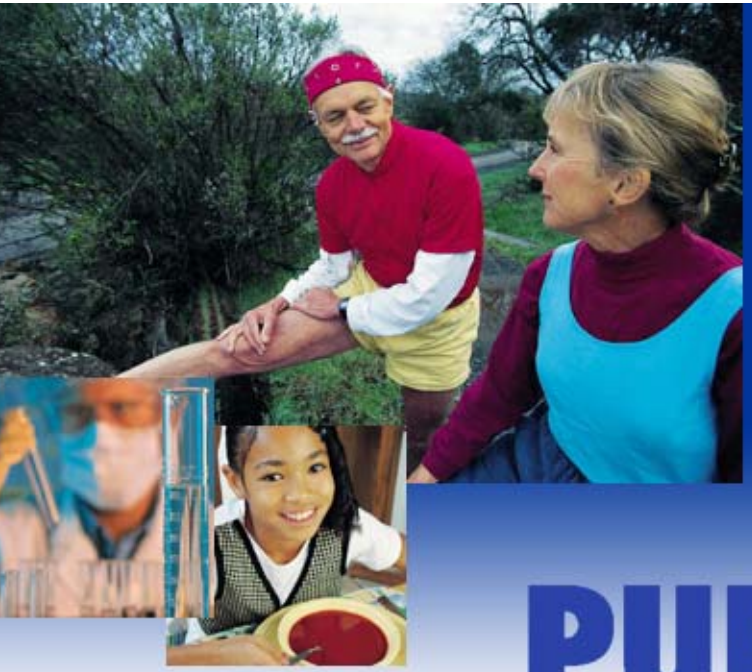

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Public Health Issues in Developing Technical Standards

Water Reclamation Rules Advisory Committee

November 14, 2007

Washington State Department of Health

Session 1

Introduction

- Define expectations
- Discussion topics
- Importance of reclaimed water
- Risks with use of water

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Presentation jobs

- Speaker – talk, deliver information
- Audience – listen, receive information

If you finish before me, someone please let me know!

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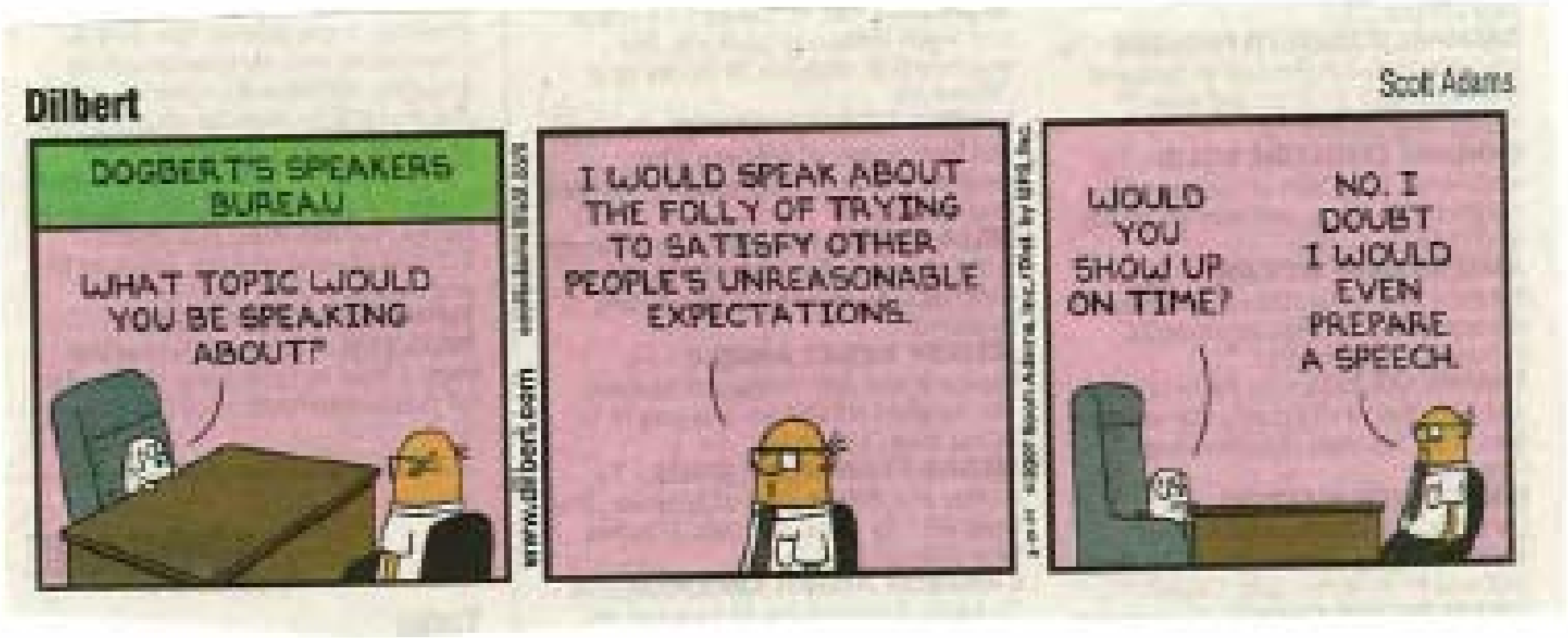
Define Expectations:



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Discussion Topics – Technical Standards Development

- Basis of the current standards
- Treatment & disinfection standards
- Reliability, controls & alarms
- Issues with current standards
- Future focus – reuse & public health issues

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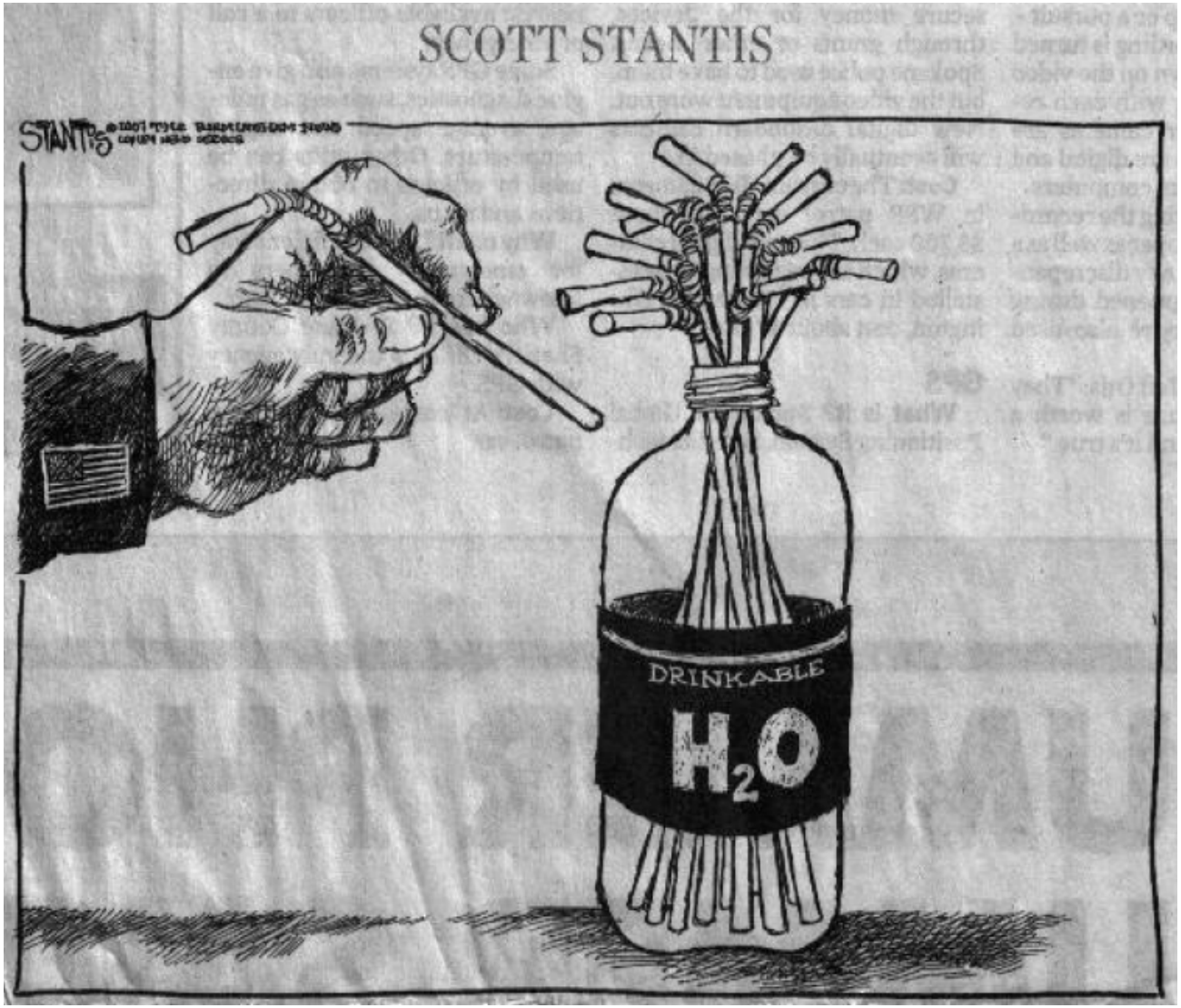
Importance of reclaimed water supply



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Limited available PWS supplies

- Reclaimed water is integral part of public water system supply portfolio's
- PWS's & regional suppliers need to invest in best quality water available for intended uses
- Reclaimed water – supply tailored for direct non-potable
- uses & indirect potable supply augmentation

Public Health Based Technical Standards

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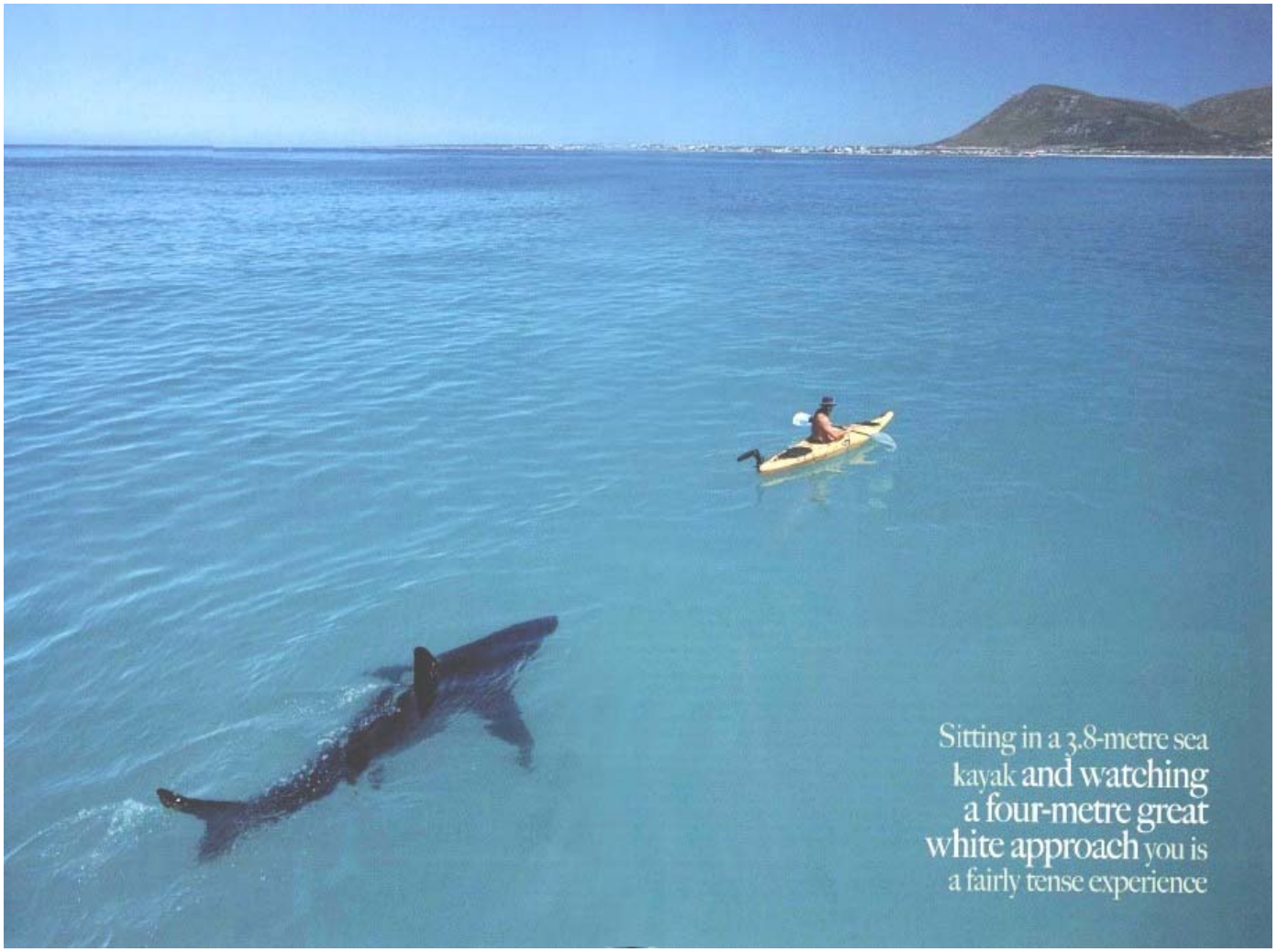
Recognizing & managing risk –



