SUSTAINABLE URBAN WATER MANAGEMENT

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URBAN WATER MANAGEMENT
Reductionism versus Systems Analysis

“There will always be room for engineering reductionism but the greatest sustainability gains in the 21\textsuperscript{st} century will be from systems analysis.”
Role of Nature in Improving Urban Water Quality

Nature plays an important role in keeping water sources reliable and clean.

According to research conducted by The Nature Conservancy (TNC) and IWA, reducing sediment and nutrients in water supplies by 10% could lead to a reduction of about 5% in treatment costs.

This makes a compelling case for local governments and water utilities to invest in conservation, enabling utilities to reduce their capital expenditures over time by using cheaper treatment technologies rather than upgrading to more complex, expensive ones.

Source: The Nature Conservancy; IWA
12 Principles of Infrastructure

Ecology

1. Interconnect rather than segregate
2. Integrate material, energy & water flows
3. Manage inherent complexity
4. Account for systems dynamics
5. Decentralize to increase response diversity and modularity
6. Maximize sustainability and resilience of material & energy investment
7. Find synergies between engineered & ecological systems
8. Take stakeholder preferences into account
9. Maximize the creation of comfort & wealth
10. Take advantage of socioeconomics as a driver in achieving change.
11. Require adaptive management as the policy strategy
12. Utilize renewable flows rather than depleting stocks
Sustainable Water Resources Management

Agriculture

Ecology / Environment

Energy

People (Municipal & Industrial)
Typical Water Resources Demand Profile in an Urban Watershed

- Thermoelectric; 39%
- Irrigation; 39%
- Urban Farming
- Decentralized Energy Production
- Industrial; 5%
- Aquaculture; 1%
- Livestock; 1%
- Domestic; 1%
- Mining; 1%
- Public Supply; 13%
- Decentralized Water Production (LID)
## Water Footprint of Agricultural Products

<table>
<thead>
<tr>
<th>Crops</th>
<th>Water Needed (in gallons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Orange</td>
<td>13.8</td>
</tr>
<tr>
<td>1 Head of Broccoli</td>
<td>5.4</td>
</tr>
<tr>
<td>1 Walnut</td>
<td>4.9</td>
</tr>
<tr>
<td>1 Tomato</td>
<td>3.3</td>
</tr>
<tr>
<td>1 Almond</td>
<td>1.1</td>
</tr>
<tr>
<td>1 Pistachio</td>
<td>0.75</td>
</tr>
<tr>
<td>1 Strawberry</td>
<td>0.4</td>
</tr>
</tbody>
</table>

**Virtual Water**

- 4500 litres of water for one steak (300g) of Beef
- 14400 litres of water for one steak (300g) of Pork
- 11700 litres of water for one breastfilet (300g) of Chicken
‘Water for Energy’ and ‘Energy for Water’ in US

**Water for Energy**

- Thermoelectric power generation accounts for ~ 52% of fresh surface water withdrawals.
- The average (weighted) evaporative consumption of water for power generation over all sectors is around 2.0 Gal/kWh.

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>Gal/kWh (Evaporative loss)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydro</td>
<td>18.27</td>
</tr>
<tr>
<td>Nuclear</td>
<td>0.62</td>
</tr>
<tr>
<td>Coal</td>
<td>0.49</td>
</tr>
<tr>
<td>Oil</td>
<td>0.43</td>
</tr>
<tr>
<td>PV Solar</td>
<td>0.030</td>
</tr>
<tr>
<td>Wind</td>
<td>0.001</td>
</tr>
</tbody>
</table>

**Energy for Water**

- About 4% of the total electricity consumption in the US is for the water and wastewater sector.
- Of the total energy required for water treatment, 80% is required for conveyance and distribution.

