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URBAN FLOOD RISK ASSESSMENT USING GIS BASED HYDRAULIC MODELLING

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ABSTRACT

Amongst the various techniques available for assessing flood risk, the ones using Geographical Information System (GIS) are most promising. GIS is used to construct and update hydraulic models which are capable of predicting one dimensional and two dimensional flooding. The paper evaluates a flood risk tool which uses two methods of risk assessment - backing up from connecting sewers and surface overland flow. Overland flows can be assessed in two ways - using a rolling ball technique and using two dimensional surface flow data from hydraulic simulation software. The paper concludes that 'Flood Risk Tool' which uses both the above methods is useful in understanding flood risk.

INTRODUCTION

The year 2007 marks a turning point in history: half of the world population now lives in cities (UN-Habitat, 2007). Urbanisation growth rates imply that, every week, a city of 1 million inhabitants will be required for the next four decades. (Zevenbergen et al, 2008)

Urbanisation demands additional land requirement for residential and commercial developments. This, in turn, invariably leads to a land use change resulting into an increase in impermeable area with a subsequent increase in the volume of surface water runoff. This increases the susceptibility towards flooding as a result of concentration of people and assets in flood prone areas. Many urbanised areas are located near major water bodies. Furthermore climate change has resulted into more frequent intense storms and resultant flash floods. To give some recent examples - In 2007, flooding destroyed 250,000 homes in Bangladesh, leaving communities cut off from supplies for quite a long time. Over 55,000 properties and 7,000 businesses were flooded in the UK. Frequent disruptions in public life due to floods in Mumbai are well known and in 2005 Mumbai faced one of the most devastating floods. The resultant in the loss of life and assets is enormous in such events.

Sources of flooding in urban environment

Urban flooding is a complex phenomenon. Sources of flooding can be listed as below –

- Pluvial flooding: high-intensity or prolonged heavy rainfall leading to overland flow and ponding
- Flooding due to exceedence or blockage of sewerage and drainage systems, or flooding caused by high water levels in receiving watercourses;
- Flooding from small, ordinary or 'lost' watercourses and culverts;
- Groundwater flooding from prolonged natural recharge;

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- Groundwater flooding from flow through alluvial aquifers adjacent to rivers;
- Groundwater rebound when pumping fails or is reduced;
- Failures of infrastructure such as canal embankments or reservoir embankments;
- Flooding from tsunami.

Flooding from these sources can occur individually or mostly in combination with each other. These require using complex integrated modelling approach, however, that proves difficult due to obtaining enough data to give true representation of hydraulics of the system. Also good evidence base of geo-located historical flooding and information on rainfall events is crucial. (Hankin et al, 2008)

USE OF HYDRAULIC MODELS

Traditionally hydraulic models have been used for predicting flooding in urban environment. A model is constructed using dynamic modeling software such as InfoWorks for an urban catchment. Performance of network model is verified in the areas of interest with the aid of flow survey and rainfall data both collected simultaneously for a short term. The model is also verified for historical events including confirmed flooding incidences. This is and then used with synthetic or design storm events to assess frequency and volume of surface flooding and surcharge areas.

Though the use of hydraulic models give an understanding of problem areas in urban catchments, a detailed analysis at each property level becomes difficult due to the limited information available in the models at the property level. Severity of affected properties depends on their connection details to the drainage system, performance of drainage system and local topography. Factors like property threshold level, presence of basement drains and proximity of overland flow paths play an important role in deciding whether a property floods or not. Considering these factors, the paper discusses a post-processing tool to assess risk due to flooding and surcharge at individual property level and producing risk maps in GIS.

