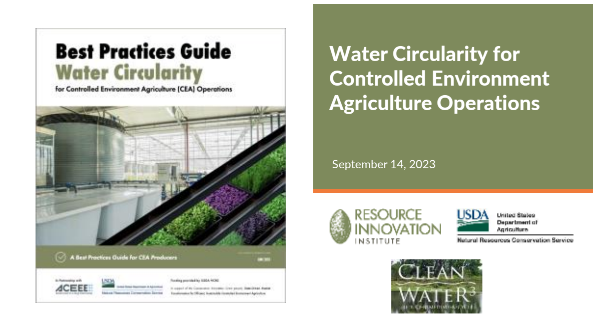
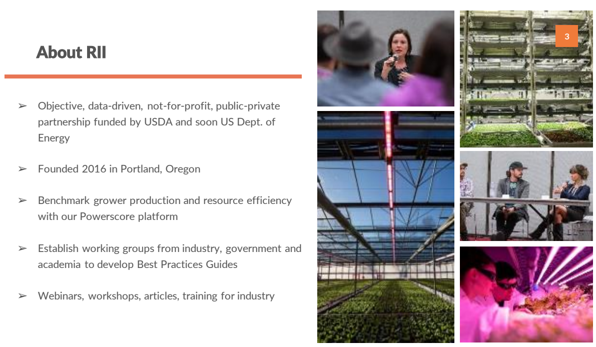

Best Practices Guide
Water Circularity
for Controlled Environment Agriculture (CEA) Operations
A Best Practices Guide for CEA Producers
Water Circularity for Controlled Environment Agriculture Operations
September 14, 2023
RESOURCE INNOVATION INSTITUTE
USDA United States Department of Agriculture
Natural Resources Conservation Service
CLEAN WATER

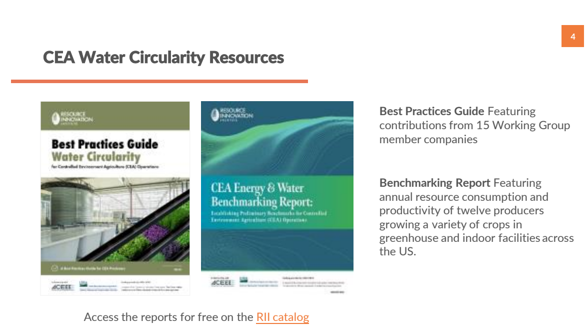
1


SECTION 01
Introduction

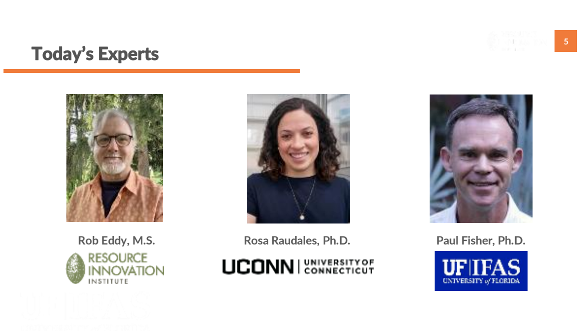
2


About RII
3
➢ Objective, data-driven, not-for-profit, public-private partnership funded by USDA and soon US Dept. of Energy
➢ Founded 2016 in Portland, Oregon
➢ Benchmark grower production and resource efficiency with our Powerscore platform
➢ Establish working groups from industry, government and academia to develop Best Practices Guides
➢ Webinars, workshops, articles, training for industry

3


CEA Water Circularity Resources
4
Best Practices Guide
Water Circularity
CEA Energy & Water Benchmarking Report:
Best Practices Guide Featuring contributions from 15 Working Group member companies
Benchmarking Report Featuring annual resource consumption and productivity of twelve producers growing a variety of crops in greenhouse and indoor facilities across the US.
Access the reports for free on the RII catalog

