

The model of low impact development of a sponge airport: a case study of Beijing Daxing International Airport

Jing Peng , Jiayi Ouyang and Lei Yu

ABSTRACT

A sponge airport is a new concept of airport stormwater management, which can effectively relieve airport flooding and promote the usage of rainwater resources, often including the application of low impact development (LID) facilities. Although many airports in China have been chosen to implement sponge airport construction, there is a lack of quantitative evaluation on the effect of LID facilities. This paper takes Beijing Daxing International Airport as a case study and develops a comprehensive evaluation on the effect of LID facilities using the storm water management model (SWMM). The performance of four LID design scenarios with different locations and sizes of the rain barrel, the vegetative swale, the green roof, and the storage tank were analyzed. After LID, the water depth of J7 reduces from 0.6 m to 0.2 m, and duration of accumulated water reduces from 5 hours to 2.5 hours. The water depth of J17 reduces from 0.5 m to 0.1 m, and duration of accumulated water reduces from 2 hours to 15 minutes. The capacity of conduits has been greatly improved (Link 7 and Link 17). The application of LID facilities greatly improves rainwater removal capacity and effectively alleviates the waterlogging risk in the study area.

Key words | flood control, LID facilities, sponge airport, SWMM model

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INTRODUCTION

In recent years, the concept of resilience has been introduced into the engineering field, in particular related to disaster mitigation and management (Cimellaro *et al.* 2016; Fotovatikhah *et al.* 2018; Kammouh *et al.* 2019). Rapid urbanization in China has caused severe water and environmental problems in recent years. Many cities are facing challenges associated with urban sustainability and urban water issues such as urban flooding, combined sewer overflow, water scarcity, and a high frequency of extreme weather. Among these, urban flooding is one of the most frequent and hazardous disasters that can cause enormous impacts on the economy, environment, and human society (Yin *et al.* 2015; Sang & Yang 2017; Zhou *et al.* 2018). In China, the number of

waterlogged cities was 234 in 2013 and 258 in 2016. To address these challenges, the Chinese government had been searching for viable options and launched pilot sponge city construction programs (Li *et al.* 2017). The content of sponge city is to advocate the construction of a 'rainwater system' with low impact, so that cities can absorb, save, store, filter, and purify rainwater when it rains like a sponge. When there is demand, it can reasonably release and make full use of the stored rainwater resources (Zhang *et al.* 2018).

With the increase of airport scale and passenger flow, the contradiction between supply and demand of airport water resources has become increasingly obvious. The water consumption data of some airports have been studied by Carvalho *et al.* (2013), who reported that the average water consumption is about 20 L/passenger, with about 800 thousand m³ of water consumption per year. In addition to potable water, a large amount of water is used to meet the non-potable water

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doi: 10.2166/wcc.2020.195

requirements (Carvalho *et al.* 2013). A variety of models has been established to calculate the cost of rainwater utilization (Fernandes Moreira Neto *et al.* 2012). In overall reporting data, a great part of the harvested rainwater in airports is used in landscape irrigation, air conditioning, washing of paved areas and aircrafts, and so on. Among these, toilet flushing occupied more than 50% of use (Zurich 2010).

Singapore Changi Airport can save about \$390,000 per year by collecting a considerable quantity of rainwater every month for flushing toilets and terminal air-conditioning systems (Shrestha 2009). Brussels Airport uses rainwater storage tanks installed on the roof to flush toilets (Brussels 2010). Atlanta Airport uses rainwater tanks to collect rainwater and irrigate plants. Atlanta Airport has installed three 11.37 m³ water cisterns, which capture water runoff from the roof. The water collected from the cisterns is used to irrigate plants and 36.37 m³ of harvested rainwater per month was used (Atlanta 2010). For the new airport in Munich, in order not to destroy the natural balance of water quality and quantity, a detailed rainwater collection and utilization design has been planned (Suppan & Graf 2000).

Some airports in China have also carried out rainwater recycling (Peng *et al.* 2018). Nanjing Lukou Airport has also set up a rainwater recovery system. Underground, one floor, is equipped with a storage tank, which can meet the 3-day toilet flushing capacity of the main building (Peng *et al.* 2016). At Changzhou Airport, the rainwater is collected by a landscaped lake and used for greening water of a green space square after treatment (Ji *et al.* 2013). Qingdao's new airport has launched an attempt to pilot the first green sponge airport in China. According to the municipal drainage design and the functional zoning of construction land, LID facilities are to be designed and applied, such as permeable pavement, biological detention, grass planting ditch, and rainwater storage tank (Peng *et al.* 2019). Beijing new airport has also carried out design planning for a sponge airport. Through the construction of a digital rainwater management system, the rainwater pipeline system of the new airport has been designed and checked, and the waterlogging risk caused by excessive rainfall evaluated (Ren *et al.* 2017; Xie *et al.* 2017).

In summary, the current rainwater utilization at the airport mainly focuses on the treatment method, utilization cost of rainwater. Few scholars have conducted research on the sponge airport, especially the impact of LID facilities

on airport rainwater utilization using a model. Traditional airport construction focuses on the fast drainage mode of rainwater by various underground pipes or open channels. The pressure of the water supply and drainage facilities increase when there is heavy rain, while the rainwater cannot be discharged quickly, increasing the frequency of waterlogging in the airport. Therefore, this paper first puts forward the construction concept of sponge airport, and the LID facilities are designed and built. The airport can respond to heavy rain disasters like a sponge city with good elasticity. When it rains, it absorbs water, stores water, and seeps water. When it is needed, it releases stored water and uses it. Then the software was applied to establish models, which can simulate the runoff of rainstorms and evaluate the effects of LID facilities. The water depth, capacity of conduits, and the number of overflow junctions and conduits are compared before and after implementation of LID facilities. The research can be applied both to sponge cities and airports. It will help to achieve the construction goal of 'safe airport, green airport, smart airport, humanities airport' and contribute to the construction of a green, environmentally friendly and harmonious sponge city.

