Essentials of Surface Water Treatment (Part 1 of 2)

Oregon Health Authority
Drinking Water Services
www.healthoregon.org/dwp

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Overview of Course:

Part 1
1. Background of Surface Water Treatment Rules
2. Filtration
3. Disinfection
4. Operations

Part 2
1. Review of Part 1
2. Reporting Requirements
3. Emerging Issues
4. Resources for Operators

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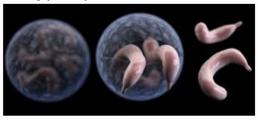
Regulations protect the public from exposure to pathogens:

- Protozoa or Parasites

Giardia Lamblia

Cryptosporidium Parvum



- Bacteria
  - *Campylobacter, Shigella, Legionella*
- Viruses
  - Hepatitis A, Norwalk Agents

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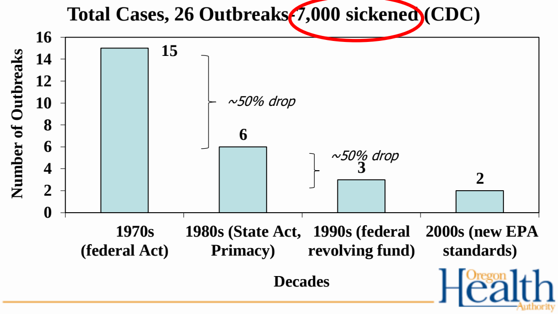
Oregon Waterborne Disease Outbreaks

(bacteria, viruses, parasites)



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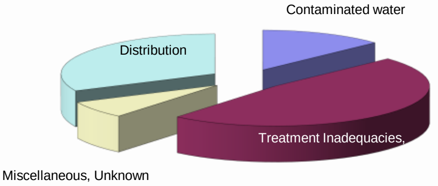
Waterborne Disease Outbreak Causes



Most of these outbreaks involve microbiological agents that would respond to proper disinfection

From August 2006 Access AWWA

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Filtration is key to preventing waterborne disease outbreaks

Common types of water filtration systems:

- Conventional Filtration (CF) & Direct Filtration (DF) – a.k.a. “Rapid Rate”
- Slow sand
- Membrane
- Cartridge/bag
- Diatomaceous Earth (DE)

We’ll learn more about these later.

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Background of Surface Water Treatment Rules

1989 SWTR

Surface Water Treatment Rule

- Required filtration for most SW and GWUDI (Groundwater Under Direct Influence).
  - States were required to identify GWUDI sources.
- Required pathogen removal/inactivation:
  3-log *Giardia* (99.9%) & 4-log virus (99.99%)
- Limited turbidity in filtered water (combined filter effluent):
  - Slow sand/DE/membrane/cartridge/bag:
    95% of turbidity readings ≤ 1 NTU; all < 5 NTU
  - CF/DF:
    95% of turbidity readings ≤ 0.5 NTU; all < 5 NTU (replaced under LT1)
- Required detectable disinfectant residual.
- Did not address *Cryptosporidium*.

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U.S. Outbreaks of *Cryptosporidiosis* in Surface Water Supplies

Location	Year	Type of System	Estimated Number of Cases
Bernalillo County, New Mexico	1986	Untreated surface water supply	78
Carroll County, Georgia	1987	Treated surface water supply	13,000
Jackson County, Oregon	1992	Medford - chlorinated spring Talent - treated surface water	15,000
Milwaukee County, Wisconsin	1993	Treated surface water supply	403,000
Cook County, Minnesota	1993	Treated surface water supply	27
Clark County, Nevada	1994	Treated surface water supply	78

- Five of the outbreaks were associated with filtered drinking waters.
- Three systems (Carroll, Jackson - Talent, and Milwaukee) were experiencing operational deficiencies and high finished water turbidities at the time of the outbreaks. All three plants utilized conventional treatment processes that included rapid mix, flocculation, sedimentation, and filtration.
- The Clark County outbreak was the only outbreak associated with a filtered drinking water for which no treatment deficiencies were noted.
- All five systems were in compliance with the federal regulations in effect at that time.

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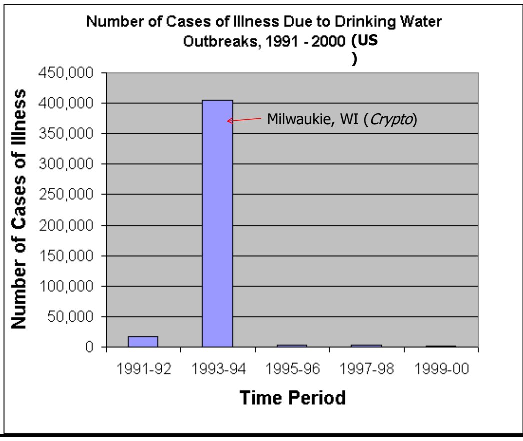

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Background (continued)

1998 IESWTR

Interim Enhanced Surface Water Treatment Rule

- Addressed concerns about *Cryptosporidium*

  required 2-log Crypto (99%) removal)
- Lowered turbidity standard for CF/DF systems:
  95% of readings ≤ 0.3 NTU, all readings <1 NTU for systems with population ≥10,000 (later extended to all CF/DF systems under LT1)
- Required Individual Filter Effluent (IFE) turbidimeters

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Background (continued)

2002 LT1

Long-Term 1 Enhanced SW Treatment Rule

- Extended 0.3 NTU requirement to CF/DF systems with <10,000 population.

2006 LT2

Long-Term 2 Enhanced SW Treatment Rule

- Requires additional Crypto treatment for systems with ≥ 0.075 oocysts/L in their source water.
- Very few systems are required to install additional treatment in Oregon.

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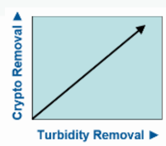
Why Measure Turbidity?



- Indicative of pathogen removal
- Relatively easy to monitor
- Turbidity removal has been shown to be directly related to removal of *Giardia* and *Crypto*.
- Turbidity maximum contaminant levels (MCLs) are based on the technology used:
  - ≤ 0.3 NTU (95% of the time) for conventional or direct filtration; always < 1 NTU.
  - ≤ 1 NTU (95% of the time) for slow sand, cartridge, and membrane; always < 5 NTU.

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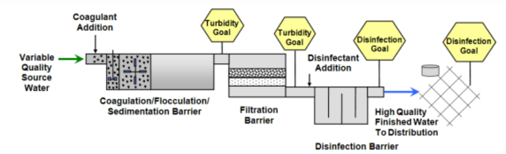
Optimize Particle Removal

Optimize treatment for pathogen removal by optimizing particle removal (i.e., turbidity)



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Source water conditions can affect turbidity/pathogens

- Watershed control
- Intake structure or configuration & pumping facilities
- Other factors affecting water quality (harmful algal blooms, point- and non-point source pollution, storms, runoff, etc.)

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Watershed Control

- Owned or managed by the water system?
  - Most systems have little control over their watersheds.
- Drinking water protection plan
- Emergency response plan
- Patrols, gates, etc.
- Inter-agency agreements (USFS, BLM, ODF, COE)

The Willamette River Basin is the largest watershed in the state, covering more than 11,500 square miles.

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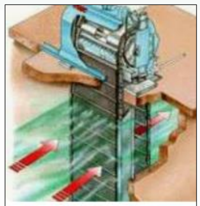
Intakes and Pumps

- Screens:
  - well screens,
  - traveling screens,
  - self-cleaning rotating drum screens.
  - Cleaned with air or water blast
- Submersible pumps in slotted or perforated pipe laid on riverbed.



Traveling Water Screens

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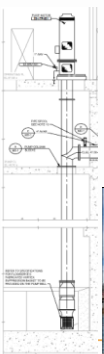
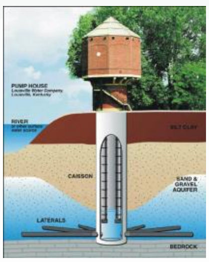
Intakes and Pumps

- Infiltration galleries: Slotted pipes or well screens underneath riverbed, provides rough filtration.
- Vertical turbine pumps in wet wells are common in larger systems.





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Other Factors

- Logging, wildfire, and storm events increase turbidity
- Recreation (gasoline engines, oil)
- Development (increased stormwater drainage with associated pollutants)
- Seasonal and/or daily fluctuations in temp or pH
- Harmful algal blooms (cyanobacteria) becoming an increasing problem
- Sewage treatment plants upstream, occasional overflows


Portland's Fiercest Advocate for Swimming in the Willamette River Is Declaring War on Algae
"I don't want to live in a city where I'm afraid to bring my dog to the river," says Willie Levenson.

August 23, 2023 - Willamette Week article on HABs in Willamette R.

2020 Wildfire Damage in Detroit, OR watershed

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FILTRATION

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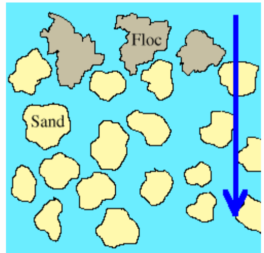
Straining

- Passing the water through a filter in which the pores are smaller than the particles to be removed



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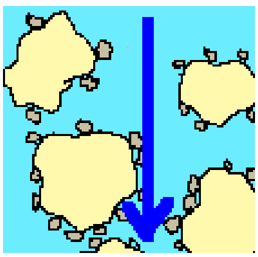
Adsorption

- The gathering of gas, liquid, or dissolved solids onto the surface of another material



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Types of Filtration

- Conventional & Direct Filtration
- Diatomaceous earth (DE, only a few in Oregon)
- Slow Sand
- Alternative (cartridge, bag & membrane)

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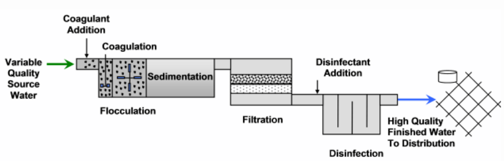
Conventional & Direct Filtration
"Rapid Rate Filtration"



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Rapid Sand Filtration

- Involves adsorption and physical straining of flocculated particles.
- Mixed media filters: layers of support gravel, sand, anthracite.
- Requires coagulation for charge neutralization, rapid mix (e.g., static mixer), and some degree of flocculation (e.g., large paddle wheel flocculator).
- Filtration rate 2-4 gpm/ft2
- Requires controllable backwash with water and perhaps air scour to clean filters.

