International Association for Hydraulics Research

Understanding Water Resilience at Scale

Dr Mark Fletcher FREng HonFSE
Arup Fellow Global Water Leader Director

September 2020

ARUP

ARUP

- Water Resilience, Shocks & Stresses
- City Water Resilience Approach
- Why Blue Green Infrastructure?
- Shanghai Blue Green Masterplan
- Summary Takeaway

ARUP

- **Water Resilience, Shocks & Stresses**
- City Water Resilience Approach
- Why Blue Green Infrastructure?
- Shanghai Blue Green Masterplan
- Summary Takeaway

Urban Water Resilience is the capacity of the urban water system - including the human, social, political, economic, physical and natural assets - to anticipate, absorb, adapt, respond to, and learn from shocks and stresses, in order to protect public health and wellbeing, the natural environment and minimise economic disruption.

CWRF 2018

THINK SYSTEMS
COPE
SURVIVE
THRIVE
CATCHMENT SCALE
GOVERNANCE

Shocks!

Theme	Shocks
Climate	Floods & Storms Drought Heat Wave
Security Related Incidents	Fire (Third Party) Terrorism / Hoax Cyber Attack / Data Fraud Vandalism False Positive Alarm Poisoning (Third Party) Water Contamination
Economic Change	Brexit Recession Fraud
Asset Related Incidents	Infrastructure Failure Fire / Explosion Operational Deaths / Drownings Poisoning & Pollution Infectious Diseases Natural Disasters Nuclear Incident
Supply Chain	Third Party Service Failure Civil Unrest Supply Chain Failure Staff Strikes & Industrial Disputes Power Outage & Comms Outage Severe Energy Price Change

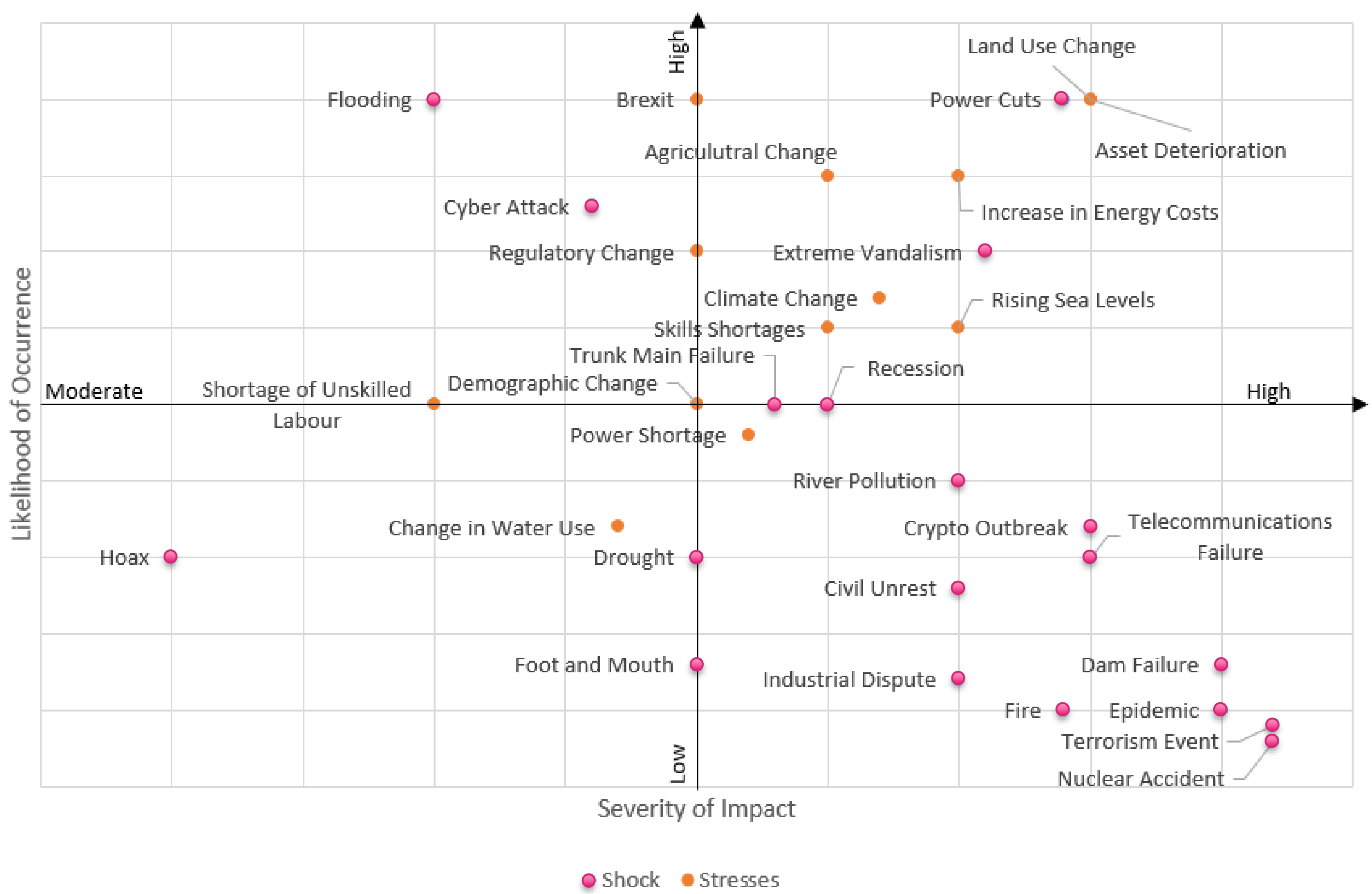
Stresses

Theme	Stresses
Climate	Changing Rainfall Patterns Regional Water Stress Sea Level Rise / Coastal Erosion Resource Scarcity
Legislative Change	Water Act Water Quality Regulations Abstraction Licenses Change Change in Land Use Sentencing Council Guidelines
Economic Change	Unmanageable Inflation Increased Cost of Borrowing Macro Industry Change
Customers	Demographic Change / Economic Development Trend of Urbanism / Urban Creep Population Change Migration Increased Water Demand Per Capita Willingness to pay
Asset Systems	Long term deterioration Loss of asset knowledge
Supply Chain	Skills Shortages Employment Costs Energy & Comms Costs

Classifying shocks and stresses

	Social	Technological	Environmental	Economic	Politico-legal
Shocks	Terrorist Attack Civil Unrest Extreme Vandalism Hoax Calls	Cyber Attacks Power Outages Asset Failure Telecommunication Failure Data fraud/theft Dam Failure Asset Failure Power Cuts False Positive Alarms	Water Supply Contamination Temperature Extremes Infectious Diseases Environmental Pollution Fire Events Nuclear Incident Flooding Storms	Energy Price Change Industrial Disputes Supply Chain Failure	License and Consent Change
Stresses	Demographic Change Urban Creep Migration Skills Shortages Lifestyle Change Shortage of Skilled Labour	Leakage Aging Infrastructure	Climate Change Drought Land Use Change Coastal Erosion Invasive Species Sea Level Rise	Recession Resource Scarcity Fuel Supply and Costs Increased Cost of Borrowing	Macro Industry Change Changing Regulation and Policy Political Change eg Brexit

Analysing shocks and stresses



- Water Resilience, Shocks & Stresses
- **City Water Resilience Approach**
- Why Blue Green Infrastructure?
- Shanghai Blue Green Masterplan
- Summary Takeaway

It is collaborative

Supported by:

The Rockefeller Foundation   The Resilience Shift

Project Partners:

ARUP   SIWI   100 Resilient Cities (Pioneered by the Rockefeller Foundation)   AGWA

Steering Group:

The World Bank   UMass Amherst   ARUP   The Resilience Shift   100 Resilient Cities (Pioneered by the Rockefeller Foundation)   The Rockefeller Foundation

Principles of the City Water Resilience Approach

Inclusive and transparent	Brings together different perspectives from water and city stakeholders and encourages collective action
Systems-based	Takes account of inter-dependencies with other systems
Holistic	Includes leadership and strategy, planning and finance, infrastructure and ecosystems and personal, household and community resilience
Action-oriented	Encourages the ownership, development and progression of actions to improve water resilience
Scalable and global	Scalable from towns through to mega cities and applicable to a global context

