



ALADYR

LATIN AMERICAN ASSOCIATION OF
DESALINATION AND WATER REUSE

IRRIGATION OF AGRICULTURAL CROPS WITH RECYCLED WATER: REGULATIONS THAT PROTECT THE PUBLIC HEALTH

By: Bahman Sheikh. PhD, PE

April 22, 2020

ABOUT OUR PANELIST



Bahman Sheikh has over 30 years of domestic and international experience in research, planning, and design of water resources projects, specializing in water conservation, reclamation, reuse, and recycling. Dr. Sheikh's career began as a university professor. His academic career was followed by consulting, technical investigations, master planning, and design of water resources facilities. Sheikh's water recycling experience includes service in both the public and private sectors. For the City of Los Angeles, he developed long-term water reuse goals, planned water recycling projects to the year 2090, and advanced public outreach.

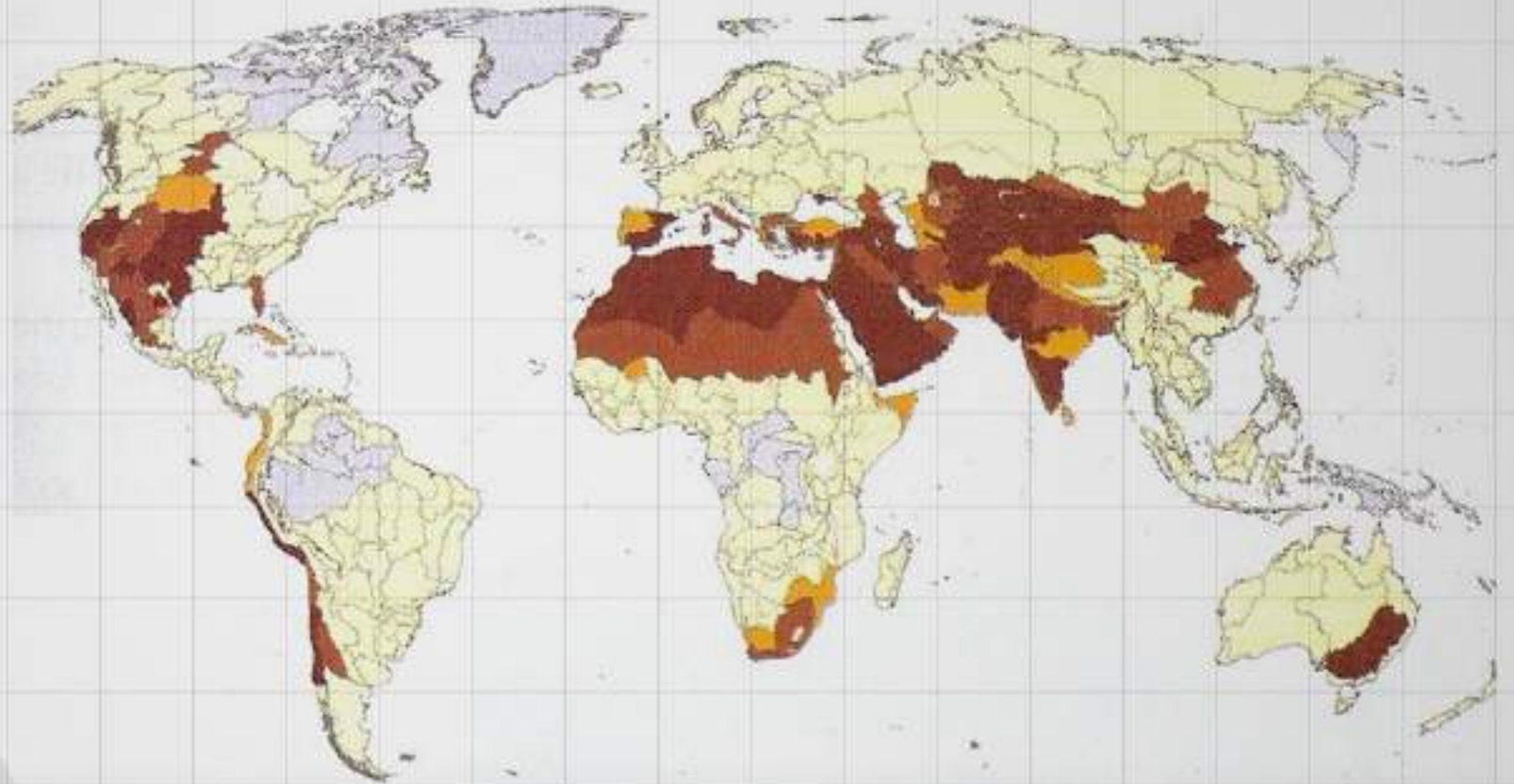
The focus of much of Dr. Sheikh's service is on public health and safety of recycled water used for irrigation, industry, and drinking applications. Most of Dr. Sheikh's service is concentrated in California, Colorado, and Hawai'i. In addition, he has served clients with water reuse projects in 21 countries, including Peru, Bonaire, Mexico, South Korea, Australia, Saudi Arabia, Egypt, India, Jordan, Kuwait, UAE, Syria, Bahrain, Morocco, and Tunisia.

OUTLINE OF PRESENTATION

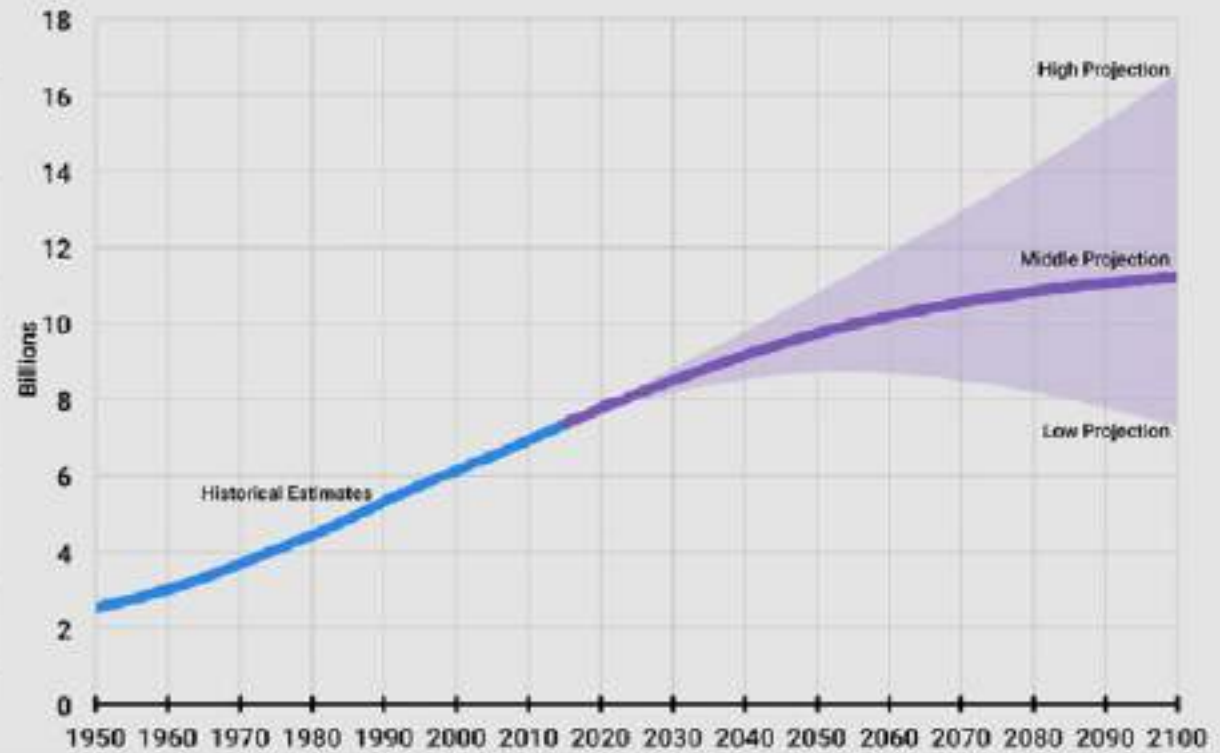
- Agricultural Use of Reclaimed/Recycled Water
- Regulations for Water Reuse
- Research Results
- Safety of Water Reuse in Agriculture
- The Record So Far



