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100 YEAR FLOOD SIMULATION FOR DHAKA CITY USING MULTIPLE MODELS

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ABSTRACT

Dhaka City experiences frequent flooding and water logging and the Agencies involved to manage Dhaka drainage system uses traditional methods to design infrastructure and improve the condition. No analysis tools or models are used to develop a comprehensive understanding of the problem and provide solutions based on analyses. Under the CORFU project several models were developed for Dhaka City to address the varied flooding problems experienced in the City. Pipe network model was developed to analyze densely populated central part of the City and open channel model was developed to analyze the flooding in the developing areas at the fringes. In order to better understand the depth & duration of flooding, coupled model based on one-dimensional (1D) network and two-dimensional (2D) surface models were developed. These models were integrated in order to better represent the flood flow process over the terrain of the project area. The development of these integrated models takes more time and effort; in addition computation time is also longer than 1D model. So it is important to understand the benefits and drawback of using these advanced models. This paper presents the simulation results of 2004 flood based on the 1D model and the 1D/2D coupled model developed for Dhaka Case Study and comments on the benefit of using these models for a City like Dhaka.

KEYWORDS
Flood resilience; urban flooding; Dhaka City flooding; flood modelling;

1. INTRODUCTION

Bangladesh is located on the extensive flood plains of the Ganges and Brahmaputra Rivers. Therefore, water is a natural part of life. Dhaka, the capital of Bangladesh is one of the major cities of South Asia. It is one of the most densely populated cities in the world with some areas have more than 100,000 persons per km^2 (BBS, 2011). The mega-city is located in central Bangladesh and is situated on the eastern bank of the Buriganga River.

Dhaka experiences about 2,000 mm of rainfall annually, of which almost 80% falls during the monsoon. The city is surrounded by a network of rivers: the Buriganga on the south-west, the Turag on the north-east and the Balu on the north-east and the Tongi Khal on the north. Internal drainage system of Dhaka consists of pipe networks and narrow canals. These conveyance systems are connected to the surrounding river systems. During the monsoon from May to October, the drainage of the city is influenced by the water levels of its peripheral river systems.

Flooding in the Dhaka Metropolitan area can be classified into two types (IWM, 2006). The first one, River flood, results from high water levels of the peripheral river systems. This results in river water intrusion and renders any natural drainage impossible. Another one, Urban Flood, is caused by high intensity storm rainfall runoff in the city area. This type of incidence causes flash flooding even though natural drainage is possible.

As Dhaka is undergoing rapid urbanization, it faces constant threat of encroachment of water bodies i.e. lakes, canals and rivers. The influx of migration and resultant growth of informal settlements, private housing and subsequent commercial developments instigate the process of encroachment. This phenomenon, unchecked, is radically changing the landscape of the city. The urban expansion is threatening its ecological balance as well. This uncontrolled and unplanned urbanization is resulting in an ever expanding city boundary.

To offset the unwelcome impact, it is necessary to understand present drainage system and the effect of urbanization on this system. For this, two 1D-2D couple models were developed to represent two different areas of Dhaka City. Mike 21-MIKE Urban couple model was developed for central part of the study area. The area mainly contains underground pipe system and some open channels. The Eastern part of Dhaka is low lying and the drainage system comprises of natural channels. Mike 21-MIKE 11 couple model was developed to analyze this part of the City. The open channels in the Eastern part are closely connected with the surrounding rivers and as previously mentioned, the water level and flow in these rivers greatly influence the drainage system. The model is designed to capture the influence of these rivers.

2. PRESENT SITUATION

Flood is a common phenomenon for a country like Bangladesh, A low lying delta of many rivers. Because of its geographical location at the centre of the country, Dhaka is also affected by flood.

The Western part of Dhaka city is protected by a city protection embankment and the eastern part is protected by “Progati Sharani”, a major highway that also acts as a as a drainage divider. Dhaka is expanding beyond “Progati Sharani” on the eastern side. The newly expanded area is unprotected so far flooding is concerned and experiences water intrusion from Balu River. The protected part of Dhaka city has a drainage system which has open channels as well as conduits. The open channels are referred as ‘khal’ in native tongue. The drainage system of Old Dhaka drains to Dholai khal, which eventually drains to Buriganga river. The drainage system of Mirpur, Kallyanpur, Mohammadpur drains through Kallyanpur khal to Turag River. A part of central Dhaka drains through Hatirjheel lake to Rampura khal and eventually reaches Balu River while another part of central Dhaka drains to Balu River through Shegunbagicha Khal, Manda Khal and Jirani Khal.

