Simulation Study on the Effect of Sponge Transformation in Old Neighborhoods Based on XP Drainage Model Construction

Ziru Zhang
Xi’an FanYi University, Shaanxi, China
zhangziru@xafy.edu.cn

Abstract. To address the practical application of runoff reduction and control effects of sponge measures at the building plot scale, XP Drainage was applied to construct a hydrological-hydraulic model and systematically analyze the runoff reduction and control effects of three typical sponge measures, such as storage pond, recessed green space and permeable pavement, by setting up and simulating sponge modification scenarios [1]. The results show that the effect of flood peak reduction and control is recessed green area > storage pond > permeable pavement, the effect of runoff reduction and control is storage pond > recessed green area > permeable pavement, and the effect of various sponge measures on rainfall runoff reduction and delay is good for the recurrence period below 1 in 10 years, and when the rainfall recurrence period reaches 1 in 10 years and above, the proportion of runoff and flood peak reduction decreases to different degrees, and the effect of rainfall storage for high recurrence period is not The results of the study can provide important reference values for the transformation of sponge measures in Xi'an urban districts.

Keywords: XP Drainage, Old Neighborhood, Sponge Retrofit.

Since 2012, China's urban construction has entered the "stock era". On February 6, 2016, the "Opinions of the Central Committee of the Communist Party of China and the State Council on Further Strengthening Urban Planning and Construction Management" pointed out that we should orderly promote the comprehensive improvement of old residential districts and the renovation of dangerous houses and non-completed houses. As an important part of urban construction, the renovation of old neighborhoods is related to the fundamental interests of the people and is an objective demand for China to fully realize a well-off society. With the strong support of Xi'an Municipal Party Committee and Municipal Government, Xi'an City plans to renovate 1,100 old neighborhoods and 19 million square meters in 2020. At present, the city has started the renovation of 1,790 old neighborhoods with an area of 25,357,400 square meters. According to the idea of "renovating a batch of mature neighborhoods" on a rolling basis, some of the practical problems such as difficult water supply, uneven roads and unknown lights have been solved by adding new parking spaces, renovating additional green areas and implementing energy-saving renovations.

However, these top-down renovation actions cannot fundamentally solve the problems of rainwater accumulation, stagnation and utilization, and effective site utilization in the living environment of residents in old neighborhoods. In this paper, we apply XP Drainage model to construct a hydrological-hydraulic model of the building district to evaluate the runoff reduction and control effects of old district-
scale rainwater storage ponds, permeable paving, and depressed green areas, and provide a basis for the construction and renovation of sponge measures in old district renovation projects.

1. Research Methodology
In this paper, XP Drainage model is selected to build a hydrohydraulic model of the study area, which covers various sponge measures such as rain gardens, bio-retention ponds, green roofs and permeable pavements, etc. The model can truly reflect rainfall runoff by setting design parameters of sponge facilities in plane and longitudinal dimensions, including side slope coefficients, porosity and infiltration rates of different structural layers, and various types of inlets [2].

(1) Flow production simulation calculation. XP Drainage model flow production calculation adopts fixed runoff coefficient method, rainfall runoff coefficient take value with reference to the recommended value of "rainwater control and utilization engineering design specification", as shown in Table 1. Simulation effect.

Table 1. Rainfall runoff coefficients for different subsurface

| No. | Type of subsurface runoff                                      | coefficient       |
|-----|----------------------------------------------------------------|-------------------|
| 1   | various types of roofing, concrete or asphalt pavement         | 0.85 ~ 0.95       |
| 2   | stone pavement or various surfaces for asphalt gravel pavement | 0.55 ~ 0.65       |
| 3   | Graded gravel pavement                                       | 0.40 ~ 0.50       |
| 4   | dry masonry or gravel pavement                               | 0.35 ~ 0.405      |
| 5   | non-paved earth pavement                                     | 0.25 ~ 0.35       |
| 6   | Park or green space                                          | 0.10 ~ 0.20       |

(2) Confluence simulation calculation. XP Drainage model uses Friend's confluence algorithm for confluence calculation, and the calculation formula is

\[ t_c = \frac{BnL^{0.333}}{S^{0.2}} \]  

Where: \( t_c \) is the confluence time/min; \( B \) is a constant, taken as 107; \( S \) is the sub-catchment slope; \( L \) is the slope confluence path length/m; \( n \) is the roughness coefficient, paved road 0.015, bare soil 0.0275, low density grass 0.035, medium density grass 0.045, high density grass 0.06.

