Critical Control Points in Potable Reuse Systems

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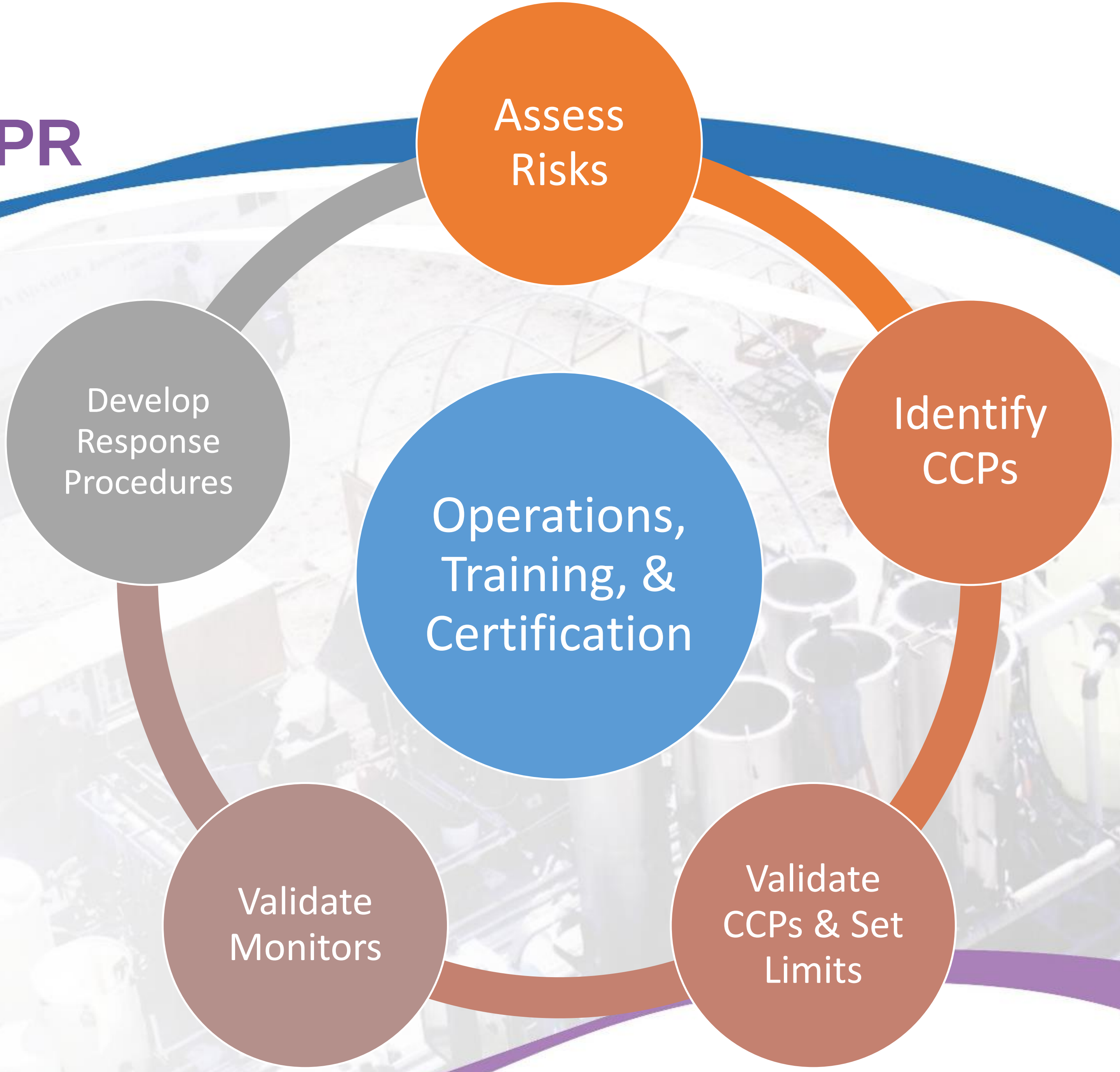
Theme: Building Confidence & Trust in DPR

- **Can we trust the technology?**
  - **Hazard Analysis and Critical Control Point (HACCP) methodology**
  - **Reliability of critical control points (CCPs)**
  - **Reliability of monitoring devices (Risk Priority Number approach)**
- **Can we trust operations?**
  - **Reliability and training of operations staff**



Potable Reuse Is Happening in the US and Abroad

Due to Drought, Big Spring Texas Is Drinking Recycled Pee Water

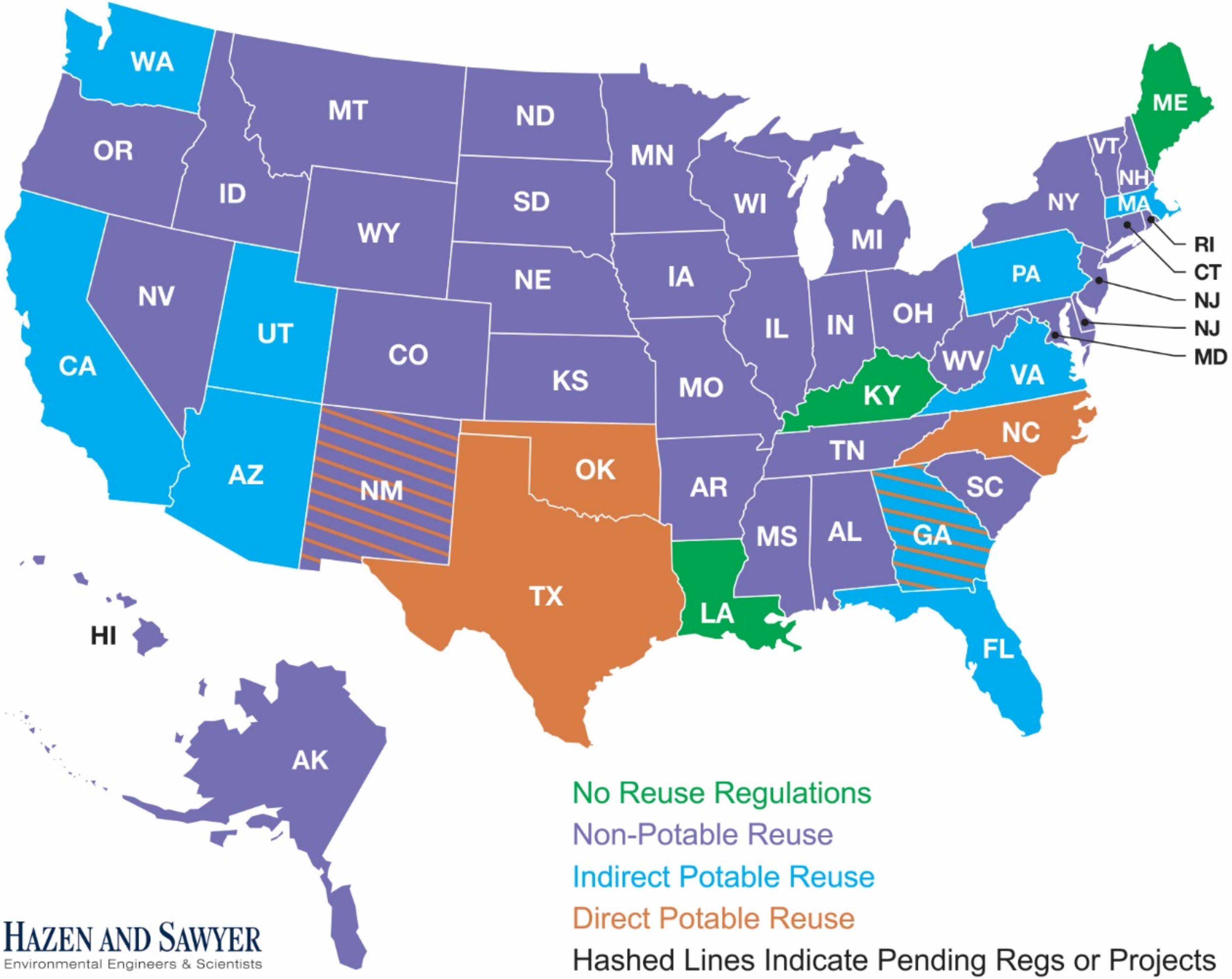
SCI/TECH, STRANGE NEWS — BY DAVE ON 2011/08/06 8:25 PM

Illustration. Image source: ohsunews.com

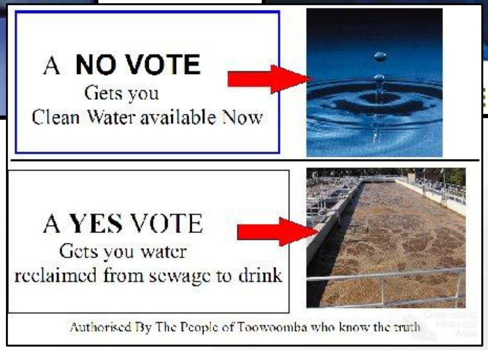
The drought in Texas is getting so bad that Big Spring, Texas will turn to recycling sewage water.

While drinking your own urine is a pretty disgusting idea for most of us, one of the worst droughts in Texas history is forcing municipal water managers to do what was once unthinkable.

Water Reuse By State in the US



DPR- Raising the Stakes



Convincing a Skeptical Public

Convincing Regulators

Can We Trust the Technology?

Can We Trust Operations?

