The Optimization Plan of Urban Drainage System of Shenyang City

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Abstract: This article takes the characters of urban as premise, based on the domestic and foreign theories of urban drainage system, to put forward the construction of storage detention and drainage combined modern urban drainage system. This article takes Shenyang city for example, through the dynamitic programming, applying the theory of dynamitic optimization, planning the optimization urban drainage system of Shenyang city. It can be known after calculation and analysis that the urban drainage system combining with storage detention and drainage has great significance on economics society and ecology. [Nature and Science. 2005;3(2):36-42].

Keywords: urban drainage; rainwater utilization; dynamic optimization theory; Shenyang

1. Introduction

Urban is the central part of politics economics culture and education of an area, also it is the impacted part and the vicissitude of the urban will affect the development of the area.

While about 90 percent of cities in China are by the rivers or seas, all the cities are liable to have flood and water logging disasters. Flood will submerge the cities and destruct the productions and affect the lives. It will take great losses to our country. Because of the special character of flood, almost all the countries have flood problems. With the development of social economic and product forces, more and more people and treasure will be assembled in cities, so if there is a flood and water logging disaster, the losses in cities will greatly surpass those in other areas.

In order to improve the standard of flood control, China has done much control work. All the length of urban levees in China has been 6500km by 1985, which protected cities effectively. While following the construction of flood control engineering and improvement of dispatching capacity, the chances that having water logging disasters are improved owing to the lift of the water level in river course. Urban can't stand up to the impact of water logging disasters.

As we all know, cities of China are short of water. Its per capita water resources are lower than the national standard that is $1000m^3$. Over excavating ground water leads to the decline of ground water level and subsidence of ground and formation of the underground funnel. So cities of China have serous flood and water logging disasters and at the same time are short of water resources, adding the importance of protecting environment, it is high time that we put forward a modern urban drainage system.

Modern urban drainage system will combine the flood and water logging disasters elimination with rainwater percolation and the utilization of rainwater. It will decrease the cost of urban drainage system and protect the water quality and environment, and have great significance to the construction of our cities.

2. Theory Of Urban Drainage and Its Calculating Methods

Urban drainage is the drainage of urban rainfall and protection of people's productions and lives from being submerged. It can use lakes, depressions, river channels and pits to detent waterlog, reducing the pressure of urban drainage.

According to the present states and characters of cities in China, it is reasonable to construct the modern urban drainage system. The modern urban drainage system is taking urban dewatering as a part of urban drainage, combining with the constructions of urban depressions, urban rivers etc, formation the urban drainage system that the combination of storage detention and drainage. It will increase water storage space as well as deduce the loss of water logging.

2.1 Urban Dewatering

Urban dewatering is the constructions of drains network of any urban departments, draining the rainstorm water of urban small areas. The task of urban dewatering is collecting and draining the rainfall, preventing from immerging of housing areas and industry and enterprise areas, protecting urban people's lives and treasures. It is rainstorm intensity formula and rainwater discharge formula to derive the designed rainwater discharge.

2.1.1 Calculated formula of discharge

Designed rainwater discharge is not only the important reference of deciding the profile dimension but also the standard of checking the capability of urban rainwater drains network. Because the area of collecting urban rainwater is small, it often uses the inference formula to calculate the designed rainwater discharge:

$$Q=\varphi F q \qquad (1)$$

There: Q—design rainwater discharge(L/s)

φ—runoff coefficient, it is smaller than one;

F—collecting area（ha）

q—design rainstorm intensity(L/(s・ha))

2.1.2 The formula of rainstorm intensity

Rainstorm intensity formula is the relations among rainstorm intensity I (or q)—rainfall duration t—reoccurrence P. In china the rainfall intensity formula in used is:

$$q=\frac{167A_1(1+cl_gP)}{(t+b)^n} \qquad (2)$$

where: q—design rainfall intensity（L/(s·ha)）; p—designed reoccurrence（a）

t—rainfall duration（min）; A_1、c、b、n—local parameter, decided in statistical methods.

2.1.3 Runoff coefficient

Runoff coefficient φ relates to collecting area, slope of ground, density and distribution of constructions, geomorphic state and paving material etc. It is difficult to determine the runoff coefficient accurately. Usually it is empirical value determined by ground covers shown in Table 1.

