上海交通大学
SHANGHAI JIAO TONG UNIVERSITY

SJTU

Adaptability of Rainwater Storage and Regulation in Multi-scale Shanghai Green Space

Bingqin YU, Associate Professor in Department of Landscape Architecture, School of Design, Shanghai Jiao Tong University

May, 15, 2020

饮 水 思 源 • 爱 国 荣 校

How I have changed in this five years?

Why I become older so quickly?
Maybe because it is really the tuff work in SJTU.

- From the year 2012 to 2015
- Graduated from Beijing Forestry University

- The year of 2017
- After post-doctorate research in SJTU

- The year of 2019
- Became an associate professor in SJTU

1.1 The main researches which I focus on

Natural Science

Landscape Hydrology

Pattern optimization of GI

Adaptability of LID techniques

Plant community design with environmental functions

- Pattern of green infrastructure
- Invention of LID techniques
- Top-level planning of sponge city
- The achievements are practiced in sponge city as Shanghai

Urban Community

Improvement of ecological benefits

Recreation behaviors and demands of residents in urban community

Functional conjugate in public open space

- Plant community design with environmental functions
- Recreation opportunity spectrum
- Ecological and recreational function conjugate as decision basis

Social Science

Garden History

History of Landscape Architecture

Culture in western and Asia gardens

- The course of History of Landscape Architecture in MOOC
- Construct the virtual reality case database for the historical landscape architecture

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Origin：Ecological Planning of Green Infrastructure

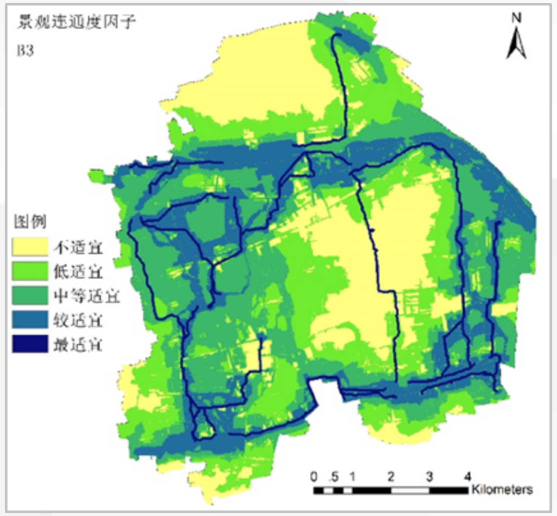
1.1 Site Selection and Suitability Evaluation of Green Infrastructure

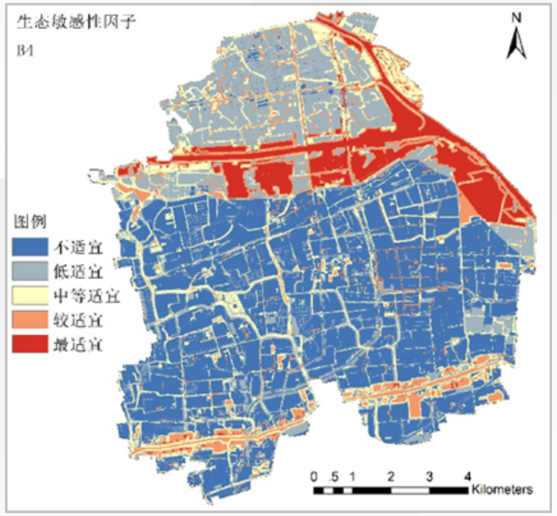
1.2 Source and Sink Process Analysis By Terms of ArcGIS

1.3 Construction of Rainwater Source Storage System in Urban and Rural Area


There are great differences between
urban and rural green infrastructure.
The urban and rural ecotone was broken.
How to evaluate the suitability and
sensitivity of green infrastructure ?

1.1 Suitability Evaluation Systems by Arc GIS

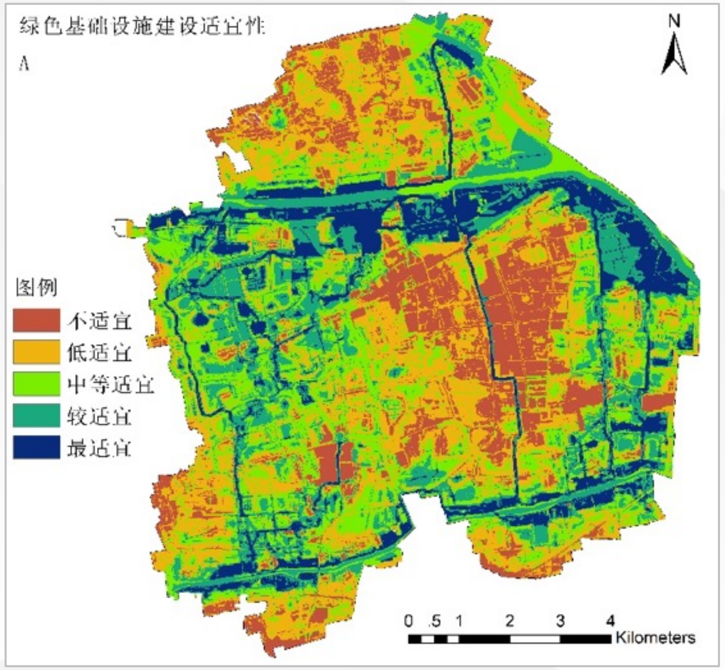


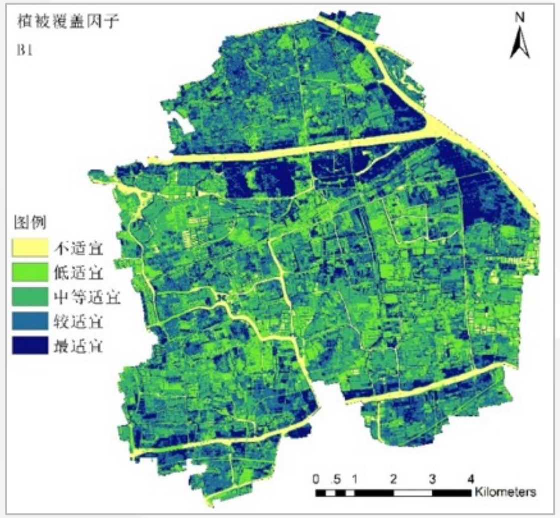


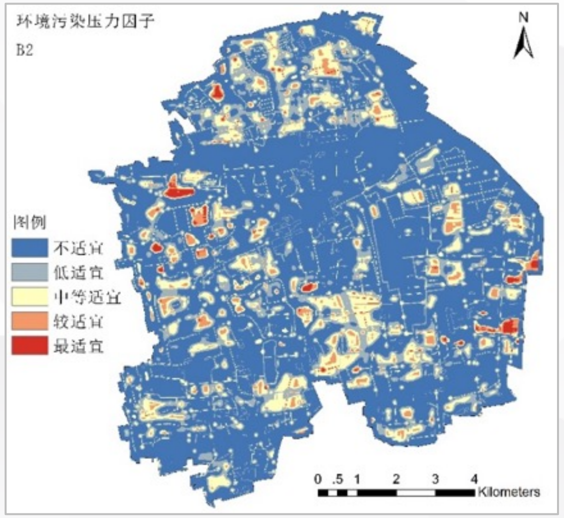
Suitability Evaluation model for GI

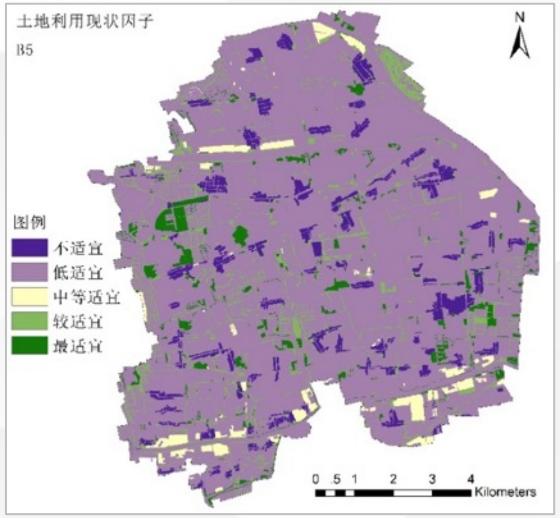
$$S = \sum_{i=1}^{n} W_i \times X_i$$

The weight of landscape connectivity is 0.3966 ,
The weight of domestic production is 0.2622 ,
Ecological sensitivity: 0.1825









How to construct GI systems by suitability evaluation?

1.2 Source and Sink Process Analysis by GIS

淀山湖为吞吐性感潮湖泊，大部分水量来自东太湖及淀泖地区，水文情势同时受上游来水和下游潮水的影响。

Wet season	Dry season	Highest level	Lowest level	Average level
July~Dec.	Nov.~Feb.	3.93m	1.76m	2.85m

淀山湖 Total area: **62km²**
上海境内 **46.7km²** in Shanghai

年降雨量 Annual rainfall
1019.29mm

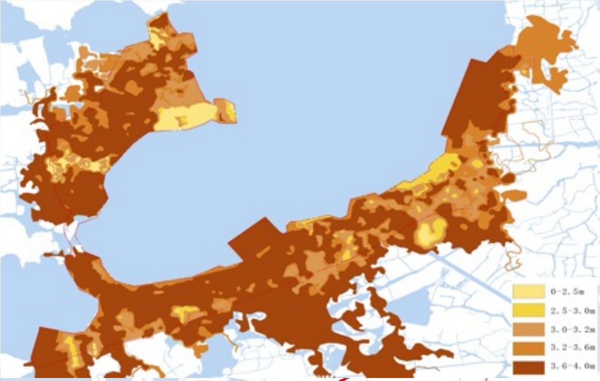
淀山湖总体水质 **劣V类**

Water quality: **Below class V**

自然村落 **42个**
Natural villages

户数 **6,640**
households

Fig1-1 Elevation diagram



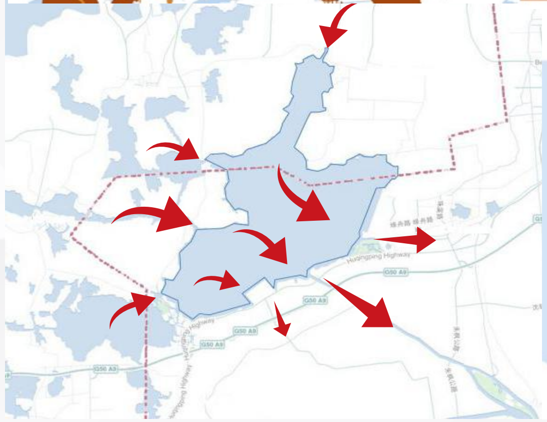


Fig1-2 Overall drainage flow

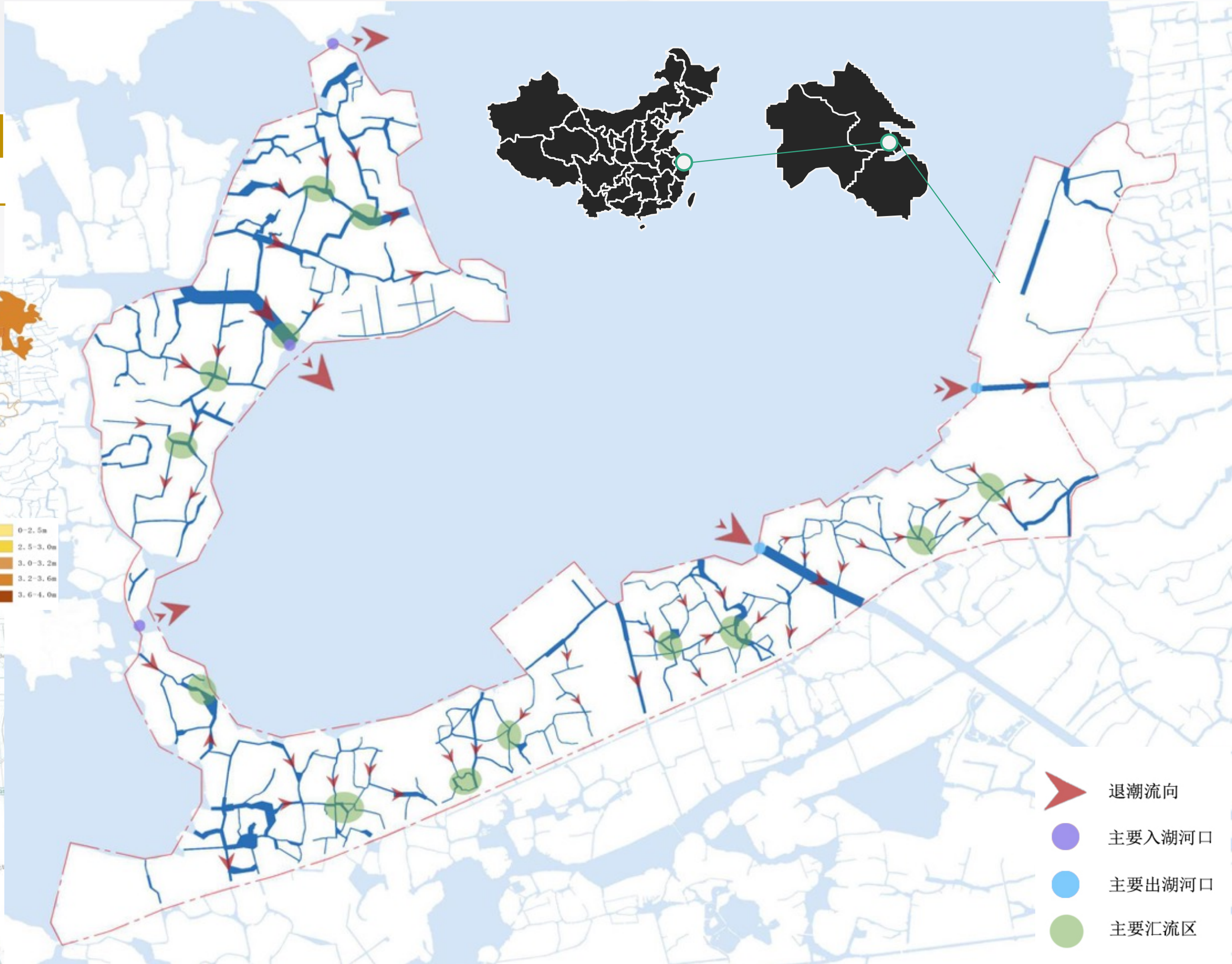
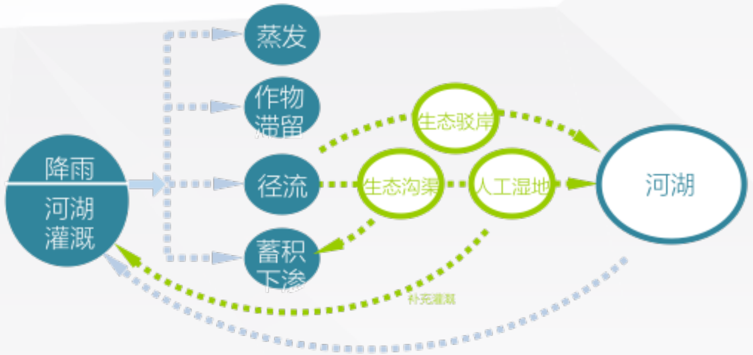


Fig1-3 Analysis on water systems in Shanghai

1.3 Construction of Rainwater Regulation System

海绵城市管控雨水循环模式(Water cycle models of sponge city)

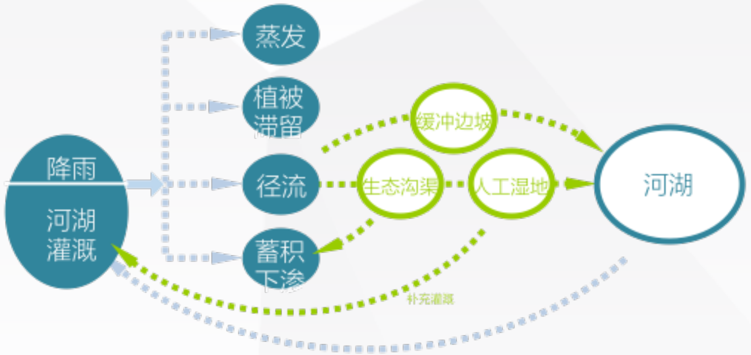
□ 规划农田雨水循环模式 Planning of cropland water cycle model



特征

- 硬质沟渠改造为生态沟渠净化径流
- 田水交错带建设生态驳岸净化径流
- 增设人工湿地过滤径流补充灌溉

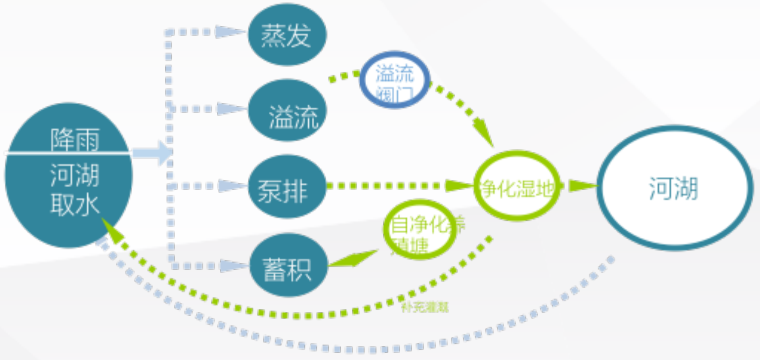
□ 规划林地雨水循环模式 Planning of woodland water cycle model



特征

- 简易沟渠改造为生态沟渠净化径流
- 林水交错带建设缓冲边坡过滤护坡
- 增设人工湿地过滤径流补充灌溉

□ 规划养殖塘雨水循环模式Planning of fishpond water cycle model



特征

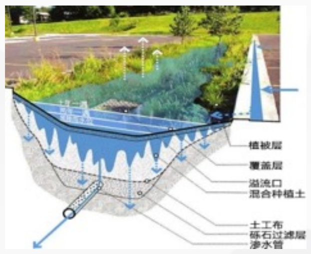
- 增设净化湿地过滤塘水补充灌溉
- 养殖塘生态化改造增强自净化能力

□ 规划道路雨水循环模式 Planning of roadway water cycle model

特征

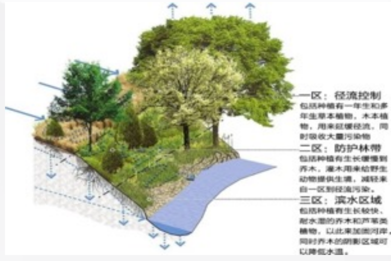
- 硬质排水沟改造为生态沟渠处理径流
- 林田塘缘路侧增设生态边坡过滤径流
- 建设雨水截流型道路绿化植物群落

Bio-swale



Roof Downspout Disconnection & Raingarden

Ecological slope



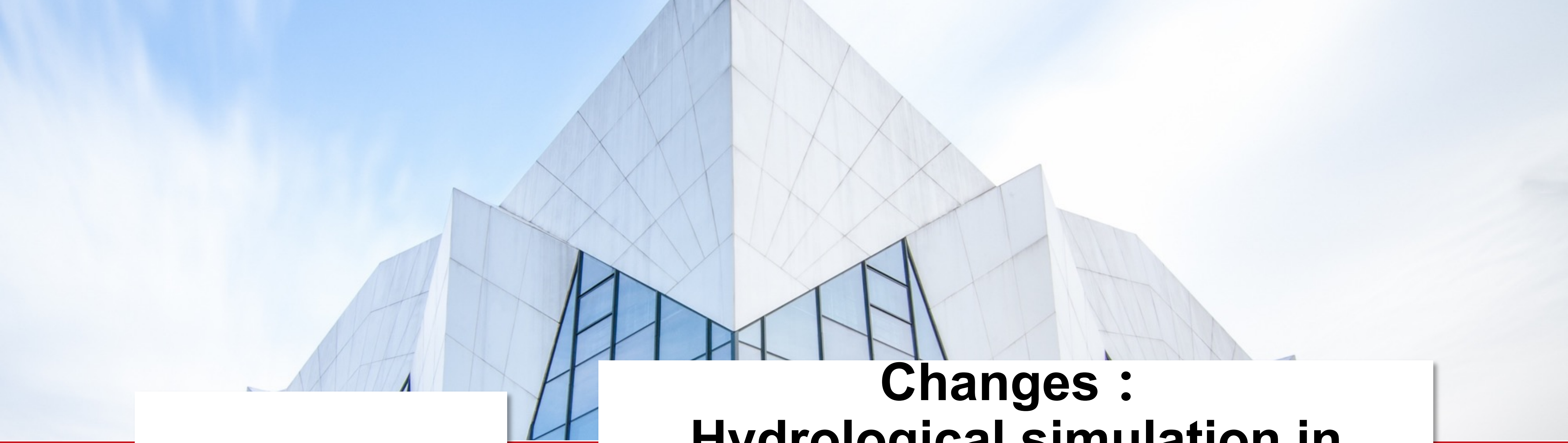
How to Solve Runoff Problems in Green Space

Reason 1 :

I am interested in the history of gardens and want to realize the practices basing on the researches.

Reason 2 :

Based on landscape ecology, statistical analysis and big data analysis techniques might be used to realize the practices.

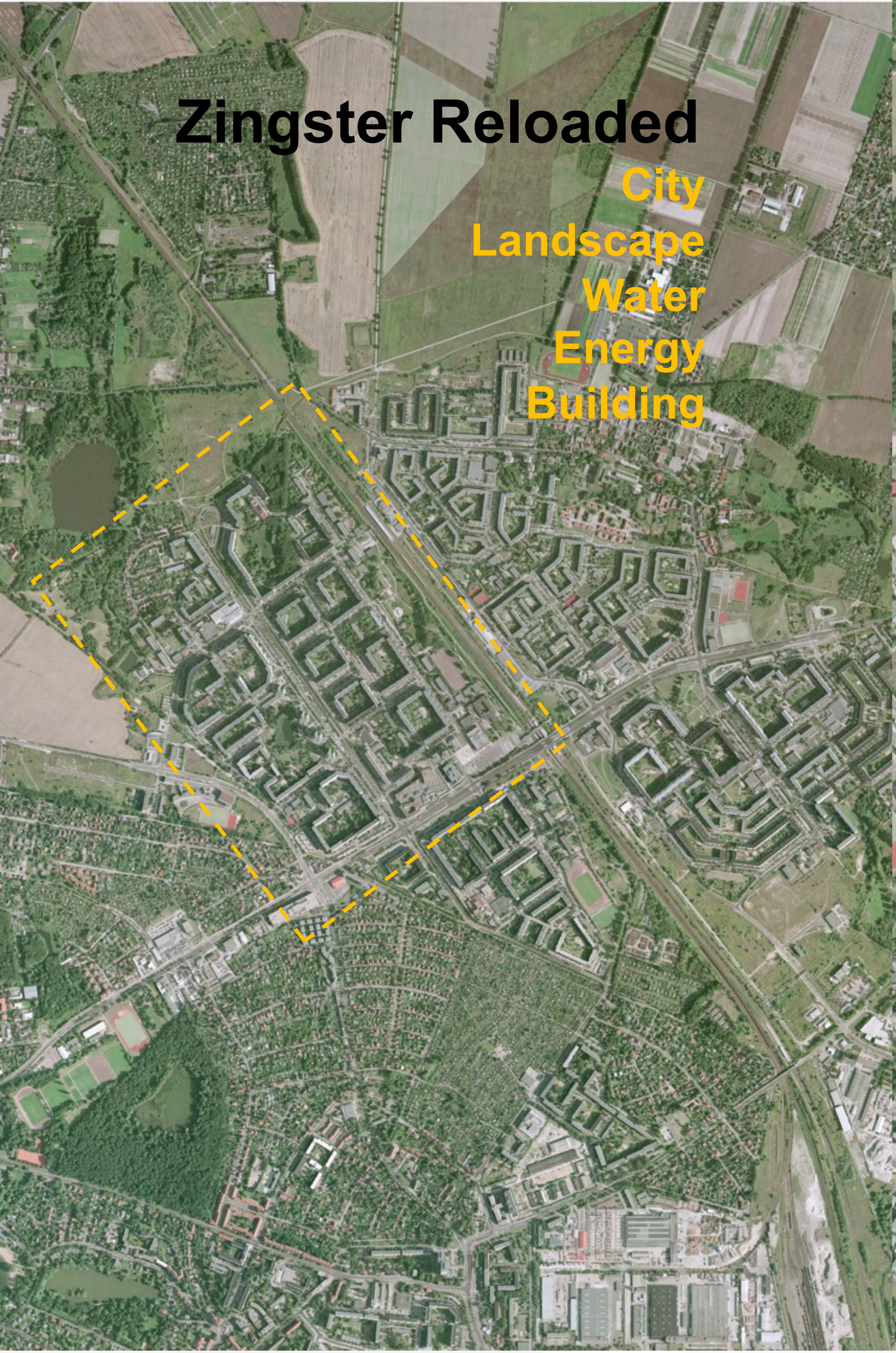


02

Changes： Hydrological simulation in Urban Communities

2.1 Ecological Planning and Design of Zingster Street in Berlin,Germerny

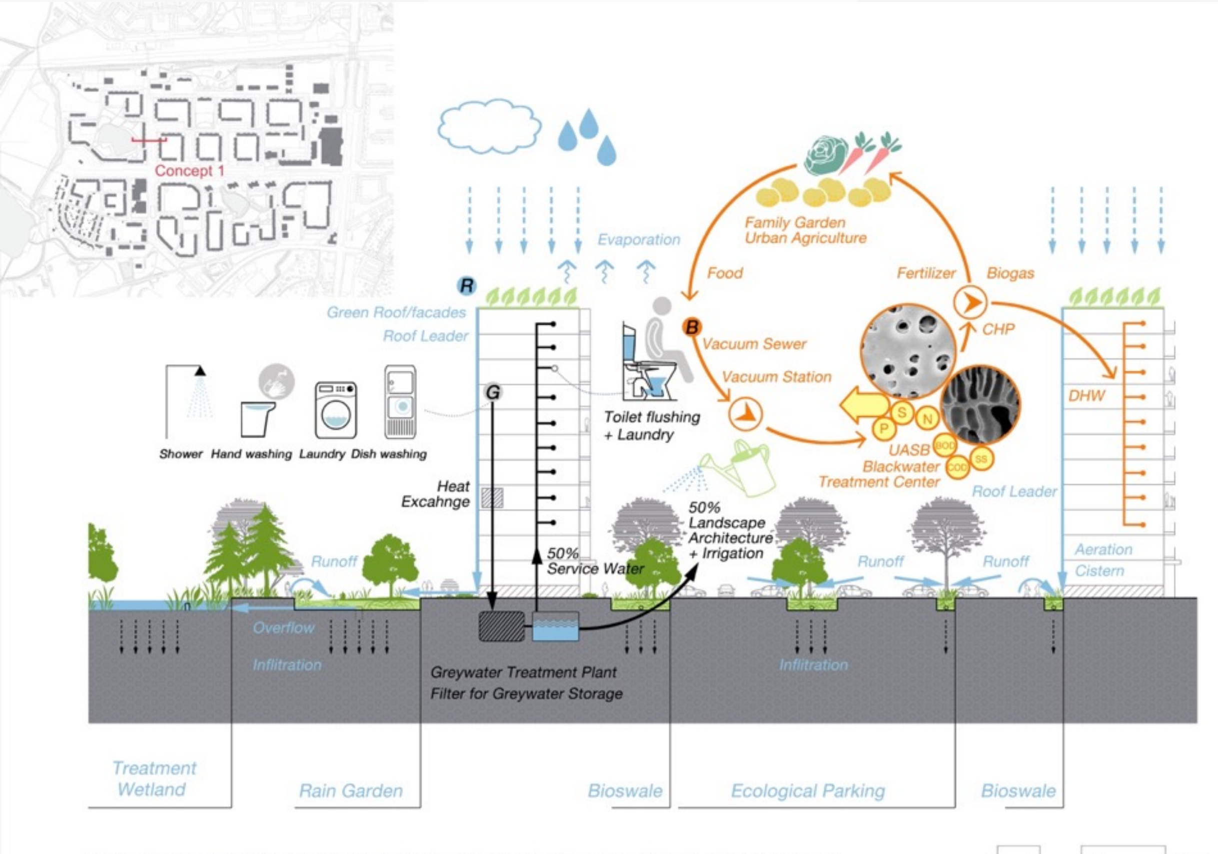
2.2 Adaptative Parameters of Hydrological Simulation model by XP-drainage


Zingster Reloaded
City
Landscape
Water
Energy
Building

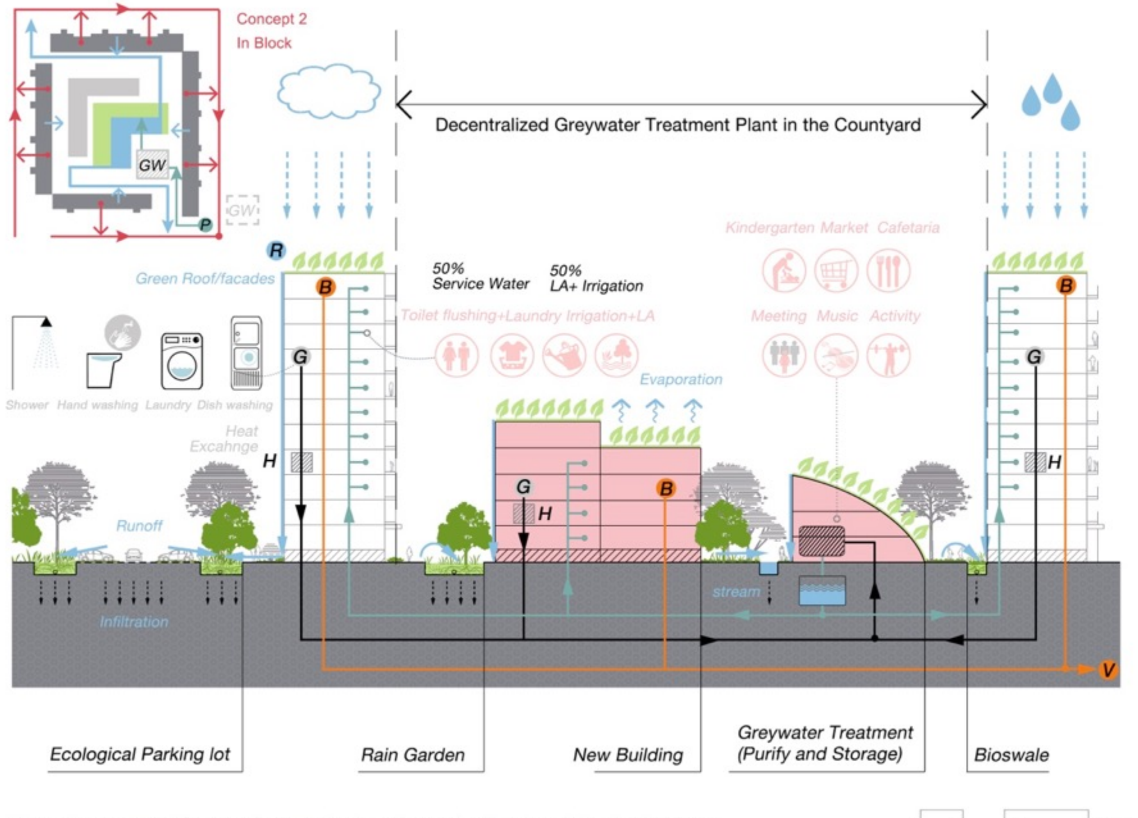
The existing pools and channels in Zingster Street, Berlin.

