Simulation and Optimization of Airport Rainwater Drainage System at Different Control Measures

Jing Peng (✉ pengjingtd@163.com)

Civil Aviation University of China <https://orcid.org/0000-0001-9729-0400>

Lei Yu

Tianjin Lonwin technology development Co.

Xiang Zhong

Tianjin International School

Tiansong Dong

Changchun Institute of Technology

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Abstract

The impervious area of the airport is high, which leads to the deterioration of the water environment and frequent waterlogging disasters. The construction of sponge airport has become an important and arduous task in the new era of civil aviation design industry in China. In order to compare the effects of different control measures at different scenarios, take the airport along China's southeast coast as an example, three scenarios were designed in this study (Scenario 1: no LID facilities and other measures; Scenario 2: two pump stations were setting; Scenario 3: both LID facilities and pump stations). Three simulation models under LID facilities and other measures were developed using SWMM with return period of 5a. The simulation results at different scenarios were compared, the number and the best opening scheme of pumps for each reservoir are finally obtained. The results of Scenario 3 show that the full-flow duration of nodes in the study area is greatly shortened. The decrease of full-flow duration of J1, J2 and J3 was 1.2, 0.8 and 0.5 hours respectively, with reduction rates of 40%, 53.3% and 28.6% respectively. The rainfall peak flows both the first and the second were reduced in this scenario, and the reduction rates were 10.68% and 12.78% respectively. However, the reduction effect of the third peak is poor with the further increase of rainfall intensity. The reduction rate of the total inflow and peak flow of rainwater buckets and permeable pavement is better than that of vegetative swale. The results of this study can provide the reference for the design of sponge airport and the airport flood control management.

1 Introduction

In recent decades, China's economy has taken off under the background of reform and opening-up. With the development of economy, the process of urbanization is speeding up. As a result, extreme rainstorms have occurred frequently and led to severe waterlogging in Chinese cities. This could also be attributed to damages to urban hydrology by rapid urbanization (Lyu et al., 2018; Xu et al., 2018). The destruction of hydrological environment has caused a series of problems of rainwater management and control, and many cities have serious waterlogging problems in flood season (Guo 2019; KUANG et al. 2018; YANG et al. 2021). According to the research, urbanization makes the rainfall runoff increase significantly, and the high proportion of impervious area will lead to the problem of heat island effect, more precipitation, less evaporation, decreasing water permeability, increasing peak flow rate and so on (Zhou et al. 2018; Jacob et al. 2019).

Airports are mostly built in areas where the terrain is flat. In order to ensure the strength of the pavement in the flight area, the proportion of hardened surfaces in the airport underlying surface is very high, rainwater can't penetrate into the ground effectively. The underground soil layer should be compressed and compacted, so the impact of rainfall runoff is particularly obvious when encountering heavy rainfall. In addition, China's traditional airport rainwater drainage mainly relies on rapid drainage, and only relies on pipes and pumps. The natural hydrological cycle is destroyed by this drainage method, and it is proved that even the drainage pipe with the largest diameter can't cope with the excessive runoff. At the same time, aviation oil pollution, heavy metals and solid suspended matter after the initial rain wash in a

short period of time into the pipeline deposition, the downstream water surrounding the airport was contaminated. This draining-without-storing method wastes rainwater resources, and many areas suffer from severe waterlogging during the rainy season and severe water shortages during the dry season (Peng et al. 2020; Li 2018; Qu et al. 2020).

In 2018, the Civil Aviation Administration of China issued the Action Plan for building a strong civil aviation country in the new era, which calls for the building of safe, green, intelligent and people-to-people airports with high quality. In the same year, the Civil Aviation Administration of China issued a consultation circular on Green Airport planning guidelines as a Green Airport planning guide. The research and design of green airport construction has become an important and arduous task in the new era of civil aviation design industry in China (Liu 2019). A sponge airport is the airport has the function of infiltration, stagnation, storage, purification and drainage when it rains like a sponge, and it can "release" and utilize the stored water when the airport needs it (Peng et al. 2021). The construction of Sponge Airport conforms to the background of the development plan of the new-type Green Airport in China, which has the function of preventing and controlling the flood disaster, improving the water environment and water ecology around the airport. It can help to ensure the safe and efficient operation of the airport and was concerned by the Civil Aviation Administration and airports.