4


Today's Experts
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Rob Eddy, M.S.
RESOURCE INNOVATION INSTITUTE
Rosa Raudales, Ph.D.
UCONN | UNIVERSITY OF CONNECTICUT
Paul Fisher, Ph.D.
UF IFAS UNIVERSITY of FLORIDA

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SECTION 02
Reducing Water Use in CEA Operations

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Fate of Water in CEA Operations

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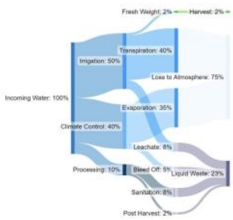
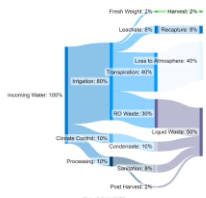


Standard Greenhouse



Standard Indoor Farm
(w/o condensate recapture)

7

Fate of Water in CEA Operations

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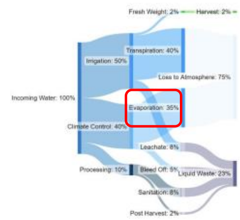
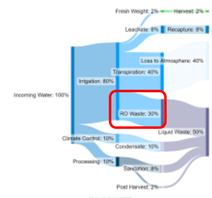
Some water loss is from climate control and processing.



Standard Greenhouse



Standard Indoor Farm
(w/o condensate recapture)

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Water Use Efficiency by Production Method

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Production Method	Country	Product water use (L/kg)	Product water use (gal/lb)
Open field, general	Israel, Spain, Turkey	100-300	12-36
Open field, drip irrigation	Israel	60	7
Greenhouse, unheated plastic	Spain	40	5
Glasshouse, unheated	Israel	30	4
Greenhouse, regulated ventilation, plastic	Spain	27	3
Glasshouse, advanced controls, CO_2	Netherlands	22	3
Glasshouse, advanced controls, CO_2, closed hydroponic system	Netherlands	15	2
Closed Greenhouse, advanced controls, CO_2, closed hydroponic system	Netherlands	4	0.5
Greenhouse, evaporative cooling	Mexico	Estimated: 100	Estimated: 12

Modified from Nederhoff, Elly & Stanghellini, Cecilia. (2010).

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Economic Rationale For Reducing Water Consumption

10

Recirculating irrigation water has been shown to reduce water consumption by 20%-40%

Reducing irrigation water has been shown to reduce fertilizer costs by **40%-50%**

CEA producers report ROI in as little as two years due to fertilizer cost reduction

Source: Mohammed, N. (2019). The Advantages of a Closed Hydroponic System in Commercial Greenhouses [Slide show; Powerpoint]. Government of Alberta. https://www1.agric.gov.ab.ca/$Department/deptdocs.nsf/all/green14458/$FILE/Nabeel%20J%20M-%20Oct%202017.pdf

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Sources of Water Waste in CEA Operations

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Priority Rank	Type of Water Waste	Relevant To All Facilities	Potential High Waste Volume	Release Causes Environmental Harm	Potential Crop Damage	Substitute for RO Water	Potential to Improve ROI on Treatment Costs	Difficult to Remediate
1	Over Irrigation and Leaks	X	X	X	X		X	
2	Irrigation Leachate	X	X	X			X	
3	Pesticide Drench/ Overspray	X		X				X
4	RO Reject Water		X					X
5	Evaporative Cooling Pad Bleed-Off		X					X
6	Condensate		X			X		
7	Washdown Water	X						X
8	Blowdown Water							X

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Reducing Irrigation Waste in Hort Substrate Culture

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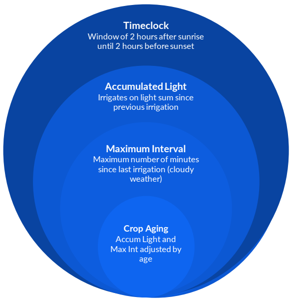
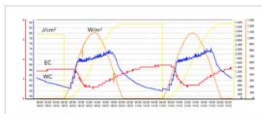