2. Model Construction
The main steps of model construction include (1) catchment area division: including the connection between LID facilities and the connection between LID and drainage system. According to the drainage network and the overall layout of the LID in the design drawings, the catchment area of each area is divided. (2) Catchment yield and sink model generalization: Select the appropriate yield and sink model according to the substrate characteristics of each catchment. Determine the production and sink parameters of each catchment. (3) LID facility generalization and parameter setting: corresponding parameter setting for different types of LID facilities to complete the LID facility generalization. (4) storm water runoff path generalization: LID facility overflow into the drainage system generalization, determine the connection between each LID facility and LID facility and drainage system connection type, and the type of inlet and outlet flow LID facility in excess of its treatment capacity, will overflow into the drainage channel. (5) Pollutant parameter setting: Determine the background concentration of pollutants in the catchment and the half-life of pollutant removal from the facility.

2.1 Watershed Division and Generalization
Consider the storm water drainage network, LID facility location, vertical elevation and sub-grade type factors in the as-built drawings to divide the catchment area within the plot; determine the catchment area and runoff collection direction [3].
2.2 Pipe Network Generalization
Through the construction of small area pipe network census, rainwater pipe network re-construction and renovation drawings and other information, and combined with the site survey to clarify the current situation within the small area and renovation of rainwater drainage pipe network connection relationship, the CAD pipe network information converted to model software in the network information, and build completed topology connection relationship, establish a model including pipe type, pipe diameter or channel length and width, upstream and downstream elevation, check well ground elevation and well bottom elevation, etc. database. And the missing or incorrect data are processed to check the connectivity of the pipeline network system [4].

2.3 LID Facility Generalization
Based on the construction drawings of the spongy transformation project of the building district, the relevant attributes of the low impact facilities are determined according to the design instructions, design samples, and after the site survey. According to different types of low impact facilities, such as rain gardens, grass trenches, permeable pavers, and storage ponds, set the corresponding model parameters, such as planting soil, water storage height, permeable pavement bedding layer, blind pipe diameter, overflow height, overflow well size, etc. [5].

| Grass gravel trench | Parameters |
|--------------------|------------|
| Planting soil 300mm | Thick A mixture of sand, compost and loamy soil. The main components are 60%–85% sand, 5%–10% organic content, and the clay content does not exceed 5% and the permeability coefficient is not less than 1 × 10 m/s |
| Gravel layer 600mm | Thick particle size range 20–50mm, porosity 30% |
| Blind pipe         | Diameter 100mm, pipe PE pipe, opening rate 0.3% |
| Overflow height    | Below ground elevation 50mm |
| Water storage depth| 200mm |

Table 2. Detail table for design of grass and gravel ditch

| Permeable Pavement - Garden Path | Parameters |
|----------------------------------|------------|
| Clearance on both sides of the lime slab | 100mm |
| Depth of gravel on both sides | 300mm |
| Blind tube | None |
| Overflow height | No overflow channel, loose discharge |

Table 3. Details of rain garden design

| Permeable concrete-with bedding layer | Parameters |
|--------------------------------------|------------|
| Pavement layer 30mm thick (0.5–1cm particle size) | colored (or black) permeable monolithic pavement base layer |
| Thick 90mm (1–2cm particle size) | colored permeable monolithic pavement substrate |
| Coarse sand layer 20mm thick | Coarse sand water consideration layer |
| Gravel layer Thickness 400, 600, 800mm | Grave |
| Blind pipe diameter 300mm, pipe PE, opening rate 0.3% | |
| Overflow height | Surface diffuse flow into the receiving well |

Table 4. Pervious concrete - design details of cushion design
2.4 Runoff Path Generalization

The runoff paths include four categories, which are the path generalization from the catchment to the drainage network, between the catchment and the low-impact facility, between the low-impact facility and the low-impact facility, and between the low-impact facility and the drainage network [6]. Among them, between low impact facilities and drainage network can be further divided into two ways: normal outflow from low impact facilities to the drainage network and overflow from low impact facilities to the roadway and then to the drainage network [7].

