ISSN: 2414-1895 DOI: 10.6919/ICJE.202401_10(1).0020

Research on Risk Assessment and Optimization Design of Urban Flooding for Civil Airport

Jian Chen, Songlei Han, Nan Zhang*

Shanghai Municipal Engineering Design Institute (Group) Co.,LTD, China

*Email: zhangnan@smedi.com

Abstract

In this paper, urban flooding model was constructed based on drainage design data from an airport in northwest China. In order to solve urban flooding problem, this study proposes four optimized design schemes for the terminal area. The four optimization design schemes are proposed under the design conditions of meeting the 5-year return period for the drainage network. These schemes include adjusting the vertical elevation, optimizing the opening and closing rules of pumps, increasing the storage space of Greenland, and combing the Green and Grey infrastructures. The optimal design scheme is obtained through intuitive quantification by numerical model. Studying the construction methods of urban flooding prevention and control systems in high-density areas through different renovation schemes can provide reference for urban flooding prevention and control planning and design in similar airport areas. Especially, the Green - Grey infrastructures can avoid economic losses and achieve dual guarantees of economy and safety, providing reference for the design of other civil airports.

Keywords

Hydrodynamic Model; Optimization Design; Green and Grey infrastructure; Urban Flood Risk Map; Civil Airport.

1. Introduction

The airport belongs to a highly urbanized area, with a high proportion of concrete land. Affected by the frequent extreme rainstorm weather, the frequent urban flooding of airports around the world has led to flight delays or cancellations, resulting in passenger detention, and bringing huge economic losses to airlines. Hunter N M [1] used a 2D hydrodynamic model to study urban floods. Ariyamingish[2] studied urban floods from the perspective of climate change. Also, there have also been recent advances in sponge cities, such as Fu G[3] researched on the role of sponge facilities in solving urban floods. Based on the advantages of these studies and the pain points of actual engineering design evaluation, some reflections were made.

Because there is very important to the evaluate in the airport drainage design process. Although the construction of urban pipeline networks meets design standards, with the intensification of climate change, cities still cannot avoid urban flooding. The standard for urban flooding in general cities is 50 – year return period or more, while the design standard for pipeline networks is 3 - 5 year return period, making it difficult for urban drainage systems to cope. Therefore, this research was conducted.

2. Study Region and Data

The airport is located in the northwest of China, and the research area is the terminal area of the airport and is about 0.7 km2. The regional characteristics are high construction density and insufficient storage space.

ISSN: 2414-1895 DOI: 10.6919/ICJE.202401_10(1).0020

The airport drainage system is divided into two major drainage zones, north and south. Each drainage zone has a drainage outlet, with the approximate drainage direction indicated by a green arrow and the drainage outlet represented by a red inverted triangle symbol, shown as the left side of Figure 1. The drainage system includes pipeline and pumping station forebay. All pipelines, pump station forebay, and terrain elevation data are design data.

It should be noted that the pumping stations are all underground and courtyard pumping stations, not the drainage pumping stations at the end of the municipal pipeline network. The rainwater from these pumping stations will enter the municipal pipeline network for discharge, and the end of the municipal drainage pipe is free outflow. The distribution of the underlying surface of the airport is shown in the right side of Figure 1.

