Sustainable urban water system
and several case studies

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July, 2017
Outlines

1. Challenge of Urban Water Sustainability
2. Development of a New Urban Water System
3. Implementations : case studies
1.1 International Movement on Sustainable Development

**Brundtland Commission:**
World Commission on Environment and Development
- Officially defines sustainable development

**World Summit on Sustainable Development**
- Resulted in Johannesburg Declaration
- Agreed to focus on threats to sustainable development

**UNEP’s Towards a Green Economy**
- Contribution to Rio+20
- Addresses poverty and sustainable development

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1972
- UN Conference on the Human Environment
  - Discussed state of global environment
  - Resulted in Stockholm Declaration
  - Presented UN’s new Environmental agenda

1987
- UN Conference on Environment and Development (Earth Summit)
  - Created plan for sustainable development
  - Brought worldwide attention to sustainable development movement

1992
- Stern Review on the Economics of Climate Change
  - Discuss effect of global warming
  - Gives several strategies for reducing environmental harms

2002
- UN Conference on Sustainable Development
  - Addressed economic and environmental goals
  - Shaped global environmental policy

2006

2011

2012

Key milestones
1.2 Introduction: Urban Water Sustainability

- The scarcity of freshwater resources directly threatens human water security and biodiversity in many rapidly urbanizing areas of the world.

- International Concerns: global climate change, population growth, water shortage, flooding, water pollution and unsustainable water use practices.

- To sustain the continuous development, a water management revolution is necessary to redesign the urban water from an aging centralized infrastructure to a new, self-sustaining urban community.
1.3 Challenge of Urban Water Sustainability

- Wastewater system focus on energy saving and resources recovery:
  - Energy intensive, sewage leakage into the environment due to long distance conveyance.
  - Mixing of grey water and black water adds unnecessary cost of pumping, treatment and difficulties on resources recovery.

- Water recycling:
  - Reclaimed water, Sea water, Storm

- Sustainable urban storm-water management.
2. Development of a New Urban Water System
Some New Urban Water System Design and Concerns

2.1 Domestic Onsite source-separation system

2.2 Sustainable Urban Stormwater Management

2.3 Wastewater recycling

2.4 Basic Water-energy-resource Nexus
2.1 Domestic Onsite source-separation system

- **Separating water at source**
  - Grey water: washing, flushing, bathing wastewater
  - Yellow water: urine wastewater
  - Brown/black water: fecal wastewater

- **Separated treatment units**
  - Grey water: Water reuse
  - Yellow water: Recovery of N, P and K
  - Brown/black water: New energy production
2.2 Sustainable Urban Stormwater Management

Outdoor: Surface runoff (Storm water)

Urban communities

Landscape & Park

Road & Parking

*Sponge city in China!*

Natural stormwater retention, permeability and cleansing abilities
Sponge city in China

  - Guidelines for construction technology of Sponge city-The establishment of LID stormwater system


- **2015, 2016**, 30 cites were selected

- **Next 3 years**, central government would provide between US$48.42 million and 80.7 million annually to each cities
Sponge city in China

- **International Attractions**
  - **Sponge City** – China’s movement toward resilient infrastructure
2.3 Wastewater Recycling

Annual water supply and reclaimed water usage in 657 cities

<table>
<thead>
<tr>
<th>Year</th>
<th>Water Supply Amount (in billion m$^3$)</th>
<th>Reclaimed Water Used</th>
<th>Ratio of Reclaimed Water to Fresh Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>50.2</td>
<td>1.6</td>
<td>0.0%</td>
</tr>
<tr>
<td>2008</td>
<td>50.0</td>
<td>1.9</td>
<td>0.0%</td>
</tr>
<tr>
<td>2009</td>
<td>49.7</td>
<td>2.3</td>
<td>0.0%</td>
</tr>
<tr>
<td>2010</td>
<td>50.8</td>
<td>2.3</td>
<td>0.0%</td>
</tr>
<tr>
<td>2011</td>
<td>51.3</td>
<td>2.7</td>
<td>0.0%</td>
</tr>
<tr>
<td>2012</td>
<td>51.6 (Estimated)</td>
<td>3.1</td>
<td>0.0%</td>
</tr>
</tbody>
</table>
In addition, large amounts of high quality reclaimed water were used in agriculture, landscaping and for ecological purposes.
2.4 Basic Water-energy-resource Nexus