In the construction of Sponge airport, many airports use the methods such as increasing the green area of the airport, building large-volume water storage facilities and Green Roof to control the rainwater runoff, and emphasize the treatment and Reuse of rainwater resources. The O'Hare International Airports has installed 232,534 ft² of vegetated roofs and is installing 126,456 ft² more (as of November 2010). The installations demonstrate that installing vegetated roofs at airports is practical and cost effective. Operational and maintenance cost savings are expected from increased roof life span, energy use reduction, and storm water quantity/quality management. Additional benefits achieved include a reduction in noise and heat islands, air quality protection, and enhanced aesthetics (Peter 2011). Amsterdam Airport Schiphol combines solar energy with green roofs to save energy, protect the environment and beautify the environment, while alleviating waterlogging in the airport and saving rainwater resources (Kuller et al. 2017). The Singapore Changi Airport uses outdoor green roofs for rainwater storage and purification, an indoor waterfall landscape, and Vegetation Irrigation to reuse rainwater, part of the roof rainwater as well as reclaimed water is collected into the interior to form a four-waterfall landscape and irrigation water (Changi 2018).

The research on urban storm flood model is very extensive, and the representative models are SWMM, STORM, Mike Urban, InfoWorks ICM, SUSTAIN and so on. Each model has its own characteristics, applicability and limitations (Jiang et al. 2021). A new drainage system was designed using the Storm Water Management Model (SWMM) to collect and channel storm water runoff generated by the airfield as well as optimize the drainage system to protect the integrity of the runways and reduce maintenance costs (Amendolara et al. 2016). The different protection alternatives of Ronald Reagan Washington National Airport were examined to compare under storm conditions. The three alternatives are: permanent sea walls, temporary flood barriers, and an improved drainage design, namely increased out flow pump

capacities. The output of the simulation is the time an airport stays flooded once a storm surge event is initialized as well as the time it takes for an airport, specifically its drainage system, to drain enough of the flood to resume operations at normal rates (Haji et al. 2017). To address the problems of high overflow rate of pipe network inspection well and low drainage efficiency, a rainwater control optimization design approach based on a self-organizing feature map neural network model (SOFM) was proposed. Through the optimization adjustment of the pipe network parameters of Beijing Daxing International Airport, the overflow rate of pipe network inspection wells has reduced by 36–67.5%, the efficiency of drainage has increased by 26.3–61.7% (Qiu et al. 2020).

The low impact development facilities generally have infiltration, regulation, storage, transmission, interception, purification and other major functions, aiming to alleviate the detrimental impacts of urbanization and climate change and enhance resilience (KANG et al. 2017; Arpita et al. 2021; Bonneau et al. 2021). In practical engineering application, the appropriate LID facilities and its combination should be selected according to the principle of local conditions and high economic efficiency, considering the regional hydrogeological conditions and water resources, and the analysis of economic indexes. Most of the existing research focuses on the construction of the pipe network model, the design of different types of LID facilities and their combination, layout location, layout area, and other scenarios. The optimal scheme of LID measures was designed to simulate the effects of different scenarios on runoff regulation and to consider the environmental, economic and ecological benefits (Liu 2017; Koc et al. 2021; Sheikh and IZANLOO 2021).

In order to evaluate the effectiveness of different sponge airport control strategies, the runoff discharge of the rainwater drainage system in the airport under LID facilities and other measures was simulated. In this study, three scenarios were designed. There was no LID facilities and other measures in Scenario 1. In Scenario 2, two pump stations were set up at Reservoir 2 and Reservoir 3 to pump water from the storage to external river, in case of the possibility of storage flooding. There were applied both LID facilities and pump stations in Scenario 3. The storm with return period of 5a was designed as inputs into the developed models to compare the effects of different control strategies at different scenarios. The LID facilities include permeable pavement, vegetative swale and rain barrel. The simulation results analyze the variation of the inflow, the maximum depth and full-flow duration of reservoirs, the full-flow duration and the peak flow decrease of typical nodes and so on. This study laid a foundation for LID facilities design of sponge airport and the real-time flood control management of the rainwater drainage system.

