Filtration

Primary Barrier to Passage of Pathogens!

5. ALASKA FILTRATION & FILTER ASSESSMENT OCT 2006

Agenda

- Optimization
- Discussion of evaluation procedures
  - Evaluating operational effectiveness
  - Filter surveillance
- Filter assessment video
- Review the assessment procedures

Goals of Training

- Impart a better understanding of
  - How filters work
  - The backwashing process
    - Surface wash air scour
  - Common problems and “some” solutions
- Provide information on worthwhile monitoring
- Make you comfortable in assessment of your filters
  - Provide data collection forms to help track filter condition
- Help you diagnose problems
  - Solutions

Sources of Information

- *Filter Maintenance and Operations Manual*, AWWARF, 2003
- *Integrated Design and Operation of Water Treatment Facilities*, Kawamura, 2000
- *Filter Evaluation Procedures for Granular Media*, AWWA, 2003
- *Handbook of Public Water Systems*, HDR Engineering, Inc, 2001
- *Water Treatment Plant Design*, Sanks, 1980
- *Water Clarification Processes*, Hudson, 1981
- *Iron and Manganese Removal Handbook*, AWWA,1999
- *Water Treatment, Troubleshooting and Problem Solving,* Tillman, 1996
- *Water Treatment Operator Handbook, Pizzi, 2002*
- *Water Treatment Plant Operation*, California Dept. of Health Services, Sanitary Engineering Branch/USEPA (Ken Kerri Manuals)

Roadblocks to Optimization

- Using the standards as operational goals
- No individual filter effluent monitoring
- No filter to waste
- Lack of calibration
- Operator application of concepts
- Starting dirty filters
- Rate changes
- Inadequate process monitoring
- No standard operating procedures

Treatment Performance Solutions

- 4 Categories
  - Administration
  - Maintenance
  - Design
  - Operational

Administrative Solutions

- Establishment of goals
- Training
- Standard operating procedures (SOPs)
- Improved communications
- Resources
  - Personnel (time on the job)
  - Funding

Administration: Setting and Achieving Goals

- Select water quality goals
- Communicate goals to staff
- Provide support to ensure goals are met

Administration: Setting and Achieving Goals

- Settled water quality
  - 1 – 2 NTU
- Filtered water quality
  - <0.10 NTU
    - 95% of measurements
    - <0.30 NTU upon start-up and after backwash
      - No more than 15 minutes
      - Filter to waste until <0.10 NTU

Administration: Setting and Achieving Goals

Composite Values	Before Optimization	After Optimization
90%	0.16 NTU	0.07 NTU
Maximum	0.40 NTU	0.21 NTU
Minimum	0.05 NTU	0.03 NTU
Largest Spike	1.0 NTU	0.5 NTU

Partnership: Summary of Turbidity Results, Pizzi, 1998

Maintenance Solutions

- Improved housekeeping practices
- Increase spare parts inventory
- Improve maintenance schedule

Design Solutions

- Upgrade or replace equipment
  - Pumps
    - VFD
  - Media
  - Underdrains
- Automation
  - SCADA
  - SCM

Operational Solutions

- Evaluating processes & making adjustments
  - Pretreatment
  - Rapid mix
  - Flocculation
  - Sedimentation
  - Filtration
    - Individual filter assessments

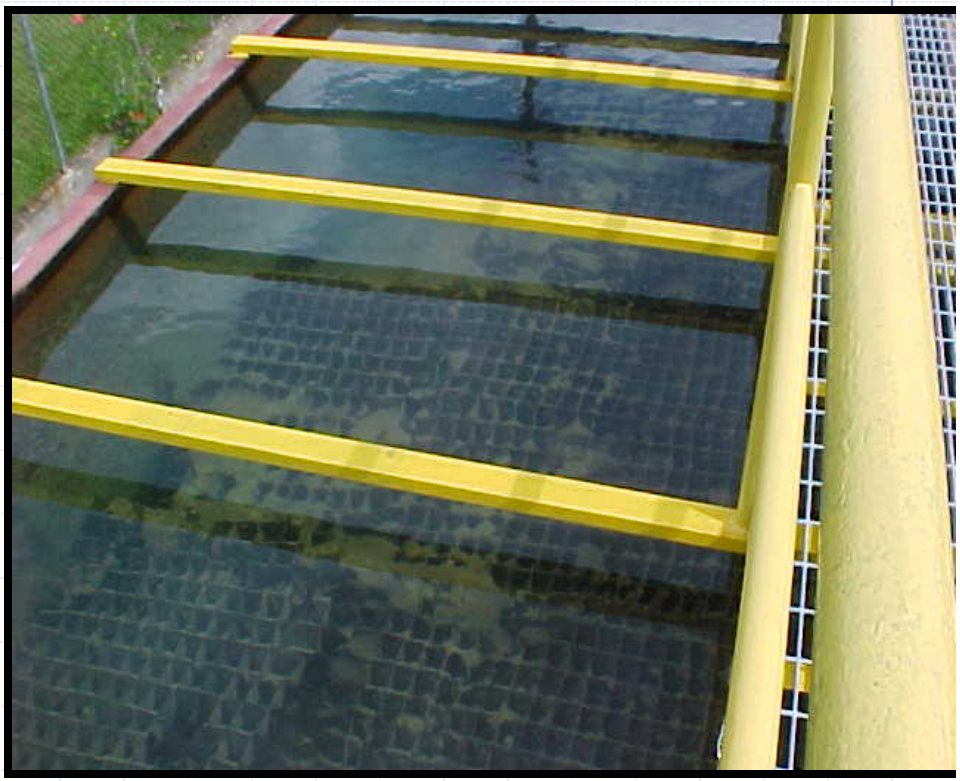
Operational Solutions

- Increase performance monitoring
  - Turbidity
    - Raw
    - Settled
    - Individual filter
- Collect accurate data
  - Pumping to turbidimeters
  - Adding chemical ahead of turbidimeters
- Calibration of
  - Chemical feeders
  - Turbidimeters & instruments

Evaluating the Treatment Processes

Evaluating Pretreatment

- Preoxidation/Chemical Coagulation
  - Type of chemical
  - Dose
    - Accurate?
    - Reacting to changes in water quality
  - Feed location(s)
  - Rapid mixing intensity
  - Detention time
  - pH
    - May vary throughout day
  - Alkalinity

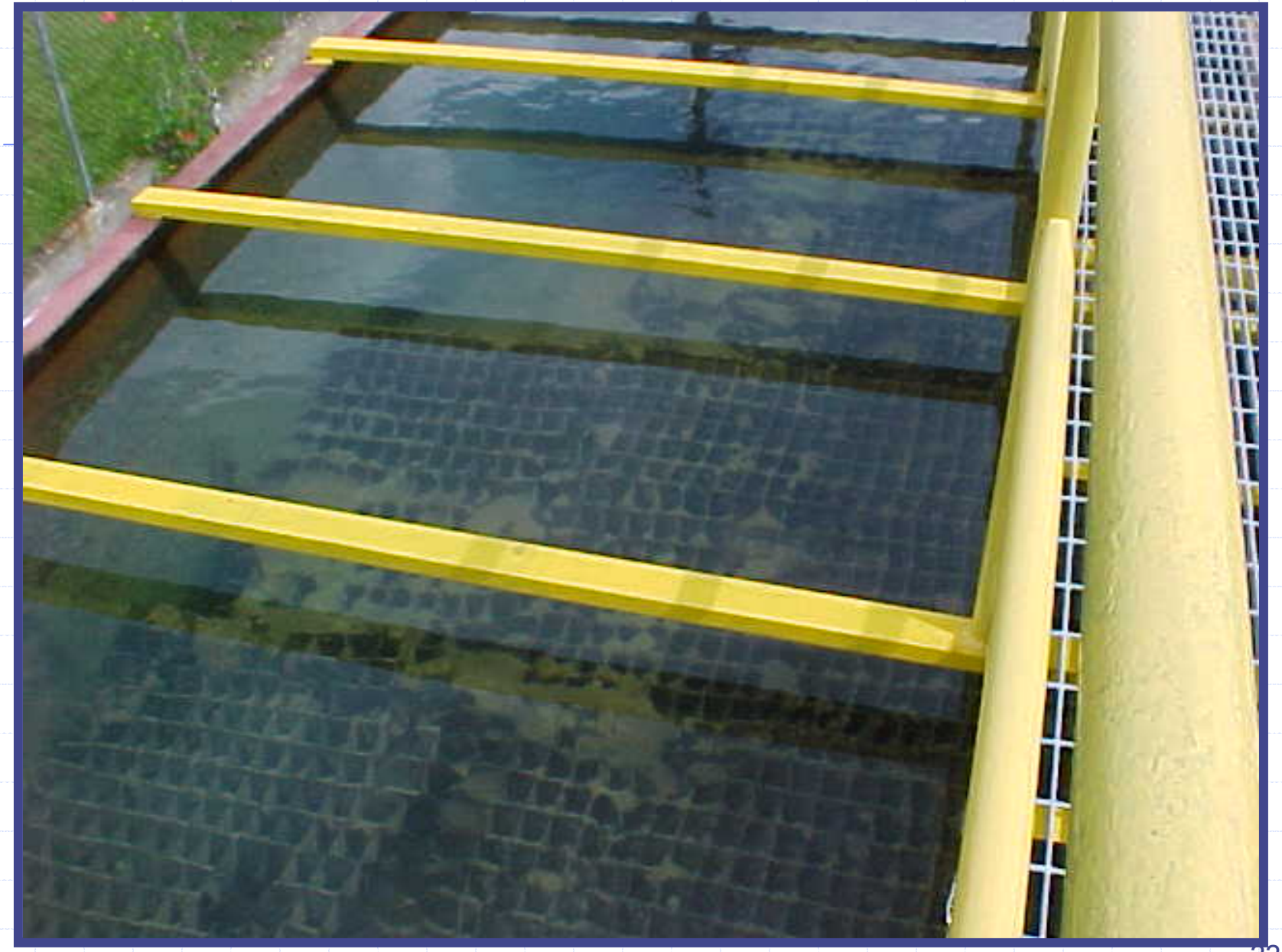


Evaluating Rapid Mix

- Mode of operation?
  - Charge neutralization
    - Mixing intensity is critical
  - Sweep floc
    - Mixing intensity not so critical

Evaluating Flocculation and Sedimentation

- Flocculation
  - Mixing intensity
  - Detention time
  - Short circuiting
  - Stages
- Sedimentation
  - Floc break-up
  - Short circuiting
  - Sludge removal



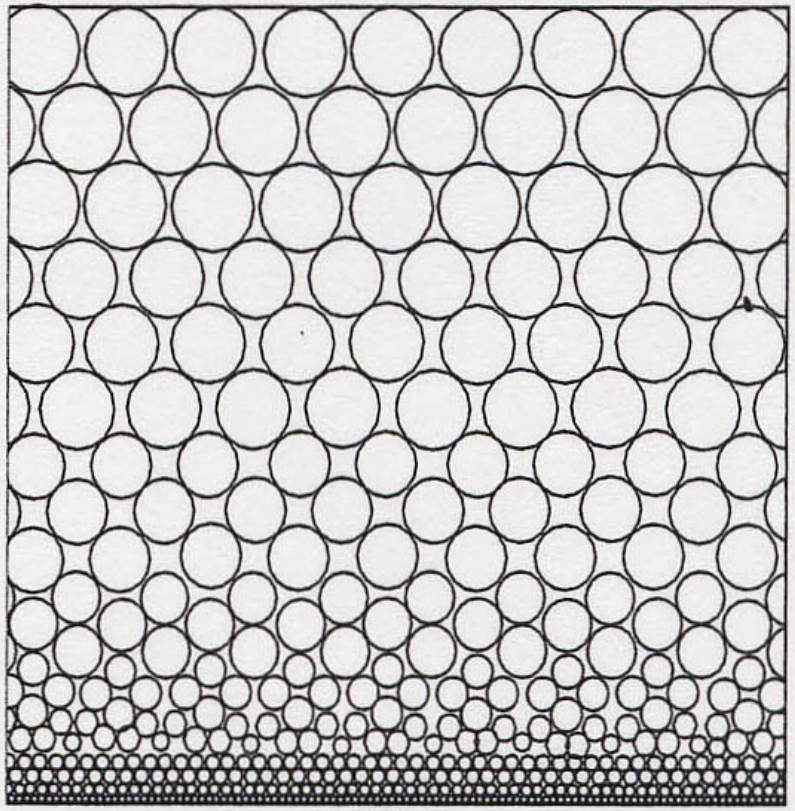
Optimization Goals for Clarifier

- $\leq$ 2.0 NTU
  - When raw water turbidity is > 10 NTU
- $\leq$ 1.0 NTU
  - When raw water turbidity is $\leq$ 10 NTU

