A Vision for Futuristic Applications of Rainwater Harvesting Systems

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Green Water-Infrastructure Academy
Washington, D.C.

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Enhance human health and quality of life in global urban environments by promoting green water-infrastructure research, education and outreach programs.

Goals

• Offer seminars and workshops, and host symposia

• Provide financial assistance to undergraduate and graduate students in the form of small grants and fellowships

• Award small grants to entities interested in conducting green water-infrastructure research
The Constant Process in Planet Earth and Human Life – The Hydrological Cycle

Hydrological Cycle

Ocean Precipitation 373
Ocean Evaporation 413
Ice 26,350
Ocean 1,335,040
Surface flow 40
Ground water flow

Atmosphere 12.7
Ocean to land
Water vapor transport 40
Land Precipitation 113
Evaporation, transpiration 73
Rivers

Soil moisture 122
Lakes 178
Vegetation

Land Percolation
Permafrost 22
Groundwater 15,300

Units: Thousand cubic km for storage, and thousand cubic km/yr for exchanges

Source: University Corporation for Atmospheric Research
Contents of This Presentation

• Causes of the Hydrologic Cycle impairment and its consequences

• The potential of rainwater harvesting in healing the Hydrological Cycle and creating a global sustainable water management system

• Integrating advanced support technologies in futuristic applications of rainwater harvesting systems
Causes and Consequences of Hydrologic Cycle Impairment

- Deforestation
- Intensive Land Development and Urbanization
- High Water Demand and Consumption
- Intensive Agriculture
- High Energy Demand and Consumption
Problem 1: 20\textsuperscript{th} Century Urbanization

“Every day, America loses more than 4,000 acres of open space to development; that’s more than 3 acres per minute”

USDA Forest Service
Over 80% of the U.S. Population Live in Urban Areas

Metropolitan and nonmetropolitan counties, 2013

Urbanization: Combination of Land Development and Population Growth

Example: Washington DC Population

1800 - 8,144  
2015 - 672,228
Impact of Urbanization on Natural Landscape and Water Flow

Source: Stream Corridor Restoration, 1998
Impact of Urbanization on Groundwater

Half-Empty Aquifers across the United States

Source: USGS
http://www.epa.gov/WaterSense/pubs/supply.htm
The Impact of Land Development on Floodplain

Source: Chester County, PA Planning Commission
Urban Flooding

In the U.S., an estimated **10 trillion gallons a year** of untreated stormwater runs off from roofs, roads, parking lots, and other paved surfaces into rivers and waterways (NRDC 2013).
Impact of Stormwater Runoff on Ecosystems

Stormwater runoff contains many contaminants that enter streams/rivers/lakes:

- Metals - particularly zinc, copper and lead
- organic compounds including pesticides, fungicides, hydrocarbons in oil and grease, etc.
- Sediment
- Nutrients (N, P)
- Pathogens

Urban stormwater runoff is a major incentive for the TMDL Program to protect and improve the quality of surface waters in the United States (The Clean Water Act 1972)
Problem 2: High Water Consumption

SOURCE: Maupin et al. (2014).
Trends in U.S. freshwater withdrawals and population growth. SOURCE: Maupin et al. (2014)
Population growth is high in water-stressed areas

Problems could be exacerbated by climate change
Problem 3: High Energy Demand and Consequences

Steam powered pump (1800s)
Fossil-Fuel Based Energy Consumption and CO2 Emission

Thermoelectricity Generation

Agriculture

Urban Infrastructure

Transportation

Water Infrastructure
Water and Energy Nexus

Source: Eric Webb
<table>
<thead>
<tr>
<th>Power Generation Method</th>
<th>Low Range Efficiency Gallons/MBTU</th>
<th>High Range Efficiency Gallons/MMBTU</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydroelectric</td>
<td>20</td>
<td>N/A</td>
<td>USDOE 2006; Gleick 1994; EIA 2008</td>
</tr>
<tr>
<td>Fossil Fuel Thermoelectric</td>
<td>1100</td>
<td>2200</td>
<td>USDOE 2006; Hutson et. Al 2004</td>
</tr>
<tr>
<td>Geothermal</td>
<td>130</td>
<td>N/A</td>
<td>USDOE 2006; EIA 2008</td>
</tr>
<tr>
<td>Nuclear</td>
<td>2400</td>
<td>5800</td>
<td>USDOE 2006; EPRI 2002a; EPPRI 2002b</td>
</tr>
<tr>
<td>Solar Thermoelectric</td>
<td>230</td>
<td>270</td>
<td>USDOE 2006</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>143</td>
<td>243</td>
<td>USDOE 2006</td>
</tr>
</tbody>
</table>

