Fundamentals of Granular Media Filtration

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Overview

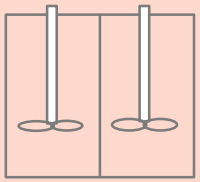
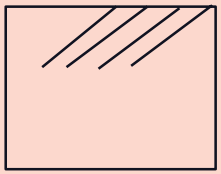
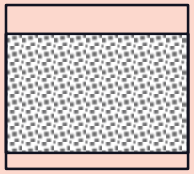
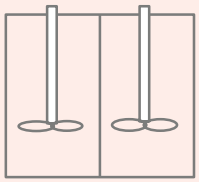
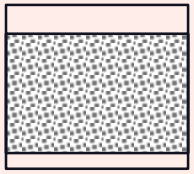
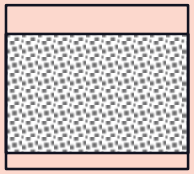
- Filtration basics
- Filtration theory
- Filter media selection and design
- Monitoring and Troubleshooting

Filtration Basics and Theory

What is filtration?

- **Definition**: any process that removes suspended particles through a porous medium
- **Types of Filters**
  - Granular media filters (GMF)
    - Slow sand filters
    - **Rapid depth filters**
  - Membrane filters (MF/UF/NF/RO)

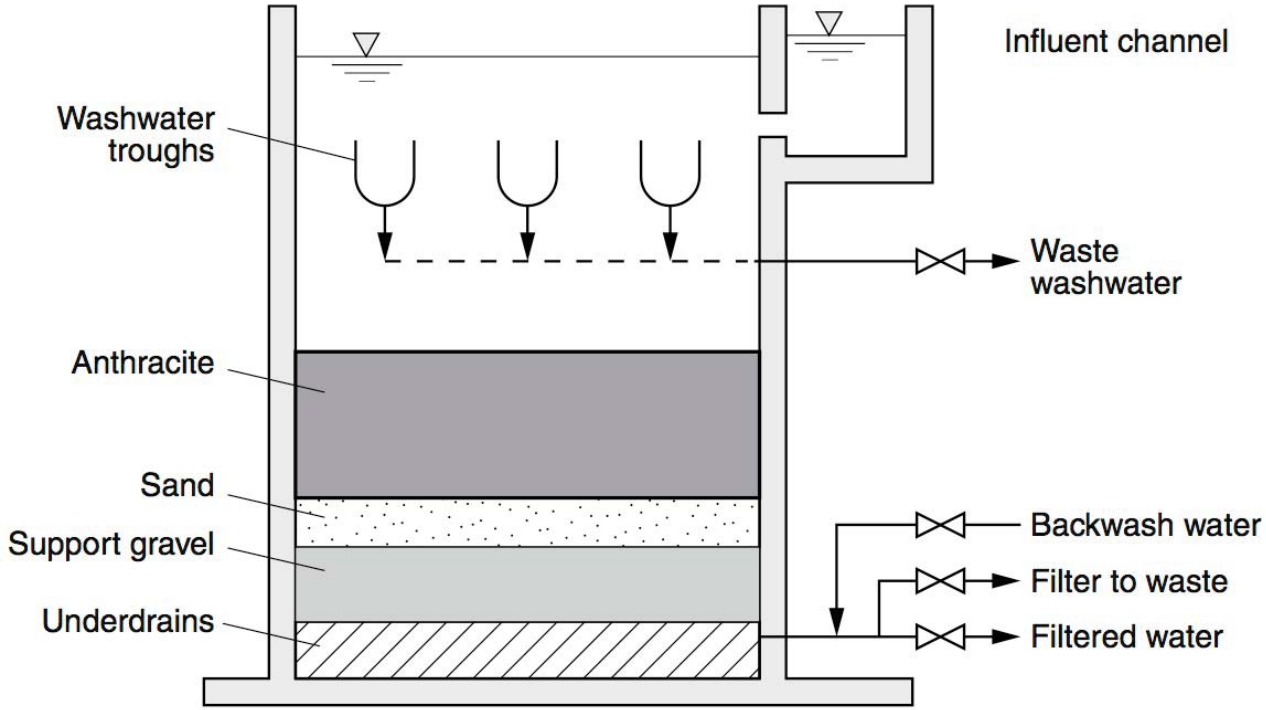
Typical Filtration Pre-Treatment

Filtration Type	Coagulation	Flocculation	Sedimentation	Filtration	NTU
Conventional					Any
Direct					<15 NTU
Contact					<10 NTU

