An evaluation of the flood diversion project due to extreme rainfall event in Taipei City

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Abstract. Governments in Taiwan attach great importance to flood control and disaster mitigation project. Good simulation and estimation in advance are the key point to prevent damages and losses caused by flood disasters. The main objective of this study is to investigate the effectiveness of the Drainage and Flood Control System in Wenshan District completed by the Taipei City Government. SWMM (Storm Water Management Model, US Environmental Protection Agency), a dynamic rainfall-runoff simulation computer program designed for runoff water quantity and quality of single or continuous events in urban areas, is utilized to perform the simulation and analysis in this study. Based on known basic data of facilities such as pipelines, channels, and water storage system, and by setting data related to typhoons and heavy rains from the past records, the runoff at a certain period in each area and the flow and depth in each pipeline are estimated and simulated. By comparing the simulation results with the results before the construction, we can evaluate the effectiveness on the Drainage and Flood diversion system and predict the possible defects. Accordingly, the engineering plan can be modified promptly before the construction to enhance the effect of flood control and disaster mitigation.

1. Background

In recent years, due to the impact of climate change, the frequency and scale of extreme hydrological events have increased. Besides, with the development of civilization, lands have been rapidly developed and utilized, such as concrete buildings, asphalt pavements, elevated roads and other facilities. They have hindered the original water cycle and reduced the flow of precipitation into the ground. This leads to increase the surface runoff flow and increase the burden on the drainage system and the drainage of the river. As a result, the extent of the disaster has risen sharply, causing harm to animals, plants, land and buildings everywhere.

Due to geographical problems, Taiwan is often harassed by typhoons and heavy rains which cause serious floods and lead to the loss of people's lives and properties. For the example of typhoon Sudile in 2015, the disaster was mainly distributed in the Greater Taipei area, and it caused many rivers to reach a level of warning [1]. Some mountain areas collapsed, traffics were interrupted, electricity power went out, etc. As stated from above, the issue of solving the flooding problem that is worth for the
government’s close attention. In order to alleviate the flooding caused by heavy rains in Fuxing Road, Wenshan District, the governments launched a water control plan to solve the flooding problem in October 2017. The plan includes diversion, flood detention and pumping station energy increasing. For example, the Fuxing Road Drainage and Sewerage Project is one of the projects to solve the flooding problems.

Through the shield tunneling method, a drainage tunnel with a diameter of 2.8 meters and a length of 631 meters was built under the ground. The rainfall runoff of the Fuxing Road is diverted to the 1st section of Xinglong Road in order to relieve the load of drainage facilities on Fuxing Road and the 2nd to 3rd sections of Xinglong Road.

The protection standard of rainfall intensity in Taipei City is 78.8 mm per hour [2]. However, the terrain in Wenshan District is low and difficult to drain, so the protection standard there is only 59.1 mm rainfall intensity per hour. Besides, the water collection range of the Sec #2 of Xinglong Road is very extensive, including the upstream catchment area of Sec #3 of Xinglong Road, Sec #4 of Xinhai Road, Xingde Road and Fuxing Road, and the drainage capacity of Xinglong trunk line is insufficient. Every time when storms occur, the water flow of Fuxing Road cannot be well discharged to the Xinglong trunk line and very easily to result in flooding.

The completion of the drainage and diversion project of Fuxing Road (shown as figure 1) will not only reduce the water volume of the Fuxing Road trunk line system, but also reduce the burden of the drainage at Sec #2 & #3 of Xinglong Road. However, from the completion of the project to the present, there has not been a strong storm with concentrated precipitation, so the actual benefits of these facilities still need to be tested. Therefore, this study is to discuss where the flooded area is located in Wenshan District, Taipei (shown as figure 2) and is conducted by SWMM software to simulate various rainfall conditions [3]. Also, this study considers comparing the results with the unfinished project and discussing the practicality of the project.

Figure 1. Completion of the drainage and diversion project of Fuxing Road.
2. Method
The analysis of this study focuses on the area of Fuxing Road, Wenshan District, Taipei. The Fuxing Road drainage diversion project under extreme rainfall events are discussed and analyzed by the five-year, ten-year, and twenty-year return period rainfall.

2.1. Hydrological analysis
   - Drawing the catchment areas by Arc-GIS software
     Arc-GIS is used to draw the catchment areas of Wenshan District and analyze slope changes of Wenshan District.
   - Generating a watershed model
     A watershed model is generated by processing, calculating, and analyzing the catchment areas drawn by the foregoing step to make the model of river basin

2.2. Hydrological analysis by combining SWMM with Arc-GIS
The study was first conducted by using the sub-catchment area obtained previously and utilizing SWMM software to draw the Wenshan District water area and different rainfall intensity data [3]. Then, the simulation of the flow conditions is set up under the conditions before and after the construction of flood diversion project. The two conditions could be used to see the effect of the Fuxing Road flood diversion project.