2 Case Study

2.1. Site

The Research Airport is located in the coastal city of southeast China, which is located between 113°46'~114°37' east longitude and 22°27'~22°52' north latitude. The area belongs to the tropical marine climate. The average annual rainfall is about 1966 mm. Most of the rainfall was concentrated in summer,

accounting for 80.85% of the annual rainfall. The rainfall in spring and autumn accounted for 6.8%, and that in winter was the least, accounting for 2–4%. Summer of the area lasts for 6 months and is hot and rainy with plenty of rain. Affected by the monsoon, the drought and flood season is obvious, April to September is the rainy season. According to the rainfall statistics of the city meteorological bureau in the past 30 years, the average rainfall from June to August was 346.5 mm, 319.7 mm and 354.4 mm respectively. The historical maximum annual average rainfall was 2,747 mm (2001) and the minimum was 912 mm (1963). The maximum annual rainfall was 2,533 mm; the maximum daily rainfall was 383 mm; the maximum hourly rainfall was 101.7 mm; and the annual average evaporation was about 1,770 mm. The airport covers an area of 1,950 million m^2 , of which the terminal area is 451,000 m^2 , the cargo area is 1.66 million m^2 , and the flight area is over 7.5 million m^2 . The Reference Height is 3.962m. The airport is surrounded by a drainage channel, the Fuyong River and the Pearl River Delta.

The study airport can be divided into three catchment areas according to the convergence direction of rainwater. In the simulation process, rainwater from the three catchment areas is confluent into three reservoirs. The catchment areas and drainage network layout are shown in the following figure. Rainwater from the Catchment A drains into Reservoir 1, rainwater from the Catchment B drains into Reservoir 2, and rainwater from the Catchment C drains into Reservoir 3. The designed water depth of the reservoir is 3.5 m, and the area of Reservoir 1 is 295,000 m^2 and the volume is 456,500 m^3 . Reservoir 2 has the surface area of 393,000 m^2 and a volume of 588,400 m^3 ; the Reservoir 3 has an area of 1.08 million m^2 and a volume of 2.485 million m^3 (Tang et al. 2018; Hu et al. 2008).

2.2. Simulation scheme

In this study, we aim to simulate the runoff discharge of the rainwater drainage system in the airport under LID facilities and other measures. Storm Water Management Model (SWMM) could compute dynamic rainfall-runoff for single event and long-term runoff quantity and quality from developed urban and undeveloped or rural areas. It is an open-source simulation tool and can efficient simulation of the effect of various LID facilities. It was selected to simulate the runoff discharge of the rainwater drainage system in this paper (James et al. 2010). For the simulation of this site, three scenarios were designed.

(1) Scenario 1: In this scenario, the runoff discharge of the rainwater drainage system was studied in the study area under 5a return period. There was no LID facilities and other measures, and the pumping was not working.

(2) Scenario 2: Two pump stations were set up at Reservoir 2 and Reservoir 3 to pump water from the storage to external river, in case of the possibility of storage flooding. Through simulation, the flow rate and number of pumping stations are designed for each storage, and the optimal drainage scheme is obtained (The location of Reservoir 2 and Reservoir 3 is shown in Fig. 1).

(3) Scenario 3: In this scenario, there were applied both LID facilities and pump stations. The LID facilities include permeable pavement, vegetative swale and rain barrel. The selection of facilities is based on the types and characteristics of land use in the study area.

2.3. Rainfall Data

Rainfall design is an important basis for airport rainwater drainage system design. It could result in the construction of a massive drainage system and significant economic burden for airport if the rainfall data far exceed reality. According to Article ninety-four of the Civil Airport Engineering Project Construction Standard, the design standard of waterlogging prevention in airfield area corresponds to the design rainstorm recurrence period once in 5 years, and that of the terminal area, cargo area and aircraft maintenance area is not less than once in 3 years, and no less than 1 year in other areas. To study the operation of airport rainwater drainage system under the condition of the design rainstorm recurrence period once in 5 years. In this study, rainfall intervals time was set as one hour and a duration of 24 hours, and the actual rainfall amount selected is equivalent to the rainfall amount with a return period of 5 years. The rainfall hydrograph can be seen in Fig. 2.

3 Application And Data Analysis

3.1. Parameter setting

Based on ArcGIS software, this study divides the catchment area using Tyson polygon method according to the existing rainwater drainage network layout of the airport. The study area is divided into terminal area, airfield area, freight area and life support area. The types of land use include building land, runway and taxiway, green land and road. Based on the division of catchment area, the pipeline layout is drawn by Computer Aided Design software. The height, length, width and other data are marked, and then the slope and length of the pipe network are evaluated.

