

Modeling Flood Disasters: Issues Concerning Data for 2D Numerical Models

Ahmad Fikri Abdullah^{3,*}, *Zoran Vojinovic*^{1,2}, and *Vorawit Meesuk*¹

¹UNESCO-IHE, Westvest 7, 2611 AX Delft, The Netherlands

²University of Exeter, EX4 4QF, UK

³Department of Biological and Agricultural Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia

Abstract. Flood disasters are one of the worst natural disasters and they occur almost daily. Correspondingly, city managers are nowadays increasingly investing in data collection and modelling activities. Typically, flows in pipes and channels have been modelled using a one-dimensional (1D) approach. Also, if the flood flows on the ground are confined to streets and curbs, the use of 1D/1D modelling approach (a.k.a. as dual drainage concept) may be a feasible way forward. However, if the flows are two-dimensional with complex interactions taking place through surface/sub-surface links, then the required approach would be the so-called 1D/2D modelling approach. The ever-increasing power of computers is now allowing a 3D fluid dynamics analysis of overflow and manhole structures, and in time these may be coupled with 1D models that may be used in situations where flow characteristics require with higher dimensionality. With the use of 2D models, the importance of terrain data has become a growing issue. The current paper discusses some of the key modelling approaches and makes particular reference to the terrain data processing and collection which can either improve or deteriorate their predictive capability.

1 Introduction

The world has been overwhelmed with growing number of natural disasters where floods are most dominating the records. With the increase in flood disasters, the process of preparing for such disasters requires investments in data and models. In doing this, collection and processing of terrain data is almost equally important as instantiation of numerical models. By acquiring reliable data and setting up appropriate models, the city managers are able to study floods and to simulate various drivers (e.g., urbanization, population growth or climate change) and effects of rehabilitation measures that they may find acceptable to stakeholders [1-15].

As described in [16-19], the models used for modelling urban floods have a sound physical basis of shallow-water equations and their accuracy will depend on the quality of the data used for analysis, complexity of equations as well as the knowledge and experience

* Corresponding author: ahmadfikri@upm.edu.my

of the modeler. Traditionally, one-dimensional (1D) approach has been used widely as it has given a good support to hydraulic engineering in design and system rehabilitation projects. Correspondingly, even nowadays, many researchers and practitioners favor such modelling approach over other approaches. This is due to the fact that 1D models are easy to instantiate, operate and maintain. In case that 1D models are incapable of capturing the required physics some researchers have attempted to combine these models with data-driven models.

With the developments in computational power, 1D-2D approaches are increasingly gaining more attention [20-23]. A possibility of how to combine data-driven and physically based models for the purpose of modelling urban drainage flows can be found in [24] and [25]. The accuracy of 2D models that can be reliably used in modelling flood disaster scenarios depends on the quality of terrain data, bathymetry and drainage network layouts [26-28]. In this paper, we discuss some of the key issues concerning data for 2D numerical models.

2 Method

2.1 Modelling Approaches

In urban flood modelling, we are typically concerned with the flood water interacting with urban environment in space and time. This objective leads us to consider different model complexities in space (one-dimensional, two-dimensional or three-dimensional) with a corresponding number of mathematical equations that describe the physical laws. Therefore, our focus is on how the geometry of physical environment affects flows at different points in the fluid, and how the changes in the geometry affect the propagation of flows. As mentioned earlier, if the flows are confined to pipes and channels a properly instantiated 1D model may be considered fit for purpose. As soon as the water spills from the drainage systems (or if it doesn't even enter the drainage system) and starts flowing on the ground our modeling efforts would require either the use of 1D/1D or 1D/2D modelling approaches.

The flows across urban floodplains are highly complex due to the presence of irregular features which may force flood flow paths to go in different directions. Developing models to reliably describe urban flood processes is a challenging task. The slopes of urban floodplains can often change which in turn can cause change in flow regimes. In such situations, the use of commercial modelling tools, which mainly use modified subcritical flow algorithms, may become an issue. It is often the case that head losses, which can form around irregular geometry of urban features, are particularly difficult to model and take into account [19]. Such issues drive the need to use 1D and 2D modelling systems which have a good predictive capability in modelling floods in urban areas; see, for example, [29-32].

Despite the advances in 1D/2D modelling algorithms, the predictive capability of 1D/2D models also depends on the quality of data and its associated processing techniques. In this paper, we investigate some of the key issues that relate to the terrain data for flood modeling applications. In our work, we apply different digital terrain models (DTMs) with different resolutions and different geometry of features as they were collected from LiDAR surveys. We applied these data sets for setting up 2D models. The resulting coupled 1D/2D model results are then mapped onto GIS maps to analyse the differences.