3. Arc-GIS analysis

3.1. Put the DEM graphic of Wenshan District to the Arc-GIS software

3.2. Fill tool
Use the Fill Tool to fill the numerical elevation map (DEM) basin to get those more realistic DEM.

3.3. Flow direction tool
The Flow Direction Tool is used to calculate the direction of the water flow. The numerical elevation map (DEM) is set to the eight-phase flow model (grid mode) and substitute each elevation into the grid. Each grid connects with 8 other grids. According to the corresponding elevation, the flow direction is obtained, just as shown in the figure 3.
3.4. Flow accumulation tool
The flow is calculated by the Flow Accumulation tool. According to the flow graph completed in the above steps to perform flow accumulation [4], as shown in figure 4.

![Figure 3. Eight-phase flow model.](image)

![Figure 4. Flow Accumulation.](image)

3.5. Basin tool
Basin tool is used to divide the different watersheds and to find out which watershed Fuxing Road is in, and then to draw one point to each confluence location by using Pour Point.

3.6. Snap pour point tool
After the pour points have been drawn, the snap pour point tool is used to convert the pour points to snap pour points. Those snap pour points are the confluence points which representing the highest flow in the area.
3.7. Creating thiessen polygon
Considering the manhole covers as rain stations, the Create Thiessen Polygon Tool is used to get the catchment areas cut by Thiessen Polygon method.

3.8. Watershed tool
The watershed then is used to divide the basin into different catchments.

3.9. Slope
A catchment area around each manhole cover is drawn and average slope is calculated.

4. SWMM analysis

4.1. Drawing the catchment area
The watershed drawn by ArcGIS is set up as the base map and the positions of the manhole covers with the Sub-Catchment Tool of SWMM is made, and finally, appropriate parameters are input and areas are as shown in figure 5.

![Figure 5. ArcGIS base map, Wenshan District, Taipei.](image)

4.2. Data of pipelines and manhole covers
Junction Node, Outflow Node and Conduit Link Tools in SWMM are used to draw the manhole covers and pipelines according to the base map. Input the appropriate parameters and the heights and depths of the man-space covers, as well as the lengths, widths, shapes, depths, and roughness of the pipelines (shown as figure 6).

4.3. Simulation of extreme rainfall intensity
Simulate the drainage system under extreme rainfall conditions, by adopting "Taipei City Rainwater and Sewage Design Protection Standard", 78.8mm rainfall per hour, to simulate. By setting a Rain Gage, entering extreme rainfall (rainfall intensity 78.8mm / hr) in the Time Series, entering the time interval, and setting the corresponding time in the Time Steps, then a simulation is run to view the flow at the rainfall intensity.

4.4. Simulation results and comparison between before and after constructions
The basic data before and after construction are completed according to the first to third steps above. After comparing the simulation results of profile plots and summary, the relationship between the inflow before and after the construction are obtained and the flood diversion benefit is calculated.
5. Results and discussion

5.1. Profile plots and summary before construction (shown as figure 7)

5.2. Profile plots and summary after construction (shown as figure 8)

5.3. Analysis of the Flood Diversion Effect After Construction

- Based on “Taipei City Rainwater and Sewage Design Protection Standard”, 78.8 mm rainfall per hour, the following results are obtained [2]. After the flood diversion, the flow could be reduced by 18.13% shown as table 1, and the improvement of the flooding situation is seen theoretically.

![Subcatchment area, Manhole covers data, Pipeline data]

![Pipeline shape]

Figure 6. SWMM parameters input.
Figure 7. Profile Plots Before Construction.

Figure 8. Profile Plots After Construction.

Table 1. Effect Analysis.

| Hours | Pre-construction | Post-construction | comparison |
|-------|------------------|-------------------|------------|
|       | Depth(m) | Total Inflow(CMS) | Depth(m) | Total Inflow(CMS) | effectiveness% |
| 00:10 | 1.1      | 2.84              | 1.04     | 2.77              | 2.46         |
| 00:20 | 1.4      | 4.66              | 1.37     | 4.02              | 13.73        |
| 00:30 | 1.43     | 5.03              | 1.37     | 4.2               | 16.50        |
| 00:40 | 1.45     | 5.16              | 1.38     | 4.34              | 15.89        |
| 00:50 | 1.48     | 5.24              | 1.41     | 4.29              | 18.13        |
Based on the “Taipei Government of twenty-year return period rainfall”, the total inflow volume in different nodes are obtained and shown as table 2. It also can be seen that the total flow could be reduced in most of the nodes after the flood diversion.