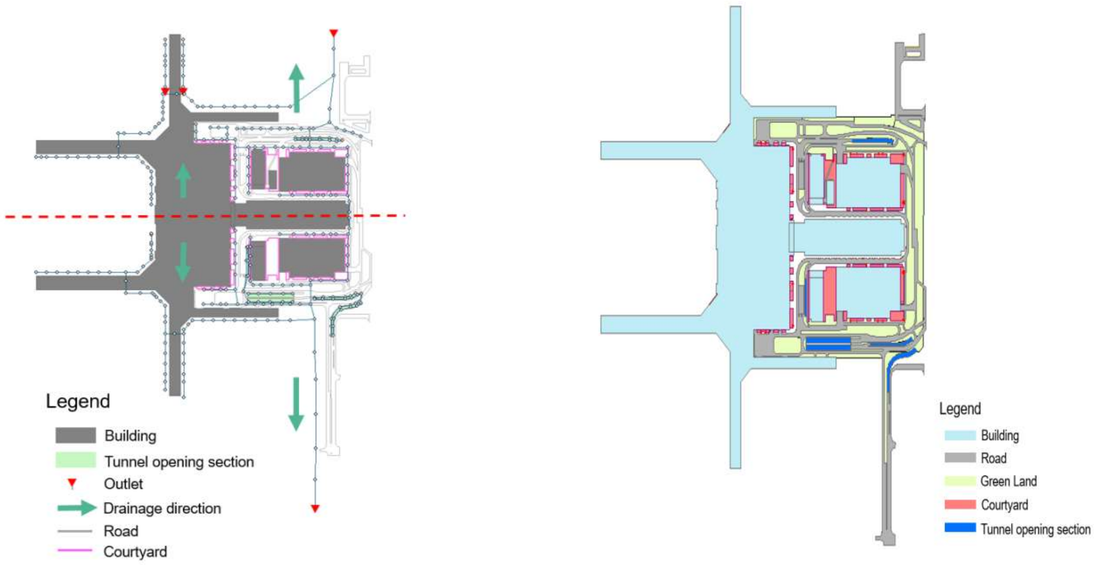

Figure 1. Airport Terminal Drainage System and Underlying Surface Distribution

3. Methodology

3.1 Model Construction

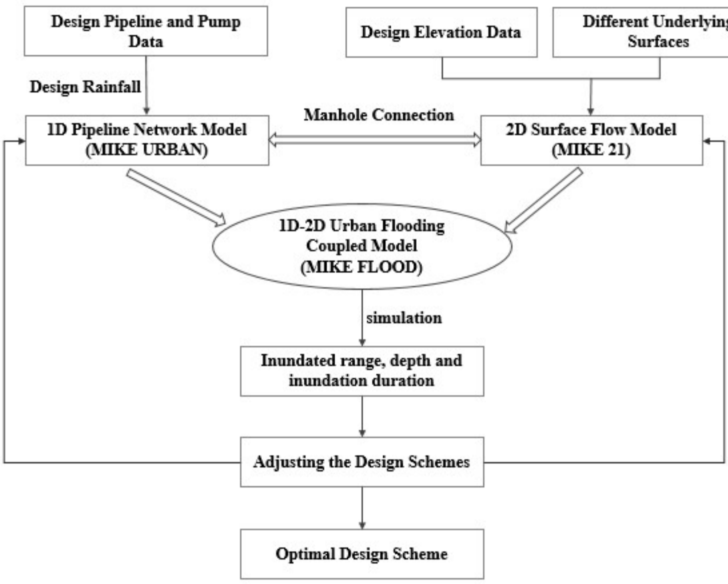

Figure 2. Research Framework

ISSN: 2414-1895 DOI: 10.6919/ICJE.202401_10(1).0020

This airport is a 4F level civil international airport. According to the Specifications for Aerodrome Drainage Design (MH/T 5036-2017), it is recommended to use mathematical model method for urban flooding simulation analysis in airports with a capacity of 4E and above. Therefore, this project has constructed a hydrodynamic model for the terminal area and used simulation methods to evaluate the drainage and urban flooding prevention system.

The methodology is based on the fact that the drainage system of the airport meets the 5-year return period design standard, but cannot meet the regional 50-year return period standard of urban flooding. The corresponding long duration (24 hours) is 129.6mm, so the boundary rainfall for constructing the urban flooding model is a 50-year return period. The research framework is shown in the following Figure 3.

1) Drainage System Data

The main situation of 1D pipeline network model is as follows Table 1.

Table 1. Summary data table for pipeline network model

Total length of pipeline (m)	Type of pipeline	Number of Manhole	Pumping station forebay	Outlet	Tunnel pumping station	Pipe diameter
9587.4	Circle pipe: 242 Quadrate culvert: 56	298	3	4	3 (including 10 pumps)	D300-D1800

2) Terrain Data

In the process of constructing the 2D surface flow model, the grid accuracy of DEM (Digital Elevation Model) is 5m × 5m. Build a one-dimensional pipeline network model, a two-dimensional surface overflow model, and a one-dimensional and two-dimensional coupling model to simulate a 50 - year return period flood model. Adjust the design plan based on the flood results and then simulate.