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Media

Water flows through progressively larger pores as it passes from coal to sand to gravel.

This example shows the following from top to bottom (as the water would flow)

1. Anthracite
2. 2 layers of sand
3. 3 layers of support gravels
4. "Block" underdrain

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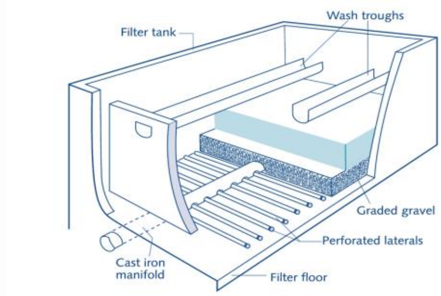
Conventional (and direct) filtration filter box



Perforated Pipe Underdrains

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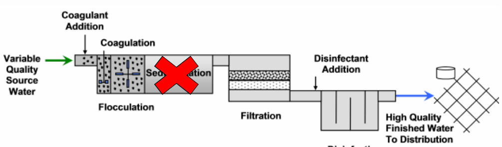
Direct Filtration Lacks Sedimentation

Direct Filtration Treatment

"means a series of processes including coagulation (requiring the use of a primary coagulant and rapid mix)



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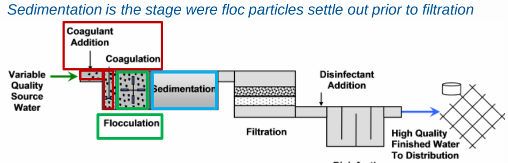
Conventional Filtration

In conventional filtration treatment..

A coagulation chemical is added and rapidly mixed to neutralize particle charges

Flocculation is a stage of gentle mixing so that a larger settleable floc forms

Sedimentation is the stage were floc particles settle out prior to filtration



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Conventional Filtration

- Sedimentation allows settling of coagulated particles, relieves burden on filter.

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Coagulants

- Aluminum sulfate (alum): very common, only effective in narrow pH range.
- Ferric chloride: More expensive, but works in wider pH range.
- Poly aluminum chloride (PACL): not affected by pH, doesn't change pH, works well with low alkalinity, leaves less sludge because dosage is low.
- Aluminum Chlorohydrate (ACH): similar to PACL.

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Factors Affecting Coagulation

- Dosage: determined by jar test for optimum qualities of floc: (size, settling rate).
- Mixing: Mechanical or static. Need to rapidly mix chemicals.
- Alkalinity: 50 mg/l or less can shift pH downward.
- Temperature: Colder water slows coagulation.
- Color: Pre-oxidation may be required.
- Turbidity: Changing conditions require more frequent jar tests.

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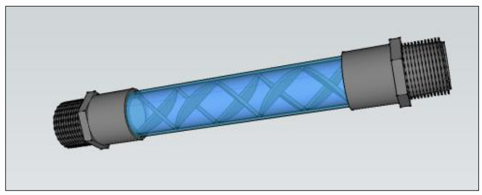
Coagulation Depends on Rapid Mixing

- Static mixers have veins or "elements" that promote mixing.
- The more water is pushed through a static mixer, the higher the head loss and better mixing you have.



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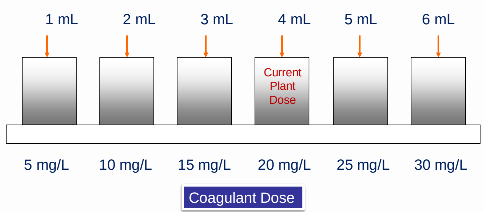
Jar testing is used to optimize coagulant dose for the best floc formation



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Jar Testing Equipment

- Jar Tester (6 jars, 300-rpm)
- Six 2-L Square Jars
- Portable or benchtop turbidimeter
- pH analyzer
- Misc. lab ware for making coagulant stock solution

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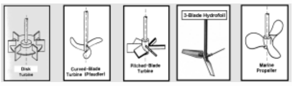
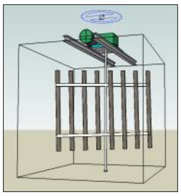
Flocculation

Flocculation involves slower mixing to bring neutralized particles together to form larger particles (floc)



Flocculation paddles - photo from 2007 CPE at Sweethome, OR



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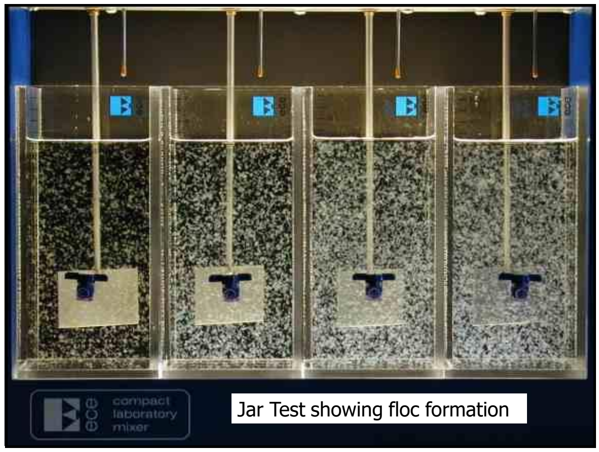

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Sedimentation (Conventional Plants)

- Standard basin:
  - Usually rectangular, goal is to slow down the water so solids settle to bottom by gravity.
  - Settled (clarified) water moves to filters slowly.
- Tube settlers:
  - Add capacity
  - Solids only need to settle a few inches
  - Water flows up through tubes, solids collect on the side and slide out of the bottom
  - Some standard sed basins can be retrofitted with tube settlers
- Plate Settlers (Lamella Plates)
  - Perform same function as tube settlers
  - Not as common in Oregon as tube settlers

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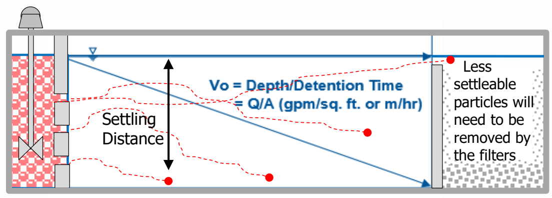
Sedimentation Basins

Sizing is such that the flocculated particles have time to settle out to the bottom of the basin before reaching the filters.



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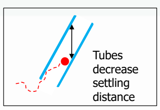
Tube Settlers



Tube settlers decrease the distance floc particles have to travel as they settle out.

In conventional basins, particles settle as much as 5-ft.

As water travel up through the inclined tube settlers, particles only settle about 2” to the floor of the tube.

City of Sweet Home, 2015

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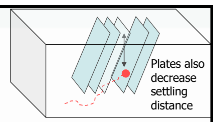
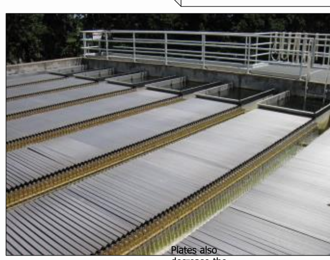
Inclined parallel plates serve a similar purpose as tube settlers





City of Corvallis, 2006

Plates also decrease the distance particles need to fall when settling out

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Adsorption (Upflow) Clarifiers

- Coagulated water flows up through clarifier.
- Clarifier media either gravel or plastic beads. Clarifier is periodically “rinsed” of solids.
- Clarified water flows onto filter.
- Configured as a package plant, small footprint, easy to increase the capacity.

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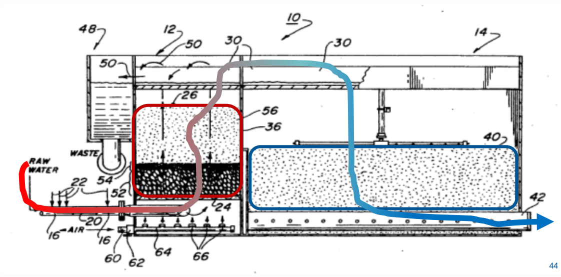
Contact Adsorption Clarifier

Roberts Filter Group Pacer II (model P-1400) ContaClarifier™



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Upflow clarifier. Note screens (upper portion) holding clarifier gravel or plastic beads in place.

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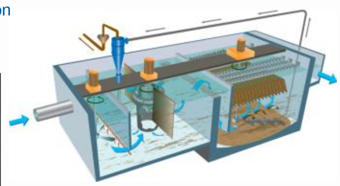
Other Forms of Sedimentation

Other forms of sedimentation/clarification include:

- Solids contact clarifiers
- Sludge blanket clarifiers
- Dissolved air flotation
- Sand ballasted



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Direct Filtration

- No sedimentation process.
- OK for small systems with consistent raw water quality.
- May be gravity or pressure filtration.
- Usually cannot observe backwash process if pressure filtration.

