Landscape Urban Rainwater Design and Defence-Based on Multi-Objective Optimization

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ABSTRACT: *With the continuous acceleration of urbanization, urban rainwater management has become an increasingly important issue. In urbanization, the increase in impervious areas and insufficient drainage systems have led to an increase in rainwater runoff and a risk of water quality deterioration. This article explores the application of multi-objective optimization in landscape urban rainwater design and defence. Against the backdrop of accelerating urbanization, rainwater management has become an important issue. By introducing multi-objective optimization methods, the aim is to seek a more comprehensive and effective rainwater design solution to address the impact of urbanization on rainwater.*

Keywords: Multi-Objective Optimization Algorithm, Urban Storm Flood, Landscape Design, Optimization Research

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1. Introduction

In recent years, the rainstorm disasters in our country have become increasingly frequent. According to the analysis, there are several reasons for this situation. The first is that the high-speed urbanization process has resulted in the hardening of a large amount of high-permeability natural ground and increased the initial runoff of the ground [1]. Second, the construction of drainage facilities cannot keep up with the pace of urban development and take more single-purpose engineering measures in urban stormwater systems. The lack of consideration of the integrity of aquatic ecosystems has resulted in the damage or even destruction of the ecological service functions of the natural ecosystems associated with rainwater Loss of function [2]. It is an irresistible factor that global warming in recent years, rising sea levels and the frequent occurrence of extreme weather have led to the destructive power of natural disasters. Rainfall has far exceeded the capacity of urban drainage and drainage facilities [3]. Water is the source of life, the blood of industry, the lifeblood of cities, and the rational management of water resources, which are the preconditions for sustainable urban health development. How to make disasters into available water resources is an important part of water resources utilization management in the new situation [4]. Given the actual situation of urban rainstorms in our country, how to scientifically use rainwater and floods for humanity is an important research topic for society. Among them, the construction of Cotton City is a combination of open source and festival the decision of important flow functions can effectively alleviate or even solve the problem of rain that distress people. However, it is still being implemented for various reasons [5].

2. State of the Art

Multi-objective Optimization Problems (MOPs) originated in designing, modelling and planning many practical complex systems in areas such as industrial manufacturing, urban transport, capital budgeting, forest management, reservoir management, new City layout and landscaping, energy distribution, etc. [6]. In almost every important real-life decision-making problem, there are several conflicting goals that must be considered while considering different constraints. These issues all involve optimizing multiple goals that do not exist independently. They are often the culprit. Together for competing goals, each goal has a different physical meaning and dimension [7]. Their competitiveness and complexity make it difficult to optimize them. Multi-objective optimization is a new discipline in applied mathematics developed rapidly in the last 20 years. It investigates the optimization problem in some sense when the vector objective function satisfies certain constraints. Since a large number of real-world problems can be summed up as optimization problems with multiple objectives, the research on multi-objective optimization has attracted great attention both nationally and internationally since the 1970s [8]. Especially in the past ten years, theoretical exploration has been deepened, the scope of application has been increasingly widened, and the research team has proliferated and shown great vitality. At the same time, as the research on large and complex systems in socioeconomic and engineering design progresses, the theories and methods of multi-objective optimization are continually challenged and rapidly developed [9].

3. Methodology

3.1. Multi-objective optimization of the Mathematical Model

Decision variables: Both water level and discharge volume need to be controlled, so the decision variables in the operation rules can be broadly divided into two categories. Category 1: Controlled water levels at the outlet section of the control section. From the water level *ZC*, flood control flood level or daily water level lower limit, the corresponding storage for the *VC*. Return water level *ZS*, daily water level cap, and the corresponding storage capacity for the *VS*. The highest flood storage *ZM* is the corresponding storage for the *VM*. Class 2: Control sluice outlet sluice characteristics. Maximum discharge; emergence time; peak recovery time *TS*. The statistical model determines type 2 operating rules. Under a set of *ZC ZS ZM* conditions, the floods of historical hydrological data are adjusted and calculated, and then, according to the inflow and discharge eigenvalue of each flood, through regression, Analyze and establish statistical models [10].