- **Drinking water supply**
  - *Source separation toilet*
- **Energy**
  - Brown water
  - Anaerobic treatment
- **Yellow water**
  - Reclaimed water
  - Grey water
  - Water tank
  - BAF-MBR process
- **Water Recycle**
  - Ultraviolet disinfection
  - Biochar-struvite reactor
  - Separation and purification
  - Treated yellow water
  - Biochar organic fertilizer
  - Resource

- **Lake, landscape**
- **Disinfection**
- **Biogas**
- **Fermented residue**
- **Fermented liquid**
3. Implementation: Case studies
3. Implementation: Case studies

- **For a toilet:** Wastewater treatment and resource system (Tsinghua University, Beijing)
- **For a building:** Vacuum and source-separation system (Tsinghua University, Beijing)
- **For an Sponge campus:** Urban Stormwater Runoff BMPs Planning (Foshan)
- **For a modern urban community:** A closed scenic urban water system by treated stormwater using LID BMPs technology in a historical revitalization district (Suzhou)
- **For a City:** Reclaimed water utilization (Beijing)
Based on a source-separation toilet system separating faeces and urine at source, this project aims to research and develop combination processes of biochar adsorption and forward osmosis concentration for treating toilet wastewater to produce eco-fertilizer and clean water.
3.1 A new toilet system

Source separated toilet

Inside: Waste separated toilet and men's urinals, washbasins
3.2 A source-separation Building

Traditional sewer system

Source-separation system

Separating toilets

Storage tanks

School of Environment, Tsinghua University
3.2 A source-separation Building

Urine-diverting toilet

- Urine is collected separately through yellow water pipes, and then enters temporary storage tanks for 3~5 days.
- Both of the brown water and grey water are collected together into septic tank.
3.3 Urban Stormwater Runoff BMPs Planning

Guangdong College of Environment Protection: New campus in Foshan city
Site Information

New campus of Guangdong College of Environment Protection

New Campus

Yellow: constructed
Red: under construction
Climate
- Subtropical monsoon climate, Plenty of sunshine
- Annual average temperature: 22–23°C,
- Annual rainfall: 1622mm

Rainfall in Typical year

Topography

Land use

Drainage system

Soil characteristics

Data collection and analysis
Watershed Delineation
Preliminary selection of suitable LID-BMPs

<table>
<thead>
<tr>
<th>BMPs</th>
<th>Landuse type</th>
<th>Pollution load intensity</th>
<th>Landuse and Location</th>
<th>Soil type</th>
<th>Groundwater level to bottom of BMPs facility</th>
<th>Topography (°)</th>
<th>Watershed characteristics</th>
<th>Space occupied (hm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infiltration Trench</td>
<td>R,C,S,T,G</td>
<td>medium</td>
<td>Building distance &gt;3m</td>
<td>buffer</td>
<td>A-B &lt;3</td>
<td>&lt;15</td>
<td>&lt;2</td>
<td>&gt;0</td>
</tr>
<tr>
<td>Infiltration Basin</td>
<td>R,C,S,G</td>
<td>medium</td>
<td>Stream distance &gt;30m</td>
<td>buffer</td>
<td>A-B &lt;3</td>
<td>&lt;15</td>
<td>1-4</td>
<td>&gt;0</td>
</tr>
<tr>
<td>Dry Detention Pond</td>
<td>R,C,S,G</td>
<td>medium</td>
<td>Higher topography</td>
<td>buffer</td>
<td>A-D &gt;1.22</td>
<td>&lt;10</td>
<td>&gt;4</td>
<td>&gt;0</td>
</tr>
<tr>
<td>Wet-Detention Pond</td>
<td>R,C,S,G</td>
<td>medium</td>
<td>Stream distance &gt;30m</td>
<td>buffer</td>
<td>A-D &gt;1.22</td>
<td>&lt;10</td>
<td>&gt;6</td>
<td>&gt;0</td>
</tr>
<tr>
<td>Vegetated Filter Strip</td>
<td>R,C,S,M,T,G</td>
<td>high</td>
<td>Around Impervious surface</td>
<td>A-D &gt;0.61</td>
<td>&lt;5</td>
<td>&lt;10</td>
<td>0.5-5</td>
<td>&gt;0</td>
</tr>
<tr>
<td>Grassed Swale</td>
<td>R,C, S, T,G</td>
<td>medium</td>
<td>Road buffer distance &lt;30m</td>
<td>A-D &gt;0.61</td>
<td>&lt;5</td>
<td>&lt;10</td>
<td>0.5-5</td>
<td>&gt;0</td>
</tr>
<tr>
<td>Constructed Wetland</td>
<td>R,C,G</td>
<td>medium</td>
<td>Stream distance &gt;30m</td>
<td>buffer</td>
<td>B-D &gt;1.22</td>
<td>4-15</td>
<td>&gt;10</td>
<td>&gt;0</td>
</tr>
<tr>
<td>Sand Filter</td>
<td>R,C,M,T</td>
<td>medium</td>
<td>Stream distance &gt;30m</td>
<td>buffer</td>
<td>A-D &gt;0.61</td>
<td>&lt;10</td>
<td>&lt;40</td>
<td>0-50</td>
</tr>
<tr>
<td>Green Roof</td>
<td>R,C,M</td>
<td>low</td>
<td>Flat roof</td>
<td></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Rain Barrel</td>
<td>R,C</td>
<td>low</td>
<td>Building buffer distance &lt;10</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
Basic scenario: the previous development scheme