METHODOLOGY

Design of LID facilities

The purpose of sponge airport construction is to design and construct a sponge airport by setting LID facilities which can store and discharge naturally, and achieve reasonable infiltrating, detention, storage, purification, reuse, and drainage of rainwater resources in the airport. That can make sponge airports, like sponges, have good 'elasticity' in adaptation to environmental changes and response to rainstorm disasters. When it rains, the airport will absorb, store, infiltrate, discharge and purify water, and, if necessary, the storage water will be released and utilized. The construction of a sponge airport can reduce the airport waterlogging crisis, realize the recycling of airport rainwater resources, improve the ecological environment to the greatest extent, and realize the natural purification and infiltration of rainwater.

The LID facilities for a sponge city mainly include biological retention, grass planting ditch, rainwater bucket,

permeable pavement, concave green space, and so on. The LID facilities for a sponge airport are designed according to the land use characteristics of the airport. The main method of rainwater collection and utilization is discharge and drainage in the runway, taxiway, and apron area. The LID facilities of seepage, stagnant storage rainwater can be adopted, such as the soil area of the flying area, terminal area, and pavement. In this paper, the performance of four LID facilities with different locations and sizes of the rain barrel, the vegetative swale, the green roof, and the storage tank are analyzed. The applied location and role of LID facilities can be seen in Table 1.

Software

Many researchers use models to predict flood, forecast river flow, and produce storm water management (Mosavi et al. 2018; Yaseen et al. 2019). Software used to simulate water drainage systems can be divided into commercial software and open source. The commercial software is easy for engineers to implement and test. Some of the popular commercial software includes PCSWM (a flexible, powerful, and comprehensive software for urban wastewater and stormwater management modeling), Info works, and MIKE URBAN

(Kang et al. 2017). The open-source tools are sufficiently flexible to modify and add to the simulation algorithm, which in turn, allows the integration of unique features for each drainage system. One of the most commonly used open-source tools is SWMM. It is a dynamic rainfall-runoff simulation model, which can simulate a single precipitation event or long-term water quality and quantity in urban areas. The model has been used in Tianjin, Shanghai, and other areas in China (Chen et al. 2015). The simulation results can be represented by time series charts, profiles, animation demonstrations, and statistical analysis (Qin et al. 2013; Rabori & Ghazavi 2018). SWMM has good versatility, relatively low demand for research data, no time step limit, and no scale limit. Therefore, the study presented in this paper investigates how SWMM can be implemented to simulate flood of the study airport.

APPLICATION AND DATA ANALYSIS

Study area

Beijing is located in the north of China, with uneven rainfall distribution in the year. There are many sudden rainstorms in summer, which often lead to flood disasters. Thus, Beijing Daxing International Airport is taken as an example to study. Beijing Daxing International Airport is located in the Daxing District of Beijing. It is about 50 km from the center of Beijing. The location is shown in Figure 1. The airport is being constructed and operated in stages. The planned land area for this period (2020) is about 27 km². In the first phase of airport construction, the flight area, maintenance area, and freight area is large. The hard-surfaced area of the airport accounts for 69%. It will naturally change the original characteristics (Ge et al. 2015).

According to the topography of Beijing Daxing International Airport, it can be divided into seven drainage zones, namely, N1, N2, N3, N4, N5, N6, and S1. Because the rainwater drainage of the airport is very complex, the rainwater drainage system of Catchment N1 is an independent system (Figure 2), so N1 was taken as an example for simulation. Other catchments (such as N2, N3, and so on) can be further studied in the future. Catchment N1 includes the maintenance area, part of the flight area, and the west part

Table 1 | Applied location and role of LID facilities at a sponge airport

Measures	Location	Function
Rain barrel	Specific location in flying area. Near the rainwater pipe of the terminal building	Save and reduce the total discharge. Staggering and storing rainwater
Green roof	Roof of buildings in working area and maintenance area	Extending the runoff duration and controlling initial pollutants. Reducing total discharge volume
Vegetative swale	The soil area in the flight area. Around the square and parking lot. The building area of work	Purifying rainwater, <i>In situ</i> infiltration. Stagnant surrounding rainwater
Storage tank	The storage tanks along the rainwater drainage system of each catchment area. Terminal reservoir	Storing, purifying rainwater. Reduce the total discharge volume, staggering drainage