3) Boundary Condition

This study mainly has two rainfall boundaries, one is short duration (2 hours) and 5-year return period rainfall, and the other is long duration (24 hours) and 50-year return period rainfall. Short duration rainfall is used to evaluate the drainage capacity of the pipeline network, while long duration rainfall is used to evaluate urban flooding. The rainfall boundary is shown in the following Figure 3. The total rainfall with a 5-year return period is 44.2 mm, with a 1-minute interval and peak rainfall 2mm. The total rainfall with a 50 year return period is 129.6 mm, with a 5-minute interval and peak rainfall 15.7 mm.

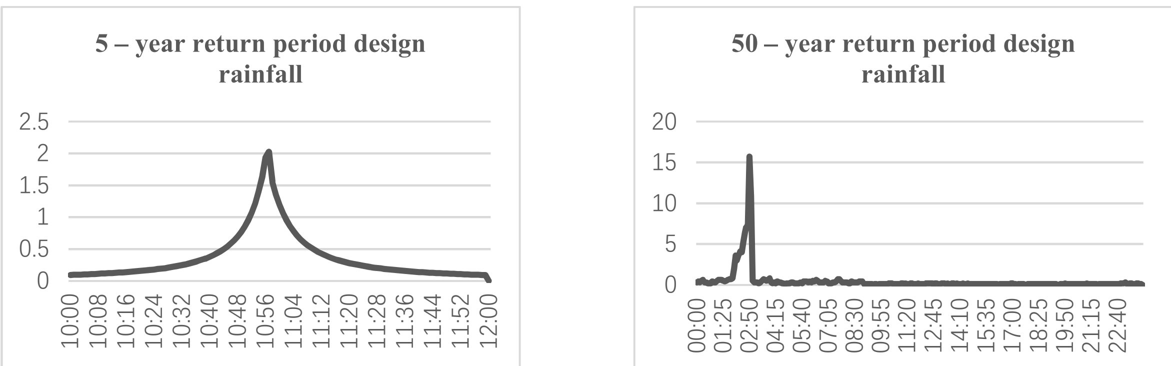

Figure 3. Design Rainfall Boundary

Volume 10 Issue 1, 2024
DOI: 10.6919/ICJE.202401_10(1).0020

3.2 Model Rationality

Due to the fact that the project site is in the planning and design stage, it is not yet possible to use simulation of the current situation to verify the model. Therefore, the rationality of the model is judged by keeping the model data consistent with the design.

The basic data and parameters of the model are consistent with the design. Both pipeline data and elevation data are design data, and the model parameter values are shown in Table 2.

Table 2. Model parameter values

Modelling	Parameter	Value
MIKE URBAN	Impermeability of concrete or asphalt pavement	0.80
	Green land	0.20
	Initial loss (mm)	0.00
	Hydrological reduction coefficient	1.00
MIKE 21	Dry (mm)	2.00
	Wet (mm)	3.00

4. Airport System Assessment

4.1 Drainage System Assessment

By constructing 1D-pipeline network model to simulate the Link Flood, which represents pipeline overflow. It means whether the pressure head of the pipeline exceeds the ground line. Therefore, the drainage capacity evaluation results show that the drainage system meets the design criteria for a 5-year return period short duration (2hours), with a corresponding design rainfall of 44.2mm, as shown in Figure 4.