Focus on final water quality of individual filters

The Filtration Barrier

Ideal Filter

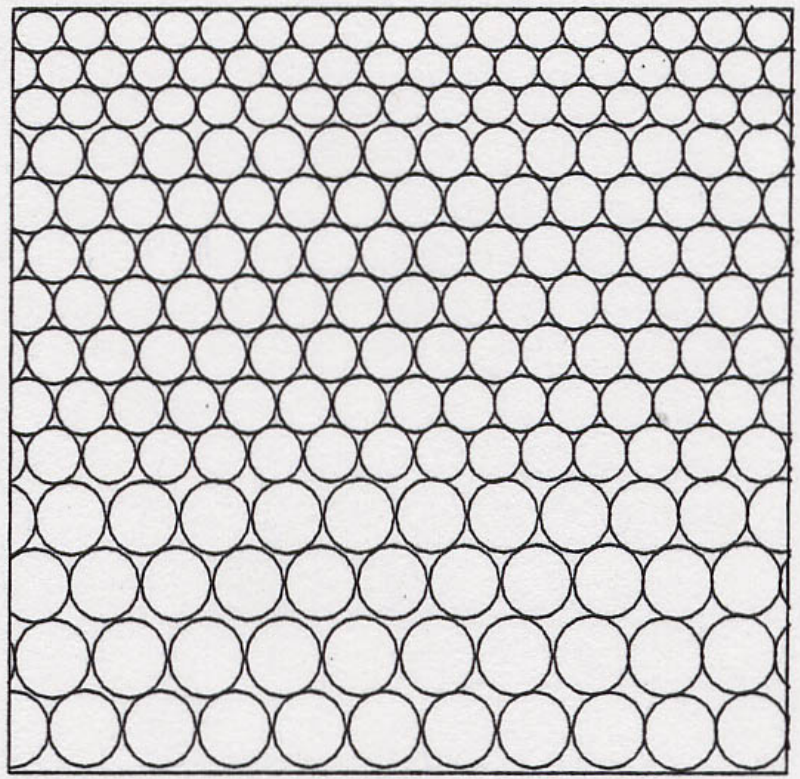


(C)
An ideal filter passes water first through coarse then fine media

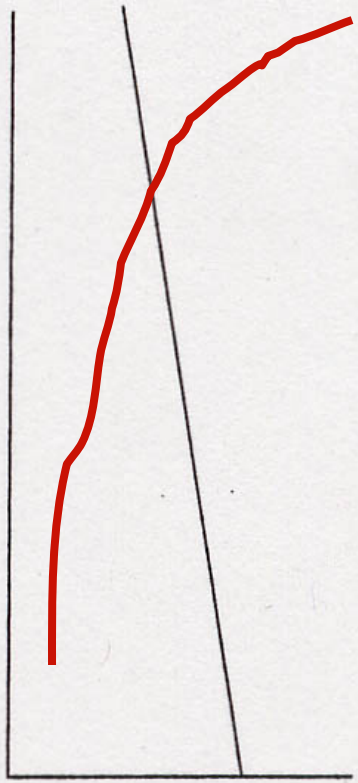
Floc Removal

HDR Engineering, Inc., 2001

Monomedia Filter



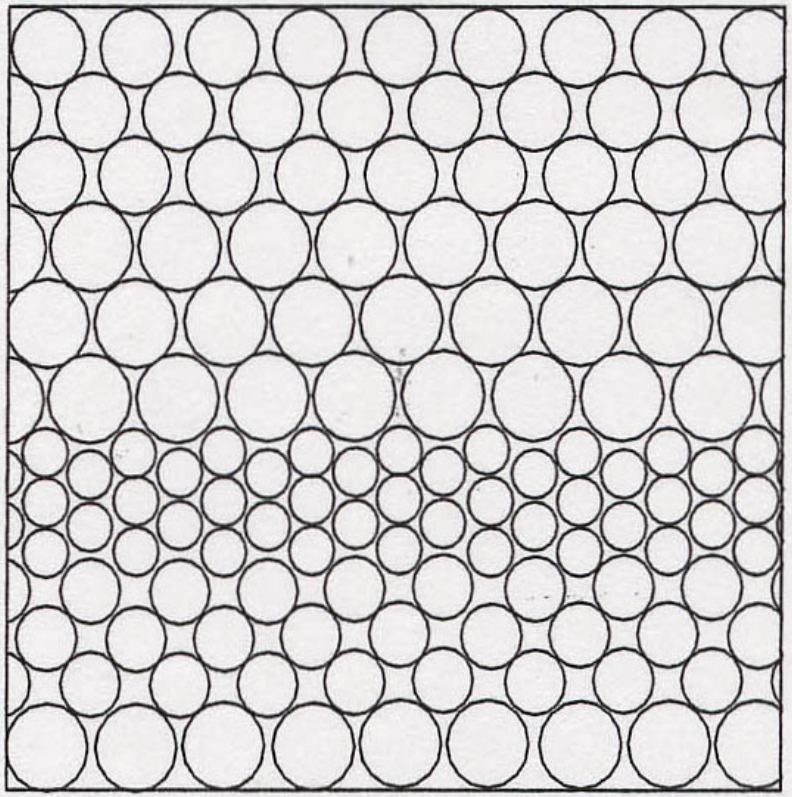
(A)
Single-media bed distributes coarse particles at the bottom



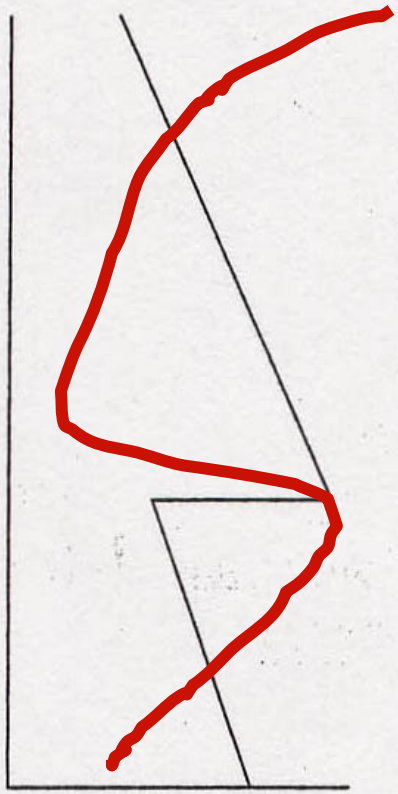
Floc Removal

HDR Engineering, Inc., 2001

Dual Media Filter



(B)
Dual-media bed provides
coarse coal above fine sand



Floc Removal

HDR Engineering, Inc., 2001

Distribution of Media in Mixed-Media Filter (HDR 2001)

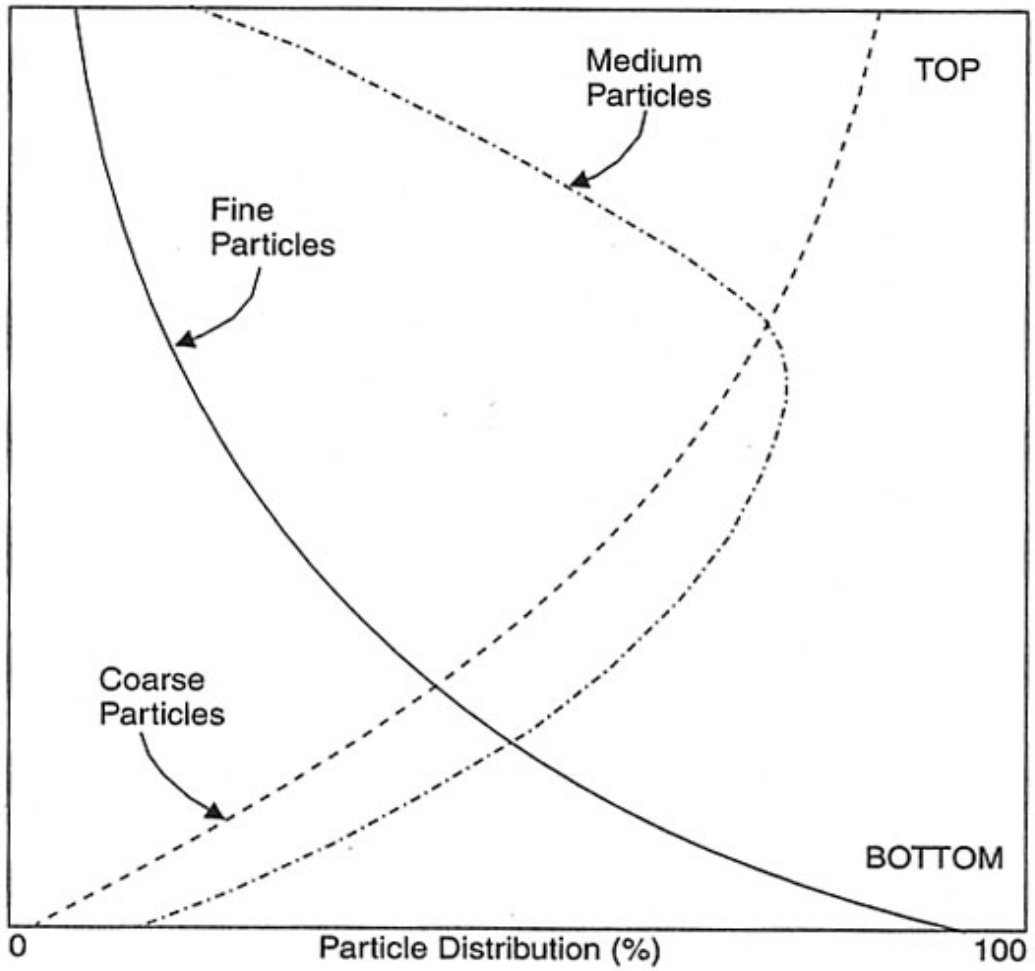
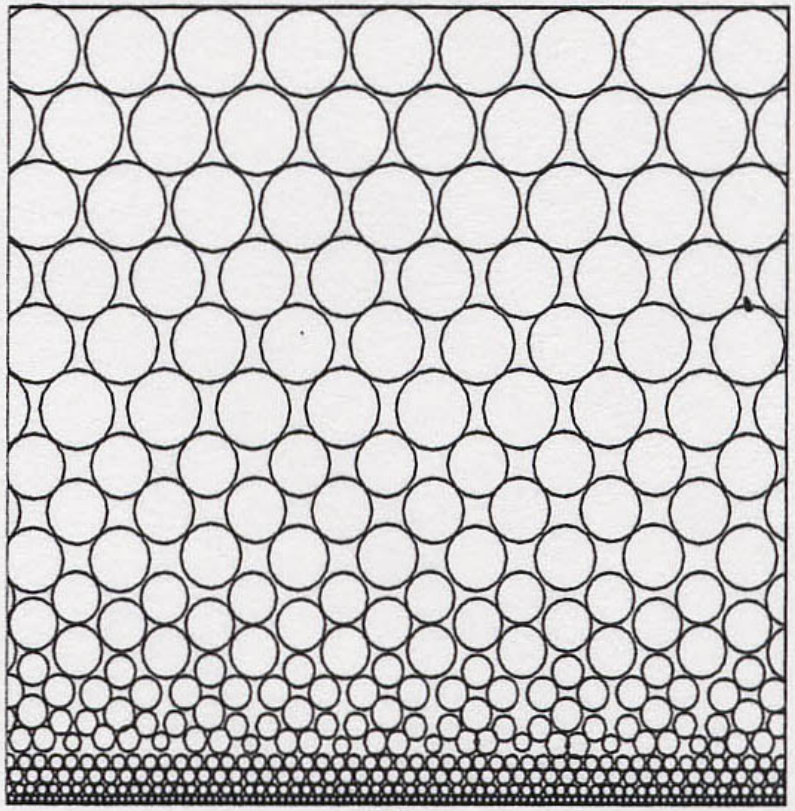


Fig. 12–3. Distribution of media in properly designed mixed-media filter

Mixed-Media Filter



(C)
An ideal filter passes water first through coarse then fine media

Coarse-to-Fine Pore Space

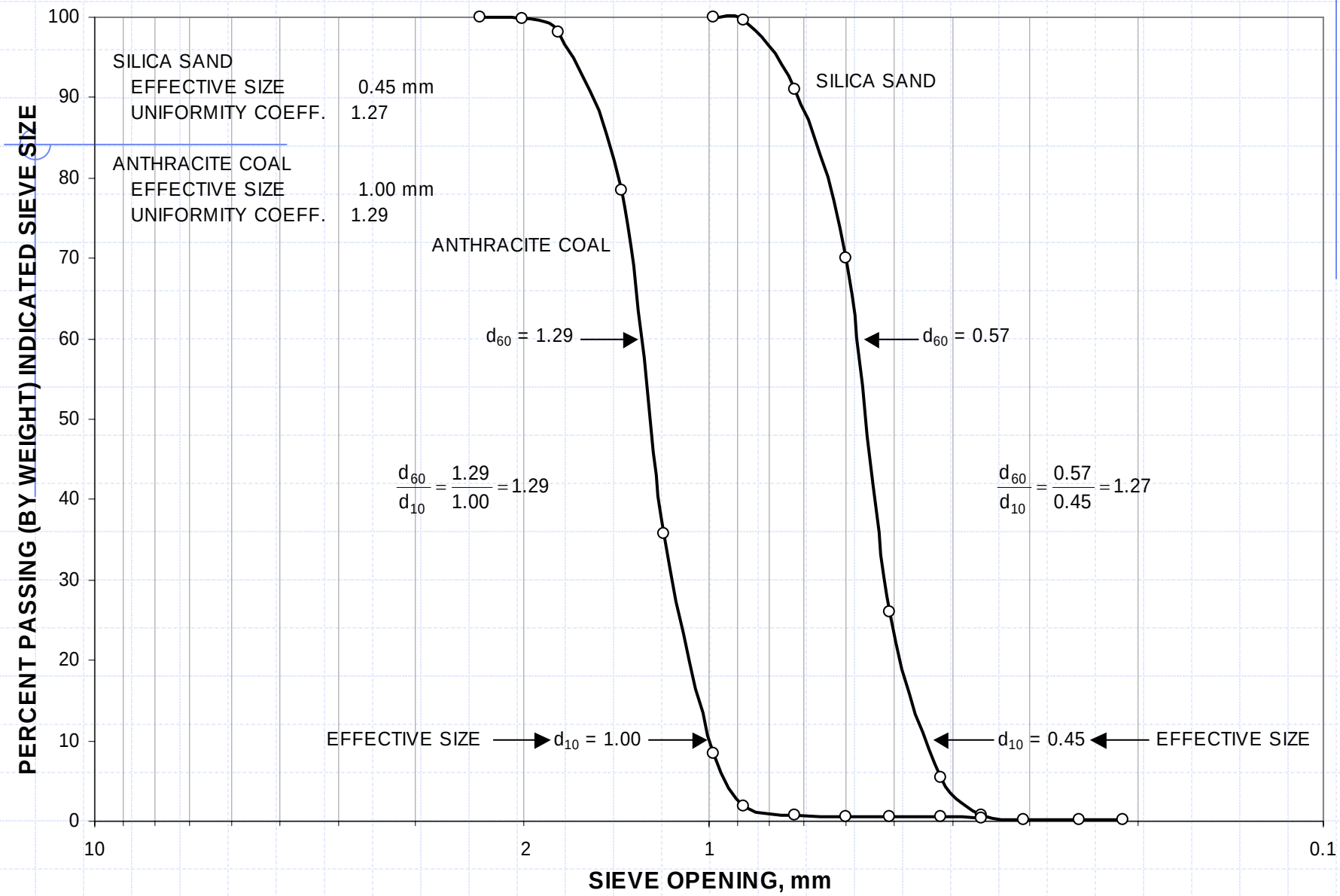
HDR Engineering, Inc., 2001

Significant Physical Properties of Media

- Media size
  - Larger media have greater porosity
  - Smaller media have lesser porosity
- Size is defined by percentage passing standard sieves (by weight)
  - Effective size
  - Uniformity coefficient

Media Sizing

- Effective size
  - Sieve size opening that will
    - pass 10% by weight
- Uniformity coefficient
  - Ratio of sieve sizes that will
    - Pass 60%
    - Pass 10%
  - The higher the U.C., the greater the range of sizes


