Holistic blue water use and life cycle cost savings of domestic and agricultural rainwater harvesting at the watershed scale in the Southeast US

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AGENDA

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- CONTEXT
  - Holistic impact assessment and cost savings of rainwater harvesting at the watershed scale
- METHODS
- RESULTS
- SUMMARY
- REFERENCES

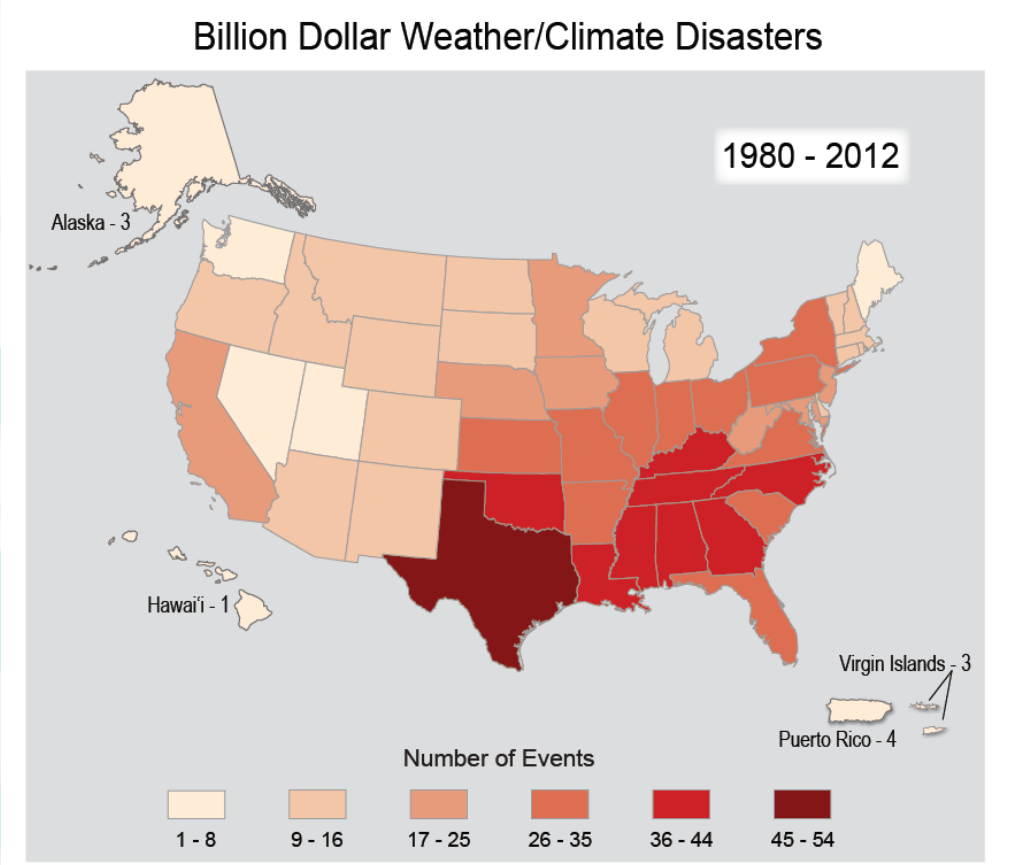
INTRODUCTION

Challenges of managing water resources due to climate change impacts and population growth

During 1980-2012 the weather and climate in the U.S. have resulted in more billion dollars damage events (Carter et al. 2014)

- The Southeast affected by more billion-dollar disasters than any other region

From 1970 to 2007 most of the Southeast U.S. received heavy downpours in recent autumns while moderate-to-severe drought increased in spring and summer (12% and 14%) (USGCRP 2012)

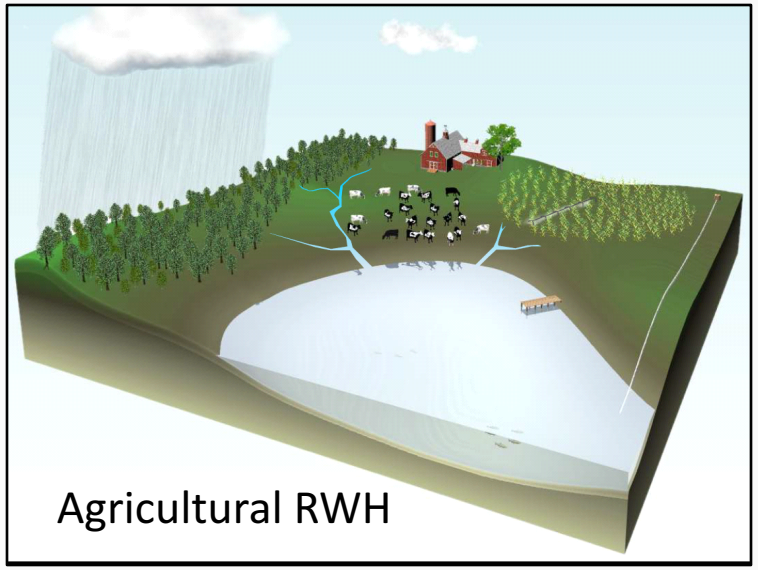


Original Figure source: NOAA NCDC (2013)
http://www.ncdc.noaa.gov/billions/events

