WRRF 15-01

POTABLE REUSE RESEARCH COMPILATION: SYNTHESIS OF FINDINGS

January 23, 2017

1:00 pm – 2:30 pm ET

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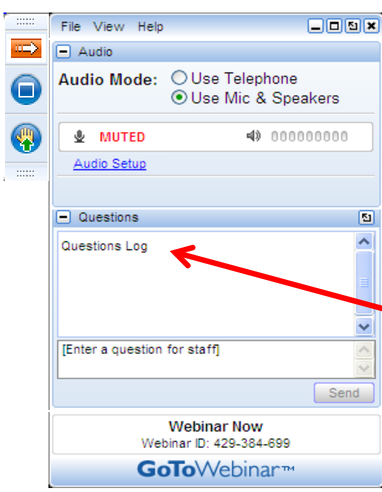
How to Participate Today



- **Audio Modes**
  - Listen using Mic & Speakers
  - Or, select "Use Telephone" and dial the conference (please remember long distance phone charges apply).
- **Submit your questions using the Questions pane.**
- **A recording will be available for replay shortly after this webcast.**

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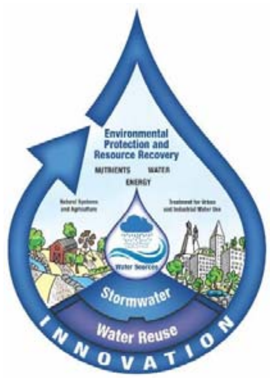
WELCOME

Julie Minton, Program Director
Water Environment &
Reuse Foundation (WE&RF)

AGENDA FOR WEBINAR

- About Water Environment & Reuse Foundation
- Background
- Purpose of the project (15-01)
- Research topics and authors
- Introduction to direct potable reuse (DPR)
- Discussion of individual report chapters
- Q&A

ABOUT WATER ENVIRONMENT & REUSE FOUNDATION



WERF and WRRF merged in May 2016

WE&RF: *Dedicated to research on renewable resources from wastewater, recycled water, and stormwater while maintaining the quality and reliability of water for the environment and communities.*

New Focus: One Water

WateReuse brings recycled water, desalination and related topics.

WERF brings wastewater, resource recovery, stormwater, receiving waters, climate change, and integrated water.

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WATEREUSE

WERF Water Environment Research Foundation Collaboration. Innovation. Results.

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BACKGROUND FOR 15-01

- **DPR Research Initiative (2012-2016)**
  - Initiated by WateReuse Research Foundation
  - Purpose: To inform the California State Water Board effort on the feasibility of developing criteria for direct potable reuse
  - $24 million in research; 34 research projects

"The Expert Panel is impressed by the research that has been funded by the WRRF and supports the continuation of such research."

- June 30 letter to DDW from Expert Panel Chairs

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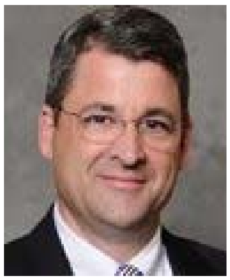
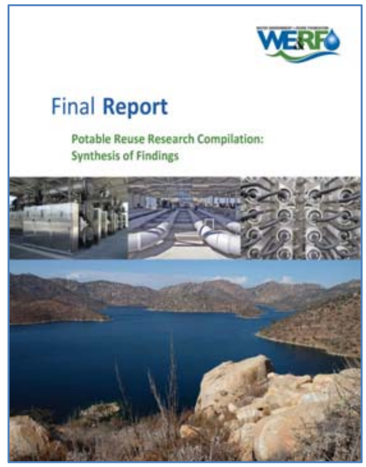
POTABLE REUSE RESEARCH COMPILATION: SYNTHESIS OF FINDINGS (15-01)

Jeff Mosher, WE&RF, Chief Research Officer (formerly, NWRI)





DPR – KEY QUESTIONS

- **Treatment requirements**
  - Need for criteria for pathogen and chemical control
- **On-line monitoring**
  - Performance monitoring
- **Treatment technologies**
  - Defining reliability
- **Source control**
  - Managing the collection system
- **Operations and operators**
- **Response time** (respond to off-spec water)
- **Public acceptance**

SEARCH ADDRESSES KNOWLEDGE GAPS

- 34 projects in Research Initiative:
  - Inform **regulations** and **regulators**
  - Resources for **implementation**

Regulatory Topics
How do we achieve treatment and process reliability through redundancy, robustness, and resilience?
23 Projects

Utility Topics
How do we address the economic and technical feasibility of DPR?
How do we train operators to run these advanced systems?
19 Projects

Community Topics
How to we increase public awareness of the water cycle and illustrate the safety of DPR to lead to acceptance?
6 Projects

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PURPOSE OF 15-01

- Summarize and synthesize **key issues and findings** from this research
- Provide **in one comprehensive document**
  - Understanding of the state-of-the-science
  - Identify unknowns that may require further research
- **Financial Support**
  - CA State Water Resources Control Board

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RESEARCH TOPICS

1. Source control	2. Evaluation of potential DPR trains	3. Pathogens: surrogates and credits
4. Pathogens: rapid/continuous monitoring	5. Removal and risk of constituents of emerging concern	6. Monitoring and critical control points
7. Operations, maintenance, training/certification	8. Failure and resiliency	9. Demonstration of reliable, redundant treatment performance

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RESEARCH TEAM

Project Manager:

– **Julie Minton**, WE&RF

Principal Investigators:

– **Jeff Mosher,** NWRI

– **Gina Vartanian,** NWRI

– **George Tchobanoglous,** Ph.D., P.E., NAE, University of California, Davis

RESEARCH TEAM

Report Co-Authors

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- **Debbie Burris**, P.E., BCEE, DDB Engineering
- **Jean Debroux**, Ph.D., Kennedy/Jenks
- **Bob Emerick**, Ph.D., P.E., Robert Emerick Associates
- **Ufuk Erdal**, Ph.D., P.E., CH2M
- **Dan Gerrity**, Ph.D., University of Nevada, Las Vegas
- **Laura Kennedy**, Kennedy/Jenks
- **Jim Lozier**, P.E., CH2M
- **Brian Pecson**, Ph.D., P.E, Trussell Technologies
- **Megan Plumlee**, Ph.D., P.E., Orange County Water District
- **Channah Rock**, Ph.D., University of Arizona
- **Andy Salveson**, P.E., Carollo
- **Larry Schimmoller**, P.E., CH2M
- **Ben Stanford**, Ph.D., Hazen and Sawyer
- **Sarah Triolo**, Trussell Technologies

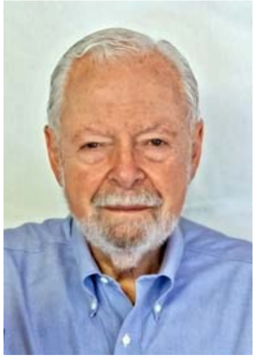
RESEARCH TEAM

WE&RF Project Advisory Committee

- **Jing Chao**, P.E., State Water Resources Control Board
- **Amy Dorman**, P.E., City of San Diego
- **Serge Haddad**, P.E., Los Angeles Dept. of Water and Power
- **Katie Henderson**, Water Research Foundation
- **Bob Hultquist**, P.E., State Water Resources Control Board
- **Phil Oshida**, U.S. Environmental Protection Agency
- **Claire Waggoner**, State Water Resources Control Board
- **Mike Wehner**, Orange County Water District
- **Mark Wong**, Ph.D., Singapore Public Utilities Board

INTRODUCTION TO POTABLE REUSE

George Tchobanoglous
University of California Davis



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INTRODUCTION TO POTABLE REUSE

- What are the different types of potable reuse?
  - ✓ *de facto* indirect potable reuse (*df*-IPR)
  - ✓ Indirect potable reuse (IPR)
  - ✓ Direct potable reuse (DPR)
- Technologies for IPR and DPR?
- What are the cost and energy implications?
- Where does potable reuse fit in the water portfolio
- What are the driving forces for IPR and DPR

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OVERVIEW: DE FACTO INDIRECT POTABLE REUSE

The downstream use of surface water as a source of drinking water that is subject to upstream wastewater discharges.

City of San Diego

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ALLEN HAZEN (1914)
"CLEAN WATER AND HOW TO GET IT"

"Looking at the whole matter as one great engineering problem, it is clear and unmistakably better to purify the water supplies taken from rivers than to purify the sewage before it is discharged into them. It is very much cheaper to do it this way. The volume to be handled is less and the per million gallons the cost of purifying water is much less than the cost of purifying sewage."

