Deep-Bed Filters

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History

1872 Slow Sand Filtration at Poughkeepsie NY

- 0.12 m/h (0.05 gpm/ft2)

1890s Conventional Treatment: coagulation-sedimentation-filtration

- 5 m/h (2.5 gpm/ft^2)
- Monomedia Sand; 24-30 in (61-76 cm) depth; E.S. 0.5 mm

1940s Dual Media

- 10-12 m/h (4-5 gpm/ft^2)
- 1.0 mm anthracite over 0.5 mm sand; 24-48 in (61-152 cm) depth
- Tri-media filters also used (anthracite/sand/garnet)

1980s Deep-Bed Monomedia at LADWP Aqueduct Filtration Plant

- 32 m/h (13 gpm/ft^2)
- 1.8 m (6 ft) of 1.5 mm anthracite

What has changed since 1940s?

- Understanding of coagulation chemistry
- Online turbidimeters mandated and particle counter use increases
- Coagulant-aid and filter aid polymer use increases
- Detailed research studies investigate Giardia and Crypto removal performance

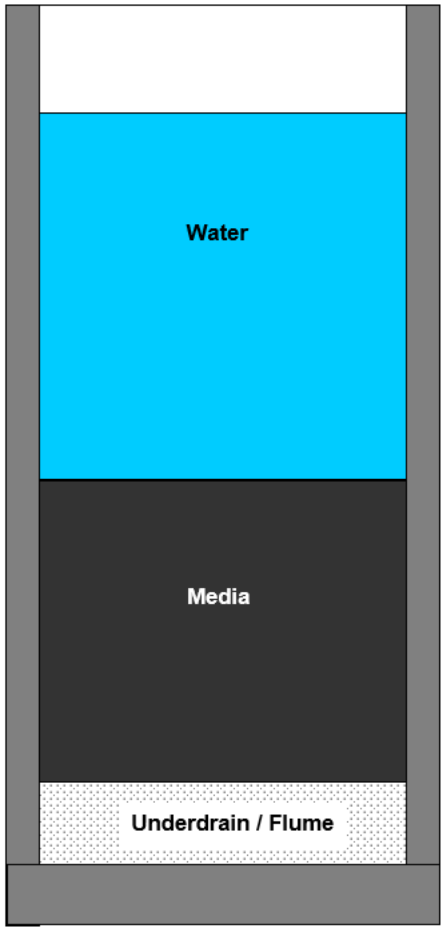
Date	NTU	Reference
1962	5	US Public Health Serv.
1975	1	Primary Standards
1989	0.5	SWTR
1998	0.3	IESWTR
Today	0.1	Partnership for Safe Water

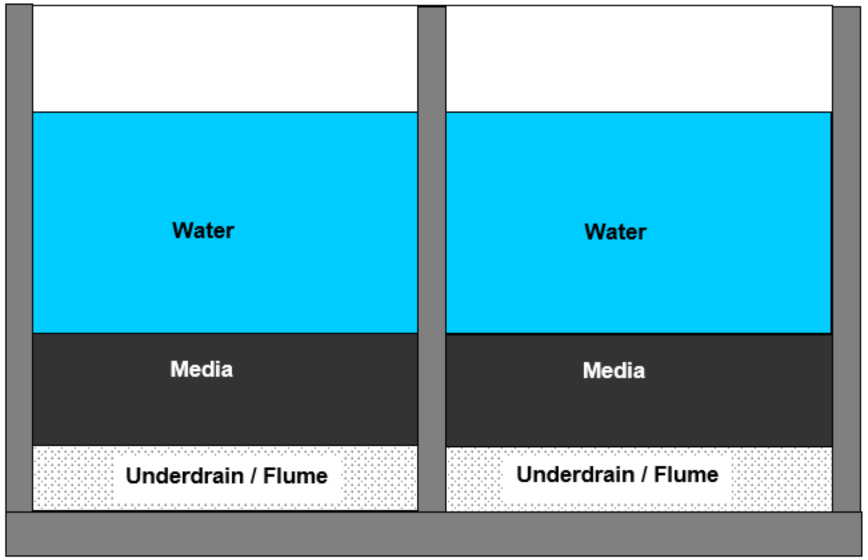
Advantages of Deep-Bed Filtration

The 1970's called, and they want their filters back…"

- Why are we still designing shallow 4 gpm/ft^2 filters?
- Filter underdrains are the most expensive part of filter construction
- A deep-bed filter with a higher loading rate requires less underdrain area for a given flow
- Cost comparison of DB vs conventional filter

Deep-Bed vs Conventional Filter Design





	Deep	Conv	Unit
Flow	20	20	mgd
Area per filter	460	460	sf
Total SF	1840	3680	sf
Number of Filters	4	8	no.
Loading Rate, one OOS	10	5	gpm/sf
Total Filter Media Depth	7	3.5	ft
Terminal HL Assumptions	12	6	ft
Filter Cell Length	20	20	ft
Filter Cell Width	23	23	ft
Total length	40	80	ft
Total length (w/ walls)	**43**	**85**	**ft**
Total Width	46	46	ft
Total Width (w/ walls)	**49**	**49**	**ft**
Total Filter Depth	**20**	**11**	**ft**
Excavation Volume	2800	1710	cf
Concrete Volume	5,520	5,500	cf
Volume of Media	12,880	12,880	cf
SF of Underdrain	1,840	3,680	sf
Valves	16	32	no.
Building SA	2,340	4,180	sf

How Do Deep-Bed Filters Work?

Particles attach to filter media via electrostatic attraction

Higher filter loading rates result in higher interstitial velocities between media grains and higher shear forces

- Good chemistry more important at higher rates

Particle removal per unit depth of media decreases at higher rates

Therefore, deeper media beds required for higher flow rates

Clean bed headloss (CBHL) increases as loading rate increases

Larger media needed to reduce CBHL

Examples of Deep-Bed Filters

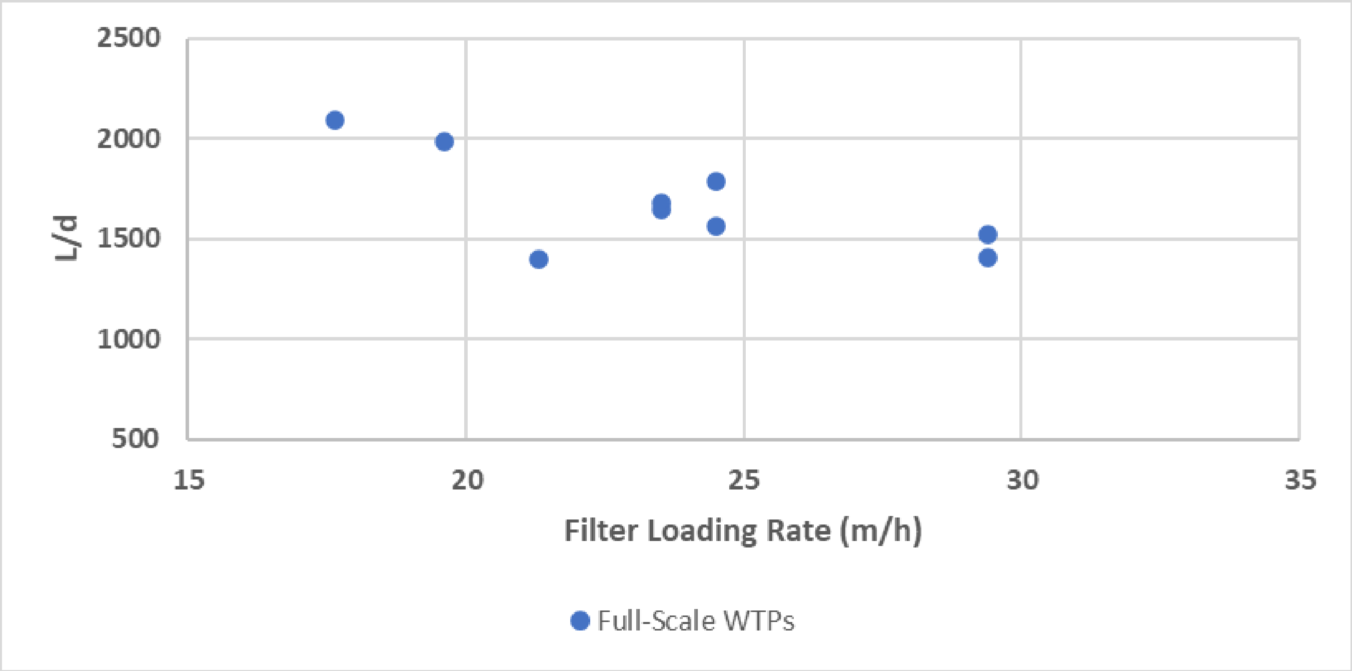
Facility Name	Aqueduct F.P.	Willamette River WTP	Seymour-Capilano WTP	Winnipeg WTP	Lake-Oswego-Tigard WTP	Mt Crosby East Bank WTP	Buffalo Pound
Location	Los Angeles, CA	Wilsonville, OR	Vancouver, BC	Winnipeg, MB	West Linn, OR	Brisbane, QLD	Regina, SK
WTP Type	DF	Actiflo-O3-BAC	DF	DAF-O3-BAC	Actiflo-O3-BAC	Coag-Floc-Sed-Filter	DAF-O3-BAC
Commissioned	1986	2001	2009	2010	2017	2020	Construction
Filter Rate (gpm/ft^2)	13	10	10	12	10	7.3	9.6
Top Media	Anthracite 1800 mm ES 1.5 mm	GAC 1830 mm ES 1.4 mm	Anthracite 1700 mm ES 1.4 mm	GAC 2100 mm ES 1.1 mm	GAC 1220 mm ES 1.3 mm	Filter Coal 900 mm ES 1.5 mm	GAC 2350 mm ES 1.4 mm
Lower Media	-	Sand 300 mm 0.45 mm	Sand 300 mm ES 0.55 mm	-	Sand 300 mm ES 0.5 mm	Sand 400 mm ES 0.65 mm	-
Total Depth (mm)	1800	2130	2000	2100	1520	1460	2350
Overall L/d	1200	1980	1640	1900	1560	1200	1680

