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Research on planning of the integration of urban and rural areas, and construction of landscape green space system, of Lucheng City

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ABSTRACT

Lucheng City has a long history, and now is the only county-level city which belongs to Shanxi Province. This city has a small population of people which are relatively concentrated. The economy of this city is based on the coal industry, which results in the fact that the secondary industry dominates while the primary and tertiary ones obviously fall behind. To respond to the call of our nation, which is that 'balance the development between the urban and rural', and to meet the needs of the urban development, it is essential to make some detailed strategies. Especially, the construction of the landscape green space system plays an important role in this process. This paper focuses on the drainage purposes of this system. In addition, to enhance this city's drainage function, it is also demanding to optimize its drainage system, which in this paper we concentrate on the urban sewer system. In this paper, we apply two mathematical models into the drainage analysis and optimization, which are the soil water characteristic curve (SWCC) method and urban sewer system model (USSM), respectively.

KEYWORDS

Lucheng city; Soil water characteristic curve; Urban sewer system model.

INTRODUCTION

Lucheng has a small population of whom the agricultural ones account for the majority. And its economy is based on the coal industry. This leads to that the secondary industry take up most of its industrial structure (as shown in Figure 1). Since our nation has come up with the planning 'balance the development between the urban and rural', which will accelerate the rate of urbanization, it will provide us many chances to develop Lucheng.

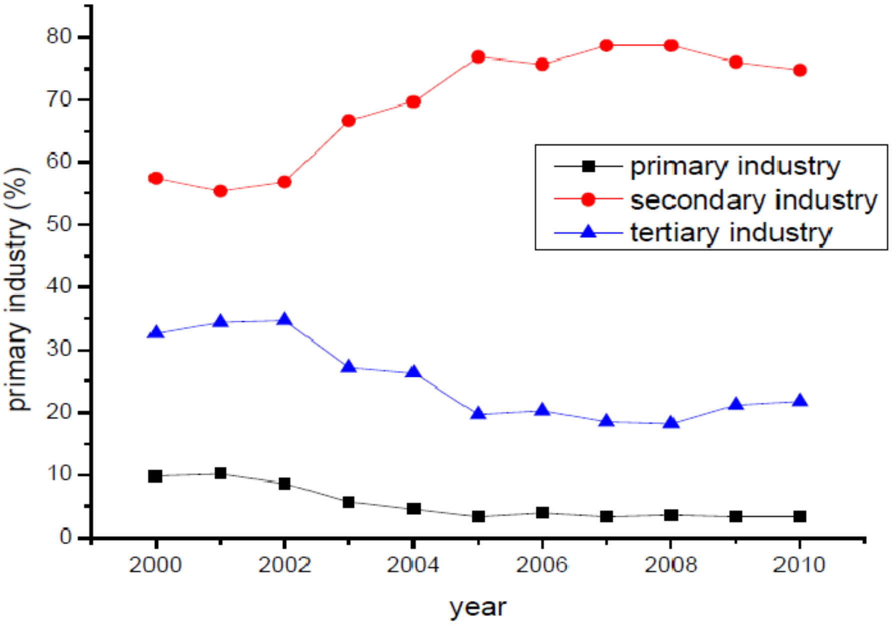

Figure 1: Industrial structure of Lucheng

Therefore, making specific plans and taking concrete measures appears rather urgent and important in this planning.

Since the 20th century, the global areas have experienced unprecedented urban sprawl and rapid population growth, which exacerbates the water consumption and causes the worldwide water resource shortage. In addition, the increased hard ground needed in the modern city building process weakens the water permeability of the surfaces greatly, and raises the surface runoff thereby. Hence, urban storm water issues should be taken into consideration in the process of the urban modernization, and now is also a topic which all countries concentrate on.

