Water efficiency in commercial-scale aquaponics

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Youth With a Mission (YWAM) and WT School of Engineering are very grateful to HPWD for funding this project. It has and will provided **valuable data for YWAM** and has provided many hours of useful learning through research for <u>two engineering students.</u>

PRESENTATION OUTLINE

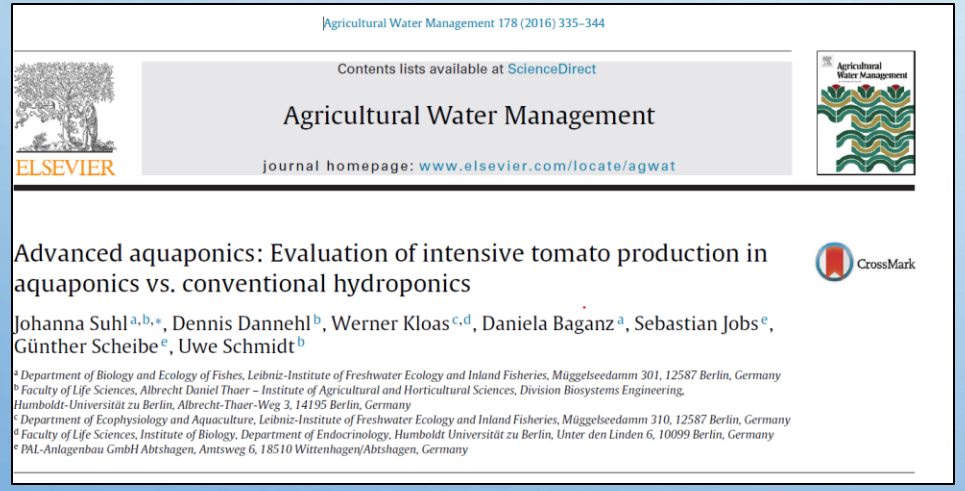
- Project 1 – commercial scale aquaponics
  - Project overview – the problem attempted, objectives, and methods
  - Results & interpretation – aquaponics system water balance
  - Results & interpretation – biomass growth studies
  - Current thoughts and future directions
- Project 2 – large & medium-scale rainwater harvesting
  - Updates on what has been achieved since last year

PROJECT 1

Water Productivity of Commercial Scale Aquaponics

THE PROBLEM: UNDERSTANDING THE CLAIMS OF WATER EFFICIENCY IN UNUSUAL AGRICULTURAL SYSTEMS

The claims that are made concerning the water productivity (or water use efficiency) are frequently cited as "good" or "better than conventional agriculture", but there is little evidence in peer-reviewed literature to validate the claims. One study that did look at this:



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Advanced aquaponics: Evaluation of intensive tomato production in aquaponics vs. conventional hydroponics

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System type	Growth time (days)	water used (L)	Tomatoes fruit produced (kg)	water use efficiency (kg fruit/1000 L)
Total system	277	14,200	677.3	47.7
Aquaponic piece	277	13,600	626.5	46.1

This is one of the few studies we have found that reports very conclusively on water use efficiency of an aquaponics system, and it is not even in the US (in Germany).

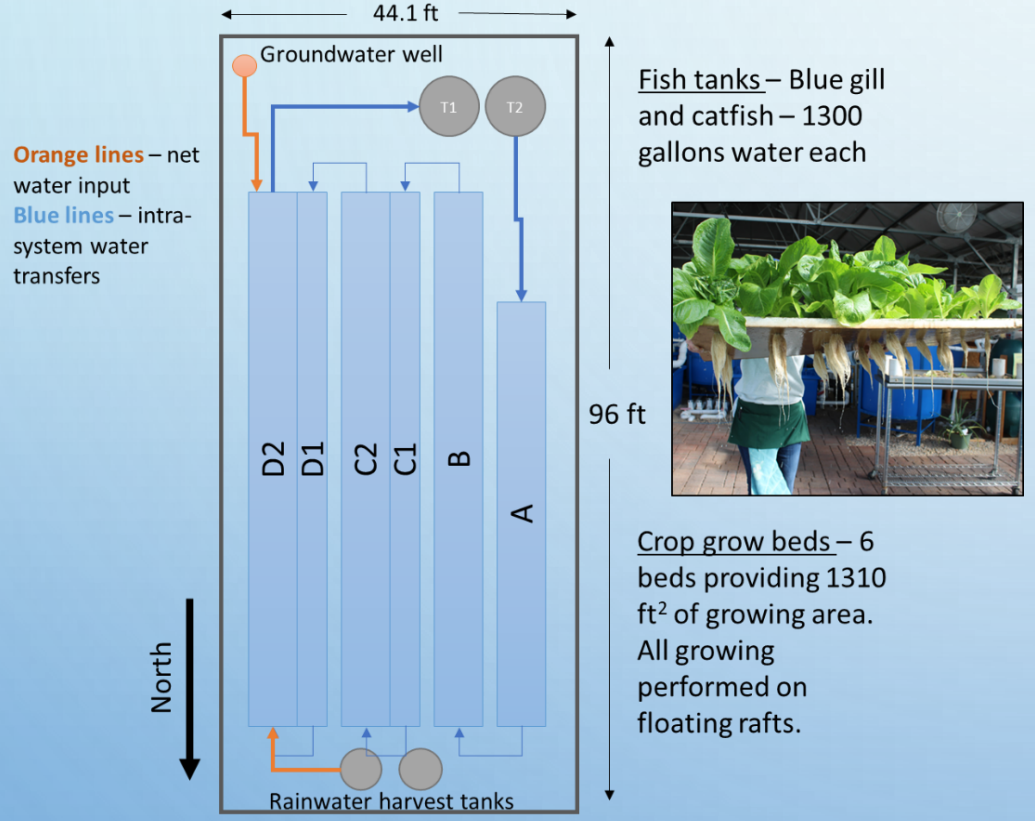
PROJECT OBJECTIVES

Quantify the **water budget** for an aquaponics system according to water supplied, water stored, and water evapotranspiration.

