Quantitative analysis of urban pluvial flood alleviation by open surface water systems in new towns:
comparing Almere and Tianjin Eco-city

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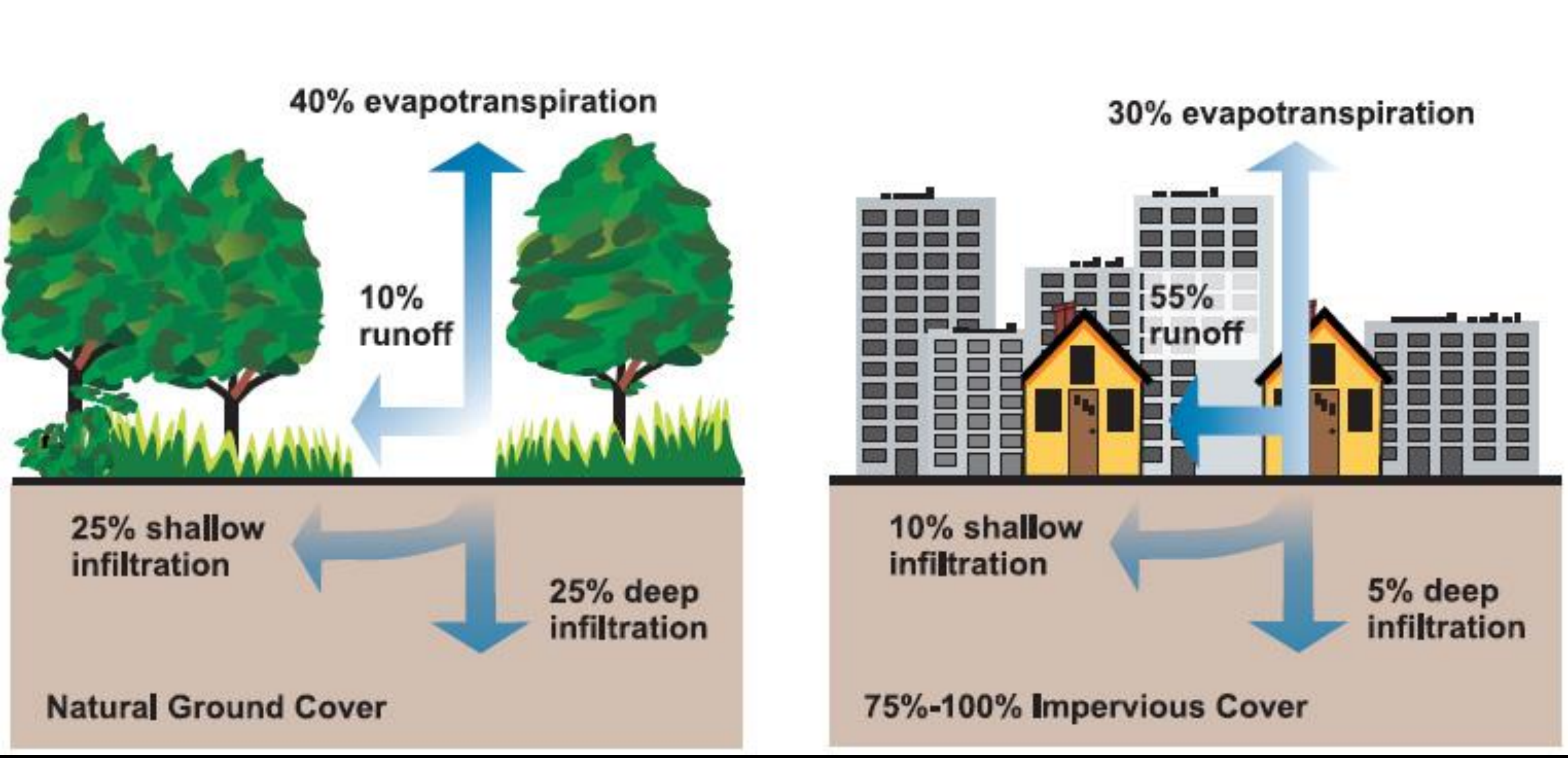
Climate Change - Extreme weather events-
Heavy rainfall

Urbanisation - Growing impervious surfaces

Pluvial flood



Relationship between impervious cover and surface runoff

Impervious cover in a watershed results in increased surface runoff

Source: EPA -United States Environmental Protection Agency, 2003

Spatial planning and design principles for pluvial flood alleviation in new towns: Comparing Almere and Tianjin Eco-city

Aim: optimising land use planning and urban design for new urban districts, from the perspective of reducing surface runoff

Methodology: quantitative analysis on weighted average runoff coefficient of urban blocks (mainly related to surface water system and ground surface typologies)
Analytical tool: ArcGIS

Keywords: Pluvial flood, runoff coefficient, surface water system, ground surface

Dealing with rainwater drainage:

Technical solutions based on underground drainage system

Rainwater drainage system designed for return periods in the range of:
0.5-3 years (China), Code for design of outdoor wastewater engineering (GB 50014-2006, 2006);
5–10 years (Europe), European standard for planning, design and operation of drain and sewer systems outside buildings (EN 752: 2008, 2008)

Alternative approaches to manage the urban water cycle

Water Sensitive Urban Design (WSUD) and Low Impact Development (LID)

Reduces the impact of built areas and promotes the natural movement of water within an ecosystem or watershed; Integrate stormwater treatment into the landscape; Reduce runoff and peak flows from urban developments by employing local detention measures and minimising impervious areas, etc.

Methodology of this research:

Reduce runoff from urban developments by optimizing spatial structure of surface water system and ground surface typologies

Quantify the overall run-off coefficient of various spatial patterns

Kerby's formula (Kerby, 1959)

$$t_c = 1.45(NL/\sqrt{s})^{0.467}$$

t_c : the overland flow time of concentration in minutes (10 minutes)
N: a dimensionless retardance coefficient, related to the land surface type (0.02)
L: the overland flow length in meters ---300m
S: the dimensionless slope of terrain conveying the overland flow (1%)

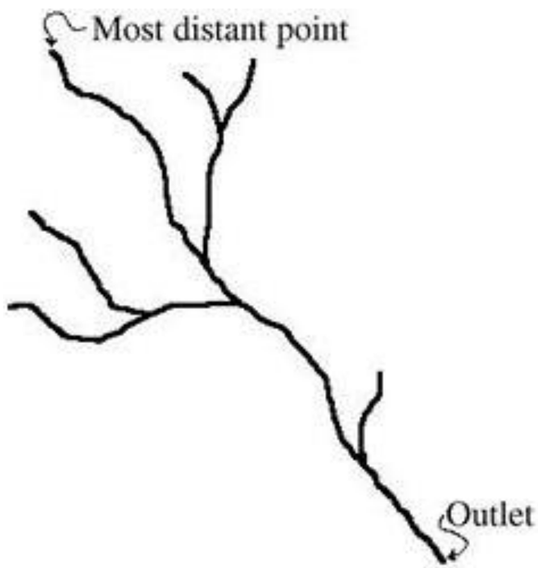


Table 1 Typical values of retardance coefficient N of Kerby (1959) formula

Generalized terrain description	Dimensionless retardance coefficient (N)
Pavement	0.02
Smooth, bare, packed soil	0.10
Poor grass/ cultivated row crops/ rough packed surfaces	0.20
Pasture/ average grass	0.40
Deciduous forest	0.60
Dense grass/ coniferous forest litter/ deciduous forest with deep litter	0.80

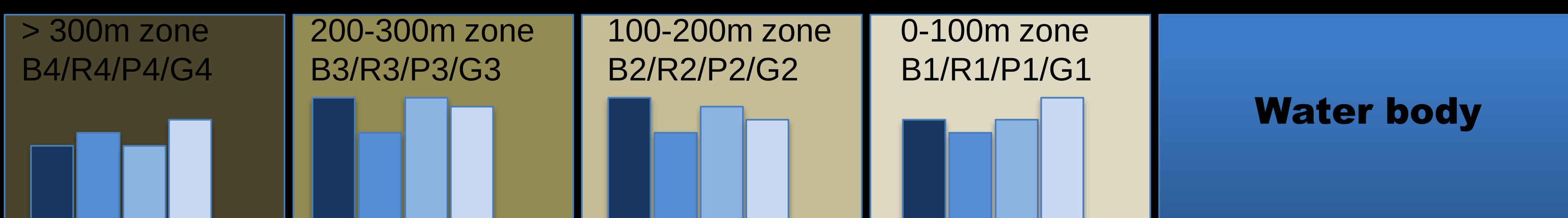
(Weighted average) runoff coefficient

$$\Psi'=[m_1\mu(B_1\Psi_B+R_1\Psi_R+P_1\Psi_P+G_1\Psi_G)+ m_2\mu(B_2\Psi_B+R_2\Psi_R+P_2\Psi_P+G_2\Psi_G)+ m_3\mu(B_3\Psi_B+R_3\Psi_R+P_3\Psi_P+G_3\Psi_G)+ (B_4\Psi_B+R_4\Psi_R+P_4\Psi_P+G_4\Psi_G)] / A$$