DEGREE OF WATER STRESS



PROJECTED WORLD POPULATION



SOURCE: United Nations Prospects 2015 Revision

RECYCLED WATER FOR AGRICULTURE

- Mexico—Mezquital Valley
- USA—California, Florida, Arizona, Texas, ...
- South Africa
- Australia—Mackay, Werribee, Virginia Pipeline Scheme
- Spain, Other Southern European Countries
- Egypt—Gabal El-Asfar
- Tunisia, Morocco
- Israel
- Jordan Valley
- Saudi Arabia, Kuwait, UAE



FARMERS' SKEPTICISM

- Sales—Public Perception
- Soils/Salts--Permeability
- Safety—Consumers', Workers' Health
- Supply Reliability

REGULATING WATER REUSE FOR AGRICULTURE

World Health Organization (WHO) Guidelines

- Commonly Adopted by Many Countries
- Pathogen Reduction:
 - Treatment
 - Irrigation Method
 - Mechanical Operations
 - Time to Harvest

California Title 22

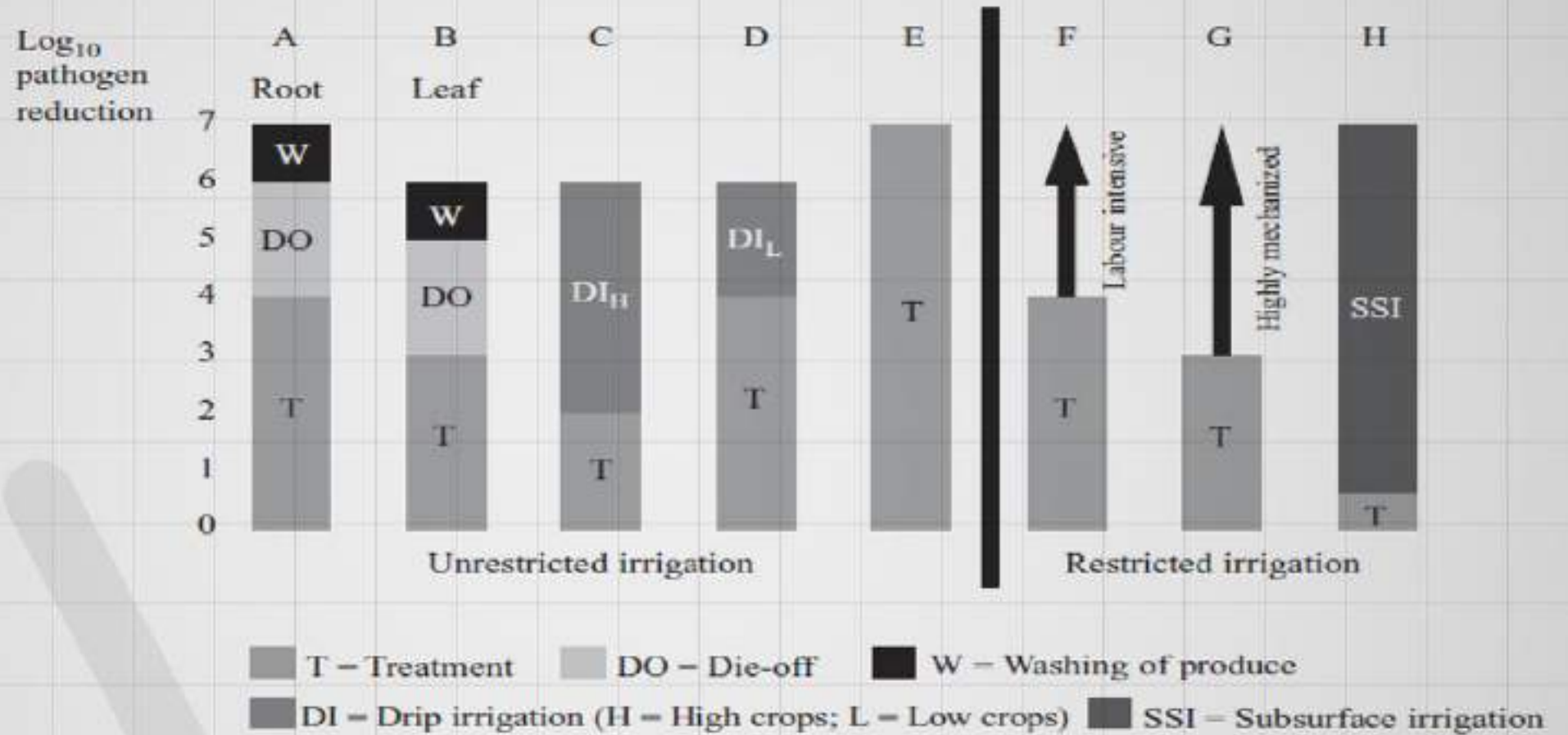
- Four Levels of Treatment, Prescribed Treatment Trains
- 43 Allowed Uses
- Food Crops Can Be Irrigated with Disinfected Tertiary Recycled Water

Recycled Water Use	Treatment Level			
	Disinfected Tertiary Recycled Water	Disinfected Secondary 2.2 Recycled Water	Disinfected Secondary 2.3 Recycled Water	Undisinfected Secondary Recycled Water
Irrigation for:				
Food crops where recycled water contacts the edible portion of the crop, including all root crops	ALLOWED	NOT ALLOWED	NOT ALLOWED	NOT ALLOWED
Parks and playgrounds				
School grounds				
Residential landscaping				
Unrestricted-access golf courses				
Any other irrigation uses not specifically prohibited by other provisions of the <i>California Code of Regulations</i>				
Food crops, surface-irrigated, above-ground edible portion, not contacted by recycled water		ALLOWED		
Cemeteries			ALLOWED	
Freeway landscaping				
Restricted-access golf courses				
Ornamental nursery stock and sod farms with unrestricted public access				
Pasture for milk animals for human consumption				
Nonedible vegetation with access control to prevent use as a park, playground or school grounds				
Orchards with no contact between edible portion and recycled water				ALLOWED
Vineyards with no contact between edible portion and recycled water				
Non food-bearing trees, including Christmas trees not irrigated less than 14 days before harvest				
Feedlot and fiber crops and pasture for animals not producing milk for human consumption				
Seed crops not eaten by humans				
Food crops undergoing commercial pathogen-destroying processing before consumption by humans				
Ornamental nursery stock, sod farms not irrigated less than 14 days before harvest				

