Astoria, OR 5 MGD plant (photo taken by Frank Wolf)

Walla Walla, WA Pilot Study 2010-2012

OHA – Drinking Water Services

SLOW SAND FILTRATION – A TIMELESS TECHNOLOGY

1

OUTLINE

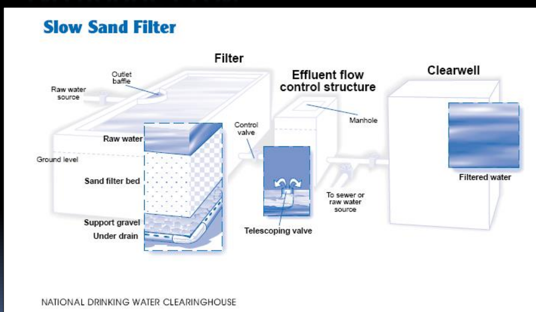
1. Introduction to a "Timeless Technology"
2. Removal Mechanisms & Expected Performance
3. Critical Variables & Raw Water Quality
4. Design
5. Operations
6. Regulatory Requirements

Tables are used to summarize info =>

Water Quality Paramenter	Removal Capacity
Turbidity	<1.0 NTU
Coliforms	1-3 log units
Enteric Viruses	2-4 log units
Giardia Cysts	2-4+log units
Cryptosporidium Oocysts	>4 log units
Dissolved Organic Carbon	<15-25%
Biodegradable	
Dissolved Organic Carbon	<50%
Trihalomethane Precursors	<20-30%
Heavy Metals	
Zn, Cu, Cd, Pb	>95-99%
Fe, Mn	>67%
As	<47%

2

INTRODUCTION



http://jica-net.jica.go.jp/lib2/08PRDM007/en.html

3

FIRST DESIGNED IN 1804 PAISLEY, SCOTLAND

Records show that an experimental slow sand filter was first designed and built by John Gibb in 1804 for his textile bleachery in Paisley, Scotland.

4

THAMES RIVER IN 1828 LONDON ENGLAND

"Monster Soup Commonly Called Thames Water"

in 1828, the artist William Heath published a scathing caricature reflecting the public's distaste for the water being supplied from the River Thames by London companies

Source: Heath, William. *Monster Soup* 1828 in Fox C (ed). *London – World City 1800-1840*, 1992

5

THAMES RIVER FILTERED IN 1829

In 1829, James Simpson (pictured) designed a slow sand filtration system for the Chelsea Water Company in London, England.

This was the first use of slow sand filtration for the express use of producing drinking water and became a model for future designs.

The benefits of the slow sand filtration system prompted the passage of the Metropolis Water Act in 1852, requiring all water derived from the River Thames within 5 miles of St Paul's Cathedral to be filtered .

6

LONDON CHOLERA REDUCTION

"The only other water company deriving a supply from the Thames, in a situation where it is much contaminated with the contents of sewers, was the Chelsea Company. But this company, which supplies some of the most fashionable parts of London, took great pains to filter the water before its distribution, and in so doing no doubt separated, amongst other matters, the great proportion of that which causes cholera."
- Snow, John. *Communication of Cholera*, 1855, p. 64

7

TODAY - WORLD-WIDE USE

In use world-wide

Micronesia
Design Tech Paper
2003

Canada
"New Horizons for SS Filtration"
2004

WHO, 1974
IRC, 1987
UNICEF, 2009

According to the World Health Organization, "Under suitable circumstances, slow sand filtration may be not only the cheapest and simplest but also the most efficient method of water treatment."

8

FIRST USED IN U.S. IN 1872
POUGHKEEPSIE, NY

Proven technology
First placed into use in the U.S. in Poughkeepsie, NY.
Used from 1872 - 1962

Chlorine was added in 1909

Poughkeepsie pronounced "puh KIP see"


PLAN OF POUGHKEEPSIE PUMPING AND PURIFICATION PLANTS

The first successful slow sand filtration plant in America was placed into service July 8, 1872. The success of this project was heralded as epidemics all but disappeared and Poughkeepsie could no longer be called a "Sickly City".

9

WASHINGTON D.C. - 1905

US Army Corps of Engineers photo of Washington D.C. McMillan Water Filtration Plant, a 25-acre, 75 MGD slow sand plant in use from 1905 – 1985 (replaced by rapid sand plant). Eliminated typhoid epidemics in the City.

10

UNDER DRAINS – PITTSBURGH, PA


A. MAIN COLLECTOR AND LATERALS BEFORE SAND AND GRAVEL WERE PUT IN.

This photo shows the main collector and laterals before support gravel and filter sand were added. Photo by Bureau of Filtration, city of Pittsburgh, PA.

11

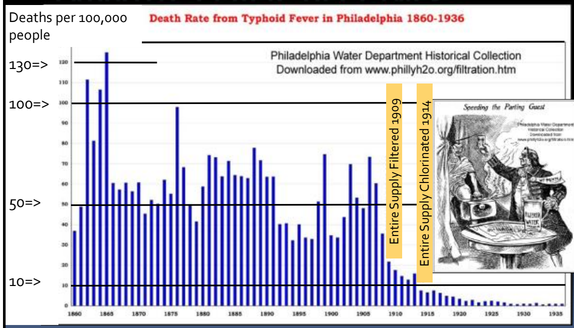
CLEANING - PHILADELPHIA, PA 1900

Between 1900 and 1911, Philadelphia, PA constructed 5 slow sand plants like the one shown above. This photo shows a filter scraping in progress.


PHILADELPHIA FILTRATION PLANTS.

12

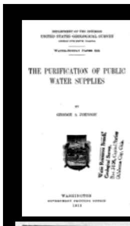
TYPHOID FEVER DECLINES



Reductions in Typhoid Fever due to filtration (1909) and disinfection (1914).

13

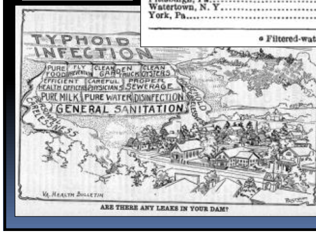
MORE REDUCTIONS IN TYPHOID FEVER



Death rate from typhoid fever per 100,000 population in cities using filters.