The catchment width is calculated by the formula in the National Engineering Handbook jointly published by the United States Department of agriculture and the Department of natural resources.

$$L = 0.4364A^{0.6} \quad (1)$$

$$W = A/L = 2.29A^{0.4} \quad (2)$$

Where L is flow length (m), A is catchment area (m^2), and W is catchment width (m).

When the actual measurement is very difficult, the empirical value can be obtained according to the literature. In order to ensure the requirements of rainwater drainage and friction for aircraft take-off and landing, the runway surface in the airfield area will be grooved and roughened to make the pavement reach a certain friction and drainage capacity. However, the uneven will lead to the accumulation of rainwater and the formation of water film in the pavement, which will affect the safety of aircraft take-off and landing.

According to "Regulations on operation management of wet runway and polluted runway for air carriers" issued by Flight Standards Department of CAAC in 2009, the definition of wet runway is more than 25%

of the surface area (the sum of single or multiple areas) within the length and width of the available part of the aircraft take-off and landing distance is covered by water more than 3 mm (0.118 inch) deep, or the equivalent thickness is equal to or light rain 3mm depth of snowmelt, wet snow, dry snow, such a runway is regarded as a wet runway (Flight, 2009). Wet runway will affect the braking effect of the aircraft and friction coefficient of pavement, when the water accumulation thickness of runway exceeds 13 mm, the aircraft is forbidden to take off and land. Therefore, the depression storage of impervious area in this paper is 2 mm. For the permeable areas such as the soil area in the airfield area, the maximum value of 10 mm should be taken according to the recommended value.

The soil area and green belt in the study area shall be set as permeable area; the roof, pavement, Apron and other hardened surface shall be set as impervious area. According to the different regional characteristics and land use types, the study area is divided into 8 areas for impermeability calculation, then the average impermeability of each sub-catchment is obtained. Manning Coefficient is a comprehensive reflection of the pipe canal wall roughness on the flow of a factor. Since the drainage facilities of the airport are mainly made of concrete, reinforced concrete and masonry, the Manning Coefficient ranges from 0.013 to 0.017 with an average value of 0.015. In this study, the Horton model was chosen, the average of the recommended values was taken. Horton maximum infiltration rate is between 30 and 100, the value is 65 (mm/hr), Horton minimum infiltration rate is between 2 and 10, the value is 6 (mm/hr).

3.2. LID facilities settings

In this paper, three low impact development facilities including vegetative swale, permeable pavement and rainwater bucket are set up in the study area. In each catchment area, vegetative swale accounts for 25%, rainwater bucket accounts for 3%, and permeable pavement accounts for 50%. The LID facilities layout of each catchment area is shown in Fig. 3: white square means no LID facilities, gray square means area is set with rainwater bucket, yellow square means area is set with vegetative swale, blue square means area is set with permeable pavement, black square means area is set with permeable pavement and rainwater bucket.

The LID control editor is set in the SWMM software, which is used to define a low impact development control that can be deployed throughout a study area to store, infiltrate, and evaporate sub-catchment runoff. The design of the control is made on a per-unit-area basis so that it can be placed in any number of sub-catchments at different sizes or number of replicates. Different low impact development facilities contain different layers of processing, including Surface Layer→Pavement Layer→Soil Layer→Storage Layer→Underdrain System. The parameters of three LID facilities(vegetative swale, permeable pavement and rainwater bucket)are set out in the Table 1.

Table 1
LID facilities main parameters setting

Categories	Parameters	Vegetative Swale	Permeable pavement	Rain Barrel
Surface	Berm Height /mm	300	2	
	Vegetation Volume Fraction	0.8	0	
	Surface Roughness(Manning n)	0.1	1.5	
	Surface Slope (%)	1		
	Swale Side Slope (%)	5		
Storage	Thickness/mm		140	2000
	Viod Ratio		0.2	
	Seepage Rate		15	
Pavement	Thickness /mm		60	
	Viod Ratio		0.2	
	Permeability(mm/hr)		250	
Drain	Offset Height /mm		6	20
	Flow Exponent		0.5	0.5