Source: Younos 2012
Energy Flow in Water Infrastructure

1. Extraction of raw water from the source and conveyance to the drinking water treatment plant
2. Drinking water treatment
3. Distribution from the drinking water treatment plant to customers
4. Use by residential and commercial/industrial/institutional customers
5. Collection from customers and conveyance to the wastewater treatment plant
6. Wastewater treatment
7. Effluent discharge

Sources: GAO. Photos: GAO, EPA, and DC Water. | GAO-16-474
The Impact of Water Consumption on Energy Use and CO2 Emission

- In the U.S., 4% of national energy consumption goes to water and wastewater services (56 billion kilowatt hours (kWh))

- 45 million tons of greenhouse gases is generated

http://www.epa.gov/waterinfrastructure/bettermanagement_energy.html#basicone
The Impact of Water Consumption on CO2 Emission

45 million tons of greenhouse gases are attributed to water sector

http://www.epa.gov/waterinfrastructure/bettermanagement_energy.html#basicone
Water and Energy Flow
Town of Blacksburg, Virginia

New River
### Case Study: Blacksburg, Virginia
(Younos et al. 2009)

Table 1. Carbon footprint of water consumption in Blacksburg, Virginia

<table>
<thead>
<tr>
<th>Infrastructure</th>
<th>Capacity (MGD)</th>
<th>Power Use (kWh/1,000 gallons)</th>
<th>Carbon Emission (lbs/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potable Water</td>
<td>3</td>
<td>1.67</td>
<td>10,000</td>
</tr>
<tr>
<td>Wastewater</td>
<td>4.85</td>
<td>2.67</td>
<td>22,000</td>
</tr>
</tbody>
</table>

In the U.S., the energy use for water treatment and delivery is reported to be in the range of 0.25 – 3.5 kWh/1,000 gallons (AWWARF 2007).
Case Study: Blacksburg, Virginia – Potable Water

(Younos et al. 2009)

70% of use energy goes to distribution

30% of energy use goes to water treatment

Consumer

Utility
Modern Water Infrastructure  
20th Century Approaches

- **Potable Water System**  
  - Water Sources, Water Treatment and Distribution

- **Wastewater Network**  
  - Wastewater Drainage, Treatment Plants, Discharge

- **Stormwater (Runoff) Drainage Network**  
  - Storage and disposal to surface waters
Potable and Drinking Water System

Energy Consumption

Wastewater Drainage
About **two-third** of the high quality and energy intensive potable water that the utilities produce is **consumed for non-potable uses** such as flushing toilets, washing cars and landscape irrigation.
Centralized Potable Water Infrastructure Is Unsustainable

- ~23 million cubic-meters of potable water is lost due to leakage in distribution (AWRA 2005).

- U.S. drinking water systems face an annual shortfall of >$11 billion to replace aging facilities and to comply with federal water regulations (ASCE 2009).

- Potable water systems are energy intensive.
Urban Stormwater Drainage Network: Combined Sewer System (772 cities in U.S.)

Sewage plus Stormwater Runoff

https://en.wikipedia.org/wiki/Combined_sewer
Combined Sewer System (772 cities in U.S.)

Urban Stormwater Drainage Network: Municipal Separate Storm Sewer System MS4

Underground Storage

Wet Pond

Discharge to Surface Waters

Wasted Waters

Source: Montgomery County, MD
Urban Water Infrastructure Characteristics and Problems

- Planned, designed and managed as separate systems
- Interconnectedness of natural landscape and engineered systems are not considered
- Dependence on water from sources outside urban boundaries is energy intensive
- Significant wastewater and stormwater runoff
- Dependence upon extensive pipe networks

Existing water infrastructure is not sustainable from environmental and cost perspectives
Challenges Facing Global Urban Water Management in 21st Century

- Surface water contamination & emerging contaminants
- Preservation of groundwater quantity and quality
- Prevention of potable water leakage and potable water contamination via pipelines
- Coping with water scarcity in urban environments
- Energy consumption and use efficiency
## Quality of Life Criteria in Urban Environments