Recycled Water Use	Treatment Level			
	Disinfected Tertiary	Disinfected Secondary 2.2	Disinfected Secondary 2.3	Undisinfected Secondary
Supply for impoundment:				
Nonrestricted recreational impoundments, with supplemental monitoring for pathogenic organisms	ALLOWED ³	NOT ALLOWED	NOT ALLOWED	NOT ALLOWED
Restricted recreational impoundments and publicly accessible fish hatcheries	ALLOWED	ALLOWED		
Landscape impoundments without decorative fountains			ALLOWED	
Supply for cooling or air conditioning:				
Industrial or commercial cooling or air conditioning involving cooling tower, evaporative condenser, or spraying that creates a mist	ALLOWED ³	NOT ALLOWED	NOT ALLOWED	NOT ALLOWED
Industrial or commercial cooling or air conditioning not involving cooling tower, evaporative condenser, or spraying that creates a mist	ALLOWED	ALLOWED	ALLOWED	

Prepared by Deborah Smith and edited by DMED Office of Water Recycling. We acknowledge this is a necessary and not the formal version of the regulations referenced above.

WHO GUIDELINES



INTERNATIONAL STANDARDS, REGULATIONS

- World Health Organization (WHO) Guidelines
- USA and Individual States
- Europe
- Japan
- Australia
- South Africa
- Middle East/North Africa
- Mexico
- India

DISINFECTION FOR UNRESTRICTED IRRIGATION (VEGETABLES EATEN RAW)

Country, Region	Total Coliform/100 mL	Fecal Coliform/100 mL
Colorado, New Mexico, Texas	Prohibition of Use	
Italy, Puglia, Emilia Romagna	≤ 2	
USEPA (G), Arizona, Utah, Japan, UK		No Detect
California, Washington	≤ 2.2	
Germany, Victoria, Australia (National Guidelines)		≤ 10
Spain		≤ 200
France, Sicily, Greece, Mexico, Mediterranean Region		≤ 1000

DISINFECTION FOR “RESTRICTED” IRRIGATION (PROCESSED FOOD, ORCHARDS, PASTURE)

State, Country, Region	Total Coliform /100 mL	Fecal Coliform /100 mL
Puglia (S. Italia)	≤ 10	
California, Italy, Emilia Romagna	≤ 23	
Australia		≤ 10
Germany	≤ 100	≤ 10
Washington	≤ 240	
Florida, Utah, Texas, USEPA (G)		≤ 200
Arizona, New Mexico, Australia, Victoria, Sicily, Mexico, Greece, Spain		≤ 1,000
Austria		≤ 2,000
Sicily	≤ 3,000	
Cyprus		≤ 3,000
Greece, Spain		≤ 10,000

DISINFECTION FOR IRRIGATION OF URBAN PARKS, CEMETERIES, PLAYGROUNDS, ATHLETICS FIELDS

Country, Region	Total Coliform /100 mL	Fecal Coliform /100 mL
Arizona, Florida, Utah		No Detect
California, Washington	≤ 2.2	
New Mexico		≤ 5
Texas		≤ 20
Greece		≤ 100
Colorado (EC),		≤ 126
Spain		≤ 200
France		$\leq 1,000$

MICROBIAL INDICATORS OF PATHOGEN KILL

Total, Fecal, Escherichia Coliforms

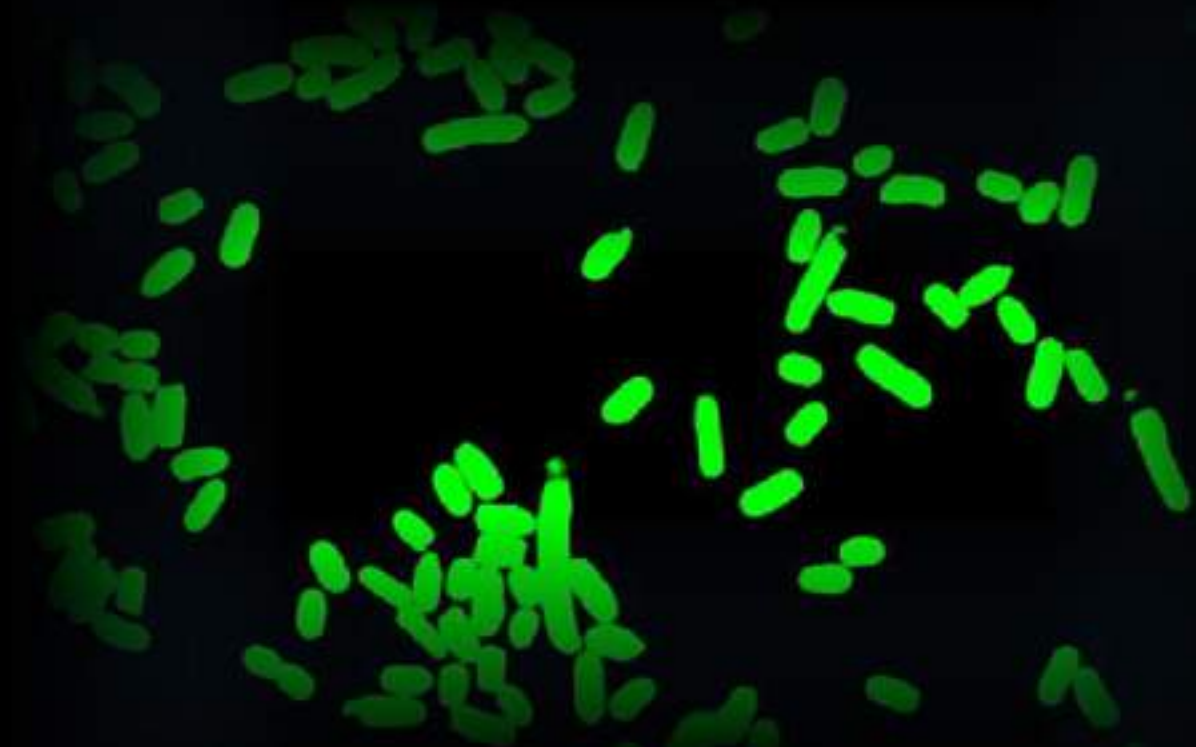
Equivalent Indicators of
Presence/Absence of Pathogens