The objective function. Optimization guideline 1: Flood loss (expressed as disaster-prone water volume) Min

$$f_1 = \min \sum_{n=1}^{N} DW_n \tag{1}$$

Optimization Criterion 2: Xingyi Benefit (expressed as effective water storage in the river channel) is the largest

$$f_2 = \max \sum_{n=1}^{N} \sum_{t=1}^{T} \left[\left(Q_{t,n} - D_{t,n} \right) \Delta t \right] \tag{2}$$

Where *n* is the rain flood sequence number, $n = 1, ..., N$; Δt for the time step, *s*; DW_n for the n^{th} flood disaster water, m^3; $Q_{t,n}$, $D_{t,n}$ respectively for the nth flood *t* inflow and discharge flow period. *m*3/S Constraints as shown below,

$$\begin{cases} ZC < ZS < ZM \le Z_m \\ ZC_l \le ZC \le ZC_m \\ ZS_l \le ZS \le ZS_m \\ ZM_l \le ZM \le ZM_m \end{cases} \tag{3}$$

Where to allow the highest flood level; with the subscript "m" for the lower limit of the water level with subscript "*m*" for the upper limit. DW_n and $D_{t,n}$ of the objective function are non-linear functions of the decision variables. Moreover, the two sub-targets are mutually contradictory. For example, *ZC* is low, good for flood control, and *DW* is small. However, in the case of small floods, the probability of losing to *ZS* will decrease, and *f*2 will fall. So, the model has more variables and multi-objective nonlinear rules (NLP) problems.

3.2. Multi-objective Optimization Algorithm Basic Principles

The essence of MOP is that, in most cases, all sub-goals may conflict. The improvement of some sub-goals may result in the reduction of the functions of the other sub-goals. At the same time, promoting many sub-goals and vice versa is unrealistic in the range of multi-objective optimization analysis. The final solution to MOP can only be to fully measure the trade-off between each sub-goal and make each sub-objective function as optimal as possible. Therefore, a certain difference exists between the optimal solution of MOP and the optimal solution of the single-objective optimization problem. To solve MOP effectively, the definition of the solution should be summarized.

Definition 1.2 (feasible solution set): A feasible solution set X_f represents a set of decision vectors x that satisfy the constraint e (x) in formula (2-1), that is,

$$X_f = \{x \in X \mid e(x) \le 0\} \tag{4}$$

Xf feasible range associated with the target space formula is as follows:

$$Y_f = f(x_f) = Y_{x \in X_f}\{f(x)\} \tag{5}$$

For Equation (2-3), we denote all x in the feasible solution set X_f, and realize a subspace in the target space through the optimization function mapping. The relevant decision vectors in that subspace belong to the feasible solution set.

One of the subspaces, the relevant decision-making vector of that subspace, belongs to the feasible solution set.

The minimization problem can be directly converted into the above maximization problem to be solved.

The feasible solution set of single-objective optimization problems can be based on its designated objective function f to determine the relationship between the advantages and disadvantages of the method. For the MOP problem, the situation is different because, in general, the decision-making vector X_f can not be completely sorted, and only some of the indicators can be sorted, that is, local sorting.

The multi-objective optimization algorithm mainly sorts k objective functions of the MOP problem by their importance. For example, it may be assumed that the k objective functions of the MOP problem have been sorted: $f_1(x)$the most critical, $f_2(x)$ times, $f_3(x)$ again,..., and the last one represents $f_k(x)$. First, find the relevant issues:

$$\begin{cases} \quad Maximize \quad f_1(x) \\ S.t. \quad e(x) = (e_1(x), e_2(x), \ldots, e_m(x)) \le 0 \end{cases} \tag{6}$$

Optimal solution to the problem $x(1)$ and optimal value f_1*. Which is:

$$f_1^* = \underset{x \in R_1}{Max}\, f_1(x) \tag{7}$$

Among them, $R_1 = Xf$ and to solve the problem:

$$\begin{cases} Maximize \quad f_2(x) \\ \quad S.t. \quad x \in R_2 \end{cases} \tag{8}$$

Optimal solution to the problem $x(2)$ and optimal value f_2*. which is:

$$f_2^* = \underset{x \in R_2}{Max}\, f_2(x) \tag{9}$$

And $R_2 = R_1 \cap \{x \mid f_1(x) \ge f_1^*\}$, continue to solve the problem:

$$\begin{cases} Maximize \quad f_3(x) \\ S.t. \quad x \in R_3 \end{cases} \tag{10}$$