Ψ': *weighted average* ***runoff coefficient*** *of the whole area*
A: *the total land use area*
B1/B2/B3/B4: *total* ***roof*** *area within zones 0-100m/ 100-200m/ 200-300m/ above 300m from the water body respectively*
R1/R2/R3/R4: *total* ***road surface*** *area within zones 0-100m/ 100-200m/ 200-300m/above 300m from the water body respectively*
P1/P2/P3/P4: *total* ***pavement*** *area within zones 0-100m/ 100-200m/ 200-300m/ above 300m from the water body respectively*
G1/G2/G3/G4: *total* ***green space*** *area within zones 0-100m/ 100-200m/ 200-300m/ above 300m from the water body respectively*
$\Psi_{B/}$ $\Psi_{R/}$ $\Psi_{P/}$ Ψ_G: *runoff coefficient of roof / road / pavement / green space respectively*
m1/m2/m3: reduction factors *within the zones that are 0-100m/100-200m/200-300m away from the water body respectively*
μ: *correction factors for the stagnation conditions*

Ψ_B (roof)=0.95; Ψ_R (road surface)=0.85; Ψ_P (pavement)=0.55; Ψ_G (green space)=0.2.
With reference to the <Code for design of outdoor wastewater engineering> (GB 50014-2006, 2011) in China

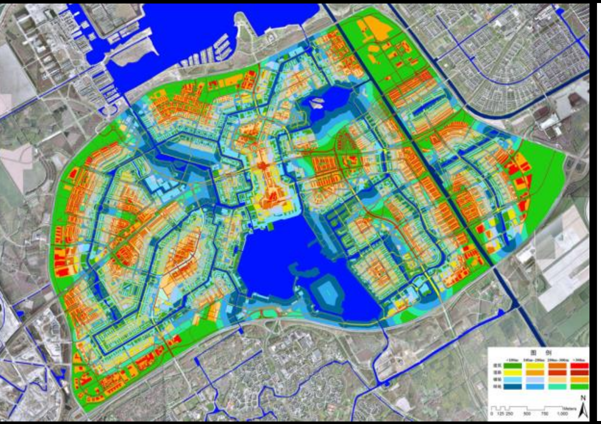
m1/m2/m3 are 0.25/ 0.5/ 0.75 respectively

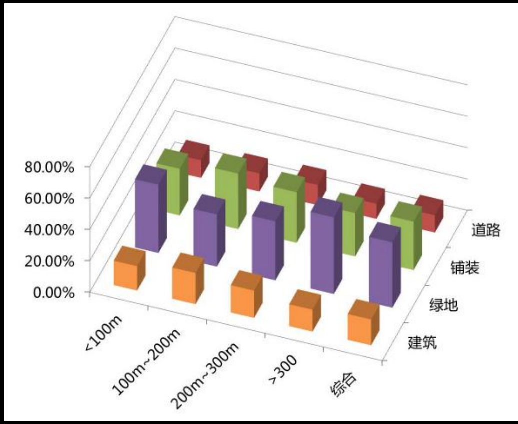


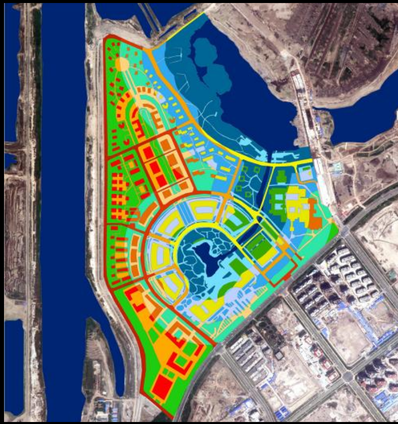
ArcGIS

Generate statistics of different scenarios, on
- runoff coefficient
- ground surface typologies

Scenarios: with/without influence of surface water system, current/desired



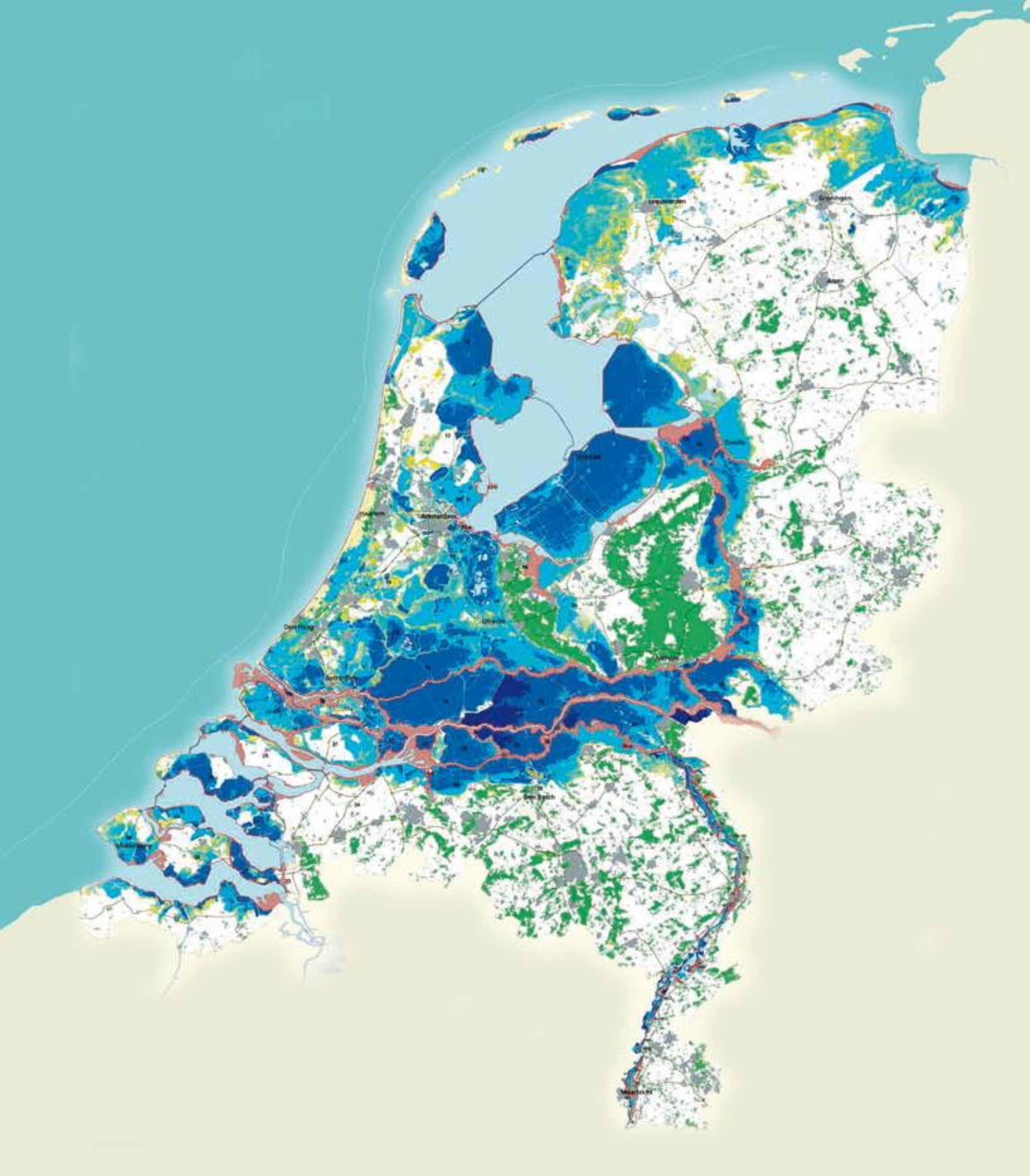


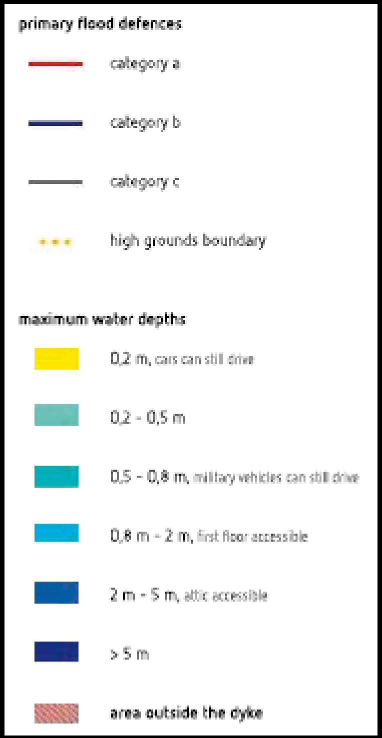


This methodology was implemented in two study cases: Almere and Tianjin Eco City (Almere Stad and Tianjin Animation Park), fast developing new towns vulnerable to flood risks

