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REVIEW ARTICLE

A review of flood modeling methods for urban pluvial flood application

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Abstract
Pluvial flood has been increasingly understood as a major threat that has presented a significant risk for many cities worldwide. Regarding flood risk management, flood modeling enables to understand, assess and forecast flood conditions and their impact. Likewise, several hydrodynamic models have been developed and their application has been spread. With respect to effective flood modeling, particularly in urbanized floodplains, the choice of an appropriate method, considering contextual requirements, is challenging. This paper gives an overview of prevailing flood modeling approaches in view of their potentials and limitations for modeling pluvial flood in urban settings. The existing methods are categorized into: rapid flood spreading, one-dimensional sewer, overland flow (1D and 2D), sewer-surface coupling approaches (1D–1D and 1D–2D). Each of these techniques is described, by taking aspects influencing the selection of a proper flood modeling method for a particular application into account. This paper would help urban flood managers, and potential users undertake effective flood modeling tasks, balancing between their needs, model complexity and requirements of both input data and time.

Keywords Urban flood · Flood risk · Hydrodynamic model · Flood hazard · Floodplain

Introduction

Nowadays, flood has become the supreme catastrophic natural hazard with significant economic damage and loss of lives, particularly in urban areas (Tsubaki and Fujita 2010; Bulti et al. 2019; Natarajan and Radhakrishnan 2019). Flooding in urban areas is associated with pluvial flood (Tingsanchali 2012; Bouvier et al. 2017; Rosenzweig et al. 2018; Meng et al. 2019), usually occurs when the volume of runoff exceeds the conveyance capacity of the storm sewer. Since recent decades, pluvial flood has been increasingly considered as a major threat and presented a substantial risk for many cities (Fritsch et al. 2016; Rangari et al. 2018).

In response to this adversity, flood inundation modeling has significant contributions. Flood modeling provides the distribution and extent of inundation alongside its dynamics. These are helpful input information for planning to mitigate the flood and reduce its effects (Tsubaki and Fujita 2010; Fan et al. 2017; Meng et al. 2019). The yields of real-time flood simulations can help emergency operations (Jiang et al. 2015; Gharbi et al. 2016). Modeling flood inundation has also been regarded as an effective way to plan, design and analyze the storm sewer in cities (Fan et al. 2017; Ahamed and Agarwal 2019; Laouacheria et al. 2019). It can support to assess the performance of the stormwater sewer network under severe events as well as to test and appraise the success of the operational and structural solutions. Besides, it has been applied in planning for environmental flows to uphold healthy aquatic ecosystems (Teng et al. 2017; Sisay et al. 2017; Abdulkareem et al. 2018).

Despite its benefits, reliable flood inundation modeling is not as simple as it sounds, due to the chaotic and multifaceted nature of flooding (Basnayaka and Sarukkalige 2011; Freer et al. 2013; Bellos et al. 2017; Fan et al. 2017). Numerous hydrodynamic models have been developed for determining the flood conditions through diverse methods. Their applications have also been realized through commercial and open-source simulation tools (Henonin et al. 2013; Jiang et al. 2015). From application point of view, different applications require diverse kinds of information and level

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of accuracy. As an example, flood risk assessment in urban areas relies on the precision of critical flow representation. The flow velocity should be sensibly modeled for flood damage assessment, while the maximum water depth and extent of inundation could be sufficient for hazard mapping, water resource planning and environmental flow assessment. Moreover, shorter computational time is needed for real-time applications, as precise information could be unusable if it is not accessible at the required time. Of these reflections, imply the users to reasonably select a model, balancing between their needs, modeling requirements and computational efficiency. This poses more demand for knowledge about the aspects of the underlying modeling methods attributed to the available hydrodynamic models.

The present paper aims to provide an overview of the existing flood inundation modeling methods for application for pluvial flood in urban settings. The relation between rainfall and runoff has been discussed, largely in hydrological literature. In order to assist urban-oriented readers in coming to grasp with this vast literature, the rainfall–runoff process in urban areas and the primer of urban pluvial flooding are presented. Following this, a review of existing flood modeling approaches is presented while discussing their advantages and limitations towards modeling urban pluvial flood.

