



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

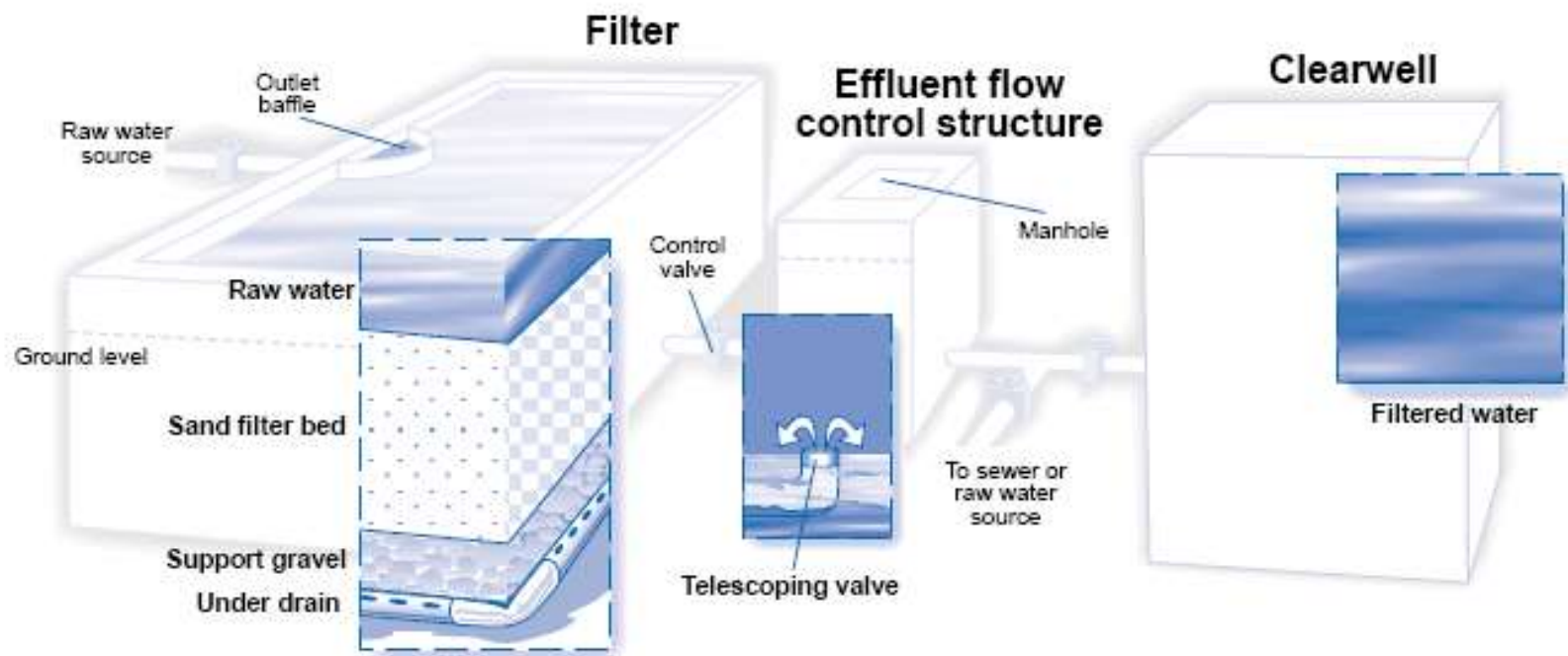
1. Introduction to a “Timeless Technology”
2. Removal Mechanisms & Expected Performance
3. Critical Variables & Raw Water Quality
4. Design
5. Operations
6. Regulatory Requirements

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    |
| <i>Giardia</i> Cysts           | 2-4+log units    |
| <i>Cryptosporidium</i> 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

## Slow Sand Filter



NATIONAL DRINKING WATER CLEARINGHOUSE

<http://jica-net.jica.go.jp/lib2/o8PRDMoo7/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.**"

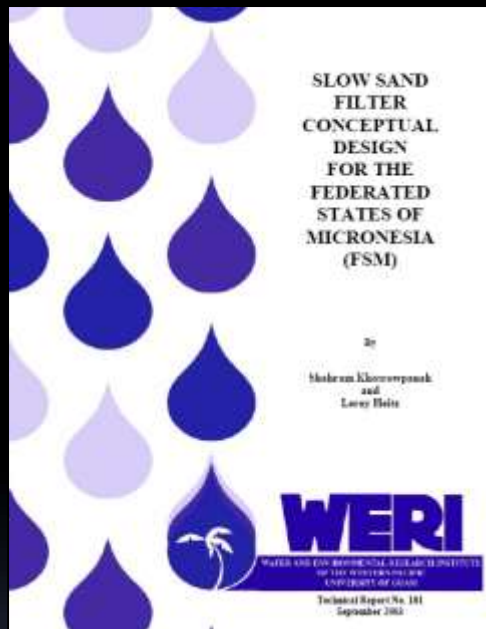
- Snow, John. *Communication of Cholera*, 1855, p. 64





# TODAY - WORLD-WIDE USE

## In use world-wide



Micronesia  
Design Tech Paper  
2003

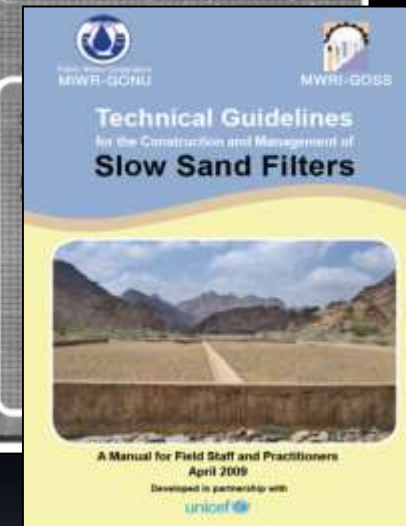


Canada  
"New Horizons for SS Filtration"  
2004



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

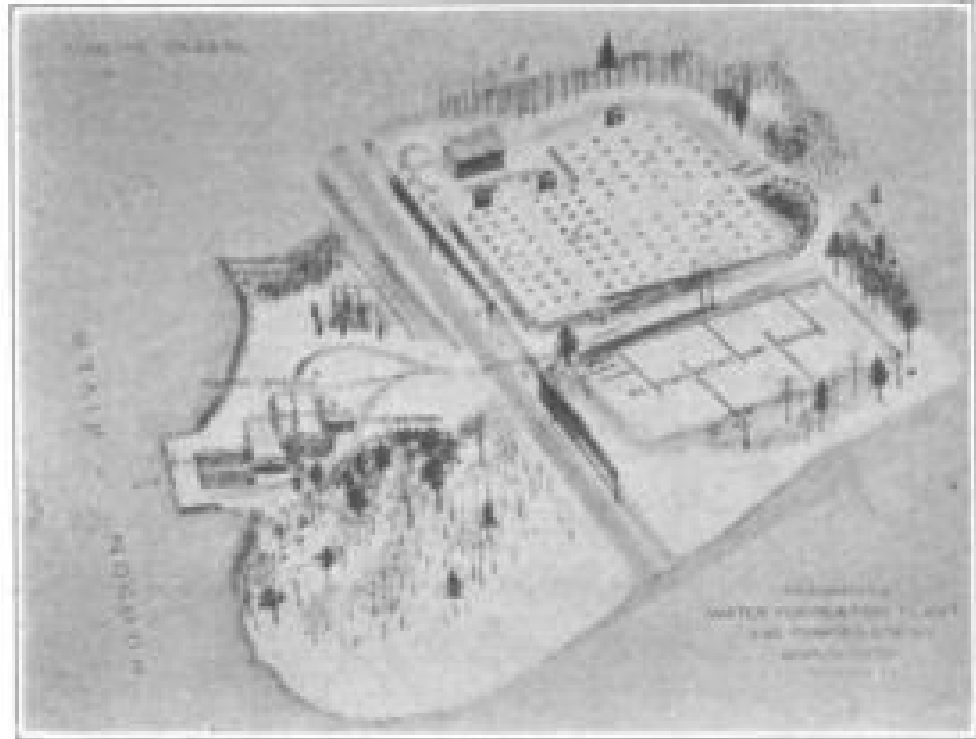
### Proven technology

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”



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”.

# 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.



B. TORRESDALE PLANT, SHOWING METHOD OF CLEANING WITH NICHOLS SEPARATOR.

## PHILADELPHIA FILTRATION PLANTS.

Photographs furnished by Department of Public Works, Philadelphia, Pa.



# TYPHOID FEVER DECLINES

Deaths per 100,000 people

## Death Rate from Typhoid Fever in Philadelphia 1860-1936

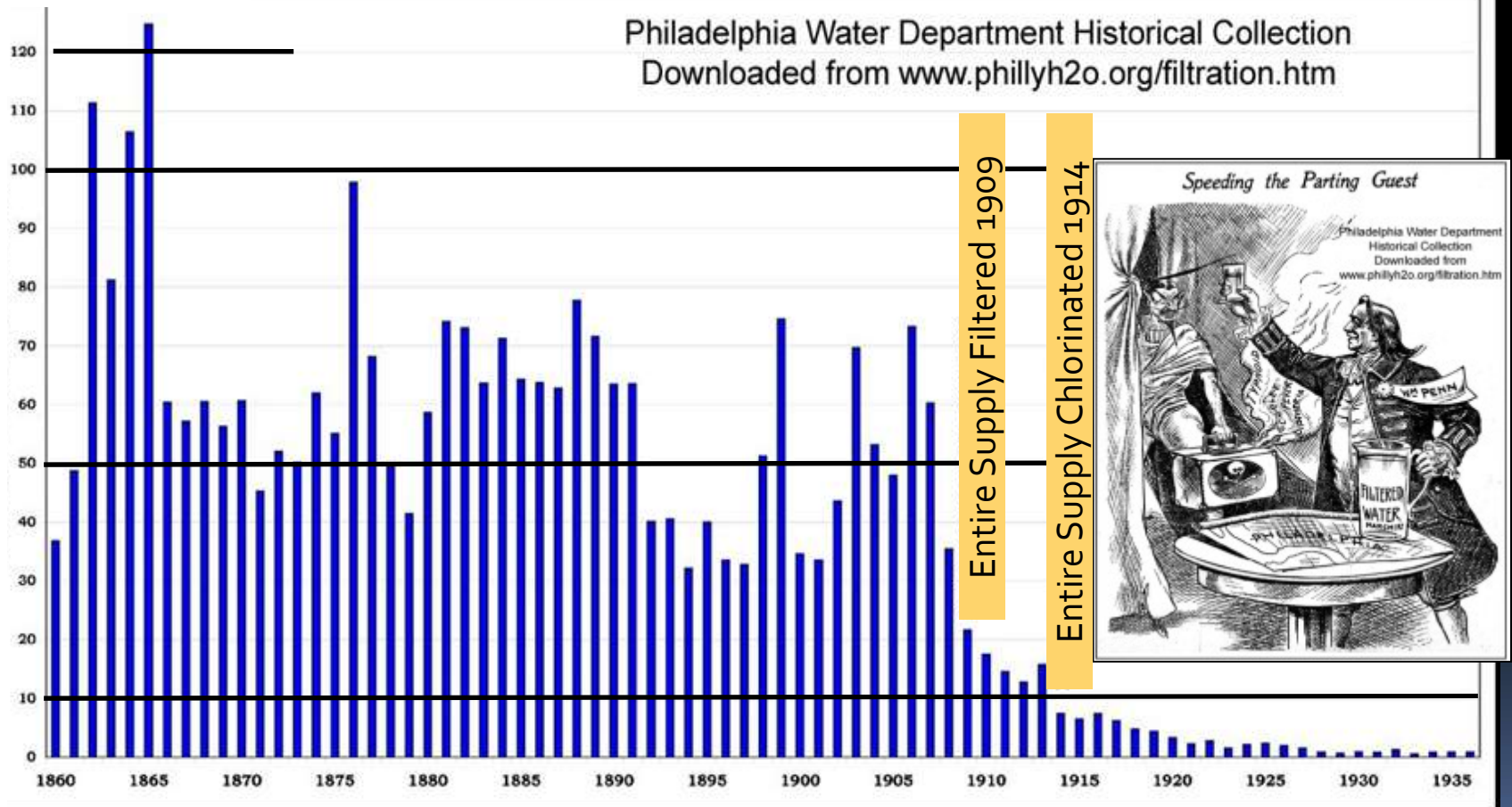
Philadelphia Water Department Historical Collection  
Downloaded from [www.phillyh2o.org/filtration.htm](http://www.phillyh2o.org/filtration.htm)