Trust but Verify

TOOLS:

WRRF 13-03

Critical Control Point Assessment to Quantify Robustness and Reliability of Multiple Treatment Barriers of a DPR Scheme

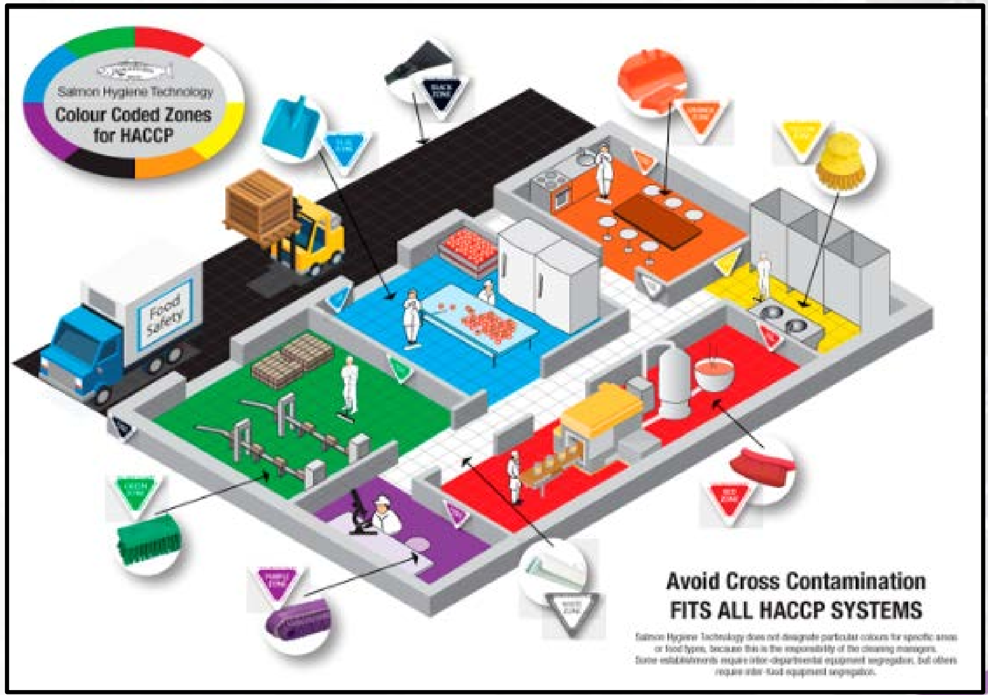
WRRF 13-13

Development of Operation and Maintenance Plan and Training and Certification Framework for Direct Potable Reuse (DPR) Systems

Hazard Analysis and Critical Control Point (HACCP) History

- Systematic preventative approach to Food Safety.
- Common with TQM – focuses on process barriers rather than end of pipe quality.
- FDA/USDA mandatory for juice and meat.
- Applied to drinking water treatment.
- A number of examples for IPR and other recycled water production

Conceived in 1960s by Pillsbury for NASA



INTERNATIONAL STANDARD

ISO 22000

First edition 2005-09-01

Food safety management systems — Requirements for any organization in the food chain

Defined in ISO 22000 – Food Safety

What Does the CCP Approach Provide?

Review and Manage Risks to Protect Public Health

Holistic Review/robust methodology – source water to distribution

What are the risks?	What are the right technologies?	How are we sure they are working?	How do we respond if a barrier fails?
Contaminants/ Hazardous Events	Treatment Barriers	Monitoring	Operating Response

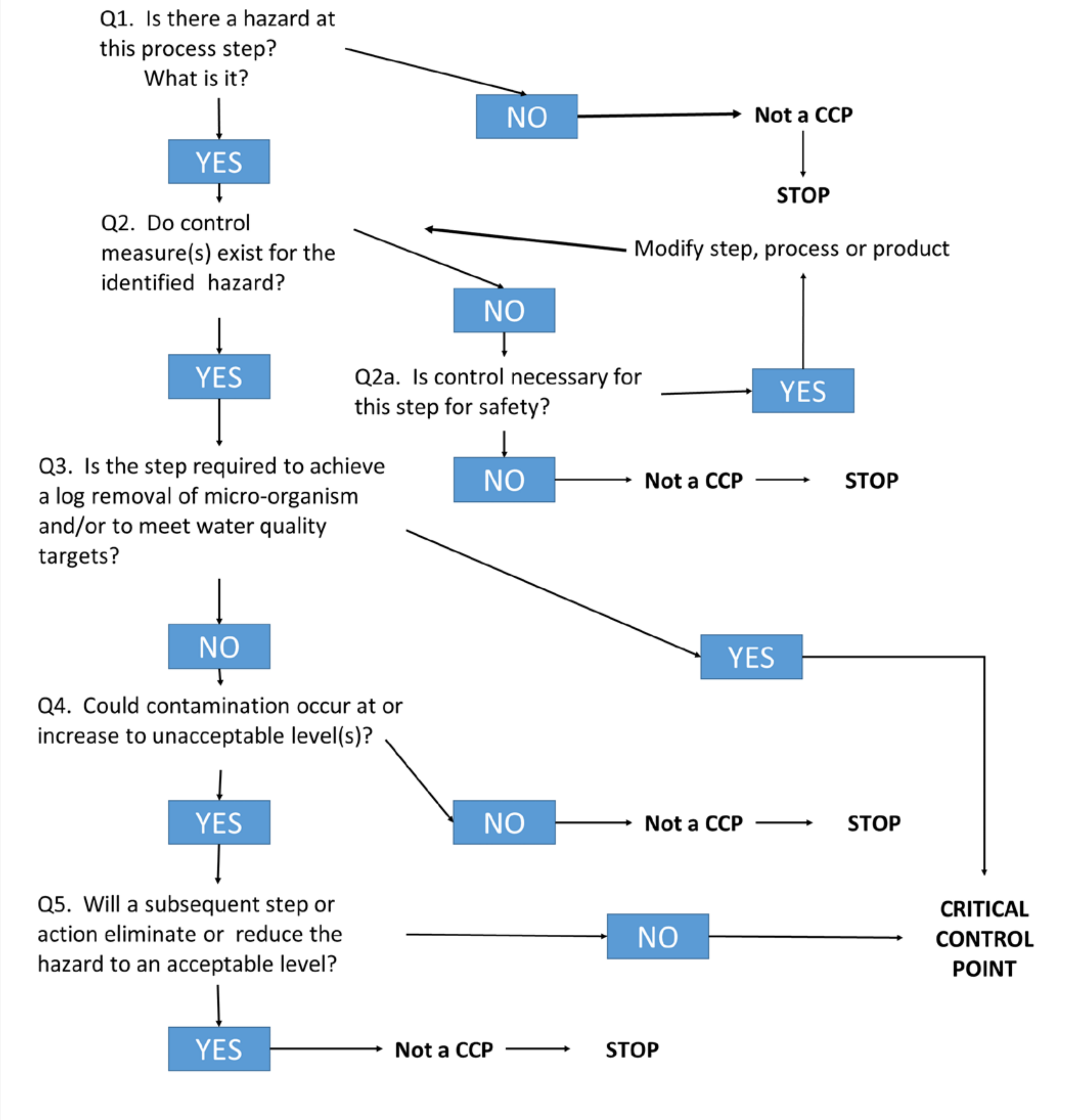
Focus is on health relevant contaminants.

Focus of CCPs is on Health-Relevant Contaminants

- **Assists in decision making. Which contaminants are of concern for a given source water/distribution system?**
- **Determines clear requirements for treatment barriers.**
- **Ensures appropriate barrier design/operation.**
- **Assists with permitting/ regulation – focuses on important requirements for public health.**
- **Is transparent and can be externally audited.**

Selecting CCPs– Methodology to Control Hazards

- Three Basic Questions:
  - Is there a hazard at this step?
  - Can it be controlled by this step in the process train?
  - Is this step intended to eliminate or reduce the risk?
- Not to be confused with Critical Operating Points (production focused)
  - Classic example: Bar Screen



How does this support design and operations?

- Informs process and what questions to ask (samples to take) during piloting
- Helps determine what process controls and monitors will be needed during full-scale design
- Establish critical limits
- Sets a point for corrective action to be performed

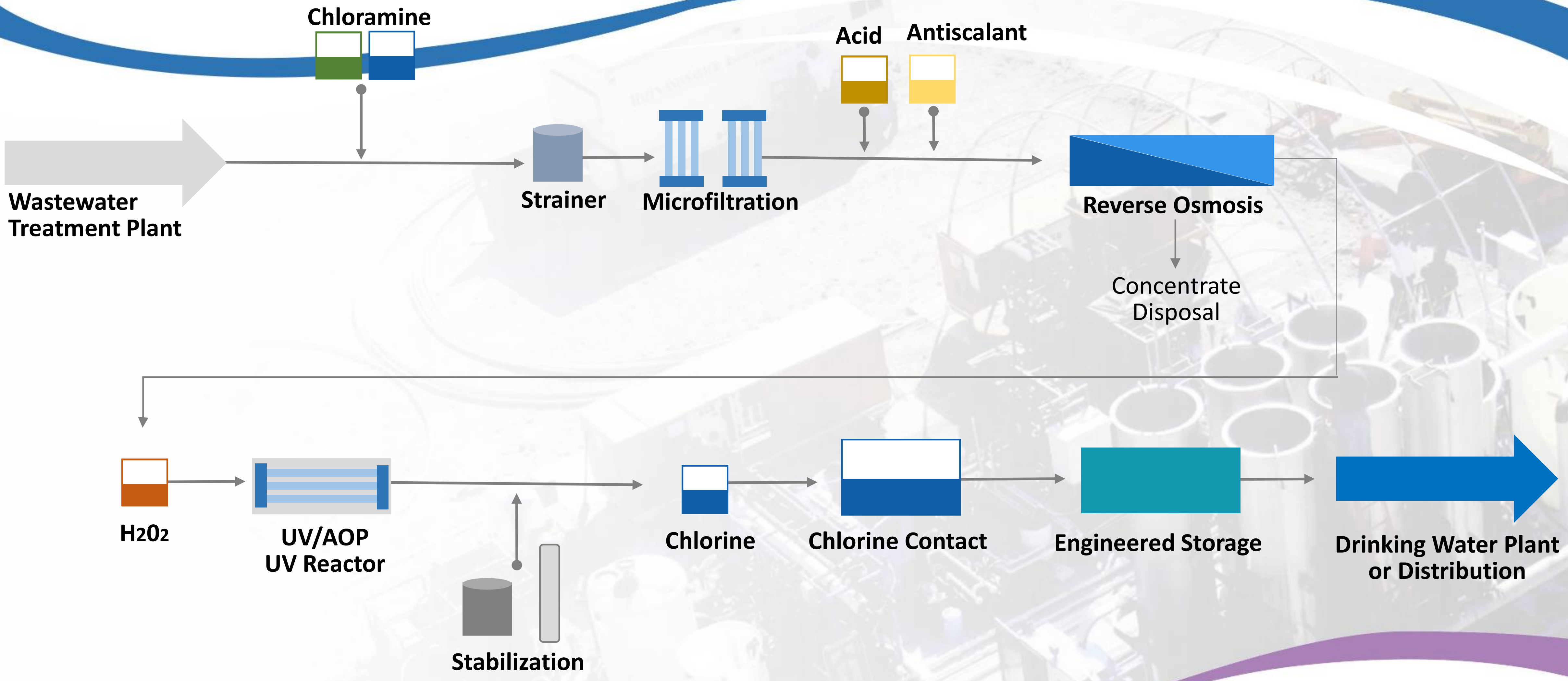
Parameter	SCADA TAG	Alert limit exceeded if	Critical limit exceeded if
Train-specific combined RO permeate	220x-05	Conductivity > 100 uS/cm	Conductivity > 150 uS/cm

