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

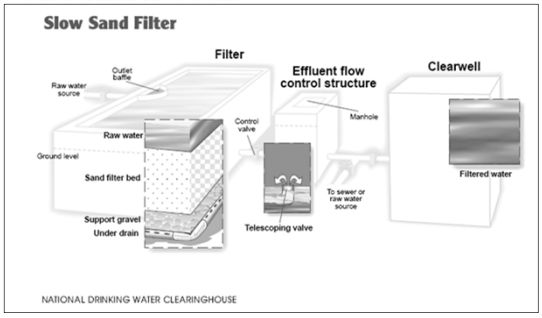
OUTLINE

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 Parameter	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%

INTRODUCTION



http://jica-net.jica.go.jp/lib2/o8PRDM007/en.html

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.

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.

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 .

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

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."

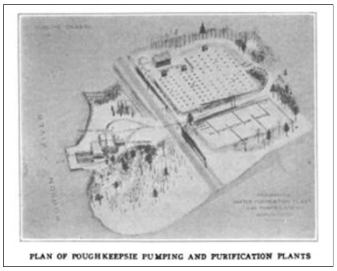
FIRST USED IN U.S. IN 1872

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"



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".

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.

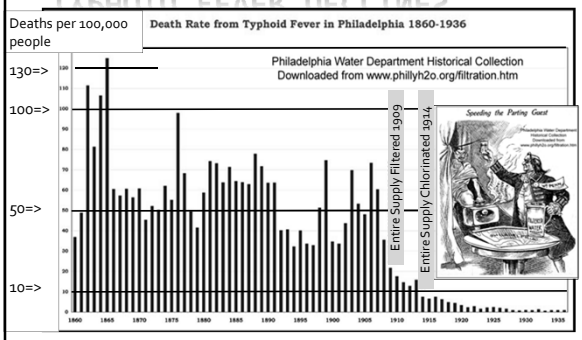
UNDER DRAINS – PITTSBURGH, PA

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.

CLEANING - PHILADELPHIA, PA 1900

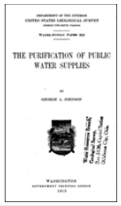
Between 1900 and 1911, Philadelphia, PA constructed 5 slow sand plants like the one shown above. This photo shows a filter scraping in progress.

TYPHOID FEVER DECLINES



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

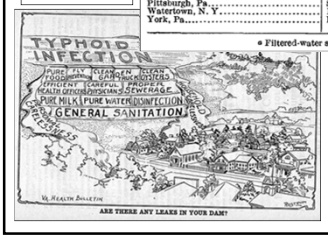
MORE REDUCTIONS IN TYPHOID FEVER



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	5	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 25
Watertown, N. Y.	Rapid	1904	5	5	100	28
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.

REVIVAL IN THE EARLY 1990'S

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

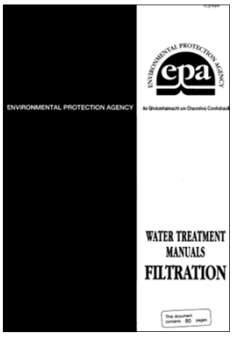
Walla Walla, WA

Jewell SD#8, OR

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

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 (d10)	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)



COST EFFECTIVE

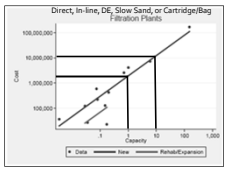
2007 Drinking Water Infrastructure Needs Survey and Assessment

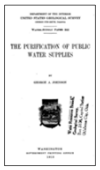
Modeling the Cost of Infrastructure

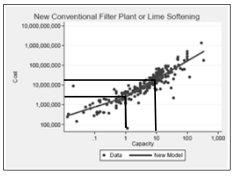
Inexpensive Design & Construction

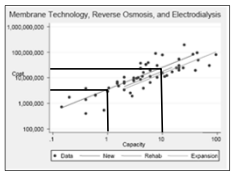
2007 Infrastructure Needs Survey Project Cost Models (~$1,000,000/MGD)