The Almere Case

National Flood risk

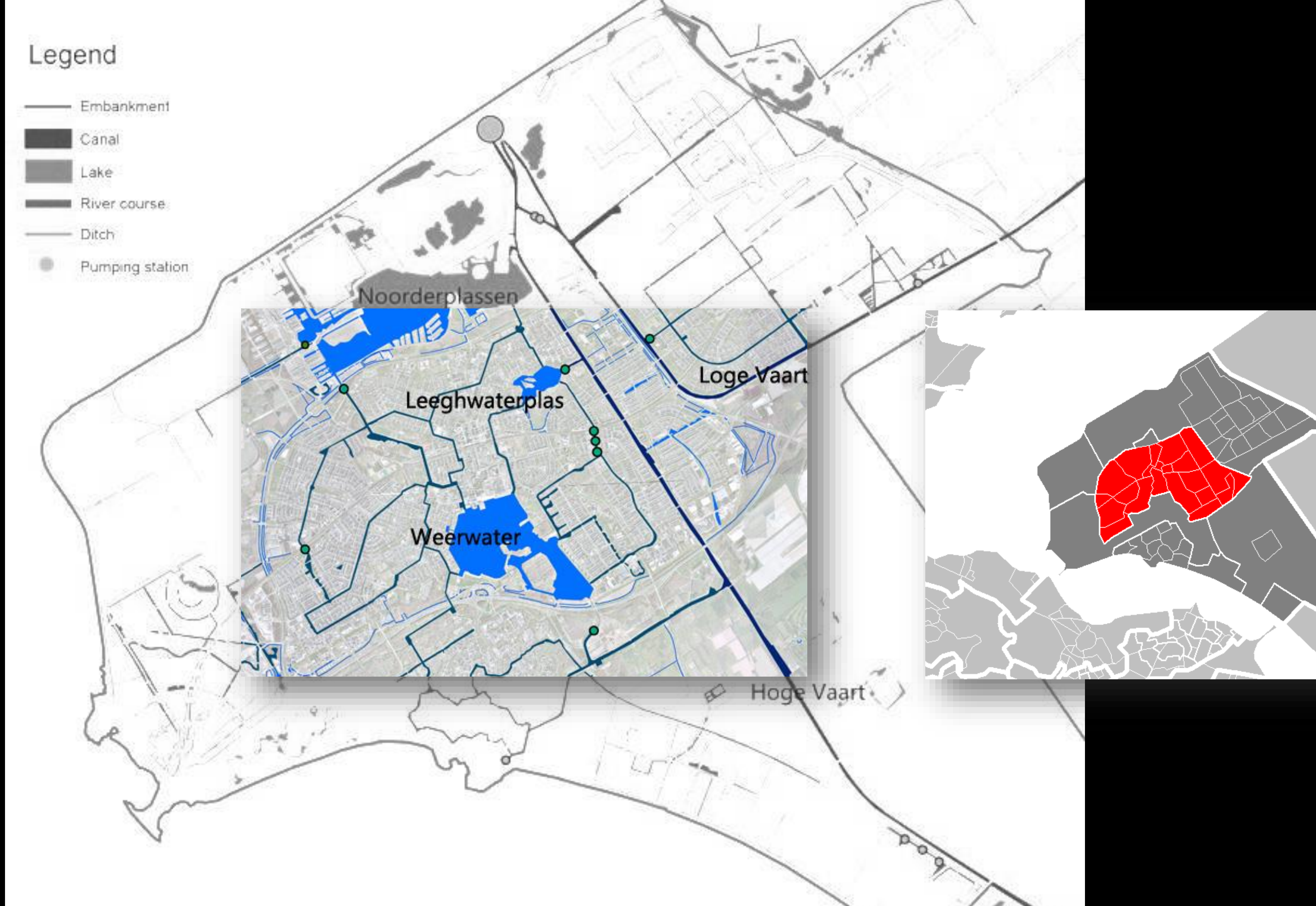




Due to constraints in the drainage of the polders and other water systems, the lower lying parts of the Netherlands are more vulnerable to flood risks.

The surface water system in Almere

Almere: a typical polder city located on reclaimed land from the sea. Following the Dutch water culture and urban development tradition, Almere now has a very densely distributed surface water system, with diversified functions related to it, and carefully managed. Such surface water system contributed to the creation of urban space and identity of landscape, while at the same time, solved many water related problems that the city is facing. The surface water system of Almere consists of lakes, canals, watercourses and ditches



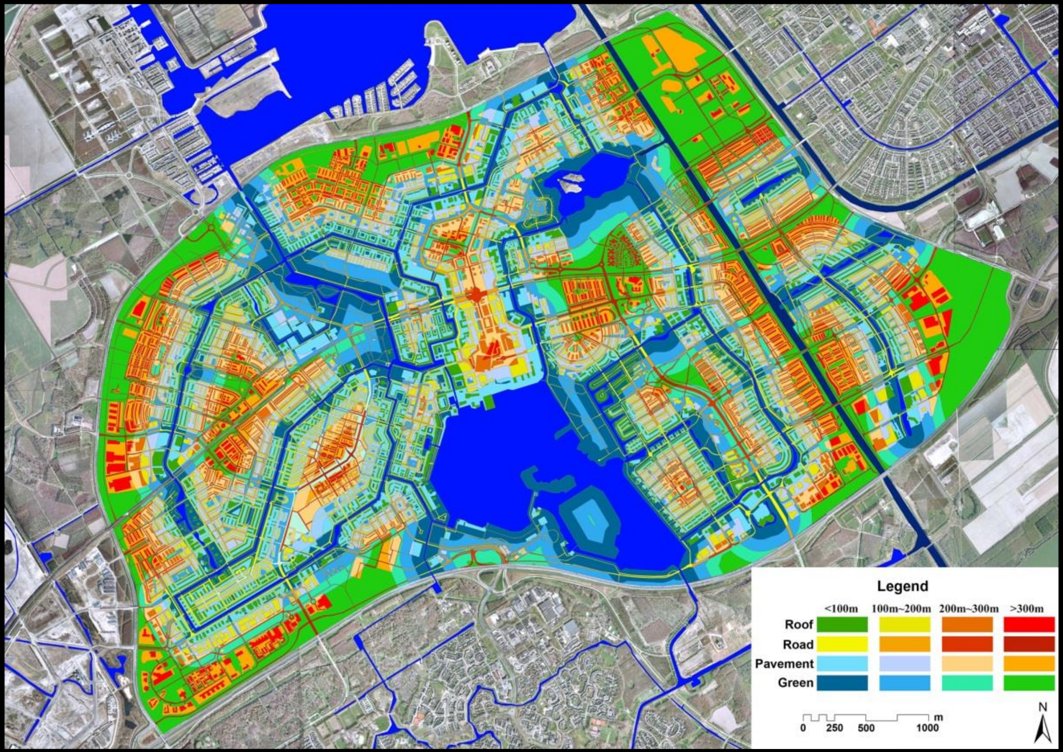
Surface water system and runoff coefficient in Almere Stad

This research chose the central area Almere Stad as the focus area of Almere, to examine the influence of the lakes and watercourses on the overall runoff coefficient of the district.