FLOOD RISK TOOL METHODOLOGY

The tool is based on MWH's existing "Data Manager" software, which allows representation of spatial data associated with sewer network models through a Geographical Information System (GIS) interface. The tool has been developed to assess two mechanisms for flooding – due to surcharge and due to overland flows. This has been depicted pictorially in Figure 1 below

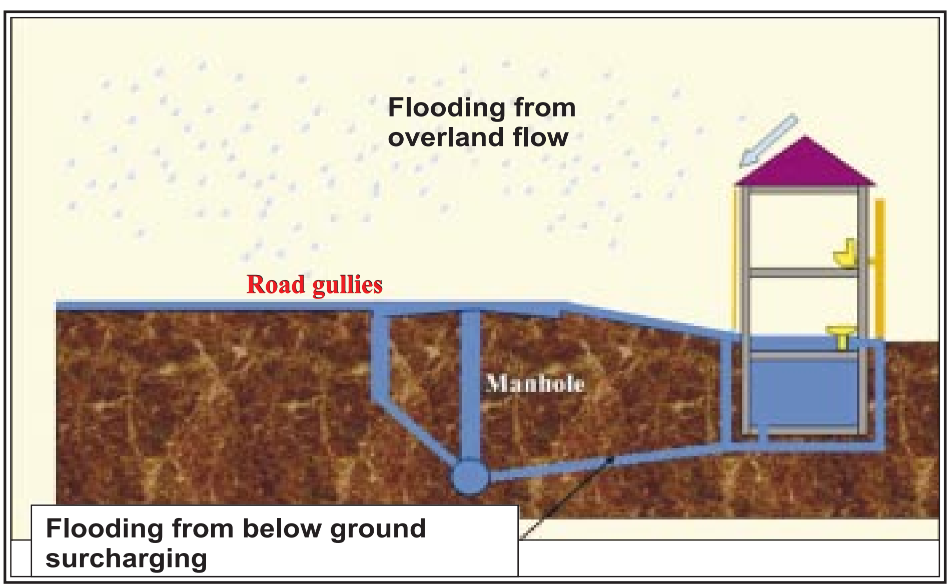

Figure 1 : Flooding Mechanisms assessed

Data Requirements

Network Model

The tool is based on network model, which has been verified to confirm its accurate prediction of frequency and volume of flooding and surcharge.

Topography data

Light Detection and Ranging (LIDAR) is an airborne mapping technique which uses a laser to measure the distance between an aircraft and the ground. This technique results in the production of a terrain map suitable for use in the assessment of flood risk. The accuracy of the data is greater when the area scanned is smaller. The LIDAR data can be produced for one, five and ten metre squares. The accuracy of the elevation is ±150mm for 1 meter square data.

Address Points data

Data on the location of individual properties is normally available in the form of address co-ordinates from water companies billing data. This is imported into the model to spatially locate individual properties. Using an innovative search algorithm, the software then compares the address point data with sewer network data and assigns each property to a modelled node. The software algorithm uses the nearest neighbour technique to locate the nearest node to each property. A downstream search is then undertaken using the connectivity defined in the network, to locate the nearest modelled node.

Rainfall simulations

The design rainfall events are used to simulate flooding conditions for various return periods i.e. 1, 2, 5, 10, 20 and 30 year events or more with durations 30, 60, 120, 360 and 480 if required 1440 minutes. The results from these simulations are imported in the form of a PRN file into the tool.