ARUP

Across the water cycle and at catchment scale

ARUP SIWI THE WORLD BANK IBRD • IDA
PIONEERED BY THE ROCKEFELLER FOUNDATION 100 RESILIENT CITIES
THE RESILIENCE SHIFT

Timeline of resilience tools and approaches

IAHR

Understanding Water Resilience at Scale

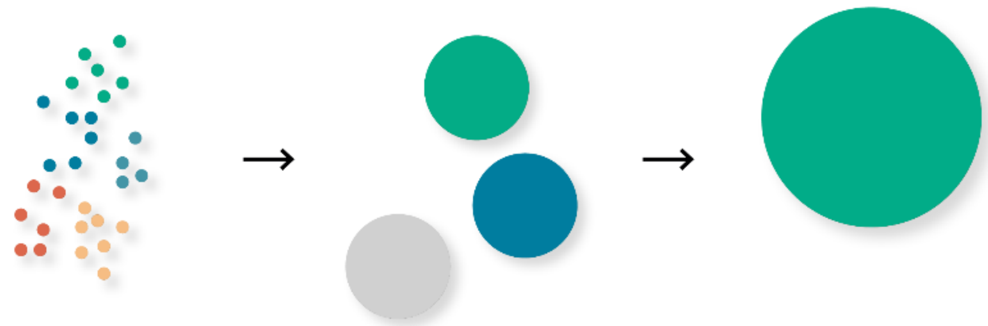
ARUP

Development of the City Water Resilience Framework

1577
factors

56
sub-goals

12
goals



City Water Resilience Framework

62 qualitative indicators
40 quantitative indicators

Leadership & Strategy

Planning & Finance

Infrastructure & Ecosystems

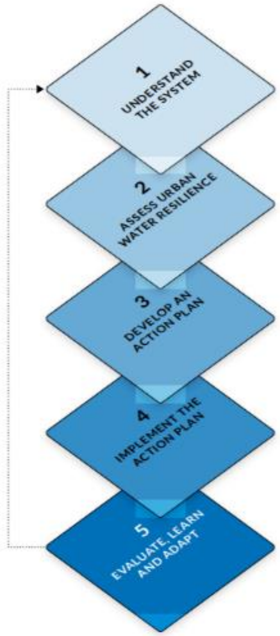
Health & Wellbeing

Literature Review

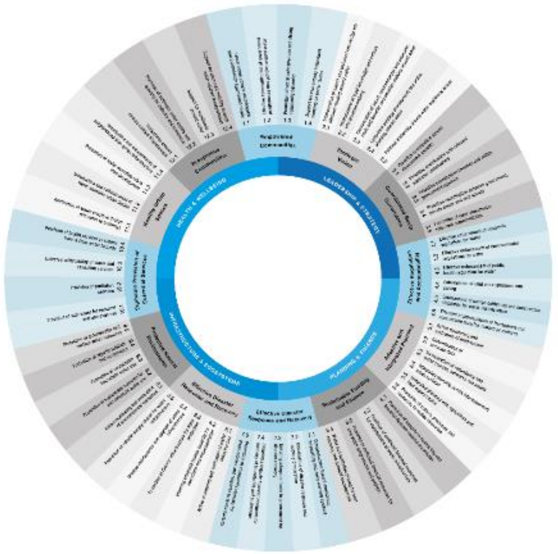
Fieldwork

Database of Factors

The 5 Steps of the City Water Resilience Approach



City Water Resilience Approach



City Water Resilience Framework

Leadership & Strategy

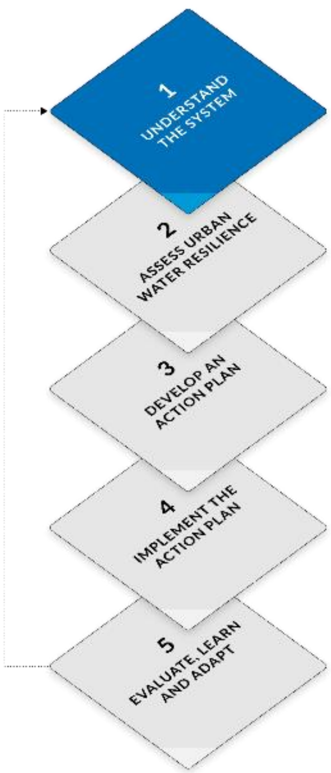
Planning & Finance

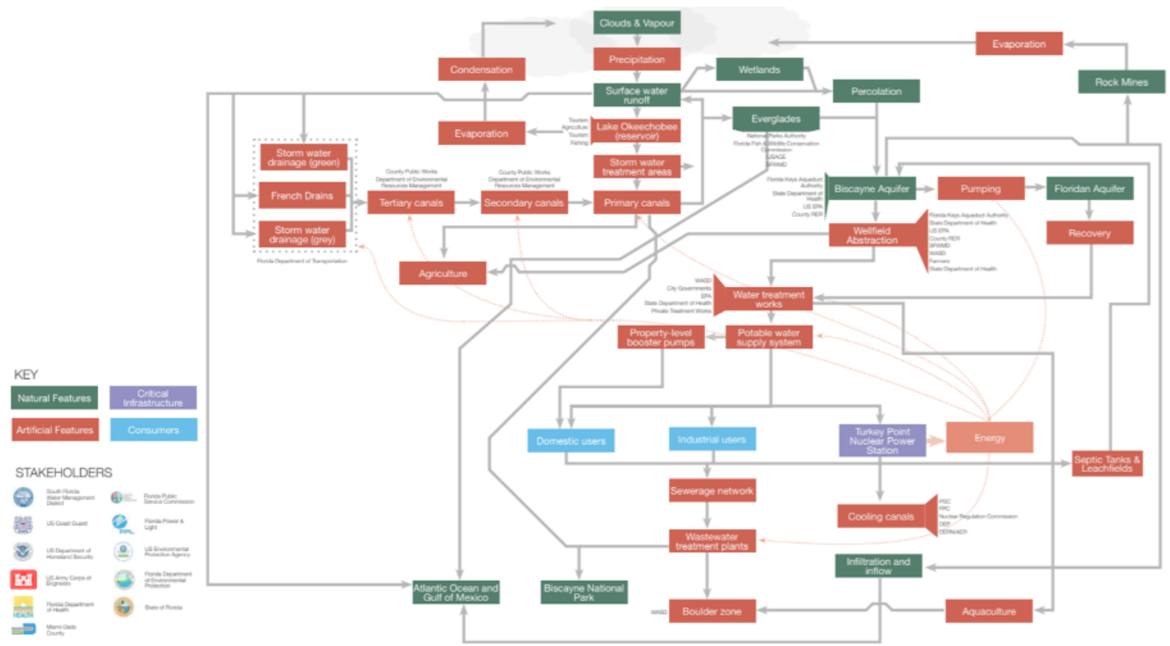
Infrastructure & Ecosystems

Health & Wellbeing

OurWater Governance Tool

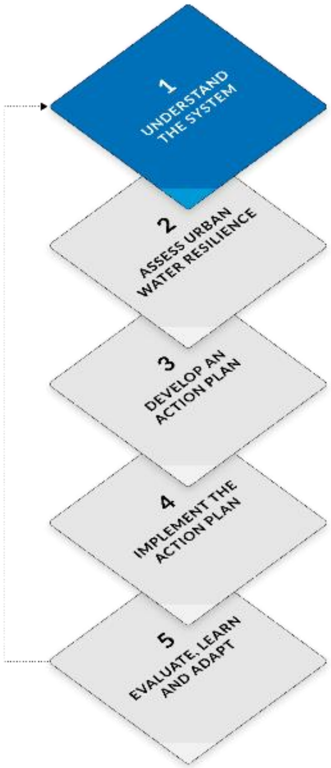
Step 1: Understand the system – governance mapping





OurWater Governance Tool

Step 1: Understand the system – fieldwork highlights MIAMI



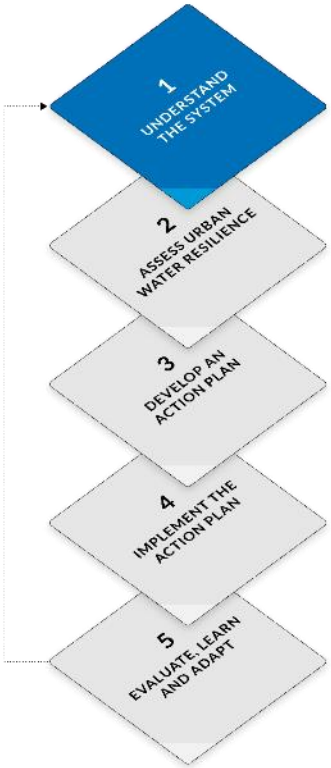
Key Shocks and Stresses

- Ecosystem/water quality degradation
- Hurricanes
- Ageing/failure infrastructure
- Flooding (all types)
- Governance and planning

Factors of resilience

- Data management / Modelling
- Emergency response
- Robustness of funding
- Land management issues
- Integration between agencies

Step 1: Understand the system – fieldwork highlights CAPE TOWN



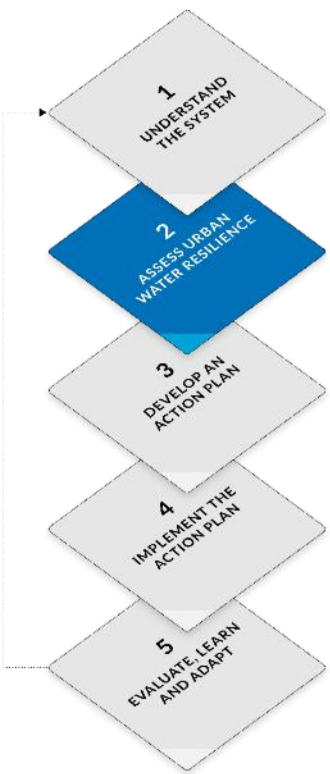
Key Shocks and Stresses

- Drought
- Flooding
- Fire
- Inadequate hygiene and sanitation
- Ecosystem loss
- Risk of over-abstraction or pollution of groundwater

Factors of resilience

- Interconnected infrastructure
- Technological solutions for demand management
- Citizen and community engagement
- Business support
- Transfer of Stormwater Dept to Water and Sanitation Dept
- Conflicting messages from government
- Governance – clarity of roles and responsibilities
- Impact of public engagement on global perception
- Limited data, particularly around groundwater
- Limited regulation and enforcement re groundwater pollution.
- Lack of funding at a National level for bulk water provision
- Social inequality