<table>
<thead>
<tr>
<th>Water Treatment*</th>
<th>kWh/MGal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface Water Treatment</td>
<td>220</td>
</tr>
<tr>
<td>Groundwater Treatment</td>
<td>620</td>
</tr>
<tr>
<td>Brackish Groundwater Treatment</td>
<td>3,900-9,700</td>
</tr>
<tr>
<td>Seawater Desalination</td>
<td>9,700-16,500</td>
</tr>
</tbody>
</table>

*Includes collection but does not include distribution
Water for Primary Energy in US

Water for Fuel Extraction and Processing

- Cellulosic ethanol: 90 gallons/MMBtu
- Corn ethanol: 1010 gallons/MMBtu
- Coal + coal to liquid: 50 gallons/MMBtu
- Natural gas + gas to liquid: 43 gallons/MMBtu
- Oil sands: 30 gallons/MMBtu
- Oil (enhanced oil recovery): 76 gallons/MMBtu
- Oil (primary - secondary): 73 gallons/MMBtu
- Uranium mining + enrichment: 9.5 gallons/MMBtu
- Coal + slurry pipeline: 9 gallons/MMBtu
- Coal mining + washing: 4 gallons/MMBtu
- Natural gas + transportation: 3 gallons/MMBtu

Water Consumption (Gallons/MMBtu)
Water for Transportation: Impact of Fuel Types and Vehicle Technologies

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>Life-cycle Water Consumption Per Vehicle Mile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal + Carbon sequestration</td>
<td>0.77 Gallons per vehicle mile traveled</td>
</tr>
<tr>
<td>Solar PV</td>
<td>0.59</td>
</tr>
<tr>
<td>Concentrated Solar Power</td>
<td>0.79</td>
</tr>
<tr>
<td>Unleaded</td>
<td>0.32</td>
</tr>
<tr>
<td>Corn ethanol</td>
<td>4.35</td>
</tr>
<tr>
<td>Switchgrass—no irrigation</td>
<td>0.44</td>
</tr>
<tr>
<td>Switchgrass—irrigation</td>
<td>12.25</td>
</tr>
<tr>
<td>Soy biodiesel</td>
<td>2.45</td>
</tr>
<tr>
<td>Algae biodiesel—open</td>
<td>3.85</td>
</tr>
<tr>
<td>Algae biodiesel—closed</td>
<td>0.97</td>
</tr>
</tbody>
</table>

Plug-in hybrid electric vehicle (PHEV) | Conventional (internal combustion engine)

(Source: Harto, C; et al., Life cycle water use of low-carbon transport fuels, Energy Policy, 2010)
Water for Mobility Network: Vehicle Electrification
Metro Atlanta, 2010 and 2030 Conditions

Source: Jeffrey Yen (2011) A system model for assessing water consumption across transportation modes in urban mobility networks, Masters thesis
SYSTEMS APPROACHES FOR URBAN WATER MANAGEMENT
Land Use and Population Density of
Eleven Residential Communities

<table>
<thead>
<tr>
<th>Zoning Code</th>
<th>People/Acre</th>
</tr>
</thead>
<tbody>
<tr>
<td>R-1</td>
<td>1.6</td>
</tr>
<tr>
<td>R-2</td>
<td>3.1</td>
</tr>
<tr>
<td>R-3</td>
<td>7.2</td>
</tr>
<tr>
<td>R-4</td>
<td>13.8</td>
</tr>
<tr>
<td>R-5</td>
<td>16.9</td>
</tr>
<tr>
<td>RG-1</td>
<td>14.7</td>
</tr>
<tr>
<td>RG-2</td>
<td>31.6</td>
</tr>
<tr>
<td>RG-3</td>
<td>63.2</td>
</tr>
<tr>
<td>RG-4</td>
<td>135.2</td>
</tr>
<tr>
<td>RG-5</td>
<td>290.4</td>
</tr>
</tbody>
</table>

Legend:
- Indigenous open space
- Irrigated open space
- Paved area
- Rooftop area
Low Impact Development - LID Best Management Practices (BMPs)

Rain Gardens for local flood control at Cuyahoga Falls, OH¹.

Green roof of City Hall in Chicago, IL.