SILICA SAND
EFFECTIVE SIZE 0.45 mm
UNIFORMITY COEFF. 1.27
ANTHRACITE COAL
EFFECTIVE SIZE 1.00 mm
UNIFORMITY COEFF. 1.29
SILICA SAND
ANTHRACITE COAL
d_{60} = 1.29
d_{60} = 0.57
$\frac{d_{60}}{d_{10}} = \frac{1.29}{1.00} = 1.29$
$\frac{d_{60}}{d_{10}} = \frac{0.57}{0.45} = 1.27$
EFFECTIVE SIZE
d_{10} = 1.00
d_{10} = 0.45
EFFECTIVE SIZE
PERCENT PASSING (BY WEIGHT) INDICATED SIEVE SIZE
SIEVE OPENING, mm
100
90
80
70
60
50
40
30
20
10
0
10
2
1
0.1

Media Sizing – Solids Storage

- Uniformity coefficient is the most important measure
  - Lower is better
  - Lower costs more
  - Ten States Standards requires <1.65
  - 1.3 is attainable for anthracite
- U.C. can be improved on-site
  - Install 110%, backwash and skim repeatedly

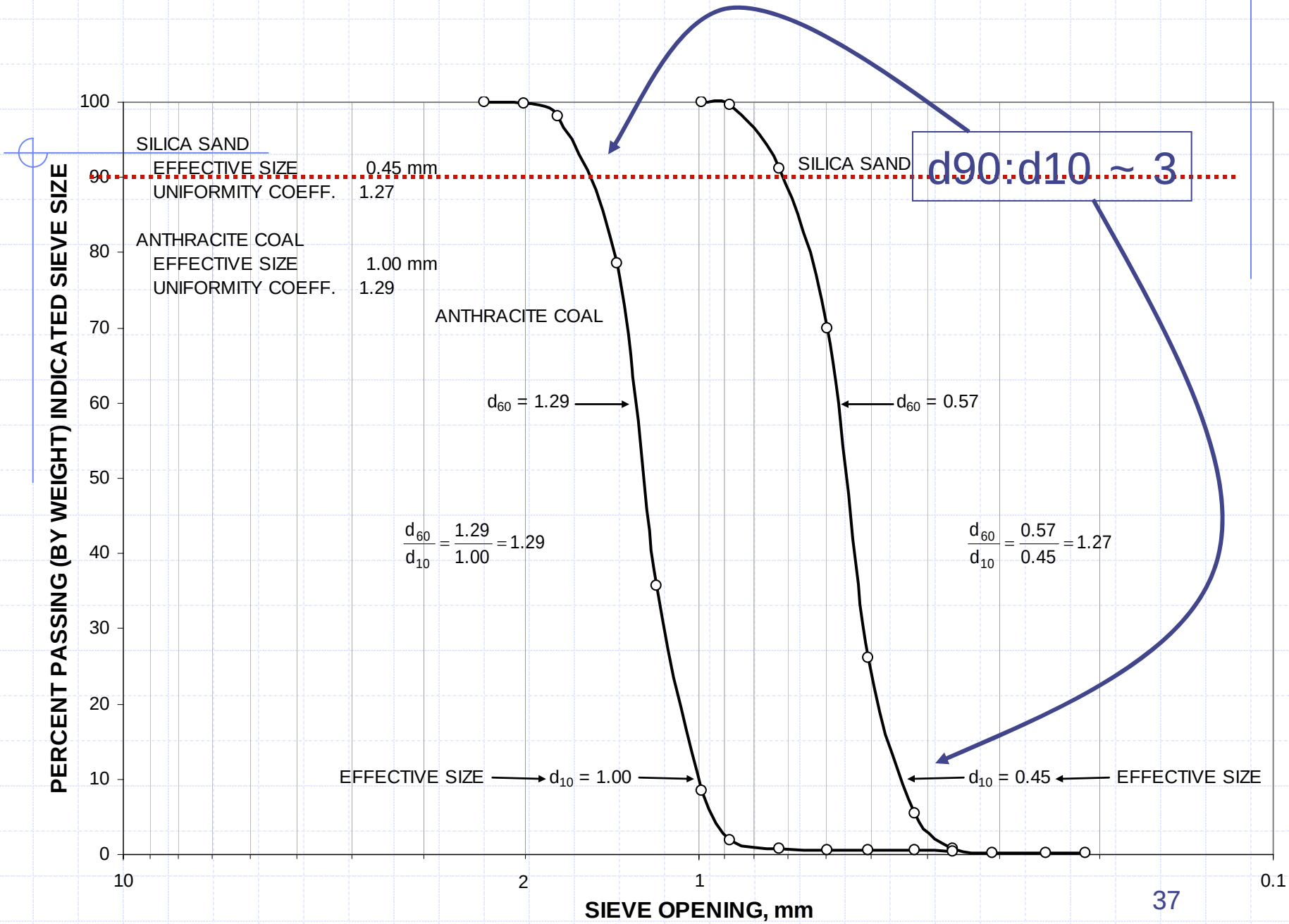
Media Sizing – Media Matching

- Effective size is most important measure for backwashing
- Media (garnet, silica, anthracite) must have similar expansion characteristics
  - Ensures optimum intermixing
  - For example:
    - If lower media is too fine it may expand too far into upper media
      - Reduces porosity
      - Causes abrasion
- Bottom of the sand (90% finer size) should fluidize at the same, or somewhat lower, flow rate as the bottom (90% finer size) of the coal
  - Ensures entire bed fluidizes at the selected backwash rate

Between U.S. Std. Sieves			Mean Size	Flow to Achieve 10% Expansion at 25 Degrees C, in gpm/sq ft		
Passing	**mm**	**Retained**	**(mm)**	**Coal**	**Sand**	**Garnet**
7	2.830	8	2.59	37.0		
8	**2.380** *	10	2.18	**30.0** *		
10	2.000	12	1.84	24.0	41.0	
12	1.680	14	1.54	20.0	33.0	
14	**1.410** *	16	1.30	15.7	**27.0** *	49.0
16	1.190	18	1.09	12.5	21.0	40.0
18	1.000	20	0.92	9.9	16.4	32.0
20	**0.841** *	25	0.78	8.4	12.6	**27.0** *
25	0.707	30	0.65	7.0	9.0	22.0
30	0.595	35	0.55		6.3	18.0
35	0.500	40	0.46		5.4	13.7
40	0.420	45	0.38		4.0	11.3
50	0.297	60	(0.25 mm)			6.3
Specific Gravity				1.7	2.65	4.1

Multiply 25° number by 0.91 = 20°
Multiply 25° number by 0.83 = 15°
Multiply 25° number by 0.75 = 10°
Multiply 25° number by 0.68 = 5°

Sand and Coal Should Mix Just a Few Inches



Media Sizing – Common Problems

- Improper size(s)
  - Doesn't meet specs
  - Improperly specified
- Poor media matching
  - Too much mixing
  - Too little mixing
    - Lose some advantages of multi media
- Case I: Coal too large and sand expands into it
- Case II: Too large U.C. in sand, therefore, fines expand into coal

Media Sizing – Replacement of Lost Media

- Monomedia rapid sand filters
  - Specify same E.S. as original
  - Specify lower U.C. (to avoid fines and shorter filter runs)

Evaluating Performance of Filters

- History
- Performance evaluation
- Filter to waste
- Backwash evaluation
- Filter assessment
  - Media
  - Appurtenances

Filter History

- As-Built Drawings
- Specifications
- Vendor or Design O & M manuals
- Operating records
- Maintenance records
- Filter assessment records

Filter Performance Evaluation

- Filter run length
- Backwash water:Produced Water Ratio
- Net filter production volume
- Filter performance index
- Filtered water quality
- Filter headloss

Filter Performance Evaluation

- Filter run length
  - Minimum of 24 hours desirable;
    - If not;
      - Problems with time and water for backwash
      - Low net filter production volume
  - Maximum of 72 – 96 hours
    - If not;
    - Air binding
    - Media compaction
    - Bacterial growths

Filter Performance Evaluation

- Backwash water : produced water ratio
  - <3% is “normal”
  - <2% is “very good”
  - >5% is “poor”

Better performance in summer with warmer ambient water temperatures and better floc formation and settling.

Filter Performance Evaluation

- Net Filter Production Volume
  - NFPV = UFRV – UBWV, where:

    UFRV = unit filter run volume

    UBWV = unit backwash volume

Example:

UFRV = 4.0 gpm/ft^2 X 48 hrs X 60 min/hr

= 11,520 gal/ ft^2

UBWV = 17 gpm/ ft^2 X 10 min. = 170 gal/ ft^2

NFPV = UFRV – UBWV = 11,520 gpm/ ft^2 - 170 gpm/ ft^2

= 11,350 gpm/ ft^2

Net Filter Production Volume (continued)

- NFPV is typically 7,500 – 12,500 gal/ ft^2
- <5,000 gal/ ft^2 is unacceptable

8 Causes of Short Filter Runs

1. Fines at the surface
2. E.S. is too small for filtration rate
3. Too much floc in influent
4. Dirty filter bed
5. Filter-clogging algae
6. Air-binding
7. Too much polymer (coagulant or filter aid)
8. Recycling poorly treated spent BW water

Filter Performance Index (FPI)

$$FPI = \frac{(NTU_a - NTU_e)G}{NTU_e}$$

Where:

FPI = filter performance index

NTU_a = turbidity applied to filter

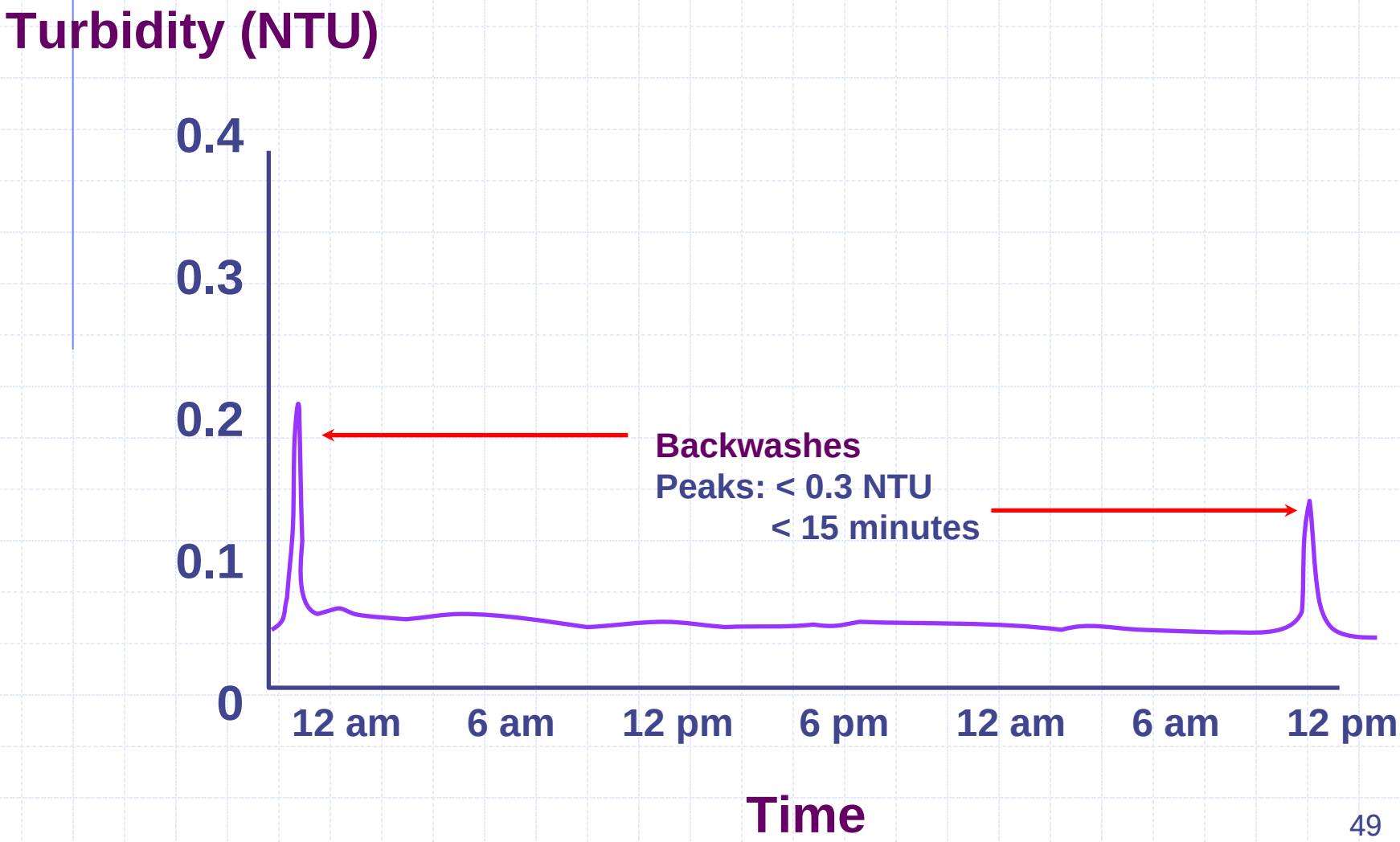
NTU_e = turbidity in filter effluent

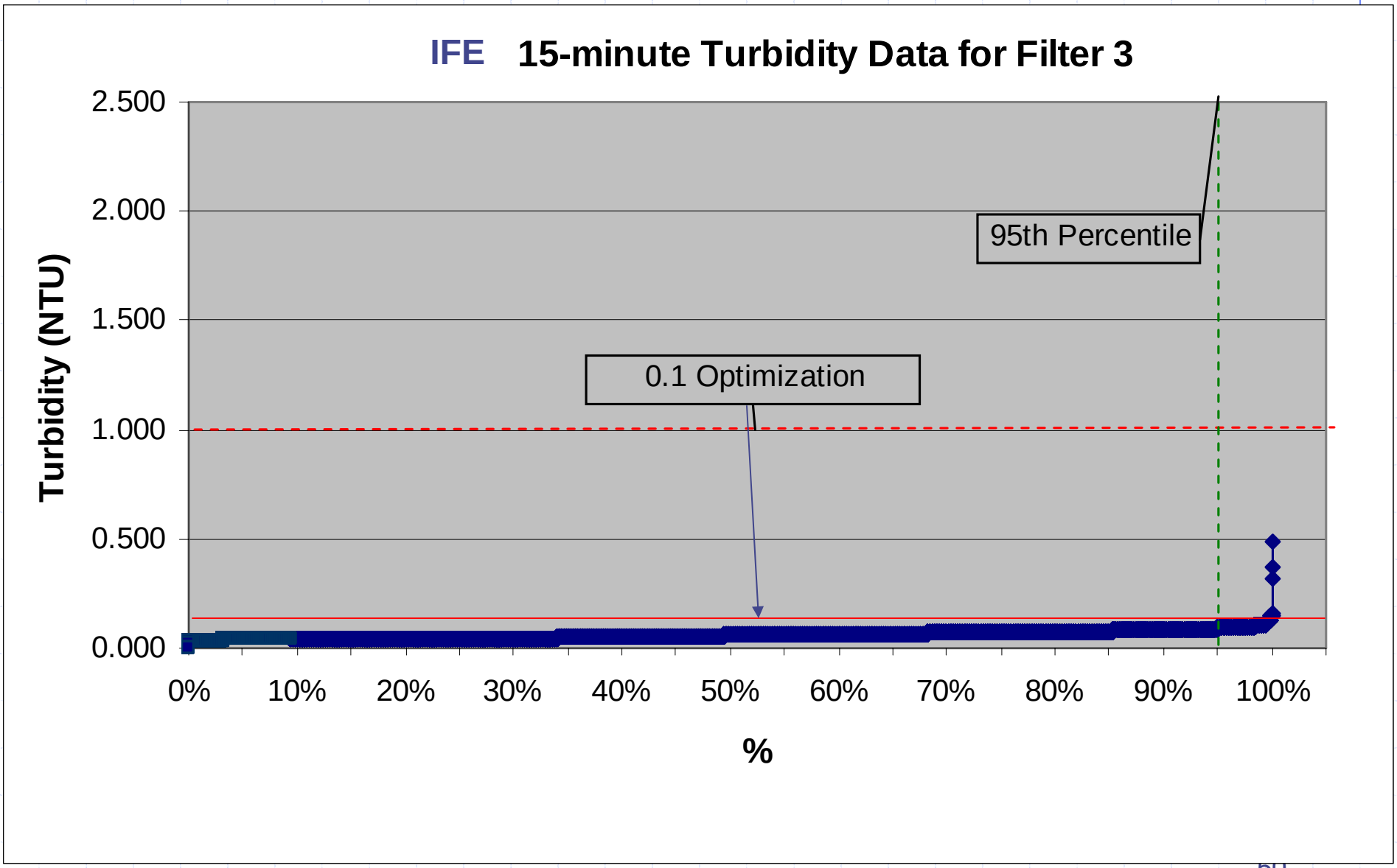
G = gallons between backwashes

Considers Quality and Quantity

Filter Performance Evaluation:

Continuous Turbidity/Particle Monitoring



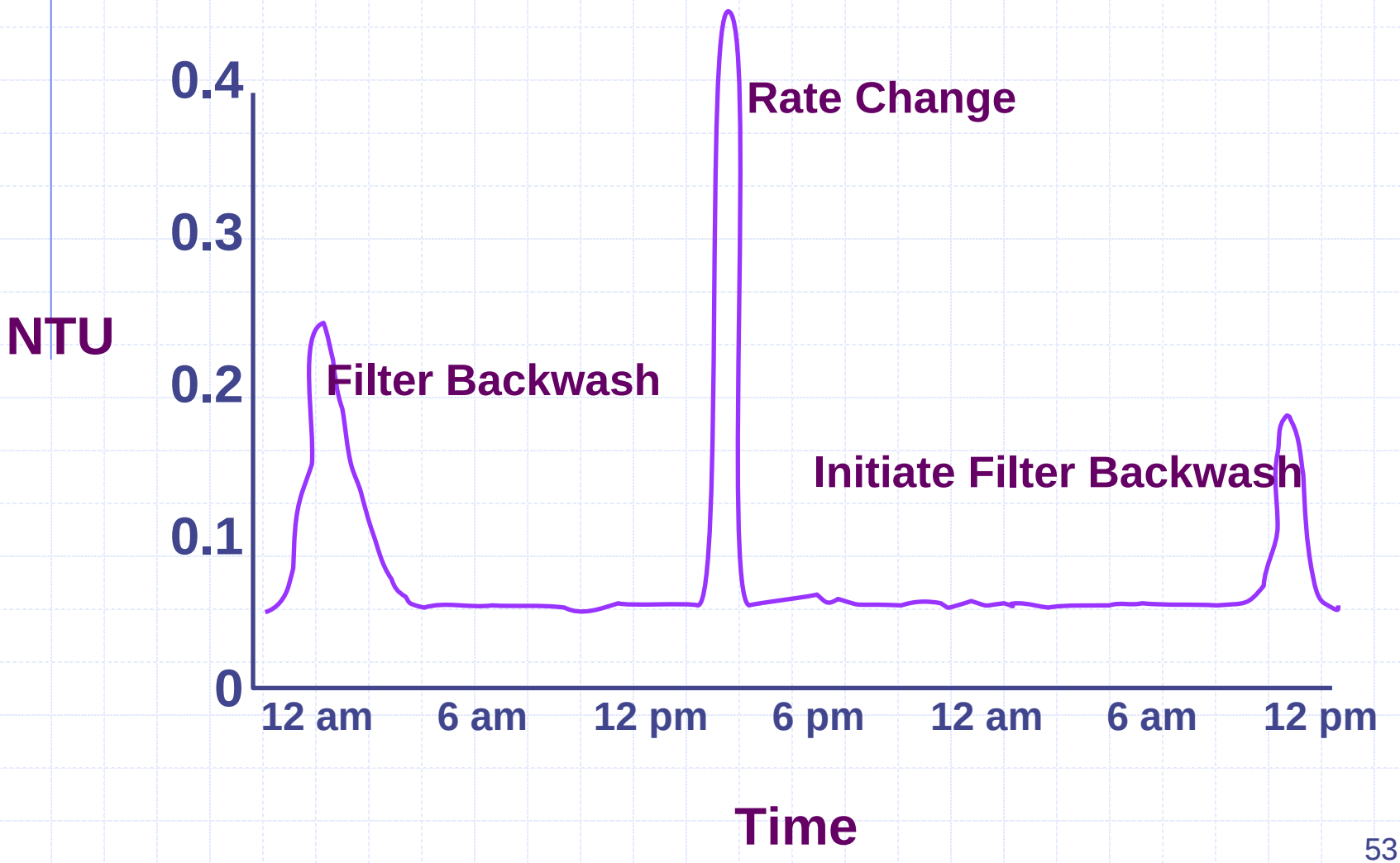

IFE 15-minute Turbidity Data for Filter 3
Turbidity (NTU)
2.500
2.000
1.500
1.000
0.500
0.000
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
%
95th Percentile
0.1 Optimization

Filter Performance Evaluation

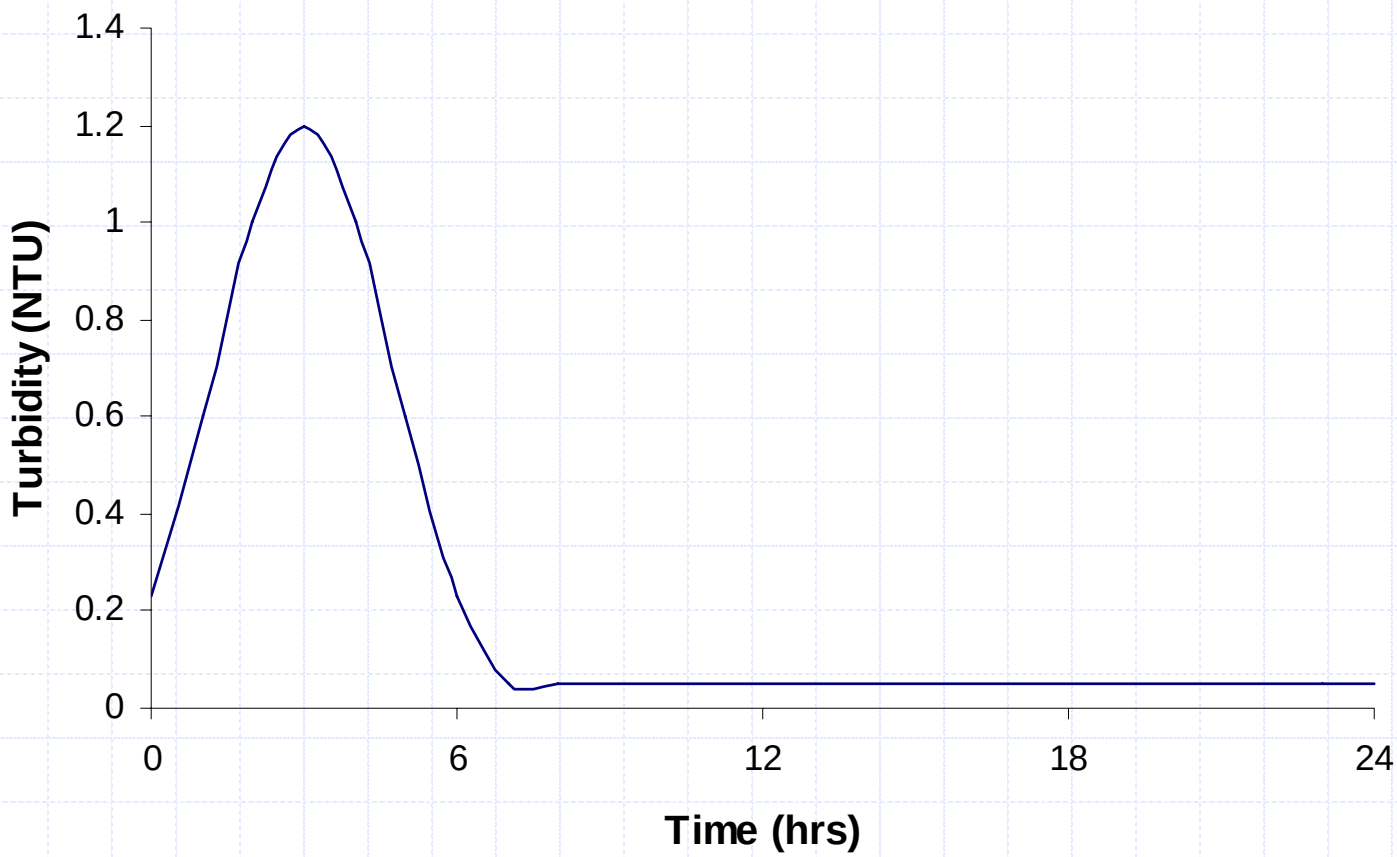
- Filtration involves removal and storage
  - "Snow resting on branches of a tree" (Logsdon & Hess)
  - Impacted by:
    - Rate increase (25% increase over 5 minutes releases 6 times as many particles as 25% over 10 minutes)
    - Floc strength
    - Headloss across filter(s)

Electron Micrograph of Sand Grains With Attached Floc

Filter Performance Evaluation— Turbidity/Particles



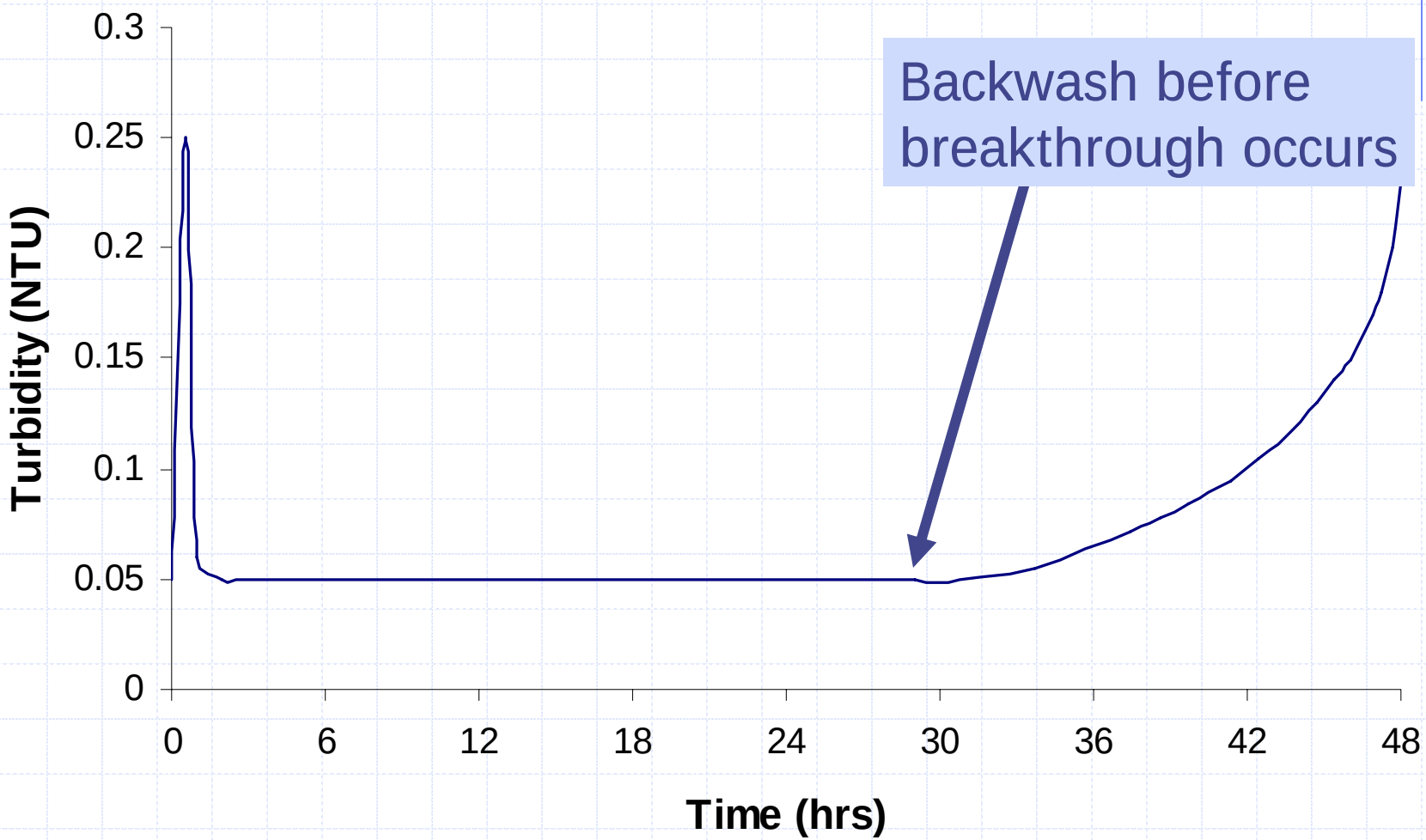
Filter Performance Evaluation -- (Ripening)