The central Dhaka has 3 lakes which works as retention basins; Gulshan Lake, Banani Lake and Hatirjheel lake. Gulshan lake and Banani lake both drains to Hatirjheel lake. Mike Urban Model was used for central part as it can simulate urbanized drainage system consisting both open channel and conduits. The urbanized drainage works are mostly in central Dhaka. It is designed with minimal diversion of the natural drainage flow. Almost all the small to medium canals/ khals had been converted to box culvert to facilitate road transport network in the city. For example, Panthapath canal is fully converted to Panthapath box culvert. Many surface drainage system has been replaced by piped system. Standard gravity drainage is not always possible as the drainage system depends on the water level of surrounding rivers. There are several drainage control structures and pumping facilities. To prevent backflow towards the city in monsoon period when water levels of surrounding Rivers are higher, the gate of these control structures are closed and excess water resulting from heavy rainfall is pumped out. But as the newly developed part of eastern Dhaka is unprotected, the flood water of Balu River causes inundation.

3. METHODOLOGY

To understand and analyse urban flooding two mathematical models are developed. These models are designed to represent present situation. The following steps are followed in the development and application of such models:

1. Understand existing drainage system and cause of congestion.
2. Collection of necessary data and cross verification.
3. Using the data, develop 1D-2D coupled model to analyze flood extent.
4. Identify cause of urban flood and suggest remediation measures

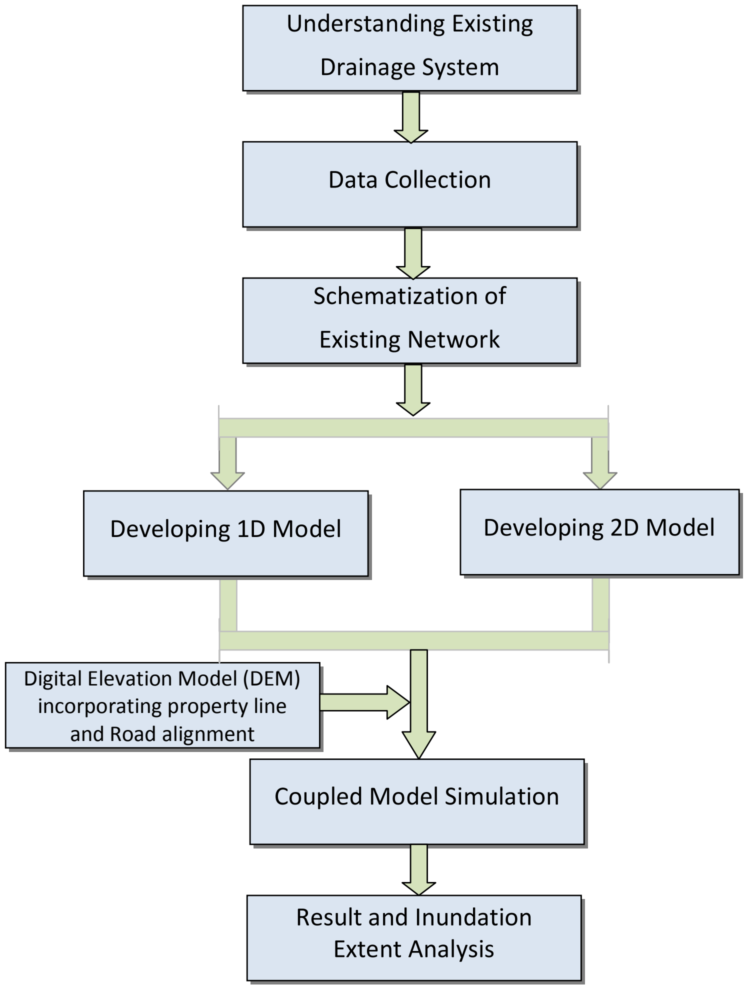

Figure 1: Steps of model analysis at a glance

Any model is as good as the data provided. In a country like Bangladesh where there is no specific database, accuracy of field data is less. Therefore, cross verification of data was done before using to construct any model. For drainage models two types of data are provided. One of them is meteorological data such as Rainfall. 3 hourly rainfall data was used which is collected by Bangladesh Meteorological Department (BMD). Another type of data is Hydraulic data. The alignment of existing drainage network and their properties such as pipe diameter, invert level etc. These data are collected from Dhaka Water Supply and Sewerage Authority (DWASA). DWASA is responsible for drainage of most of the areas of Dhaka city.