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Pressure filters

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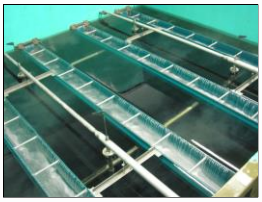
Conventional/Direct Filtration Optimization Objectives



- Achieve filtration performance goals.
- Minimize turbidity spikes during routine filter operation.
- Minimize turbidity spikes following filter backwash.

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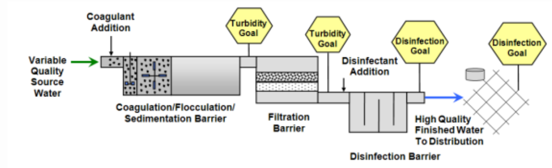
Optimization Goals for Conventional/Direct Filtration

1. Practice should embrace the multiple barrier approach
2. Adopt optimized performance goals

   (e.g., settled water turbidity ≤ 1 NTU, filtered water turbidity ≤ 0.1 NTU)



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Diatomaceous Earth (DE) Filtration

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Diatomaceous Earth (DE)

- Common in swimming pools, also approved for drinking water.
- Fine, porous, angular media processed from fossil skeletons of microscopic diatoms.
- Requires a continuous “body feed” injection of DE, which collects on a filter screen (“septum”).
- Only a few DE systems in Oregon.

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DE filter stack

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DE cake (pink layer)

Sediment that’s been filtered out (brown layer)

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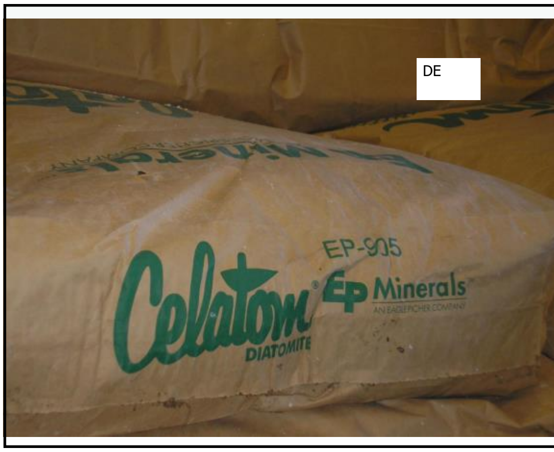

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Slow Sand Filtration

- Filtration rate < 0.1 gpm/ft2
- Need raw water < 5 NTU
- No coagulants used
- Pathogen removal occurs due to biochemical processes and adsorption.
- Cleaned by raking, and eventually removing, top 1/8" to ½" of sand.
- Credited with 2.0-log *Giardia/Crypto* removal

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Slow Sand Filtration

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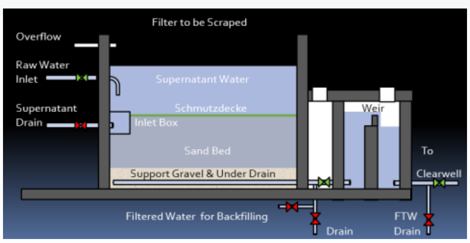

- In a typical slow sand filter, water passes first through about 36 inches of sand, then through a layer of gravel, before entering the underdrain.
- The sand removes particles from the water through adsorption, straining, and biological/biochemical processes.
- A layer of dirt, debris, and microorganisms builds up on the top of the sand.
- This layer is known as **schmutzdecke**, which is German for "dirt blanket"
- The schmutzdecke breaks down organic particles in the water biologically and is also very effective in straining out even very small inorganic particles from water.

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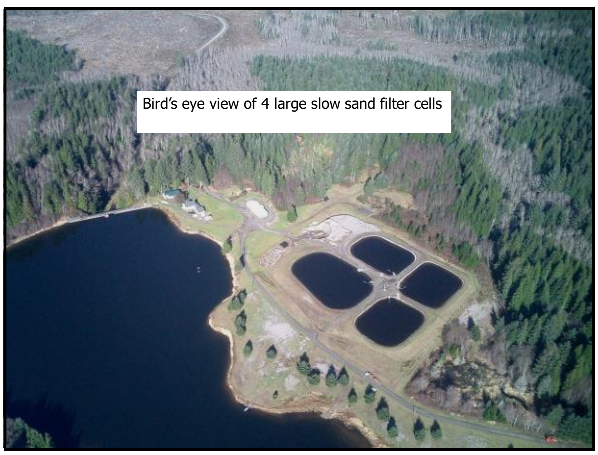

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Slow Sand Filtration - Cleaning

Cleaned by scraping (manually with shovels or with a specially designed machine), and eventually removing schmutzdecke and top 1/8” to ½” of sand.

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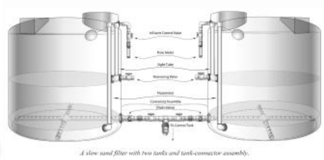
Slow Sand Filtration - Cleaning

Some filters are designed to be “wet harrowed”



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Self-contained slow sand filters at a school designed for wet harrowing.

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Alternative Filtration Technologies

- Cartridge / Bag Filters
- Membranes
- Need approved models that have met challenge studies (third party verification of performance) or on-site pilot data.

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Cartridge & Bag Filtration

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Cartridge Filters

- Good for small systems with low flow rates (5-20 gpm).
- Some cartridges require a specific pre-filter.
- No backwash, cartridges are replaced when pressure differential reaches specified limit.
- Must pass a challenge study in order to be approved.

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- •The state maintains a list of approved cartridge units on its website
- •Operational boundaries (max flow, max pressure drop) associated w/ approval & log removal credit

Alternative Treatment Technologies Meeting Challenge Study Standards
Oregon Administrative Rule 333-061-0050(4)(c)(J)
Oregon Health Authority, Drinking Water Program

CARTRIDGE & BAG FILTERS

(Other units not on this list may meet the standards. Contact DWP for details on verfications for units not listed.)

Manufacturer	Model			Log_{10} Removal Credit			Maximum Flow/Module (gpm)	Maximum Pressure Drop (psi @ 20°C)
	Pre-Filter	Main Filter	Housing	Crypto.	Giardia	Virus		
Strainrite	HPM99-CC-2-SR	HPM99-CCX-2-SR	AQ2-2	2.0	2.0	0	20	25[b]
Filtration Systems	500-P000-P2-DP	700-P001-P2-IP	NS-122	2.0	2.0	0	15	15[c]
Rosedale	not applicable	PS 740 PPP 356	830-2P[A]	2.0	2.0	0	10	15[d]
	not applicable	PS 740 PPP 356	18435-2F-1-150-SB700	2.0	2.0	0	80	31[d]

[A] Adapter basket required
[b] Absolute pressure drop across both filters.
[c] Pressure drop relative to new filters' startup pressure drop on the respective filters (pre- or final). For example, if the pre-filter exceeds 15 psid, replace pre-filter.
[d] Absolute pressure drop across the final filter. If using a pre-filter, see that manufacturer's specifications for that device.

For more information, please call the OHA Drinking Water Program at ph. 971-673-0405 (8am-5pm PT, Mon-Fri)

Updated: 14 September 2011

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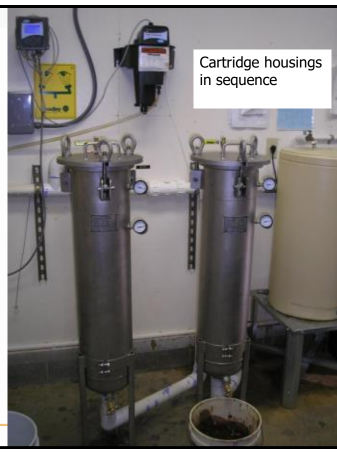

Cartridge housings in sequence

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Membrane Filtration

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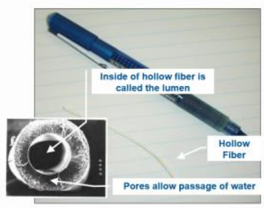
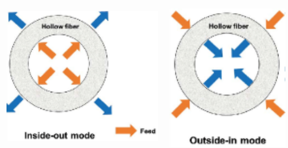
Membrane Filtration

- Remove pathogens based on pore size
- Typically consist of bundles of hollow fibers.





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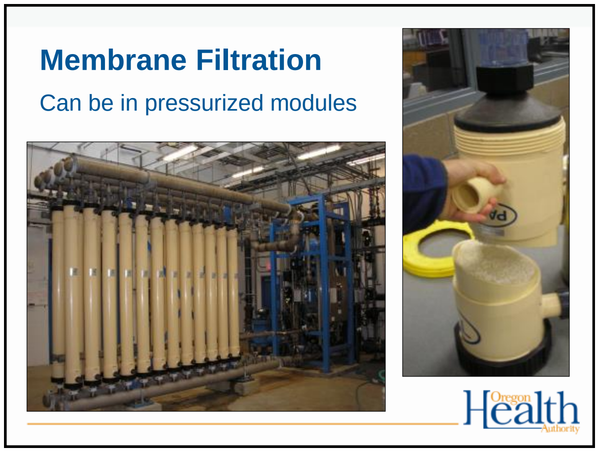

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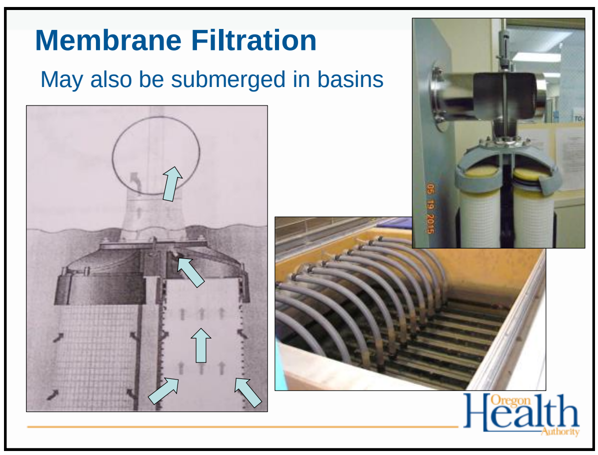

