Study on Runoff Simulation in Xinglong Area Jinan Based on Low Impact Development

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Abstract. This paper uses SWMM software to build stormwater model in different land use scenarios (natural model, traditional urban development mode, low impact development mode), and simulates runoff processes of different return periods (2-year return period, 10-year return period, 20-year return period). Comparing and analyzable the runoff effect under different land use situations according to the simulation results, the result shows that the comparison from excellent to poor is followed by low impact development mode, natural mode and traditional urban development mode, it fully proved the role of low-impact development model in absorbing runoff and reducing flood peak.

1. Introduction
Low impact development (LID) is the new way of urban water environment protection and sustainable development flood management. It is a rain management way which based on simulating natural holographic condition, taking source controlling and combining control and usage of rain. Nowadays, the widely applicable simulation software of low impact development is SWMM[1]. SWMM is made by Environmental Protection Agency. It’s mainly used in simulating urban runoff process. In new edition, software adds LID (Low Impact Development) mode. It can simulate low impact development measures through parameters setting[2].

Xinglong area is important conservation of water resource, direct supply area of spring water in Jinan. Now, only Sun Lijun adjusted hydrologic cycle through taking a series of accelerating infiltration measures according to hydrographic data of Xinglong area[3]. In a word, existing studies have not used SWMM to simulate hydrologic process, and the data space is too simple and has poor direction. This paper regards Xinglong area as object of study, and builds SWMM model according to the hydrogeology conditions and related data, adjusted and checked through a lot of monitoring data of river cross section. We use checked SWMM model to simulate hydrologic process, providing support for low impact development of Xinglong area.

2. Material and methods
2.1 Study Area
Xinglong area is located at Shizhong district, Jinan. It belongs to Xingji river basin, and it is the important part of Jinan south mountain area. It is in Xingji river basin. There is seasonal descending spring in hillside, a seasonal reservoir (Xinglong reservoir) in the middle, a seasonal reservoir (Daling...
reservoir) in northeastern hillside. The topography is totally high surrounding, low center. The natural ground level is from 135m to 542m.

According to the Xinglong’s plan provided by Jinan architectural design and research institute, the total floor area is 354.51 hm². In terms of function, Xinglong area is divided into 3 groups (commercial and service district, residential district, entertainment district), the planning land block is 41. As shown in Table 1.

| Number | Group                  | Area (hm²) | Main construction project                      |
|--------|------------------------|------------|------------------------------------------------|
| 1      | Commercial and Service district | 71.07 | Office, Business retailing and Travel service |
| 2      | Residential district   | 149.4      | Residence and School                            |
| 3      | Entertainment district | 134.04     | Park                                            |
|        | Total area             | 354.51     |                                                 |

2.2. Modeling in SWMM

2.2.1. Regional Generalization. According to the geomorphologic map and drainage pipe system distribution map, following generalization rules, the study area is divided into 31 catchment area, the pipe section of drainage pipe system is 75, the node is 75, the discharge outlet is 9. Division result is shown in Figure 1, 2.

2.2.2. Parameter Rating. This paper mainly rates model under natural mode, choosing 3 catchment area according to impervious rate, above regional survey and area of impervious zone. The catchment area are much crowding center district (B7) that refers to no.1 catchment area, the imperviousness rate is 77.09%; crowding residential district (Z4) that refers to no.2 catchment area, the imperviousness rate is 66.81%; sparse entertainment district (E2) that refers to no.3 catchment area, the imperviousness rate is 27.23%.

Defining model parameter’s initial value through parameter valuing. We get every given catchment area’s calculated runoff coefficient through contrasting simulation results. Analyzing the rationality of parameter setting and using particle swarm optimization to do optimization selection for model.
parameter, we can get optimum solution of model parameter. The optimum solution is shown in Table 2.

Table 2. The optimum solution.

| Catchment area | Imperv (%) | N-imper N-perv (%) | Zerot-imperv N-perv (%) | Maxrate | Minrate | De-cav | Drying time (day) |
|----------------|------------|--------------------|-------------------------|---------|---------|--------|------------------|
| B7             | 70.09%     | 0.013              | 0.15                    | 25%     | 88.9    | 2      | 4                |
| Z4             | 61.81%     | 0.015              | 0.24                    | 25%     | 98.85   | 3      | 4                |
| E2             | 17.23%     | 0.016              | 0.24                    | 25%     | 119     | 4      | 4                |

2.3 Model validation

According to the Xinglong area’s actual runoff, checking model’s accuracy. Choosing Xinglong – Xingji river as controlling streamway, rainfall data and measured water level of Xinglong streamway as checking basis. Setting section flow of Xinglong streamway as import flow, checking and simulating changes of water level of controlling streamway. The results are shown in Figure 3 and Table 3.

Figure 3. Contrasting measured clauses with simulated clauses.