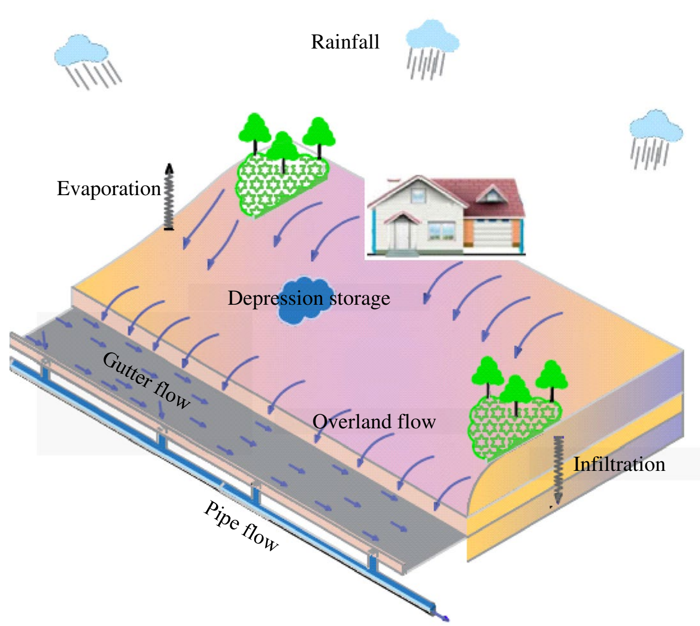
Urban hydrological process

Rainfall-runoff in urban areas

Flood modeling needs an adequate understanding of important processes that occur in the drainage system from the input (rainfall) to the output (outflow) (Josef 2012; Jaafar et al. 2015). Figure 1 demonstrates the rainfall–runoff process in urban regions. Rainfall, a prominent type of precipitation, is the main source of runoff in most urban areas (Butler and Davies 2011; Tingsanchali 2012). It is usually expressed as a depth of liquid water measured in millimeters, indicating the water depth that would store on the ground surface, if all the rain remained where it had dropped. The amount of the rainfall fluctuates over time and space. The variation is small for storms with short duration and small distances (Loucks et al. 2005; Subramanya 2008). Intense rainfall tends to originate from small rain cells, approximately one kilometer in diameter. Such storms, usually last for a short period and their intensity changes considerably in space. Conversely, the fluctuation in intensity is smaller for extended storm events, arising from the larger rainfall cells.

Not all rainwater falling on the catchment surface is converted to runoff, rather it is subjected to initial and continuing losses. Initial loss refers to the portion of stormwater conserved on vegetation and buildings. It also includes rainwater trapped in surface puddles, and ditches occur on any surfaces, paved or otherwise. The volume of initial loss is commonly considered as a minimum quantity of rainfall causing runoff (Loucks et al. 2005). On the other hand, continuing loss occurs as a result of the processes of infiltration and evapotranspiration, and they are assumed to proceed as far as the stormwater is available on the surface of the ground. The amount of both types of losses relies on the catchment characteristics and duration of the storm. For instance, in urbanized catchment with dominant impervious surfaces, the loss prior to runoff is smaller for periods with intense rainfall (Josef 2012). Infiltration is usually higher at

Fig. 1 Schematic representation of rainfall–runoff processes in urban areas



the start of a rain and tends to diminish exponentially, once the soil became saturated (Gupta 2017).

If the amount of precipitation exceeds the combined initial and continuing losses, the excess rain known as runoff starts flowing across the surface to enter the drainage network. The flow will be changed to gutter flow as it reaches streets or natural flow paths. Finally, it becomes pipe flow once it enters the storm water drainage system.

Urban pluvial flooding

The main processes explained in "Rainfall-runoff in urban areas" section are useful in flow modeling in urban settings if the discharge is less than the conveyance capacity of the storm sewer system. However, when the capacity is reached or exceeded, the exceedance flow is induced refers to *pluvial flood*. The exceedance can occur either before the water reaches the minor drainage system or when outflow from the system occurs, or as the combination of the two cases (Rosenzweig et al. 2018).