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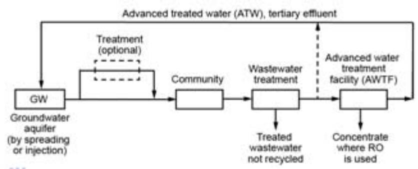
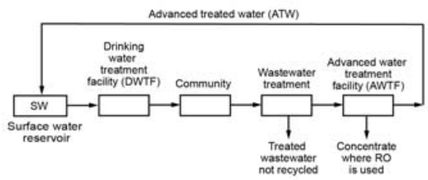
OVERVIEW: INDIRECT POTABLE REUSE



Typical injection well - OCWD



San Vicente reservoir, San Diego, CA

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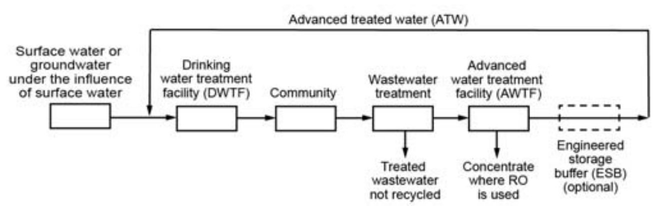
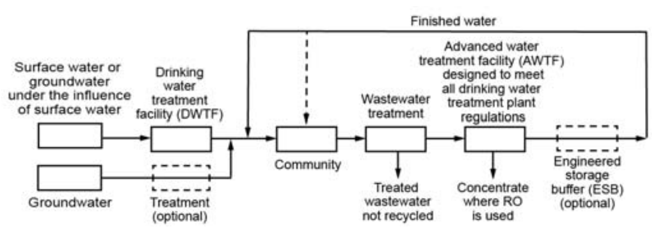
OVERVIEW: DIRECT POTABLE REUSE



DPR with *Advanced Treated Water (ATW)* (often identified as *raw water*)



DPR with *Finished Water* (often identified as *pipe-to-pipe*)

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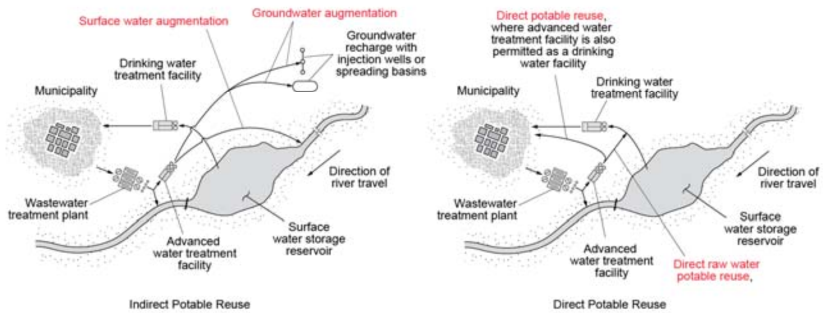
PICTORIAL VIEW OF IPR AND DPR



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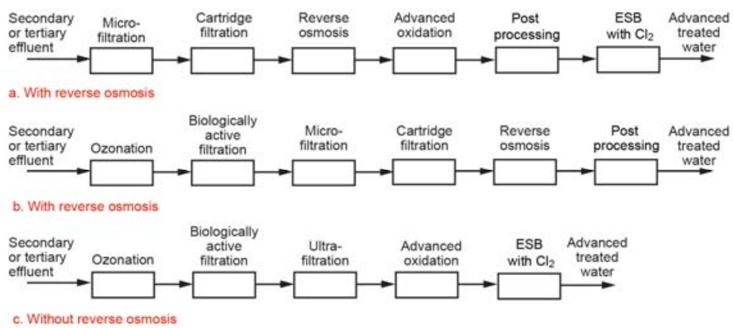
TECHNOLOGIES FOR THE INDIRECT AND DIRECT POTABLE REUSE



TECHNOLOGY IS NOT A LIMITING CONSTRAINT!!

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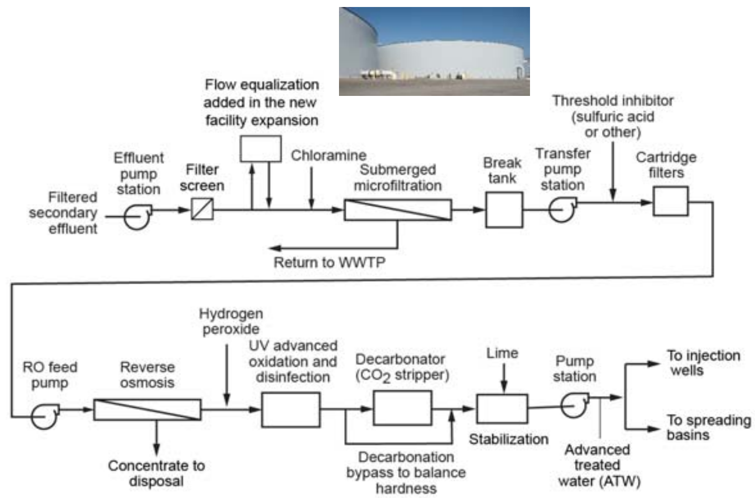
TECHNOLOGIES FOR THE INDIRECT AND DIRECT POTABLE REUSE - OCWD



Adapted from Orange County Water District (OCWD)

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MICROFILTRATION, CARTRIDGE FILTERS, REVERSE OSMOSIS, AND ADVANCED OXIDATION (UV) TECHNOLOGIES AT OCWD

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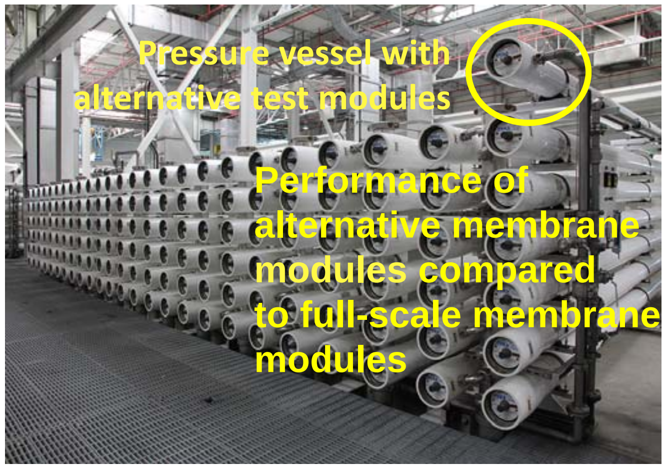
ONGOING RESEARCH AT OCWD
TESTING OF NEW MEMBRANE MODULES



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DECARONATION AND LIME SATURATION AT OCWD

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WHAT DOES DPR COST?

Supply option	Cost, $/10³ gal ($/AF)			
	Treatment	Residuals management	RO concentrate management	Conveyance facilities
ATW with RO	2.10 – 2.76 ([illegible] 900)	0.03 – 0.15 (10 – 50)	0.21 – 2.38 (70 – 775)	0.31 – 3.07 (100 – 1,000)
ATW without RO	1.23 – 2.15 (400 –700)	0.03 – 0.15 (10 – 50)	n.a.	0.31 – 3.07 (100 – 1,000)
Brackish groundwater desalination (inland)	2.76 – 3.84 (900 – 1,250)	0.06 – 0.31 (20 – 100)	0.21 – 2.15 (70 – 700)	0.92 – 6.14 (300 – 2,000)
Seawater desalination	5.52 – 6.44 (1,800 – 2,100)	0.06 – 0.31 (20 – 100)	0.31 – 0.61 (100 – 200)	1.23 – 9.21 (400 – 3,000)
Retail cost of treated imported surface water	1.23 – 3.99 (400 – 1,300)		n.a.	0.31 – 1.84 (100 – 600)
Water use efficiency, conservation, and use restrictions	1.38 – 2.92 (450 – 950)			0.31 – 1 .23 (100 – 400)

Note: $/10³ gal x 325.89 = $/AF

Data from original OCWD AWTF

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DPR ENERGY USAGE

Technology/water source	Energy required			Carbon footprint kg CO_{2e}/10³ gal
	Range, kWh/10³ gal	Typical		
		kWh/10³ gal	kWh/m³	
Secondary treatment without nutrient removal	1.35 – 1.05	1.25	0.33	0.63
Tertiary treatment with nutrient removal effluent filtration	1.95 – 1.60	1.85	0.49	0.93
Advanced water treatment	3.25 – 3.50	[illegible]	0.87	1.65
Ocean desalination	9.50 – 14.75	12.00	3.17	6.00
Brackish water desalination	3.10 – 6.20	5.85	1.55	2.93
Interbasin transfer of water, California State Water Project	7.92 – 9.92	9.20	2.43	4.60
Interbasin transfer of water, Colorado River water	6.15 – 7.40	6.15	1.62	3.07
Conventional water treatment	0.30 – 0.40	0.37	0.10	0.19
Membrane-based water treatment	1.00 -1.50	1.25	0.33	0.63

Note: kWh/10³ gal x 325.89 = kWh/AF

Data from original OCWD AWTF

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WHERE DOES POTABLE REUSE FIT IN THE WATER PORTFOLIO?

WATER SOURCES
- Local surface water
- Local groundwater (shallow and deep)
- Imported water
- Potable reuse (DPR and IPR, potential 20 to 40%)
- Desalination (brackish and sea water)
- Stormwater (?)

OTHER MEASURES
- Centralized non-potable reuse (e.g., purple pipe)
- Decentralized non-potable reuse (e.g.,greywater)
- Conservation and curtailments

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DRIVING FORCES FOR IPR AND DPR

- The value of water will increase significantly in the future (and dramatically in some locations).
- Population growth, formation of megacities, and global warming will lead to severe water shortages in many locations throughout the world.
- De facto indirect potable reuse is largely unregulated.
- Infrastructure requirements limit most urban reuse opportunities (e.g., dual distribution systems).
- Existing and new technologies can meet the water quality challenge to protect public health.
- More stringent environmental regulations.

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WE&RF 15-01 RESEARCH TOPICS

1. Source control programs
2. Evaluation of DPR treatment trains
3. Surrogates and log reduction credits for pathogens
4. Rapid and continuous monitoring of pathogens
5. Removal and risk of contaminants of emerging concern
6. Monitor DPR systems and the critical control point approach
7. Operation and maintenance and operator training and certification
8. Resilience in potable reuse
9. Demonstration reliable redundant treatment performance

INFORMATION SOURCES

- **34 WRRF, WRF, and WRA Project Reports**
- **Over 120 Literature citations**

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Chapters 1,2,3

Andy Salveson

Carrollo Engineers

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1

SOURCE CONTROL

When pursuing and planning for DPR, keeping constituents of concern out of the wastewater system through a robust source control program can be the most beneficial, efficient, and cost-effective strategy for managing and treating industrial, commercial, and other contributions to the wastewater supply.