Drainage System simplification

Reclassification of Landcover: Roof; Road; Grass; water

Basic scenario

Water Quantity simulation
- Total runoff
- Peak flow

Water Quality simulation
- COD
- SS
- TN
- TP
Scenario: The least-cost scenario

Maximum efficiency scenario

LID-BMPs Scenarios Design

Legend:
- Green Roof
- Bioretention
- Grassed Swale
- Rain Barrel
- Simplified Rain well
- Exit Rain well
- Runoff Transportation Way
- Roof
- Road
- Green Space
- Water
- Rain Barrel
- Wet Detention Pond
- Grassed Swale
- Simplified Rain Well
- Porous Pavement
- Exit Rain Well
- Runoff Transportation Way
LID-BMPs Scenarios Simulation

Pollutants removal

- COD: +53.1% (Pre-development), +24% (Basic scenario), +5.1% (Least-cost BMP scenario), +3% (Maximum efficiency BMP scenario)
- SS: +12.9% (Pre-development), -45.1% (Basic scenario), +13.8% (Least-cost BMP scenario), +25.9% (Maximum efficiency BMP scenario)
- TN (Expand ten times): -19% (Pre-development), -38.9% (Basic scenario), -6% (Least-cost BMP scenario), -19.1% (Maximum efficiency BMP scenario)
- TP (Expand one hundred times): -10.9% (Pre-development), -38.9% (Basic scenario), -6% (Least-cost BMP scenario), -19.1% (Maximum efficiency BMP scenario)
A closed scenic urban water system by treated stormwater using LID BMPs technology in a historical revitalization district
Along with the rapid urbanization, many cities have faced serious urban water system problems:
  – water area was decreased
  – river was truncated

Numbers of blocked off river and closed water system became more and more, which has weak self-purification ability and degraded ecosystem

How to incorporate the LID strategy in the new urban development or old urban revitalization has been the focus.
Suzhou, an important historical city, water pollution control and urban river rehabilitation have been the main task.

A revitalization project of the Taohuawu Cultural District in Suzhou old historical area is proposed.

Taohuawu Cultural District is the former residence areas of Tang Yin, a very famous Chinese scholar, painter, and poet of the Ming Dynasty period.

There were river and lotus ponds in the past. However, all the water bodies are missing now.