The dual-drainage concept is usually used to explain the exceedance flow (Fig. 2). It divides the urban drainage system into two components: minor system and major system (Maksimović et al. 2009; Simões et al. 2011; Rao and Ramana 2015). The minor drainage system encompasses the traditional storm drainage hardware (manholes, gully inlets, storm sewer and roadside ditches) and culverted watercourses. This drainage system is generally capable of conveying the flow during more frequent storm conditions with the flow kept below the ground surface. The major drainage system is the route followed by stormwater when

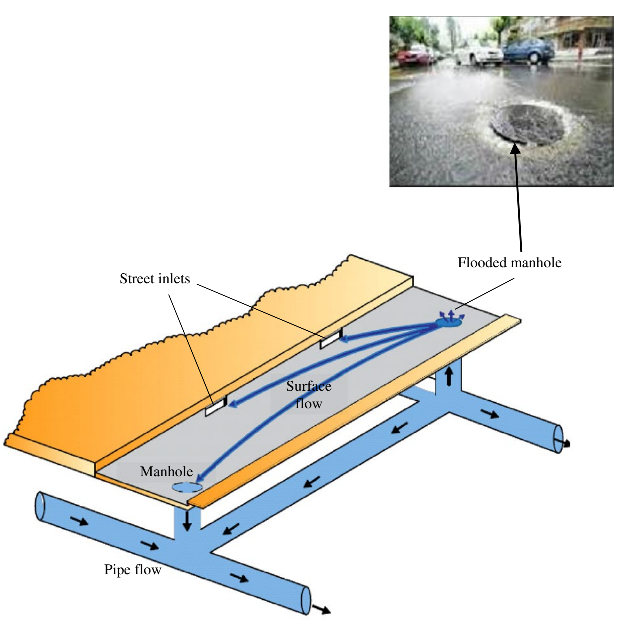


Fig. 2 Illustration of dual-drainage concept

the conveyance capacity of the minor drainage system is surpassed (Jahanbazi and Egger 2014). It consists of the flow pathways along the surface whose primary purpose is generally not to convey flow, such as streets and other artificial and natural channels and temporary storage areas (e.g., Playing Fields).

The interface points of the minor and major systems are vital features of exceedance. The flow exchange between the two systems takes place at gully inlets, manholes and river outfalls (Leandro et al. 2009; Hénonin et al. 2015). Generally, gully inlets are provided for runoff to enter into the storm sewer and manholes are access points for maintenance and services of the storm sewer. Nonetheless, if the conveyance capacity of the storm sewer is reached or the inlets are obstructed, water cannot enter into the system and will be retained on the surface. Likewise, if the capacity of the sewer is surpassed, the water can exit the system at the inlets and manholes. The river outfalls are also used as outlet points for the minor system, yet if the level of water in the receiving watercourse rises, a backwater can be formed and induces exceedance.

Flood modeling approaches

There are various underlying approaches for modeling flood inundation attributed to the existing hydrodynamic models. They can be categorized as: rapid flood spreading (RFS), one-dimensional sewer (1D-S), one-dimensional overland (1D), two-dimensional overland (2D), coupling sewer-overland (1D–1D and 1D–2D). The selection of a proper method for a particular flood modeling application needs to take various factors into account. The underlying modeling technique should be capable of representing important flood processes, as accurate results of flood modeling can only be derived if no important process is missed out (Butler and Davies 2011). Potential outputs are also needed to meet requirements of the intended applications in terms of quality and type (Chen et al. 2014; RainGain 2015). Further, the time required for computation should be feasible to meet the run-time requirements of the planned applications (Moore et al. 2015; Teng et al. 2017), as accurate information would be useless, if it is not available at the right time. Finally, the collection and processing of the required input data must be feasible within the modeling project period and also the availability of other kinds of resources, like hardware, technical skills and simulation tools. These facets were taken into concern to guide the extraction of information from the documents, such as journal articles, guidelines and reports related to the respective approaches. The features of each of the inundation modeling methods are discussed within the remainder of this section, and Tables 1 and 2 show the summary of the main features of the methods.