2.2 Terrain data collection and processing for flood modelling

A digital terrain model (DTM) term refers to a topographic map of an area, which contains terrain elevations and its characteristics. Unlike the DTM, the digital elevation model (DEM) term refers to the elevations of any surface, which can not necessarily be only the land (e.g., water surface, etc.). The DTM data can be acquired from different techniques. This is usually done through traditional ground surveys, aerial stereo photography and light detection and ranging (LiDAR) surveys.

Aerial Stereo Photography is one of the oldest remote sensing techniques. Satellite stereo imagery is yet another remote sensing technique, which combines images from two satellites, acquired from two different positions. Interferometric synthetic aperture radar (IfSAR) is a radar technique that can be applied in remote sensing. IfSAR mapping is a process of generating 3D maps from airborne IfSAR system, see for example [33]. The experience to date is that the coarser the IfSAR spatial resolution is, the more difficult it will be to produce the terrain elevation data [34].

Airborne Laser Scanning (ALS) or Light Detection and Ranging (LiDAR) is yet another remote sensing technique that is used to obtain elevation data from a particular area. LiDAR is based on an optical remote sensing technology to measure elevation points. LiDAR is a surveying method, which can give us accurate x and y coordinates, and z (height) positions. It can generate terrain data to a particular resolution. The LiDAR scanning provides a large number of elevation points which are spread across an area. The complexities that are inherent in processing such large amounts of data have called for better processing of raw data in order to deliver a more reliable set of points. Typically, operations that are referred to as thinning, filtering and interpolation are part of this process. Recently, a number of algorithms have been developed to enhance the processing of data that are acquired from LiDAR surveys (Fig. 1).

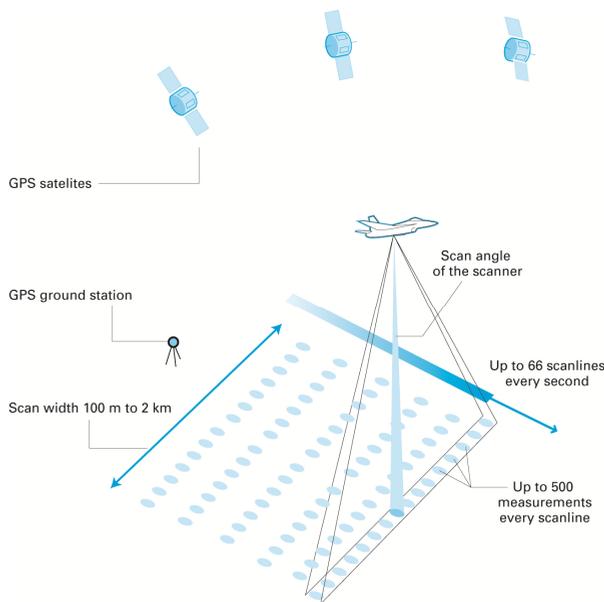


Fig. 1. LiDAR survey [19]. A large number of data points is collected.

The demand in LiDAR technology has increasing. Terrestrial LiDAR also known as terrestrial laser scanning (TLS) is establishing as an option to fulfill the demand. TLS is a ground based method to measure the position and create three dimensional information about the objects. It has the ability to collect very high accuracy point cloud from ground based platforms to model an object or scene. This TLS combines with a highly accurate differential GPS like RTK GPS, enables the user to register the georeference. TLS is a technique that provides detailed information for small-scale area [35]. TLS is often used for geomorphological analysis because it allows a fast and detailed 3D reconstruction of the sample object [36].

3 Results

3.1 Issues concerning DTM resolution

It is often assumed that a more detailed 2D model (or a 2D model with higher resolution) will be able to provide better distribution of flows over a particular urban floodplain. It is important to note that higher resolution of 2D data will inevitably increase computational time and mapping of such results will also take more considerable time. Correspondingly, coarsening the data will reduce model simulation time, but it will also reduce the level of details around urban features. Therefore, there is always a trade-off between the model simulation time and the level of details that can be captured within the domain of a 2D model.

In general terms, the work to date has shown that the results from 2D models with different DTM resolution can produce significant difference in flow depths [20] (Fig. 2).