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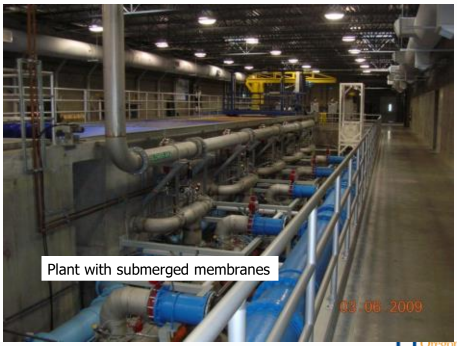
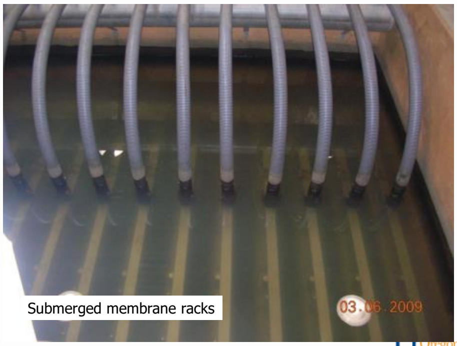


Plant with submerged membranes

85



Submerged membrane racks

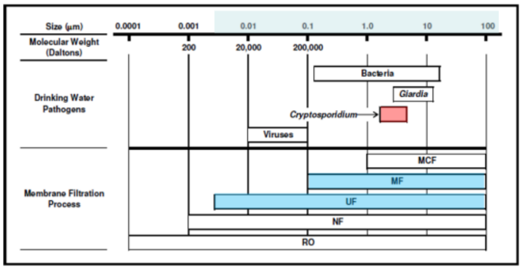
86

Membrane backwash, submerged membranes

87

Membrane Filtration

Very small pore sizes, 1 micron or less



88

Membrane Filtration

- Often need pre-filter/screening (30 – 300 micron screens)
- May also need coagulant to remove soluble organics

89

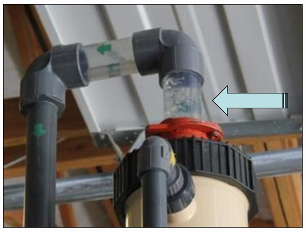
Membrane Filtration

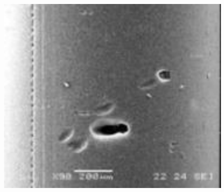
Requires direct integrity test daily (usually air-hold pressure decay testing which is pre-programmed into automated controls).

90

Membrane Filtration

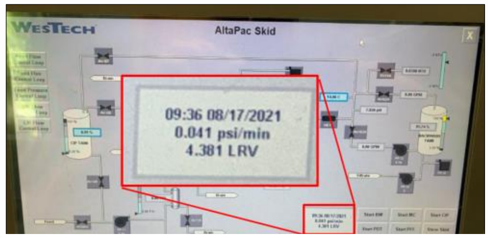
Holes in the membrane fibers or broken fibers result in a measurable pressure drop during direct integrity testing as shown by the air bubbles in site tubes.





91

Membrane Filtration



Control panel showing DIT (pressure decay test) info:

DIT= direct integrity test - sometimes called membrane integrity test (MIT), pressure decay test (PDT), or air hold test.
LRV=log removal value

92

Membrane Filtration

Damaged or broken membrane fibers can be “pinned” (plugged).

93

Membrane Filtration

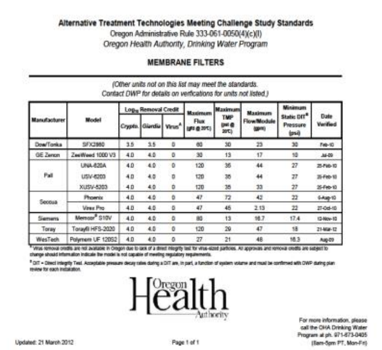
Membranes are periodically cleaned with acid, caustic, and/or chlorine.

Membrane clean-in-place chemicals

94

Membrane Filtration

- **The state maintains a list of approved membrane units on its website**
- **Approved under certain operating conditions (max flow, test pressures)**



Alternative Treatment Technologies Meeting Challenge Study Standards
Oregon Administrative Rule 333-061-0050(4)(c)(I)
Oregon Health Authority, Drinking Water Program

MEMBRANE FILTERS

(Other units not on this list may meet the standards. Contact DWP for details on verfications for units not listed.)

Manufacturer	Model	Log_{10} Removal Credit			Maximum Flux (gfd @ 20°C)	Maximum TMP (psi @ 20°C)	Maximum Flow/Module (gpm)	Minimum Static DIT[B] Pressure (psi)	Date Verified
		Crypto.	Giardia	Virus[A]					
Dow/Tonka	SFX2860	3.5	3.5	0	60	30	23	30	Feb-10
GE Zenon	ZeeWeed 1000 V3	4.0	4.0	0	30	13	17	10	Jul-09
Pall	UNA-620A	4.0	4.0	0	120	35	44	27	25-Feb-10
	USV-6203	4.0	4.0	0	120	35	44	27	25-Feb-10
	XUSV-5203	4.0	4.0	0	120	35	33	27	25-Feb-10
Seccua	Phoenix	4.0	4.0	0	47	72	42	22	6-Aug-10
	Virex Pro	4.0	4.0	0	47	45	2.13	22	27-Oct-10
Siemens	Memcor® S10V	4.0	4.0	0	80	13	16.7	17.4	12-Nov-10
Toray	Torayfil HFS-2020	4.0	4.0	0	120	29	47	18	21-Mar-12
WesTech	Polymem UF 120S2	4.0	4.0	0	27	21	48	16.3	Aug-09

[A] Virus removal credits are not available in Oregon due to lack of a direct integrity test for virus-sized particles. All approvals and removal credits are subject to change should information indicate the model is not capable of meeting regulatory requirements.

[B] DIT = Direct Integrity Test. Acceptable pressure decay rates during a DIT are, in part, a function of system volume and must be confirmed with DWP during plan review for each installation.

For more information, please call the OHA Drinking Water Program at ph. 971-673-0405 (8am-5pm PT, Mon-Fri)

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Different methods of filter cleaning:

- Conventional/Direct Filtration
  - Backwashing (every 8 – 72 hours)
  - Replacing/adding media eventually
- Slow sand
  - Scraping/ripening (every 1 – 6 months)
  - Replacing/adding sand eventually
- Cartridge/bag
  - Discard/replace used filters
- Membrane
  - Backwash (every 60 – 90 minutes)
  - Chemical cleaning

96

15 Minute Break

97

15 Minute Break

- 10 minutes left

98

15 Minute Break

- 5 minutes left

99

Disinfection

- For this section on disinfection, you will need Exercise Handouts #1 - #3 found at the link posted in the chat window on the right.

100

Disinfection Overview

- What is disinfection?
- Types of disinfectants
- Forms of chlorine
- NSF/ANSI Standard 60
- Disinfection requirements for surface water
- CTs
- Tracer Studies and Contact Time
- Impact of disinfectants on organics

101

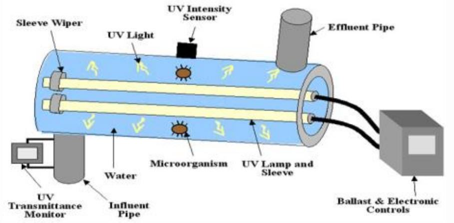
What is disinfection?

- Process of killing microorganisms in water that might cause disease (pathogens)
- Should not be confused with sterilization which is the destruction of all microorganisms
- Two types:
  - Ultraviolet Light (UV) Radiation
  - Chemical (chlorine, chloramines, chlorine dioxide, ozone)

102

Ultraviolet Light (UV)

Works by subjecting water to ultraviolet (UV) light rays as water passes through a tube



https://www.unh.edu/wttac/WTTAC_Water_Tech_Guide_Vol2/uv_homepage.html

Oregon Health Authority

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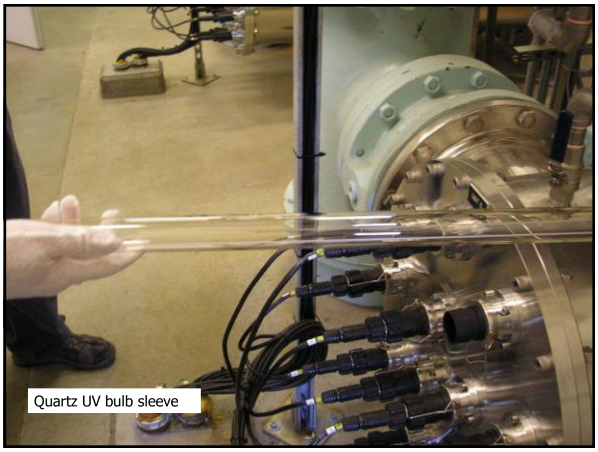
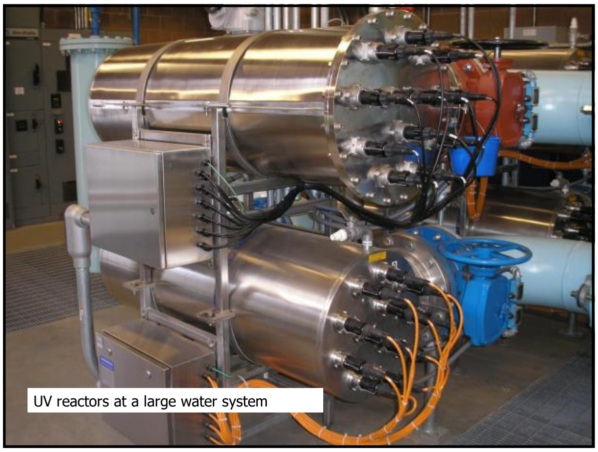