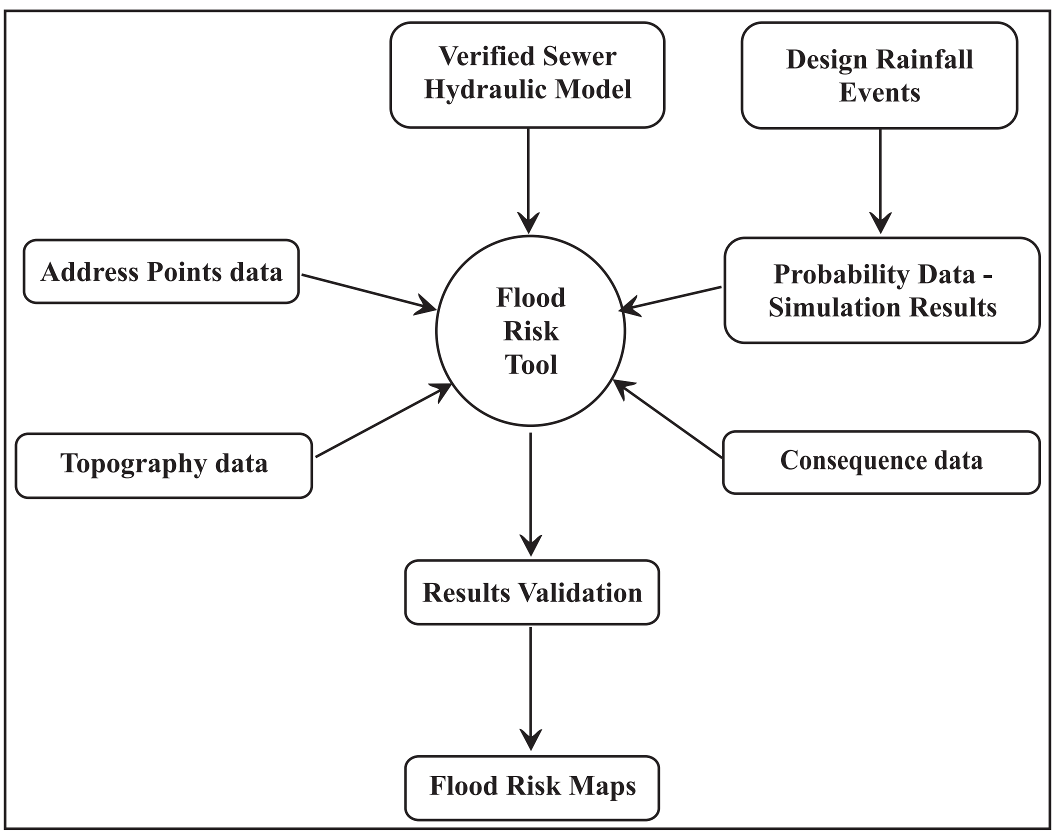

Figure 2 : Data flow in Flood Risk Tool

Impact Calculations

Flooding Impact due to surcharge is calculated as follows -

Is = [Surcharge Level] - [Property Threshold Level]
The parameters have been shown in the Figure 3 below.

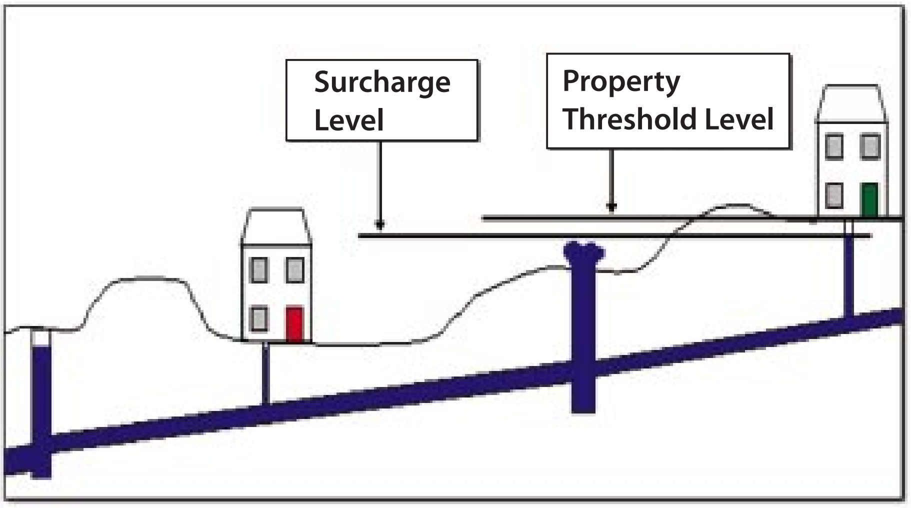

Figure 3 : Flood Impact Due to Surcharge

Flooding impact due to overland flow is calculated as follows –

$$Sum\,of\left[\frac{Path\,Flood\ Volume}{Path\,proximity}\right]\div X$$

X is a weighing factor. This represents possible depth of flooding that might occur due to overland flow.