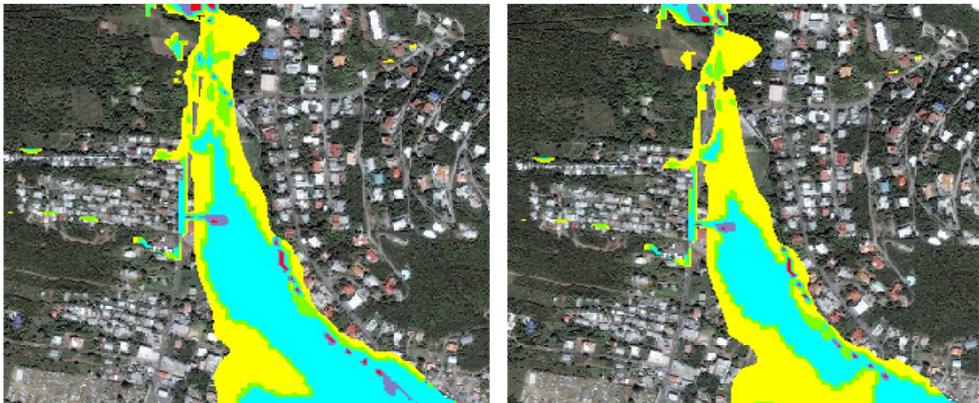


Fig. 2. Impacts of different DTM resolutions on model results (5m and 10m DTM resolutions);

3.2 Issues concerning filtering algorithms

In addition to the issues related to DTM resolution, there are also issues associated with the efficacy of LiDAR filtering algorithms [31-32]. The work to date has shown that different filtering algorithms can produce different DTM data sets which in turn can cause different results from 2D models. Some of the most commonly used algorithms in the practice are considered in the present paper. These algorithms are: the morphological algorithm and a TIN based algorithm.

3.3 Flood maps with different filter algorithms

The morphological algorithm points over a particular height range and the underlying processing used in this algorithm are dilation and erosion.

For the TIN based algorithm, the nearby points are only used in the processing. This algorithm is capable of successfully removing small urban features but it does not work satisfactorily in removing some larger features.

Fig. 3 depicts the 1D/2D model results for which the data was processed with the morphological algorithm (left) and TIN based algorithm (right).