Quartz UV bulb sleeve

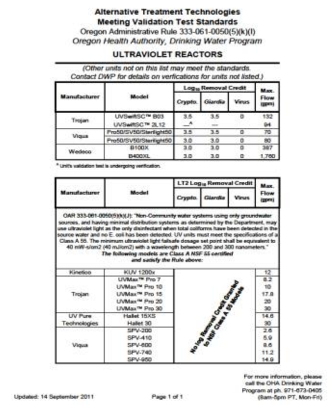
104



UV reactors at a large water system

105

- The state maintains a list of approved UV units on its website
- **NSF 55 units not allowed for SW treatment** (only allowed for GW TC+ with small distribution)



Alternative Treatment Technologies
Meeting Validation Test Standards
Oregon Administrative Rule 333-061-0050(5)(k)(I)
Oregon Health Authority, Drinking Water Program

ULTRAVIOLET REACTORS

(Other units not on this list may meet the standards. Contact DWP for details on verfications for units not listed.)

Manufacturer	Model	Log_{10} Removal Credit			Max. Flow (gpm)
		Crypto.	Giardia	Virus	
Trojan	UVSwiftSC™ B03	3.5	3.5	0	132
	UVSwiftSC™ 2L12	—[A]	—		94
Viqua	Pro50/SV50/Sterlight50	3.5	3.5	0	70
	Pro50/SV50/Sterlight50	3.0	3.0	0	80
Wedeco	B100X	3.0	3.0	0	387
	B400XL	3.0	3.0	0	1,760

[A] Unit's validation test is undergoing verification.

Manufacturer	Model	LT2 Log_{10} Removal Credit			Max. Flow (gpm)
		Crypto.	Giardia	Virus	
OAR 333-061-0050(5)(k)(J): "Non-Community water systems using only groundwater sources, and having minimal distribution systems as determined by the Department, may use ultraviolet light as the only disinfectant when total coliforms have been detected in the source water and no E. coli has been detected. UV units must meet the specifications of a Class A 55. The minimum ultraviolet light failsafe dosage set point shall be equivalent to 40 mW-s/cm2 (40 mJ/cm2) with a wavelength between 200 and 300 nanometers." ***The following models are Class A NSF 55 certified and satisfy the Rule above:***					
Kinetico	KUV 1200x	No log Removal Credit Granted to NSF Class A 55 Models			12
Trojan	UVMax™ Pro 7				8.2
	UVMax™ Pro 10				10
	UVMax™ Pro 15				17.8
	UVMax™ Pro 20				20
	UVMax™ Pro 30				30
UV Pure Technologies	Hallet 15XS				14.6
	Hallet 30				30
Viqua	SPV-200				2.6
	SPV-410				5.9
	SPV-600				8.6
	SPV-740				11.2
	SPV-950				14.9

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For more information, please call the OHA Drinking Water Program at ph. 971-673-0405 (8am-5pm PT, Mon-Fri)

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UV Drawbacks

Drawbacks for UV include:

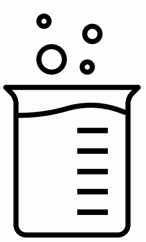
- Interfering agents such as turbidity can screen pathogens from the UV light
- Effective against *Giardia* and *Cryptosporidium* but not viruses at normal doses
- No residual is present in the water to continue disinfecting throughout the distribution system
- For this reason, chlorination for residual maintenance is required when UV is used

Oregon Health Authority

107

Chemical Disinfection

- Chlorine
- Chloramines
- Chlorine dioxide
- Ozone



Oregon Health Authority

108

Chlorine

- Most widely used form of disinfection
- Also used as an oxidizing agent for iron, manganese and hydrogen sulfide and for controlling taste and odors
- Effectiveness as a disinfecting agent depends on factors such as pH, temperature, free chlorine residual, contact time and other interfering agents

109

Forms of Chlorine

- Sodium Hypochorite
- Onsite generated sodium hypochorite
- Calcium Hypochlorite
- Chlorine Gas

110

Sodium hypochlorite

- The liquid form of chlorine
- Clear and has a slight yellow color
- Ordinary household bleach (~5% chlorine by solution) is the most common form
- Industrial strength: 12% and 15% solutions

111

Sodium hypochlorite (continued)

- Can lose up to 4% of its available chlorine content per month; should not be stored for more than 60 to 90 days
- Very corrosive; should be stored and mixed away from equipment that can be damaged by corrosion

112

Diaphragm Pump/Tank for Chlorine

113

On-site generated sodium hypochlorite

- 0.8% sodium hypochlorite is produced on demand by combining salt, water & electricity
- Electrolysis of brine solution produces sodium hydroxide and chlorine gas, which then mix to form sodium hypochlorite
- Hydrogen gas byproduct; vented to atmosphere
- Alleviates safety concerns associated w/ hauling and storing bulk chlorine
- Higher initial cost, high power cost
- Mixed oxidants (proprietary)

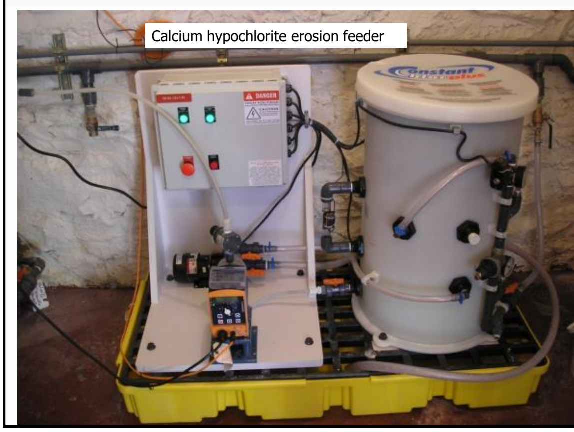
114

115

Calcium hypochlorite

- The solid form of chlorine
- Usually tablet or powder form
- Contains ~65% chlorine by weight
- White or yellowish-white granular material and is fairly soluble in water
- Important to keep in a dry, cool place
- More stable than liquid
- Used by small systems w/ low flows or no power

116



117

Calcium hypochlorite hopper interior

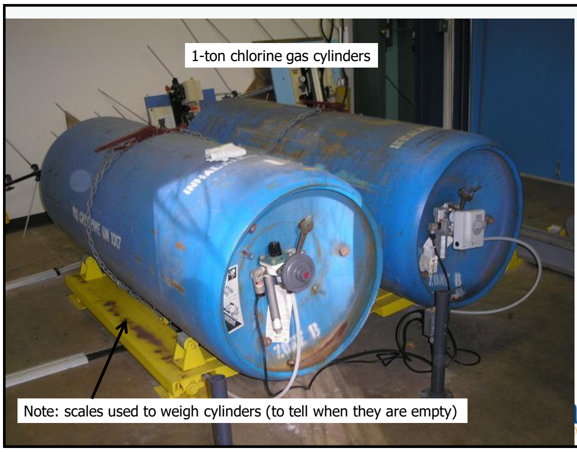
118

Chlorine gas (Cl_2)

- 99.5% pure chlorine
- yellow-green color 2.5x heavier than air
- Liquified at room temperature at ~107 psi – hence the pressurized cylinders actually contain liquified chlorine gas.
- Liquified Cl_2 is released from tanks as chlorine gas, which is then injected into the water stream.
- usually used only by large water systems
- Smaller systems may find initial cost of operation prohibitive

119

120



121

122

Chloramines

- Chlorine + ammonia = chloramination
- Two advantages to regular chlorination:
  - produce a longer lasting chlorine residual (helpful to systems with extensive distribution systems)
  - may produce fewer by-products depending on the application
- Disadvantage:
  - Need a lot of contact time to achieve CTs compared to free chlorine (300 times more) which is why not used for primary disinfection
  - Requires specific ratio of chlorine to ammonia or else potential water quality problems

123

124

Ozone

- Colorless gas (O_3)
- Strongest of the common disinfecting agents
- Also used for control of taste and odor
- Extremely Unstable; Must be generated on-site
- Manufactured by passing air or oxygen through two electrodes with high, alternating potential difference

125

126

Large water system ozone

127

Ozone contactors

128

Ozone is to reactive to store, so liquid oxygen is used for making ozone

129

Ozone advantages

- Short reaction time enables microbes (including viruses) to be killed within a few seconds
- Removes color, taste, and odor causing compounds
- Oxidizes iron and manganese
- Destroys some algal toxins
- Does not produce halogenated DBPs

130

Ozone disadvantages

- Overfeed or leak can be dangerous
- Cost is high compared with chlorination
- Installation can be complicated
- Ozone-destroying device is needed at the exhaust of the ozone-reactor to prevent smog-producing gas from entering the atmosphere and fire hazards

131

Ozone disadvantages (continued)

- May produce undesirable brominated byproducts in source waters containing bromide
- No residual effect is present in the distribution system, thus postchlorination is required
- Much less soluble in water than chlorine; thus special mixing devices are necessary