The analysis on existing situation were used to improve the ecological environment in the Zingster Street.

2.1 Scheme: Optimal Way for water Management



Water Management Concept 1- Decentralized Greywater Treatment Plant in the Basement

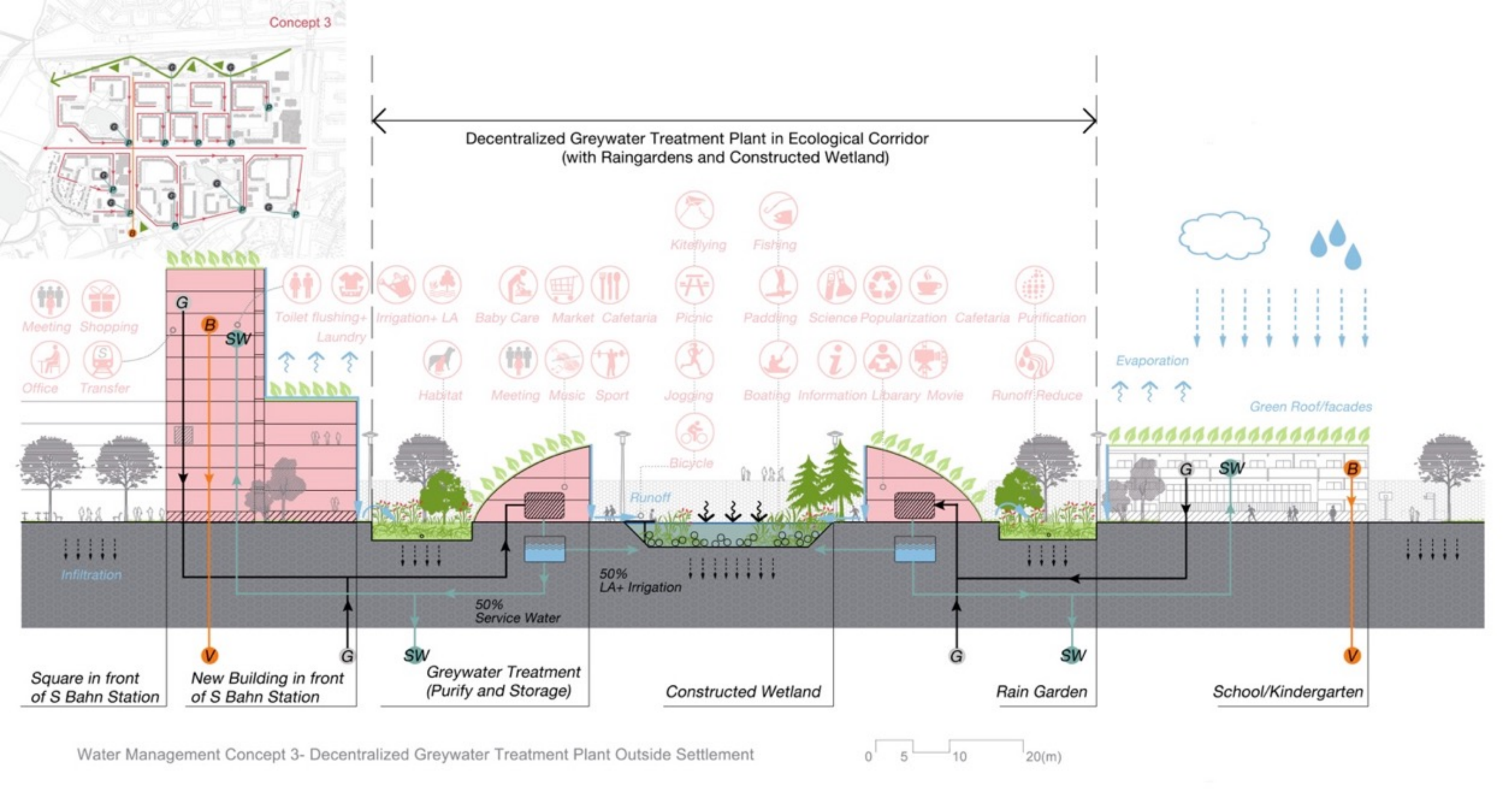


Water Management Concept 2- Decentralized Greywater Treatment Plant in the Block

Scheme 1 : distributed grey water treatment equipment located under the building

Scheme 2 : distributed grey water treatment equipment located in the counrtyard

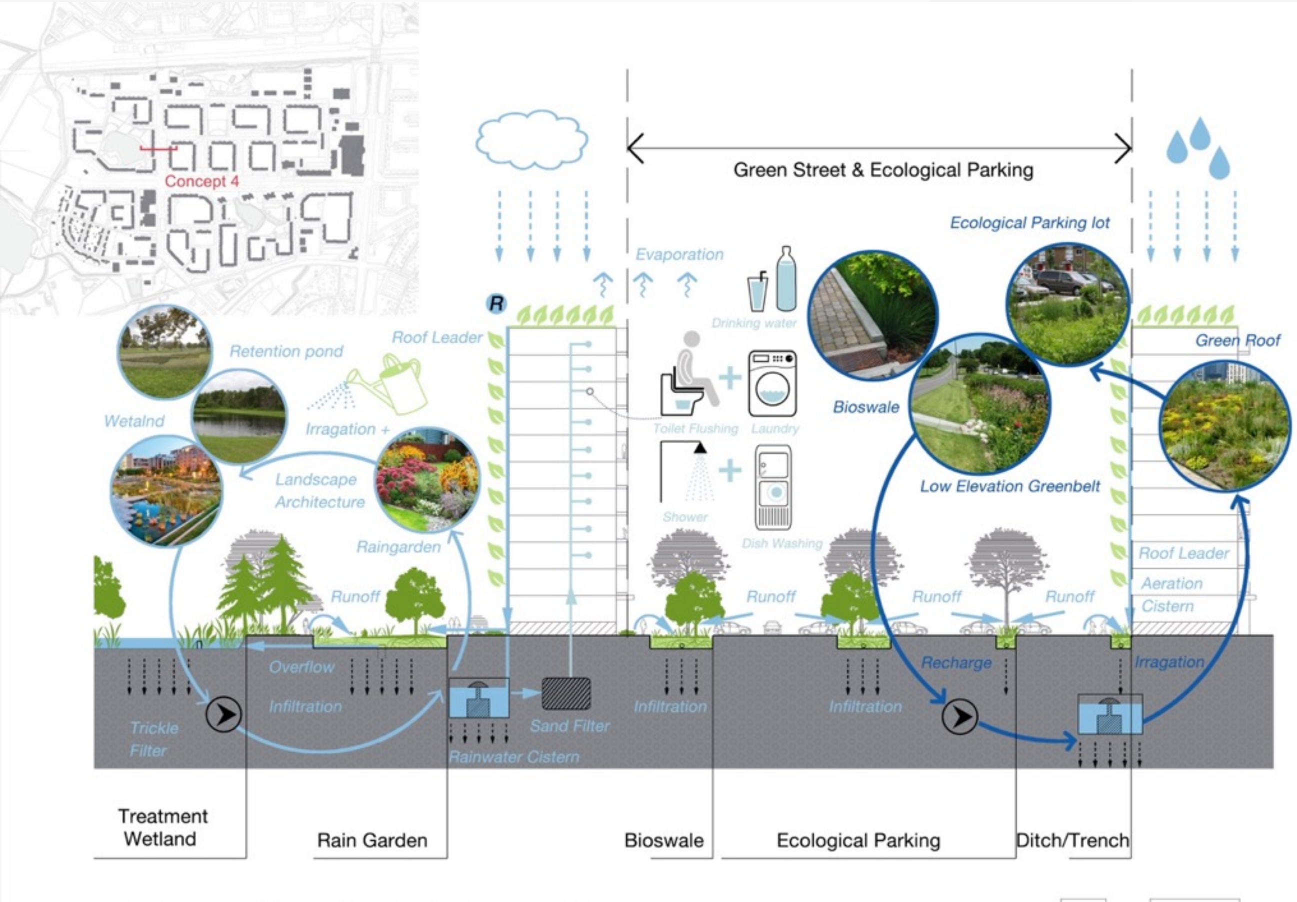
2.1 Scheme: Optimal Way for water Management



- 方案3：将灰水集中到位于生态公园中的处理设备中进行净化，并与生态公园中的湿地及雨水花园结合，为居民提供科普教育展示、休闲娱乐的场所。

- 以景观化的手法处理灰水处理设备的外表面
- 使工程化的灰水处理设备与景观融合

2.1 Scheme: Optimal Way for water Management

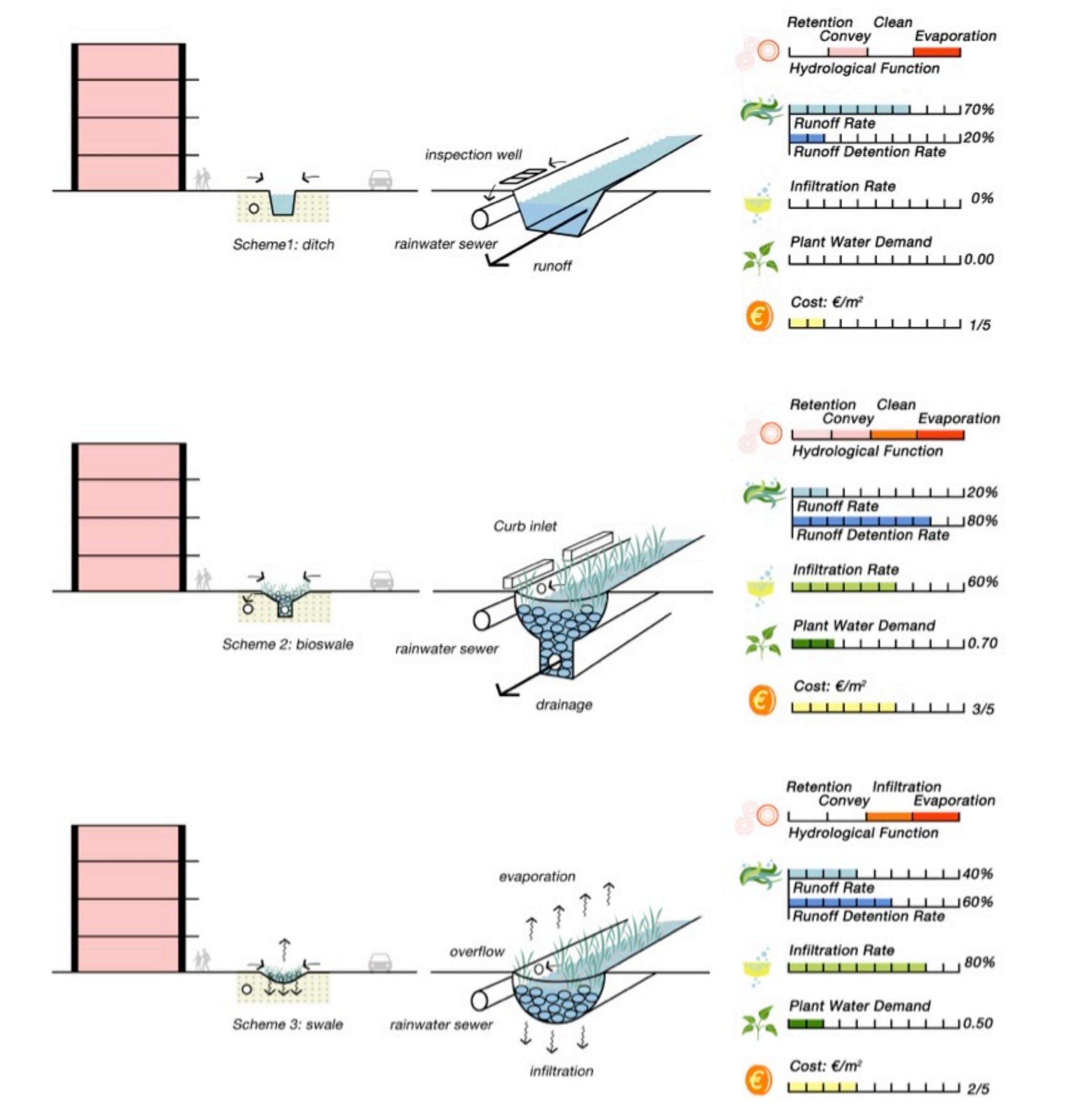


Water Management Concept 4-Rainwater Storage and Reuse

The rainwater was collected and purified by green roof, bio-swale and raingardens.

Solar energy devices could be installed in the courtyard, without the utilization of space.

2.1 Scheme: Optimal Way for water Management



- **Green street design scheme 1**
- Open channel: The cost is relatively low, and easy to clean, with the runoff rate of 70%, runoff retention rate of about 20%, but it is hard to promote infiltration.
- **Green street design scheme 2：**
- Bio-swale: The cost is higher, as well as the cost of plant maintenance, with the runoff rate of 20% and runoff retention rate of about 80%, promoting infiltration of 60%.
- **Green street design scheme 3：**
- Swale: The cost of plant maintenance is moderate, with runoff rate of 40% and runoff retention rate of about 60%, promoting infiltration of 80%.

2.2 Landscape Renewal to Realize Resource Recycling

- The blue and green axis through the urban community, connecting the community park and green space system
- Providing diverse public open space
- Sustainable use of water resources by terms of runoff regulation, grey water reuse and black water purified

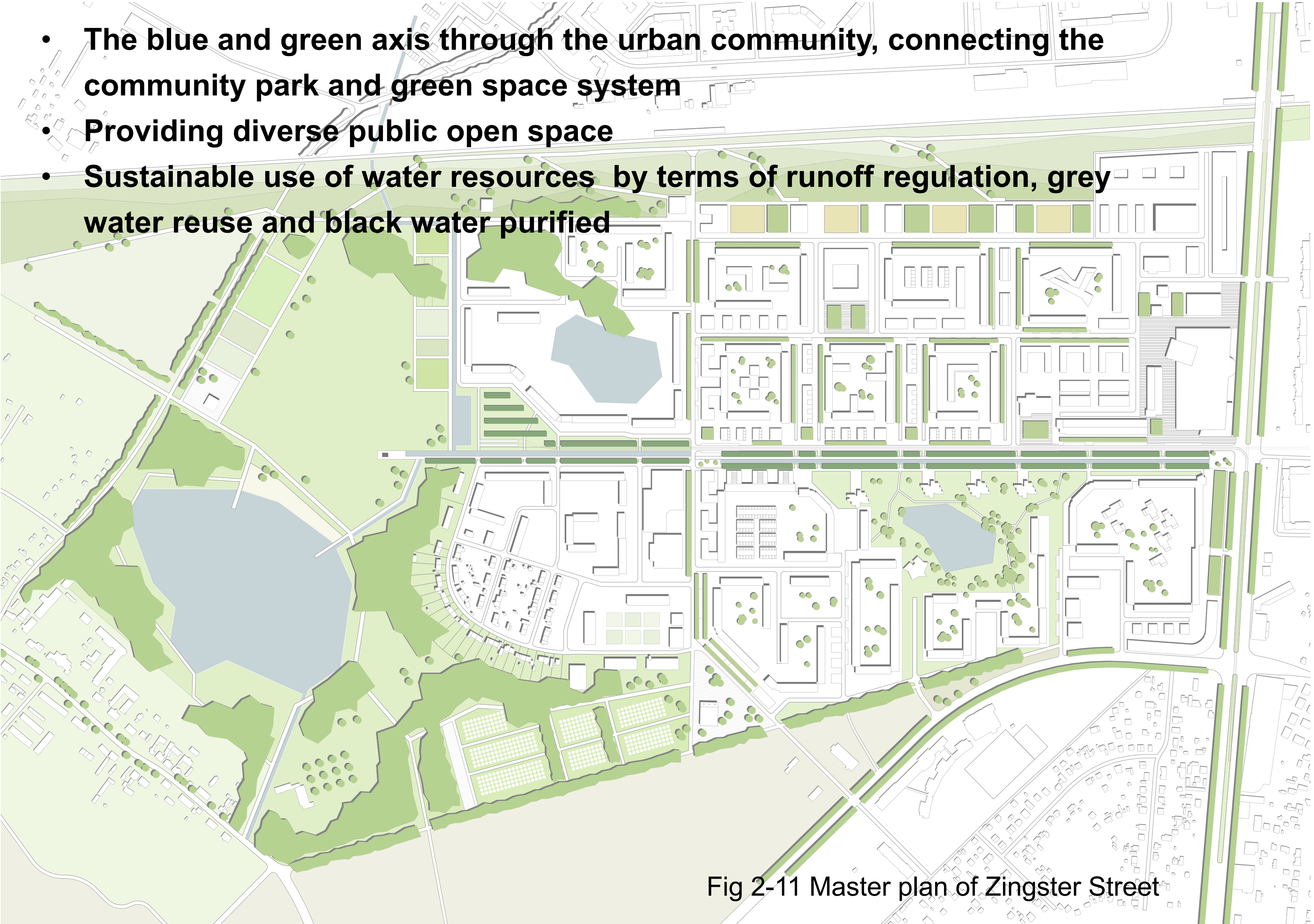


Fig 2-11 Master plan of Zingster Street

Fig 2-8 community was surrounded by farmland

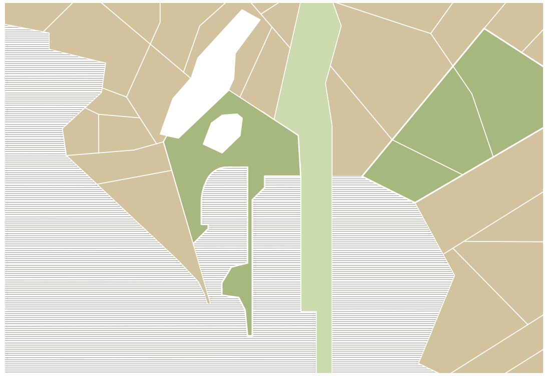


Fig 2-9 Space type division of green space in Zingster

Fig 2-10 Public open space network in Zingster

2.2 Rainwater Regulation by LID Techniques

- The water level of the channel will depend on the amount of rainfall, which will vary from time to time in a “tidal” manner.
- This kind of design provide the seasonal experience in Zingster.

2.2 Open Channel Lead the Runoff into Blue Axis

Fig 2-14 The new mode of transportation saves more public space

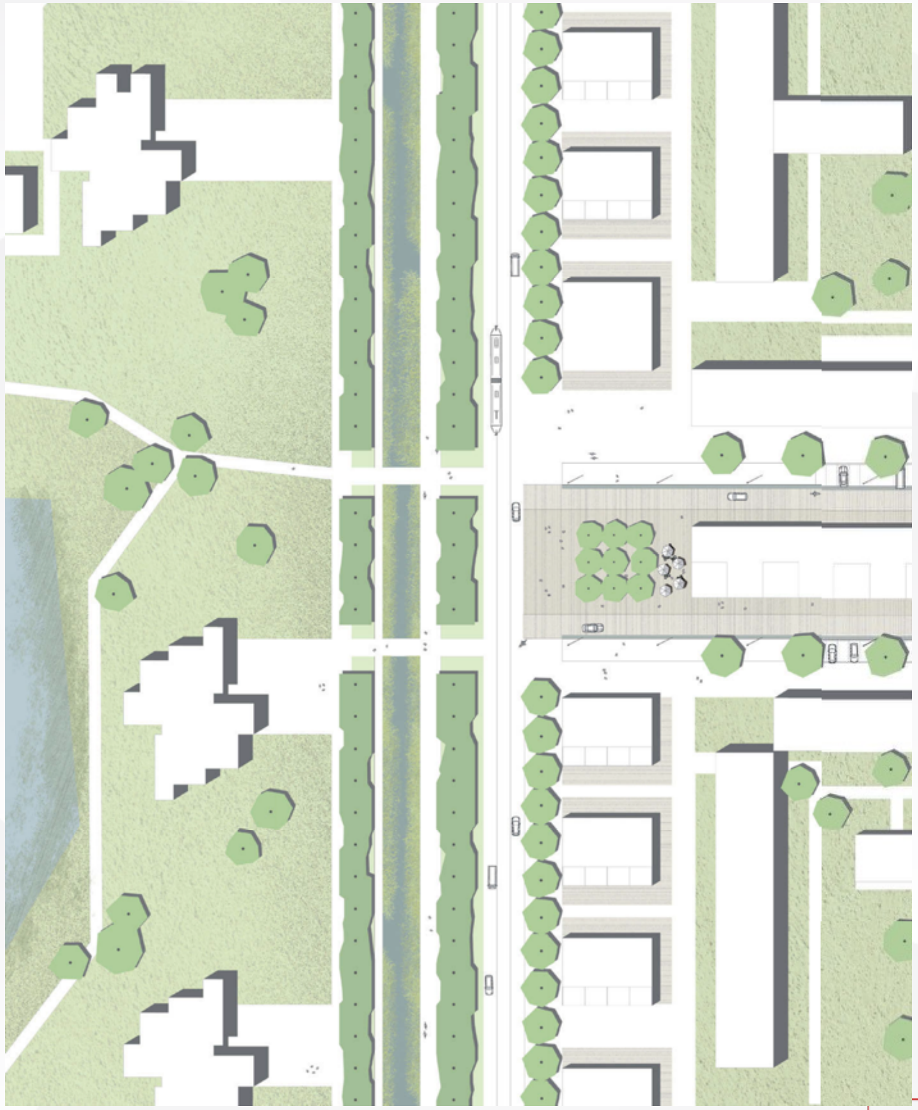
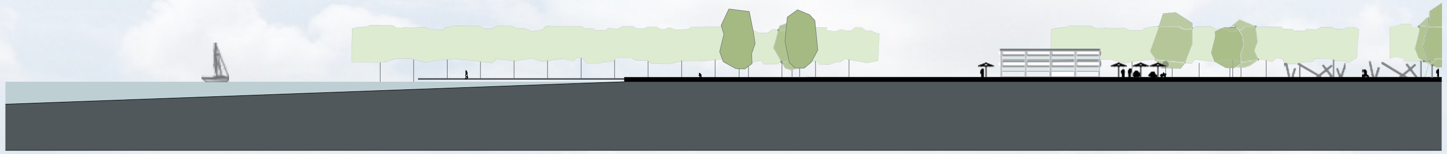
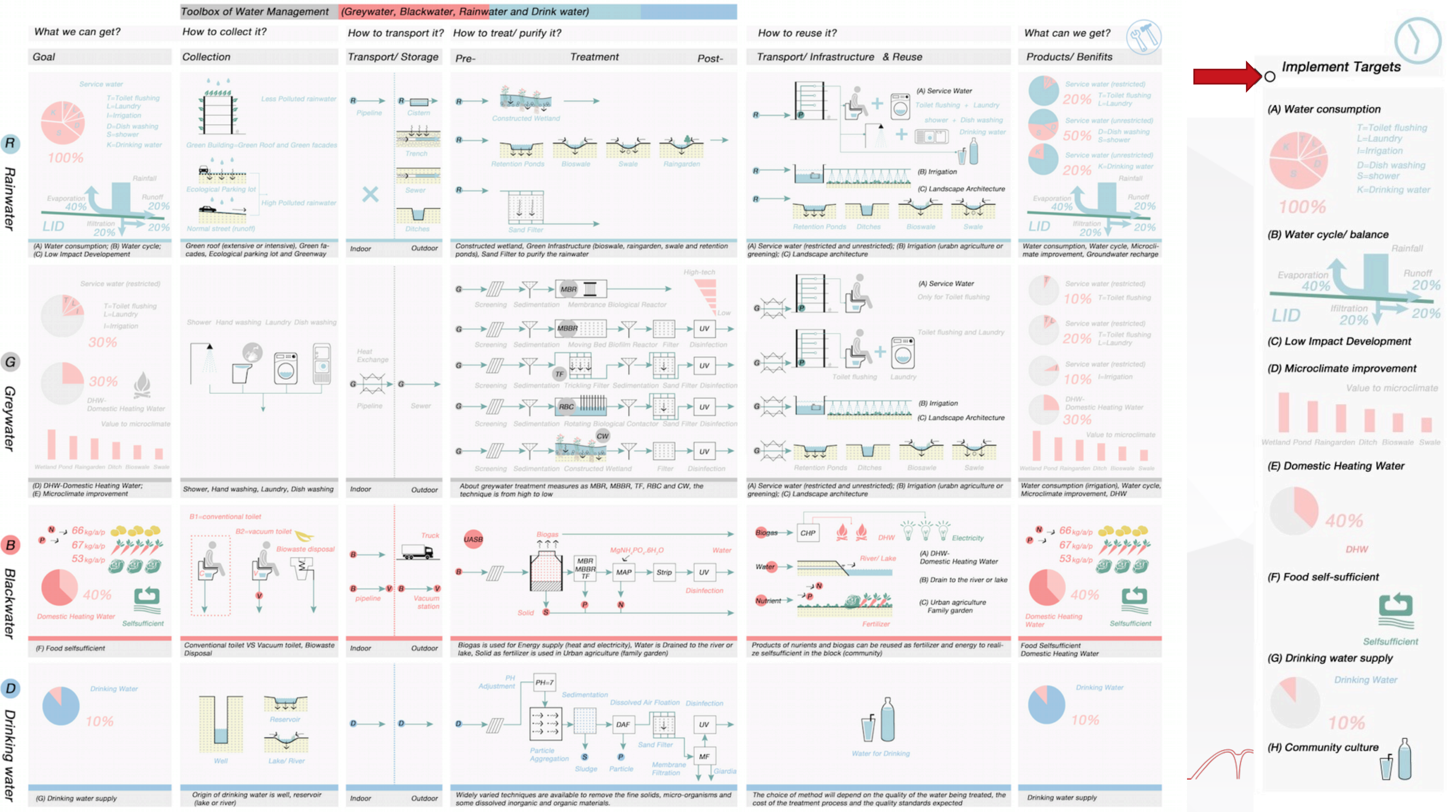