City.	Kind of filter.	Plant completed.	Years, in average— Before filtration.	Years, in average— After filtration.	Typhoid-fever death rate— Before filtration.	Typhoid-fever death rate— After filtration.
Albany, N. Y.	Slow	1899	10	10	90	21
Binghamton, N. Y.	Rapid	1902	5	5	47	15
Cincinnati, Ohio	Rapid	1908	4	2	50	13
Columbus, Ohio	Rapid	1908	11	2	78	15
Lawrence, Mass.	Slow	1893	7	15	114	25
Paterson, N. J.	Rapid	1902	5	8	32	10
Pittsburgh, Pa.	Slow	1907	8	3	133	a 26
Watertown, N. Y.	Rapid	1904	5	5	100	38
York, Pa.	Rapid	1899	2	8	76	22

a Filtered-water section. Allegheny not included.



Death rates from typhoid fever for the cities shown dropped an average of 73% once filtration was installed. The 3 cities that installed slow sand experienced an average drop in the death rate of 78%.

Source: *Water-Supply Paper 13*. USGS 1913.

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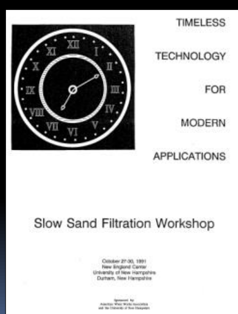
REVIVAL IN THE EARLY 1990'S

Proven technology in use in the U.S. Since 1872 (Poughkeepsie, NY)

Walla Walla, WA

Jewell SD#8, OR



2-log to 4-log removals of bacteria, viruses, and cysts for mature sand bed conditions (Hendricks, 1991)

15

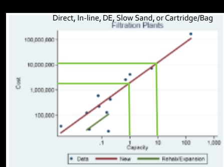
1995 GUIDELINES BY USEPA

Chapter 3 Slow Sand Filtration (EPA, 1995)	
Min # of Filters	3 (allows for 1 out of service)
Filtration Rate	0.1 – 0.2 m/hr (0.04 – 0.08 gpm/ft²)
Sand Effective Size (d_{10})	0.15 – 0.35 mm
Uniformity Coefficient (UC)	< 3 (little added benefit for cost if < 1.5)
Scraping depth	10-15 mm (0.4 – 0.6 in)
Ripening Period	1 – 2 days
Min Bed Depth	12 inches (prior to re-sanding)

16

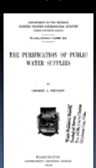
COST EFFECTIVE

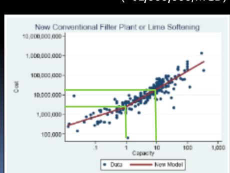
Inexpensive Design & Construction

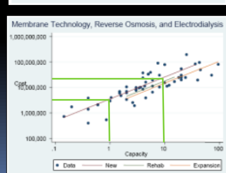


$24,000/MGD in 1913

2007 Infrastructure Needs Survey Project Cost Models (~$1,000,000/MGD)







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SIMPLE TO OPERATE

Simple to operate/maintain

Frequency	Labor (person hours)	Slow Sand Filter Maintenance Task
Daily	1 - 3	✓Check raw water intake ✓Check/adjust filtration rate ✓Check water level in filter ✓Check water level in clear well ✓Sample & check water quality (raw/finished NTU, raw temp) ✓Check pumps ✓Enter observations in logbook
Weekly	1 - 3	✓Check & grease any pumps & moving parts ✓Check/re-stock fuel ✓Sample & check water quality (coliform) ✓Enter observations in logbook
1 – 2 months	5 / 1,000 ft² 50 / 1,000 ft² /12 inches of sand for re-sanding (Letterman & Cullen, 1985)	✓Scrape filter beds ✓Wash scrapings & store retained sand ✓Check & record sand bed depth ✓Enter observations in logbook

Frequency and tasks are adapted from WHO, 1996. *Fact Sheets on Environmental Sanitation, Fact Sheet 2.12: Slow Sand Filtration*

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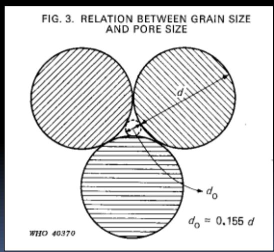
REMOVAL MECHANISMS

So what makes them effective at filtration?

More than just physical straining at work.



Particulate	Diameter (d_o = 0.155d)	Grain Diameter Needed for Straining Alone (d)
Colloids	0.1 µm	0.000645 mm
Bacteria	15 µm	0.0968 mm
Giardia	10 µm	0.0645 mm
Crypto	5 µm	0.0323 mm

Slow Sand Media	Range
D10	0.15 - 0.35 mm
D60	0.3 - 0.7 mm
UC (D60/D10)	1.5 – 3.0
Pore size	~ 60 µm (WHO, 2003)

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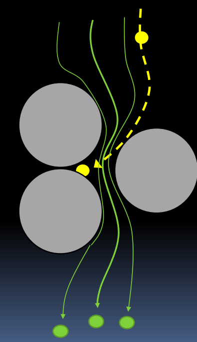
REMOVAL MECHANISMS



Other removal mechanisms are at work.

Sand grains 0.5-1.0 mm in diameter can remove bacteria with sizes of 0.001 mm through physical processes (transport and attachment due to electrical and molecular forces)

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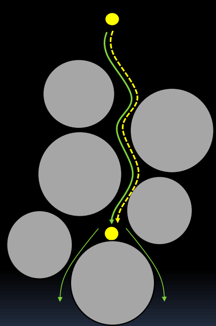
REMOVAL MECHANISMS – FLOW SPLITTING

Flow splitting increases the chance that particles will collide with sand grains.

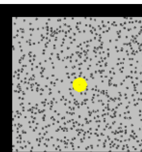
Flow splitting increases with smaller sand grain size.

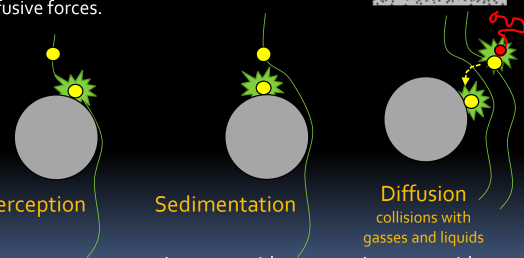


21

η REMOVAL MECHANISMS - COLLISION PROBABILITY

Particles are carried or transported by stream flows to sand grains and are either intercepted, settle out, or collide through diffusive forces.