RWH Green Infrastructure

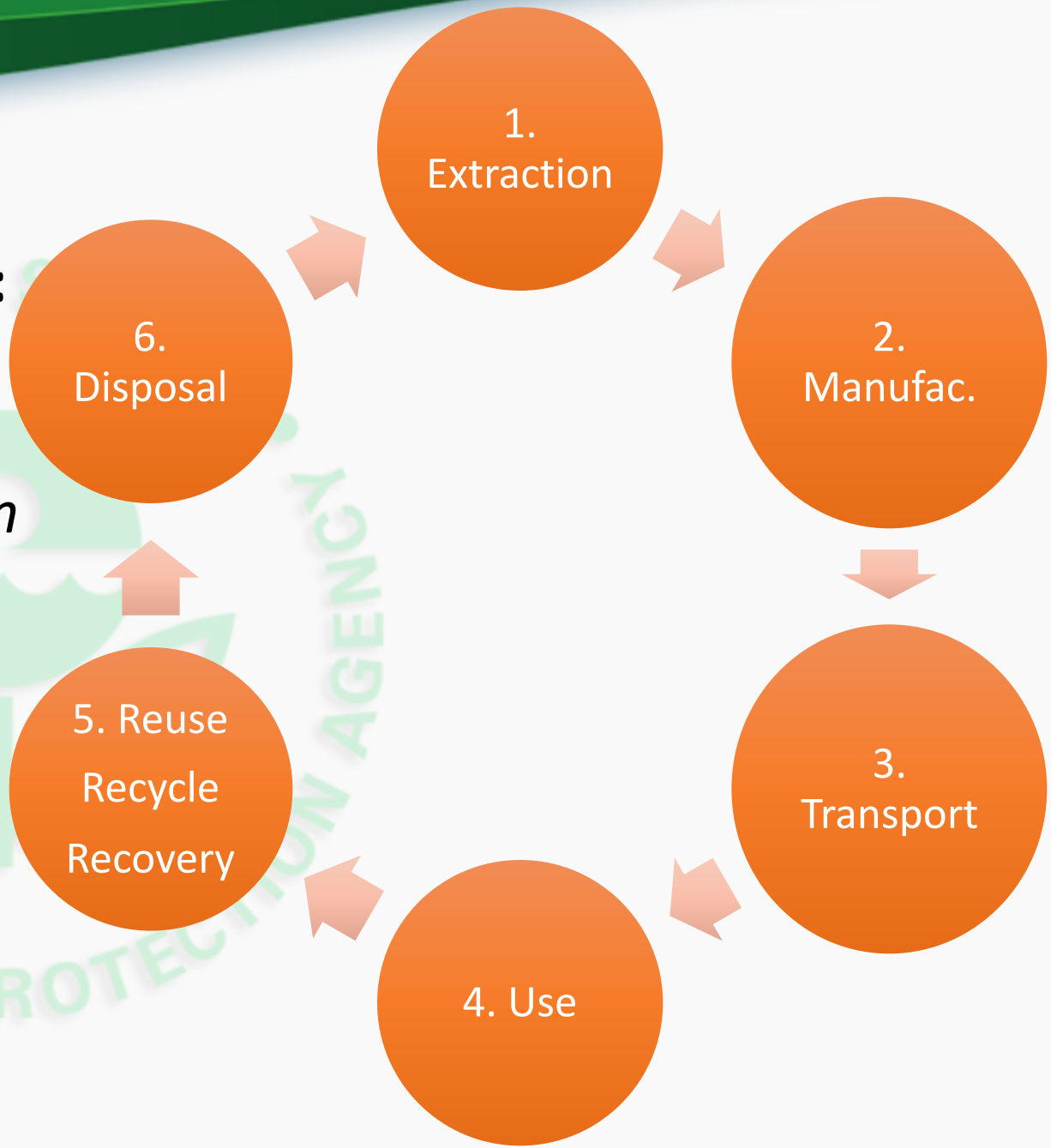
- Rainwater harvesting (RWH) practices are receiving renewed interest as green infrastructure options
- Potential benefits of RWH:
  - reduced environmental and human health impacts
  - reduced stormwater runoff and combined sewer overflows
  - water savings and economic benefits
- Lack of scientific knowledge of holistic impacts (life cycle environmental, human health, and economic viability) of RWH hinders the formulation of clear policies for its use

Ghimire et al. (2014)



Life Cycle Assessment (LCA): a holistic perspective

ISO 14040 Cradle to Grave Perspective:
"Entire life cycle of a product, from raw material extraction and acquisition, through energy and material production and manufacturing, to use and end of life treatment and final disposal."
(ISO 2006)