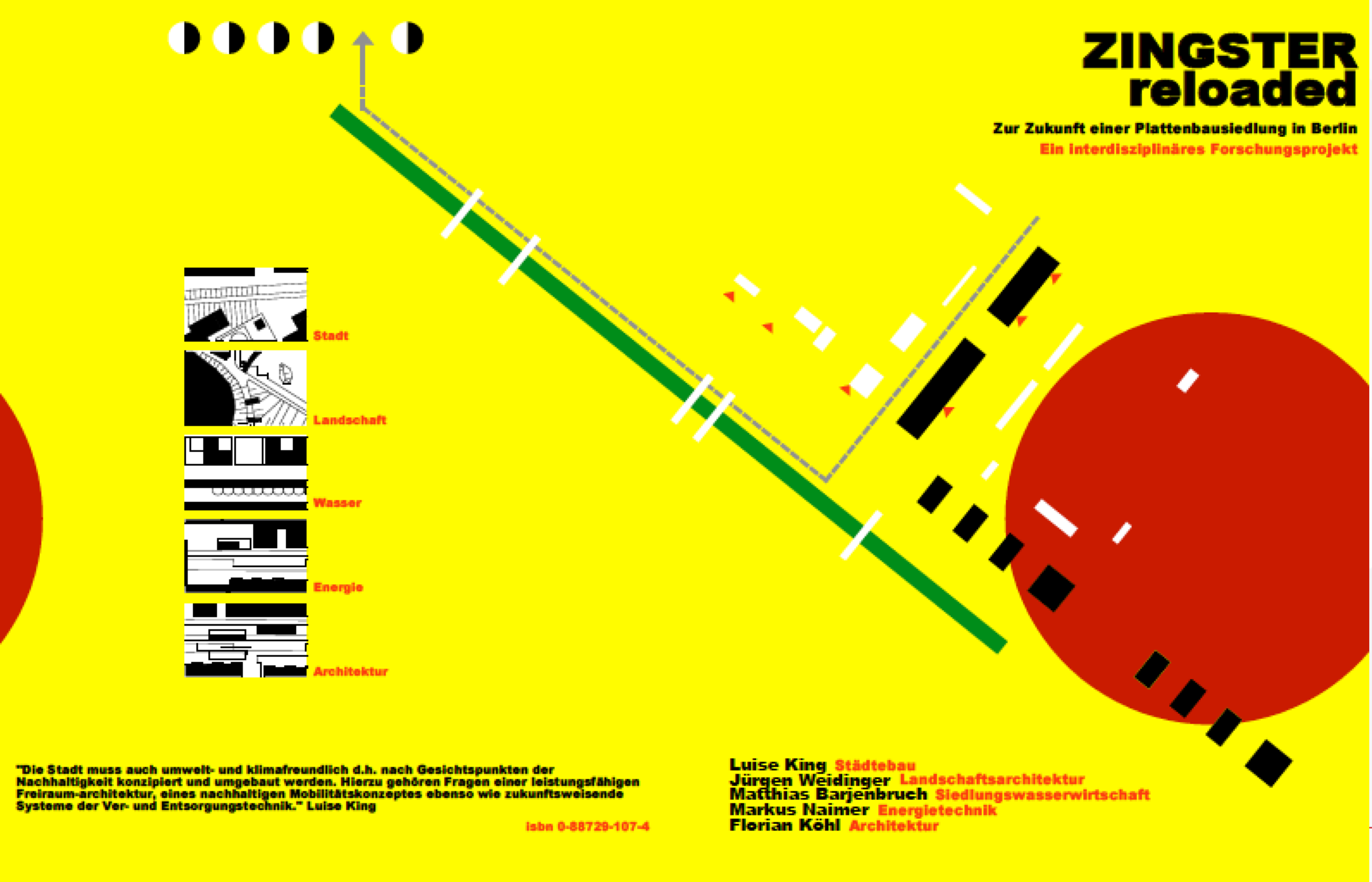
Fig 2-15 Open channels lead the runoff into blue & green axis



The rainwater storage facilities such as open channels and ecological grass gully transfer the runoff to the accepting water lake in the community park.


Toolbox of Water Management (Greywater, Blackwater, Rainwater and Drink water)
What we can get?
How to collect it?
How to transport it?
How to treat/ purify it?
How to reuse it?
What can we get?
Goal
Collection
Transport/ Storage
Pre-
Treatment
Post-
Transport/ Infrastructure & Reuse
Products/ Benifits
R Rainwater
G Greywater
B Blackwater
D Drinking water
(A) Water consumption; (B) Water cycle; (C) Low Impact Developement
Green roof (extensive or intensive), Green facades, Ecological parking lot and Greenway
Indoor
Outdoor
Constructed wetland, Green Infrastructure (bioswale, raingarden, swale and retention ponds), Sand Filter to purify the rainwater
(A) Service water (restricted and unrestricted); (B) Irrigation (urabn agriculture or greening); (C) Landscape architecture
Water consumption, Water cycle, Microclimate improvement, Groundwater recharge
(D) DHW-Domestic Heating Water; (E) Microclimate improvement
Shower, Hand washing, Laundry, Dish washing
About greywater treatment measures as MBR, MBBR, TF, RBC and CW, the technique is from high to low
Water consumption (irrigation), Water cycle, Microclimate improvement, DHW
(F) Food selfsufficient
Conventional toilet VS Vacuum toilet, Biowaste Disposal
Biogas is used for Energy supply (heat and electricity), Water is Drained to the river or lake, Solid as fertilizer is used in Urban agriculture (family garden)
Products of nutrients and biogas can be reused as fertilizer and energy to realize selfsufficient in the block (community)
Food Selfsufficient Domestic Heating Water
(G) Drinking water supply
Origin of drinking water is well, reservoir (lake or river)
Widely varied techniques are available to remove the fine solids, micro-organisms and some dissolved inorganic and organic materials.
The choice of method will depend on the quality of the water being treated, the cost of the treatment process and the quality standards expected
Drinking water supply
Implement Targets
(A) Water consumption
T=Toilet flushing
L=Laundry
I=Irrigation
D=Dish washing
S=shower
K=Drinking water
100%
(B) Water cycle/ balance
Rainfall
Evaporation 40%
Runoff 20%
LID
Illtration 20%
20%
(C) Low Impact Development
(D) Microclimate improvement
Value to microclimate
Wetland Pond Raingarden Ditch Bioswale Swale
(E) Domestic Heating Water
40%
DHW
(F) Food self-sufficient
Selfsufficient
(G) Drinking water supply
Drinking Water
10%
(H) Community culture

The German version was published in 2015



The Chinese version of this book will be published in 2020.

2.3 Challenge: How to manage rainwater in Shanghai

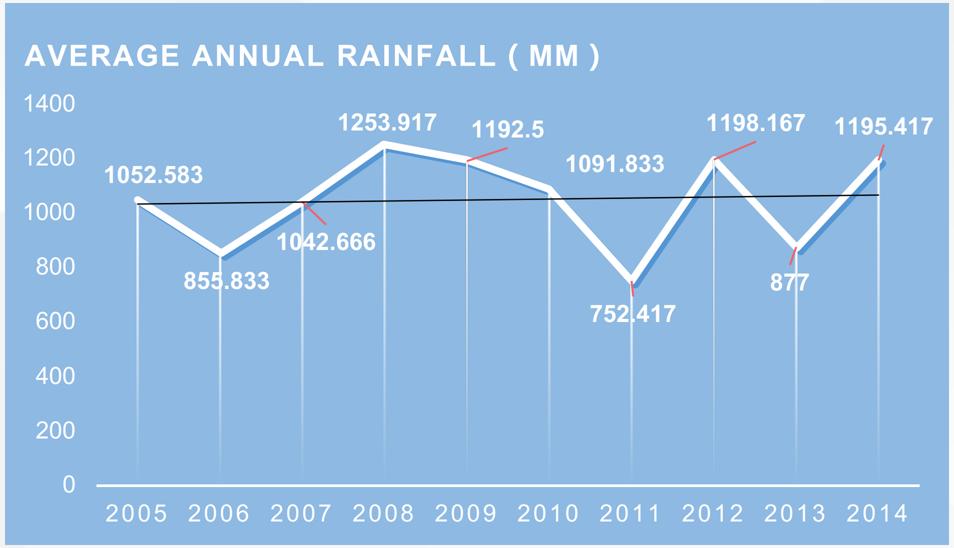
Due to the environmental condition in Shanghai, the applicability of storm simulation model and parameters is limited.

- Higher underwater level
- Higher utilization rate of land
- Higher impermeable area
- Lower soil infiltration rate

The key problems of storm water management in Shanghai

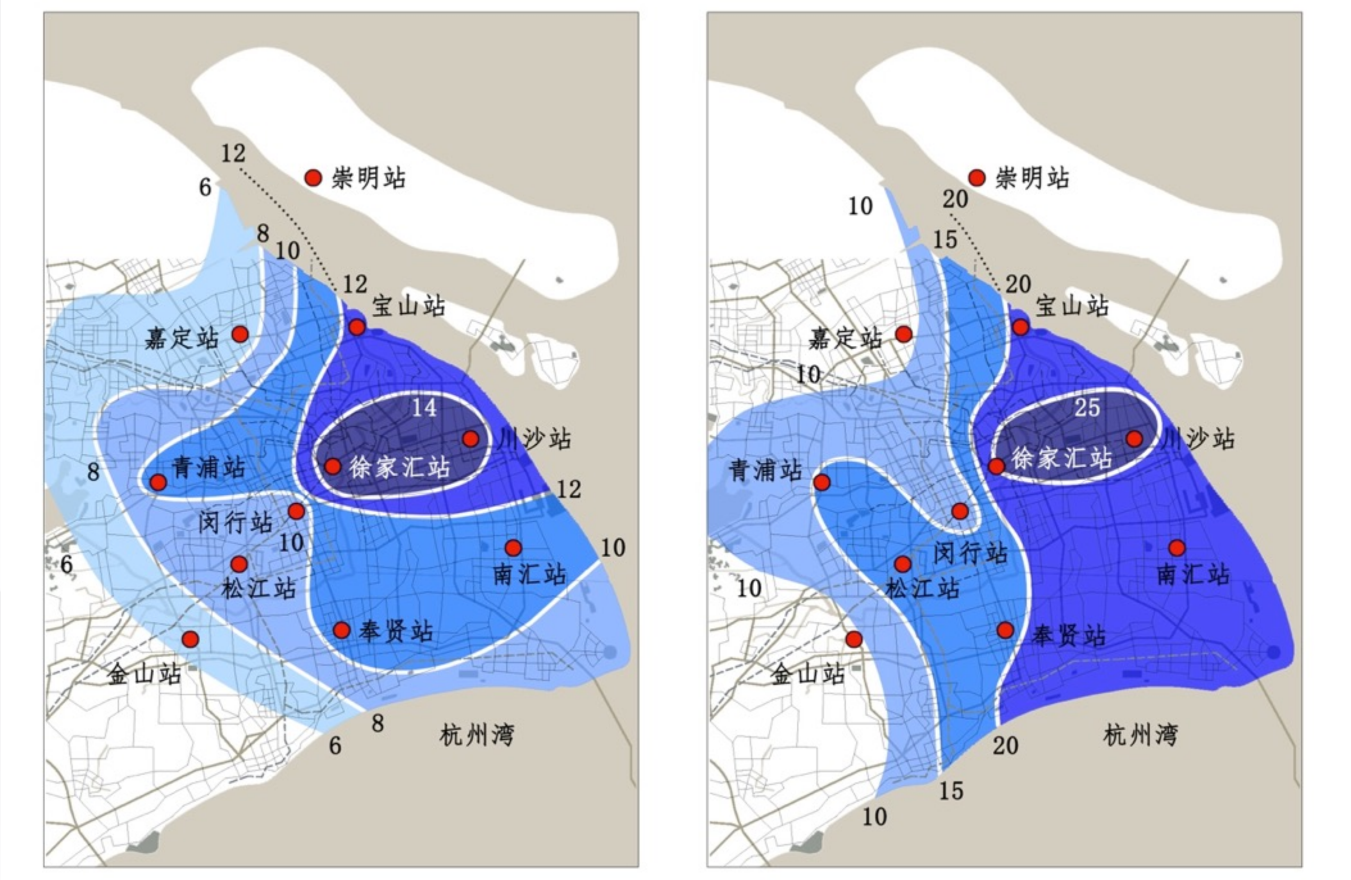
The rainfall accounts for about 90% of the year. The uneven distribution of rainfall aggravates the burden of urban drainage system, resulting in serious runoff pollution, and also leads to salinization of the soil.

2.3 Rainfall Condition in Shanghai, China



Average rainfall at Shanghai area form 2005 to 2014

The average annual rainfall in Shanghai is about 1132.9mm, with more than 70% of the annual rainfall, which concentrated in June to September. The average annual rainfall is about 11% higher than that of 30 years ago.



上海年（左）和汛期（右）降水距平百分率区域分布图（来源：上海气象中心资料）

Regional distribution of rainfall from center to suburb

2.3 Parameters Adaptability of XP-drainage

The Difficulties and Needs in Shanghai

Construction of Multi-scale rainwater regulation systems

- **Calculate before construction**
  - runoff
  - pollutant
- **Estimation of runoff**
  - runoff control
  - pollutant control
- **Layout of LID**
  - LID infrastructures
  - Runoff path
- **Comparative analysis**
  - Runoff & pollutant removal rate
- **Feedback & adjustment**

XP-drainage advantage：

- Integration of CAD
- Clear visual design
- Parameters is suitable for planning and design
- Multi-stage processing mode

Through simulation, feedback and iteration to modify scheme and optimal layout.

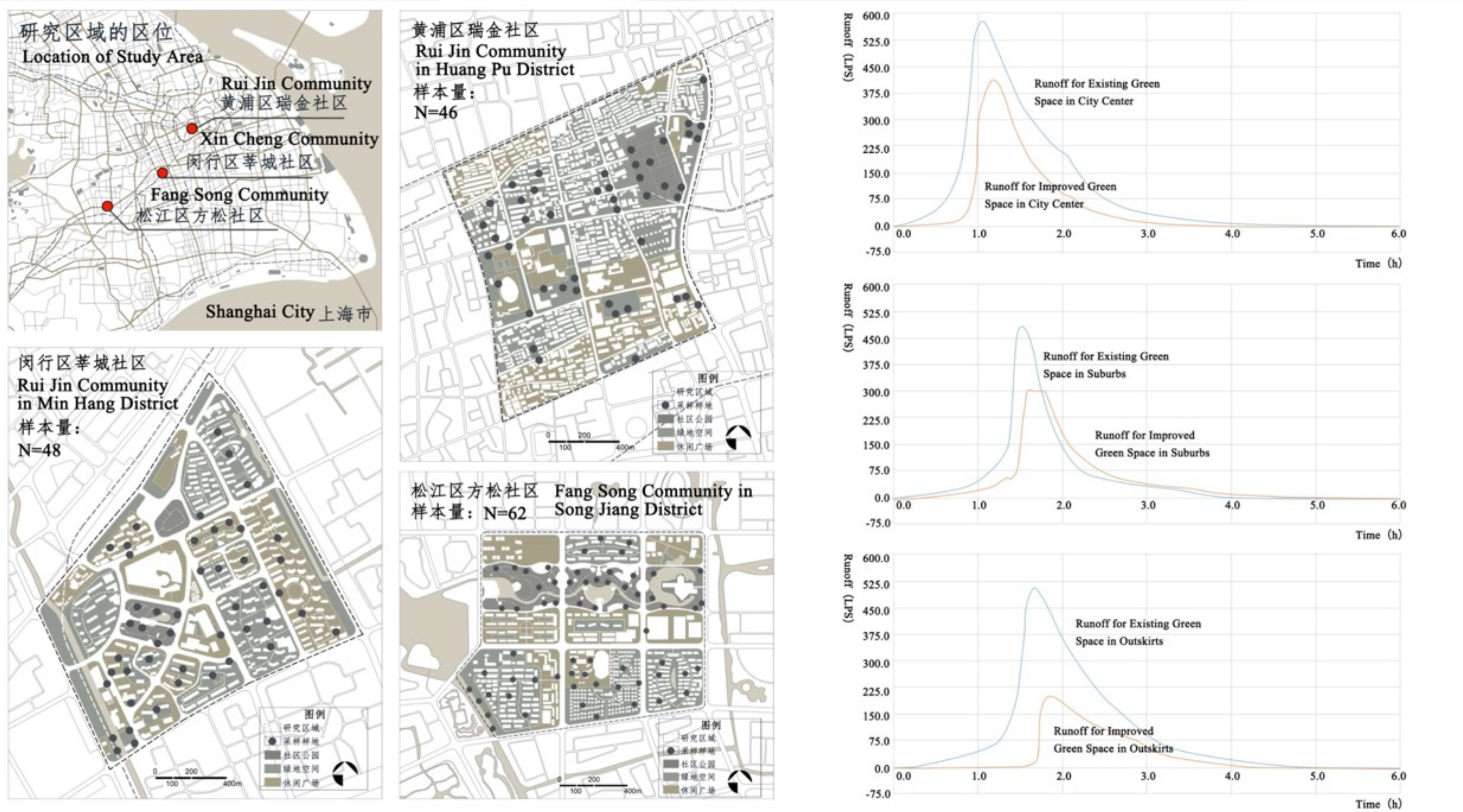


Fig 2-17 Runoff simulation results in Shanghai

2.3 Parameters Adaptability of XP-drainage

2.3.2 基地条件参数——气象条件数据+实地采样调查分析






- 降雨曲线 Rainfall intensity
- 降雨量条件 Rainfall
- 温湿度条件 Humiture
- 土壤条件 Soil situation
- 蒸发量 Evapotranspiration
- 径流系数 Volumetric runoff coefficient
- 设施底部入渗率 Base infiltration rate
- 设施侧向入渗率 Side infiltration rate
- 水力传导系数 Hydraulic conductivity

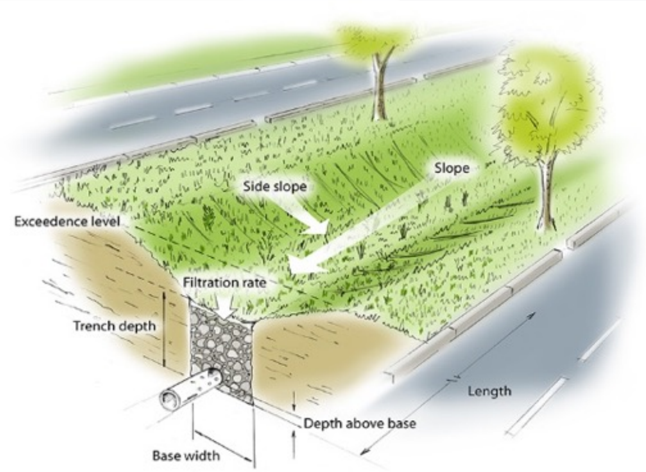
2.3 Parameters Adaptability of XP-drainage

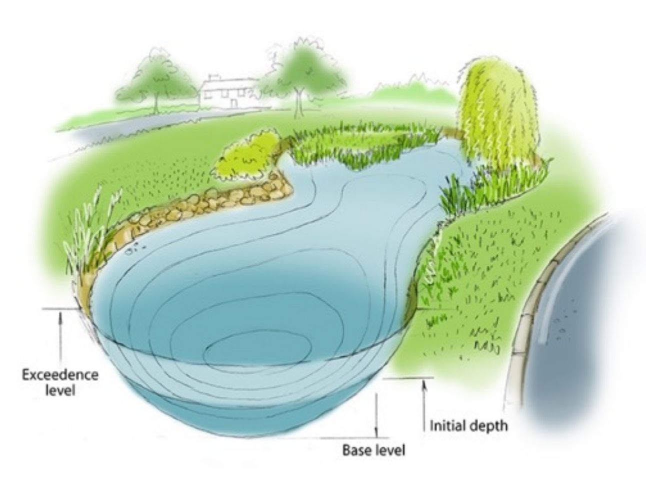
2.3.3 设施条件参数——人工降雨模拟实验+文献比较分析

人工降雨模拟实验

调蓄型生态植草沟

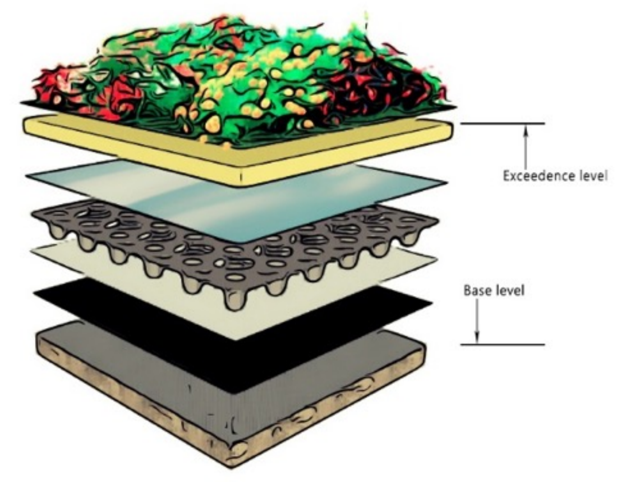
净化型生态植草沟





文献比较分析

生态调蓄设施



调蓄型雨水花园

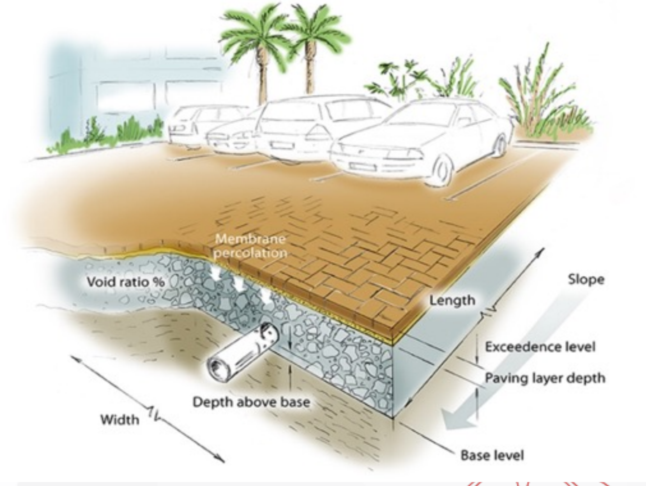
净化型雨水花园

人工降雨模拟实验

调蓄型绿色屋顶

净化型绿色屋顶

人工降雨模拟实验



文献比较分析

透水铺装

2.3 Parameters Adaptability of XP-drainage

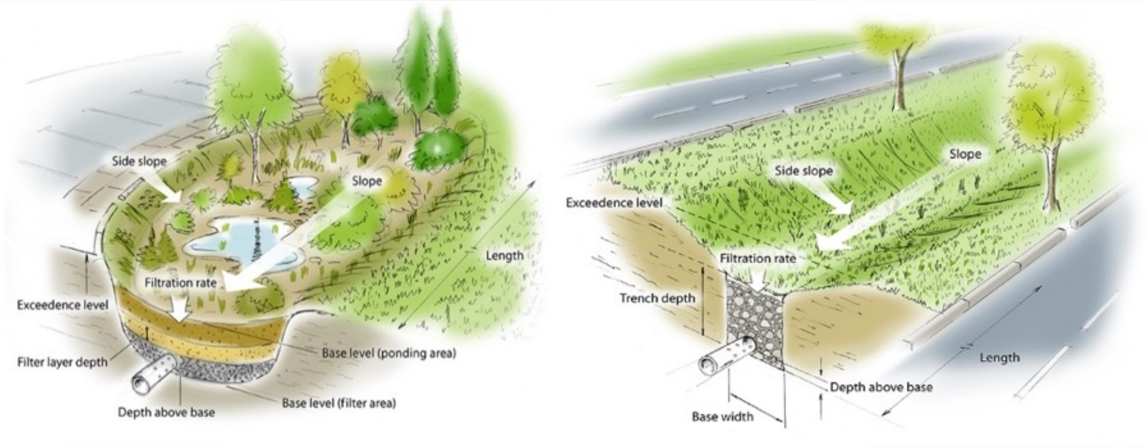
2.3.4 Parameters in Shanghai：site conditions + facility conditions

Tabel 2-1 Parameters of regular rain gardens in Shanghai

设施尺寸（Dimensions）			
蓄水层（Ponding area）		过滤层（Filter area）	
顶部标高（Exceedence Level）	-	底部标高（Base Level）	-
深度（Depth）	200mm	埋管高度（Height Above Base）	-
底部标高（Base Level）	-	管径（Diameter）	12-17cm
顶部面积（Top Area）	30±10㎡	管数（No of Barrels）	1
边坡斜率（Side Slope）	1/4		
底部面积（Base Area）	30±10㎡		
溢流标高（Freeboard）	210mm		
宽度（Length）	-		
底部斜率（Slope）	<5%		

过滤层（Filtration layers）			
结构层名称（Filtration Layer Name）	结构层深度（Filtration Depth）	蓄水空间（Void Ratio）	渗透率（Filtration Rate）
砾石、有机覆盖物等	0.05m	30%	70（m/d）
改良种植土	0.3m		
中砂	0.05m		
沸石	0.5m		
ϕ1-2cm砾石	0.3m		

污染物（Pollution）	
污染物名称（Pollution Name）	去除率（Percentage Removal）
COD	65%
TN	60%
TP	45%

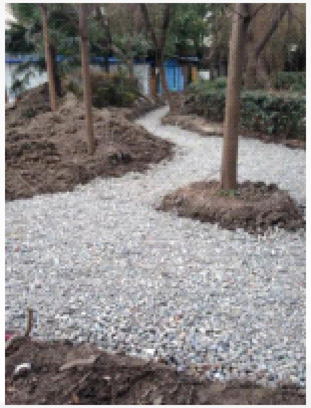


- To develop adaptive parameters for runoff simulation mode in Shanghai;
- A patent for rainwater regulating technique: a method for construction rainwater regulation systems (CN201910869923.3).