Table 3. The result of clauses validation.

| Clause       | Relative coefficient | Determination coefficient | Nash coefficient | Relative error of peak (%) |
|--------------|-----------------------|---------------------------|------------------|---------------------------|
| Water level  | 0.995                 | 0.991                      | 0.915            | 0.192                     |
| Flow         | 0.999                 | 0.999                      | 0.998            | 2.43                      |

According to the analysis of Table 3 and Figure 3, the relative coefficient, determination coefficient and nash coefficient of measured water level and simulated water level are all close to 1, the relative error of peak is 0.192%, simulated water level of controlling streamway is in allowable error (5%), simulated water level are fitting measured water level well. The relative coefficient, determination coefficient and nash coefficient of measured flow and simulated flow are all close to 1, the relative error of peak is 2.43%, it’s in allowable error (5%), simulated water level are fitting measured water level well. In a word, the relative coefficient, determination coefficient and nash coefficient of measured value and simulated value of controlling steamway, checking result is reasonable, model parameter’s setting is also reasonable.

3. Results and analysis

The paper uses rated SWMM model to investigate the controlling effect of low impact development on runoff, infiltration and evaporation capacity under different land use types.

3.1 Setting Different Rainfall Conditions

This paper choose Chicago storm pattern as design storm pattern, the duration of rainfall is 2h, relative position of rain peak is 0.4, other parameters are set by rainfall density formula of Jinan, the design return periods are 2-year return period, 10-year return period, 20-year return period, the
precipitation is 64mm, 93.2mm, 105.5mm. The rainfall schedule of 2h under different rainfall density is shown in Figure 4.

Figure 4. The rainfall schedule of 2h under different rainfall density

3.2 Runoff Simulation Under Different Land Use Types
Runoff under different land use types are mainly based on 3 land use types (natural mode, traditional urban development mode, low impact development mode) to build different models. Building urban storm models based on 3 land use types and simulating runoff volume and runoff peak of 3 land use types based on rainfall event, then showing runoff effect characteristics of different land use types.

3.2.1 Runoff simulation in natural mode. Land use type in natural mode is based on present land use. Nowadays, there are 5 villages in Xinglong area, the area of building site is about 293.55 hm². In a word, impervious area accounted for 75%, pervious area accounted for 25%. Urban runoff simulation in natural mode mainly builds SWMM model, and simulating runoff process of 2-year return period, 10-year return period, 20-year return period, the rainfall duration is 120min. The result of runoff volume, infiltration capacity and evaporation capacity are shown in Table 4 and Figure 5.

Table 4. Simulation results of different return periods.

| Clause                      | 2-year return period | 10-year return period | 20-year return period |
|-----------------------------|----------------------|-----------------------|-----------------------|
| Runoff volume / (10^4 m³)   | 372.78               | 564.96                | 624.56                |
| Infiltration capacity / (10^4 m³) | 226.24           | 433.81                | 490.29                |
| Evaporation capacity / (10^4 m³)   | 117.23             | 128.53                | 139.64                |
| Runoff coefficient           | 0.68                 | 0.703                 | 0.709                 |

According to Table 5 and Figure 5, with increase of return period, runoff volume is from 372.78*10⁴ m³ to 624.56 *10^4 m³, infiltration capacity is from 226.24*10^4 m³ to 490.29 *10⁴ m³, evaporation capacity is from 117.23*10⁴ m³ to 139.64 *10⁴ m³. Runoff volume, infiltration capacity and evaporation capacity are all in escalating trend, but runoff volume is greater than infiltration capacity. With the increase of return period, runoff coefficient is greater and greater, it’s from 0.68 to 0.709. In natural mode, with the increase of return period, runoff volume is greater and greater.
3.2.2 Runoff simulation in traditional urban development mode. Land use in traditional urban development mode is based on urban development plan of Jinan to distribute land. In this mode, the construction area is 354.51 hm², impervious area accounted for 90.41%, pervious area accounted for 9.59%. This paper is based on master planning of Jinan to build traditional urban storm model, and simulating runoff process of 2-year return period, 10-year return period, 20-year return period, the rainfall duration is 120min. The result of runoff volume, infiltration capacity and evaporation capacity are shown in Table 5 and Figure 6.

| Clause                        | 2-year return period | 10-year return period | 20-year return period |
|-------------------------------|----------------------|-----------------------|-----------------------|
| Runoff volume (10⁴m³)         | 398.45               | 588.26                | 670.80                |
| Infiltration capacity (10⁴m³) | 216.47               | 400.93                | 480.91                |
| Evaporation capacity (10⁴m³)  | 161.96               | 179.22                | 185.39                |
| Runoff coefficient            | 0.848                | 0.868                 | 0.874                 |

According to Table 6 and Figure 6, with increase of return period, runoff volume is from 398.45*10⁴ m³ to 670.8 *10⁴ m³, infiltration capacity is from 216.47*10⁴ m³ to 480.91 *10⁴ m³, evaporation capacity is from 161.96*10⁴ m³ to 185.39 *10⁴ m³. Runoff volume, infiltration capacity and evaporation capacity are all in escalating trend, but runoff volume is greater than infiltration capacity. With the increase of return period, runoff coefficient is greater and greater, it’s from 0.848 to 0.874.