Examples of Deep-Bed Filters

- Plot of Filter Loading Rate vs L/d in Full-Scale Facilities is confusing
- Do we really need less media at higher rates?

- Many Factors in this chart
  - Piloted vs non-piloted
  - Various degrees of conservatism
  - Early vs later adoption

- Design Guidelines for Deep-Bed filters based on modern experience would be useful:
  - Can we still use L/d?
  - Do we still need a sand layer?
  - What diameter of media is too large?



Modeling Deep-Bed Filtration

A lot of deep-bed filters are designed based on piloting.

But what can we learn from filter models?

Filter models can be used to provide insights into three fundamental requirements for deep-bed, high-rate filtration:

- Sufficient L/d ratio for depth removal even at high rate
- Sufficient media size for good hydraulics and filter run time
- Sufficient submergence to avoid low pressure in the bed

Particle Transport Model

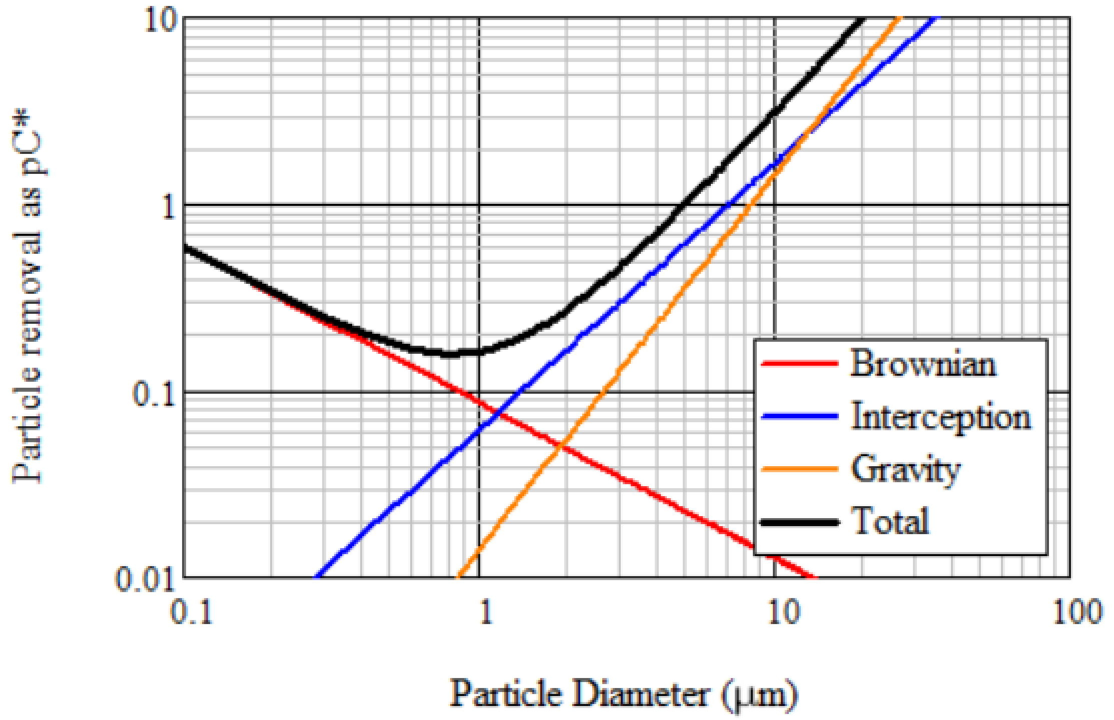
Sufficient L/d ratio for depth removal → **particle transport model**

- Theoretical model accounts for removal by interception, gravity settling, and Brownian motion.
- Based on Single-Collector Efficiency equation by Tufenkji and Elimelech (2004)

Let's examine a "conventional" dual media filter:

- 300 mm of 1.0 mm anthracite
- 200 mm of 0.45 mm sand
- L/d = 744
- 20°C
- Particle S.G. = 1.8 (clay or silt)

Brownian motion dominates for small particles
Interception for medium particles
Gravity for large particles



Particle Removal for a Conventional Dual Media Filter at 10 m/h Loading Rate

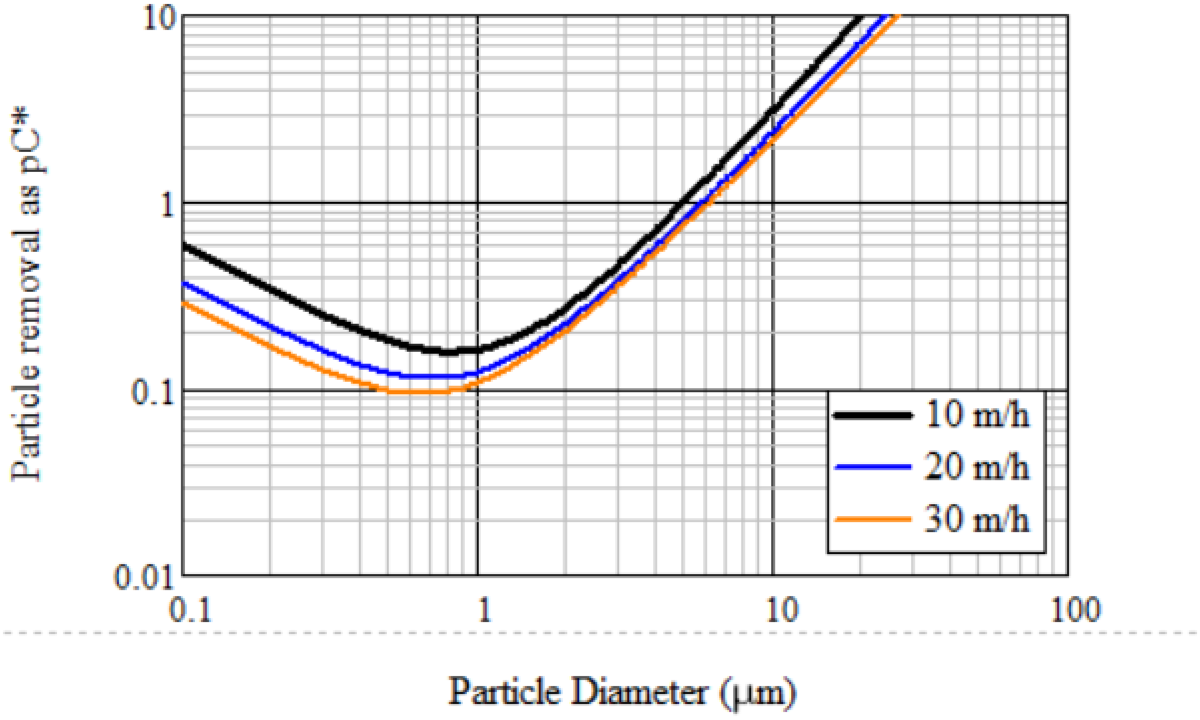
Effect of Loading Rate

Sufficient L/d ratio for depth removal → **particle transport model**

- Theoretical model accounts for removal by interception, gravity settling, and Brownian motion.
- Based on Single-Collector Efficiency equation by Tufenkji and Elimelech (2004)

For a given media design, particle removal decreases as filter loading rate increases