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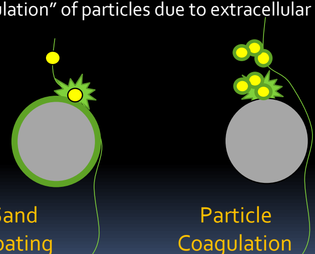
α REMOVAL MECHANISMS - ATTACHMENT

Whether particles attach to grains depends on:

1. Coating of the sand grains due to biofilm development; and
2. "Coagulation" of particles due to extracellular enzymes



With newly sanded filters, coliform removals are near zero (α ~ 0). After the filter matures, removals range from 99 – 99.99% (α ~ 1).

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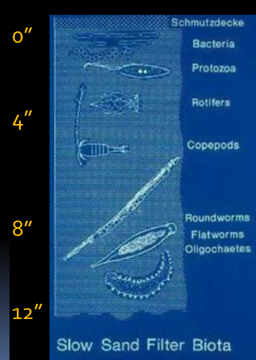
REMOVAL MECHANISMS - BIOTA

- Schmutzdecke – Top
- 1"-4" Bacteria, Protozoa, Rotifers
- 4" – 8" Copepods
- 8" – 12" Roundworms, Flatworms, & Oligochaetes (segmented worms)



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REMOVAL MECHANISMS

Although sometimes seen as a nuisance, the presence of midge flies can improve performance by keeping head loss in check.

6 Chironomid midges: the forgotten water industry engineers?

S.P. Hurley* and R.S. Wotton**

*Research & Development, Thames Water Utilities Ltd, Kempton Park AWT, Feltham Hill Road, Hanworth, TW13 6XH, U.K.
**Department of Biology, UCL, Gower Street, London WC1E 6BT, U.K.

Abstract Slow sand filters appear simple, yet their efficient functioning is dependent on extensive microbial and invertebrate communities, with chironomid midges often the most conspicuous organisms. Known to package material, they may occur in huge numbers and can be regarded as biological engineers. A series of trials demonstrated that midge larvae have a consistent effect on headloss development in pilot scale filters. It is suggested that the larvae reduce blockage at the filter surface through their burrowing action and by the packaging of materials, both the compacting of small food particles into larger faecal pellets and the production of silk dwelling tubes which become covered in adsorbed detritus and dissolved organic matter.

Midge Fly & Larvae
(Diptera: Chironomidae)

Burrowing reduces head loss. Silk dwelling tubes become covered with adsorbed detritus and dissolved organic matter

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REMOVAL MECHANISMS

	Primary Mechanism	Depth	Activity
Headwater	Sedimentation	Headwater (within the 39-59" (1-1.5 m) water column above the media)	Heavier particles settle out and lighter particles acquiesce. Algae absorb carbon dioxide, nitrates, phosphates, and other nutrients to form cell material and oxygen. The oxygen produced by algae reacts with organic matter to make it more assimilable for other organisms.
Schmutzdecke	Biological	Schmutzdecke ("dirt blanket")	Filamentous algae, plankton, protozoa, rotifers, bacteria, and diatoms work to break down organic matter and dead algae cells forming simple inorganic salts. Nitrogenous compounds are broken down, nitrogen is oxidized to form nitrates, and some color is removed.
12-16"	Biochemical	Below a depth of 12-16" (30-40 cm) from the top of the sand bed	Bacteriological activity is small, but biochemical activity consists of converting amino acids (microbiological degradation products) to ammonia, nitrites, and nitrates (nitrification). (WHO, pg 32)
16-24"	Adsorption	Down to 16-24" (40-60 cm) in depth	Electrical forces, mass attraction, and chemical bonds contribute to adsorption of particulates.

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FACTORS AFFECTING REMOVAL

Schmutzdecke biological removal mechanisms

Effectiveness relies on:

1. Wet sand (to keep microbes alive)
2. Adequate food (organic mater supplied by continuous inflow of raw water)
3. High enough oxygen content (above 3 mg/l in the filter effluent) in order for metabolism of biodegradable compounds and avoid anaerobic decomposition, which can release hydrogen sulfide, ammonia, and other taste and odor causing compounds.

Oxygen levels can be maintained by:

- Continuous raw water influent
- Aeration

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SLOW SAND PERFORMANCE

Water Quality Paramenter	Removal Capacity
Turbidity	<1.0 NTU
Coliforms	1-3 log units
Enteric Viruses	2-4 log units
Giardia Cysts	2-4+log units
Cryptosporidium Oocysts	>4 log units
Dissolved Organic Carbon	<15-25%
Biodegradable	
Dissolved Organic Carbon	<50%
Trihalomethane Precursors	<20-30%
Heavy Metals	
Zn, Cu, Cd, Pb	>95-99%
Fe, Mn	>67%
As	<47%

Expected log removal efficiencies for slow sand filtration.

Source: Adapted from Collins, M.R. 1998.
http://www.nesc.wvu.edu/ndwc/pdf/OT/TB/TB14_slowsand.pdf

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SLOW SAND PERFORMANCE

Failing (minimum) and optimal (maximum) pathogen log removal efficiencies for various filtration technologies.