The 7 HACCP Principles

1. Conduct a Hazard Analysis
2. Determine Critical Control Points
3. Establish Critical Limits
4. Establish System to Monitor the Control of a CCP
5. Establish Corrective Action to be Taken When Monitoring a CCP is Not Under Control
6. Establish Procedures for Verification to Confirm that HACCP System is working effectively
7. Establish Documentation Concerning All Procedures and Records Appropriate to These Principles and Their Application

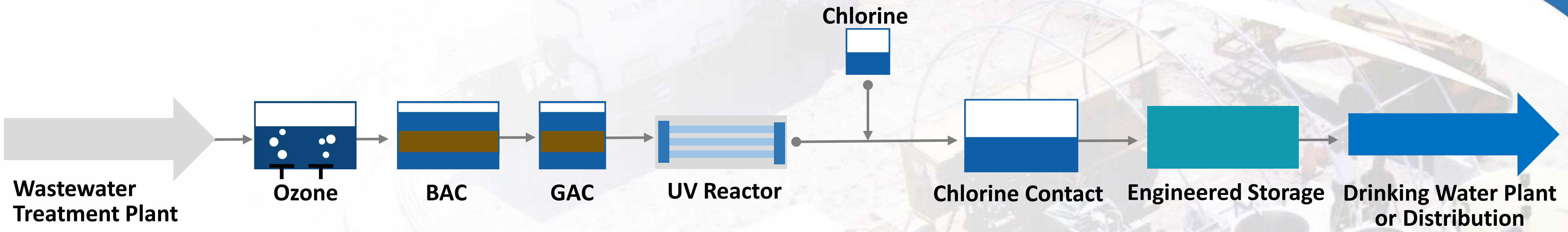
DPR Option 1: Desalting (RO Membrane-Based) Treatment

MF/UF – RO – UV/H_2O_2 – Cl_2 – Engineered Storage



DPR Option 2: Non Desalting Treatment, Initial Concept

O_3 – BAC – GAC – UV – Cl_2 – Engineered Storage



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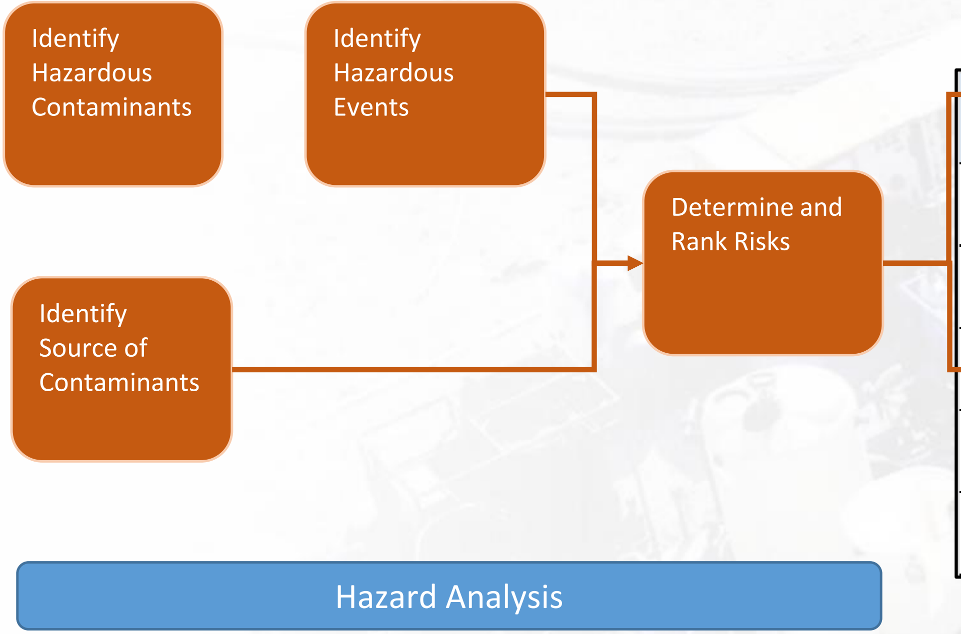
Step 1: Conduct a Hazard Analysis (Risk Assessment)

- **Identify hazards and hazardous events.**
- **Assess and quantify those risks.**
- **Describe how hazards and hazardous events are to be managed and which control measures need to be implemented.**

Source Water Analysis



Likelihood	Consequence				
	Insignificant	Minor	Moderate	Major	Catastrophic
Almost Certain	Low (E1)	Moderate (E2)	High(E3)	Very High (E4)	Very High (E5)
Likely	Low (D1)	Moderate (D2)	High (D3)	Very High (D4)	Very High (D5)
Possible	Low (C1)	Moderate (C2)	High (C3)	Very High (C4)	Very High (C5)
Unlikely	Low (B1)	Low (B2)	Moderate (B3)	High (B4)	Very High (B5)
Rare	Low (A1)	Low (A2)	Low (A3)	High (A4)	High (A5)

Identify Hazardous Events

- Disease outbreak – high pathogen load
- Accidental contamination of the catchment
- Failure of biological processes
- Formation of DBPs in the process train
- High rainfall event – bypassed treatment
- Catastrophic membrane integrity breach
- Overdosing, underdosing or contamination of chemicals

Conduct a Semi Quantitative Risk Assessment

- **Extensive monitoring and source water characterization is recommended for each location.**

Contaminant **Risk before treatment** **Risk post treatment**

Inherent Risk and Assessment of Treatment Barriers

These assessments determine the hazards in the source at an unacceptable level and whether the treatment process is adequate to treat them.

Hazard	Target (lower of EPA & CDPH)	Max concentration in source	Unit	Ratio Max/Target	Impact	Source	Notes	Inherent Risk (based on drinking feedwater directly at 2L per day): Consequence	Inherent Risk: Likelihood	Inherent Risk: Risk	Uncertainty	Required treatment efficiency	Treatment Barriers	Barrier Assessment (based on drinking the product water assuming all barriers worked as designed): Consequence	Barrier Assessment: Likelihood	Barrier Assessment: Risk
Biological																
Cryptosporidium	0				Acute Health	Domestic waste - human and animal faecal matter Contamination of storage reservoirs		Catastrophic	Almost Certain	Very High (E5)	Certain	10 log	UF, RO, UV, Chlorine	Insignificant	Rare	Low (A1)
Giardia lamblia	0				Acute Health	Domestic waste - human and animal faecal matter Contamination of storage reservoirs		Catastrophic	Almost Certain	Very High (E5)	Certain	10 log	UF, RO, UV, Chlorine	Insignificant	Rare	Low (A1)
Heterotrophic plate count (HPC)					N/A	?	Only an indicator									
Legionella	0				Acute Health	Cooling tower bleed?	Not really expected but TBC	Catastrophic	Unlikely	Very High (B5)	Uncertain	10 log	UF, RO, UV, Chlorine	Insignificant	Rare	Low (A1)

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Step 2, Identify CCPs: RO Membrane-Based Treatment