Table 1. Runoff coefficient

Variety of ground covers	φ	Variety of ground covers	φ
All kinds of roofs and concretes and asphalt pavements	0.90	Dry brick and macadam pavement	0.40
Block stone pavement and macadam pavement treated with asphalt surface	0.60	Not paved earth road surface	0.30
Graded macadam pavement	0.45	Park and grassland	0.15

2.2 Urban rainwater utilization

Urban rainwater utilization is the use of construction and non-construction measures, impounding and utilizing the urban rainwater, reducing the chances of water logging disasters and adding the water resources of urban, improving the water ecological environment, constructing a water loved and water saved society.

There are many kinds of forms that urban rainwater is used, the main forms are infiltration and median water utilization.

(1) Infiltration to supply the ground water

An important method to use rainwater is enforcing the infiltration with all kinds of artificial measures, making more rainwater penetrate into the ground. It can not only improve the urban ecological environment but also reduce the discharge of downstream and decrease the harm of flood and water logging .There are many measure in infiltration. One of them is using permeable material to construct parking and street and pedestrian way ground surface. The second is constructing storage infiltration system: collecting the runoff on the road, after the treatments of device between water and oil and filter, supplying the ground water or irrigating the plants by the roads. It also can use percolation pits and leaky pipes to adding the infiltration.

(2) Median water utilization

Median water utilization is mainly using the roof rainwater which is easy to be collected and has high quality, after treatment it can be used for the supply resources of greening spraying streets etc. Through analyzing the quantity and quality of rainwater, the utilized rainwater quantity can be calculated by the formula:

$$Q=\Psi\cdot\alpha\cdot\beta\cdot A\cdot(H\cdot 10^{-3}) \qquad (3)$$

where: Q—annual average utilized quantity of roof rainwater, m^3;

Ψ—runoff coefficient, it is 0.9;

α—seasonal reduction coefficient;

β—primary waste coefficient;

A—roof level projection area,m^2;

H—annual average rainfall, mm.

Seasonal reduction coefficient α should be divided by analysis of multi-years statistical data from local meteorological department; primary waste coefficient β should be determined by rainfall data and water quality.

3. Research Method of Optimization Plan of Urban Drainage System

There are many measures in improving the urban drainage capacity. Under the condition that attains the designed standard of drainage, how to place the reasonable ratio of all kinds of drainage measures so that when the capacity is given the cost to the measures is the smallest or when the cost is given the capacity to the drainage is the biggest is the problem of optimization plan. Because the relation between engineering measure and cost or engineering measure and drainage capacity is complex, and it is difficult to description. So it has special significance using DDDP to optimize the drainage system.

Although the model of urban drainage system is a one-dimensional problem of DP, its state variable and decide variable is continuous, and its feasible fields are big. If using DP method to study the model, the storage and calculation quantity will surpass the capacity of the computer. So DDDP is the best method to study the model. DDDP method doesn't optimize in all feasible fields but in the some scope of test trace, after successive optimizing, it will attain the best-optimized trace. In the optimization of urban drainage system the DDDP method is often used to simply the calculation.

According to the relation between state variable and decide variable of each phase, we can construct the system formula:

$$S_n = S_{n-1} + x_n(d_n) \quad n = 1,2,3,\ldots N \qquad (4)$$

boundary conditions are $S_0 = 0, S_N \geq W$,

where: W—designed runoff of drainage district.

Adopting sequence succession, the recurrence formula is:

$$\begin{cases} f^*_n(S_n) = \min\limits_{d_n} \{L(S_n, d_n) + f^*_{n-1}(S_{n-1})\} & n = 1,2,3,\ldots N \\ f^*_0(S_0) = 0 \end{cases} \qquad (5)$$

Where: $f^*_n(S_n)$ ——the lowest investment of 1～n stages.

Under the restrict conditions of system equation boundary conditions water balance engineering dimension cost labor and equipments etc, urban drainage system can be optimized. According to the successive equations, urban drainage system can be optimized by phases and we can achieve the best-optimized strategy including engineering dimensions and locations. Because the problem of urban drainage is not a protruding programming, it is needed to seek the best-optimized strategy from different original strategies.

4. Optimization Plan of Urban Drainage System of Shenyang City

4.1 General situation of Shenyang city

Shenyang is the central part of politics economics and culture technology of Liaoning province; and it is the biggest city transportation hinge and material distributing center of northeast region of China. Entire area of Shenyang city is 12,980km^2. The physiognomy of Shenyang gives priority to plain. Shenyang is the transition belt of hill of east of Liaoning province to the alluvial plain of Liao. There are muddy river, thin river, pu river etc. natural rivers and new opening river, such as south canal guard project river, among which muddy river is the main river.