130=>

100=>

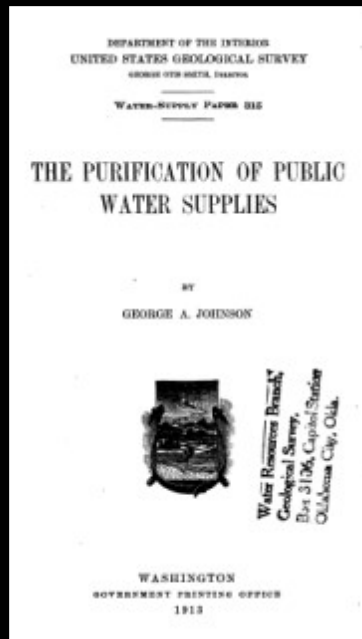
50=>

10=>



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

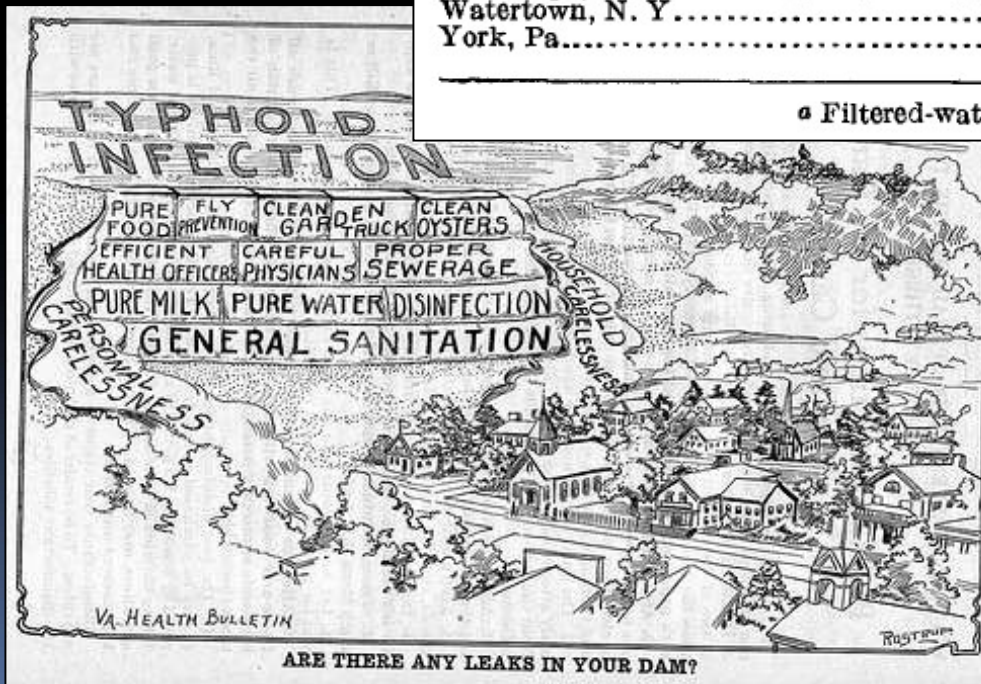
# MORE REDUCTIONS IN TYPHOID FEVER



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

| City.                  | Kind of filter. | Plant completed. | Years, in average— |                   | Typhoid-fever death rate— |                   |
|------------------------|-----------------|------------------|--------------------|-------------------|---------------------------|-------------------|
|                        |                 |                  | Before filtration. | After filtration. | Before filtration.        | 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                       | <sup>a</sup> 26   |
| Watertown, N. Y. ....  | Rapid ....      | 1904             | 5                  | 5                 | 100                       | 38                |
| York, Pa. ....         | Rapid ....      | 1899             | 2                  | 8                 | 76                        | 22                |

<sup>a</sup> 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)



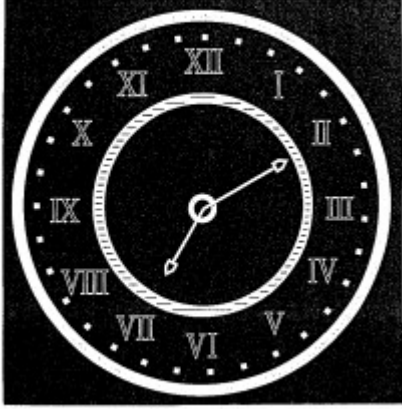
Walla Walla, WA



Jewell SD#8, OR

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

TIMELESS  
TECHNOLOGY  
FOR  
MODERN  
APPLICATIONS



Slow Sand Filtration Workshop

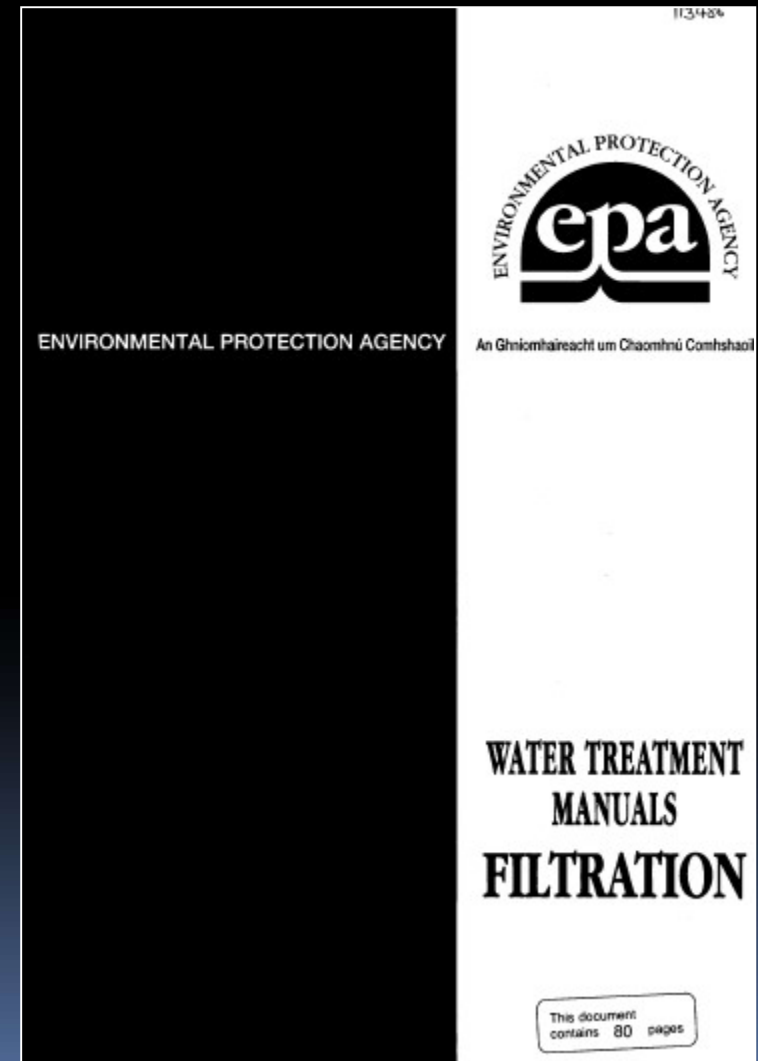
October 27-30, 1991  
New England Center  
University of New Hampshire  
Durham, New Hampshire

Sponsored by  
American Water Works Association  
and the University of New Hampshire

# 1995 GUIDELINES BY USEPA

## Chapter 3 Slow Sand Filtration (EPA, 1995)

|  |  |
|--|--|
| Min # of Filters                       | 3<br>(allows for 1 out of service)                   |
| Filtration Rate                        | 0.1 – 0.2 m/hr<br>(0.04 – 0.08 gpm/ft <sup>2</sup> ) |
| Sand Effective Size (d <sub>10</sub> ) | 0.15 – 0.35 mm                                       |
| Uniformity Coefficient (UC)            | < 3<br>(little added benefit for cost if < 1.5)      |
| Scraping depth                         | 10-15 mm<br>(0.4 – 0.6 in)                           |
| Ripening Period                        | 1 – 2 days   |
| Min Bed Depth                          | 12 inches<br>(prior to re-sanding)                   |





