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Development of 3Di Flood Model for Ayutthaya City Island

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ABSTRACT

This paper presents the development of 3Di flood model in Ayutthaya City Island. This area is the confluence of Chao Phraya River, Lopburi River and Pasak River caused frequent flooding. The sub-grid and quad tree techniques in 3Di model are capable of using high resolution LIDAR based elevation data as input to the flood model. 3Di is an innovative new model system for making high speed hydraulic computations to support decision making in water management. It can immediately show decision makers, including non-water specialists, the impact of their ideas in various scenarios.

KEY WORDS: 3Di; flood; Ayutthaya; flood management.

INTRODUCTION

Ayutthaya Province as a part of lower Chao Phraya River Basin suffers from frequent flooding throughout the history. The flood in 2011 emphasized this with 5 tropical storms hit Thailand causing a widespread flooding more than half of a country especially in the Chao Phraya River Basin. With its importance as one of the UNESCO world heritage site registered since 1991 and country's major industrial estates, Ayutthaya suffered from serious damages with almost all area were under water for months. In response to this crisis there is a need for a fast flood model that can support decision making and at the same time enhance the understanding and communication among various parties who involve in the flood management. A 3Di model is a fast 2D hydrodynamic model that can provide a 3D interactive web portal and realistic 3D-animations of flooding. Higher resolutions of digital elevation maps could be enhanced with the sub-grid technique that allows a faster computation. Different scenarios can be easily compared and analyzed with a possible decent time. The 3Di model has been designed to operate on cloud. This allows an easy access to the flood model and its applications via smart phone or tablet with internet connection. Flood management becomes more manageable and effective.

STUDY AREA

Ayutthaya Province is located on an island in the lower Chao Phraya River Basin. The focus of this study is on the Historical City of Ayutthaya or so called Ayutthaya City Island. This 8 sq. km. study area is surrounded by three rivers, Chao Phraya, Pasak and Lopburi Rivers connecting the city to the sea (Fig 1). Ayutthaya Historical Park was internationally inscribed as a UNESCO World Heritage Site in 1991. In Ayutthaya City Island there are three major canals which are Thor canal, Maha Chai canal and Makham Rieng canal. The elevation of Ayutthaya City Isand is in general rather low with an average height of about 3 – 4 m.MSL. Due to this low lying area Ayutthaya has experienced frequent flooding throughout the history.

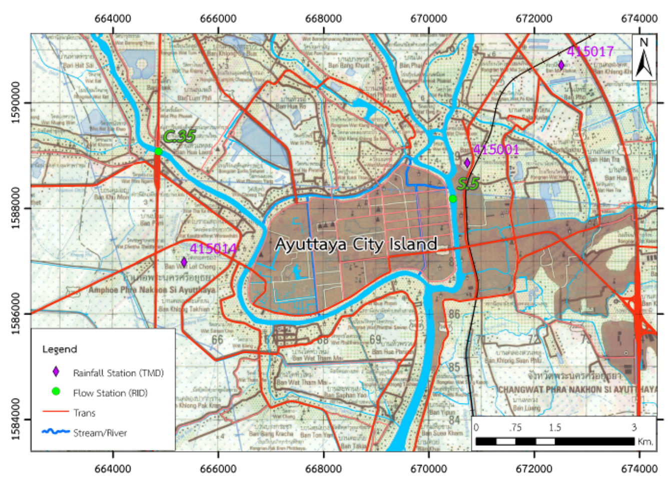

Fig. 1 Ayutthaya City Island

Meteorological Condition

Ayutthaya province has an annual rainfall of about 1,097 mm. Maximum rainfall occurs in September and is equal to 256.2 mm. Minimum rainfall occurs in January and is equal to 5 mm. The avg. maximum and minimum temperatures are 40.1ºC and 35.6ºC occur in May and in October respectively.

RECENT INUNDATION EVENTS

The Chao Phraya River Basin frequently faces flood inundation events (pluvial and/or fluvial). There was an extreme flooding event in the fall of 2011. This is the worst flooding event which Thailand has experienced in decades. The capacity of the Chao Phraya River at Ayutthaya is about 1,500 m^3/s but the total inflow on 4th October 2011 was about 3,300 m^3/s. Fig 2 shows a true-color satellite image showing flooding in Ayutthaya (right), compared to the situation before the flooding (left).

Fig. 2 True-colour satellite image showing flooding in Ayutthaya and Pathum Thani Provinces in Central Thailand (right), compared to before the flooding (left).