132

Chlorine dioxide

Advantages

- More effective than chlorine and chloramines for inactivation of viruses, *Cryptosporidium,* and *Giardia*
- Oxidizes iron, manganese, and sulfides
- May enhance the clarification process
- Controls T&O resulting from algae and decaying vegetation, as well as phenolic compounds
- Under proper generation conditions halogen-substituted DBPs are not formed
- Easy to generate
- Provides residual

133

Chlorine dioxide (continued)

Disadvantages

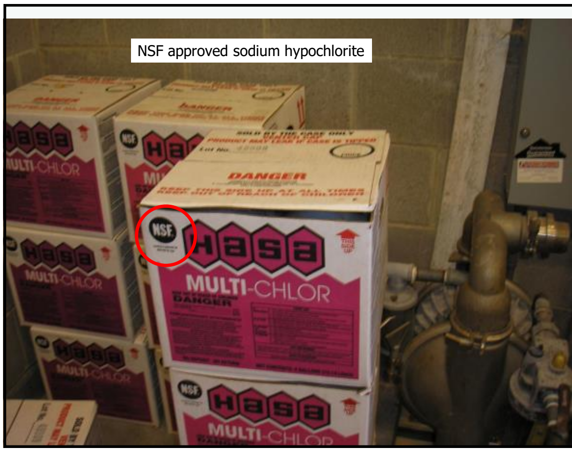
- Forms the DBP chlorite
- Costs associated with training, sampling, and laboratory testing for chlorite and chlorate are high
- Equipment is typically rented, and the cost of the sodium chlorite is high
- Explosive, so it must be generated on-site
- Decomposes in sunlight
- Can lead to production noxious odors in some systems.

134

NSF/ANSI Standard 60

- Addresses the health effects implications of treatment chemicals and related impurities.
- The two principal questions addressed are:
  - Is the chemical safe at the maximum dose, and
  - Are impurities below the maximum acceptable levels?

135



136

Disinfection Requirements for Surface Water

- Surface Water Treatment Rule (SWTR) requires 3-log reduction of *Giardia* using a combination of **disinfection** and **filtration**
- 2.0 to 2.5-log removal is achieved through **filtration**
- 0.5 to 1.0-log inactivation is achieved through **disinfection**
- Determines which column of EPA tables used to calculate CTs (0.5 or 1.0-log)

137

What are CT's?

- It's a way to determine if disinfection is adequate

CT = Chlorine **C**oncentration x Contact **T**ime

- Do not confuse "CT" and "Contact Time"

138

How do we calculate CT's?

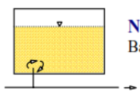
- We use the EPA tables to determine the CTs needed to inactivate *Giardia* ($CT_{required}$)
  - We need to know pH, temperature, and free chlorine residual at the first user in order to use the EPA tables.
- Then we compare that with the CTs achieved in our water system (CT_{actual})
- CT_{actual} must be equal to or greater than $CT_{required}$

139

Tracer Studies and Contact Time:

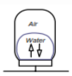
- Used to determine contact time (T) which is used in calculating CT's
- Determines the time that chlorine is in contact with the water from the point of injection to the point where it is measured (sometimes referred to as the "CT segment")
  - May be at or before the 1st user
  - May be more than one CT segment
- Estimates of contact time are not allowed for calculating CT's for surface water!
  - ***The degree of short-circuiting is only approximately known until a tracer study is conducted.***

140

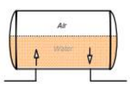


No Circulation
Baffling Efficiency = 0%

What effects short-circuiting?
1) Flow rate
2) Flow path

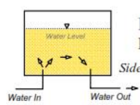


No Circulation
Baffling Efficiency = 0%
Bladder-Type Pressure Tank

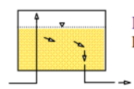


Poor Circulation
Baffling Efficiency = 10%
Hydropneumatic Tank

141

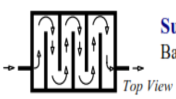


Poor Circulation
Baffling Efficiency = 5-10%
Side View

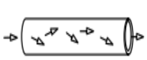


Poor Circulation
Baffling Efficiency = 10%

142

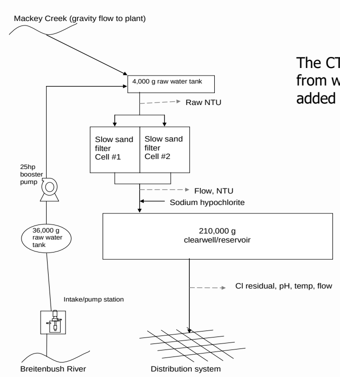


Superior Circulation
Baffling Efficiency = 70%
Top View



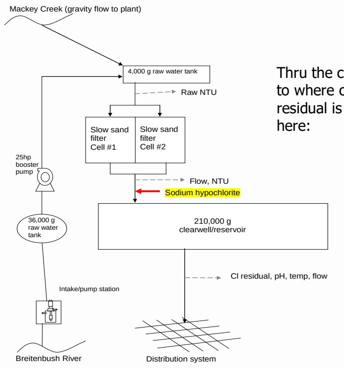
Perfect Circulation
Baffling Efficiency = 100%
Plug flow through a length of pipe

143



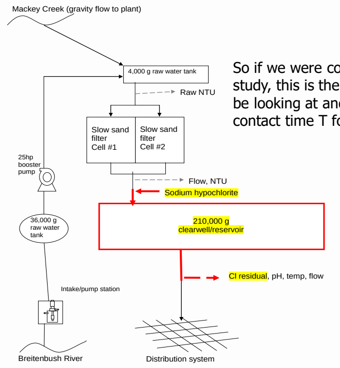
The CT segment is from where chlorine is added here:

144



Thru the clearwell, to where chlorine residual is measured here:

145



So if we were conducting a tracer study, this is the segment we would be looking at and determining the contact time T for.

146

Tracer studies (continued):

- Different methods:
  1. If water is pumped from the clearwell at different rates depending on time of year, do tracer study at each of those flow rates
  2. Do at typical winter/summer peak hour demand flows
  3. Otherwise use "worst-case scenario" parameters:
     - Highest flow rate out of clearwell (conduct during peak hour or conditions that simulate e.g. open a hydrant)
     - Keep flow rate constant
     - Keep clearwell water level close to normal minimum operating level

147

Tracer studies (continued):

- Must redo if peak hour demand flow increases more than 10% of the maximum flow used during the tracer study
- Community water systems with populations <10,000 and non-profit non-community systems can use the circuit rider to perform a tracer study
- Must submit a proposal to DWS for approval prior to conducting the tracer study (even if using the circuit rider).

148

Exercise #1

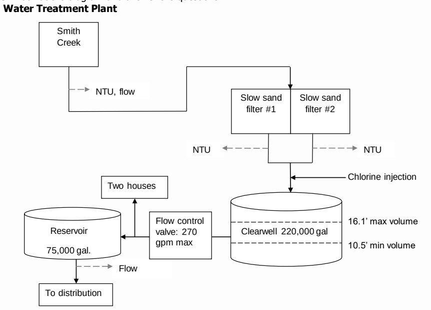
- **Tracer studies**

149

Exercise #1: Tracer studies

Directions: Look at the diagram and answer the questions.

Figure 1: Water Treatment Plant



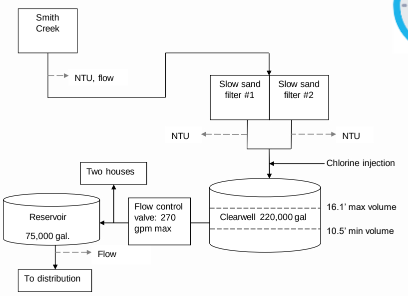
Questions:
- If this was your treatment plant, highlight the part of the plant where you might conduct a tracer study.
- In a "worst-case scenario" tracer study, what would the flow rate be? ______
- In a "worst-case scenario" tracer study, what would the clearwell level be? ______

150

Exercise #1: Tracer studies

Directions: Look at the diagram and answer the questions.

Figure 1: Water Treatment Plant



Questions:

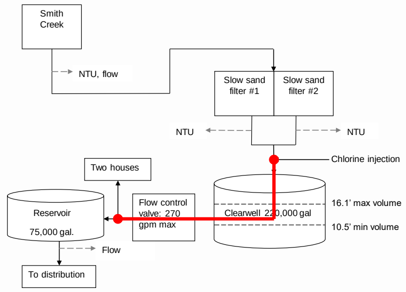
- If this was your treatment plant, highlight the part of the plant where you might conduct a tracer study.
- In a "worst-case scenario" tracer study, what would the flow rate be? ______
- In a "worst-case scenario" tracer study, what would the clearwell level be? ______

151

Exercise #1: Tracer studies

Directions: Look at the diagram and answer the questions.

Figure 1: Water Treatment Plant



Questions:

- If this was your treatment plant, highlight the part of the plant where you might conduct a tracer study.
- In a "worst-case scenario" tracer study, what would the flow rate be? **270 gpm**
- In a "worst-case scenario" tracer study, what would the clearwell level be? **10.5 feet**

152

How info from tracer study is used to calculate CTs

- Use the time T from the tracer study on the monthly reporting form in the "Contact time (min)" column
  - Use the smallest T (highest flow) if the tracer study was done at multiple flow rates
- This may not be your exact time, but it represents your worst case (as long as the peak flow is less and clearwell volume is more than they were at the time of the tracer study)

153

How info from tracer study is used to calculate CTs (cont.)