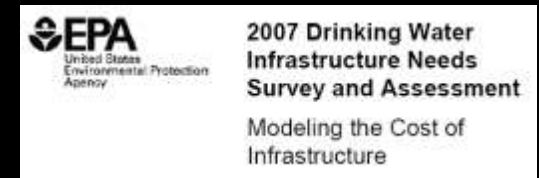
# COST EFFECTIVE

## Inexpensive Design & Construction

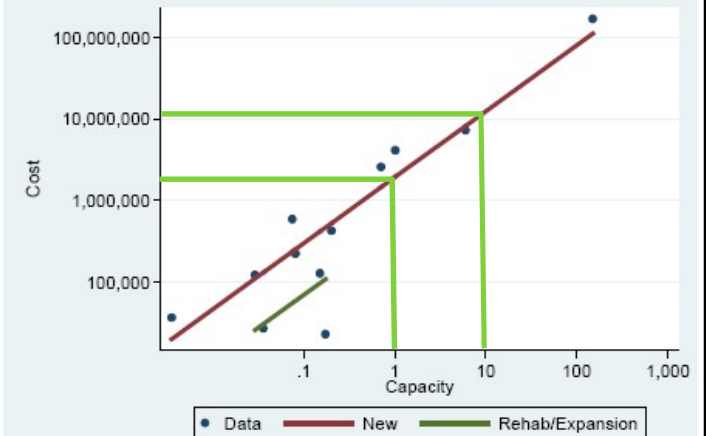
\$24,000/MGD  
in 1913



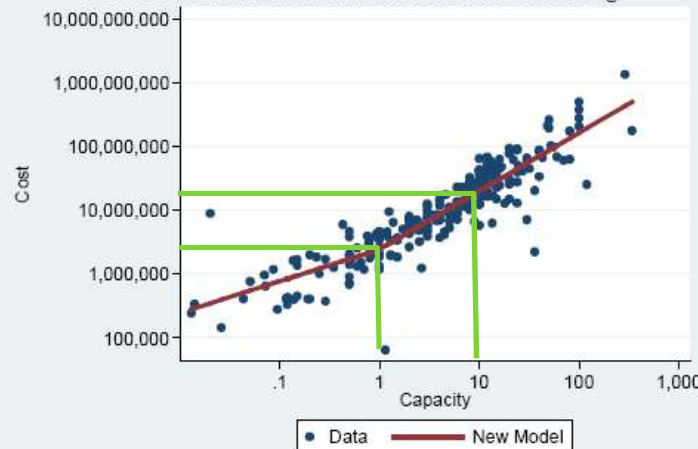
2007 Infrastructure Needs Survey  
Project Cost Models  
(~\$1,000,000/MGD)



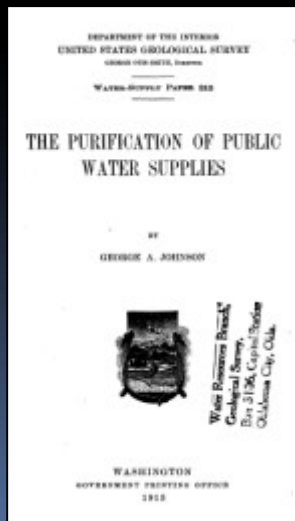
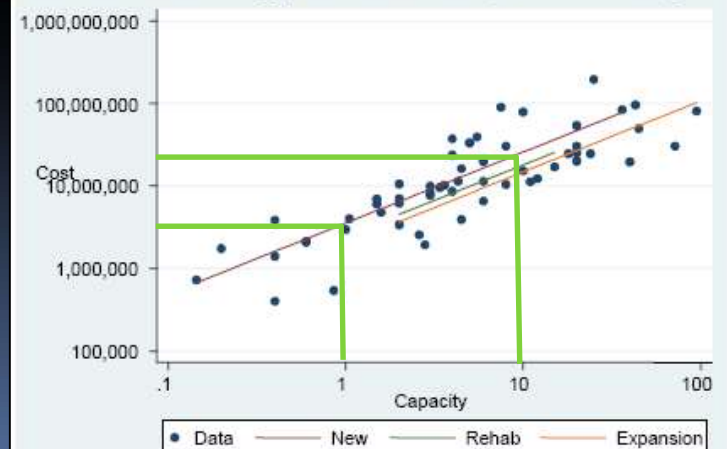
Direct, In-line, DE, Slow Sand, or Cartridge/Bag Filtration Plants



New Conventional Filter Plant or Lime Softening



Membrane Technology, Reverse Osmosis, and Electrodialysis



# SIMPLE TO OPERATE

## Simple to operate/maintain

| Frequency       | Labor<br>(person hours)  | Slow Sand Filter Maintenance Task   |
|-----------------|--|---|
| Daily           | 1 - 3  | <ul style="list-style-type: none"><li>✓ Check raw water intake</li><li>✓ Check/adjust filtration rate</li><li>✓ Check water level in filter</li><li>✓ Check water level in clear well</li><li>✓ Sample &amp; check water quality (raw/finished NTU, raw temp)</li><li>✓ Check pumps</li><li>✓ Enter observations in logbook</li></ul> |
| Weekly          | 1 - 3  | <ul style="list-style-type: none"><li>✓ Check &amp; grease any pumps &amp; moving parts</li><li>✓ Check/re-stock fuel</li><li>✓ Sample &amp; check water quality (coliform)</li><li>✓ Enter observations in logbook</li></ul>   |
| 1 – 2<br>months | 5 / 1,000 ft <sup>2</sup><br><br>50 / 1,000 ft <sup>2</sup> /12 inches<br>of sand for re-sanding<br><br>(Letterman & Cullen, 1985) | <ul style="list-style-type: none"><li>✓ Scrape filter beds</li><li>✓ Wash scrapings &amp; store retained sand</li><li>✓ Check &amp; record sand bed depth</li><li>✓ Enter observations in logbook</li></ul>   |

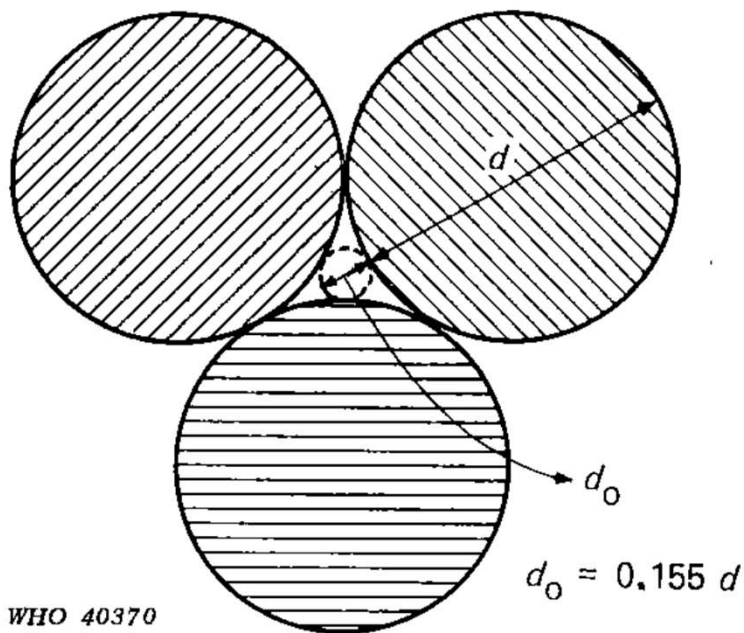
Frequency and tasks are adapted from WHO, 1996. *Fact Sheets on Environmental Sanitation, Fact Sheet 2.12: Slow Sand Filtration*

# REMOVAL MECHANISMS

So what makes them effective at filtration?

More than just physical straining at work.

FIG. 3. RELATION BETWEEN GRAIN SIZE AND PORE SIZE

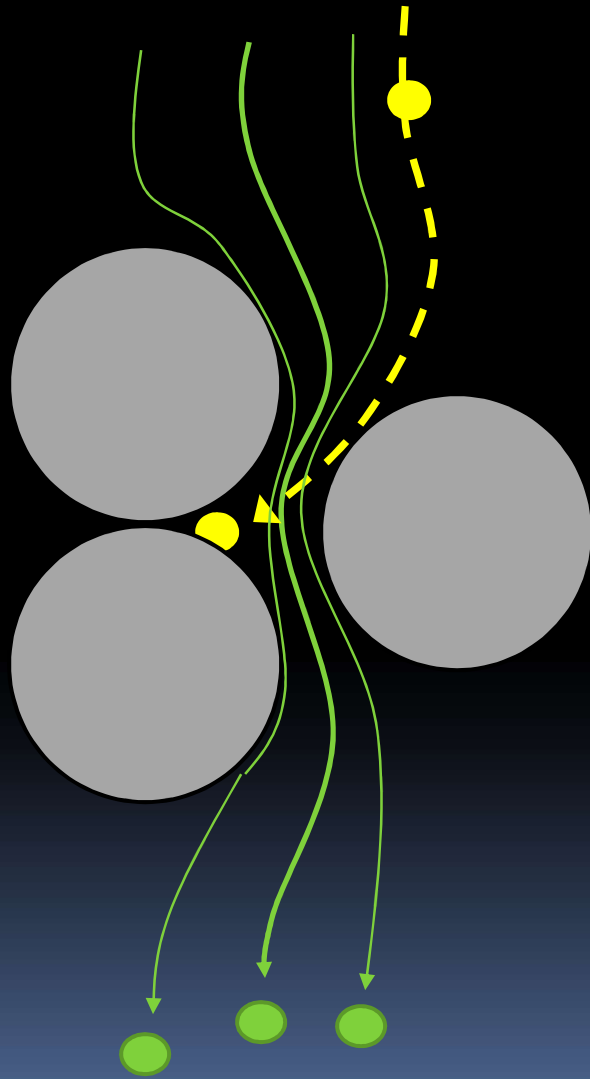


| Particulate | Diameter<br>( $d_o = 0.155d$ ) | Grain Diameter<br>Needed for<br>Straining Alone<br>( $d$ ) |
|-------------|--------------------------------|--|
|-------------|--------------------------------|--|

|          |                   |             |
|----------|-------------------|-------------|
| Colloids | 0.1 $\mu\text{m}$ | 0.000645 mm |
| Bacteria | 15 $\mu\text{m}$  | 0.0968 mm   |
| Giardia  | 10 $\mu\text{m}$  | 0.0645 mm   |
| Crypto   | 5 $\mu\text{m}$   | 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 $\mu\text{m}$<br>(WHO, 2003) |

# REMOVAL MECHANISMS



Other removal mechanisms are at work.

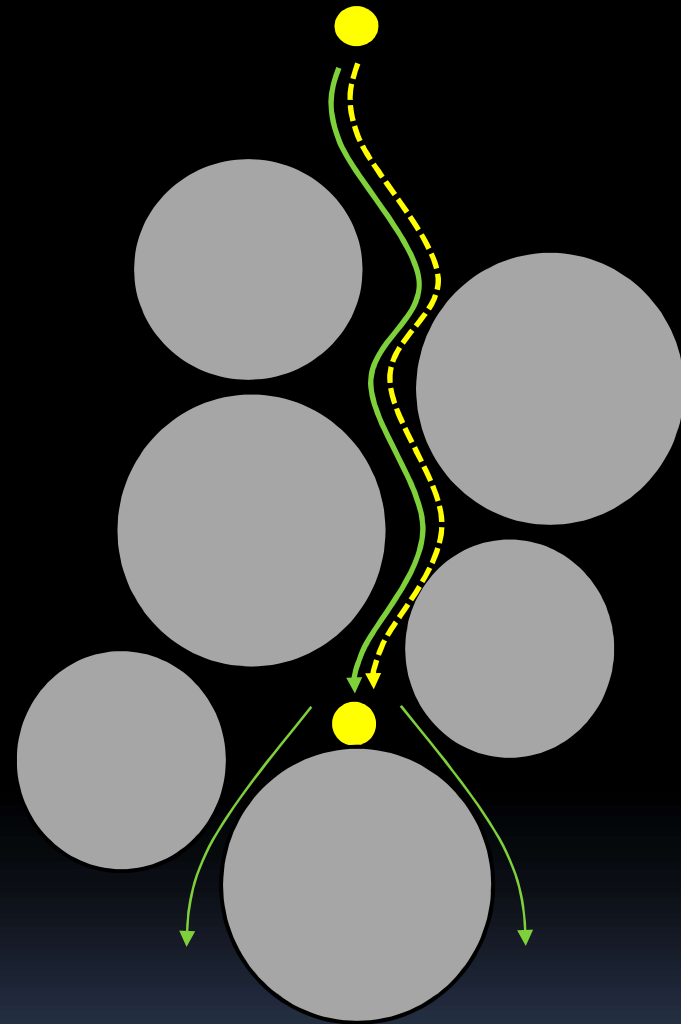
Sand grains 0.5-1.0 mm in diameter can remove bacteria with sizes of 0.001 mm through physical processes (transport and attachment due to electrical and molecular forces)