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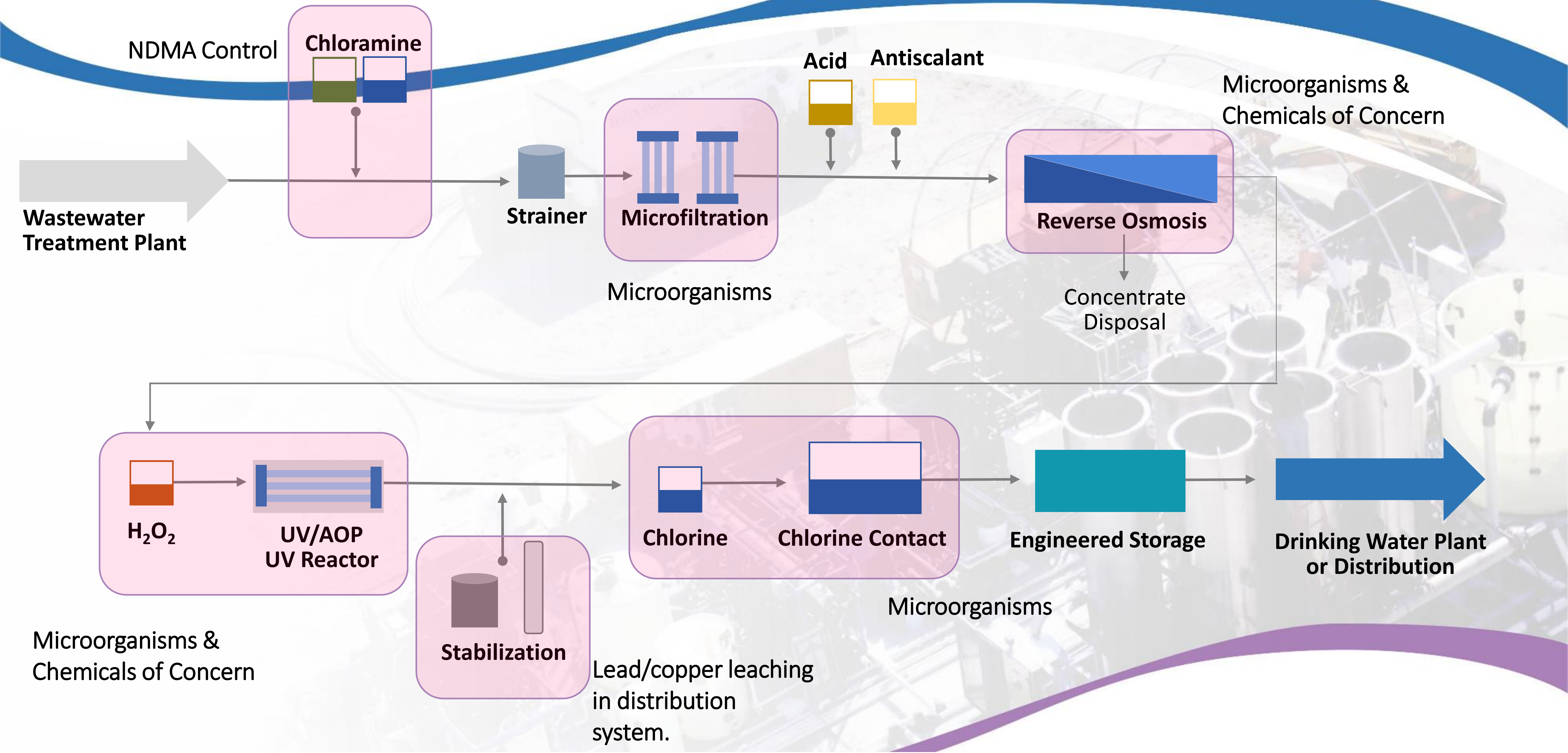
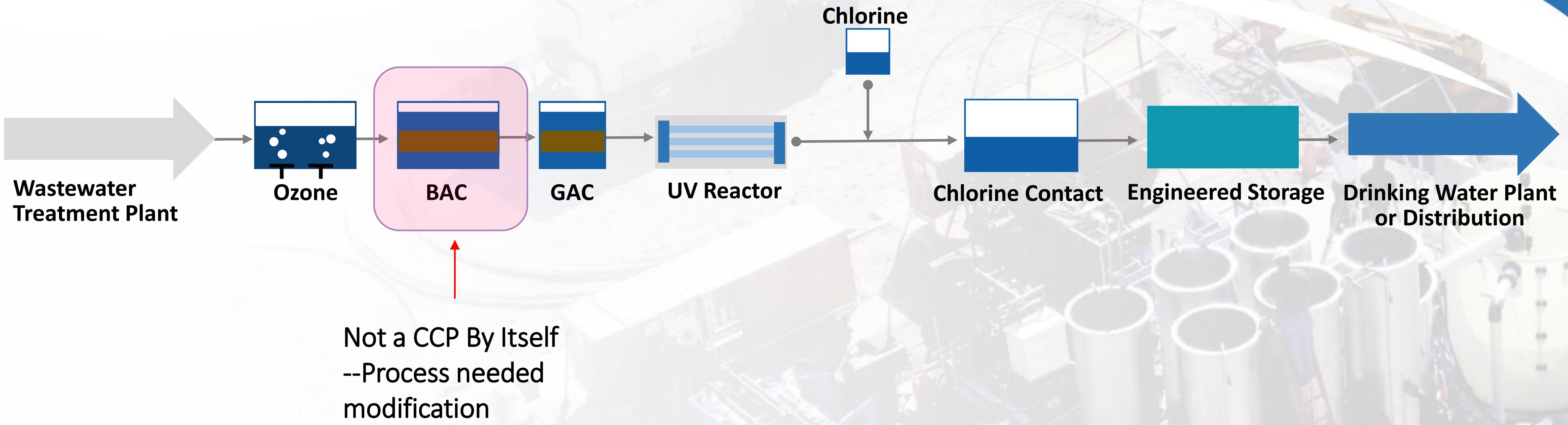


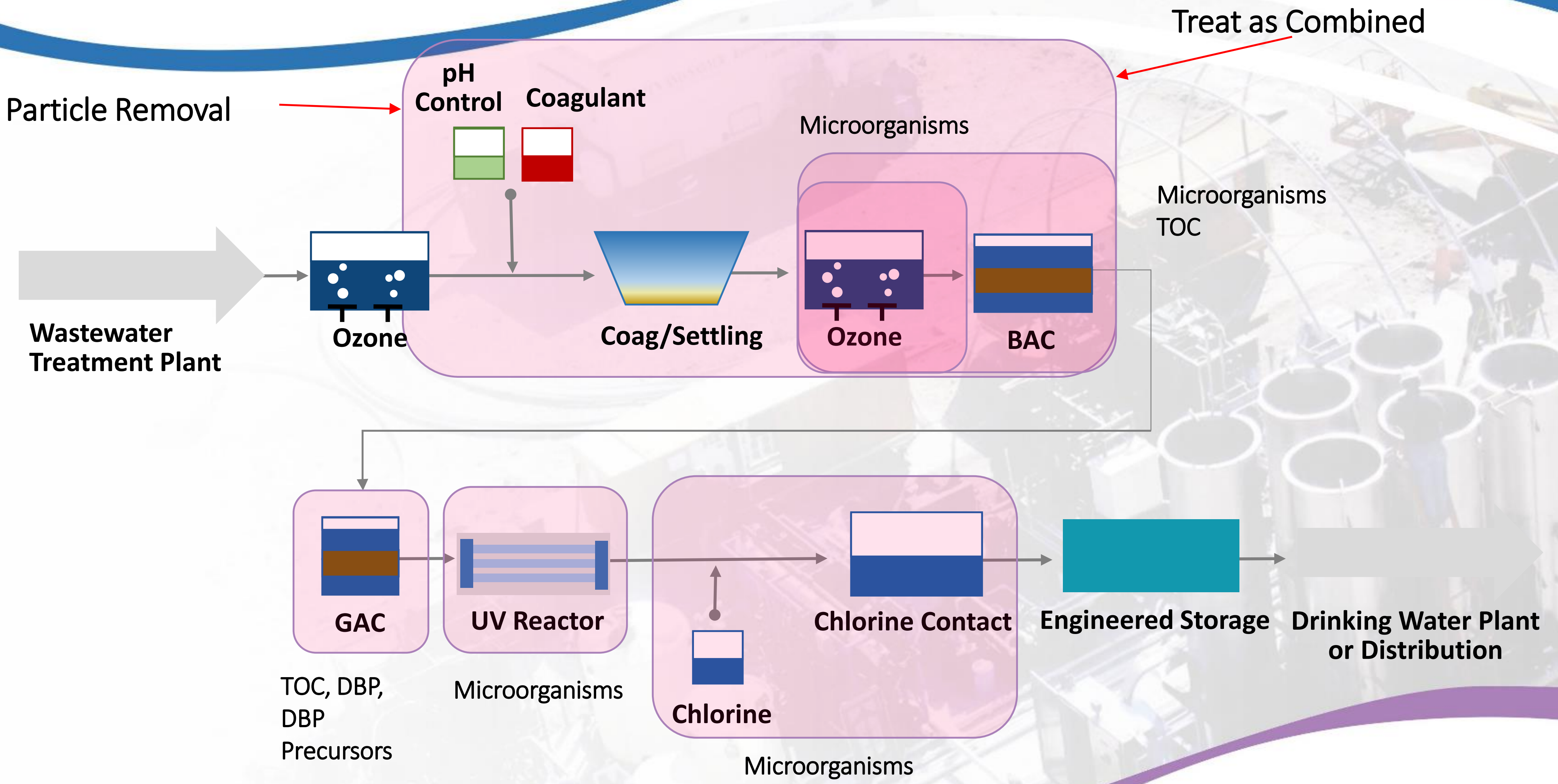
CCPs for Non Desalting Treatment, Initial Concept

O_3 – BAC – GAC – UV – Cl_2 – Engineered Storage



CCPs: Non Desalting Treatment, Modified

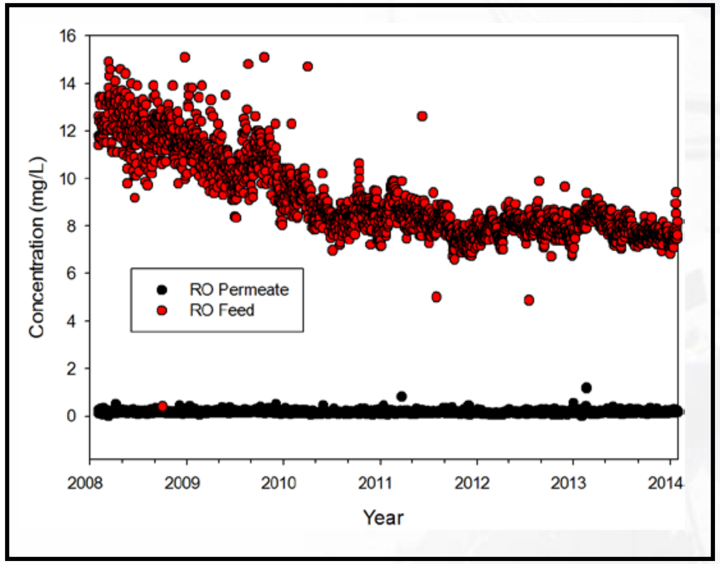
O_3 – BAC – GAC – UV – Cl_2 – Engineered Storage