In the revitalization project, the restoration of the disappeared river system is included.
The roadmap of research

- Investigation and analysis of study area
- Regional situation and development requirements

Planning objectives of LID BMPs
- Rainwater harvest
- Rainwater treatment
- Waterlogging control

Selection of suitable LID BMPs

Engineering planning of LID BMPs

Effect assessment of LID BMPs

Water quantity requirement
- Water quantity maintenance of closed water system

Water quality objective
- Water quality maintenance of closed water system

Pollution loads assessment

Water sources deployment
- Water pollution load removal measure
The primary objective of the LID BMPs planning is to
- select the suitable LID BMPs according to the local condition, and then
- draft the integrated LID BMPs scheme to harvest and treat the local runoff to serve as the water sources for Taohuawu closed water system.

Meanwhile, considering the increasing of storm disasters in recent years, the secondary objective is to reduce waterlogging disasters in Taohuawu by LID BMPs facilities.
There are many types of LID BMPs and each type has its own technical and/or economical characteristics and limitations for installation.

A multi-criteria selection index system was proposed considering the characteristics of regional suitability, runoff control, and economics.

According to the local condition, bioretention cell, permeable pavement, infiltration pit, grassed swale, buffer strip, and constructed wetland are selected.

The treated stormwater by bioretention cell, permeable pavement, and infiltration pit et al. are then harvested through pervious pipe system linked with closed waters system.
LID BMPs selection and planning scheme

Stormwater runoff from most areas would be collected and treated.

- The total area of LID facilities in Taohuawu are 3303 m², 4.8% of the whole:
  - constructed wetland 1718 m²,
  - bioretention cell 337 m²
  - permeable pavement 300 m²
  - grassed swale 445 m²
  - infiltration pit 288 m²
  - buffer strip is 215 m²
Water quantity maintenance

- The development of runoff simulation model
  - EPA-SWMM based Taohuawu urban runoff simulation model was developed

- Effect assessment on rainwater harvest
  - a typical Suzhou average year (2005) data
  - total annual rainfall is 45,346 m³

<table>
<thead>
<tr>
<th></th>
<th>Scenario 1 (m³)</th>
<th>Scenario 2 (m³)</th>
<th>Change ratio (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Runoff could be used</td>
<td>0</td>
<td>7598</td>
<td>/</td>
</tr>
<tr>
<td>Runoff could not be used</td>
<td>29700</td>
<td>17877</td>
<td>-39.81</td>
</tr>
<tr>
<td>Infiltration</td>
<td>10021</td>
<td>14316</td>
<td>42.86</td>
</tr>
<tr>
<td>Evaporation of river and lake</td>
<td>5555</td>
<td>5555</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>45346</td>
<td>45346</td>
<td>0</td>
</tr>
</tbody>
</table>
Water quantity maintenance

• Water quantity requirement
  – It includes the water replenishment for evaporation, leakage and the water consumption by on-site filtration equipment.
  – According to the local conditions, the water requirement are calculated. The annual total is about 21,802 m$^3$. The monthly demand is between 1,540 – 2,038 m$^3$.

• Water sources deployment
  – types of water: harvest rain water, groundwater.
  – Harvested rainwater priority.
  – Due to seasonal variation, local groundwater is used as the supplemented to guarantee the water quantity requirement.
Water quantity maintenance

- it could be found that
  - In wet season, rainwater could be the main source, and the maximum monthly groundwater water requirement is 914 m$^3$.
  - In dry season, groundwater is the only water sources. The maximum monthly groundwater water requirement is 1855 m$^3$.
  - The total annual water requirement is 21,802 m$^3$, in which, 7,598 m$^3$ by harvested rainwater, 14,204 m$^3$ by groundwater.
  - the amount of infiltration by LID BMPs facilities is 14,316 m$^3$. It could be considered that the closed water system could maintain water quantity by itself.
**Water quantity maintenance**

- **Effect assessment on flood control**
- Flooding would not occur in the stormwater with 5 years recurrence interval in scenario 2.
- Even in the stormwater with 20 years recurrence interval, the flooding situation is not serious in scenario 2.
- **Water quality objectives**

  - Based on the comprehensive analysis of beneficial use and the ecological function of the closed water system, Class V in GB3838-2002 is chosen as the water quality objectives.