## REMOVAL MECHANISMS – FLOW SPLITTING

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

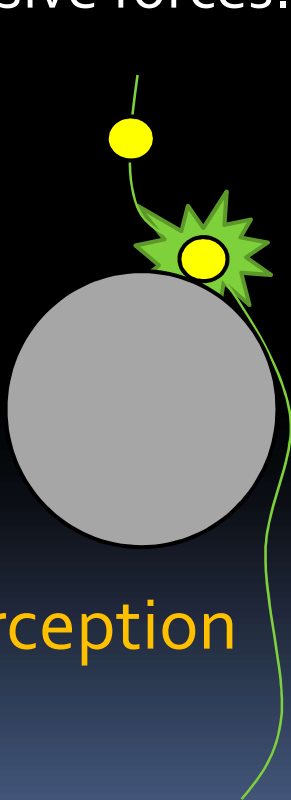
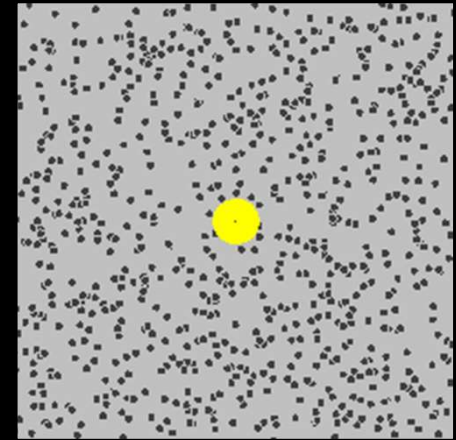
Flow splitting increases with smaller sand grain size.



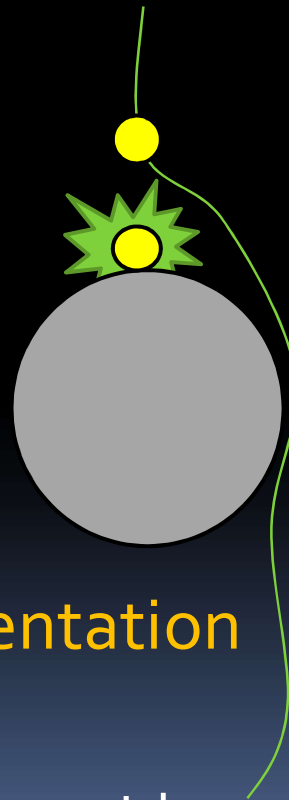


## REMOVAL MECHANISMS - COLLISION PROBABILITY

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

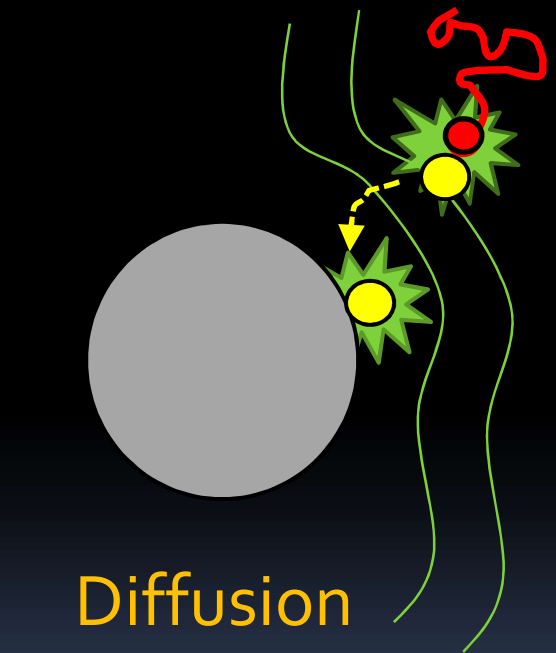


Interception



Sedimentation

Increases with  
lower flows



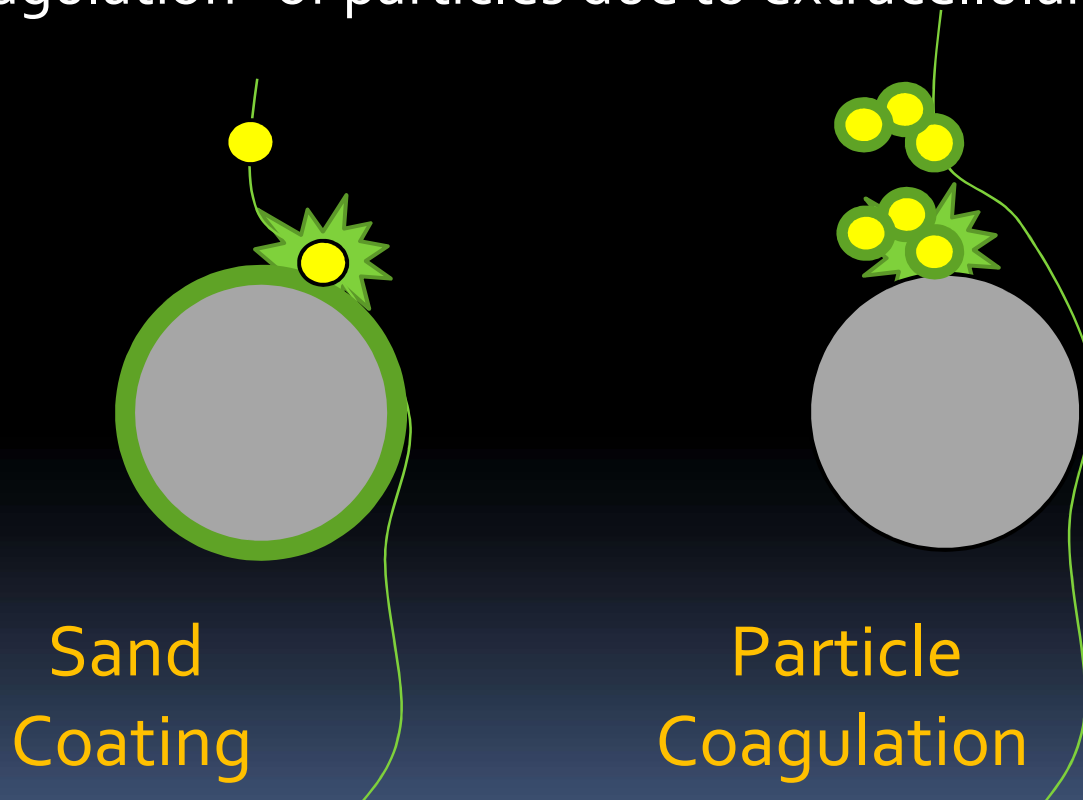
Diffusion  
collisions with  
gasses and liquids

Increases with  
high temps & low flows

# $\alpha$ 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 ( $\alpha \sim 0$ ).  
After the filter matures, removals range from 99 – 99.99% ( $\alpha \sim 1$ ).

# REMOVAL MECHANISMS - BIOTA

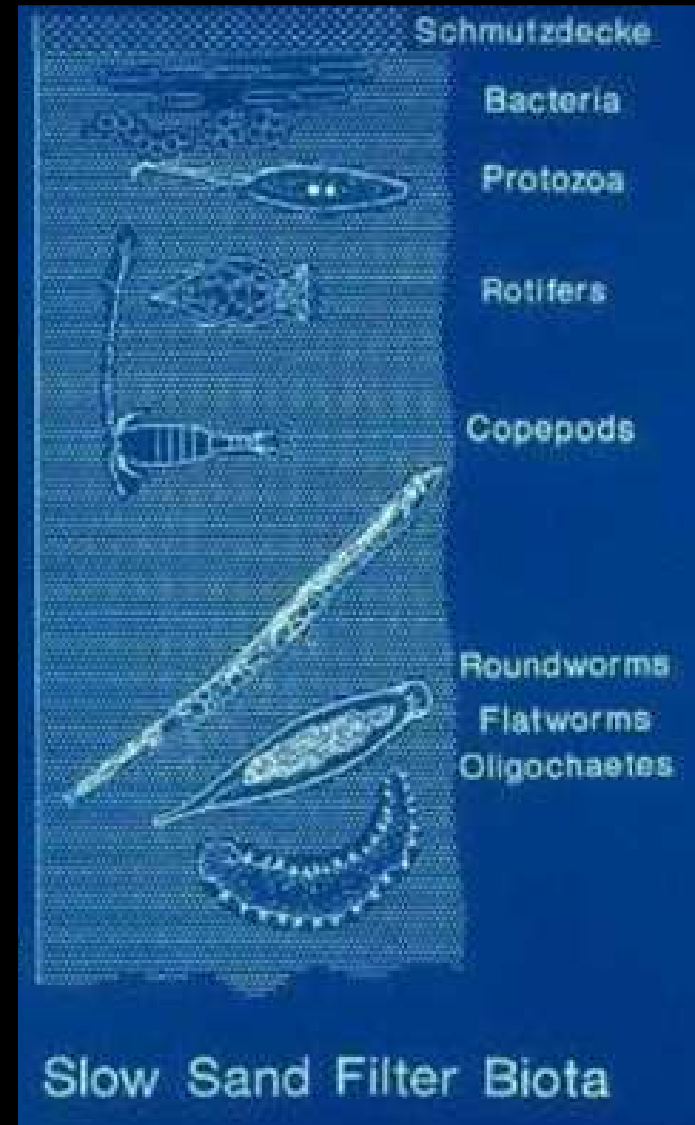
- Schmutzdecke – Top
- 1"-4" Bacteria, Protozoa, Rotifers
- 4" – 8" Copepods
- 8" – 12" Roundworms, Flatworms, & Oligochaetes (segmented worms)

0"

4"

8"