$24,000/MGD in 1913









SIMPLE TO OPERATE

Simple to operate/maintain

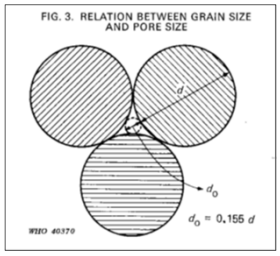
Frequency	Labor (person hours)	Slow Sand Filter Maintenance Task
Daily	1 - 3	✓Check raw water intake ✓Check/adjust filtration rate ✓Check water level in filter ✓Check water level in clear well ✓Sample & check water quality (raw/finished NTU, raw temp) ✓Check pumps ✓Enter observations in logbook
Weekly	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*

REMOVAL MECHANISMS

So what makes them effective at filtration?

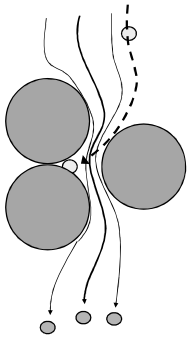
More than just physical straining at work.



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)

REMOVAL MECHANISMS



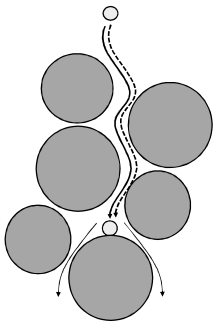
Other removal mechanisms are at work.

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)

REMOVAL MECHANISMS – FLOW SPLITTING

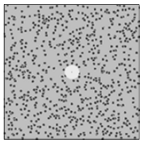
Flow splitting increases the chance that particles will collide with sand grains.

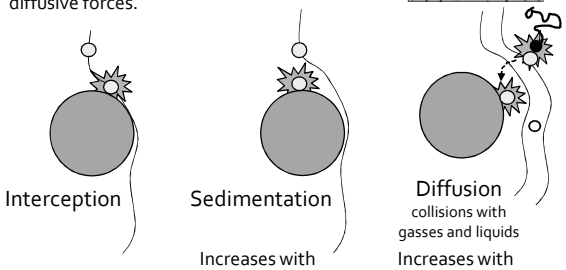
Flow splitting increases with smaller sand grain size.



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.





Interception

Sedimentation

Increases with lower flows

Diffusion

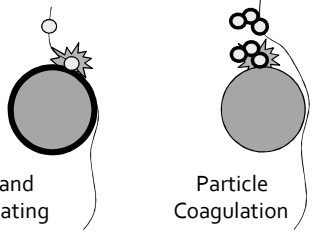
collisions with gasses and liquids

Increases with high temps & low flows

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



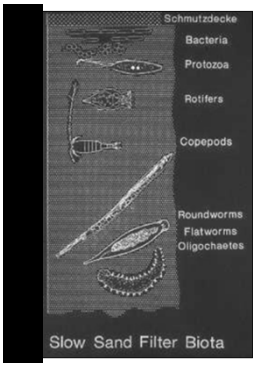
Sand Coating

Particle Coagulation

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

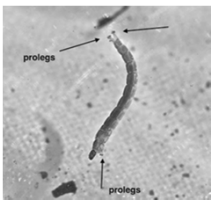
REMOVAL MECHANISMS - BIOTA

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



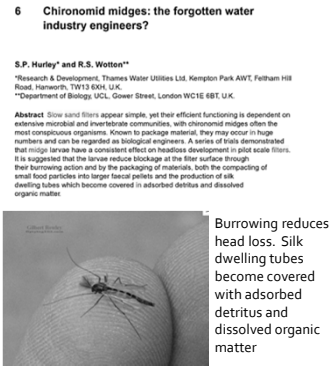
REMOVAL MECHANISMS

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



Midge Fly & Larvae

(Diptera: Chironomidae)



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.

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

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.

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 anearobic 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

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%

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

Expected log removal efficiencies for slow sand filtration.