4. MODEL DEVELOPMENT

4.1 General

Dhaka city is divided in two major Catchments; Central catchment and Eastern catchment. The Highway named "Pragati Sharani" is considered as the main drainage divider. Due to more urbanized composition of central Dhaka catchment, the impervious area is higher. As a result, there is increased runoff due to less infiltration which reaches the outlets at a shorter period of time. The catchment of eastern part of Dhaka city is in the process of development and it is outside the city protection embankment. The area of this catchment is more pervious, has more natural channels. The runoff is less due to more infiltration. Mike Urban is used for Central Catchment as it can handle the urban hydrology more efficiently and can concurrently simulate closed conduit flow and open channel flow.

Mike 11 is chosen for Eastern catchment as it can simulate open channel flow and rural and semi-urbanized area overland flow more efficiently. A prior model developed to assess construction of a bypass road also provided useful information (IWM, 2006).

The 1-D mathematical models were updated to 1D-2D coupled model using Mike21 for better simulation of overland flow. The models for Central Dhaka and Eastern Dhaka are linked at the outfalls. The water level generated at Rampura sluice gate by Mike11 model for Eastern Dhaka is used as boundary condition for the Mike21-Mike Urban coupled model. The water level of surrounding rivers of Dhaka governs the drainage system in the eastern side. 1D-2D couple models are used to generate flood maps. These maps are essential to analyze urban flood.

4.2 Eastern Model

Drainage catchment of eastern Dhaka is rural in nature and has three major sub-catchments. The area is predominantly agricultural land. The parameters were chosen accordingly to reflect the characteristics of rural catchment which are shown in ***Table 1***. Using spatial analysis based on aerial images and data collected from City Development Authority RAJUK, the impervious areas were determined for each of the catchments.

Table 1: % of impervious area

Compartments	Total Area	% of Impervious area at present
Compartment-1	40,638,407	10%
Compartment-2	37,013,326	8%
Compartment-3	43,796,418	17%

The eastern Dhaka drainage model is developed based on IWM's existing North Central Region Hydrodynamic (NCRHD) Model to simulate the monsoon season flows and water levels of the river. The NCRHD is developed using Mike 11. The calibrated NCRHD model was truncated and the khals (natural channels) in the Eastern Dhaka were incorporated into the model. Surface runoff flows generated from rainfall was estimated for each catchment using a rainfall-runoff model. This flow was then used as input to the hydrodynamic model as shown in ***Figure 2*** to simulate the flow of water through drainage channels and surrounding rivers.