In the process of the urbanization, the safety problems caused by the damage to natural water cycle are not rare and shouldn't be ignored, which is the same challenge that the global areas all face up to. The developed countries are more experienced in dealing with the urban storm water issues since they have gone through massive urbanization earlier. And they have developed relatively mature theoretical systems and technical specifications. There have been more than 40 countries in the world conducting the research about the storm water management and utilization since the concept of rainwater planning was proposed in 1970s in America. Up to now, America, England, Australia, German and some other countries have produced complete technology.

Besides, to enhance Lucheng's drainage performance, we introduce the urban sewer system model in this paper, which is widely used in the optimization of the urban drainage reliability[1-6].

SPECIFIC PLANNING

To implement the specific measures of the planning, we consider the following aspects in this paper.

Planning of urban land layout

The development of the construction land of Lucheng presents two main characteristics which should be attached importance to. The first one is that the residential land holds larger proportion. The residential land in built-up areas occupies 345.76 hectares, which takes up 30.22% of the total area, which is higher than the average level among the cities in Shanxi Province. This shows that the relocation and transformation of the old residential is inadequate, and the phenomenon of ‘urban villages in the city’ hasn’t been well dealt with. The other one is that the urban green space, especially the public green is little compared to other cities in China, and needs to be improved at once. The two points mentioned above indicate that the land structure and layout of Lucheng is not reasonable and needs some adjustment.

We propose 4 principles that the overall planning of the land should follow[1,2]:

a). This planning should create and reflect city features;

b). Optimize the urban functional layout;

c). Enhance the advantage of the natural environment and build a garden city;

d). Combine the short-term planning with the long-term one, and try to make a progressive development.

According to the rules, we summarize the functional layout of the planning land as ‘one core, one area and three industrial groups’. The core refers to the central urban area; the area refers to Tianji Area; and the industrial groups refer to Tianji industrial group, Wangqu and Jinshui industrial group, central urban area industrial group, respectively.

Planning of the drainage project

The water needed to be drained is divided into two categories, of which one is the domestic and industrial waste water and the other is rainwater.

For urban domestic water, it can be discharged into the sewers directly which ends in the sewage treatment plant in the west of the city. And the industrial wastewater can be drained to the newly built-up sewage treatment plant.

The urban sewage system is made up of the sewage pipe networks distributed in the urban district and the sewage treatment plant. The sewage pipe networks include two parts, one of which is the urban central area system and the other one is the Tianji industrial group system. The trunk sewers are placed in the middle of the urban paths. The peripheral sewage enters the trunk pipe from the outside to inside, through which the water will run to the sewage treatment plant. The soil thickness which covers the sewage pipes should be 2.5m on average, and the diameter of the pipes should be between 400 to 800 mm.

For rainwater, we have to calculate the rainfall intensity at first. According to eq. (1), we can have a good knowledge of the local rainfall intensity.

$$q = 432.36(1+\lg P) / t^{0.635} \qquad \textbf{(1)}$$

In eq. (1), q is the rainfall intensity, whose unit is L/(s·ha), of which ha means hectare. P is the rainfall return period, whose unit is a, which means year. ***t*** is the total time the rainfall lasts, whose unit is s.

With the formula above, we can predict the rainfall in this area. Thus it will provide some guidance to the design of the capacity of the drainage pipes.

The drainage system gives priority to the ditches and underground pipes, and should be combined with the terrain of the blocks and streets[3,4].

Planning of the construction of urban landscape green space

The total area of the green land in Lucheng has achieved 2.555 million m^2 at the end of 2010, among which the public green land occupies 0.6384 million m^2. The green coverage is 24.9% and the green rate is 35%. The park green area per capita is 9.36 m^2.

The urban green space system consists of 5 parts, which are the parkland, green area for environmental protection, square green area, appendage green area and aesthetic forests, respectively. It is an important intermediary in recovering the natural water cycle, enhancing the circulation between the surface and underground water. The green space system can be used for the storage and drainage of the rainwater since it has permeable soil. Thus, this system can be used to improve the urban water environment[5].