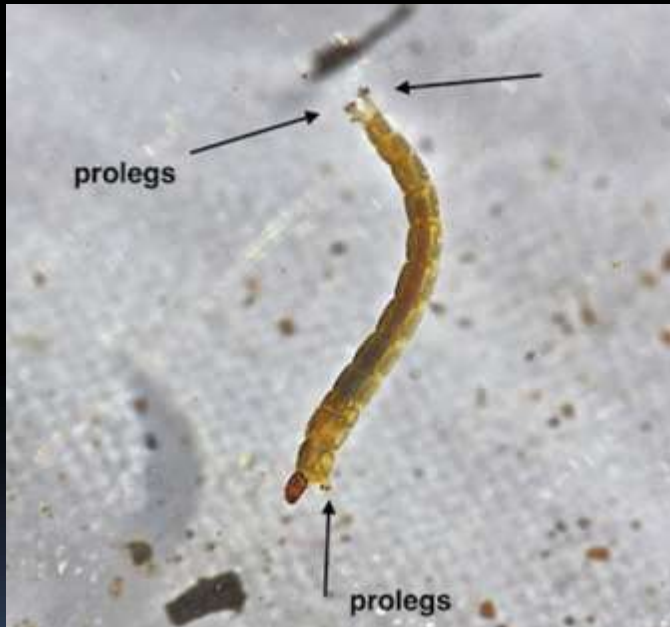
12"





# 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 matter 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

# SLOW SAND PERFORMANCE

| Water Quality Parameter        | Removal Capacity |
|--------------------------------|------------------|
| Turbidity                      | <1.0 NTU         |
| Coliforms                      | 1-3 log units    |
| Enteric Viruses                | 2-4 log units    |
| <i>Giardia</i> Cysts           | 2-4+log units    |
| <i>Cryptosporidium</i> 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.*

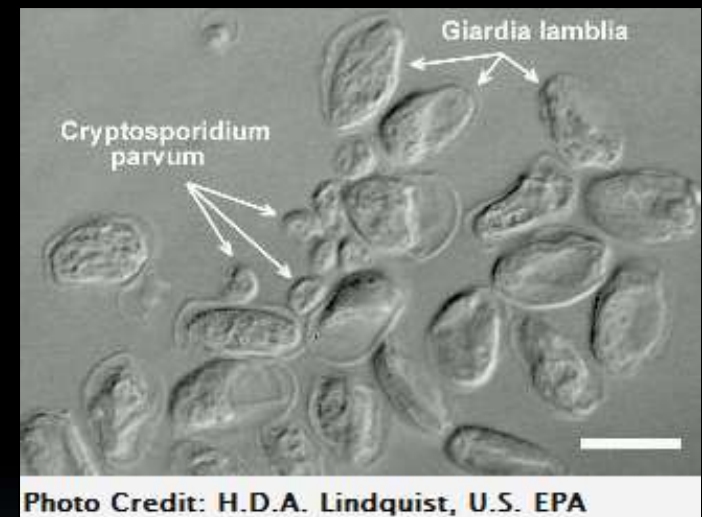


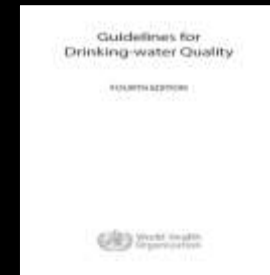
Photo Credit: H.D.A. Lindquist, U.S. EPA

Source: Adapted from Collins, M.R. 1998.

[http://www.nesc.wvu.edu/ndwc/pdf/OT/TB/TB14\\_slowsand.pdf](http://www.nesc.wvu.edu/ndwc/pdf/OT/TB/TB14_slowsand.pdf)

# 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   |
|---|------------------------|-----------------------|-----------------------|---|
| <b>Filtration</b>   |                        |                       |                       |   |
| 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  $< 1 \text{ mg/l}$

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  $1 \text{ mg/l}$ , 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  $\mu\text{g}$  of carbon/liter is needed to promote heterotrophic bacteria growth.
  - Rivers typically have AOC of 123  $\mu\text{g}$  C/l.
  - Coliform bacteria need AOC of 50  $\mu\text{g}$  C/l.
  - AOC is typically 10% of TOC (LeChevallier et al. 1991)

# RAW WATER - PROTOZOA

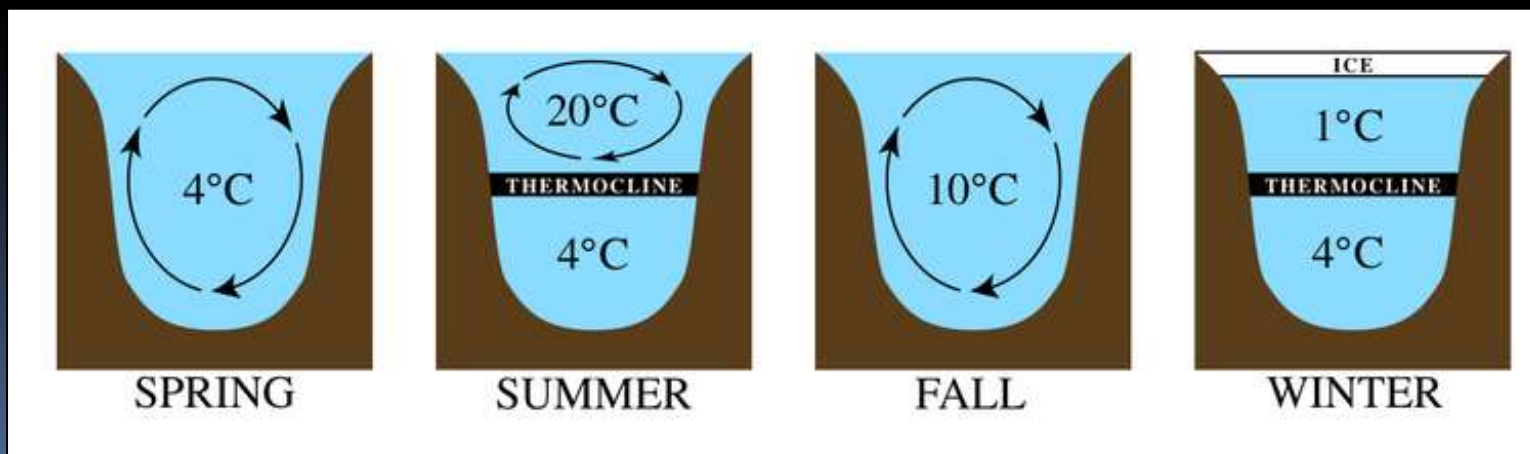
## Protozoa:

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 (cyanobacteria)

# RAW WATER - TEMPERATURE

## Temperature:

1. Temperature impacts microbial growth in slow sand filters
2. Microbial growth occurs in the range of  $10 - 45^{\circ}\text{C}$  (outside of this range, growth ceases)
  - Minimum range is  $10 - 15^{\circ}\text{C}$
  - Max range is  $35 - 45^{\circ}\text{C}$
  - Optimum range is  $24 - 40^{\circ}\text{C}$
3. When air temperature drops to below  $2^{\circ}\text{C}$  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 CHOLERAЕ

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 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

# 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:

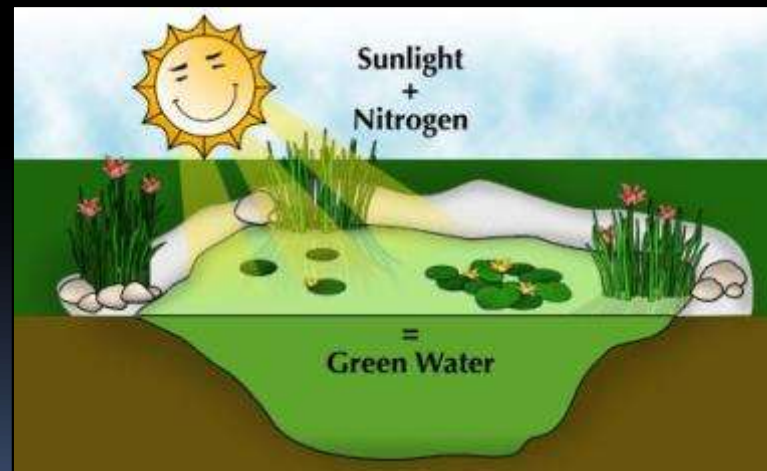
$6\text{CO}_2$   
Carbon Dioxide

$+ 6\text{H}_2\text{O}$   
Water

+ sunlight =>

$\text{C}_6\text{H}_{12}\text{O}_6$   
Sugar

$6\text{O}_2$   
Oxygen

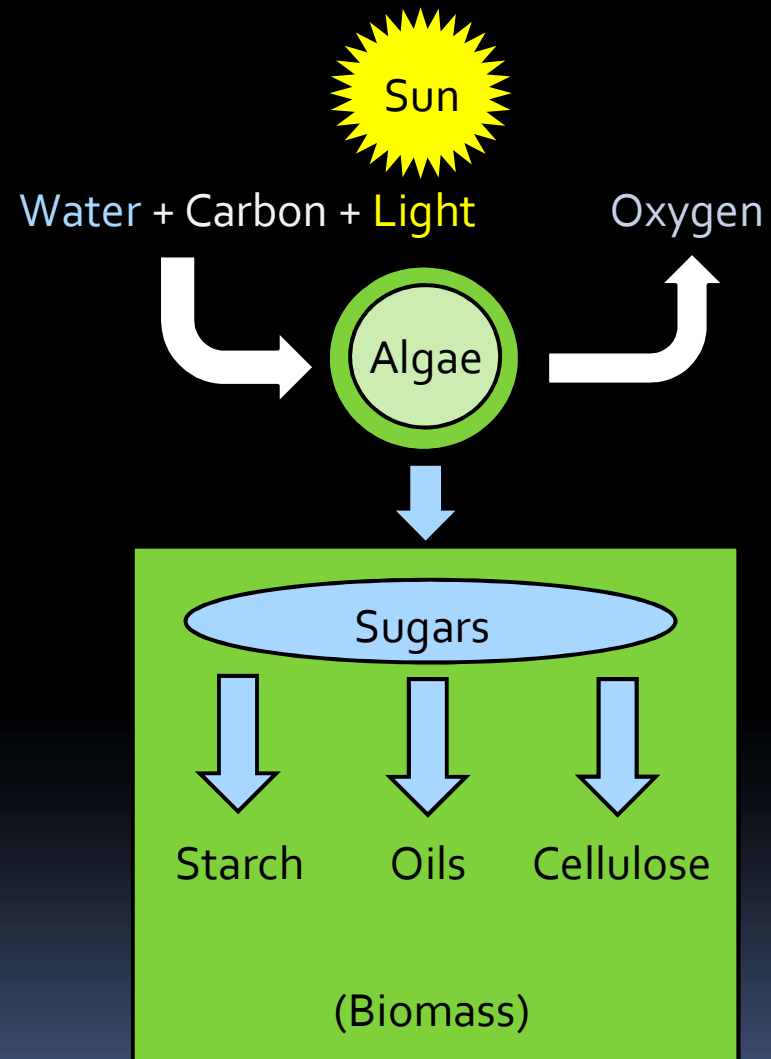


The reverse reaction occurs when algal cells die and decompose (WHO, pp 34-35)