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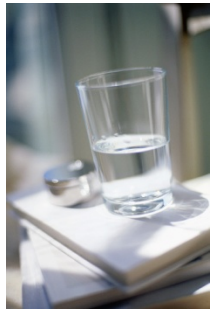
Using water – risks based

- Public has a difficult time with relative risk*
- Public applies ‘presence / absence’ litmus test
- Adverse health effects are presumed if contaminant present



* Dr. Shane Snyder

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Water reclamation risk management- multiple barrier approach

- Source, basis & model – Safe Drinking Water Act
- Protective barriers
  - Source control
  - Treatment process
  - Storage, transmission & distribution
  - Use area

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Source control

- Collection system pre-treatment program
  - Organic chemicals & metals (metal plating shops)
  - Pharmaceuticals
  - Cooling water & water softener discharges
    - Quincy experience
    - TDS affects ground water quality & can inhibit biological process if sufficiently concentrated
    - Inorganic nitrogen without carbon
      - Impact on nitrogen / nitrate removal

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Treatment process

- Reliability assessments, plant components
  - Cannot be fail safe but can plan to fail safely
- Emergency & reliability storage
  - Permitted waste disposal site
- Alarms & controls
- Operator certification / adequate operations
- Bypasses prohibited

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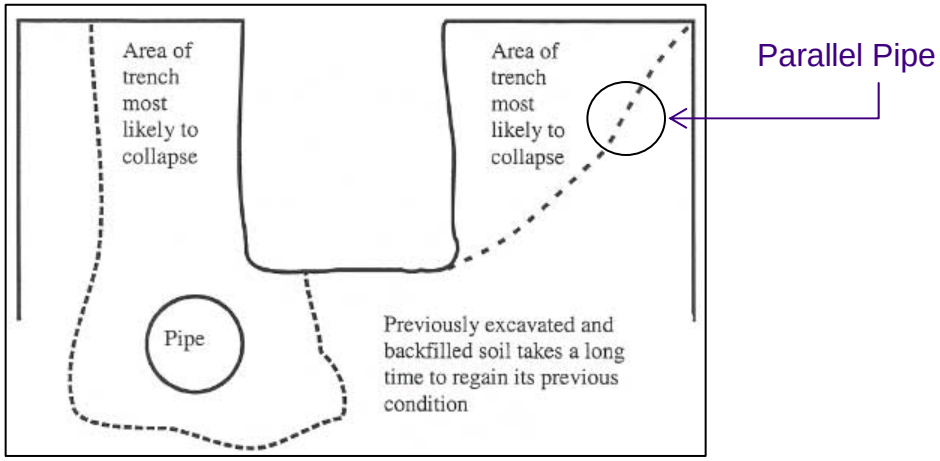
Storage, distribution & transmission

- Cross connection control / backflow prevention
- Pipe line separation



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Use area protectioins

- Warning signs
- Buffer zones
- Cross connection control
- End-user agreements
- User notifications

San Diego Water Dept.
Residential Irrigation
Backflow Assembly

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Public Health Agencies Join Citizens Against Drinking Sewage in their Cautions!

Recommended Warning Signs

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Treatment technique requirements

- Treatment technique requirement – based on SDWA
- Requirement for specific treatment processes & process monitoring in lieu of effluent quality monitoring
- Tracks water quality requirements that cannot be monitored economically, timely or effectively
  - Viruses
  - Protozoan cysts
  - Specific bacterial pathogens
- Provides real time data through effective surrogate measures
  - Turbidity – real time data on filtration efficiency & consistency
  - Chlorine residual, temperature, pH & flow – chlorination performance
  - UVT, intensity, power &flow – UV system performance
- Treatment tracking assures minimum equivalent reduction
  - Specific microbial reduction targets
    - 3-log Cryptosporidium & Giardia removal / inactivation
    - 5-log virus removal / inactivation

Log removal ⇒ % reduction

3-log = 99.9%, 5-log – 99.999%

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Session 2

Basis of current standards

- Public health protection first
- Developed based mostly on California regulations
  - CA began regulating water reuse ≈ 1912
  - Best experience
  - Highest water quality, most uses
- Best of other states included

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Public health protection & technical standards

- "Making reclaimed water safe for any intended use is achieved by eliminating or reducing the concentrations of *health-significant microbial and chemical constituents* through wastewater treatment and/or by limiting public or worker exposure to the water via design or operational controls."[1]

- Reclaimed water is a water supply - intended for use in populated areas [e.g. public exposure expected]

- Public health protection is accomplished through technical standards for water quality and the reliable design of treatment processes, transmission, storage, distribution and use area controls.

[1] Crook, *PUBLIC HEALTH ISSUES ASSOCIATED WITH RECLAIMED WATER*, 2007

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1997 Technical Standards & public health

- Current standards are basically public health-based standards
- Sections 1 and 3 define allowable uses, water quality limits required for specific uses, treatment processes required for production, environmental buffers, site buffers, reliability, use area design to assure limited public exposure

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Public Health Technical Standards

Uses tied to water quality

- **SECTION 1 - GENERAL REQUIREMENTS**
- **Article 1. Irrigation**
- **Article 2. Impoundments**
- **Article 3. Groundwater Recharge by Surface Percolation**
- **Article 4. Commercial and Industrial Uses**
- **Article 5. Other Uses of Reclaimed Water**
- **Article 6. Other Methods of Treatment**
- **Article 7. Sampling and Analysis**
- **Article 8. Engineering Report**
- **Article 9. Operational Requirements**
- **Article 10. General Requirements of Design**
- **Article 11. Alternative Reliability Requirements**
- **Article 12. Use Area Requirements**
- **Article 13. Summary of General Requirements**

- **SECTION 3 - STANDARDS FOR DIRECT AQUIFER RECHARGE**
- **Article 1. Applicability**
- **Article 2. Treatment Requirements**
- Section 1. Potable Ground Water.
- Section 2. Nonpotable Ground Water
- **Article 3. Reclaimed Water Quality Requirements**
- **Article 4. Sampling and Analysis**
- **Article 5. Operational Requirements**
- **Article 6. General Requirements of Design**

Water quality, treatment & use area requirements

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Health risk comparisons – potable water

- Microbial risks levels
  - 5-log virus removal & inactivation through filtration & disinfection
  - Effectively equivalent to SDWA
  - Risk levels @ 1/10,000
  - SDWA – no microbial source monitoring requirements for SWTP effluents
  - Coliform monitoring for distribution system only
  - Ground water rule – source monitoring only if:
    - Distribution system coliform detections & source vulnerable
- Chemical
  - Adopts SDWA MCL's
  - 1 additional cancer per 1,000,000
  - Some MCL levels raised due to economic, monitoring limitations or controls

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Treatment & disinfection standards

- Pathogens & microbial monitoring
- Physical – chemical contaminants
- Source control & removal through treatment
- Use-based water quality concerns

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Pathogens & microbial monitoring

- Types & occurrence of organisms
- Indicator organisms
- Pathogen removal & survival
- New & re-emerging pathogens

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Types & occurrence

- Bacteria
- Protozoan cysts
- Viruses
- Helminths

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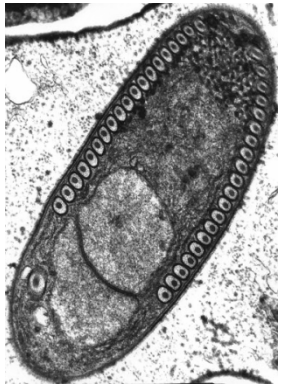
Microbial Contaminants – current & future

- Current
  - E. coli
  - Giardia
  - Cryptosporidium
  - Enteric viruses
  - Legionella
- Monitored by total and fecal coliform



* Adenovirus used as basis for UV disinfection due to resistance to UV

- Newly Discovered Toxicities
  - Adenoviruses*
  - Caliciviruses [Norwalk virus]
  - Coxsackieviruses
  - Cyanobactera [blue-green algae] other freshwater algae & toxins
  - Echoviruses
  - Heliobacter pylori [stomach ulcers]
  - Mycrosporidia (Entercytozoon & Septata)
  - Mycobacterium avium intrracellulare (MAC) [upper respriatory]

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Typical levels of microbials

Table 1.2 Microbial densities in municipal raw sewage

	Average count per 100 ml	
	Worcester sewage	Pietermaritzburg sewage
Aerobic plate count (37 °C; 48 hr)	1,110,000,000	1,370,000,000
Total coliforms	10,000,000	–
E. coli type 1	930,000	1,470,000
Fecal streptococci	2,080,000	–
C. perfringens	89,000	–
Staphylococci (coagulase positive)	41,000	28,100
Ps. aeruginosa	800,000	400,000
Salmonella	31	32
Acid-fast bacteria	410	530
Ascaris ova	16	12
Taenia ova	2	9
Trichuris ova	2	1
Enteroviruses and reoviruses ($TCID_{50}$)	2,890	9,500

Data from Grabow and Nupen (1972) for two cities in South Africa

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Typical Bacteria Composition in Wastewater

Process	Total Coliform #/100 mL	Fecal Coliform #/100 mL
Raw Wastewater	10^7 To 10^8	10^6 To 10^7
Primary Effluent	10^7 To 10^8	10^6 To 10^7
Secondary	10^5 To 10^6	10^4 To 10^6
Filtered	10^4 To 10^6	10^3 To 10^5
Nitrified	10^4 To 10^6	10^3 To 10^5
Filtered Nitrified	10^4 To 10^6	10^3 To 10^5

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Indicator organisms

- Too expensive & time consuming to test for specific pathogens
- Cannot test for all pathogens potentially found in wastewater
- Coliform used as indicator of microbial quality – **Coliform Index**
  - Often found in intestinal tract of humans & animals
    - Also aquatic environment, in soil & on vegetation
  - Easy to culture
  - Presence indicates potential for other pathogenic organisms of fecal origin

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Coliform Index

- Coliform Index – rating of the purity of water based on a count of fecal bacteria.
- Coliform Index used –difficult to test for pathogenic bacteria directly
- Many types of pathogenic bacteria
- Usually present in low numbers which do not always show up in tests
- Thermotolerant coliforms present in higher numbers than individual types of pathogens
- Imperfect – don’t indicate how many pathogens are present and no idea of whether pathogenic viruses or protozoa are present
- Results are not always accurate or useful

Coliform Bacteria

- Commonly-used bacterial indicator of sanitary quality of foods and water
- Rod-shaped, Gram-negative bacteria that ferment lactose with the production of acid and gas when incubated at 35°-37°C
- Fecal coliform
  - Subgroup
  - Incubation at 45°C
  - General proportion: 10% of total coliform
- Typical bacteria genera & species
  - Citrobacter (12)
  - Enterobacter (7)
  - Escherichia (7)
  - Hafnia (1)
  - Kelbsiella (12)
  - Serratia (12)
  - Yersina (3)

54 bacterial species

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Total Coliform use in reclaimed water[1]

Total coliform bacteria These organisms, which are used as indicators of the general sanitary quality of treated drinking water supplies, proved most useful for reclaimed water because of the following reasons:

1) When detected in advanced treatment stages, isolates can be purified and identified, and the presence of *Escherichia coli* renders almost conclusive evidences of fecal pollution
2) The count includes organisms such as *Klebsiella* and *Aerobacter* species which are generally more resistant to disinfection processes than most pathogens including viruses
3) The organisms multiply in certain process units, which facilities assessment of the efficiency of subsequent units
4) Counts can be determined by simple and inexpensive methods which yield results within 24h

[1] McFeters, Gordon A., *Drinking Water Microbiology*, Springer-Verlag, 1990

Coliforms as pathogens:

Originally, coliform bacteria were considered as harmless indicator organisms, many of which are normal inhabitants of the human gastrointestinal tract. Gradually, however, their status changed and today they should be regarded as potential pathogens. The reason is that the incidence of members of the group, such as *E. coli*, which carry plasmids coding for transferable enteropathogenicity, enterotoxicity, and resistance to antimicrobial chemotherapeutic agents, has been increasing rapidly. This is another important reason for including total coliforms in the assessment of the quality of directly reclaimed drinking water.