Accepted and Used World-wide

Europe Uses E. Coli, as does Australia,
and WHO

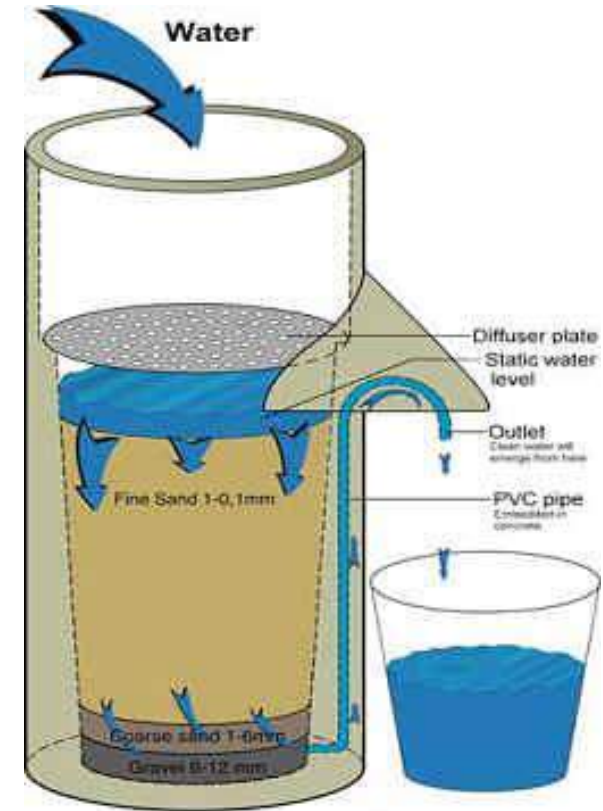
Wide Range of Numerical Standards in
Different Jurisdictions

Choice of Indicator is Based on Historical
Practice, Level of Comfort, and ... Habit



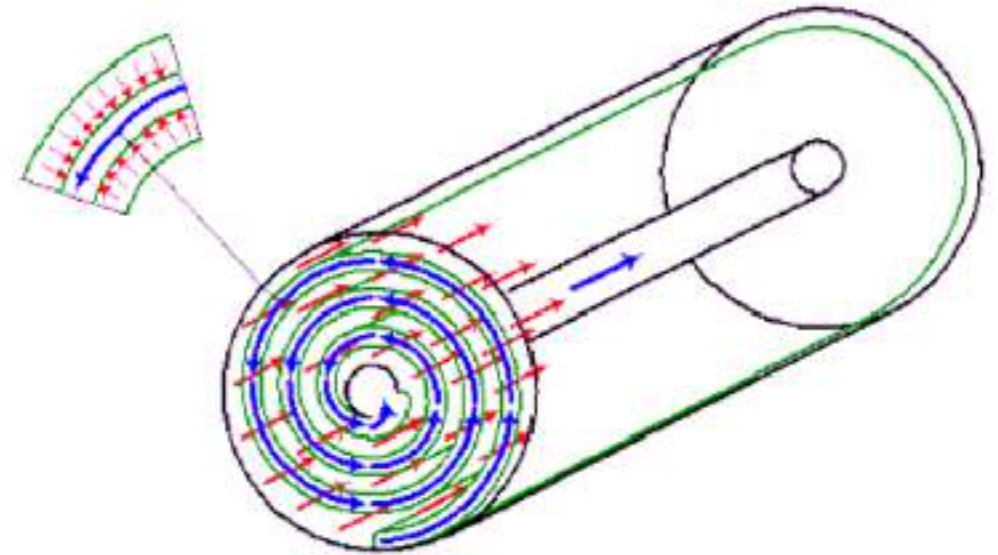
TREATMENT FOR REMOVAL/INACTIVATION OF MICROBES

- Protozoans
 - Filtration
- Bacteria
 - Filtration and Disinfection
- Viruses
 - Coagulation/Sedimentation,
Filtration and Disinfection



TREATMENT FOR REMOVAL OF CHEMICALS

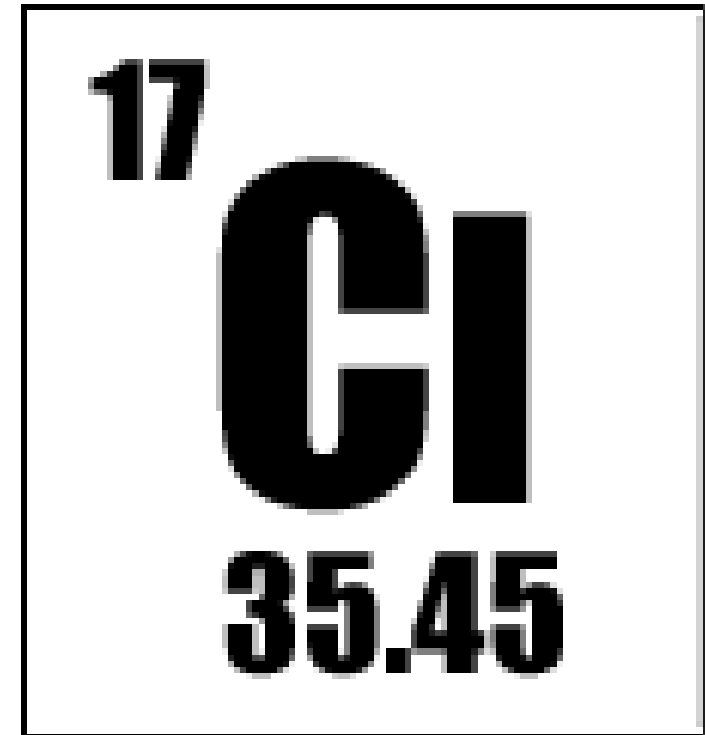
- Heavy Metals
 - Removed in Sludges
- Nutrients
 - Biological Nutrient Removal—if Needed
 - Beneficial for Irrigation of Food Crops—
Not Necessary for Irrigation
- Microconstituents
 - Reverse Osmosis—where Needed
 - Not Necessary for Irrigation



DISINFECTANT, CHLORINE

Chlorine

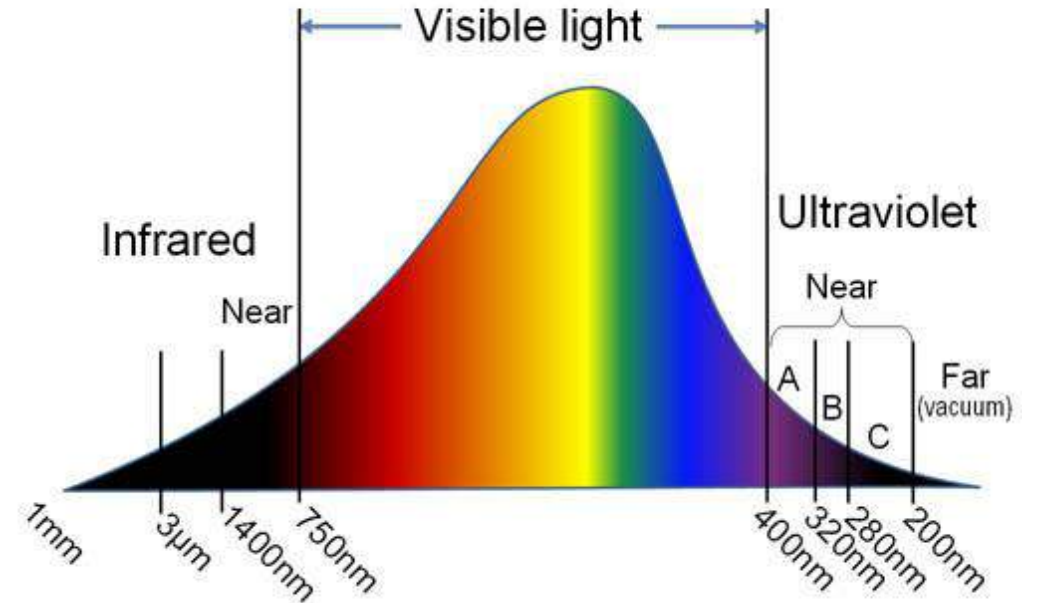
- Gaseous chlorine
- Hypochlorite
- Chloramines
- Chlorine Dioxide