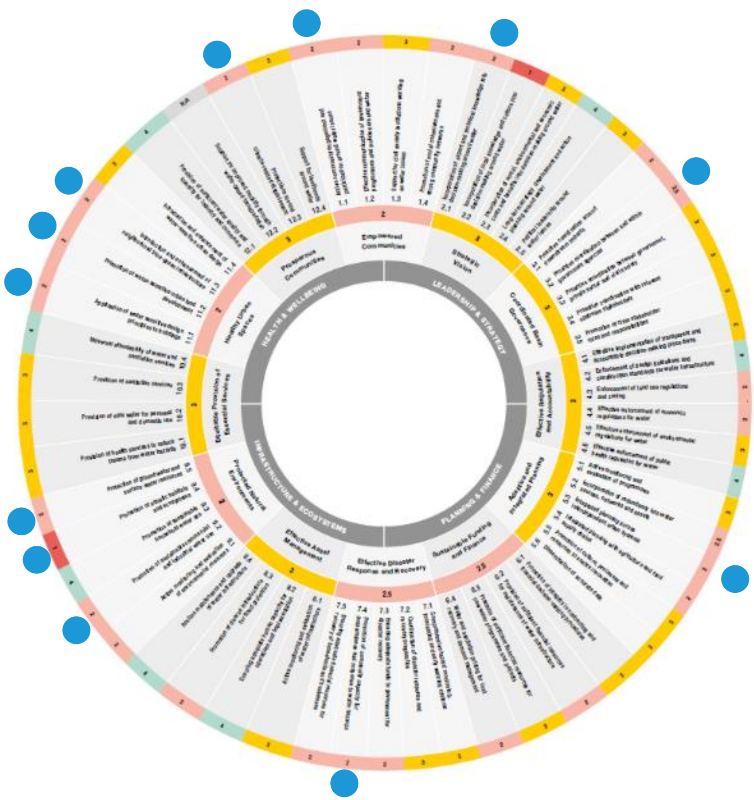
Step 2: Assess urban water resilience



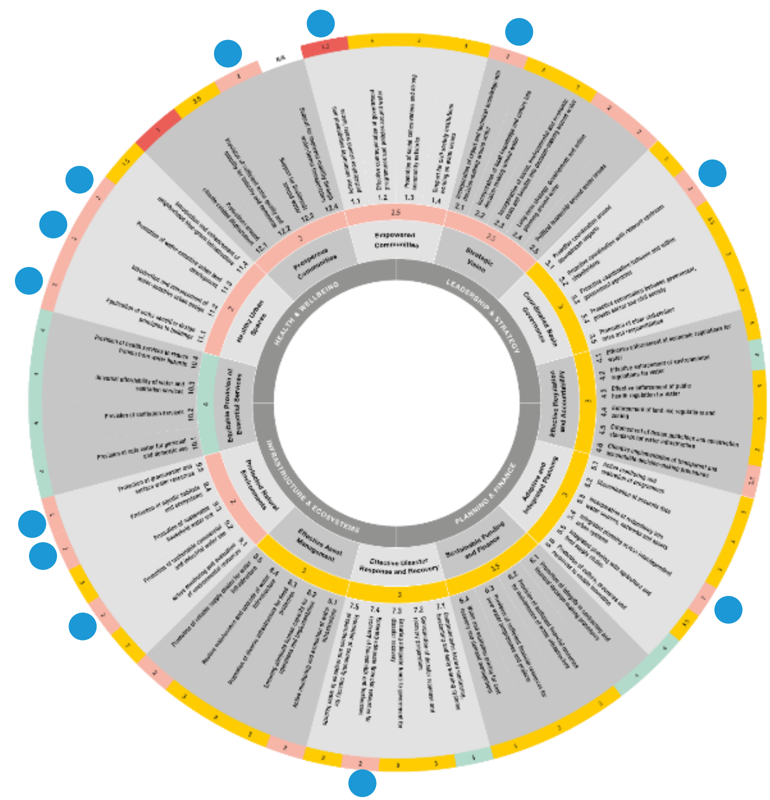
5 OPTIMAL	4 GOOD	3 FAIR	2 LOW	1 POOR	N/A
The indicator fully reflects current conditions in the city. No improvement is required.	The indicator mostly reflects conditions in the city. Minimal improvement is required.	The indicator somewhat reflects conditions in the city. Some improvement is required.	The indicator mostly does not reflect conditions in the city. Significant improvement is required.	The indicator does not at all reflect current conditions in the city.	The indicator is not relevant to the city.

ARUP

Step 2: Assess urban water resilience

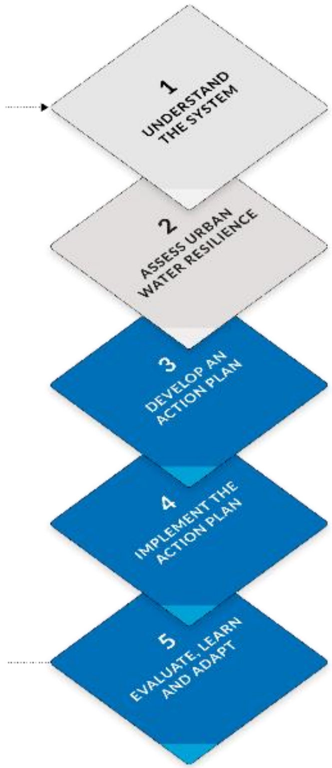


Cape Town
Water Resilience Profile



Greater Miami and Beaches
Water Resilience Profile

Step 3&4: Develop & implement an action plan



Includes initiatives like:

- Develop data and information platforms
- Resilience capability building for practitioners and decision-makers
- Improved transparency of data for the public on water issues and engagement with community champions and groups
- Improving GI policies and governance structures and developing pilot projects
- Improved coordination through convening organisation / catchment groups
- Source water protection using engagement with agriculture, improved canal management and wetland restoration

ARUP

Water Resilience, Shocks & Stresses

City Water Resilience Approach

Why Blue Green Infrastructure?

Shanghai Blue Green Masterplan

Summary Takeaway

ARUP

Why Blue and Green Infrastructure?

"Urban wetland and permeable surfaces provide flood resilience"

*

'URBAN GREEN CAN SLOW DOWN & REDUCE STORM WATER RUNOFF BY UP TO 8%'

HERRERA ENVIRONMENTAL CONSULTANTS (2008) 'THE EFFECTS OF TREES ON STORM WATER RUNOFF

Why Blue and Green Infrastructure?

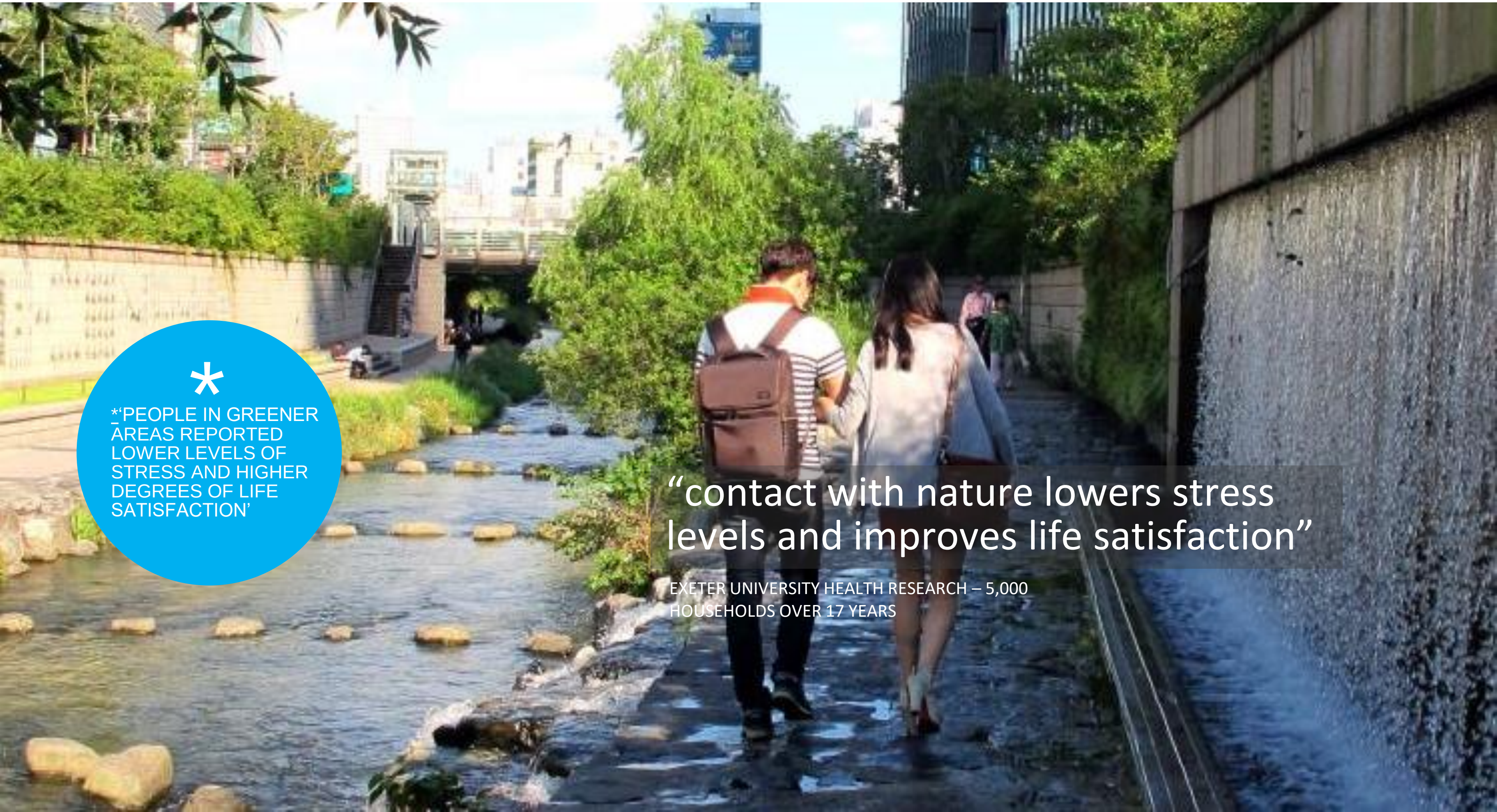
*

'GREEN+ BLUE STREETS CAN CUT POLLUTION BY 30%'

PUGH T, MACKENZIE A, WYATT J, HEWITT C, 'EFFECTS OF GREEN INFRASTRUCTURE FOR IMPROVEMENT OF AIR QUALITY IN URBAN STREET CANYONS – ENVIRONMENT, SCIENCE + TECHNOLOGY (2012)

"Urban blue + green streets cut pollution & clean the environment"

Why Blue and Green Infrastructure?