McFeters, *Drinking Water Microbiology*, Springer-Verlag, 1990

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Total coliform water quality limits

- Current standard: < 2.2 total coliform / 100 mL as median of last 7 days of samples, no sample to exceed 23 TC / 100 mL
- Source: adopted from California Title 22 Regulations during standard development
- Original source: adopted in California regulations prior to 1968

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Basis of standard

- Based on most probable number (MPN) determined by multiple tube fermentation technique test method [MPN/100 mL]
- Multiple tube fermentation technique:
  - Developed in 1914
  - Based on principal of dilution to extinction

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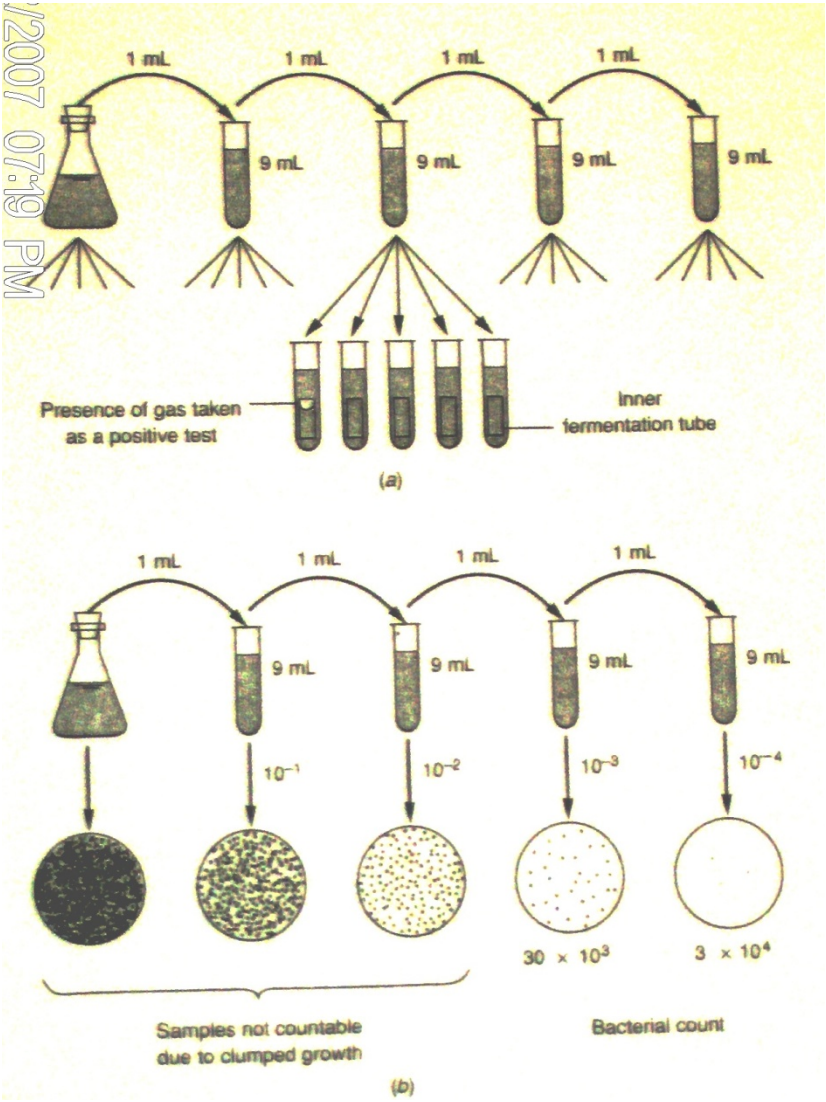
Multiple Tube Fermentation



Step 1: Serial dilution from sample

Step 2: transfer 1 mL sample to 5 fermentation tubes w/ lactose culture medium & gas collection tube

Step 3: incubate at 35°C – 24 hours

Step 4: read # tubes with gas

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MPN Determination

- Method 1: joint probability based on Poisson distribution

$$y = \left[\frac{1}{a}\right]\left[\left(1-e^{-n_1\lambda}\right)^{p1}\left(e^{-n_1\lambda}\right)^{q1}\right]\left[\left(1-e^{-n_2\gamma}\right)^{p2}\left(e^{-n_2\lambda}\right)^{q2}\right]\left[\left(1-e^{-n_3\lambda}\right)^{p3}\left(e-^{n_3\lambda}\right)^{q3}\right]$$

- Thomas Equation

$$MPN\ /100_mL = \frac{Number_positive_tubes_x_100}{\sqrt{(mL_negative_tubes)x(mL_all_tubes)}}$$

- Standard Methods MPN Tables

Where:

y = probability of occurrence

a = constant

n1,n2,n3 = sample size in each dilution

λ= coliform density, number / mL

p1,p2,p3 = # positive tubes in each sample dilution

q1,q2,q3 = # negative tubes in each sample dilution

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Standard Methods MPN tables

MPN Calculation Chart

0-0-0	<2	3-0-0	8	5-0-0	23	5-3-3	170
0-0-1	2	3-0-1	11	5-0-1	30	5-4-0	130
0-1-0	2	3-1-0	11	5-0-2	40	5-4-1	170
0-2-0	4	3-1-1	14	5-1-0	30	5-4-2	220
		3-2-0	14	5-1-1	50	5-4-3	280
1-0-0	2	3-2-1	17	5-1-2	60	5-4-4	350
1-0-1	4			5-2-0	50	5-5-0	240
1-1-0	4	4-0-0	13	5-2-1	70	5-5-1	300
1-1-1	6	4-0-1	17	5-2-2	90	5-5-2	500
1-2-0	6	4-1-0	17	5-3-0	80	5-5-3	900
		4-1-1	21	5-3-1	110	5-5-4	1600
2-0-0	4	4-1-2	26	5-3-2	140	5-5-5	≥1600
2-0-1	7	4-2-0	22	0	<1.1	5	6.9
2-1-0	7	4-2-1	26	1	1.1	6	9.2
2-1-1	9	4-3-0	27	2	2.2	7	12.0
2-2-0	9	4-3-1	33	3	3.6	8	16.1
2-3-0	12	4-4-0	34	4	5.1	9	23.0
						10	≥23.0

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MPN accuracy

# Positive Tubes	MPN #/100 mL	95% CI – Lower Limit	95% CI – Upper Limit
0 – 0 – 0	<2.2	0	6.0
0 – 0 – 1	3	< 0.5	13
1 – 0 – 0	4	< 0.5	20
3 – 0 – 0	23	4	120
5 – 0 – 0	23	7	70

Public health implications – MPN test results

- < 2.2 TC / 100 mL essentially pathogen free
- Standard of sanitary quality under SDWA until 1990's
  - Change focus on distribution system quality vs. source quality
  - Larger sample sizes
  - Presence / absence test with larger # samples
- 23 TC / 100 mL: coliform happens! Allows excursion that <u>may</u> be attributed to sampling error or sources other than human or animal origin

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Session 3

Pathogen removal & survival

- Basic removal technologies
  - Secondary treatment
  - Coagulation/flocculation/filtration*
  - Membranes filtration
  - Disinfection - *primary mode of protection*
- Crook, 2007: "The main function of the filtration step is to prepare the water for disinfection"

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Disinfection Efficiency

Approximate Removal of Microorganisms Through Disinfection Processes			
Process	Bacteria	Protozoa	Viruses
Primary Treatment	0.5 log	27%	50%-68%
Enhanced Primary		76%	
Secondary Treatment	@ 90%	92%-98%	90%
Tertiary / Filtration		90%-99.9%	99.99%
Membranes	100%	100%	37%-99.96%
Chlorine Disinfection		99%	99.999%
UV Disinfection		99.9%-99.99%	99.999%

Notes:

Membranes - non detect for coliform in @ 50% of samples

Membrane virus removal variable depending on level of fouling

Chlorine & UV systems designed for virus removal results in non-detectable bacterial samples

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Disinfection requirements

- Disinfection required by definition of reclaimed water
- Quality measured by total coliform as indicator
- Different quality for different uses
- Class A – effectively pathogen free
  - Defined as assuring 5-log (99.999%) virus inactivation & removal in filtration and disinfection

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Coliform quality limits by class of water

Total Coliform Requirement

Class	7-Day Median Value	Sample Max
A	≤ 2.2 / 100 mL	23 / 100 mL
B	≤ 2.2 / 100 mL	23 / 100 mL
C	≤ 23 / 100 mL	240 / 100 mL
D	≤ 240 / 100 mL	no standard

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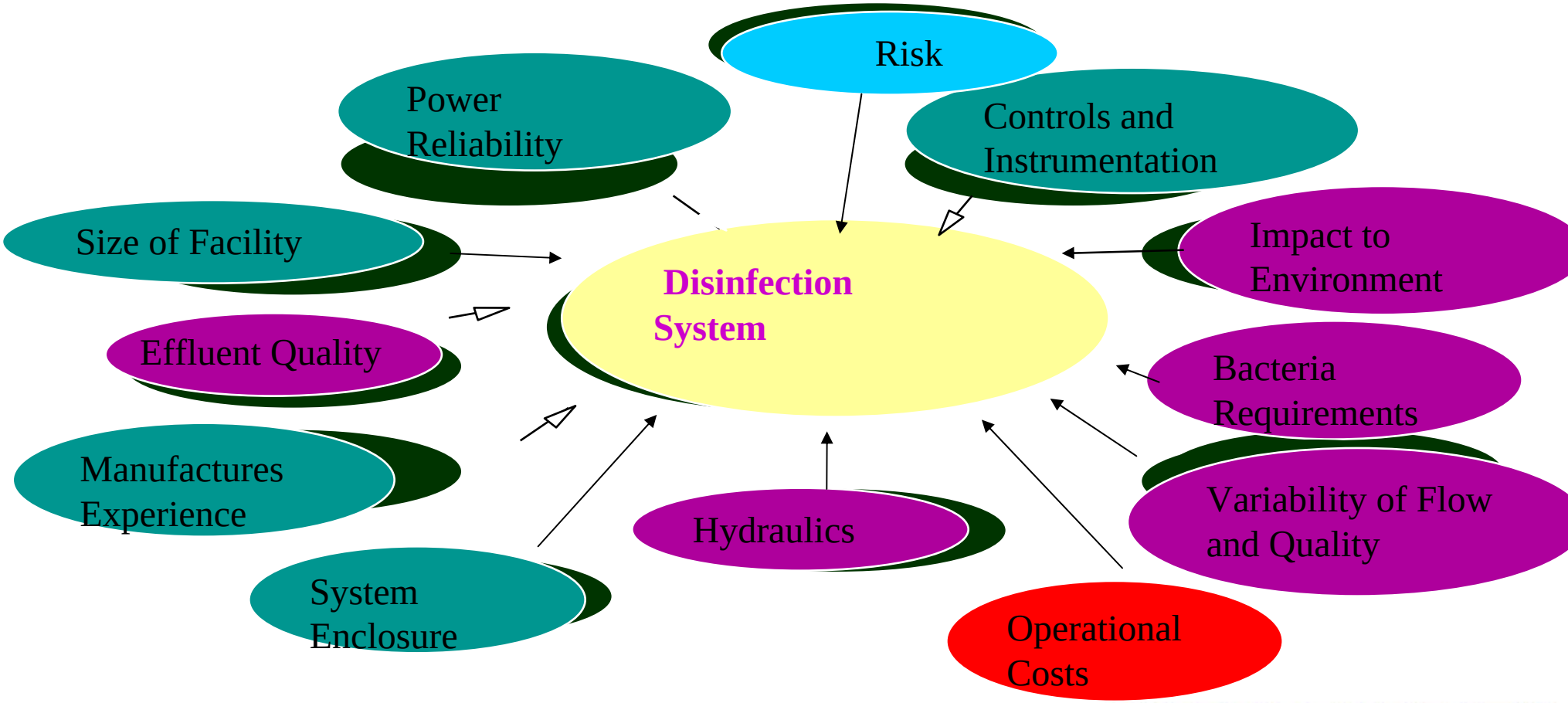
Factors in Effective Disinfection Selection