The urban green space plays an significant role in connecting the urban and natural water environment. Concerning about the urban waterlogging, rainfall runoff pollution and the shortage of water resource and so on, it stands out by implementing its eco-efficiency. This system has a better effect in waterlogging prevention, compared with improving water qualities and implementing the re-use of rainwater[6].

Therefore, it is necessary to make several rules to follow, which are as follows:

a). Ecological priority;

b). Take the measure to increase the green area that suit the local circumstances;

c). Balance the overall effectiveness between the economic and environmental effectiveness.

In a word, this paper focuses on the construction of the green space, of which the storm water management is attached most importance to. To enhance the drainage performance, we also use two models which are the soil water characteristic curve method (SWCC) and urban sewer system model (USSM), respectively.

CONSTRUCTION OF GREEN SPACE SYSTEM

As mentioned in the former part of this paper, it is necessary to take the storm water management capability into account in the planning of the green space system. Therefore, this part focuses on the design and optimization of this system's water management capability. We apply the soil water characteristic curve (SWCC) method in this part to analyze the water storage capability.

As shown in Figure 2, SWCC method includes many models which could be used in different conditions.

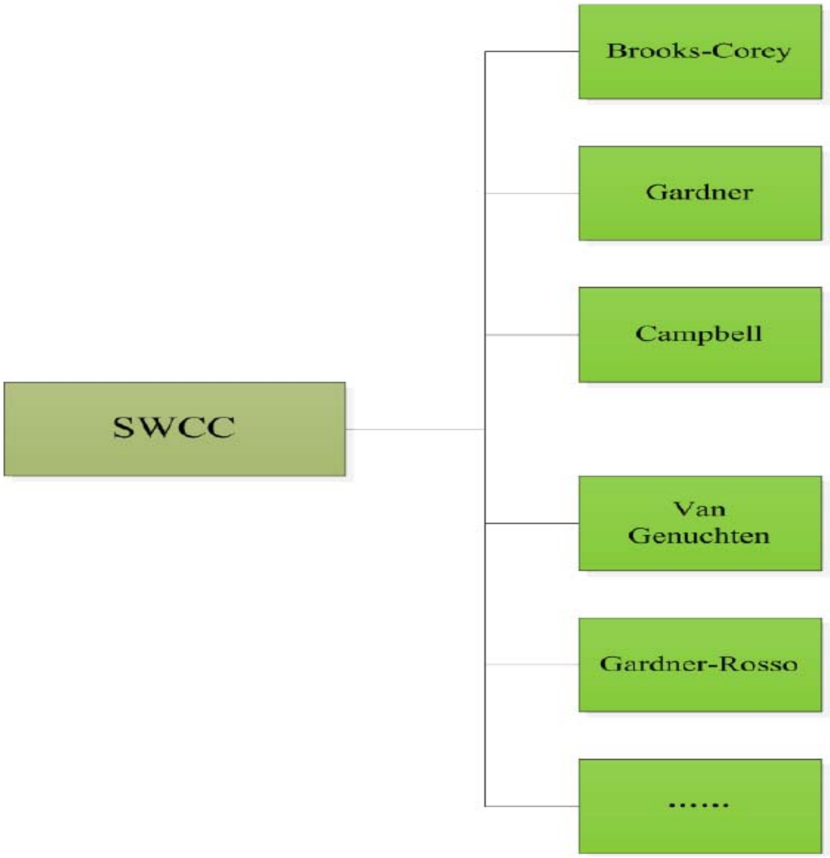

Figure 2: Component models of SWCC

Analysis of soil infiltration properties

Urban rainwater runoff is a significant part of the water resource which urban green space needs, and can reduce the pressure of drainage in flood seasons, besides. The infiltration property of soil is the most important factor that affects the surface irrigation performance, and it is also an essential reference in the design of ground irrigation system. Therefore, it is necessary to select feasible infiltration models and accurate parameters.