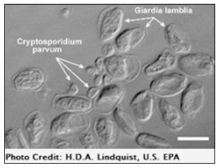


Photo Credit: H.D.A. Lindquist, U.S. EPA

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

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)

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%.

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)

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)

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)

RAW WATER - PROTOZOA

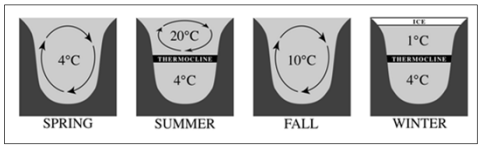
Protozoa:

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

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

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

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 anearobic 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

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)

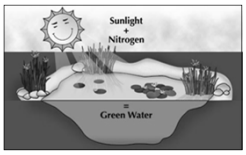
2013. Lyons Mehama, OR

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

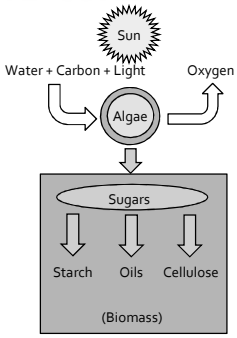


The reverse reaction occurs when algal cells die and decompose (WHO, pp 34-35)

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).



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:

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

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.

RAW WATER – ALGAE, CONT.

Algae, continued:

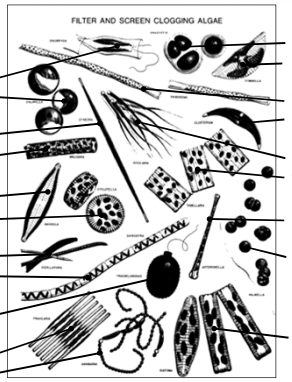
Algae < 200,000 cells/L (depending upon type)

- 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

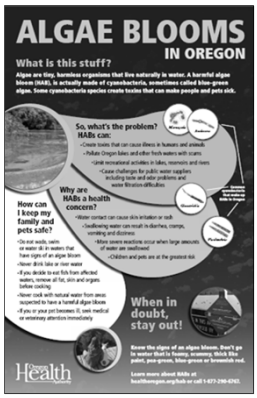
[1]Table adapted from Table 10.2 Water Treatment Plant Design, AWWA/ASCE/EWRI, 2012
[2]Diatoms of all species can generally cause clogging due to their rigid inorganic shells
[3]Can also release algal toxins (Microcystin and Anatoxin-a, among others)

RAW WATER – ALGAE, CONT.



HARMFUL ALGAE BLOOMS

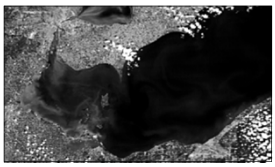
WHAT IS THIS STUFF?



http://public.health.oregon.gov/HealthyEnvironments/Recreation/HarmfulAlgaeBlooms/Documents/HABSinOregon_FINAL_Web.pdf

HARMFUL ALGAE BLOOMS – CAN BE EXTENSIVE

Lake Erie – 2012 Bloom



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

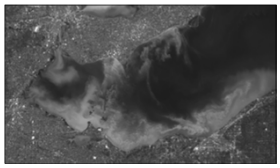
Algae blooms can be extensive

In addition to meteorological conditions, other factors contribute to Lake Erie algae 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 algae growth.