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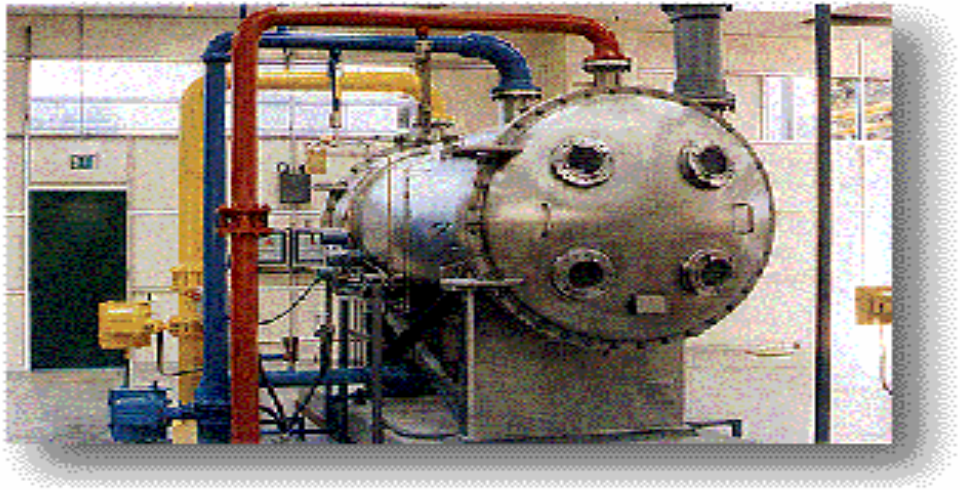
Available disinfection technologies

- Chemical
  - Chlorine Gas
  - Hypochlorite
    - Liquid
    - On-site Generation
  - Chlorine Dioxide
  - Chloramines
- UV
- Ozone
- Emerging
  - Pulsed UV
  - PAA
  - Peroxide, BDCMH



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Chlorine

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Chlorine Chemistry

- Chloramine Disinfection versus Free Chlorine Disinfection
- Chlorine is a Stronger Oxidant and Participates in More Unwanted Side Reactions – Formation of Disinfection by-products (THM)
- Both are Good Disinfectants
- Breakpoint Chlorination

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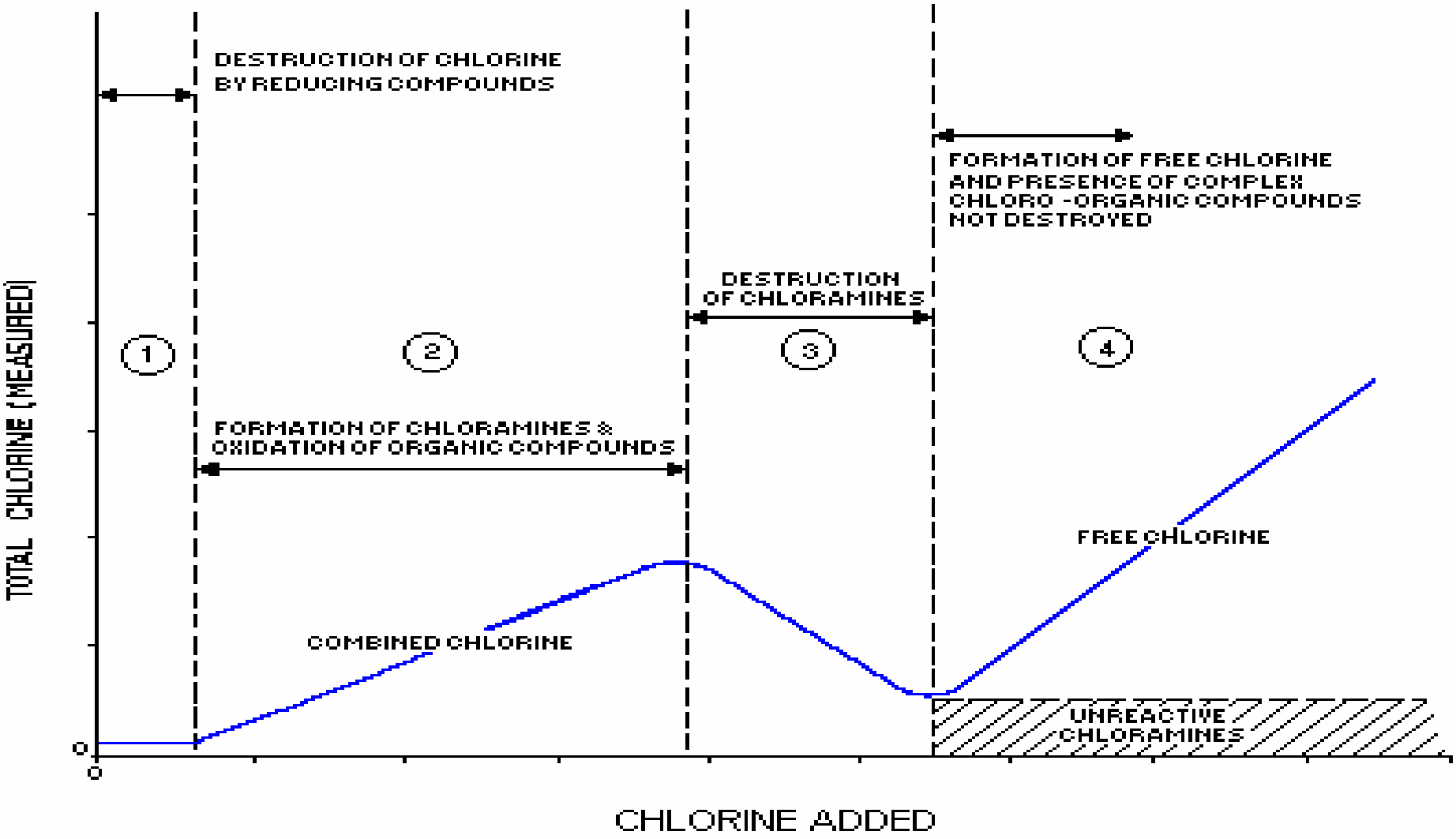

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Chlorine Gas

- Requires chemical and contact time (Ct)
- Has been an effective disinfectant used for a number of years.
- Loosing favor due to risk (RMP), security, and vulnerability
- May have lower Capital and Operating Cost…O&M may be very high due to RMP compliance.
- Easy to maintain chlorine residual in the reuse distribution system
- CA has established 5 mg/L with ***90 minute modal contact time*** [vs. calculated or T10]

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Hypochlorite

- 1 pound of chlorine = 1 gallon of Hypochlorite at 12.5% solution.
- Storage Tank, Pump, and contact basin
- Still has hazards (off gassing, Considered hazardous chemical solution pH above 12.5)
- Results of pilot studies with hypochlorite have indicated formation of DBP.
- Easy to maintain residual in the reuse distribution system
- May need to add dechlorination agent.

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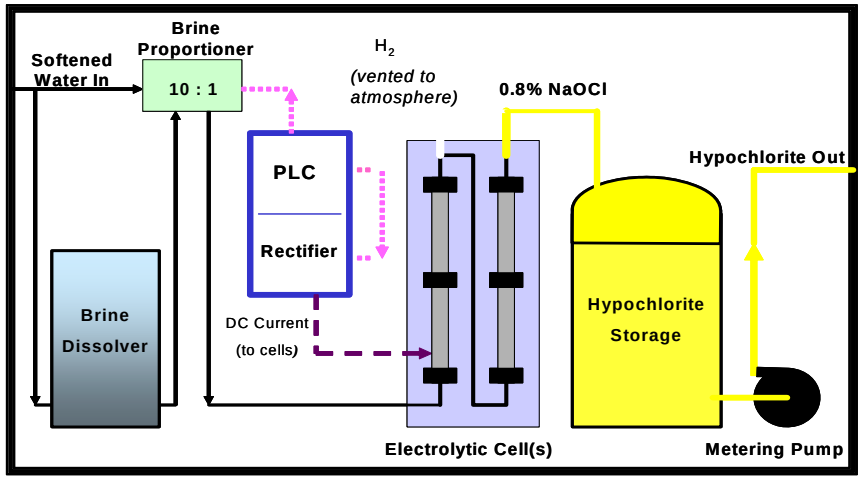
On-site Generation of Hypochlorite

- Raw Materials
  - Salt
  - Electricity
  - Water
- Older systems Generates 0.8% hypochlorite solution.. Newer systems generate 12.5%
- Survey of Facilities
  - Few WW facilities
  - All primary disinfection
- Other applications include
  - Filament control
  - Odor control
- Becoming more cost efficient



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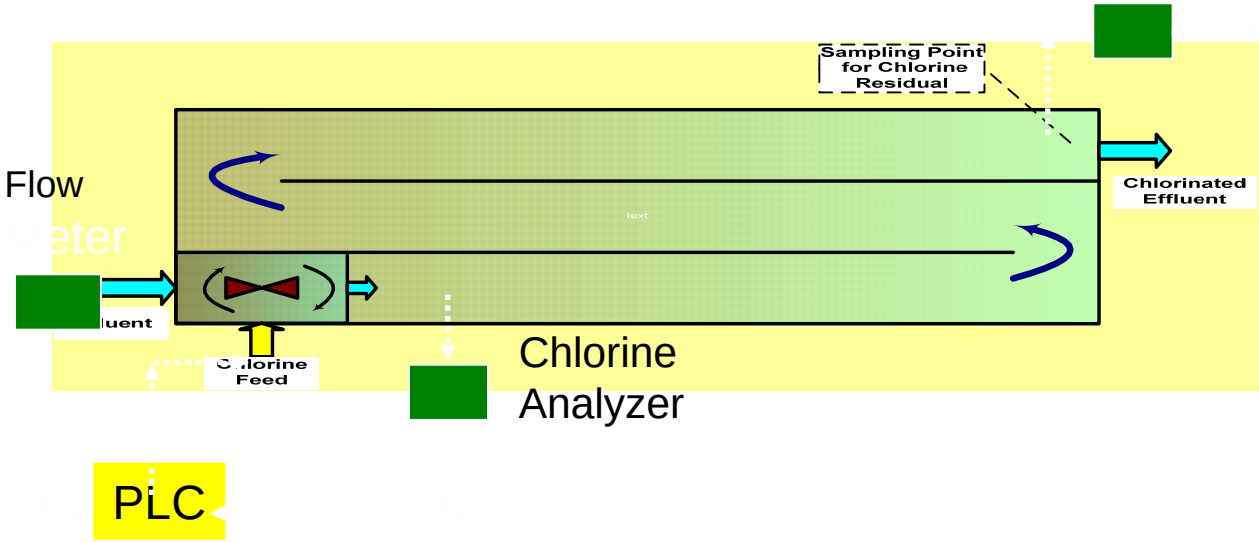
Contact Time

- Contact chamber required
- Minimum residual at exit controlled
- Flow pacing –best first choice
- Control difficult due to time lag through contact chamber, loss of residual & equipment response time



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Contact time under current standards

- Section 1, Article 9, Section 5
- Minimum residual of 1 mg/L after a contact time of at least 30 minutes
- Translates to inactivation ratio [Ct] of
  - 1 mg/L x 30 min = 30 mg-min/L
- Measured as T10
- Based on free chlorine residual