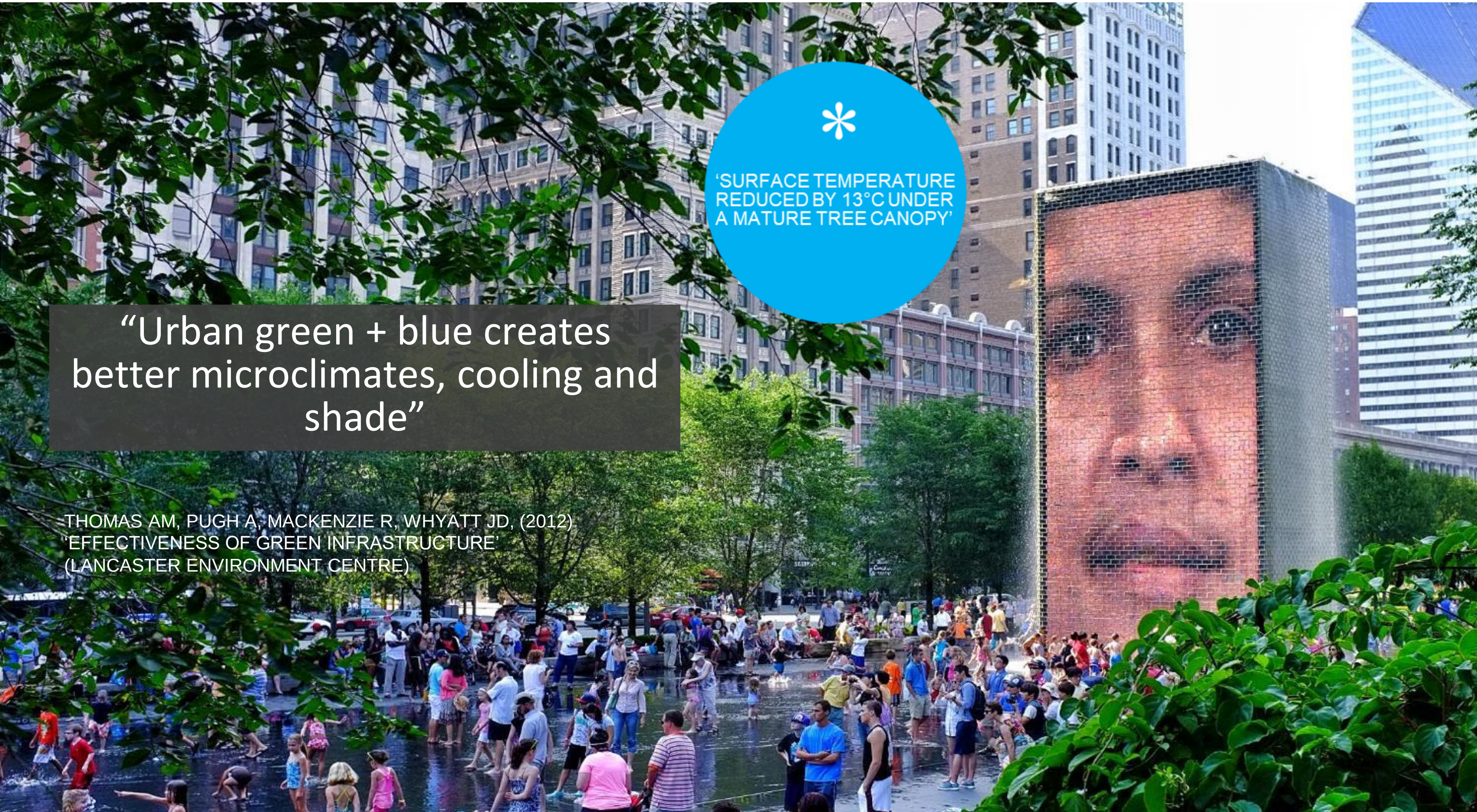
*

*'PEOPLE IN GREENER AREAS REPORTED LOWER LEVELS OF STRESS AND HIGHER DEGREES OF LIFE SATISFACTION'

"contact with nature lowers stress levels and improves life satisfaction"

EXETER UNIVERSITY HEALTH RESEARCH – 5,000 HOUSEHOLDS OVER 17 YEARS

Why Blue and Green Infrastructure?



Why Blue and Green Infrastructure?

“A green + blue environment stimulates better physical health”

*

*RESIDENTS IN GREEN ENVIRONMENTS WERE 3.3 TIMES MORE LIKELY TO TAKE FREQUENT PHYSICAL EXERCISE’

FORESTRY COMMISSION UK (2010) ‘THE CASE FOR TREES IN DEVELOPMENT AND THE URBAN ENVIRONMENT’

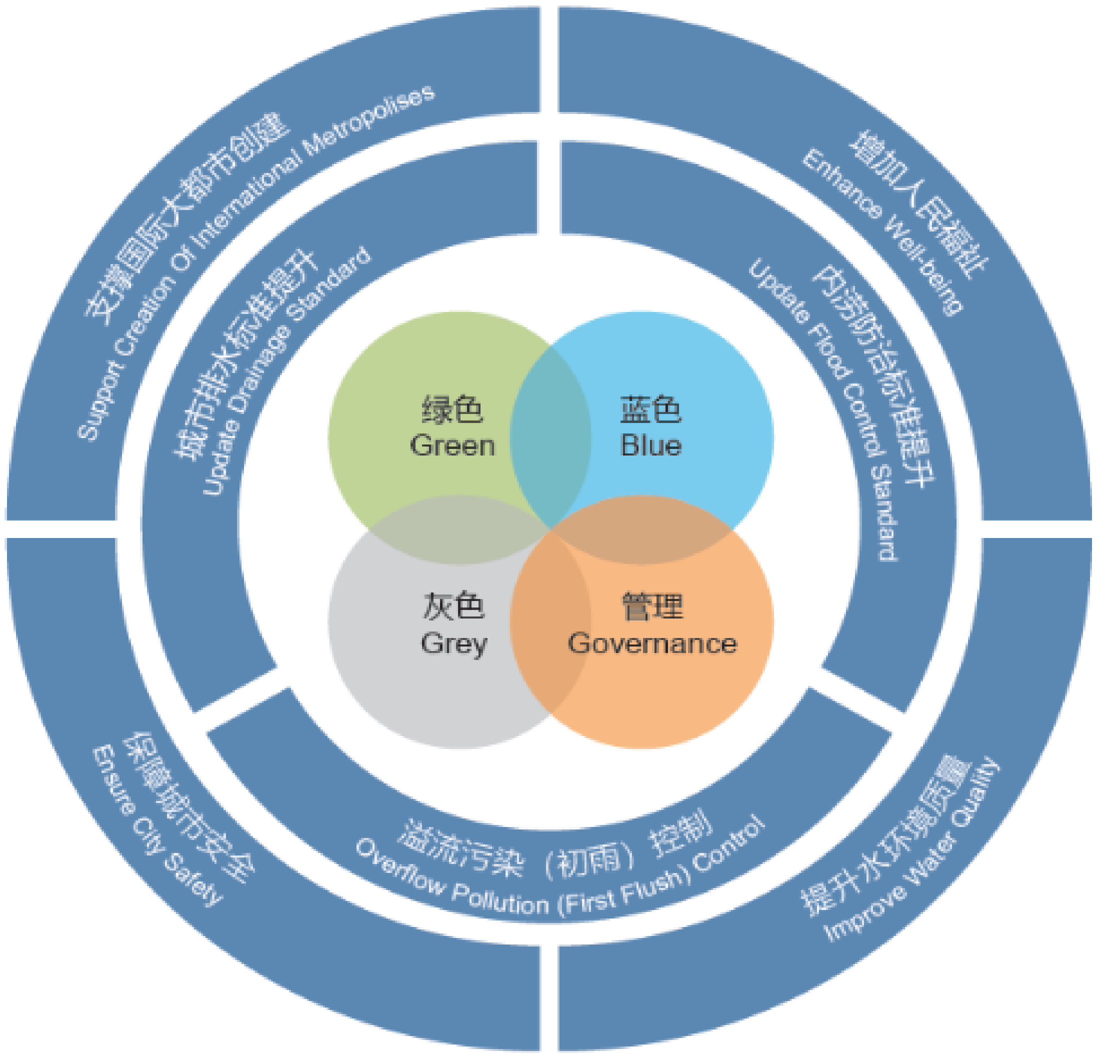
- Water Resilience, Shocks & Stresses
- City Water Resilience Approach
- Why Blue Green Infrastructure?
- **Shanghai Blue Green Masterplan**
- Summary Takeaway