HARMFUL ALGAE BLOOMS – CAN WORSEN

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

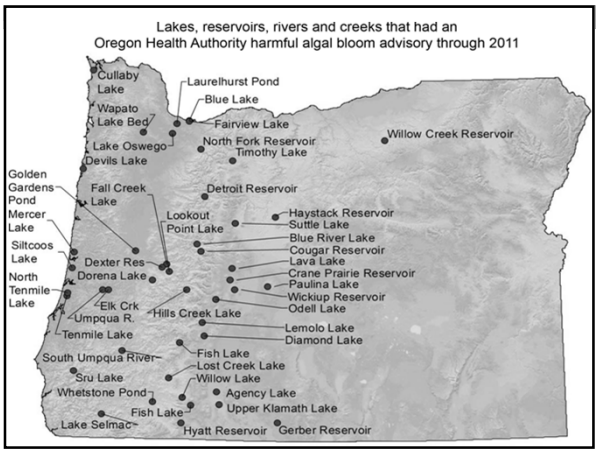
Lake Erie – 2011 Bloom



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



2013 Harmful Algae 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/

2014 Harmful Algae Bloom Recreational Advisory Information

Waterbody	County	Dominant Species/ Toxin	Cell Count (cells/ml) / Level (ppb)	Start Date	End Date	Duration (days)
Lost Cr Lake	Jackson	Anabaena flos-aquae	3,222,251	6/3/14	6/26/14	22
Odell Lake	Klamath	Microcystin	675 ppb	7/21/14	8/8/14	18
Devils Lake	Lincoln	Microcystin	>25 ppb	8/1/14		
Walterville Pond	Lane	Microcystis	53,000	8/5/14	10/02/14	58
Tenmile Lakes	Coos	Microcystin	107 ppb	9/15/14		
Willamette River	Multnomah	Microcystis	2,250,000	9/16/14	10/02/14	15
Wickiup Res	Deschutes	Microcystin	20.6 ppb	09/19/14	11/10/14	52
Cullaby Lake	Clatsop	Cylindro-spermopsin & Microcystin	12 ppb & 16 ppb	09/22/14	10/03/14	39

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

HARMFUL ALGAE - CYANOBACTERIA

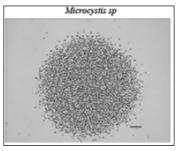
Cyanobacteria (blue-green algae)

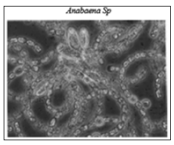
- A phylum of bacteria
- Obtain energy through photosynthesis
- "cyanobacteria" comes from the color of the bacteria (Greek: κυανός (kyanós) = blue).
- Produce oxygen as a byproduct of photosynthesis (converting reducing to oxidizing environment)

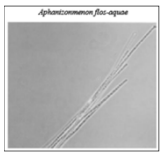
Photomicrograph of cyanobacteria, Cylindrospermum.
Photo taken by Matthew Parker.

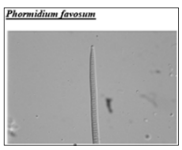
HARMFUL ALGAE – COMMON GENERA

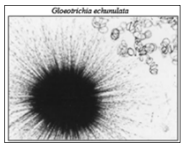
Cyanobacteria Common in Oregon











HARMFUL ALGAE - TOXINS

Cyanobacteria:

- 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
- Guidelines and labs are available on our website:

healthoregon.org/hab

Then click link: "Algae and Drinking Water"

HARMFUL ALGAE - TOXINS

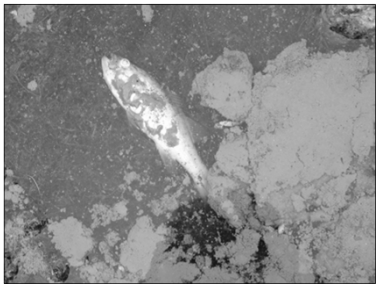
Algal Toxins

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

Algal Toxins	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
Anabaena	+		+	+	+		+	+		+	
Anabaenopsis	+									+	
Aphanizomenon (except A. flos-aquae)			+	+			+			+	
Arthrospira	+									+	
Cyanobium	+									+	
Cylindrospermopsis			+				+			+	
Gloeotrichia	+									+	
Hapalosiphon	+									+	
Limnothrix	+									+	+
Lyngba							+		+	+	
Microcystis	+			+				+		+	
Nodularia		+								+	
Nostoc	+							+		+	
Oscillatoria	+			+		+			+	+	+
Phormidium	+			+						+	
Planktothrix	+			+		+	+			+	
Raphidiopsis			+	+		+				+	
Schizothrix								+	+	+	+
Synechocystis	+									+	
Umezakia			+							+	

HARMFUL ALGAE BLOOMS - IDENTIFICATION

What does a harmful algae bloom look like?