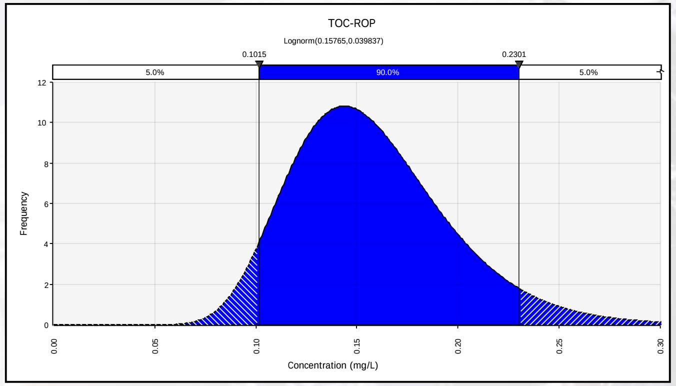


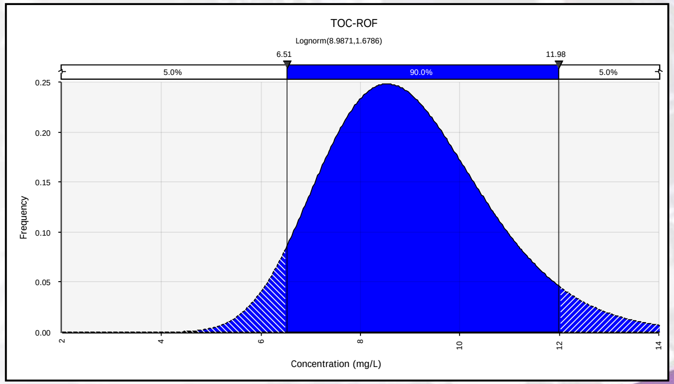
How Reliable are these CCPs?

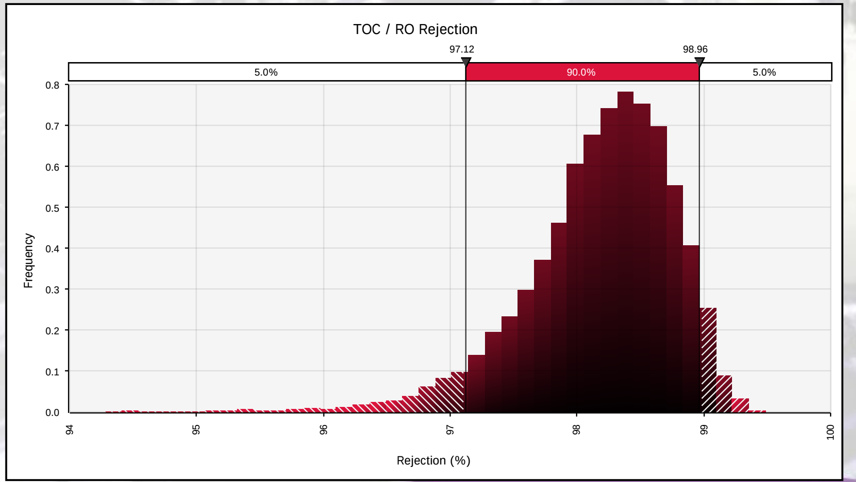
- **Quantify Reliability with Statistical Analysis**