Reducing Irrigation Waste by Smart Programming

Example of layering environmental variables to trigger irrigation



Priva and Grodan

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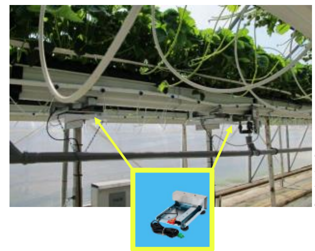
Reducing Irrigation Waste by Weight Scale Measurement



Powerplants Australia

Drain Sensors (volume, EC)

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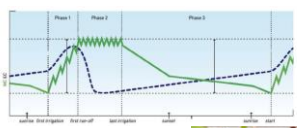
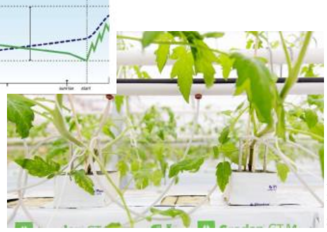
Reducing Irrigation Waste by Water Content Sensing



Sensor (WC and EC)



Priva and Grodan

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Reducing Irrigation Waste by Using Recirculating Systems

Nutrient Film Technique

Raft Culture

Aeroponics

Deep Water Culture

Vertical NFT/Aeroponics

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An Often Overlooked Source of GH Water Waste…

Production Method	Country	Product water use (L/kg)	Product water use (gal/lb)
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Modified from Nederhoff, Elly & Stanghellini, Cecilia. (2010).

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Reducing Climate Control Water Waste

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SECTION 03

Water Quality for Circularity

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Water Quality for Circularity

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Rosa E. Raudales, Ph.D.
Associate Professor & Extension Specialist
University of Connecticut

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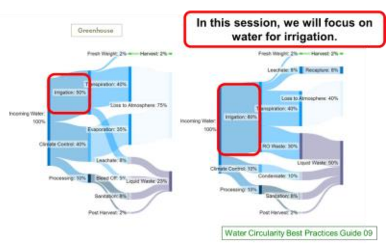
Water Quality for Circularity

UCONN 21



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UCONN 22

The suitability for a process is determined by **its quality.**

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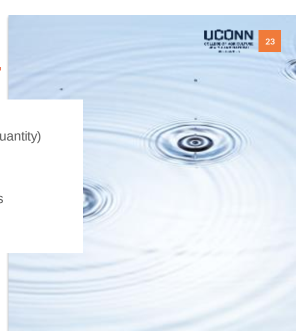
Ultimate goals of water circularity

UCONN 23

1. Reduce the amount of freshwater use (quantity)
2. Reuse water (quality)
   a. Recover/ keep valuable compounds
   b. Remove potential contaminants



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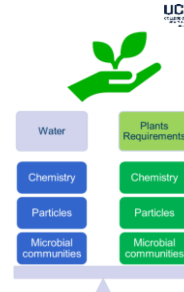
UCONN 24

Improving operational efficiency of CEA requires understanding **water quality.**



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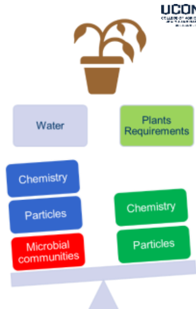
Improving operational efficiency of CEA depends on understanding **water quality.**



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Water quality is characterized by:

1. Chemical: pH, concentration of total or and specific salts, sanitizers, and agrochemicals.

2. Microbial: plant pathogens, algae, and biofilm

3. Physical: organic particles or inorganic precipitates, temperature

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Chemical parameters: Essential for plant production

PARAMETER	THRESHOLD	COMMENTS
Calcium (Ca)	<150 ppm	High levels of calcium potassium can limit plant uptake of other required nutrients such as potassium and magnesium. As levels increase in the water source, decrease applied fertilizer.
Iron (Fe)	<2 ppm	High iron results in crop phytotoxicity in sensitive crops, especially when the substrate pH is low. Treatment includes maintaining substrate-pH above 5.8. Remove iron from water if staining or iron bacteria are an issue via chemical oxidation with chlorine, ozone or potassium permanganate followed by sand filtration and settling in ponds.
Boron (B)	< 0.5 ppm	Boron can cause toxicity in sensitive plants. Treatment includes keeping the substrate-pH above 6.0 and use calcium-based fertilizers, or blend with a more pure water source.