# 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:





# RAW WATER CHARACTERISTICS

## Algae, continued:

5. When filamentous algae predominate, a zoogeleal 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<sup>1</sup>

| Filter Clogging <sup>2</sup> | Filamentous                | Floating                 |
|------------------------------|----------------------------|--------------------------|
| 1. Tabellaria                | 1. Hydrodictyon            | 1. Protococcus           |
| 2. Asterionella              | 2. Oscillaria <sup>3</sup> | 2. Scenedesmus           |
| 3. Stephanodiscus            | 3. Cladophora              | 3. Symara                |
| 4. Synedra                   | 4. Aphanizomenon           | 4. Anaboena <sup>3</sup> |
|                              | 5. Melosira                | 5. Euglena               |

<sup>1</sup>Table adapted from Table 10.2 Water Treatment Plant Design, AWWA/ASCE/EWRI, 2012

<sup>2</sup>Diatoms of all species can generally cause clogging due to their rigid inorganic shells

<sup>3</sup>Can also release algal toxins (Microcystin and Anatoxin-a, among others)

# RAW WATER – ALGAE, CONT.

## Filter clogging algae

Dinobryon (1,500x)

Chlorella (5,000x)

Synedra (500x)

Melosira (1,000x)

Navicula (1,500x)

Cyclotella (1,500x)

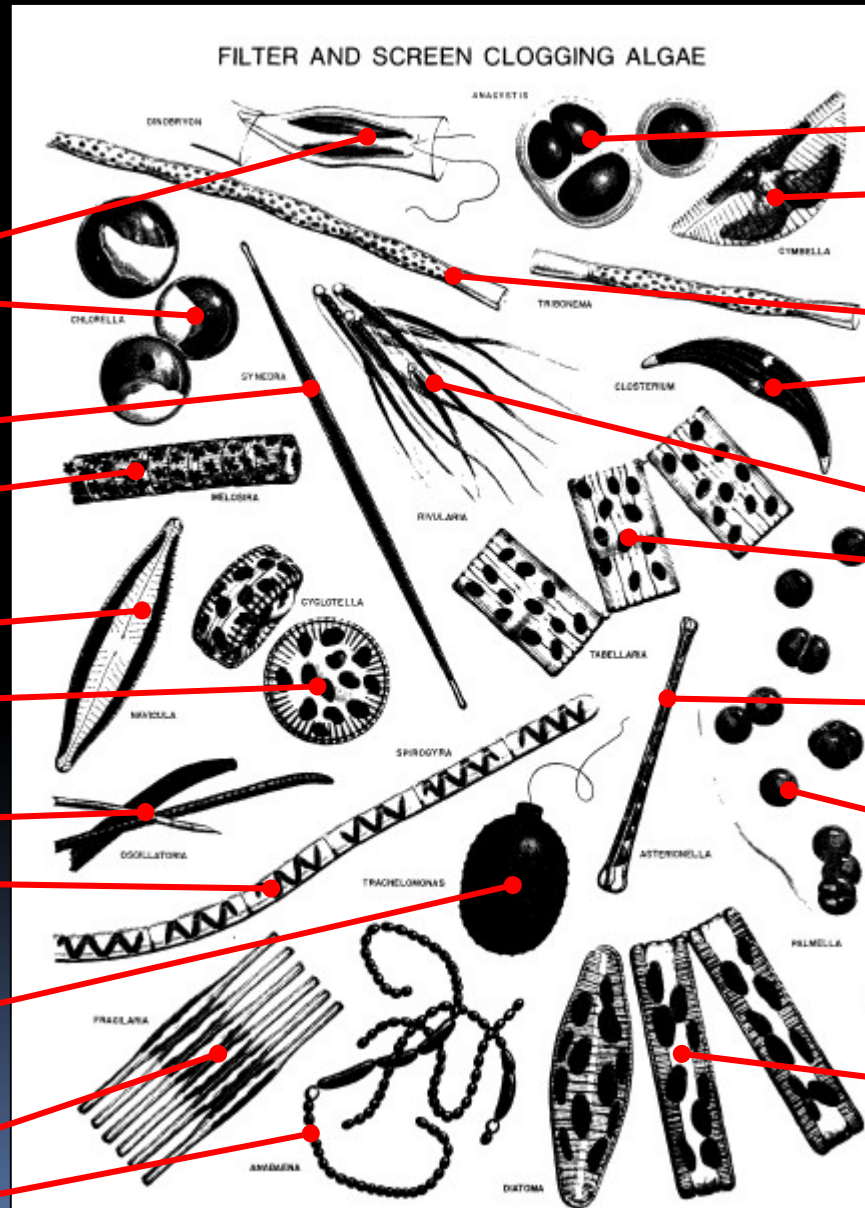
Oscillatoria (500x)

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)

# HARMFUL ALGAE BLOOMS (CYANOBACTERIA)

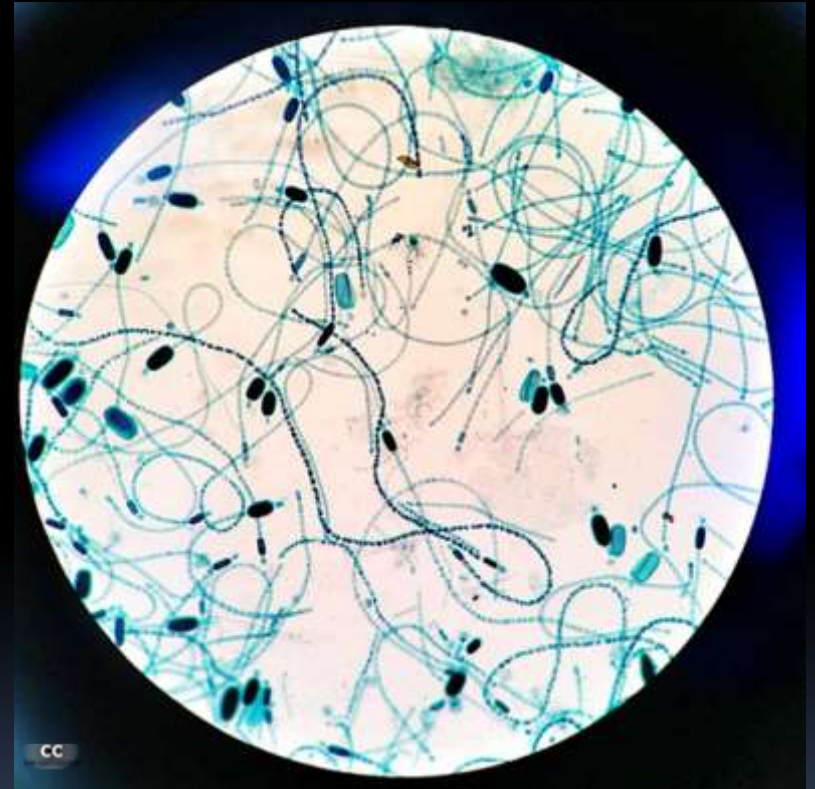
*WHAT IS THIS STUFF?*



# 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*.

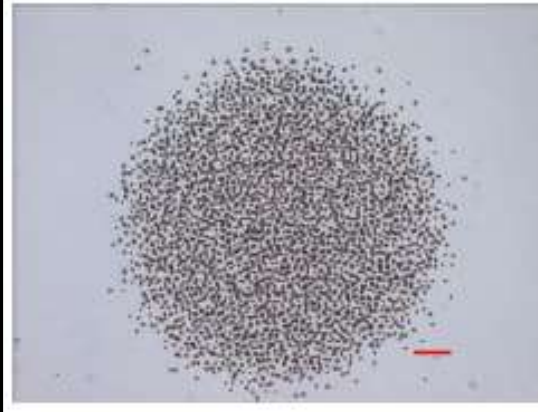
Photo taken by Matthew Parker.



# COMMON GENERA

Cyanobacteria  
Common  
in Oregon

*Microcystis sp*



*Anabaena Sp*



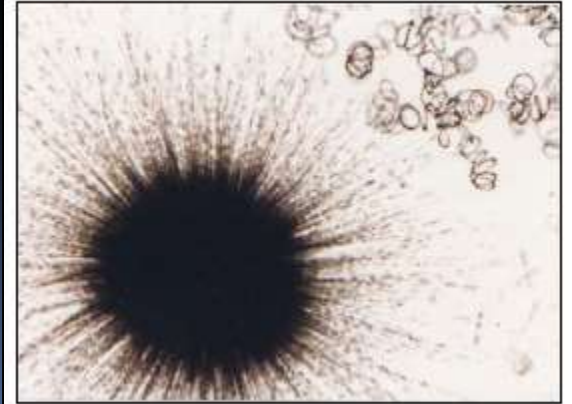
*Aphanizomenon flos-aquae*



*Phormidium favosum*



*Gloeotrichia echinulata*



# 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](http://www.healthoregon.org/dwcyanotoxins)



# COMMON CYANOTOXINS

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

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

# 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.

# CYANOBACTERIA BLOOMS CAN WORSEN WITH THE PRODUCTION OF TOXINS

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



Lake Erie – 2011 Bloom



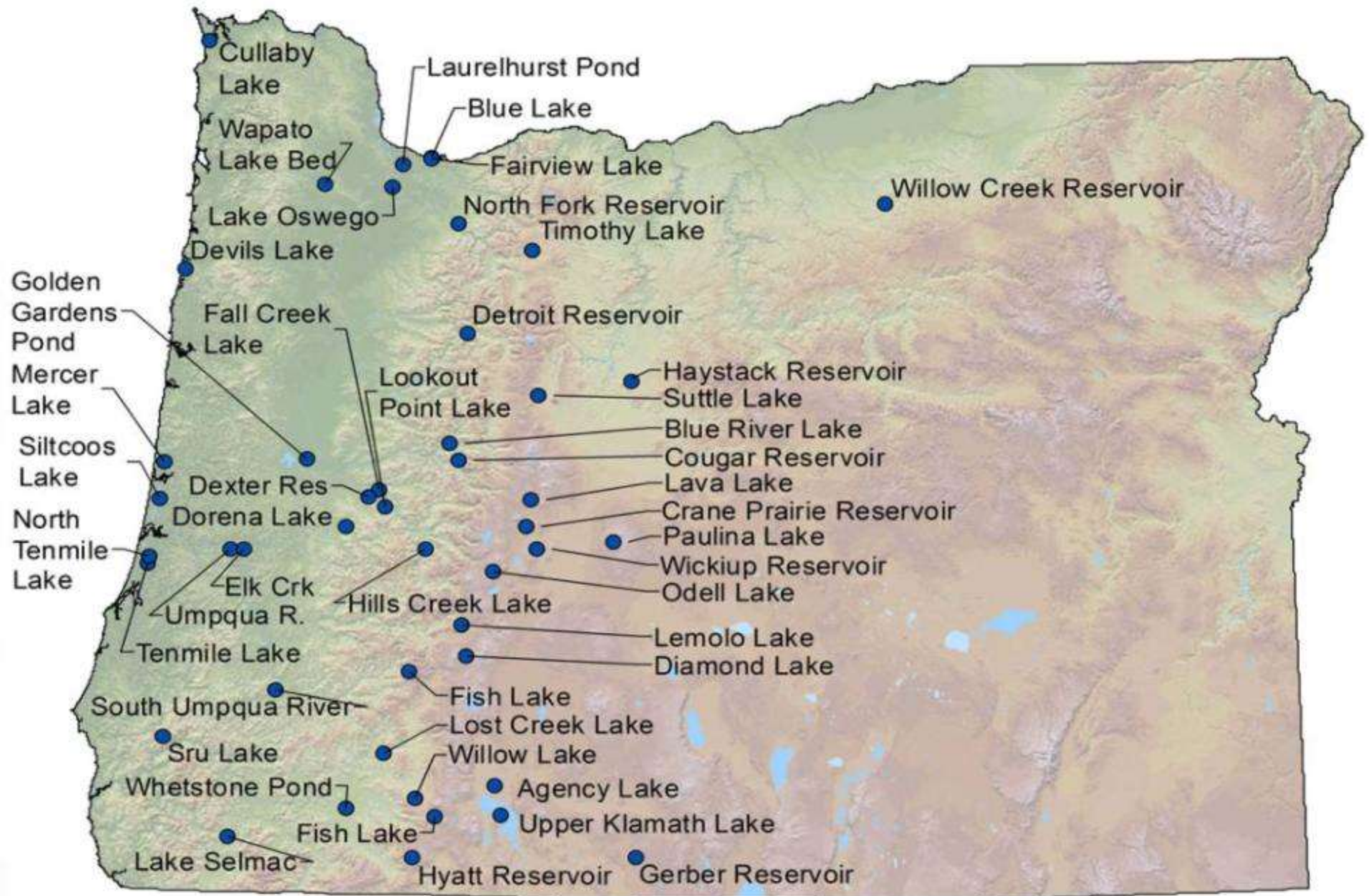
The 2011 Lake Erie bloom was composed almost entirely of toxic blue-green *Microcystis* algae. Concentrations of microcystin, a liver toxin produced by the algae, peaked at about 224 times World Health Organization guideline of 1 µg/l.