3.3. Model calibration

The calibration and validation of urban rainfall-runoff models are usually carried out by comparing the measured data with the model data. It is based on the correlation of measured rainfall and runoff series, calibration objective functions include the root mean square error and average relative error of peak flow, average flow and peak current time. The construction of rain water pipe network monitoring system in China is lagging behind and can't meet the development needs of rain water pipe network modeling. Moreover, it needs a long period to build a perfect rainwater pipe network monitoring system, and the rainwater pipe network modeling in China will be faced with a lack of calibration data in the near future. In order to solve the problem of lack of calibration data of urban rainfall runoff model, it was proposed to calibrate the model with runoff coefficient (Liu 2009). However, the rainwater pipe network monitoring system of study area is not perfect, the measured flow data is scarce, so it is suitable to use the method of runoff coefficient to verify the model. It takes the runoff coefficient as the objective function of model parameter calibration, and compares the synthetic runoff coefficient of prior and rainwater pipe network design with the runoff coefficient of computer model simulation to calibrate the model parameter. The runoff coefficient in the rainy area of south China is larger than 0.7 in the coastal area. The annual rainfall ranges from 913 mm (2001) to 2747 mm (1963) in the region where the research airport is located. The annual rainfall deviation is large, and it is still in the initial stage of the construction of the

sponge airport. The designed value of the overall runoff coefficient of the airport is set to 0.7. It is verified that the simulated runoff coefficient of study area in 5-year rainstorm return period is between 0.67 and 0.75 at different scenarios. The maximum errors with the design values of the synthetic runoff coefficients is 7%. The model is stable and has good reliability.

4 Results And Discussion

In this study, storm with return period of 5a was designed as inputs into the developed models to compare the effects of different control strategies at different scenarios (without any control strategy; with pumps; with both pumps and LID facilities).

In Scenario 1, there are 7 nodes in the study area with full-flow under the intensity of rainstorm with return period of 5a. The full-flow duration of two nodes is about 3 hours, that of four nodes is 1–2 hours, and that of one node is 0.5 hours. When the pump station is not opened during the whole rainfall process, the capacity of Reservoir 1 is relatively sufficient and the maximum depth is 3.1 m; Reservoir 2 reaches the upper limit at 26:30 and the maximum depth is 3.5 m, which is at full capacity; Reservoir 3 reached its upper limit at 19:00 and the maximum depth is 3.5 m. Under the design rainstorm intensity, the drainage condition of the study area is relatively good, and there is no water accumulation. but the water depth of Reservoir 2 and Reservoir 3 is high, so the pumping station should be used to strengthen the drainage. The situation of rainwater drainage system at Scenario 1 is given in Table 2.

Table 2
The situation of rainwater drainage system at Scenario 1

Full-flow nodes		Storage			
Numbers	Maximum duration (hour)	Maximum Depth of Storage 2(m)	Hour of Maximum Depth	Maximum Depth of Storage 3(m)	Hour of Maximum Depth
7	3(2 nodes) ;Less than 2 (5 nodes)	3.5	26:30	3.5	19:00

According to the simulation results of Scenario 1, the water depth of Reservoir 2 and Reservoir 3 are higher and the duration of full water level is longer. Therefore, an appropriate number of pumping stations should be set for the reservoir, and the opening time of the pumping stations should be adjusted to meet the requirements of rainwater storage at Scenario 2. Through the simulation of different design schemes, the number and the best opening scheme of pumps for each reservoir are finally obtained. Reservoir 2 needs to be equipped with two pumping stations with a design flow rate of 1.5 m³/s, and when the water level of Reservoir 2 reaches 3 meters, one pump station is started; When the water level rises to 3.3 m, two stations are started to operate. Under this scheme, the maximum water level of Reservoir 2 is 3.38 m, it will not be filled to capacity. Reservoir 3 needs to be equipped with three pumping stations with a designed flow rate of 3.6 m³/s, and when the water level of Reservoir 3 reaches 2.5 m, two

pumping stations are started; When the water level reaches 3 m, three pumping stations will be activated. Under this scheme, the maximum water level of Reservoir 3 is 3.3 meters, and there is not at full capacity.

In Scenario 3, the appropriate LID facilities (vegetative swale, permeable pavement and rainwater bucket) are designed based on the characteristics of land use types in each subarea of the study area, in order to reduce total inflow, flood peak flow, alleviate the drainage pipe network and reservoir drainage and storage pressure. According to the simulation of scenario 3, the full-flow duration of nodes in the study area is greatly shortened under the rainstorm with return period of 5a. The full-flow duration of typical nodes (J1, J2 and J3) in three catchment regions is given in Table 3. The full-flow duration of J1 at the Catchment A was reduced from 3 hours to 1.8 hours with a reduction rate of 40%; the full-flow duration of J2 at the Catchment B was reduced from 1.5 hours to 0.7 hours with a reduction rate of 53.3%; the full-flow duration of J3 at the Catchment C was reduced from 1.75 hours to 1.25 hours with a reduction rate of 28.6% (The location of J1, J2, and J3 is shown in Fig. 1).