Table 7.7 Reductions of bacteria, viruses and protozoa achieved by water treatment technologies at drinking-water treatment plants for large communities

Treatment process	Enteric pathogen group	Minimum removal (LRV)	Maximum removal (LRV)	Notes
Filtration				
Granular high-rate filtration	Viruses	0	3.5	Depends on filter media and coagulation pretreatment
	Bacteria	0.2	4.4	
	Protozoa	0.4	3.3	
Slow sand filtration	Viruses	0.25	4	Depends on presence of schmutzdecke, grain size, flow rate, operating conditions (mainly temperature, pH)
	Bacteria	2	6	
	Protozoa	0.3	> 5	
Precoat filtration	Viruses	1	1.7	If filter cake is present
	Bacteria	0.2	2.3	Depends on chemical pretreatment
	Protozoa	3	6.7	Depends on media grade and filtration rate
Membrane filtration: microfiltration, ultrafiltration, nanofiltration reverse osmosis	Viruses	< 1	> 6.5	Varies with membrane pore size (microfilters, ultrafilters, nanofilters and reverse osmosis filters), integrity of filter medium and filter seals, and resistance to chemical and biological ("grow-through") degradation
	Bacteria	1	> 7	
	Protozoa	2.3	> 7	

WHO Min – Max Removal
Viruses: 0.25 – 4 log
Bacteria: 2 – 6 log
Protozoa: 0.3 – 5+ log

Depends on:
1. Schmutzdecke
2. Sand grain size
3. Flow rate
4. Temp and pH

Source: Guidelines for Drinking-Water Quality, Fourth Edition. World Health Organization, 2011

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CRITICAL VARIABLES THAT CAN IMPACT PERFORMANCE

Critical Variables

1. Raw water characteristics (temperature, particle characteristics, color, algae, nutrients, organic compounds, oxygen content).
2. Sand size (d_{10}) and uniformity coefficient (UC)
3. Flow control and air binding
4. Head loss allowed
5. Sand bed depth
6. Filtration rate and variability
7. Maturity of the sand bed and biological organisms
8. Filter cleaning (frequency, length of time the filter is out of operation, ripening period)

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RAW WATER - IRON & MANGANESE

Iron and Manganese

Iron and Manganese both < 1 mg/l

1. Slow sand filters remove iron and manganese by precipitation at the sand surface. This can enhance organics removal, but too much iron and manganese precipitate can clog the filters.
2. Some slow sand filters have been specifically designed and installed to remove iron and manganese at levels higher than 1 mg/l, with removals as high as > 67%.

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RAW WATER - ORGANICS

Organic Matter:

1. The removal of natural organic matter (NOM) is related to filter biomass in that NOM removal increases with increasing biomass concentrations in the filter.
2. For every 1 mg of carbon removed by the schmutzdecke, 0.04 mg of nitrogen and 6 micrograms of phosphorous are required (Skeat, 1961).
3. SSF also have the ability to remove up to 3 mg/L of ammonia from source water as it is used by algae as a source of nitrogen.
4. SSF can remove between 14 and 40% of Assimilable Organic Carbon (AOC) averaging 26% AOC removal (Lambert and Graham, 1995)

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RAW WATER - BACTERIA

Bacteria:

The net accumulation of bacteria in porous media is controlled by:

1. DOC and phosphorous concentrations needed to promote growth;
2. Substrate utilization (bacteria need a substrate to cling to - a smaller effective sand size provides more attachment points). Organic carbon exudates produced by algae also produce a substrate for bacterial growth.
3. Deposition (bacteria coming into contact with the substrate)
4. Decay (end of life cycle)
5. Detachment (detachment increases at higher filtration rates or if scouring occurs at filter bed influent and other turbulent areas)

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RAW WATER – BACTERIA, CONT.

Bacteria, continued:

1. Bacterial growth is also influenced by assimilable organic carbon (AOC) exuded by algae (decomposition)
2. AOC of at least 10 µg of carbon/liter is needed to promote heterotrophic bacteria growth.
   - Rivers typically have AOC of 123 µg C/l.
   - Coliform bacteria need AOC of 50 µg C/l.
   - AOC is typically 10% of TOC (LeChevallier et al. 1991)

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RAW WATER - PROTOZOA

Protozoa:

1. Graze on algae, bacteria, and sometimes smaller protozoa
2. Temperature increases grazing.
3. Most are obligate aerobes (DO is critical)
4. Algae provide assimilable nutrients
   - Higher assimilation from algae than detritus and bacteria
   - Lower assimilation from blue-green algae (cyanobacteria)

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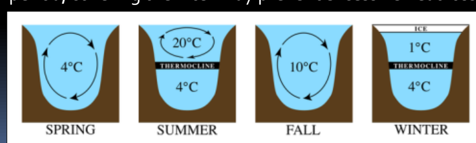
RAW WATER - TEMPERATURE

Temperature:

1. Temperature impacts microbial growth in slow sand filters
2. Microbial growth occurs in the range of 10 – 45°C (outside of this range, growth ceases)
   - Minimum range is 10 – 15°C
   - Max range is 35 – 45°C
   - Optimum range is 24 – 40°C
3. When air temperature drops to below 2°C for any prolonged period, covering the filter may prevent excessive heat loss.



Seasonal Lake Turnover

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RAW WATER – TEMPERATURE, CONT.

Temperature Continued:

Open filters should not be used where temperatures can drop below freezing.

VIBRIO CHOLERAE

Surface-water sources should generally be considered to be susceptible to faecal contamination and, therefore, to contamination by *V. cholerae*. However, the organism can be easily eliminated from drinking-water by appropriate treatment. It has long been accepted that slow sand filtration is effective for removal of *V. cholerae* during drinking-water treatment. The biological processes that are responsible for water purification occur more slowly at low temperatures, and ice formation on filter surfaces has been associated with unacceptable deterioration in effluent water quality. The use of open filters should therefore be avoided in regions where temperatures can drop below 0 °C.

G.B. Nair, National Institute of Cholera and Enteric Diseases, Calcutta, India

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RAW WATER – DISSOLVED OXYGEN

Dissolved Oxygen (DO):

1. DO above 3 mg/l in the filter effluent is a good indicator that aerobic conditions remain in the filter. Filter influent DO should be above 6 mg/l in order to ensure DO is present in the effluent.
2. Maintaining oxygen levels promotes metabolism of biodegradable compounds, prevents dissolution of metals, and avoids anaerobic decomposition, which can release hydrogen sulfide, ammonia, and other taste and odor causing compounds.
3. DO is critical for the survival of protozoa that graze on pathogens since most are obligate aerobes.
4. Oxygen levels can be maintained by:
   - Continuous raw water influent
   - Aeration

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RAW WATER – ALGAE

Algae:

Algae in influent water may be a different species than that of algae in the headwater above the filter bed.

2009. Cannon Beach, OR (filter is off-line)

2013. Lyons Mehama, OR

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RAW WATER – ALGAE, CONT.