To improve removal at higher rates, we need to add more media depth

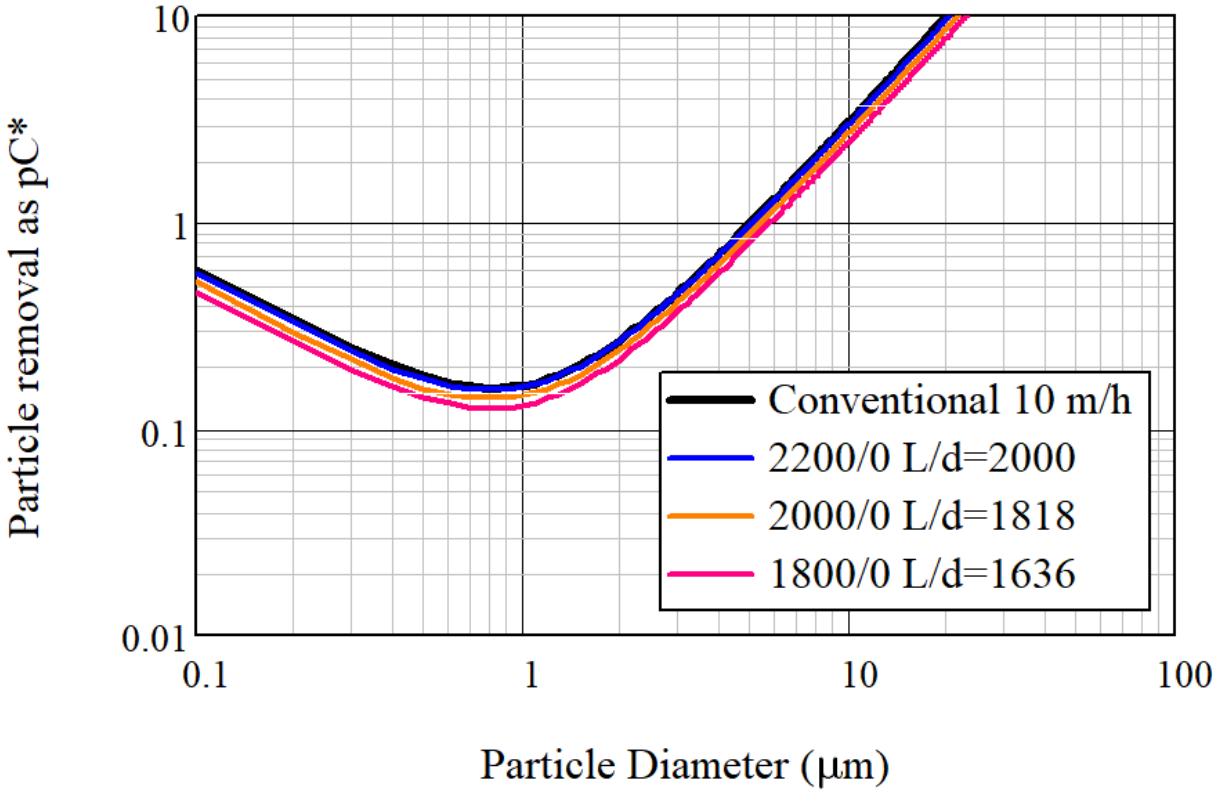


Particle Removal for a Conventional Dual Media Filter at Various Loading Rates

Monomedia Deep Beds

Compare Deep Bed **Mono Media** designs at 30 m/h to Conventional Dual Media design

Depth Anth	Dia Anth	Depth Sand	Dia sand	L/d
2200	1.1	0	0.55	2000
2000	1.1	0	0.55	1818
1800	1.1	0	0.55	1636

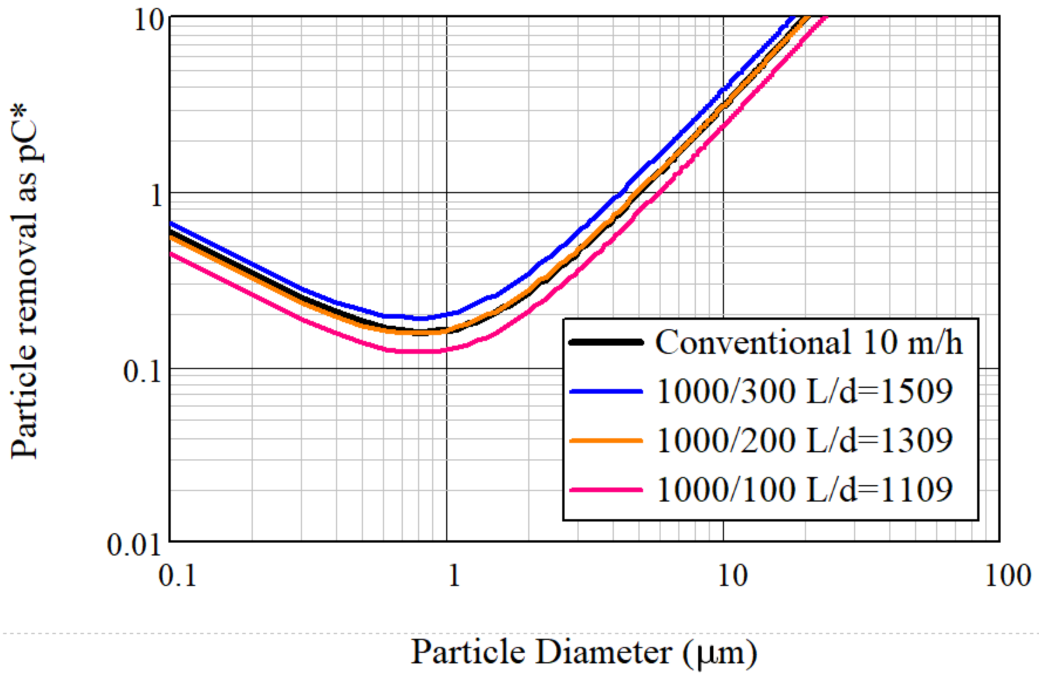


At 30 m/h, a design with an L/d of 2000 gives equivalent removal to our conventional design at 10 m/h

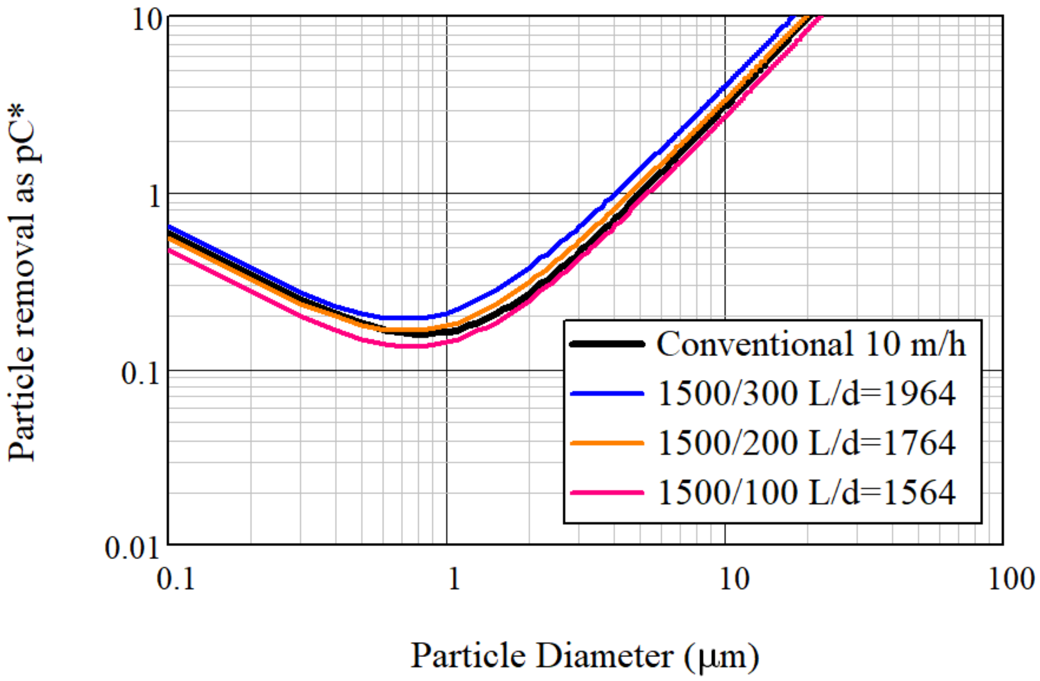
5. Impact of L/d on Deep Bed Monomedia Filters (Anthr E.S.=1.1 mm, loading rate=30 m/h)