It begins in 1903 that urban drainage network of Shenyang constructed. After many years continue and improvement, there are three rainwater drainage systems, and the all drainage area is 186.97km^2. By the year of 1993, the length of drainage network is 1691km; the drainage network density is 9.14km/km^2, the rate of popularization of it is 88.4%. There are 31 pumping stations in Shenyang including corrupting raining and cloverleaf junction pumping stations. The drainage system of Shenyang is confluence's system or cut-flow confluence's system, and parts of them are distributary's system.

Among the three rainwater drainage systems, there are peace district, Shenhe district, south of Dadong ,part of Dongling and east of Tiexi district Xinghua Street in south drainage system, the all area of it is 74.09km^2; there are west of Tiexi district Xinhua Street and building exploitation section of Shenyang in west drainage system, the all area of it is 44km^2 not including exploitation section of Shenyang; there are Huanggu district north of Dadong district in north drainage system, the all area of it is 68.88 km^2. There are 31 pumping stations in Shenyang drainage system such as Wuai, Gongnong, Congshandong, Congshanxi, Zhonggong, Lianhelu, Zhulin, Jingqin and so on.

The construction of urban drainage system of Shenyang lags to the development of urbanization. During the planning and constructing of city, it takes much important to the new constructions of urban drainage while do less on the inhere urban drainage measures which leads to the non-corollary of the drainage measures and restrict the sustainable development of Shenyang city, and it can not meet the requirement of the market economy development.

4.2 The plan of urban drainage system of Shenyang city

Based on the problems in urban drainage system of Shenyang city and plan thought of urban drainage, we plan the urban drainage system of Shenyang city. On account of there are three urban drainage districts in Shenyang city and the optimization method to each district is the same, we take the south drainage district for example to plan the optimized system of urban drainage. The plan of urban drainage of Shenyang city is shown in Figure 1.

4.2.1 Construction of Mathematics Models of Urban Drainage System

Studying out the urban drainage standard of Shenyang city is half an hour's rainfall to be drained in one hour while the working hour of pumping station is one hour. The reservoir quantum of urban drainage measures is decided by the style of drainage engineering, the material function relation as follows:

Roof rainwater reservoir quantum is $x1 = \Psi q \beta A t d_1$; grassland reservoir quantum is: $x2 = H_2 A d_2$;

Lakes reservoir quantum is $x3 = H_3 A d_3$; river network reservoir quantum is $x4 = H_4 A d_4$;

Pumping station takes out and tonnages quantum is $x5 = 0.36 T_p d_5$;

Where: d_1—the ratio of roof area, d_1 = roof area/all the drainage area，takes as decimal fraction；

d_2—the ratio of grasslands, d_2 = grasslands area/all the drainage area, takes as decimal fraction；

d_3—the ratio of lakes area, d_3 = lakes water surface area/all the drainage area, takes as decimal fraction;

d_4—the ratio of river network area, d_4 = river network water surface area/all the drainage area, takes as decimal fraction;

d_5—designed discharge of pumping station, m^3/s； A—all the drainage area, km^2;

H_2—storage deep of grasslands, m; H_3—storage deep of lakes, m;

H_4—storage deep of river networks, m; T_p—working hour of pumping station in all the drainage period, h;

Ψ—runoff coefficient, there it is 0.9; q—rainfall intensity, L/s·ha;

β—rainfall cut-flow coefficient; there it is 0.8; t—last period of rainfall, h.

Sequence and reservoir quantum of planed drainage measures in south drainage district of Shenyang city is shown in Table 2.

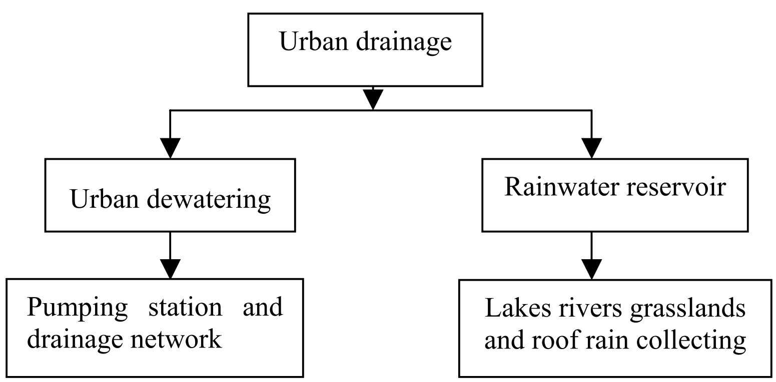

Figure 1. Plan picture of urban drainage of Shenyang city

Table 2. Drainage measurements and engineering investment

Establishment sequence	1	2	3	4	5
Drainage establishment	Roof surface collecting	Grasslands	Lakes	River networks	泵站
Reservoir quantum	$\Psi \cdot q \cdot \beta \cdot A \cdot t \cdot d_1$	$0.3A \cdot d_2$	$0.5A \cdot d_3$	$0.8A \cdot d_4$	$3600d_5$
Engineering investment (Units)	185 (Yuan/m^2)	30.2 (Yuan/m^2)	90 (Yuan/m^2)	90 (Yuan/m^2)	7 (10^4 Yuan /m^3/s)