Estimate the **water-use efficiency (WUE)** of **vegetables** grown in an aquaponics system

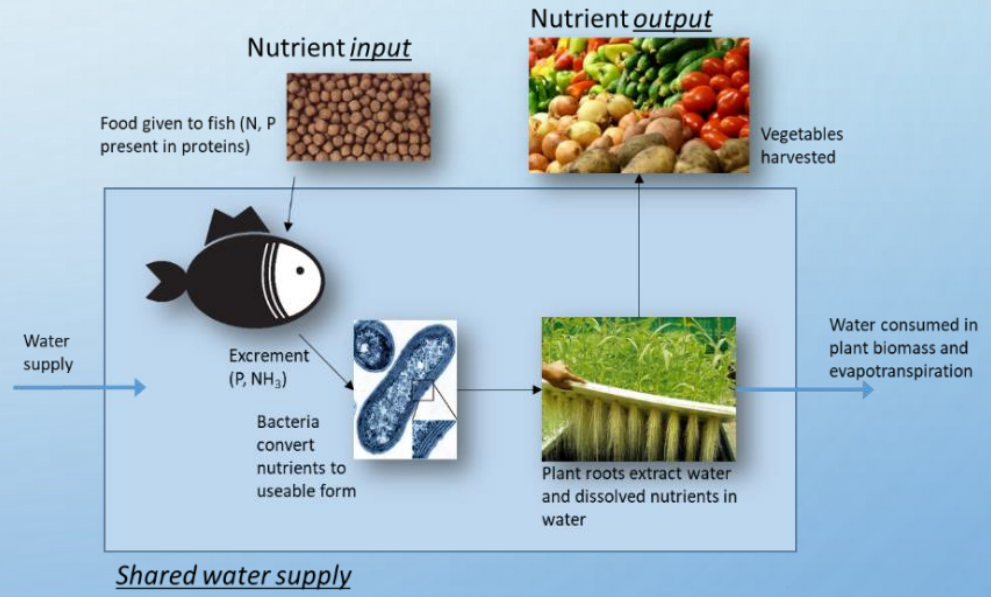
Estimate the effect of changing **water quality** conditions on **crop growth** and **WUE** in an aquaponics system.

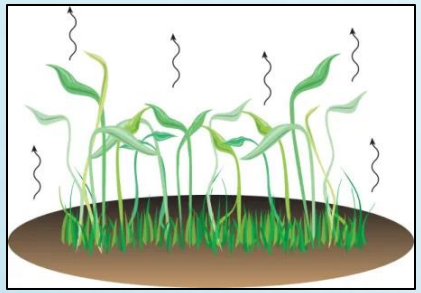
AQUAPONICS SYSTEM OF STUDY



Spatial layout of youth with a mission (YWAM) aquaponics growing system in Amarillo, TX.

Nutrient and water conceptual balance for aquaponics agricultural system





WATER USE EFFICIENCY

harvestable crop mass (kg/ha)

$$WUE = \frac{CY}{ET_c}$$

Evapotranspiration (mm/ha)

- Crop evapotranspiration ET_c – The crop evapotranspiration value. Must understand in terms of a **total system water balance.**
- Crop yield (CY) – Valuable to determine both the total above water biomass and also the harvestable crop to understand how aquaponics water is being used productively in the plant. Use **biomass studies** to determine.

PROGRESS UPDATE: WHERE ARE WE SO FAR?

Completed Tasks:

- ✓ Developed method to **monitor biomass**
- ✓ Started growth experiment to develop **biomass relationship**
- ✓ Determined **sensor placement** throughout the aquaponics system
- ✓ Determined the aquaponics system dimensions to understand total volume and changes in total volume
- ✓ Rapid **water sensor and climate sensor processing system** using Python programming and MS-Excel

Upcoming Tasks:

- ❑ Combined multi-week monitoring period of **both** biomass growth and water use to determine weekly and seasonal estimates of WUE.
- ❑ Finish biomass growth experiments to determine a **relationship between an easy-to-measure growth characteristic and the above water biomass**
- ❑ Ascertain how much **water quality information** we can afford to gather and interpret.