Dual Media Deep Beds

Compare Deep Bed **Dual Media** designs to Conventional Dual Media design



10. Impact of L/d on Deep Bed Dual Media Filters (Anthr E.S.=1.1 mm, loading rate=20 m/h)

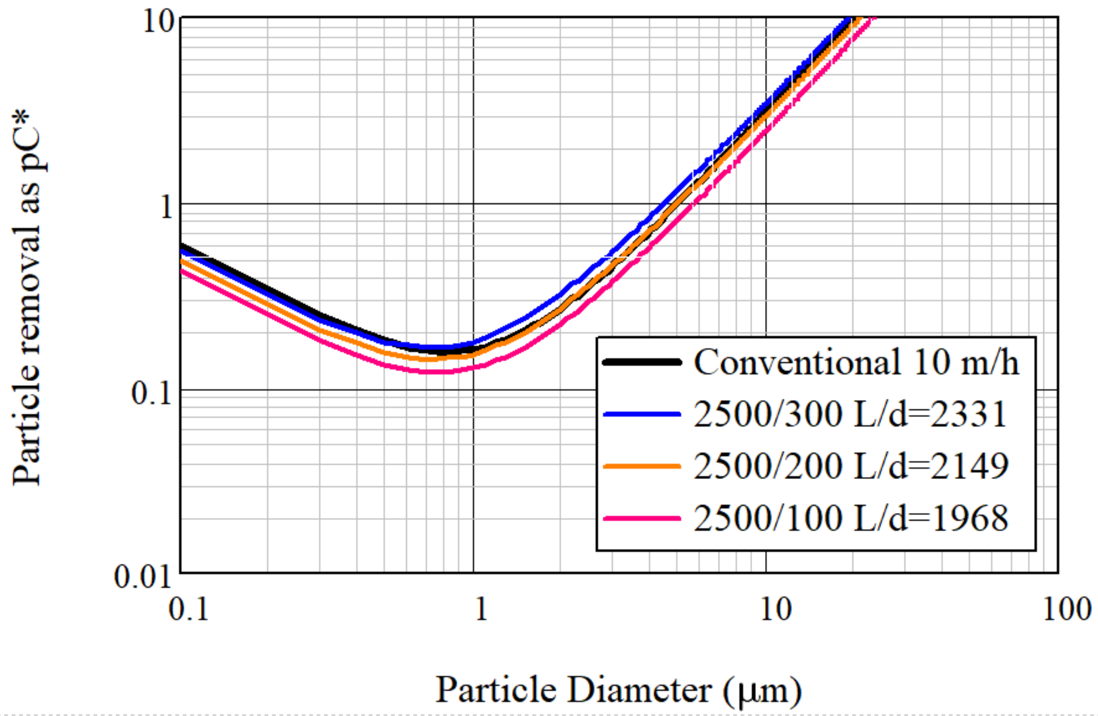


11. Impact of L/d on Deep Bed Monomedia Filters (Anthr E.S.=1.1 mm, loading rate=30 m/h)

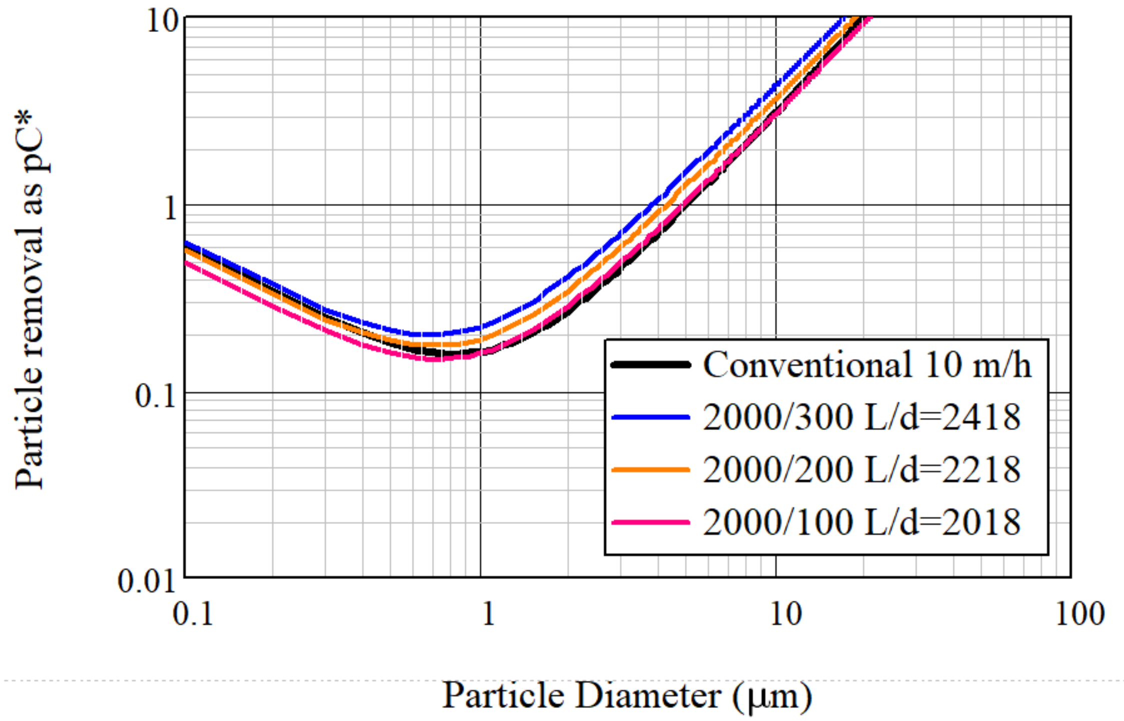
- Sand does make a difference
- Sand is less important as the anthracite gets deeper
- Dual Media 1500/200 (L/d=1764) equivalent to Monomedia 2200/0 (L/d=1818)
- L/d ratio seems to hold for mono vs dual media for same anthracite diameter

Effect of Media Size – Dual Media

Dual Media designs: 1.4 mm anth / 0.55 mm sand versus 1.1 mm anth / 0.50 mm sand, 40 m/h