Algae, continued:

2. Primary benefit to water purification is build-up of cell material through photosynthesis and metabolism of carbon dioxide, nitrates, phosphates, and other nutrients. Photosynthesis reaction is as follows:

6CO_2 Carbon Dioxide	+ 6H_2O Water	+ sunlight =>	$C_6H_{12}O_6$ Sugar	6O_2 Oxygen

The reverse reaction occurs when algal cells die and decompose (WHO, pp 34-35)

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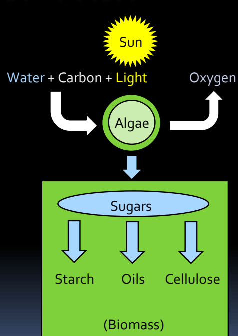
RAW WATER – ALGAE, CONT.

Algae, continued:

3. Algae increase oxygen content (keeping aerobic conditions in filter bed). If dissolved oxygen of the filtered water drops below 3 mg/l, this may signify anaerobic conditions in the filter bed, which could lead to the formation of hydrogen sulfide, ammonia, dissolved iron and manganese, and other taste and odor causing compounds (WHO, pp 32-33).



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RAW WATER CHARACTERISTICS

Algae, continued:

4. Algae decrease carbon dioxide. If too much carbon dioxide is decreased (e.g. during algal blooms), this may cause bicarbonates to dissociate to insoluble carbonates and carbon dioxide. The lowering of the bicarbonate content will cause a decrease in the temporary hardness and will cause the insoluble carbonate to precipitate out, clogging the filter. Reaction is as follows:

$Ca(HCO_3)_2 \Rightarrow CaCO_3 + CO_2 + H_2O$

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RAW WATER CHARACTERISTICS

Algae, continued:

5. When filamentous algae predominate, a zoogleal mat is formed that contains tightly woven filaments giving the mat high tensile strength (high enough that the Schmutzdecke mat can be rolled up in some cases). When sunlight is strong and able to reach the mat layer (dependent upon the clarity of headwater), oxygen bubbles can form within and under the mat, increasing its buoyancy, reducing the filter resistance and increasing the filtration rate.

6. When diatomaceous algae predominate, the filter resistance and clogging increases due to their hard inorganic shells. Diatoms generally increase in number in late winter, often with 2-3 additional blooms occurring during the spring.

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RAW WATER – ALGAE, CONT.

Algae, continued:

Algae < 200,000 cells/L (depending upon type)

- Filamentous may improve filtration
- Diatomaceous algae can cause severe plugging
- Floating algae does not generally cause clogging, but can lead to poor filter effluent quality

Classification of Algal Species[1]

Filter Clogging[2]	Filamentous	Floating
1. Tabellaria	1. Hydrodictyon	1. Protoccous
2. Asterionella	2. Oscillaria[3]	2. Scenedesmus
3. Stephanodiscus	3. Cladophora	3. Symara
4. Synedra	4. Aphanizomenon	4. Anaboena[3]
	5. Melosira	5. Euglena

[1]Table adapted from Table 10.2 Water Treatment Plant Design, AWWA/ASCE/EWRI, 2012
[2]Diatoms of all species can generally cause clogging due to their rigid inorganic shells
[3]Can also release algal toxins (Microcystin and Anatoxin-a, among others)

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RAW WATER – ALGAE, CONT.

Filter clogging algae

Dinobryon (1,500x)
Chlorella (5,000x)
Synedra (500x)
Melosira (1,000x)
Navicula (1,500x)
Cyclotella (1,500x)
Oscillatoria (500x)
Sprogyra (125x)
Trachelomonas (1,500x)
Fragilaria (1,000x)
Anabaena (500x)

Anacystis (1,000x)
Cymbella (1,500x)
Tribonema (500x)
Closterium (250x)
Rivularia (250x)
Tabellaria (1,500x)
Asterionella (1,000x)
Palmella (1,000x)
Diatoma (1,500x)

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HARMFUL ALGAE BLOOMS (CYANOBACTERIA)

WHAT IS THIS STUFF?

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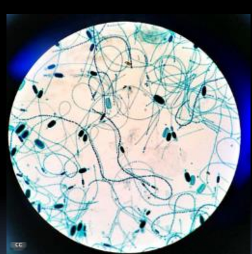
CYANOBACTERIA

Cyanobacteria (blue-green algae)

- A phylum of bacteria
- Obtain energy through photosynthesis
- "cyanobacteria" comes from the color of the bacteria (Greek: κυανός (kyanós) = blue).
- Produce oxygen as a byproduct of photosynthesis (converting reducing to oxidizing environment)



Photomicrograph of cyanobacteria, Cylindrospermum.
Photo taken by Matthew Parker.

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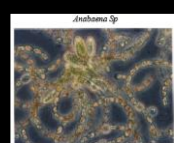
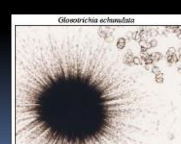
COMMON GENERA

Cyanobacteria Common in Oregon





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CYANOTOXINS

Cyanobacteria:

- May produce toxins that can be harmful
- Occur in warm, slow moving water
- Increasing in frequency and duration
  - happening more or better reporting?
  - more people, more nutrients, warmer water
- No known human deaths in United States; known dog deaths in Oregon
- Guidance and monitoring requirements are available on our website:

  www.healthoregon.org/dwcyanotoxins

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COMMON CYANOTOXINS

Type of Algae	Toxin Produced	Type of Toxin
Dolichospermum (formerly Anabaena)	Anatoxin, Saxitoxin	Neurotoxin
	Microcystin, Cylindrospermopsin	Hepatotoxin
Planktothrix (Oscillatoria)	Anatoxin	Neurotoxin
	Microcystin	Hepatotoxin
Cylindrospermopsis	Cylindrospermopsin	Hepatotoxin
Gloeotrichia	Microcystin	Hepatotoxin
Microcystis	Microcystin	Hepatotoxin