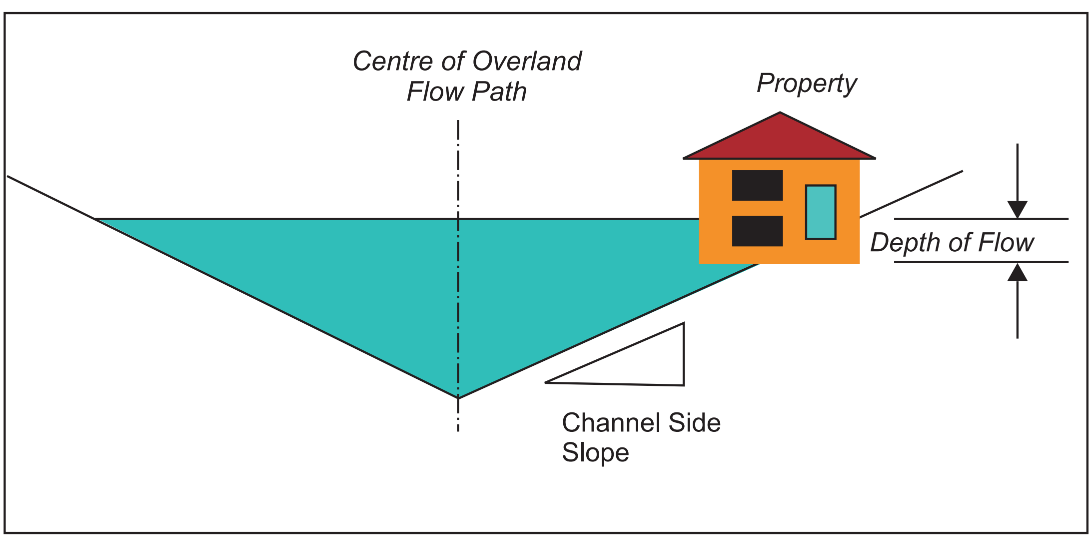

Figure 4 : Overland Flow Impact Assessment

The depth of overland flow was then given by subtracting the elevation of the property from that of the elevation of the nearest point on the overland flow path plus depth of flow as shown in the Figure 4. Typical overland flow paths have been shown in Figure 5 below.

Figure 5 : Typical Overland Flow Paths 1D

The depths of overland flow for all overland flow paths within the vertical tolerance and also within 100m of a property were summed to give the overall depth of overland flow expected at that property. This allowed for the convergence of overland flow paths in low lying areas. No allowances are made for losses in the flooding routing as it is deemed to be insignificant during storm events. The flood risk tool terminates the overland flow paths by looking at surrounding levels when it reaches the lowest point it does check to see whether there are any routes left for the path for a given radius.

2D – Results from InfoWorks 2D can be imported into the flood risk tool. The results are analysed to estimate water level at each property location providing an alternative approach to 1D flow paths in notional V shaped channel. InfoWorks simulates overland flow wave on a mesh of triangular elements. Figure 6 shows an example of a set of InfoWorks 2D mesh cells bounding each property polygon shown with solid fill.

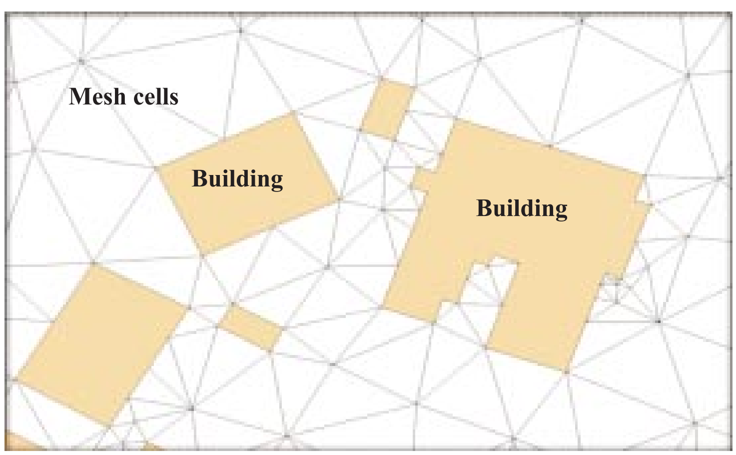

Figure 6 : Overland Flow Impact - 2D

Combined scores for surcharge and overland flow have been categorised into default risks from ‘No Impact’ to ‘Very High Impact’ as shown in Table 1. These can be defined by a user.