![Figure 1](image.png)

**Figure 1.** Schematic diagram of runoff path generalization

2.5 Production Sink

The SCS curve method is used in the rainfall production model to simulate the buckling and flow production characteristics of permeable and impermeable sub-bedding surfaces [8]. The SCS curve method is an internationally used simulation analysis method and is now also widely used in China. The SCS curve method equation is as follows.

\[
Q = \frac{(P - I_a)^2}{(P - I_a + S)}
\]

where, 
- \(Q\) - surface runoff, mm.
- \(P\) - amount of rainfall, mm.
- \(S\) - maximum infiltration in the watershed, mm.
- \(I_a\) - Initial loss of rainfall, mm.

The initial rainfall loss \(I_a\) is related to vegetation retention, infiltration, puddle filling, and pre-soil moisture content. In order to estimate the maximum possible infiltration of soil in the watershed, the SCS curve method proposes the runoff curve number (denoted as CN) indicator as a comprehensive parameter reflecting the characteristics of the watershed before rainfall, namely.

\[
S = \left(\frac{25400}{CN}\right) - 254
\]

The greater the CN value, the smaller the runoff, and vice versa. The main factors that determine the CN value are pre-soil moisture, soil type, vegetation cover type, management status, etc. Urban areas with different substrates the values of the runoff curve parameters can be found in the following table.

**Table 5.** Runoff Curve Parameters of different underlying surfaces

| Surface type and hydrological condition | Runoff curve parameters for different hydrological soil groups |
|----------------------------------------|-------------------------------------------------------------|
|                                        | A   | B   | C   | D   |
| Grassland Coverage <50%                | 68  | 79  | 86  | 89  |
| Grassland Cover 50%~75%                | 49  | 69  | 79  | 84  |
| Grassland Coverage >75%                | 39  | 61  | 74  | 80  |
| Parking lots, roofs, private driveways and other areas | 98  | 98  | 98  | 98  |
3. Model Rate Determination
When the model is used for effect evaluation and supporting operation and maintenance management, rate validation is required. After the model is constructed, model rate validation is performed to check the reasonableness. The monitoring data may have deviations or even local errors (flow rate monitoring is more susceptible than water level monitoring) due to the influence of sediment in the pipe network, installation conditions and other comprehensive factors. Before the model rate determination, a comprehensive analysis of the monitoring data is needed to select the actual measured data and monitoring periods with high credibility for the model rate determination [9]. In general, the hydrological-hydraulic model based on XPDrainage model has reasonable and reliable parameters and high simulation accuracy, which can be used for simulation analysis of different rainfall scenarios. The results of the simulation parameter rate determination [10].

The model rate determination is mainly based on comparative flow data and uses the Nash-Sutcliffe efficiency factor (NSE) the NSE indicators are calculated as follows.

\[
E_{ns} = 1 - \frac{\sum_{i=1}^{n} (Q_{s} - Q_{m})^2}{\sum_{i=1}^{n} (Q_{s} - Q_{a})^2}
\]  

Where, \(Q_{m}\), \(Q_{s}\), \(Q_{a}\) are model simulation value, actual observed value, actual observed average value respectively; \(n\) is Number of observed data. The Nash-Sutcliffe coefficient \((E_{ns})\) indicates the deviation of the measured value from the simulated value, and the value ranges from \((-\infty, 1)\), the closer to 1, the smaller the deviation of the simulated value from the measured value, the better the simulation effect, \(E_{ns}<0\), the simulation reliability is low, \(E_{ns}>0.5\), the simulation effect is good. When \(E_{ns} \geq 0.65\), the simulation result is very good.

4. Conclusion
This paper takes the old building district as the study area, establishes the building district scale flooding model based on XP Drainage model, introduces the application simulation model XP Drainage, and focuses on the model construction steps and methods of XP Drainage low impact development simulation software, mainly divided into six steps: catchment division and generalization, pipe network generalization, LID facility generalization, runoff path generalization The model is divided into six steps, including catchment delineation and generalization, pipe network generalization, LID facility generalization, runoff path generalization, runoff production and sink simulation, and storm water runoff pollution simulation. The computational principles of the model are outlined, and the advantages of the XP Drainage model in the simulation of low impact development are described. The set of model design parameters obtained through the rate and validation of the measured data is generally applicable to the evaluation of the effect of spongiosity retrofitting projects in old urban areas of Xi’an city.

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