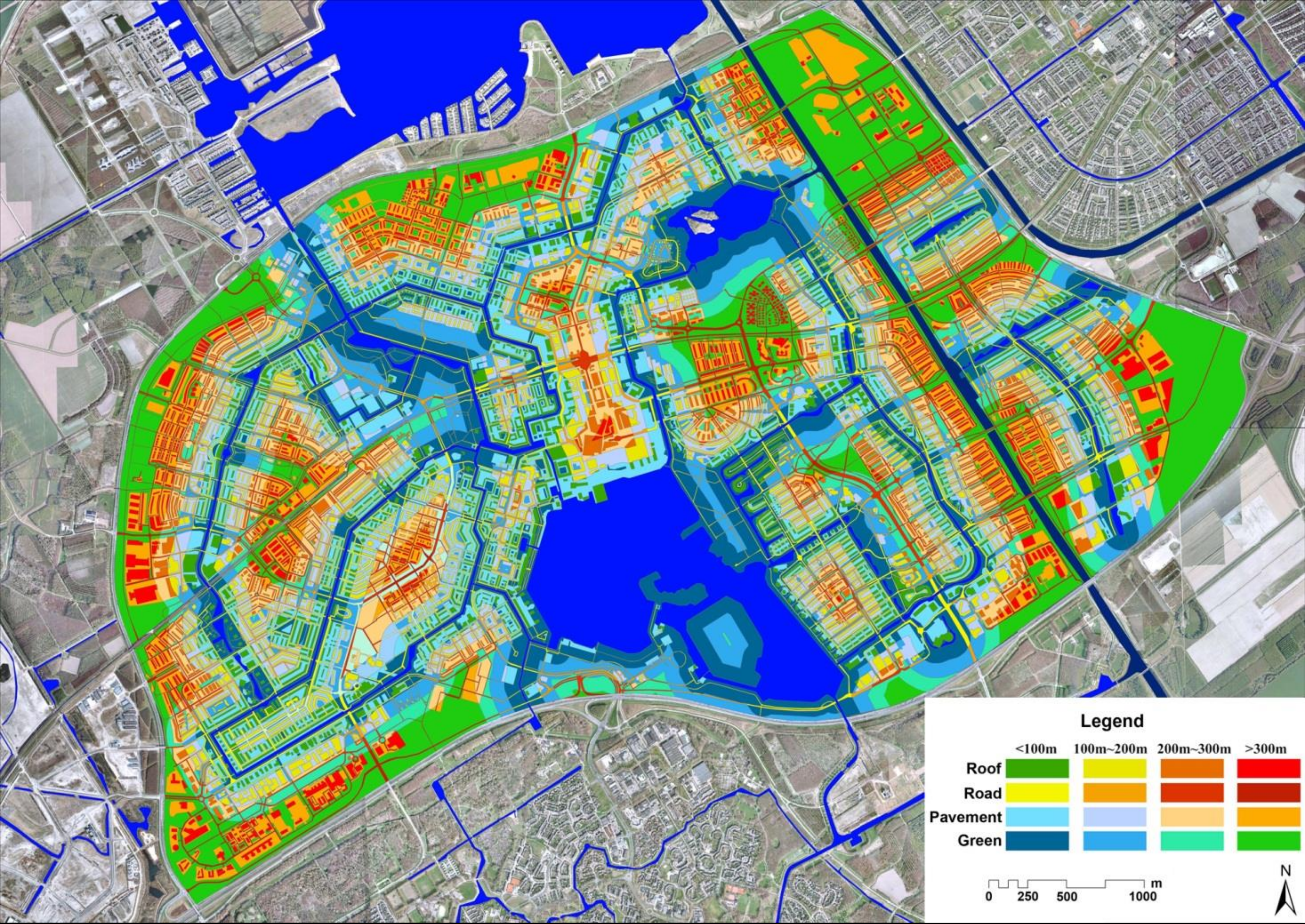
A scenario without considering the influence of surface water system

The ArcGIS analysis result shows that most of the areas in Almere Stad have an weighted average runoff coefficient of around 0.45-0.6, a scenario without considering the influence of the surface water system. This result indicates Almere Stad a densely built urban area

A scenario considering the influence of surface water system

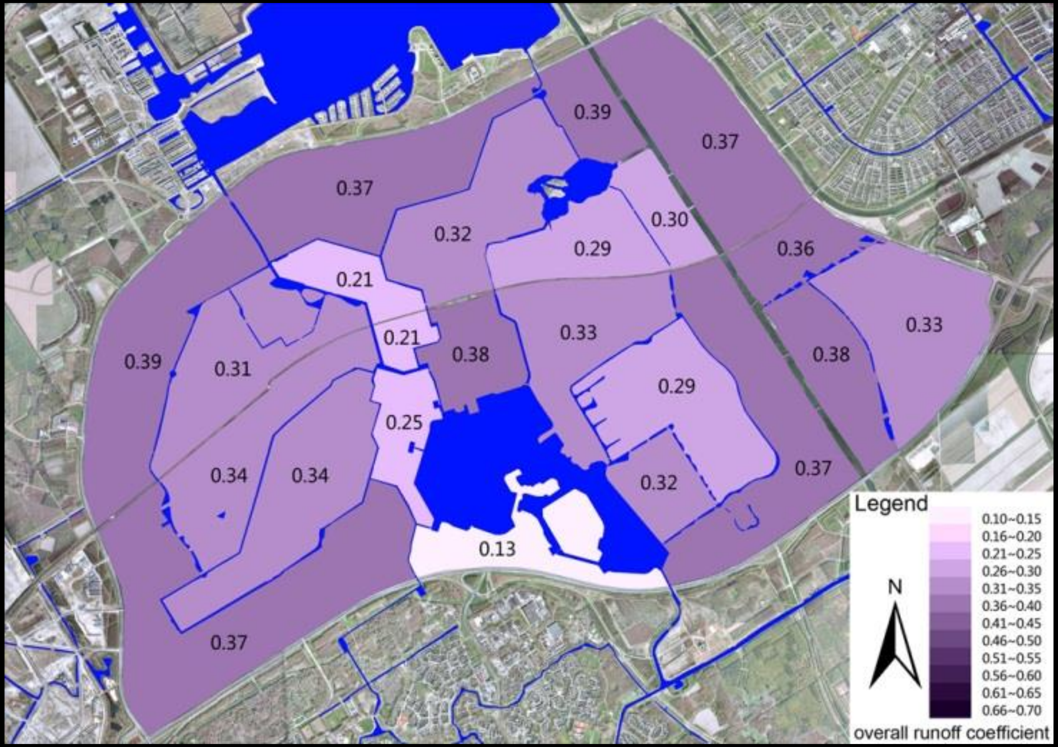


The spatial distribution of the four types of ground surface in Almere Stad (roof, road surface, pavement and green space), which were already classified into four waterfront zones, which are 0-100m/ 100-200m/ 200-300m/ above 300m away from the water body respectively



Spatial distribution of different types of ground surface in Almere Stad

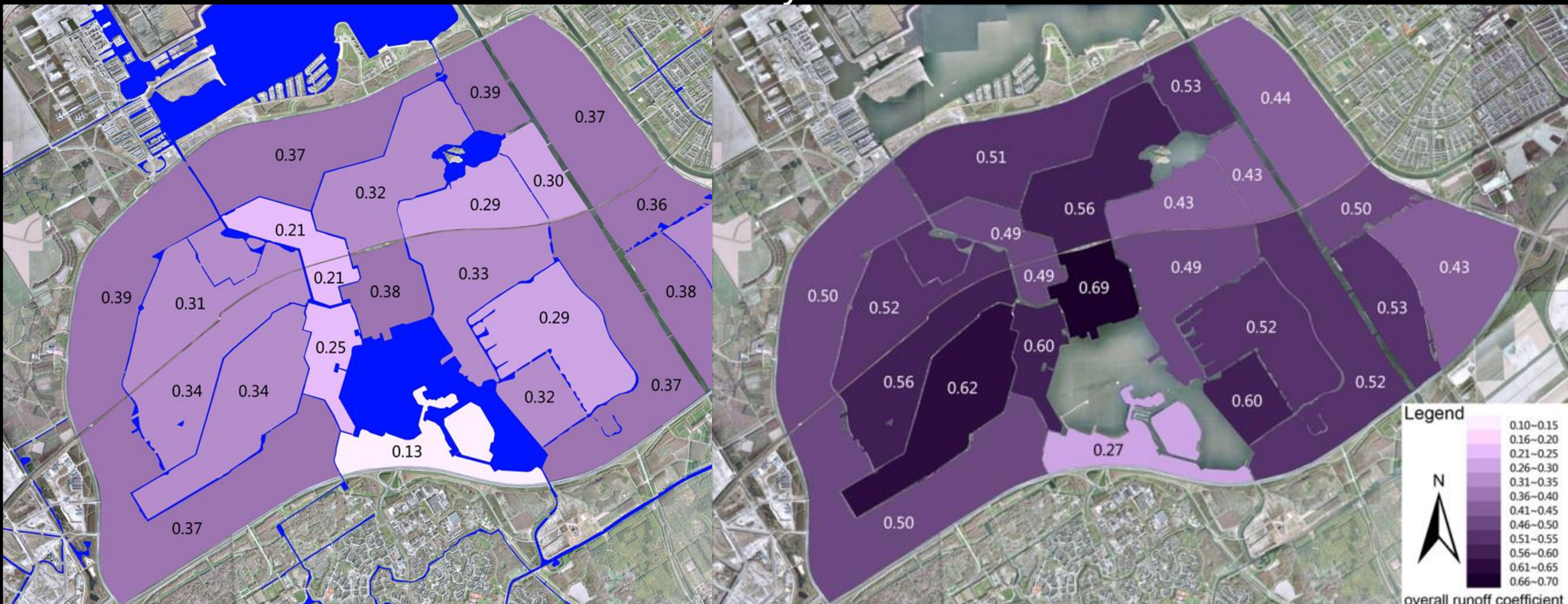
A scenario considering the influence of surface water system



Considering the reduction effects brought by the surface water systems of waterways and lakes, another ArcGIS analysis result shows the actual scenario. In this scenario, the weighted average runoff coefficients of all the urban blocks decreased to 0.2~0.45, which is equivalent to sparsely built up areas.