Based on the “Taipei Government of five-year, ten-year, and twenty-year return period rainfall”, the results obtained are shown as table 3. It can be seen that the heavier rainfall occurs, the inflow reducing is more effective after the construction.

### Table 2. Effect Analysis.

| Node Number | Pre-construction Total Inflow Volume 10^6 Ltr | Post-construction Total Inflow Volume 10^6 Ltr |
|-------------|---------------------------------------------|-----------------------------------------------|
| 235         | 75.6                                        | 66.7                                          |
| 258         | 4.28                                        | 4.29                                          |
| 281         | 69                                          | 59.3                                          |
| 303         | 37.8                                        | 37.2                                          |
| 323         | 22.4                                        | 15.5                                          |

### Table 3. Effect Analysis.

| Hours | Pre-construction | Post-construction | Comparison |
|-------|------------------|-------------------|------------|
|       | Depth (m) | Total Inflow (CMS) | Depth (m) | Total Inflow (CMS) | Effectiveness% |
| 01:00:00 | 0.14 | 0.12 | 0.14 | 0.12 | 0 |
| 02:00:00 | 0.37 | 0.53 | 0.36 | 0.51 | 3.77 |
| 03:00:00 | 1.18 | 3.4 | 1.13 | 3.17 | 6.76 |
| 04:00:00 | 1.18 | 2.13 | 1.17 | 2.09 | 1.88 |
| 05:00:00 | 0.74 | 0.37 | 0.7 | 0.36 | 2.70 |
| 06:00:00 | 0.63 | 0.23 | 0.63 | 0.22 | 4.35 |

### Table 4. Effect Analysis.

| Hours | Pre-construction | Post-construction | Comparison |
|-------|------------------|-------------------|------------|
|       | Depth (m) | Total Inflow (CMS) | Depth (m) | Total Inflow (CMS) | Effectiveness% |
| 01:00:00 | 0.94 | 2.31 | 0.91 | 2.18 | 5.63 |
| 02:00:00 | 1.2 | 2.87 | 1.14 | 2.54 | 11.50 |
| 03:00:00 | 1.4 | 4.59 | 1.33 | 3.72 | 18.95 |
| 04:00:00 | 1.43 | 3.68 | 1.43 | 3.28 | 10.87 |
| 05:00:00 | 1.24 | 2.71 | 1.2 | 2.29 | 15.50 |
| 06:00:00 | 1.11 | 2.33 | 1.08 | 2.17 | 6.87 |

### Table 5. Effect Analysis.

| Hours | Pre-construction | Post-construction | Comparison |
|-------|------------------|-------------------|------------|
|       | Depth (m) | Total Inflow (CMS) | Depth (m) | Total Inflow (CMS) | Effectiveness% |
| 01:00:00 | 0.98 | 2.48 | 0.95 | 2.34 | 5.65 |
| 02:00:00 | 1.25 | 3.05 | 1.18 | 2.7 | 11.48 |
| 03:00:00 | 1.45 | 4.89 | 1.36 | 3.85 | 21.27 |
| 04:00:00 | 1.47 | 4.06 | 1.45 | 3.35 | 17.49 |
| 05:00:00 | 1.28 | 3 | 1.23 | 2.41 | 19.67 |
| 06:00:00 | 1.16 | 2.54 | 1.14 | 2.35 | 7.48 |

The project used in this study focuses only on the Fuxing Road area in Wenshan District, Taipei. Because the small scope is very suitable for the first operation, experiment and attempt, this area is chosen to explore the benefits of the water management project of the Taipei Municipal Government in
Fuxing Road, Wenshan District. Through our analysis and simulation, Fuxing Road's project does have the purpose of achieving flood diversion, but an economic benefit analysis of this project have not conducted yet. It is only confirmed that the water control effect of this project through simulation, but whether it is the best solution remains to be discussed. It is suggested that continuing to work in this direction to fulfill the completion study works.

In addition, although this study only analyzes the pipeline construction in the Fuxing Road area of Wenshan District, Taipei, it is hoped that this study could be expanded to other heavily flooding areas in the future. Moreover, due to the implementation of the green urban flood diversion plan in some areas, it is possible to use facilities in many Taiwan regions to reduce damage during heavy rain. If the goal is successfully achieved in the future, the benefits of the green urban plans included in the study is suggested.

References
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