Table 1 Potentials of modeling approaches to represent dominant flow process and likely outputs

Modelling approach	Overland flow representation	Outputs (Inundation characteristics)				Main spatial data required
		Overflow Location	Inundation extent	Inundation depth	Flow velocity	
RFS	No	No	Yes, but only the final state	Yes, but only the final state	No	DTM
1D surface	Yes, but only in surface networks	No	Yes, but only in surface networks	Yes, but only in surface networks	Yes, but in one-direction	DTM, Surface networks (major system)
1D sewer	No	Yes	Yes, but approximation with virtual storage	Yes, but approximation with virtual storage	No	DTM, Stormwater drainage network (minor system)
2d surface	Yes, in 2D	No	Yes	Yes	Yes, in two-direction	DTM and Topographic data
1D–1D coupled	Yes, but only in surface networks	Yes	Yes, but only in surface networks	Yes, but only in surface networks	Yes, one directional	DTM, surface networks and stormwater drainage network
1D–2D coupled	Yes, in 2D	Yes	Yes	Yes	Yes, two directional	Surface network, sewer network and Topographic data, DTM

Table 2 Relative accuracy, run-time requirements and suitable scale of applications of flood modeling approaches

Model type	Accuracy for flood risk analysis	Run-time	Suitable spatial scale of application
	Low	*One minute*	*Macro*
RFS 1D surface 1D sewer 1D-1D coupled 2D surface 1D-2D coupled	↓	↓	↓
	High	*Hours*	*Micro*

Rapid flood spreading

Rapid flood spreading (RFS) method is the simplified flood simulation approach that takes the total floodwater volume as an input and spread over the floodplain (Liu and Pender 2010; Bernini and Franchini 2013). The spreading of the floodwater is carried out based on the flat-water supposition, in which the levels of water in neighboring cells are equalized (Yang et al. 2015). The floodwater is assigned to local low points in the respective impact zones and can also cross the boundaries of the zones.

The overall process involves two stages: pre-calculation routine and inundation routine. In the former stage, areas where the storm water accumulates during flood events known as impact zones are delineated using a digital terrain model (DTM). In addition, an array of grid cells (storage cells) is established on the floodplain (Fig. 3), and then, the cell with lower elevation is identified in which the spreading of floodwater starts. In the later stage, using the total volume of floodwater from respective zones, the inundation is computed by spreading the volume over the individual grid cells (Krupka et al. 2007). The process starts by filling the lowest cell adjacent to the input points and spilling the excess to the neighboring cells. This process is repeated till the inundation reaches its final state, i.e., no excess volume of water. The output is a gird of the floodwater depth of the floodplain area.

This approach mainly requires terrain data and two minutes or less, for computation (Liu et al. 2015; Yang et al. 2015; Shen et al. 2016), enabling a several scenarios to be built and

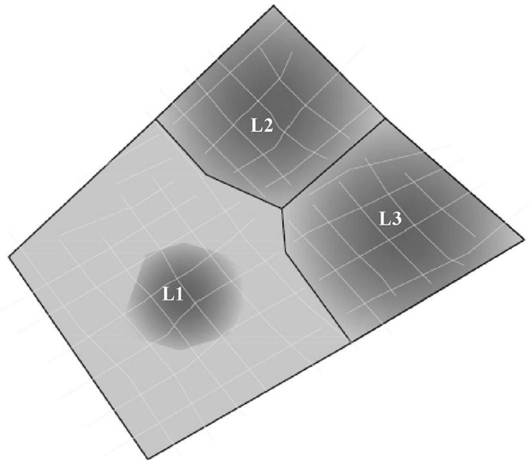


Fig. 3 Illustration of flood catchment delineation for rapid flood spreading (L: pit cell)