Horton model which is shown in eq. (2), is the most accurate compared to other model listed in Figure 2.

$$Z = \gamma(1 - e^{-r_m T}) + \delta T \tag{2}$$

where $\boldsymbol{Z}$: cumulative infiltration, cm
γ: constant parameter, cm
r_m: constant parameter, min^{-1}
T: infiltration time, min
δ: constant parameter, cm/min

To get the constant parameters, we use particle swarm optimization to make the residual sum of square minimum. The formula is shown as follows.

$$\min S_2 = \sum_{j=1}^{n} (Z_j - \hat{Z}_j)^2 \tag{3}$$

where S_2: residual sum of square, cm^2
Z_j: observed value of j-th cumulative infiltration, cm
$\hat{Z}_j$: simulated value of j-th cumulative infiltration, cm

With this algorithm, we could get the parameters used in Horton model. TABLE 1 shows the observed values and simulated values in six different cases.

TABLE 1: Comparison of observed and simulated values of six cases

case	Observed (cm)	Simulated (cm)
1	0.95	1.06
2	2.17	2.04
3	2.30	2.22
4	2.49	2.41
5	2.78	2.90
6	2.95	3.05

From TABLE 1, we can obviously see that simulated values match well with the observed values and it indicates Horton model is rather accurate in describing and predicting the infiltration performance of soil.

Analysis of vertical transport of water

The infiltration process is closely linked with the transport of moisture in soil. This part introduces the HYDRUS-1D model which has an excellent performance in simulating the water transport process. This model takes the water transport, heat transport and the hysteresis and so on. Therefore, this model can be used to simulate porous media and saturated/non-saturated conditions.

For boundary conditions, we can choose flux boundary, atmosphere boundary and seepage boundary and so on. Crank-Nicholson finite element method is used in temporal discretion; and Galerkin finite method is applied in spatial discretion.

The transport equation of moisture is as follows from eq. (4) to eq. (12):

$$\frac{\partial\theta}{\partial t}=\frac{\partial}{\partial z}\left[K\left(\frac{\partial h}{\partial z}-1\right)\right]-S(z,t) \tag{4}$$

$$\theta_e=\frac{\theta-\theta_r}{\theta_s-\theta_r}=(1+\left|\alpha h\right|^n)^{-m} \tag{5}$$

$$K(h)=K_s\theta_e^l\left[1-(1-\theta_e^{l/m})^m\right]^2 \tag{6}$$

$$S(z,t)=\alpha(h,t)\cdot b(z)\cdot T_p \tag{7}$$

$$\alpha(h)=\begin{cases}1\cdots\cdots\cdots\cdots\cdots h_1\le h<0\\ \dfrac{h-h_2}{h_2-h_1}\cdots\cdots\cdots h_2\le h<h_1\\ 0\cdots\cdots\cdots\cdots\cdots h\le h_2\end{cases} \tag{8}$$

$$b(z)=\frac{b^{'}(z)}{\int_{L_R}b^{'}(z)dz} \tag{9}$$

$$T_p=ET_0(1-e^{-K\cdot LAI}) \tag{10}$$

$$LAI=0.24GH \tag{11}$$

$$IC=0.25LAI(1-\frac{1}{1+SCF\cdot PR/(0.25LAI)}) \tag{12}$$

where $\boldsymbol{K}$: hydraulic conductivity of unsaturated soil, cm/h
$\boldsymbol{K_s}$: hydraulic conductivity of saturated soil, cm/h
$\boldsymbol{\theta_e}$: effective rate of moisture, dimensionless
$\boldsymbol{\theta}$: rate of moisture, dimensionless
$\boldsymbol{\theta_r}$: residual rate of moisture, dimensionless
$\boldsymbol{\theta_s}$: saturated rate of moisture, dimensionless
$\boldsymbol{l}$: empirical factor, dimensionless
$\boldsymbol{t}$: time, h
$\boldsymbol{z}$: depth of soil, cm
$\boldsymbol{h}$: pressure of the water attraction of soil, kPa
$\boldsymbol{\alpha}$: scale parameter, cm^{-1}
$\boldsymbol{n, m}$: soil moisture characteristic parameters, dimensionless (rest of the parameters can be seen in[8])