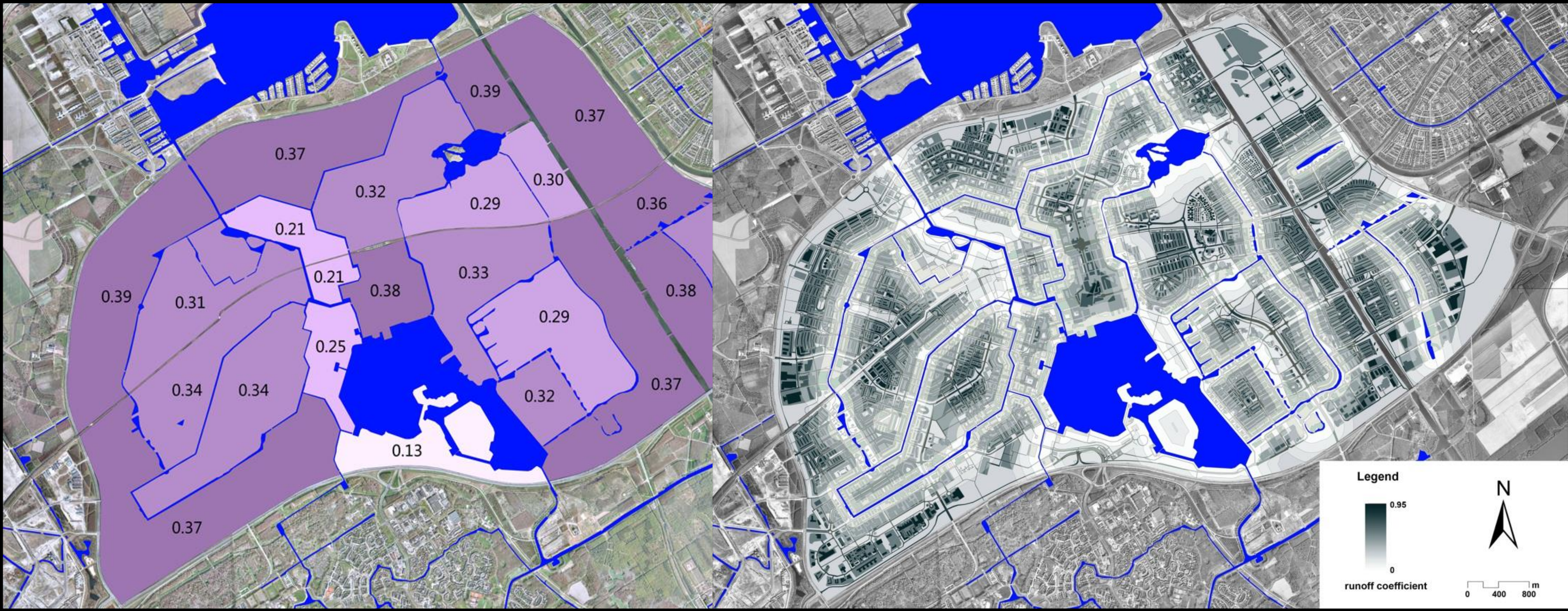
Comparing the two scenarios

With/without the influence of surface water system



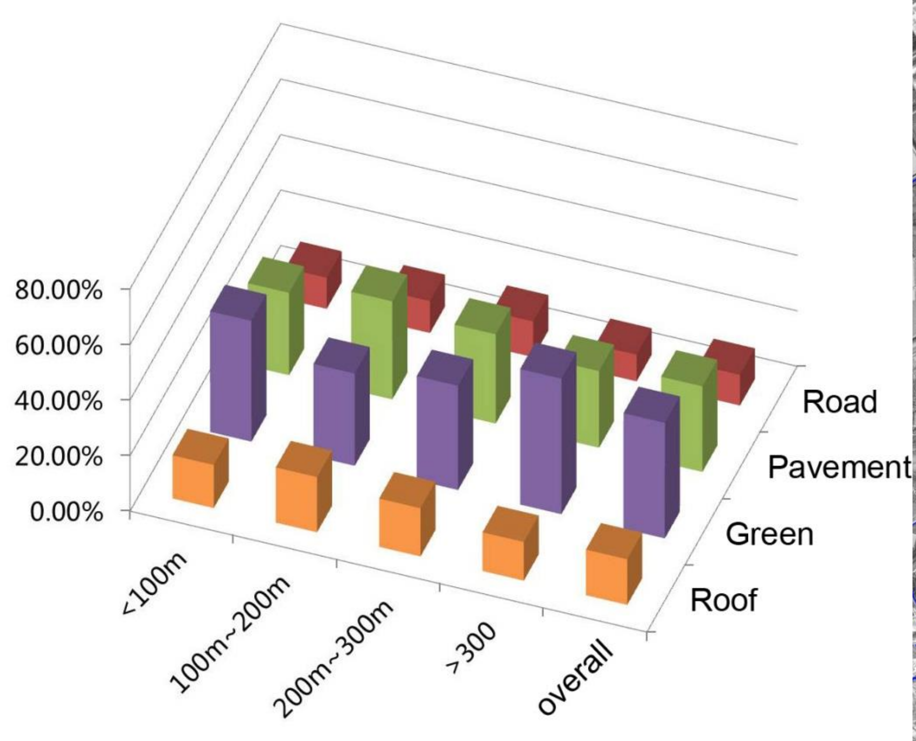
Comparing the two figures, it might prove that the surface water system in Almere Stad could help to reduce the risk of severe storm water logging in parts of the district.

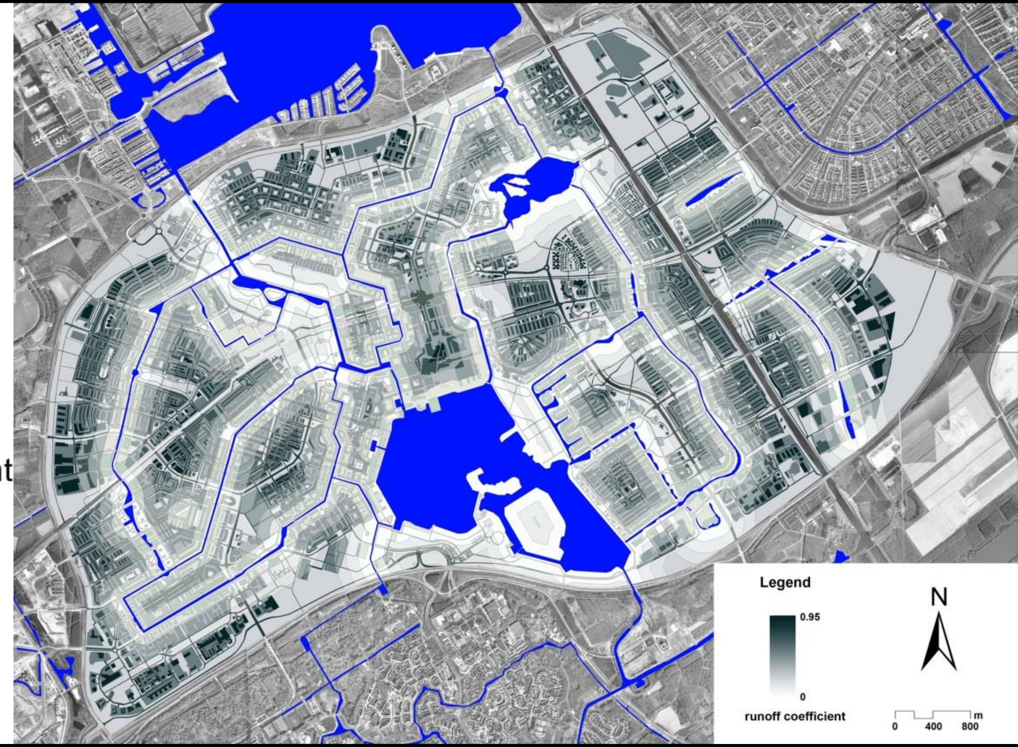
Runoff coefficients of waterfront zones in Almere Stad