PART 1: WATER BALANCE

Because the water is recirculating in an aquaponics system, the water balance itself is fairly simple:

$$\Delta S = I_{gw} + I_{rwh} - ET_{crops}$$

Change in system storage (liters)

Makeup water to system by groundwater (L)

Makeup water to system by rainwater (L)

System losses by crop ET (L)

Equipment

- Four HOBO U20L-04 Water Level Loggers
- HOBO UX Temperature/Relative Humidity Logger
- Assured Automation Digital Flow Meter

Methods

- Data recorded to track volume, temperature, relative humidity
- All variables logged continuously at synchronized one-minute intervals
- Processed using Microsoft Excel and Python

LOGGING OF WATER BALANCE DATA

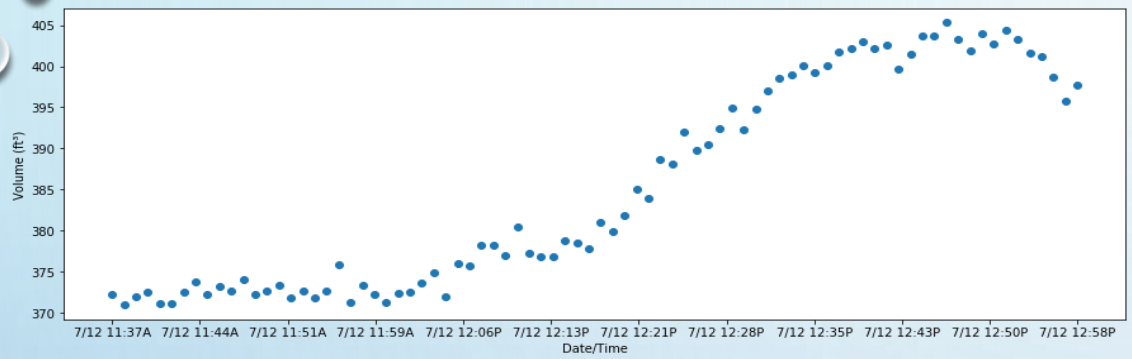
***Measured* values**

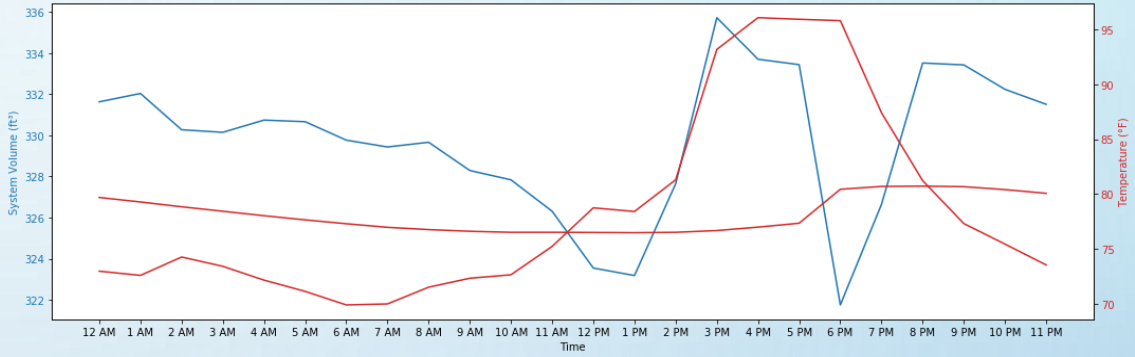
1. Atmospheric pressure
2. Trough 1 pressure
3. Trough 2 pressure
4. Evaporation trough pressure
5. Air temperature 1
6. Air temperature 2
7. Trough 1 water temperature
8. Trough 2 water temperature
9. Evaporation trough water temperature
10. Relative humidity

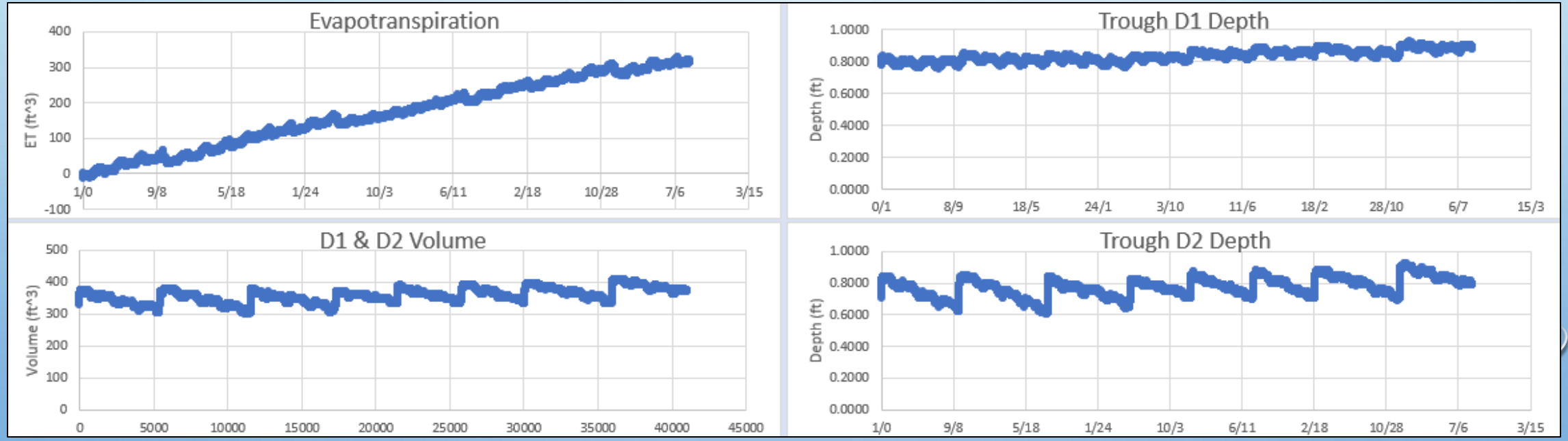
***Derived* values**

1. Trough 1 Depth
2. Trough 2 Depth
3. Trough 1 & 2 Volume
4. Change in System Volume
5. Evapotranspiration
6. Evaporation
7. Transpiration
8. Temp/RH to ET Relationships