Use valuable elements from the "*source*".

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Chemical parameters: Non-Essential for plant production

PARAMETER	THRESHOLD	COMMENTS
Fluoride (F)	1 ppm	Fluoride can cause toxicity symptoms in some crops. Water treatment with activated carbon filters can remove fluoride and keeping the substrate-pH above 6.0 with calcium-based fertilizers can be used for sensitive crops.

Treat when the levels are above the threshold.
Ignore if levels are under the threshold.

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Simple decision making framework for circularity

- Match the water chemistry to plant needs
  - Water > plant needs → Dilute, treat, or use in other process.
  - Water ≤ plant needs → Reuse
- Use the most limiting factor to determine:
  - Reuse or restore (treatment)
  - Use in an alternative process

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Consider the effect of chemical precipitates on the irrigation system

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High-quality water can also cause problems

Water source: City water

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Measure the chlorine in your water

Cora McGehee,
Ph.D. student, UConn

	Tap Water	Post-activated carbon filter	Deep Water Pond
pH	7.9	7.9	5.1
EC (µs/cm)	422	435	1963
Dissolved oxygen (mg/L)	9.6	9.6	9.3
Total Chlorine (mg/L)	1.86	0.60	0.56
Free Chlorine (mg/L)	1.56	0.49	0.51
ORP (mV)	789	725	690
Total suspended solids (mg/L)	0	0.4	0.2
Pythium spp.	-	-	-
Total bacteria (cfu/mL)	0	24	7,400

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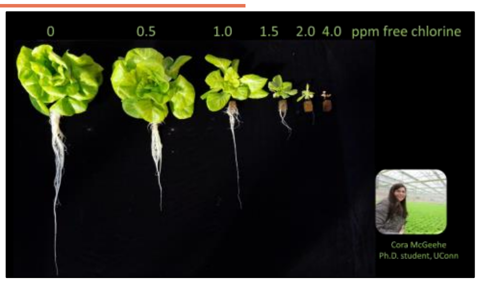
Measure the chlorine in your water



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Common plant pathogens in hydroponics

Water molds (Oomycetes): *Pythium, P. dissotoccum, Globisporangium irregulare, G. ultimum, Phytophthora*
Zoospores have flagella: actively move freely in the water.
Other stages: move with organic matter.

Fungi: *Rhizoctonia, Fusarium, Thielaviopsis, Alternaria, Sclerotinia, Botrytis,, etc.*
Most structures move with organic matter.

Bacteria: *Xanthomonas* spp.
Virus: Depends on the crop.

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Dispersion of pathogens in solutions

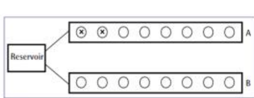

Figure 1. Cultivation Unit

x *Pythium aphanidermatum*

Figure 2. Mortality of poinsettia plants in an inoculated (left) and noninoculated (right) ebb-and-flow units.