目标
Objectives

Urban Drainage Management

Flood Control

Pollution Control



Planning strategy: Systems-led

管理

Governance

绿色基础设施

Green Infrastructure

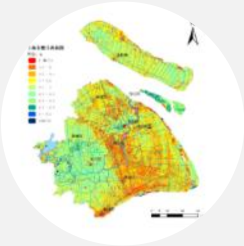
蓝色基础设施

Blue Infrastructure

灰色基础设施

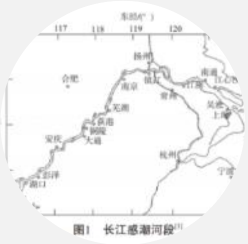
Grey Infrastructure

Drivers and Challenges

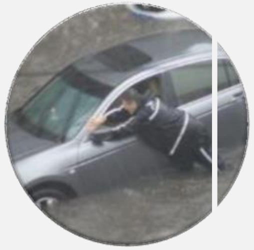


地势平坦
Topography

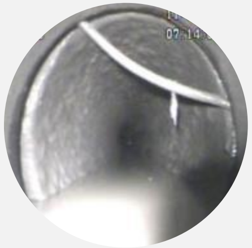
高密度城市化
Urbanisation



潮汐河流
Tidal Rivers

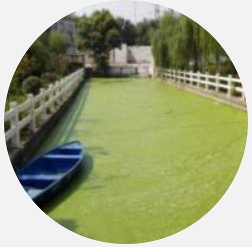


降雨和台风
Rainfall & Typhoons

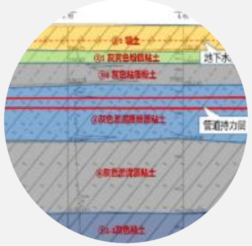


老旧基础设施
Ageing Infrastructure

环境污染
Environmental Pollution



河流污染
Polluted Rivers

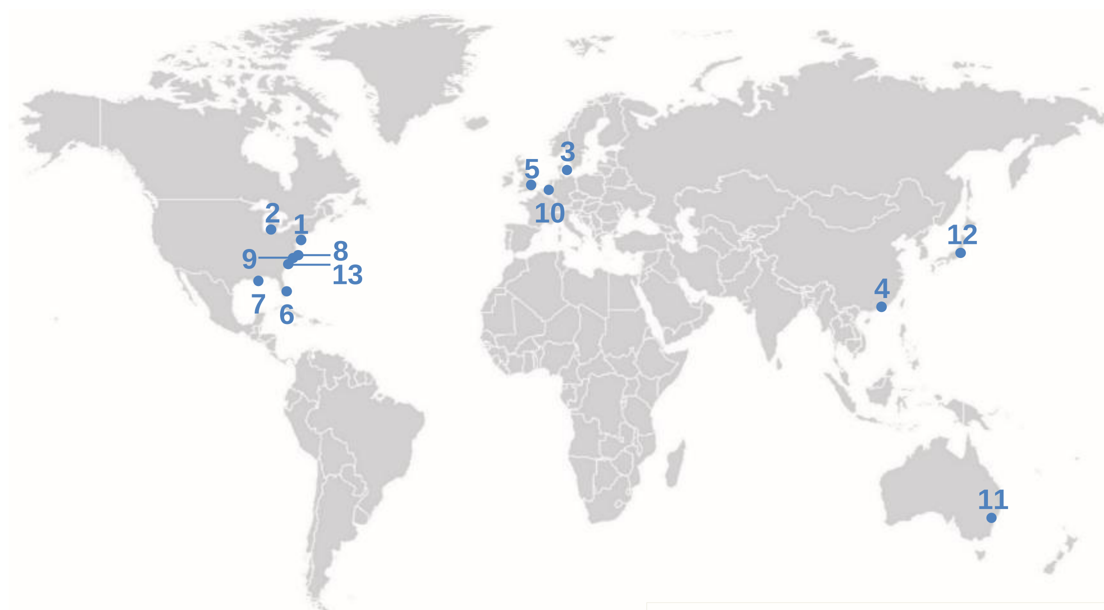


高水位
High Water Table

超负荷运转
Lack of Capacity

合流制溢流污染
Combined Systems

国际经验借鉴： 案例
Learning from others: Case Studies



		人口总数	人口密度	海拔	地理位置	气候	温度	年平均降雨量	降雨强度
1	Boston, USA	Not relevant	Somewhat relevant	Relevant	Relevant	Not relevant	Somewhat relevant	Relevant	Somewhat relevant
2	Chicago, USA	Not relevant	Relevant	Not relevant	Not relevant	Not relevant	Somewhat relevant	Relevant	Somewhat relevant
3	Copenhagen, Denmark	Not relevant	Relevant	Somewhat relevant	Relevant	Relevant	Not relevant	Somewhat relevant	Not relevant
4	Hong Kong, China	Not relevant	Not relevant	Somewhat relevant	Relevant	Relevant	Somewhat relevant	Not relevant	Somewhat relevant
5	London, UK	Somewhat relevant	Somewhat relevant	Relevant	Relevant	Relevant	Not relevant	Somewhat relevant	Not relevant
6	Miami, USA	Not relevant	Relevant	Relevant	Relevant	Not relevant	Not relevant	Relevant	Relevant
7	New Orleans USA	Not relevant	Not relevant	Relevant	Relevant	Relevant	Somewhat relevant	Somewhat relevant	Relevant
8	New York City, USA	Somewhat relevant	Not relevant	Relevant	Relevant	Relevant	Not relevant	Relevant	Somewhat relevant
9	Philadelphia, USA	Not relevant	Relevant	Relevant	Relevant	Relevant	Relevant	Relevant	Somewhat relevant
10	Rotterdam, Netherlands	Not relevant	Relevant	Relevant	Relevant	Relevant	Not relevant	Relevant	Somewhat relevant
11	Sydney, Australia	Not relevant	Not relevant	Relevant	Relevant	Relevant	Not relevant	Somewhat relevant	Somewhat relevant
12	Tokyo, Japan	Somewhat relevant	Somewhat relevant	Somewhat relevant	Relevant	Relevant	Somewhat relevant	Somewhat relevant	Relevant
13	Washington DC, USA	Not relevant	Relevant	Somewhat relevant	Relevant	Relevant	Relevant	Relevant	Somewhat relevant

- 有可借鉴性 Relevant (green)
- 有一些可借鉴性 Somewhat relevant (yellow)
- 没有可借鉴性 Not relevant (white)

案例：费城
Case Study: Philadelphia
Green City – Clean Waters

⚠ 挑战 Challenges

排水系统超负荷，导致每年向河流排放160亿加仑的未经处理的污水
许多之前的城市河道及溪流被填埋，变成了下水道或硬质街道。

Overloading of sewer network leading to 16 billion gallons of raw sewage being discharged to rivers annually
Many former creeks have been filled, turned into sewers or paved streets.

Solutions

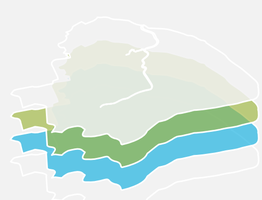
绿色基础设施：采用绿色基础设施，将85%的雨水保持在地面
新的运河和开放的排水渠道可以储存雨水。

Green infrastructure: Employing green infrastructure to hold 85% of storm water at surface

New canals and open drainage channels to store water.

分级 Ratings

Population	○○○
Population density	●○○
Elevation	●○○
Location	●○○
Climate	●○○
Temperature	●○○
Average annual rainfall	●○○
Rainfall intensity	○●○



案例：哥本哈根
Case Study: Copenhagen
‘Cloudburst Management Plan’

⚠ 挑战 Challenges

大部分**排水系统为合流制。**
排水系统**缺乏足够的能力**来处理极端降雨事件。

The majority of **sewerage system is combined.**
The sewerage system **lacks sufficient capacity** to handle extreme rainfall events.

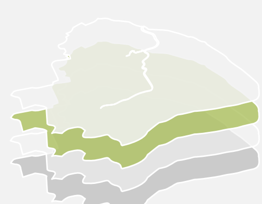
✓ 结论 Solutions

绿色基础设施：为了补充灰色基础设施，多功能调蓄河道用来适应洪水。
新的深/浅地下储存：建立旁路隧道管网系统。
洪水输送：设计城市街道安全地传输超标降雨流量

Green infrastructure: To complement the grey infrastructure, a multi-functional retention basin in a lake which adapts to flooding.
New deep/shallow underground storage: Cloudburst pipes and creation of a by-pass tunnel under Sankt Jørgens Sø.
Flood conveyance; design of urban streets to convey flows safely

分级 Ratings

Population	○○○
Population density	●○○
Elevation	○●○
Location	●○○
Climate	●○○
Temperature	○○○
Average annual rainfall	○●○
Rainfall intensity	○○○



ARUP

案例：新奥尔良

Case Study: New Orleans

Urban Water Plan (post Katrina)

⚠ 挑战 Challenges

由于管道系统缺乏排水能力和弹性导致内涝。
地下水开采过多导致城市沉降。

Flooding from drainage systems due to lack of capacity and resilience.
Excessive groundwater extraction leading to sinking of city

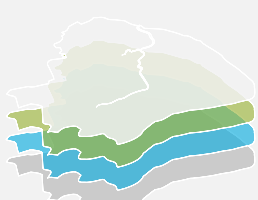
✓ Solutions

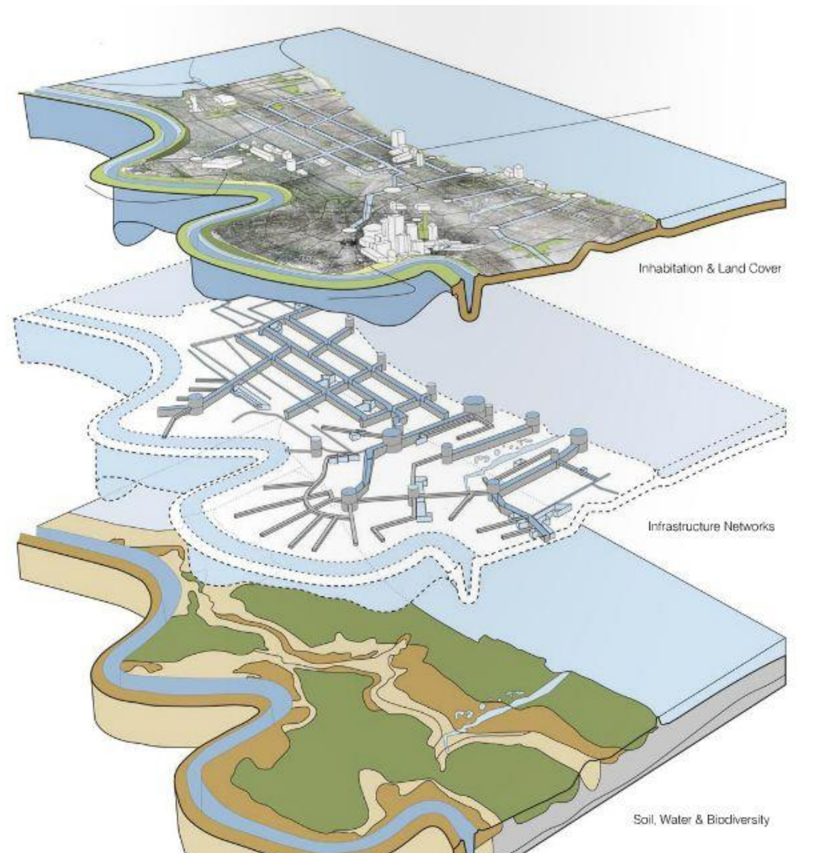
城市排水计划：以综合的愿景和规划驱动城市重新发展。
城市河网改造：优化运河（循环网络），人工湿地。
绿色基础设施：从源头上管理雨水的新设计指南。

Urban Water Plan: an integrated vision and plan for redevelopment of the city.
Improved waterway: optimised canals (circulating network), constructed wetlands.
Green infrastructure: new design guidelines to manage rainwater at source.

