Simulating the storm water runoff and drainage of the south urban district in the Taiyuan Basin with a 1D – 2D model

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Abstract. The flood of the urban in a basin might be more serious than the urban district in the plain. In this paper, we take the south urban district in the Taiyuan Basin as a case, and set up a 1D-2D model to analyse the runoff and drainage during different designed storm scenarios. The hydrological model calibrated by the designed storm and flood is taken as an inflow boundary of the plain, instead of observed data series. The 1D-2D model is used to model the drainage, surface flow, and flooding. The model shows that the flooding might occur in the urban district during the three designed 24-hour rainfalls, 20 years, 50 years and 100 years, and the roads between building blocks and the low-lying farmland might experience heavy flooding.

1. Introduction

The urban flood caused by storm water has been widely recognized as one of the main scientific issues that need to be addressed with priority[1]. The urban district is usually covered with a large amount of impervious surface which lead to the rapid runoff producing and conflux. If the urban district locates in a basin, the steep land slop could speed up the runoff producing and conflux, and the urban flood might be more serious than the urban district in the plain[2]. Modelling the runoff and drainage of the urban district in the basin could be helpful to evaluate the flood risk, make the developing scheme, and manage the storm water.

In this paper, we take the south urban district in the Taiyuan Basin as a case, and set up a 1D-2D model to analyze the runoff and drainage of the area in different designed storm scenarios. This work might be useful for flood prevention, city programming, and LID development of the Taiyuan city or other similar cases.

2. Study area

The study area is the south urban district of the city of Taiyuan which lies in the outlet of the Taiyuan Basin (Figure1). The south part of this area has the lowest elevation, and the west of it is mountain area. The Fen River flow across the area from the north to the south, and the Fengyu River (including the Kaihua Channel), Mingxian River, and Mafang River flow from the west to the east and converge into it in the area[3]. There is a rubber dam on the Fen River. Many pumps could lift the flooding water from the urban area to the river. The study area is experiencing the urbanization. The north of it has become urban area which covers by blacktops and modern buildings, while the south of it is still farmland irrigated by some channels which also are used to drain the storm water. The whole study
area could be taken as a completed drainage system, so we suppose that all the water gets into or out of the area is conveyed by the rivers and channels, except by the rainfall and evaporation[4]. As the biggest water body in the area, the Jingyang Lake could store 24 million m³ of water. There are two small ponds locate in the area. Both the lake and the ponds could be used to decrease the flood and be taken as the artificial sights in the area. Because the land slop is steep and the drainage system is incomplete, storm always leads to urban flood. Two typical urban floods occurred in the Taiyuan in 2012 and 2016, they also impacted our study area.

3. Model setup
The model is a recommended way to analyse the urban flooding[5, 6]. In order to analyse the flooding of the pipeline and land surface, we setup a 1D-2D model to simulate the runoff and drainage in the urban district located in the plain in the south of the Taiyuan Basin. The 1D conduit represents the pipelines under the ground or the irrigation channels. The 2D meshes are used to model the broad roads, wide river channels, and farmland. We introduce the model setup as follows.

3.1. Water balance
The water balance in the study area contains inflow, outflow and storage (Figure2). The Inflow contains rainfall and the external inflow. The outflow contains evaporation and external outflow. The Storage is the difference between the inflow and outflow.
3.2. Inflow
Rainfall is an important inflow of the study area. Two kinds of rainfall data are used in the study. The observed rainfall caused urban flood is used to calibrate the model. Several designed rainfalls, 20 years, 50 years and 100 years, are used to model the corresponding runoff and drainage in different scenarios.

Because we want to model the urban district located in the plain in the south of the Taiyuan Basin, the inflow of the rivers flowing across the area are the external inflow that we have to take account of. We need the observed river flow data corresponded to the observed rainfall mentioned above to calibrate the model. However, only the observed data of the Fen River could be obtained, there are no observed stations in the west mountain area. We build the hydrological model of the west mountain area, and use the hydrological model as the inflow boundary of the west area. We calibrate the hydrological model by the designed storm and flood which are calculated with the method recommended by the Shanxi Hydrology Handbook. When the observed rainfall is added to the model, it will give the inflow from the west mountain area to the urban district.

For different designed rainfalls, the corresponding inflows of the Fen River could be found in the flooding control management studies or rules. And the corresponding inflows of the west mountain area could be calculated by the hydrological model.

3.3. Outflow
Evaporation is an important outflow for the long-term modelling or water resources evaluating. In this study, we focus on the runoff and drainage during a short storm process, so we neglect the evaporation.