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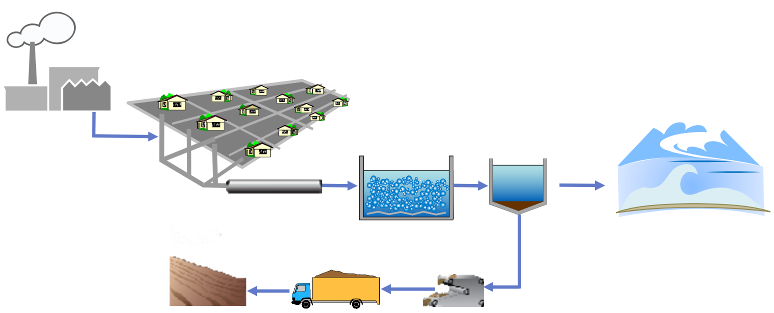
SOURCE CONTROL PROGRAMS ARE DESIGNED TO PROTECT THE WWTP AND THE NPDES REGULATED EFFLUENT



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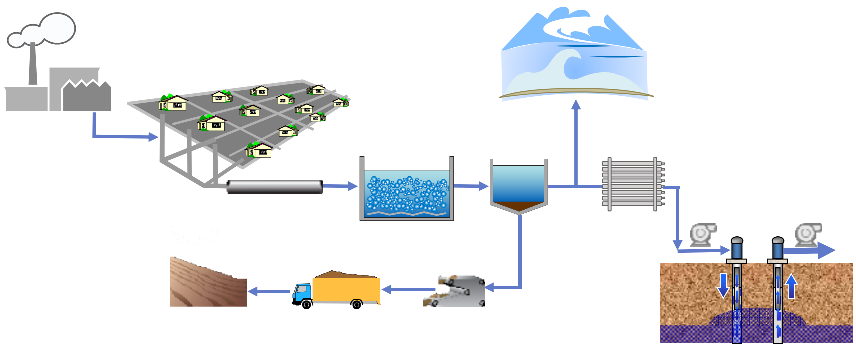
ENHANCED SOURCE CONTROL PROGRAMS ARE DESIGNED TO PROTECT THE NEW POTABLE WATER

Water First!



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A GOOD DPR SOURCE CONTROL PROGRAM AGGRESSIVELY TARGETS KNOWN RISKS AND REPEATEDLY SEARCHES FOR UNKNOWN IMPACTS

Landfill Leachate. Either remove from the collection system or engineer treatment specifically to handle challenging water.

Waste Haulers. Broad spectrum wastes, watch out for unregulated disposal!

Industry. Rigorous analysis of chemical use and disposal allows for source control modifications or tailored treatment for purification.

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A GOOD DPR SOURCE CONTROL PROGRAM ALSO LOOKS INSIDE THE FENCE

Chlorinated DBPs, including NDMA

Ozonated DBPs, including Bromate

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ENHANCED SOURCE CONTROL INVOLVES BOTH PROACTIVE MONITORING AND RAPID RESPONSE ACTION PLAN

PROACTIVE MONITORING

- Specific contaminant inventory
- Characterize industrial and residential wastewater
- Routine sampling of industries/commercial businesses

RAPID RESPONSE

- Action Plan to respond to elevated concentrations
  - Trace up through WWTP and collection system
  - Establish sampling zones

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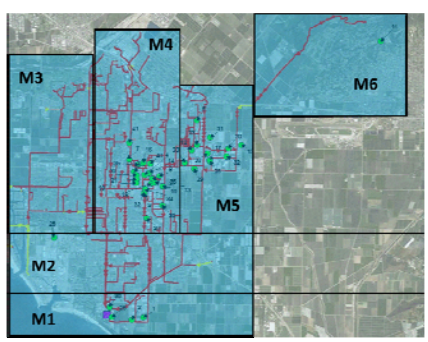
THE PROACTIVE MONITORING PROGRAM INCLUDES IN-LINE AND PERIODIC MONITORING

Class of Constituents	Sampling/Monitoring Plan		
	Collection System	Secondary Effluent	Purified Water
Industrial Discharge	Monthly and Internally (bi-weekly)	Monthly	Monthly
Local Limits	Monthly	Monthly (year 1) and Quarterly (starting year 2)	Monthly
NPDES Permit	Monthly	Monthly	Monthly
Regulated (MCLs)		Monthly (year 1) and Quarterly (starting year 2)	Monthly
Secondary Treatment Goals MCLs		Monthly (year 1) and Quarterly (starting year 2)	Monthly
Notification Levels		Monthly (year 1) and Quarterly (starting year 2)	Monthly
Contaminants of Emerging Concern (CECs)		Monthly (year 1) and Quarterly (starting year 2)	Monthly

THE ENHANCED SOURCE CONTROL PROGRAM INCLUDES A SOURCE MAPPING STRATEGY

- Routine Monitoring & Action Plan Events
- Local limits monitored at major junctions (monthly)
- Routine data trending
- Industry correlations



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2

EVALUATION OF POTENTIAL DIRECT POTABLE REUSE TREATMENT TRAINS

Advanced water treatment processes that have been applied at full-scale IPR projects will be appropriate for DPR projects. Currently, a number of IPR plants employ advanced water treatment facilities (AWTFs) that include the following treatment barriers: microfiltration (MF), reverse osmosis (RO), and ultraviolet (UV) disinfection with advanced oxidation processes (AOPs).

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TREATMENT TRAINS DESIGNED TO PROVIDE MULTIPLE BARRIERS TO BROAD SPECTRUM POLLUTANTS

- [x] MCLs
- [ ] Pathogens
- [ ] CECs

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TREATMENT TRAINS DESIGNED TO PROVIDE MULTIPLE BARRIERS TO BROAD SPECTRUM POLLUTANTS

- ☑ MCLs
- ☑ Pathogens
- ☐ CECs

Pathogen	EPA Drinking Water Goal	TX Example for DPR (does not include WWTP)	CA Example for IPR (includes WWTP)
Virus	$<2.2x10^{-7}$ MPN/L	8	12
Giardia	$<6.8x10^{-6}$ cysts/L	6	10
Crypto	$<3.0x10^{-5}$ oocysts/L	5.5	10

TREATMENT TRAINS DESIGNED TO PROVIDE MULTIPLE BARRIERS TO BROAD SPECTRUM POLLUTANTS

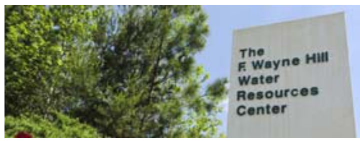
- ☑ MCLs
- ☑ Pathogens
- ☑ CECs

Constituents	Reporting Level, ng/L
17-alpha-estradiol	0.5
Caffeine	10
DEET	10
Iodinated Contrast Media (Iopromide)	10
Triclosan	10
NDMA	10

CA IPR Example

MULTIPLE PROCESSES CAN BE USED TO ACHIEVE CHEMICAL AND PATHOGEN CONTROL

- Namibia DPR Model: WWTP-DAF-Ozone-BAF-GAC-UF-Chlorine



- GCDWR DPR Pilot: Multi-Stage Ozone-BAC; Superior to de facto reuse

- CRMWD/Big Spring Model: MF-RO-UV/AOP-Conventional Water Treatment

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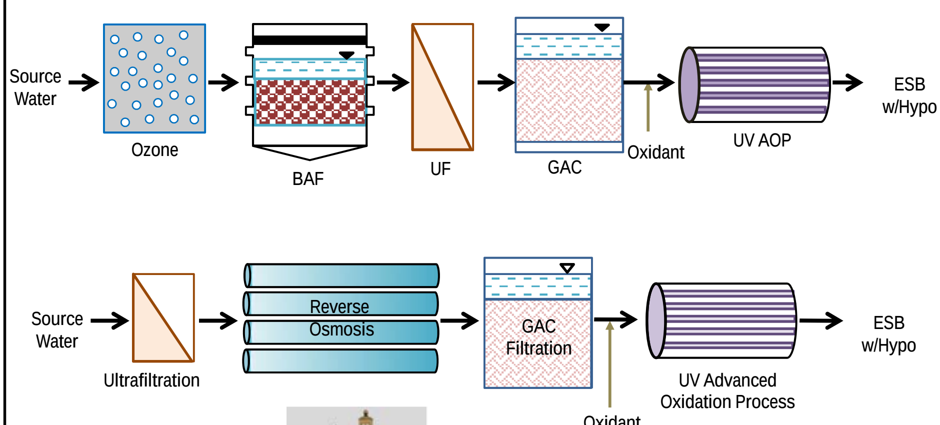
EXAMPLE TREATMENT TRAINS



Altamonte Springs

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MULTIPLE BARRIER PERFORMANCE

Target	Ozone	BAF	UF	GAC	UV AOP	ESB w/Hypo
Pathogens	X		X		X	X
MCLs	X	X		X	X	
CECs	X	X		X	X	~
DBPs!	X		X			X

O_3/BAF Core Train

Target	UF	RO	GAC	UV AOP	ESB w/Hypo
Pathogens	X	X		X	X
MCLs		X	X	X	
CECs		X	X	X	~
DBPs!	X				X

RO Core Train

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RESEARCH QUESTIONS

- What is the impact (or relevance) of low mg/L TOC?
- Are sub ng/L DBPs relevant?
- What emerging online advanced monitoring can give us more confidence in process performance?

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3

SURROGATES AND LOG REDUCTION CREDITS FOR PATHOGENS

To protect human health from the harmful effects of pathogenic microorganisms, three issues must be addressed: (1) selection of pathogenic microorganisms and microbial indicators; (2) establishment of acceptable risk-based levels and ensuing log reduction requirements for pathogenic microorganisms; and (3) establishment of technology-based log reduction credits for various treatment processes.