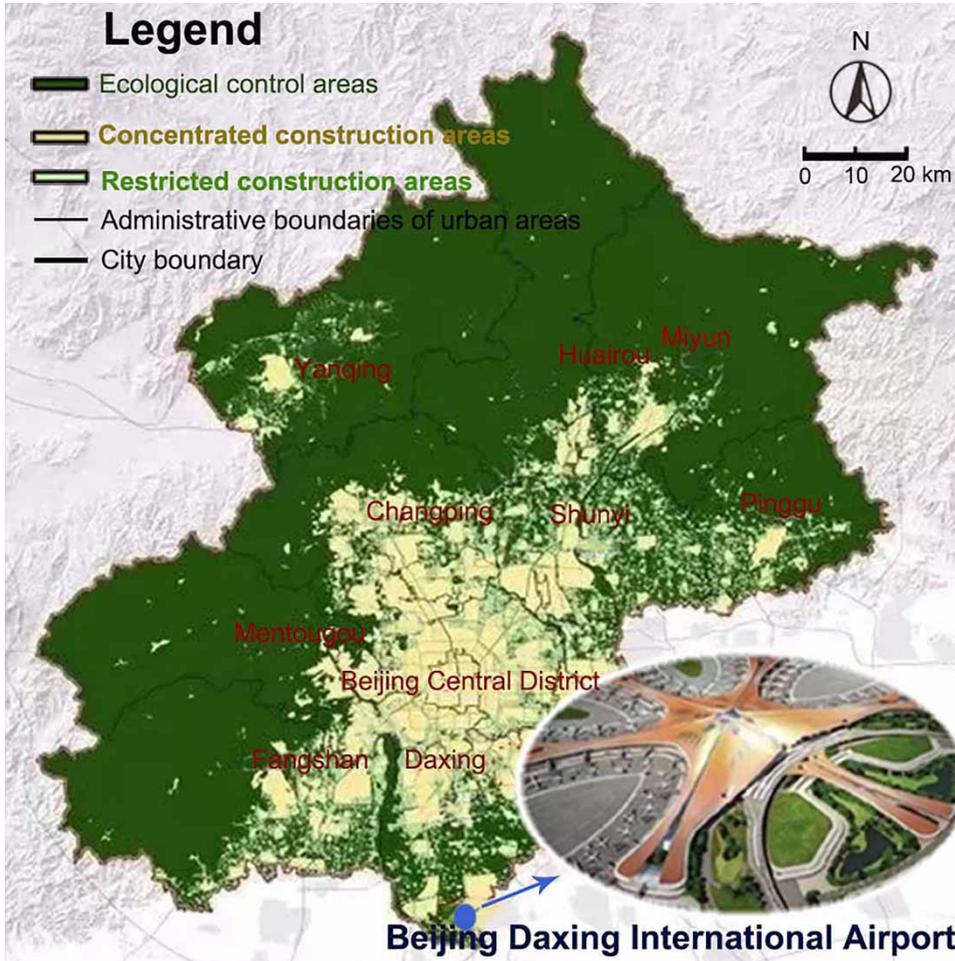


Figure 1 | The location of Beijing Daxing International Airport.

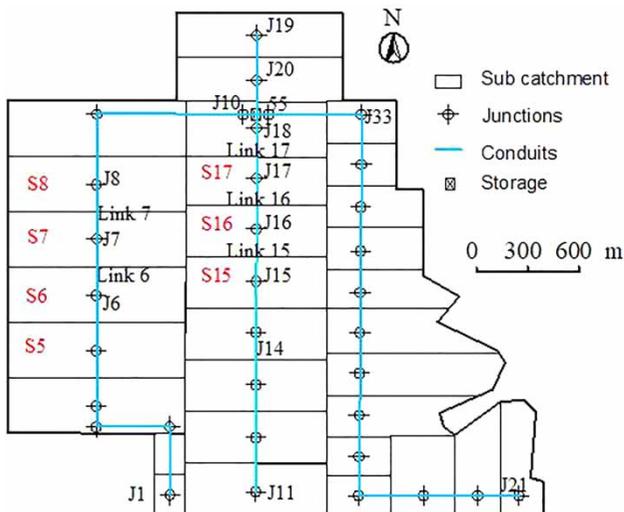


Figure 2 | The distribution of rain water drainage system in the simulation area.

of the terminal area. There are three main rainwater drainage networks. According to the flow direction of rainwater, they are J1 to J10, J11 to J18, and J21 to J33. There is rainwater storage N1 at the northern end of Catchment N1. The storage has an area of $1.0 \times 10^5 \text{ m}^2$ and a capacity of $2.7 \times 10^5 \text{ m}^3$. Storm water was conveyed to the storage N1 through the nearest channels or pipes in the form of catchment surface runoff. The layout of rainwater junctions, conduits, and storage N1 in Catchment N1 is shown in Figure 2.

Rainfall data

Beijing has a temperate continental climate, which is hot and rainy in summer and prone to severe rainstorms. The aim of this paper is to verify whether the rainwater drainage

system of the airport at the initial design stage meets the flood control requirements. It is suitable for the use of hourly rain type for longer hours. The rainfall scenario in 1 hour with five-year and 100-year return period is representative and can meet the research purposes of this paper. Based on the historical rainfall data collected by the observation station, frequency analysis approach was used to derive the design of torrential rain in Beijing. In this study, the runoff process of the study area is simulated and the model is checked in a one-hour rainfall scenario with a five-year return period (Figure 3). The objective function for model calibration is to verify the number and water depth of overflow junctions meet the requirements of design. At this rainfall intensity, only J7 and J8 junctions have overflow for a short period of time, which can meet the requirements of the design. The simulation results of storm runoff in this model are close to the theoretical and measured values and the error is small.

On this basis, the model is simulated in a 1-hour rainfall scenario with a 100-year return period (Figure 3). The rainfall series used in this simulation is assumed to be an independent rainfall event. There is no rainfall before it (if there is rainfall before it, the junctions and conduits may have water accumulation before simulation. The simulation results will be affected by the previous rainfall, so it is impossible to evaluate the effect of this rainfall).

Model parameters' setting

The parameters of SWMM include hydrologic parameters and hydraulic parameters. The hydraulic parameters include the diameter, length, shape, and elevation of rainwater drainage pipes, which can be set according to the drainage engineering design drawing. The hydrologic parameters include area of the

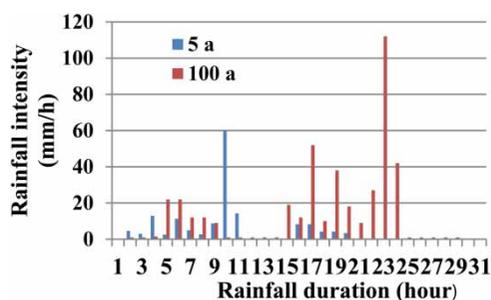


Figure 3 | One-hour rainfall scenario with different return periods.

sub-catchment, width, percent slope, percent of impervious, Manning's n of impervious (N-Imperv), depth of depression storage of pervious (Dstore-Imperv), and so on. Some parameters can be set according to land use type of the study area. Some parameters are purely empirical, or empirical parameters with certain physical significance.