Optimal solution to the problem $x(3)$ and optimal value f_3*. which is:

$$f_3^* = \underset{x \in R_3}{Max}\, f_3(x) \tag{11}$$

And $R_3 = R_2 \cap \{x \mid f_2(x) \geq f_2^*\}$. So go on until you find the *kth* question:

$$\begin{cases} Maximize \quad f_k(x) \\ S.t. \quad x \in R_k \end{cases} \tag{12}$$

Optimal solution to the problem $x(k)$ and optimal value f_k*. which is:

$$f_k^* = \underset{x \in R_k}{Max}\, f_k(x) \tag{13}$$

And $R_k = R_{k-1} \cap \{x \mid f_{k-1}(x) \geq f^*_{k-1}\}$, the resulting $x(k)$ is the optimal solution of the MOP problem in the sense of hierarchical sequence, that is, $x^*=x(k)$.

$$F^* = (f_1(x^*), f_2(x^*), \ldots, f_k(x^*)) \tag{14}$$

F^* represents the optimal value of the MOP problem. In most cases, the optimal solution close to the single-objective optimization is not among the multiple-objective optimization problems; only the Pareto optimal solution exists. The Pareto optimal solution of multiple objective optimization problems is only one of its satisfying or non-inferior solutions that can be adopted, while the general multi-objective optimization problems often have multiple Pareto optimal solutions. Suppose a multi-objective optimization problem has a so-called optimal solution. In that case, the optimal solution must be the Pareto optimal solution, while the Pareto optimal solution comprises only those optimal solutions and does not include other solutions. So, the Pareto optimal solution is usually valid for multiple objective optimization problems. The general Pareto optimal solutions to multiple objective optimization problems belong to a category of ensembles. For the practical application problem, one or more of the Pareto optimal solutions of the multiple objective optimization problems need to be considered as the optimal solution of the numerous objective optimization problems to be solved by grasping the degree of the problem and the decision maker's preference. Therefore, the solution to multiple objective optimization problems is to find as many Pareto optimal solutions.

3.3. Multi-objective Optimization Solution

Because the non-linear function between the objective function and the decision variable is difficult to express analytically, it can only get the corresponding target value by adjusting the calculation under the control of the first category of operation rules. Therefore, the direct search method is used to seek the optimal solution. The author proposes to combine grid search with subsection control lumped water division adjustment calculation method to solve the above model and get two sub-objective values under various decision vectors $X = (ZC\ ZS\ ZM)t$, and then make multi-objective decision to obtain a satisfactory solution.

Grid search method: the *ZC ZS ZM* in the feasible domain is used by a certain number of discrete elements to form a grid. Only for the entire network-related decision-making vector to be adjusted to calculate, through a specific calculation to obtain the target value of f_1, f_2; and then select the satisfactory solution through the multi-objective decision-making program, that is, the first class of operation requirements of the three control water level(*ZC ZS ZM*).

Segmented control lumped water partitioning method: This method controls the water level and allows the maximum flood water flow requirements under the river flood adjustment calculation. Under the control of the river's exit gate, the gate's upper reach can be regarded as a storage area with the capability of detention. Given the characteristics of a river-type detention basin, the author proposes the subsection control lumped water division method to simulate flood regulation. The so-called sub-control refers to the urban area is divided into North Protection, South Care and Dongzhimen, Longtan gate to Lejia Garden, three major rivers; lumped refers to the three major sections of the rainfall-runoff, respectively, to focus on the downstream of the river control Section of the inflow process said; water cut refers to the runoff is divided into sluggish, venting, flood diversion, disaster several parts, through the water cut to determine the release process.

The basic principle of segmentation is water balance. The total amount of water in a flood control section is divided into WS water storage capacity WS, the amount of discharge DC, outward flood diversion DF and in case of heavy rain due to lack of flood control capacity caused by the amount of water DW.

$$W = WS + DC + DF + DW \tag{15}$$

According to the total amount of floods and system operation characteristics of W classification control:

Firstly, $W \le S_s (S_s = VS\text{-}VC)$, W, is fully stored in the river:

$$W = WS \tag{16}$$

Secondly, $S_s \le W \le S_m$ ($S_m = VM\text{-}VC$), the flood water is first stored in the river, part of the water after the peak discharge *DS*, the water level back to the *ZS*, as shown in Figure 1.

$$W = WS + DC\text{-}DS \tag{17}$$

Thirdly, $W \ge S_m$, according to the flood control conditions of the outflow basin, the following three conditions:

$$\begin{cases} Q_m \le QK, W = S_m + DC - DS \ \text{Not flood} \\ Q_m > QK, W = S_m + DC + DF - DS \ \text{flood} \\ Q_m > QK + QF_m, W = S_m + DC + DF + DW - DS \ \text{flood} \end{cases} \tag{18}$$

In the formula, Q_m is the peak flow, QK is the flood diversion critical flow, QF_m is the outward flow basin maximum flood flow. If the water return duration is less than two consecutive rainfall intervals, then adjust the single peak, as shown in Figure 1, 2; otherwise, according to the bimodal adjustment, shown in Figure 3.