A typical gravity depth GMF

Components

- Flow control
- Media
- Underdrain and support
- Backwash system



Picture from MWH (2005) Water Treatment Principles and Design

Granular Media Types

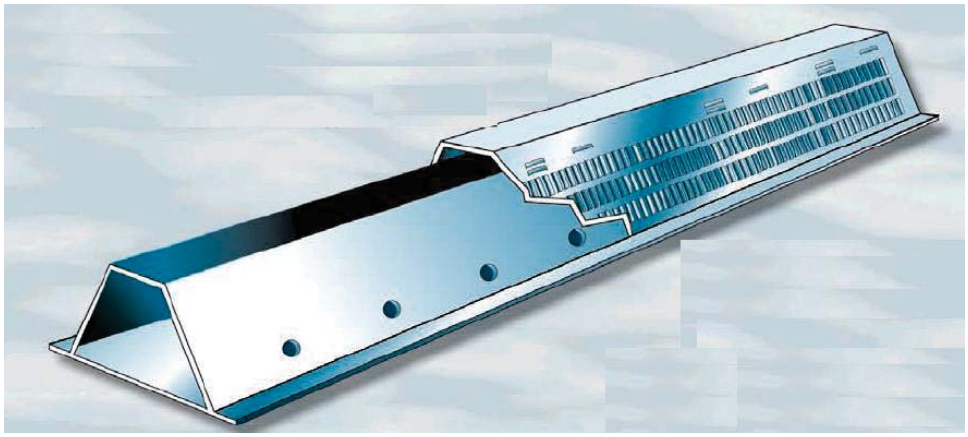
Configuration

- Mono media
- Dual media
- Multimedia

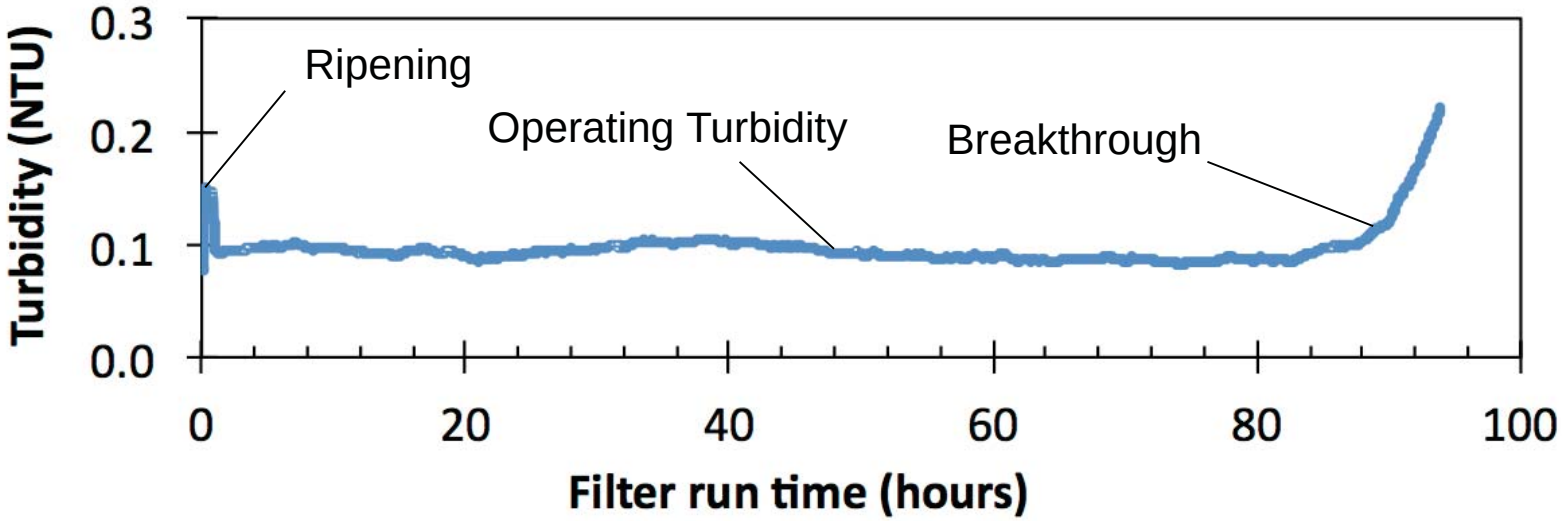
Types

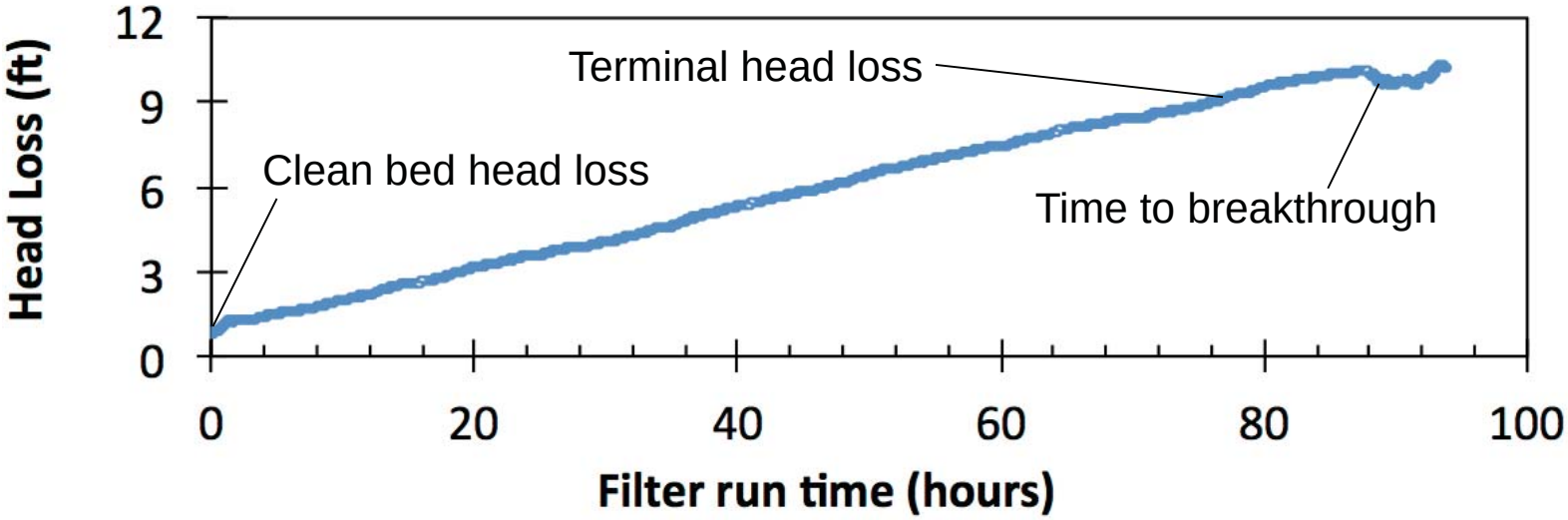
- Silica sand
- Anthracite coal
- GAC
- Other (e.g. garnet)

Filter Underdrains and Support



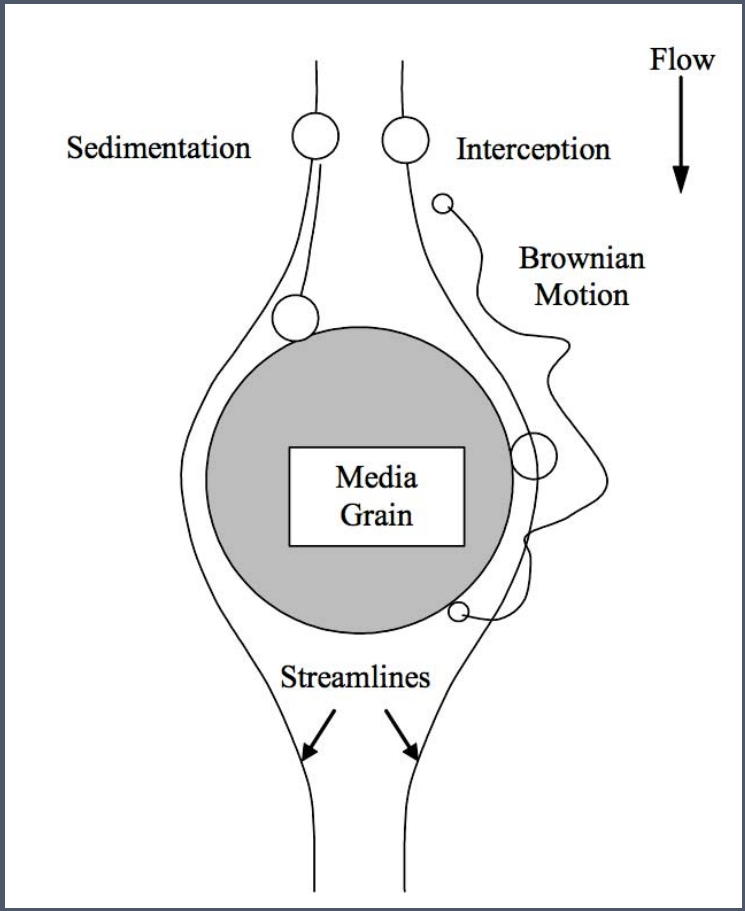
Understanding a Filter Run





Surface vs. Recycled Water Filtration

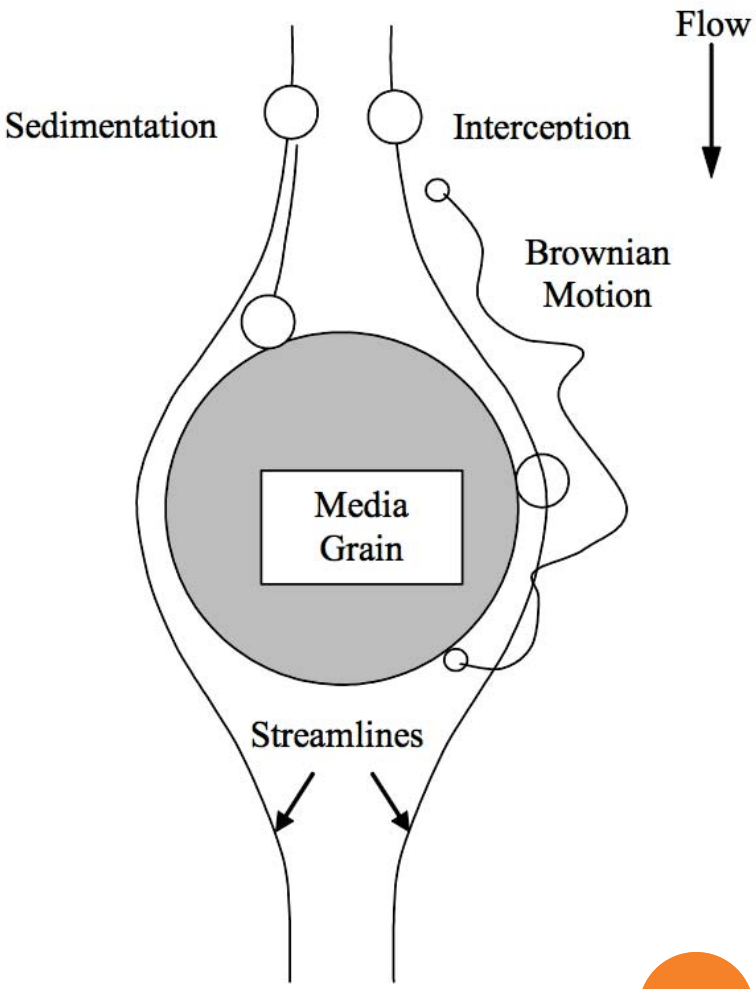
Typical	Surface Water	Recycled Water
Drivers	sediment, pathogens, organic solids	pathogens, organic solids
Pretreatment	Any	direct/contact
Source Water	1 to 100 NTU	1 to 10 NTU
Turbidity Req'd	0.3 NTU/0.1 NTU	2 NTU
Filtration Rate (gal/ft^2-min)	3/6 (mono/dual)	5 (up to 7.5)



Filtration Theory

FILTRATION THEORY

- Modeled as 2-step process
  1. Particle transport
  2. Particle attachment
- Particle transport mechanisms
  - Sedimentation
  - Interception
  - Brownian motion (diffusion)
- Straining *not* desirable
- Overall removal is sum of all mechanisms