Monte Carlo Simulation from Full Scale Operating Data

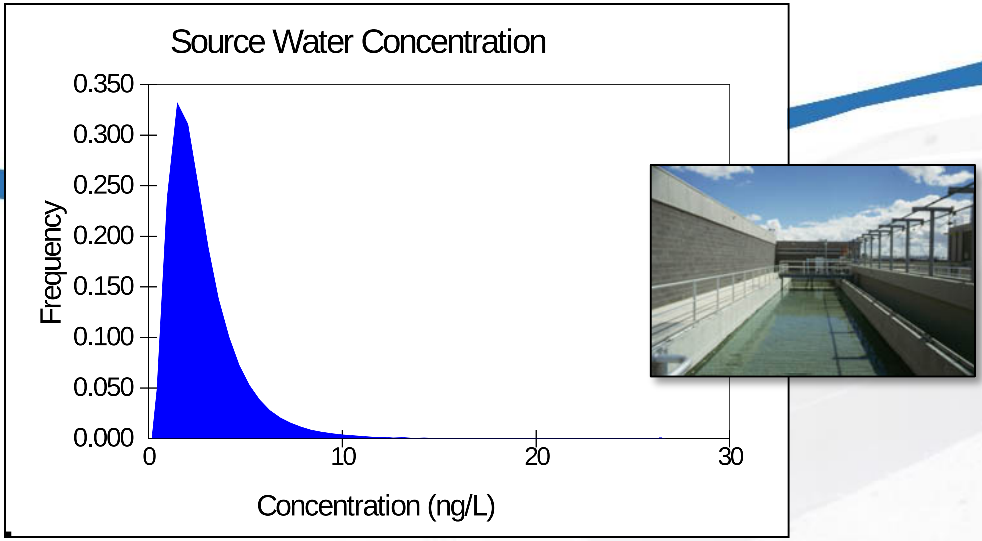


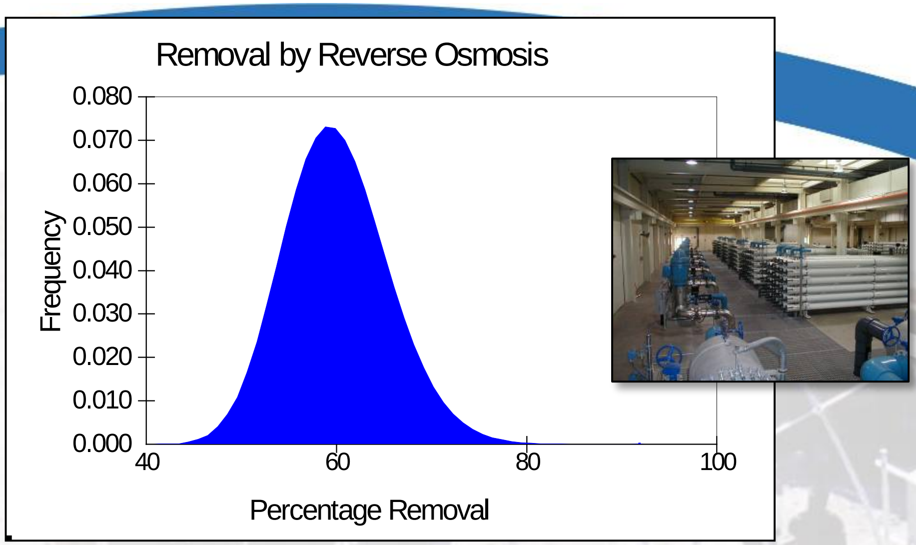


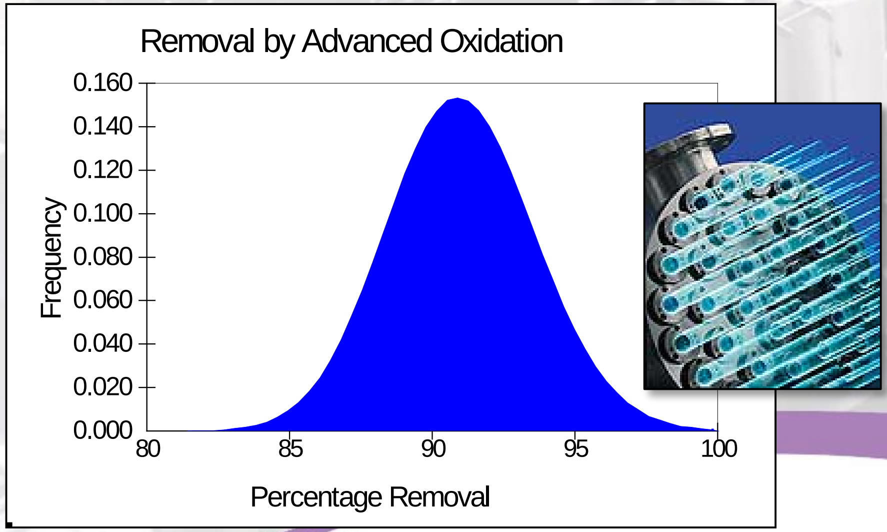


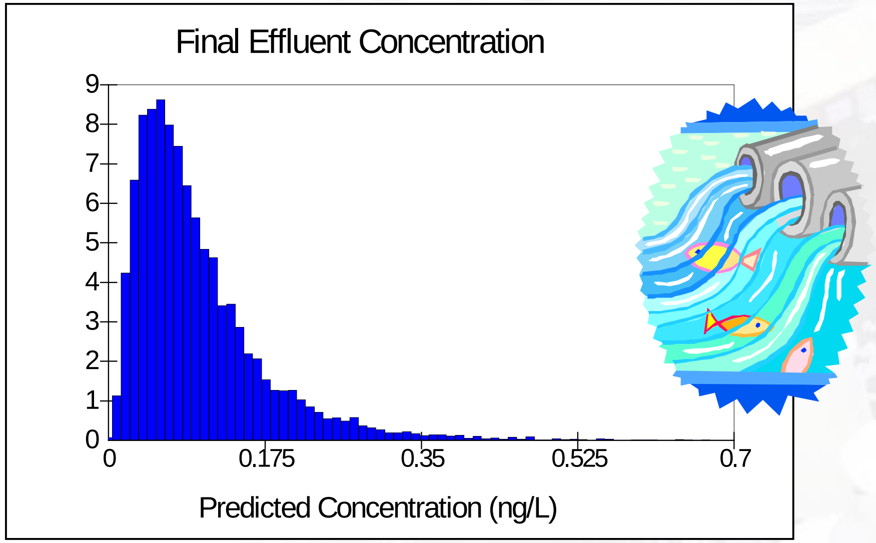


Probabilistic exposure assessment

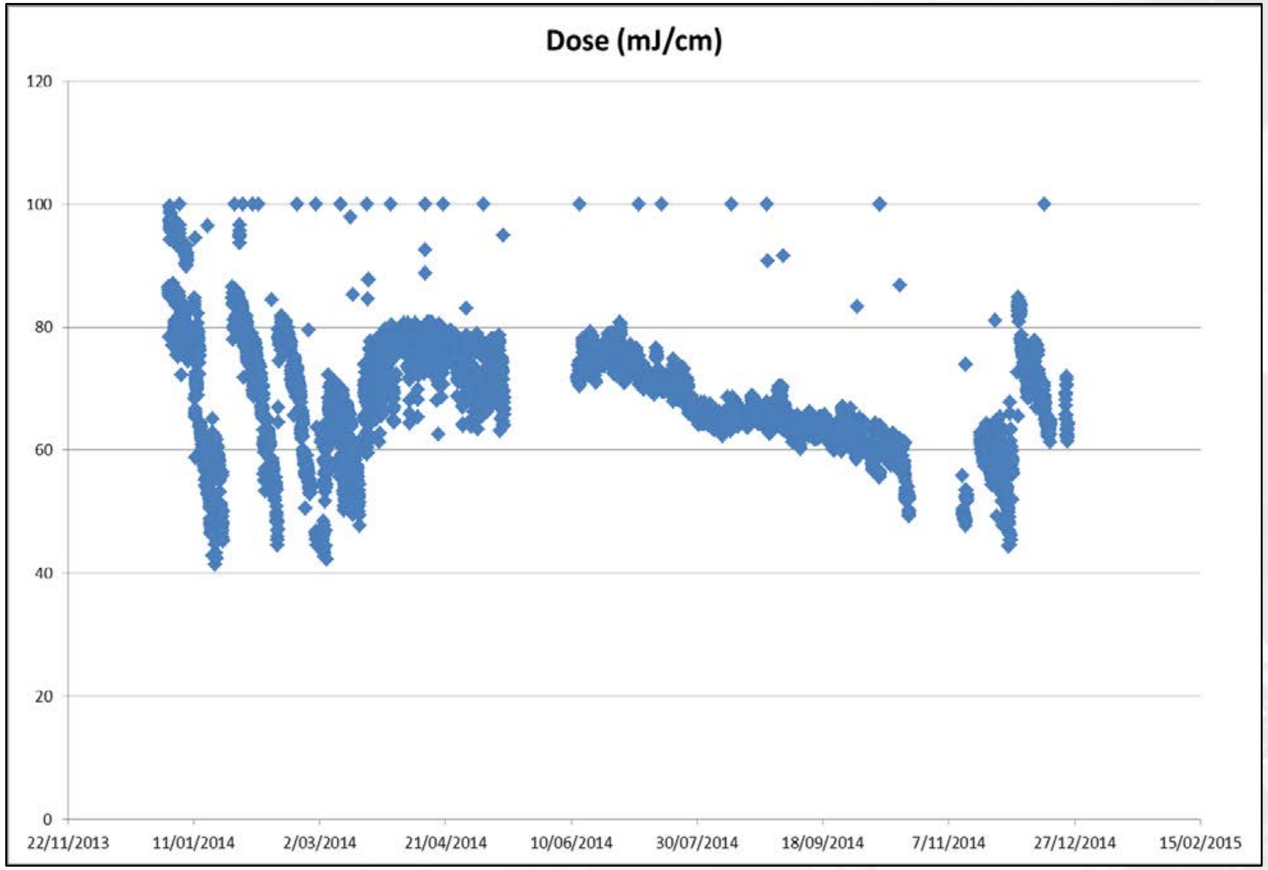


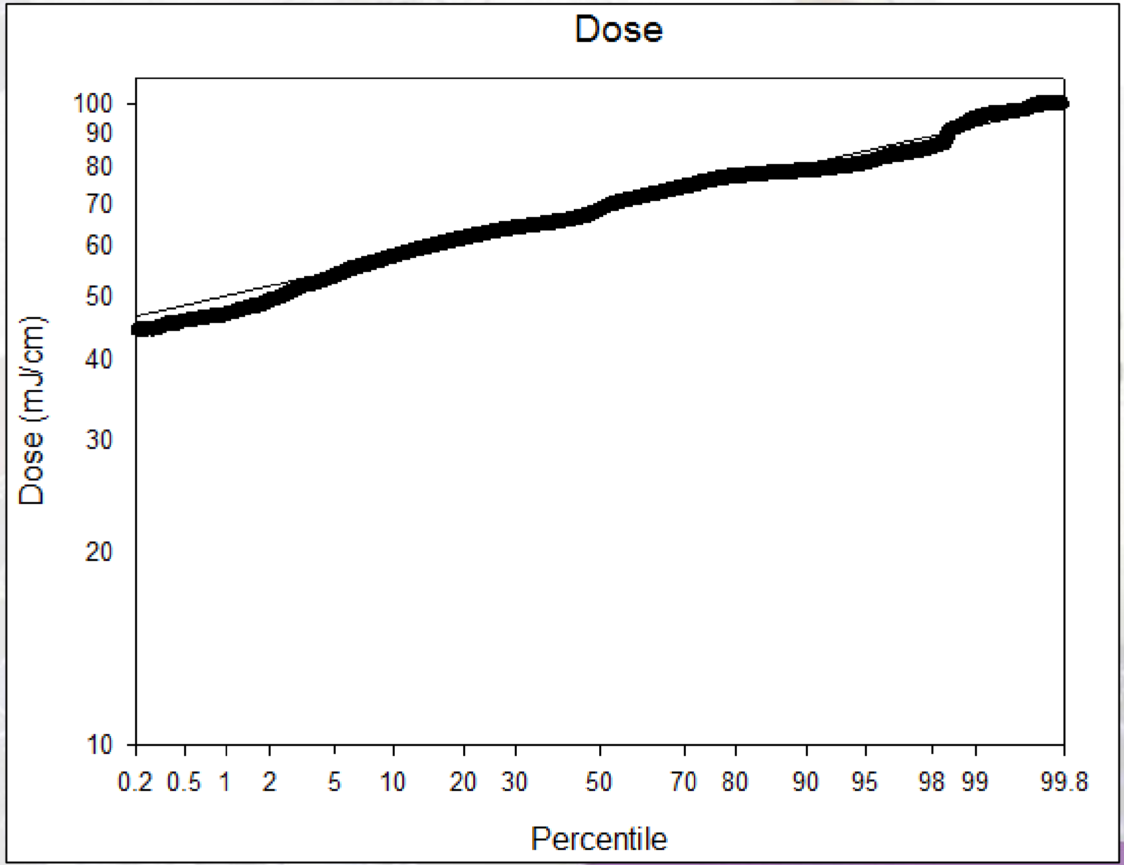






Example: UV Disinfection Data from Full-Scale Plant, USA

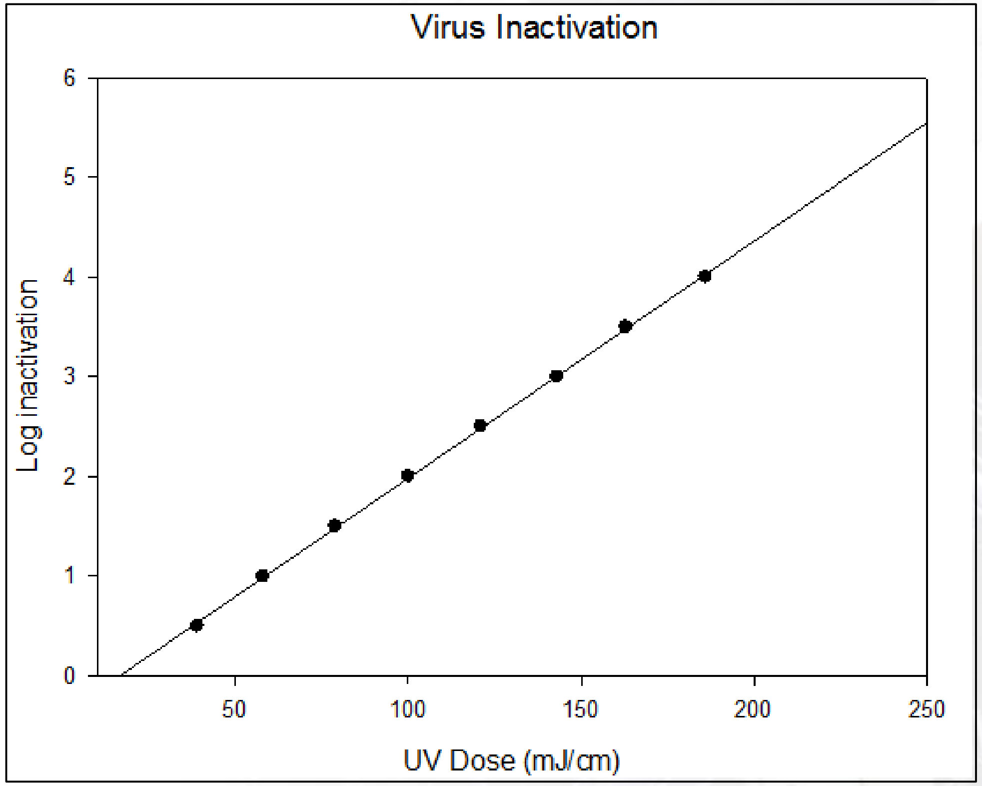


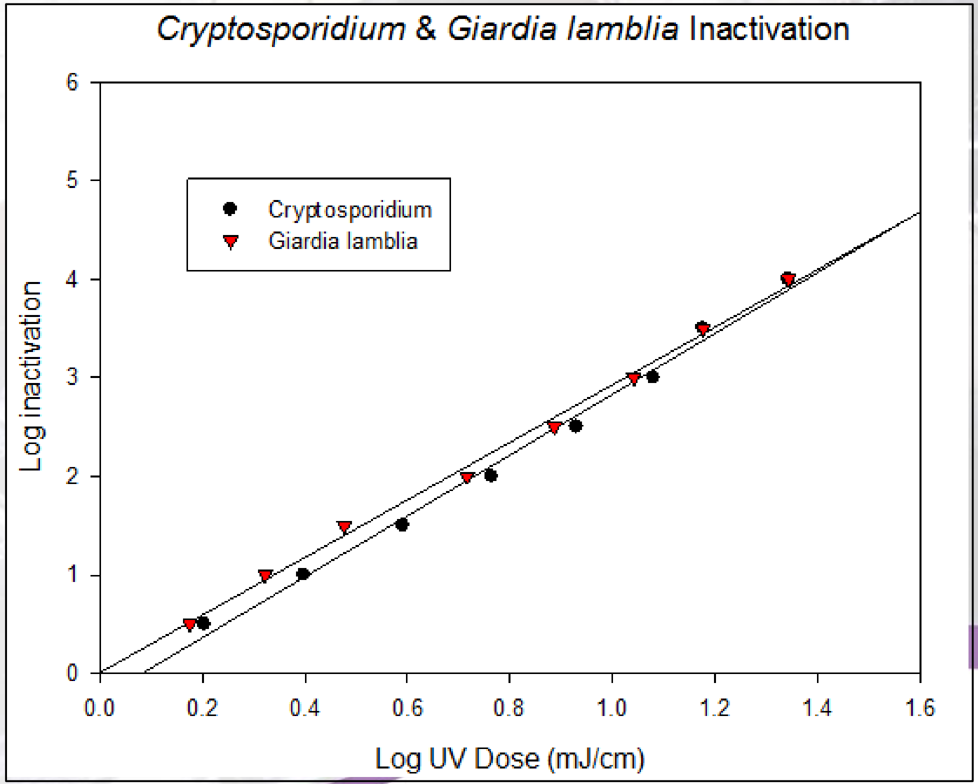


Use US EPA Disinfection Curves

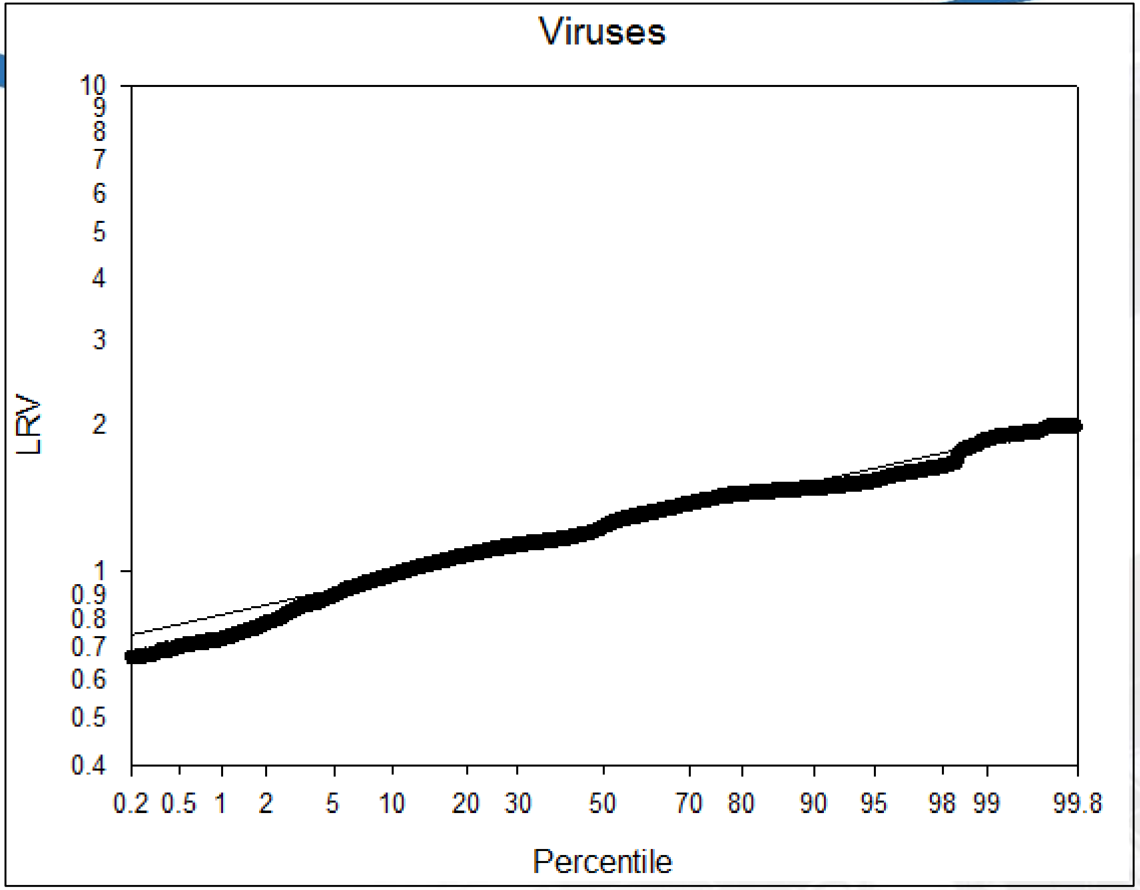