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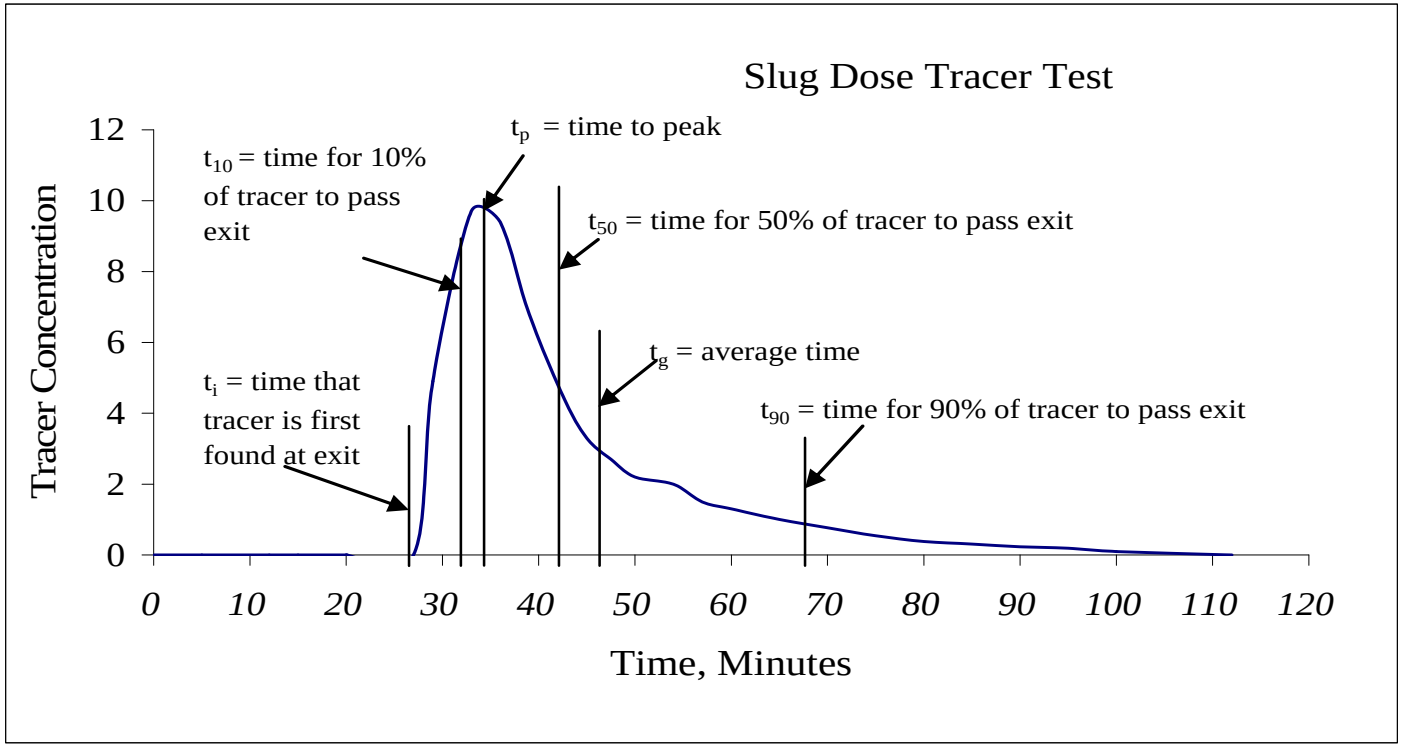
From work published by
Marske & Boyle, 1978

		Recommended Values
Index of average detention time	$t_g/T =$	0.8
Index of mean detention time	$t_{50}/T =$	0.8 - 1.2
Index of modal detention time	$t_p/T =$	> 0.9
Morrill Index	$t_{90}/t_{10} =$	< 2.0
Short circuiting index	$t_i/T =$	> 0.5
Dispersion Number	d=	< 0.01
Dispersion Coefficient	E =	< 100



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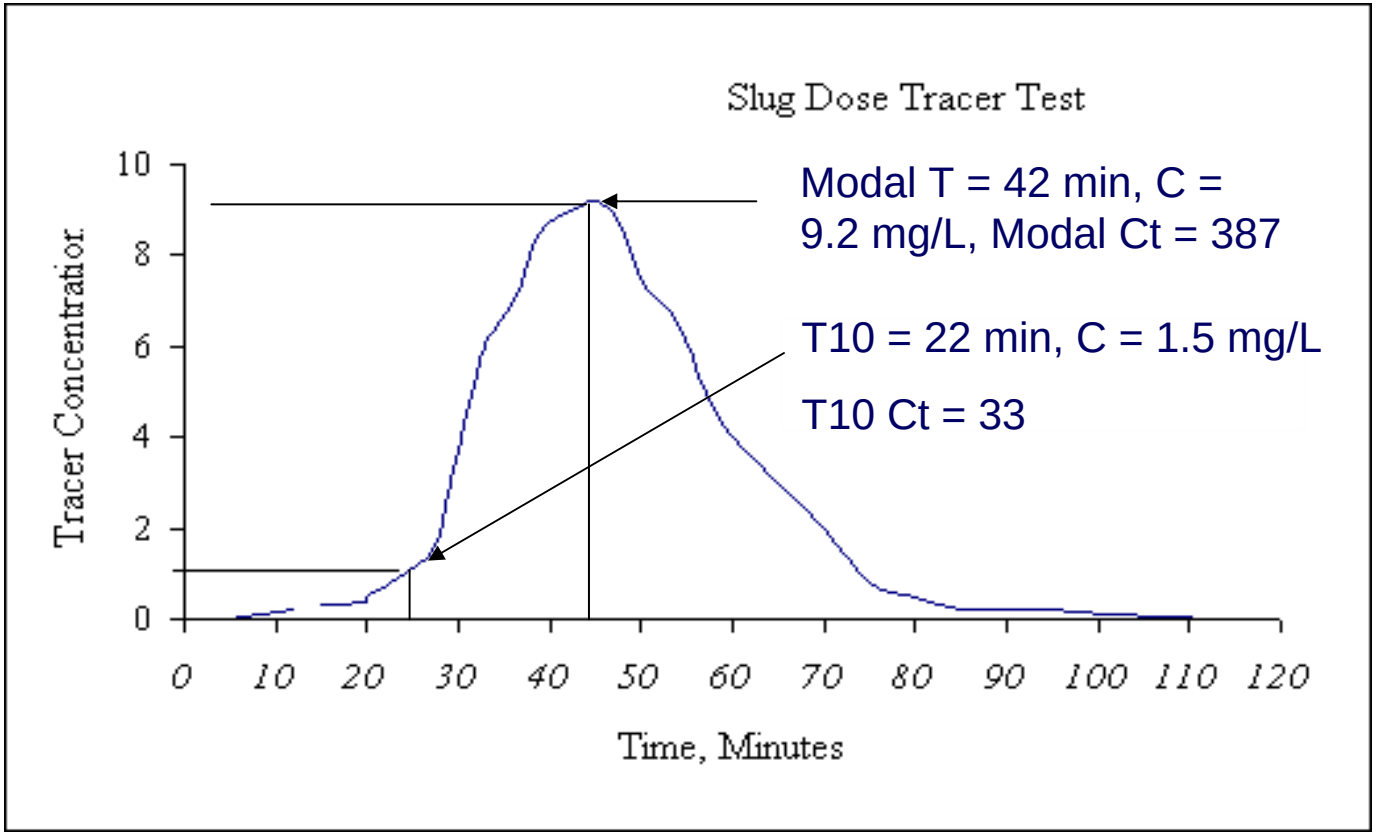
Modal vs T10 Ct



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UV Disinfection

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Water Reuse Guidelines for UV- selected as basis for design

- UV Dose
- Reactor Design
- Reliability design
- Monitoring and Alarm Design
- Field Commissioning Test
- Performance Monitoring
- Engineering Report

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UV Dose

- Delivered UV Dose – Based or reactor validation testing (measured by collimated-beam apparatus)
- Design UV Dose – Required for a specific log inactivation of the target microorganism
- Operational UV Dose – Established based on the results of the equipment validation testing. The operational UV dose, index of reactor behavior, while maintaining the design UV dose

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Determining UV Dose

- Design Dose depends on the type of filtration technology preceding it
- Minimum criteria for three types of filtration
  - Media Filtration
  - Membrane Filtration
  - Reverse Osmosis

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UV Transmittance

- Collected by measuring absorbance and converting to transmittance.
- T% = (10^-absorbance)*100
- Most Critical Parameter
- Site specific testing before Design –
- Typically No need for separate Filtered testing

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UV Design Dose For Reuse

	Media Filtration	Membrane Filtration (MF and UF)	Reverse Osmosis
Minimum UV Design Dose (mJ/cm^2)	100	80	50
%T	55	65	90
Turbidity Requirements.	Avg 2 NTU Peak 5 NTU	Avg 2 NTU Peak 5 NTU	Avg 2 NTU Peak 5 NTU

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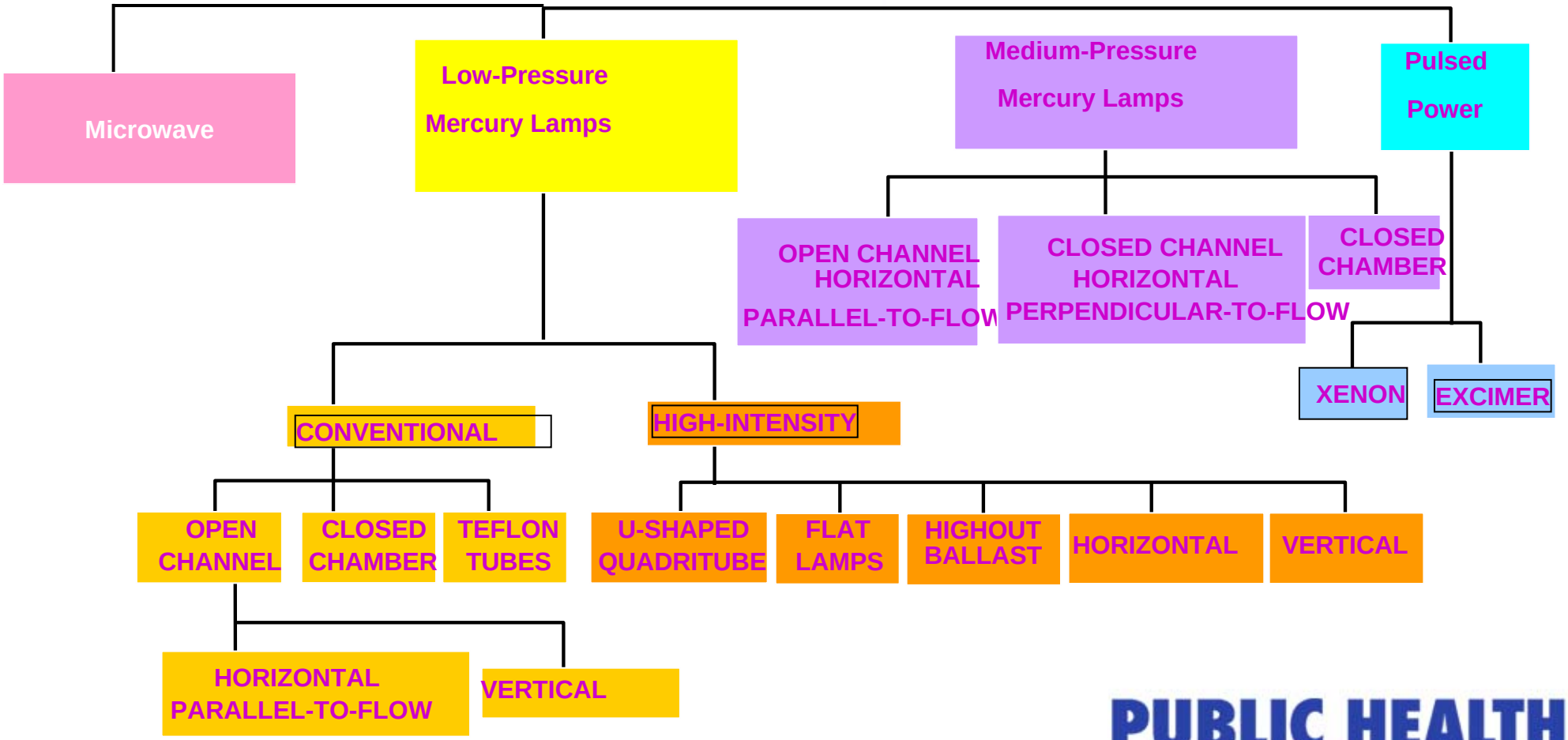
Current UV Disinfection Systems



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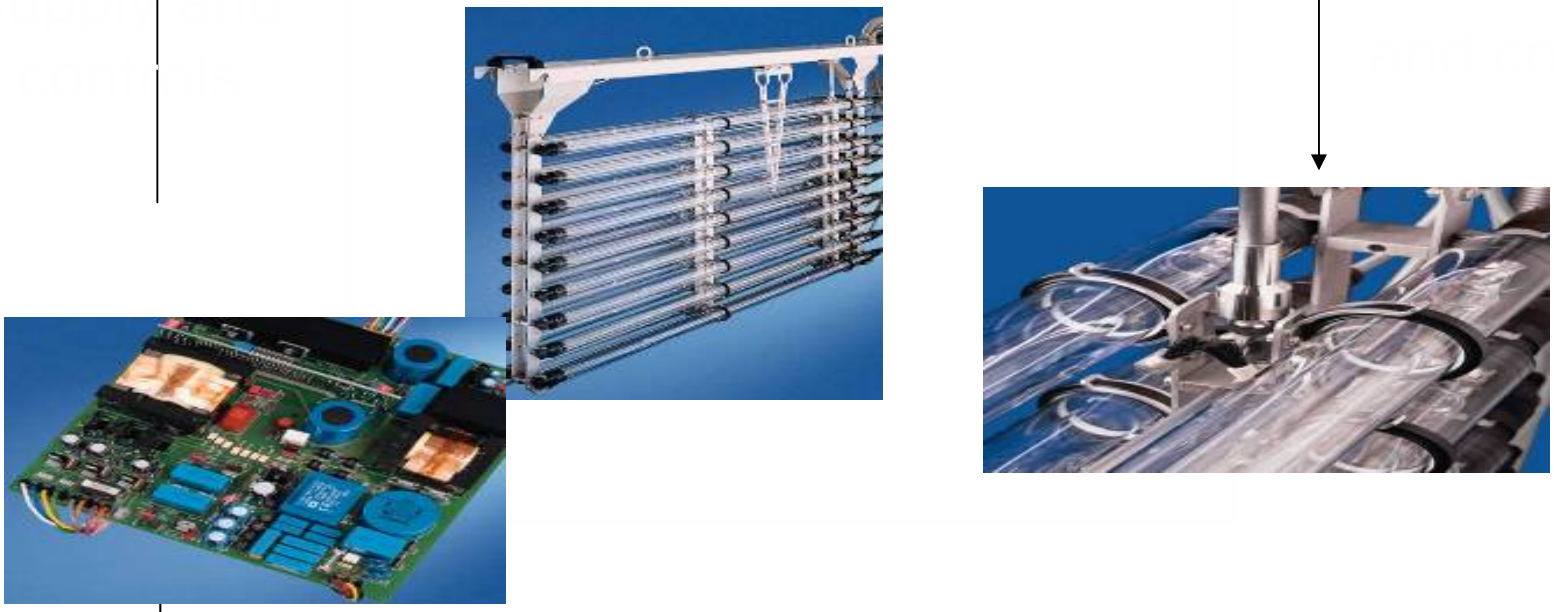
How Does this Thing Work?