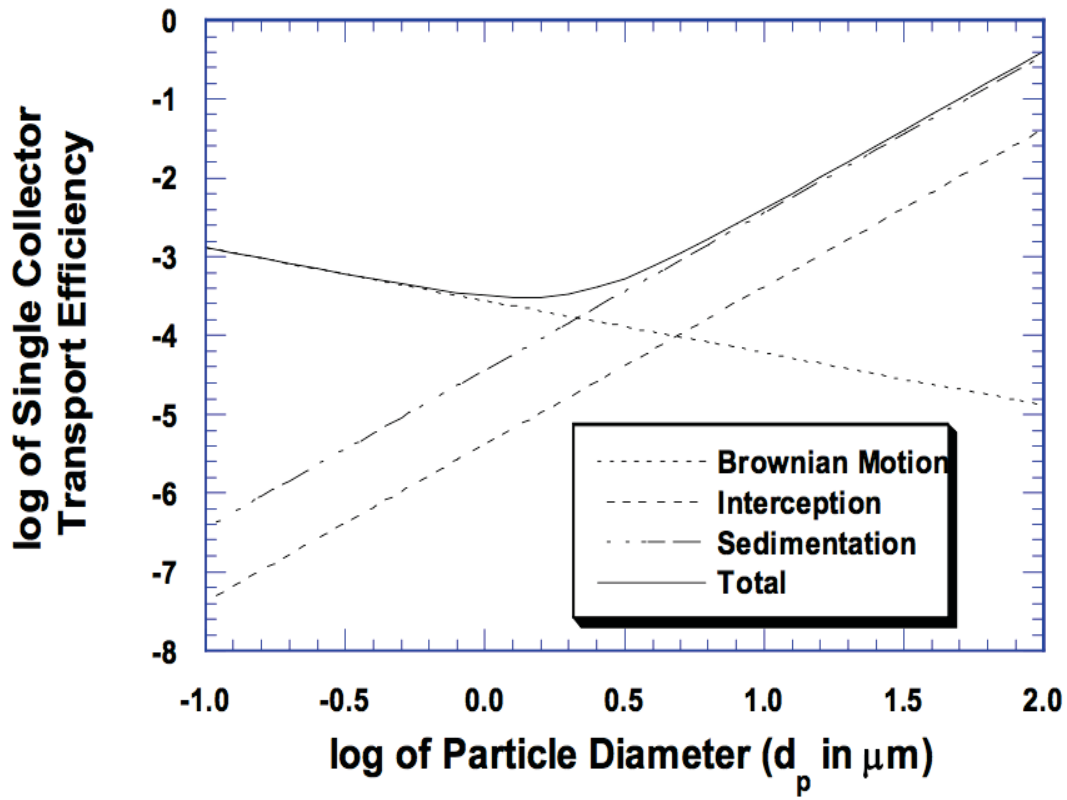


Picture from Lawler and Benjamin 2006

Particle transport efficiency

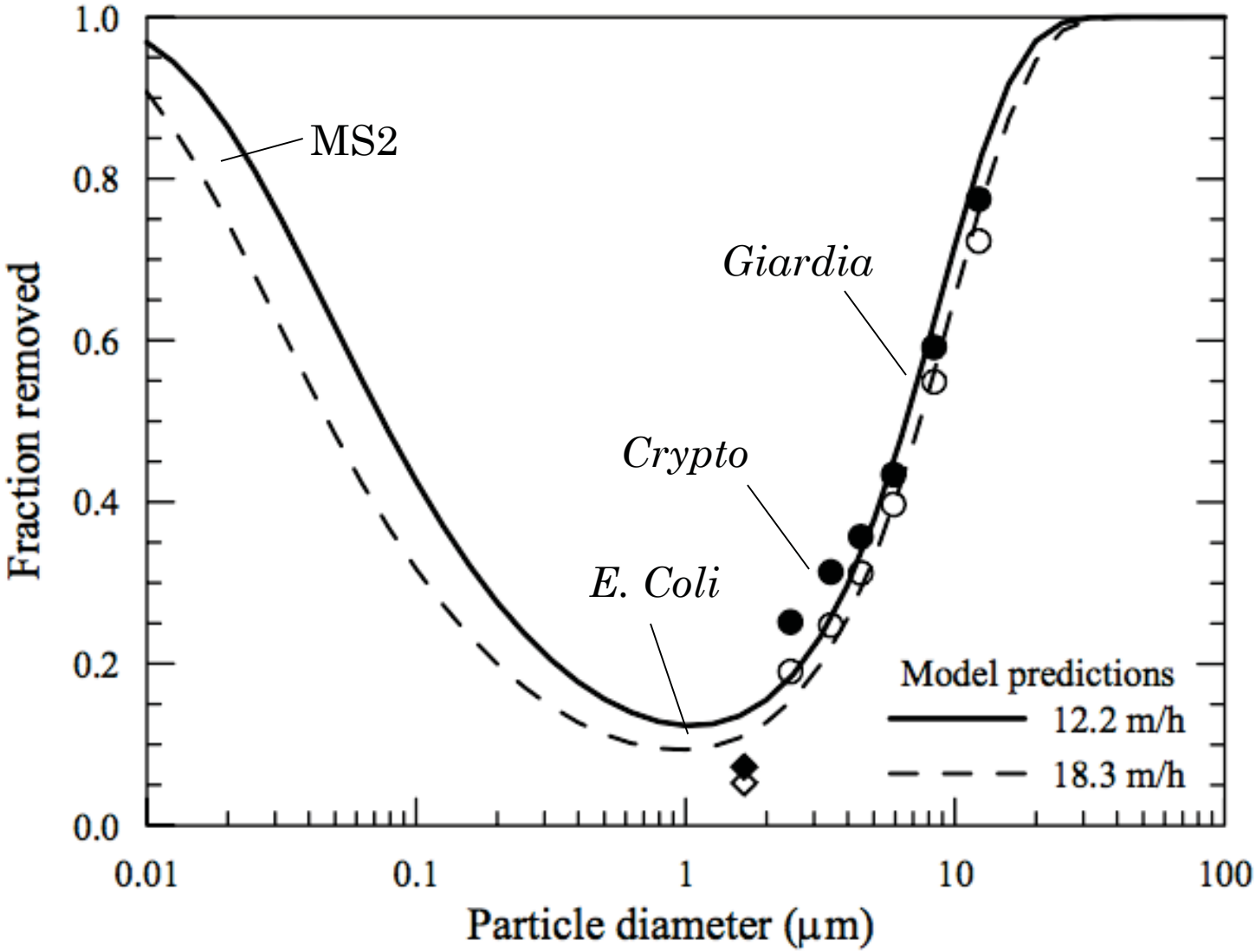
Transport efficiency driven by:

- Filtration rate
- Media design
- Particle size
- Temperature
- Density (sed. only)



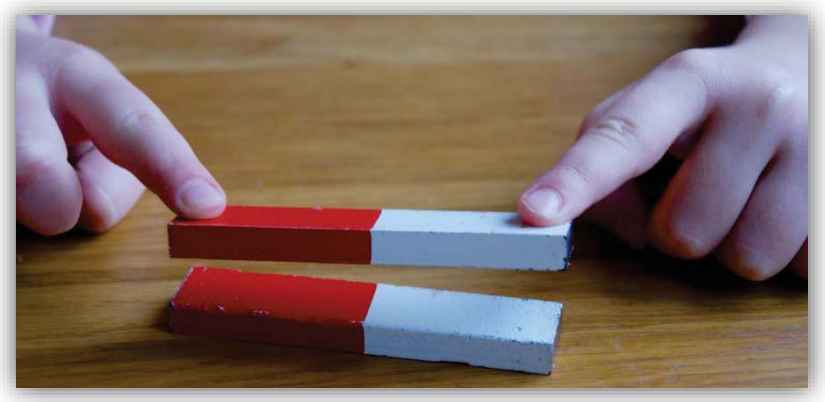
Graph from Lawler and Benjamin 2006

ACTUAL DATA MATCHES UP WITH THEORY!