The spatial structure of the surface water system is also essential. By changing the areas for calculation, ArcGIS could show the runoff coefficient of the different waterfront zones in detail, instead of the average data of urban blocks defined by waterways

Statistics on ground surface typologies in Almere Stad

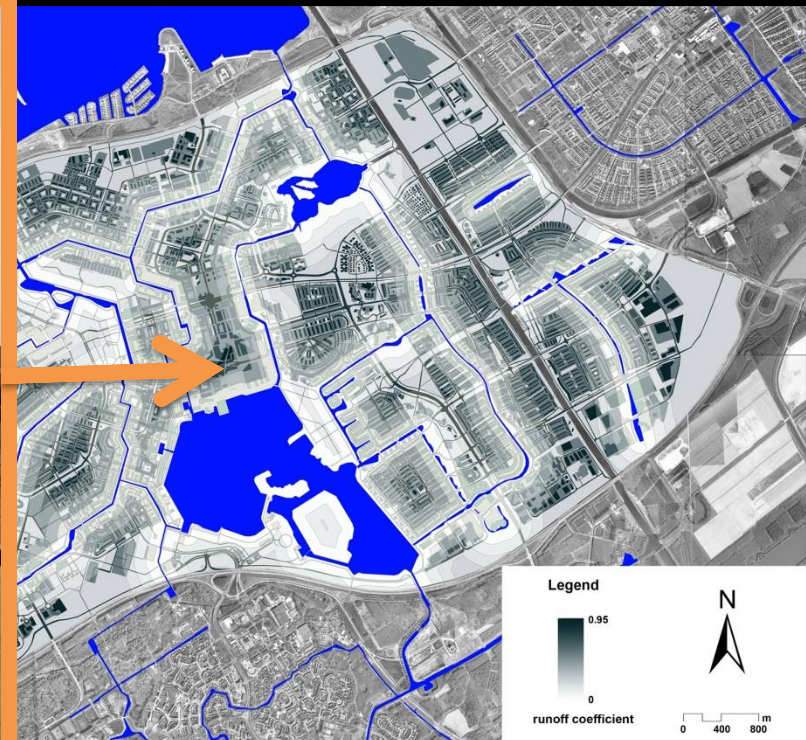




Areas highlighted with darker color represent zones that still have a relatively high runoff coefficient. For these areas, the standard of underground drainage system should be raised correspondently, or otherwise more permeable surfaces and water storage should be added. This leads to spatial planning and design principles related to ground surface typologies.

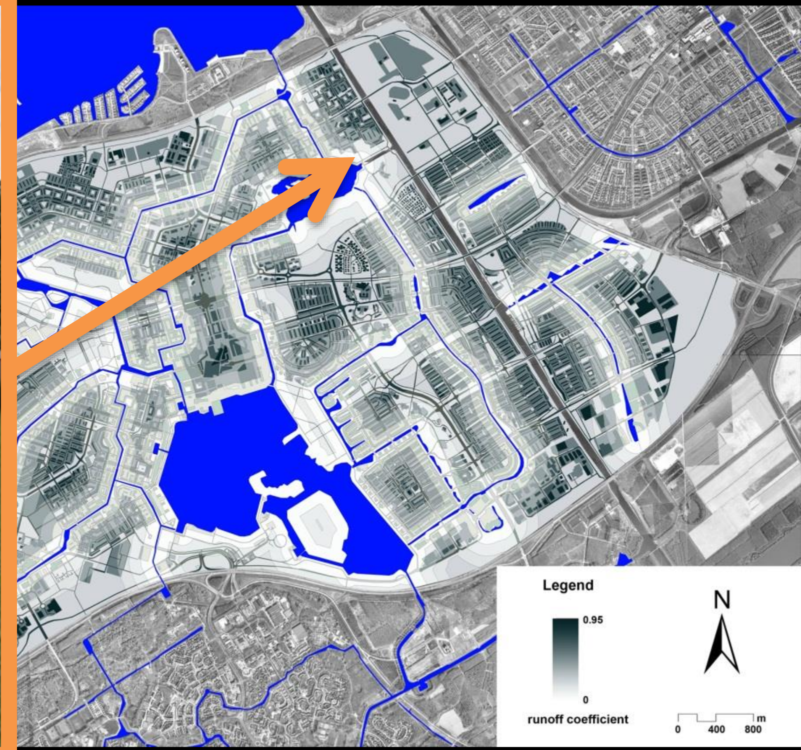
Ψ_B (roof)=0.95; Ψ_R (road surface)=0.85; Ψ_P (pavement)=0.55; Ψ_G (green space)=0.2

Water Sensitive Urban Design



For instance the central area of Almere Stad is a commercial block with relatively high building density, and the open space is mostly covered by hard surfaces. This implies a high runoff coefficient. In response to the risks of storm water ponding, as well as the need to diversify the urban landscape, elements like permeable pavement, green roof and waterscape are adopted in urban design schemes.

Water Sensitive Urban Design

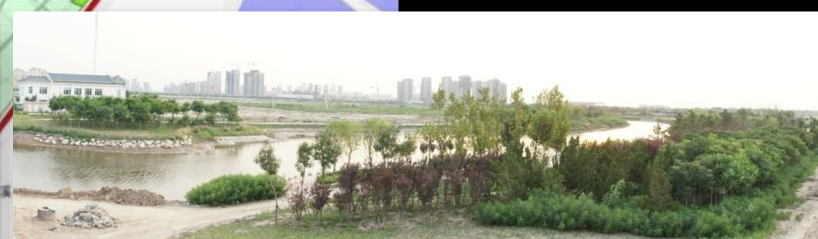


Similarly, such integral approach is also implemented in residential areas with relatively low building density, where usually greater amount of green space is planned. Based on the topography, artificial wetlands are very often designed on the lower lying sites, to collect and purify rainwater.

The Tianjin Eco City Case

The Tianjin Eco City Case

The surface water system in Tianjin Eco City



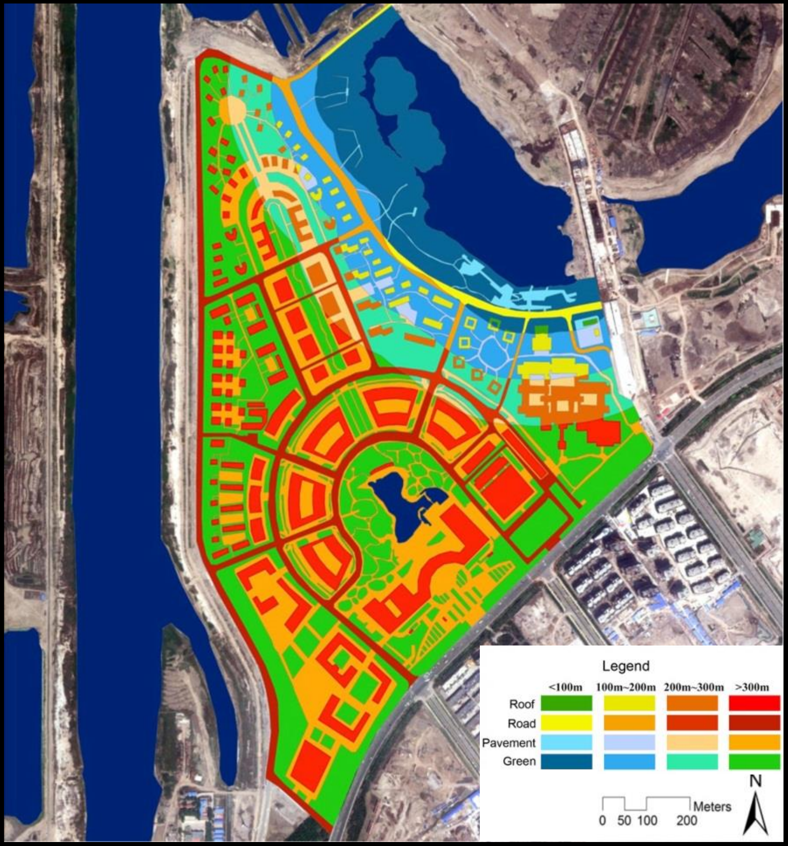
Comparing to Almere, the surface water system in Tianjin Eco City has much wider waterways but less dense waterway network in the built up areas. This is partly related to the fact that Tianjin is a city seriously lacking water resources