System equation is $S_n = S_{n-1} + x_n(d_n)$

n＝1，2，3，4，5

Objection function is $\min F = \sum_{n=1}^{N} L(S_n, d_n)$

Namely min F＝$1370665d_1 + 223751.8d_2 + 666810d_3 + 666810d_4 + 7d_5$ (ten thousand Yuan)

Total runoff Q=φA q, where φ＝0.6，while

$$q = \frac{1825（1+0.774 l_g P）}{（t_1+2t_2+8）^{0.724}} = \frac{1825（1+0.774 l_g 0.7）}{（10+2\times 20+8）^{0.724}}$$

=84.93L/s·ha

Therefore Q is 37754.78 m^3/s, while W is 6796×10^4 m^3. Water equilibrium equation is

$81.55d_1+2222.7d_2+3704.5d_3+5927.2d_4+0.36d_5=6796$

4.2.2 The Calculation Method of DDDP

Given the allowed precision requirement of reducing increment ε_1＝2% and successive convergent ε_2＝10% and increment of the k time lower than the tenth of elementary increment, we calculate the model as follow steps:

（1）supposing the beginning decision of d（n）, we can calculate the engineering investment of urban drainage system which is shown in Table 3.

（2）Given the beginning increment of {□s（n）}, all the other states are discrete into 3 values except the beginning and terminal states which are fixed value. Supposing the 3 increments of □s_j（n）are 50, 0, -50, then the first iterative results of state fields derived from beginning tracks of s（n）are shown in Table 4.

（3） The first iteration. According to the state points, we can use the DP method to optimize the model. When n=5 n=4 and n=3 the optimized results are shown in Table 5, Table 6 and Table 7. While n=3 and n=2 the method to calculation is the same, so the calculation process is omitted. From Table 8 we can conclude that the minimum engineering investment is $F^1=216194.69\times10^4$ Yuan. Figuring from the given beginning states of s（0）, we can achieve the best-optimized tracks strategies and engineering investment which were shown in Table 9.

Table 3. Drainage engineering investment

Title \ Phases	0	1	2	3	4	5
Beginning decision	0	0.2	0.2	0.08	0.02	16445.2
Beginning states	0	16.31	460.85	757.21	875.754	6796
Engineering investment	500680.76					

Table 4. The state points of the first iteration process

States \ Phases	0	1	2	3	4	5
s（n）＋□s_1（n）	0	66.31	510.85	807.21	925.754	6796
s（n）＋□s_2（n）	0	16.31	460.85	757.21	875.754	6796
s（n）＋□s_3（n）	0	0	410.85	707.21	825.754	6796

Table 5. Values of optimization on n=5

Sequence of netting points	S(4)	S(5)	d(5)	F(5)	d※(5)
S(4)+△S_1(n)	925.754	6796	16306.24	114143.67	
S(4)+△S_2(n)	875.754	6796	16445.13	115115.89	
S(4)+△S_3(n)	825.754	6796	16584.02	116088.12	

notes: $d(5) = [s(5) - s(4)]\times10^4/3600; f(5) = 7\times d_5\times10^4 (Yuan)$

Table 6. Values of optimization on n=4

Sequence of netting points	S(0)	S(1)	D(1)	f(1)	$\sum_{i=1\sim5} f(i)$	d※(1)	d※(2)	d※(3)	d※(4)	d※(5)
0	0	66.31	0.813	1114350.6	1323870.13					
0	0	16.31	0.20	274131.89	488684.702					
0	0	0	0	0	216194.69	0	0.23	0.053	0.02	16584.02

Notes: $d(1) = [s(1) - s(0)] \times 10^5 / (0.9 \times 74.09 \times 84.93 \times 1800 \times 0.8)$ $f(1) = 185 \times 74.09 \times 10^2 d_1 \times 10^4 (Yuan)$

note: $d(4) = [s(4) - s(3)] / (0.8 \times 74.09 \times 10^2)$ $f(4) = 90 \times 74.09 \times 10^2 d_4 \times 10^4 (Yuan)$