Cyanobacterial accumulation at Binder Lake, IA, dominated by the blue green algae *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/

HARMFUL ALGAE BLOOMS – EXAMPLE 1

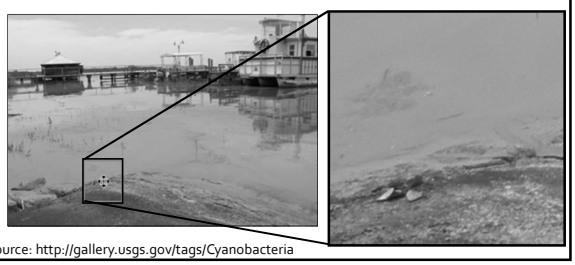
You may notice a green, red or brown film

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

HARMFUL ALGAE 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

HARMFUL ALGAE BLOOMS – EXAMPLE 3

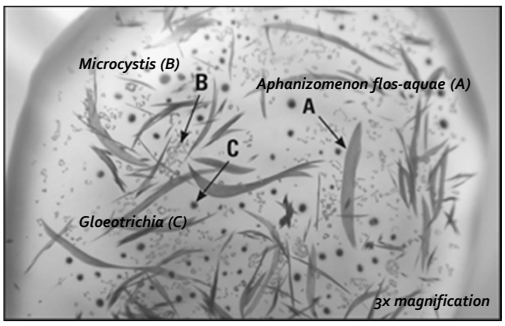
Location: Upper Klamath Lake
Aphanizominon flos-aquae (AFA) bloom in 2008. Although AFA blooms are not considered harmful, the microcystis that sometimes accompanies AFA later in the summer can produce toxins.

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

HARMFUL ALGAE BLOOMS EXAMPLE 4

Location: Willamette River, Portland, OR
Microcystis = 2.25 million cells/ml
16 day recreational advisory (9/16/14 – 10/2/14)

Photos taken by Evan Hofeld at Hadley's Landing on Sauvie Island, 2014



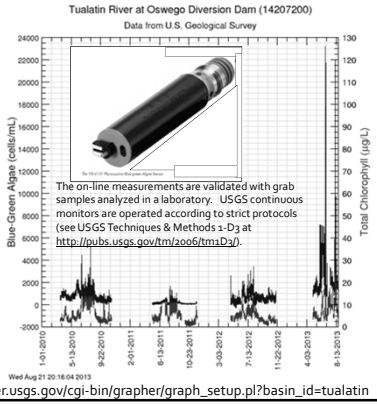
Lake water subsample containing colonies of Aphanizomenon flos-aquae (A), Microcystis (B), and Gloeotrichia (C). Although Aphanizomenon flos-aquae does not produce toxins, Microcystis and Gloeotrichia can both produce the hepatoxin mycrocystin. Magnification = 3x. Photograph by Sara Eldridge, U.S. Geological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

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

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

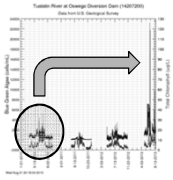
The blue-green algae data at the Oswego Dam site is collected with a YSI model 6131 probe. Chlorophyll is monitored with a YSI model 6025. More info on YSI probes is on-line at: http://www.ysi.com

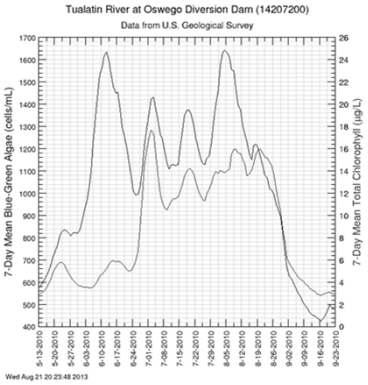


Source: http://or.water.usgs.gov/cgi-bin/grapher/graph_setup.pl?basin_id=tualatin

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

HARMFUL ALGAE – MINIMIZING BLOOMS

How do I minimize algae blooms?