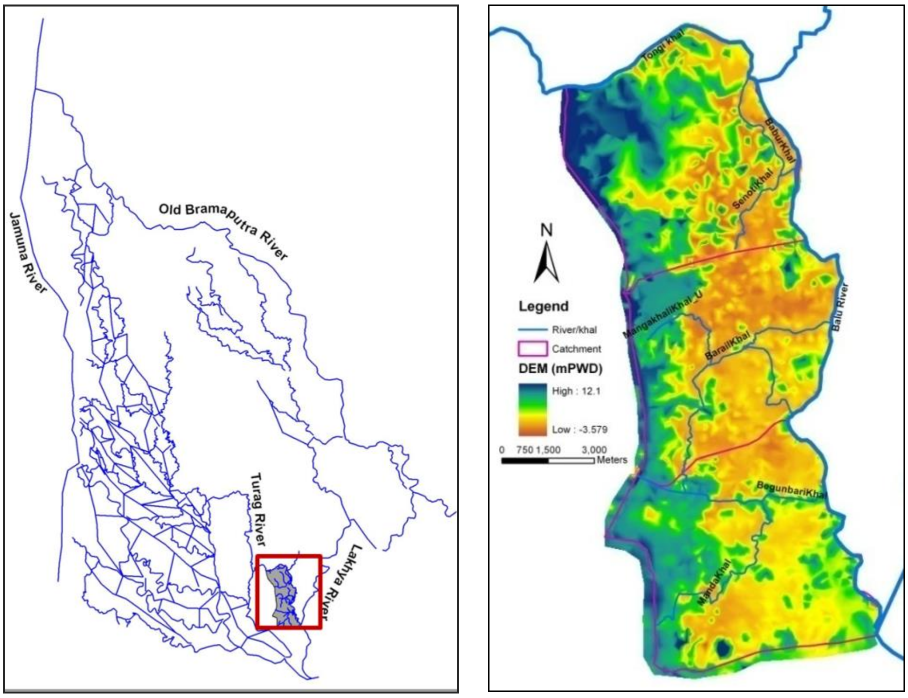

Figure 2: Regional model and Eastern Dhaka model

The eastern model is an open channel system and consists of several rivers and their tributaries. There are about 90 km khals in the Eastern part of Dhaka, out of them only 42.24 km khal is schematized for CORFU project.

4.3 Central Model

The Central model covers nearly 45 km^2 of Dhaka City. It covers important commercial and administrative locations of Dhaka City as well as major residential areas. The area is highly urbanized and as a result the natural channels were replaced with underground storm sewers and box culverts. The area is protected from river flooding by embankment, so during rainy season storm water needs to be pumped outside. There are also some large lakes within the area which works as detention ponds for the catchment. The model was built from scratch and contains nearly 134 km of storm water pipes, 40 km of open channel and 10 km of box culvert. The catchment of Central part is divided into 13 major catchments. In the model these catchments are subdivided into smaller catchments based on local drainage hydraulics like roads, elevation, outlets etc. The hydrology of these catchments is based on land-use information collected from RAJUK (City Development Authority). Pumps, sluice gates, detention ponds and related control mechanisms were also incorporated from the model. The control mechanisms of the major structures and their locations are shown in ***Figure 3***. DWASA is responsible for the underground storm sewer system of Dhaka City and the information used to build the model was collected from the Agency.