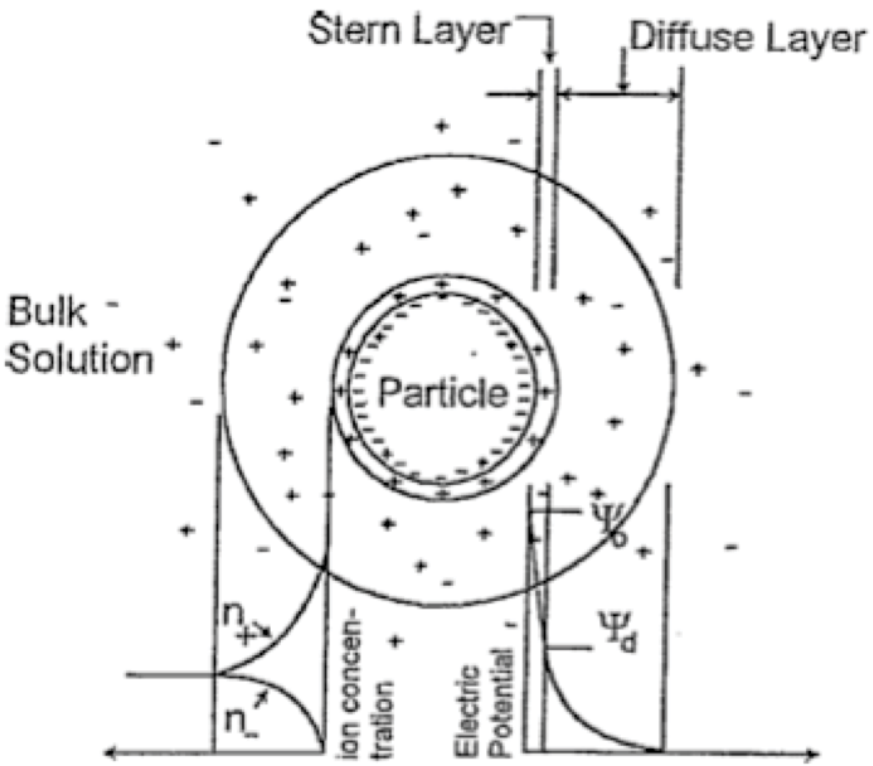
Why is chemistry so important?

- Chemistry needs to be right for particles to “stick”
- Both particles and media are naturally negatively charged and thus *repelled* by each other
- For excellent filtration, the surface chemistry of target particles must be modified – coagulation!

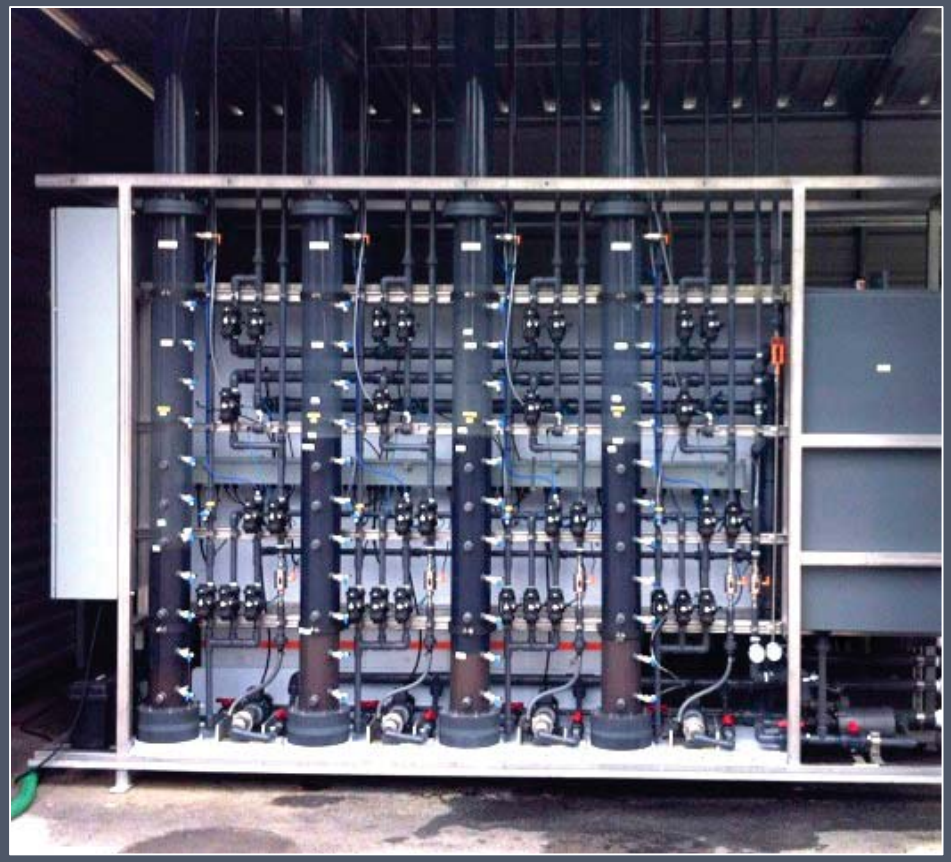


Particle attachment efficiency

- Attachment is driven by chemistry
- Attraction/repulsive forces
  - London-van der Waals force
  - Electrical double-layer interaction
  - Born repulsive force
  - Hydration force



From V. Jegatheesan and S. Vigneswaran (2005)

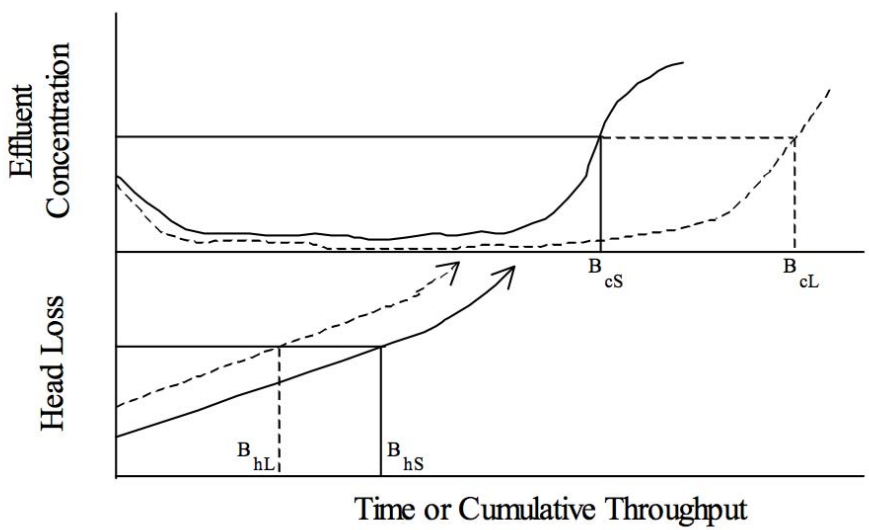


Filtration Media Selection and Design

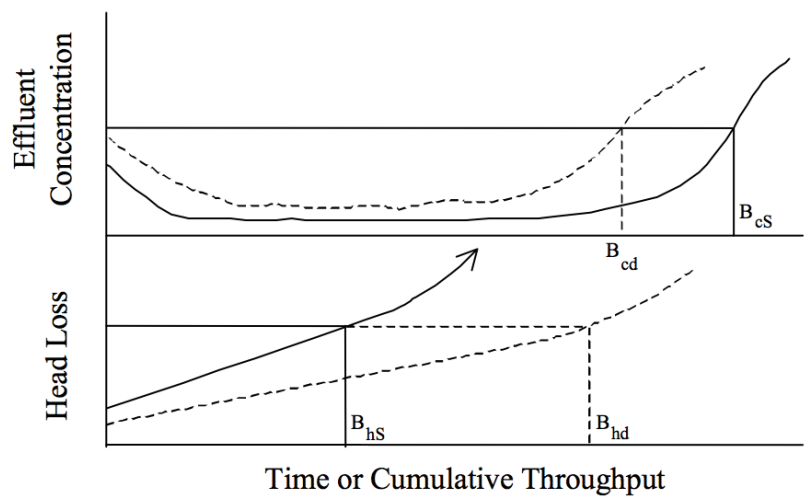
How does theory affect design?