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Cyanotoxins	Hepatotoxins (Liver Toxins)			Neurotoxins (Nervous System Toxin)					Skin Irritants		
Cyanobacterial Genera	Microcystin	Nodularin	Cylindrospermopsin	Anatoxin-a	Anatoxin-a(s)	Homoanatoxin-a	Saxitoxin	N-methylamino-L-alanine	Aplysiatoxin	Lipopolysaccharides	Lyngbyatoxin
Anabaenopsis	+									+	
Aphanizomenon (except A. flos-aquae)			+	+			+			+	
Arthrospira	+									+	
Cyanobium	+									+	
Cylindrospermopsis			+				+			+	
Dolichospermum (formerly Anabaena)	+		+	+	+		+	+		+	
Gloeotrichia	+									+	
Hapalosiphon	+									+	
Limnothrix	+									+	+
Lyngba							+		+	+	
Microcystis	+			+				+		+	
Nodularia		+								+	
Nostoc	+							+		+	
Oscillatoria	+			+		+			+	+	+
Phormidium	+			+						+	
Planktothrix	+			+		+	+			+	
Raphidiopsis			+	+		+				+	
Schizothrix								+	+	+	+
Synechocystis	+									+	
Umezakia			+							+	

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CYANOBACTERIA BLOOMS – CAN BE EXTENSIVE

Lake Erie – 2012 Bloom

Credit: MERIS/NASA; processed by NOAA/NOS/NCCOS

Cyanobacteria blooms can be extensive

In addition to meteorological conditions, other factors contribute to Lake Erie blooms. Chief among them is the widespread adoption, since the mid-1990s, of no-till farming and other agricultural practices that have increased the availability of a type of phosphorous, known as dissolved reactive phosphorous or DRP, that promotes cyanobacteria growth.

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CYANOBACTERIA BLOOMS CAN WORSEN WITH THE PRODUCTION OF TOXINS

Lake Erie – 2012 Bloom (1/6 the size of 2011)

Lake Erie – 2011 Bloom

The 2011 Lake Erie bloom was composed almost entirely of toxic blue-green Microcystis algae. Concentrations of microcystin, a liver toxin produced by the algae, peaked at about 224 times World Health Organization guideline of 1 µg/l.

Credit: MERIS/NASA; processed by NOAA/NOS/NCCOS

http://www.ns.umich.edu/new/releases/21342-record-breaking-2011-lake-erie-algae-bloom-may-be-sign-of-things-to-come

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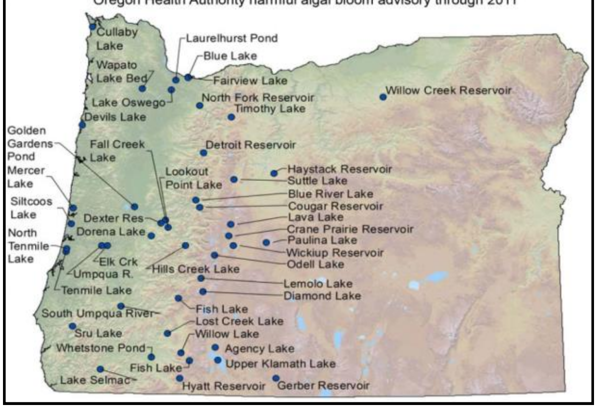
Lakes, reservoirs, rivers and creeks that had an Oregon Health Authority harmful algal bloom advisory through 2011



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2013 Cyanobacteria Bloom Recreational Advisory Information

Waterbody	County	Dominant Species/ Toxin	Cell Count (cells/ml) / Level (ppb)	Start Date	End Date	Duration (days)
Willow Creek Reservoir	Morrow	Anabaena flos-aquae	3,551,625	6/18/2013	8/13/2013	56
Lost Creek Lake	Jackson	Anabaena flos-aquae	1,175,333	6/20/2013	7/05/2013	15
Dexter Reservoir	Lane	Anabaena flos-aquae	2,228,000	7/03/2013		
Dorena Reservoir	Lane	Anabaena flos-aquae	556,000	7/25/2013		
Devils Lake	Lincoln	Microcystis	Unknown	8/01/2013		
Blue Lake	Multnomah	Visible Scum	Unknown	8/06/2013	8/09/2013	3
Fern Ridge Reservoir	Lane	Visible Scum	Unknown	8/15/2013		

Source: http://healthoregon.org/hab/

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CYANOBACTERIA BLOOMS – IDENTIFICATION

What does a cyanobacteria bloom look like?

Cyanobacterial accumulation at Binder Lake, IA, dominated by *Microcystis sp.*

Total microcystin concentrations were 40 µg/L measured by enzyme-linked immunosorbent assay. Date 6-29-06. Credit: U.S. Geological Survey Department of the Interior/USGS U.S. Geological Survey photographer Dr. Jennifer L Graham.

Source: http://toxics.usgs.gov/highlights/algal_toxins/

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CYANOBACTERIA BLOOMS – EXAMPLE 1

You may notice a green, red or brown film

Location: Mozingo Lake, MO, USA
Credit: U.S. Geological Survey Department of the Interior/USGS U.S. Geological Survey/photo by Dr. Jennifer L. Graham , U.S. Geological Survey

Source: http://gallery.usgs.gov/tags/Cyanobacteria

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CYANOBACTERIA BLOOMS – EXAMPLE 2

Location: Lake Dora, FL, USA
Credit: U.S. Geological Survey Department of the Interior/USGS U.S. Geological Survey/photo by Nara Souza , Florida Fish & Wildlife

Source: http://gallery.usgs.gov/tags/Cyanobacteria

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CYANOBACTERIA – EXAMPLE 3

Location: Upper Klamath Lake
Aphanizominon flos-aquae (AFA) bloom in 2008. Although AFA blooms are not considered harmful, the microcystis that sometimes accompanies AFA later in the summer can produce toxins.

Source: http://pubs.usgs.gov/fs/2009/3111/

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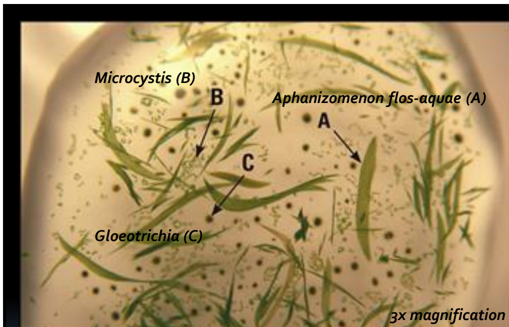

Lake water subsample containing colonies of Aphanizomenon flos-aquae (A), Microcystis (B), and Gloeotrichia (C). Although Aphanizomenon flos-aquae does not produce toxins, Microcystis and Gloeotrichia can both produce the hepatoxin mycrocystin. Magnification = 3×. Photograph by Sara Eldridge, U.S. Geological Survey..