The flood event of 2011 has been worsened by a number of failures of dykes and structures in the Lower Chao Phraya basin and the flood defense systems of industrial estates around Bangkok. Several large breaches occurred in the canal dykes in the Lower Chao Phraya River Basin mainly due to overflow and consequent erosion of the dyke body that consisted of clay. Most breaches occurred at weak spots in the system at lower parts of the dyke, near connections with structures and at obstructions (Jonkman et al., 2012). The Ayutthaya City Island flooded because the Uthong dike breached on 7th October 2011 leading to significant flooding (Vojinovic et al., 2014). The Wat Chai Wattanaram temple, located at the river bank is protected by movable flap gates on the river site and masonry walls on the other sites of the area. Flooding occurred at the southern corner at the connection of the movable gates and the wall, illustrating the vulnerability of such connections (Jonkman et al., 2012). Ayutthaya City Island is located on the flood prone area with the flood frequency repeats every 1 – 3 times in every 10 years. (Fig 3)

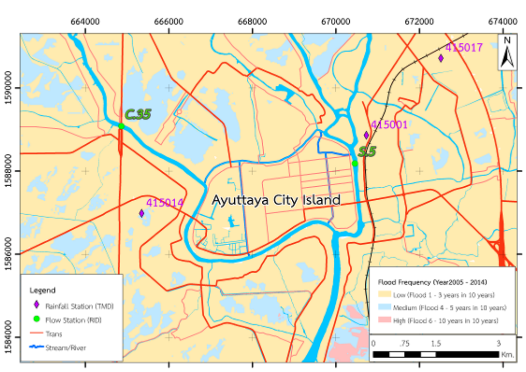

Fig. 3 Flood Frequency

DEVELOPMENT OF 3Di MODEL

3Di Model

3Di is a flood model developed in the Netherlands by the 3Di consortium consisting of Deltares, the Delft University of Technology, Nelen & Schuurmans consultancy and regional water authorities. 3Di combines four methods in its solver: the sub-grid method (Casulli, 2009), bottom friction based on the concepts of roughness depth (Stelling, 2012), the finite-volume staggered grid method (Stelling et al, 2003) and quad tree techniques (Wang et al, 2004). 3Di uses Cartesian grids with the square grid.

Sub-grid: The sub-grid technique is based on two grids with different resolution. Bottom values are given in DEM or a find grid. For the computation of water level and velocities the grid cell are clustered into larger cell show in Fig 4, $\zeta_{l,m,n}$ is the water level above the reference plane, $e_{i,j}$ is the bottom elevation above the reference plane and $\Omega_{l,m,n}$ is the hierarchical quad tree ordering. 3Di uses the relation between water level and volume for the large cell. Therefore detailed information aggregated and used when solving the 2D shallow water equations. The sub-grid technique cans faster analysis.

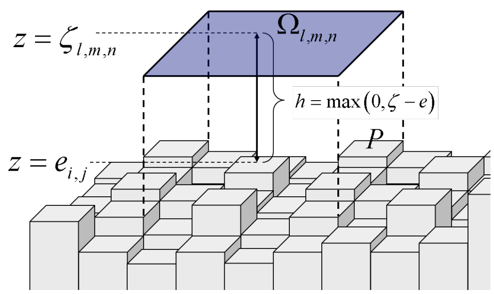

Fig. 4 Example of sub-grid

Quad tree: 3Di is the use of quad tree. The cell size is small on locations where large detail is required. Local grid refinements are made by recursively splitting cells in 4 quadrants. In 3Di, the minimum and maximum cell size to be used in the computations must be specified. 3Di can generate a quad tree grid as shown in Fig 5.

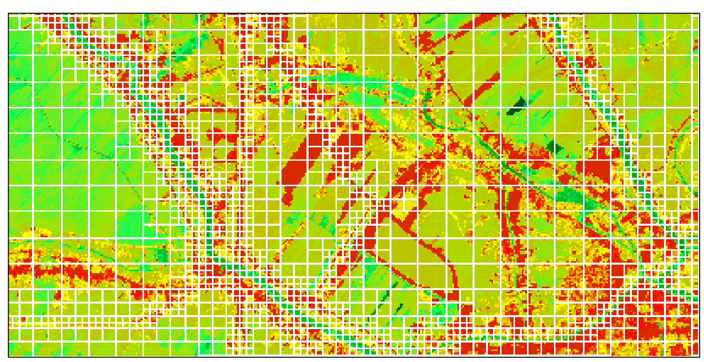

Fig. 5 Example of quad trees

Digital Elevation Model: DEM

For the Ayutthaya City Island and surrounding area, a LIDAR DEM with resolution of 2x2 meter is used (Fig 6).