9. Impact of L/d on Deep Bed Dual Media Filters (Anthr E.S.=1.4 mm, loading rate=40

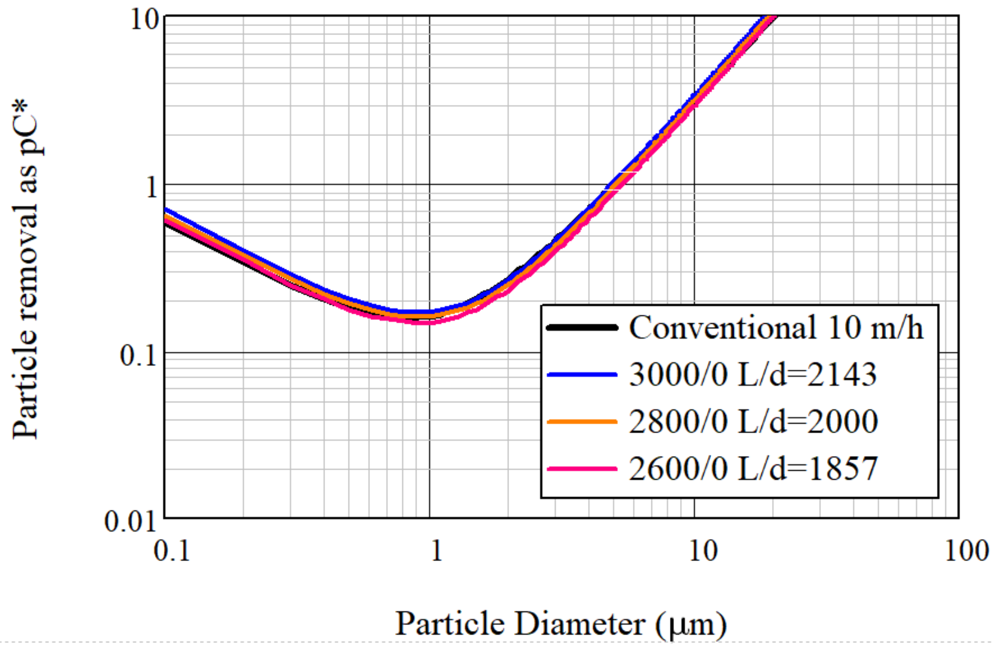


12. Impact of L/d on Deep Bed Monomedia Filters (Anthr E.S.=1.1 mm, loading rate=40 m/h)

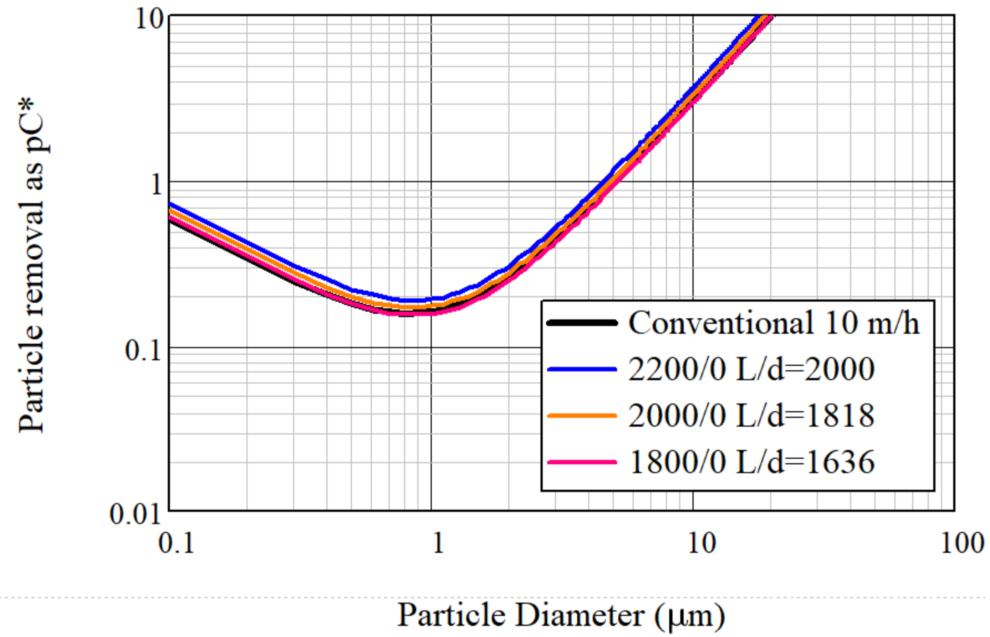
- Large Dual Media (1.4/0.55) with L/d=2331 (2500/300) equivalent to Small Dual Media (1.1/0.5) with L/d = 2218 (2000/200)
- Equivalency of L/d still reasonable for dual media deep beds

Effect of Media Size - Monomedia

Dual Media designs: 1.4 mm anth / 0.55 mm sand versus 1.1 mm anth / 0.50 mm sand, 20 m/h



13. Impact of L/d on Deep Bed Monomedia Filters (Anthr E.S.=1.4 mm, loading rate=20 m/h)



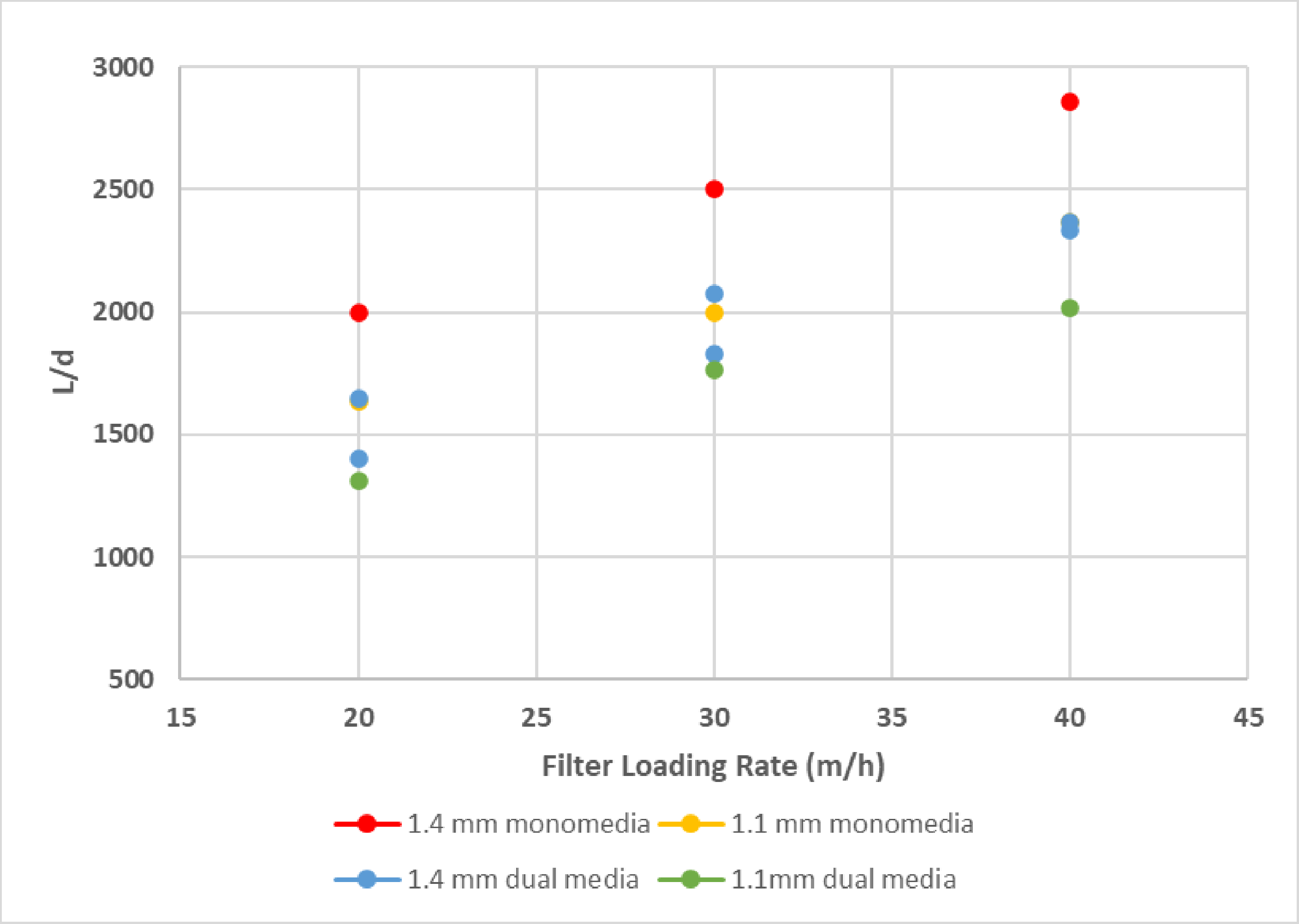
4. Impact of L/d on Deep Bed Monomedia Filters (Anthr E.S.=1.1 mm, loading rate=20 m/h)

- Large Monomedia (1.4mm) with L/d=2000 (2800/0) equivalent to Small Monomedia (1.1mm) with L/d = 1818 (2000)
- Equivalency of L/d not so good for deep bed monomedia
- Beds get pretty deep with 1.4 mm anthracite

Modeling Deep-Bed Filtration - Summary

For equivalent treatment:

- More depth required for monomedia designs
- More depth required for larger media
- Sand depth can be reduced for deeper beds



L/d Required to Achieve Same Particle Removal as a Conventional Filter at 10 m/h

Modeling Deep-Bed Filtration

Sufficient media size for good filter runs → **filter run progression model**

- Semi-empirical model predicts headloss development and particle breakthrough.
- Model calibrated with pilot and full-scale data over range of conditions
- Deep-bed filter with coarser media achieves much longer filter runs, particularly at high rate.

Predicted Run Time (hr)

	Conventional	Deep-Bed
0.5NTU, 10m/h	74	131
1NTU, 10m/h	37	65
0.5NTU, 14.5m/h	47	80
1NTU, 14.5m/h	23	40
0.5NTU, 20m/h	30	49
1NTU, 20m/h	15	25

Unit Filter Run Volume (gal/ft^2)

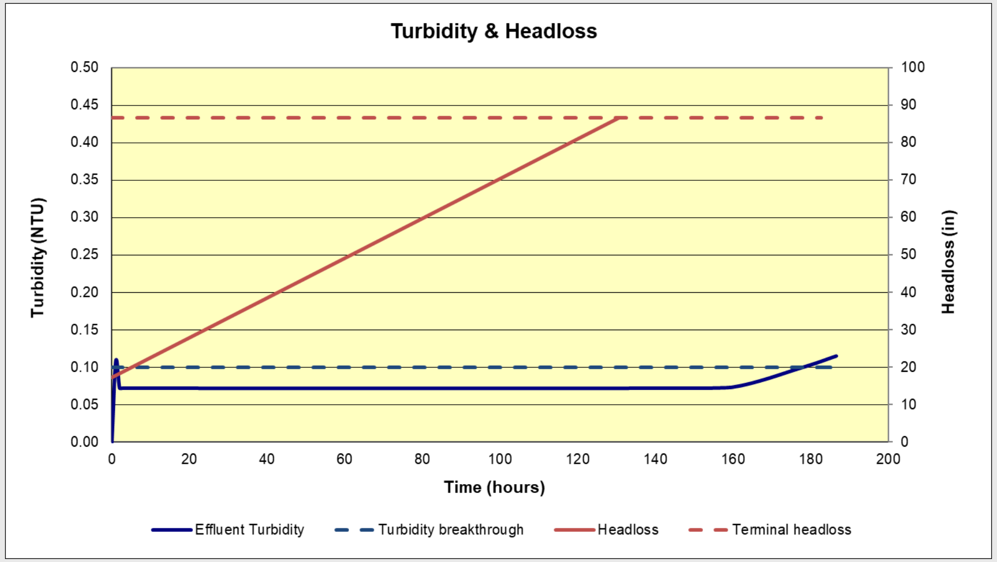
	Conventional	Deep-Bed
0.5NTU, 10m/h	18,216	32,047
1NTU, 10m/h	9,108	16,024
0.5NTU, 14.5m/h	16,615	28,468
1NTU, 14.5m/h	8,308	14,234
0.5NTU, 20m/h	14,659	24,093
1NTU, 20m/h	7,329	12,047