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Low Pressure - UV Systems

- Vendor of Selection - Ultra Tech, IDI, Trojan
- Low pressure mercury vapor lamps
- Intensity sensor to determine cleaning frequency – flow paced
- Separate Dip tank for cleaning. Air scour also provided.

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Open Channel Low Pressure – High Output UV

- High Wattage Lamps (165 – 1,000 Watt)
- 12,000 to 13,000 hour lamp life
- Automated Cleaning (chemical/mechanical)
- Wide Range of flow—largest 370 mgd.

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Reactor Design – Hydraulic Constraints

- Required approach length and conditions prior to first reactor (uniform velocity field)
- Last reactor not affected by level-control device
- Spacing between multiple reactors (maintenance, hydraulic performance)
- Any device, component, or feature used to accomplished or enhance uniform velocities
- Cleaning device/mechanism

Reactor Train Layout

- Walls - consistent with manufacturer's recommendations
- Each reactor train can be isolated
- Concrete channels must be lined or coated to ensure microorganism do not become embedded within crevices
  - Preferred Material – Elastomeric High-Solids Urethane Lining System ("Polibrid 705", "Geothane 5020", Geothane "502")

Reactor Train Layout

- All material exposed to UV must be UV resistant
- Upstream and downstream portions of the UV reactor must be water/light tight (covered)
- Cleaning system

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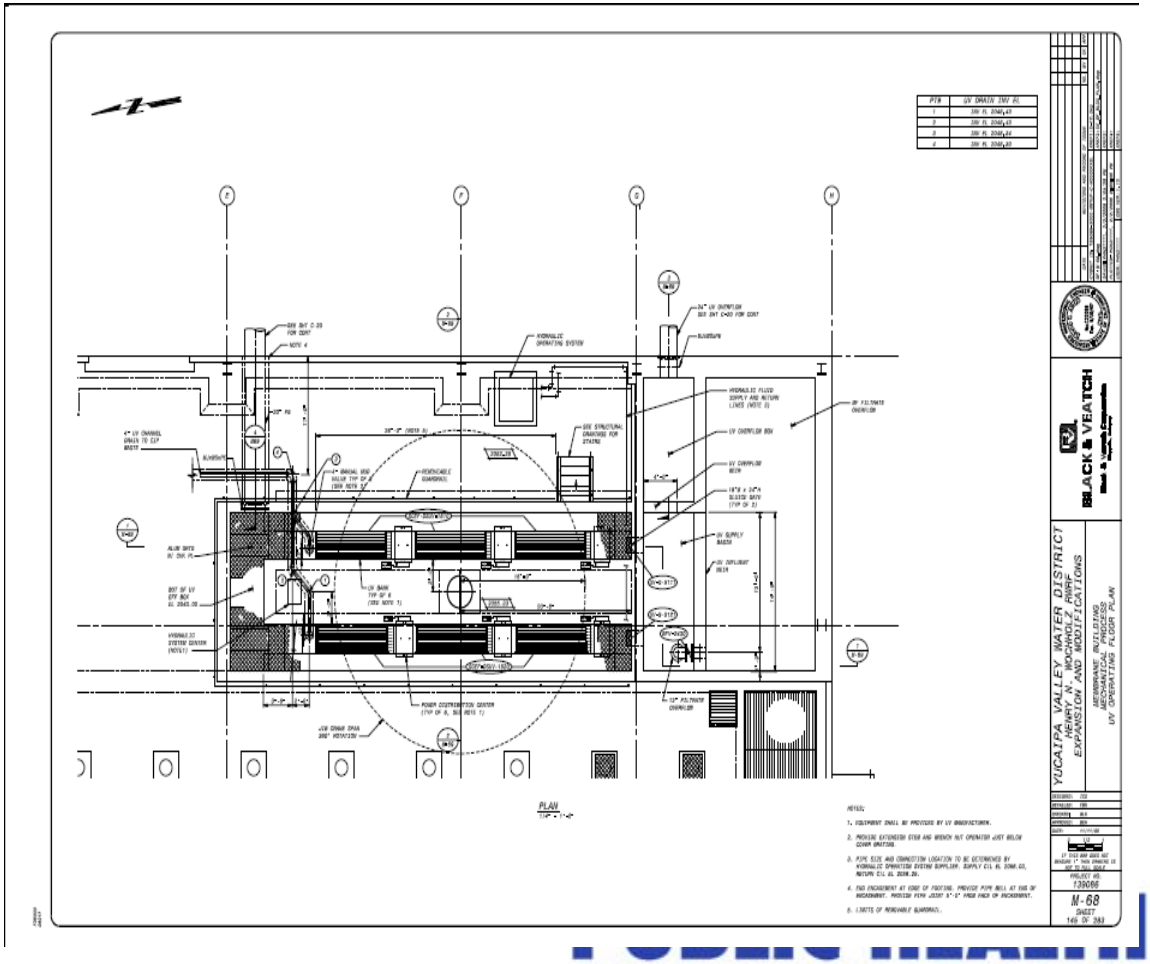
Reliability Design

- At a minimum two reactors must be simultaneously operated in any one-line reactor train
- One of the following two options (note additional cost and area:
  - A standby reactor per reactor train
  - A standby train
- Feed water quality (high turbidity, low transmittance)



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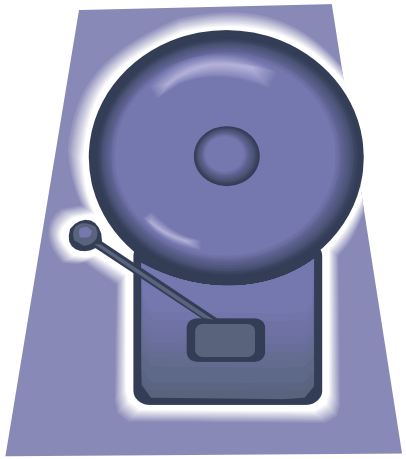
Power Supply Reliability

- Continuous supply of power – standby power and a looped power-distribution system.
- Disinfection system component of the same type (banks) must be divided among two or more power-distribution panel boards to prevent a common mode of failure
- Storage or alternate disposal methods of improperly treated water must be available of a continuous power supply is not provided

Power Supply Reliability

- Short-term power interruptions – If adequate storage/disposal is not provided, UPS is required. Also need to look at switch gear and startup time of on-site power.
- Ambient temperature – Effect on ballast cooling and other electrical components. Note MP if used will require a chiller be added to remove heat. WEDECO systems generally installed in Air cooled building
- Electrical harmonics generated by the UV system on the plant power supply

MONITORING AND ALARM DESIGN



- Continuous monitoring
  - Flowrate
  - UV Intensity - sensor
  - UV Transmittance – pumped or sensor
  - Turbidity – pumped sample
  - Operational UV Dose – based on Flowrate and intensity
- PLC monitoring and control

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Alarms

- High-priority alarms
  - Adjacent lamp failure
  - Multiple lamp failure
  - Low-low intensity
  - Low-low UV transmittance
  - High-high turbidity
  - High/Low water levels
  - GFI
- Low-Priority Alarms
  - Individual lamp failure
  - Low UV intensity
  - Low UV transmittance
  - High Turbidity
  - Low operational UV dose
- All alarms shall be recorded

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Engineering Report

- Contingency Plan
  - Lamp breakage (mercury release)
  - Low-low UV dose and intensity, High-high turbidity
- Power supply interruption
- Standby equipment

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They don't operate themselves

- Operation Certification Training
  - Description according to individual state requirements
- Operation and Maintenance
  - O&M Plan for the UV system – control description, alarm functions, records, reports, procedures and frequency (sleeve cleaning, calibration)

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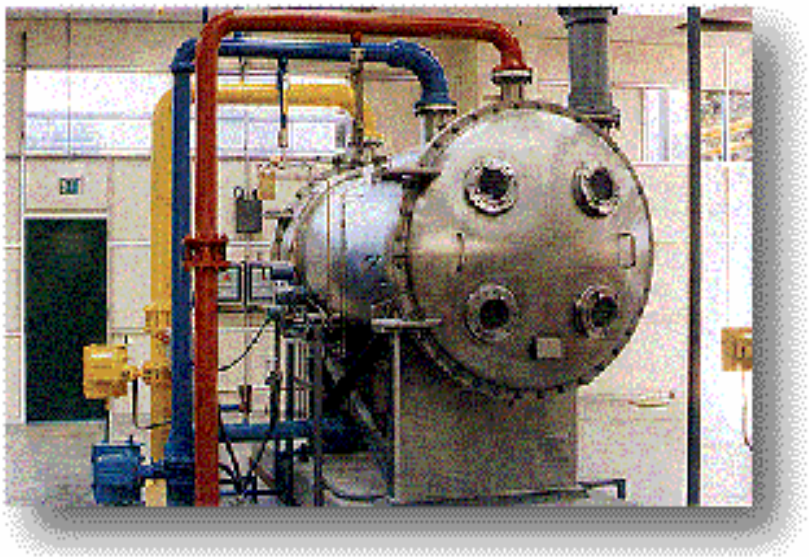
Ozone

- Not typically used for WW disinfection. Past History in US with Pure Oxygen Activated Sludge plants.
- Used a primary disinfectant for drinking water
- Like UV – no residual for distribution
- Major obstacle – reliable ozone sensors to track ozone residual and decay in contactor
- Receiving new interest to THM/EDC
- Ozone will oxidize remaining COD before bacteria
- Becoming cost competitive at larger facilities by using LOX or PSA generation equipment



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New disinfection systems

- Pulsed power UV
- Peroxide
- Peracetic acid
- BCDMH
  - 1-Bromo-3-chloro-5,5-dimethylhydantoin
  - Effective Component – 96% effective halogen decomposes into HOCl, HOBr, and Cl in water

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Advanced oxidation processes (AOP)

- Mix of two or three disinfection processes:
  - UV + ozone + peroxide
  - Ozone + peroxide = peroxone
- Used to remove trace organics, not as advanced disinfection
  - Disinfection properties of peroxone less than ozone or peroxide individually

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Session 4

Physical – chemical contaminants

- Metals
- Organic chemicals.
- Micro-constituents
- Disinfection byproducts

Of concern only in blended waters used for indirect potable ground water recharge or surface water [reservoir] augmentation; blended water or effluent conform to SDWA MCLs

DBP precursor control – necessary for use to recharge ground water or augment reservoirs for indirect potable reuse; TOC monitoring equivalent to DBP2 Rule may indicate need for softening or enhanced coagulation to reduce pre-cursor levels

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What are Microconstituents:

- Endocrine disrupting compounds -estrogen
- Pharmaceuticals
  - Steroids
  - Ibuprofen
  - Selected serotonin reuptake inhibitors - Fluoxidine
- Personal care products
  - Hair spray
  - Perfumes
  - Deodorants
  - Flame retardants – PBDE's
- Pesticides
- Cleaning solvents – Formula 409
- Natural metals – arsenic, uranium, strontium
- Nanoparticles

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What is known (unknown)?