OUTPUT OF WATER BALANCE DATA



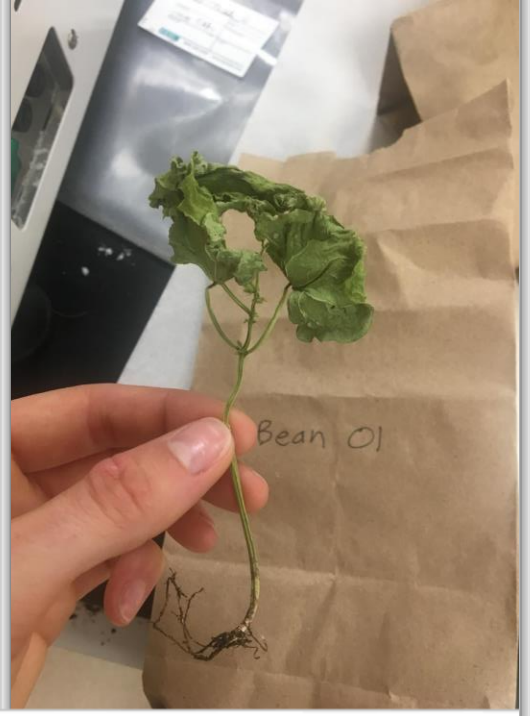




$$\Delta S = I_{gw} + I_{rwh} - ET_{crops}$$

PART 2: BIOMASS MEASUREMENT

- Using an **indirect method** to measure biomass
  - Allows us to estimate the biomass produced without destroying plants
  - Based on developing a relationship between plant weight and an easy to measure attribute such as plant height, stem diameter, or leaf count



GROWTH RELATIONSHIP EXPERIMENT

Grow	Grow type of plants used in aquaponics system
Measure	Measure attributes of plants
Harvest	Harvest at regular intervals
Weigh	Measure dry biomass of plant
Develop	Develop relationship between biomass and measured attributes
Measure	Measure attributes of plants in aquaponics system
Estimate	Use relationship to estimate amount of biomass

RESULTS: DRY BIOMASS

Bag ID	weight of empty bag (g)	wet weight (g)	dry weight (g)	Δ weight (g)	drying time (hours)	moisture content (%)
B1	7.28	4.14	0.21	-3.93	45	94.9
B2	7.30	4.12	0.19	-3.93	45	95.4
B3	7.28	4.14	0.21	-3.93	45	94.9
B4	7.30	4.12	0.19	-3.93	45	95.4
B5	7.28	4.14	0.21	-3.93	45	94.9
B6	7.30	4.12	0.19	-3.93	45	95.4
B7	7.20	4.21	0.29	-3.93	36	93.2
B8	7.24	4.17	0.25	-3.93	36	94.1
T1	7.28	4.60	0.28	-4.32	45	93.91
T2	7.30	5.90	0.32	-5.58	45	94.57
T3	7.30	22.04	2.07	-19.97	54	90.61

- HAVE 8 BIOMASS DATA POINTS FOR KENTUCKY WONDER BEAN AND 3 FOR ATOMIC TOMATO SO FAR
- AVERAGE MOISTURE CONTENT = 94%
- AVERAGE DRYING TIME = 44 HOURS