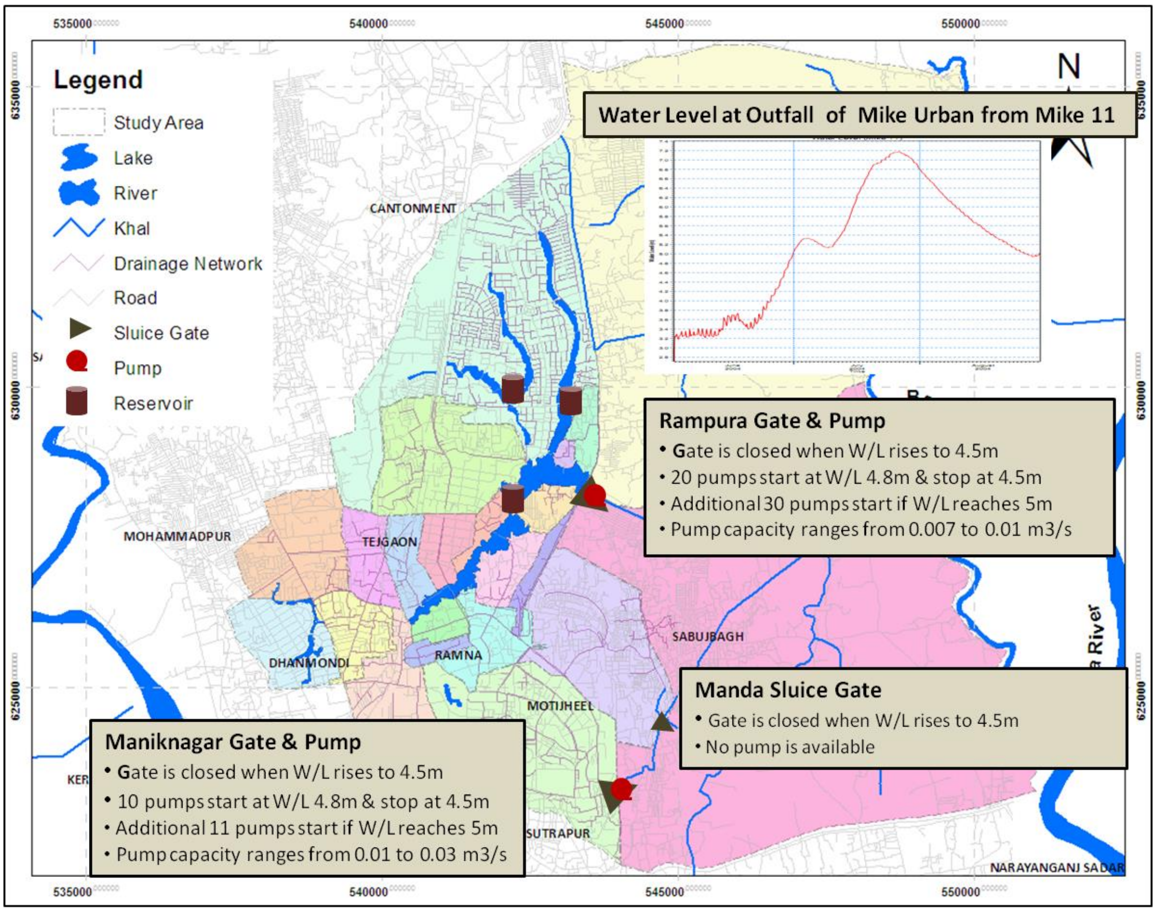

Figure 3: The components of Central Dhaka model and their properties

5. 2004 FLOOD EVENT AND SIMULATION

5.1 Description of the Event

Flood-2004 in Dhaka West was characterized by aggravated internal flooding especially around Begunbari Khal, Hateer jheel, Gulshan lake areas, etc. Dhaka West was free from river flood water intrusion from Balu and the Buriganga Rivers. Still Dhaka West faced unprecedented water logging in many parts of the city. The spill water from the Gulshan lake areas entered the adjacent residential houses and water was logged for quite a long time. During 1998 flood, flood water intrusion from river side was dominant, while 2004 flood internal flooding is dominant. The quality of logged water was also very bad. The duration of floods of 2004 was from around mid-July to mid-August, a prime part of Gulshan, Banani, Baridhara and Nikunja inhabited areas remained under water for a long time. The Motijheel Commercial area, including Arambagh and Gopibagh, was flooded for a few days. The eastern part of the city suffered the worst condition. About 124 sq. km area, approximately 176,000 families and around 900, 000 people were affected by the 2004 floods (Hossain et al 2006). In all, 40% of the city and habitats were directly suffered by the 2004 floods.

5.2 Rainfall and River Water Level

The affect of 2004 flood was observed for several months. The highest rainfall was observed during the month of September. This high rainfall severely affected the central protected part of Dhaka City, where the drainage system is designed for smaller sized storms. On the hand the unprotected eastern is influenced by river flooding, so downstream water level is important. It can be seen from ***Figure 5*** that the highest water level was observed at the end of June that year and the water level above 5 mPWD remained for 2.5 months. The highest precipitation was observed during the month of September which can be seen in ***Figure 4***.