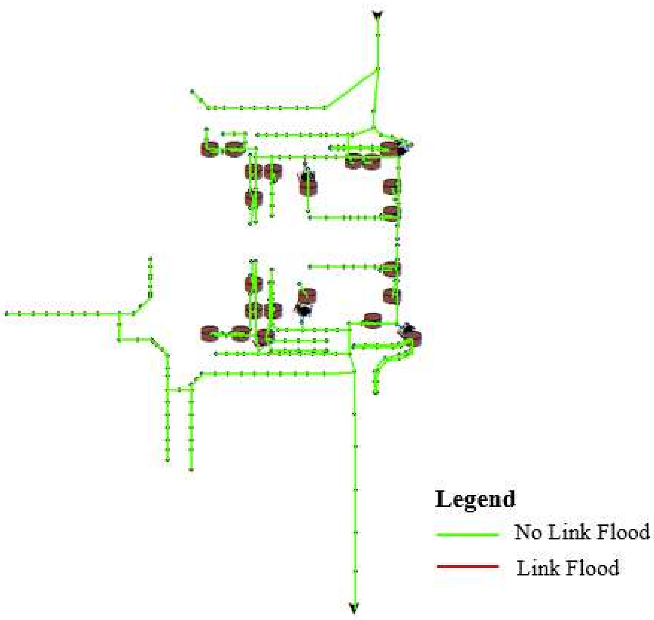

Figure 4. Distribution of Maximum Link Flood with 5-year return period

4.2 Airport Flooding Assessment

The key to this study is how to optimize the design scheme to solve the flooding problem without improving the design standards of the pipeline network.

ISSN: 2414-1895 DOI: 10.6919/ICJE.202401_10(1).0020

In this study, in addition to using a model that meets the design standards of the pipeline network to simulate a 50-year return period urban flood scenario, this study also simulated four design scenarios. After all, simply raising the design standards for the pipeline network is not scientific, it is necessary to respond to urban floods from a systematic perspective. The four design schemes are as follows:

1) Raising the vertical elevation of the site;

2) Optimizing the pump operating rule;

3) Increasing water storage space of green land;

4) Combing the Green and Grey infrastructures.

4.2.1 Evaluation Criteria

According to the Specifications for Aerodrome Drainage Design (MH/T 5036-2017), the airfield index is 4C and above, and the design return period of rainstorm for urban flooding prevention is 50 - year. Require that the bottom layer of the building should not enter water; The depth of accumulated water in one lane of an important road shall not exceed 150mm; The runway surface and shoulders in the flight area should not accumulate water, and communication and navigation equipment should not be flooded. Another drainage standard Technical code for urban flooding prevention and control (GB 51222-2017) of China also recognizes urban flooding as accumulated water depth exceeding 150 mm.

Moreover, the classification principle of urban flooding risk map level considers two dimensions, accumulated water depth and inundation duration. The specific classification standards refer to local regulations and the actual situation of the airport, and are finally determined as shown in the table below.

Table 3. The risk zone classification standards

h (m) / t (hour)	0.15<h≤0.3	0.3<h≤0.5	h>0.5
1<t≤2	Low risk zone	Low risk zone	Low risk zone
2<t≤3	Low risk zone	Medium risk zone	Medium risk zone
t>3	Low risk zone	Medium risk zone	High risk zone

4.2.2 Scenario Simulation

1) Original basic scenario

Figure 5. Distribution of maximum inundated depth and urban flooding risk map

ISSN: 2414-1895 DOI: 10.6919/ICJE.202401_10(1).0020

The original basic scenario simulation is the 50-year return period flood situation, and its model is based on the model which meets the 5-year return period drainage design criteria. The distribution map of maximum flooding depth and urban flood risk map are shown in the Figure 4. Therefore, it can be seen from the simulation results that the blue areas (left side of Fig.4) are all flooded areas. Also, the low risk zone is blue, and the medium risk zone is yellow, and the high risk zone is red (right side of Fig.4). The north and south courtyards of the airport are important locations for the terminal, with numerous personnel, so it is necessary to ensure that there is no risk under urban flooding standards. However, from Figure 4, it can be seen that there is severe flooding in the north and south courtyards, so design optimization is needed to solve the problem.

