfall-runoff modelling could be performed using HEC-HMS. Then peak flow probabilities need to be evaluated using the flood hydrograph resulted from the simulation of HEC-HMS and flow statistics. This analysis will yield a hydrograph that requires for specifying the boundary condition in hydraulic analysis using HEC-RAS. The water-surface elevation, flow rate, and velocities at various cross-sections of a river reach could be traced through performing HEC-RAS simulations using the digital terrain model (DTM) and inflow hydrographs. The DTM would be generated using the existing topographic and bathymetric data. The topographic data contain the spot heights of the flood plain collected from the field, and the bathymetric data is from the river under study.

HEC-GeoRAS is a set of procedures, tools, and utilities for processing geospatial data in ArcGIS. The GeoRAS helps in preparing the geometric data for importing into HEC-RAS and processing results exported from HEC-RAS for performing more calculations such as flood inundation and hazard mapping. To create the import file, the DTM of the river system in TIN or GRID format is necessary. The TIN model would be generated in ArcView GIS using the spot heights acquired from different sources which included:

- GPS surveyed data collected along the two river banks
- The spot heights of the flood plains taken from the surveyed data
- River bed cross section elevation data

The RAS layers include layers created for stream centreline, cross-section cut-lines, flow-path centrelines, and main channel banks. Additional layers like land use (for Manning's 'n' extraction), ineffective flow areas, bridges and culverts, storage areas, etc., could be developed and imported. Finally running the GeoRAS would be carried out to generate the flood depth maps. Boundary conditions for the upstream as well as the downstream are chosen in terms of water levels corresponding to input discharges of the gauge stations or the results obtained from the hydrologic analysis. Hydraulic analysis is performed and the resulting flood depth would be compared with the field surveyed data. Field data needed to be collected by surveying the floodplain at the selected locations during the flood events and it requires for model verification.