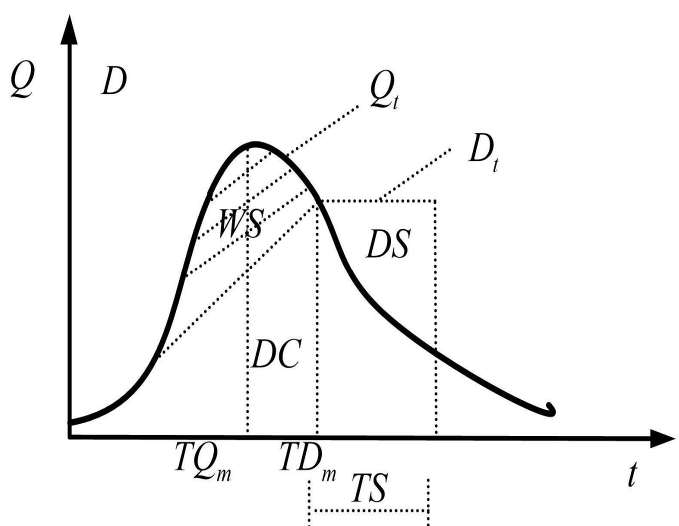


Figure 1. Unimodal regulation *a*

Drainage form of choice: To consider the benefits of flood control and prosperous, flood gates continue to open to achieve the maximum discharge D_m after D_m, until the water level sluices back to the *ZS*, will reduce the opening, the control discharge ≈ To flow, so the actual discharge part was ladder-shaped. In the analysis of operational rules, the flood section of the discharge section is simplified to a straight line; see the dotted line in Figures 1, 2, and 3.