For the boundary conditions, we can use the first boundary condition (see eq. (13)), the second boundary condition (see eq. (14)) and the free drainage boundary condition (see eq. (15)).

$$h(x,t)\big|_{x=0,L} = h(t)\big|_{x=0,L} \tag{13}$$

$$(-K\frac{\partial h}{\partial z}+K)\big|_{z=0,L} = q(t)\big|_{z=0,L} \tag{14}$$

$$\frac{\partial h}{\partial z}\big|_{z=L} = 0 \tag{15}$$

Using the HYDRUS-1D model, the simulation was done to compare with three different cases, which is shown in TABLE 2.

TABLE 2: Degree of agreement between the observed and simulated values

Depth (cm)	Case 1	Case 2	Case 3
0	bad	middle	bad
5	middle	good	good
20	excellent	excellent	excellent
60	excellent	excellent	excellent
145	good	excellent	good

HYDRUS-1D model can describe the infiltration process of urban green land well, and it also predict the rainfall runoff so accurately that the linearity degree of the simulated and observed values reaches 0.9876, which is rather good compared to other models.

Due to the high performance of the model, it is used to analyze the effects of the rainfall intensity, soil type and the concave depth to the detention and storage of rainwater in this paper.

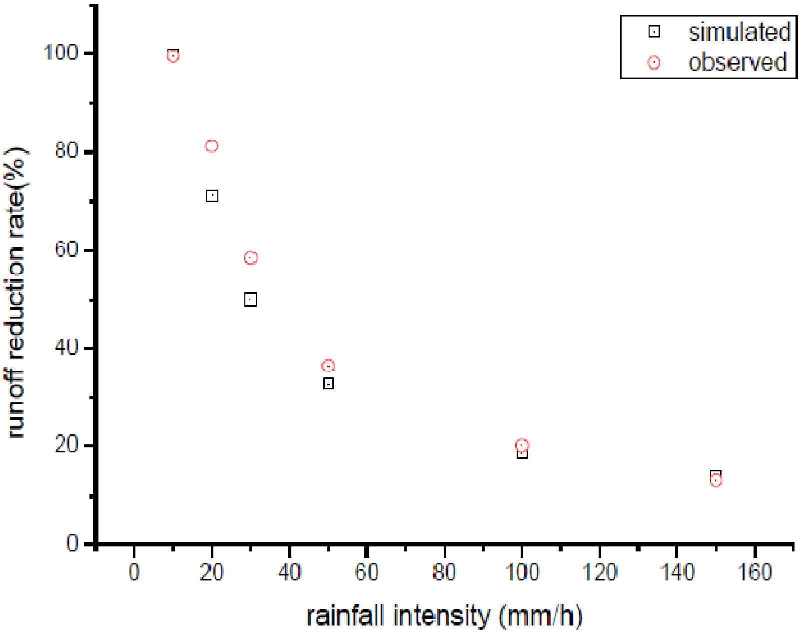

Figure 3: Rainfall intensity VS. Runoff reduction rate

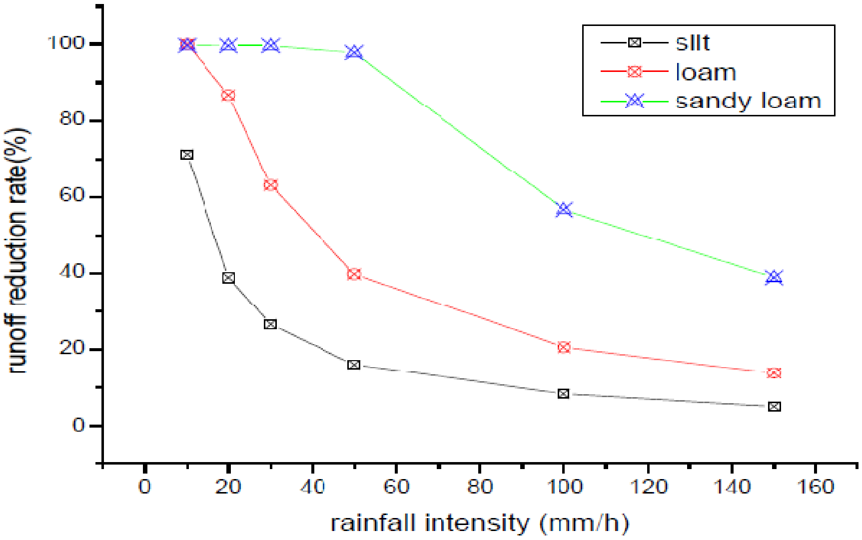

Figure 4: Soil types VS. Runoff reduction rate

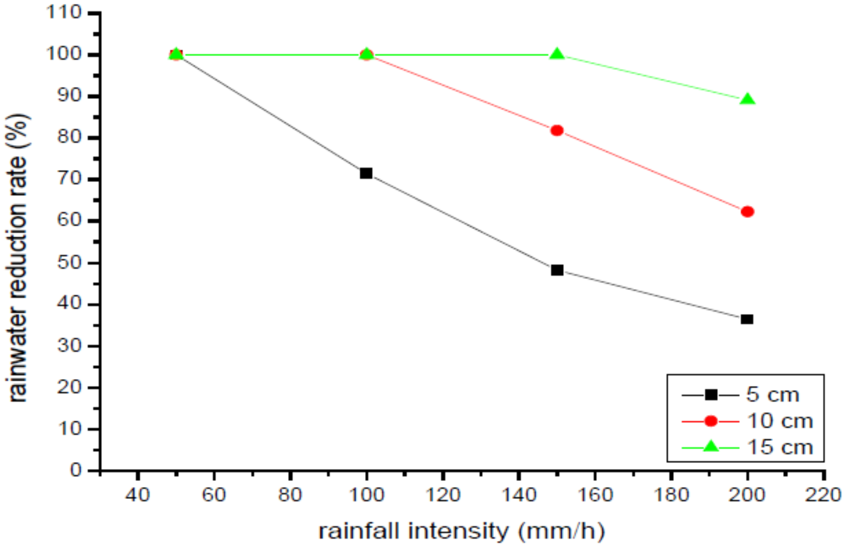

Figure 5: Concave depth VS. Runoff reduction rate

From Figure 3, we can see clearly that with the growth of rainfall intensity, the runoff reduction rate decreases from 100% to 18% gradually and the decline rate becomes slow with the rainfall intensity. Figure 4 shows us that sandy loam is the best material in reducing rainwater runoff, and silt is the worst among the three soil types listed. In the same way, we can see from Figure 5 that, the rainfall reduction performance will be better as the concaves deepen.

In conclusion, rainfall intensity, soil types and concave depth all have important impacts on the rainfall reduction property. The SWCC method provides a platform to describe and predict the rainfall runoff reduction of green land based on hydraulic theories[7,8,9].

OPTIMIZATION OF URBAN SEWER SYSTEM

The construction of the sewer systems are attached more and more attention to in recent years since it plays the most important role in urban drainage and could weaken or remove the damage brought by floods. However, it is so complex to manage the process of the urban drainage that we have to request the help from mathematic models to help us have a better understanding of it. To meet the urgent need, hundreds of models burst out in recent years to fulfill different needs. These models have a positive effect on undermining the damage caused by storms or floods and reasonable use of water resource.

In this part, we especially introduce the urban sewer system model (USSM) because of its superiority over other models.