Headloss Accumulation Rate (m/hr)

	Conventional	Deep-Bed
0.5NTU, 10m/h	0.02	0.01
1NTU, 10m/h	0.05	0.03
0.5NTU, 14.5m/h	0.04	0.02
1NTU, 14.5m/h	0.07	0.04
0.5NTU, 20m/h	0.05	0.03
1NTU, 20m/h	0.10	0.05

Predicted Turbidity (NTU)

	Conventional	Deep-Bed
0.5NTU, 10m/h	0.08	0.07
1NTU, 10m/h	0.08	0.07
0.5NTU, 14.5m/h	0.09	0.08
1NTU, 14.5m/h	0.09	0.08
0.5NTU, 20m/h	0.10	0.08
1NTU, 20m/h	0.10	0.08

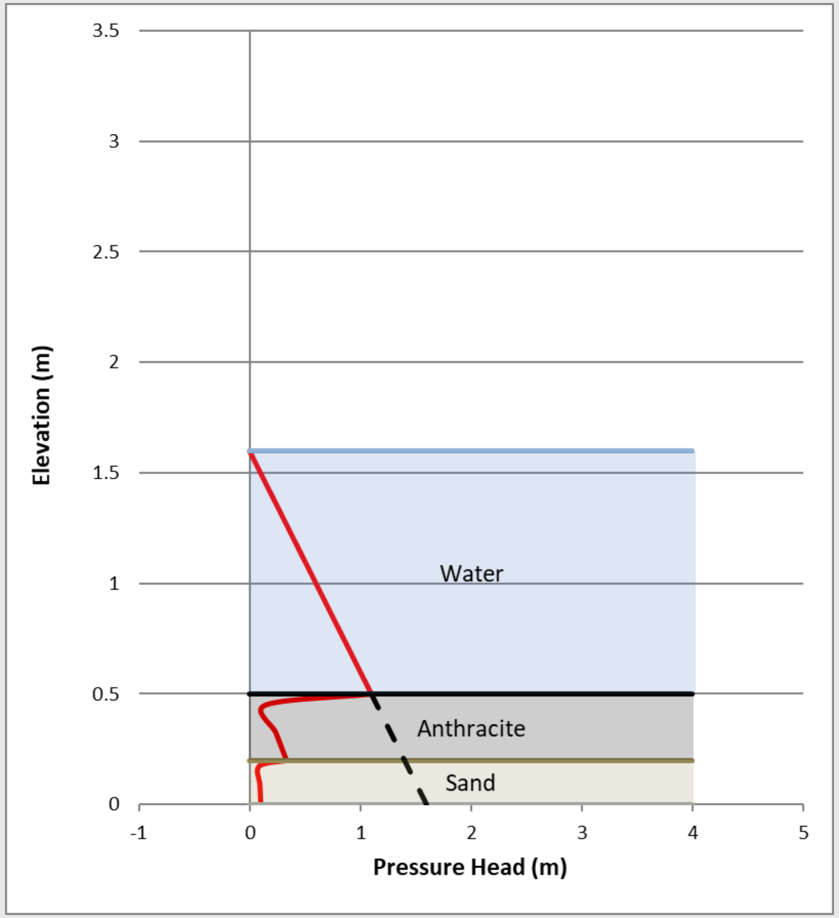


Modeling Deep-Bed Filtration

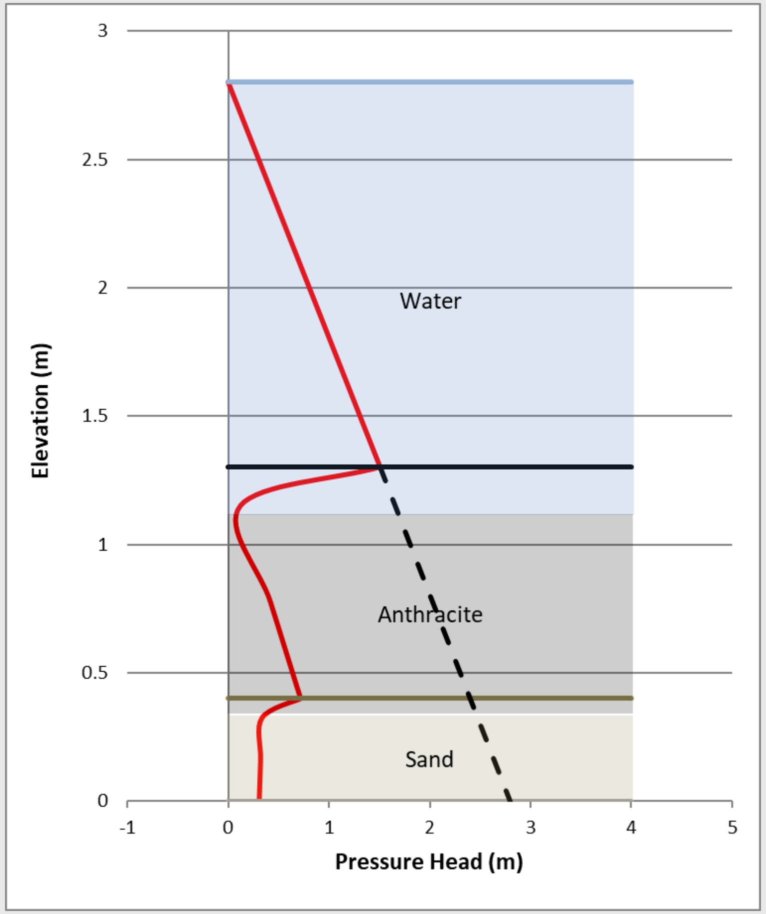
Sufficient submergence → **filter bed pressure profile model**

- Model accounts for pressure profile development due to clean-bed and accumulated headloss
- Deep-bed filter needs 1.5m submergence (116% of bed depth)
- Conventional filter needs 1.1m submergence (220% of bed depth)
- Higher rate pushes particles deeper into bed and distributes headloss through more of bed

Conventional 10 m/h



Deep Bed 20 m/h



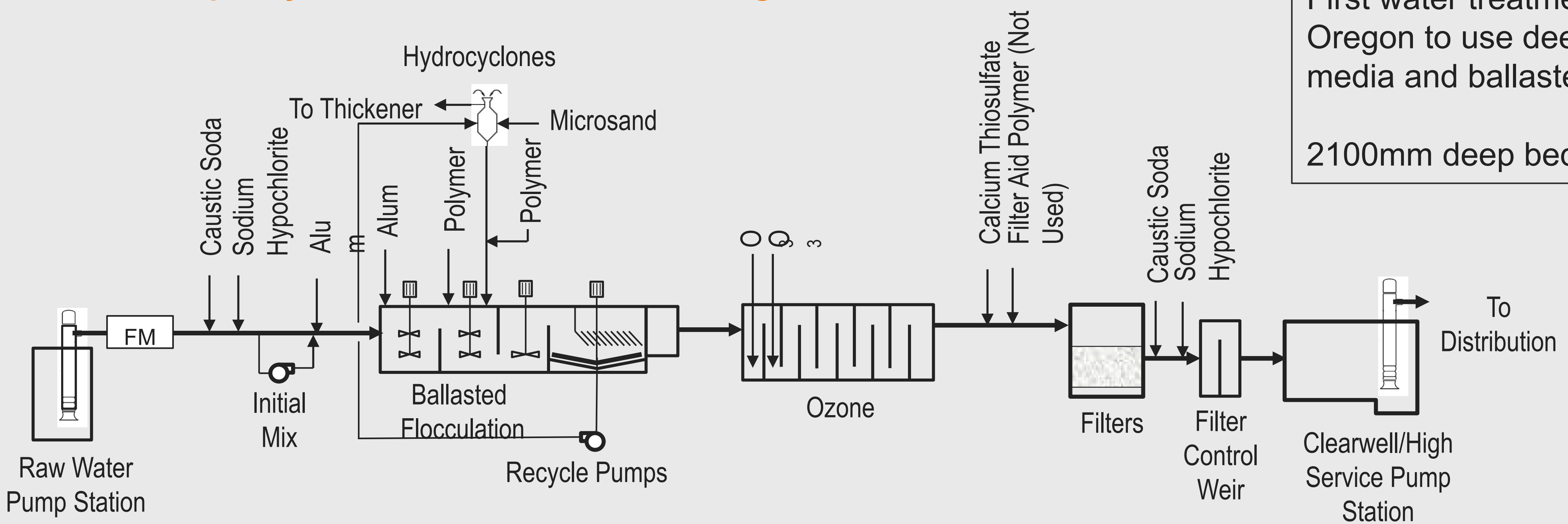
Case Study: Willamette River Water Treatment Plant (WRWTP) Filtration Pilot