Rainwater Harvesting tanks for residential water supply at Perth, Australia².

Increased walkability through greening of alleyways at Vancouver.

Porous parking lot at the Reliant stadium, Houston, TX³.
LID: Flood Control Capability

For extreme rainfall events (Atlanta)

<table>
<thead>
<tr>
<th>Return period</th>
<th>Rainfall intensity, in./24hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-yr</td>
<td>3.36</td>
</tr>
<tr>
<td>2-yr</td>
<td>4.08</td>
</tr>
<tr>
<td>5-yr</td>
<td>4.8</td>
</tr>
<tr>
<td>10-yr</td>
<td>5.52</td>
</tr>
<tr>
<td>25-yr</td>
<td>6.48</td>
</tr>
<tr>
<td>50-yr</td>
<td>7.2</td>
</tr>
<tr>
<td>100-yr</td>
<td>7.92</td>
</tr>
</tbody>
</table>

Rain gardens occupying 11 % (R-1) ~ 16% (RG-6) of community size control 100 % of stormwater runoff generated in extreme rainfall events up to 8 in.
Water Flows within the Urban System with LID Implementation: Case Study of Atlanta, GA

- Individual water use (91 Gpcd) in 2-story apartment (RG-1)
- **Implemented LID technologies**: rainwater harvesting, grass pavement, rain gardens, and xeriscaping
- Reduces dependence on the centralized potable water system by ~50% (entire non-potable demand)
- Uncontrolled Stormwater runoff: None even for a 100 year storm

![Diagram of water flows](image-url)
Life-Cycle Analysis of LID Techniques for Stormwater Management

CWTS: centralized wastewater treatment system; CWSS: centralized water supply system; CSS: combined sewer system; SSS: separate sewer system
CI: Centralized Infrastructure
HI: Hybrid Infrastructure (Centralized+ LID)

<table>
<thead>
<tr>
<th>Infrastructure Type</th>
<th>Wastewater (CWTS)</th>
<th>Water (CWSS)</th>
<th>Rainwater harvesting</th>
<th>Stormwater (CSS)</th>
<th>Stormwater (SSS)</th>
<th>Stormwater (rain garden)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R-1</td>
<td>1.6 Person/acre</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R-5</td>
<td>16.9 Person/acre</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RG-1</td>
<td>14.7 Person/acre</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RG-5</td>
<td>290.4 Person/acre</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

% of annual world average environmental load per capita

1.6 Person/acre
16.9 Person/acre
14.7 Person/acre
290.4 Person/acre
Typical Greywater Reclamation System at the Household Level

Approved by the N.S.W. Department of Health

Used to treat grey-water, bathwater, hand basin water and washing machine water to acceptable Department of Health standards for re-cycle and re-use to flush toilets, car washing, garden irrigation and even re-filling washing machines.

Note: N.S.W. denotes New South Wales, Australia

Water Flows within the Urban System with Reclamation Option: Case Study of Atlanta, GA

- Individual water use (91 Gpcd) in 2-story apartment (RG-1)

Smaller Flow, More Concentrated; Smaller Plant: Better energy and nutrient recovery.
Energy Required for Greywater Reclamation with Membrane Bioreactor

\[ y = 25.583x^{-0.326} \]

\[ R^2 = 0.8569 \]
Comparative Life-Cycle Analysis of Centralized and Hybrid Infrastructure (CI and HI)

Hybrid Infrastructure combines Greywater Reclamation for non-potable use with centralized supply for potable use only.
Potential of Water Supply by Combining Greywater Reclamation & Rainwater Harvesting