CONTEXT

ELEMENTA
Science of the Anthropocene

Ghimire, S R and Johnston, J M 2017 Holistic impact assessment and cost savings of rainwater harvesting at the watershed scale. *Elem Sci Anth*, 5: 9, DOI: https://doi.org/10.1525/elementa.135

RESEARCH ARTICLE

Holistic impact assessment and cost savings of rainwater harvesting at the watershed scale

Santosh R. Ghimire* and John M. Johnston†

We evaluated the impacts of domestic and agricultural rainwater harvesting (RWH) systems in three watersheds within the Albemarle-Pamlico river basin (southeastern U.S.) using life cycle assessment (LCA) and life cycle cost assessment. Life cycle impact assessment (LCIA) categories included energy demand, fossil fuel, metals, ozone depletion, global warming, acidification, smog, blue and green water use, ecotoxicity, eutrophication, and human health effects. Building upon previous LCAs of near-optimal domestic and agricultural RWH systems in the region, we scaled functional unit LCIA scores for adoption rates of 25%, 50%, 75%, and 100% and compared these to conventional municipal water and well water systems. In addition to investigating watershed-scale impacts of RWH adoption, which few studies have addressed, potential life cycle cost savings due to reduced cumulative energy demand were scaled in each watershed for a more comprehensive analysis. The importance of managing the holistic water balance, including blue water (surface/ground water), green water (rainwater) use, and annual precipitation and their relationship to RWH are also addressed. RWH contributes to water resource sustainability by offsetting surface and ground water consumption and by reducing environmental and human health impacts compared to conventional sources. A watershed-wide RWH adoption rate of 25% has a number of ecological and human health benefits including blue water use reduction ranging from 2–39 Mm^3, cumulative energy savings of 12–210 TJ, and reduced global warming potential of 600–10,100 Mg CO_2 eq. Potential maximum lifetime energy cost savings were estimated at $5M and $24M corresponding to domestic RWH in Greens Mill and agricultural RWH in Back Creek watersheds.

Objectives and Scope

Comprehensively addressed the holistic impacts of RWH at the watershed scale

- **Energy Use**
- **Global Warming Potential**
- **Blue Water Use**
- **Green Water Use**
- **Life Cycle Water Balance**
- **Life Cycle Energy Cost Savings**
- Fossil Fuel Depletion
- Metal Depletion
- Ozone Depletion
- Acidification
- Smog
- Ecotoxicity-total
- Eutrophication-total
- Human Health Criteria Pollutants
- Human Health Cancer
- Human Health Non-cancer

Only the first six (**bolded**) impacts will be discussed

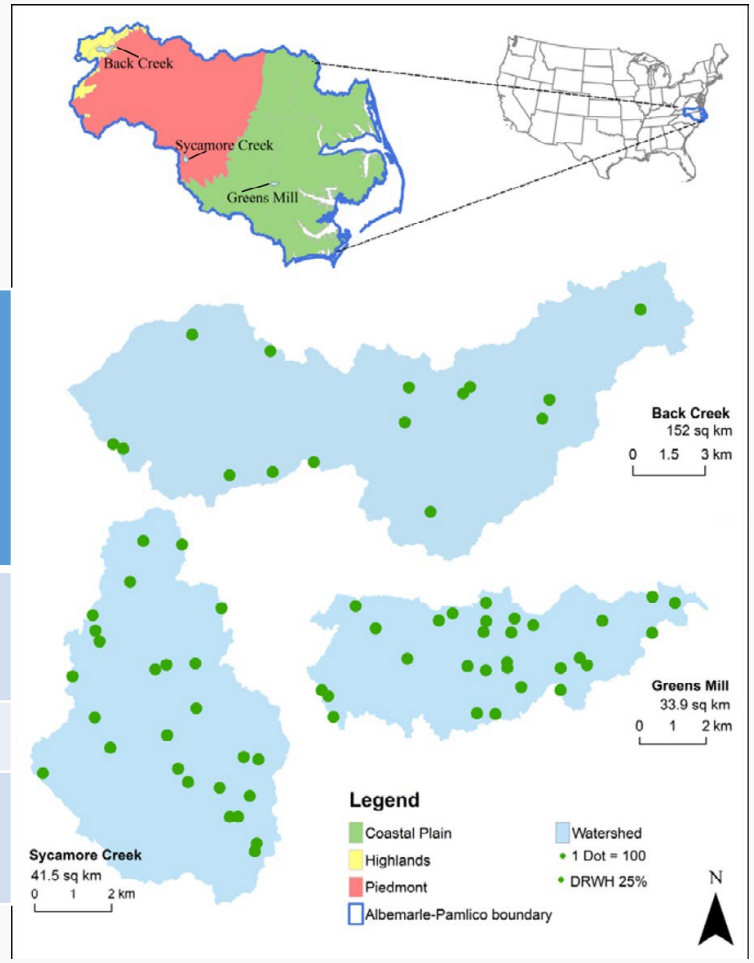
METHODS

- Watershed selection
- RWH systems design and adoption rates
- Holistic impact assessment at the watershed scale
  - Life cycle assessment (LCA)
  - Life cycle cost assessment (LCCA)
  - Holistic water balance