Surface water system and runoff coefficient in Tianjin Animation Park

National Animation and Comic Industry
Comprehensive Demonstration Park

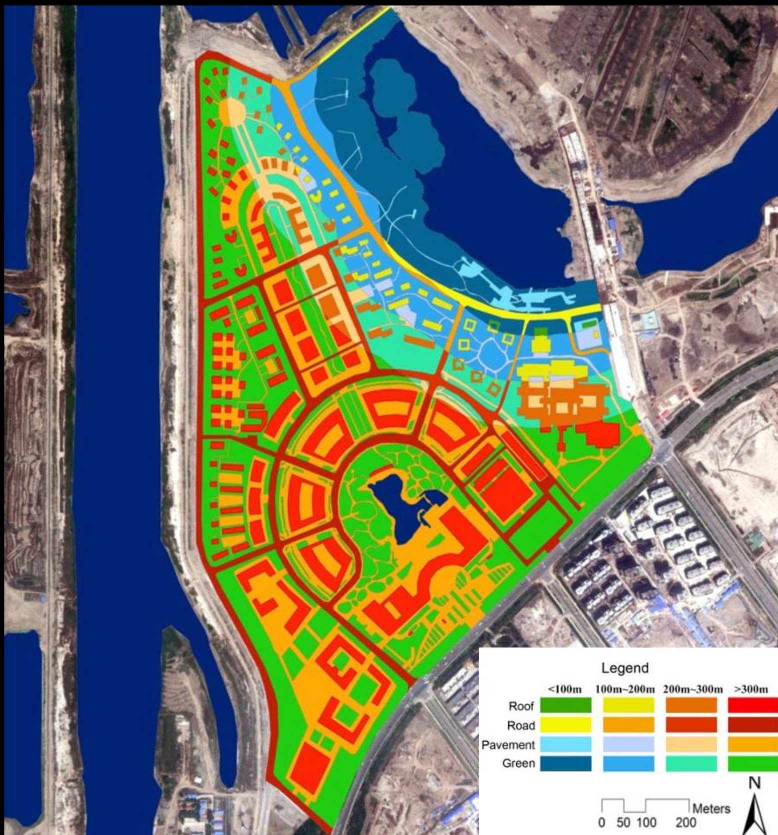
The purpose of such comparative study is to improve spatial planning and design approaches for newly built up areas in Chinese cities

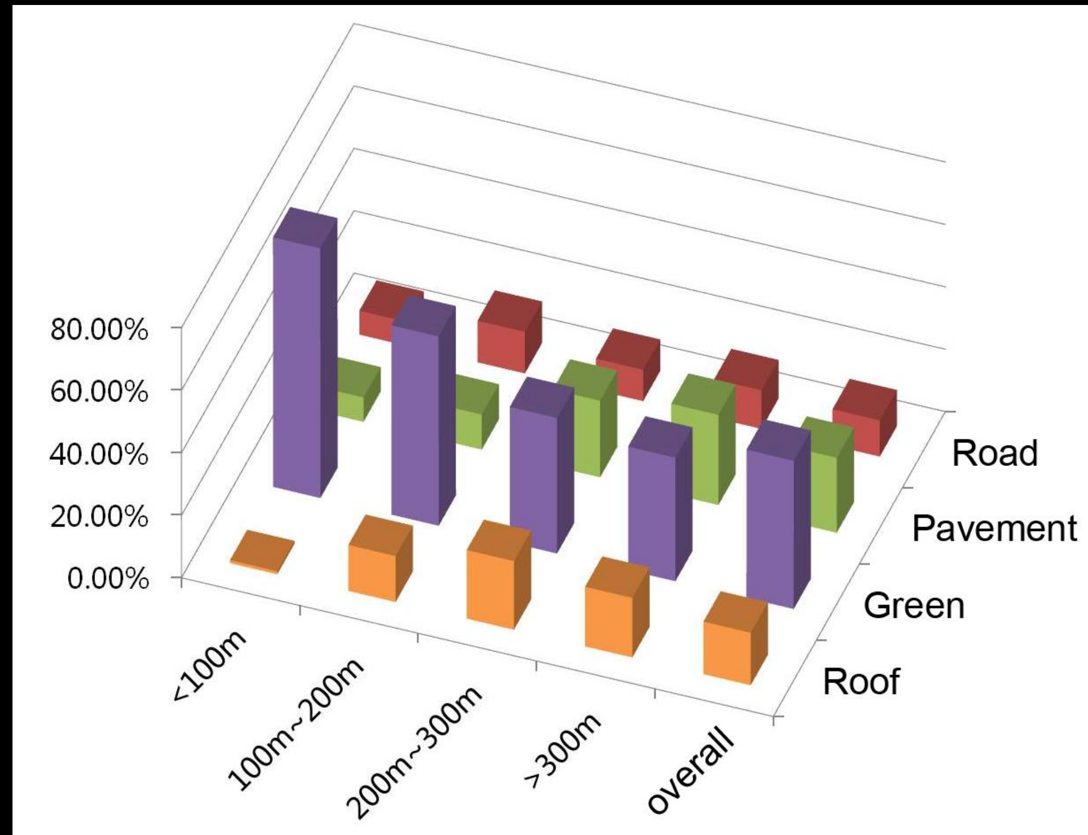
The current situation



Taking into account the reduction effect brought by the old course of Ji canal on pluvial flooding, calculation result of the weighted average runoff coefficient of Tianjin Animation Park is 0.46. It’s slightly lower than the scenario without considering surface water, which is 0.51.