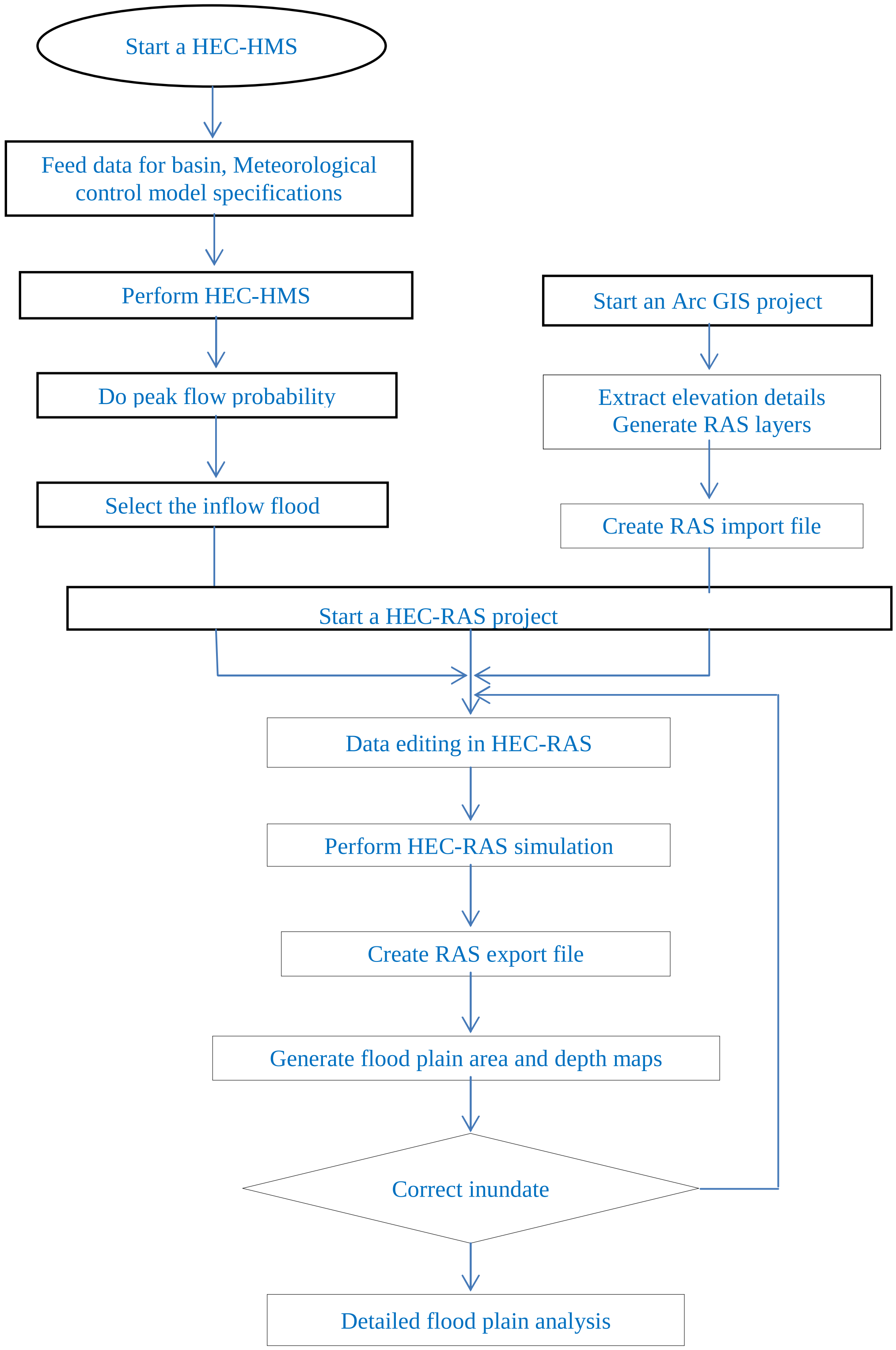

Fig. 1 Methodology flow chart for flood plain modelling

CONCLUSION

Flood hazard mapping is an important component for appropriate land use planning in flood plain areas. It creates easily-read, rapidly-accessible charts and maps which facilitates the administrators and planners to identify areas of risk and prioritize their mitigation or response efforts. This paper outlined a methodology framework that integrates advanced techniques to accurately delineate the flood-hazard areas. Floodplain mapping requires both hydrologic and hydraulic analysis. For ungaged watersheds rainfall-runoff modelling is inevitable and it could be effectively carried out using HEC-HMS. As watershed possesses drastic spatial and temporal variation GIS became an important tool for floodplain modelling. HEC-GeoRAS is an ideal package that could map the floodplain areas and flood water-surface elevation for various design storms with different return periods.

REFERENCES

[1] AK Singh and AK Sharma, GIS and a Remote Sensing based Approach for Urban Floodplain Mapping for the TAPI Catchment, India, *Hydroinformatics in Hydrology, Hydrogeology and Water Resources at the Joint IAHS &IAH Convention*, Hyderabad, India, **2009,** 389-394.

[2] JM Scheuren, O de Waroux, R Below, D Guha-Saphir and S Ponserre, *Annual Disaster Statistical Review*, CRED Brussels, Belgium, **2008**.

[3] VS Kale, Flood Studies in India: A Brief Review, *Journal of Geological Society of India*, **1997**, 49, 359-370.

[4] VS Kale, Geomorphic Effectiveness of Extraordinary Floods on Three Large Rivers of the Indian Peninsula, *Geomorphology*, **2007**, 85, 306-316.

[5] G Nageswara Rao, Occurrence of Heavy Rainfall around the Confluence Line in Monsoon Disturbances and its Importance in Causing Floods, *Proceedings of Indian Academy of Sciences Earth and Planetary Science*, **2001**, 87-94.

[6] DH Hoggan, Computer-Assisted Floodplain Hydrology and Hydraulics, 2nd Edition, McGraw-Hill, New York, **1997**.

[7] Cooperative Research Centre for Catchment Hydrology, Series on Model Choice: General Approaches to Modelling and Practical Issues of Model Choice, *http://www.toolkit.net.au/pdfs/MC-1.pdf*, **2006**.

[8] Tamás Krámer, János Józsa An Overview of River Floodplain Modelling, *Name of Journal (in italic)*, **2004**.

[9] S Kopp, *Developing a Hydrology Extension for ArcView Spatial Analyst*. Arc User, Esri, **1998**, 18-20.

[10] RA Kraus, Flood Plain Determination using ArcView and HEC-RAS, *Proceedings of the User Conference*, San Diego, Esri, **1999**.

[11] SC Sollers, A Rango and DL Henninger, Selecting Reconnaissance for Flood Plain Surveys, *Water Resources Bulletin*, **1978,** 14, 359-373.

[12] TA Cameron, TA Avans and GW Brunner, HEC-GeoRAS: Linking GIS to Hydraulic Analysis using ARC/INFO and HEC-RAS, Proceedings of the User Conference, San Diego, Esri, **1999**.

[13] PD Bates and APJ De Roo, A Simple Raster Based Model for Flood Inundation Simulation, *Journal of Hydrology*, **2000**, 236, 54–77.

[14] IC Overton, Modelling Floodplain Inundation on a Regulated River: Integrating GIS, *Remote Sensing and Hydrological Models, River Research and Applications*, **2005**, 21(9), 991-1001.