- Estimates of 70,000 – 85,000 individual chemicals
- 70+ have <u>known</u> health effects when consumed – covered by SDWA
- Others being considered by EPA
  - 7,250 yrs @ 1 compound per month
- Health effects of individual chemicals largely unknown
- Synergistic effects – largely unknown

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Where Do They Come From

Source: *Sources of Microconstituents and Endocrine Disrupting Compounds*
Water Environment Federation, Technical Practice Update, July 2007

- Natural products from the environment
- Household & personal care products
- Pharmaceutical products
- Pesticides
- Processed foods
- Plants
- Plastics
- Industrial chemicals
- Animals & veterinary sources
- Air sources

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Relation to Drinking Water MCL's.

Contaminant	mg/L	Contaminant	mg/L	Contaminant	mg/L	Contaminant	mg.L
1,1,1-Trichloroethane	0.2	Dichloromethane (Methylene chloride)	0.005	Toluene	1	Chloride (Cl)	250
1,1,2-Trichloroethane	0.005	Dinoseb	0.007	Toxaphene	0.003	Fluoride (F)	2
1,1-Dichloroethylene	0.007	Diquat	0.02	trans-1,2-Dichloroethylene	0.1	Iron (Fe)	0.3
1,2,4-Trichlorobenzene	0.07	Endothall	0.1	Trichloroethylene	0.005	Manganese (Mn)	0.05
1,2-Dichloroethane (Ethylene chloride)	0.005	Endrin	0.002	Vinyl chloride	0.002	Silver (Ag)	0.1
1,2-Dichloroprane	0.005	Ethylbenzene	0.7	Xylenes (total)	10	Sulfate (SO4)	250
2,3,4,7,8-TCDD (Dioxin)	3E-08	Ethylene dibromde	0.00005	Antimony (Sb)	0.006	Zinc (Zn)	50
2,4,5-TP (Silvex)	0.05	Glyphosate	0.7	Arsenic (As)	0.01	TDS	500
2,4-D	0.07	Heptachlor	0.0004	Asbestos (fibers/liter > 10 µm)	7.00E+06	Color [color units]	15
Alalchlor	0.002	Heptachlor expoxide	0.0002	Barium (Ba)	2	Specific conductivity	700
Aldicarb	0.003	Hexachlorobenzene	0.001	Berylium (Be)	0.004	Gross alpha particle activity	15
Aldicarb sulfone	0.002	Hexachlorocyclo-pentadiene	0.05	Cadmium (Cd)	0.005	Gross beta particle radioactivity	4
Aldicarb sulfoxide	0.004	Lindane	0.0002	Chromium (Cr)	0.1	Tritium	20,000
Atrazine	0.003	Methoxychlor	0.04	Copper (Cu) 1.3 mg/L]	* 1.3	Strontium-90	8
Benzene	0.005	Monochlorobenzene	0.1	Cyanide (HCN)	0.2	Radium 226 & 228	5
Benzo[a]pyrene	0.0002	o-Dichlorobenzene	0.6	Fluoride (F)	4	Radium 226	
Carbofuran	0.04	Oxyamyl (Vydate)	0.2	Lead (Pb)	* (0.015)	Uranium	30
Carbon tetrachloride	0.005	para-Dichlorobenzene (1,4-dichlorobenzene)	0.075	Mercury (Hg)	0.002	Total Trihalomethanes (TTHM)	0.8
Chlorodane	0.002	Pentachlorophenol	0.001	Nickel (Ni)	0.1	Haloacetic acids (HAA5)	0.6
cis-1,2-Dichloroethylene	0.07	Picloram	0.5	Nitrate (as N)	10	Bromate	0.01
Dalapon	0.2	Polychlorinated biphenyls (PCB's)	0.0005	Nitrite (an N)	1	Chlorite	1
Di(2-ethylhexyl) adipate	0.4	Simazene	0.004	Selenium (Se)	0.05		
Di(2-ethylhexyl) phthalate	0.006	Styrene	0.1	Sodium (Na)	* 20		
Dibromochloropropane	0.0002	Tetrachloroethylene	0.005	Thallium (Ti)	0.002		

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Establishing Health Effects

- Eventually?
- Some known – SWDA
- Existing backlog
  - 1 compound / month assessed [hyperspeed]
  - 7,250 years to complete assessment of *known* chemicals
  - Assumes chemical industry does NOT create any new chemicals

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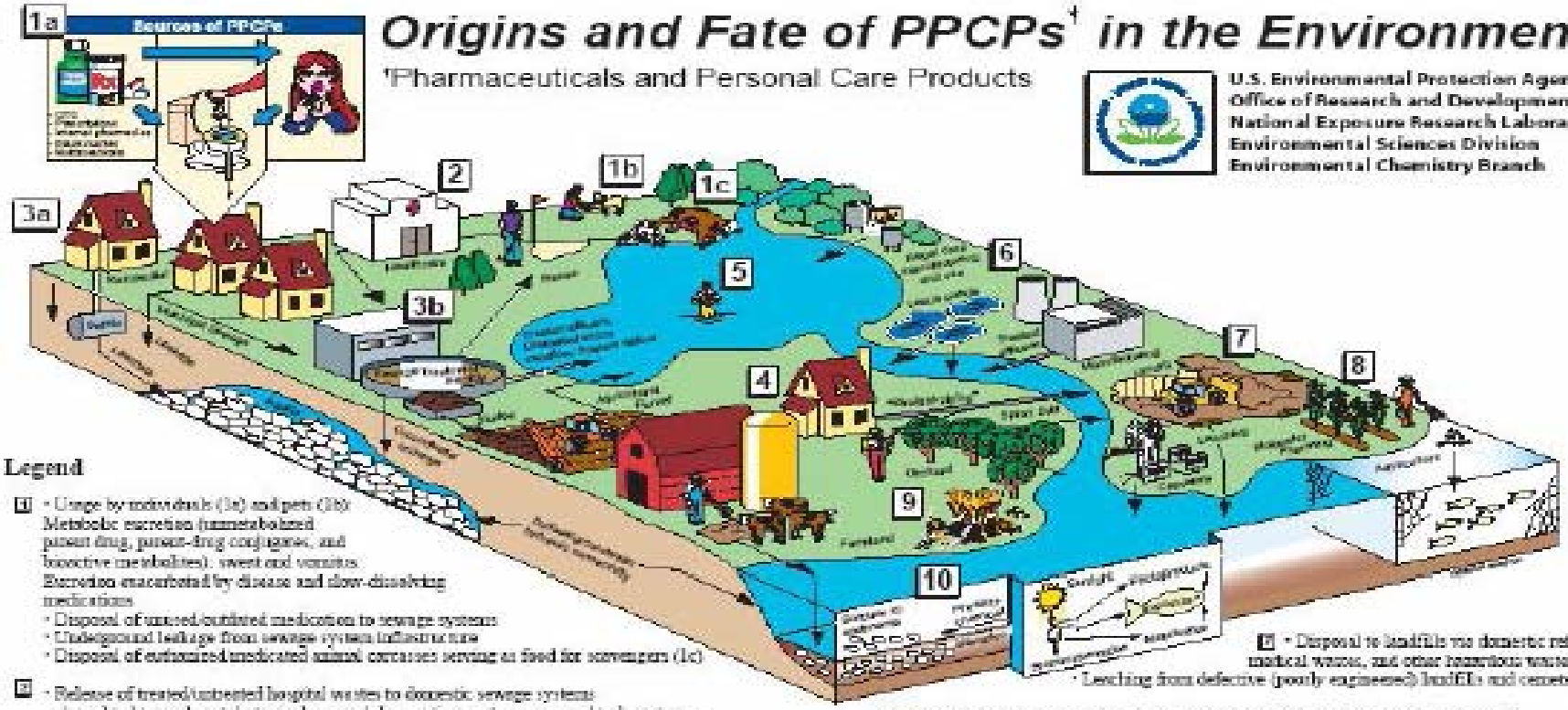
Origins and Fate of PPCPs[1] in the Environment

[1]Pharmaceuticals and Personal Care Products

U.S. Environmental Protection Agency
Office of Research and Development
National Exposure Research Laboratory
Environmental Sciences Division
Environmental Chemistry Branch



Legend

1 • Usage by individuals (1a) and pets (1b)
Metabolic excretion (unmetabolized parent drug, parent-drug conjugates, and bioactive metabolites); sweat and vomitus
Excretion exacerbated by disease and slow-dissolving medications
• Disposal of unused/outdated medication to sewage systems
• Underground leakage from sewage system infrastructure
• Disposal of euthanized medicated animal carcasses serving as food for scavengers (1c)

2 • Release of treated/untreated hospital wastes to domestic sewage systems (weighted toward acutely toxic drugs and diagnostic agents, as opposed to long-term medications); also disposal by pharmacies, physicians, humanitarian drug supplies

3 • Relates to private septic leach fields (3a)
• Treated effluent from domestic sewage treatment plants discharged to surface waters, re-injected into aquifers (recharge), recycled/reused (irrigation or domestic uses) (3b)
• Overflow of untreated sewage from storm events and system failures directly to surface waters (3b)

4 • Transfer of sewage solids ("biosolids") to land (e.g., soil amendment/fertilization)
• "Straight-piping" from homes (untreated sewage discharged directly to surface waters)
• Release from agriculture: spray drift from tree crops (e.g., antibiotics)
• Drug from medicated domestic animals (e.g., feed) - CAFOs (confined animal feeding operations)

5 • Direct release to open waters via washing/bathing/swimming

6 • Discharge of regulated/controlled industrial manufacturing waste streams
• Disposal/release from clandestine drug labs and illicit drug usage

7 • Disposal to landfills via domestic refuse, medical waste, and other hazardous waste
• Leaching from defective (poorly engineered) landfills and cemeteries

8 • Relates to open waters from aquaculture (medicated feed and resulting excreta)
• Future potential for release from molecular pharming (production of therapeutics in crops)

9 • Release of drugs that serve double duty as pest control agents:
examples: 4-aminopyridine, experimental multiple sclerosis drug → used in rodenticide; warfarin, anticoagulant → rat poison; cholestyramine, antilipidemics → mice/rodent reproductive inhibitors; certain antibiotics → used for orchard pathogens; acetaminophen, analgesic → brown tree snake control; caffeine, stimulant → coqui frog control

10 Ultimate environmental transport/fate
• most PPCPs eventually transported from terrestrial domain to aquatic domain
• phototransformation (both direct and indirect reactions via UV light)
• physicochemical alteration, degradation, and ultimate mineralization
• volatilization (mainly certain anesthetics, fragrances)
• some uptake by plants
• respirable particulates containing sorbed drugs (e.g., medicated feed dusts)

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Environmental effects vs. public health

- Differences
  - Exposure in water: 24-7 ingestion, respiration & full dermal contact
  - 2-liters per day ingestion
- Organism mass
  - 10 oz trout vs. 185 1b human
- Exposure levels
  - Multiple chemical exposures
  - Incomplete data on organism responses
- Reponses equivalent to environmental effects not being definitively defined in public health

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Current Treatment Options

- Aerobic treatment with extended solids contact time – membrane bioreactors
  - 95%-98% reduction in MC's common
- Advanced Treatment
  - RO
  - Activated carbon
  - AOP/Peroxone [peroxide & ozone]
- The downside [note: removal not destruction]
  - RO – high energy, brine disposal (w/ concentrated MCs)
  - Activated Carbon – limited carbon regeneration sites; Spent carbon - hazardous waste depending on compounds removed
  - AOP/Peroxone - inhibited disinfection capability; no residual

Keys to High Removals*

- Some EDC's are theoretically fully biodegradable
- Activated sludge processes have potential to remove large fraction of several suspected EDCs often below detection limits
- Solids retention time (SRT) has pronounced effect on removal of some EDCs
- SRT's of 10 to 15 days – better removal
- MBR or integrated fixed-film activated sludge processes increase SRTs
- MC's sorbed to solids retained by membrane & system solids
- Advanced oxidation processes (AOP) being implemented to reduced EDC & MC
  - UV + peroxide + ozone [peroxone] increases formation of hydroxyl radicals [HO▪] to oxidize MCs

* WEF Technical Practice Update: Effects of Wastewater Treatment on Microconstituents, May 2007

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Treatment Needs & Unknowns *

- Full understanding of health & environmental impacts not yet available for most known & suspected MCs
- Individual vs. population-level effects of MC exposure not fully understood
- Risk assessment studies needed to develop appropriate regulatory actions
- Developing surrogate model compounds for treatment process assessment should be examined
- Fate studies required for compounds with demonstrated negative effects
- Fate of MC' adsorbed to particulate matter needs investigation
- Performance of engineered and natural treatment systems research necessary
- Hazard potential of byproduct formed in AOP treatment requires further investigation