DISINFECTANT, UV

Ultraviolet Light

- Cost-competitive with Chlorine
- Safer To Use and Transport
- No Hazardous Disinfection Byproducts
- Effective Against Parasites Such As *Cryptosporidium*, *Giardia* And Many Bacteria.
- Chlorine for Residual

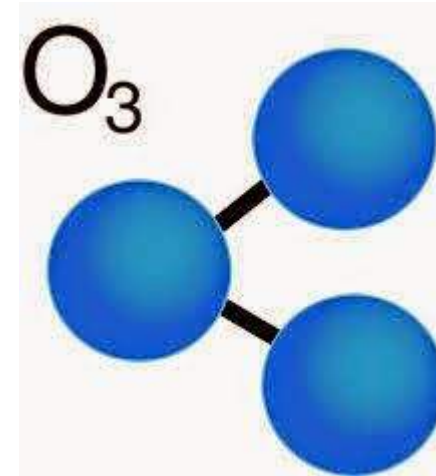


UV + CHLORINE

Where UV is used for disinfection, chlorine is often added to the reclaimed water prior to its entrance to a pipeline distribution system to prevent microbial regrowth, reduce the formation of biological growths and slimes in pipelines, and to oxidize organic matter to prevent odors.

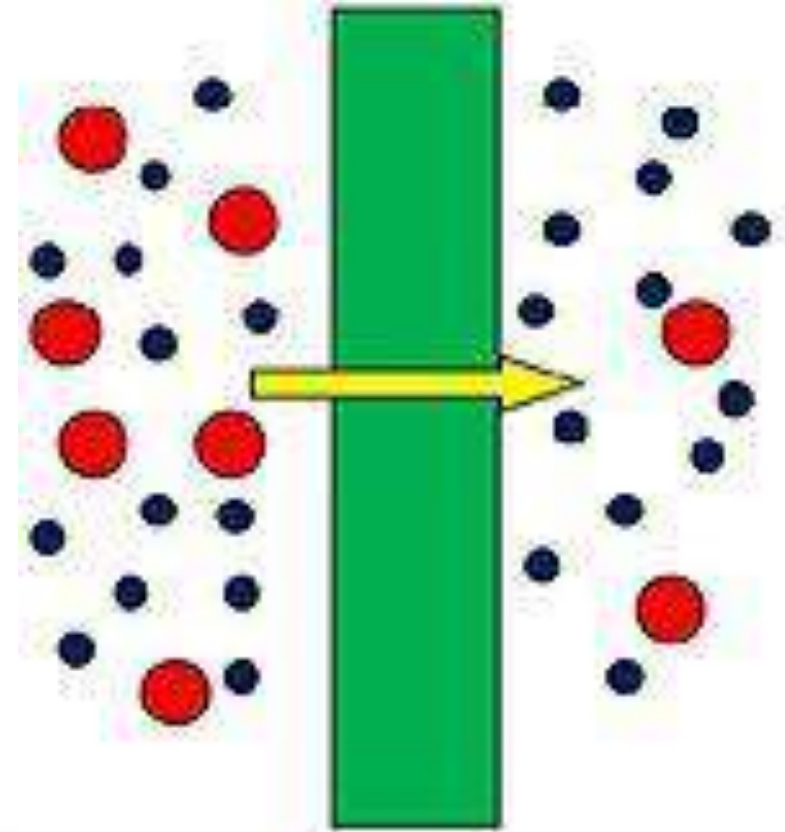
DISINFECTANT, O₃

- Powerful Oxidant
- Removes Organic Compounds
- Removes Color
- Oxidizes Potentially Toxic Chemicals To Non-hazardous Substances.
- High Operation and Maintenance Costs



DISINFECTANT, MEMBRANES

- Remove Some Pathogens
 - Size Exclusion
- Microfiltration Effectively Removes
 - *Cryptosporidium*
 - Giardia
 - Many Bacteria
- Reverse Osmosis Can Remove All Pathogens From The Water, Including Viruses



FARMERS' SKEPTICISM

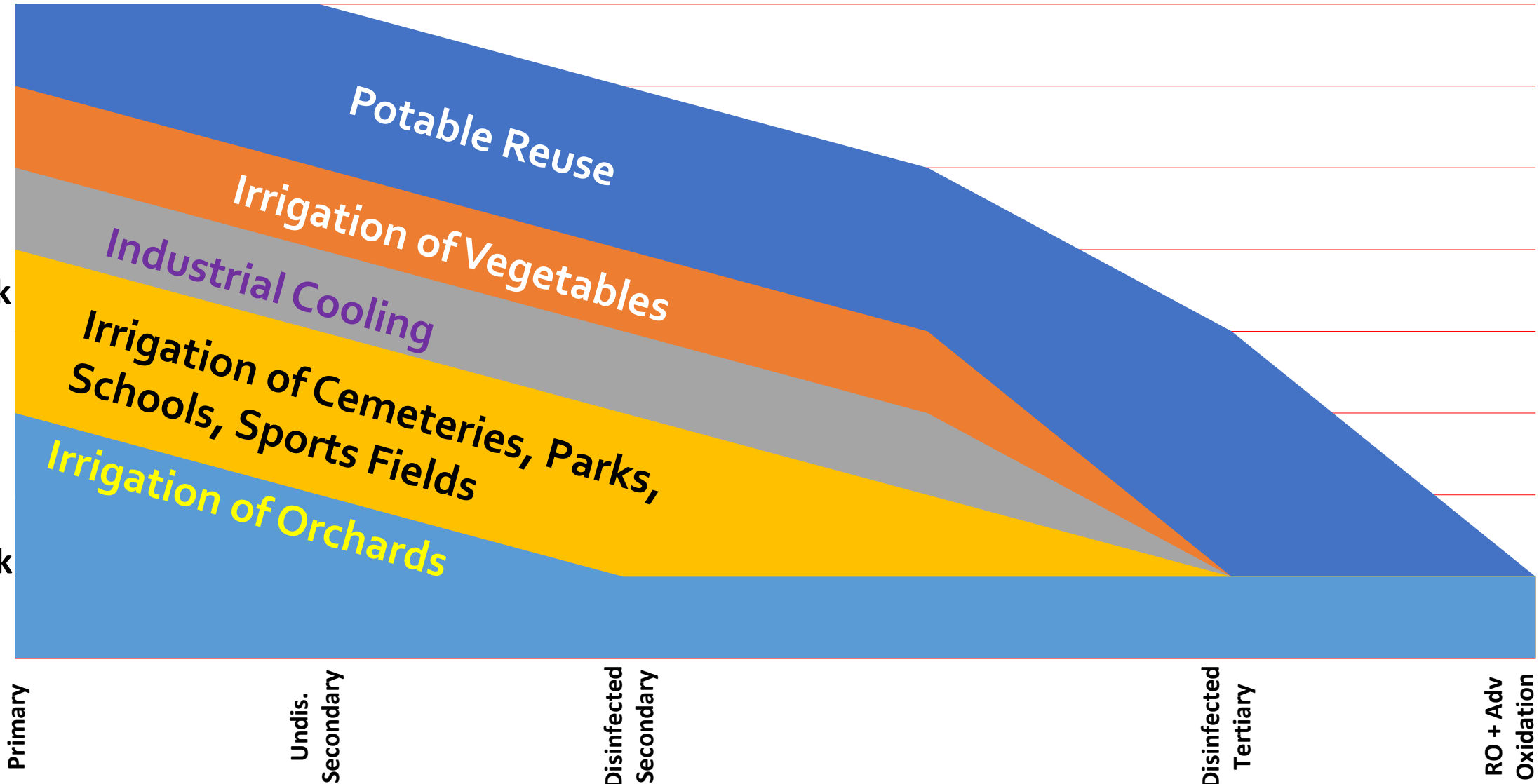
- Sales—Public Perception
- Soils/Salts--Permeability
- Safety—Consumers', Workers' Health
- Supply Reliability