2.3.5 Empirical verification of parameters：green space in Shanghai

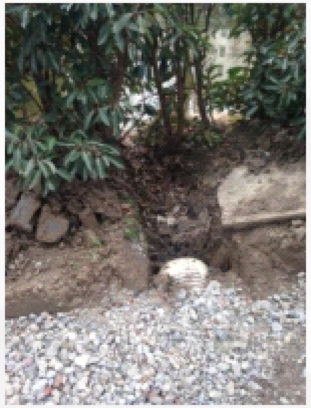
Table 2-2 Real-time monitoring and feedback of Gong Kang Green Space in Shanghai

No, of infrastructure	Simulate the duration of overflow (min)	Real overflow time measured (min)
No.1 Raingarden	-	-
No.2 Raingarden	-	-
No.3 Raingarden	940	895
No.4 Raingarden	-	-
No.5 Raingarden	1280	1020
No.6 Raingarden	-	-
No.7 Raingarden	-	1365



Foundation of permeable pavement

Drainage system in the urban green space



Runoff drained to constructed wetland

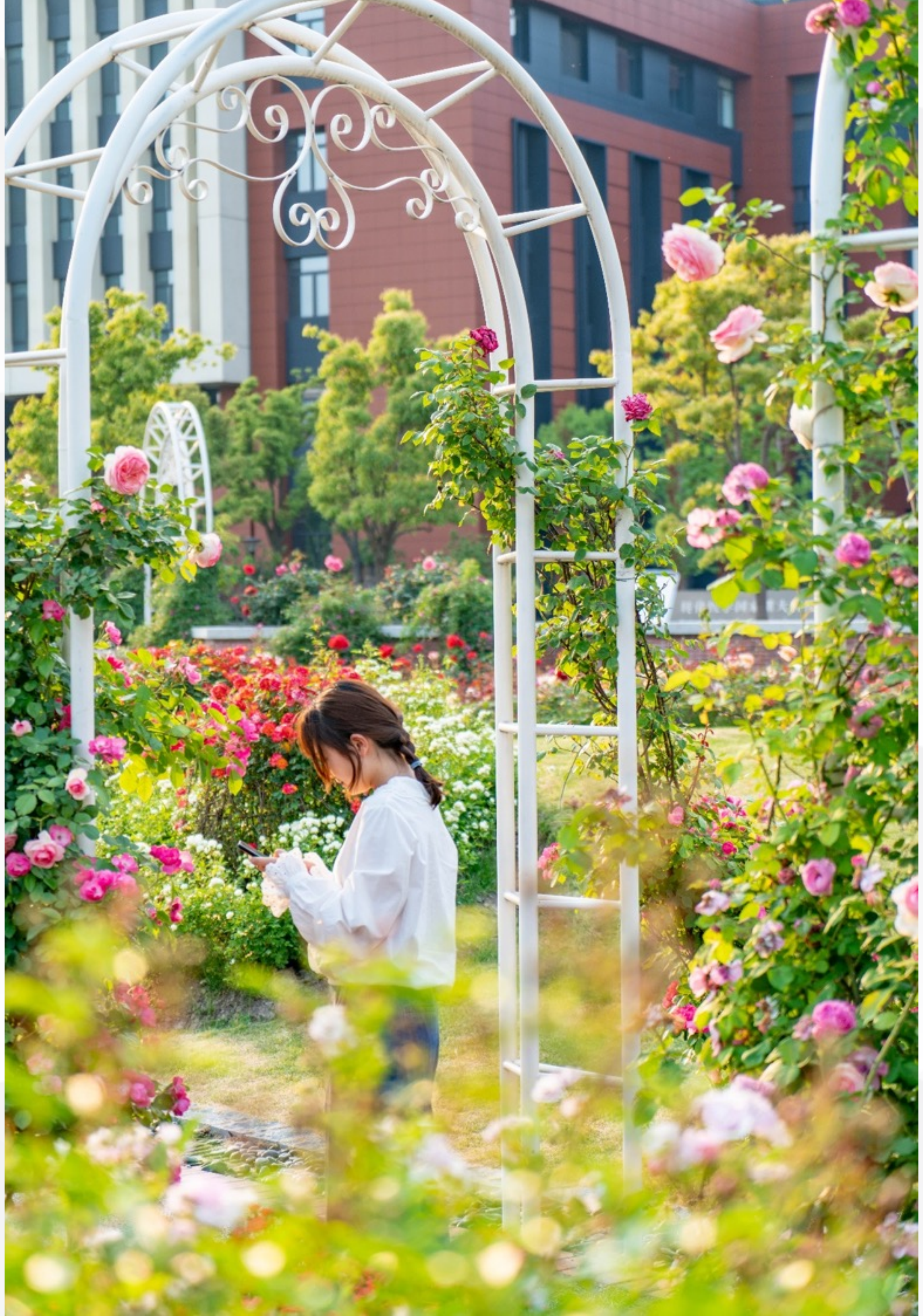
No.1, No.2, No.4, No.6 raingardens: the results of measurement conforms to the simulated condition.
No.3 and No.5 raingardens: simulation error is 9.25% and 8.99% respectively.
No.7 raingardens: the simulation results showed there is no overflow, but actually the overflow happened in 1355 min.

- Based on the real-time monitoring and feedback of facilities used in Shanghai sponge city construction, the parameters are verified empirically.
- The error is less than 10%, which meets the requirement of general engineering needs.

2.3 Parameters Adaptability of XP-drainage

Bioswale with environmental functions

Rain garden to collect and purify runoff



03

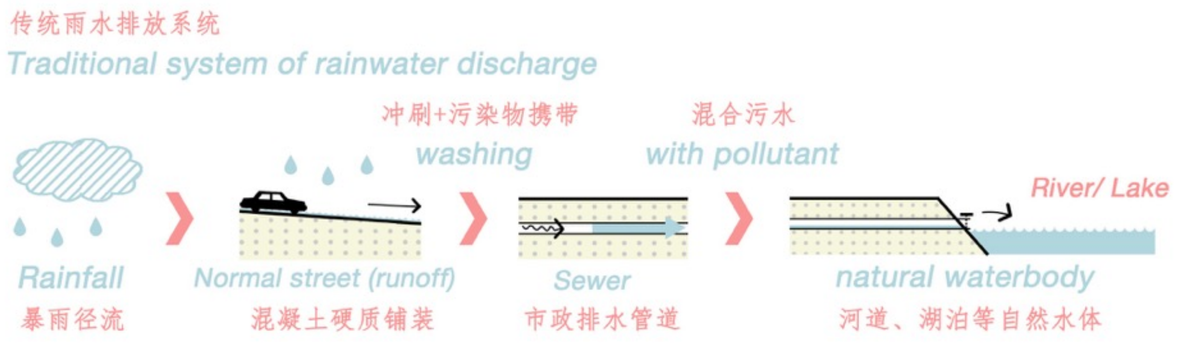
Challenge：Adaptative LID techniques

3.1 LID techniques adaptive for Shanghai environmental conditions

3.2 Invention of LID techniques adaptive for coastal saline and alkline area

SJTU

3.1 Structure Optimization of LID Adaptive in Shanghai



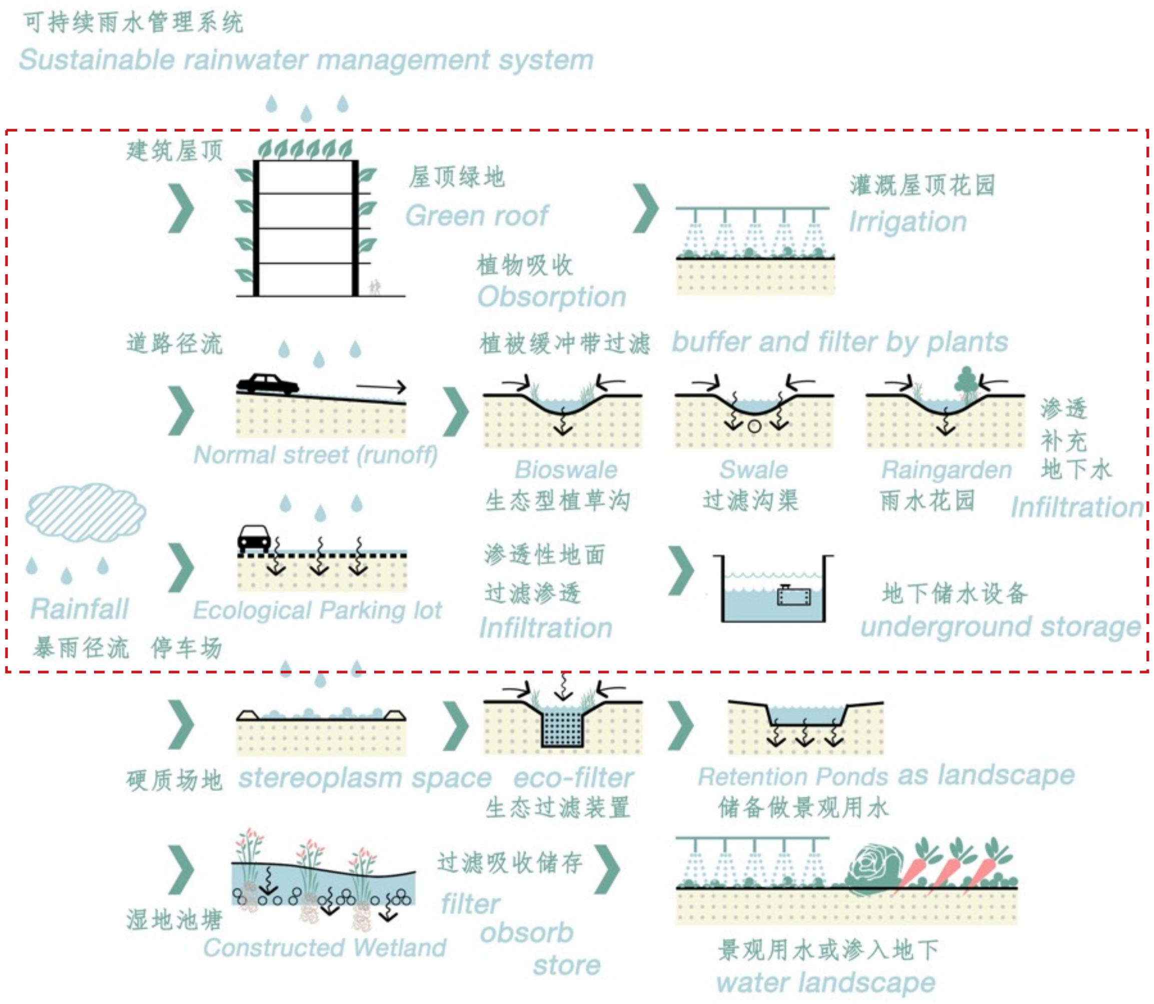
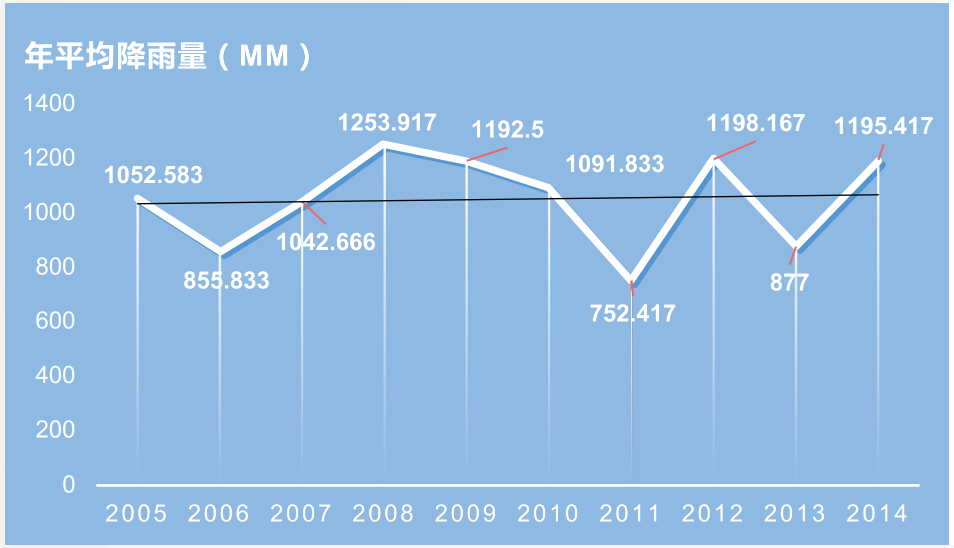


Fig 3-2 Structure Optimization of LID techniques in Shanghai



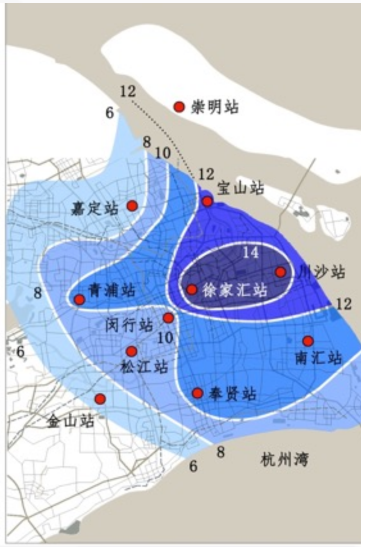
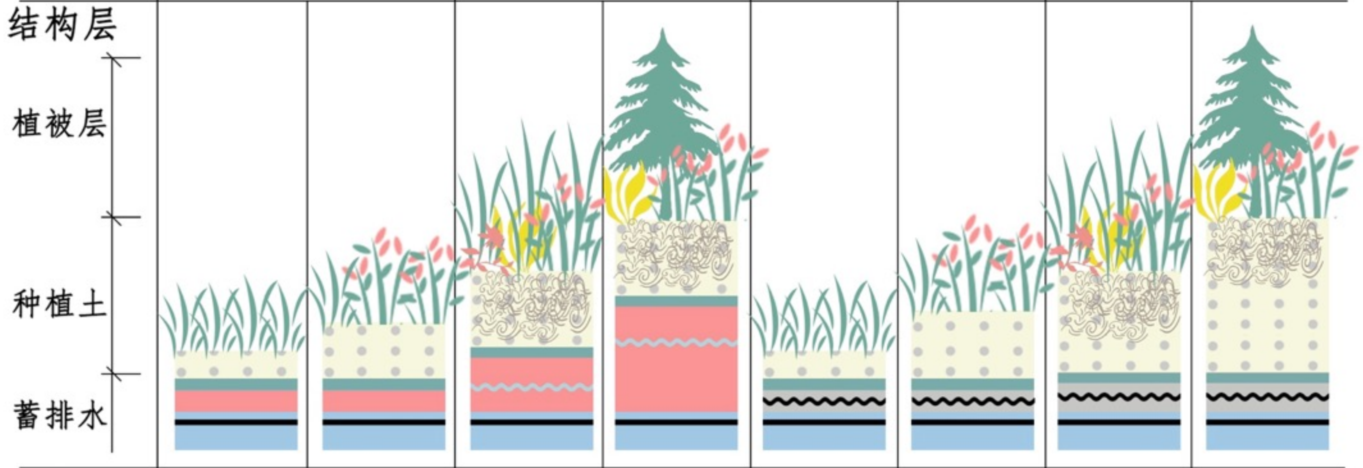
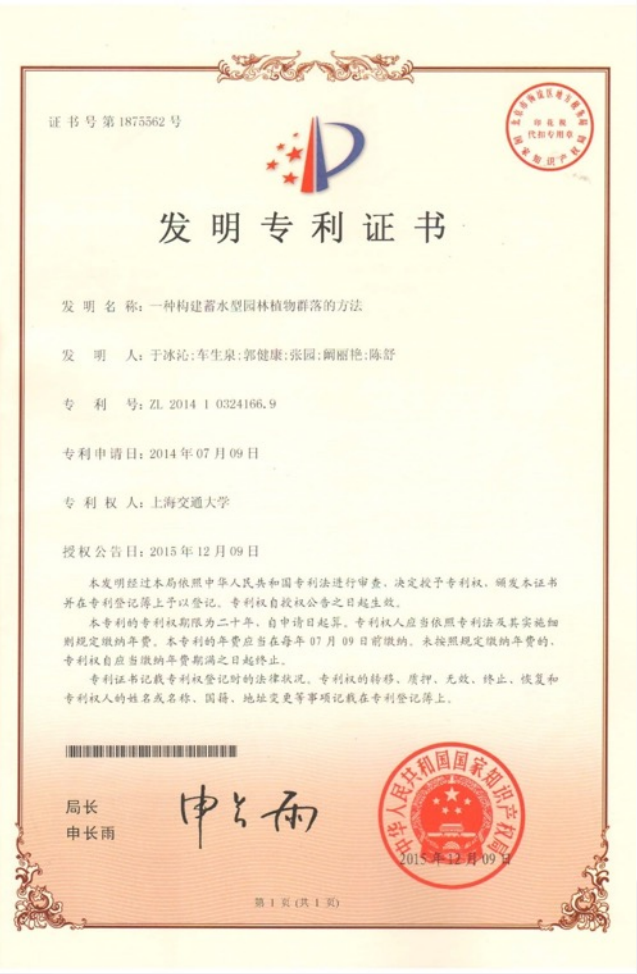


图3-1 上海年降雨量（左）和汛期（右）降水距平百分率区域分布图（来源：上海气象中心资料）

Fig 3-1 Regional distribution of rainfall from center to suburb

3.1 Structure optimization of LID adaptive in Shanghai

类型	拓展型		密集型		拓展型		密集型	
结构层								
排水设施	基质层				排水板			
植被组成	景天 草本	景天 草本 宿根	宿根 草本 灌木	草本 灌木 乔木	景天 草本	景天 草本 宿根	宿根 草本 灌木	草本 灌木 乔木
干重	93kg/m²	137kg/m²	219kg/m²	337kg/m²	68kg/m²	112kg/m²	166kg/m²	254kg/m²
持水重量	127kg/m²	200kg/m²	341kg/m²	512kg/m²	112kg/m²	180kg/m²	278kg/m²	415kg/m²
雨水蓄积量	50%	60%	70%	80%	50%	60%	70%	80%



证书号第1875562号

发明专利证书

发明名称：一种构建蓄水型园林植物群落的方法

发明人：于冰沁；车生泉；郭健康；张园；阚丽艳；陈舒

专利号：ZL 2014 1 0324166.9

专利申请日：2014年07月09日

专利权人：上海交通大学

授权公告日：2015年12月09日

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局长
申长雨

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2015年12月09日

第1页(共1页)

By artificial rainfall simulation experiments, the optimized structure of green roof, bio-swale and raingardens were proposed to adapt the environmental condition in Shanghai.
The achievements have been applied for 7 national invention patents and practiced in Shanghai.

3.2 Estimation Method for Rainwater Storage Capacity

- **Rainfall storage capacity was therefore calculated as**

$$L_i = (A_i * B_i * H + C_i * D_i * H + E) * S_i$$

- where, for i type of plant community, Li=rainfall storage amount (m^3), Ai=annual average rainfall interception percentage due to tree canopy density (%), Bi=annual average rainfall interception percentage due to tree form (%), H=annual average rainfall (mm), Ci=shrub cover rate (%), Di=annual average rainfall interception percentage by shrub (%), E=soil water storage capacity (mm), and Si=area of community (m^2).

$$V_t = \Sigma L_i + W$$

$$W = 0.5 * K_1 * S$$

$$R = V_t / (S * H) * 100\%$$

- The structure optimization of LID techniques and green space rainwater storage capacity estimation method provide support for Shanghai sponge city construction.

- where R=total rainfall interception rate of a green space, Vt=annual rainfall interception amount of the green space, Li=rainfall storage amount of each plant community, W=storage capacity of eaters, K1=area percentage of water, S=area of the green space, and H=annual average rainfall.

3.3 Adaptative LID in Shanghai Coastal Saline Area

3.1.1 Problems for sponge city in coastal saline area

Salinization of soil

In Chinses coastal areas, saline-alkali soil is widely distributed and has long been faced with problems as salinization of soil, high level of unground water and single vegetation species.

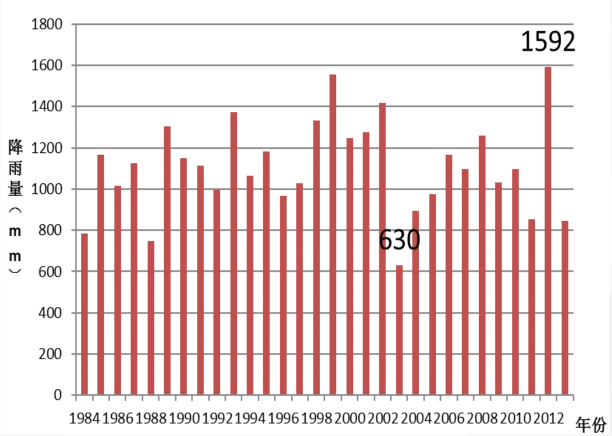


Fig 3-1 Annual rainfall regular in Lin Gang New City, Shanghai

3.1.2 Actual demands for sponge city in Shanghai

- As a typical coastal saline-alkali land, Lin Gang New City is also a national pilot for sponge city construction. As a result, it is urgent to do researches and practices as adaptive LID techniques.

SJTU

3.1.3 Design Orthogonal Experiment

- According to relevant researches as to salt separation, standard structure of rain gardens, and environmental conditions of Shanghai coastal saline area,

- Three variables were set up (material of salt insulation layer A, thickness of packing layer B, and position of salt insulation layer C) for the orthogonal test.

Table 3-1 正交试验因素与水平设计

Level	Factor A	Factor B (cm)	Factor C
1	River sand	10	Between planting and transition layer
2	Zeolite	20	Between transition and packing layer
3	Ceramsite	30	Between packing and drainage layer

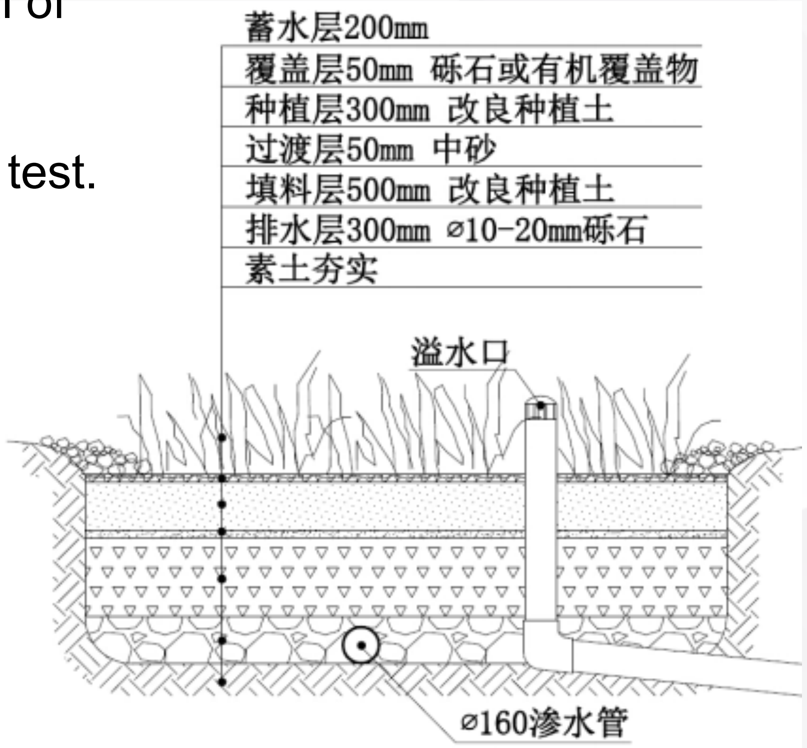


Fig 3-1 stand structure of raingarden

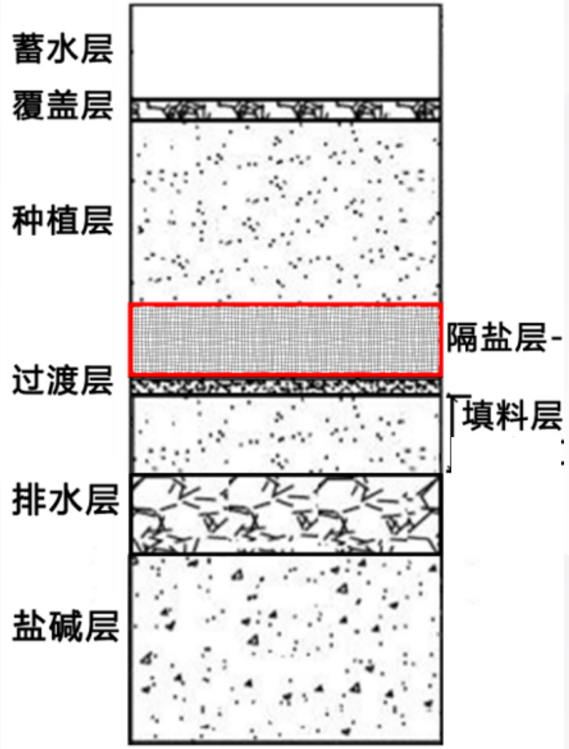
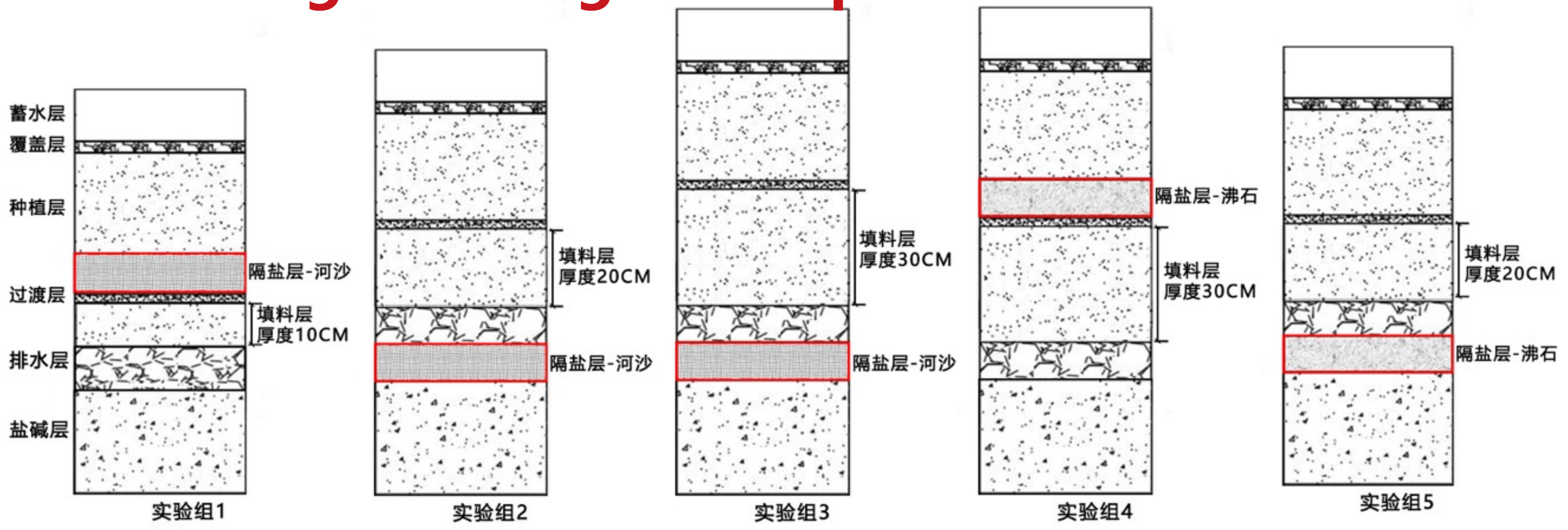
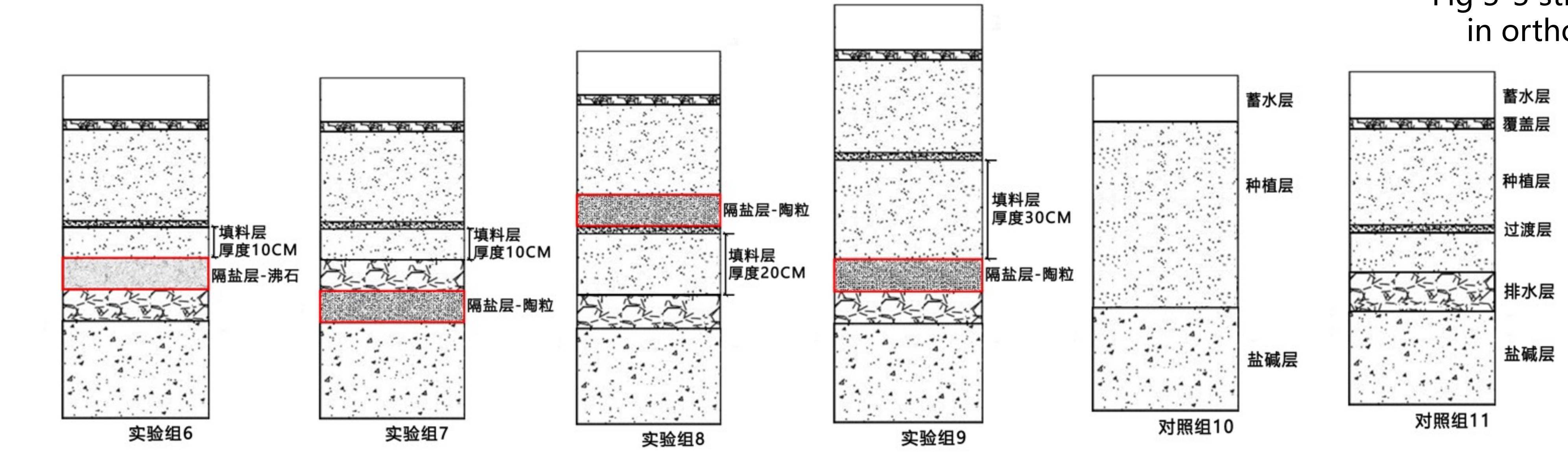