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>



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



## 2013 Cyanobacteria Bloom Recreational Advisory Information

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

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



# 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/](http://toxics.usgs.gov/highlights/algal_toxins/)

# 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>

# 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>



# CYANOBACTERIA – EXAMPLE 3

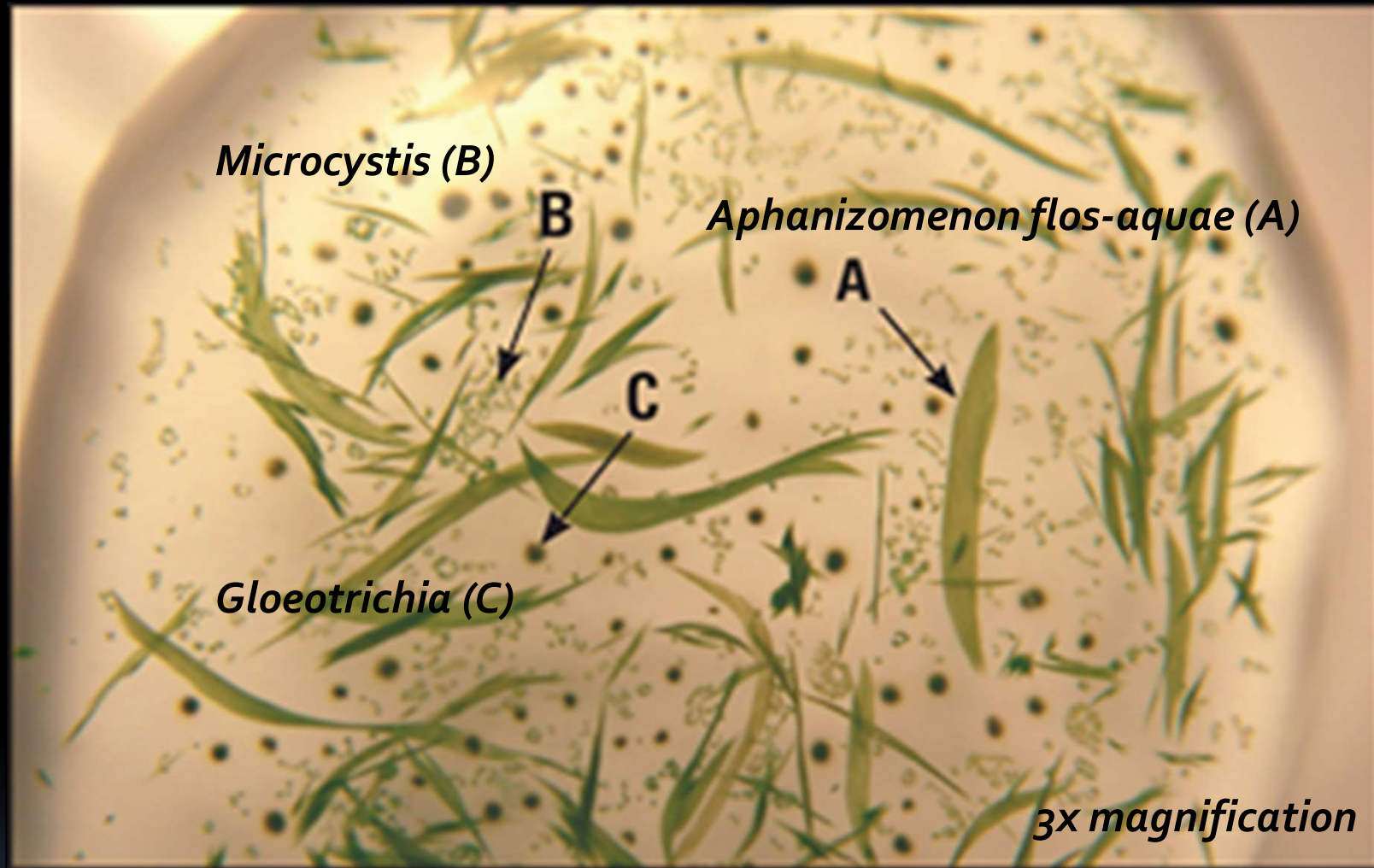
**Location:** Upper Klamath Lake

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/>





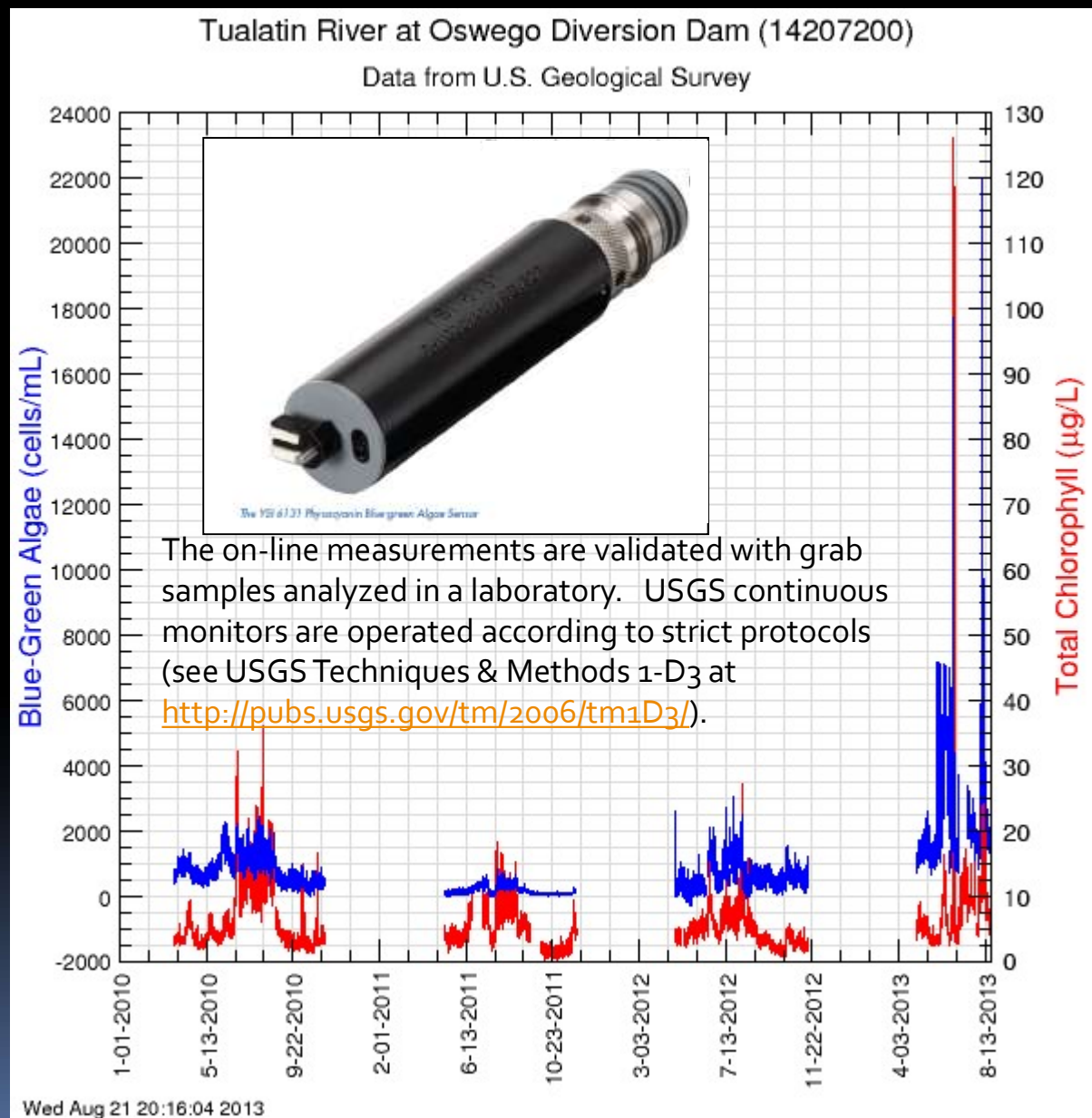
*Lake water subsample containing colonies of Aphanizomenon flos-aquae (A), Microcystis (B), and Gloeotrichia (C). Although Aphanizomenon flos-aquae does not produce toxins, Microcystis and Gloeotrichia can both produce the hepatotoxin microcystin. Magnification = 3x. Photograph by Sara Eldridge, U.S.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