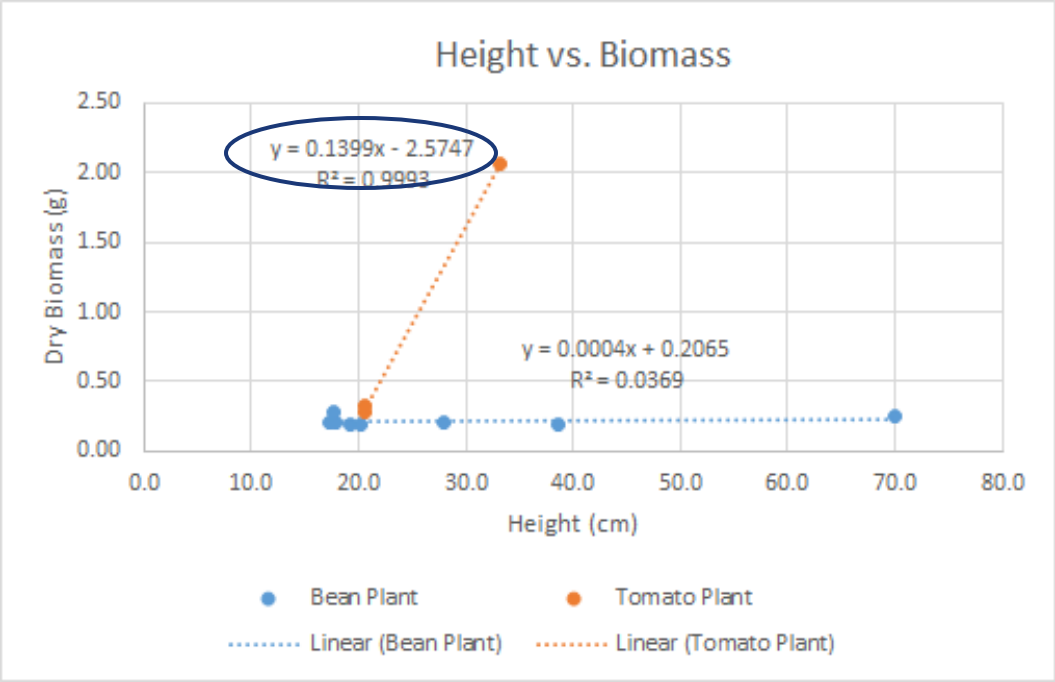
RESULTS: BIOMASS RELATIONSHIPS

Kentucky Wonder Bean Biomass Correlation Table

	Number of leaves	*Number of shoots*	*height*	*leaf length*	*leaf width*	*shoot length*	*dry weight*
Number of leaves	1						
Number of shoots	0.977825	1					
height	0.984926	0.943607	1				
leaf length	0.654813	0.703503	0.694752	1			
leaf width	0.192367	0.203845	0.312338	0.752503	1		
shoot length	0.97231	0.963344	0.962456	0.763097	0.302711	1	
dry weight	0.205642	0.095437	0.192169	-0.33893	-0.36643	0.030688	1

Brad's Atomic Tomato Biomass Correlation Table

	height	*shoot length*	*Leaf count*	*Shoot count*	*dry weight*
height	1				
shoot length	0.999606	1			
Leaf count	0.988484	0.992342	1		
Shoot count	0.505917	0.529935	0.630624	1	
dry weight	0.999651	0.998516	0.984142	0.4829584	1



CONVERTING PLANT DATA TO BIOMASS

1. Measure height of plants in aquaponics system
2. Plug height into the dependent variable of the biomass relationship to obtain an estimate for biomass
3. Repeat for all plants in aquaponics system

Amount of biomass (g)

Height of plant (cm)

$$y = .13999x - 2.5747$$

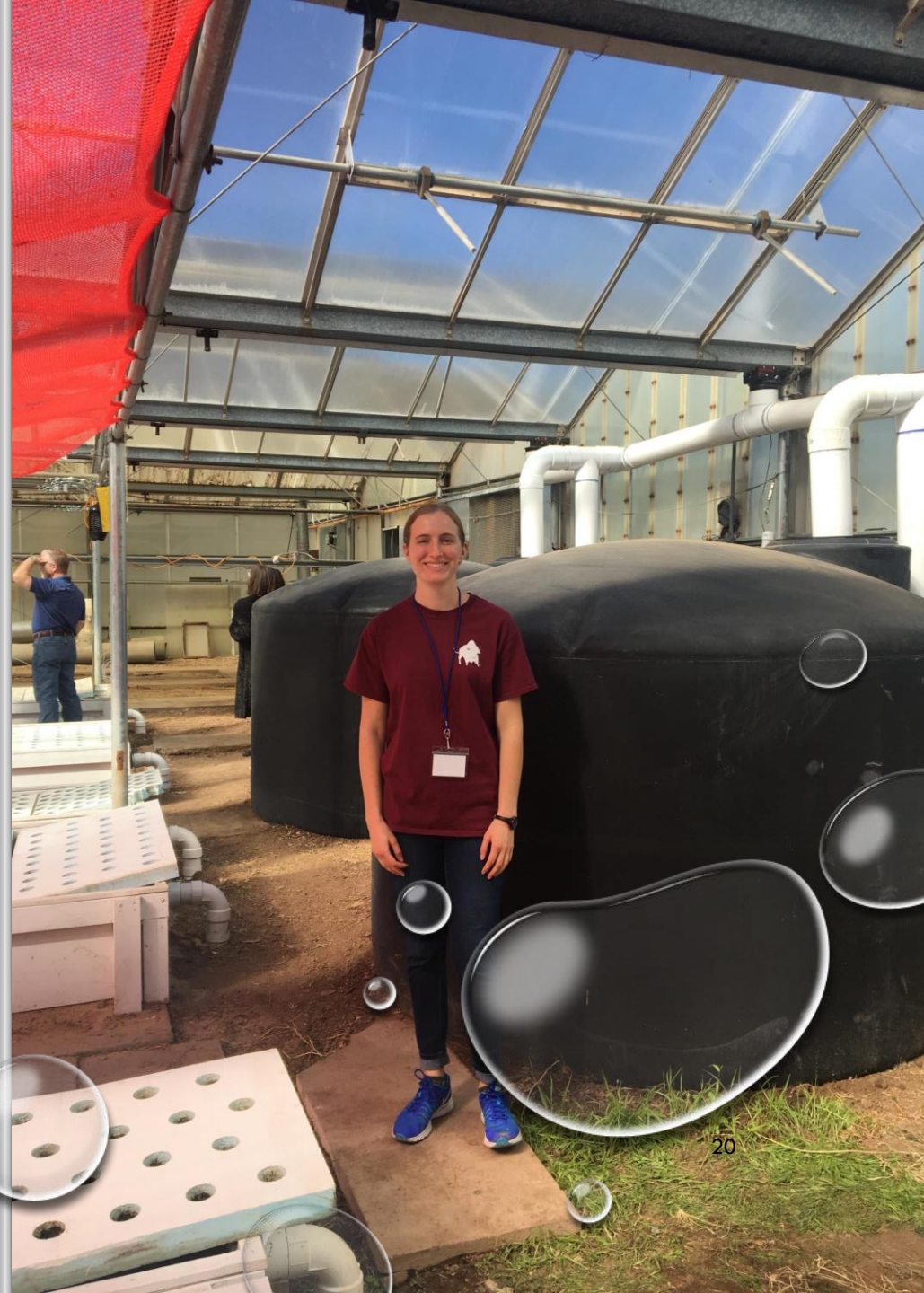
tomato plant no.	measured height (cm)	dry biomass (g)
1	86	9.5
2	82	8.9
3	205	26.1
4	205	26.1
5	154	19.0
6	257	33.4
7	243	31.4
8	243	31.4
9	264	34.4