Solutions for Ripening Spikes

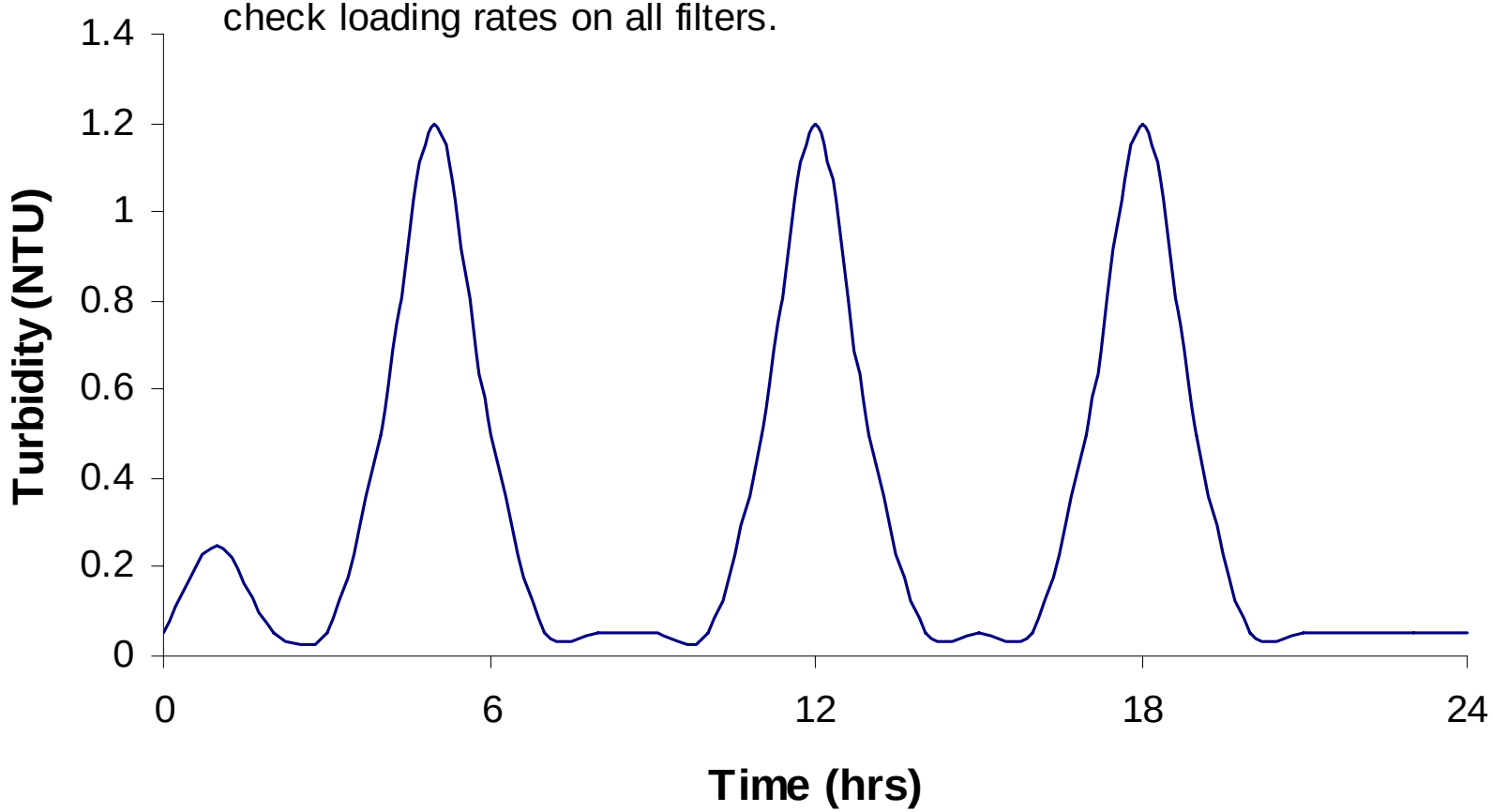
- Filter to waste until < 0.10 NTU
- Delayed start (resting)
- Slow start
- Optimal cleaning
- Adding polymer or coagulant to BWW
  - Last 3 – 5 min. of BW
  - Stop addition for an interval before end of BW
    - Keeps chemical from entering clearwell

Turbidity/Particle Breakthrough



Breakthrough Caused by Rate Changes

Multiple spikes due to hydraulic surge as a result of variable raw water rates or one or more filters taken out of service. You probably want to check loading rates on all filters.



Management of Filtration Rates

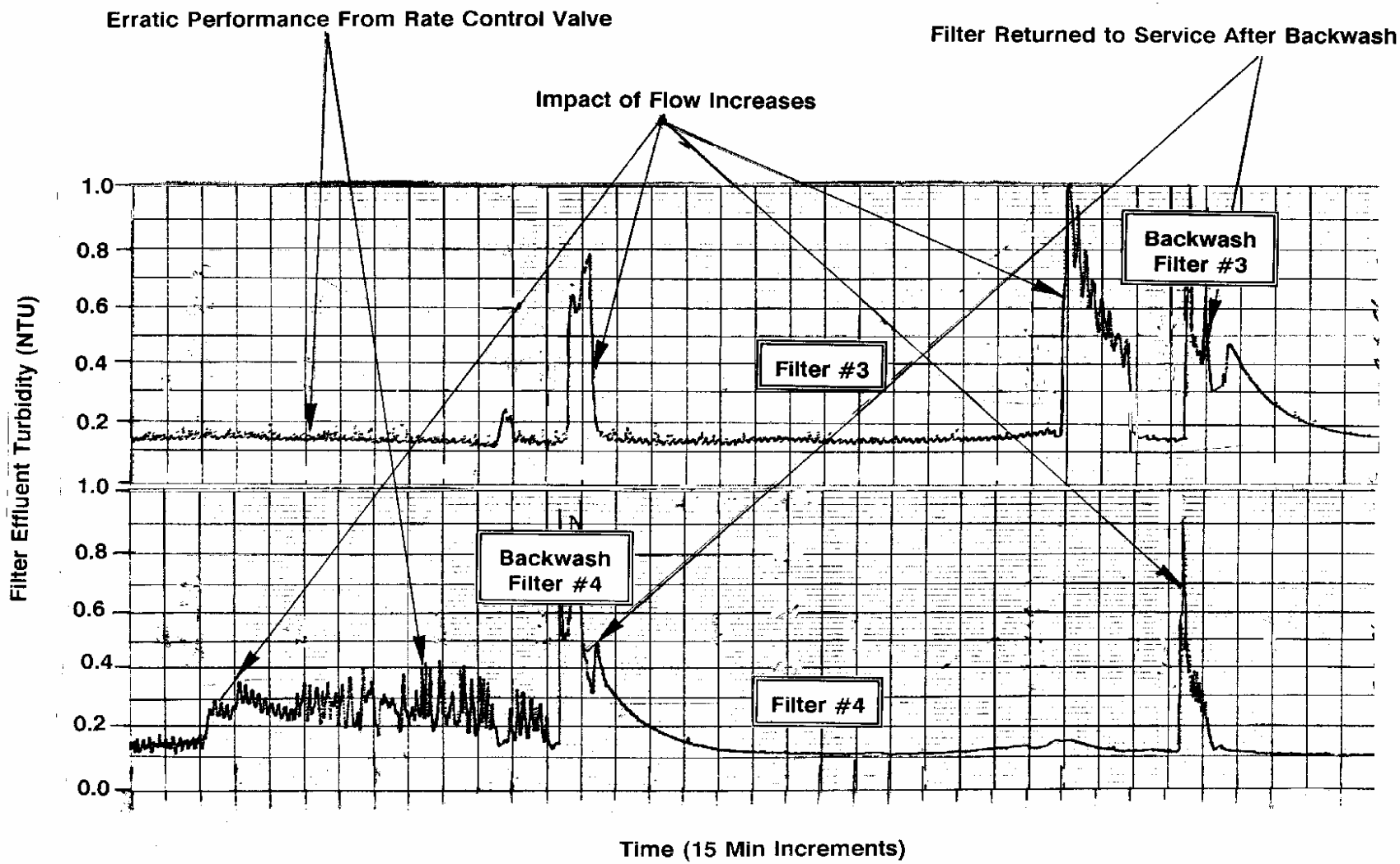
- Increasing production
  - Put idle filter into service
  - Slowly increase rates on filters
    - Valving or VFDs
    - More risk during final hours of filter run (higher headloss)
  - Increase treated water storage
    - Buffers demand vs. production

Management of Filtration Rates

- Removing filters for backwashing
  - Put idle filter into service
  - Slowly increase rates on filters (slow stopping)
    - More risk during final hours of filter run (higher headloss)
  - Decrease raw water flow
    - VFD pumps and flow paced chemical feed
  - Maintain rate and let level rise in basins
  - Use of multiple approaches

Returning a Filter to Service After Backwash

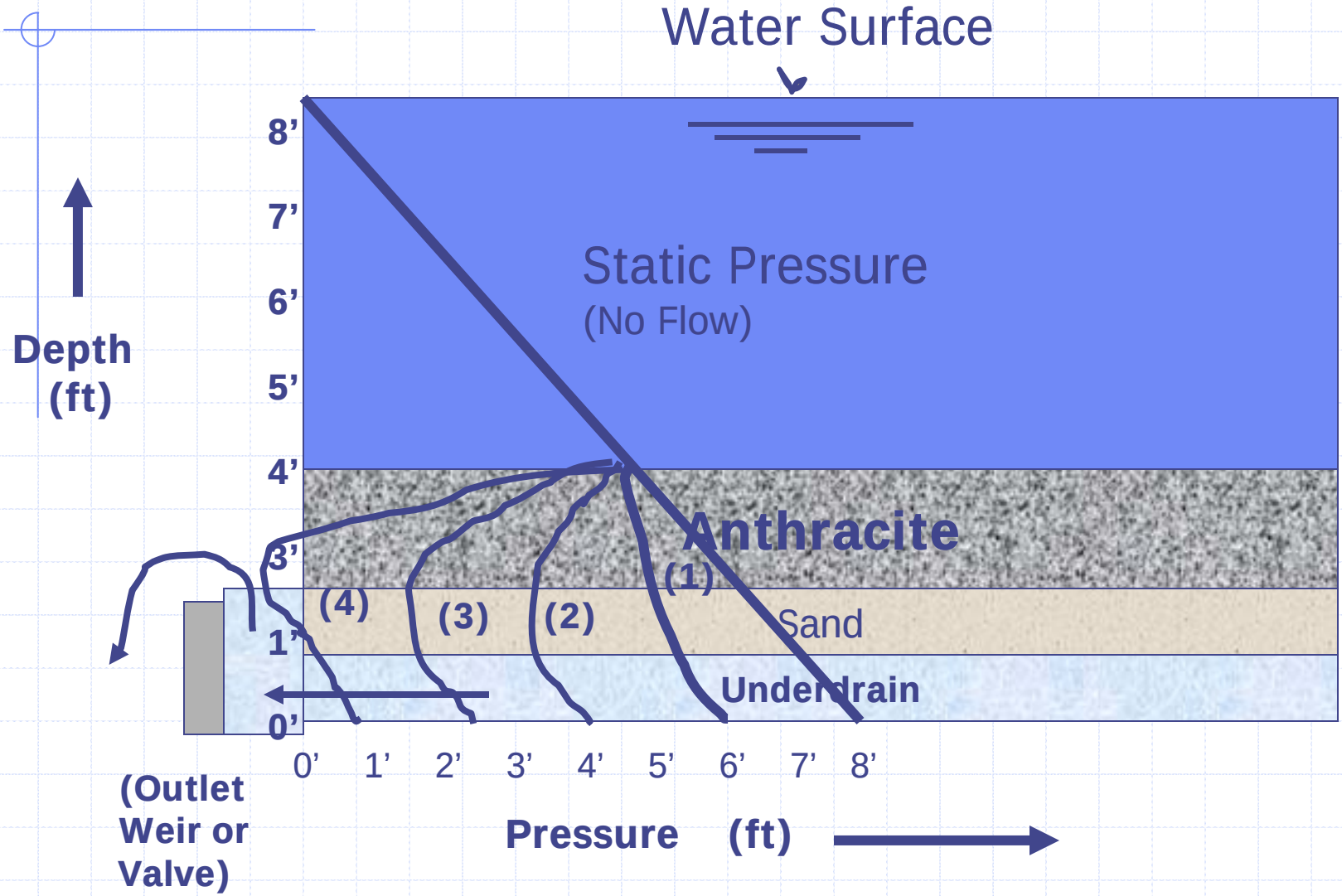
- Can cause a decrease in flow followed by a surge
  - More pronounced if water rushes into the backwashed filter
  - A function of controls
    - When effluent control valves are tied into level of filter influent channel,
      - they adjust as level falls,
      - then readjust when filter box is filled and level increases.
- Solution:
  - Try filling filter slowly


Erratic Performance From Rate Control Valve
Filter Returned to Service After Backwash
Impact of Flow Increases
Backwash Filter #3
Filter #3
Backwash Filter #4
Filter #4
Filter Effluent Turbidity (NTU)
1.0
0.8
0.6
0.4
0.2
1.0
0.8
0.6
0.4
0.2
0.0
Time (15 Min Increments)

Filter Performance Evaluation

Filter Headloss

Gravity Filter Headloss Diagram



Contributors to Air Binding

- Headloss creates less than atmospheric pressure conditions
  - Fines at surface
  - Supersaturated water
  - Cold water
  - Algae

Air Binding Solutions

- Design
  - Allow for 6’ or more of water over filter
  - Have outlet weir’s elevation above media surface
- Operational
  - Shorter filter runs (less headloss)
  - Take filter off-line and
    - Drop water level below washwater troughs
    - Set idle for ½ hour before backwash
  - Start with gentle backwash
  - Do not use surface wash

Backwash Evaluation

Backwashing Filters:

4 Basic Methods, (Cleasby, 1999)

Backwashing Methods

1. Up-flow wash with full fluidization
   - Least effective
2. Up-flow wash with surface wash
3. Up-flow wash preceded by air scour
4. Up-flow wash in combination with air scour
   - Sub-fluidization in combination with air is most effective

Backwash Considerations

- Flow rate
  - Open valve slowly (>30 seconds)
  - Keep bed expansion below bottom of troughs
  - Ramp down at termination
    - Especially for dual and mixed media

Backwash Considerations

- Monitoring clean bed headloss
  - Headloss after backwash and return to service
    - Must be adjusted to account for changes in
      - Water temperature
      - Filtration rate
        - See AWWARF, 2003 pages 6-34 through 6-37
  - Good indicator to use after change in BW procedure

*A difference in temperature of 49 ^{0}F (27 ^{0}C) can double headloss.