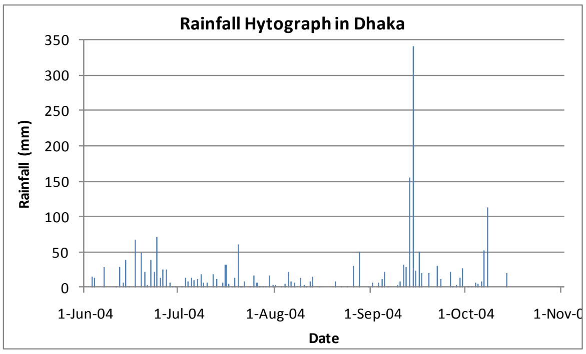

Figure 4: Rainfall Hyetograph of Dhaka

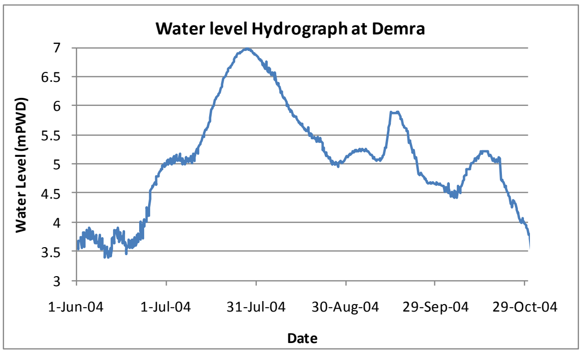

Figure 5: Water Level Hydrograph at Demra

6. MODEL INTEGRATION

6.1 1D-2D Coupled Model

Couple models for Dhaka case study were developed by combining Mike21 and the two 1D models. A digital elevation model (DEM) of 25m grid was used to translate the model result into flood maps. The 2D model was very much dependent on the quality of the digital elevation model (DEM). To reflect the property line and road alignment a downscaled DEM is needed. The overland flow in urban area of Dhaka usually flows along the roads. The drainage system is also designed along the road as the roads are built from higher to lower ground. The available existing DEM in IWM is based on SoB topo-sheet and IWM past surveys. It was observed that the elevation of Eastern Dhaka effectively ranges from 0.6-8 mPWD. This DEM was used as bathymetry for the 2D model development. The schematized khals and the right bank of Balu River and Tongi khal were linked with the bathymetry in the couple model for Eastern Dhaka.

The coupled model, DEM framework was simulated for different scenarios. The simulation generated flood maps corresponding to each scenario. This map was compared to the flood extent of that period and the model was calibrated to match the simulated inundation with the observed inundation extent.

6.2 U/S and D/S Boundary Conditions

The models used in Dhaka case study had to be setup in a way so that the two separate models can jointly reflect the 2004 flooding condition. The catchments in the Central model are separated from the eastern model by embankment. The models are connected through some regulators which drain the storm water from Central model to eastern model. The regulators in central model were set according to the down stream conditions from eastern model. The eastern model is heavily influenced by down stream river condition, so water level from NCRHD model was used. Flow from upstream rivers and water level from downstream rivers dictates the hydrodynamic condition of the eastern model. Boundary condition data were applied as in Table 2 accordingly to the model. The Central model is protected from river flooding so the main input is the rainfall information and control mechanism of the regulators based on water level from eastern model.

Table 2: Model boundary

River	Chainage	Type	Data
Balu	0	Inflow	Qc = 0.0
Lakhya	70000	Inflow	Simulated data from NCRM
Lakhya	120000	Water level	Simulated data from NCRM
Tongi khal	1000	Inflow	Simulated data from NCRM
Begunbari Khal	0	Inflow	Qc = 2.5
Manda khal	0	Inflow	Qc = 1.5
Senoti khal	4200	Inflow	Qc = 0.0
Mongakhali khal_up	382	Inflow	Qc = 0.0
Shahzadpur khal	0	Inflow	Qc = 0.0

7. RESULTS

7.1 Calibration or Validation

It was decided that 2004 event will be used for calibration. It was a large event (100 year return period) for which there was data available. The Eastern Dhaka Model was calibrated in several locations along Balu River. The cross sections were updated and the run-off parameters were adjusted to calibrate the model. As no data of temporary pump stations are kept by DWASA the calibration data was unavailable for the outlets of the Central Dhaka Model. A flood map produced in a study by IWFM on '2004 Flood' was used for calibration. That flood map is a schematic map, was done by field investigation and do not provide flood depth. For calibration the flood extent was matched as shown in ***Figure 6***. The red circles areas were selected for model calibration.