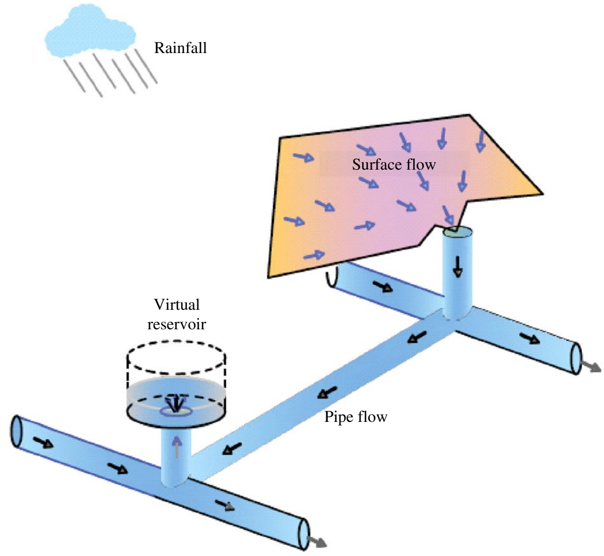


Fig. 4 Illustration of 1D sewer flow modeling approach, showing the virtual reservoir at the flooded manhole

run. However, the result can only show the final state of inundation and fail to describe actual flood information, such as sources of the flood, flow pathways, flow velocity and duration (Lhomme et al. 2009; Fritsch et al. 2016). Moreover, it does not contemplate the effects of the flow in the minor drainage system. RFS method is recommended when an overview of the flooding condition in the general basin is required, and for rapid assessment, specifically when adequate input data to run complex models are not available (Aksoy et al. 2016). It can also be used in probabilistic models that consider defense failure, involving the analysis of a range of loading with various defense failure combinations (Liu and Pender 2012).

One-dimensional sewer

One-dimensional (1D) for sewer flow modeling approach attempts to simulate the flow in the storm sewer and simplify the situations when the system conveyance capacity is exceeded. It represents the minor system as a set of links (represent conduits) and nodes (represent manhole or gullies). With this approach, the overflow is considered as stagnant water temporarily stored in a virtual storage on the top of the manholes (Fig. 4), and it is supposed that the water starts returning from the storage when the situation of hydraulic head in the node permits (Henonin et al. 2013). The hydraulics are solved using the Saint–Venant equations: continuity equation (Eq. 1) and dynamic equation (Eq. 2).

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = 0 \tag{1}$$

$$\frac{\partial Q}{\partial t} + \frac{\partial\left(\frac{Q^2}{A}\right)}{\partial x} + gA\frac{\partial y}{\partial x} - gA\left(S_0 - S_f\right) = 0 \tag{2}$$

where Q discharge (m^3/s), t time (s), A area of the wet cross section (m^2), x distance (m), y flow depth (m), B water surface width (m), g gravity acceleration; S_0 bed slope, S_f friction slope.

Storm sewer network and DTM are the main spatial data for modeling flood inundation using this method. The required time for computation ranges from 1 min to 1 h (Chen et al. 2014; Henonin et al. 2013), allowing to run multiple scenarios. This approach enables to identify the potential overflow locations and the corresponding volume of floodwater accurately. The volume of overflowed water at each node can help to identify the distribution of hotspots. It can also be used for approximating the average inundation depth over the storage cross section. Nonetheless, besides the challenges associated to, how to define the dimensions of the virtual storage, the floodwater depth computed in the reservoir rarely represents the realistic behavior of the floodwater (Mark et al. 2004; Jiang et al. 2015). Therefore, the floodwater depth may not be determined precisely.

This modeling approach is suitable for urban applications, normally for planning and management of storm water drainage (Walsh et al. 2014; Zhu et al. 2016; Ahamed and Agarwal 2019). They are also recommended for rapid studies that do not require too much precision of surface runoff routing, including real-time application, emergency operation and early warning (Jiang et al. 2015; Gharbi et al. 2016).