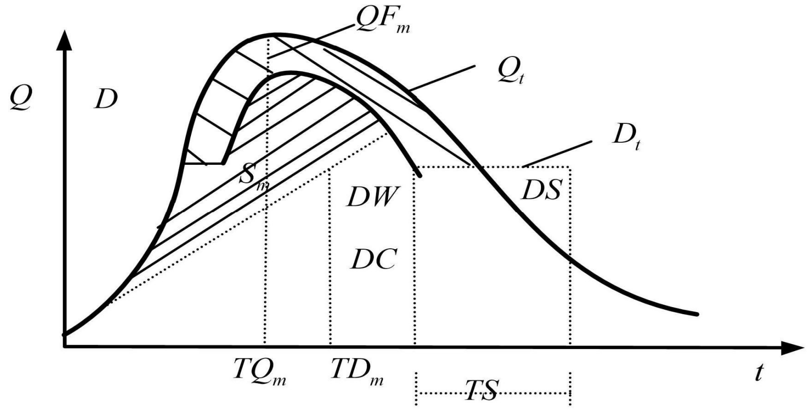


Figure 2. Unimodal regulation *b*

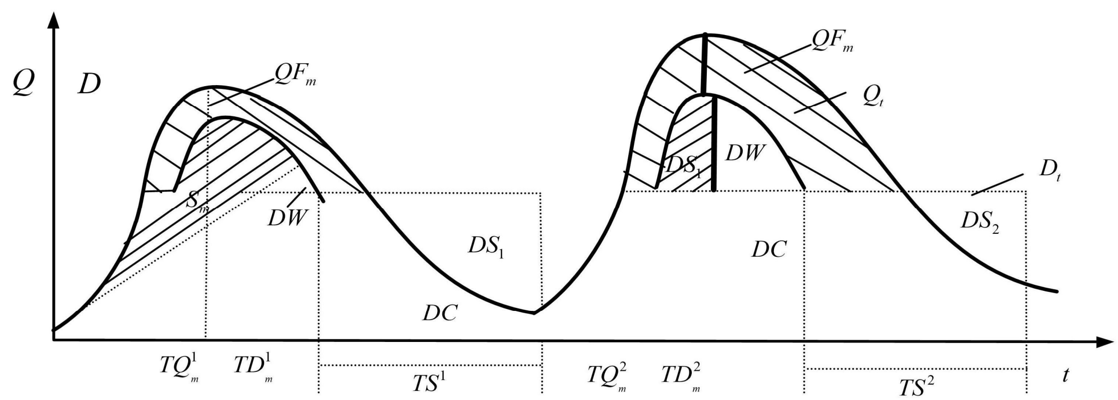


Figure 3. Shuangfeng regulation

The core steps of the preferred operation rules are: First, the decision vector *X=(ZC ZS ZM)t* is assigned to the first type of operation rules by the grid search method. Secondly, according to the given ZC ZS ZM , the total sub-target values related to the entire decision vector are calculated and adjusted for each flood in the historical hydrological information by the lumped water cut method. Thirdly, a satisfactory solution is sought using the multi-objective grey situation decision-making method, the preferred Class 1 operating rules *X**=(*ZC ZS ZM*)*. Fourth, with the selected long series of (*ZC ZS ZM*)* corresponding to adjust the calculation results, regression analysis, and the establishment of D_m, TD_m, the *TS* statistical scheduling model.

4. Result Analysis and Discussion

4.1. Experimental Results and Analysis

Applying the above models and solving methods, taking the collected data of the maximum rainfall of 1 ~ 2 times in 1977 ~ 1992 years and the data of 1959 and 1963 heavy rainfalls as the model input, a long series of calculations were made and a satisfactory multi-objective Conversion algorithm operation rules. Grid of the first type of operation rules *ZC*, *ZS* and *ZM* of the two control sections of Dongzhimen and Longtan gates are discretized by their respective increments in their feasible domains to form a grid. The discrete values are shown in Table 1. Each dot corresponds to a decision vector *X*.

Control section name	$ZC(m)$	$ZS(m)$	$ZM(m)$	$QK(m^3/s)$	$QF_m(m^3/s)$	Number of constituent dots
Dongzhimen sluice	38.5	39.5	40.5	60	30	9
	38.6	39.6				
	38.7	39.7				
Longtan sluice gate	35.7	36.7	37.5	120	40	6
	35.8	36.8				
	35.9					

Table 1. Combination Schemes for operation Rules of the First Type

Corresponding adjustment capacity of each network point: For Songlin Gate ~ Dongzhimen Gate of North Guard and You'an Dam ~ Longtan Sluice of South Protection, the surface waterlines corresponding to *ZC*, *ZS* and *ZM* are respectively calculated by the non-uniform flow channels of the open channel. According to the river section data, the inventory of Xing Li and flood control capacity were obtained; see Table 2 and Table 3.

$ZC(m)$	$ZS(m)$	$ZM(m)$
38.5	39.5	40.5
	39.6	
	39.7	
38.6	39.5	40.5
	39.6	
	39.7	

Table 2. Storages Responding to Characteristic Water Levels of Dongzhimen Sluice

$ZC(m)$	$ZS(m)$	$ZM(m)$	$S_m(10^4m^3)$
35.7	36.7	37.5	61.5
	36.8		
35.8	36.7		59.6
	36.8		
35.9	36.7		57.4
	36.8		
35.7	36.4	37	51.5
	36.5		
35.8	36.4		49.4
	36.5		
35.9	36.4		47.4
	36.5		

Table 3. Storages Responding to Characteristic Water Levels of Longtan Sluice

Goal decision-making - the first type of operation rule is preferred, which is the event of the optimized scheduling of north protection and south-guard rain-flood system, respectively. The first category of operation rules is the countermeasure, and the two constitute the situation. Each situation has a corresponding sub-goal *f*1 and *f*2, constitute the effect of the whitening value matrix, the use of multi-objective grey situation decision-making method, and the choice of a satisfactory type 1 operating rules:

North rain rains system: $(ZC\ ZS\ ZM)^* = (38.5\ 39.7\ 40.5)$

South rain rains system: $(ZC\ ZS\ ZM)^* = (35.7\ 36.7\ 37.5)$

The second type of statistical operation model of the scheduling model corresponds to the long series of flood regulation calculation results for the sample, statistics, the main discharge characteristic value of D_m, TD_m, TS and incoming water characteristic value of Q_m: peak flow and its occurrence time of TQ_m, Secondary rainfall P, rainfall intensity i, secondary net depth R and so on. Then, the regression relationship between the discharge characteristic value and the incoming water eigenvalue is analyzed to establish a statistical scheduling model. North East Protection Gate is now an example as follows:

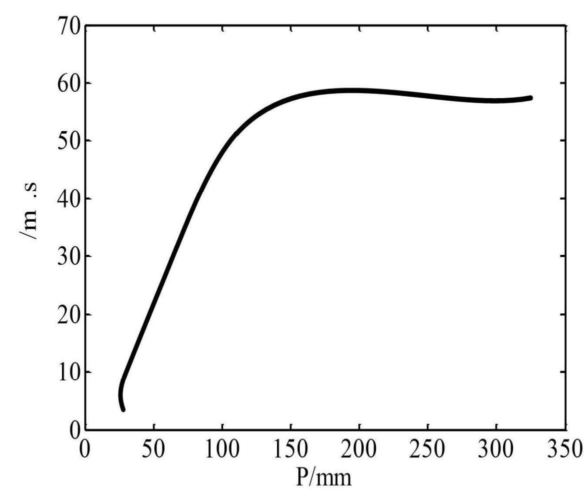
First, the maximum discharge D_m is related to the characteristic value of incoming water. Several regression relationships of D_m~P, D_m~i, D_m~R and D_m~Q_m have been tested. The correlation between D_m~P is the most significant, and P can be measured directly Got it. Second, the occurrence of D_m, TD_m and water comes from the eigenvalue test TD_m~Q_m, TD_m~ TQ_m, TD_m~ P several relations, with TD_m~TQ_m correlation is very significant. Thirdly, the relation between TS -TS and water inflow eigenvalue was tested in the relationship of TS ~ P, TS~Q_m and TS~D_m, and the most significant correlation was TS~D_m. The regression analysis, the establishment of Dongzhimen gate type 2 operating rules of the statistical model is:

$$D_m = \begin{cases} -0.0028P2 + 0.9216P - 16.5237 & 20 \le P \le 166.5\ mm \\ 60 & P \ge 166.5\ mm \end{cases} \tag{19}$$

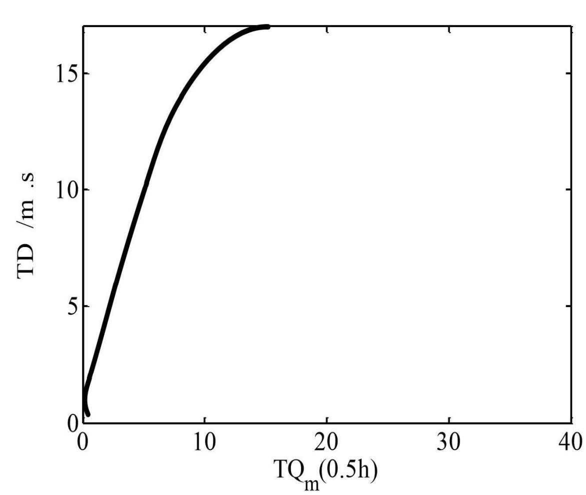
$$TD_m = -\ 0.0631TQ^2_m + 2.1992TQ_m - 2.2707 \tag{20}$$

$$TS = 1/\ (-0.00016D^2_m + 0.0176D_m - 0.0445) \tag{21}$$

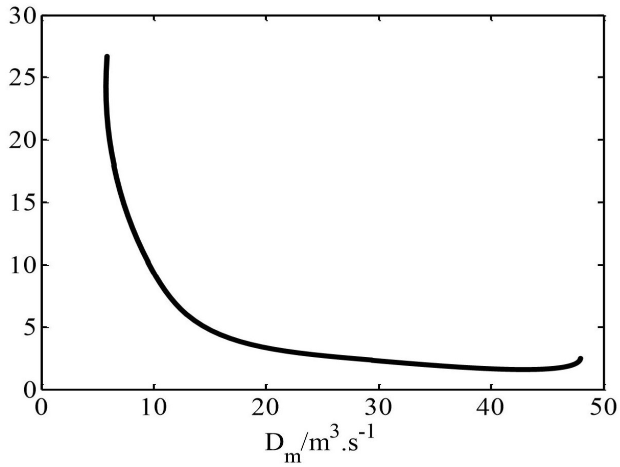
Figure 4 (a), (b), (c) gives D_m ~ P, TD_m ~ TQ_m , TS ~ D_m correlation diagram