Source Water Management (long-term & lasting)

Control Factors Affecting Algae Growth

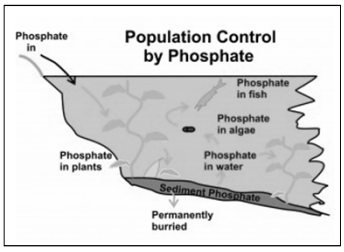
- Minimize phosphorus (P) through use reductions & source control from erosion. Target: <15-40 ppb Total Phosphorus
- Other Nutrients (Nitrogen)
- Temperature (shading riparian areas)
- Mixing/Stratification (e.g., SolarBee®)
- Sunlight (covers or floating materials or aquatic dyes)

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

HARMFUL ALGAE – 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).

HARMFUL ALGAE – MINIMIZING BLOOMS

Are there other ways to control algae blooms?

Non-chemical

1. Non-chemical options:
   - Barley straw (fungi decompose straw releasing chemicals that prevent algae growth)
   - Raking (physical removal of algae mats)
   - Triploid Grass Carp (a fish species native to Asia that must be certified disease free and sterile. Also called "white amur", they live for 5-6 years)

Triploid Grass Carp =>
Photographer: Eric Engbretson,
U.S. Fish & Wildlife Service

HARMFUL ALGAE – OTHER CONTROLS

Minimizing algae blooms?

Other measures

- 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.

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

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.

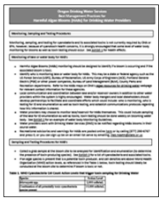
HARMFUL ALGAE – SLOW SAND

Effectiveness of Slow Sand Filtration:

Algal 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

HARMFUL ALGAE BLOOMS – BEST PRACTICES

Best Management Practices (BMPs) for Harmful Algae Blooms for Drinking Water Providers is available on-line at:

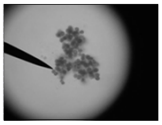


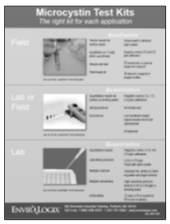
http://public.health.oregon.gov/HealthyEnvironments/DrinkingWater/Operations/Treatment/Documents/algae/BMP-HABs.pdf

IN THE EVENT OF AN ALGAE BLOOM

In the event of a bloom…

- 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
- Use PAC/GAC if available
- Monitor cells
- Monitor toxins





ALGAE CELL ID/COUNT TRIGGERS

Triggers for algae cell identification and enumeration:

Contact the State if a visible bloom develops, as evidenced by visible scum. (more on what that might look like will be presented later)

TOXIN TESTING TRIGGERS

Triggers for Toxin Testing:

Cyanobacteria Cell Count Action Levels that trigger toxin sampling for Drinking Water (World Health Organization)	
Microcystis spp.	2,000 cells/ml
Combination of all potentially toxic cyanobacteria species present	15,000 cells/ml

Contact the State if blooms indicate toxin testing should be done (financial assistance may be available)

TOXIN TESTING

Recommended Toxin Testing:

1. If there is an algae bloom in your source water, contact the Drinking Water Program for instructions on sampling raw water from the intake and finished water (after all treatment). Testing costs may be covered by the State.
2. If a bloom is present in the source water, a paired raw water intake and finished water sample should be taken at the same time:
   1. Have raw water tested for toxins.
   2. If raw water has toxins, also have finished water tested for toxins.
3. Raw and finished water sampling should continue weekly until the bloom is gone.