<table>
<thead>
<tr>
<th>Zoning code (people/acre)</th>
<th>Total water demand, MGal/yr</th>
<th>% supplied by greywater reclamation</th>
<th>% supplied by rainwater harvesting</th>
<th>% supplied by greywater reclamation and rainwater harvesting</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1 (1.6)</td>
<td>0.64</td>
<td>100%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>R2 (3.1)</td>
<td>1.05</td>
<td>60%</td>
<td>40%</td>
<td>100%</td>
</tr>
<tr>
<td>R3 (7.2)</td>
<td>2.21</td>
<td>40%</td>
<td>60%</td>
<td>100%</td>
</tr>
<tr>
<td>R4 (13.8)</td>
<td>4.10</td>
<td>20%</td>
<td>80%</td>
<td>100%</td>
</tr>
<tr>
<td>R5 (16.9)</td>
<td>4.98</td>
<td>20%</td>
<td>80%</td>
<td>100%</td>
</tr>
<tr>
<td>RG-1 (14.7)</td>
<td>4.42</td>
<td>20%</td>
<td>80%</td>
<td>100%</td>
</tr>
<tr>
<td>RG-2 (31.6)</td>
<td>9.27</td>
<td>20%</td>
<td>80%</td>
<td>100%</td>
</tr>
<tr>
<td>RG-3 (63.2)</td>
<td>18.35</td>
<td>20%</td>
<td>80%</td>
<td>100%</td>
</tr>
<tr>
<td>RG-4 (135.2)</td>
<td>39.15</td>
<td>20%</td>
<td>80%</td>
<td>100%</td>
</tr>
<tr>
<td>RG-5 (290.4)</td>
<td>83.88</td>
<td>20%</td>
<td>80%</td>
<td>100%</td>
</tr>
</tbody>
</table>
Life Cycle Assessment: Impacts on Human and Ecosystem Health, Resource Damage

- Centralized infrastructure was similar to hybrid infrastructure (LID plus Smaller Centralized Infrastructure) for all zoning codes and no uncontrolled stormwater runoff occurred for even a 100 year storm (does not consider storm water impacts)

- Grey water reclamation had a much higher LCA score for lower density developments because of greater energy demand for smaller reclamation facilities (Does not consider smaller flow, energy and nutrient recovery)
System-based Benefits of LID Best Management Practices

Water Resources
- Rainwater
- Surface water
- Groundwater
- Reclaimed water

Water Retained/Slowed by Green Infrastructure

Green Infrastructure

Wastewater/Stormwater
- Storm sewers
- Combined sewers
- Wastewater systems

More Concentrated Wastewater

Reduced/Delayed Flow

Enables:
- Energy Efficiency and Recovery (reduces energy demand)
- Nutrient Recovery (can be utilized for green infrastructure projects)

Transportation Infrastructure
- Pedestrian walkways
- Cycling

Food Infrastructure
- Urban agriculture

Energy Infrastructure
- Reduced heat island

Can Enhance Other Infrastructures

Social Benefits
- Well-being
- Public health
- Property values
- Urban gardens

Water & Wastewater
- Stormwater management
- Stormwater treatment
- Water recharge
INFRASTRUCTURAL SYMBIOSIS

Saving Water by Switching to Decentralized Energy Production: Combined Heating, Cooling and Power (CCHP)
Recapturing Lost Heat in Combined Heat & Power System

Separate Electric Power

Combined Heat and Power

Electricity

Eliminates the need of ‘Water for Energy’
Decentralized Energy Production at Perkins + Will, Atlanta Office

- Microturbines are used to for heating and cooling using Absorption Chillers and supply 40% of the total electricity.

**Adding Distributed Generation as part of the Grid:**

- **Water Reduction:** >50%
- **CO\textsubscript{2} Reduction:** 15 - 40%
- **NO\textsubscript{x} Reduction:** ~90%

![Absorption Chiller](image1)

![65 kW Microturbine](image2)

![Perkins+Will Office Building](image3)
The SMARTRAQ project

- Supports research on land use impact on transportation and air quality
- 1.3 million parcels in the 13 metropolitan Atlanta non-attainment counties
SMARTRAQ Data and Attributes

- Address
- Road Type
- City
- Zip Code
- Owner Occupied
- Commercial/Residential
- Zoning
- Sale Price
- Sale Date
- Tax Value
- Assessed Value
- Improvement Value
- Land Value
- Year Built
- No. of Stories
- Bedrooms
- Parking
- Acreage