Watershed Selection

Watershed Characteristics

Watershed	Total area (km^2)	Average farm area (km^2)	Total farm area (km^2)	Number of agricultural RWH systems	Urban area (%)	Number of domestic RWH systems
Back Creek	152	0.34	11.7	34	18	5,768
Sycamore	41.5	0.42	0.91	2	49	10,296
Greens Mill	33.9	1.6	4.6	3	62	11,582



Albemarle-Pamlico basin with 25% adoption rate for domestic RWH systems (1 dot = 100)

RWH Systems Design and Adoption Rates

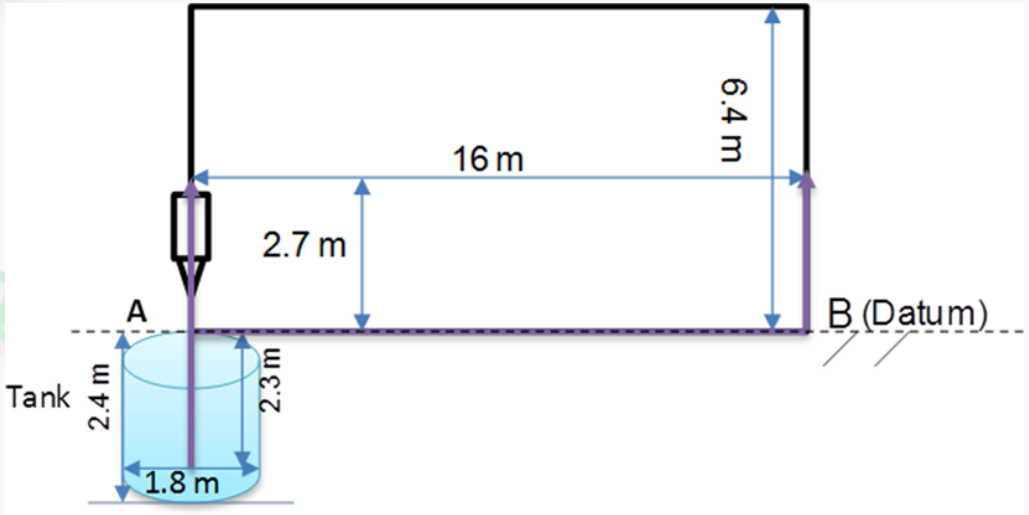
Near-optimal RWH system designs minimized infrastructure (Ghimire et al. 2014):

- The domestic RWH systems:
  - a polyethylene (PE) storage tank of 6.2m^3
  - reduced pipe length (5m) of chlorinated polyvinyl chloride
  - no pump or pumping energy

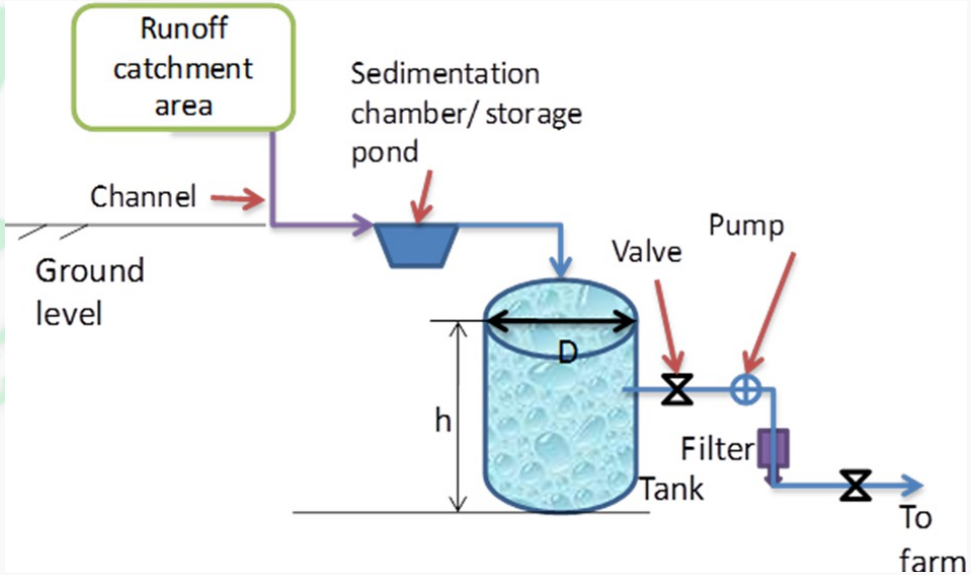
- The agricultural RWH:
  - polyvinyl chloride pipe of 150m
  - PE storage tank of 606m^3
  - no pump or pumping energy.