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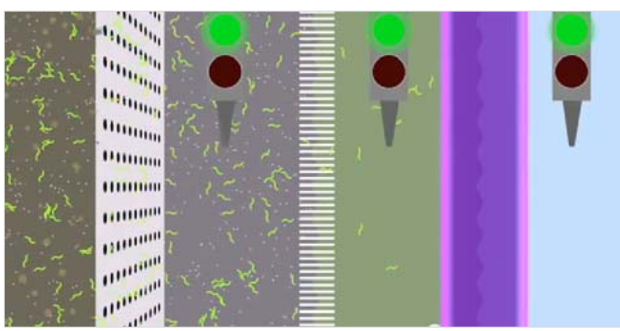
DPR SYSTEM WOULD USE A MULTI-FACETED MONITORING SYSTEM FOR REAL-TIME WATER QUALITY CONFIDENCE



Screenshot from "Ways of Water"
https://www.youtube.com/watch?v=RwrYFJEJSQ0

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SOME STANDARD METHODS FOR ONLINE MONITORING DO NOT TRACK PERFORMANCE IN RECLAIMED WATER OPERATIONS

No good dose/response correlation or control!!

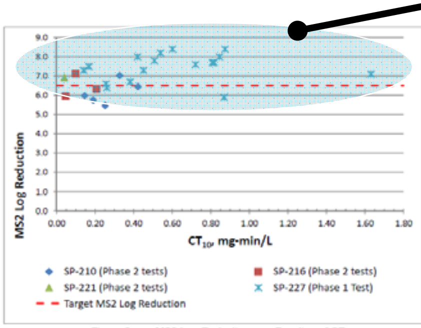

Figure 8 MS2 Log-Reduction as a Function of CT

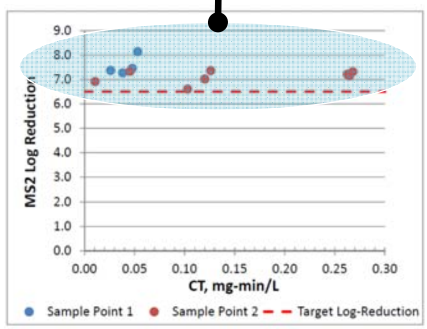

Figure 12 LSD Pilot-Scale Test – CT vs. MS2 Log reduction

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CONSERVATIVE PRECISE MONITORING NOW PROVEN FOR KEY PROCESS COMPONENTS

- ☑ MF/UF – MIT
- ☑ RO – Fluorescent Dye
- ☑ Ozone – Ozone/TOC
- ☑ UV – Sensor based dose
- ☑ UV AOP – Oxidant Weighted Dose
- ☑ …and more

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OZONE/(TOC+NITRITE) PROVIDES BEST CORRELATION YET FOR OZONE DISINFECTION

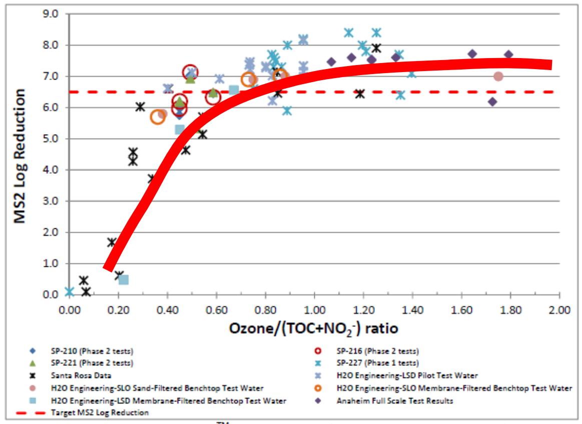

Figure 11 Comparison of MiPRO™ MS2 Log Reduction-Ozone/(TOC+NO_2^-) Relationship with Results of Different Studies

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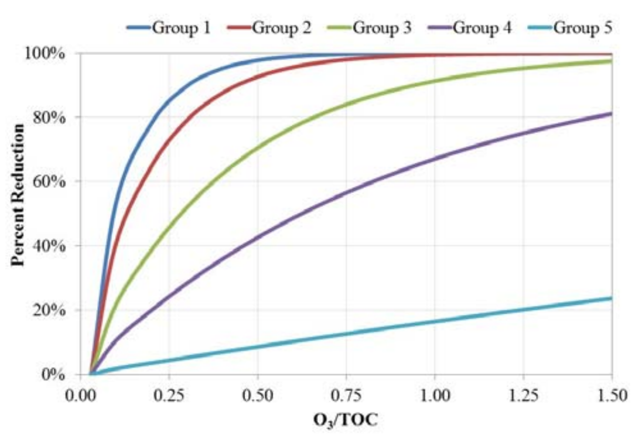
SIMILAR RESEARCH SUGGESTS PREDICTABLE CEC DESTRUCTION



Source: Dan Gerrity UNLV

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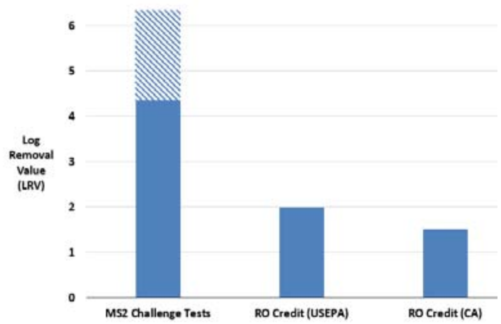
RO PROVIDES BROAD SPECTRUM REMOVAL OF ORGANICS, MINERALS, AND PATHOGENS



- However, there is a discrepancy between actual removals and LRV credit

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NOVEL FLUORESCENT DYE SHOWS MUCH IMPROVED RO SYSTEM MONITORING

- WRRF 14-10 / WRF 4536
- 2:1 pilot test in Ventura, CA
- CSM RE404-FEN (4”-elements)

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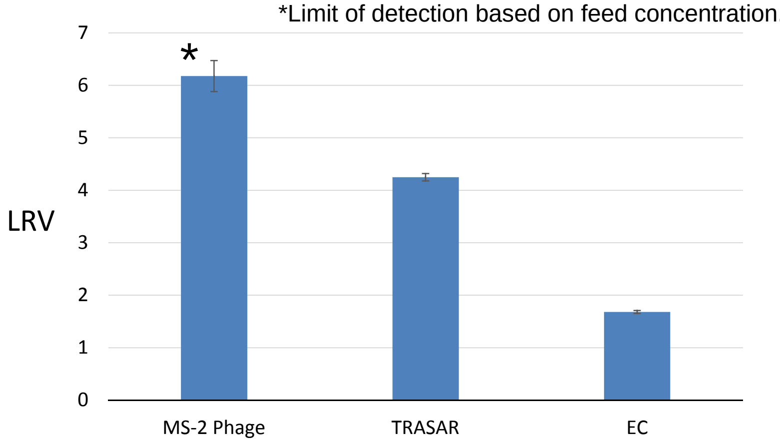
NOVEL FLUORESCENT DYE SHOWS MUCH IMPROVED RO SYSTEM MONITORING

*Limit of detection based on feed concentration.



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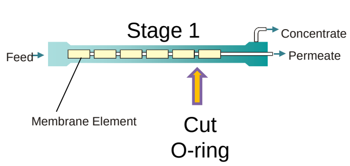
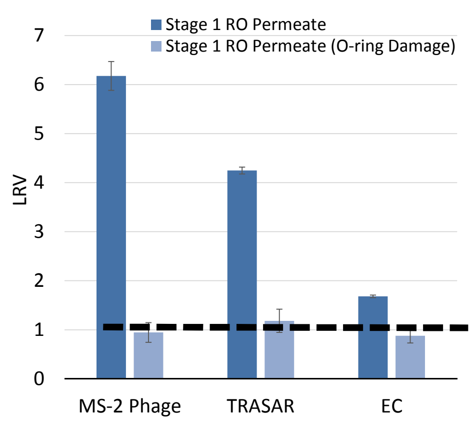
NOVEL FLUORESCENT DYE SHOWS MUCH IMPROVED RO SYSTEM MONITORING





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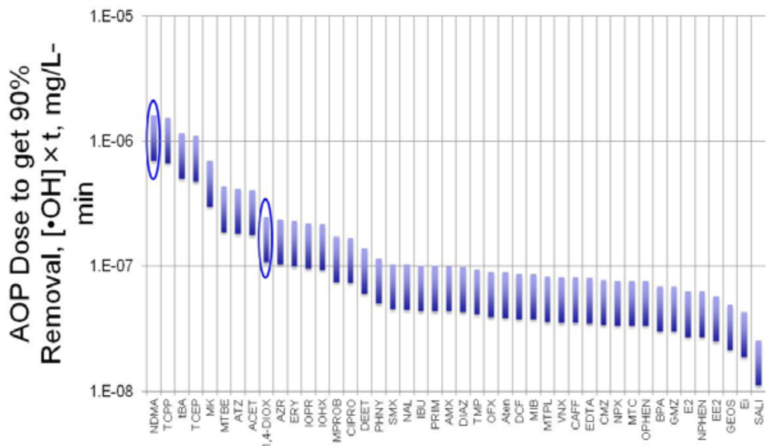
1,4-DIOXANE CONSERVATIVE SURROGATE FOR AOP PERFORMANCE ON TRACE POLLUTANTS



Hokanson et al., 2011

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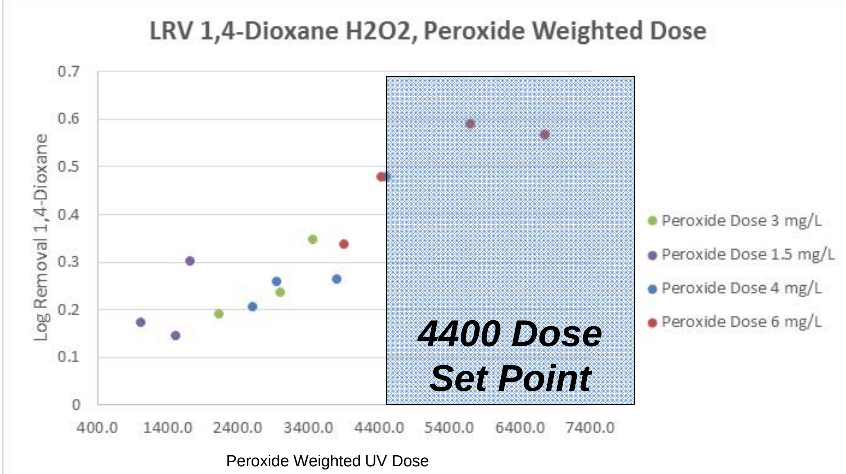
FOR UV/H2O2 AND FOR UV/NAOCL, OXIDANT WEIGHTED DOSE MAY BE AN IDEAL SURROGATE FOR 1,4-DIOXANE DESTRUCTION