Source: http://pubs.usgs.gov/fs/2009/3111/

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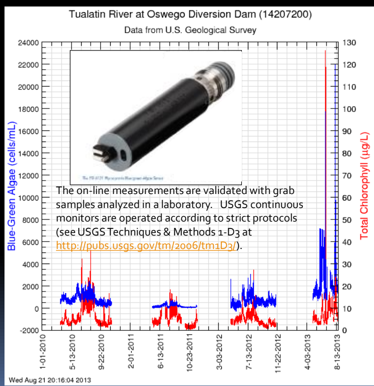
Total Chlorophyll

Total chlorophyll and blue-green algae concentrations from the Oswego Diversion Dam located in the Tualatin River at river mile 3.4. 1/1/2010 – 8/21/13

The blue-green algae data at the Oswego Dam site is collected with a YSI model 6131 probe. Chlorophyll is monitored with a YSI model 6025. More info on YSI probes is on-line at: http://www.ysi.com



Source: http://or.water.usgs.gov/cgi-bin/grapher/graph_setup.pl?basin_id=tualatin

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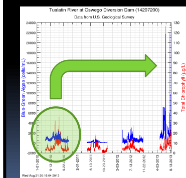
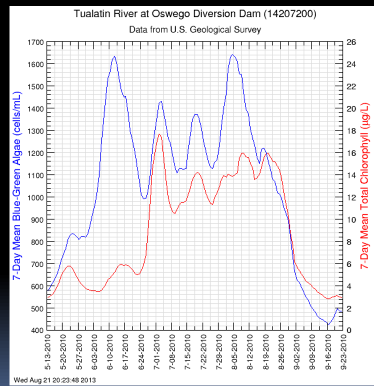
7-day moving average total chlorophyll & blue-green algae

(concentrations from the Oswego Diversion Dam located in the Tualatin River at river mile 3.4. 5/13/2010 – 9/22/10)





Source: http://or.water.usgs.gov/cgi-bin/grapher/graph_setup.pl?basin_id=tualatin

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MINIMIZING BLOOMS

How do I minimize cyanobacteria blooms?

Source Water Management (long-term & lasting)

Control Factors Affecting Growth

- Minimize phosphorus (P) through use reductions & source control from erosion. Target: <15-40 ppb Total Phosphorus
- Other Nutrients (Nitrogen)
- Temperature (shading riparian areas)
- Mixing/Stratification (e.g., SolarBee®)
- Sunlight (covers or floating materials or aquatic dyes)

SolarBee® on raw water impoundment for City of Seaside =>

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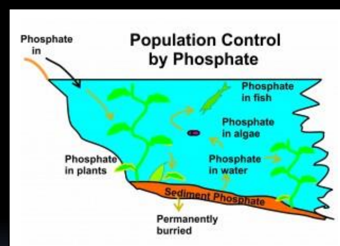
PHOSPHORUS CONTROL

Phosphorus Control

Target:
<15-40 ppb TP



The reduction of phosphorus loading is the most effective means of reducing phytoplankton biomass in eutrophic lakes, even if Nitrogen is initially limiting. (Lewis and Wurtsbaugh, 2008, Schindler et al, 2008).

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MINIMIZING BLOOMS

Are there other ways to control blooms?

Non-chemical

1. Non-chemical options:
   - Barley straw (fungi decompose straw releasing chemicals that prevent algae growth)
   - Raking (physical removal of algae mats)

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OTHER BLOOM CONTROLS

Other measures can include

- Algaecides (not during a bloom)
  - Copper-based (cupric)
  - Peroxides (e.g. GreenClean Pro)
  - Follow manufacturer's instructions
- Treatment (roughing filters, GAC, PAC, Ozone)

  (Plan review & approval is needed for treatment)

DETERMINING WATER VOLUME

Measure length (L), width (W), and average depth (D) in feet (ft) or meters (m) and calculate volume using one of the following formulas:

1 acre-foot of water =
208.7 ft long x 208.7 ft. wide x 1 ft. deep
43,560 ft.³ = 325,851 gal. = 2,780,000 lbs.

$$\frac{\text{Avg. L (ft) x Avg. W (ft) x Avg. D (ft)}}{43{,}560} = \text{acre-feet of water}$$

Applications Rates	Heavy Algae Growth	Low Algae Growth/ Maintenance
Granular: Large Volume For example: Lakes, Ponds, Lagoons.	**20-90 pounds** of GreenClean Pro Granular Algaecide per acre-foot of water -or- **50-250 pounds** of GreenClean Pro Granular Algaecide per million gallons of water.	**2-9 pounds** of GreenClean Pro Granular Algaecide per acre-foot of water -or- **5-25 pounds** of GreenClean Pro Granular Algaecide per million gallons of water.

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EFFECTIVENESS OF SLOW SAND

Effectiveness of Slow Sand Filtration:

Cyanobacteria Cell and Toxin Removal Efficiency of Various Filtration Technologies		
Slow Sand	~ 99% cell removal with low lysis of cells (cell breakage), reducing toxin release	Efficiency of dissolved microcystin is likely to depend on biofilm formation and filter run length, but is anticipated to be significant
Membrane	> 99% cell removal (low lysis)	Depends upon size of membrane pores and toxin molecule
Conventional & Direct Filtration	70-100% (CF, low lysis) > 80% (DF, low lysis)	< 10% of toxins

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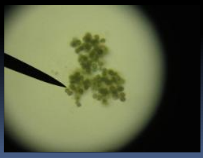
IN THE EVENT OF A BLOOM

In the event of a cyanobacteria bloom…

- Consider monitoring toxins
- Do not add algaecide
  (lysed cells can release 50-95% of the toxins)
- Do not use oxidants like chlorine prior to filtration
  (lyses cells)
- Use alternate source if possible
- Slow filtration rate if possible
- Use GAC if available



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TOXIN LIMITS

Toxin Limits in Finished Water:

Toxins should not exceed those listed in the table below. If they do, consult with the State.