Backwash Considerations

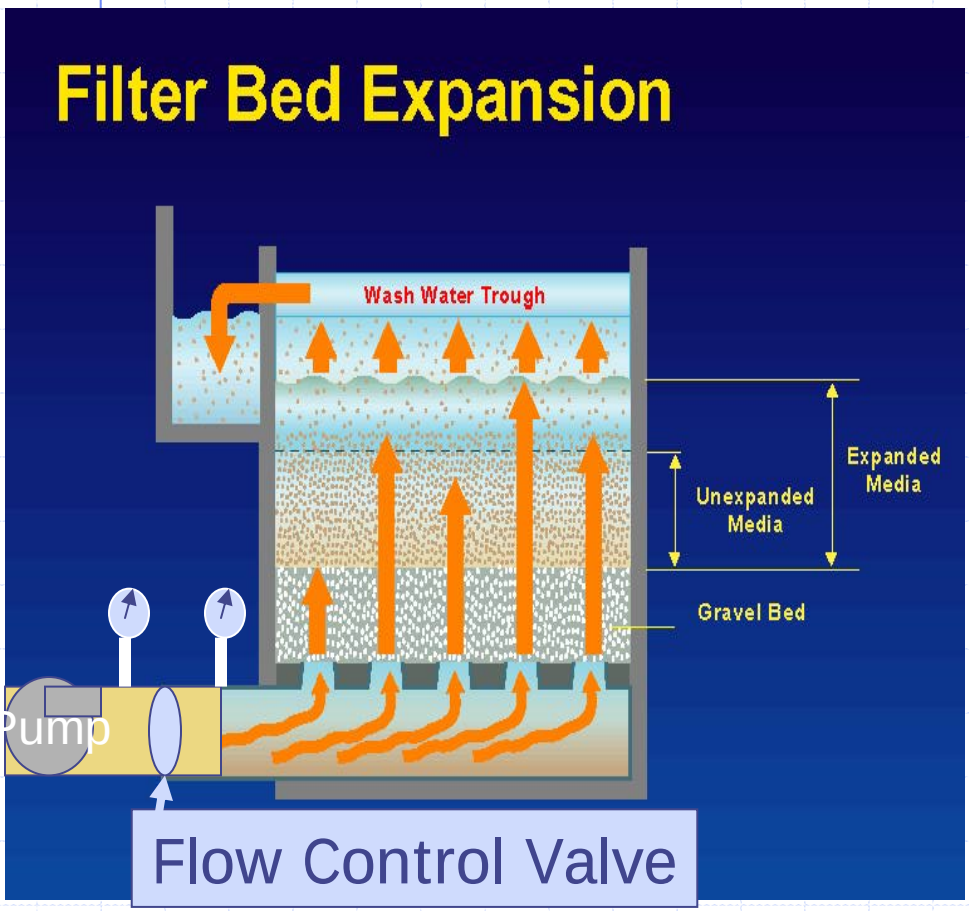
- Effect of water temperature
  - Upward force of water is directly proportional to the viscosity
  - The rate necessary for 10% bed expansion at 77 ^{0}F is ~150% of that needed at 41 ^{0}F (Baumann)
  - Rate should be adjusted based on
    - 18 ^{0}F or 10 ^{0}C change

See Table 6-1, p. 6-20

Backwash Considerations

- Backwash water usage
  - 200 gal/ft^2 may be typical (Montgomery, 1985)
    - < 5% of produced water should be used
    - AWWA utility survey
      - 1 – 7% range

Monitoring Backwash Water Pressure



1. To assess condition of filter underdrains
   - Measure pressure
     - <u>downstream of the flow control valve</u>
     - At maximum flow for each filter
   - Log data and trend
2. To assess condition of BW pump
   - Measure pressure at given flow rate <u>between the pump and flow control valve</u>

Filter to Waste

- Some plants filter at normal rate
- Some plants filter to waste at rates much lower than normal
  - Generally a token to satisfy the regulator
  - Results in a rate increase at a crucial time

Filter to Waste

- When?
  - After backwash
  - After backwashing contact adsorption clarifier
  - Upon start-up
- How long?
  - Until target goal is met
    - e.g. <0.1 NTU

Do not control Filter to Waste based on time!

Filter to Waste

- A well-designed filter to waste system should
  - Smoothly open the filter outlet valve while smoothly closing the filter to waste valve
  - With no change in rate through the filter

Individual Filter Assessments

Full Assessment Performed Annually (or As-Needed)

Filter Assessment Video

Individual filter assessment

- General description of filter
- Filter profile
- Hydraulic loading conditions
- Condition and placement of media

Methodology

- Drain filter
  - Observe
- Measure freeboard
- Perform work on the filter as necessary
- Backwash filter
- Document entire backwash
  - Rates
  - Times
- Determine bed expansion
  - Secchi disk
  - Pipe organ tool
- Drain again
- Perform work on the filter

Filtration Rate Test

Rise Rate Test

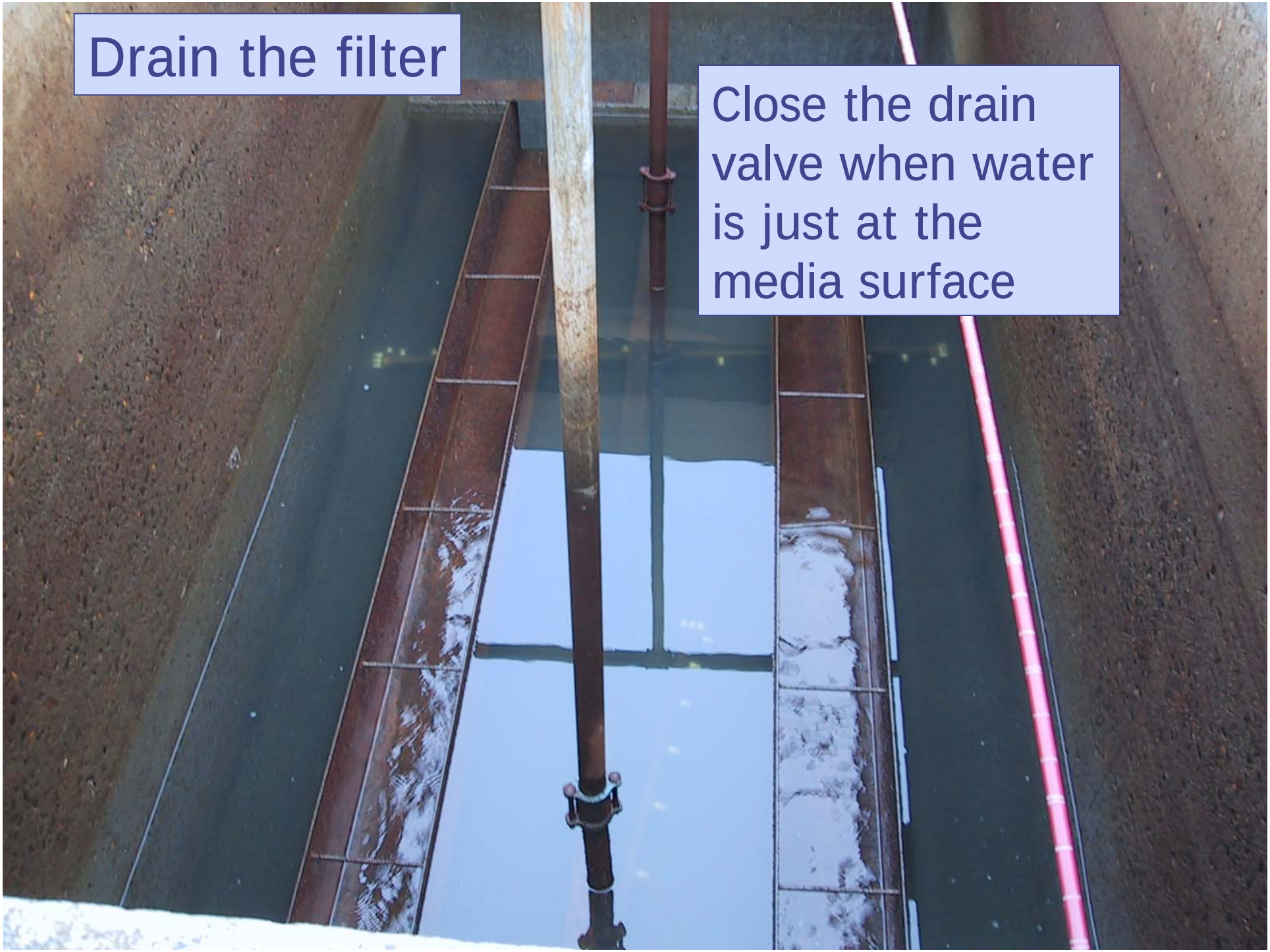
Floc Retention Analysis

Tools (see section 4.2)

- Safety equipment
- Plywood
- Electrical & duct tape
- Probe
- Coring tool
- Expansion tool or
- Secchi disk
- Benchtop turbidimeter
- Media collection tool
- 4’ – 6’ level
- Laser level or transit
- Tape measure
- Yard stick
- Backwash water sample collection tool
- Zip-lock bags
- 50 mL beaker
- 500 mL Erlenmeyer flasks
  - Water bottles
- 1 L beakers
- Excavation box

Physical Filter Testing

- Levelness of troughs
- Freeboard
  - Media loss
- Condition of piping
- Condition of surface wash
- Filter excavations
- Condition of concrete/steel
- Flow rate through filter
- Probing
  - Media depth
  - Support media mapping
- Filter excavations
  - Mudballs
  - Fines
- Core samples
- Condition of underdrains
- Condition of valves and controls

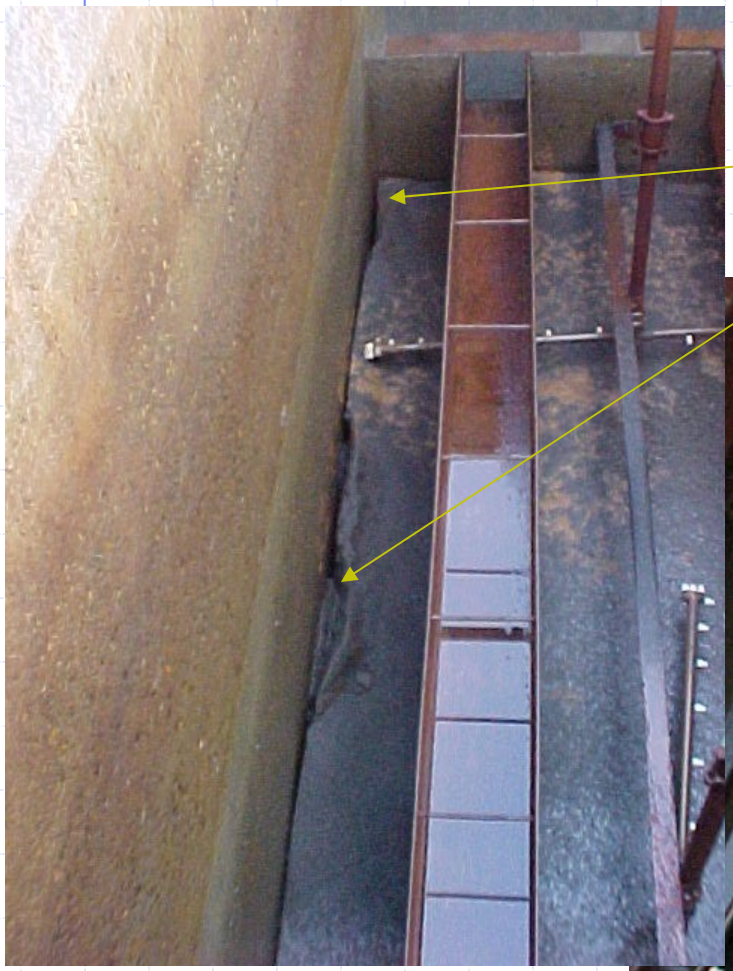

Drain the filter
Close the drain valve when water is just at the media surface

Safety

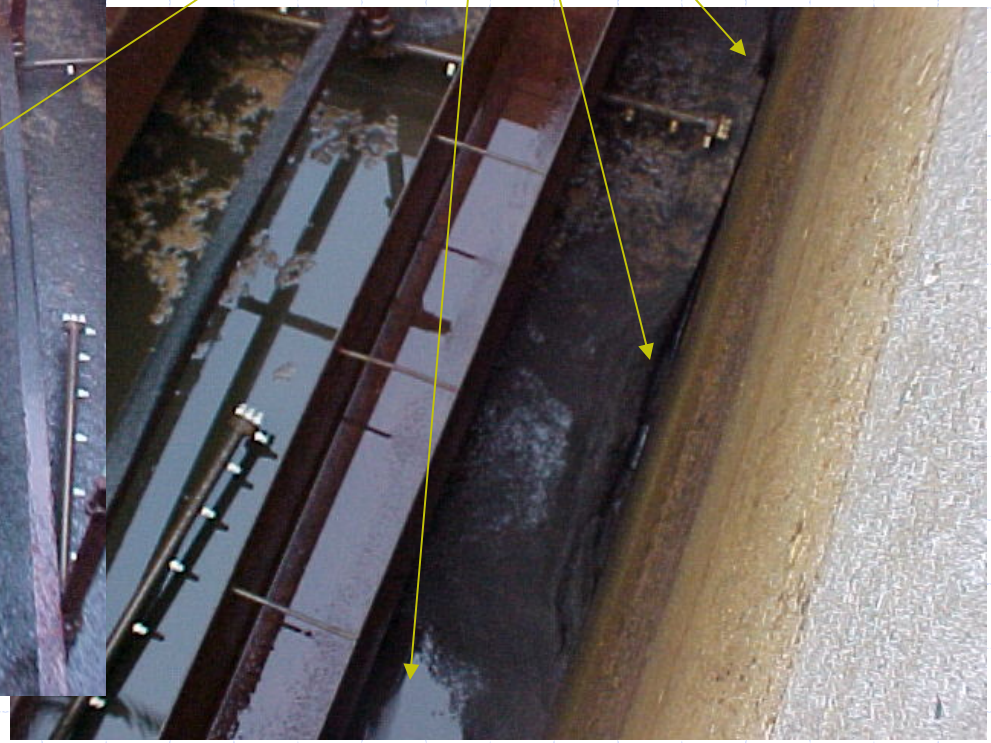
- Confined space entry
  - Air monitoring
- Fall protection