RWH adoption rates of 25%, 50%, 75%, and 100%

Schematic of domestic RWH



Schematic of agricultural RWH



(Figs. From Ghimire et al. 2014)

Holistic Impact Assessment at the Watershed Scale

$$I_w = A \times N_t \times Q_y \times T \times \Delta i$$

I_w = change in watershed-scale impacts with respect to conventional water supply (Units, e.g., TJ for energy demand)

A = RWH adoption rates: 25%, 50%, 75%, and 100% (decimal)

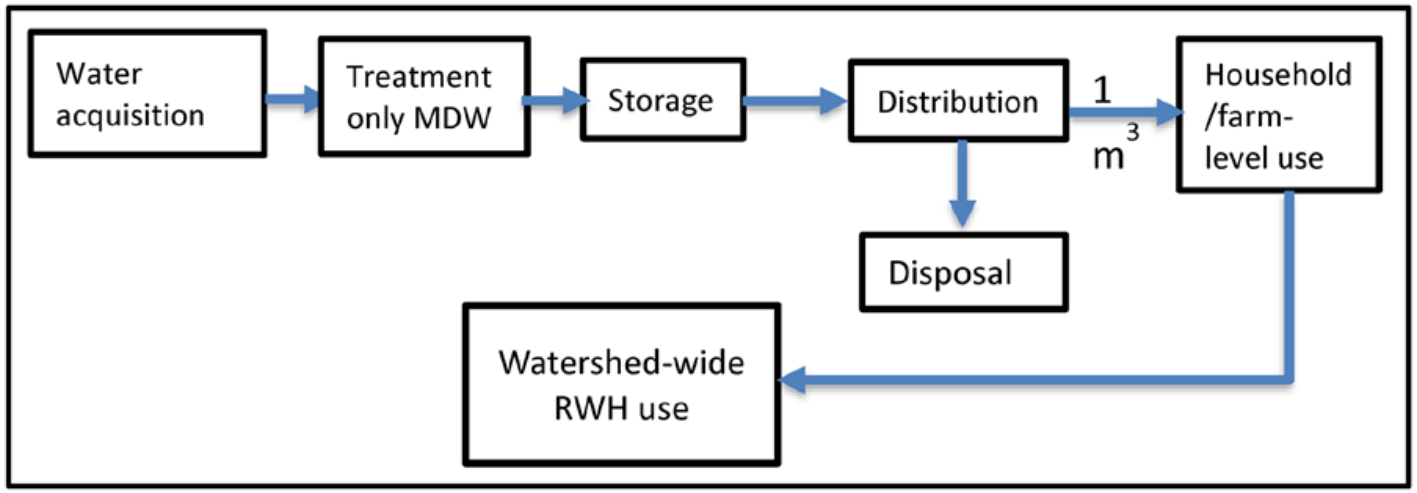
N_t = total number of RWH systems

Q_y = annual water demand for a household toilet flushing or a crop irrigation (m^3y^{-1})

T = service life of RWH system (50yr)

$\Delta i = i_{con} - i_{rwh}$ = difference in impact per $1m^3$ of rainwater delivery with respect to conventional water supply (Units/m^3)

i_{rwh} and i_{con} are the LCIA impacts per m^3 of rainwater and conventional water supply, respectively



Watershed-scale LCA system boundary

LCA

- A prior study (Ghimire et al. 2014) provided functional unit LCIA impacts (per m^3 water delivery) of:
  - domestic RWH at household level
  - agricultural RWH at farm level
  - conventional municipal drinking water for toilet flushing
  - well water for irrigation
- Calculations were performed using OpenLCA (OpenLCA 2013) linked to the life cycle inventory databases and the EPA's LCIA methods, and TRACI (Tool for the Reduction and Assessment of Chemical and other environmental Impacts) version 2.0 (USEPA 2013)
- Results scaled to watershed

LCCA

Life cycle cost assessment (LCCA) of an agricultural RWH system performed

LCCA defined as the sum of the present values of a project, product, or measure over the lifetime (U.S. guidelines for LCCA) (Register 1999):

- investment costs
- capital costs
- installation costs
- energy costs
- operating costs
- maintenance costs
- disposal costs

Illustrated a holistic view of economic viability of agricultural RWH by combining the cumulative energy cost savings with life cycle costs

Holistic Water Balance

Holistic life cycle water savings estimated by incorporating the loss in annual water yield due to watershed-wide RWH:

$$B_H = BU_y - W_a \times R_y$$

B_H = annual blue water savings due to domestic or agricultural RWH compared to conventional water supplies by integrating rainfall (m^3/y)

BU_y = annual net savings in life cycle blue water use (m^3/y)

W_a = watershed area contributing to total water yield (m^2)

R_y = the loss in annual water yield due to domestic or agricultural RWH compared to no-RWH annual water yield (m/y)

The loss in water yield incorporates rainfall influences combining:

- surface runoff
- lateral flow
- groundwater contribution (return flow from shallow aquifer)
- transmission losses and
- pond abstractions.