(Reference: Stanghellini M and CJ Nielson, OFA Bulletin 927:21-23, 2011)

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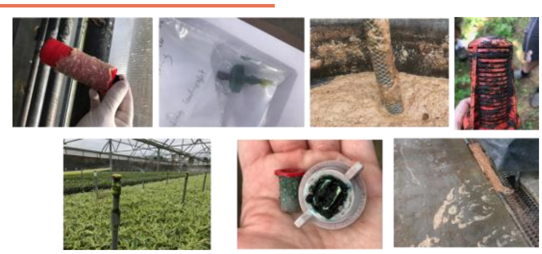
Algae and biofilm = Clogging



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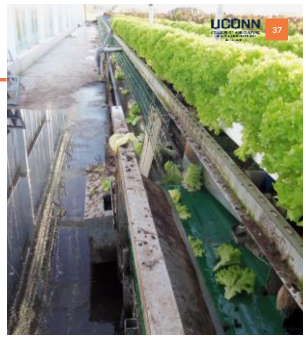
Physical parameters:
Particles come in all sizes

Particles:

- Clog the systems
- Carry pathogens
- Reduce sanitizing efficacy



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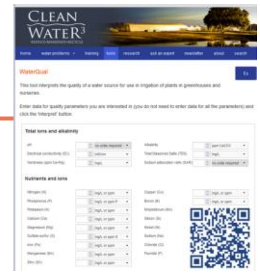
Available Tools



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Key Points

1. Test the quality of the water source and solutions periodically to understand potential risks
2. Match water quality to crop needs
3. Use risk thresholds to determine suitability for use or treatment needs

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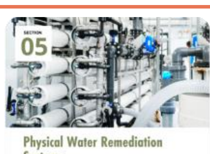
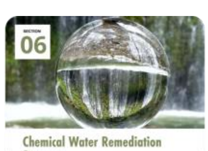
Remediation Technologies





Paul Fisher, Ph.D

UF | IFAS Extension UNIVERSITY of FLORIDA

REDUCE, REMEDIATE, RECYCLE
CLEANWATER3.ORG

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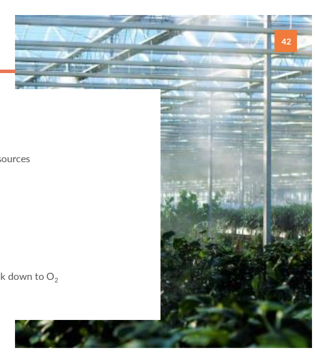
Key Points

1. Every technology can solve a limited range of issues
2. Different goals in the pump house and grow room
3. Lots of ways to compare technologies from great info sources
4. Apply the recommended dose
5. Avoid underdosing
6. Don't mix clean and dirty water
7. Particle filters help every subsequent step
8. Point treatments or active ingredients that rapidly break down to O_2
9. pH and EC control do not guarantee nutrient balance



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1. Every technology can solve a limited range of issues

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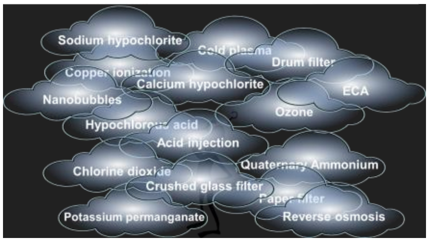

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2. We have different goals in the pump house and grow room

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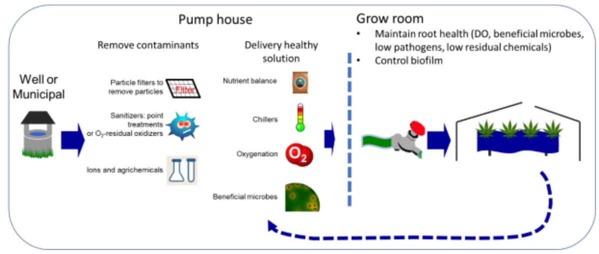

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3. Many ways to compare technologies, & great info sources

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Many ways to compare technologies, & great info sources

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Also…

CleanWater3.org

Greenhouse Training Online course "Irrigation water quality & treatment"

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4. For pathogen control, provide adequate dose