(a) $D_m \sim$ P



(b) $TD_m \sim TQ_m$



(c) TS ~ D_m

Figure 4. Correlatographs between D_m and P, TD_m and TQ_m , and TS and D_m at Dongzhimen sluice

The first type of operating rules is mainly used for long-term flood season operation, not with the year and rainfall changes in size. No matter how much flood water you encounter, Dongzhimen Gate and Longtan Gate all control the storage, drainage, flood diversion, and storage of the flood tail according to the preferred Class 1 operation rules (*ZC ZS ZM*). The second type of operation rules are mainly used for the second flood regulation, hydrological forecasting needs to be used. After each rainfall, first, according to the measured hourly rainfall, the hydrological model is used to predict the total inflow of *Dongzhimen gate* and *Longtan gate*, and the peak flow Q_m and its time appear TQ_m; then D_m, TD_m TS are predicted by the above statistical model. Due to the inability to accurately predict the rainfall process in real-time dispatch, D_m, TD_m and TS can only be amended on a time-by-hour basis as the rainfall progresses. Type 2 operating rules are the upper bound for the period-by-period decision.

5. Conclusion

Water is the source of life, the blood of industry, the lifeblood of cities and the rational management of water resources are the preconditions for the sustainable development of urban health. How to make disasters into available water resources is an important part of research on water resources utilization management in the new situation. In view of the actual situation of rainstorm in our country, a multi-objective optimization algorithm for city rainwater landscape design optimization is proposed, and the approaches and methods of urban rainwater landscape design are explored. The research shows that the multi-objective is divided into two categories, which are more reasonable and suitable for medium and long-term control and sub-flood scheduling respectively. The proposed multi-objective optimization algorithm can not only reduce the flood but also save the tail of the flood in time. After the example test, the algorithm has the advantages of high accuracy, strong simulation and adaptability, moderate amount of calculation and can meet the general multi-objective optimization analysis needs. This algorithm has strong versatility and provides the future development direction for the urban rainwater landscape design optimization.

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References

[1] Li, F., Duan, H. F., Yan, H., et al. (2015). Multi-Objective Optimal Design of Detention Tanks in the Urban Stormwater Drainage System: Framework Development and Case Study. *Water Resources Management*, 29(7), 2125-2137.

[2] Backhaus, Antje., Dam, Torben., Bergen Jensen, Marina. (2012). Stormwater management challenges as revealed through a design experiment with professional landscape architects. *Urban Water Journa*l, 9(1), 29-43.

[3] Chiandet, A.S., Xenopoulos, M.A. (2016). Landscape and morphometric controls on water quality in stormwater management ponds. *Urban Ecosystems*, 19(4), 1645-1663.

[4] Burns, M. J., Walsh, C.J., Fletcher, T. D., et al. (2015). A landscape measure of urban stormwater runoff effects is a better predictor of stream condition than a suite of hydrologic factors. *Ecohydrology,* 8(1), 160-171.

[5] Holtmann, L., Philipp, K., Becke, C., et al. (2017). Effects of habitat and landscape quality on amphibian assemblages of urban stormwater ponds. *Urban Ecosystems*, (2), 1-11.

[6] Wang, M., Sun, Y., Sweetapple, C. (2017) Optimization of storage tank locations in an urban stormwater drainage system using a two-stage approach. *Journal of Environmental Management*, 204(Pt 1), 31-38.

[7] Bettez, N.D., Groffman, P.M. (2012). Denitrification potential in stormwater control structures and natural riparian zones in an urban landscape. *Environmental Science & Technology*, 46(20), 10909-17.

[8] Tixier, G., Lafont, M., Grapentine, L., et al. (2011). Ecological risk assessment of urban stormwater ponds: Literature review and proposal of a new conceptual approach providing ecological quality goals and the associated bioassessment tools. *Ecological Indicators*, 11(6), 1497-1506.

[9] Loperfido, J.V., Noe, G.B., Jarnagin, S.T., et al. (2014). Effects of distributed and centralized stormwater best management practices and land cover on urban stream hydrology at the catchment scale. *Journal of Hydrology*, 519 (Part C), 2584-2595.

[10] Sharma, A., Pezzaniti, D., Myers, B., et al. (2016). Water Sensitive Urban Design: An Investigation of Current Systems, Implementation Drivers, Community Perceptions and Potential to Supplement Urban Water Services. *Water*, 8(7), 272.