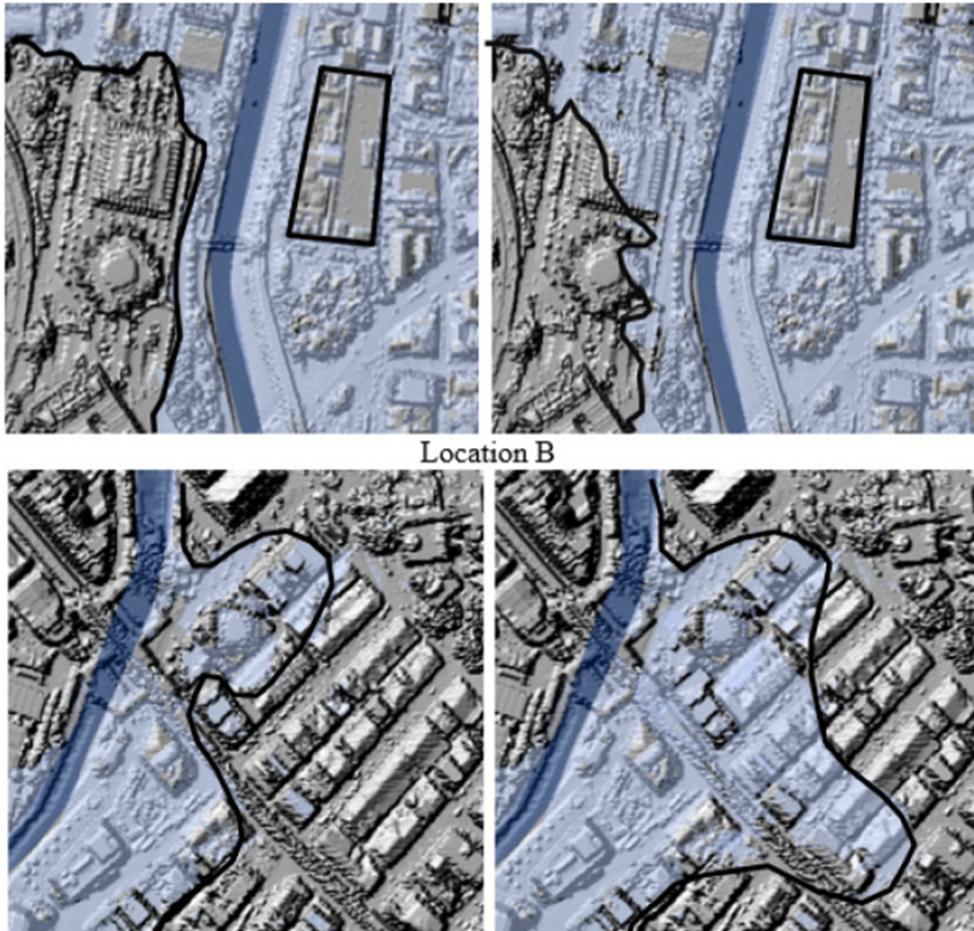


Fig. 3. Example of 1D/2D model results where different filtering algorithms are used in setting up 2D models (morphological algorithms – left; TIN based algorithms – right);

3.4 Fusion of top-view LiDAR and ground-view SfM data

Careful application of filtering algorithms can help in identification and representation of features that can be detected from top-view LiDAR data. However, if the features are hidden beneath vegetation and structures, the LiDAR filtering algorithms cannot detect such features. In this regard, the so-called Structure from Motion (SfM) technique can be

used effectively to compensate for this shortcoming, [37]. This technique can be easily implemented by incorporating overlapping photos and video scenes.

With fusion of top-view LiDAR and ground-view SfM data it is possible to detect and take into account small urban features which may have substantial influence on propagation of flood flows. Fig. 4 depicts the results with SfM-LiDAR DTM (left) and conventional LiDAR DTM (right), see also [24].

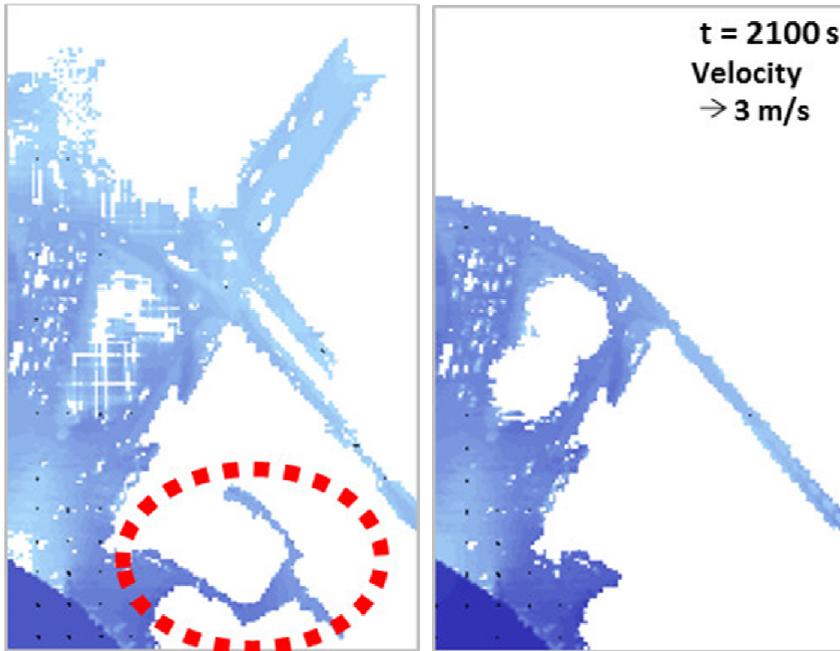


Fig. 4. Flood simulation results with SfM-LiDAR DTM (left) and conventional LiDAR DTM (right). The differences are found to be substantial and the 2D model based on SfM-LiDAR DTM gave more realistic results (the results were compared with the eye witness records from a flood event).

4 Conclusion

The present paper describes the differences that can be incurred due to different DTM data sets when processed at different grid resolutions and with different LiDAR filtering algorithms. In the present work, several LiDAR filtering algorithms were compared and it was found that none of them is fully reliable in capturing some important urban features.

Furthermore, the present work also considered the fusion of LiDAR data with Structure from Motion (SfM) data which proved to be capable of detecting urban features that are hidden beneath vegetation and other urban structures. When compared to the conventional DTM data, the results generated with SfM-LiDAR DTM were much more close to reality and on the ground measurements.

Although numerical models are invaluable for modelling floods and flood-related disasters, the overall analysis of results presented here suggests that straightforward application of LiDAR data may restrict the predictive capability of such models. Hence, incorporation of urban features within the DTM through appropriate filtering algorithms as well as with the fusion of ground-view SfM data can lead to a significant improvement of model results.

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