TOXIN LIMITS

Acute Toxicity Limits in Finished Water:

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

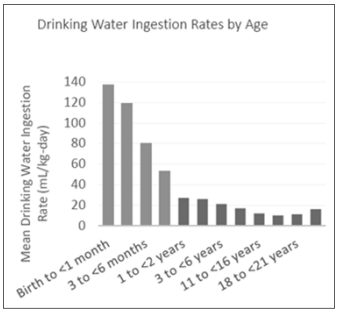
Oregon Health Authority Drinking Water Acute Toxicity Guidelines for Algal Toxins				
Toxin =>	Anatoxin-a	Cylindrospermopsin	Total Microcystin	Total Saxitoxin
<6 Years of Age	0.7 µg/l	0.7 µg/l	0.3 µg/l	0.3 µg/l
6 Years and Older	3 µg/l	3 µg/l	1.6 µg/l	1.6 µg/l

Utilities should be prepared to communicate the risks to customers should finished water toxin results exceed these levels.

TOXIN LIMITS

Why an age-specific guideline?

- Bottle-fed infants consume large amounts of drinking water compared to their body weight (when formula is prepared using tap water).
- Exposure to children < 12 months is 5x higher than for adults > 21 years of age, on a body-weight basis.
- At 6 years and older, exposure on a body weight basis is similar to that of an adult.



TOXIN LIMITS

How was an age-specific guideline developed?

- 10 day HA for bottle-fed infants

$$HA_{10day} = \frac{50\ \mu g/Kg/d}{1000 \times 0.15\ L/kg/d} = 0.3\ \mu g/L$$

LOAEL = 50 µg/kg/day
UF = 1000
intraspecies:10; interspecies: 10; LOAEL to NOAEL: $10^{0.5}$; database: $10^{0.5}$
BW/DW = 0.15L/kg/day

- 10 day HA for adult

$$HA_{10day} = \frac{(50\ \mu g/Kg/d) \times (80\ Kg)}{1000 \times 2.5\ L/d} = 1.6\ \mu g/L$$

LOAEL = 50 µg/kg/day
BW = 80 Kg
UF = 1000
intraspecies:10; interspecies: 10; LOAEL to NOAEL: $10^{0.5}$; database: $10^{0.5}$
DW = 2.5 L/d

Oregon Health Authority Drinking Water Acute Toxicity Guidelines for Algal Toxins				
Toxin =>	Anatoxin-a	Cylindrospermopsin	Total Microcystin	Saxitoxin
<6 Yrs of Age	0.7 µg/l	0.7 µg/l	0.3 µg/l	0.3 µg/l
6 Yrs and Older	3 µg/l	3 µg/l	1.6 µg/l	1.6 µg/l

- LOAEL = Lowest Observed Effect Level
- UF = Uncertainty Factor
- BW = Body Weight
- DW = Drinking Water Intake
- 10 day HA = 10-day exposure duration is an expected exposure pattern

WHEN TO ISSUE AN ADVISORY

A "Do Not Drink" advisory should be issued for drinking water if the toxin limits are exceeded in the finished water. A recreational advisory may also be needed.

< Permanent sign flipped down for recreational health advisory.

DO NOT DRINK WATER ADVISORY

IMPORTANT INFORMATION ABOUT YOUR DRINKING WATER

[System] Has Levels of Algae toxin Above Drinking Water acute toxicity values

(Water System Name) routinely monitors for the presence of contaminants in our finished drinking water that is provided through our treatment and distribution system. Our water system recently exceeded the Oregon Health Authority's acute toxicity value for a cyanotoxin (toxin detected, date sampled and value detected) which is a by-product of certain algae species that naturally grow in water. Although this is not currently a regulated contaminant, as our customers, you have a right to know this acute toxicity value was exceeded, what you should do, and what we are doing to correct this situation.

What should I do?

- Drinking water above the acute toxicity value of [x] µg/L of [toxin] is not advised. You may want to use an alternative (e.g., bottled) water supply. If you have specific health concerns, consult your doctor.

What does this mean?

Human health effects from cyanotoxins are diverse and may include skin rashes and lesions, vomiting, gastroenteritis, conjunctivitis, headaches, eye, ear and throat irritations, abdominal cramps, nausea, diarrhea, fever, sore throat or hay fever-like symptoms. [Long-term exposure to microcystin can lead to damage to the liver, including cancer].