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MONITORING AND MINIMIZATION OF HYDROXYL RADICAL SCAVENGING IS THE "NEXT STEP" FOR UV AOP

$$LRV = A + B * NH_2Cl + C * UV\ Fluence + D * [H_2O_2] \qquad \text{Equation 3}$$

Where

- LRV = Log removal value of target analyte 1,4-dioxane
- UV dose = UV dose applied to the sample (mJ/cm^2)
- NH_2Cl = Chloramine concentration (mg/L)
- H_2O_2 = Hydrogen peroxide concentration (mg/L)

Direct Potable Reuse Monitoring:
Testing Water Quality in a Municipal Wastewater Effluent Treated to Drinking Water Standards
Volume 1 of 2

FINAL

Texas Water Development Board

Portions co-funded by WRRF 14-10

RESEARCH QUESTIONS

- Can online analytics maintain precision and accuracy over extended periods of time?
- How can we incorporate advanced online testing to minimize the need for Engineered Storage?

Chapter 4

Channah Rock,

Water Quality Specialist &

Associate Professor

The University of Arizona

4

RAPID AND CONTINUOUS MONITORING OF PATHOGENS

Pathogen and indicator monitoring are key issues for DPR, in determining if treatment process performance is sufficient to achieve stringent public health criteria.

Currently, no online pathogen monitoring technologies are available for implementation in DPR applications.

Emerging monitoring technologies include advanced molecular assays and biosensors.

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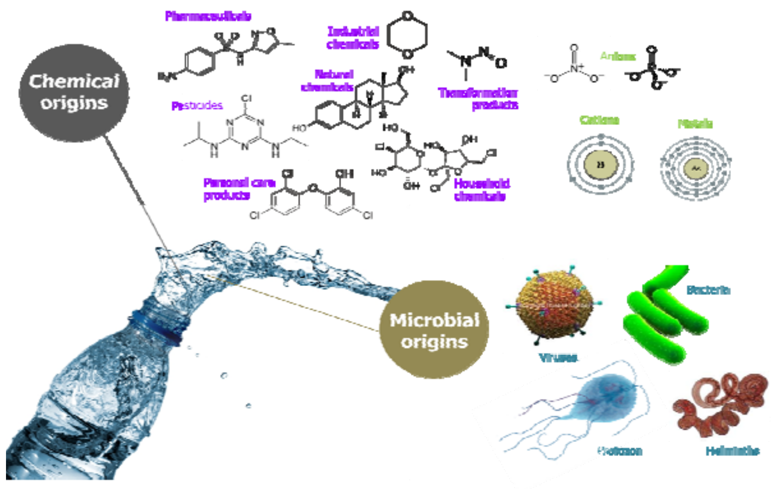
POTENTIAL CONTAMINANTS



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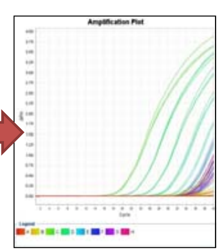
METHODS FOR MICROBIAL WATER QUALITY ANALYSIS



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CULTURE BASED *E.COLI* METHODS

- IDEXX Colilert
- ENDETEC TECTA-B16™
- BACTcontrol

- Total coliform bacteria and *E.coli* in water by enrichment
- Chromogenic media and automated evaluation
- Real-time fluorescence monitoring

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BEYOND *E.COLI* CULTURE METHODS

- Biological Molecule Assays
  - Adenosine Triphosphate (ATP)
- Molecular Biological Assays
  - PCR and qPCR
  - Droplet Digital PCR
  - Pyrosequencing
- Immunological Assays
  - Enzyme -linked Immunosorbent Assay (ELISA)
- Biosensors and Immunosensors
  - Optical (fluorescence), electrochemical (surface plasmon resonance)
  - Light scattering

QCM (Qsense)

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GENETIC TECHNIQUES

- Advancements in genetic techniques can be used to answer environmental questions not answered by traditional cultural methods.

- Disadvantages to cultural methods
  - Rely on growth of organism
  - Time consuming
  - Cost
  - Detection limit (# of organisms)
  - Must know who you are looking for….

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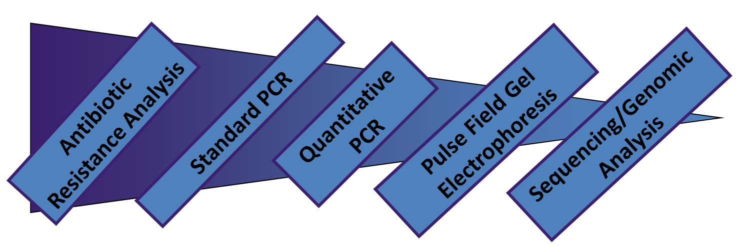
ABILITY OF METHODS TO DISCRIMINATE DIFFERENCES BETWEEN BACTERIAL/VIRAL TARGETS

Lowest Discrimination | **Highest Discrimination**



Which method or combination is best?

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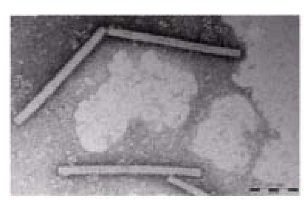
VIRAL CONCERNS

- Although unable to replicate outside of their host, viruses have a greater ability to persist in treated water than bacteria due to
  - their small size (which hinders physical removal)
  - the resistance of some viruses to certain disinfection processes (e.g., ultraviolet [UV] resistance of adenovirus).

ALTERNATIVE VIRAL INDICATORS AND SURROGATES

- Bacteriophages
  - Easy to detect but no "perfect" indicator
- Pathogens
  - Molecular methods: infectivity?
  - WRRF 14-17 "White Paper on the Application of Molecular Methods for Pathogens for Potable Reuse"
- Aichi, Calici, & Pepper Mild Mottle Virus (PMMoV)
  - Abundant in wastewater; limited seasonality
  - Not effectively removed in WWTP

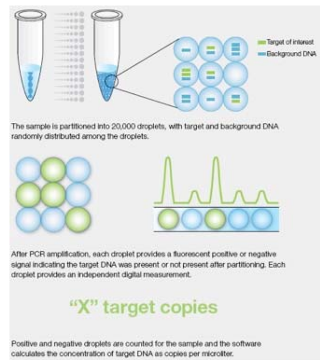
Aichi virus *(Springer Images)*



PPMoV virus isolated from Tabasco sauce *(Colson et al, 2010)*

INNOVATIVE SEQUENCING AND DIGITAL TECHNOLOGIES

- Roche 454 “pyrosequening”
  - Sequence by synthesis
  - Long sequences ~800bps
- Illumina HiSeq/MiSeq
  - 600 GB of DNA
  - Accuracy 99.6%
  - Personal genome analyzers
- Digital Droplet PCR (ddPCR)
  - Sample partitioning in 20,000 droplets



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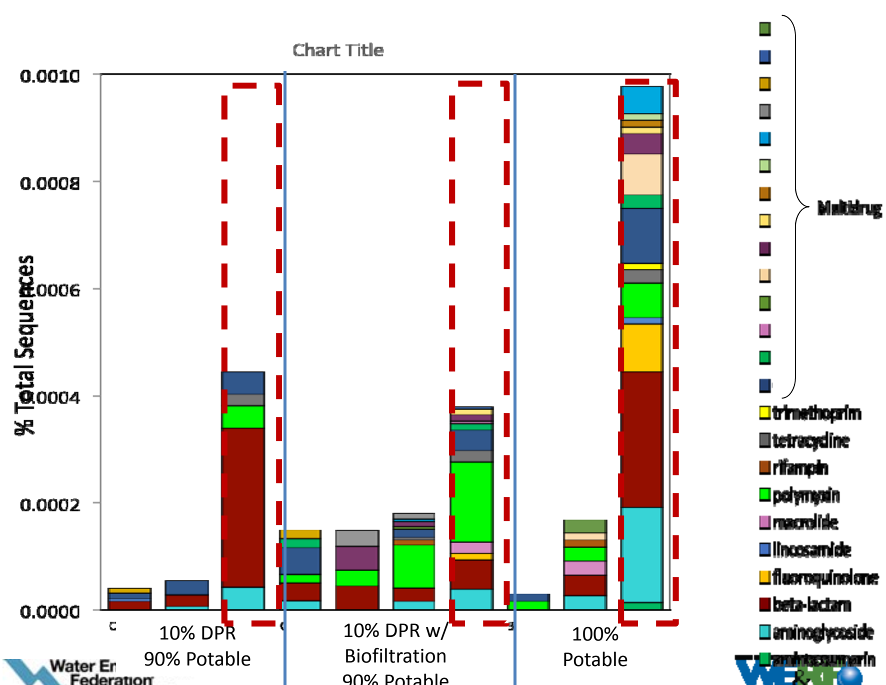

KEY TAKE-AWAY MESSAGES

- Rapid and continuous monitoring for pathogen detection remains challenging
  - small particle size, method sensitivity (including limits with detection and quantification), and the low concentrations of pathogens in purified water, particularly with respect to verifying risk benchmarks (e.g., 10^{-4} annual risk of disease).
- Due to their small size and the lack of highly sensitive technologies, there is great difficulty in detecting viruses in water.
- Ideal monitoring systems include the following characteristics:
  - high specificity,
  - rapid/real-time online capability,
  - high sensitivity,
  - high accuracy (i.e., minimal false positives and false negatives),
  - high robustness with low failure rates,
  - simplicity, and affordability for operation and maintenance (WRRF 12-06).