Filter Surface

Check the Wash Water Troughs for Level
- -Lengthwise
- -Side to side
- -With each other

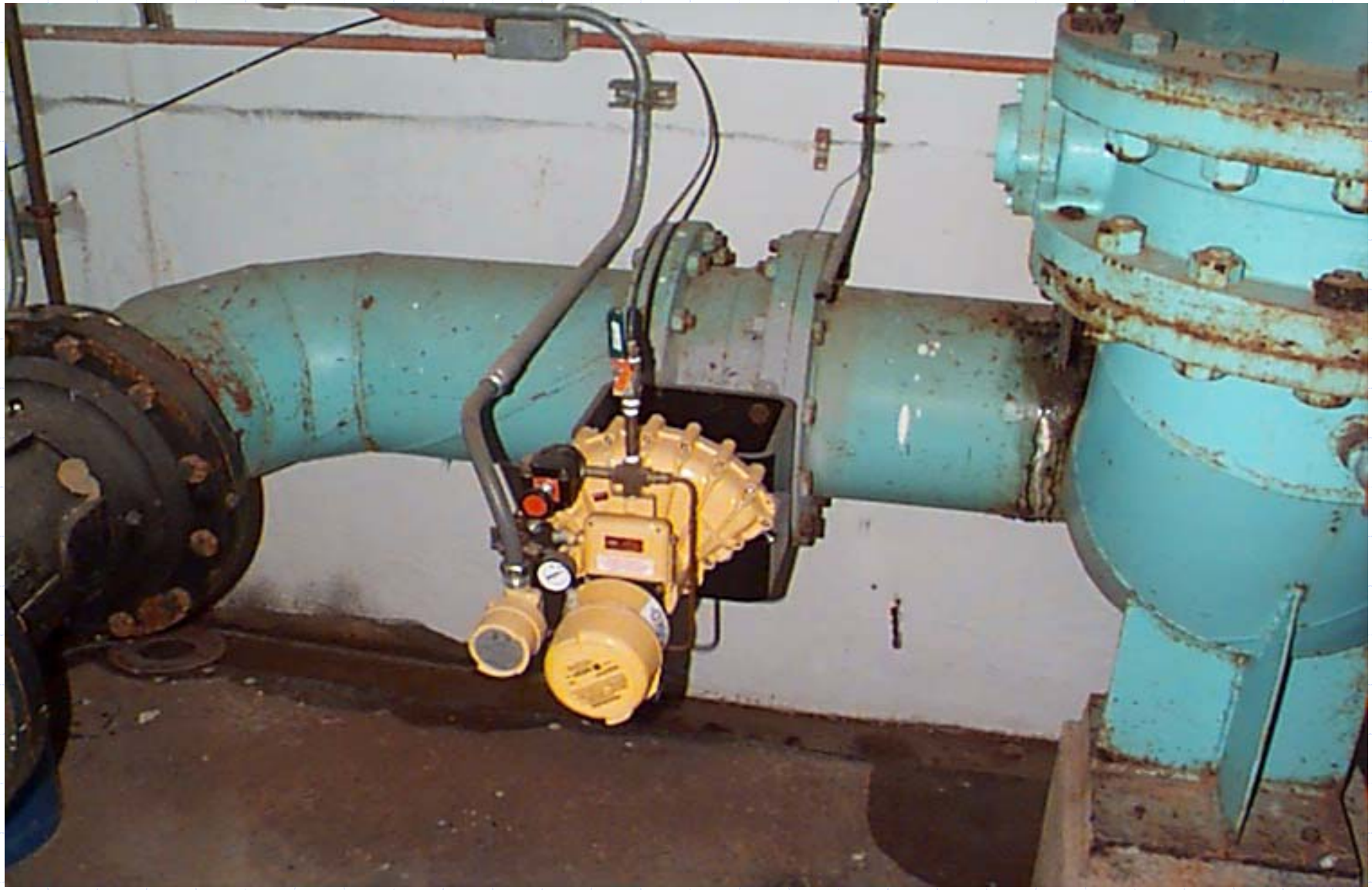


Abnormalities



Craters

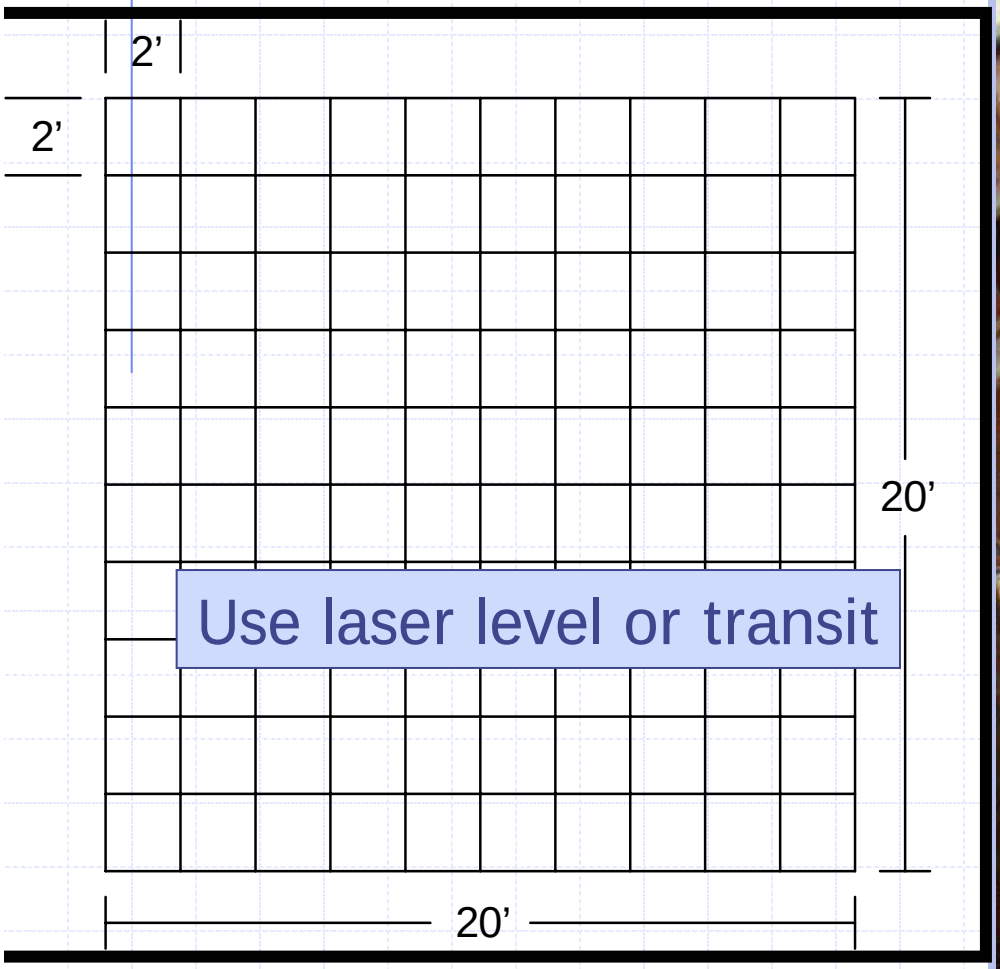
Check hydraulic loading



Filter Evaluation

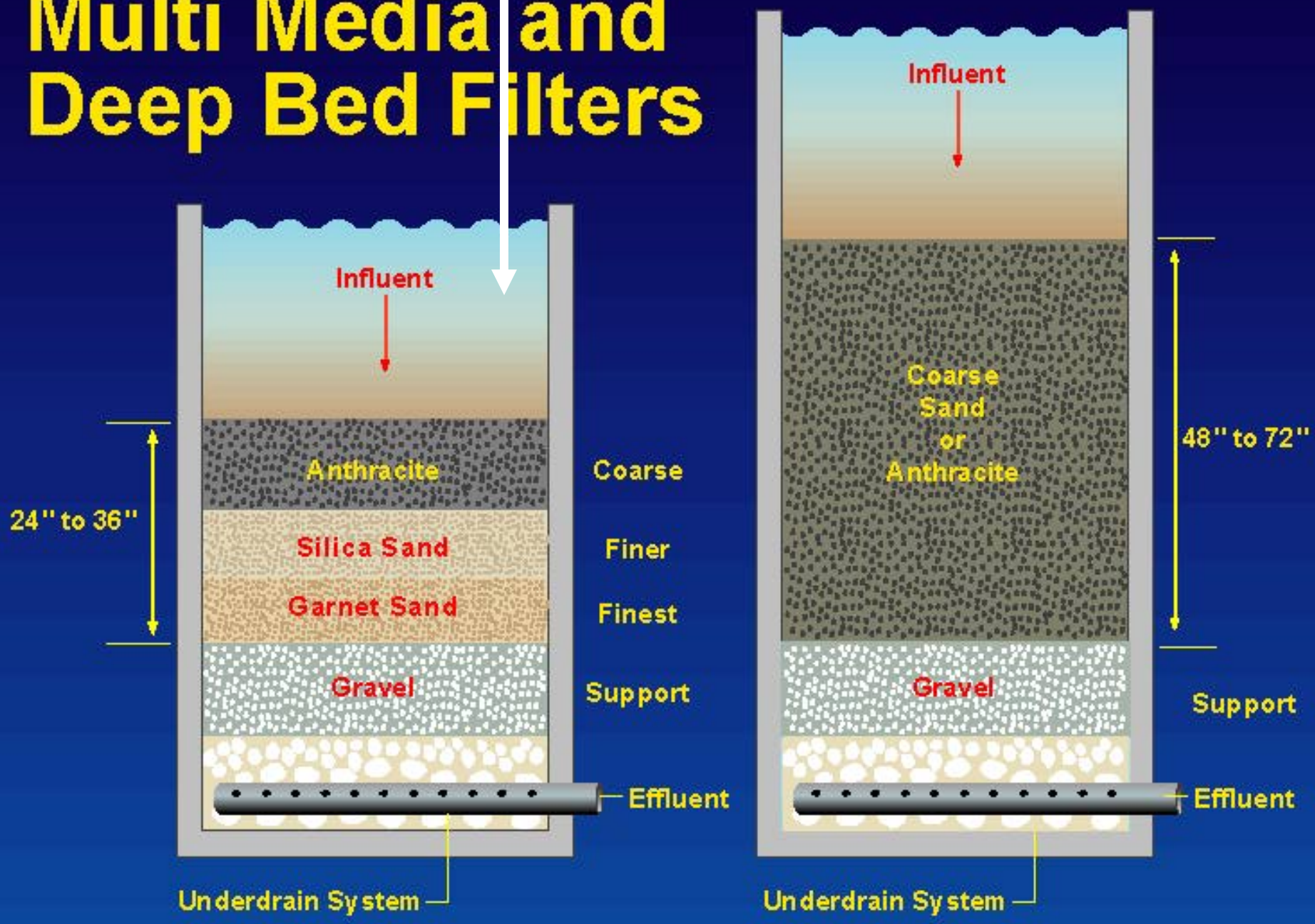
- Bed depth
  - Original specs
  - Probing
- Support gravel Mapping
- Media sampling and testing
- Floc retention profile

Filter probing



Use laser level or transit

Multi Media and Deep Bed Filters



Hand Excavate and Examine Media

Measure depths:
✓ to interface
✓ to bottom of interface
✓ to support gravel
Look for areas with compacted media

Concentrate on Areas Where Surface Wash May not Reach

Look for Mud Balls

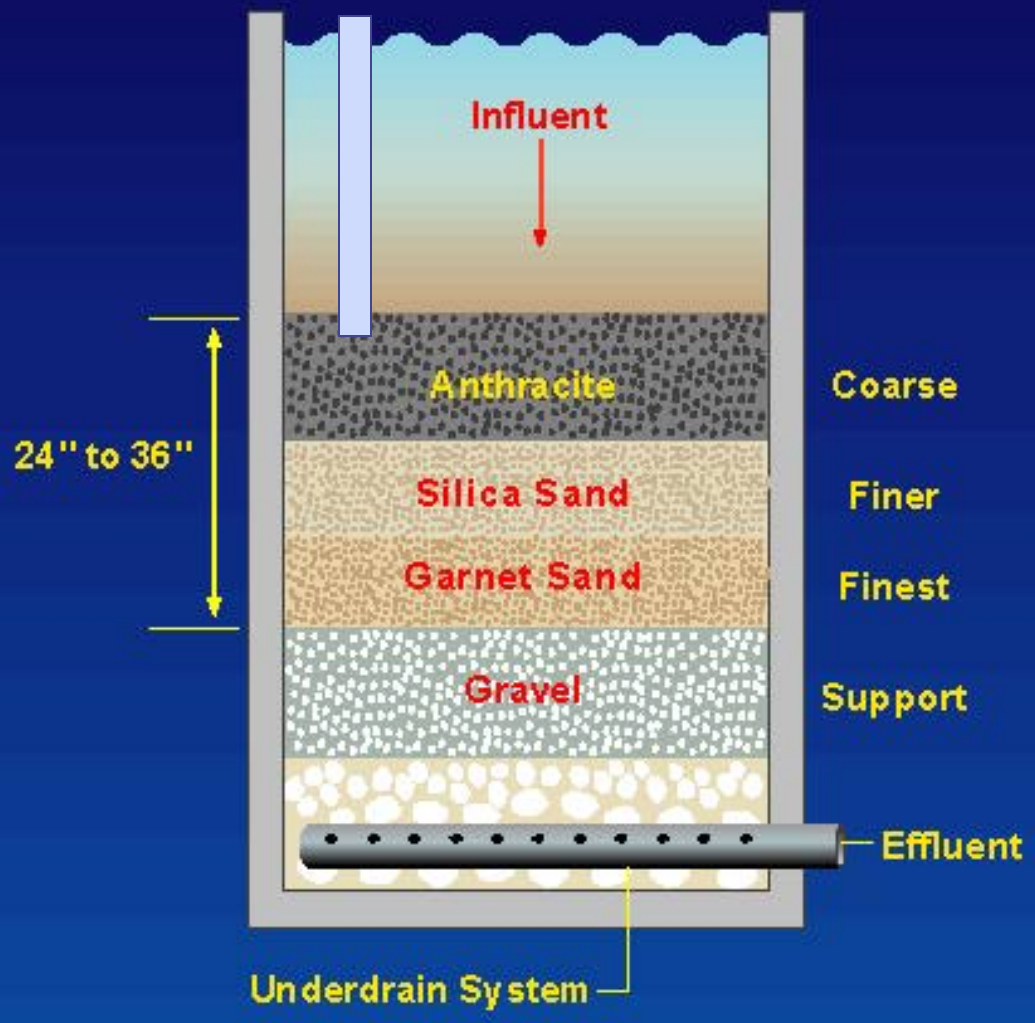
Coring the Filter to Obtain Representative Samples