Table 1 : Conversion of flood heights to flood risk categories

Relative Flood Level	Impact Surcharge	Impact Overland Flow
>0.2	Very High Internal (VHI)	Very High Internal (VHI) Medium External (ME)
0 to 0.2	High Internal (HI)	High Internal (HI) Low External (LE)
-4m to 0	Medium Internal (MI)	No Internal Impact (NI) Low External (LE)
<-0.4m	No Impact (NI)	No Impact (NI)

TOOL RESULTS AND DISCUSSION

Flood Risk Map

The results can be displayed in tabular format or graphically by generating thematic maps of flood risk as illustrated in Figure 7. Various colours indicate varying risk levels – i.e. red colour indicates Very High Risk, blue colour indicates Medium risk and yellow colour – Low risk. Thematic of 2D elements show varying depths with dark triangles indicating higher depths.

Figure 7 : Typical Results presented in form of a Flood Risk Map

Damage Costs Calculations

The impact of property flooding depends on type of property and depth of flooding and property threshold levels. Various types of residential as well as commercial and industrial properties have different damage costs considering varying flood depths. A standard database for this can be built for Indian conditions and can b used for assessing damage costs. Figure 8 shows typical different flood depth damage costs for types of residential buildings i.e. Type 1 – flats, Type 2 - individual bungalow.

Applicability

The tool has been proven to be quick and straight forward to use. This can be used in the assessment of following –

- New development impacts
- Climate change
- Operational issues – blockage , structural loss
- Flood mitigation measures
- Effect of other changes in the network

Real time predictions against flood risk assessments

An alternative to the use of the risk assessments and development of inundation maps is to estimate risk prone areas in a real time environment during, or immediately before, a flood so that the particular characteristics of the rainfall and flood hydrograph are well represented in the hydraulic modelling. The limitation of this approach is that the models must be run operationally in real time for each event and that results must be distributed quickly to emergency management officials and all other interested parties. Moreover, based on the model accuracy and reach, there will be some uncertainty in the forecast flows. The models as well as data collection modes for such a system are not in place in India. Therefore risk assessment and creating a micro risk/ inundation map-library approach can offer some operational advantages.

CONCLUSION

Urban flooding is complex and hydraulic models coupled with risk assessment tools can greatly assist in understating the impacts due to flooding.

The approach of urban flooding considering source, pathways and receptor in risk calculation and interpretation of hydraulic modeling data is helpful in planning for dealing with floods. The risk maps can be used by the Disaster Management Cells in cities to do better planning towards flood resilience.

Risk scores based on probability and consequence can be used to calculate damage costs related to flooding. This can be useful while understanding and plan financial aspects of mitigation projects.

Considering the variation in rainfall intensity due to climate change the tool is helpful in understanding various scenarios evaluation for an urban area.

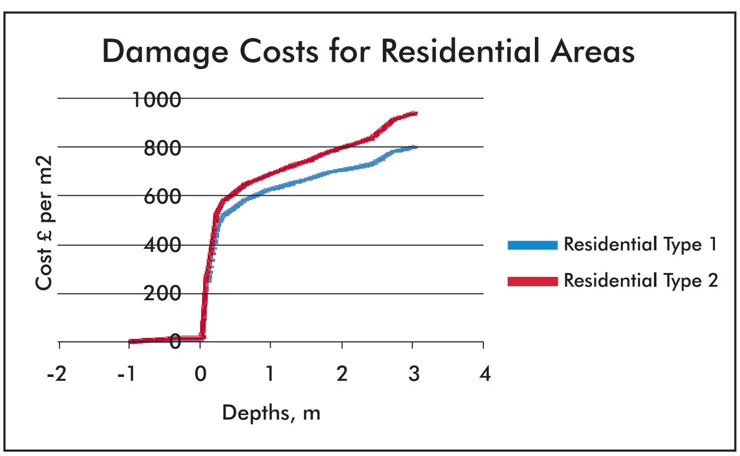

Figure 8 : Typical Damage Costs Curves for Residential Areas

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