What is being done?

[Water system name] continues to work with [Insert Water Body Manager] to monitor and test the algal bloom for harmful toxins. In addition [water system name] is adjusting their treatment process to more successfully mitigate for the presence of cyanotoxins. Weekly testing will continue until toxin levels are below the acute toxicity values.

For more information, please contact [name of contact], at [phone number] or [mailing address].

Please share this information with all the other people who drink this water, especially those who may not have received this notice directly (for example, people in apartments, nursing homes, schools, and businesses). You can do this by posting this notice in a public place or distributing copies by hand or mail.

This notice is being sent to you by [system]. State Water System ID# _____ Date distributed _____

WHEN TO END TOXIN TESTING & ADVISORY

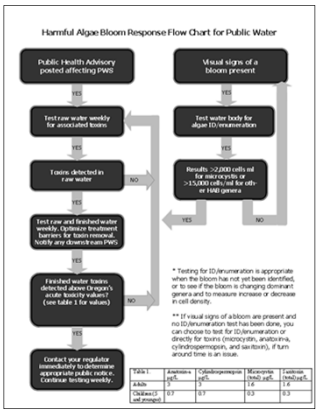
Monitoring and advisory status can return to pre-bloom conditions, once the bloom has subsided, as evidenced by the falling toxin levels and, if monitored, lower cell counts.

< Permanent sign flipped down for recreational health advisory.

Sign flipped up > when advisory is lifted

HARMFUL ALGAE BLOOM RESPONSE SUMMARY

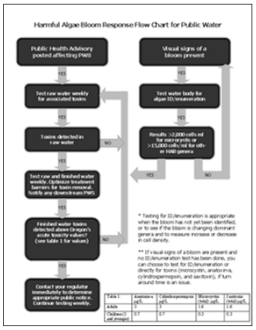
http://public.health.oregon.gov/HealthyEnvironments/DrinkingWater/Operations/Treatment/Documents/algae/HABResponseFlowChart.pdf



HAVE A BLOOM IN THE FILTER?

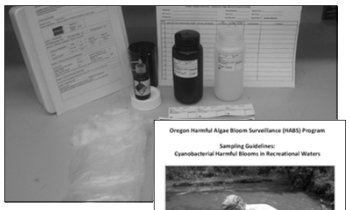
Apply the same steps if the bloom is occurring in your filter.

City of Joseph, OR. Slow Sand filter in August 2013



BE PREPARED

"HABS readiness kit"



A "HABS readiness kit" can help you respond:

1) Quickly,
2) Predictably, and
3) Consistently

http://public.health.oregon.gov/HealthyEnvironments/Recreation/HarmfulAlgaeBlooms/Pages/resources_for_samplers.aspx

HARMFUL ALGAE RESOURCES

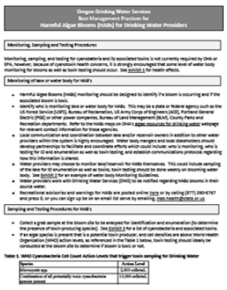
Oregon Health Authority – Drinking Water Services
http://public.health.oregon.gov/HealthyEnvironments/DrinkingWater/Operations/Treatment/Pages/algae.aspx

Oregon Health Authority – HABS Program
www.healthoregon.org/hab

Oregon DEQ
http://www.deq.state.or.us/wq/algae/algae.htm

USEPA
http://www2.epa.gov/nutrientpollution/harmful-algal-blooms

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



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.

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).

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.

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).

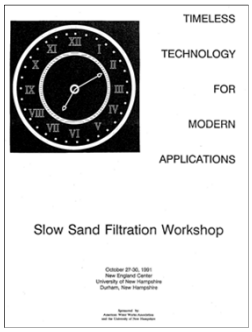
APPLIED WATER CHARACTERISTICS RECOMMENDED FOR SLOW SAND FILTRATION

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.

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)

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