Fig 3-2 structure of raingarden in experiment

3.3 Adaptative LID in Shanghai Coastal Saline Area

3.1.3 Design Orthogonal Experiment





- ***9*** **orthogonal test groups (EG)**
- **Control group** ***10*** **(CG10)**
- **Control group without salt insulation layer** ***11*** **(CG11)**

Fig 3-3 structure of raingarden in orthogonal experiment

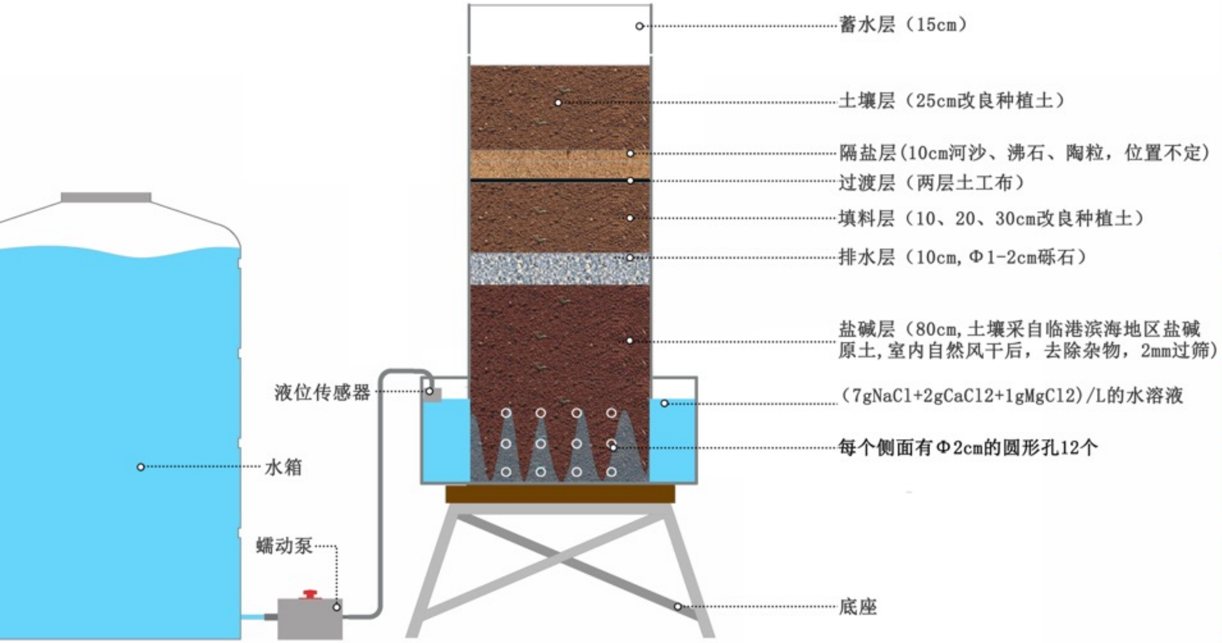
3.3 Adaptative LID in Shanghai Coastal Saline Area

3.1.4 Artificial rainfall simulation experiment

- **Rainfall design in experiment**
- According to the statics of daily rainfall data from the year 1988 to 2017 in Lin Gang area, the rainfall intensity of 16.8mm/h was carried out, with rainwater inflow as 8.4ml/s。

- **Pollutant design in experiment**

According to the composition of pollutants of runoff, the runoff water quality in the experiments was as following: **COD content is 220mg/L, TN content is 7.38mg/L、TP content is 1.45mg/L。**



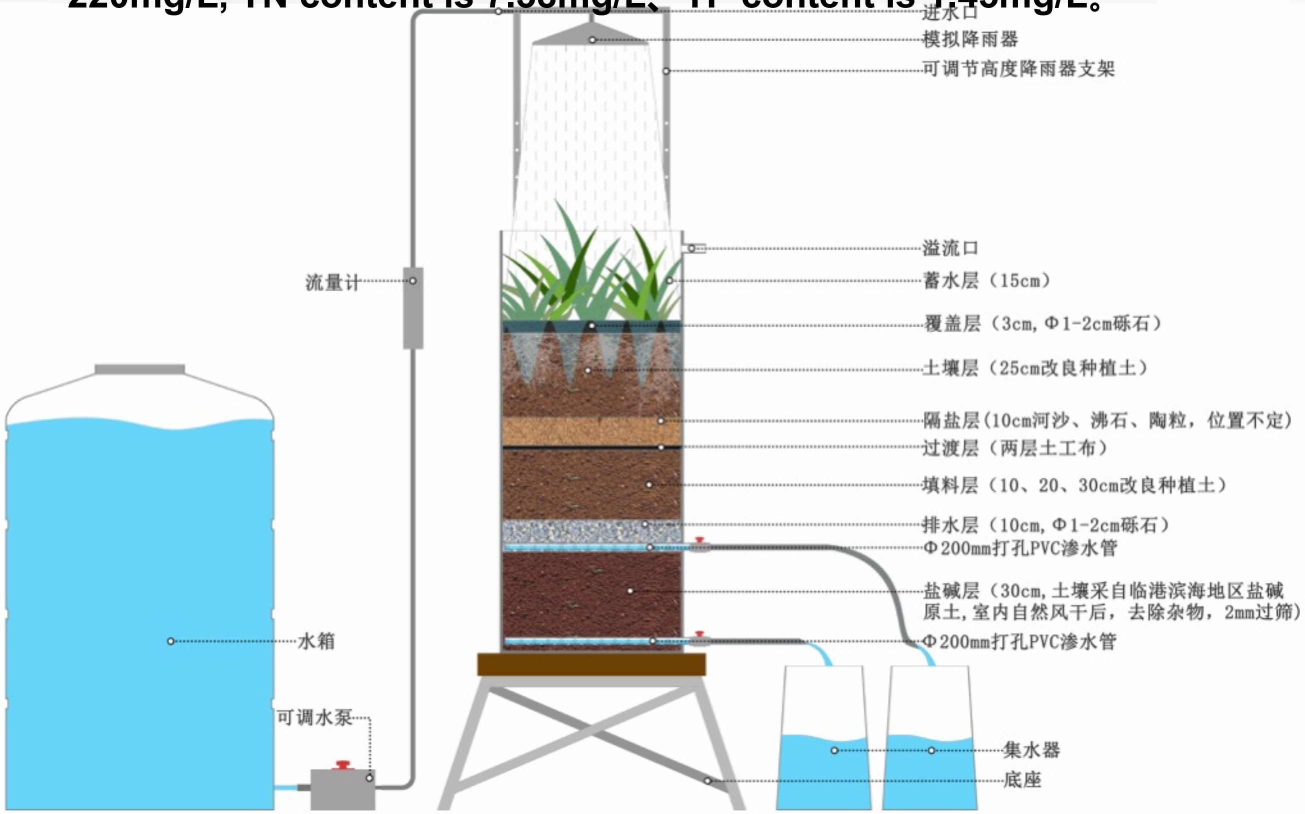


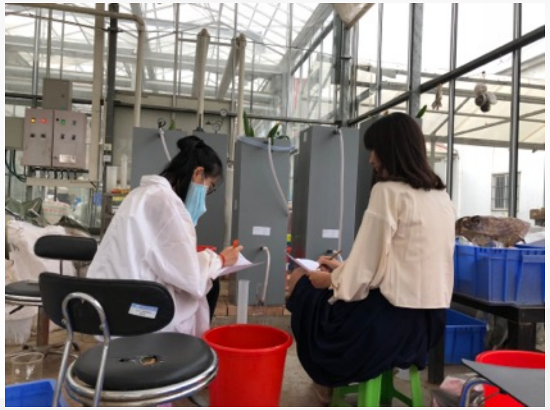
Fig 3-4 Diagram of raingarden device for desalination

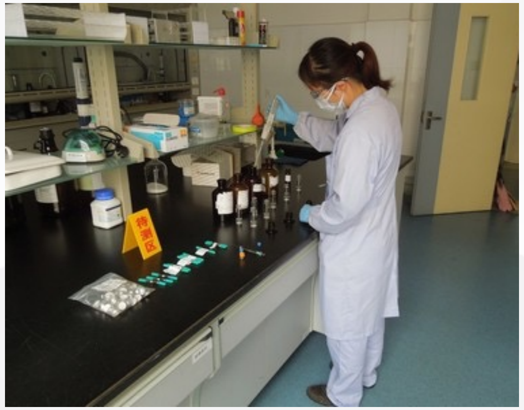
Fig 3-5 Diagram of raingarden device for runoff quality simulation

3.3 Adaptative LID in Shanghai Coastal Saline Area

3.1.4 Artificial rainfall simulation experiment



Process of experiments

2017.11- 2018.08 , during for 10 months

3.1.5 Methods of data collection and analysis

Referring to the indoor soil column test and key indexes of the hydrological characteristics of rain gardens, the following indexes were selected as the salt-proof rain gardens.

Table 3-2 Indicators and methods for experiment

Indicators		Measure methods
Salt isolation characteristic	Salt in soil	PET-2000 soil active meter
Hydrological characteristics	Runoff delay time	In the rainfall simulation experiment, to record the time when runoff peak arrived.
	Total runoff reduction rate	The ratio of the difference between the total input water quantity and the total output water quantity and the water quantity q is calculated
	Permeability	The infiltration rate of runoff relative to saturation was calculated.
	Water storage rate	Calculate the difference between the total inflow and outflow, when runoff is. Relatively saturated. And then, calculate the radio of that to the volume V of the device.
Water quality characteristics	COD reduction rate	Rapid digestion spectrophotometry
	TN reduction rate	Ultraviolet spectrophotometry for alkaline potassium persulfate digestion
	TP reduction rate	Ammonium molybdate spectrophotometry

3.1.6 Results of Difference Comparison by T, Variance and HSD Test

3.1.5.1 Influence of rain garden structure on salt isolation effect

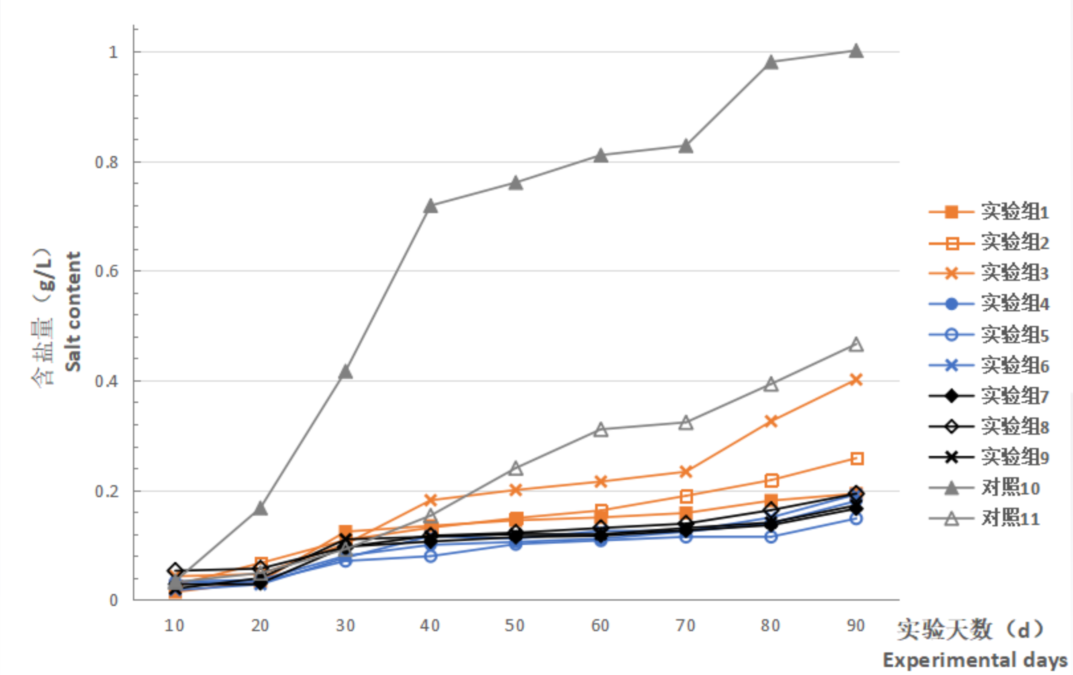


Fig 3-6 The salt content of planting layer under salt-returning condition

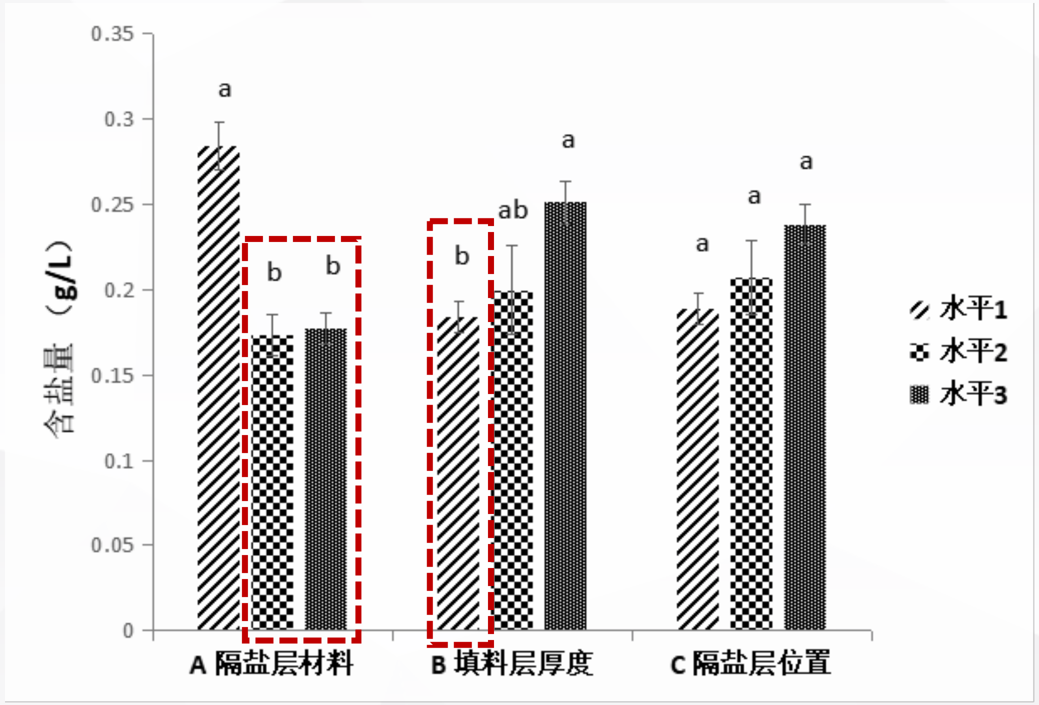


Fig 3-7 The salt content of planning layer in different level

- **Salt insulation effect: rain gardens with salt insulation layer>the one without that**
- **The salt layer is made of zeolite, which is located between the planting layer and the transition layer. The thickness of the packing layer is a structural parameter of 10cm.**

3.1.5.2 Influence of raingarden on runoff hydrology

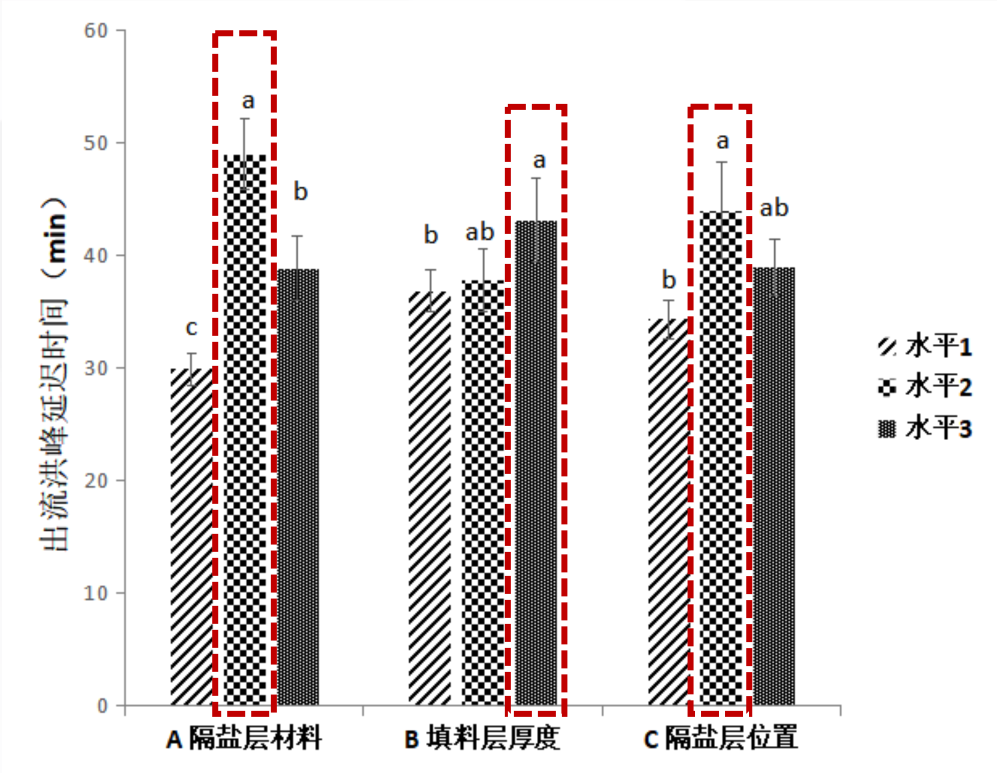


Fig 3-8 The delay time of runoff peak at different levels of each factors

It is recommended to use zeolite as the material of salt insulation layer, the thickness of the packing layer is 20-30cm, and the salt insulation layer is located in the salt-proof rain garden between the packing layer and the drainage layer to deal with the hydrological problem of site runoff

Table 3-2 Comprehensive evaluation of rainwater regulation

Factors	Level	The score				Weighted average score
		Delay time of runoff	Total reduction rate	Permeability	Water storage rate	
Material of salt isolation layer	Significance proportion	100%	100%	100%	67%	--
	River sand	1	5	1	5	2.59
	Zeolite	5	1	5	3	3.25
	Ceramicite	3	3	3	1	2.42
Thickness of packing	Significance proportion	34%	67%	0%	100%	--
	10cm	1	1	1	5	1.50
	20cm	3	3	3	3	1.51
	30cm	5	5	5	1	1.51
Location of salt isolation	Significance proportion	67%	34%	67%	0%	--
	Between planting and transition layer	1	5	1	5	0.76
	Between packing and drainage	5	3	3	1	1.60
	Between drainage and saline layer	3	1	5	3	1.43

3.3 Adaptative LID in Shanghai Coastal Saline Area

3.1.5.2 Influence of rain garden structure on runoff quality

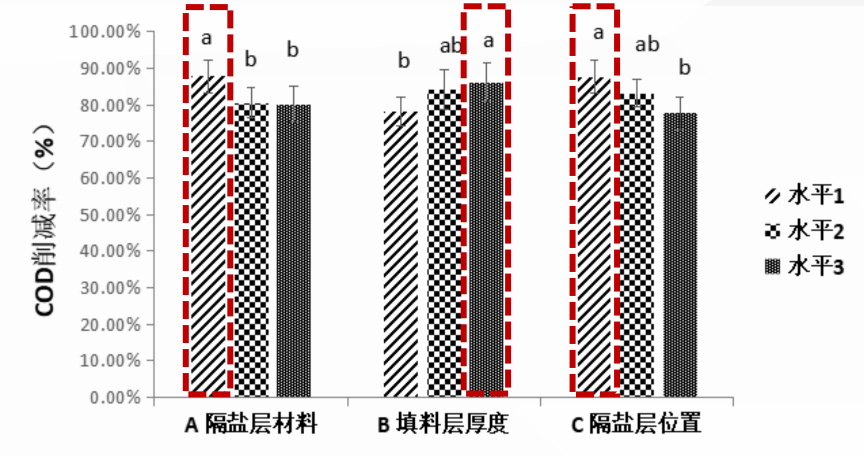


Fig 3-9 COD removal rate of each factor

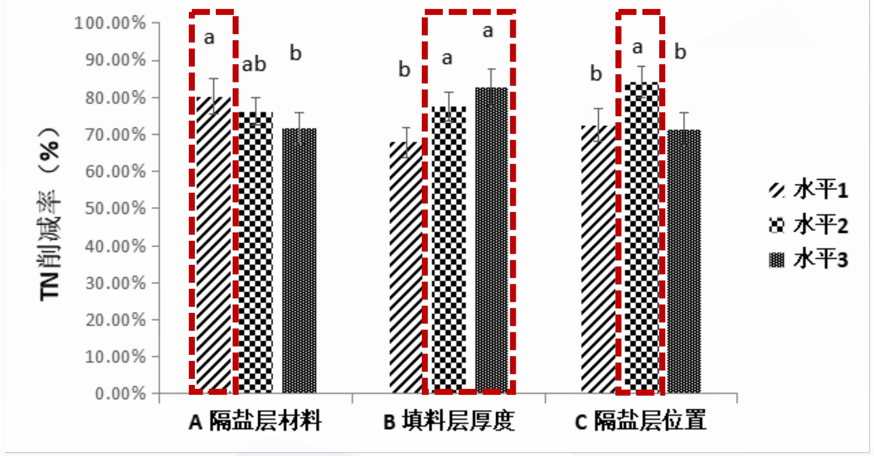


Fig 3-10 TN removal rate of each factor

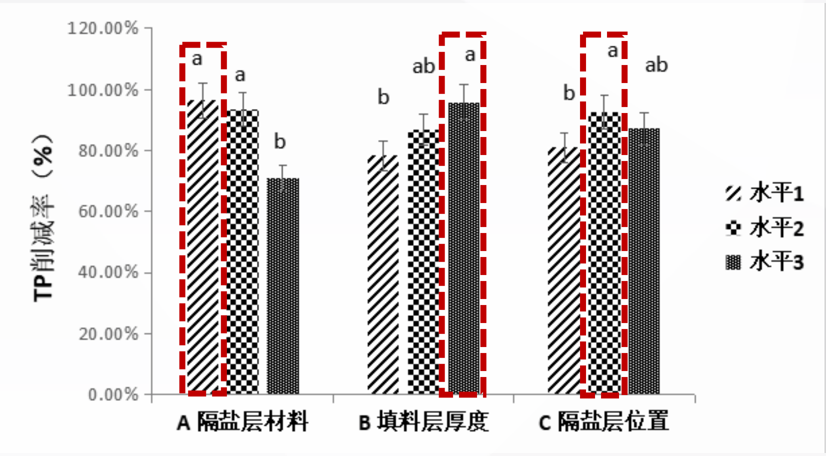


Fig 3-11 TP removal rate of each factor

Note 1: a, b and c are the classification results of HSD test method;
Note 2: the levels 1-3 in factor A are: river sand, zeolite and ceramsite, respectively. Factor B: the level 1-3 of packing thickness are 10, 20 and 30cm, respectively. In factor C, levels 1-3 in the salt layer are between the planting layer and the transition layer, the packing layer and the drainage layer, and the drainage layer and the saline layer, respectively

- Considering the structural parameters with strong ability to improve water quality: river sand is used as the material of salt insulation layer, which is located between the packing layer and the drainage layer, and the thickness of the packing layer is 30cm.
- The salt barrier packing with the best comprehensive capacity is zeolite and river sand. The thickness of the salt barrier layer is 30cm. The salt barrier layer is located between the filling layer and the drainage layer.