UV DOSE TABLE FOR *Cryptosporidium*, *Giardia lamblia*, AND VIRUS INACTIVATION CREDIT

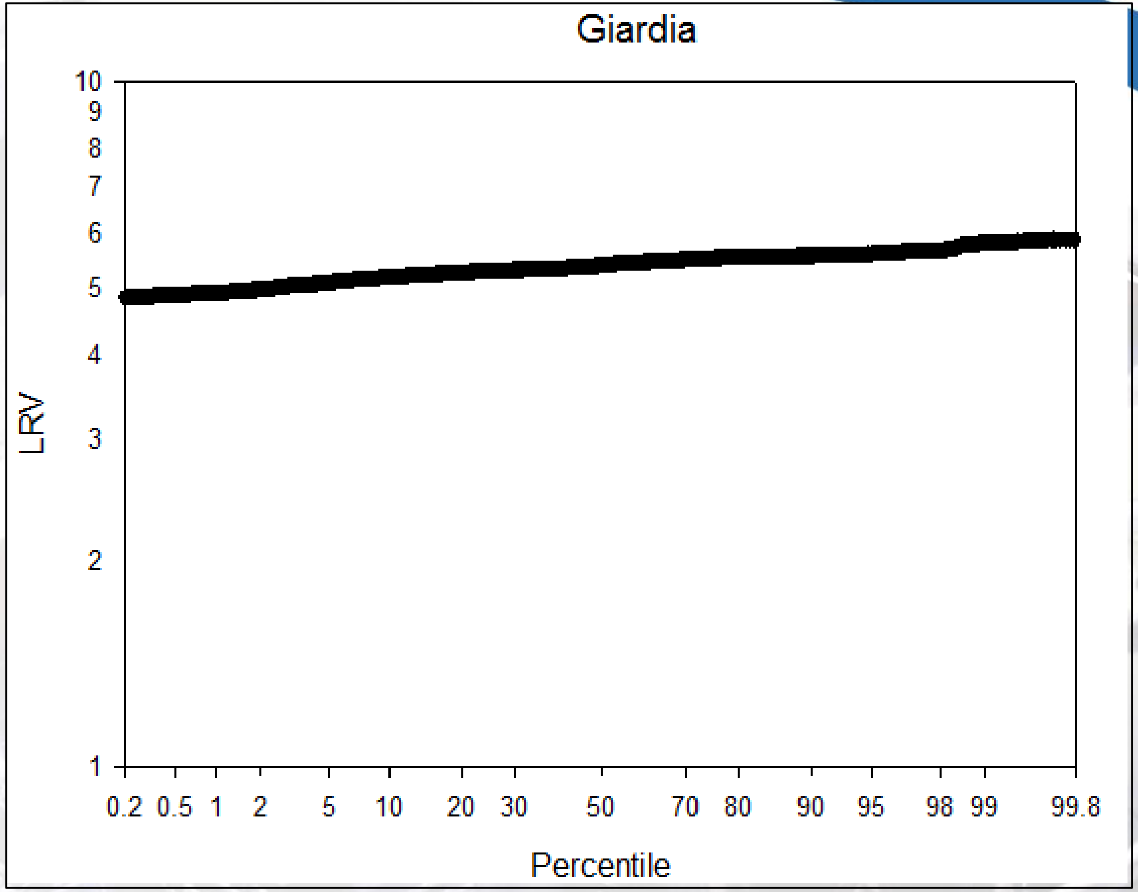
Log credit	*Cryptosporidium* UV dose (mJ/cm²)	*Giardia lamblia* UV dose (mJ/cm²)	Virus UV dose (mJ/cm²)
(i) 0.5	1.6	1.5	39
(ii) 1.0	2.5	2.1	58
(iii) 1.5	3.9	3.0	79
(iv) 2.0	5.8	5.2	100
(v) 2.5	8.5	7.7	121
(vi) 3.0	12	11	143
(vii) 3.5	15	15	163
(viii) 4.0	22	22	186





Calculate Realized Log Removal Values to Verify Performance





Note: Maximum creditable LRV = 0.5 for virus, 4 for crypto, and 4 for giardia!