分级 Ratings

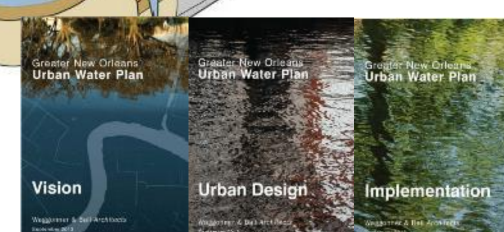
Population	○○○
Population density	○○○
Elevation	●○○ (green)
Location	●○○ (green)
Climate	●○○ (green)
Temperature	○●○ (yellow)
Average annual rainfall	○●○ (yellow)
Rainfall intensity	●○○ (green)





Layered Planning Process

Working from the ground up to determine how to integrate the natural flows of the landscape into infrastructure networks and the physical shape of our communities



案例：鹿特丹

Case Study: Rotterdam

Temporary Flood Storage in the Public Realm

⚠ 挑战 Challenges

排水系统缺乏处理较大降雨事件的能力。 河流系统缺乏能力。 这个城市低于海平面。

The sewer system lack capacity to handle larger rainfall events. The fluvial system lacks capacity. The city is below sea level.

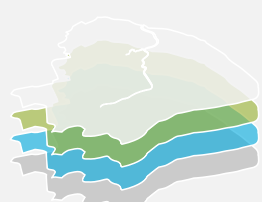
结论： Solutions

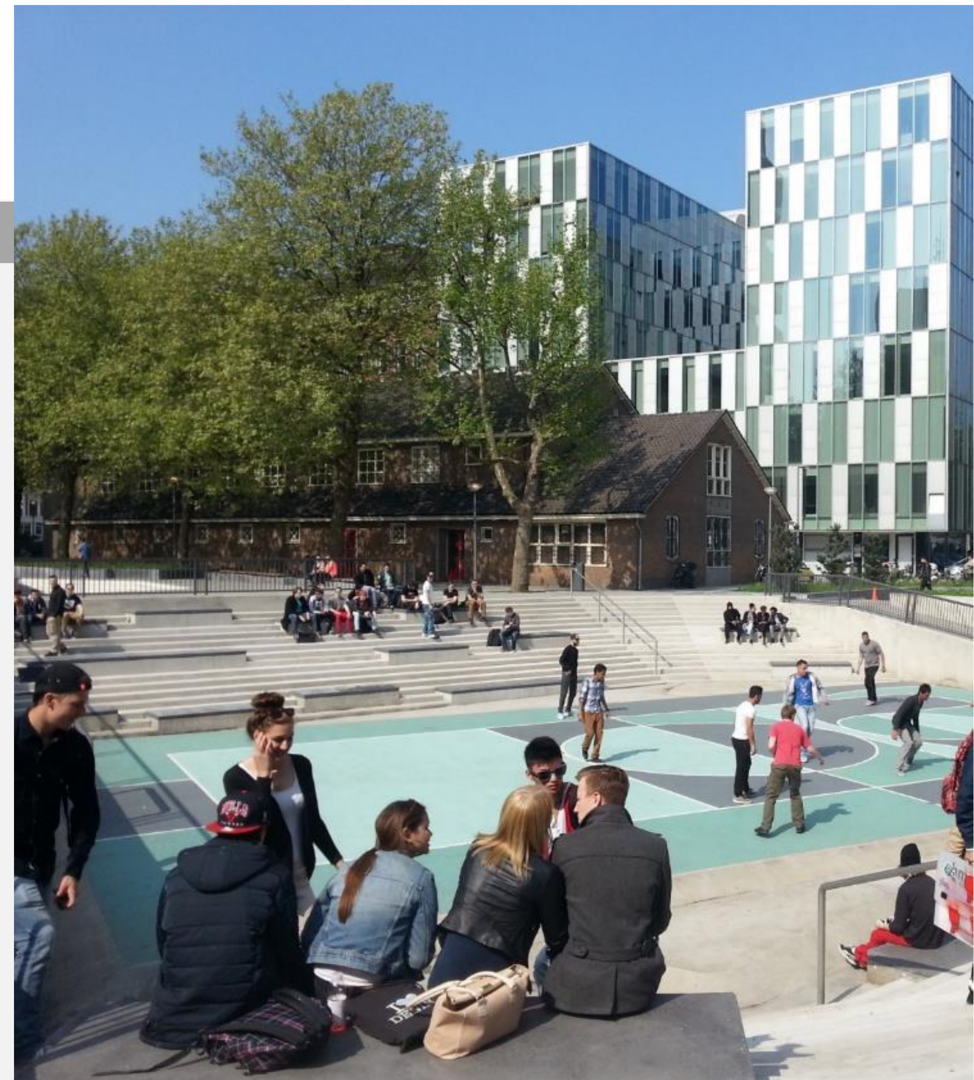
绿色基础设施：延迟地表径流，辅以多功能调蓄和非机动车道。
运动场和休闲区域下的地下储存：在现有建筑物空隙中也使用水储存
新的分散调蓄和增加的泵站能力。

Green infrastructure: to delay the run-off supplemented by multi-functional retention basin and cycle lanes.
Underground storage beneath sport fields and recreational areas: Also used water storage in existing building voids:
New shallow underground storage and increased pumping capacity.

分级 Ratings

Population	○○○
Population density	●○○
Elevation	●○○
Location	●○○
Climate	●○○
Temperature	○○○
Average annual rainfall	●○○
Rainfall intensity	○●○





上海与纽约概况对比

Shanghai VS New York City

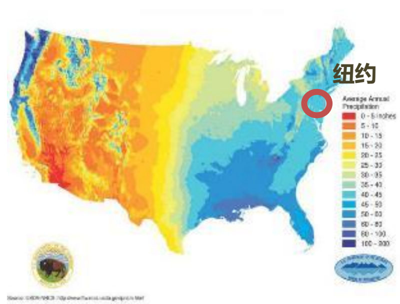
Climatic Similarities

纽约
New York

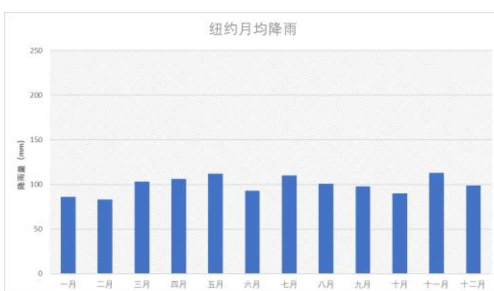
- 年平均降雨量为**1140mm**
- 全年总降雨量较为平均，主要集中在**3月至8月**，7月份雨量最多，占全年的10%。
- 最高日降雨量为198.12mm（2011年），次高日降雨量为159.258mm （1984年）

上海
Shanghai

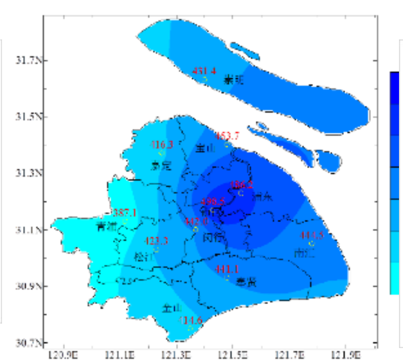
- 多年平均降雨量**1191mm**
- 全年总降雨量的60%集中在**5月至9 月**。9 月份雨量最多，占全年的14.9%。