It is found that the main sensitive parameters affecting the output of SWMM model are N-imperv, N-perv, Dstore-perv, conduit roughness (Hu 2016). The slope of sub-catchment is obtained by analyzing the slope of regional digital elevation model (DEM) data. Dstore-Imperv and Dstore-perv are obtained by analyzing subsurface properties of the airport. Referring to the experience value of literature and combining with the actual situation, Manning's n can be set. After sensitivity analysis and simulation calculation, the appropriate parameter values are finally set. In this study, the rainwater drainage pipe is concrete channels. Manning's n of concrete channels is set to 0.013. Impervious area includes runway, taxiway and apron, which is mainly cement concrete pavement. N-imperv is set to 0.012. Permeable area is mainly soil surface area with grass. N-perv can be set to 0.2. Dstore-perv is set to 3 mm in the model without LID facilities. Dstore-perv will be increased to 10 mm.

The infiltration parameters depend on which infiltration model was selected for the project: Horton, Green-Ampt, or curve number. Green-Ampt requires very high soil data. Curve number only reflects the underlying surface of the basin and does not reflect the rainfall process. It is only suitable for large basins. Horton is often used in rainfall-runoff simulation of urban small watersheds. Therefore, Horton is adopted in this study.

RESULTS AND DISCUSSION

In this study, a traditional hydrological model was built without LID facilities in any sub-catchment. In order to verify the effect of LID facilities' implementation, a model with LID facilities is built in some sub-catchments. This study focuses on the analysis of rainwater-runoff process of Catchment N1 under a 1-hour rainfall scenario with a 100-year return period. The full flow and overflow of each junction and conduit are analyzed in detail. The appropriate LID facilities are added to the sub-catchments where the

overflow junction appears. The results of before LID and after LID are compared.

Simulation before applied LID facilities

The first simulation condition is simulated before applying LID facilities. The capacity of conduits and water depth of junctions are analyzed and summarized. All junctions and conduits do not overflow before 17:00 from J1 to J10. With the increase of rainfall intensity, J7 and J8 appear at full flow at 17:45 and 19:45, respectively, and one conduit (Link 7) is at full flow (Figure 4(b)). It lasts for a short time, and there is no water accumulation at junctions. With the further increase of rainfall intensity, the number of overflow junctions and full-flow conduits continues to increase. J7 begins to overflow at 23:30, there is a full-flow junction and a full-flow conduit. There are three overflow junctions and two full-flow conduits at 25:15. It lasts for 5 hours and the maximum depth of water accumulation is 0.6 m (the maximum allowable water depth of the junction is 2.2 m), which will seriously affect the operation of the airport. The water depth of J6, J7, and J8 in the whole simulation process can be seen in Figure 4(a). The capacity

of conduits (Link 6 and Link 7) in the whole simulation process can be seen in Figure 4(b).

All junctions and conduits do not overflow before 23:00 from J11 to J18. The full-flow junctions and conduits began to appear at 23:30. With the increase of rainfall intensity, the situation of overflow and full flow are the most serious cases at 24:00. There is one full-flow junction, three overflow junctions, and three full-flow conduits at 24:00 (Figure 5). It lasts for 1.5 hours and the maximum depth of water accumulation at junctions is about 0.5 m (the maximum allowable water depth of the junction is 2.2 m).

The results of simulation show that part of the rainwater pipe network is the key to restricting the rainwater drainage system, and there is a bottleneck area. Due to the full flow of Link 6 and Link 7, rainwater cannot be discharged in time and quickly, resulting in water accumulation at J7 and J8. Due to the full flow of Link 14, Link 15, and Link 16, rainwater cannot be discharged in time and quickly, resulting in water accumulation at J15, J16, and J17. These conduits are the cause of bottlenecks in the rainwater drainage system in the study area. In order to avoid water accumulation, the size of these conduits can be expanded. It is difficult to modify the size of conduits for the designed drainage system, so the LID facilities are adopted in the bottleneck area and studied to see whether they can improve the drainage capacity of the study area.

Simulation after applied LID facilities

It can be seen that many junctions and conduits appear as overflow or full flow in the simulation before applying the LID facilities. In order to avoid water accumulation and to improve the drainage capacity of Catchment N1, the LID facilities are added according to the land use characteristics in the bottleneck area. According to the preliminary design drawings of the rainwater drainage system at Beijing Daxing International Airport, the maintenance area is located in the west of Catchment N1. The middle part of N1 is the flight area. The west part of the terminal area is located in the east of Catchment N1. Combined with the features and suitability of the LID facilities, the rain barrel and green roof are set up along the rainwater drainage pipelines from J1 to J10. There is a large maintenance area in the sub-catchments S5–S8, and meanwhile they are the bottleneck area. Due to

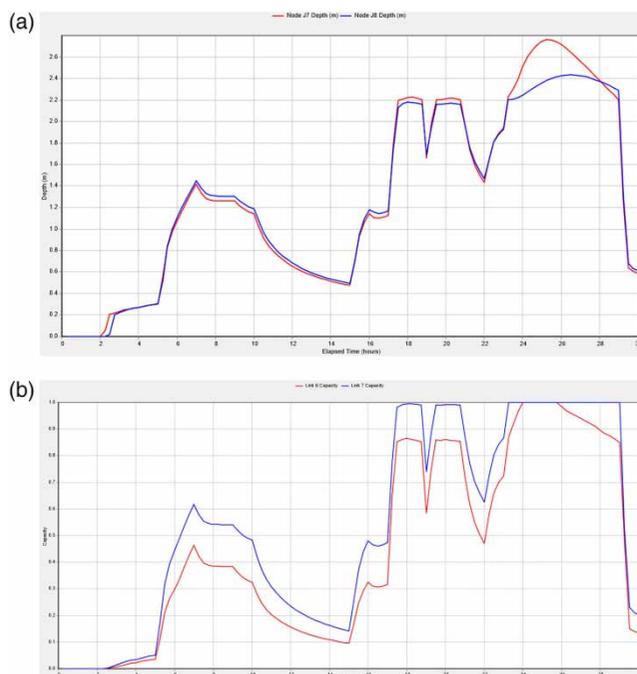


Figure 4 | The water depth at J7–J8 (a) and the capacity of conduits (b).