- Land Use Type
- Number of Units
- X,Y Coordinate
- Estimated Sq Feet
- Total Sq Feet
Projected Growth Scenarios for Atlanta

Business As Usual
Year 2030

More Sustainable Development
Year 2030
Atlanta Water Demand Projections for More Compact Growth (with low flow fixtures + decentralized CCHP system)

Installation of Air Cooled Microturbines Save 2.4 times the amount of water used for domestic consumption

Water Demand (Withdrawal)

Water Consumption (Evaporation)
Potential GHG and Cost Reductions in 2030

By 2030, implementation of CHP in all new residential and commercial buildings will reduce the CO$_2$ emissions by ~ 0.007 Gt CO$_2$, NOx emissions by ~ 15000 Tons, and the energy costs by $680 million per year for the Metro Atlanta region.

<table>
<thead>
<tr>
<th>CO$_2$ Emissions</th>
<th>NO$_x$ Emissions</th>
<th>Energy Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>NoCCHP</td>
<td>25,000</td>
<td>$10</td>
</tr>
<tr>
<td>CCHP only</td>
<td>20,000</td>
<td>$9</td>
</tr>
</tbody>
</table>

- CO$_2$ Emissions: -23%
- NO$_x$ Emissions: -65%
- Energy Cost: -8%
INFRASTRUCTURAL SYMBIOSIS

Harnessing the synergistic benefits of coupled urban infrastructure systems
Water as a Heat Source: False Creek Neighborhood Energy Utility Vancouver, BC

Sewage heat recovery supplies 70% of annual energy demand and reduces GHG emission by 50%
Future Research: Expanding the Current CCHP System 2.0

Conventional System

Proposed CCHP System

Alternative 1: Thermal Storage

Absorption Chiller

Alternative 2: Battery/Electric Vehicle

Alternative 3: Photovoltaics

Wind
## Controlled Environment Agriculture (CEA) Hydroponic Indoor Farms vs. Traditional Field Growth

<table>
<thead>
<tr>
<th></th>
<th><strong>CEA Fresh Farms Romaine (Local Grown, Georgia)</strong></th>
<th><strong>Field-Growth Romaine (California)</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Land Requirements</td>
<td>20 Acres</td>
<td>620 Acres</td>
</tr>
<tr>
<td>Leafy Green Production Yields Per Year</td>
<td>33 Million Heads</td>
<td>33 Million Heads</td>
</tr>
<tr>
<td>Fossil Fuel used during Growth Cycle (not including crop transport)</td>
<td>200 Gallons equiv. Diesel</td>
<td>3,720 Gallons Diesel</td>
</tr>
<tr>
<td>Food Miles</td>
<td>100 miles/truckload</td>
<td>2,577 miles/truckload</td>
</tr>
<tr>
<td>Fossil Fuel to Transport 100 Miles or CA to Local Markets (GA)</td>
<td>22,200 Gallons Diesel</td>
<td>571,000 Gallons Diesel</td>
</tr>
<tr>
<td>Carbon Footprint</td>
<td>3,000 metric ton CO2</td>
<td>12,000 metric ton CO2</td>
</tr>
<tr>
<td>Fresh Water used during Growth Cycle</td>
<td>1.2 Gallons per Head</td>
<td>9-42 Gallons per Head</td>
</tr>
<tr>
<td>Fresh Water Used to Wash Lettuce per heat for market</td>
<td>0.7 Gallons-One Washing per Head</td>
<td>2.5 Gallons - Three Washings per Head</td>
</tr>
<tr>
<td>Total Fresh Water Annually</td>
<td>64 Million Gallons</td>
<td>0.3-1.5 Billion Gallons</td>
</tr>
<tr>
<td>Time from Harvest to Market</td>
<td>6-12 Hours</td>
<td>4-7 Days</td>
</tr>
</tbody>
</table>
CLOSING THE URBAN WATER, NUTRIENT AND CARBON LOOP: URBAN FARMING - COMBINED CARBON CAPTURE, COOLING, HEAT AND POWER