USSM includes three sub-models, which are rainfall model, ground runoff model and the network convergence model respectively.

In terms of the rainfall model, Chicago approach (CHK) is widely used and we choose it as the method applied in the rainfall model. With this method, we get the instantaneous rainfall intensity which is shown in eq. (16) and (17).

$$i_a = \frac{a}{\left(t_1/r+b\right)^c}\left(1-\frac{ct_1}{t_1+rb}\right) \tag{16}$$

$$i_b = \frac{a}{\left(t_2/(1-r)+b\right)^c}\left(1-\frac{ct_2}{t_2+(1-r)b}\right) \tag{17}$$

where $\boldsymbol{i_a}$, $\boldsymbol{i_b}$: instantaneous rainfall intensity of the ascent and descent periods, respectively

$\boldsymbol{a, b, c}$: local parameters

$\boldsymbol{t_1, t_2}$: time before and after the peak

$\boldsymbol{r}$: parameter of the rain peak

When it comes to the ground runoff model, several models related to the physical properties of water are developed during the development process of the urban sewer systems, such as isochrones method, kinetic wave method and nonlinear reservoir method. Especially, the kinetic wave method which can be seen in eq. (18)-(19) has a rather good performance.

$$q = Zy^n \tag{18}$$

$$\frac{\partial y}{\partial t} + \frac{\partial q}{\partial x} = i_e \tag{19}$$

where $\boldsymbol{i_e}$: net intensity of rainfall

$\boldsymbol{y}$: depth of water

$\boldsymbol{Z, n}$: constant parameters

$\boldsymbol{q}$: flow flux

$\boldsymbol{x}$: length

Concerning about the network convergence model, the Saint-Venant equations are employed here which are continuity equation (eq. (20)) and energy equation (eq. (21)).

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = q \tag{20}$$

$$\frac{1}{gA}\frac{\partial Q}{\partial t} + \frac{Q}{gA}\frac{\partial}{\partial x}\left(\frac{Q}{A}\right) + \frac{\partial h}{\partial x} - (S_0 - S_f) = 0 \tag{21}$$

where $\boldsymbol{A}$: area of cross-section which has water

$\boldsymbol{Q}$: flow flux

$\boldsymbol{t}$: time

x: length along the flow direction
q: lateral inflow
g: gravity acceleration
h: depth of water
S_0: bottom slope of the pipes
S_f: height reduction of the resistance slope

With the models stated above, the USSM is a quite good platform in simulating the flow in sewer systems. This model has been used widely and reported of its excellent performance. In addition, this model can be a feasible tool for simulation and furthermore for optimization of the urban sewer systems[10,11,12].

CONCLUSION

Urbanization is an important stage that marks the level of development in a country. In China, our urbanization rate is 36% at present and will reach 70% or more in the next 40 years, which means the urbanization rate increases by almost 1% each year, that is more than 10 billion people migrate from the rural places to the urban. However, urbanization brings lots of problems when it benefits us. Especially, the ground impervious areas grow fiercely due to the rapid urbanization, which results in the disconnection between the ground runoff and underground water. And this may lead to the water resource shortage and floods.

Therefore, it is necessary to enhance the connectivity between the ground and underground water bodies. In this paper, we introduce the soil water characteristic curve (SWCC) method and urban sewer system model (USSM). They have excellent performance in describing the soil infiltration and optimization of urban sewer systems. Especially, SWCC method is emphasized in the design of landscape green space system. Besides, rainfall intensity, soil types and concave depth are quantitatively analyzed of the influences on runoff reduction rate in this paper. However, these two model are not enough to describe the details of urban drainage performance. For example, SWCC method doesn’t take slope degree into account and USSM doesn’t consider pressure loss along the pipe. All data are from previous studies and are processed for further conclusion.

In spite of the imperfections mentioned above, this paper offers a significant reference on the design and optimization of urban water circulation systems through combining SWCC and USSM methods.

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