Life Cycle Energy Cost Savings

Potential translated cost savings due to watershed-wide life cycle energy use were derived:

$$C_s = 2.78 \times 10^5 \times P_e \times E_s$$

C_s = potential cost savings ($)

E_s = cumulative energy savings (TJ)

P_e = energy price ($0.103/kWh) (USEIA 2014)

2.78×10^5 = a conversion factor (i.e., 1TJ = 2.78×10^5 kWh)

RESULTS

Reduction in watershed scale impacts of domestic RWH adoption with respect to conventional municipal drinking water in three watersheds: Back Creek = BC, Sycamore Creek = SC, Greens Mill = GM

LCA impact category	Unit	Reduction in watershed-scale impacts of domestic RWH adoptions in three watersheds												Reduction (%)
		100%			75%			50%			25%			
		BC	SC	GM	BC	SC	GM	BC	SC	GM	BC	SC	GM	
Energy Demand	TJ	85	152	171	64	114	128	42	76	85	21	38	43	58
Global Warming	Mg CO_2 eq	4667	8331	9372	3501	6248	7029	2334	4166	4686	1167	2083	2343	52
Green Water Use	Mm^3	-11	-19	-21	-8	-14	-16	-5	-10	-11	-3	-5	-5	--
Blue Water Use	Mm^3	13	23	26	10	17	19	6	11	13	3	6	6	100

The relative reductions in impacts ranged from 52% (Global Warming) to 100% (blue water use)

RESULTS

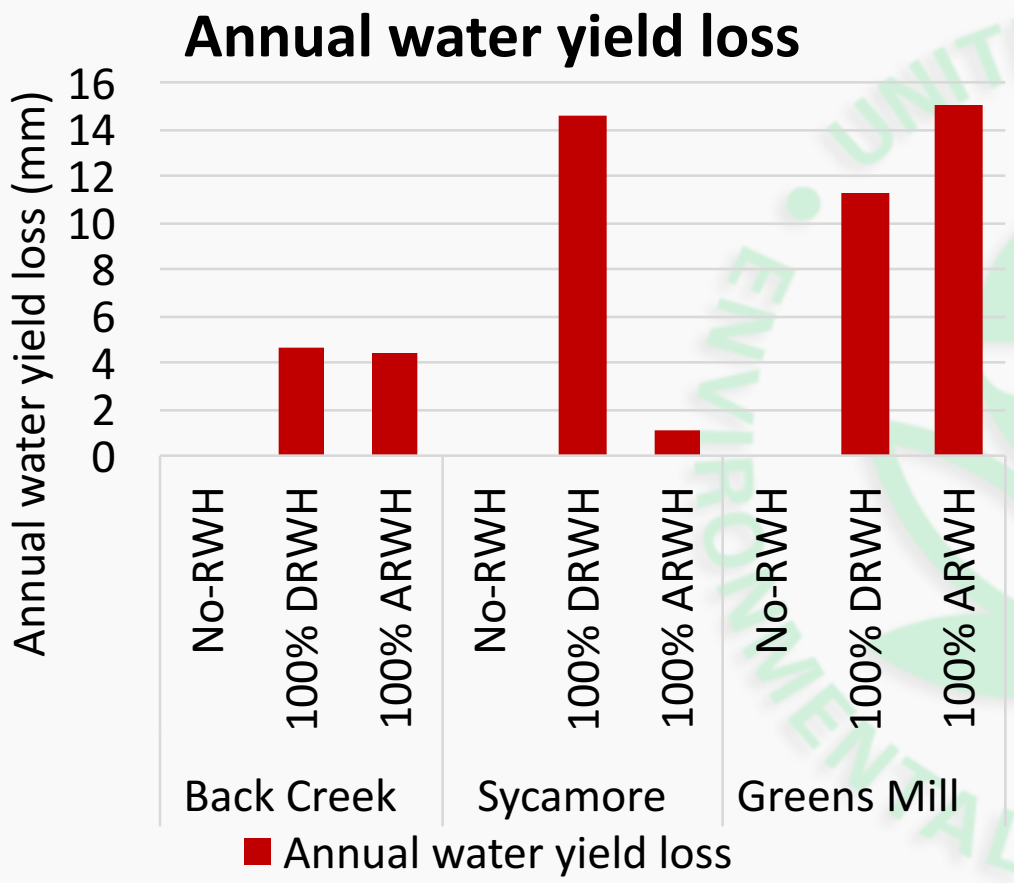
Reduction in watershed scale impacts of agricultural RWH adoption with respect to conventional practices in three watersheds: Back Creek = BC, Sycamore Creek = SC, Greens Mill = GM