2) Four design scenarios simulation

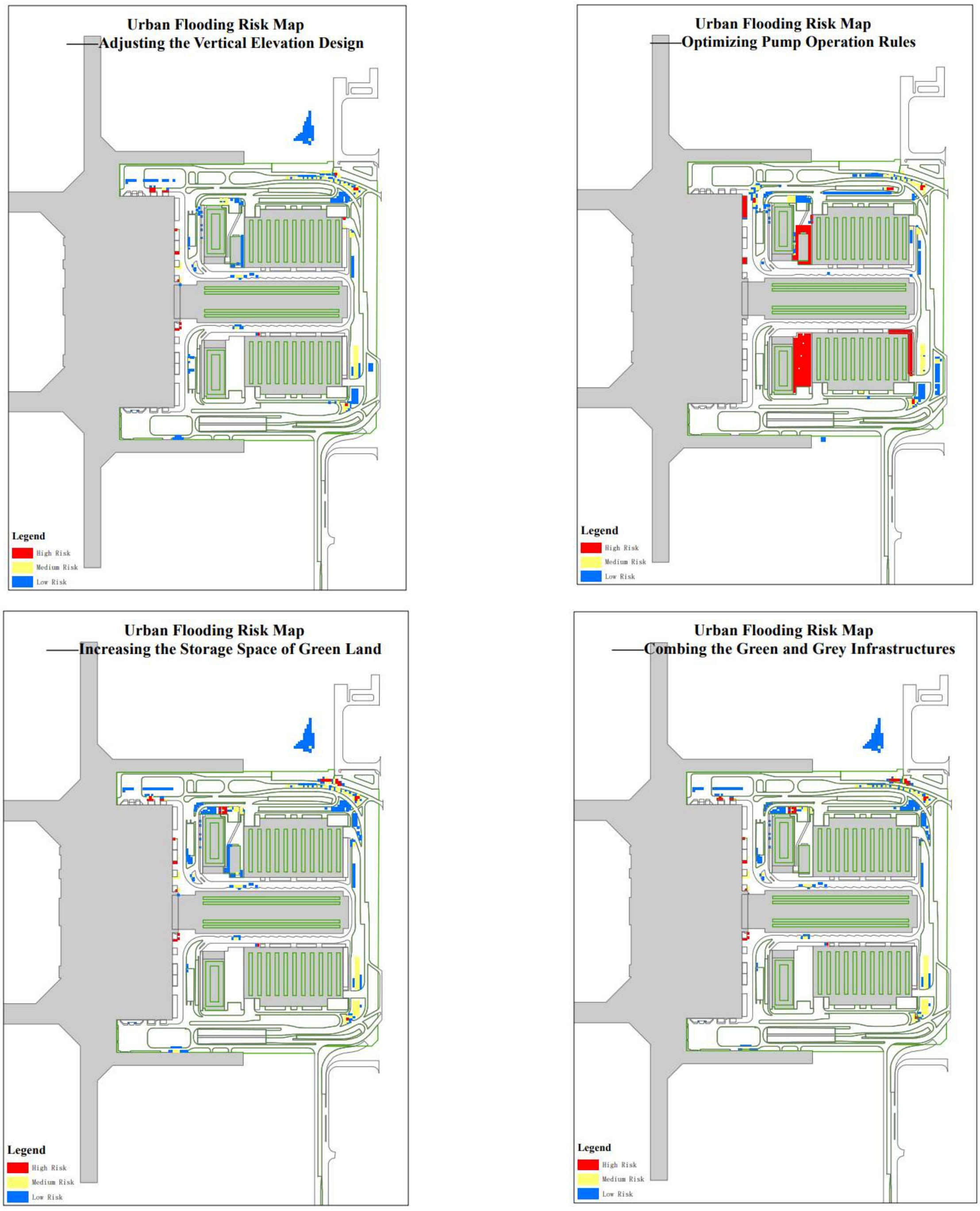

Figure 6. Urban Flooding Risk Maps for Different Design Schemes

In order to solve the problem of urban flooding in the site, especially to eliminate the risk zone of the north and south courtyards, a total of four optimization design schemes were adopted. These are respectively raising the elevation of the plot, optimizing the opening and closing rules of the pump station, increasing the storage space of green spaces, and combing Green-Grey infrastructures, using these design schemes to simulate, distribution maps of urban flooding risk levels are created, which are shown in the following Figure 6.