Cyanotoxin	For Vulnerable People (ppb)	For Age 6 and Above (ppb)
Total Microcystins	0.3	1.6
Cylindrospermopsin	0.7	3

Utilities are required to communicate the risks to customers should finished water toxins exceed these levels.

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CYANOBACTERIA RESOURCES

Oregon Health Authority – Drinking Water Services (OHA-DWS)
www.healthoregon.org/dwcyanotoxins

Oregon Health Authority – Recreational Surveillance Program
www.healthoregon.org/hab

Oregon Department of Environmental Quality (DEQ)
https://www.oregon.gov/deq/wq/Pages/Harmful-Algal-Blooms.aspx

Washington Dept of Ecology
http://www.ecy.wa.gov/programs/wq/plants/algae/lakes/controloptions.html

USGS
https://toxics.usgs.gov/highlights/algal_toxins/algal_faq.html

USEPA
https://www.epa.gov/nutrient-policy-data/monitoring-and-responding-cyanobacteria-and-cyanotoxins-recreational-waters

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APPLIED WATER CHARACTERISTICS RECOMMENDED FOR SLOW SAND FILTRATION

Recommended Applied Water Quality (following any pre-treatment)		
Turbidity	< 10 NTU (colloidal clays are absent)	Operation is more efficient with lower, consistent turbidity in the 5-10 NTU range. Most slow sand plants successfully treat source water with a turbidity of less than 10 NTU (Slezak and Sims, 1984), which is recommended for an upper limit in designing new facilities. Colloidal clays may penetrate deeper into the filter bed causing long-term clogging and higher effluent turbidity. Effluent turbidity is typically < 1.0 NTU. Roughing filters can provide up to 50-90% of turbidity removal.

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APPLIED WATER CHARACTERISTICS RECOMMENDED FOR SLOW SAND FILTRATION

Recommended Applied Water Quality (following any pre-treatment)		
True Color	< 5 platinum color units	The source of color should be determined. Color from iron or manganese may be more effectively removed than color from organics. The point of consumer complaints about water aesthetics is variable over a range from 5 to 30 color units, though most people find color objectionable over 15 color units (USEPA). The secondary Standard for color is 15 color units, which is also identified as a maximum level for slow sand filtration under the Recommended Standards for Water Works, 2012 Edition. True color removals of 25% or less were reported by Cleasby et al. (1984). Pre-ozonation or granular activated carbon may be used to reduce color.
Coliform Bacteria	< 800 /100 ml (CFU or MPN)	Coliform removals range from 1 to 3-log (90 - 99.9%) (Collins, M.R. 1998).

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APPLIED WATER CHARACTERISTICS RECOMMENDED FOR SLOW SAND FILTRATION

Recommended Applied Water Quality (following any pre-treatment)		
Dissolved Oxygen (DO)	> 6 mg/l (filtered water DO should be ≥ 3 mg/l)	Dissolved oxygen is critical for maintaining a healthy schmutzdecke for proper filtration. Potential problems resulting from low DO include tastes and odors, dissolution of precipitated metals such as iron and manganese, and increased chlorine demand (Ellis, 1985).
Total Organic Carbon (TOC)	≤ 3.0 mg/l (low TOC to prevent DBP issues)	TOC removal is variable and ranges from 10 – 25% (Collins et. al, 1989; Fox e al, 1994). About 90% of TOC is Dissolved Organic Carbon (DOC). DOC removal is < 15-25% (Collins, M.R. 1989). Determining DBP formation potential may provide additional information by simulating DBP formation in the distribution system due to the addition of disinfectants in the presence of organics.

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APPLIED WATER CHARACTERISTICS RECOMMENDED FOR SLOW SAND FILTRATION

Recommended Applied Water Quality (following any pre-treatment)		
Iron & Manganese	Each < 1 mg/l	Slow sand filters remove iron and manganese by precipitation at the sand surface. This can enhance organics removal, but too much iron and manganese precipitate can clog the filters. The Secondary Standard for iron is 0.3 mg/l and the Secondary Standard for manganese is 0.05 mg/l. Iron and Manganese removal can be > 67% (Collins, M.R. 1998).

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APPLIED WATER CHARACTERISTICS RECOMMENDED FOR SLOW SAND FILTRATION

Recommended Applied Water Quality (following any pre-treatment)		
Algae	< 200,000 cells/L (depends upon type)	Certain types of filamentous algae are beneficial for filtration by enhancing biological activity by providing greater surface area for particle removal, but in general, the presence of algae reduces filter run length. Filter clogging species are detrimental to filtration and the presence of floating species may shorten filter run length due to the associated poorer-quality raw water. Microscopic identification and enumeration is recommended to determine algae species and concentration.

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APPLIED WATER CHARACTERISTICS RECOMMENDED FOR SLOW SAND FILTRATION

Summary Recommended Applied Water Quality (following any pre-treatment)	
Turbidity	< 10 NTU (colloidal clays absent)
True Color	< 5 platinum color units
Coliform Bacteria	< 800 CFU or MPN/100 ml
Dissolved Oxygen (DO)	> 6 mg/l (DO ≥ 3 mg/l in filter effluent)
Total Organic Carbon (TOC)	≤ 3.0 mg/l (<2.5 – 3.0 mg/l DOC) (low TOC/DOC to prevent DBP issues)
Iron & Manganese	Each < 1 mg/l
Algae	< 200,000 cells/L (depends upon type)

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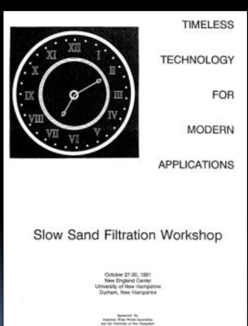
QUESTIONS?




2009. Jewell School District #8, OR. "Blue Future" covered filter (left) and raw water control tank (right)


US Army Corps of Engineers photo of Washington DC McMillan Water Filtration Plant, a 25-acre, 75 MGD slow sand plant in use from 1905 – 1985

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