- Or, once you know the time T from the tracer study, you can back-calculate to determine the baffling factor of the clearwell
  - $$\text{Baffling factor (\%)} = \frac{\text{Time (min) x Flow During Tracer Study (gpm)}}{\text{Clearwell Volume During Tracer Study (gal)}}$$
- T can be adjusted based on flow (at <110%) with the following equation:
  - $$T = \frac{\text{Current clearwell Volume (gal) x Baffling Factor (\%)}}{\text{Peak Hourly Demand Flow (gpm)}}$$
- If tracer study includes pipeline segments or multiple tanks, contact the state for guidance on using baffling factors

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Impact of chlorine and ozone on organics

- Disinfectants can react with organics to form disinfection byproducts
  - Chlorine: TTHMs & HAA5s
  - Ozone: Bromate
- Pre-chlorination
- TOC

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OPERATIONS

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Overview

- Proper instrument sampling locations
- Proper treatment plant sampling locations
  - Turbidity
  - Chlorine residual
  - TOC
- Instrument calibration
  - Turbidimeters
  - Chlorine analyzers
  - Chemical feed pumps
- Operations & Maintenance Manuals

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Proper instrument sampling location

- Data provided by instruments provides the basis for assessing water quality – important to get it right!
- Common problems
  - Sampling location
  - Measurement techniques
  - Calibration frequency and approach
- Possible solutions
  - May require investigations (special studies)
  - Modifications to sample lines
  - Establish guidelines on sample line cleaning
  - Establish calibration procedure

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Sampling for Turbidity

- Raw turbidity
  - Applies to all SW systems
  - Location: pre-treatment
  - Frequency: no regulatory requirement but need to know for proper treatment plant operation
- Settled turbidity
  - Water systems using conventional filtration must measure settled water turbidity every day (e.g., grab sample 1x/day).
- Individual filter effluent (IFE) turbidity
  - CF, DF & membranes only
  - Location: after each individual filter
  - Frequency: continuous (every 15 minutes)
  - Know what the triggers are!

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IFE Triggers (Conventional/Direct)

- Report the following events immediately and conduct a filter profile within 7 days (if no obvious reason exists) if the IFE turbidity is:
  - > 1.0 NTU in 2 consecutive 15-min readings
  - > 0.5 NTU in 2 consecutive 15-min readings within 4 hours of being backwashed or taken off-line
- Report the following events and conduct a filter self assessment within 14 days if the IFE turbidity is:
  - > 1.0 NTU in 2 consecutive 15-min readings at any time in each of 2 consecutive months.
- A CPE must be done within 30 days if the IFE turbidity is:
  - > 2.0 NTU in 2 consecutive 15-min readings at any time in each of 2 consecutive months.

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Proper treatment plant sampling locations: Turbidity (cont.)

- Combined filter effluent (CFE) turbidity
  - Applies to all SW systems
  - Location: post all filtration prior to chemical addition and any storage
  - Frequency:
    - CF/DF > 3,300 pop. – continuous
    - CF/DF ≤ 3,300 pop. – every 4 hrs
    - Alternative - daily

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Proper treatment plant sampling locations: Chlorine residual

- Must be at least 0.2 ppm all times at the entry point (EP) to the system
  - EP = post clearwell, at or before 1st user
- EP chlorine residual sampling frequency
  - Continuous > 3,300 population
  - 1-4x/day for ≤ 3,300 population
- If EP residual falls < 0.2 ppm or required continuous monitoring equipment fails, grab sampling must be done every 4 hours until the residual is ≥ 0.2 ppm and/or equipment is repaired.

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Proper treatment plant sampling locations: Chlorine residual

OAR 333-061-0032(5)

(5) Disinfection requirements for water systems utilizing surface water or GWUDI sources with filtration.

(a) Disinfection treatment must be sufficient to ensure that the total treatment processes at a water system achieve at least 99.9 percent (3-log) inactivation or removal of *Giardia lamblia* cysts and at least 99.99 percent (4-log) inactivation or removal of viruses as determined by the Authority.

(b) The residual disinfectant concentration in the water entering the distribution system, measured as specified in OAR 333-061-0036(5)(b)(D), cannot be less than 0.2 mg/l for more than 4 hours.

(c) The residual disinfectant concentration in the distribution system, measured as free chlorine, total chlorine, combined chlorine or chlorine dioxide, as specified is OAR 333-061-0036(5)(b)(D) cannot be undetectable in more than 5 percent of the samples each month, for any two consecutive months that the system serves water to the public.

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Proper treatment plant sampling locations: Chlorine residual

OAR 333-061-0036(5)(b)(D)

(D) Monitoring for the residual disinfectant concentration entering the distribution system shall be performed as prescribed in paragraph (5)(a)(E) of this rule.

(E) Monitoring for the residual disinfectant concentration in the distribution system shall be performed as prescribed in paragraph (5)(a)(F) of this rule.

(F) Water systems using membrane filtration must perform direct integrity testing on each filter canister at least daily, per OAR 333-061-0036(5)(d)(B).

Note - OAR 333-061-0036(5)(b) – addresses monitoring for SW and GWUDI systems that provide filtration. Section - 0036(5)(a) is for unfiltered systems, but the disinfectant residual monitoring under (5)(a)(E) still applies.

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Proper treatment plant sampling locations: Chlorine residual

OAR 333-061-0036(5)(a)(E) – EP Chlorine Residual

(E) The residual disinfectant concentration of the water entering the distribution system must be monitored continuously, and the lowest value must be recorded each day. If there is a failure in the continuous monitoring equipment, grab sampling every 4 hours may be conducted in lieu of continuous monitoring, but for no more than 5 working days following the failure of the equipment, and systems serving 3,300 or fewer persons may take grab samples in lieu of providing continuous monitoring on an ongoing basis at the frequencies prescribed in Table 29. The day's samples cannot be taken at the same time. The sampling intervals are subject to Authority review and approval. If at any time the residual disinfectant concentration falls below 0.2 mg/l in a system using grab sampling in lieu of continuous monitoring, the system must take a grab sample every 4 hours until the residual disinfectant concentration is > 0.2 mg/l.

Table 29

Population	Samples per day
500 or Less	1
501 to 1,000	2
1,001 to 2,500	3
2,501 to 3,300	4

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Proper treatment plant sampling locations: Total organic carbon (TOC)

- Applicability
  - CF (2.5-log plants): required raw TOC & alkalinity and filtered TOC
  - All others: raw TOC required to qualify for DBP monitoring reduction (>500 population)
- Frequency
  - Monthly; may be reduced to Quarterly if filtered TOC is <2.0 ppm for 2 years, or <1.0 ppm for 1 year
  - Quarterly if DBP reduction is granted

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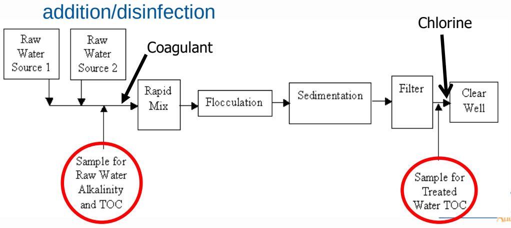
Proper treatment plant sampling locations: Total organic carbon (TOC) (cont.)

- Location
  - Raw TOC & alkalinity: pre-treatment
  - Filtered TOC: CFE prior to chemical addition/disinfection



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Exercise #2

- Proper sampling locations for turbidity, chlorine residual, and TOC
  - Determine proper sampling locations on WTP diagrams for conventional and membrane filtration

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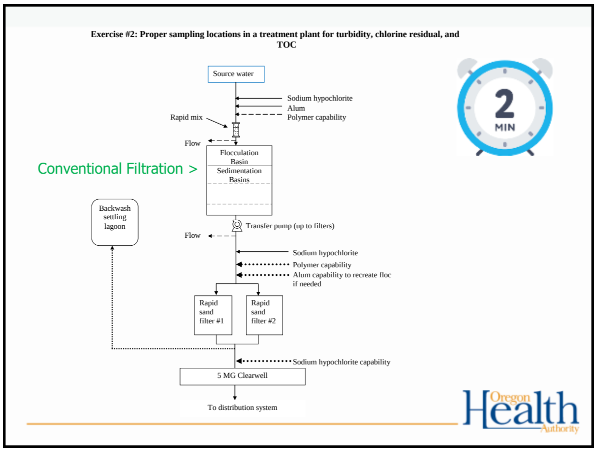
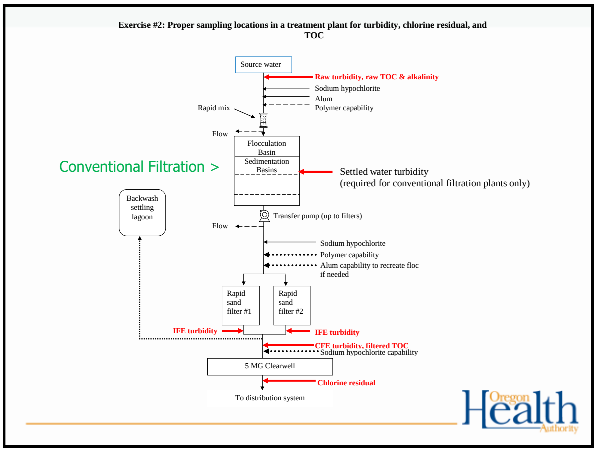
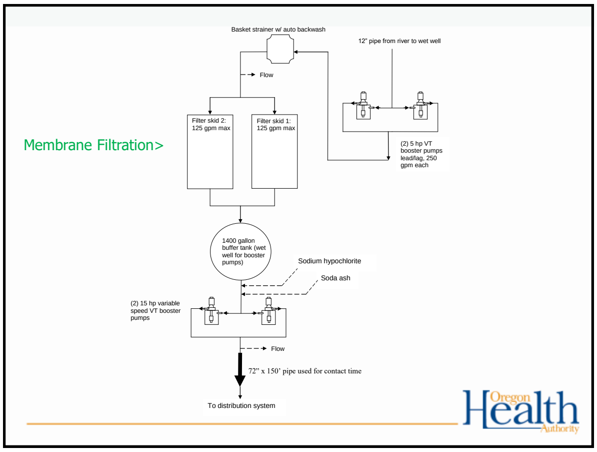