Independent Variable	Head Loss		Effluent Quality	
	Time	Cumulative Volume	Time	Cumulative Volume
Depth ↑	↓[a]	↓	↑	↑
Media Size ↑	↑	↑	↓	↓
Velocity ↑	↓	↔	↓↓	↓
Influent Conc.↑	↓	↓	↓	↓

Increased media depth

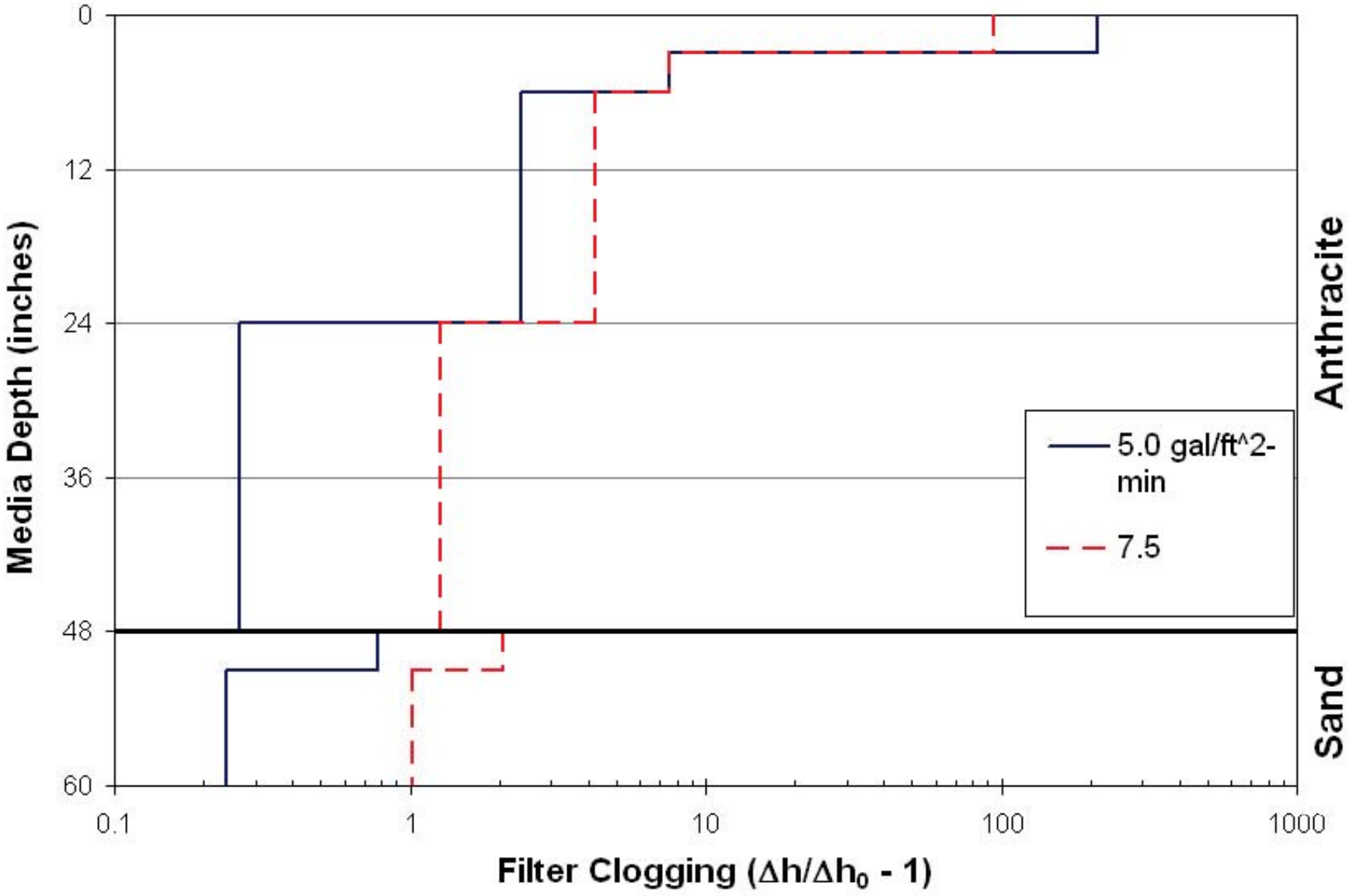


Increased media size



from Lawler and Benjamin 2006

Headless across filter bed



What makes design GMF complicated?

Two competing goals:

1. Particle removal (i.e., effluent quality)
2. Filter run length (i.e., head loss accumulation)

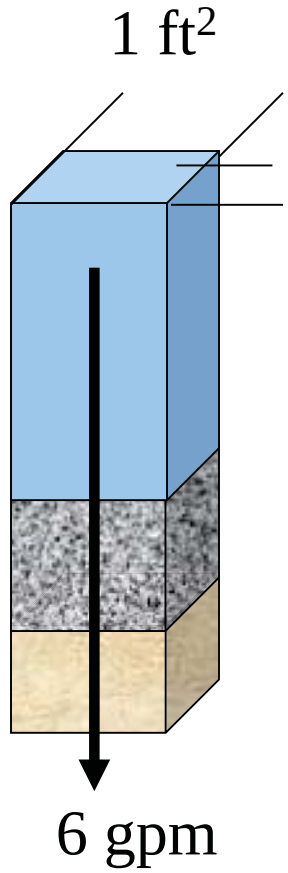
How do we balance competing variables?

Modifying three basic design parameters

- Media selection
- Depth of media
- Filtration rate (flow velocity)

In terms of cost

- Biggest cost driver will be filtration rate
  - Filter area is function of filtration rate



Approach to Media Selection

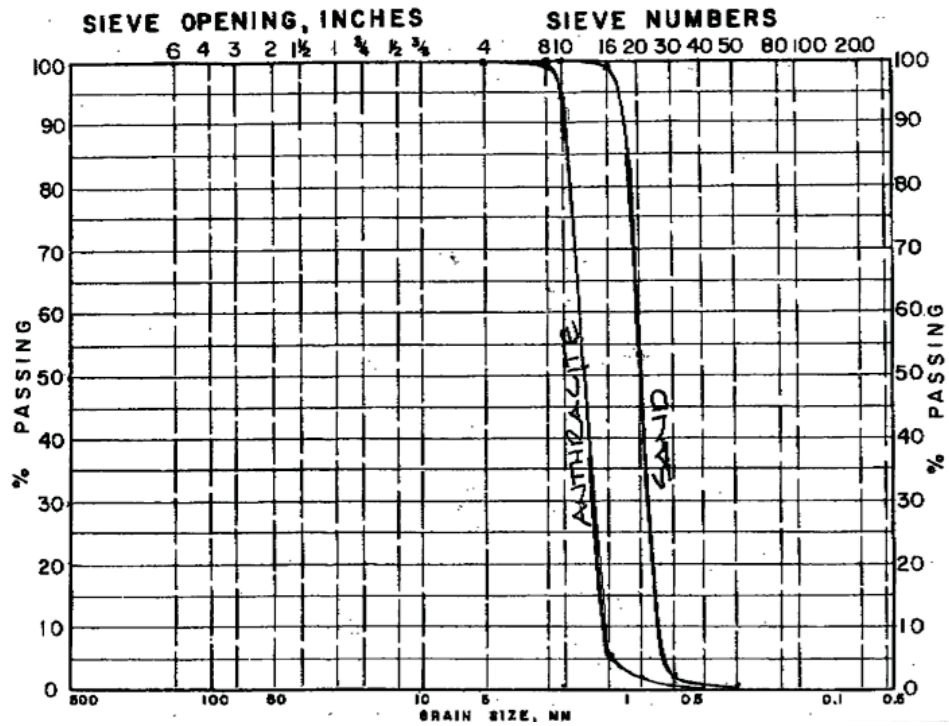
Begin with good understanding of treatment goals and water quality

Approaches to Design

- Follow industry design standards
- Modeling approach
- Filter piloting

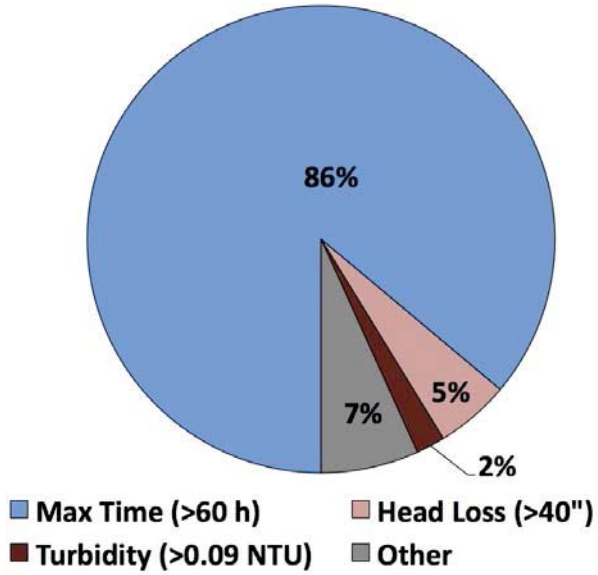
Specifying GMF Media

- Effective grain size (d_{10})
- Uniformity coefficient (UC)
  - UC = d_{60}/d_{10}
  - Smaller the better
  - Typically <1.5
- Media depth (L)
- $L/d_{10} > 1000$
- Trends over time
  - Deeper and coarser
  - Higher filtration rates