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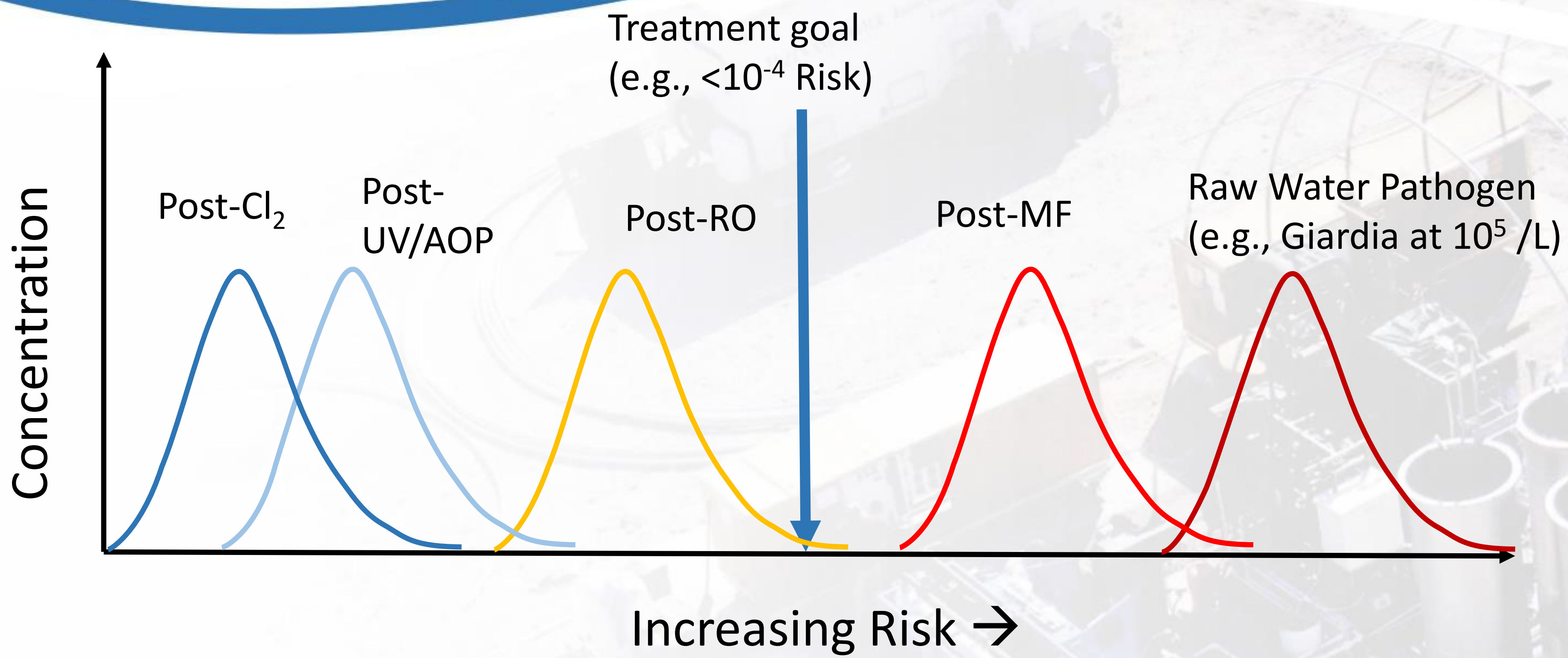
Step 3. Establish Critical Limits: Pathogen Removal through Multiple Processes-- MF-RO-UV/AOP-Chlorine



Quantitative evaluation allows us to define critical limits to achieve water quality goals

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Step 4. Determine Monitoring Needs for CCPs

Process Step	Risk Management	Monitoring Parameters
Pre-chloramination	RO maintenance; NDMA control mechanism. No disinfection credit	• Total (combined) chlorine
MF/UF	Microorganism Control	• Pressure Decay Integrity Test • Individual filter effluent
RO	Microorganism and chemicals of concern	• Electrical conductivity • On line TOC
UV/H2O2	Microorganisms and chemicals of concern.	• UV Present Power Ratio • Hydrogen peroxide • UVT of Feed Water • Turbidity of Feed Water
Stabilization	Lead or copper leaching due to poor water stability	• pH, TDS, Alkalinity (periodic) • applied chemical dose • CCPP & LSI (calculation)
Chlorine	Final Disinfection	• Free chlorine residual & dose • CT (calculated)

Characterizing the Reliability of Monitors/Instrumentation

- 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

Risk Priority Number Ranking Concept

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

RPN Example: Identifying “Bottlenecks” in the System

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/H_2O_2	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
Conductivity 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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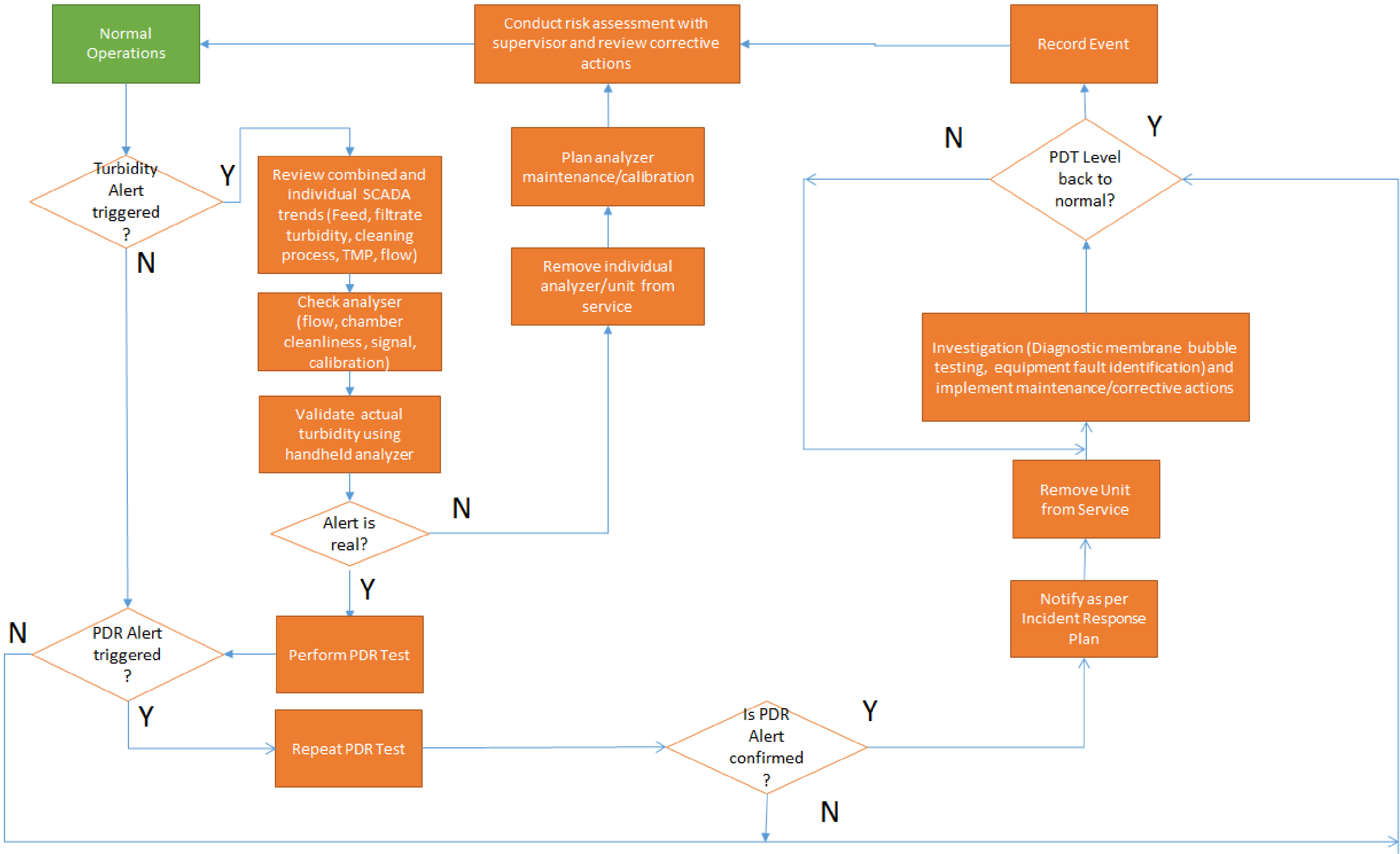
Step 5 – Corrective Action

Parameter	Alert level
Unit Pressure Decay Rate (Daily Integrity Test)	PDR > 0.2 psi/min (eq 4 LRVs)
Unit Filtrate Turbidity (15 min moving average)	> 0.2 NTU (unit/combined)



Summary and Key Messages: Critical Control Points

- Provides a valuable means to focus evaluation, design, and operation of DPR facilities
- HACCP can provide a means of validating specific processes and water quality goals
- HACCP approach can be used to provide cost savings on analytical costs during testing phase by focusing on health relevant contaminants
- Provides confidence to regulators that the proposed process scheme will provide public health protection

Acknowledgments

HAZEN AND SAWYER
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- SPI—Jim Vickers
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Questions?

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