External outflow is the amount of water flowing out of the study area though the rivers, channels, pipelines (Figure2). The surface runoff is modelled by the 2D meshes connected by the conduits which could be taken as special channels, so we take the overland outflow as the outflow from these special channels.

3.4. Storage
Lake and pond can store the storm waters and decrease the flood. The Jinyang Lake could store 24 million m$^3$ of water\[7\]. There are two small ponds in the area which could be taken as the artificial sights in the park (Figure2). They could store 238 thousand m$^3$ of water\[4\].

A part of rainfall might infiltrate into the soil, and be stored. Soil storage capacity is a function of soil type, water table depth, and prior rainfall.
3.5. Flow process
Channel and pipeline are model by 1D conduit. Surface runoff of broad road and farmland are modelled by the 2D meshes connected by the 1D conduits. Wide rivers are model by both 1D conduits and 2D meshes. 1D conduits with irregular transects are used to model the river channel, 2D meshes are used to represent flooding. This method assumes that the water elevation in the 1D channel won’t be accounted for by the 2D mesh until the water has hit the elevation of the bank station and flooding occurs[8]. The 1D conduits and 2D meshes are directly connected by orifices which is represented as a link connecting two nodes. Both the flow in 1D conduit and 2D mesh are calculated by 1D St-Venant equations.

The rubber dam is modelled as a transverse weir. The pump is used to drain the flood ponding water at the lower location. A pump is represented as a link used to lift water to higher elevations. A pump curve describes the relation between a pump’s flow rate and conditions as its inlet and outlet nodes.

4. Result and analysis

4.1. Model Calibration
For the data-less west mountain area, a hydrological model is built to act as an inflow boundary of these west branches, instead of the observed data series. The hydrological model is calibrated by the designed storm and flood which are calculated with the method recommended by the Shanxi Hydrology Handbook. Figure shows the flood given by the hydrological model has good agreement with the designed flood based on the Shanxi hydrology handbook[9].

![Figure 3. Model calibration of the west mountain area](image)
When the west mountain area is calibrated, the observed rainfall, from July 30 to 31 in 2012, which caused urban flood, is used to calibrate the whole 1D-2D model. Because the observed system of the area is incomplete, there are only 6 flooding observation points that could be used to calibrate the 1D-2D model (Figure1), and the depths are observed at AM 1:20 on July 31. The Figure4 shows the relative error and absolute error of these points. The calibration result might be acceptable, but it is not perfect. Though most of the absolute error is under 0.2m, only the absolute error of OP1 exceeds 0.2m. The observed depth at an observation point is measured at the point, but the calculated flooding depth at the observation point is the average depth of the area which contains the point. The average depth is decided by the depth of the nearest junctions and 2D conduits. The OP1 is under an overpass, but the DEM data which is used to create the elevation of the 1D-2D model is not fine enough to display the micro topography. Most of the observed depth are less than 1m, so a small difference between the observed and calculated error could significantly affect the relative error.

4.2. Runoff and drainage corresponding to the designed storms
We model the runoff and drainage corresponding to the three designed 24-hour rainfalls, 20 years, 50 years and 100 years. All the three storms might cause the flooding in the urban district. The flooding water depth might reach 1m on the roads between building blocks. The river channel could store some water which cause the water depth deeper than 1m. The farmland locates in the west part experience heavy flooding (Figure5). The external outflow conveyed by the pipelines, rivers and channels could be more than 3 million m$^3$ (Figure6).

The topography is the most important natural factor which decides the flooding location. Because the bottom of the Fen River is higher than the land along it, the storm water in the land between the Fen River and the mountain area could not be drained to the Fen River by gravity. The pipeline and channel are very old, and cannot drain all the storm water out of the low area, so it is liable to flooding in the study area. The road is often higher than the land along it, and with the land it often makes up a depression which could become a pond during a heavy rainfall.
5. Conclusions

(1) As an alternative of observed data series, the hydrological model calibrated by the designed storm and flood could be taken as an inflow boundary of the plain. (2) If we need to take account of the river, channel, pipeline, road, and farmland, the 1D-2D model could be used to modelling the drainage, surface flow, and flooding. The 1D conduit could be used to represent the pipeline, channel, and small river. 2D meshes could be used to represent the surface runoff of broad road and farmland. Wide rivers are model by both 1D conduits and 2D meshes in order to avoid double accounting of channel volume. (3) The flooding might occur in the urban district during the three designed 24-hour rainfalls, 20 years, 50 years and 100 years. The roads between building blocks and the low-lying farmland could experience heavy flooding.

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