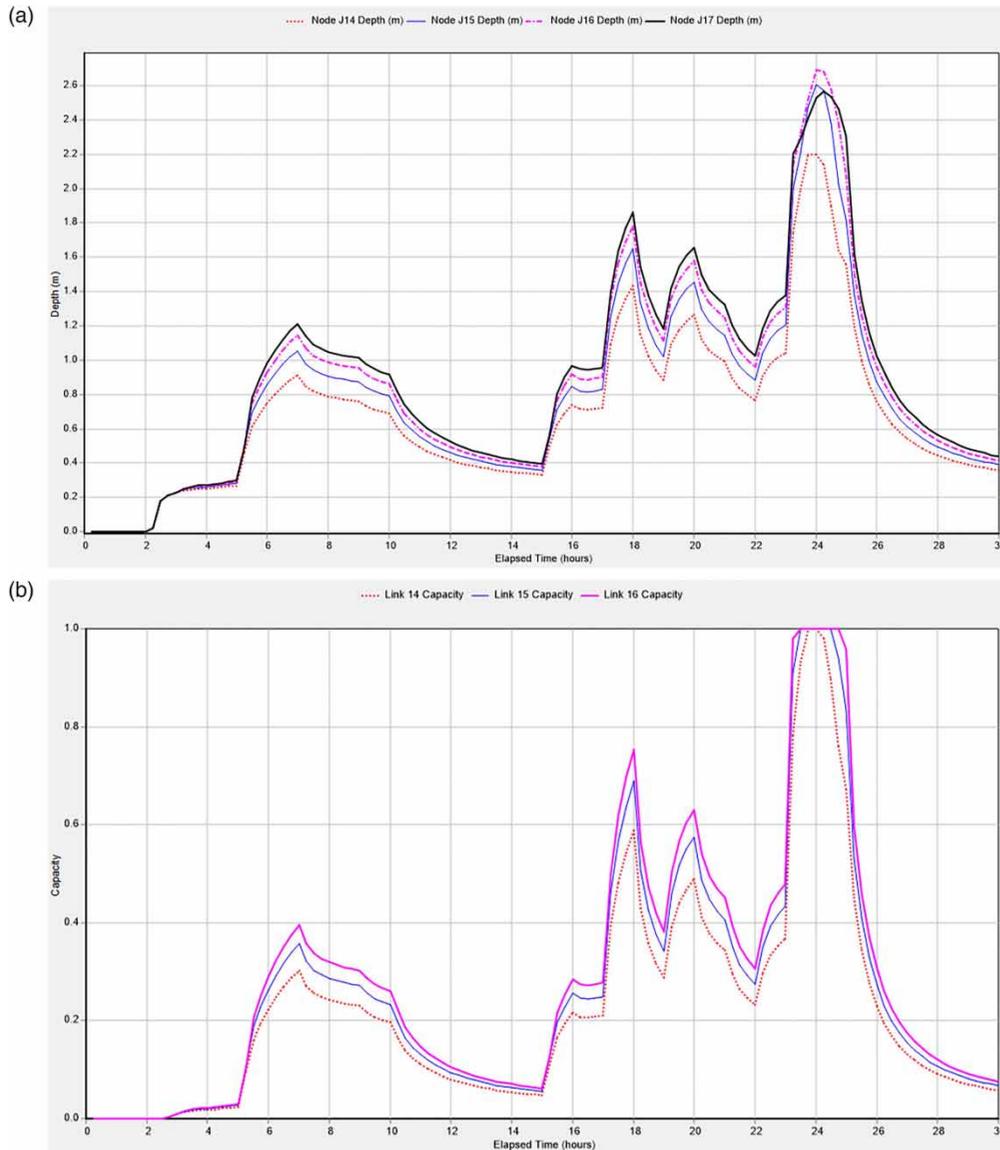


Figure 5 | The water depth at J14–J17 (a) and the capacity of conduits (b).

there being mainly runway, taxiway, and soil area in the sub-catchments S15–S17, the vegetative swale is installed. In addition, in order to relieve the rainwater drainage pressure of Link 14, Link 15, and Link 16, it is necessary to set storage tanks along the way to store some rainwater. The storage tanks along the way are set up between J16 and J18, and the volume of storage is $4.0 \times 10^4 \text{ m}^3$. The situation of the applied LID facilities can be seen in Table 2.

Based on the analysis of simulation results of the model after setting LID facilities, the water elevation profiles and

Table 2 | The location and area of LID facilities

Applied sub-catchment	LID type	Land use characteristics	% of area	% From Imperv
S5–S8	Rain barrel	A large area of maintenance room	36	40
	Green roof		50	20
S15–S17	Vegetative swale	A large area of soil zone	50	50
	Storage tanks		16	30

water depth of junctions and conduits can be obtained (Figure 6). It can be seen that the most disadvantageous situation of rainwater drainage systems in N1 occurs at 24:00. There is one junction (J7) overflow, two junctions (J8 and J17) full flow, and two conduits (Link 6 and Link 7) overflow. The maximum depth of water accumulation at J7 is about 0.5 m. It lasts for a very short time. It is obvious that the number of overflow junctions and conduits is greatly

reduced. The drainage pressure of the rainwater drainage system of N1 is greatly relieved.