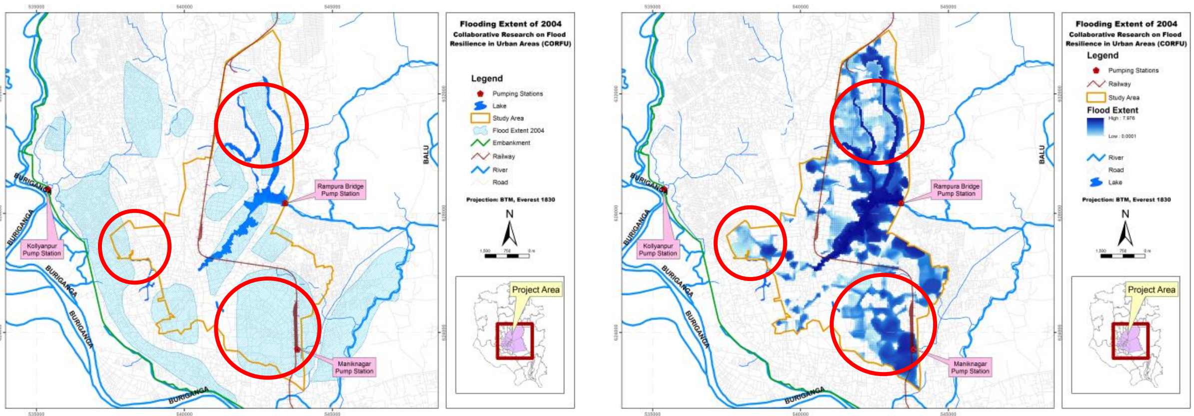

Figure 6: Flood extent comparison from hydraulic model and field investigation

7.2 Outputs from 1D and 1D-2D Coupled Model

The outputs from the modelling exercise provided understanding of several dimensions of the 2004 flooding process. The model simulations provided information on the over land flooding process and the performance of the existing drainage network. Depth and extent of flooding was generated from 1D and 1D-2D coupled models. The results from the models were compared and difference was observed in the outputs from the two models. Additional information was possible to extract from the 1D-2D coupled models which included duration of flooding and also issues related to velocity. These can be very important parameters to determine the impact of flooding. Figure below shows the comparison of flooding extent between 1D and 1D-2D coupled models and the percentage area under different durations of flooding generated from 1D-2D coupled model. It can be seen in ***Figure 8*** that the coupled model shows higher extent of flooding for middle range depth of flooding where as 1-D model shows higher of flooding for marginal depth of flooding. This indicates the coupled model simulate the detail of flooding better. Another output generated from the coupled showed 6% of project area experienced flooding 1 to 4 days in 2004 (***Figure 9***). During flooding velocity of flow in some areas went above 1.5 meters, which can be seen in ***Figure 7***. These areas will need special consideration during flood management strategy development.