COMMERCIAL SCALE AQUAPONICS SUMMARY

- Work on development of both biomass growth understanding and water balance to determine ET is **85% complete.**
- Weekly monitoring of YWAM greenhouse for both biomass growth and water balance will **begin this month (Oct 2019)** with new fall crops (tomatoes, Swiss chard, celery, and lettuce).
- **Daily ET values in the greenhouse can be reasonably determined** in August, one of the hottest months for the greenhouse.
- Nature of **water quality measurements** still need to be determined for adding to the monitoring.
- This spring, our team will have the data processed from the fall to wintertime period and will be able to (1) **report findings** in general and (2) find WUE values from conventional agriculture against which to compare.

PROJECT 2

Water Capture Efficiency and Water Quality Variation in Semi-arid Medium to Large Scale Rainwater Harvest Systems



PROJECT OBJECTIVES

Inventory RWH water **quantity** and **quality** in the HPWD region.

Assess **performance** and **usefulness** of RWH as a water supply in current systems in use for residential and commercial settings.

Ascertain the **economic value** that RWH systems bring to current owner-operators balanced against the **costs** of purchasing and maintaining the systems.

PROGRESS UPDATE

Completed Tasks:

✓ Selected and prepared four sites in the HPWD for RWH monitoring.

✓ Monitored RWH water level and rainfall continuously and water quality biweekly over six month study period.

✓ Created database of daily water quantities in RWH storage and biweekly water quality.

✓ Began analyzing water quality and capture efficiency- 1 site analyzed in detail so far

✓ Presented current findings at Operation and Maintenance of Stormwater Control Measures conference in August.

Upcoming Tasks:

❑ Further analyze data for all sites to gain a better understanding of capture efficiency and water quality.

❑ Perform final reporting for HPWD staff and those served in the district.

❑ Organize and submit peer-reviewed papers on RWH results.

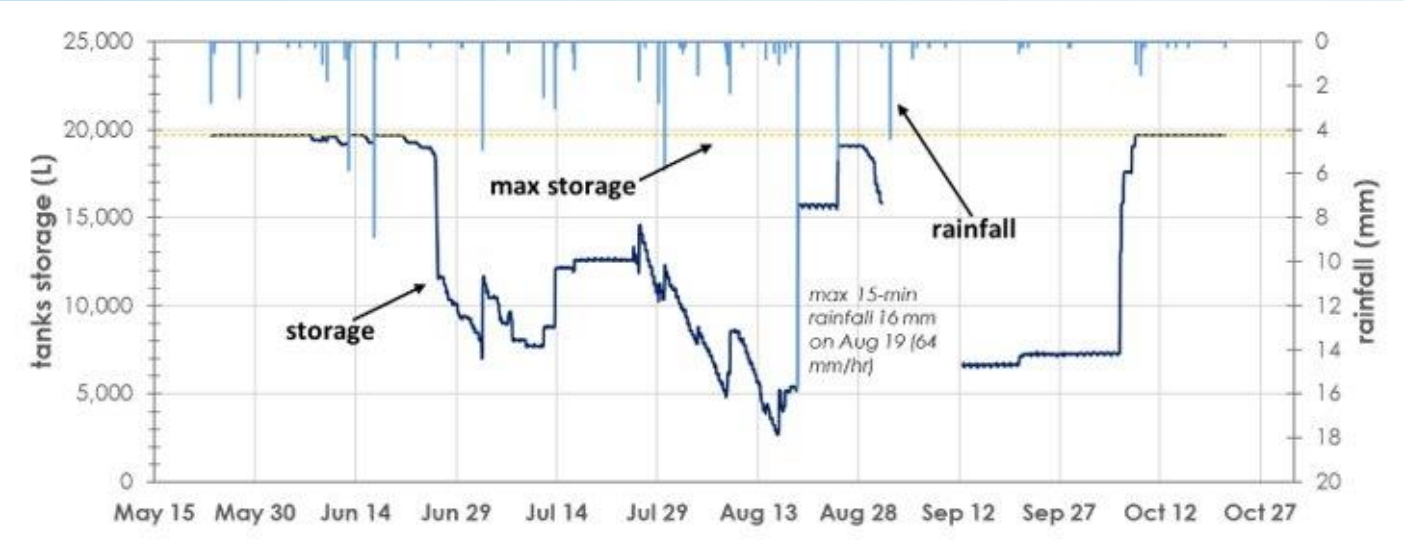
❑ Present finding during spring RWH workshops and solicit feedback.