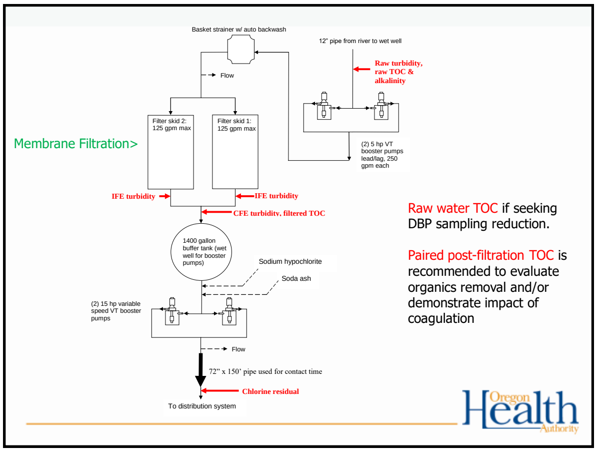
169



170



171



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Instrument calibration

- Turbidimeters (online, portable or benchtop)
  - Must be calibrated per manufacturer or at least quarterly with a <u>primary</u> standard
    - Formazin solution
    - Stablcal (stabilized formazin)
  - Secondary standards used for day-to-day check
  - dayCheck is used to determine if calibration with a primary standard is necessary
    - Gelex
    - Manufacturer provided (e.g. Hach ICE-PIC)

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Portable turbidimeter

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Instrument calibration

- Chlorine analyzers
  - Handheld
    - Follow manufacturer’s instructions
  - Inline
    - Check calibration against a handheld that has been calibrated
    - At least weekly
    - Follow manufacturer’s instructions if out of calibration

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Instrument calibration

- Chemical feed pumps
  - Calibration measures both the speed and the stroke (amount of chemical pumped) so accurate dosages can be calculated
  - Create a “pump curve”;
    - Set the stroke at half way point
    - On a graph, plot speeds of 10% to 100% on X axis
    - Plot chemical output amount on Y axis (ml/min)
    - Record drawdown in graduated cylinders for 1 minute

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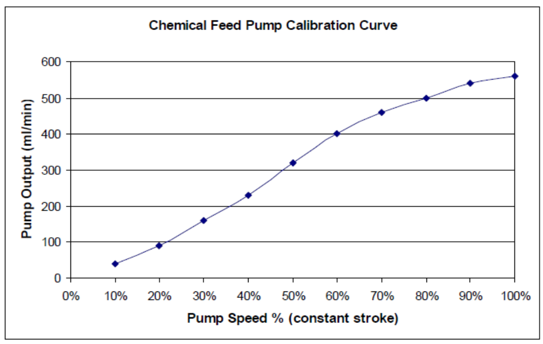
Calibration Graphs: Pump Output Vs. Pump Speed



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Instrument calibration (cont.)

- Chemical feed pumps (cont.)
  - Pump curve is an important tool to identify when a pump may be in need of maintenance or replacement
  - A smooth pump curve is good (should fit close to a straight line)
  - Must compare information at varying speeds to be a full pump calibration process
  - Suggested frequency: no less than annual

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Exercise #3

- Create a pump curve using made-up data points
- **Directions:** Use the data provided in Exercise #3 to create a pump curve. Pump curves should be smooth and fairly linear. A bouncing or jagged pump curve indicates the pump needs maintenance. Maintenance needed may include cleaning, diaphragm replacement and/or seal replacement.

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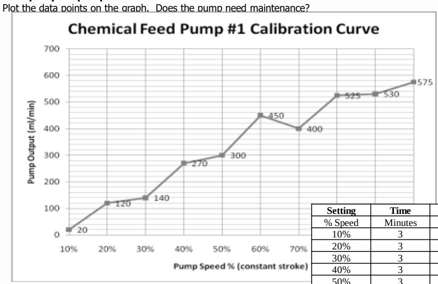
Exercise #3: Creating a chemical feed pump curve
Directions: Use the data provided in the examples below to create a pump curve. Pump curves should be smooth and fairly linear. A bouncing or jagged pump curve indicates the pump needs maintenance. Maintenance needed may include cleaning, diaphragm replacement and/or seal replacement.

Feed pump #1 pump curve data:
Plot the data points on the graph. Does the pump need maintenance?



Setting	Time	Volume	Flow Rate
% Speed	Minutes	ml	ml/min
10%	3	60	20
20%	3	360	120
30%	3	420	140
40%	3	810	270
50%	3	900	300
60%	1	450	450
70%	1	400	400
80%	1	525	525
90%	1	530	530
100%	1	575	575

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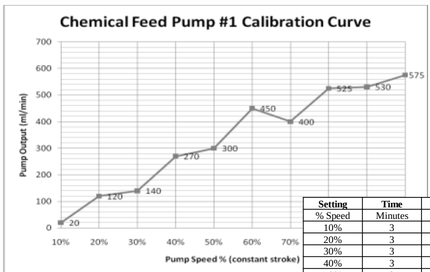
Exercise #3: Creating a chemical feed pump curve
Directions: Use the data provided in the examples below to create a pump curve. Pump curves should be smooth and fairly linear. A bouncing or jagged pump curve indicates the pump needs maintenance. Maintenance needed may include cleaning, diaphragm replacement and/or seal replacement.

Feed pump #1 pump curve data:
Plot the data points on the graph. Does the pump need maintenance? **Yes (jagged line)**



Setting	Time	Volume	Flow Rate
% Speed	Minutes	ml	ml/min
10%	3	60	20
20%	3	360	120
30%	3	420	140
40%	3	810	270
50%	3	900	300
60%	1	450	450
70%	1	400	400
80%	1	525	525
90%	1	530	530
100%	1	575	575

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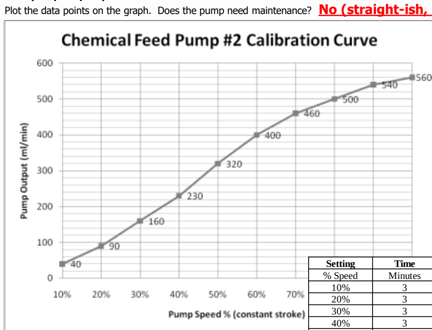
Feed pump #2 pump curve data:
Plot the data points on the graph. Does the pump need maintenance? **No (straight-ish, smooth line)**



Setting	Time	Volume	Flow Rate
% Speed	Minutes	ml	ml/min
10%	3	120	40
20%	3	270	90
30%	3	480	160
40%	3	690	230
50%	3	960	320
60%	1	400	400
70%	1	460	460
80%	1	500	500
90%	1	540	540
100%	1	560	560

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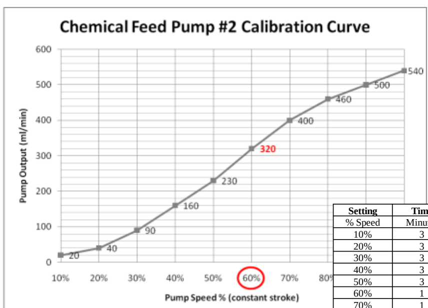
Bonus question: Referring to feed pump #2 data above, if you normally have your speed set at 50% in order to maintain 1 ppm of chemical, what speed do you need to change it to if you do a new pump curve and get the following results:

Feed pump #2 *NEW* pump curve data
Answer: **60%**



Setting	Time	Volume	Flow Rate
% Speed	Minutes	ml	ml/min
10%	3	60	20
20%	3	120	40
30%	3	270	90
40%	3	480	160
50%	3	690	230
60%	1	320	320
70%	1	400	400
80%	1	460	460
90%	1	500	500
100%	1	540	540

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Lessons learned from data assessments done in the past

- Common findings:
  - Most systems have some problems with the way they monitor, record, assemble, and/or report data
  - Operators do not know which data to report and which to exclude
  - Operators do not know how to correctly use their tracer studies/calculate CTs
  - Most system managers and operators are surprised by what they find out from a data assessment

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Data assessments (cont.)

- Even automated systems require a knowledgeable person to correctly assemble data
- Data assessments often used to justify invalidation of turbidity data which would have triggered a CPE
- Effective optimization can only be achieved when using valid performance data

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How can operators become better data managers?

- Make data reliability a plant goal
- Only collect data used for process control or compliance reporting
- Establish protocols for collection and recording of data
- Establish a data verification process that can be routinely used to confirm data integrity
- Turn data into information!

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Operations & Maintenance Manual

Keep written procedures on:

- Instrument calibration methods and frequency
- Data handling/reporting
- Chemical dosage determinations
- Filter operation and cleaning
- CT determinations
- Responding to abnormal conditions (emergency response plan)

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End of Part 1

- Attend Part 2 to receive an additional 3 Contact Hours.
- Complete the application for both parts attended to get all 6 contact hours online at: https://www.oregon.gov/oha/PH/HEALTHYENVIRONMENTS/DRINKINGWATER/OPERATIONS/TREATMENT/Pages/sw-essentials.aspx
- The link to attend Part 2 of the training and application for contact hours is online under “Free Training Resources” at www.healthoregon.org/swt
- E-mail questions to: DWS.SurfaceWater@odhsoha.oregon.gov

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