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Chapters 5, 6, 7, 8, 9

Ben Stanford

Hazen and Sawyer

Water Environment Federation the water quality people

5

RISK AND REMOVAL OF CONSTITUENTS OF EMERGING CONCERN

A wide variety of wastewater-derived organic compounds have been quantified in water. Most are not regulated in drinking water by the USEPA. The term “constituents of emerging concern” (CECs) is used to refer to these unregulated organic compounds, and may be extended to include other unregulated constituents found in water, such as trace metals, pathogens, and nanomaterials.

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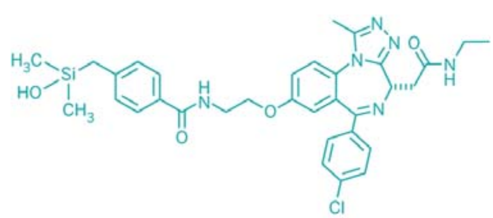
OVER 100,000,000 REGISTERED CHEMICAL SUBSTANCES

- On June 23, 2015, a compound to treat leukemia became the 100 millionth registered substance
- 75 million chemicals have been added in the past 10 years alone

http://cen.acs.org/articles/93/web/2015/06/Chemical-Abstracts-Service-Marks-Multiple.html



CAS Registry's 100 millionth substance

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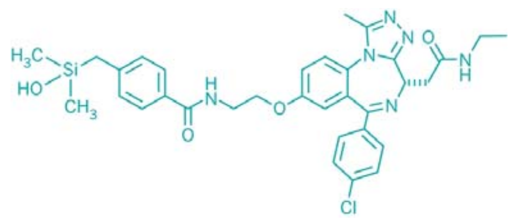
126,000,000 OVER ~~100,000,000~~ REGISTERED CHEMICAL SUBSTANCES

There have been over 26 million additional chemicals added to CAS since June of 2015

http://cen.acs.org/articles/93/web/2015/06/Chemical-Abstracts-Service-Marks-Multiple.html



CAS Registry's 100 millionth substance

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WHAT ELSE IS IN MY WATER?

- Despite risk assessments and massive public education campaigns, people are still concerned—headline from 2015


WHAT TO DO ABOUT THE ANTIDEPRESSANTS, ANTIBIOTICS AND OTHER DRUGS IN OUR WATER

As pharmaceuticals taint rivers and lakes, scientists search for solutions.

Photo by Gatis Gribusts (Flickr/Creative Commons)

WRITER
Elizabeth Grossman

August 11, 2015 — There's no way around it, the headlines are disturbing. And they come, not from tabloids or click-bait blogs, but from papers published in scientific journals. They describe fish and birds responding with altered behavior and reproductive systems to antidepressants, diabetes medication, and other psychoactive or hormonally active drugs at concentrations found in the environment. They report on opiods, amphetamines and

http://ensia.com/features/what-to-do-about-the-antidepressants-antibiotics-and-other-drugs-in-our-water/

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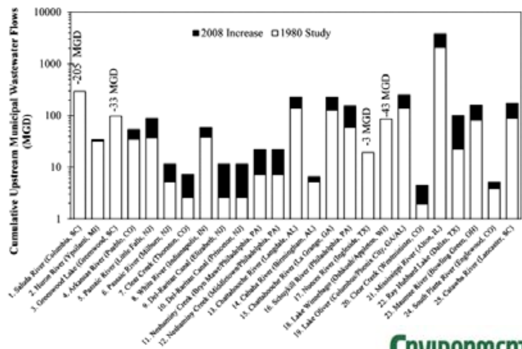
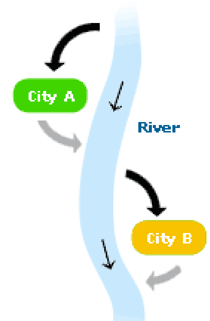
WE ARE CONFRONTING THE REALITY OF RISING DE FACTO REUSE

One Water: We Are All Connected





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10 OF 25 CITIES HAD 100% DE FACTO REUSE IN LOW FLOW

One Water: We Are All Connected

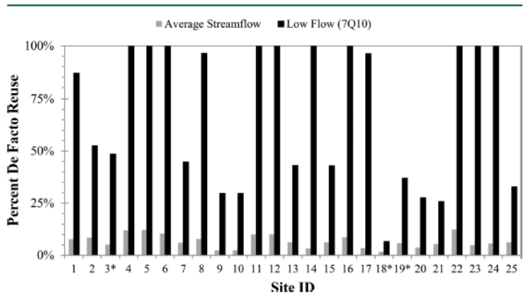
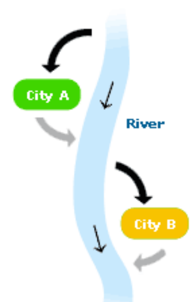


Figure 4. De facto reuse under average flow and low-flow conditions (modeled by 7Q10). Cities marked with an asterisk are calculated on the basis of 7Q10 streamflow values from the EPA 1980 study. (The *x*-axis gives same site IDs as in Figure 2.)



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CONCENTRATIONS OF CECS TYPICALLY ORDERS OF MAGNITUDE BELOW DRINKING WATER EFFECT LEVELS

Data from Reuse-05-05, 08-05, 11-02, and Benotti et al 2009, ES&T 43 (3), 597-603

	Max Secondary WWTP Conc (µg/L)	Max UF-Ozone-BAC Conc. (µg/L)	Max Drinking Water Conc. (µg/L)	DWEL (µg/L)	Liters per day to meet DWEL
Phenytoin	0.11	<0.001	0.019	6.8	700
Carbamazepine	0.14	<0.0005	0.018	12	1,300
Fluoxetine	Not Reported	<0.0005	0.0082	34	82,000
Diazepam	Not Reported	<0.0003	0.00033	35	210,000
Gemfibrozil	0.031	<0.0003	0.0021	45	43,000
Atenolol	0.71	<0.001	0.018	70	7,800
Meprobamate	0.041	0.008	0.042	260	13,000
Bisphenol A	<0.05	<0.005	0.025	1,800	140,000
Sulfamethoxazole	0.57	<0.0003	0.003	18,000	12,000,000

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KEY TAKE-AWAY MESSAGES

- Many known and unknown CECs exist in the chemical “universe” and may end up in water
- This is not unique to DPR and Planned IPR: All water supplies are impacted
- The vast majority of pharmaceuticals and personal care products are already far below risk thresholds in wastewater and conventional drinking water
- Advanced treatment provides additional removal and is important as part of multi-barrier approach

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6

MONITORING DIRECT POTABLE REUSE SYSTEMS AND THE CRITICAL CONTROL POINT APPROACH

Because treatment processes *do* degrade and *may* fail, the operation, maintenance, and monitoring of these processes is of critical importance. A critical control point (CCP) is a point in the treatment train (i.e., a unit treatment process) designed specifically to reduce, prevent, or eliminate a human health hazard and for which controls exist to ensure the proper performance of that process.

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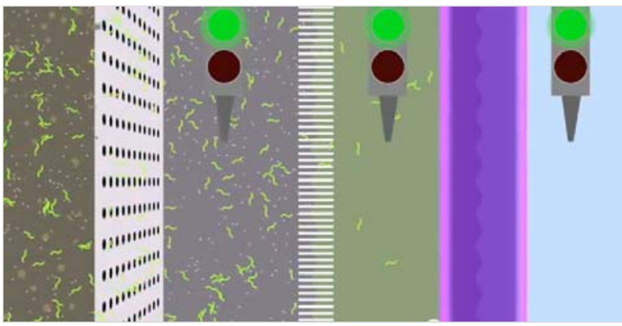
DPR SYSTEMS NEED A MULTI-FACETED MONITORING SYSTEM FOR REAL-TIME WATER QUALITY CONFIDENCE



Screenshot from "Ways of Water"
https://www.youtube.com/watch?v=RwrYFJEJSQ0
Reuse-12-06

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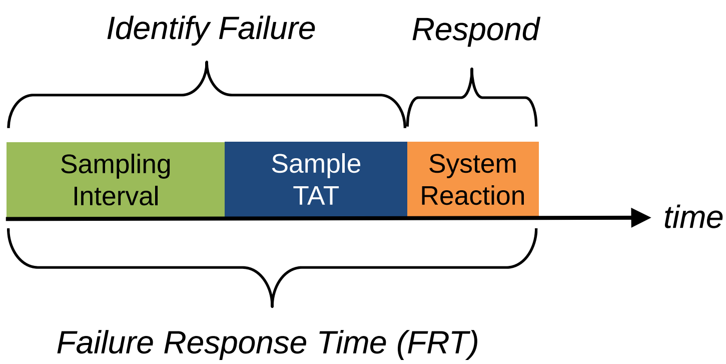
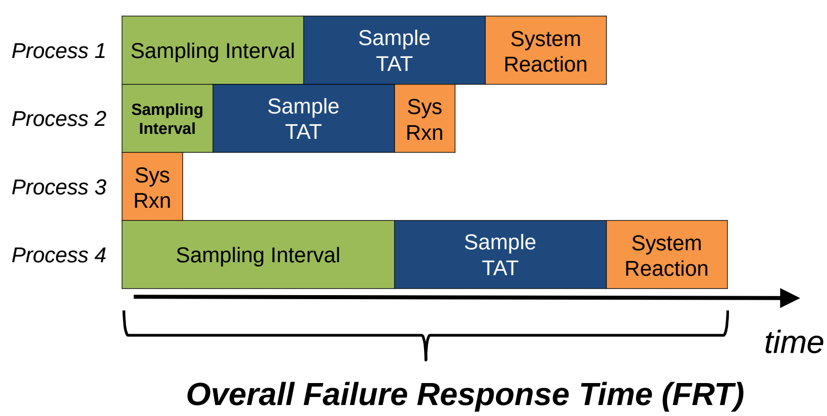
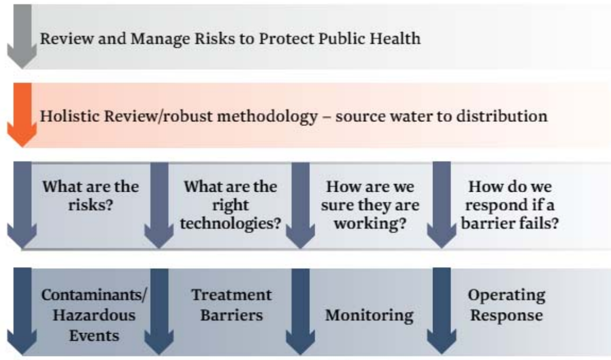
A GOOD DESIGN ACKNOWLEDGES THAT FAILURES OCCUR, CREATING A NEED FOR ENGINEERED STORAGE AND DIVERSION: REUSE-11-10 AND 12-06