Overland flow modeling

One-dimensional surface

One-dimensional (1D) modeling of surface flow aims to represent the major system flow in one dimension. In this case, the floodplain is discretized as a set of linked nodes (Leandro et al. 2009; RainGain 2015). The links represent surface flow pathways, and characterized by linear geometry. The nodes represent ponds and junctions, and characterized by storage capacity and represented by nodes. The surface network is extracted manually or automatically from digital elevation models (DEM) of the floodplain using different tools, such as Automatic Overland Flow Delineation. With this technique, the floodplain is deemed as a user-defined network of open channels and ponds. The governing equations are solved similar to pipe flow ("one-dimensional sewer" section).

Modeling flood inundation using this approach requires few types of input data (DTM and surface networks) and short run-time (Abderrezzak et al. 2009; RainGain 2015), but the setup of models of this type seems to be time demanding (Henonin et al. 2013). This modeling technique allows to determine the characteristics of inundation as far as the flow is well channeled and the water is confined within the surface network (RainGain 2015). However, it is not capable of simulating multidirectional flow conditions, for instance, when the flow overtops the street curbs (Basnayaka and Sarukkalige 2011; Chen et al. 2014). Besides, since it does not take the impacts of the flow in the minor drainage system into account, the accuracy of the output information can be affected. Accordingly, the application of 1D modeling of overland flow is limited when it comes to the development of precise and reliable flood maps.

Two-dimensional surface

Two-dimensional (2D) modeling of surface flow attempts to model the overland flow propagation, by taking the two orthogonal components of the flow into account. In this approach, the catchment is discretized as a structured or unstructured mesh of hydraulic grid cells. Structured mesh usually consists quadrilateral cells, whereas unstructured type is composed of triangular or mixed triangular and quadrilateral cells (Kim et al. 2014). Every grid cell is depicted by a point with coordinates (X, Y, Z), and the catchment parameters and rainfall are assumed to be spatially homogeneous within each element (RainGain 2015). The hydraulics are solved using the two-dimensional shallow water equations: continuity equation (Eq. 3) and dynamic equations.

$$\frac{\partial h}{\partial t} + \frac{\partial (hu)}{\partial x} + \frac{\partial (hv)}{\partial y} = 0 \tag{3}$$

$$\frac{\partial (hu)}{\partial t} + \frac{\partial \left(hu^2 + \frac{1}{2}gh^2\right)}{\partial x} + \frac{\partial (huv)}{\partial y} = gh\left(S_{0x} - S_{\mathrm{fx}}\right) \tag{4}$$

$$\frac{\partial (hv)}{\partial t} + \frac{\partial (huv)}{\partial x} + \frac{\partial \left(hv^2 + \frac{1}{2}gh^2\right)}{\partial y} = gh\left(S_{0y} - S_{\mathrm{fy}}\right) \tag{5}$$

where h water depth (m); g acceleration of gravity (m^2/s); u and v depth-averaged velocity (m/s) components in X and Y directions, respectively; S_{0x} and S_{fx} water surface gradient and friction resistance in X direction; S_{0y} and S_{fy} water surface gradient and friction resistance in Y direction.

2D modeling of surface flow enables to determine maximum inundation extent and dynamics of the flow, such as water depth and velocity (Liu et al. 2012). In addition, the capability of representing the flow around small scale topographic features is the main advantage of this method that makes it suitable for application in urban settings (Hénonin et al. 2015; Nkwunonwo et al. 2020). Nonetheless, the accuracy is at the expense of high capability of the computing tools, high-resolution DEM and more computational time, generally more than one hour (Moore et al. 2015; Chang et al. 2015).

Urban applications require a fine 2D grid, usually less than 5 m for accurate simulation of the flow on streets and around the buildings (Mark et al. 2004). Likewise, high-resolution topographic data are needed to represent small urban features (Nielsen et al. 2008; Gourbesville 2009). However, it should be noted that decreasing the size of hydraulic grid cells increases the density of the mesh, and requires more run-time (Fewtrell et al. 2008; Liu and Pender 2012; Shen et al. 2015; Gharbi et al. 2016). Although 2D surface flow models can provide descriptions of the overland flow propagation, it fails to provide overflow locations and to represent in channel flow, particularly for narrow watercourses. Further, such models do not consider the influences of the flow in the minor drainage system, and therefore, the accuracy of the output information could be affected. Accordingly, this approach is more suitable for applications in urban areas where there is no actual stormwater drainage or the influence of stormwater drainage is considered insignificant on the flood phenomenon under the study.