Table 3
Comparison of full-flow duration of typical nodes

Typical nodes	Location	Maximum full-flow duration of nodes(Hours)		
		Scenario 1	Scenario 2	Reduction(%)
J1	A	3	1.8	40
J2	B	1.5	0.7	53.3
J3	C	1.75	1.25	28.6

The catchment area of Reservoir 2 is the Catchment B, and corresponding LID facilities are set for each sub-catchment, the control effect of runoff is better. The maximum water level of Reservoir 2 during the whole rainfall process is only 2.57 m, and no pumping station needs to be opened. The catchment area of Reservoir 3 is the Catchment C. Vegetative swale is primarily LID Facility in this area, the layout area accounts for less than 20% of the total area of Catchment C, the control effect of runoff is poor. Reservoir 3 requires two pumping stations with a designed flow rate of 3.6 m³/s. When the water level of Reservoir 3 reaches 2.5 m, two pumping stations need to be opened, and when the water level reaches 3 m, three pumping stations need to be opened. The maximum water level of Reservoir 3 is 3.32 meters in this scheme, and the reservoir is not at full capacity.

The results of scenario 1 show that Reservoir 1 can meet the requirement when no measures are taken under 5-yearreturnperiod. Therefore, this study focuses on Reservoir 2 and Reservoir 3. In scenario 3, most of the sub-catchment areas in Catchment B were provided with permeable pavement and rainwater bucket. The total inflow of Reservoir 2 was reduced from 27.51 m³/s to 19.58 m³/s, with a reduction rate of 28.83% and a delay of 1 minute of the peak flow time. Only a few sub-catchments in Catchment C were planted with vegetative swale. The effect of total inflow reduction in Reservoir 3 was moderate, and the peak flow time was delayed by 2 minutes. It can be seen from Fig. 5, both the first and the second

rainfall peaks were reduced in this scenario, and the reduction rates were 10.68% and 12.78% respectively. However, the reduction effect of the third peak is poor with the further increase of rainfall intensity. This is due mainly to the fact that the LID facility in Catchment C is primarily for vegetative swale and has a low layout ratio. Through the comparison of Reservoir 2 and Reservoir 3, it can be seen that the reduction rate of the total inflow and the peak flow of rainwater buckets and permeable pavement is better than that of vegetative swale.

5 Conclusions

In this paper, take the airport along China's southeast coast as an example, three simulation models under LID facilities and other measures (without any control strategy; with pumps; with both pumps and LID facilities) were developed using SWMM with return period of 5a. For the simulation of this site, three scenarios were designed to compare the effects of different control strategies at different scenarios. According to the results and discussions, the following key findings could be concluded:

(1) The three developed models were used to calculate the water depth, full-flow duration of typical nodes and total inflow of Reservoir 2 and Reservoir 3 under one-hour rainfall with 5a return period. The simulation results of three developed models under LID facilities and other measures were analyzed and compared.

(2) It can be seen from results of Scenario 1, the water depth of Reservoir 2 and Reservoir 3 are higher and the duration of full water level is longer. The plans with different number of pumping stations and opening times were set up in scenario 2. Through simulation of different design schemes, the number and the best opening scheme of pumps for each reservoir are finally obtained.

(3) In order to compare the effects of different control strategies at different scenarios, there were applied both LID facilities and pump stations in Scenario 3. The LID facilities include permeable pavement, vegetative swale and rain barrel. It can be seen from results of Scenario 3, the full-flow duration of nodes in the study area is greatly shortened. The decrease of full-flow duration of J1, J2 and J3 was 1.2, 0.8 and 0.5 hours respectively, with reduction rates of 40%, 53.3% and 28.6% respectively. The rainfall peak flows both the first and the second were reduced in this scenario, and the reduction rates were 10.68% and 12.78% respectively. However, the reduction effect of the third peak is poor with the further increase of rainfall intensity. The reduction rate of the total inflow and peak flow of rainwater buckets and permeable pavement is better than that of vegetative swale.

(4) The results of this study can help the airport designer to design the LID facilities for the sponge airport, and it provides the reference for the airport flood control management.