SITES

Site	Total storage capacity, L (gal)	Capture area, m² (ft²)	Rain depth capacity, mm (in)	water use
Sharing Hope Ministries	19,700 (5,200)	801(8,600)	12 (0.48)	Community garden
Southwest Bank	52,900 (14,000)	1,220 (13,300)	43 (1.7)	Landscape irrigation
Panhandle Greenhouse	132,000 (35,000)	2,120 (22,900)	62 (2.5)	Commercial greenhouse
Youth With a Mission Urban Food Outreach	11,700 (3,100)	281(3,000)	21 (0.82)	Aquaponics greenhouse

RESULTS: WATER QUANTITY

Rainfall and Storage



Capture Efficiency

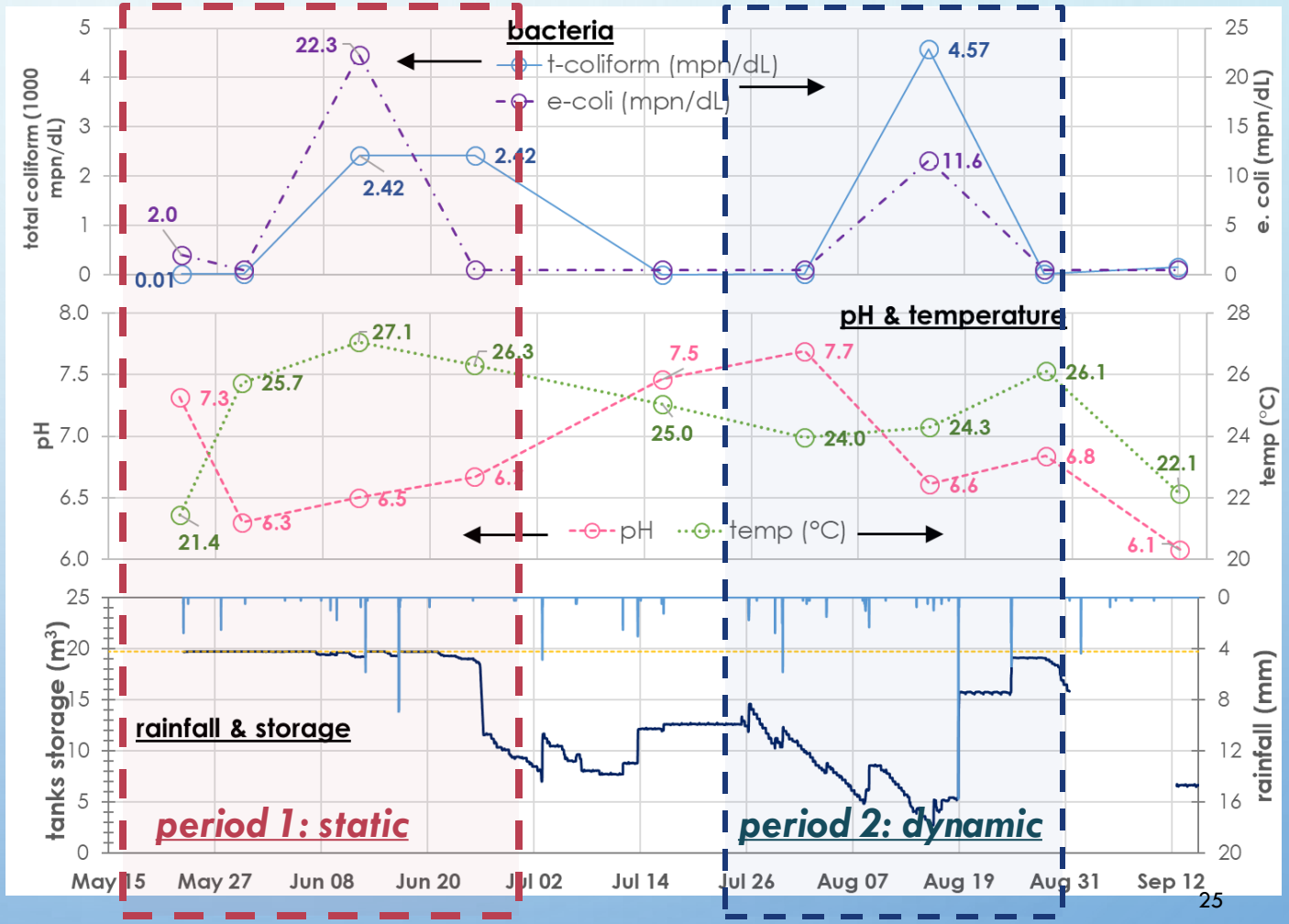
$$\text{eff} = \frac{\text{stored water}}{\text{rain water}}$$

event	raw eff	eff = raw/max-curr	eff = raw/max-empty	loss-keep ratio (current)	loss-keep ratio (empty)
9	**31%**	**85%**	**31%**	**0.17**	**2.23**
20	67%	67%	67%	0.49	0.49
28	30%	30%	30%	2.34	2.34
35	**20%**	**20%**	**20%**	**3.89**	**3.89**
13	2%	100%	2%	-	44.96
43	**53%**	**72%**	**53%**	**0.39**	**0.88**

RESULTS: WATER QUALITY

- Water temperature increase in spring and decrease in summer rain.
- Correlations of pH and bicarbonate concentration not terribly strong (0.06). **pH more affected by recent rainfall influx and water outflow.**
- Period 2 of *high rainfall inflow show strong increase in total coliform* while Period 1 of little flows into tanks have lower total coliform.
- Indicator e. *coli* fairly low at all times compared to contact standards (126 mpn/dL*)