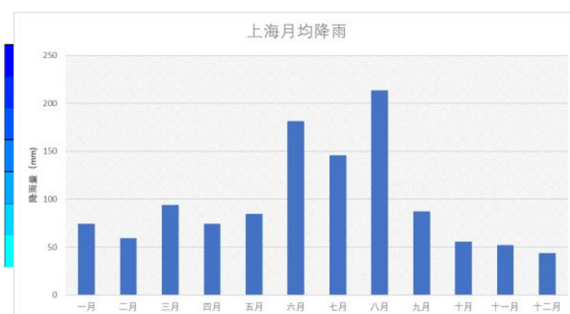
美国1961年至1990年平均年降雨量——USDA-NRCS



纽约月均降雨量



上海市平均暴雨量分布图——《上海市海绵城市专项规划》



上海月均降雨量

案例：纽约

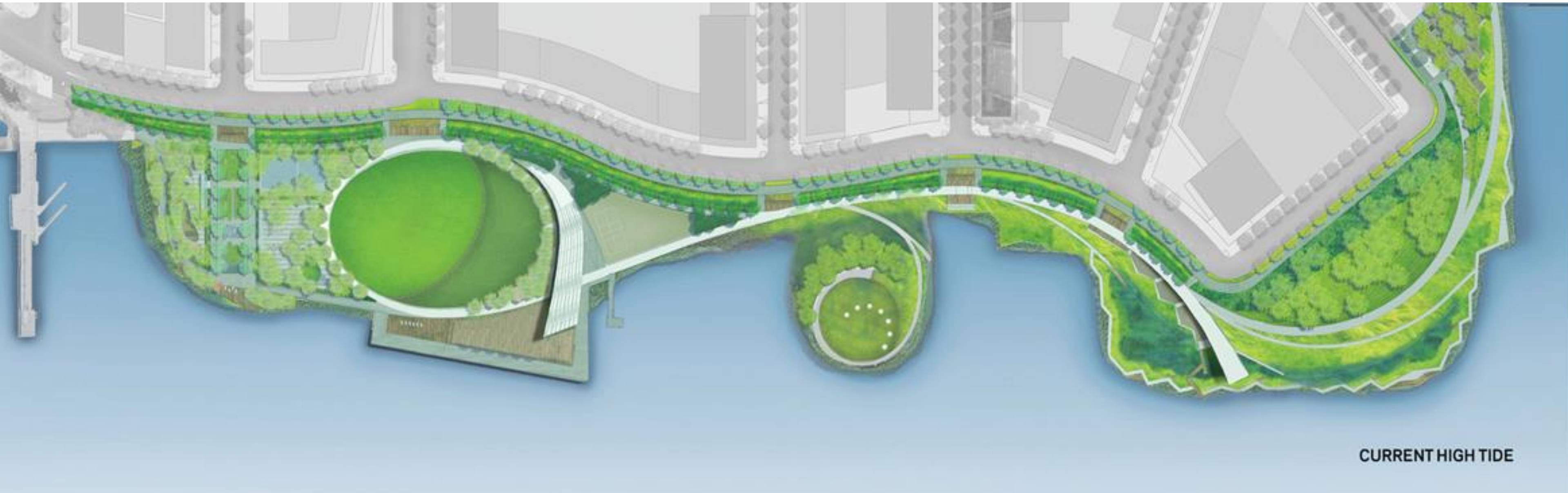
Case Study: New York City

Green Infrastructure Implementation at Scale

Hunters Point South
One of the most ambitious waterfront projects in New York City history

Understanding Water Resilience at Scale

ARUP



案例：纽约 纽约交通局的选址标准

Case Study: New York City

Design Guidelines – Urban Bioswales

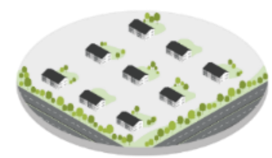
分析：城市用地特征类型
Analysis: City Characterisation