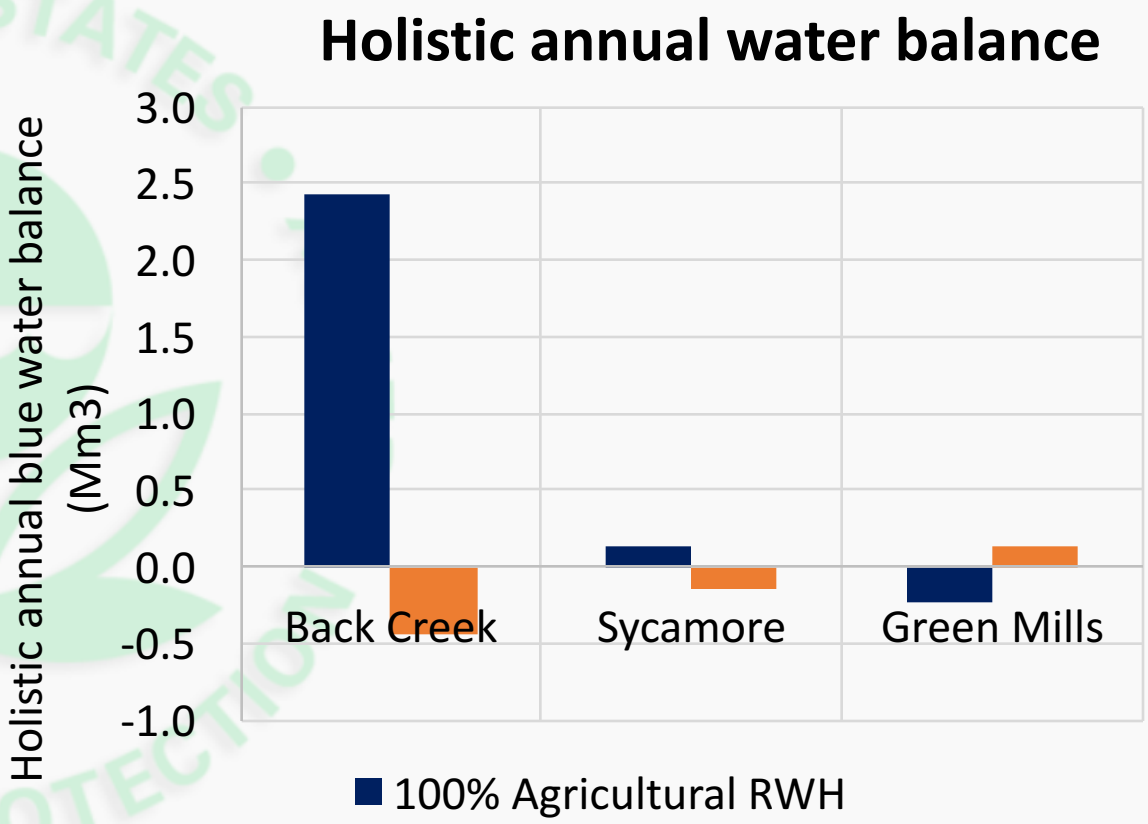
LCA impact category	Unit	Reduction in watershed-scale impacts of agricultural RWH adoptions in three watersheds												Reduction (%)
		100%			75%			50%			25%			
		BC	SC	GM	BC	SC	GM	BC	SC	GM	BC	SC	GM	
Energy Demand	TJ	838	49	74	629	37	55	419	25	37	210	12	18	78
Global Warming	Mg CO_2 eq	40369	2375	3562	30277	1781	2671	20185	1187	1781	10092	594	890	76
Green Water Use	Mm^3	-154.5	-9	-14	-116	-7	-10	-77	-5	-7	-39	-2	-3	---
Blue Water Use	Mm^3	154.7	9	14	116	7	10	77	5	7	39	2	3	100

The relative reductions in impacts ranged from 76% (Global Warming) to 100% (blue water use)

RESULTS

Water yield loss and holistic water balance for 100% domestic RWH and agricultural RWH adoption in three watersheds