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	Efficacy tests for Phytophthora zoospores	Contact Time
Filtration	0.1 - 0.5 microns (membrane)	Point
Chlorine	2 ppm at pH 6.0 to 7	< 2 min
Chlorine dioxide	2.6 ppm	2 min
Copper	0.8 to 5.8 ppm depending on formulation	10 min to 2h
H_2O_2 / peroxygens	185 ppm H_2O_2 + 120 ppm PAA (1:1,000 SaniDate 12.0)	1 min
Ozone	1.5 ppm	8 min
Slow Sand Filtration/ Constructed wetlands	Antagonistic microbes + filtration	Hours to days
UV light	75 % transmittance of 254 nm	Point

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5. Typical design: Avoid Underdosing

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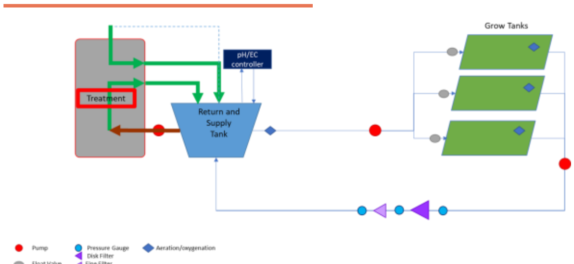

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Avoid Underdosing

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Table 8. Critical level and exposure time for ozone disinfection of nine common biological contaminants of tap water.[73]

Microorganism	Critical Level (ppm)	Exposure Time (min)
Algae	.01-.05	N/A
Alternaria zinniae	0.7	16
Biofilm	0.2	30
Cucumber Green Mottle Virus	7.9	75
Fusarium oxysporum	1.6	2
Phytophthora capsici	1.5	23
Phytophthora cinnamomi	0.8	8
Pythium ultimum	1.2	2
Tobacco Mosaic Virus	100	30

Untreated fertilizer solution

Ozone-treated fertilizer solution

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6. Typical design: Avoid mixing cleaned water with dirty water

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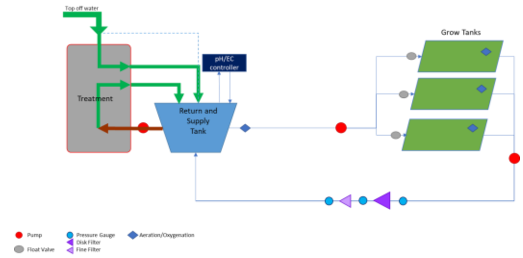

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Better Treatment System Design

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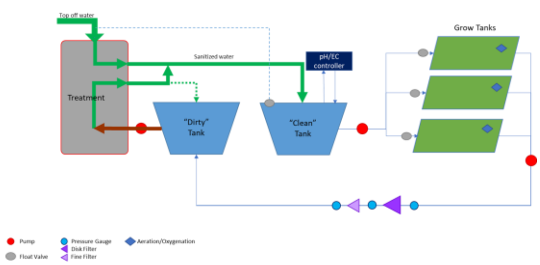

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We have different goals in the pump house and grow room

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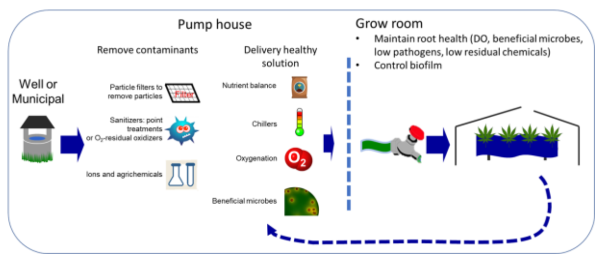

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7. Particle filter first to reduce sanitizing "demand"

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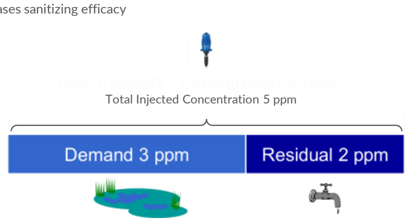
- Reduces chemical cost
- Increases sanitizing efficacy



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Choose the right kind of filter