Comparison of simulation results

There are many overflow junctions and full-flow conduits before applying the LID facilities. J7 and J17 have the most serious water accumulation in all junctions. Link 7

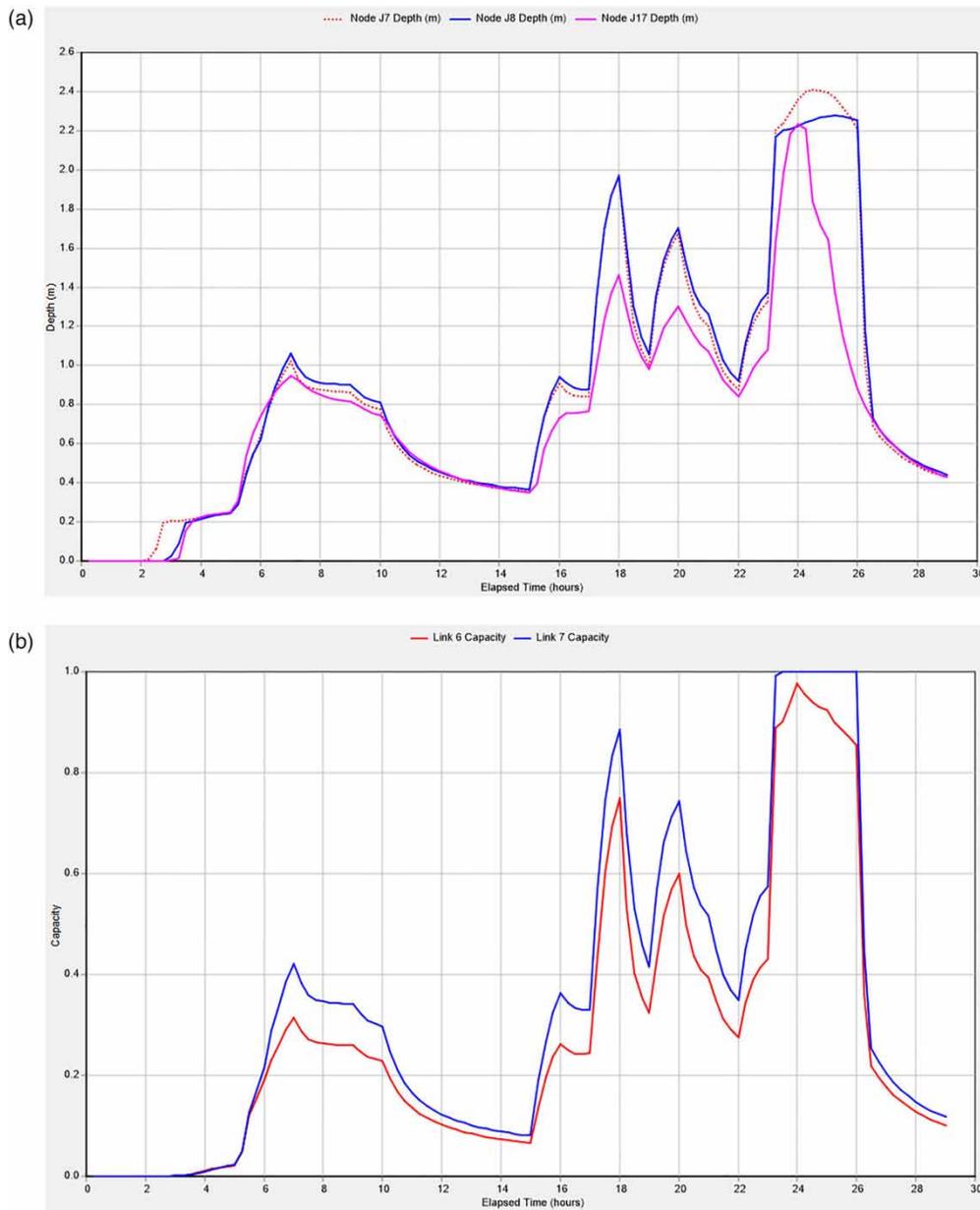


Figure 6 | The water depth of J7, J8, and 17 (a) and the capacity of Link 6 and Link 7 (b).

and Link 16 have the most serious full flow. Thus, they are selected as the objects of comparative analysis and study in this section. Figure 7(a) is the water depth of J7 and J17 before the applied LID facilities. Figure 7(b) is the water depth of J7 and J17 after the applied LID facilities. Figure 7(c) is the capacity of Link 7 and Link 16 before the applied LID facilities. Figure 7(d) is the capacity of Link 7 and Link 16 after the applied LID facilities. Before LID facilities, J7 has accumulated water many times which lasted nearly 5 hours. The maximum depth of water accumulation is 0.6 m. After LID, the maximum depth of water accumulation is only 0.2 m, and the duration of water accumulation is shortened to 2.5 hours. It is the same as that of J7. The maximum depth of water accumulation of J17 reduces from 0.5 m to 0.1 m. The duration time reduces from 2 hours to 15 minutes. The full-flow time of Link 7 reduces from 9 hours to 3 hours. The full-flow time of Link 16 reduces from 2 hours to zero.

Through the analysis before and after implementation of LID facilities, it can be seen that the number of full-flow conduits and overflow junctions, the maximum accumulated water depth of junctions, and duration of accumulated water have improved significantly. The comparison of simulation results are shown with detailed information listed in Table 3. The LID facilities greatly increase the reduction rate of surface runoff of rainwater, and also increase the reduction rate of the number of overflow junctions and full flow conduits to a certain extent. A series of LID facilities has been adopted to greatly improve the rainwater removal capacity and effectively alleviate the risk of waterlogging in the study area.

CONCLUSIONS

At present, the research on sponge airports mainly focuses on the design of LID facilities and the construction of