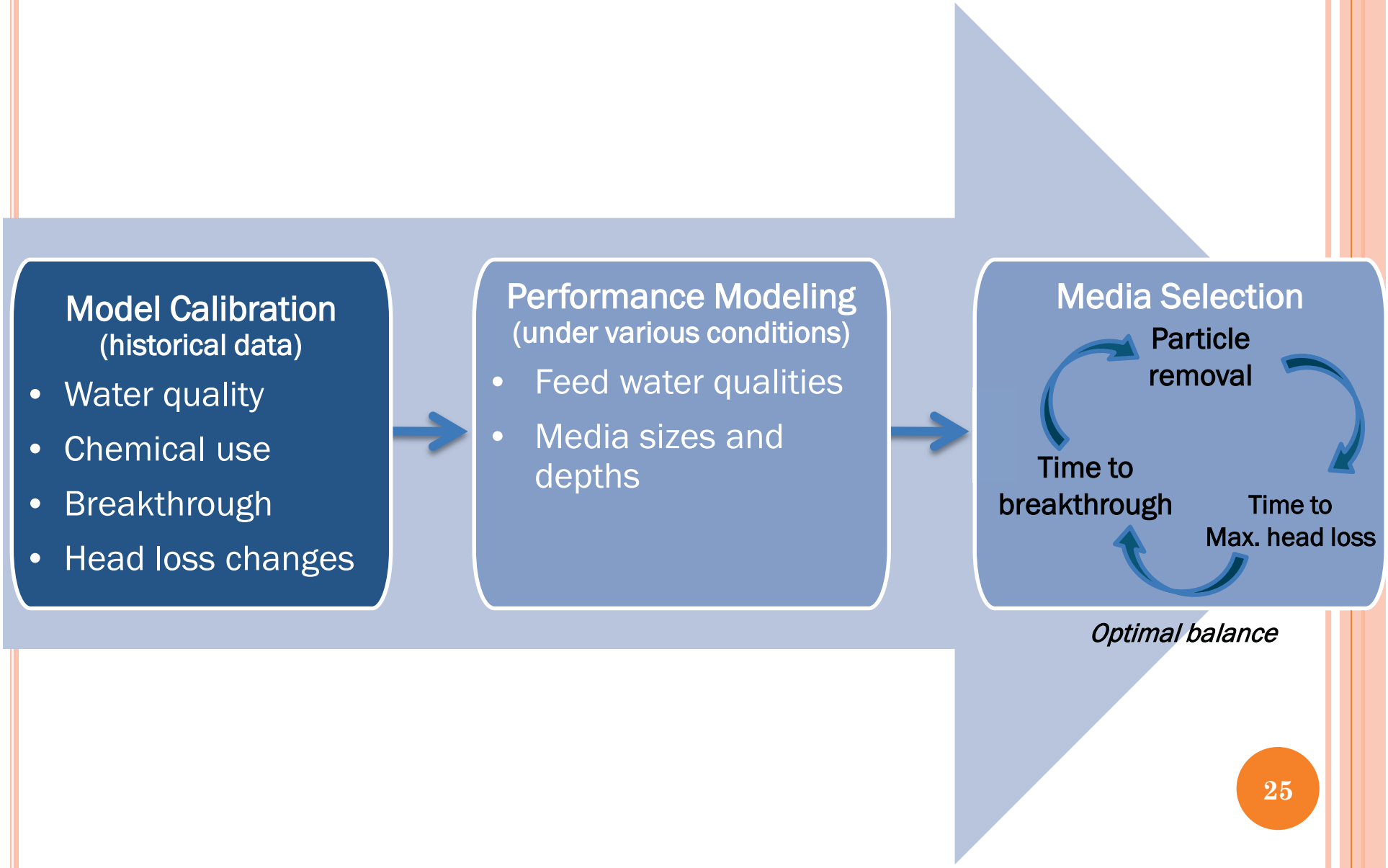


Define Filter Media Goals

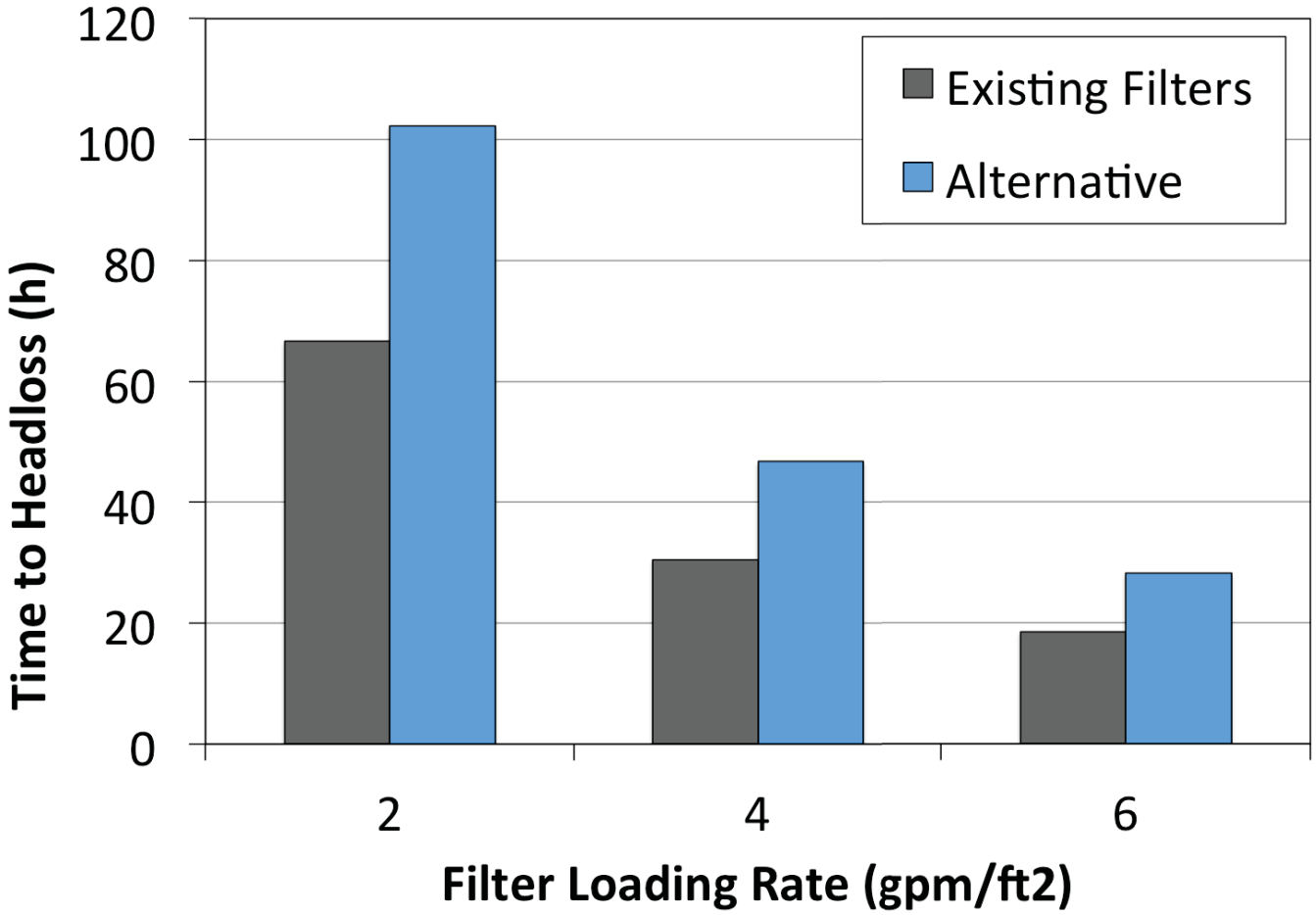
- What does better performance mean?
  - Reduce head loss accumulation
  - Improve effluent water quality
  - Reduce risk of breakthrough
  - Manage a combination of goals for multiple source waters