3.2.3 Runoff simulation in low impact development mode. Low impact development construction of Xinglong area is mainly reformed in green park, residential district and business district, controlling rainwater in sweeping, storing, stagnating and stagnating. In this mode, simulating runoff process of 2-year return period, 10-year return period, 20-year return period, the rainfall duration is 120min. The result of runoff volume, infiltration capacity and evaporation capacity are shown in Table 6 and Figure 7.

| Clause                        | 2-year return period | 10-year return period | 20-year return period |
|-------------------------------|----------------------|-----------------------|-----------------------|
| Runoff volume (10⁴m³)         | 369.12               | 551.68                | 627.5                 |
| Infiltration capacity (10⁴m³) | 229.99               | 425.96                | 489.25                |
| Evaporation capacity (10⁴m³)  | 123.83               | 135.52                | 145.85                |
| Runoff coefficient            | 0.677                | 0.701                 | 0.706                 |
Figure 7. Runoff process of different return periods.

According to Table 8 and Figure 7, with increase of return period, runoff volume is from $369.12 \times 10^4$ m$^3$ to $627.5 \times 10^4$ m$^3$, infiltration capacity is from $229.99 \times 10^4$ m$^3$ to $489.25 \times 10^4$ m$^3$, and evaporation capacity is from $123.83 \times 10^4$ m$^3$ to $145.85 \times 10^4$ m$^3$. Runoff volume, infiltration capacity, and evaporation capacity are all in escalating trend, and the change rates are much the same. With the increase of return period, runoff coefficient is greater and greater, it’s from 0.677 to 0.706.

3.3 Comparative analysis of runoff effect

3.3.1 Comparative analysis of runoff effect between the low-impact development mode and natural mode. According to the above content, runoff volume, infiltration capacity and evaporation capacity in low impact development mode are very close to those in natural mode. The difference between low impact development mode and natural mode is very small.

3.3.2 Comparative analysis of runoff effect between the low-impact development mode and traditional urban development mode. For the runoff of low-impact development mode and traditional urban development mode in different return periods, building model based on traditional urban development mode and adding low impact development measures, getting new urban stormwater model. Simulating runoff process of low-impact development mode and traditional urban development mode in different return periods, and carrying out comparative analysis, the chosen return periods are 2-year return period, 10-year return period, 20-year return period.

Runoff volume

The runoff process of natural mode and low-impact development mode under different return periods is shown in the following figure.
Figure 8. The comparison of runoff process between the low-impact development mode and the traditional urban development mode.

According to the above simulation result, in terms of runoff volume, comparing with traditional urban development mode, runoff volume of low impact development mode reduced 29.33*10^4 m^3 in 2-year return period, 36.58*10^4 m^3 in 10-year return period, 43.3*10^4 m^3 in 20-year return period. In terms of change range of runoff curve, the change range of traditional urban development mode is larger than that of low impact development mode in different return periods, and the maximum runoff value of traditional urban development mode is greater than that of low impact development mode. The main factor resulted in it is the impermeability of city underlying surface. Impervious area of traditional urban development mode is much larger than that in low impact development mode. It shows that the low impact development plays an important role in changing urban runoff.
Figure 9. The comparison of runoff coefficient between the low-impact development mode and the traditional urban development mode.

From Figure 9, we can see that runoff coefficient curve in both modes shows the same trend with the change of time. With the extension of rainfall duration, the runoff coefficient shows an upward trend, with the change first small and then large, finally approaching zero, and finally the runoff coefficient will tend to a stable value. In these two urban development modes, the runoff coefficient increases with the decreasing proportion of water permeable area and tends to be stable at 80min. In conclusion, the low-impact development and construction model can control urban runoff effect to a large extent.

4. Conclusion
1. Firstly, we build urban stormwater model based on SWMM, it can simulate runoff process of different development modes in different return periods, and the simulation result is reasonable.
2. Through the analysis of simulation of urban runoff effect in natural mode and traditional urban development mode, the result shows impervious area traditional urban development mode is larger than that in natural mode, in the same rainfall conditions, with the increase of return period, runoff volume and runoff coefficient are greater and greater.
3. According to the low impact development plan of Xinglong area and the principle of sweeping, storing, stagnating and stagnating. Based on simulation result in low impact development mode, in different design rainfall conditions, the runoff volume, infiltration capacity, evaporation capacity and runoff coefficient becomes lower. From the simulation results of different development modes, the comparison from excellent to poor is followed by low impact development mode, natural mode and traditional urban development mode, the function of low impact development model in absorbing runoff and reducing flood peak is fully proved.

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