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Contaminant types, Labor, Complexity, Consumables, Pressurized, Backflushing, Flow Rate, Staging

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Combine multiple filter stages

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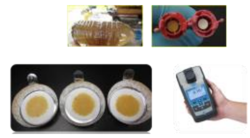
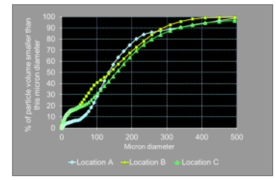
Test your filters are working to remove particles





For most irrigation needs: Less than 5 mg/L total suspended solids (TSS) or <5 NTU turbidity, and filter to a finer pore size than your smallest emitter

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8. In recirculating hydroponics, choose technologies with point treatment or low residual activity that break down to O_2

Technology	Residual (high = ***)	Residual ingredients	Residual risk (high = ***)
Copper ionization	***	Cu	***
Chlorine	***	HOCl, cations, chloramines, Cl^-	***
Surfactants	***	Surfactant	***
Chlorine dioxide	**	ClO_2, Cl^-	**
H_2O_2/Peroxygens	***	H_2O_2, O_2	**
Ozone	*	O_2	*
Cold plasma	*	O_2	
Ultraviolet light			
Ultrafiltration			

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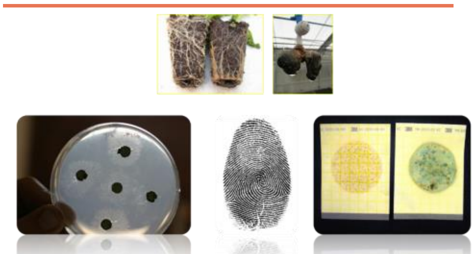
Test your sanitizer is working to remove microbes & pathogens



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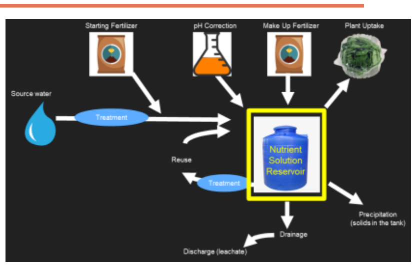
9. pH and EC control do not guarantee nutrient balance in closed systems



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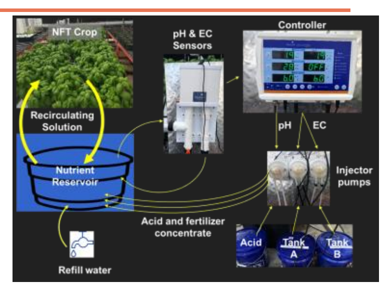
pH and EC control helps but does not ensure nutrient balance



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Test your nutrient solution and water source

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CleanWater3.org > Tools > WaterQual

Measurement	Test value	Result	Explanation of result
pH	7.8	High (>7)	*Interpreting the pH and alkalinity results together*
Alkalinity	240 ppm $CaCO_3$	High (>150.01ppm $CaCO_3$)	pH and alkalinity levels this high means some pH adjustment (addition of acid) will be required in the spray tank with certain agrichemicals - check the pesticide label. Acidification is needed for hydroponic growers to lower pH to 6. For irrigation of containerized plants, injection of acid is recommended to reduce alkalinity and avoid an increase in substrate-pH over time. You may also need to include ammonium or urea nitrogen at 40% or above of total N in fertilizer to help avoid a rise in pH when using hydroponics or a container substrate.
Electrical conductivity (EC)	0.55 mS/cm	Low (<0.75 mS/cm)	Low concentration of dissolved ions. Generally not a problem for irrigation of container crops in terms of total salt accumulation. However, also check sodium and chloride levels. Levels below 0.5 mS/cm are most suitable for plant propagation.
Hardness (ppm Ca+Mg)	68 mg/L	Moderate (>50 mg/L)	Not generally a problem, but as Ca and Mg levels increase there is greater risk of scale forming in irrigation equipment, boilers, and on plants.