3.1.6 Strong salt-isolated raingarden——suitable for severely saline areas

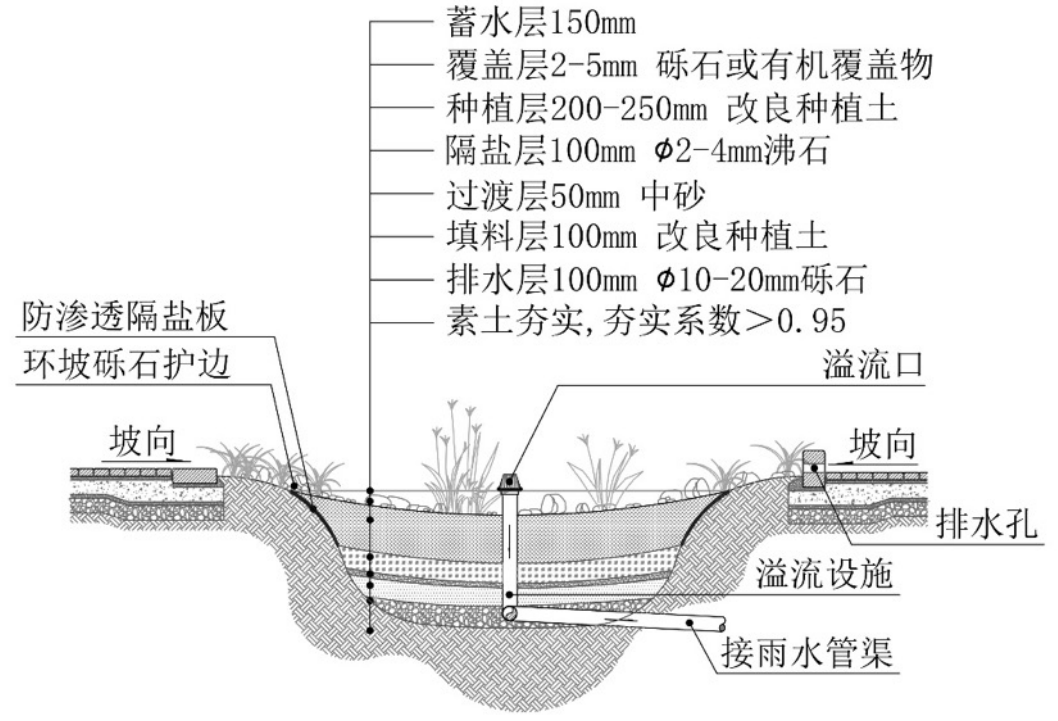


Fig 3-12 Structure of strong salt-isolated raingarden

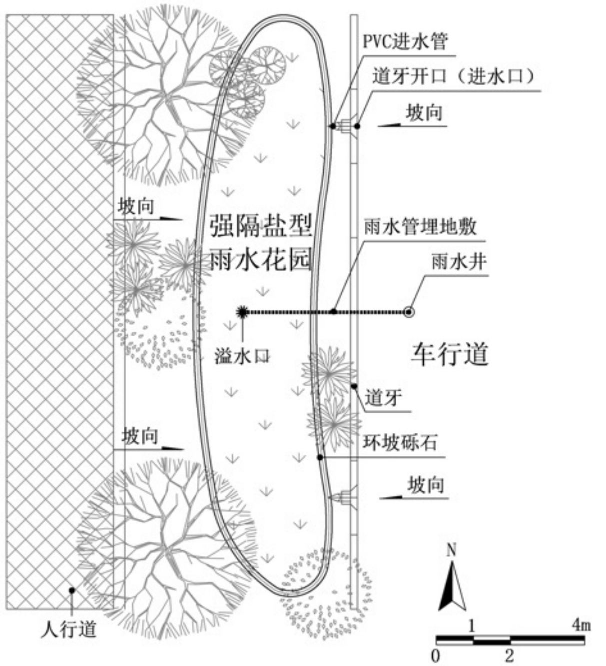


Fig 3-13 plan of street green space with strong salt-isolated raingarden

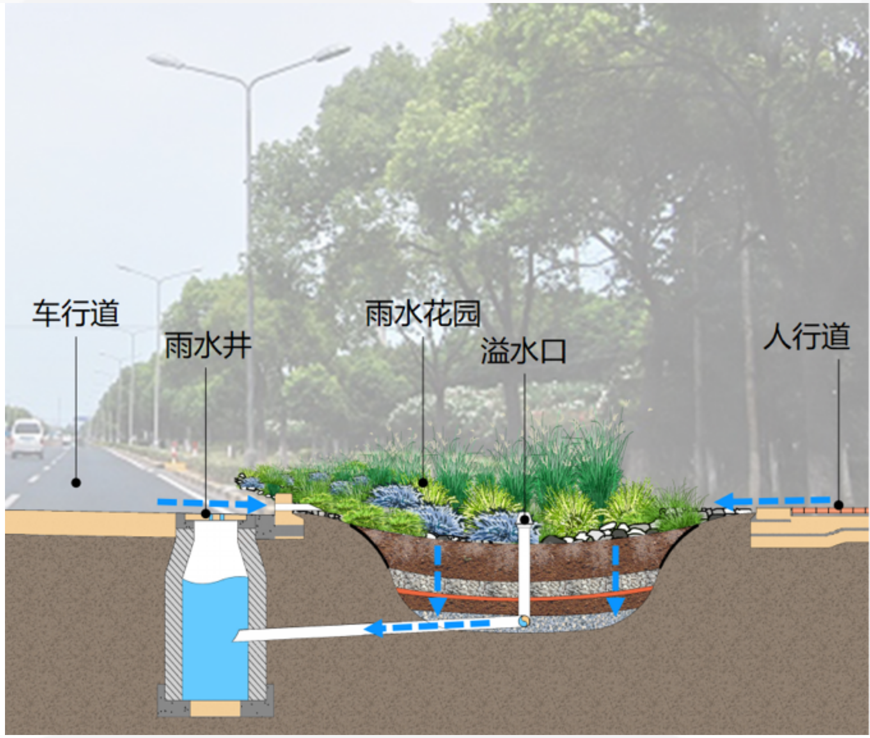


Fig 3-14 Rending of strong salt-isolated raingarden

- Close to the hard paving layout
- The existing road infrastructure and vertical water supply and drainage design are planned according to the current situation
- An opening is set at the tooth for drainage

3.1.7 Salt-isolated raingarden for rainwater regulation——suitable for moderated saline-alkali areas with light pollution

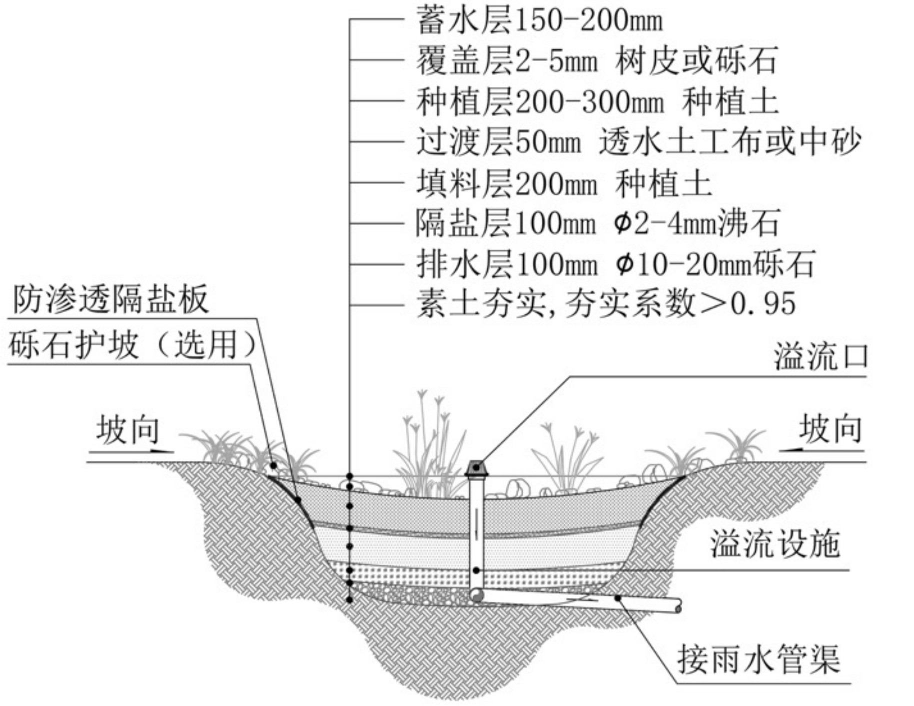


Fig 3-15 Structure of salt-isolated raingarden for water regulation

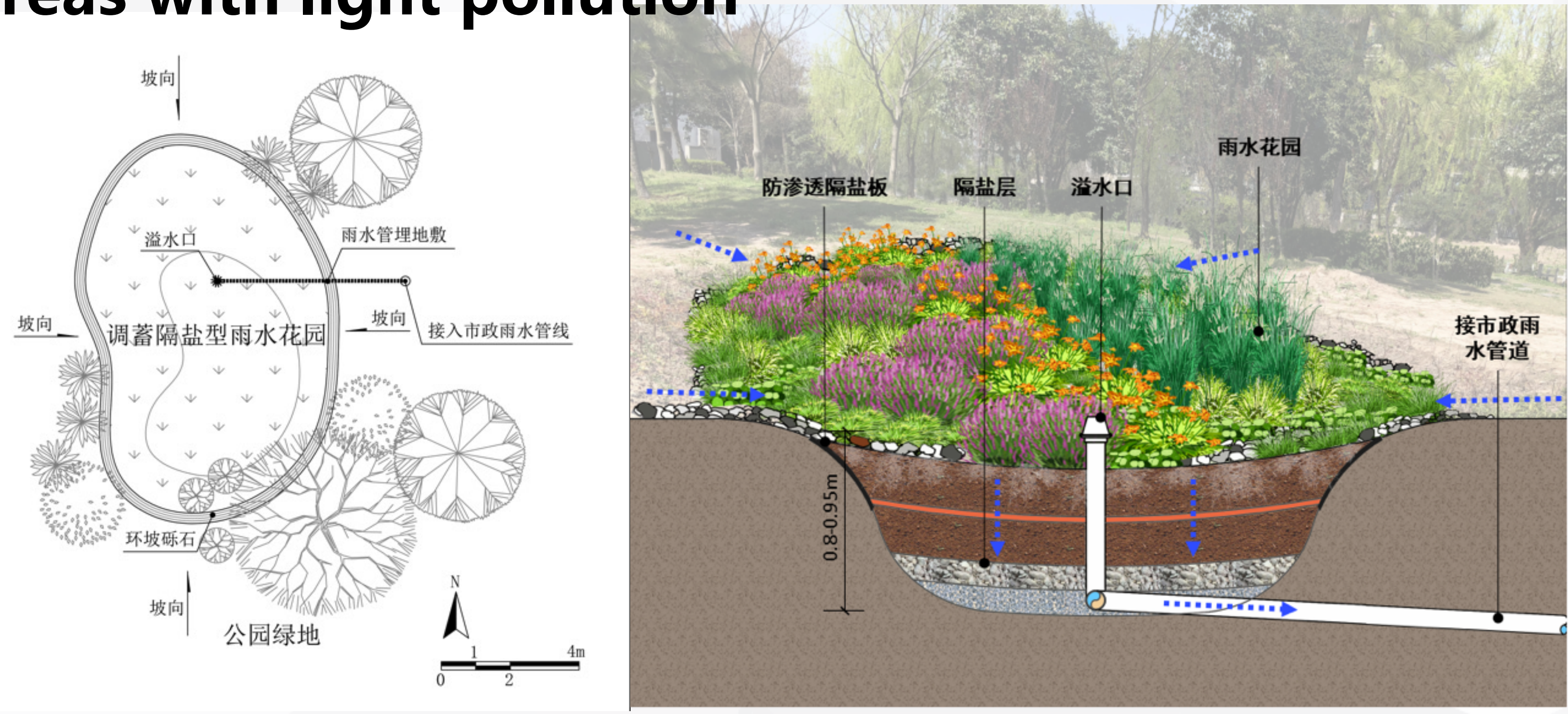
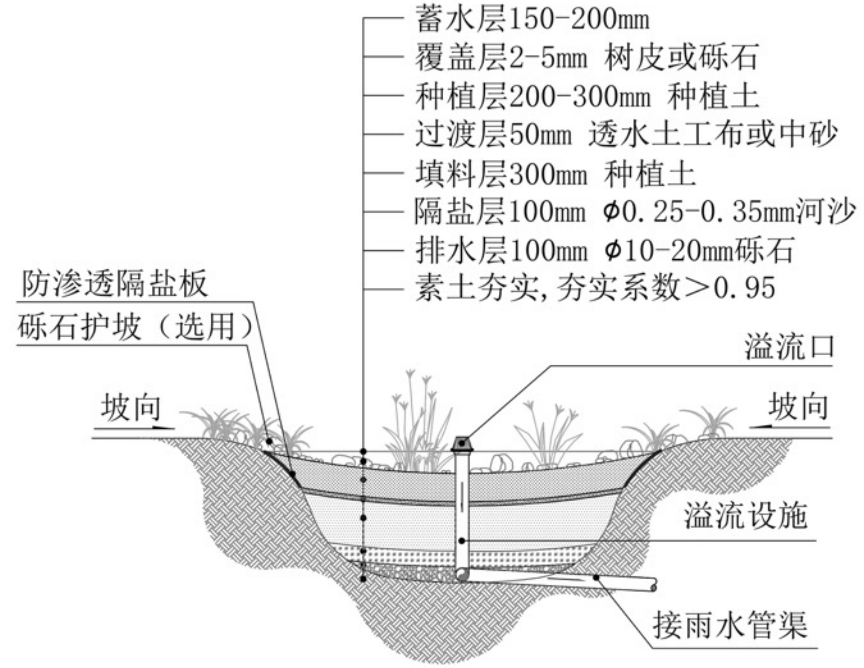


Fig 3-16 plan and rendering of salt-isolated raingarden in the public parks

- Use the vertical landscape design of the park
- Combine the existing rainwater facilities in the park
- Combined with other water landscape design

3.3 Adaptative LID in Shanghai Coastal Saline Area

3.1.8 Salt-isolated raingarden for purification——suitable for moderate saline areas with severe runoff pollution



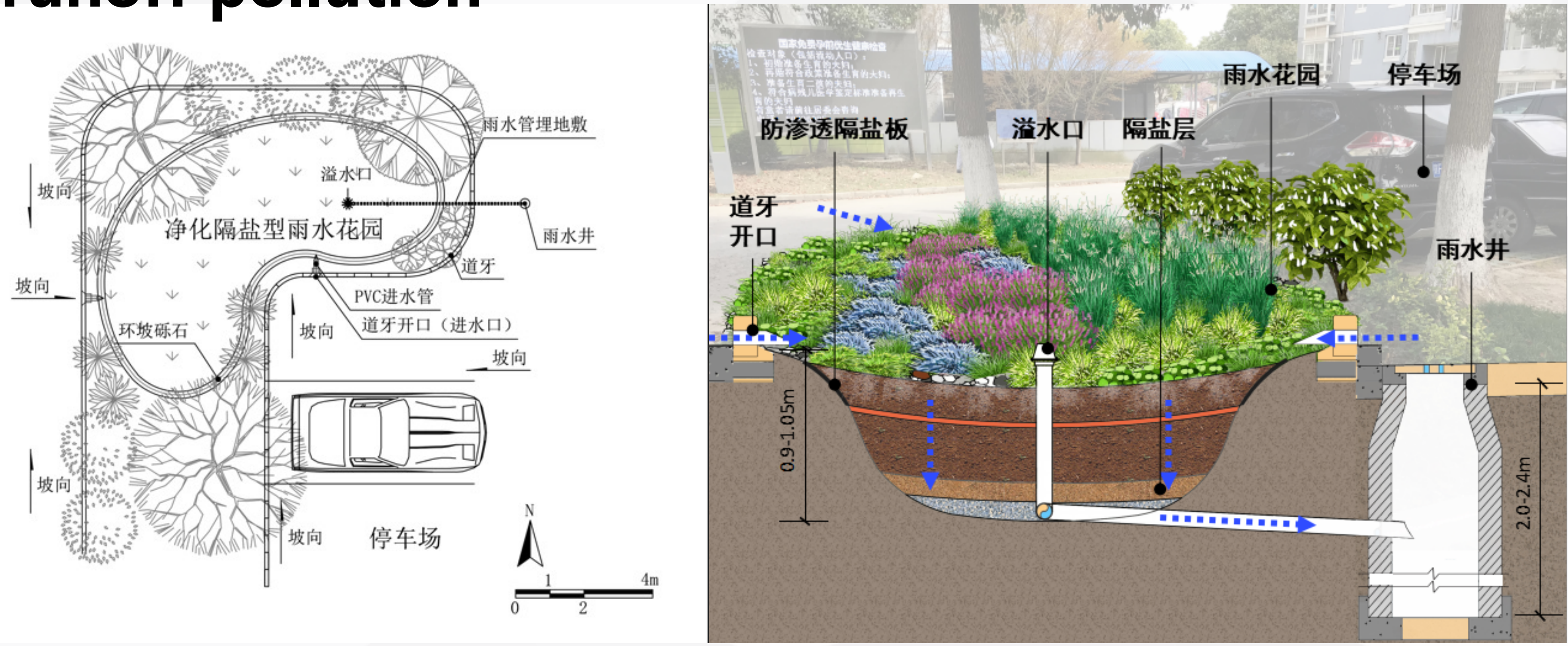


Fig 3-17 Structure of salt-isolated raingarden for purification

Fig 3-18 Plan and rendering of salt-isolated raingarden used in parking lots

- Ecological parking lot is built with permeable pavement
- According to the current drainage slope and direction, choose the location with large flow
- The diversion pipe is used to assist drainage

3.3 Adaptative LID in Shanghai Coastal Saline Area

3.1.9 Comprehensive salt-isolated raingarden——suitable for moderate saline-alkali areas with heavy runoff and serious pollution

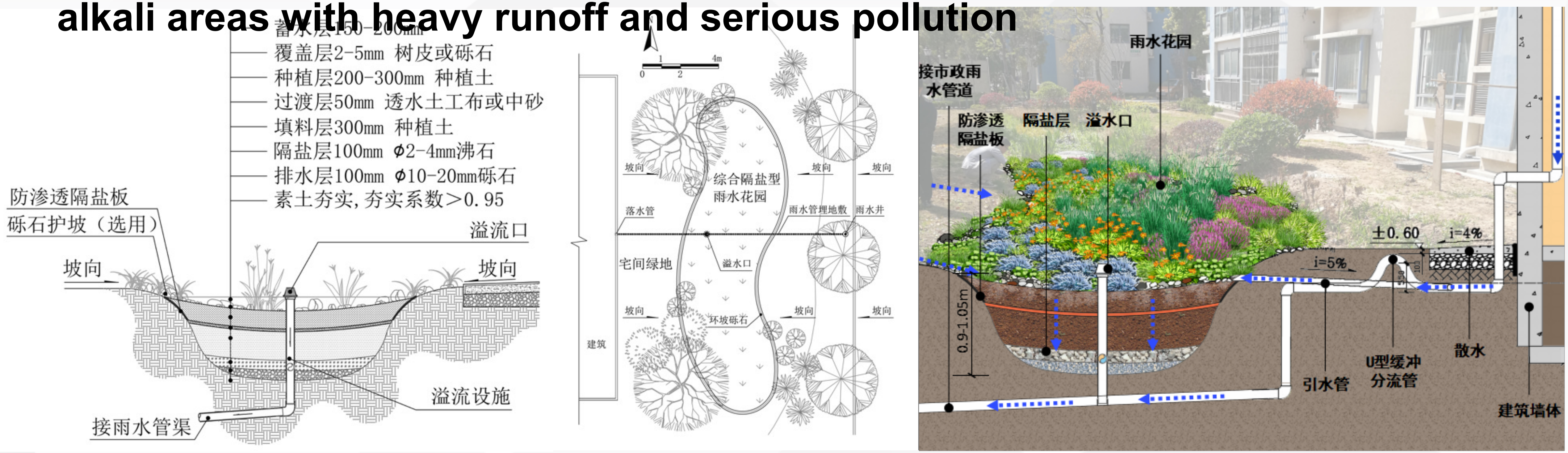


Fig 3-19 plan, structure and rendering of comprehensive salt-isolated raingardens in residential green space

- The site selection takes into account the location and drainage slope of road square, building roof and green land
- It is at least 3m away from the building foundation. Residents are protected
- Connectivity to building downpipes and roadside infrastructure
- Coordinate with other low impact facilities in the residential area

3.3 Adaptative LID in Shanghai Coastal Saline Area

3.1.10 The salt-isolated raingarden have been applied in Shanghai

- Through the sponge construction in Shanghai, such as dry stream, rain garden, constructed wetland, water storage module and permeable pavement, the environmental condition has been improved.
- SLID techniques are constructed as a complete rainwater management and ecological purification system.
- When it rains, there is no residual rain on the ground, which effectively reduces the water accumulation and waterlogging, and also reduces the environmental pollution caused by the direct discharge of road sewage.

04

Reflection：Interception & infiltration of plant communities

4.1 Selection and application of plants with environmental resistance

4.2 Prediction model of canopy rainfall interception ability

4.3 Relation model of infiltration capacity of rainwater in plant roots

4.4 Improvement and effect evaluation of soil in LID facilities

4.1 Selection & Application of Plants in LID

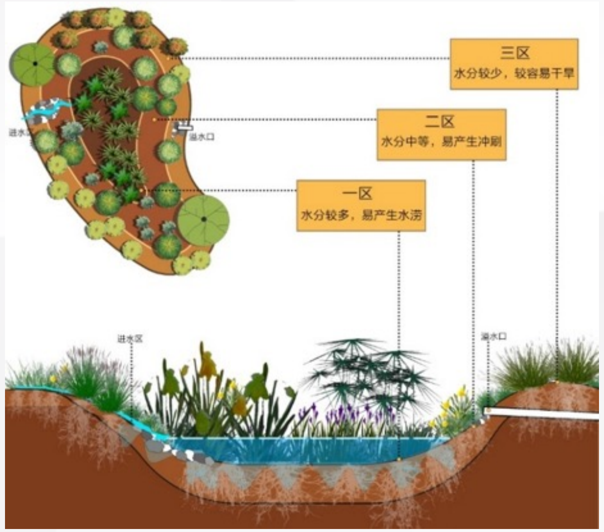


Fig 4-1 Raingarden for rainwater regulation

Fig 4-2 Raingarden for runoff purification

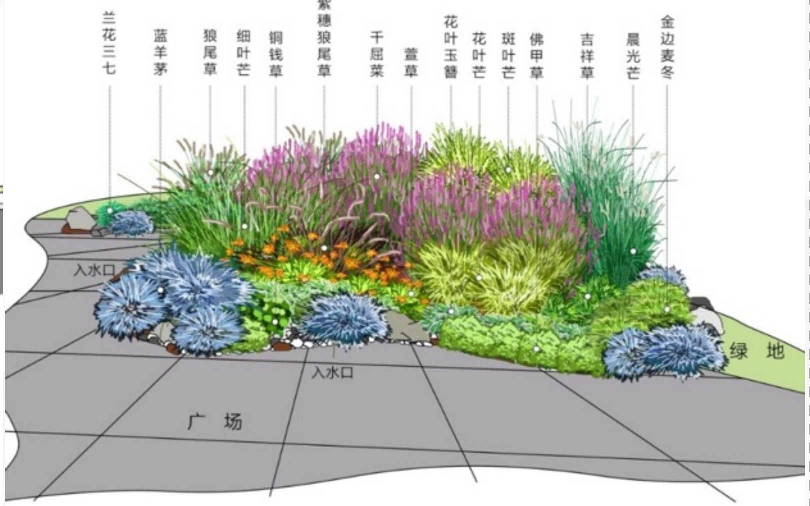


Fig 4-3 Comprehensive raingardens

调蓄型雨水塘
Water pond for water storage

Area 120㎡

Typha orientalis + *Lythrum salicaria* + *Alisma plantago-aquatica* + *Arundo donax* + *Thalia dealbata* + *Acorus gramineus* + *Iris pseudacorus* + *Eichhornia crassipes* + *Nymphoides peltatum* + *Pontederia cordata* +*Ceratophyllum demersum*

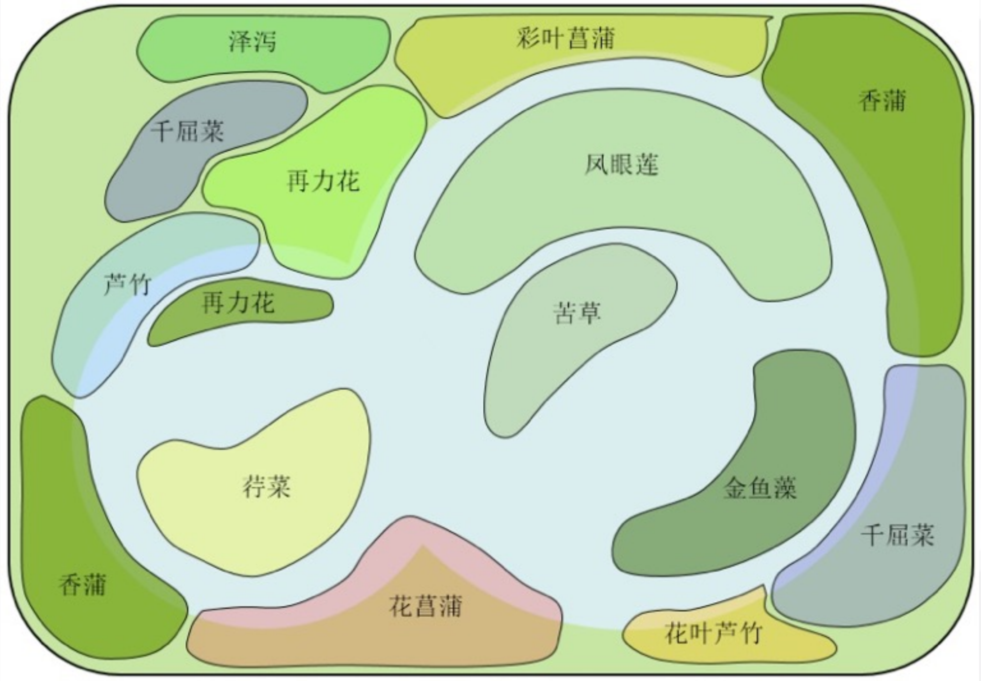


Fig 4-4 Plant selection and design of raingardens for water regulation

Does the Canopy of Coniferous or Broad-leaved Trees Intercept More Rainwater?

- **The water storage per unit leaf area and leaf area index of coniferous trees were relatively high, indicating that the rainwater storage potential of coniferous trees canopy was also the largest.**
- **Although the rainwater storage amount per unit leaf area of broad-leaved trees was higher, the average rainwater storage amount in canopy was lower than that of shrubs due to its lower leaf area index. Herbs have the lowest ability to store rainwater.**

4.2 Prediction Model of Canopy Rainfall Interception

Table 4-1 Perdition model of rainwater interception capacity of trees in Shanghai

Table 3 RIC predicted models and signification testing results of landscape trees

	Species	Models	k	F	Sig. F	R^2	Sig. a	Sig. b	Sig. c	Sig. d
BrE	*C. camphora*	$RIC = 1.939DBH^{0.519} \times k$	0.5960	79.342	0.000	0.824	0.002	0.000	–	–
	D. racemosum	$RIC = 2.782H^{0.578}Cw^{0.286} \times k$	0.2239	31.400	0.000	0.787	0.000	–	0.000	0.014
	L. lucidum	$RIC = 0.3513Cw^{1.385} \times k$	0.4678	30.731	0.000	0.631	0.002	–	–	0.000
	M. grandiflora	$RIC = 3.290H^{0.828}Cw^{0.925} \times k$	0.8405	19.961	0.000	0.701	0.046	–	0.038	0.000
	O. fragrans	$RIC = 0.6170H^{0.860} \times k$	0.2095	67.810	0.000	0.781	0.049	0.000	–	–
	T. fortunei	$RIC = D^{0.427}Cw^{0.505} \times k$	0.4228	479.461	0.000	0.982	–	0.000	–	0.028
BrD	*K. paniculata*	$RIC = 0.2108DBH^{0.885} \times k$	0.4315	26.112	0.000	0.592	0.006	0.000	–	–
	A. palmatum	$RIC = 0.4453DBH^{0.710} \times k$	0.2898	95.311	0.000	0.880	0.000	0.000	–	–
	B. thunbergii	$RIC = 0.1624DBH^{0.496}H^{0.818}Cw^{0.651} \times k$	0.2598	14.886	0.000	0.736	0.001	0.044	0.011	0.020
	G. biloba	$RIC = 0.1389DBH^{0.723}H^{0.647}Cw^{0.327} \times k$	0.3385	13.828	0.000	0.722	0.001	0.002	0.012	0.040
	M. alba	$RIC = 0.6447Cw^{1.390} \times k$	0.3840	38.362	0.002	0.536	0.045	–	–	0.000
	P. acerifolia	$RIC = 0.5764H^{0.964} \times k$	0.5788	46.591	0.000	0.721	0.023	–	0.000	–
	P. lannesiana	$RIC = 0.5951DBH^{0.346}H^{0.533} \times k$	0.3996	46.654	0.000	0.838	0.018	0.005	0.010	–
	Z. schneideriana	$RIC = 0.3938DBH^{0.206}Cw^{0.897} \times k$	0.5721	27.092	0.000	0.772	0.007	0.046	–	0.007
Con	*C. deodara*	$RIC = 0.3144DBH^{0.691} \times k$	1.1781	90.486	0.000	0.804	0.000	0.000	–	–
	M. glyptostroboides	$RIC = 0.5066H^{0.882} \times k$	0.8740	51.029	0.000	0.739	0.017	–	0.000	–
	P. macrophyllus	$RIC = DBH^{0.528} \times k$	0.3905	1362.910	0.000	0.985	–	0.000	–	–

RIC is tree canopy rainfall interception in mm. *DBH* is diameter at breast height in cm. *H* represents height of tree in m. *Cw* means crown width in m, and *k* is per unit leaf area water storage ability in mm

- The rainwater storage capacity of canopy of common garden plants in Shanghai was sorted and a mathematical model was proposed to predict the rainwater retention capacity of canopy plants.

Jiankang Guo, Bingqin Yu, Yuan Zhang, Shengquan Che. Predicted models for potential canopy rainfall interception capacity of landscape trees in Shanghai, China [J]. European Journal of Forest Research, Vol.136, Issue 2, April 2017.