### Our Goals and Expectations

<table>
<thead>
<tr>
<th>Quality of Life Criteria 20th Century</th>
<th>Quality of Life Criteria 21st Century</th>
</tr>
</thead>
<tbody>
<tr>
<td>Running tap water in each household</td>
<td>Running tap water free of lead and other chemicals, microbes and emerging contaminants</td>
</tr>
<tr>
<td>Sewer disposal for each household and community</td>
<td>Permitted pollutant discharge limits, surface water quality &amp; ecosystem protection</td>
</tr>
<tr>
<td>Water availability: develop surface water resources – build dams Excessive groundwater withdrawal</td>
<td>Develop alternative water sources - rainwater and stormwater capture, wastewater reuse, desalination of salt and brackish water Groundwater preservation</td>
</tr>
<tr>
<td>Accelerated urban development (paved surfaces) and stormwater drainage network</td>
<td>Low Impact Development and green urban environment, urban aesthetics</td>
</tr>
<tr>
<td>Affordable and spacious housing &amp; buildings</td>
<td>Water and energy efficient housing &amp; buildings</td>
</tr>
<tr>
<td>Develop and use fossil-fuel energy resources</td>
<td>Generate local clean and renewable energy resources - decentralize</td>
</tr>
<tr>
<td>Import food, use pesticides for increased food production</td>
<td>Organic farming, urban agriculture, mixed land use</td>
</tr>
<tr>
<td>Develop communication infrastructure</td>
<td>Wireless communication, Internet technologies, Satellite</td>
</tr>
</tbody>
</table>
Sustainable Management of Water Resources: Interactive System

Water

Land Use
Energy Consumption
Food Production

Policy

Technology
Paradigm Shift: Holistic Approach for Urban Water Management

Decentralized Green-Water Infrastructure (DGWI)

DGWI are systems that integrate locally available water and renewable energy resources for small-scale water treatment, water delivery, and water use at the local level.

Locally available water:
Rainwater, stormwater, wastewater, saltwater, groundwater

Locally available energy:
Solar, wind, micro-hydro, geo-thermal, biomass, other?
Rainwater Harvesting Systems: Significant DGWI Practice

Definition of Rainwater Harvesting Systems

- Stormwater runoff capture from urban impervious surfaces for beneficial uses
- Rooftop rainwater capture for beneficial uses
Potential Uses of Captured Rainwater

- **Outdoor uses**
  - Lawn irrigation, fountains, gardening, car washing

- **Indoor Uses**
  - Potable water
  - Non-potable uses (flushing toilets, laundry, cooling)

- **Groundwater Recharge**

- **Urban Agriculture**

- **Urban Aesthetics**
Benefits of RWH Systems

- Reduces stormwater runoff volume - A TMDL solution
- Flood control
- Reduces potable water use
- Reduces energy consumption/fossil-fuel based energy use
- Supports local food production and food security
- Enhances urban aesthetics and urban environment
- Groundwater preservation and drought management
Examples of Stormwater Runoff Harvesting Practices
Stormwater Capture for Aesthetics

Stormwater capture can be aesthetic

Example: Ornamental water feature at the Cincinnati Zoo replenished by a stormwater capture system

Captured Stormwater for Turf Irrigation

Installation of a 250,000-gallon (950,000-liter) cistern beneath the National Mall in Washington, DC. Source: NAP Report (2016) Credit, M. Stachowicz
Progression of Rooftop Rainwater Harvesting Systems

- Traditional Household Rooftop Rainwater Harvesting
- Modern Rainwater Harvesting Systems
  - Household
  - Buildings (schools, commercial, other)
- Futuristic Rainwater Harvesting Systems
Traditional Rooftop Rainwater Harvesting Systems
1,000 sq. ft. rooftop area can collect 620 gallons of water per 1 inch of rainfall
Traditional Small-Scale Household Rainwater Capture and Use

- Where public water supply is not available
- Where extending public water lines are expensive
  - Mountaintops
  - Isolated and rural communities

Source: Younos et al. (1998)
About 50 million people in rural and isolated communities in the U.S. depend on private well water and other sources including traditional rainwater cisterns!

There is significant potential for modern rooftop rainwater systems in these communities!
For treatment, rainwater flows through three canisters:

- The first canister houses a dual-density polypropylene sediment filter, (nominal 25-micron pre-filtration and 1-micron post-filtration)
- The second houses a 5-micron nominal carbon block
- The third canister is a 115-volt ultraviolet (UV) chamber for disinfection

Source: Hammerstrom and Younos (2014)
Modern Urban Household and Commercial Rooftop Rainwater Harvesting

Rainwater Capture System
Source: www.rainwater-solutions.com
First Flush Filter

**Diverts the first few millimeters of rainfall** at the start of a rainfall event and filter out large particles:

- Leaves
- Dirt
- Bird droppings, etc.