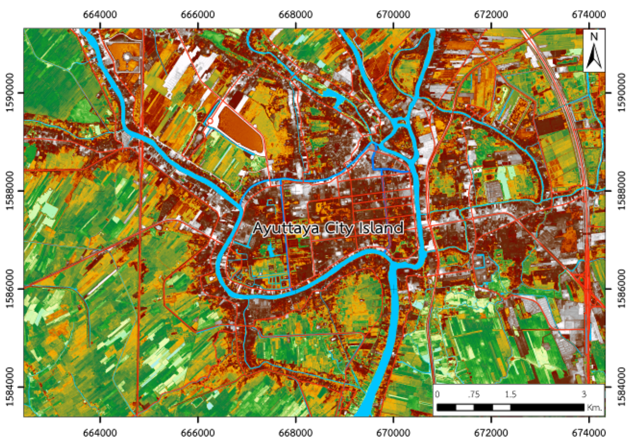

Fig. 6 Lidar data resolution 2 x 2 m.

Model Boundaries

The existing Chao Phraya River model used in the forecasting system developed at Hydro and Agro Informatics Institute (HAII) in 2012 (Sisomphon, 2013) has been used as a baseline model providing 2D input for the 3Di. Although the study is mainly focused on Ayutthaya City Island but to simulate the 2011's flood correctly the model boundary has to be carefully defined as the inundation occurred in a large extent. Fig 7 shows selected a model boundary.

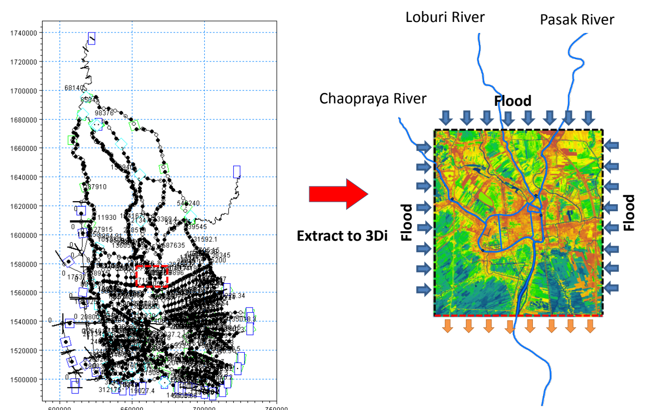

Fig. 7 Boundary area

3Di model was developed to simulate the discharge and water level in the 1D river network, 2D flow model of the inundation areas and coupling 1D2D for simulating natural river channels with floodplains. In this study, the existing Chao Phraya River Basin model was used to generate the 2D lateral flow input for the 3Di model. The discharges from Chao Phraya River, Pasak River and Lopburi River were added. For downstream use 1D rating cure boundary and 2D downstream discharge boundary.

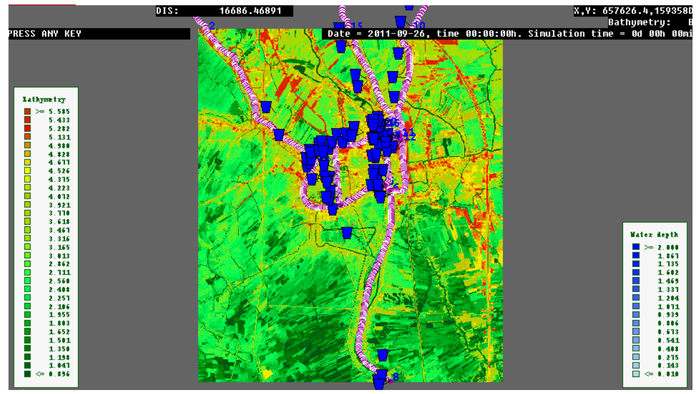

Fig. 8 Example of 3Di model in Ayutthaya City Island

Model Validation

3Di model was setup and simulated the flood in 2011. The results were validated with the observations. Fig. 9 shows the comparison results between observed and computed discharges at C.35 station in Chao Phraya River and S.5 in Pasak River. It can be seen that there is good agreement between the observations and the computed discharges. Although the model tends to over compute the observed discharge which might due to unclear water management data. In overall picture the model is able to illustrate the flood propagation and its extent satisfactorily. Fig. 10 shows the comparison between the 2D simulated inundation area with the satellite image.