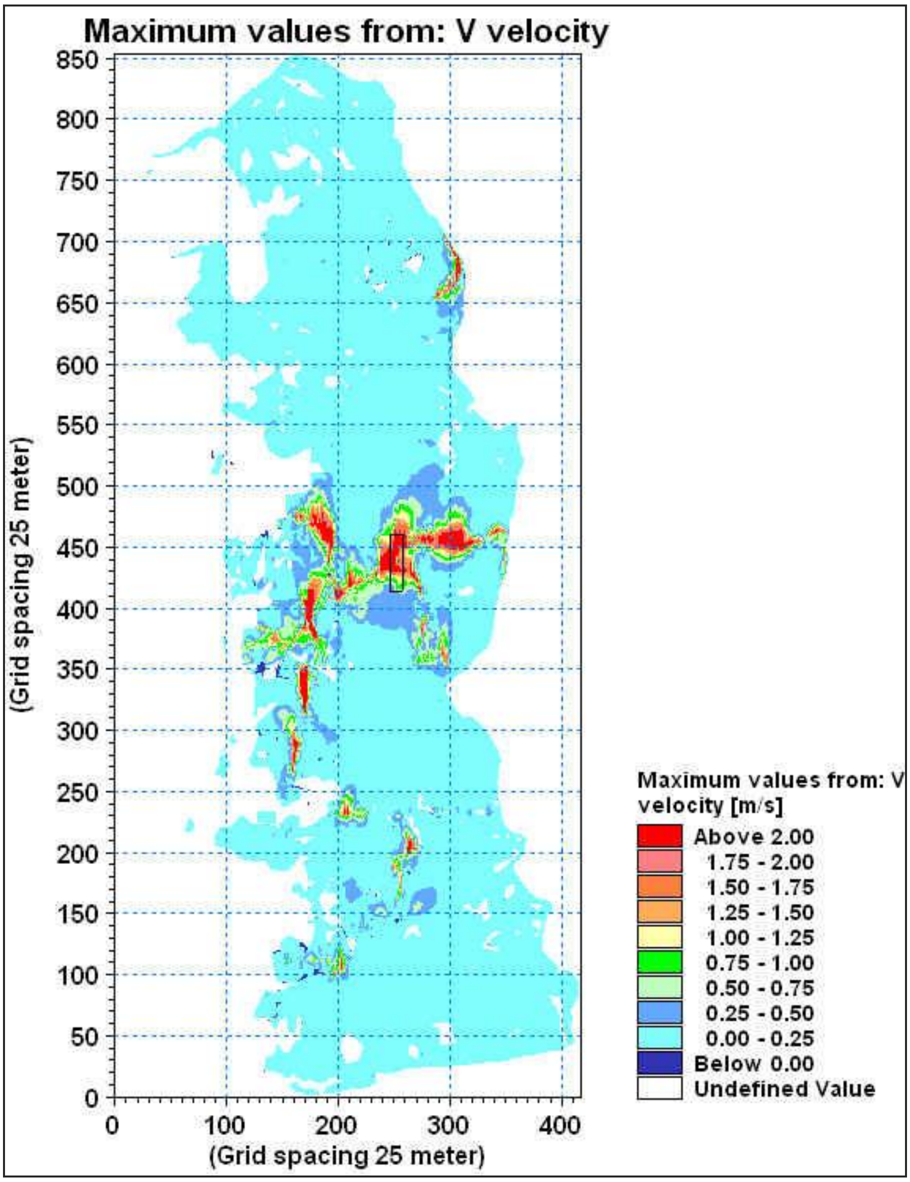

Figure 7: Velocity gradient in flood water

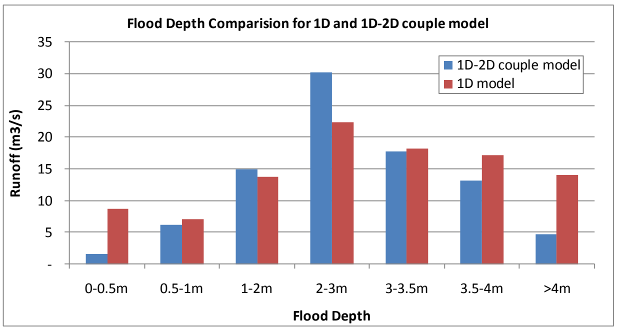

Figure 8: Flood depth Comparision between 1D & 1D-2D couple models

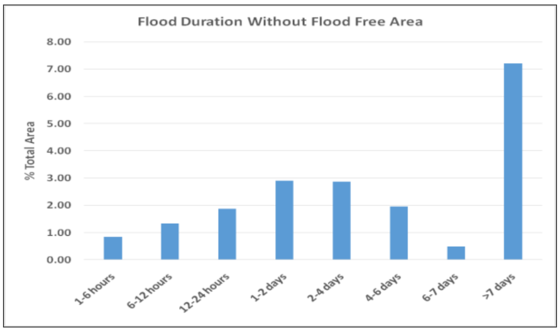

Figure 9: Flood duration

8. CONCLUSION

The CORFU project gave the opportunity to develop the first 1D-2D coupled model for Dhaka City. Extensive data is needed to build this kind of models. Availability of more data helps to develop a better model. This is true for both 1D and 1D-2D coupled model, except that coupled models require additional data for overland condition or urban bathymetry. For Dhaka Case Study these data was collected from different Agencies and lot of the times it was found that the available data can not be readily used. The collected data was analyzed and processed before it was used. When data was not available assumptions were considered in developing these models. During collection of data and the development of the drainage models, useful information was found on the existing drainage system and its condition. This also provided insight into current drainage design guidelines and flood management strategies adopted by different Agencies responsible for Dhaka City.

Within CORFU it was possible to see the benefit of developing an integrated model for Dhaka City. Application of models is not limited to only designing systems, but it can also help to develop a comprehensive solution for flood management. It was found that coupled model can provide more information which can help develop these strategies. The experience from Dhaka is that there are challenges to develop integrated model, but the model can be a very useful tool to device strategies to make the City flood resilient.

9. ACKNOWLEDGEMENTS

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