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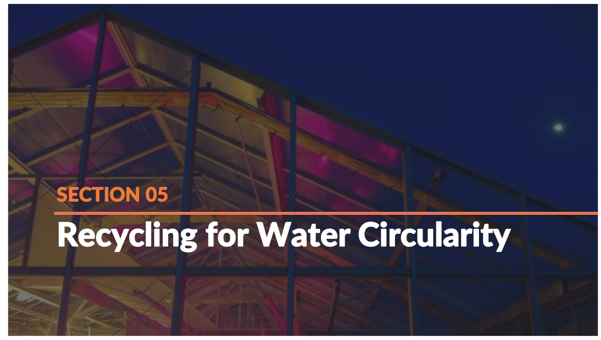

SECTION 05
Recycling for Water Circularity

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Recycling Irrigation Water

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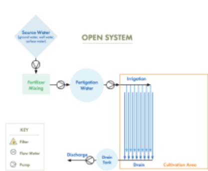

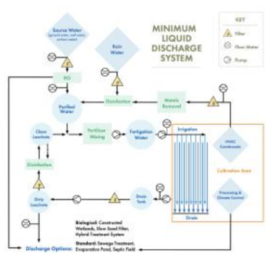

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Recycling Condensate from HVAC Units

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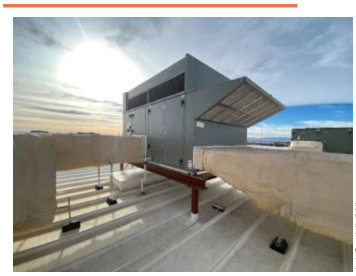

Research published in 2020 showed condensate water recovery accounted for **67% of the annual water demand** for lettuce in a vertical farm

Other vertical farm producers have reported **conserving 80%** of their water through condensate reclamation.

Source: Pacak, A., Jurga, A., Drąg, P., Pandelidis, D., & Kaźmierczak, B. (2020). A Long-Term Analysis of the Possibility of Water Recovery for Hydroponic Lettuce Irrigation in Indoor Vertical Farm. Part 1: Water Recovery from Exhaust Air. Applied Sciences, 10(24), 8907.

Source: Hansen, J. (2018). Slash your Water Use by 50% or More. CBT. July 2018

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Recycling Rain/Condensate Also Reduces RO Brine Waste!

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Quality level	EC (mS/cm)	Na (ppm)	Cl (ppm)	Suitability for hydroponics	Suitable use
1	< 0.5	< 34	< 53	++	Suitable for all crops
2	0.5 - 1.0	34 - 57	53 - 87	+	Some discharge required in recirculating systems
3	1.0 - 1.5	57 - 92	87 - 142	±	Not suitable for salt-sensitive crops or recirculated closed systems

Hydroponic producers commonly purify source water using reverse osmosis, with a typical 50% efficiency, meaning they create **1 gallon of brine waste for 1 gallon of purified water**.

High-efficiency RO units can increase efficiency to 85% or higher.

Alternatively, rainwater or HVAC condensate can be used as near-pure water sources.

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Storing Water for Reuse

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SECTION 06
Q & A

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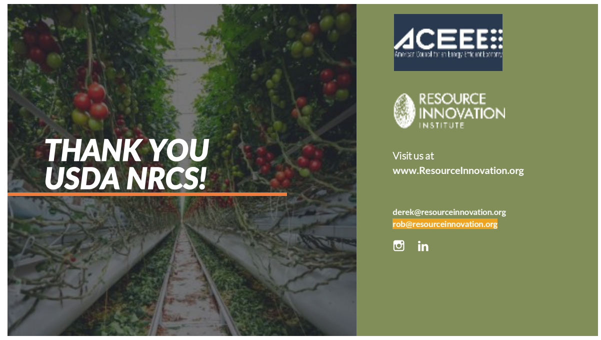
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