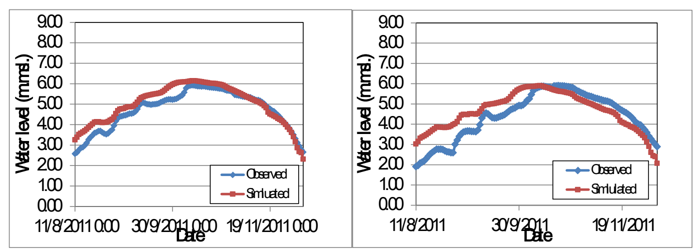

Fig. 9 Comparison of 3Di model at C.35 Chaopraya river (left) and S.5 Pasak river (right).

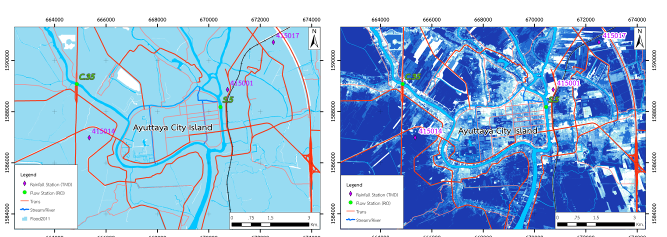

Fig. 10 Comparison of the flood area from 3Di modeling (right) between satellite image (left).

The computed flood levels were also compared with the observed flood marks. It is found that the computed flood levels are in good agreement with the observed flood marks. (Fig. 11).

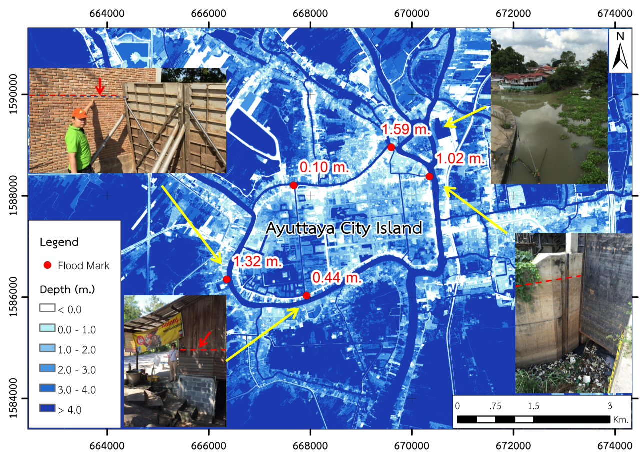

Fig. 11 Comparison between observed flood marks and computed flood level

VISUALIZATION

Interactive visualization is one of the key performances of the 3Di model. The visualization system helps enable the understanding of the event and verify the effectiveness of possible measures in an easy way. During the calculation, the user can retrieve information and make changes in the model scenarios. As the model is running on cloud it is an easy access from everywhere with internet connection. Fig. 12 shows the interactive view to see the cross-sectional discharge in the Ayutthaya City Island.

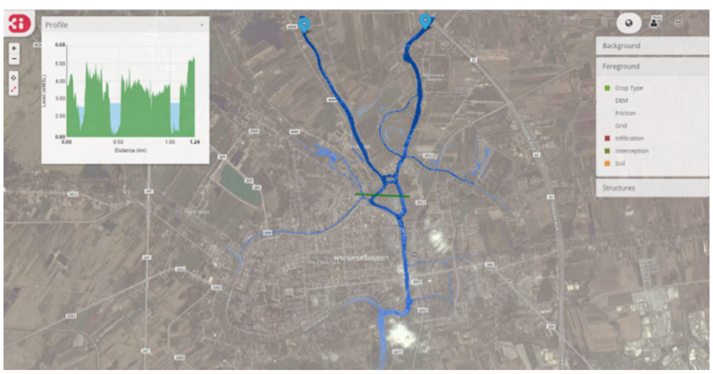

Fig. 12 The 3Di flood simulation in Ayutthaya City Island

CONCLUSIONS

With the sub-grid technique developed in 3Di model, high resolution of DEM can be effectively use for the flood simulation. This allows more accurate coupling between 1D river and 2D overland flows in the higher resolution DEM with a faster speed. In this study the 3Di model developed for Ayutthaya City Island has shown its performance in simulating the flood event in year 2011. The computed flood map provides good detail and more realistic of the inundation area.

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