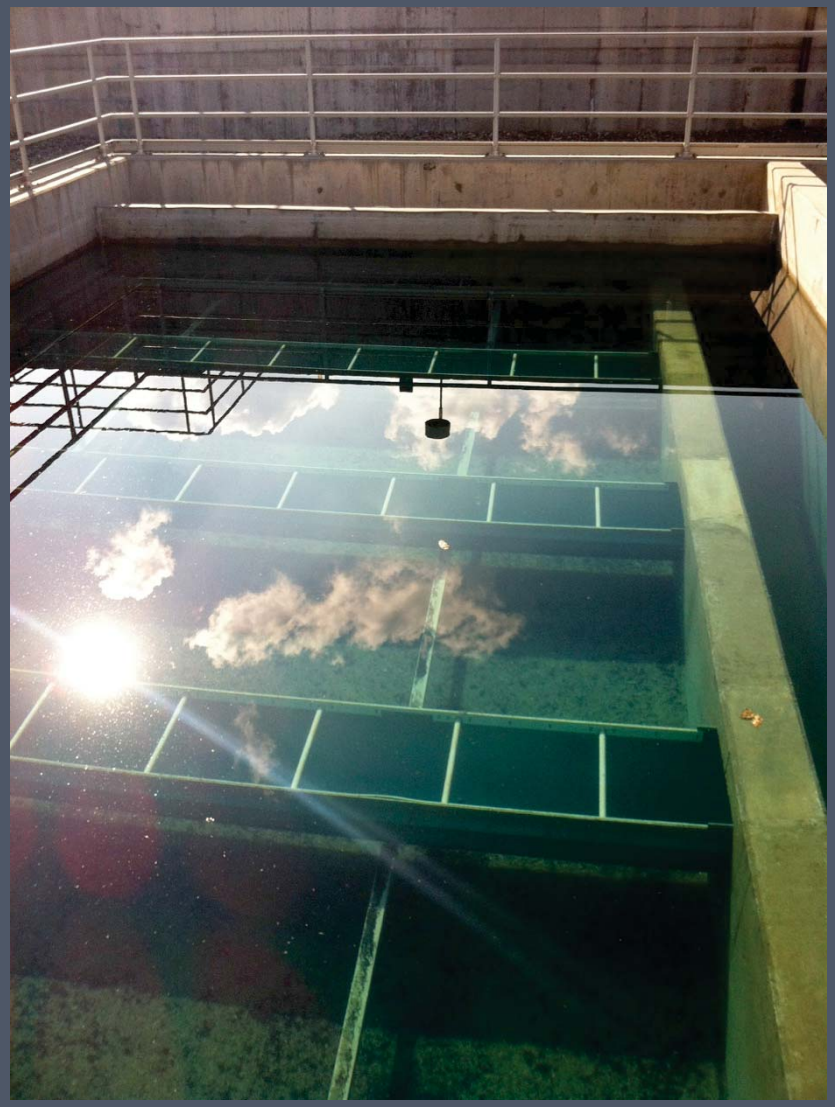
Modeling Approach to Media Selection



Example of Modeling Results

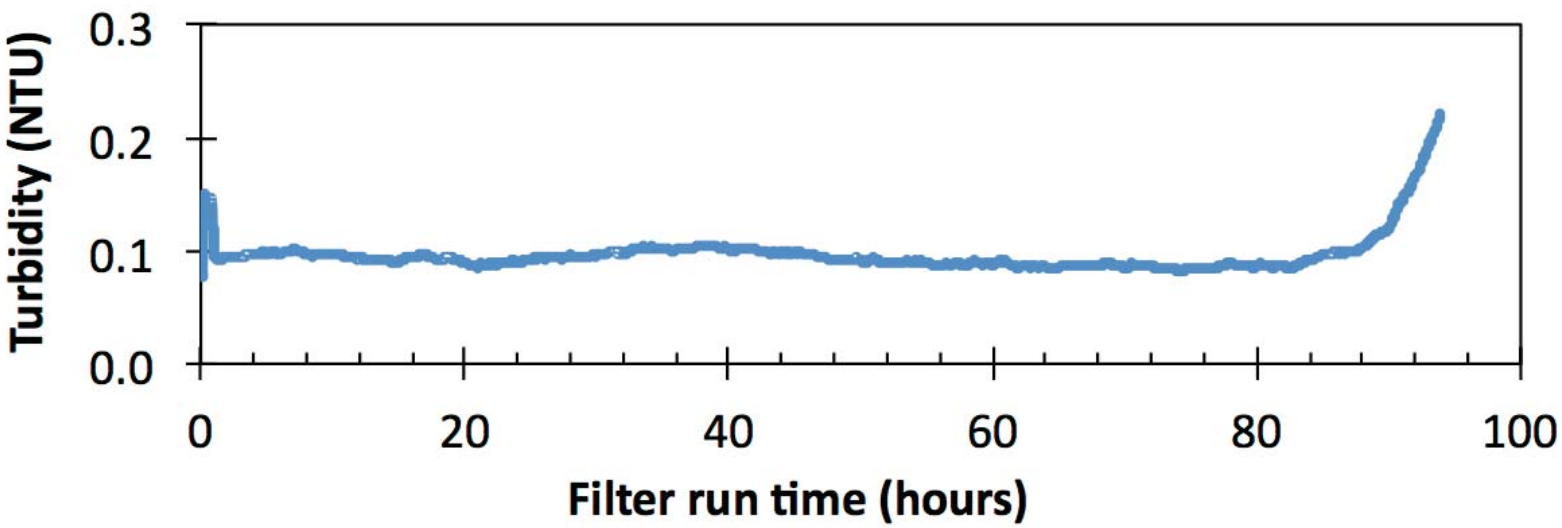


Filter Operations



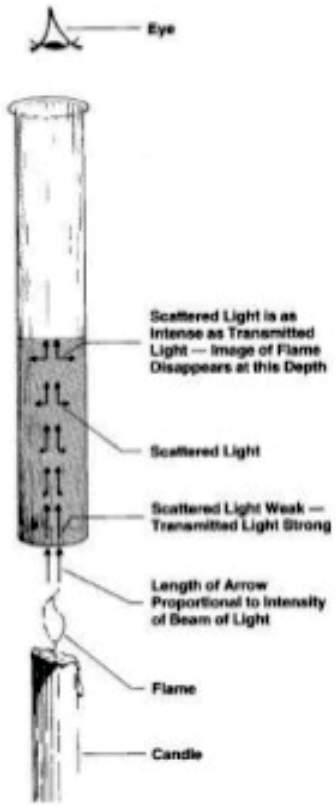
Clean-bed removal and ripening

- Surface chemistry is improved through chemical conditioning (coagulants and polymers)
- Particle-particle attachment is more efficient than particle-media attachment
- Ripening needed for excellent removal
- Typical practice to have a filter-to-waste step