4.2 Prediction Model of Canopy Rainfall Interception

- 对植物胸径、树高、冠幅和叶面积指数的ln值做K-S正态分布检验
- K-S testing results of D, H, Cw and L's log kow

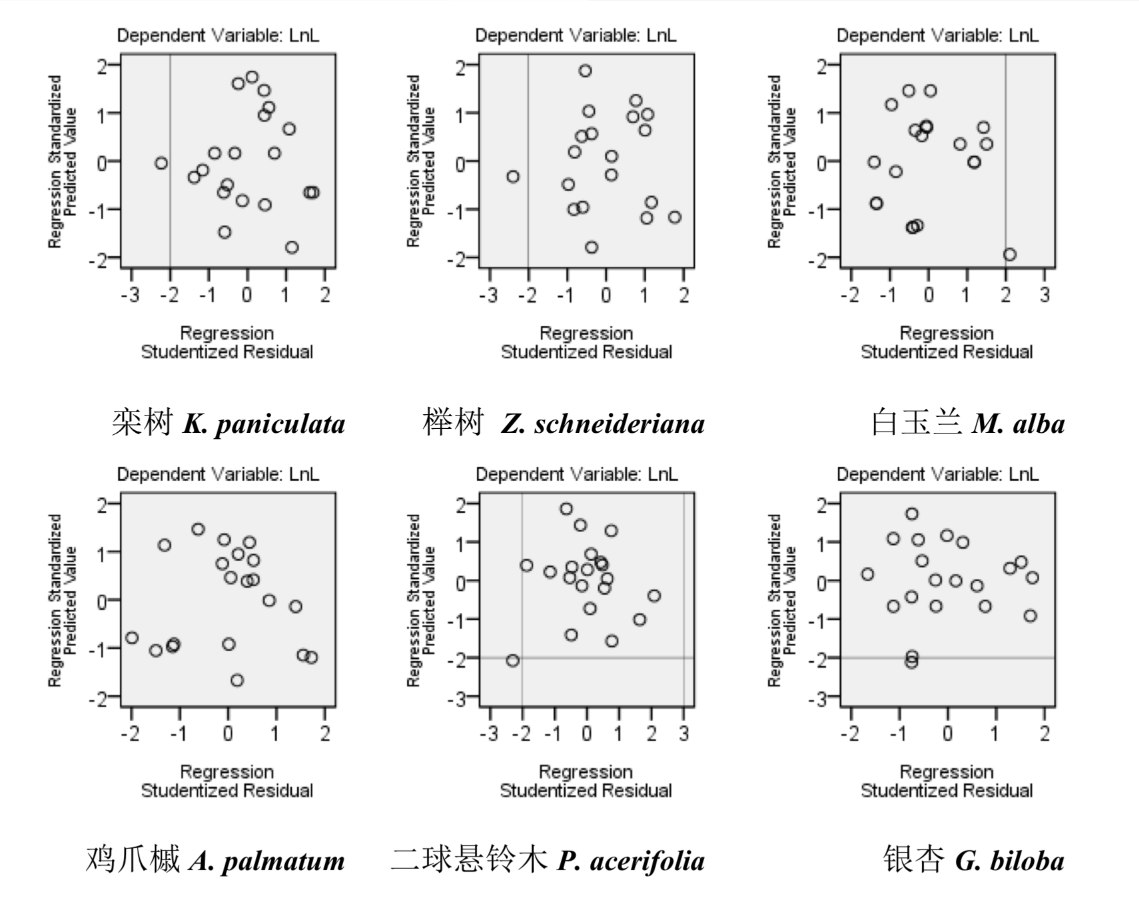
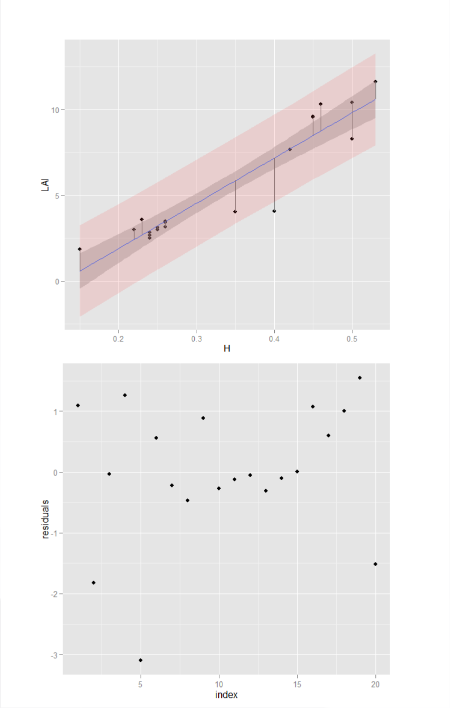


Fig 4-6 The normal distribution test of tree DBH, tree height, crown width and leaf area index

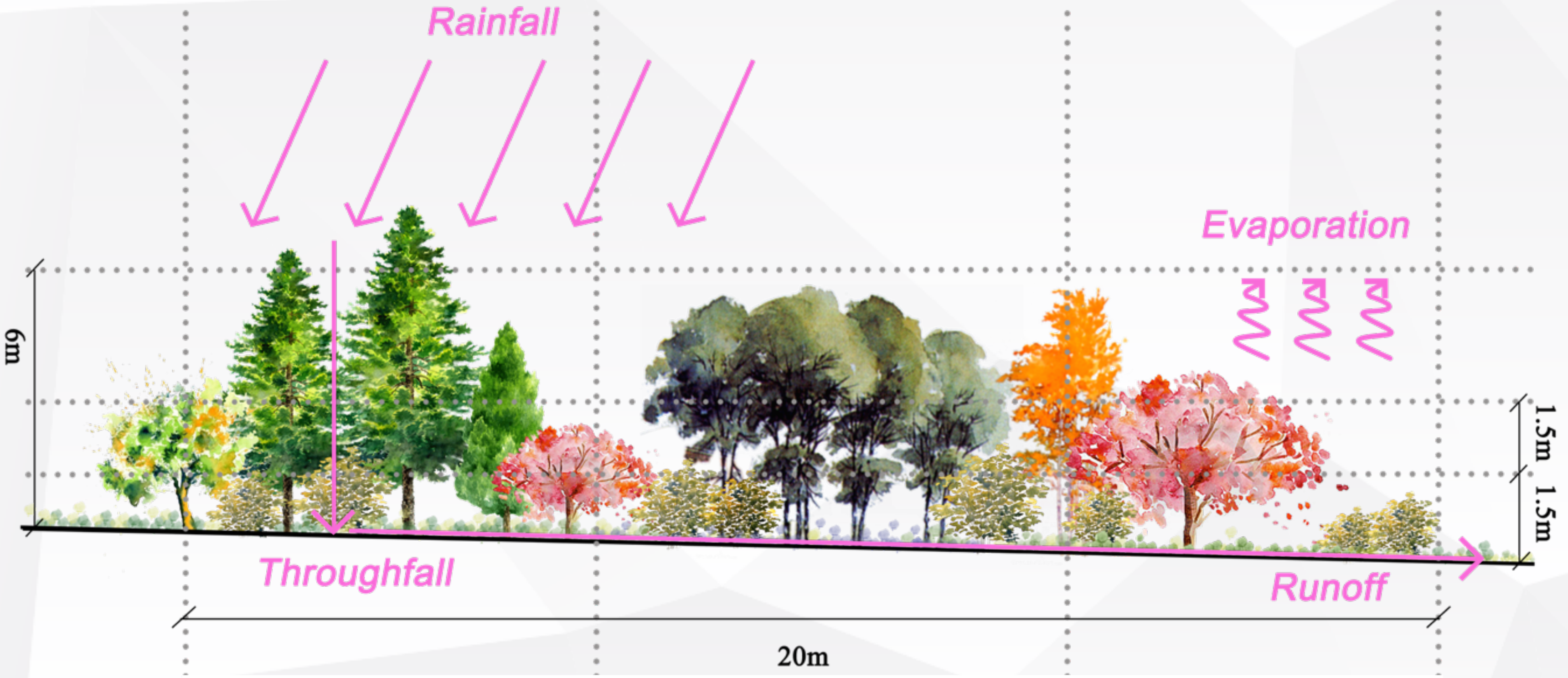
- When the value of a, b, c, and d were identified, formula (2) could be logged by Formula (3), and then with RIC. from formula (1), the predicted model could be expressed as:

$$S=aD^{b}H^{c}Cw^{d}*k$$

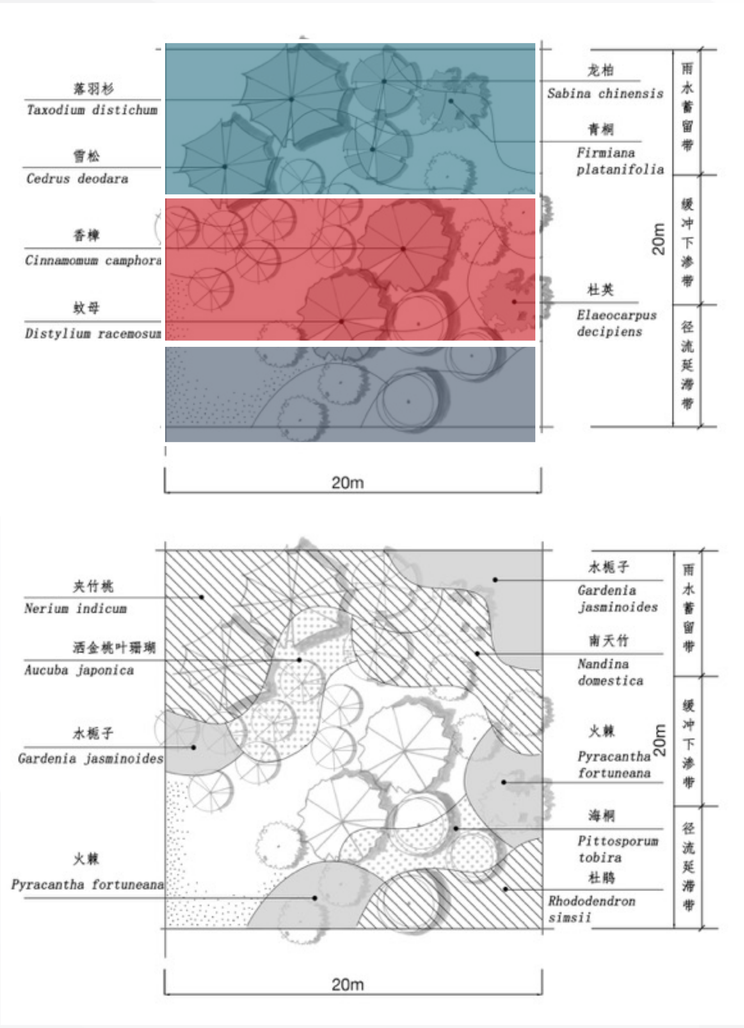
- 回归分析建立了17种乔木冠层截留模型，回归分析残差基本位于-2到+2之间，表示模型的 **预测精度较高**。



- 具有雨水截留能力的复层混交植物群落水平和垂直结构
- Vertical structure of stratified mixed plant communities



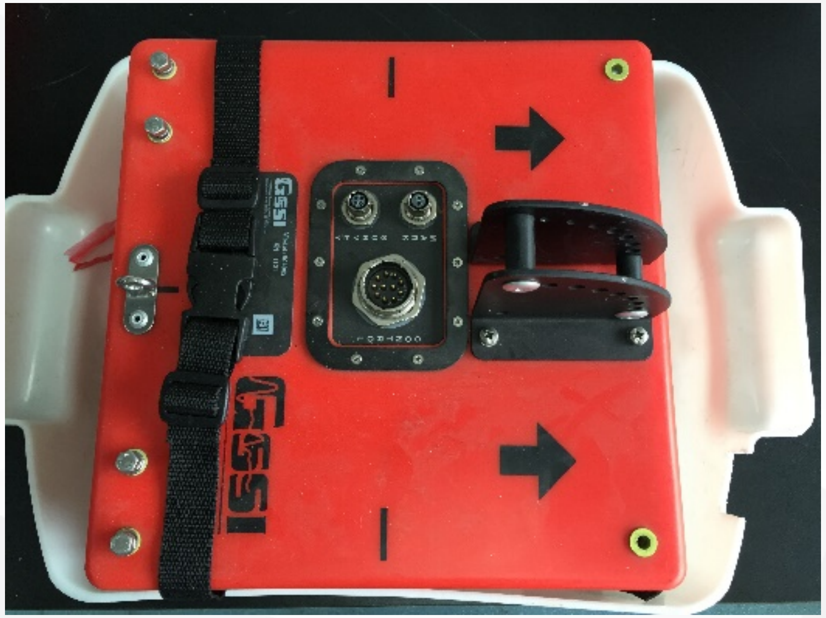
• 雨水蓄留带 • Rainfall interception area	• 缓冲下渗带 • Buffer & Infiltration area	• 径流延滞带 • Runoff retention area



4.3 Relation Model of Infiltration Capacity of Roots

Tree roots were eradicated using the TreeRadar system (TRU) developed by TreeRadar, inc., in the United States. Through Roots radar, the data of root number and distribution location can be obtained, and the root density at specific points can be calculated, and the spatial distribution characteristic diagram of the whole root can be generated.

Roots ground penetrating radar vehicle



Scanning radar

Field data manager

4.3 Relation Model of Infiltration Capacity of Roots

When sampling, the surface ground was removed first, and the center of the tree trunk was taken as the center point, at a horizontal distance of 1m from the center of the tree. In the process of sampling, ring cutter (100cm3) and soil drill were used to sample soil layers of 15-30cm, 30-45cm and 45-60cm respectively in a vertical downward direction. Unmodified soil from each soil layer was taken. Three duplicate groups were taken for each sample.

Deep soil is taken with a soil drill and ring knife

Soil auger

Soil drill and ring knife

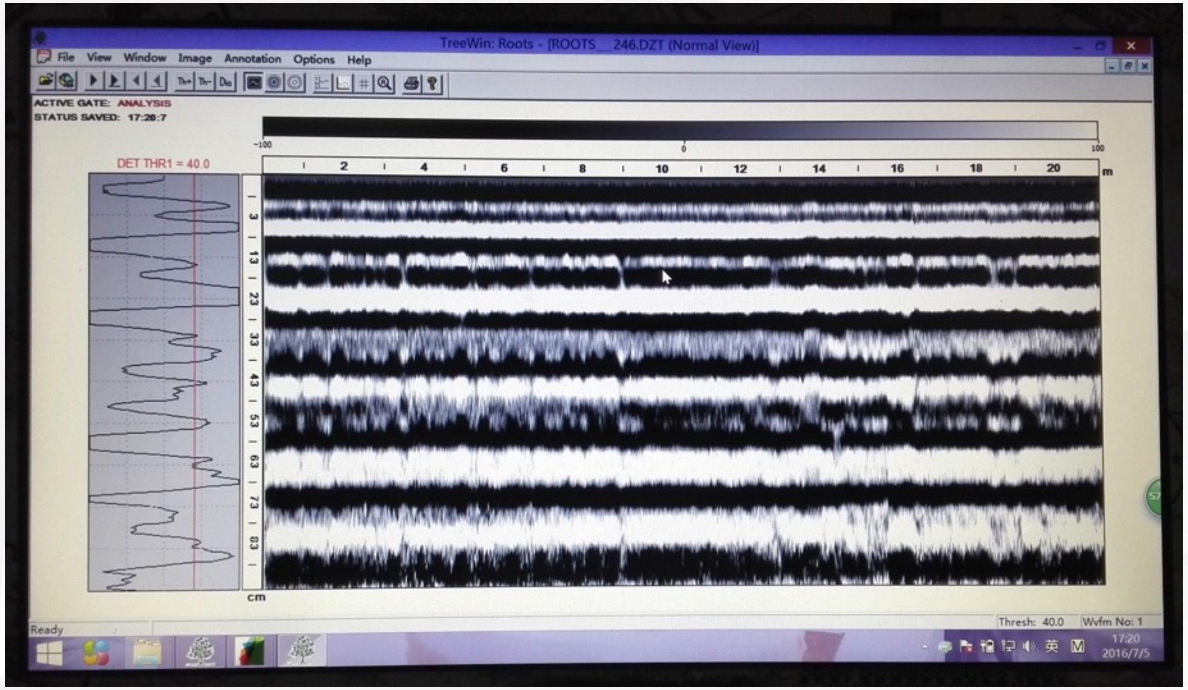
SJTU

4.3 Relation Model of Infiltration Capacity of Roots

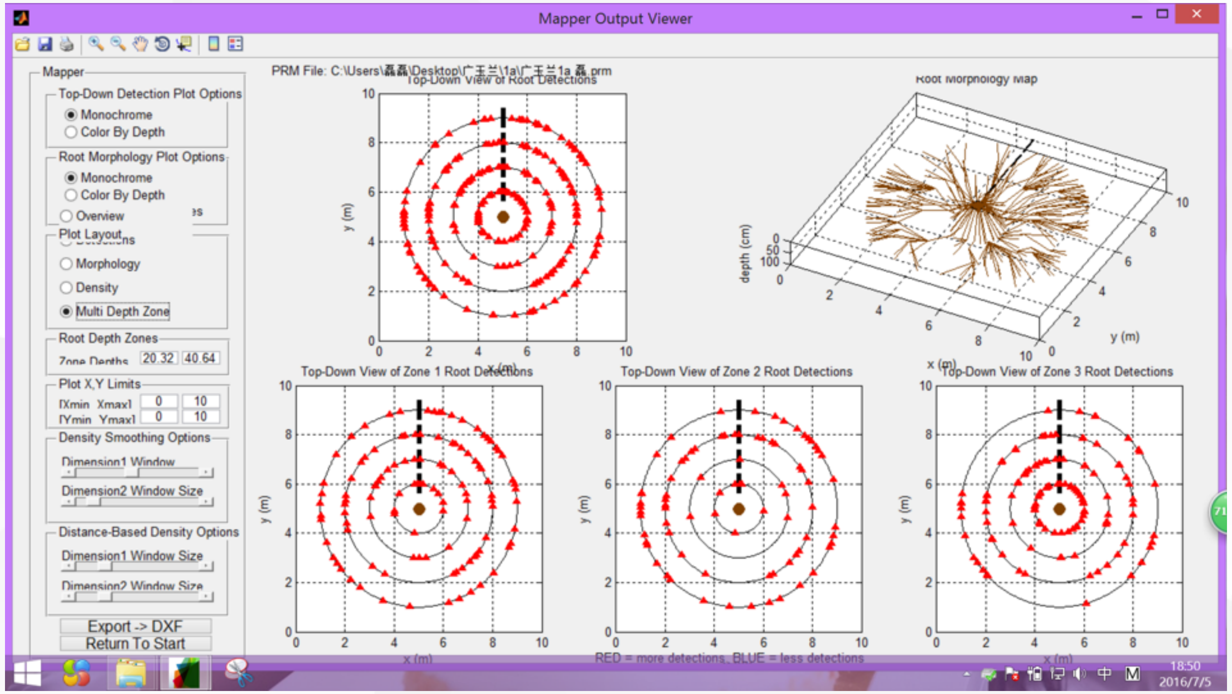
根长密度：根长密度(Root Length Density，RLD)是指单位土壤体积或土壤面积内根系的长度。

$$Y=L/\pi R^2 h$$

式中L——每10cm土层中的根系总长度，cm;R——根钻的半径，cm；h——每层土的深度，cm。

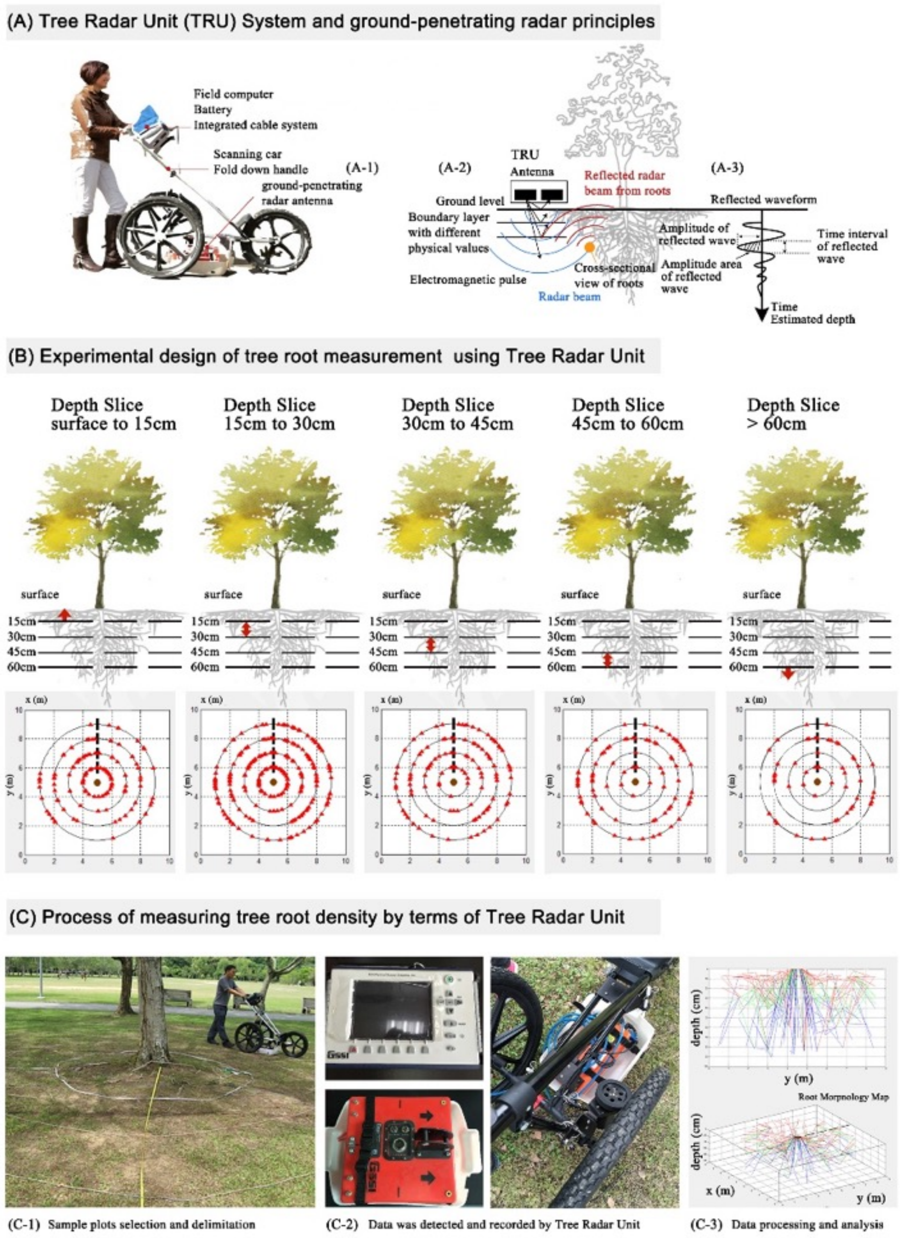


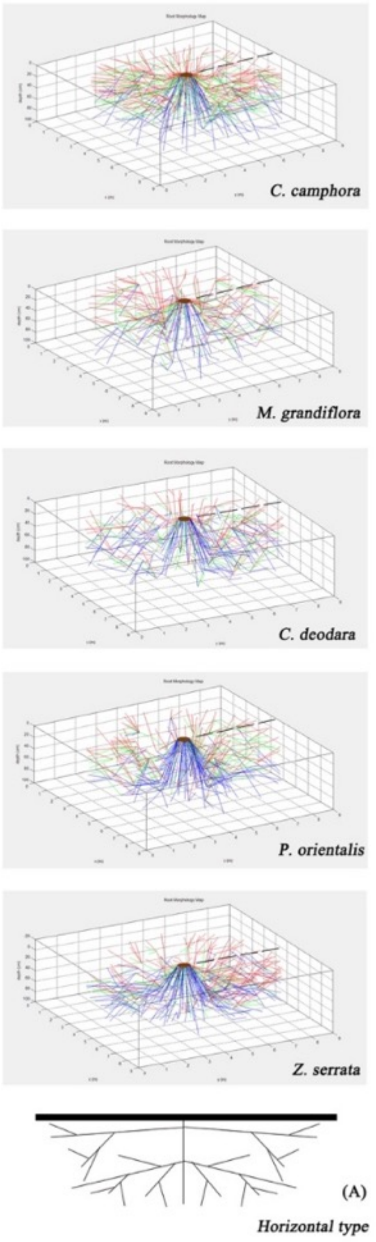
Radar Scan

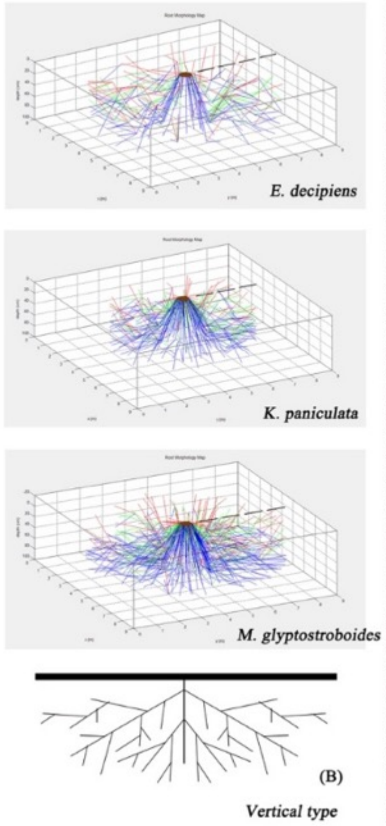


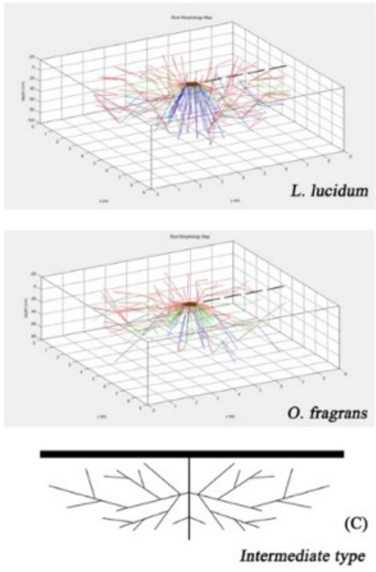
TreeWin Software Analysis

4.3 Relation Model of Infiltration Capacity of Roots







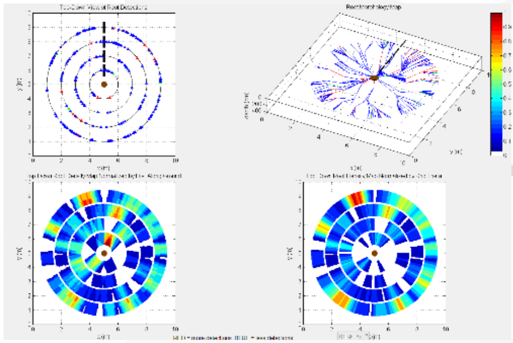


- Three - dimensional and sectional images of roots were obtained by ground penetrating radar.
- The differences in root distribution characteristics of trees significantly affected the water holding capacity of soil samples under different trees.

Legend

- Root system in soil depth slice from surface to 30 cm
- Root system in soil depth slice from 30 cm to 60 cm
- Root system in soil depth slice deeper than 60 cm

Note: The effective length of horizontal axis of the above images is 8 meters, and the length of vertical axis is slightly different due to the fact that the detecting depth is affected by soil texture, but all detecting depth is between 70 cm to 100cm. The scale was various for horizontal and vertical axis, to present arbor root system features clearly.