- **Stormwater Management with Low-Impact Development**
  - More Concentrated Wastewater
  - Stormwater treated through LID
  - Harvested Rainwater

- **Urban Agriculture** (Aquaponics, Urban Farming, Greenhouse Farm)
  - Fertilizer for Farms, Food for Aquaponics
  - Harvested Rainwater
  - Heat and Energy
  - CO2 Injection

- **On-site Energy and Nutrient Recovery**
  - Source of Fertilizer
  - Natural Gas from Compost
  - Natural Gas from Anaerobic Digestion
  - Natural Gas from Air-cooled microturbines

- **Combined Carbon Capture, Cooling, Heating and Power**
  - Heat and Energy
  - Heat
  - Natural Gas from Compost

**Natural Gas**

**Heat and Energy**

**Water**

**Fertilizer**

**CO2**
Unsustainable Animal Farming

Resource and pollution
• Livestock uses 30% of the world’s ice-free landmass (geoengineering)
• Livestock produces 14.5% of all greenhouse emissions

Food and water consumption: 1kg (2.2lb) meat

- 2.5kg feed
  - 5.5 lb
- 3.8m³ water
  - 1000 gallons

- 5kg feed
  - 11 lb
- 5.5m³ water
  - 1500 gallons

- 10kg feed
  - 22 lb
- 16.7m³ water
  - 4400 gallons

Growing appetite for MEAT!

Population growth

- 2015: 7.2 billion
- 2050: 9 billion

Source: Green Food. Economist Technology Quarterly Q1 2015
Green Food: Urban Farms??

- Sustainable “Meat” and “Dairy” from Plants
  (14,000 species of plants and each plant species has 1000s of proteins)

Tech Startups are trying to create plant-based foods

• Cheaper
• Healthier
• Satisfying as animal-based products
• MUCH LOWER ENVIRONMENTAL IMPACT

Mimic the taste of animal-derived foods with plants

Enormous efficiency in terms of energy, water and other inputs

Source: Green Food. Economist Technology Quarterly Q1 2015
Examples of “Green Foods”

- Plant-based chicken strips
  *Beyond Meat*

- Eggless mayonnaise
  *Hampton Creek*

- Plant “beef” burger patty
  *Impossible Foods (Rancid Polenta)*

- Beverage as complete substitute for food
  *Soylent (Occasional Recreational Eating)*

Source: Green Food. Economist Technology Quarterly Q1 2015
Transit-oriented Development: Reduce Water Demand for Transportation

• Creation of compact, walkable, mixed-use communities centered on high quality public transit services

• Affordable housing
• Walkable community
• Mixed land use
• Reasonable density
• Multiple modes of transport
The Connection between Autonomous Vehicles and Water

- 80% penetration of autonomous vehicles
- 28% of the cars we have today
- At least 72% reduction in parking space
- 24.7% reduction of impervious area and stormwater runoff
- Additional 17% of city land for green space and stormwater management
The Synergistic Effects of “Infrastructural Symbiosis”

The accumulated synergistic effects:

- reduced water and energy consumption,
- lower dependence on centralized systems,
- larger share of renewables in the electricity mix,
- reduced vehicle-miles travelled, &
- an increase in tax revenue.
Summary

• Sustainable water resources management needs to consider all sectors that exert demand on a watershed.

• Decentralized stormwater management using Low Impact Development can control the runoff of a 100-yr rainfall event.

• Combining rainwater harvesting with greywater reclamation can supply
  • 100% of water demand for single-family residences, and
  • 60% water demand for multi-family homes.

• Significant water savings can be achieved through switching the mode of energy supply.

• Caveat: We need to test the ideas that were presented
THANK YOU!

John C Crittenden, Ph.D., P.E., U.S. and Chinese N.A.E.
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Web Site: http://www.sustainable.gatech.edu/