Design and built in 1999-2001

First water treatment plant in Oregon to use deep-bed filter media and ballasted flocculation

2100mm deep bed at 7.6 gpm/ft^2

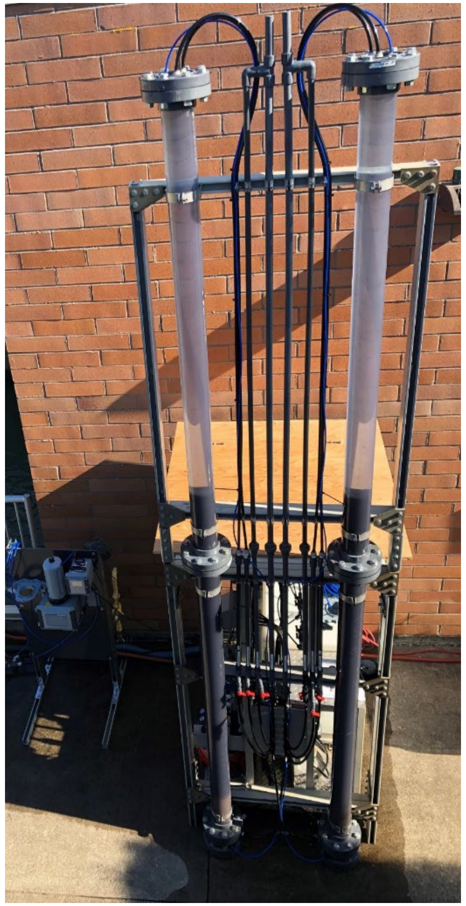
Can capacity be increased without building new filters?



Plant Design Flow Rate	15 mgd
Planned Design Flow Rate	20 mgd

WRWTP: Full-Scale and Pilot Filter Design

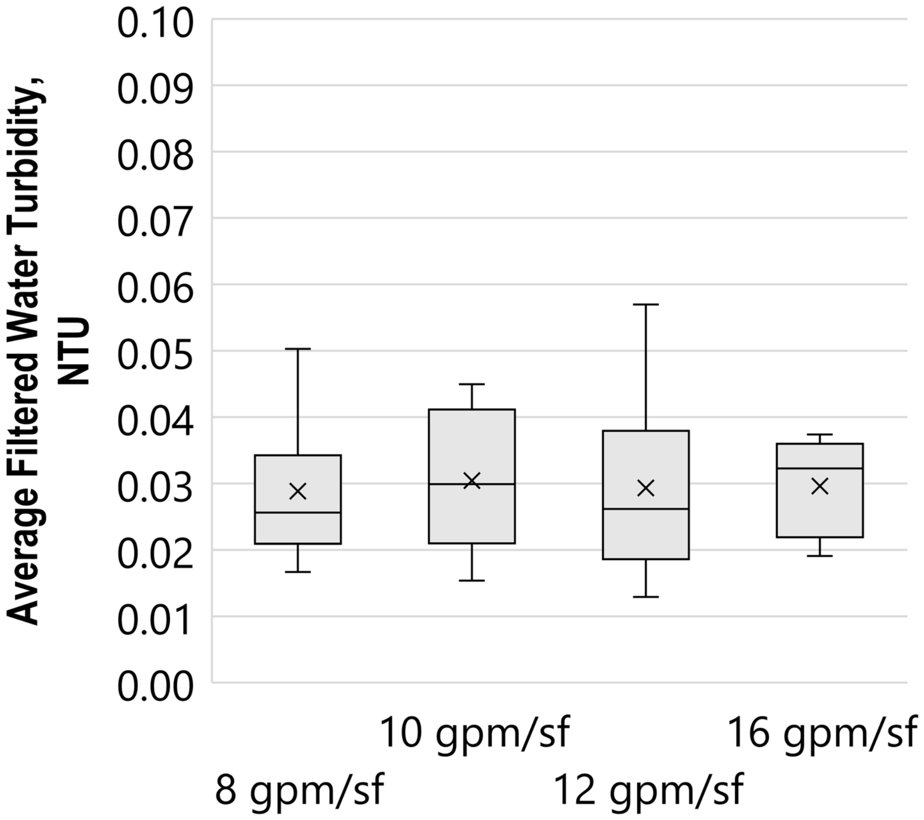
	Units	Full-Scale and Pilot Filters
Top Media	-	GAC
Depth	in	72
Effective Size	mm	1.4
Specific Gravity	-	1.4
Uniformity Coefficient	-	< 1.4
Bottom Media	-	Sand
Depth	in	12
Effective Size	mm	0.45
Specific Gravity	-	> 2.63
Uniformity Coefficient	-	< 1.4
Overall L/D Ratio	-	1,984

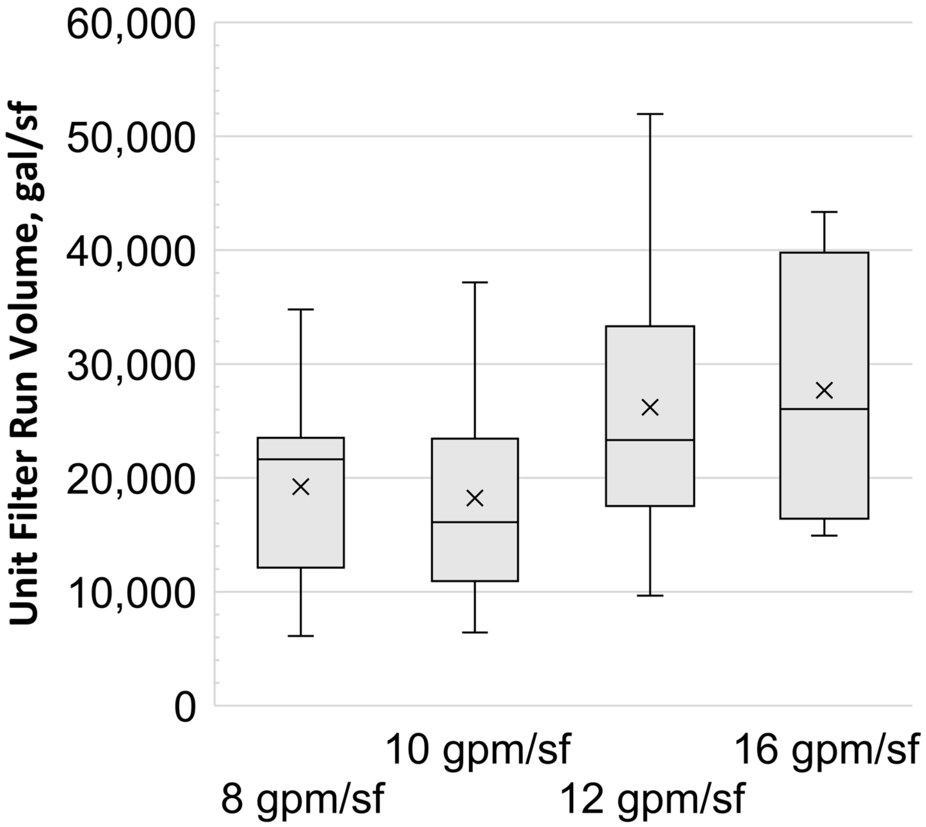


WRWTP Filtration Pilot: Impact of Filtration Rate

Higher filtration rate was approved by OHA, **saving the City $5-10M** by not having to build additional filters.