THE OVERALL FAILURE RESPONSE TIME IS DETERMINED BASED UPON THE LONGEST FRT; ENGINEERED STORAGE MUST ACCOUNT FOR THIS



HAZARD ANALYSIS AND CRITICAL CONTROL POINT (HACCP) PROVIDES FRAMEWORK FOR RISK MANAGEMENT IN DPR

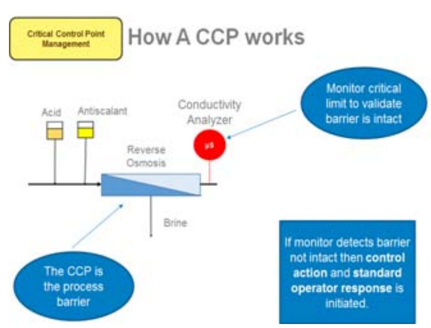


Critical Control Point Approach to Potable Resue

Focus is on health relevant contaminants.
Reuse-09-03 and 13-03

CRITICAL CONTROL POINTS DEFINED

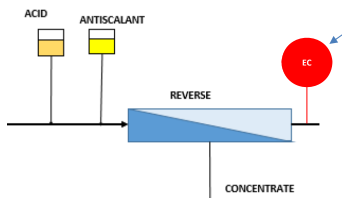
CCPs are points in the treatment process that are specifically designed to reduce, prevent, or eliminate a human health hazard and **for which controls exist** to ensure the proper performance of that process.

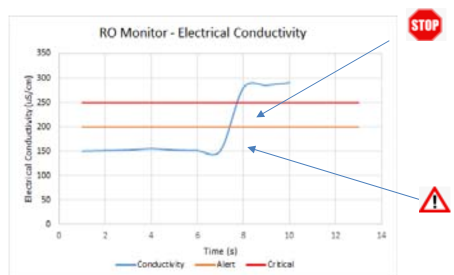


EXAMPLE CRITICAL CONTROL POINT – RO

- Risk : Chemicals of concern and microorganisms.

Monitor validates the barrier.





If monitor detects barrier not intact then **control action** and **standard operator response**.

KEY TAKE-AWAY MESSAGES

- A hazard analysis framework is needed to identify and manage risks
- Monitoring is a key aspect of ensuring water quality goals are met through process function
- CCPs allow teams to focus on public health protection
- Relationship between CCPs, monitors, failure response time impacts design and operation

7

OPERATIONS, MAINTENANCE, AND OPERATOR TRAINING AND CERTIFICATION

Proper O&M is critical to the success and reliability of DPR projects. Because a DPR project will involve complex treatment processes, equipment, monitoring, and control systems, the development of a comprehensive asset management program is of fundamental importance. To protect public health, well-qualified operators with appropriate training, certifications, and experience are needed to manage normal conditions and respond to challenges.

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FOUR BARRIERS OF PROTECTION TO PROVIDE CLEAN WATER FOR POTABLE REUSE

MANAGERIAL AND TECHNICAL CAPABILITY

- Assure compliance
- Provide resources

OPERATIONS

- Capable and Qualified Operators, Technical, and Support Staff

TREATMENT

- The "right" technology is installed
- Facility performs as intended
- No violations

SOURCE CONTROL

- Industrial Pretreatment Program
- Local Limits
- Contaminant source Investigations
- Pre-emptive and Responsive

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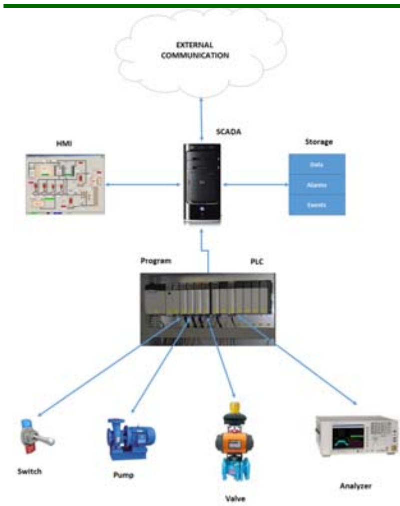
HIGHLY AUTOMATED DPR SYSTEMS PROTECT AGAINST MAJORITY OF FAILURES (REUSE-13-03 AND 13-13)




Warning/Alert – Take Action

Critical/Shutdown – Stop Process

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WE RELY HEAVILY ON ANALYZERS

Maintenance, calibration, and verification of analyzers is critical

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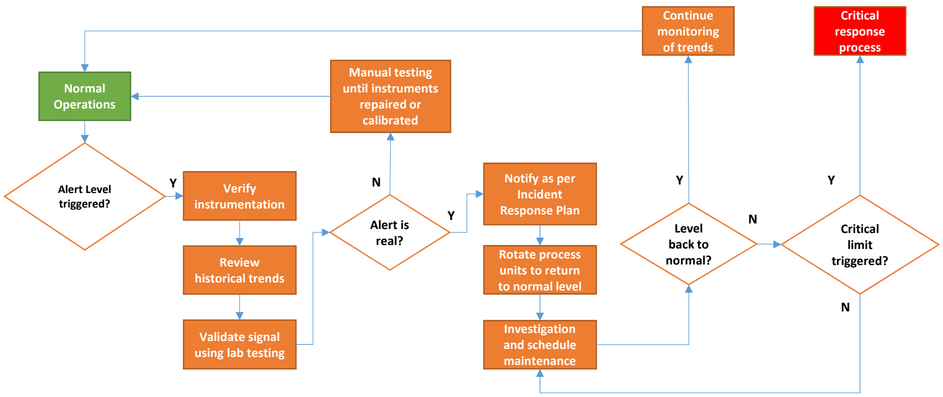
CORRECTIVE ACTION: ALERT LEVEL PROVIDES VERIFICATION STEPS FIRST



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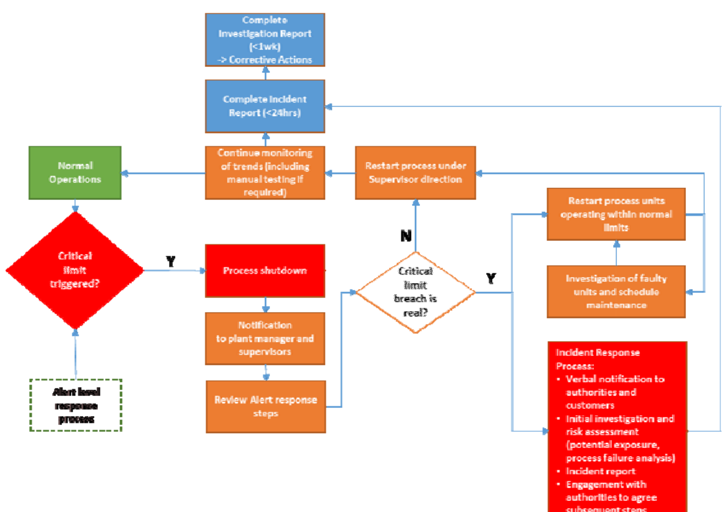
CORRECTIVE ACTIONS: CRITICAL LEVEL PROVIDES IMMEDIATE UNIT SHUTDOWN



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OPERATIONS TEAMS ARE A KEY TO THE SUCCESS OF DPR

- High Expectation Of Operator Performance.
- A Solid O&M Plan is Critical.
- Critical Control Point Approach is integral to manage risk to Public Health.
- Good communication is critical.
- Training and Certification must be applied for DPR.

WRRF-15-05: DEVELOPING CURRICULUM AND CONTENT FOR DPR OPERATOR TRAINING

8

RESILIENCE IN POTABLE REUSE

Resilience is considered the ability of organizations, groups, and individuals to recognize, adapt to, and absorb variations, changes, disturbances, disruptions, and surprises. The application of "resilience" principles to engineered processes is a relatively new endeavor. To be resilient and protective of public health, DPR systems must be designed on the basis of *failure prevention* and *failure response*.

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9

DEMONSTRATION OF RELIABLE, REDUNDANT TREATMENT PERFORMANCE

Reliable treatment performance of the various unit treatment processes used in AWTFs is critical, as the processes serve as barriers in terms of mitigating public health risks. Operating data are available from a number of full-scale AWTFs that provide a solid basis for assessing and validating the performance of both individual unit treatment processes and treatment trains.