Declarations

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Authors Informations

Affiliations

Institute of Transportation Science and Engineering, Civil Aviation Univ. of China, No. 2898 Jin Bei Road, Dongli District ,Tianjin, China;

Jing Peng(彭晶)

Tianjin Lonwin Technology development Co., Ltd., No. 15 Longtan Road, Hedong District ,Tianjin, China

Lei Yu(俞磊)

Power and energy department , Tianjin Binhai International Airport, No.1 Airport Avenue, Dongli District, Tianjin, China

Xiang Zhong (钟祥)

Changchun institute of technology吉林 Changchun 130012 China, No. 395 Kuanping Road, Changchun, Jilin Province, China

Tiansong Dong(董天松)

Contributions

All authors contributed to the study conception and design. Material preparation and data collection were performed by Jing Peng, Lei Yu and Xiang Zhong. Analysis were performed by Jing Peng, Lei Yu and Tiansong Dong. The first draft of the manuscript was written by Jing Peng. All authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Corresponding author

Correspondence to Jing Peng

Ethics declarations

Ethical Approval

Not applicable.

Consent to Participate

Authors give their permission.

Consent to Publish

Authors give their permission.

Competing Interests

The authors declare no conflicts of interest.

Availability of data and materials

Some or all data, models, or code that support the findings of this study are available from the corresponding author upon reasonable request (water withdrawals, water supply, and airport rain drainage system).

References

1. Arpita Islam, Sonia Hassini, Wael El-Dakhakhni. (2021). A systematic bibliometric review of optimization and resilience within low impact development stormwater management practices, *Journal of Hydrology*, 599:126457
2. Amendolara J, Wolhaupter B, Bogdan E, et al. (2016). Coast Guard Airport Rigid Pavement Rehabilitation and Storm Water Mitigation, *Geotechnical Special Publication*,94-102
3. Bonneau Jérémie, Gislain Lipeme Kouyi, Laurent Lassabatere, Tim D. Fletcher. (2021). Field validation of a physically-based model for bioretention systems. *Journal of Cleaner Production*, 312:127636.
4. Changi Airport T3 indoor vertical green landscape. (2018).
https://bbs.zhulong.com/101020_group_201878/detail32547866/
5. Flight Standards Department of CAAC. (2009). Regulations on operation management of wet runway and polluted runway for air carriers: AC-121-FS- 2009-33. Beijing: Civil Aviation Administration of China, 2009:2.
6. GuoYumeng. (2019). Research on Sponge Block Design Strategy Based on the Concept of Low Impact Development (LID) Anhui University of architecture. (in Chinese)
7. Haji Mohammad, De Julio Marcelo, De Sousa Junior Wilson Cabral, etc. (2017). Design and analysis of a storm surge protection system for Reagan National Airport, 2017 Systems and Information Engineering Design Symposium (SIEDS)
8. Hu Xianqiong, Li Yan, NIU Yuan-yuan. (2008). Study on Storm Water Utilization Feasibility of expansion project in Shenzhen Airport. *CHINA WATER & WASTEWATER*, (05):17-19