RECYCLED WATER, FOOD SAFETY CONCERNS

- Public health officials' and regulators' concerns
 - Responsibility to the public at large (sewage is the raw material)
 - Balancing the need for water with the need for conservatism
- Farmers'/growers' concerns
 - Health of the consumers; safety of farm workers
 - Public perception and sales
 - Long-term impacts on soils from salts
- The consumers' concerns

IMPORTANCE OF TREATMENT; RISK REDUCTION

Extreme Risk
High Risk
Moderate Risk
Low Risk
Near-Zero Risk



Primary

Undis.
Secondary

Disinfected
Secondary

Disinfected
Tertiary

RO + Adv
Oxidation

RESEARCH INTO SAFETY OF WATER REUSE

- Monterey County, CA
 - 1980s Long-term field trials
 - 1990s food safety
 - 2000s CECs in recycled water
- Water Research Foundation
 - CECs in Water
 - Significance to Public Health



MONTEREY WATER RECYCLING STUDY FOR AGRICULTURE RANDOMIZED SPLIT PLOTS DESIGN

- Lettuce
 - Iceberg, Romaine, Red Leaf, Green Leaf, Butter Lettuce
- Broccoli
- Cauliflower
- Celery
- Artichokes



MONTEREY FIELD RESEARCH

- Five years of field research/demo
- Three water types
- Four fertilizer rates
- Six types of food crops
- Four replications
- 96 random plots
- Thousands of samples
- Analysis of variance
 - Designed for detection of minute differences
 - With 99 percent confidence level



96 RANDOMIZED SPLIT PLOTS



VIRUS SURVIVAL TESTING



MONTEREY FIELD RESEARCH: RESULTS

- No virus in the recycled water
- Seeded virus
 - Five-log removal
- Crop quality was unaffected
- Yield was mostly unaffected
 - Increased in some cases
- Worker safety (medical exams)
- Soil permeability was unaffected
- Heavy metals were below detection limit
- Customer acceptance issues



SUCCESSFUL FIELD EXPERIENCE

- Monterey, California
-5,000 hectares since 1998
- Watsonville, California
>3,000 hectares since 2009
- Santa Rosa, California
-2,400 hectares since 1986
- Orange County Florida (ConservII)
-1,100 hectares since 1986



MONTEREY COUNTY: 5,000 HECTARES IRRIGATED WITH RECYCLED WATER SINCE 1998



CONSERV II, ORANGE COUNTY, FLORIDA



SANTA ROSA, CALIFORNIA, WINE GRAPES IRRIGATED WITH RECYCLED WATER



WATSONVILLE, CALIFORNIA, STRAWBERRIES IRRIGATED WITH RECYCLED WATER



PROOF OF SAFETY OF WATER REUSE FOR AGRICULTURE

- Record of experience with recycled water
- Proving the negative is impossible, however:
 - No adverse public health outcomes
 - No legal liability in contested cases
 - Increasing acreage of usage
 - No Back-sliding
 - Conversion of skeptics to advocates

E. COLI EPIDEMIC & SPINACH RECALL

- 2006 outbreak of Cyclospora in spinach
- From recycled water?
- CNN investigation, interviews
 - No story there
- Feral pigs transferring livestock feces to spinach fields irrigated with well water
- Additional food safety studies



FOOD SAFETY STUDY

Protocol

- Sample Recycled Water
- Sample Influent to the Tertiary Plant
- Sample Raw Wastewater
- Sample Well Water--as “Control”

Analytic Program

- *Salmonella*
- *Cyclospora*
- *E. Coli* 0157:H7
- *Legionella*
- *Giardia*
- *Cryptosporidium*
- Fecal Coliform, Turbidity, Cl Residual

SALMONELLA (CFU/100ML)

Raw Wastewater	ND* to 16
Secondary Effluent	2.2 to 9.2
Disinfected Tertiary Water	ND
Well Water	ND



* ND = None Detected In Sample

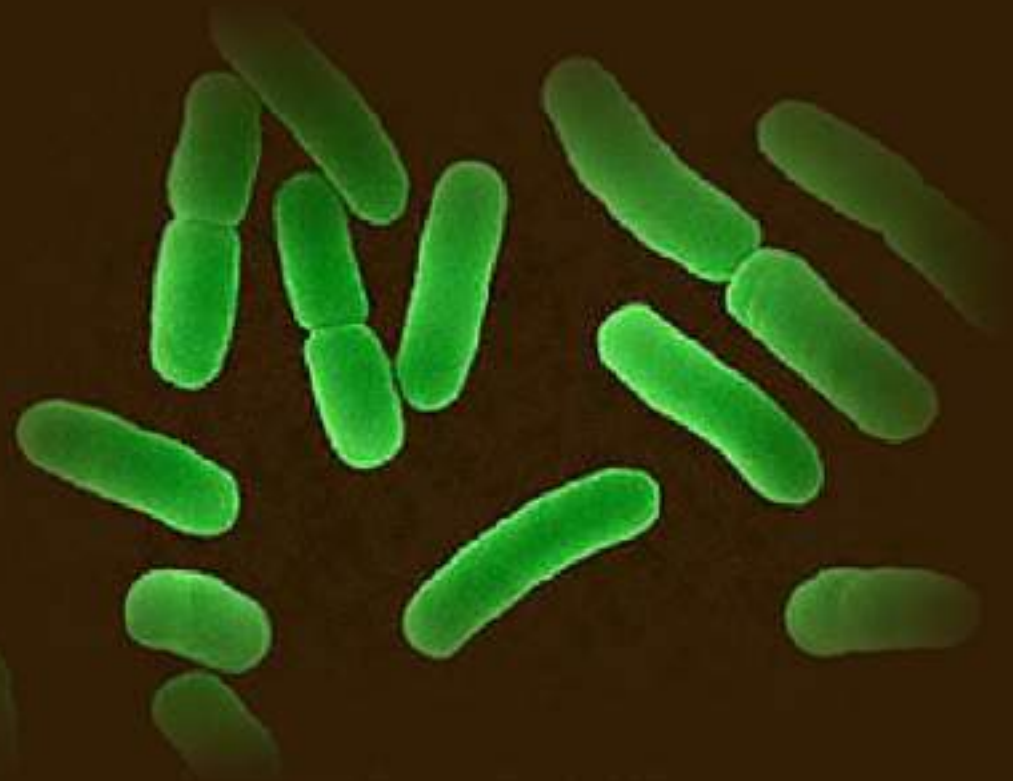
CYCLOSPORA (/L)