Source: Rainwater Management Solutions
Pre-tank filtration removes organic matter and other contaminants, and improve the overall quality of harvested rainwater. It may also reduce or eliminate debris build-up in the storage tank, thus reducing the need for maintenance. Source: RMS
Sample rainwater storage tanks: Aboveground a) corrugated metal tank with a membrane liner, b) 2.1 cubic-meter polyethylene tank; Belowground c) two 9.5 cubic-meter polyethylene tanks, and d) four 114 cubic-meter fiberglass storage tanks). Source: RMS
Guidelines for Rainwater Quality and Intended Use (EPA Low Impact Development Center)

<table>
<thead>
<tr>
<th>Use</th>
<th>Suggested Treatment Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potable indoor uses</td>
<td>* Pre-filtration – first flush diverter</td>
</tr>
<tr>
<td></td>
<td>* Cartridge filtration – 3 micron sediment filter followed by 3 micron activated carbon filter</td>
</tr>
<tr>
<td></td>
<td>* Disinfection – chlorine residual of 0.2 ppm or UV disinfection</td>
</tr>
<tr>
<td>Non-potable indoor uses</td>
<td>* Pre-filtration – first flush diverter</td>
</tr>
<tr>
<td></td>
<td>* Cartridge filtration – 5 micron sediment filter</td>
</tr>
<tr>
<td></td>
<td>* Disinfection – chlorination with household bleach or UV disinfection</td>
</tr>
<tr>
<td>Outdoor uses</td>
<td>* Pre-filtration – first flush diverter</td>
</tr>
</tbody>
</table>

Source: Kloss (2008)
http://water.epa.gov/infrastructure/greeninfrastructure/upload/gi_munichandbook_harvesting.pdf
Commercial Rainwater Harvesting Systems

Advances in rooftop rainwater harvesting system technology have facilitated its implementation as a decentralized green technology in commercial buildings, schools and other sites.

Rooftop areas constitute 30-40% of impervious areas in urban settings.
A Few Examples of Rooftop Rainwater Capture and Benefits
Rainwater Harvesting Systems: Large Scale and Commercial Applications

LBJ Wildflower Gardens RWH System, Austin, TX
Rainwater Harvesting Systems: Laundry, Roanoke, VA

Rooftop Area: 250,000 sq. ft.

Four 30,000 gallon below ground tanks

Use rainwater to wash inmates’ clothes

Source: Rainwater Management Solutions
Rainwater Harvesting Systems: Schools

- Rooftops area: 7711 square-meter
- Captured rainwater: 5,000 cubic-meter
- Uses: flushing toilets/urinals and landscape irrigation

Anacostia High School, Washington, D.C.

Source: RMS Inc.
## Impact of Rooftop RWH on Runoff Volume

<table>
<thead>
<tr>
<th>Location &amp; Building Type</th>
<th>Rooftop Area (m²)</th>
<th>Annual Rainfall (cm)</th>
<th>Rooftop Runoff (m³/year)</th>
<th>Projected Rainwater Use &amp; Purpose (m³/year)</th>
<th>Balance to Stormwater Drainage (m³/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elementary School, Manassas Park, VA</td>
<td>5713</td>
<td>91.95</td>
<td>4991</td>
<td>4922 Indoor toilet use Landscape Irrigation</td>
<td>69</td>
</tr>
<tr>
<td>Area Transit Facility, Charlottesville, VA</td>
<td>2443</td>
<td>108.10</td>
<td>18671</td>
<td>16057 Indoor toilet use Bus washing facility</td>
<td>2614</td>
</tr>
</tbody>
</table>

Source: Rainwater Management Solutions, Inc.
Younos T, Lawson S (2011)
## Impact of RWH on Potable Water & Energy Savings and CO2 Emission

<table>
<thead>
<tr>
<th>Building &amp; Location</th>
<th>Type of Water Use</th>
<th>Harvested Rainwater(^1) (Potable Water Saving) (m(^3)/Year)</th>
<th>Estimated Energy Savings (kWh)(^2)</th>
<th>Estimated CO(_2) reduction (kg/Year)(^3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oscar Smith Middle School, Chesapeake City, Virginia, U.S.</td>
<td>Landscape Irrigation &amp; Toilet Flushing</td>
<td>14,118</td>
<td>5,409</td>
<td>5,194</td>
</tr>
<tr>
<td>Western Virginia Regional Correction Facility, Roanoke County, Virginia, U.S.</td>
<td>Laundry Facilities</td>
<td>17,411</td>
<td>6,670</td>
<td>6,387</td>
</tr>
</tbody>
</table>

\(^1\) Source: Rainwater Management Solutions, Inc.  [http://www.rainwatermanagement.com/](http://www.rainwatermanagement.com/)

\(^2\) Based on average energy use of 0.38 kWh/m\(^3\) (Kloss, 2008).