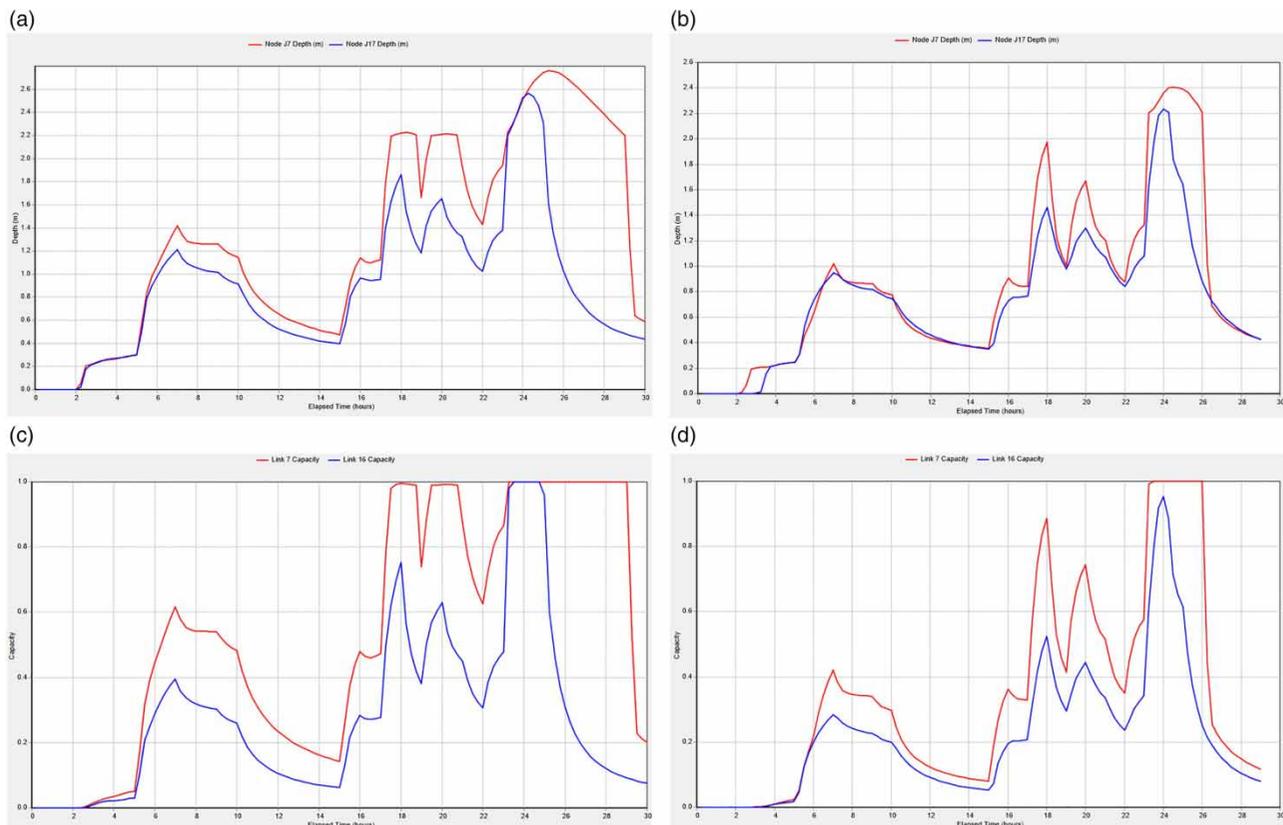


Figure 7 | The water depth of J7 and J17 before and after LID ((a) and (c)) and the capacity of Link 7 and Link 16 before and after LID ((b) and (d)).

Table 3 | Comparison of simulation results before and after LID facilities

Simulation results		Before LID facilities	After LID facilities	Reduction percentage %
Number of full-flow conduits	From J1 to J10	6	2	70
	From J11 to J17	3	0	100
Number of overflow junctions	From J1 to J10	4	1	75
	From J11 to J17	3	1	70
Maximum accumulated water depth of junctions (m)	J7	0.6	0.2	75
	J17	0.5	0.1	80
Duration of accumulated water (hour)	J7	5	2.5	50
	J17	2	0.25	87
Full flow times of conduits (hour)	Link7	9	3	70
	Link16	2	0	100

sponge airports, and few researchers use software to simulate the implementation effect of LID facilities. In this paper, rainwater-runoff simulation models before and after implementation of LID facilities were developed using SWMM. The developed models were applied on a rainwater drainage system at a catchment of Beijing Daxing Airport. The sponge airport models were implemented to calculate the water depth, the number of full-flow conduits and overflow junctions, duration of accumulated water before and after applying LID facilities. According to the results and discussions, the following key findings can be concluded:

1. SWMM can be applied to simulate the rainwater drainage performance of catchment N1, Beijing Daxing Airport in China. The SWMM models developed in this paper were set up according to the study area land surface information and drainage engineering design drawing. Sensitivity analysis showed the robustness of the key parameters of the model.
2. Preliminary application of the developed models was used to calculate the water depth and the capacity of conduits under 1-hour rainfall with return periods of 100 years. The simulation results of two developed models before and after application of LID facilities were analyzed and compared.

3. The application of LID facilities greatly improve the rainwater removal capacity and effectively alleviate the risk of waterlogging in the study area. The maximum depth of water accumulation of J7 reduces from 0.6 m to 0.2 m. The duration time reduces from 5 hours to 2.5 hours. The maximum depth of water accumulation of J17 reduces from 0.5 m to 0.1 m. The duration time reduces from 2 hours to 15 minutes. The full-flow time of Link 7 reduces from 9 hours to 3 hours. The full-flow time of Link 16 reduces from 2 hours to zero.
4. The results can help engineers and administrators to understand and select the sponge airport facilities.

There are some limitations in the study. For future research, more sensitivity of parameters should be studied in detail, and further calibration of the model with more practical measured data. In addition, we can further simulate the rainwater drainage system operation of other areas in Beijing Daxing Airport, selecting the optimal LID and control strategy and realizing accurate rainwater-runoff simulation and improving flood control and management.

ACKNOWLEDGEMENTS

This research was funded by Civil Aviation University of China Central University Fund (grant number 3122018C015) and Tianjin Municipal Education Commission Scientific Research Plan Project (Study on simulation of rainwater runoff at sponge airport, grant number 2019KJ125). The authors wish to thank the anonymous reviewers for their comments and suggestions and the people who have supported this study.

REFERENCES

- Atlanta Department of Civil Aviation Hartsfield-Jackson Atlanta International Airport 2010 *Annual Environmental Report*. Available from: <http://www.atl.com/>.
- Brussels Airport Company 2010 *Environmental Report*. Available from: https://www.baidu.com/s?word=Brussels%20Airport%20Company.%20Environmental%20report.&tn=site888_3_pg&lm=-1&ssl_s=1&ssl_c=ssl1_166be9a6e1d.