Table 7. Values of optimization on n=1

Sequence of netting points	S(3)	S(4)	d(4)	f(4)	f(4)+f(5)	d※(4)	d※(5)
S(3)+△S_1(n)	807.21	925.754	0.02	13336.2	127479.87		
S(3)+△S_1(n)	807.21	875.754	0.012	8001.72	123117.61		
S(3)+△S_1(n)	807.21	825.754	0.003	200.43	118088.55	0.003	16584.02
S(3)+△S_2(n)	757.21	925.754	0.028	18961.2	133104.87		
S(3)+△S_2(n)	757.21	875.754	0.02	13336.2	128452.09		
S(3)+△S_2(n)	757.21	825.754	0.012	7711.2	123799.32	0.012	16584.02
S(3)+△S_3(n)	707.21	925.754	0.037	24586.2	138729.87		
S(3)+△S_3(n)	707.21	875.754	0.028	18961.2	134077.09		
S(3)+△S_3(n)	707.21	825.754	0.02	13336.2	129424.32	0.02	16584.02

Table 8. The optimized states strategies and engineering investment

Phases / Titles	0	1	2	3	4	5
s(n)	0	0	510.85	707.21	825.754	6796
d(n)	0	0	0.23	0.053	0.02	16584.02
Engineering investment	216194.69					

Table 9. The optimized strategies

Phases / Titles	0	1	2	3	4	5
Optimized decision	0	0	0.2467	0.0328	0.02	16688
Optimized state	0	0	548.4	669.7	788.3	6796
Engineering investment	207200					

Table 10. Optimized values on different beginning

Sequence of beginning strategies	d1	d2	d3	d4	d5	d※1	D※2	d※3	d※4	d※5	F_{min}
1	0.2	0.2	0.08	0.02	16445.2	0	0.2467	0.0328	0.02	16688	207200
2	0.1	0.1	0.05	0.04	17064.5	0	0.1430	0.0028	0.04	17308	181670
3	0.4	0.3	0.1	0.1	14259.4	0	0.3	0.0818	0.1	14502	291130

(4) Take the first improved iteration trace {s^1（n）}□as the second iteration test trace. Comparing the objection function values attained before and after iterations, we can know if it meets the condition to

reduce the increment.

$$\frac{|F^1-F^0|}{F^0}=\frac{|216194.69-500680.76|}{500680.76}=56.81\%>2\%,$$

So we do not reduce the increment.

(5) The second iteration. Firstly rounding {s^2（n）} we construct new state points by the original increment with the same method as the first iteration. Then we do the second optimized iteration with DP method on the new state points. Though iterating we can get new improved trace {s^2（n）}□ new improved strategy {d^2（n）}□ and new corresponding optimized objection function value F^2. Comparing the objection function values before and after iterations, we can conclude that if it doesn't meet the condition that reducing increment we will continue iteration at the original increment, while if it meets the condition, we will construct new corridor with the descending increment, which is half of the original increment and continue iterating calculation. When it meets the condition of reducing increment again we will reduce increment again. At the k time when iterating increment meets the condition that {□s^k（n）}≤0.1{□s^1（n）} the iteration calculation ends.

Through the discrete differential dynamic planning program in Matlab, after three iterations we can attain the best-optimized trace and best-optimized strategy that are shown in Table 9.

(6) Because this problem not always to be protruding plan, we should optimize the strategy from different beginning strategies. The calculating results are shown in Table 10.

4.2.3 Results

After optimized calculation we can conclude that under the condition of obtaining the standard of urban drainage when d_1 gets 0, d_2 gets 0.1430, d_3 gets 0.0028, d_4 gets 0.04, d_5 gets 17308 the urban drainage system gets the lowest investment that is 181670×10^4 Yuan.

5. Conclusions

This plan aims at reducing the pressure of urban drainage, combining flood control and draining water logging with the utilization of rainwater resources. It is in favor of the sustainable utilization and management of water resources and the sustainable development of social economics.

When the plan brought into effect, it will decrease the runoff effectively and delay the time of conflux and increase the capacity of drainage protecting people's lives and property adding the supplement for groundwater and in some degree relaxing the water resource crisis of Shenyang city. It can also lessen the surpass water on the roads and reduce the spread of contamination with water, improving city environment.

The combination of utilization of rainwater and engineering of gardens makes Shenyang city watery and green and creates a graceful living conditions for Shenyang city people.

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