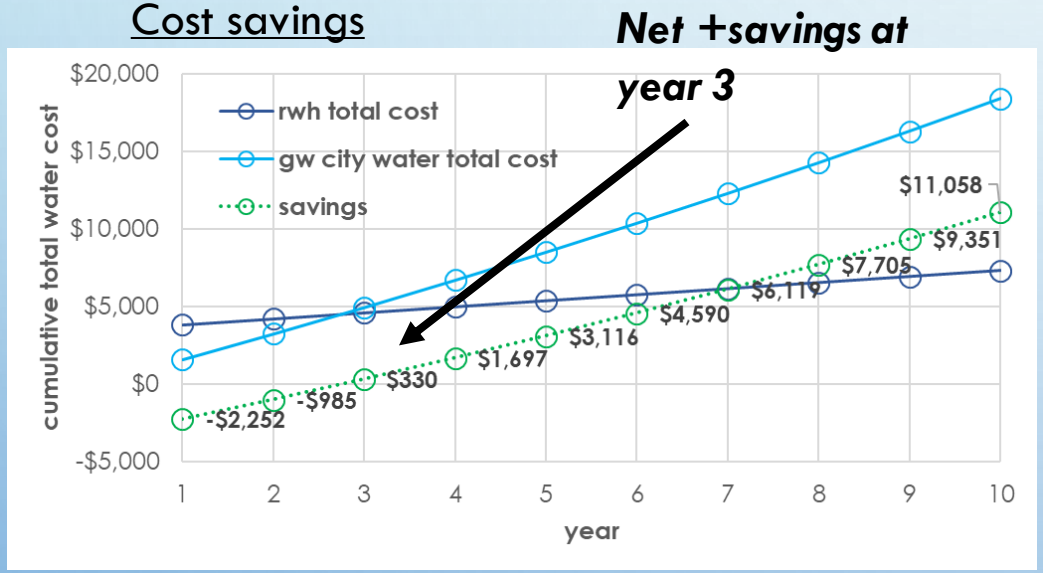
*2012 EPA Recreational Water Quality Criteria



ECONOMIC VALUE

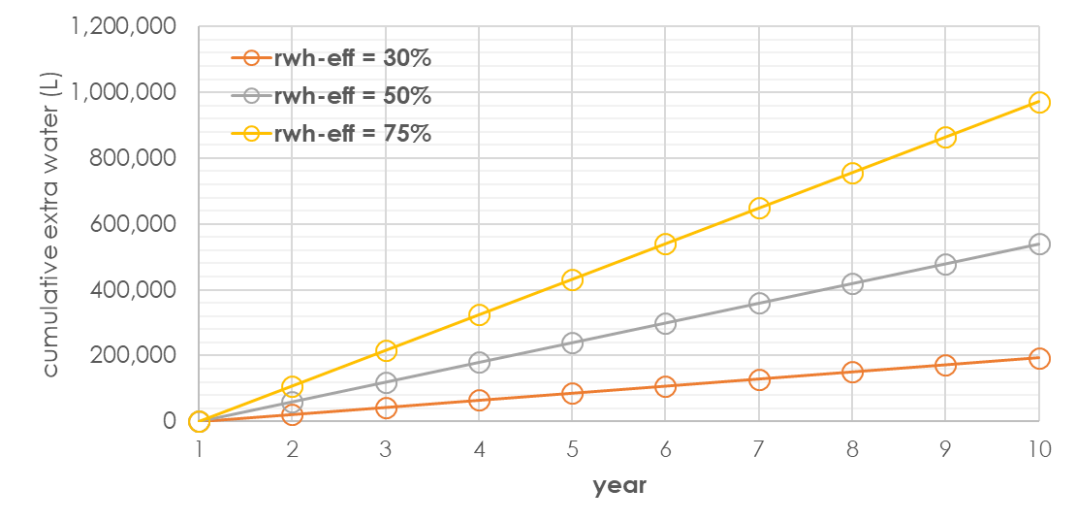
10-year Cost Savings and Water Surplus Using Rainwater Harvesting Over City-supplied Groundwater

Cost savings



water source	cost ($/1000 gal)
city groundwater	$192
rwh 30% efficiency	$48
rwh 50% efficiency	$29
rwh 75% efficiency	$19

Water surplus beyond gardening need



All efficiencies of 30-75% provide enough water for vegetable garden. Efficiency must drop below 19% to not provide enough water from direct and harvested rainfall alone.

SUMMARY OF CURRENT RESULTS

- Average capture efficiency ranges 35-54%. **Capture efficiency dependent on how efficiency is defined** and if storage is when rainfall occurs. Comparison with other studies also needed.
- Capture efficiency is a performance parameter, but not the only one. **If RWH operators have enough water when they need it, efficiency may not be as important.**
- Compared to dwindling groundwater supply water quality, **Texas panhandle captured rainfall is far superior for most uses** especially considering hardness, pH, and salinity.
- The price and quantity of water needed for the community garden makes rainwater harvesting highly favorable with **projected total savings of $11,000 over 10 years** and net savings on investment by year 3. (Caveat: Must be updated with more recent information from Sharing Hope Ministries.)