高密度，低层 – 老城区
High density, low-rise – historic urban fabric


中央商务区/高密度高层住宅区
CBD / dense urban high rise


中密度住宅楼
Medium-rise residential blocks


中密度高层住宅区
High-rise residential blocks in parkland


低密度住宅区
Low-density residential


公园和水域的开放空间
Parkland and green-blue open space

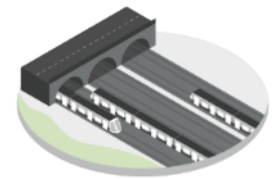

河道网络
Rivers


校区
Campus

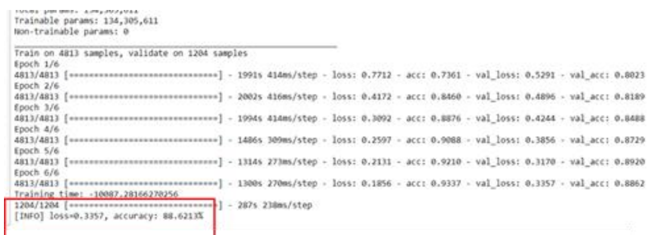

工业区
Industrial

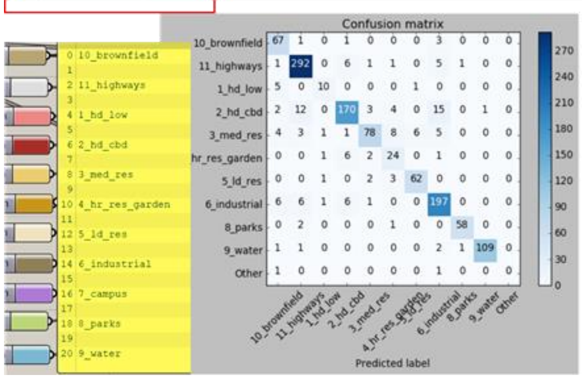

弃置工业商业用地
Brownfield


城市干路
Major highways

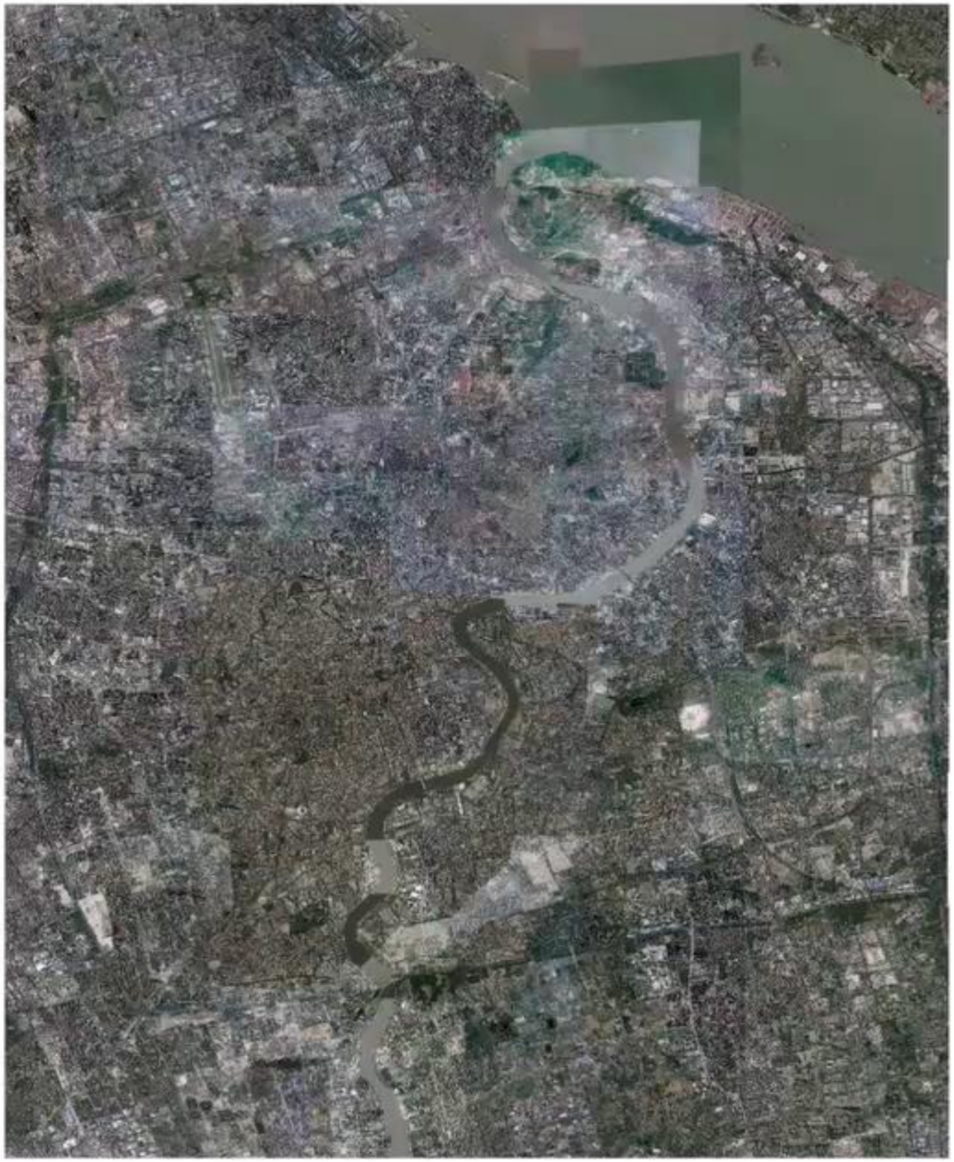

火车站
Rail infrastructure

Machine Learning

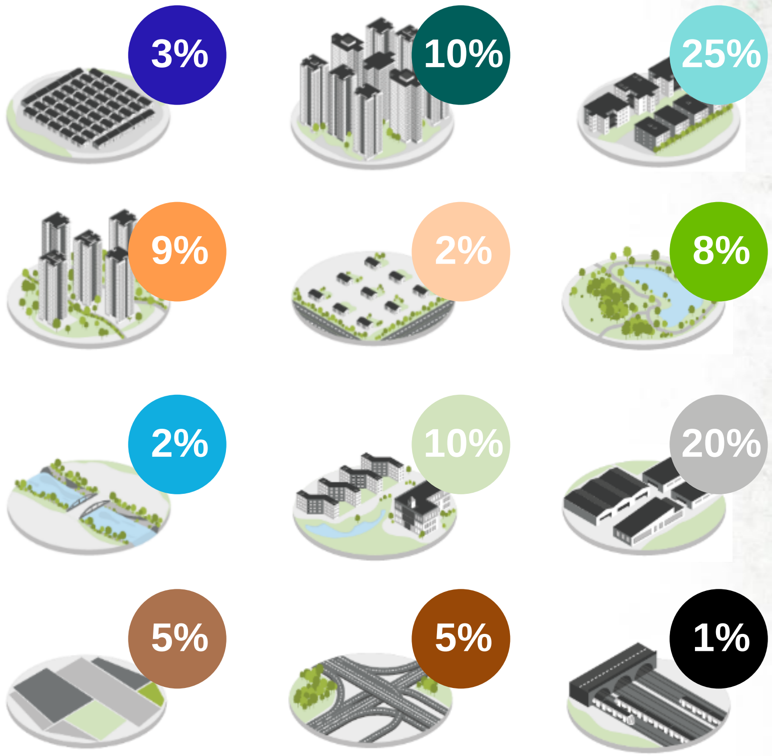


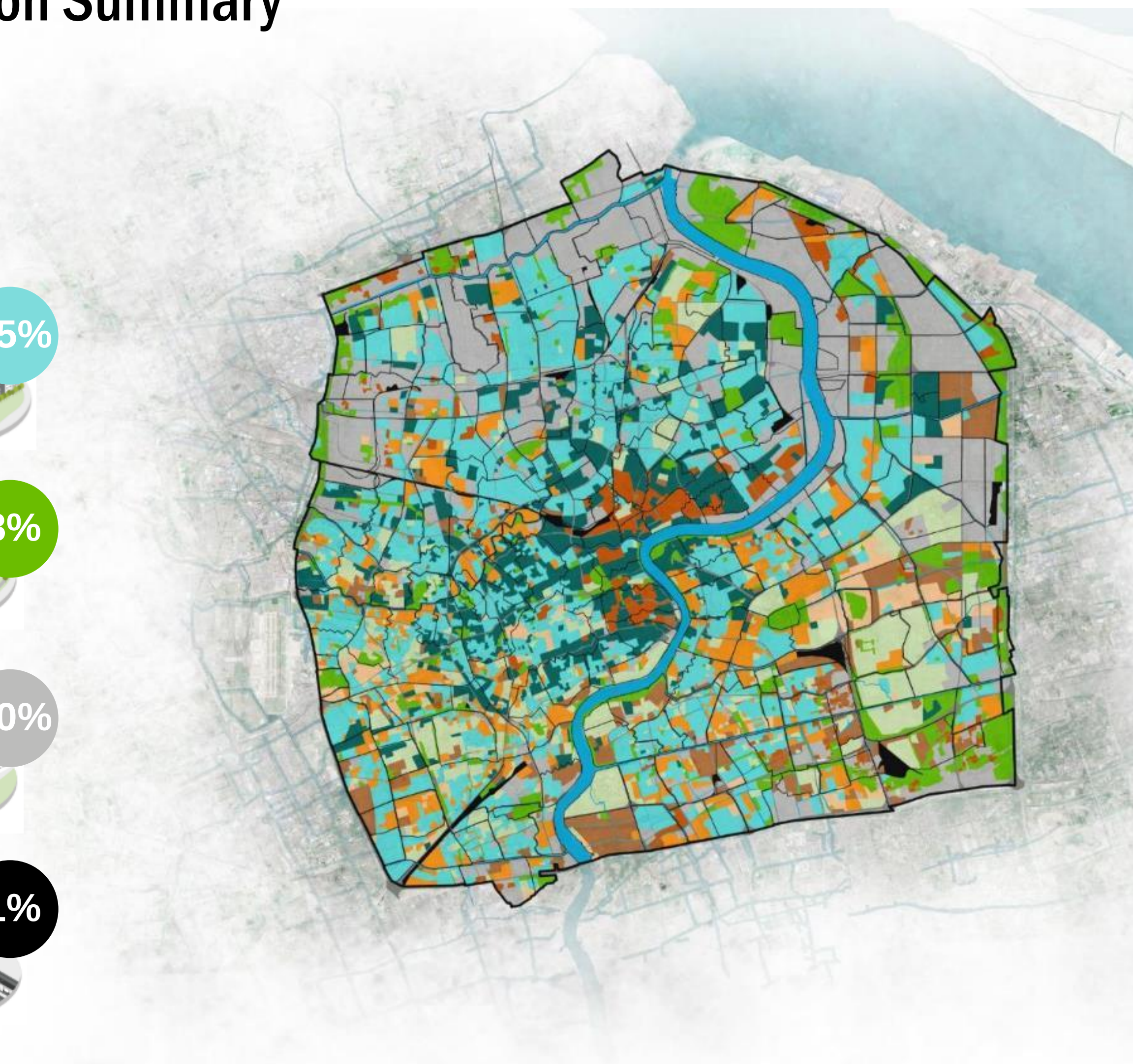


	10_brownfield	11_highways	1_hd_low	2_hd_cbd	3_med_res	4_hr_res_garden	5_ld_res	6_industrial	8_parks	9_water	Other
10_brownfield	67	1	0	1	0	0	0	3	0	0	0
11_highways	1	292	0	6	1	1	0	5	1	0	0
1_hd_low	5	0	10	0	0	0	1	0	0	0	0
2_hd_cbd	2	12	0	170	3	4	0	15	0	1	0
3_med_res	4	3	1	1	78	8	6	5	0	0	0
hr_res_garden	0	0	1	6	2	24	0	1	0	0	0
5_ld_res	0	0	1	0	2	3	62	0	0	0	0
6_industrial	6	6	1	6	1	0	0	197	0	0	0
8_parks	0	2	0	0	0	1	0	0	58	0	0
9_water	1	1	0	0	0	0	0	2	1	109	0
Other	1	0	0	0	0	0	0	1	0	0	0



分析：城市用地特征类型总结
Analysis: City Characterisation Summary





规划策略：综合管理、绿色、蓝色及灰色基础设施

Integrating Governance, Green, Blue and Grey Infrastructure

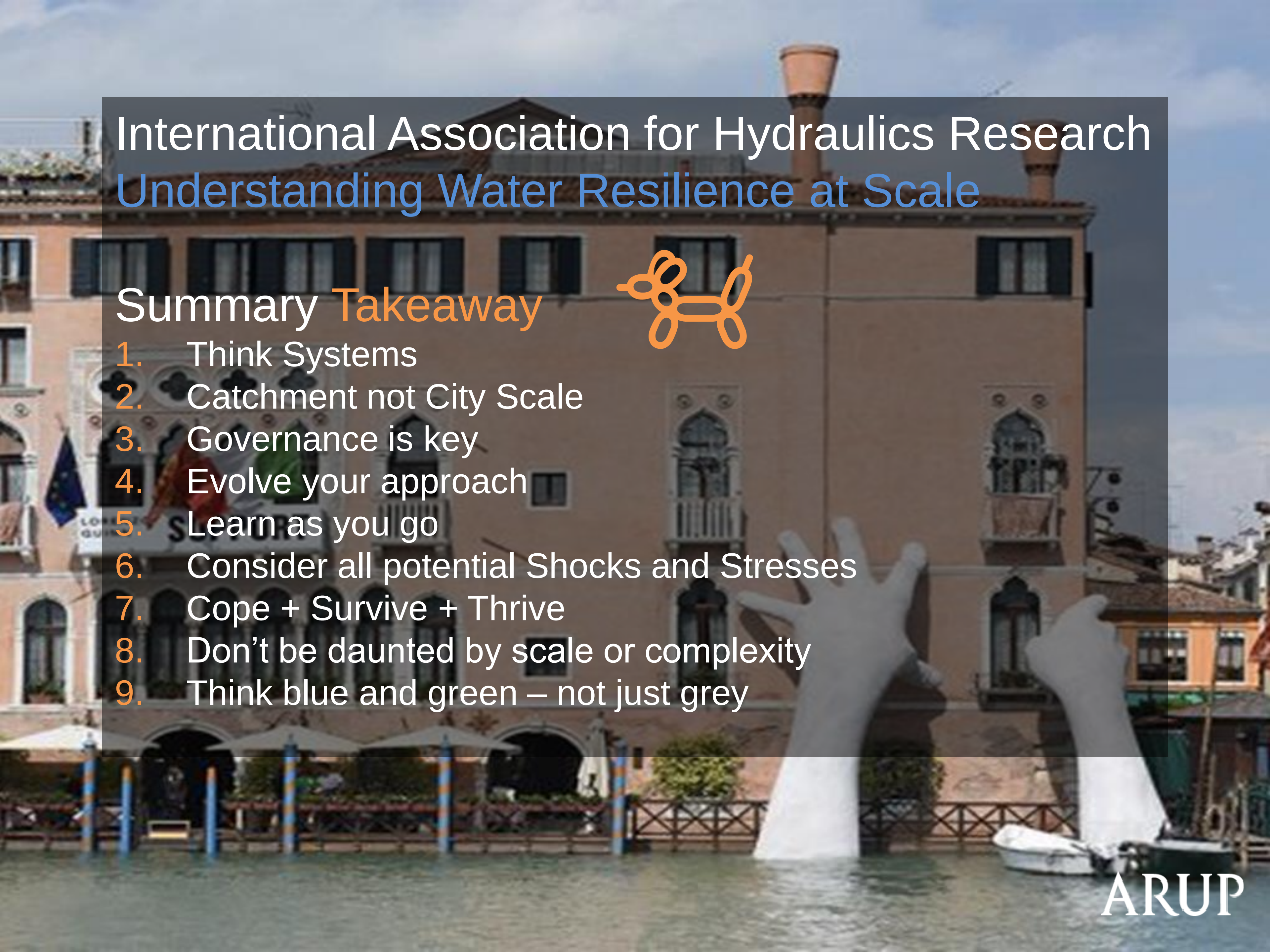
在城市范围内对区域分析和新灰色基础设施机会进行审查，以制定优化战略，其中包括：

- 现有灰色：优化建议隧道和计划基础设施的使用
- 绿色：整个城市的源头控制，最初的重点是公众
- 蓝色：基于进一步建模，优化网络
- 新灰色：基于优先级排序结果的集中和分散调蓄

Our stormwater masterplan integrates elements across all four systems:

- **Governance:** implementation of the most cost-effective and feasible controls, including the refurbishment of the existing assets and network
- **Green:** source control across the city with initial focus on public
- **Blue:** optimising the network and assets, based on further modelling
- **New grey:** tunnels and and decentralised storage based on the outcomes of the prioritisation

- Water Resilience, Shocks & Stresses
- City Water Resilience Approach
- Why Blue Green Infrastructure?
- Shanghai Blue Green Masterplan
- **Summary Takeaway**


International Association for Hydraulics Research
Understanding Water Resilience at Scale
Summary Takeaway
1. Think Systems
2. Catchment not City Scale
3. Governance is key
4. Evolve your approach
5. Learn as you go
6. Consider all potential Shocks and Stresses
7. Cope + Survive + Thrive
8. Don’t be daunted by scale or complexity
9. Think blue and green – not just grey
ARUP