  - NH$_3$-N, TN and TP are selected as the main concerned water quality indicator

<table>
<thead>
<tr>
<th>Indicator</th>
<th>DO$\geq$</th>
<th>COD$_{Mn}$ $\leq$</th>
<th>COD$_{Cr}$ $\leq$</th>
<th>BOD$_5$$\leq$</th>
<th>NH$_3$-N$\leq$</th>
<th>TP$\leq$</th>
<th>TN$\leq$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Values</strong></td>
<td>3</td>
<td>10</td>
<td>30</td>
<td>6</td>
<td>1.5</td>
<td>0.3</td>
<td>1.5</td>
</tr>
</tbody>
</table>
Water quality maintenance

- Pollution loads assessment and the required pollution loads removal rate
  - All the loads are from diffuse pollutants.
  - Export Coefficient Model is used.
  - pollution removal rate is about 60%.

<table>
<thead>
<tr>
<th>Underlying surface</th>
<th>Areas proportion</th>
<th>TP (mg/L)</th>
<th>TN (mg/L)</th>
<th>NH₃-N (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road</td>
<td>31.15%</td>
<td>0.28</td>
<td>5.10</td>
<td>3.00</td>
</tr>
<tr>
<td>Green space</td>
<td>12.70%</td>
<td>0.20</td>
<td>4.00</td>
<td>1.80</td>
</tr>
<tr>
<td>Yard</td>
<td>9.90%</td>
<td>0.28</td>
<td>4.90</td>
<td>2.70</td>
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<tr>
<td>Piazza</td>
<td>6.76%</td>
<td>0.28</td>
<td>4.90</td>
<td>2.70</td>
</tr>
<tr>
<td>Building</td>
<td>39.50%</td>
<td>0.22</td>
<td>4.50</td>
<td>2.10</td>
</tr>
<tr>
<td>The aggregated water quality of runoff</td>
<td></td>
<td>0.25</td>
<td>4.69</td>
<td>2.44</td>
</tr>
<tr>
<td>Water quality objectives</td>
<td></td>
<td>0.40</td>
<td>2.00</td>
<td>2.00</td>
</tr>
<tr>
<td>Pollution processing degree</td>
<td></td>
<td>0.00</td>
<td>57.4%</td>
<td>18.1%</td>
</tr>
</tbody>
</table>
Water quality maintenance

• Water pollution load removal measure and water quality maintenances
  – LID BMPs facilities are used as the first step to reduce the pollution loads, reduce about 35-50% of the pollutants by model assessment.
  – Then, integrated with the hydraulic optimization, a continuous on-site river water filtration equipment will be built to purify the urban water
Water quality maintenance

• Hydraulic optimization
  – 1.5KW flow-pushing device with 360 m³/h.

• Ecological river
  – Floating islands
  – Ecological bank
3.5 For a City: Reclaimed water utilization in Beijing

Beijing highly values the importance of reclaimed water.

Reclaimed water was taken into consideration when balancing the allocation of water resources, which simultaneously resulted in relief in the water resources crisis and in the reduction of pollutants discharge.

In 2012, reclaimed water usage in Beijing was 750 million m$^3$, which was nearly 60% of the total wastewater treated and accounted for 20% of all the water consumed (including agriculture).
Reclaimed water in Beijing

Structure of total water consumption in Beijing in 2000-2012 (including agriculture)
Reclaimed water usage in different sectors in Beijing in 2011

- Industrial cooling: 21.10%
- Agricultural irrigation: 39.40%
- Waterscape supplement: 35.20%
- Municipal (grassland irrigation, car washing, road and toilet flushing): 4.20%
Qinghe Reclaimed Water Plant in Beijing, largest using Membrane (500,000m3/d)

Beixiaohe Reclaimed Water Plant in Beijing, using RO
Reclaimed Water Usage in Beijing

- Grassland Irrigation
- Agricultural Irrigation
- Road Flushing
- Reclaimed Water Filling Auto-service Station in Beijing
Reclaimed Water Usage in Beijing

- **Huaneng Power Plant** using reclaimed water for cooling
- **The Birds Nest** using reclaimed water for landscape
- **Yuanmingyuan Park** using reclaimed water for landscaping
- **Beitucheng River** using reclaimed water as a supplement
Thank you for your attention !!!

Questions and Comments ??

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