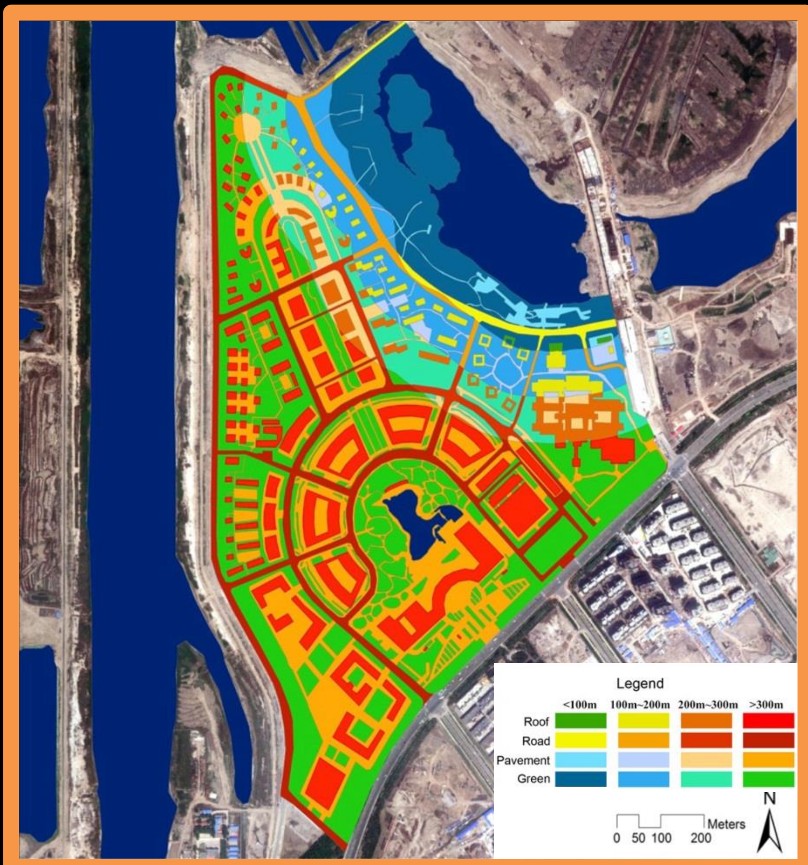
The current situation

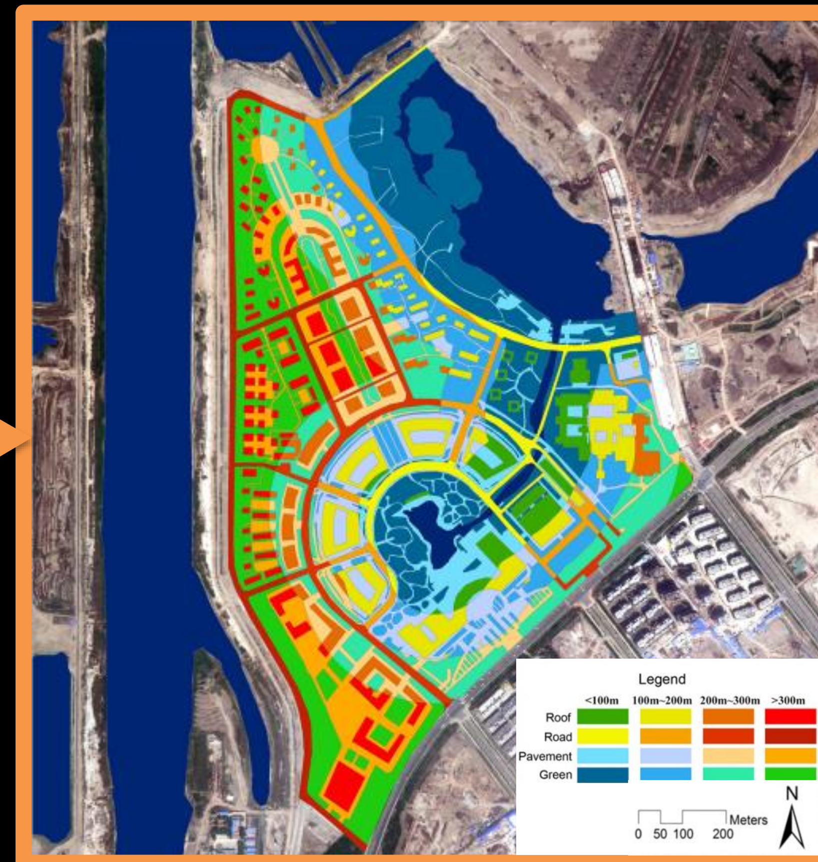




Ground surface in areas close to water have rather high percentage of green space, while quite low percentage of building roof. This might lead to a high quality of waterfront landscape, however, those areas far away from water might have to rely more on the underground drainage system in pluvial flood alleviation.

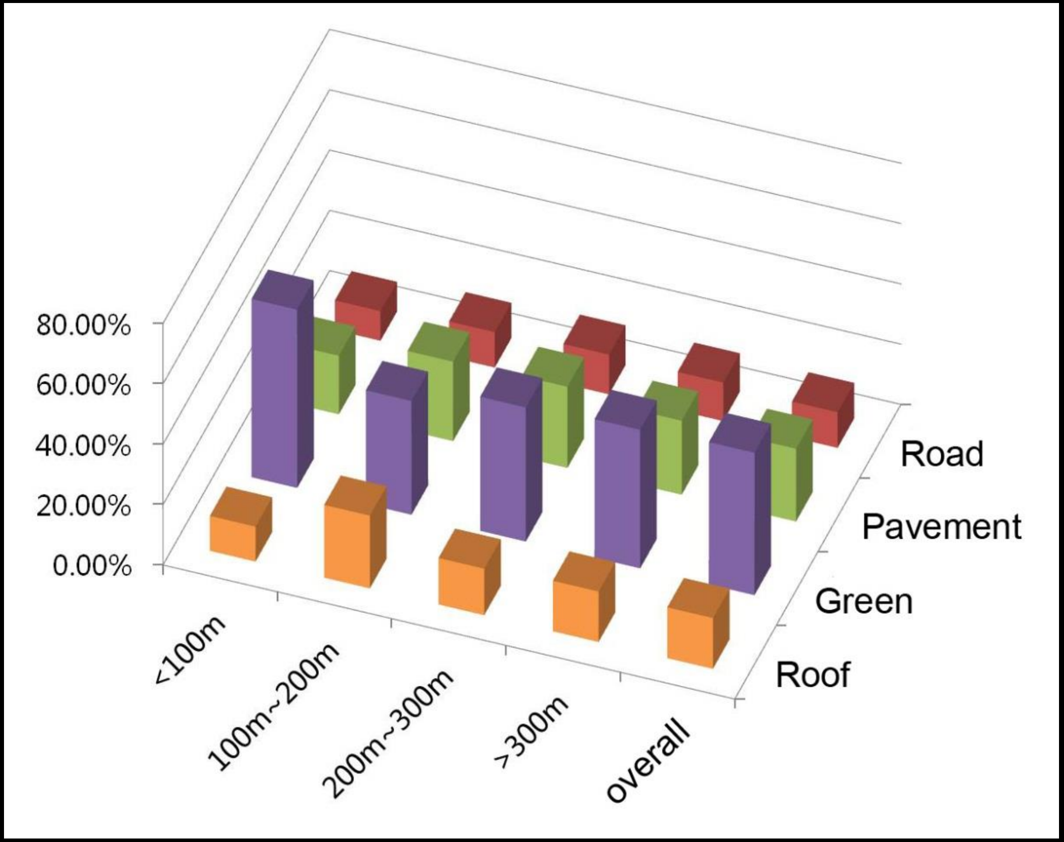
A modified surface water system

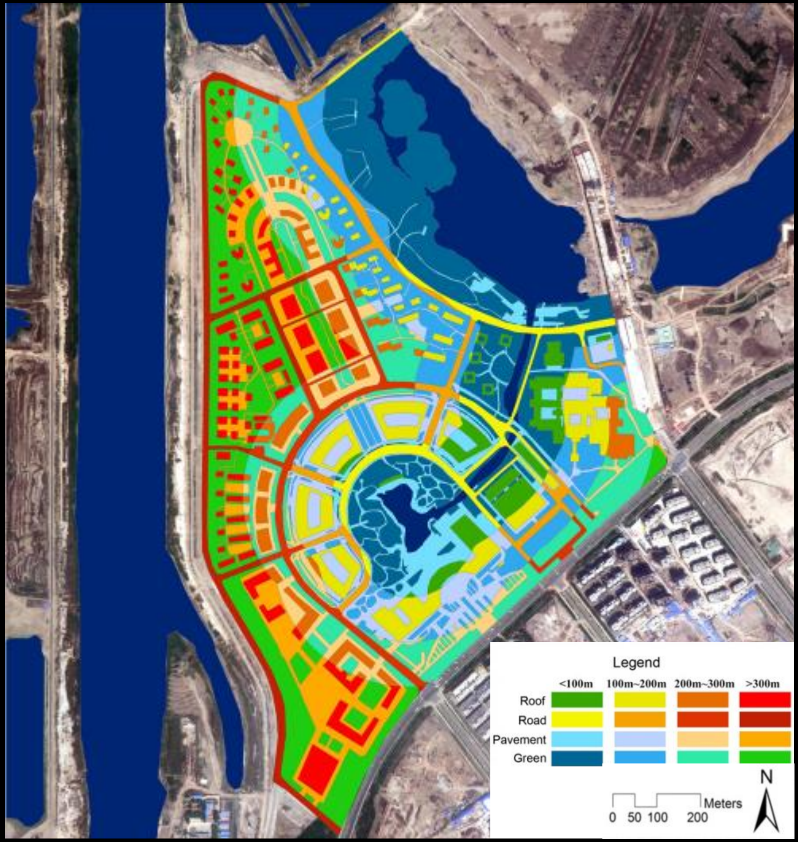




Learning from Almere Stad, especially the way green space and artificial waterscape are planned and designed to reduce the risks of stormwater ponding, a slightly modified surface water system is proposed. This is mainly about connecting the artificial waterscape in the middle of the block with the old course of Ji canal, integrating it into the surface water system.

A modified surface water system





The calculation result of weighted average runoff coefficient based on such modified proposal for Tianjin Animation Park is 0.36, showing a dramatic reduction effect. Statistics generated from this proposal show that, spatial distribution of the ground surface typologies is quite comparable to Almere Stad

Conclusions

By comparing the two cases of Almere and Tianjin Eco City, the paper further proved that the surface water system has great potential in reducing overall runoff coefficient of an urban district. An effective way of realising this is to modify the spatial structure of the surface water system and ground surface typologies in the water front areas, according to quantitative analysis on runoff coefficients, as shown with ArcGIS statistics.

Some principles for planning and design have been generated along with the quantitative analysis and case studies in this research, for instance: with the same amount of water surface and quantity, a relatively de-concentrated morphology of surface water system works better in reducing rainwater runoffs than the concentrated large water surface; when making the land use plan for areas far away from surface water, the land occupation rate of green space should be relatively high, so as to reduce the amount of hard ground surface, and thus alleviate pluvial flood risks; in areas with high runoff coefficient, the capacity of water storage and drainage of the place could be strengthened by adding green roof, artificial waterscape, artificial wetland, drainage ditches, etc. Choosing measures accordingly could contribute effectively to the reduction of pluvial flood risks.