4.3 Relation Model of Infiltration Capacity of Roots

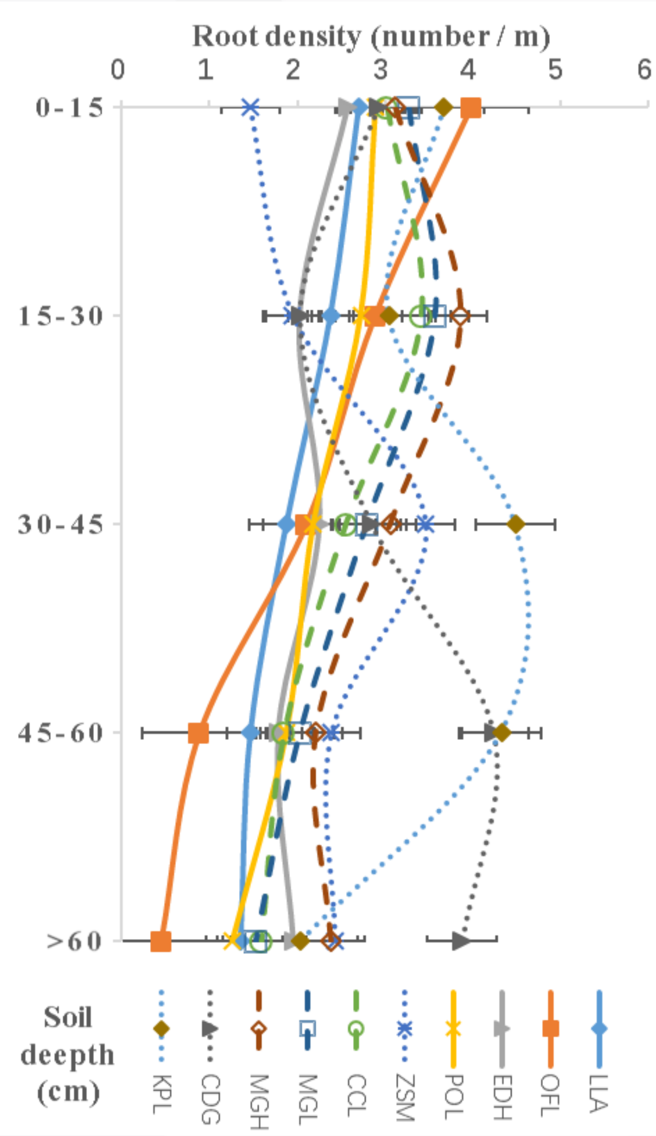


Fig 4-7 Changes of root density in vertical direction of roots

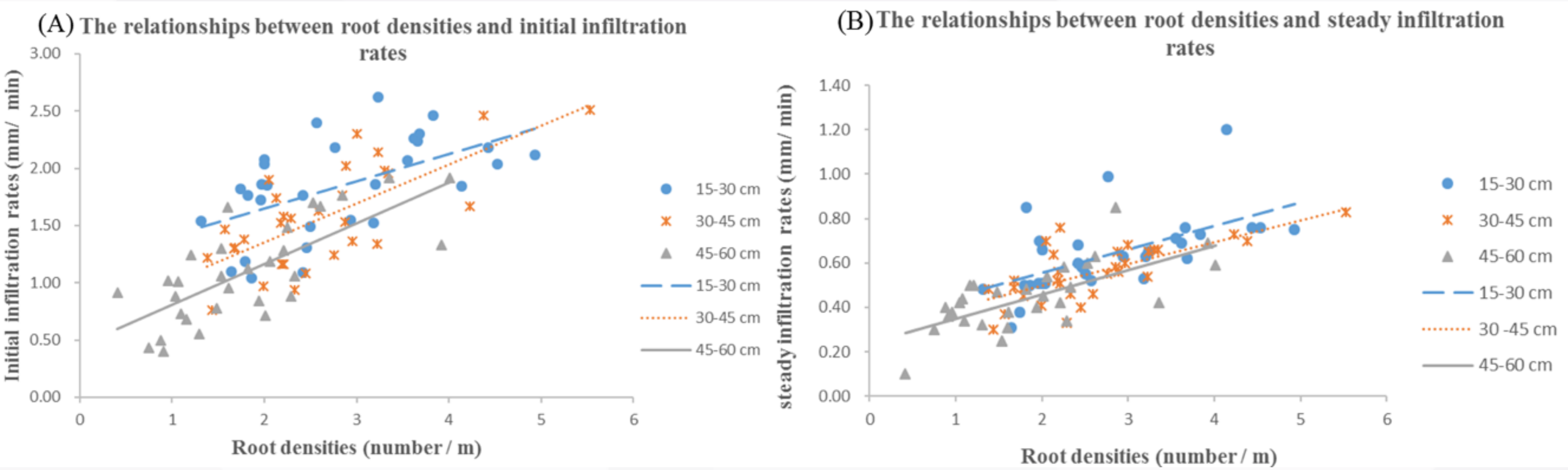


图4-8 10种常见园林乔木不同土层根系密度与土壤初始入渗率和稳定入渗率之间的关系分析

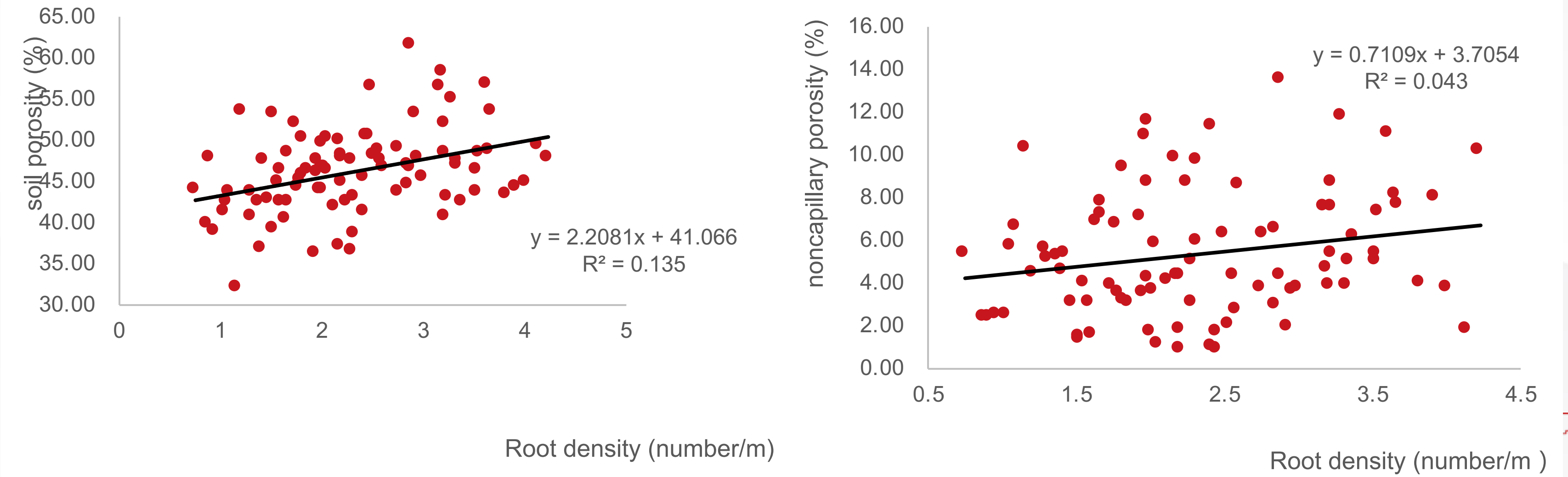


Fig 4-7 Changes of root density in vertical direction of roots

Fig. 4-9 Regression relation between root density and soil total porosity, as well as non-capillary porosity.

4.3 Relation Model of Infiltration Capacity of Roots

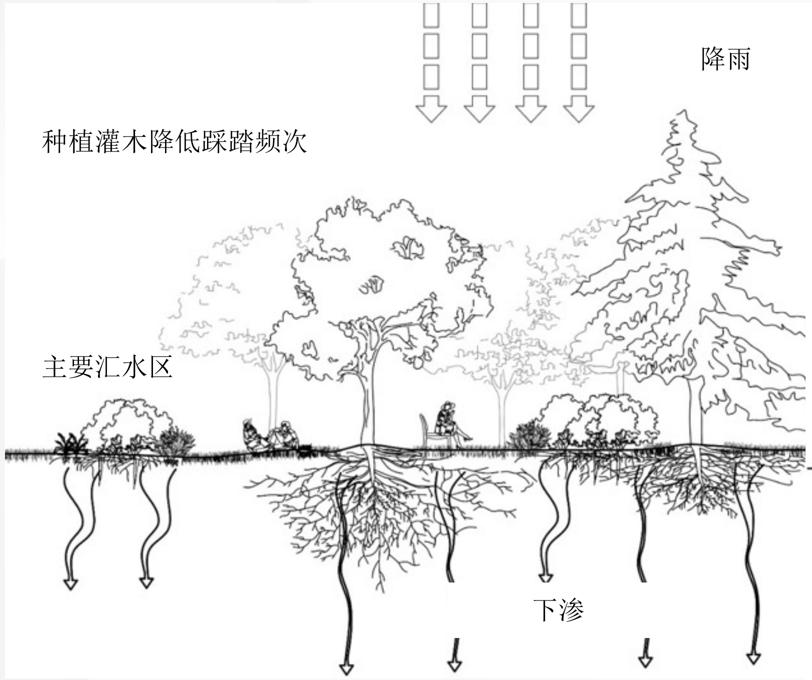


Fig 4-10 Plant design for high trample frequency

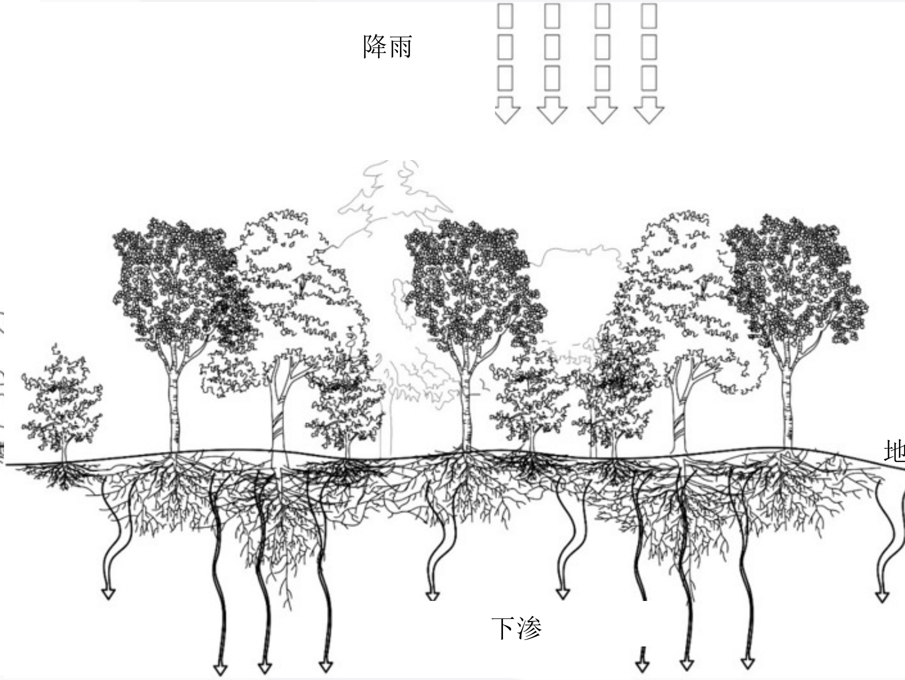


Fig 4-11 Plant design for low trample frequency

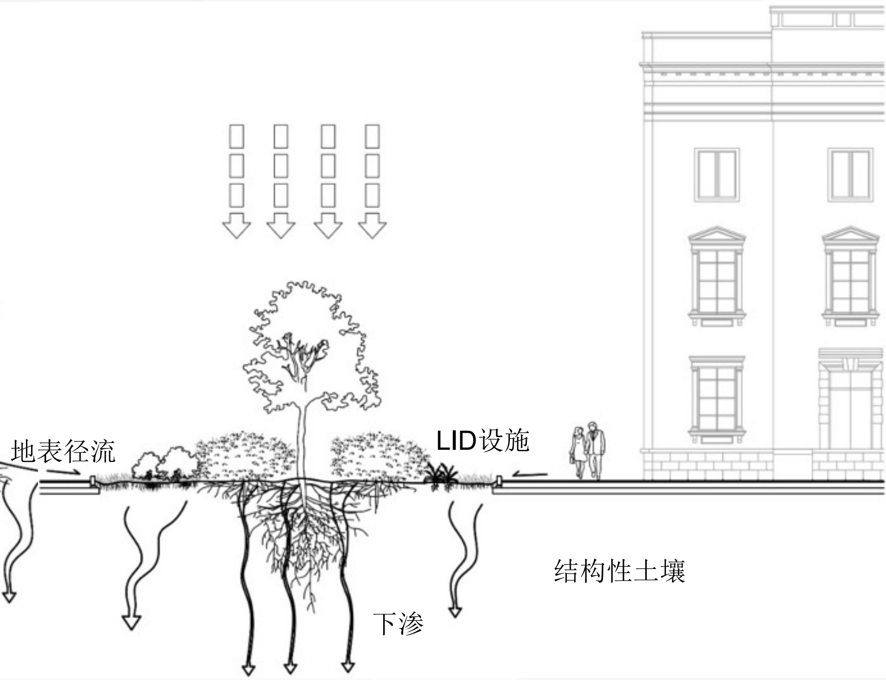


Fig 4-12 Plant design for square

- According to the model of the relationship between plant roots and soil infiltration of common garden trees in Shanghai;
- The impermeability of rainwater in the root system of common trees was sorted, and the plant communities with environmental functions such as impermeability were constructed.

- Yu B Q, Chen Y, Lv Y P, et al,. Effects of tree root density on soil total porosity and non-capillary porosity using a ground-penetrating Tree Radar Unit in Shanghai, China. Sustainability, 2018, 10 (12): 4640
- Yu B Q, Chen Y, Lv Y P, et al,. How to calculate stormwater management and storage capacity for urban green space: a multidisciplinary methods used in Shanghai City. Shanghai Jiao Tong University, 2018, 36(12): 234-243.

4.4 Improvement of saline soil in LID facilities

实验组:

1.草炭 2.有机肥 3.石膏 4.黄沙 5.污泥 6.椰糠 7.混合土

对照组:

1.盐碱土 2.原种植土 3.无机轻质土 4.有机介质土

Treatment 1: add 15% peat by volume
Treatment 2: add organic fertilizer by volume ratio of 1
Treatment 3: add volume to 11% of gypsum
Treatment 4: add 15% yellow sand by volume
Treatment 5: addition of sludge by volume ratio of 15%
Treatment 6: add 10% coconut bran by volume
Treatment of 7:4% sand, 6% peat, 2% organic fertilize
2% sludge, 2% coconut bran

实验组:

草炭 有机肥 石膏 黄沙 污泥 椰糠 混合土

对照组:

盐碱土 原种植土 无机轻质土 有机介质土

Control 1: saline-alkali soil
Control 2: original planting soil
Control 3: inorganic light soil
Control 4: organic medium soil

4.4 Improvement of saline soil in LID facilities

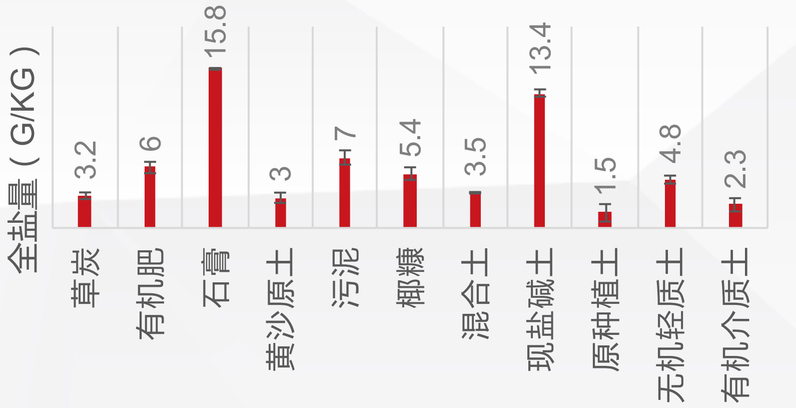


Fig 4-13 Comparative analysis of total salt content

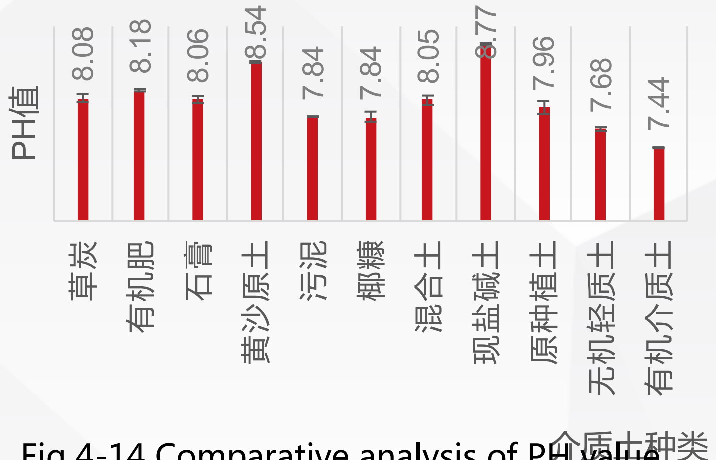


Fig 4-14 Comparative analysis of PH value

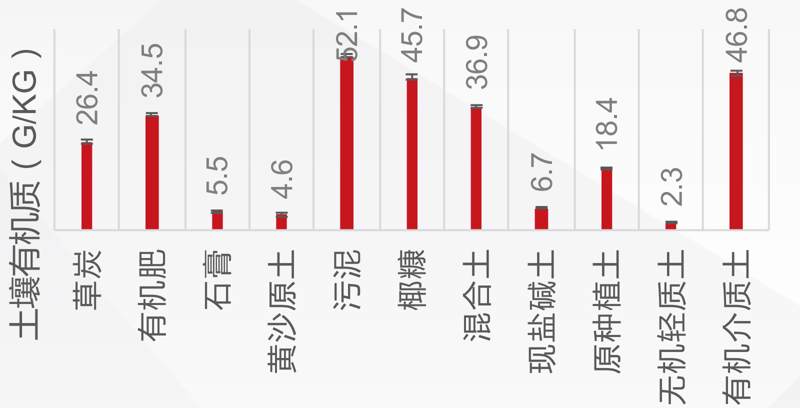


Fig 4-15 Analysis on soil organic matter

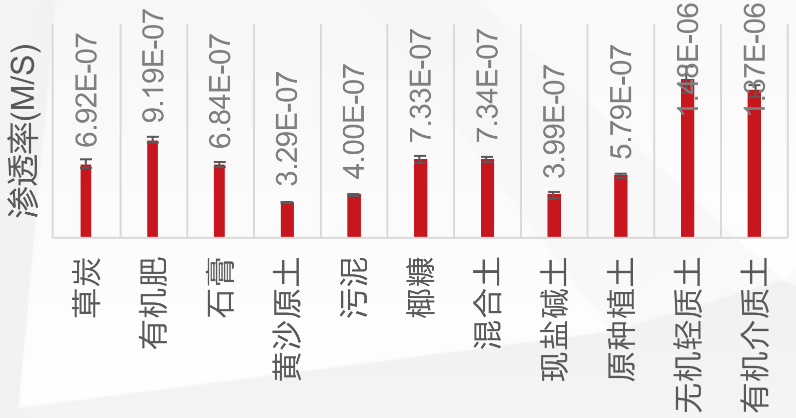


Fig 4-16 Analysis of soil permeability

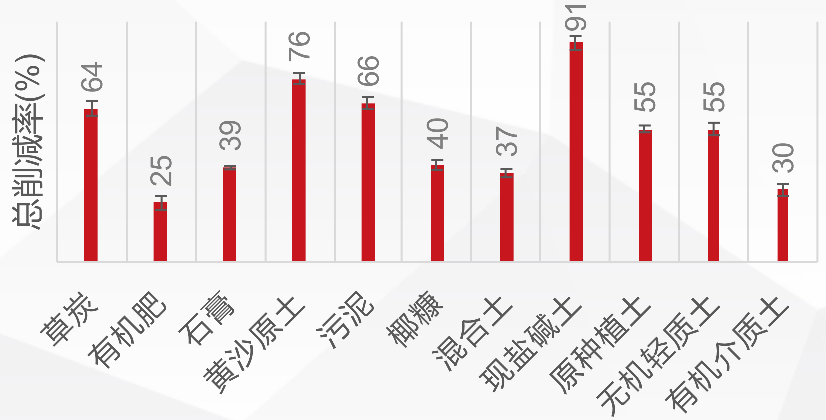


Fig 4-17 Analysis of runoff reduction rate

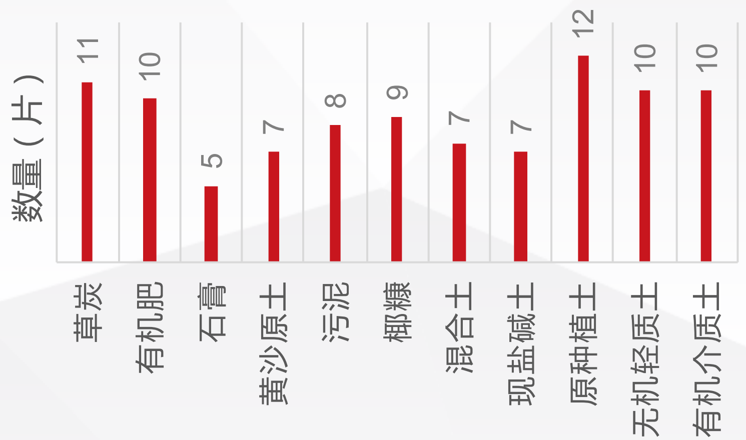


Fig 4-18 Influence of soil on plants

4.4 Improvement of saline soil in LID facilities

Table 4-1 Index of soil salinity

Groups	Total salt（g/kg）	pH value
group1	↓10.2	↓0.69
group2	↓7.4	↓0.59
group3	↑2.6	↓0.71
group4	↓10.4	↓0.23
group5	↓6.4	↓0.93
group6	↓8.0	↓0.93
group7	↓9.9	↓0.72

Table 4-2 Soil organic index

Groups	Soil organic（g/kg）	Soil fertility（mg/kg）		
		P	K	N
1	↑8.0	↓6.2	↑70	↓56.9
2	↑16.1	↑53.1	↑740	↓26.5
3	↓12.9	↑27.0	↑24	↓59.1
4	↓13.8	↓9.1	↑1.0	↓62.2
5	↑33.7	↑49.4	↑181	↑29.2
6	↑27.3	↑0.7	↑975	↓64.6
7	↑18.5	↑18	↑198	↓44.4

After adding different media, the saline-alkali content of saline-alkali soil was improved, and the pH value of soil tended to be neutral.

The elevation of soil organic matter content is arranged in the order from high to low: Sludge > coconut bran > mixed soil > organic fertilizer > peat.

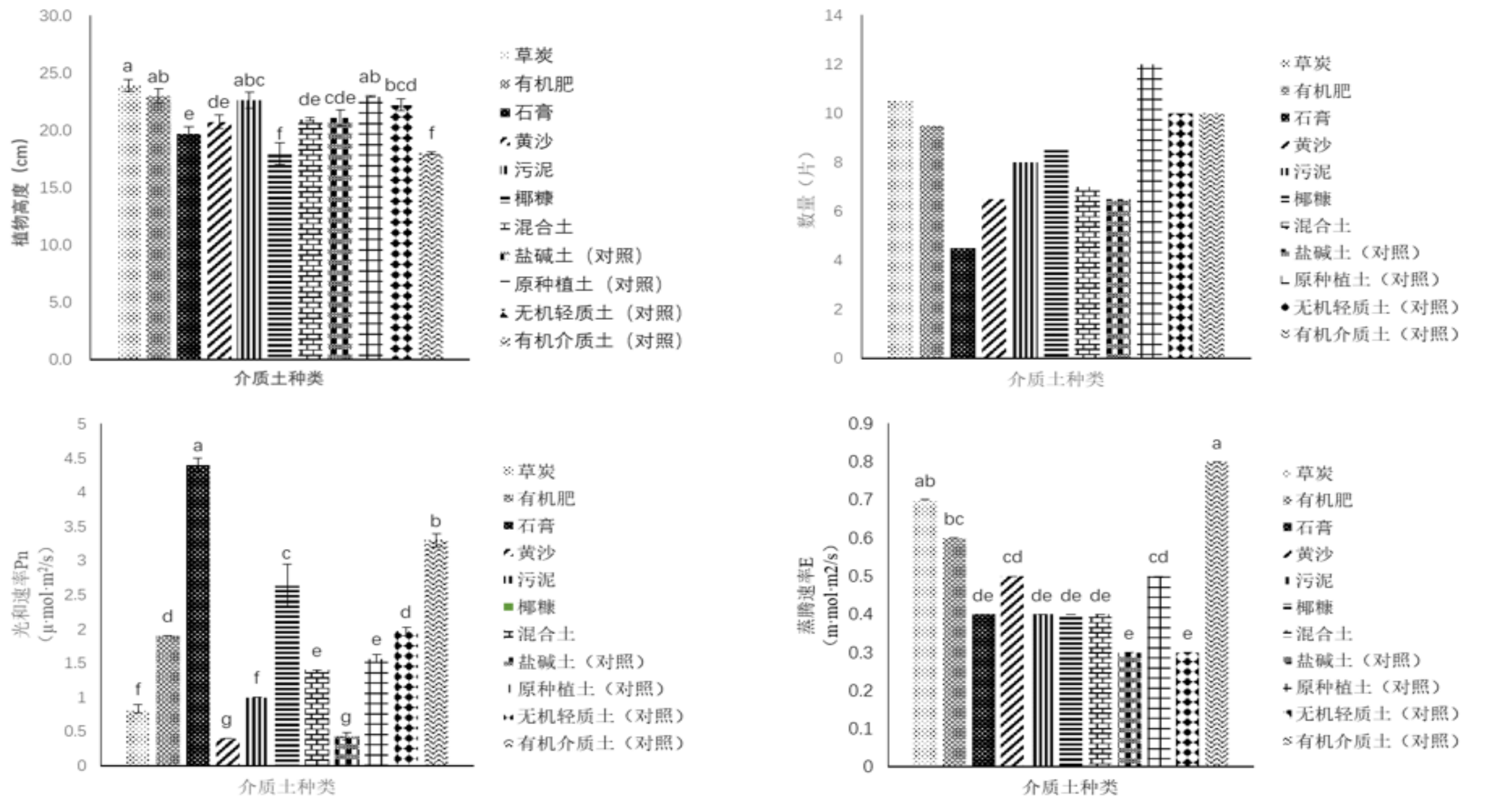
4.4 Improvement of saline soil in LID facilities

Table 4-3 water quality of sludge

Sample	Cadmium mg/L	Mercury ug/L	Arsenic ug/L	Copper mg/L	Lead mg/L	Chrome mg/L	Zinc mg/L	Nickel mg/L
Sludge	<0.003	0.28	2.0	<0.005	<0.03	<0.003	0.082	<0.009

Sludge water samples are rich in organic matter, but also prone to contain the natural environment and harmful to the human body of heavy metals, such as mercury, clamp, chromium and other substances. The discharge water sample flowing through the sludge medium was taken out and tested for heavy metals. The results are shown in the table above. According to the GB/ t14848-2017 groundwater quality standard, the effluent water is only type V water, in which the mercury content exceeds the standard. Therefore, if the sludge used in the experiment is used, purification treatment should be carried out.

4.4 Improvement of saline soil in LID facilities



百子莲生长高度方差分析

	平方和	df	均方	F	显著性
组间	119.769	10	11.977	37.515	.000
组内	7.024	22	.319		
总数	126.792	32			

百子莲光和速率方差分析

	平方和	df	均方	F	显著性
组间	46.076	10	4.608	370.859	.000
组内	.273	22	.012		
总数	46.350	32			

百子莲蒸腾速率方差分析

	平方和	df	均方	F	显著性
组间	.769	10	.077	23.073	.000
组内	.073	22	.003		
总数	.842	32			

According to the results of variance analysis, the significance of the change of medium soil was less than 0.01, so it could be seen that the change of medium soil had a significant influence on the growth of plants.

4.4 Improvement of saline soil in LID facilities

Table 4-2 Effect of soil on hydrological and water quality characteristics of rainwater

Function	Control Groups	Yellow Sand	Expected effect
Total salt （g/kg）	13.4	3.0	Reduce 77.6%
PH value	8.77	8.54	Reduce 2.6%
Soil organic（g/kg）	6.7	4.6	Reduce 31.3%
P（mg/kg）	9.1	8.9	Reduce 2.2%
K（mg/kg）	204	123	Reduce 39.7%
N（mg/kg）	3.37	3.08	Reduce 8.6%
Delay time of outflow（min）	55	43	Reduce 21.8%
Runoff reduction rate at peak flow time（%）	72	87	Increase 15%
Runoff reduction rate in the first 1 hour（%）	56	76	Increase 20%
Infiltration rate（m/s）	5.8E-07	3.3E-07	Reduce 43.1%
COD of outflow（mg/l）	29	28	Reduce 3.4%
TP of outflow（mg/l）	0.14	0.11	Reduce 21.4%
TN of outflow（mg/l）	41.3	6.6	Reduce 84.1%
SS of outflow（mg/l）	<4	<4	——

- **Purification of salt-proof medium soil: add 15% yellow sand**
- **Integrated salt-proof medium soil: add 15% peat**
- **Salt-insulating medium soil: add 4% yellow sand +6% peat +2% organic fertilizer +2% sludge +2% coconut bran**

Whether it is Meaningful to Study the Regulation Effect of Green Space ?

In my opinion :

The green space is a part of ecosystem, and it has significant value on rainwater interception, infiltration and regulation.

感谢聆听

Thanks for listening and reading!

yubingchin1983@sjtu.edu.cn