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Next Steps & Recommendations*

- Presently premature to design for MC removal
- Source control – far more difficult & expensive to remove EDCs & MCs than prevent contamination
- WWTPs [RWPs] are one of many sources and pathways into the environment
  - Comparison to control of other sources – ag runoff, industrial discharges & wet-weather overflows
- Ecolabeling & source separation (e.g. urine or rainwater segregation) possible measures for reducing MC loads to environment
- Balance MC removal with increase in carbon footprint – removal may result in negative environmental impact – higher carbon emissions

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Current Research

- Health effects research based on classes of chemicals showing similar health effects and similar responses to removal in treatment
- Research – analytical accuracy & repeatability between labs
- Research – define series of adequate indicator chemicals & surrogates for effective removal in treatment
- Research – Threshold of Toxicological Concern
  - Calculate benchmarks
  - Establish “reference quotients” [RQ’s]
  - Concentration of MC / established health level [Tier 1, Tier 2 or Tier 3]
    - Tier 1 – chemicals with established MCLS / regulatory guidelines
    - Tier 2 – unregulated chemicals with available toxicity information
    - Tier 3 – unregulated chemicals without available toxicity information

Table 4. Pharmaceuticals tested above LOR at point 1 and calculated risk quotients at point 1

Pharmaceutical	LOR	Point 1	TTC Class	Benchmark TTC	RQ TTC	MRTD (mg/k/d)	Benchmark MRTD	RQ MRTD	LTD (mg/k/d)	Benchmark LTD	RQ LTD	IARC IRIS
Gemfibrozil	0.1	0.86	2	255	0.003	20	560	0.002	20	5600	0.0002	3
Carbamazepine	0.01	0.552	3	42	0.01	26.7	748	0.0007	3.3	924	0.0006	ne
Phenytoin	0.02	0.065	3	42	0.002	5	140	0.0005	5	1400	0.00005	2B
Indomethacin	0.1	0.135	3	42	0.003	3.3	92*	0.001	0.8	224	0.0006	ne
Azithromycin	0.01	0.166	3	42	0.004	na	na		8.3	2324	0.00007	ne
Sulfamethoxazole	0.01	0.704	3	42	0.02	50	1400*	0.0005	26.7	7476	0.00009	3
Metronidazole	0.01	0.131	3	42	0.003	33.3	932	0.0001	12.5	3500	0.00004	2B
Trimethoprim	0.02	0.377	3	42	0.009	5.33	149	0.003	5	1400	0.0003	ne
Diclofenac	0.1	0.21	3	42	0.005	3.75	105	0.002	1.25	350	0.0006	ne
Ibuprofen	0.1	0.3	1	840	0.0004	40	1120	0.0003	13.3	3724	0.00008	ne
Salicylic acid	0.1	2.1	1	840	0.003	66.7	1868	0.001	topic	-	-	ne
Naproxen	0.1	0.57	3	42	0.01	20.83	583*	0.001	7.3	2044	0.0003	ne
Clarithromycin	0.05	0.17	3	42	0.004	8.33	233	0.0007	8.3	2324	0.00007	ne
Erythromycin	0.05	0.41	3	42	0.01	66.7	1868	0.0002	11.7	3276	0.0001	ne
Roxithromycin	0.05	0.17	3	42	0.004	na	na		5	1400	0.0001	ne
Clindamycin	0.05	0.12	3	42	0.003	30	840	0.0001	10	2800	0.00004	ne
Iopamidol	0.1	1.6	3	42	0.04	100	2800	0.0006	13.3	3724	0.0004	ne
Iopromide	0.1	1.8	3	42	0.04	100	2800	0.0006	25	7000	0.0003	ne
Amidotrizoic acid	0.1	1.9	3	42	0.05	100	2800	0.0007	36.7	10276	0.0002	ne
Iohexol	0.1	1.6	3	42	0.04	110	3080	0.0005	24	6720	0.0002	ne

Note: values are in µg/L for benchmark values at point 1; na: not available; TCC: threshold of toxicological concern; MRTD: maximum recommended therapeutic dose; * source MRTD (Contrera et al. 2004); LTD: Lowest therapeutic dose. ne: not evaluated

LOR – Limit of Reporting

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Main Messages (as of Today)*

- Due to significant advances in analytical technologies, microconstituents are being detected in the environment; however the fact that a compound is detected as a microconstitutent does not necessarily mean that it is harmful or detrimental to the environment
- Compounds that have most often been implicated in endocrine disruption in aquatic organisms are the natural estrogens estrone (E1) and estradiol (E2), which are excreted by all humans; the synthetic estrogen ethinylestradiol (EE20, which is the active ingredient in birth control pills; and nonlyphenol and octyphenol. It should be noted that "safe" environmental levels of these compounds have not been agreed upon by the scientific community.
- Many microconstituents have been in commerce for a long time and considered safe but, due to the discovery of new toxicological endpoints (e.g. endocrine disruption), additional scrutiny of these are now warranted. Also, analytical technologies have advances to the point that we are no able to detect these at lower concentrations. However, just because a compound can be detected does not mean that it is detrimental to the environment and must be removed.

* WEF TPU – Effects of Wastewater Treatment on Microconstituents; May 2007; Prepared by Microconstituents Community of Practice, Technical Practice Committee

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Treatment removal efficiencies

- Conventional vs. satellite vs. on-site
  - Expectation for performance – if reclaimed water is produced – same regardless or plant size
- Expected treatment removals by conventional wastewater treatment processes following slide
- Application for membranes follow
  - BOD, TSS < 5 mg/L
  - Turbidity < 0.1 NTU
  - Coliform ≈ no detects in 50% effluent samples

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Table 12 Macro-contaminant removal in various wastewater treatment processes (Adapted with permission from *Wastewater Engineering: Treatment and Reuse*, Metcalf & Eddy et al., ©2003 The McGraw-Hill Companies, Inc.)

		Unit process or operation % reduction												
				Advanced		Attached Growth		Tertiary Treatment Processes					Chemical Oxidation	
	Constituent	Primary	Secondary	Nitrifi-cation	Denitrifi-cation	Trickling filter	RBC	Coag-Floc-Sed.	Filtration after A/S	Adsorp-tion	Stripping	Reverse osmosis	Chlorine	Ozone
Solid	TSS	>50%	>50%	>50%	≤ 25%	> 50%	> 50%	> 50%	> 50%	> 50%		> 50%		
	TDS											> 50%		
	Turbidity	25% to 50%	> 50%	> 50%	≤ 25%	≤ 25%		25% to 50%	> 50%	> 50%		> 50%		
Organic Content	BOD	25% to 50%	> 50%	> 50%	≤ 25%	> 50%	> 50%	> 50%	25% to 50%	> 50%		> 50%		≤ 25%
	COD	25% to 50%	> 50%	> 50%	≤ 25%	> 50%		> 50%	25% to 50%	25% to 50%	≤ 25%	> 50%		> 50%
	TOC	25% to 50%	> 50%	> 50%	≤ 25%	≤ 25%		> 50%	25% to 50%	> 50%	≤ 25%	> 50%		> 50%
	Color	≤25%	25% to 50%	25% to 50%		≤ 25%		> 50%	25% to 50%	> 50%		> 50%		> 50%
Grease and Oil	Oil and grease	>50%	> 50%	> 50%		≤ 25%		25% to 50%		25% to 50%				
Nutrients	NH_3-N	≤25%	> 50%	> 50%	25% to 50%		> 50%	≤25%	25% to 50%	25% to 50%	> 50%	> 50%		
	NO_3-N				> 50%				25% to 50%	≤ 25%				
	Phosphorous	≤25%	25% to 50%	> 50%	> 50%			> 50%	> 50%	> 50%		> 50%		

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Table 11 Application of membrane technologies for the removal of specific constituents in wastewater (Adapted with permission from *Wastewater Engineering: Treatment and Reuse*, Metcalf & Eddy et al., ©2003 The McGraw-Hill Companies, Inc.)

	Membrane Technology			
Wastewater constituents	MF	UF	NF	RO
Biodegradable dissolved organics		x	x	x
Hardness			x	x
Heavy metals			x	x
Monovalent ions (salts)			x[a]	x
Nitrate			x	x
Priority organic pollutants		x[a]	x	x
Total dissolved solids			x	x
Total suspended solids	x	x		
Bacteria	x[a]	x	x	x
Protozoan cysts and oocysts, and Helminth ova	x	x	x	x
Viruses			x	x

[a] Variable performance.

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Cannot plan to be fail safe, but can plan to fail safely

Reliability, controls & alarms

- Current requirements
  - Reliability assessment
  - Approach
    - Identify critical, vital, non-critical processes & equipment – treatment plant
    - Use area controls
    - Users protections
    - Cross connections
    - Pipe location & separations
    - Define alarm conditions, alarm responses – plant, distribution & use area
    - Color coding

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Section 5

Use-based water quality concerns

- Commercial / industrial uses
- Irrigation uses
- Surface water uses
- Ground water uses
- Distribution and storage

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Commercial / industrial uses

- Health protection
- *Public acceptance*
- Cross connection control
- Cooling towers / aerosol
- Scaling & corrosion
- Color & staining
- High purity requirements (boilers & electronics)
- Blow-down disposal
  - Impact on plant treatment capacity

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Irrigation uses

- Health protection [food crop & direct consumption]
- Marketing crops / public acceptance
- Buffer zone requirements [other than Class A]
- Aerosol control [potential concern for wastewater disposal]
- Residual disinfectants
- Run-off control
- Water quality impacts on soils & groundwater
- Blending with other supplies

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Surface water uses

- Health protection
- In-stream user liability
- Water quality protection
- Water supply source blending
  - Impact of dilution / blending percentage
  - Use of stream / reservoir for potable supply
  - Conform to raw water quality requirements of SDWA
- Storage, conveyance and recovery
- Public acceptance

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Ground water uses

- Health protection
- Water quality protection
- Aquifer storage and recovery
- Availability of suitable sites
- Salt & mineral build-up
- Public acceptance

Blended water quality conforms

To SDWA MCL; access to water

Concern to operation of PWS

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Distribution & storage

- Algae growth in storage
- Storage stagnation
- Open storage contamination
- Loss disinfectant
  - Storage ponds
  - Pipe line residual loss
- Pipeline regrowth
- Pipeline separation [potential for pipeline failure & cross connection]

Potential public health concern, research ongoing

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Reliability design:

- Required by definition in statute: "at all times adequately & reliably treated"
- Higher reliability than either wastewater or potable water designs
- Specific requirements in Section 1 – Articles 10 & 11 of Standards
- Specific requirements for oxidation, filtration & disinfection processes in plants
- Reliability extends to storage, distribution & use areas
- Ultimate public health issue

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Sequim's "L" structure

Divert & store, return, retreat, then reuse

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Issues with current standards

- Membrane application
- Disinfection issues
  - Nitrite lock
  - Chlorine Ct determination
  - UV controls & reliability
- Operator certification
- Ground water standards vs. ground water recharge criteria -surface percolation
- Public information – public health concern

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Operator certification

- Design & build anything – means nothing if it doesn't work
- Only skilled, competent operators assure functioning system
- Certification measures and maintains skills
- Water & wastewater operators require certification
  - Wastewater plant operators
  - Water treatment plant operators'
  - Water distribution managers
  - Cross connection control specialists
  - Backflow assembly testers
- No specific requirements for reclaimed water
  - Combination & hybrid of skills required
  - Ultimate quality requires operations focused on water reclamation
- Ongoing national issue

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Focus – reuse & public health issues

- Treatment processes: ability to readily assess & accept new & innovative processes
- Disinfection issues:
  - DBP / TOC control – ground water recharge
  - New & emerging microbial responses
- User & use area
  - Pipeline & storage regrowth – disinfection & system management
  - Operator certification – field operations, distribution & use
- Operator certification – water reclamation operators

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Focus – reuse & public health issues

- Chemical
  - Response to public concerns re: microconstituents through source control, treatment & use management
  - Establish RQ system to estimate impacts or importance of MC's that may be present
- Sources
  - Compatibility between GW standards and GW recharge criteria; focus on public health & implementation of SDWA limits plus any other credible health information

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Future issues – public health & technical standards

- New treatment technologies – assessment & acceptance protocols & procedures
- Microconstituent control & removals
  - Huge public concern if not significant public health issue
- Reaction to new contaminants – chemical & microbial
  - Source control
  - Treatment & removal
  - Use are protections

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