- Raw Wastewater ND to 330
- Secondary Effluent ND
- Disinfected Tertiary Water ND
- Well Water ND



E. COLI 0157:H7

- Raw Wastewater ND
- Secondary Effluent ND
- Disinfected Tertiary Water ND
- Well Water ND



LEGIONELLA

- Raw Wastewater ND
- Secondary Effluent ND
- Disinfected Tertiary Water ND
- Well Water ND



GIARDIA LAMBLIA(/L)

Raw Wastewater	2,000 to 22,400
Secondary Effluent	0.4 to 12.2
Disinfected Tertiary Water	ND to 0.09
Well Water	ND



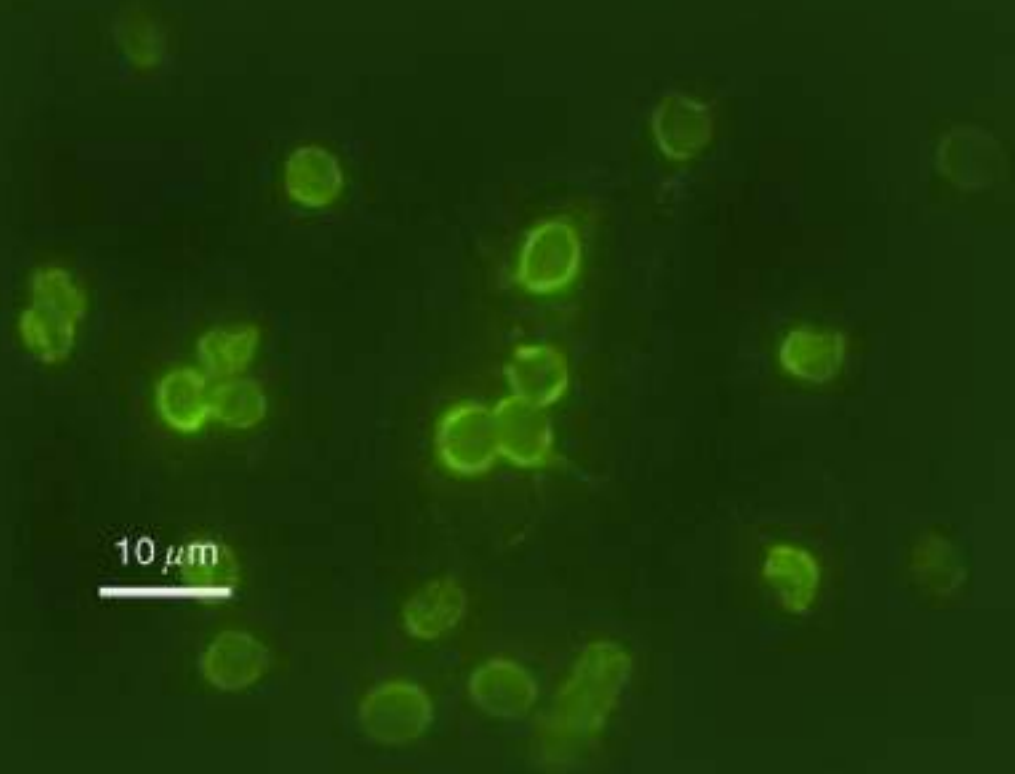
GIARDIA, IN CONTEXT

Water Type	% Positive	Range (/100L)
Recycled, Monterey	80	ND to 9
Recycled, St. Pete.	25	ND to 3.3
Groundwaters	0 to 9.5	ND to 16
Surface Waters	3 to 81	ND to 6,600
Drinking Waters	0 to 17	ND to 64

SOURCE: York, 1998

CRYPTOSPORIDIUM (/L)

Raw Wastewater	ND to 200
Secondary Effluent	ND to 1.8
Disinfected Tertiary Water	ND
Well Water	ND



FECAL COLIFORM (MPN/100ML)

Raw Wastewater	7E6-3E7
Secondary Effluent	2.3E5-8E5
Disinfected Tertiary Water	ND
Well Water	--



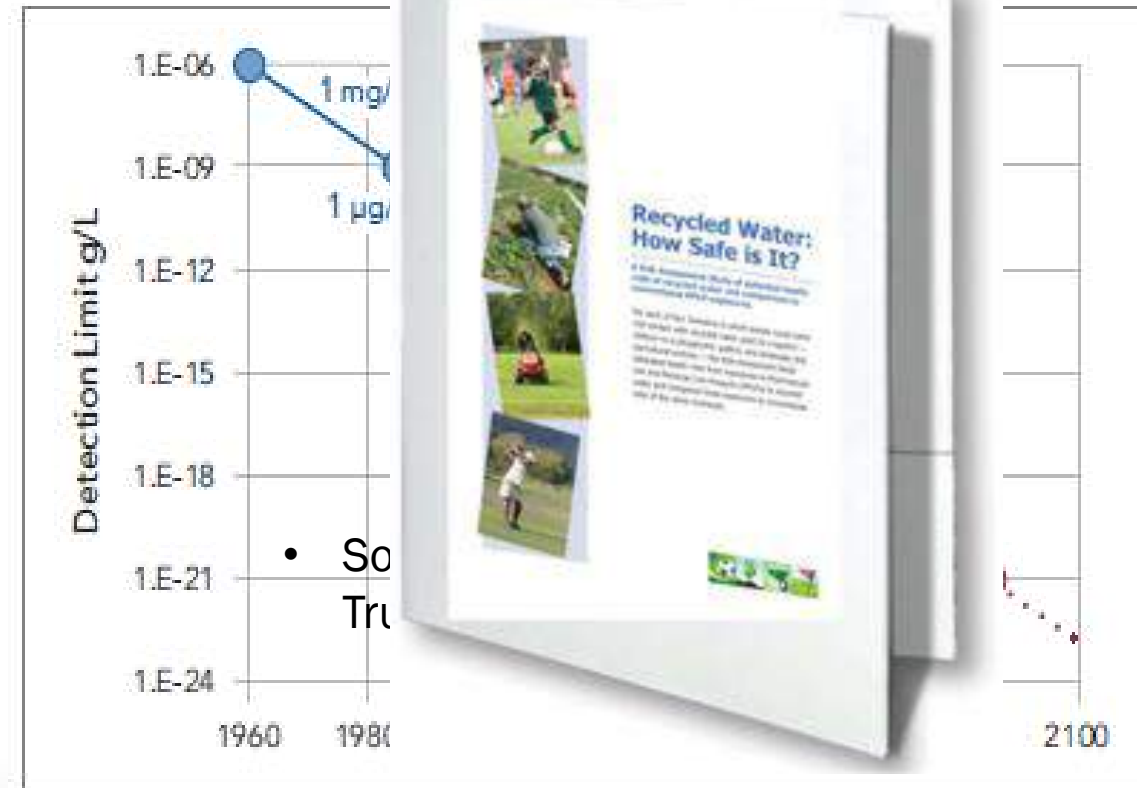
MICROCONSTITUENTS OF EMERGING CONCERN

- Pharmaceuticals
 - Prescription Drugs
 - Over-the Counter (e.g., Aspirin, Ibuprophen, Coffee)
 - Illicit Drugs
- Endocrine Disruptors
 - Estrogen, Dioxin, Estrogen-Mimicking Compounds
- Personal Care Products
 - Fragrances, Lotions, Sunscreens, Cleaning Products (Triclosan)
- Ability to Detect at Extremely Low Concentrations
- Relevance to Human Health [ppm, ppb, ppt, ppq]
- Removal Mechanisms through Treatment
 - Reverse Osmosis
 - Advance Oxidation
 - Ultraviolet Radiation



CHEMICALS OF EMERGING CONCERN

- Detection limits
- Significance
 - To human health
 - To the environment
- WaterReuse Research Foundation
 - Recycled Water:
How Safe Is It?