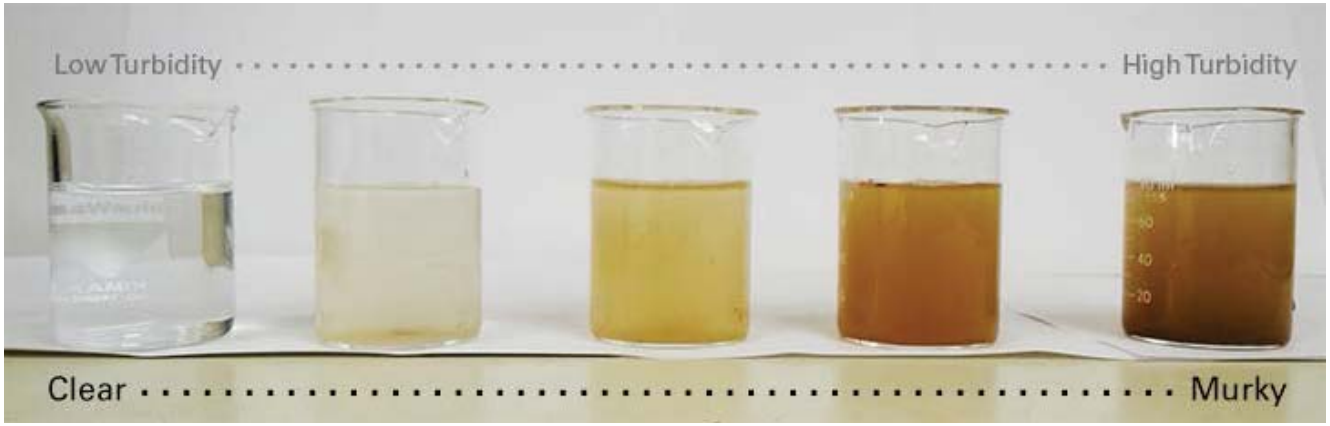


Filter Performance Monitoring

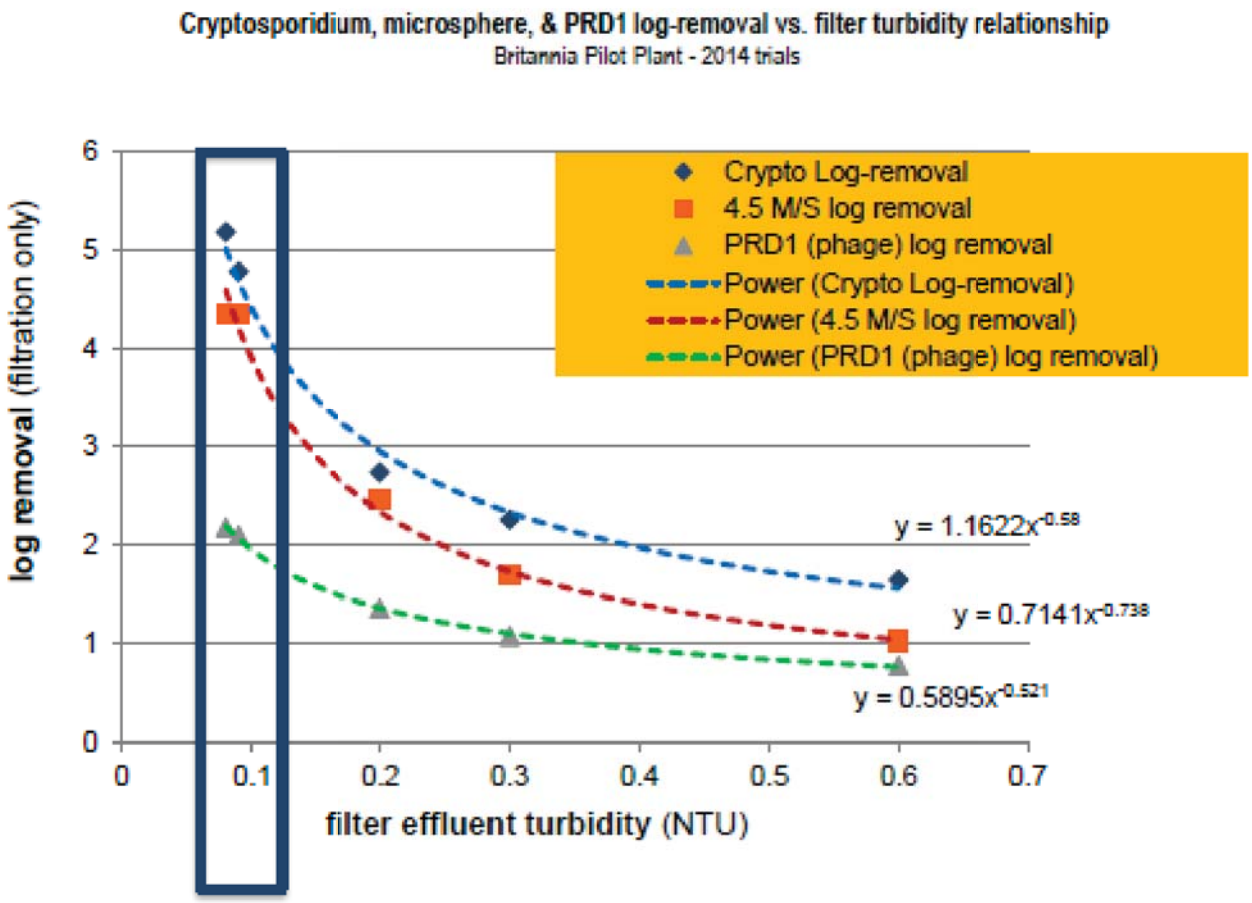
- Turbidity standard performance metric
  - NTU = Nephelometric Turbidity Unit
  - Based on light *scattering*
- Particle counters – based on light *blockage*
- Surrogate parameter for treatment performance
- Regulatory limits of 0.3 or 0.1 NTU



Old school turbidity by Jackson candle (JTU)



Filter Performance Data: Douglas et al, 2015, City of Ottawa



Slide from Ben Stanford, AWWA IPRS 2016, Long Beach, CA

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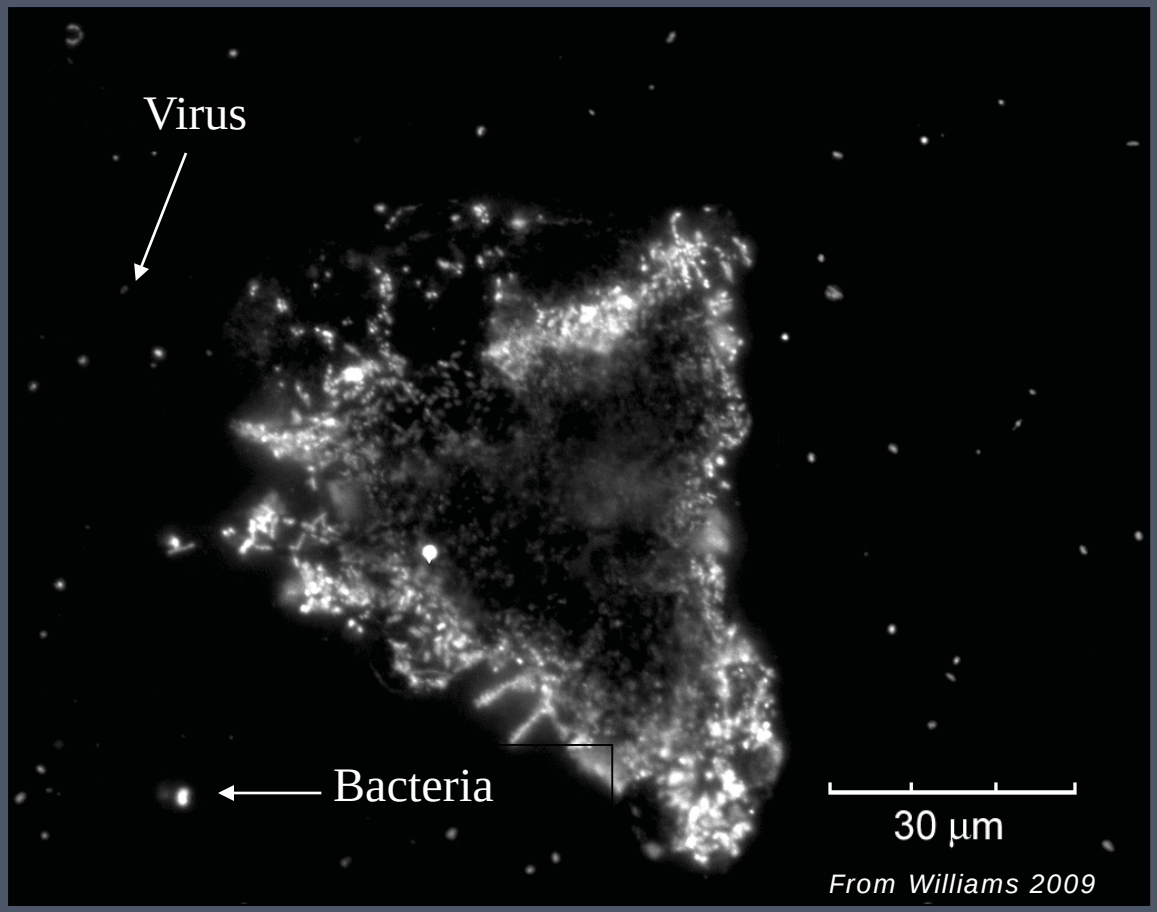
GMF Filter O&M Troubleshooting

- Excellent influent water quality = ease of operation
- Balance turbidity and head loss using chemical dose
- Backwash management
- When issues arise - filter surveillance!
  - Visual observation
  - UFRV
  - Filter coring – media changes/mudballs
  - Watch head loss – air binding
  - Backwash profile – improved sequence



Questions?

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Understanding the Existing Media

Sieve Analysis

Filter Coring of Existing Media