- Carvalho, I., Calijuri, M. L., Peixoto Assemany, P., Dornelas Freitas Silva, M., Fernandes Moreira Neto, R., Santiago, A. & Batalha de Souza, M. H. 2015 Sustainable airport environments: a review of water conservation practices in airports. *Resources, Conservation and Recycling* **74**, 27–36.
- Chen, H., Li, J. K. & Li, Y. J. 2015 Progress on research and application of storm water management model (SWMM). *Journal of Northwest A & F University* **43** (12), 225–234.
- Cimellaro, G. P., Renschler, C., Reinhorn, A. M. & Arendt, L. 2016 PEOPLES: a framework for evaluating resilience. *Journal of Structural Engineering* **142** (10), 04016063.
- Fernandes Moreira Neto, R., Calijuri, M. L., Carvalho, I. & Santiago, A. 2012 Rainwater treatment in airports using slow sand filtration followed by chlorination: efficiency and costs. *Resources, Conservation and Recycling* **65**, 124–129.
- Fotovatikhah, F., Herrera, M., Shamshirband, S., Chau, K., Ardabili, S. F. & Piran, M. J. 2018 Survey of computational intelligence as basis to big flood management: challenges, research directions and future work. *Engineering Applications of Computational Fluid Mechanics* **12** (1), 411–437.
- Ge, W., Song, X. & Lu, H. 2015 Practice of sponge airport construction: a case study of Beijing new airport. *China Investigation Design* **7**, 56–59.
- Hu, X. 2016 Study on the Impact of Intercepting Agricultural Runoff of Interception Trunk of the Dianchi Lake on Intercepting Capability Based on SWMM. Master's Thesis, Chongqing University, China.
- Ji, Z., Ding, L. & Fu, E.-k. 2013 Design and operation of rainwater utilization engineering in Changzhou airport. *Water & Wastewater Engineering* **39**, 432–434.
- Kammouh, O., Zamani-Noori, A., Cimellaro, G. P. & Mahin, S. 2019 Resilience assessment of urban communities. *ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part A: Civil Engineering* **5** (1), 04019002.
- Kang, Z., Guo, Q., Lian, J. & Cheng, L. 2017 Advances in simulation models for whole-life-cycle effectiveness of sponge city construction. *Journal of Hydroelectric Engineering* **36** (11), 82–93.
- Li, H., Ding, L. Q., Ren, M. L., Li, C. Z. & Wang, H. 2017 Sponge city construction in China: a survey of the challenges and opportunities. *Water* **9**, 594.
- Mosavi, A., Ozturk, P. & Chau, K. W. 2018 Flood prediction using machine learning models: literature review. *Water* **10** (11), 1536.
- Peng, J., Ouyang, J. Y. & Yu, L. 2019 The model and simulation of low impact development of sponge airport, China. *Water Supply* ws2019170.
- Peng, J., Yue, R.-c. & Zhang, X.-m. 2016 Research on present situation of rainwater utilization in airport. *Water & Wastewater Engineering* **42**, 208–210.
- Peng, J., Zhang, X. M. & Zhang, Y. H. 2018 Study on combining flood control with rainwater utilization of airports in China. *IOP Conference Series Earth and Environmental Science* **191** (1), 1–6.
- Qin, H. P., Li, Z. X. & Fu, G. T. 2013 The effects of low impact development on urban flooding under different rainfall characteristics. *Journal of Environmental Management* **129**, 577–585.
- Rabori, A. M. & Ghazavi, R. 2018 Urban flood estimation and evaluation of the performance of an urban drainage system in a semi-arid urban area using SWMM. *Water Environment Research* **90** (12), 2075–2082.
- Ren, Y., Meng, R. M., Luo, K., Liu, J. Y. & Zhang, Y. 2017 Rainwater system construction in water sensitive area – taking Beijing new airport as an example. *Water & Wastewater Engineering* **43** (9), 25–32.
- Sang, Y. F. & Yang, M. Y. 2017 Urban waterlogs control in China: more effective strategies and actions are needed. *Natural Hazards* **85**, 1291–1294.
- Shrestha, R. R. 2009 Rainwater harvesting and groundwater recharge for water storage in the Kathmandu Valley. *Sustainable Mountain Development* **56**, 27–30.
- Suppan, P. & Graf, J. 2000 The impact of an airport on regional air quality at Munich, Germany. *International Journal of Environment & Pollution* **14** (1/2/3/4/5/6), 375–381.
- Xie, G., Wang, X.-d., Yin, X.-l. & Cheng, C. 2017 Study on ecological and rainwater utilization of large airport in the northern plains – a case of Beijing's new airport. *Environmental Engineering* **3**, 5–9.
- Yaseen, Z. M., Sulaiman, S. O., Deo, R. C. & Chau, K. W. 2019 An enhanced extreme learning machine model for river flow forecasting: state-of-the-art, practical applications in water resource engineering area and future research direction. *Journal of Hydrology* **569**, 387–408.
- Yin, J., Ye, M., Yin, Z. & Xu, S. 2015 A review of advances in urban flood risk analysis over China. *Stochastic Environmental Research and Risk Assessment* **29**, 1063–1070.
- Zhang, S. H., Li, Y. K., Ma, M. K., Song, T. & Song, R. N. 2018 Storm water management and flood control in sponge city construction of Beijing. *Water* **10**, 1040.
- Zhou, J. J., Liu, J. H., Shao, W. W., Yu, Y. D., Zhang, K., Wang, Y. & Mei, C. 2018 Effective evaluation of infiltration and storage measures in sponge city construction: a case study of Fenghuang City. *Water* **10**, 937.
- Zurich International Airport 2010 Annual Report. Available from: <https://www.zurich-airport.com/>.

First received 17 September 2019; accepted in revised form 5 December 2019. Available online 6 February 2020