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MULTIPLE PROCESSES CAN BE USED TO ACHIEVE CHEMICAL AND PATHOGEN CONTROL

Namibia DPR Model: WWTP-DAF-Ozone-BAF-GAC-UF-Chlorine

GCDWR DPR Pilot: Multi-Stage Ozone-BAC; Superior to de facto reuse

CRMWD/Big Spring Model: MF-RO-UV/AOP-Conventional Water Treatment

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REUSE-08-08: MULTIPLE BARRIERS CAN REMOVE CHEMICAL CONTAMINANTS IN POTABLE REUSE

	Units	MBR Influent	MBR Filtrate	RO Permeate (no oxidation treatment)	RO Permeate (1. 5 mg/L O3 pre-oxidation)
Atenolol	ng/L	**3,000**	**600**	< 25	< 25
Atrazine	ng/L	< 10	< 10	< 10	< 10
Carbamazepine	ng/L	**180**	**150**	**110**	< 10
DEET	ng/L	**130**	**85**	< 25	< 25
Meprobamate	ng/L	**2,000**	**430**	< 10	< 10
Dilantin	ng/L	**240**	**170**	< 10	< 10
Primidone	ng/L	**310**	**170**	< 10	< 10
Sulfamethoxazole	ng/L	**2,800**	**1,400**	< 25	< 25
Trimethoprim	ng/L	**1,500**	**100**	< 10	< 10
TCEP	ng/L	**800**	**540**	< 200	< 200
Bisphenol A	ng/L	**250**	< 50	< 50	< 50
Diclofenac	ng/L	**700**	**160**	< 25	< 25
Gemfibrozil	ng/L	**5,200**	**62**	< 10	< 10
Ibuprofen	ng/L	**30,000**	**30**	< 25	< 25
Musk Ketone	ng/L	< 100	< 100	< 100	< 100
Naproxen	ng/L	**29,000**	**31**	< 25	< 25
Triclosan	ng/L	**67**	**160**	< 25	< 25

MBR-Ozone-RO

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REUSE-13-03 VALIDATED CHEMICAL AND PATHOGEN REMOVAL ACROSS MULTIPLE BARRIERS AT FULL SCALE

Table ES.1. Log Removal Summary across Multiple Barriers by RO Membrane-Based Process Train

Contaminant	$CINH_2$	MF	RO	UV–AOP	Cl_2	Combined Mean	Combined Min
Viruses	N/A	N/A	2.7	9.4	120	130	46
Viruses capped	**N/A**	**N/A**	**2**	**4**	**4**	**10**	**10**
Giardia	N/A	4.6	5.4	7.7	3.9	22	16
***Giardia* capped**	**N/A**	**4**	**2**	**4**	**3**	**12**	**11**
Cryptosporidium	N/A	4.6	5.4	7.8	N/A	18	15
***Cryptosporidium* capped**	**N/A**	**4**	**2**	**4**	**0**	**10**	**10**

Notes: AOP=advanced oxidation process; MF=microfiltration; RO=reverse osmosis; UV=ultraviolet; "Mean" is meant to describe central tendency of the distribution of log removal values, not a true "average" of log-numbers

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EVALUATING SOURCE RISK AND BARRIER FUNCTION SUPPORTS PROCESS SELECTION & OPERATION

Table 9-1: Assessment of Treatment Processes as Contaminant Barriers[a]

Process Configuration	Treatment Process	Microorganisms and Pathogens				Regulated Chemicals					Unregulated Chemicals		
		Cryptosporidium	*Giardia lamblia*	Total Coliforms	Viruses	Inorganics and Metals	Radionuclides	Volatile Organics	Synthetic Organics	DBPs and Disinfectants	Trace Organic Contam.	1,4-dioxiane	NDMA[b]
RO membrane-based treatment train	Microfiltration (MF)	A	A	A	B	B	B	C	B	B	B	C	C
	Reverse Osmosis (RO)	A	A	A	A	A	A	B	A	A	A	B	B
	UV/AOP[c] (UV/H_2O_2)	A	A	A	A	C	C	C	B	B	A	A	A
	Chlorination	B	A	A	A	B	C	B	B	A	B	C	B
Alternative ozone-biofiltration-based treatment train	Flocculation/ Sed/Filtration	A	A	A	A	B	B	C	B	B	C	C	C
	Ozone	A	A	A	A	B	C	C	A	A	A	B	B
	Ozone + Biofiltration (BAC)	A	A	A	A	B	C	B	A	A	A	B	A
	Granular Activated Carbon (GAC)[d]	C	C	C	C	B	C	A	A	A	A	B	B
	UV	A	A	A	A	C	C	C	C	A	C	C	C
	Chlorination	B	A	A	A	B	C	B	B	A	B	C	B

A = Barrier intended to manage this risk
B = Barrier provides ancillary removal but not its primary purpose
C = Barrier not intended to manage this risk

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REUSE-13-03 EVALUATED ANALYZER RELIABILITY AND PROVIDED FRAMEWORK FOR EVALUATING REDUNDANCY NEEDS

- Risk Priority Number (RPN) allows HACCP team to assess vulnerability from process monitors
- The risk is NOT from device failure…
  - Most PLC systems have safeguards to notice when a device is responding out of range
- Instead, risk is from failing to observe device failure
  - Instrument drift
  - Calibration errors
  - Signal-to-noise errors
- RPN = Occurrence x Severity x Detection

Real problem is if we don't know the analyzer has failed

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RISK PRIORITY NUMBER RANKING FRAMEWORK FOR IDENTIFYING VULNERABILITIES

Occurrence Ranking Index (Frequency for customer):		**Severity Ranking Index (Think of the customer's problem)**		**Detection Ranking Index (Can Customer See Defect?)**	
Score	Criteria	**Score**	Criteria	**Score**	Criteria
1	Remote chance for failure (>99.999% reliability)	**1**	Undetectable effect on system	**1**	Almost certain detection of failure mode
2	Extremely low failure rate based on previous designs (99.9%-99.999% reliability)	**2**	Minor effect on system, automatic recovery bulit-in	**2**	Very high likelihood of detecting failure mode
3	Very low failure rate based on previous designs (99%-99.9% reliability)	**3**	Minor effect on system, resolved through remote diagnosis and repair	**3**	High likelihood of detecting failure mode
⋮	⋮	⋮	⋮	⋮	⋮
9	Ultra High failure rate based on previous designs (70%-80% reliability)	**9**	Severe problem involving potential safety problem or major non-conformity	**9**	Very remote likelihood of detecting failure mode
10	Unreliable (<70% reliability)	**10**	Critical problem with serious safety and legal/compliance implications	**10**	Can not detect failure mode

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RPN APPLICATION: QUANTIFYING "BOTTLENECKS" IN THE SYSTEM TO IDENTIFY ADDITIONAL MONITORING NEEDS

Component Name	Component Function	Cause(s) Of Failure	Effect(s) Of Failure	Failure Mode(s)	Occurrence Index (O)	Severity Index (S)	Detection Index (D)	Risk Priority Number O*S*D
UVT meter	UV/H2O2	Insufficient dose of UV	Micro-organisms and chemicals of concern	Failure of UV Transmittance Analyzer reading higher than actual resulting in UV underdose.	2	9	4	72
pH analyzer	Stabilization	Incorrect chemical dose	Lead and copper in distribution system	Failure of pH Analyzer	4	6	4	96
Cond. analyzer	Stabilization	Insufficient hardness addition	Lead and copper in distribution system	Failure of correct conductivity analyzer reading.	2	6	2	24
Chlorine analyzer	Chlorine	Insufficient dose	Micro-organisms	Chlorine analyzer reads false high result, leading to underdose.	4	9	4	144

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KEY TAKE-AWAY MESSAGES

- A multi-barrier approach is key to protecting public health
- DPR treatment processes are capable of reliably controlling acute and chronic public health risks
- Process reliability AND analyzer reliability must be considered in design and operation
- Even under failure modes, multi-barrier approached maintain health protection

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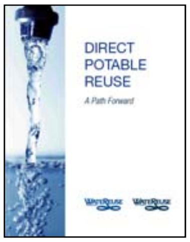
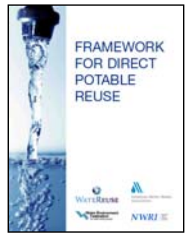
USEFUL INFORMATION SOURCES FOR DPR

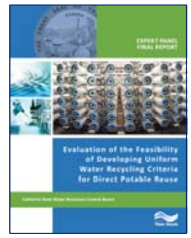


2011

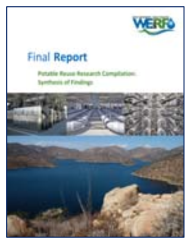
2014



2015



October 2016



POTABLE REUSE RESEARCH COMPILATION: SYNTHESIS OF FINDINGS
WE&RF PROJECT NO. 15-01
December 2016

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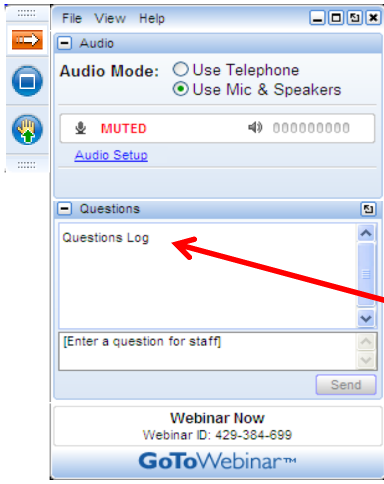
WRAP-UP

- WE&RF Report 15-01 will serve as an important reference document as the water industry begins the process of developing plans and criteria for DPR.
- In its Final Report to the State Water Board (dated Aug. 2016), the Expert Panel concluded: “it is feasible for the State of California to develop and implement a uniform set of water recycling criteria for DPR that would incorporate a level of public health protection as good as or better than what is currently provided in California by conventional drinking water supplies. . .”

Questions?



- **Audio Modes**
  - Listen using Mic & Speakers
  - Or, select "Use Telephone" and dial the conference (please remember long distance phone charges apply).
- **Submit your questions using the Questions pane.**
- **A recording will be available for replay shortly after this webcast.**

Thank you for joining us!

Adjourn