\(^3\) Based on 0.96 kg CO\(_2\)/kWh for coal as electricity source (Kloss, 2008).
Futuristic Rainwater Harvesting Systems: Interactive & Supporting Technologies

- Small-scale advanced water treatment technologies
- Geospatial technologies
- Artificial groundwater recharge
- Urban agriculture & plant science
- Renewable energy technologies
Futuristic Applications and Potential for RWH Systems

- Stand-alone Applications
- RWH for Urban Food Production (& Job Creation)
- RWH for Bottled Water Production (& Job Creation)
- Rainwater Sharing Cooperatives
- Direct Groundwater Recharge & Groundwater Preservation
- Integrated Rainwater & Wastewater Use in Buildings
- Integrated RWH and Renewable Energy systems
The future is already here.
It’s unevenly distributed.

William Gibson
Science Fiction Writer
1948 -
Living Building
Bullitt Center, Seattle

- **Designed as a net-zero water site**: A site must not transport water from outside the site or discharge water off the site.

- **Potable-rainwater harvesting system** is a key feature of the site.

Sources: Morton, J (2013), One Year In (2014)
https://www.google.com/?gws_rd=ssl&q=bullitt+center+seattle+washington
Potential Rooftop RWH Applications

Car Dealerships

Car wash Facilities
Potential Rooftop RWH Applications
High-Rise Buildings

Hotels

Residential Buildings & College Campuses
Potential Rooftop RWH Applications

Fast Food Restaurant

Shopping Center
Potential Rooftop RWH Applications

Airports

Stadiums
Food, Water and Energy Nexus in Urban Environments

Holistic Sustainable & Green Systems

- Food
- Water (Energy)
- Energy (Water)
Integrating RWH System and Food Security – Urban Agriculture

- Urban agriculture provides an opportunity for creation and efficient use of greenspaces for food production in and food security in urban areas.

- Urban agriculture can enhance human health and sustainability, include reducing energy use, enhancing water and air quality, and increasing greenspaces.

- Job creation at local level
Scale and Size of Urban Agriculture

Macro-Scale: Community Gardens and Urban farms

Community Garden

Urban Farm

Source: Parece et al. 2016
In: Younos, T. and T.E. Parece (2016)
Rainwater Harvesting and Urban Agriculture

Source: Parece et al. 2016
In: Younos, T. and T.E. Parece (2016)
Scale and Size of Urban Agriculture

Roof Gardens

Photo Source: Virginia DEQ

Source: Orsini et al. 2016
In: Younos, T. and T.E. Parece (2016)
Plant factory (PF) on the Kashiwa-no-ha campus of Chiba University, Japan. Nearly 3,000 leaf lettuce heads per day or one million per year, 10 workers with 7 working hours per day. Source: Toyoki Kozai
RWH for Bottled Water Production and Job Creation

Source: Bogle and Yonos 2008
Rainwater Sharing Cooperatives: Potential for Community Gardens

Source: Parece et al. 2016
In: Younos, T. and T.E. Parece (2016)

2011 VBMP aerial imagery (left); the same plots in GoogleEarth™ display of 2012 NAIP imagery (right)

Use Geospatial Technology
Rainwater Sharing Cooperatives: Potential for Swimming Pools and Community Lakes

Use Geospatial Technology

Rainwater Harvesting for Groundwater Recharge

- **LID Practices: Small-Scale Infiltration/Recharge**
  - Bioretention cell (rain gardens)
  - Porous Pavement
  - Other LID practices

- Basin-Wide Infiltration (for example, LA Project)

- **Direct Groundwater Recharge of Rainwater**
  - Significant potential and need for rooftop rainwater groundwater recharge particularly in coastal urban areas
About 50% of US population lives in coastal areas
The potential for RWH and groundwater recharge

Problems

- High Water Demand
- Groundwater decline
- Saltwater intrusion
Groundwater Recharge in Coastal Aquifers
Prevent Saltwater Intrusion

Captured Rainwater
Integrating Renewable Energy Use in Water Infrastructure
Photovoltaic system at NJAW Canal Road Water Treatment Plant

Source: New Jersey American Water
Integrating RWH and Greywater Recycling
Futuristic Decentralized Model

Lee, Bae and Younos (2017)
Integrated Natural and Engineered Systems: The GWI Academy Vision

Decentralized Water-Infrastructure

Small-Scale Advanced Water Treatment System

Wastewater

Solar PV

Urban Ag

Stormwater

Treated Water

Solar PV
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