RECYCLED WATER EXPOSURE SCENARIOS, IBUPROFEN

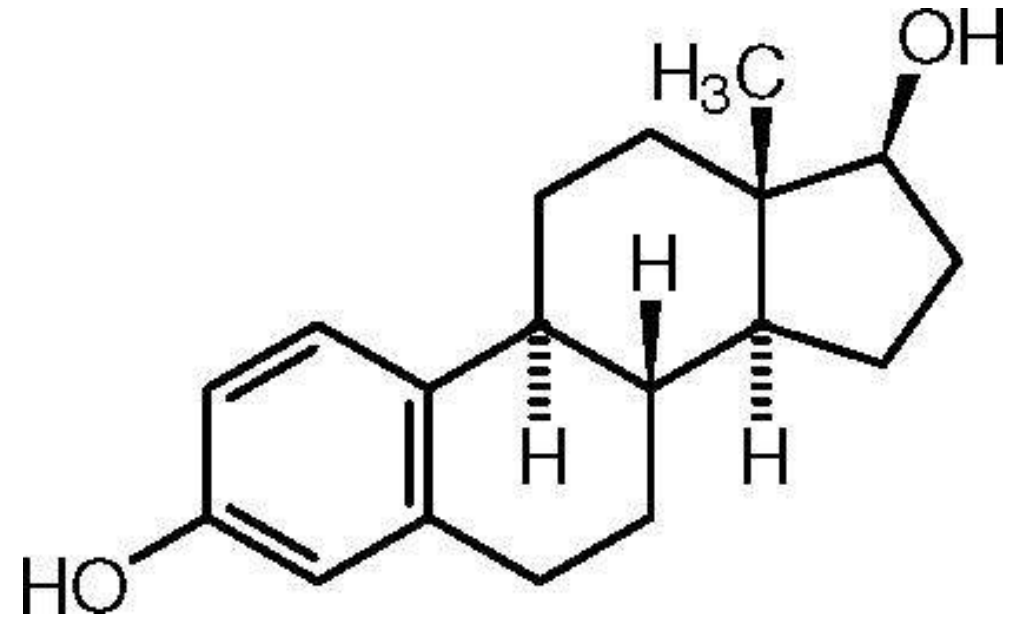
- Agricultural worker
-28,000 years
- Landscaper
-8,600 years
- Child at play
-67,000 years
- The golfer
-26,000 years



RECYCLED WATER EXPOSURE SCENARIOS, 17-BETA ESTRADIOL

hormone replacement

- Agricultural worker
-16,000 years
- Landscaper
-5,000 years
- Child at play
-160,000 years
- The golfer
-13,000 years



RECYCLED WATER EXPOSURE SCENARIOS, FLUOXETINE

antidepressant

- Agricultural worker
-83,000 years
- Landscaper
-26,000 years
- Child at play
-220,000 years
- The golfer
-91,000 years



RECYCLED WATER EXPOSURE SCENARIOS, SULFAMETHOXAZOLE

antibiotic (urinary infection, sinusitis)

- Agricultural worker
-220,000 years
- Landscaper
-69,000 years
- Child at play
-1,900,000 years
- The golfer
-1,100,000 years



RECYCLED WATER EXPOSURE SCENARIOS, DEET

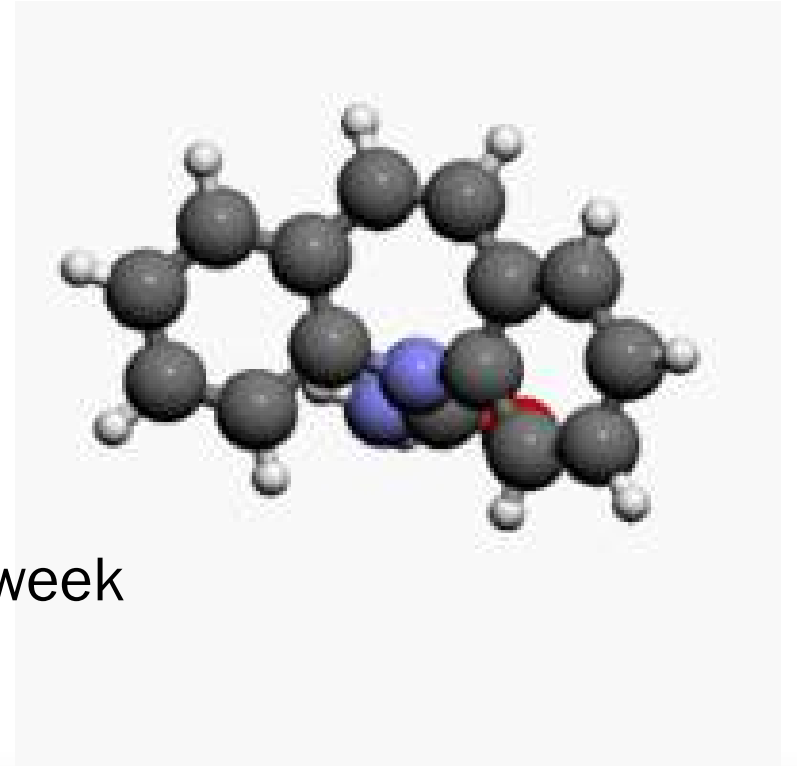
- Agricultural worker
-85,000,000 years
- Landscaper
-26,000,000 years
- Child at play
-110,000,000 years
- The golfer
-190,000,000 years



RECYCLED WATER EXPOSURE SCENARIOS, CARBAMAZEPINE

epileptic seizure

- Israeli paper published in ES&T
- “Proof of concept”
- Carbamazepine was detected in
 - Recycled water
 - Vegetables and fruits irrigated with recycled water
 - Urine of 17 people who ate those vegetables for a week
- Calculation: 200 to 2,000 years to reach ADI



RESEARCH RESULTS

- Treatment Level Fit for the Intended Use
- No Significant Differences with Well Water
- Worker Exposure to Water Is Not A Problem
- Constituents of Emerging Concern
 - Extremely Low Concentrations
 - Thousands of Years of Exposure before Safe Dose Is Reached
- Soil Infiltration Rate Was Unaffected
- Acceptance of Produce by Wholesale Buyers
- Public Acceptance

ADDITIONAL BENEFITS OF WATER REUSE

- Increase in community's water supply
- Preservation of community's quality of life
- Maintenance of local jobs and tax base
- Reduction in energy demand
- Reduction in carbon footprint