Coupled sewer-surface

1D–1D

1D–1D (sewer-surface) coupling is a condition in which a one-dimensional for minor system flow is coupled with a one-dimensional representation of surface flow. In this case, the floodplain is treated as a user-defined network of open channels and ponds connected to the stormwater drainage system (Fig. 5). This approach enables to capture the interaction between the belowground flow and aboveground flow (Mark et al. 2004). The flow exchanges bi-directionally (i.e., Surcharging and spilling) between the two systems and takes place through coupling links: gully inlets and manholes (Leandro et al. 2009; Hénonin et al. 2015). In this case, the overflowed water at the nodes is directly discharged on the surface network to surcharge the surface flow.

The main input data include surface network, stormwater drainage network and DTM. Using moderate computation time, ranging from 5 min to 1 h, this approach enables to determine overflow location, flow-depth and velocity (one-dimension) with sufficient accuracy, assuming that the surface flowpaths are well defined (Henonin et al. 2013; Bisht et al. 2016; Kourtis et al. 2017). Conversely, it is not capable of providing the flood information when the water leaves the defined surface flow pathways. Accordingly, this modeling approach is suggested for planning and management of storm sewer, early warning and emergency operation.

1D–2D

1D–2D (sewer–surface) coupled method is a condition in which a 1D sewer flow is connected with a 2D surface flow representation. The flow interaction between the two systems takes place at the gullies and manholes and 2D grid cells (Jahanbazi and Egger 2014). In this approach, the flow

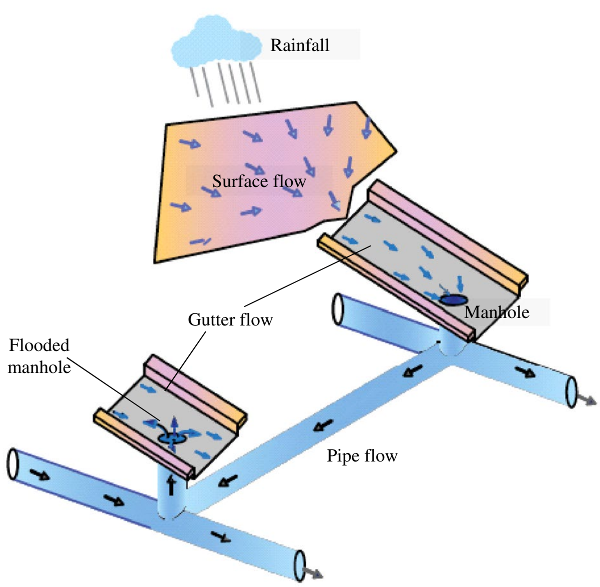


Fig. 5 Illustration of 1D–1D coupled modeling approach, simulating the flow in major and minor drainage systems

in the minor system is modeled in one-dimensional, while the surface flow is modeled as a two-dimensional problem.

The applications of 1D–2D coupled modeling method for a complex urban topography have been realized (Tayefi et al. 2007; Leitão 2009; Aksoy et al. 2016; Schlauß and Grottker 2016). This mode of coupling enables to determine the flood information (overflow location, extent, depth and velocity). The results of the simulations using this technique are more accurate than other methods (Hankin et al. 2008; Rangari et al. 2018), yet it attains this accuracy at the cost of high computational burden in terms of run-time and data requirements (Bamford et al. 2008; Leandro et al. 2009; Schlauß and Grottker 2016; Kourtis et al. 2017). This is usually considered as the main limitation of 1D–2D modeling approach when it comes to real-time simulations. Moreover, it leads to applications for smaller catchments or the use of a coarser-resolution terrain data in order to have an acceptable period of calculation.