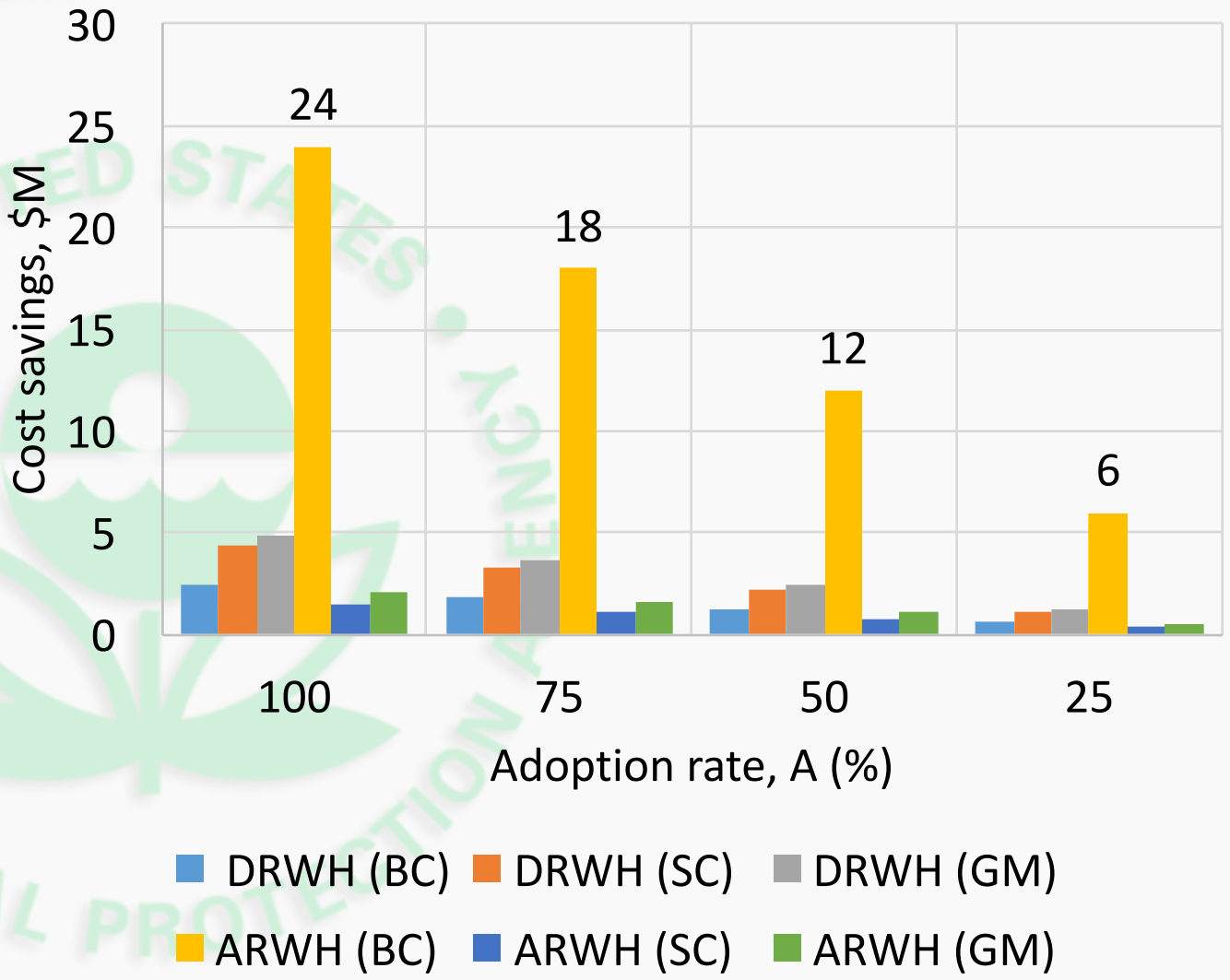


From a life cycle perspective, the water loss due to RWH can be offset by life cycle blue water savings

RESULTS

Life cycle energy cost savings due to cumulative energy reductions by domestic RWH (DRWH) and agricultural RWH (ARWH) adoption rates in three watersheds:

- Back Creek (BC)
- Sycamore Creek (SC)
- Greens Mill (GM)



SUMMARY

- A holistic view of environmental and economic viability of domestic and agricultural RWH at the watershed scale in the southeastern U.S. was discussed
- Watershed-scale impact reductions due to agricultural RWH were 17 times higher for Back Creek than Sycamore due to more farms in the former watershed
- Domestic RWH impact reductions for Sycamore and Greens Mill were twice those of Back Creek due to more households in the first two watersheds
- Holistic water balance analysis revealed greater annual blue water savings for agricultural RWH (at 100% adoption) for Back Creek (2.4 Mm^3/y) than Sycamore Creek (0.1 Mm^3/y)
- Potential maximum lifetime energy cost savings were estimated at $5M and $24M corresponding to domestic RWH in Greens Mill and agricultural RWH in Back Creek
- 25% DRWH and ARWH adoption led to a number of ecological and human health benefits including:
  - blue water use reduction ranging from 2–39 Mm^3
  - cumulative energy savings of 12–210 TJ
  - reduced global warming potential of 600–10,100 Mg CO2 eq.

SUMMARY

- Impacts vary with system design, RWH regulations, water use, water treatment processes and pumping energy
- The methodology is generally applicable to regions with comparable watershed characteristics and water treatment options
- RWH sustainability should be well studied across scales
  - Upscaling agricultural RWH impacts at the river basin scale
  - Coupling of RWH with centralized water systems as well as with innovative decentralized wastewater management options (e.g., water reuse)

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Thank You!

Questions/Comments are Welcome

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DISCLAIMER/ACKNOWLEDGMENTS

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