- Over **150 filter runs** completed
- Avg **Filtered Water Turbidity was <0.05 NTU** during each run regardless of filtration rate.
- UFRV increased with filtration rate, **increasing filter efficiency to >98%**





Media Skimming

- CBHL and developed headloss vary with media porosity and effective size and are directly proportional to loading rate.
- After backwash, finer material accumulates on the top of media layer
- In a deep bed, if this is not skimmed, can increase headloss
- Suppose fine material reduces the porosity and effective size of the anthracite layer by 5%.
  - Conventional Filter → CBHL increases from 10” to 11” at 10 m/hr
  - Deep-Bed Filter → CBHL increases from 24” to 27” at 20 m/hr
  - Floc particles can accumulate in fine layer and reduce run time

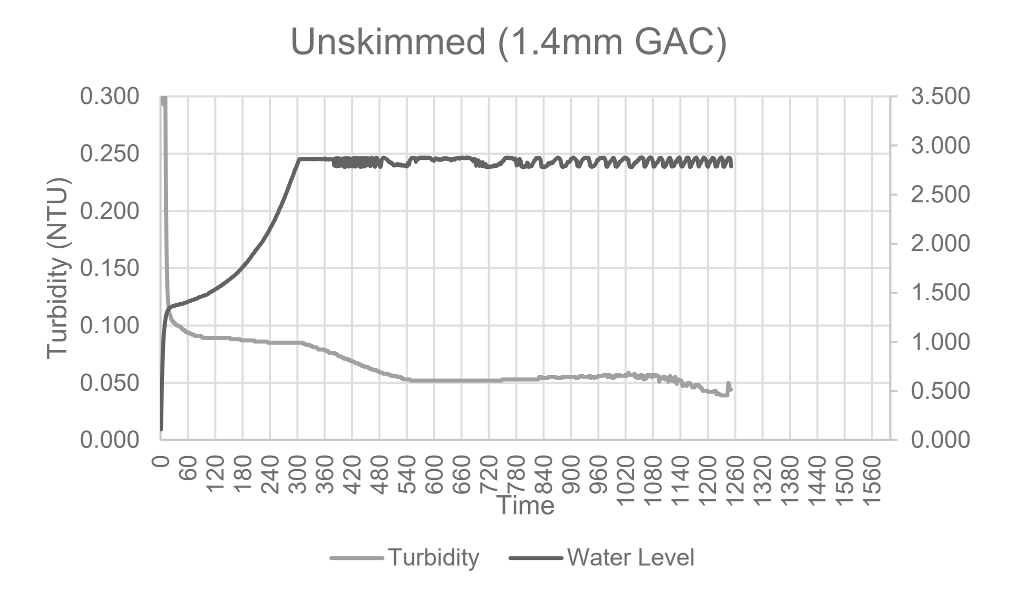
High Headloss Due to Unskimmed GAC

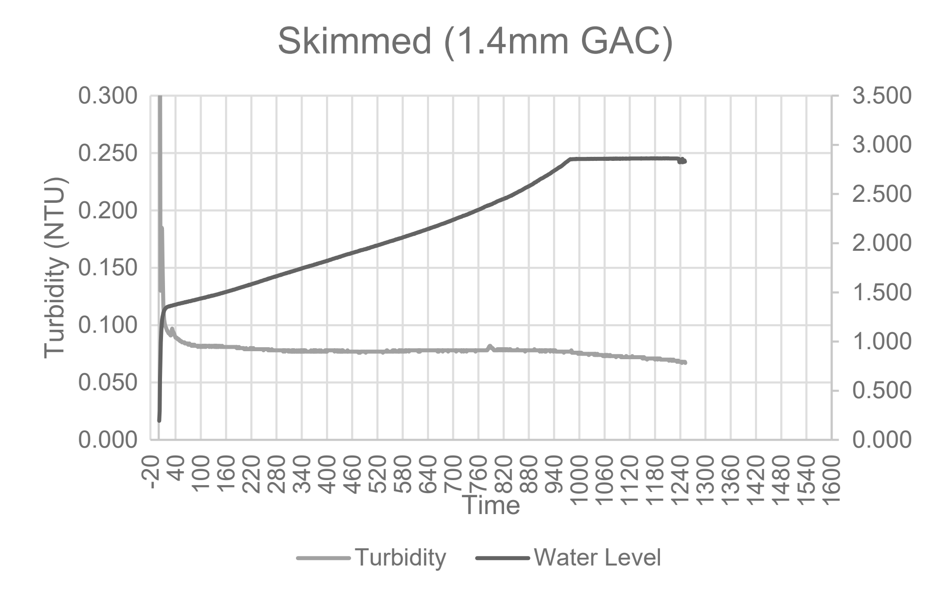
Modeling Example:

- 2.0 m deep bed w/ 1.4 mm GAC @ 20 m/h
- Filter model predicts UFRV = 12,200 gal/ft^2
- Assume just 5 mm of 1.2 mm GAC on top
- Filter model predicts UFRV = 9861 gal/ft^2

Pilot Example:

- Parabolic headloss curves, suggesting clogging
- Pre-chlorine had no impact
- Reducing loading had limited impact
- Removing top 10% of bed solves problem





Backwashing

Backwash rate depends on media diameter, not media depth

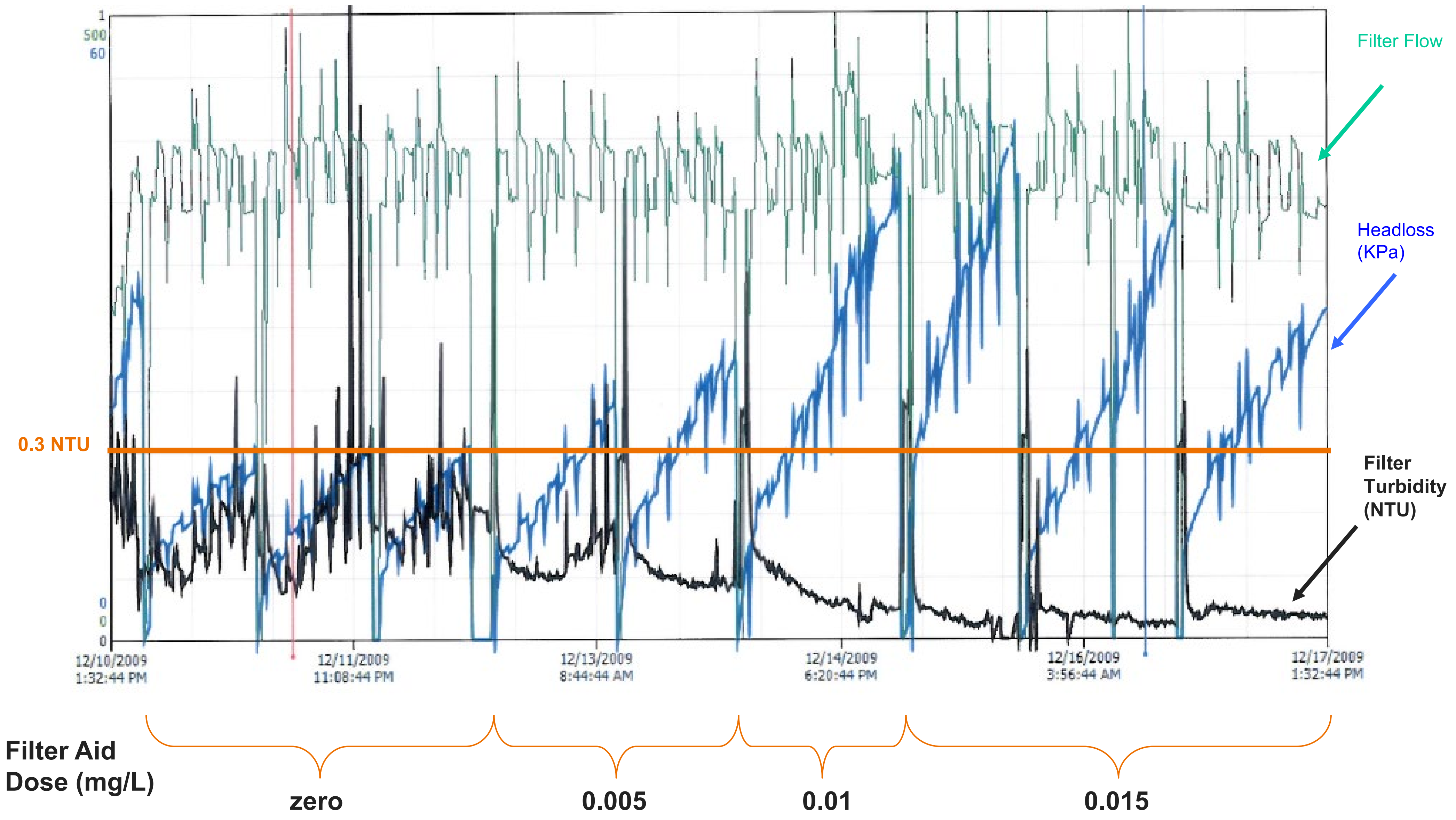
$$V_{Backwash} = \kappa \left(\frac{\rho_{Media} - \rho_{Water}}{\rho_{Water}} g \right)^{\frac{2}{3}} \nu_{Water}{}^{-\frac{1}{3}} d_{60}$$

Backwash rates and power requirements same for deep-bed and conventional filters

Filter Aid Use

Higher loading rates can lead to larger hydraulic shear forces in the bed, although larger media offsets this

Filter Aid Polymer can be required for strengthening floc attachment to media grains and maintaining filter turbidity for deep bed designs



1
500
60
0
0
0
0.3 NTU
12/10/2009 1:32:44 PM
12/11/2009 11:08:44 PM
12/13/2009 8:44:44 AM
12/14/2009 6:20:44 PM
12/16/2009 3:56:44 AM
12/17/2009 1:32:44 PM
Filter Flow
Headloss (KPa)
Filter Turbidity (NTU)
Filter Aid Dose (mg/L)
zero
0.005
0.01
0.015

Questions?

Thank You

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