This modeling approach is more suitable for the design/analysis of complex systems, in which a fully interactive analysis is required with on-site verification as appropriate and the capacity of the inlets is explicitly modeled (Vojinovic and Tutulic 2009; Butler and Davies 2011). The outputs of 1D–2D can also be used for calibrating a 1D–1D model in the absence of adequate field data (Leandro et al. 2011).

Strength of coupling

In model coupling process, the relationship between the belowground and aboveground flows can be defined in a loose or tight manner. For each of the coupling approaches (1D–1D and 1D–2D), both loose and tight coupling are possible. In a loose coupling mode, the sewer model is seen as a pre-processor to create input data for the surface model (Butler and Davies 2011). Therefore, the models can be operated in isolation and the results of the two models could be derived from different simulation software packages. This mode of coupling has been used in several urban studies (Adeogun et al. 2012; Burns et al. 2015; Bellos et al. 2017; Rangari et al. 2018). It can also be applied for analyzing and designing large systems with lower precision. For instance, the minor system can be designed accurately using 1D sewer, and then, surface conveyance capacity is defined by flow pathways determined in the field and modeled without detailed consideration of the interaction between the minor and major systems. It can also be used when explicit modeling of inlet capacity is not required, or when the flood risk level is expected in terms of areal extent or groups of properties.

In tight coupling mode, the interaction between the sewer and surface models cannot be split into distinct processes (Sui and Maggio 1999; WeiFeng et al. 2009), indicating a high level of nonlinearity. This way of coupling enables to implement real-time interactions between the two models. Governing equations for network nodes, channel ends, pipes and surface channel flow are solved simultaneously. Tightly coupled models could be operated as a single unit (single simulation package). There are several commercial and open-source simulation packages that provide such access (e.g., XPSWMM and MIKE FLOOD).

Conclusions

This paper gives a review of the state-of-the-art of prevailing flood modeling approaches in view of their potentials and limitations for modeling pluvial flood in urban settings. It shows that there are various flood modeling approaches, each of which has benefits and drawbacks for applications in urban areas. The rapid flood spreading modeling approach is easy to use and required limited data and short run-time, yet it provides only the final state of inundation. The outputs of 1D sewer encompass the overflow locations and maximum floodwater volume. In addition, by simplifying the situation of the overflow using a virtual reservoir, it helps to estimate the maximum inundation extent and floodwater depth. Still, as it is not capable of describing the surface flow, the actual flood conditions could not be predicted precisely.

Flood modeling methods for surface flow can give the dynamics of the floodwater. Nonetheless, the results of 1D surface are limited to the surface network profile and one-dimensional flow velocity, and the 2D approach requires more computation time and detailed data. Besides, both approaches do not consider the influence of the flow in the stormwater drainage system, and the accuracy of the output information can be affected. In fact, the sewer-surface coupling approach enables to represent the urban dual-drainage system, as it considers the flow exchange between the major and minor systems, and provides accurate descriptions of flood conditions. However, the 1D–1D approach cannot provide information about surface flow velocities when the flow overtops the defined surface networks. On the other hand, although the 1D–2D coupling approach is capable of providing the most accurate and detailed information, it is computationally expensive both in terms of run-time and data requirements.

Given the importance of flood modeling in flood risk management, this paper provides a comprehensive understanding of the main features of existing modeling methods, such as capabilities to represent dominant flood processes, input data requirements, potential output information and run-time requirements. Accordingly, it would help urban flood managers and potential users undertake effective modeling tasks, balancing between their needs and modeling requirements.

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Author contributions DTB has conceived of the study and made contributions in design, analysis, interpretation of the results and drafted the manuscript. BGA supervised the study and reviewed the whole content. Both authors read and approved the manuscript.

Compliance with ethical standards

Conflict of interest The authors declare that they have no competing interests.

Consent for publication We have agreed to submit for Modeling Earth Systems and Environment journal and approved the manuscript for submission.

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