4.3 Result Analysis

Through statistical analysis, the maximum accumulated water volume, average water depth and different risk areas are determined as follows:

Table 4. Statistical analysis table

Results	Original Basic State	Raising Elevation	Optimizing Pump Operation	Increasing Storage Space of Green Land	Combing the Green-Grey Infrastructures
Maximum flood volume (m3)	30773	17086	31243	16861	**16690**
Average water depth (m)	0.027	0.016	0.028	0.016	0.016
Low risk area (m2)	8050	10825	8150	10050	9525
Medium risk area (m2)	2400	4900	2450	5350	5325
High risk area (m2)	8875	800	8825	1125	1125

From the statistical results, the scheme of Green-Grey infrastructures has the best effect on reducing the maximum flood volume. Regarding the statistics of risk areas, the green space within the area can be a risk area, but the two courtyards in the north and south cannot be a risk area.

From the perspective of reducing water accumulation in the north and south courtyards, the combination of Green-Grey infrastructures is better than the vertical elevation scheme and the increase in green space scheme. Optimizing the rules of courtyard pumps is not significantly effective in solving water accumulation in courtyards. There are two reasons for the analysis. One is the courtyard pumping station, which has a relatively small drainage capacity. The other is that the rainwater is pumped into the municipal pipeline network, but during the rainy duration, there is no time to quickly discharge it, and the surface water enters the pump station again. This circulation makes the effect less obvious.

5. Conclusion

In the engineering design process, it is often encountered that the pipeline network, storage basin or pumping station meets the design standards, but cannot meet the urban flooding standards. Moreover, engineering design methods are different from model evaluation methods. How model evaluation can better assist design? In limited spaces with high urban density, heavy rainfall and long duration can result in the inability to quickly drain rainwater. Therefore, by adjusting the vertical design to introduce water into green measures for storage, extending the time of concentration, and then discharging through pipe networks, it will ensure that important areas do not experience floods. This study provides a solution case. By simulating different scenarios and comparing the design results, the optimal solution combining Green – Grey infrastructures is given. This study can be used to support urban drainage system planning and risk management, while also contributing to the promotion of other airports construction.

Acknowledgments

Funding: This study was supported by the National Key Research and Development Program of China (No.2022YFC3800500).

References

[1] Hunter N M , Bates P D , Neelz S ,et al.Benchmarking 2D hydraulic models for urban flooding[J].Water Management, 2008, 161(1).DOI:10.1680/wama.2008.161.1.13.

[2] Ariyaningsih, Sukhwani V , Shaw R .Vulnerability assessment of Balikpapan (Indonesia) for climate change-induced urban flooding[J].International journal of disaster resilience in the built environment, 2023.DOI:10.1108/IJDRBE-08-2021-0111.

[3] Fu G , Zhang C , Hall J W ,et al.Are sponge cities the solution to China's growing urban flooding problems?[J].Wiley Interdisciplinary Reviews: Water, 2023.

[4] Li Z , Wang Z , Wu L ,et al.Evaluating the effect of building patterns on urban flooding based on a boosted regression tree: A case study of Beijing, China[J].Hydrological processes, 2023.

[5] Lin L , Tang C , Liang Q ,et al.Rapid urban flood risk mapping for data-scarce environments using social sensing and region-stable deep neural network[J].Journal of Hydrology, 2023, 617:128758-.

[6] Zhou Q , Feng J , Feng W .How does flow connection path and vertical spatial layout of LIDs affect urban runoff? A new LID construction method based on refined landuse and hydrologic characterization[J]. Journal of Hydrology, 2023.

[7] Zhou Y , She D , Wang Y ,et al.Evaluating the Impact of Low Impact Development Practices on the Urban Flooding over a Humid Region of China[J].Journal of the American Water Resources Association, 2022.

[8] Zhang C , Wang G , Tiejian L I .Prevention Countermeasures and Suggestions for Urban Rainstorm Disasters Under Changing Environment[J].Bulletin of Chinese Academy of Sciences, 2022, 37(8):1126-1131.DOI:10.16418/j.issn.1000-3045.20220625002.

[9] Qin Y .Control of Runoff Peak Flow for Urban Flooding Mitigation[J].Water, 2021, 13.DOI:10.3390/ w13131796.

[10] Liu W , Chen W , Peng C .Assessing the effectiveness of green infrastructures on urban flooding reduction: A community scale study[J].Ecological Modelling, 2014, 291(1):6–14.DOI:10.1016/ j.ecolmodel.2014. 07.012.