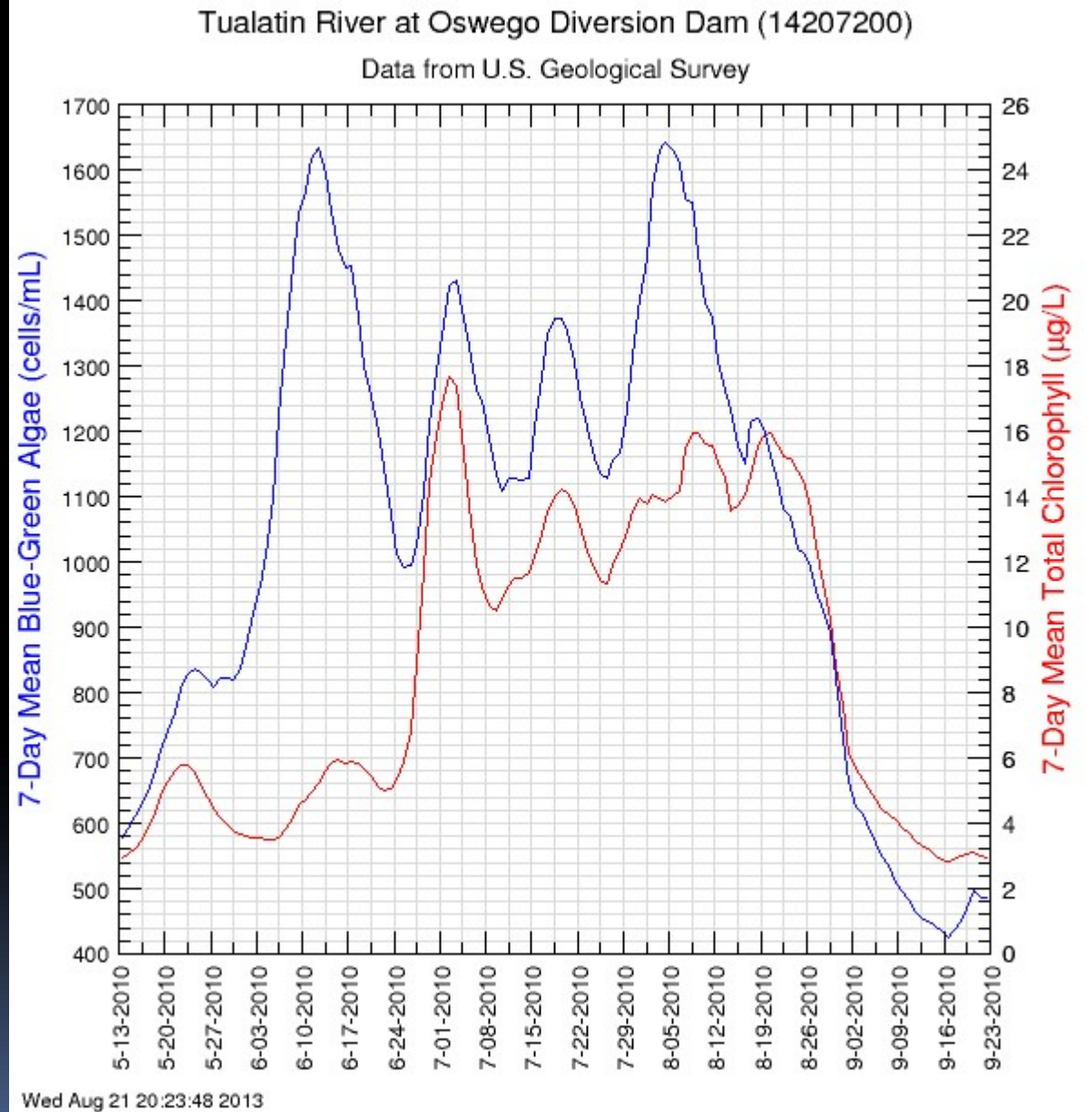
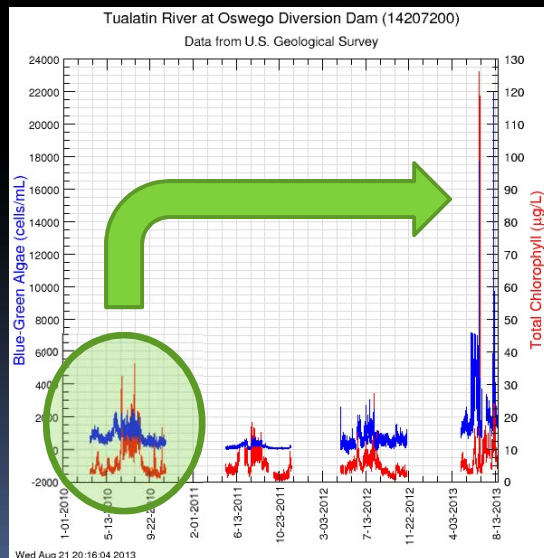
The blue-green algae data at the Oswego Dam site is collected with a YSI model 6131 probe. Chlorophyll is monitored with a YSI model 6025. More info on YSI probes is on-line at: <http://www.ysi.com>



Source: [http://or.water.usgs.gov/cgi-bin/grapher/graph\\_setup.pl?basin\\_id=tualatin](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](http://or.water.usgs.gov/cgi-bin/grapher/graph_setup.pl?basin_id=tualatin)



# 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)

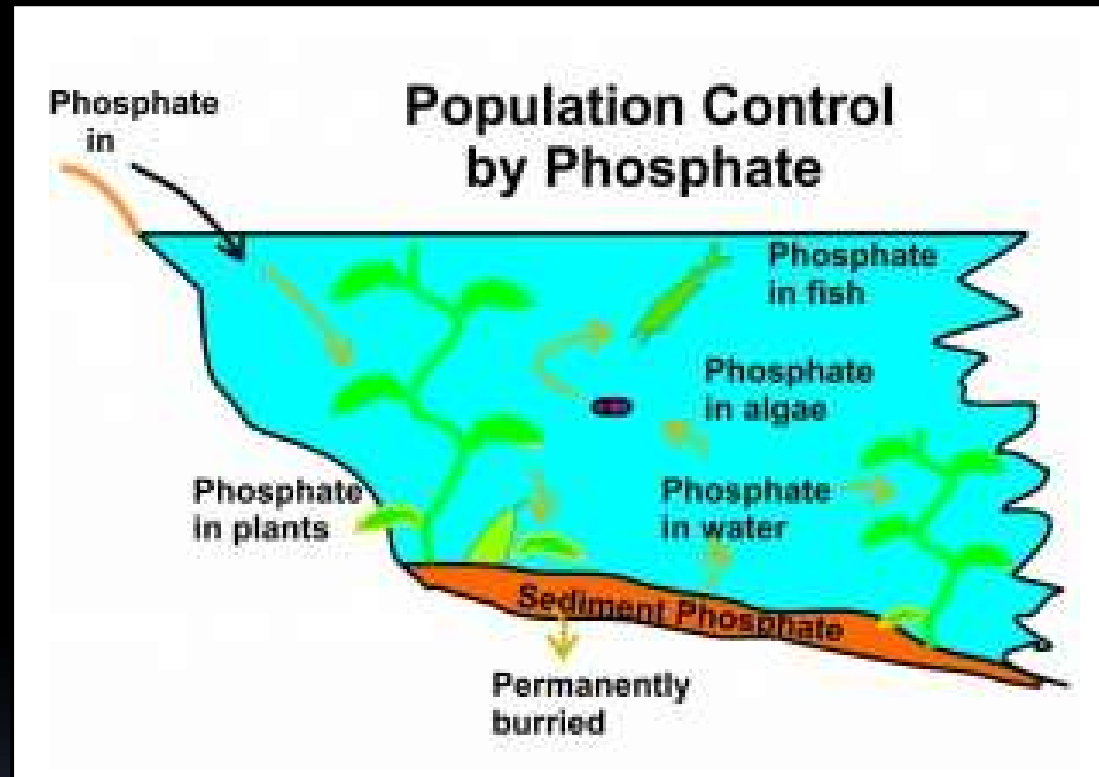
SolarBee® on raw water impoundment for City of Seaside =>



# 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).

# 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)



# 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.<sup>3</sup> = 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  |
|--|--|--|
| <b>Granular:</b><br><b>Large Volume</b><br>For example: Lakes, Ponds, Lagoons. | <b>20-90 pounds</b> of GreenClean Pro Granular Algaecide per acre-foot of water<br>-or-<br><b>50-250 pounds</b> of GreenClean Pro Granular Algaecide per million gallons of water. | <b>2-9 pounds</b> of GreenClean Pro Granular Algaecide per acre-foot of water<br>-or-<br><b>5-25 pounds</b> of GreenClean Pro Granular Algaecide per million gallons of water. |



# 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)<br>> 80% (DF, low lysis)                                   | < 10% of toxins  |

# 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



# 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<br>(ppb) | For Age 6 and Above<br>(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.

# CYANOBACTERIA RESOURCES

Oregon Health Authority – Drinking Water Services (OHA-DWS)

[www.healthoregon.org/dwcyanotoxins](http://www.healthoregon.org/dwcyanotoxins)

Oregon Health Authority – Recreational Surveillance Program

[www.healthoregon.org/hab](http://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](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>

# APPLIED WATER CHARACTERISTICS RECOMMENDED FOR SLOW SAND FILTRATION

## Recommended Applied Water Quality (following any pre-treatment)

|           |   |   |
|-----------|---|---|
| Turbidity | < 10 NTU<br>(colloidal clays are<br>absent) | <p>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 &lt; 1.0 NTU.</p> <p>Roughing filters can provide up to 50-90% of turbidity removal.</p> |
|-----------|---|---|



# 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<br>(filtered water DO should be $\geq 3$ 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) | $\leq 3.0$ mg/l<br>(low TOC to prevent DBP issues)      | TOC removal is variable and ranges from 10 – 25% (Collins et. al, 1989; Fox et 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.

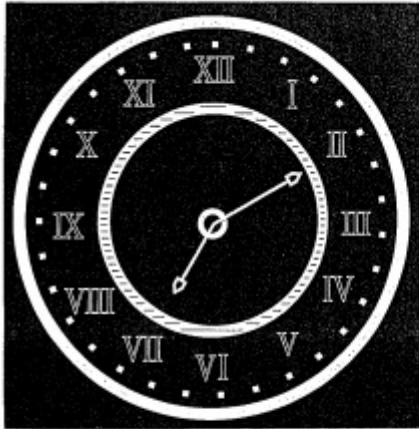
# APPLIED WATER CHARACTERISTICS RECOMMENDED FOR SLOW SAND FILTRATION

## Summary

### Recommended Applied Water Quality (following any pre-treatment)

|                            |  |
|----------------------------|--|
| Turbidity                  | < 10 NTU<br>(colloidal clays absent)   |
| True Color                 | < 5 platinum color units   |
| Coliform Bacteria          | < 800 CFU or MPN/100 ml  |
| Dissolved Oxygen (DO)      | > 6 mg/l (DO $\geq$ 3 mg/l in filter effluent)                               |
| Total Organic Carbon (TOC) | $\leq$ 3.0 mg/l (<2.5 – 3.0 mg/l DOC)<br>(low TOC/DOC to prevent DBP issues) |
| Iron & Manganese           | Each < 1 mg/l  |
| Algae                      | < 200,000 cells/L (depends upon type)  |

# QUESTIONS?



TIMELESS  
TECHNOLOGY  
FOR  
MODERN  
APPLICATIONS

## Slow Sand Filtration Workshop

October 27-30, 1991  
New England Center  
University of New Hampshire  
Durham, New Hampshire

Sponsored by:  
American Water Works Association  
and the University of New Hampshire



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