9. Jacob, ACP; Rezende, OM; de Sousa, MM; Ribeiro, LBD; de Oliveira, AKB; Arrais, CM; Miguez, MG. (2019). Use of detention basin for flood mitigation and urban requalification in Mesquita, Brazil. *WATER SCIENCE AND TECHNOLOGY*, (79)11: 2135-2144
10. James William, Rossman Lewis A., W. Robert C. James. (2010). User's guide to SWMM5. Published by CHI, Guelph, Ontario, Canada.
11. JIANG Chunbo, LI Jiake, GAO Jiayu, LÜ Peng, YAO Yutong, LI Huai'en. (2021). Research progress of grey-green rainwater infrastructure optimal configuration in sponge city construction. *Journal of Hydroelectric Engineering*. <https://kns.cnki.net/kcms/detail/11.2241.TV.20201112.1308.004.html>
12. KANG Hongzhi, GUO Qizhong, LIAN Jijian, et al. (2017). Advances in simulation models for whole-life-cycle effectiveness of sponge city construction. *Journal of Hydroelectric Engineering*, 36(11): 82-93. (in Chinese)
13. KUANG W H, YANG T R, YAN F Q. (2018). Examining urban land-cover characteristics and ecological regulation during the construction of Xiong'an New District, Hebei Province, China. *Journal of Geographical Sciences*, 28(1): 109-123.
14. Kuller M., Dolman N.J., Vreeburg J.H.G., Spiller M. (2017). Scenario analysis of rainwater harvesting and use on a large scale – assessment of runoff, storage and economic performance for the case study Amsterdam Airport Schiphol. *Urban Water Journal*, 14(3): 237-246.
15. Koc K, Ekmekcioğlu Ö, Özger M. (2021). An integrated framework for the comprehensive evaluation of low impact development strategies. *J Environ Manage*. 2021 Sep 15;294:113023. doi: 10.1016/j.jenvman.2021.113023. Epub 2021 Jun 10. PMID: 34119982.
16. Li Peng. (2018). Research on technical framework of rainwater system in Sponge Airport. Civil aviation university of china. (in Chinese)
17. Liu Jun. (2019). Technical measures of water supply and drainage of green airport, taking the overall planning of Kunming airport as an example, *Low Carbon World*, 9(08):257-258. (in Chinese)
18. Liu X.-p. (2009). Parameter calibration method for urban rainfall-runoff model based on runoff coefficient. *Water & Wastewater Engineering*, 45(11):213-217. (in Chinese)
19. Liu Zijing. (2017). Optimization technique of the low impact development facilities in Shenzhen Qianhai district. Beijing: Tsinghua University. (in Chinese)
20. Lyu, H.M., Xu, Y.S., Cheng, W.C., Arulrajah, A., 2018. Flooding hazards across Southern China and prospective sustainability measures. *Sustainability* 10 (5),1682.
21. Peng Jing, Ouyang Jiayi, Yu Lei, Wu Xinchun. (2020). The model and simulation of low impact development of sponge airport, China. *Water Supply*, 20(2): 383-394.
22. Peng Jing, Ouyang Jiayi, Yu Lei. (2020). The model of low impact development of a sponge airport: a case study of Beijing Daxing International Airport. *Journal of Water and Climate Change*, (12)12.
23. Peters, G. (2011). Vegetated roof installations at O'Hare and Midway International Airports. T and DI Congress 2011: Integrated Transportation and Development for a Better Tomorrow - Proceedings of the 1st Congress of the Transportation and Development Institute of ASCE, p 977-986.

24. Qiu Dongwei; Xu Hao; Luo Dean; Ye Qing; Li Shaofu; Wang Tong; Ding Keliang. (2020). A rainwater control optimization design approach for airports based on a self-organizing feature map neural network model. *PloS one*, 15(1): e0227901.
25. Qu Ziyi, Ouyang Jie, Han Xingang. (2020). Research on the Design of Comprehensive Storm Flood Prevention and Treatment Project of Sponge Airport. *IOP Conference Series: Earth and Environmental Science*, 568(1): 012024-.
26. Sheikh Vahedberdi and Izanloo Razieh. (2021). Assessment of low impact development stormwater management alternatives in the city of Bojnord, Iran. *Urban Water Journal*, 18(6): 449-464.
27. Tang Zhong; Zhang Liang; Lu Yu; Le Zheng; Niu Yuanyuan. (2018). Exploration on the Sponge Construction Strategies of a Coastal Airport in South China. *China Water & Wastewater*, 34(20):1-6. (in Chinese)
28. Xu, Y.S., Shen, S.L., Lai, Y., Zhou, A.N., 2018. Design of sponge city: lessons learnt from an ancient drainage system in Ganzhou, China. *J. Hydrol.* 563, 900e908.
29. YANG Fengru, CHEN Liang, ZHANG Yazhuo, GUO Qizhong, LIAN Jijian, LI Mengmeng. (2021). Review of low impact development rainwater system planning. *Journal of Hydroelectric Engineering*, 40(6):62-78. (in Chinese)
30. Zhou, J.J.; Liu, J.H.; Shao, W.W.; Yu, Y.D.; et al. (2018). Effective Evaluation of Infiltration and Storage Measures in Sponge City Construction: A Case Study of Fenghuang City. *Water*, 10, 937.

Figures

Figure 1

The Sketch Map of study area

Figure 2

One-hour rainfall hydrograph with 5 a return period

Figure 3

The layout of LID facilities at each catchment area

Figure 4
The water depth of Reservoir 2 and Reservoir 3 at Scenario 2

Figure 5

Comparison of total inflow of Reservoir 2 and Reservoir 3 under different scenarios