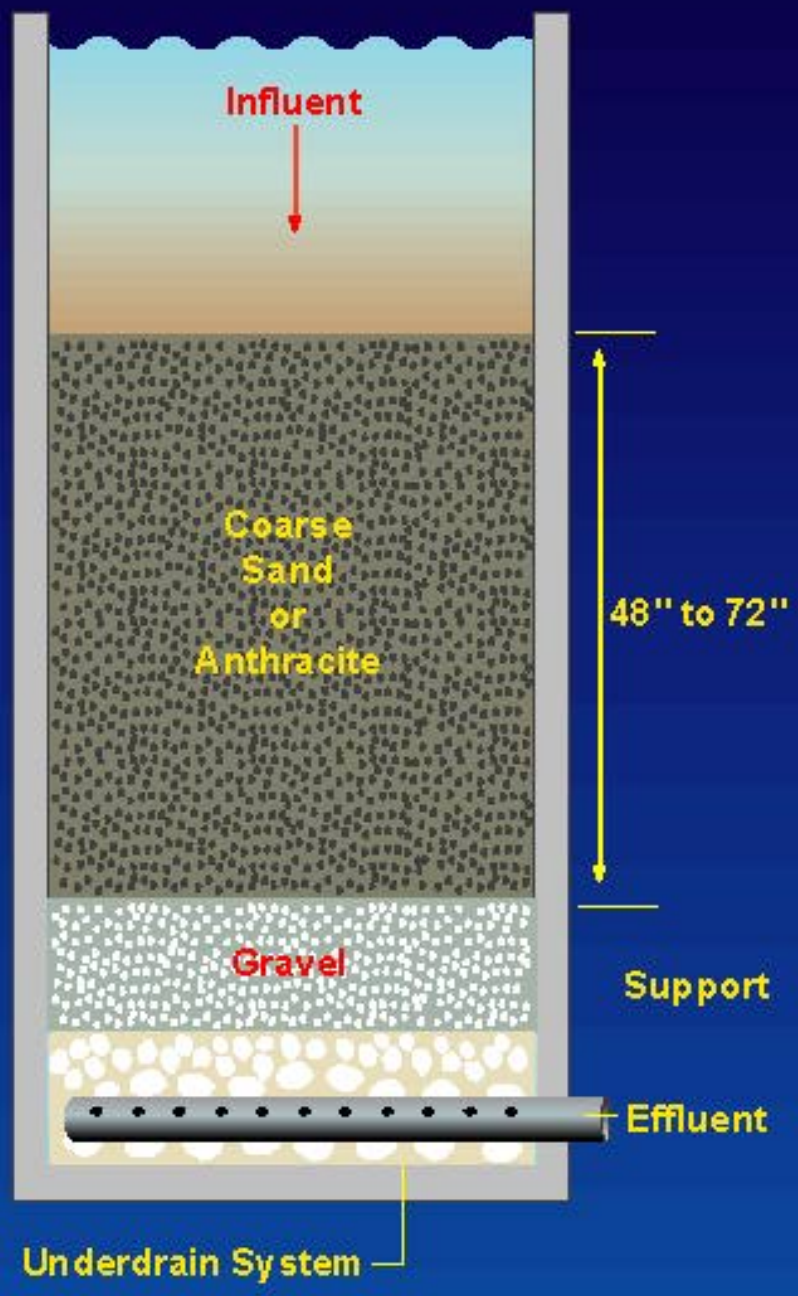
Check the interface

Floc Retention Profile

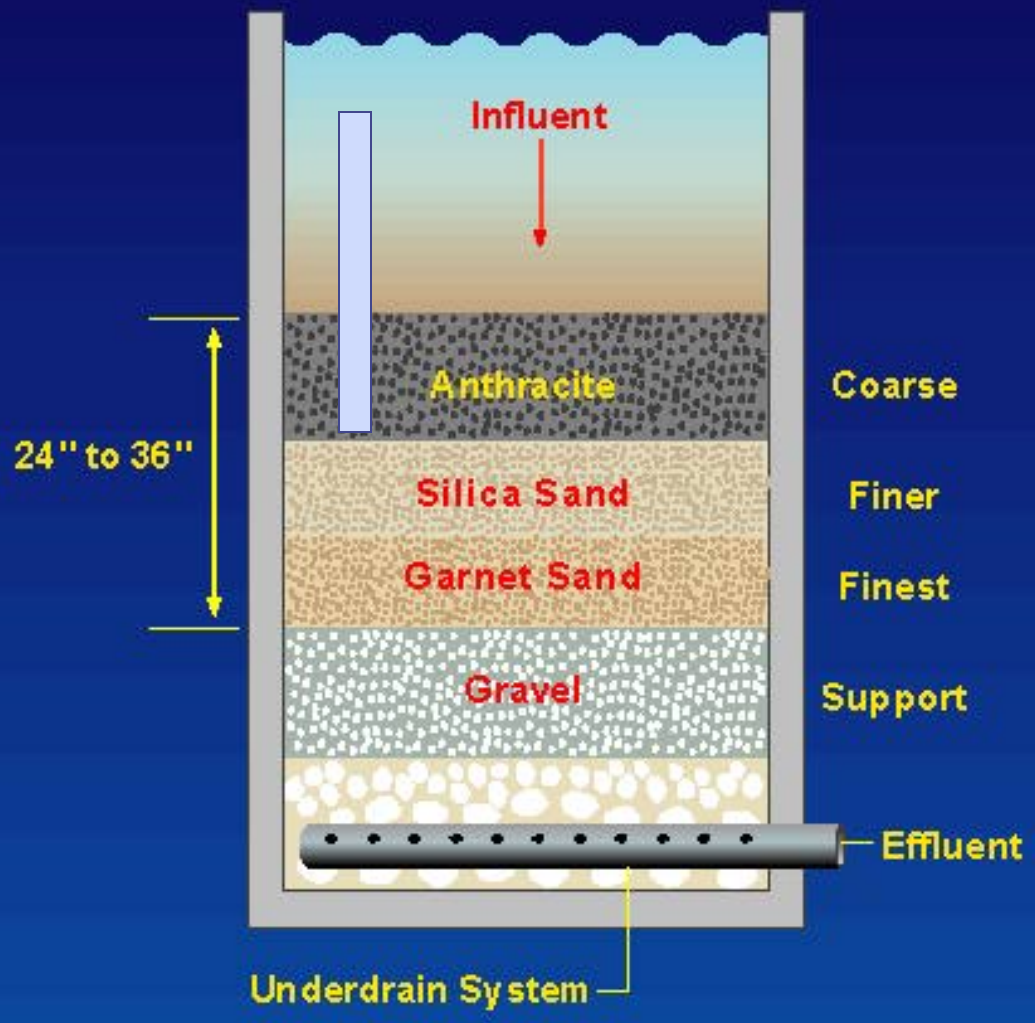
1. Drain filter
2. Collect samples in 5 – locations
   i. 0-2 inches
   ii. 2-6 inches
   iii. 6-12
   iv. 12-18
   v. 18-24
   vi. 24-30
   vii. 30-36
3. Place media samples in marked baggies
4. Wash the filter
5. Drain filter
6. Repeat step 2
7. Repeat step 3

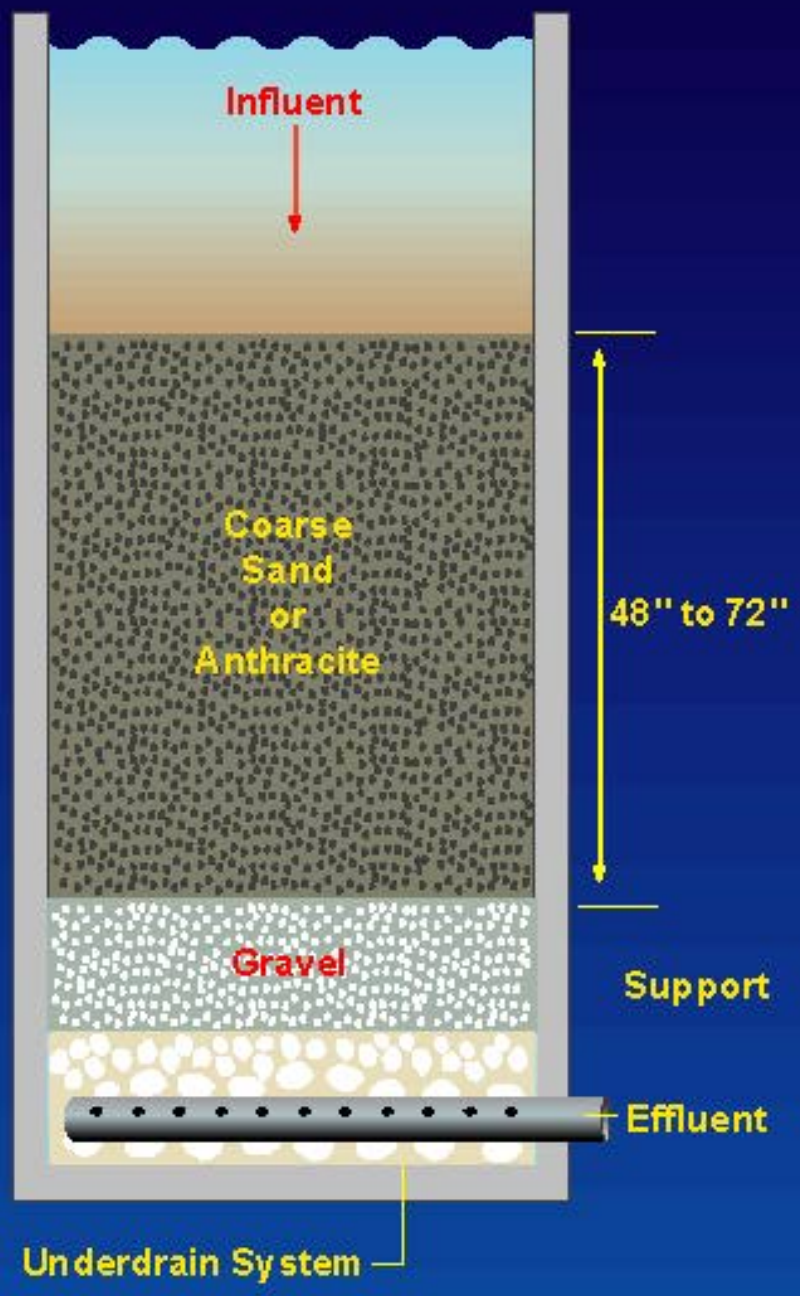
Multi Media and Deep Bed Filters



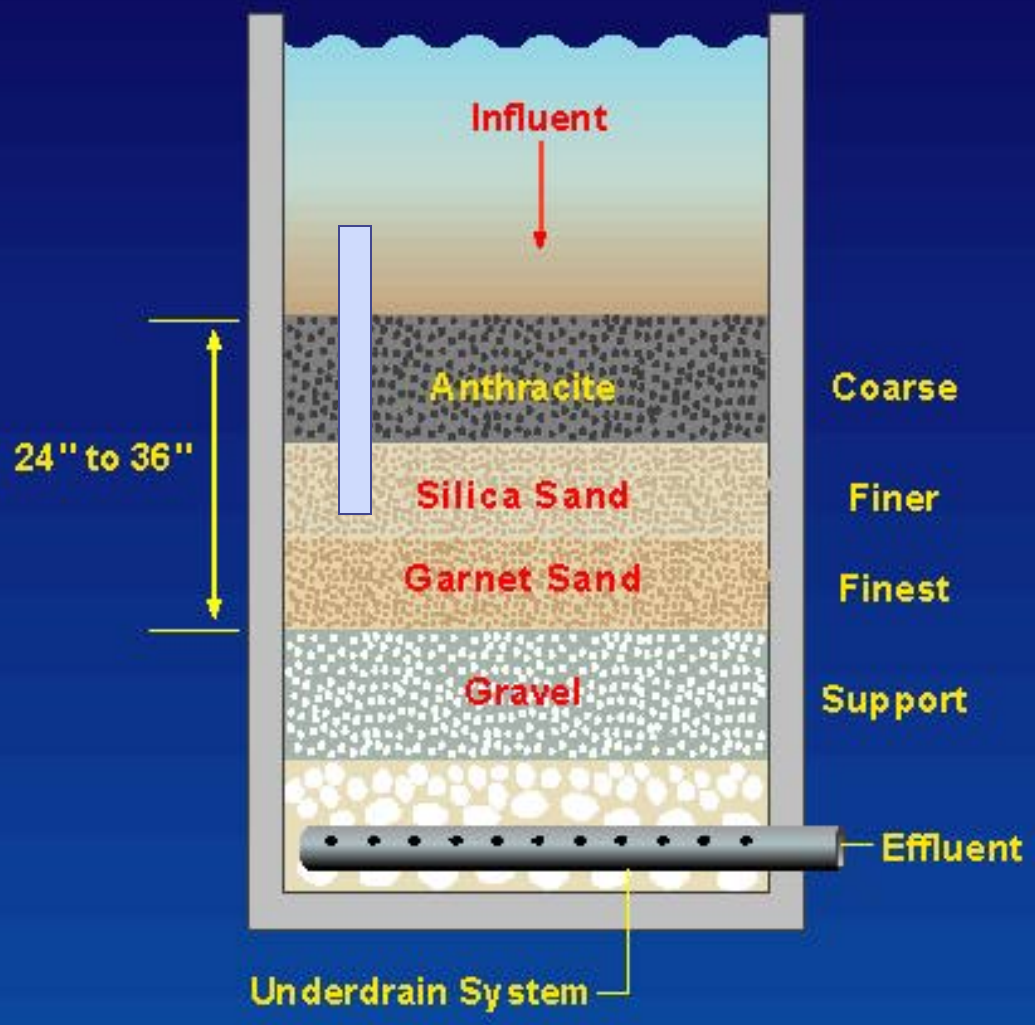


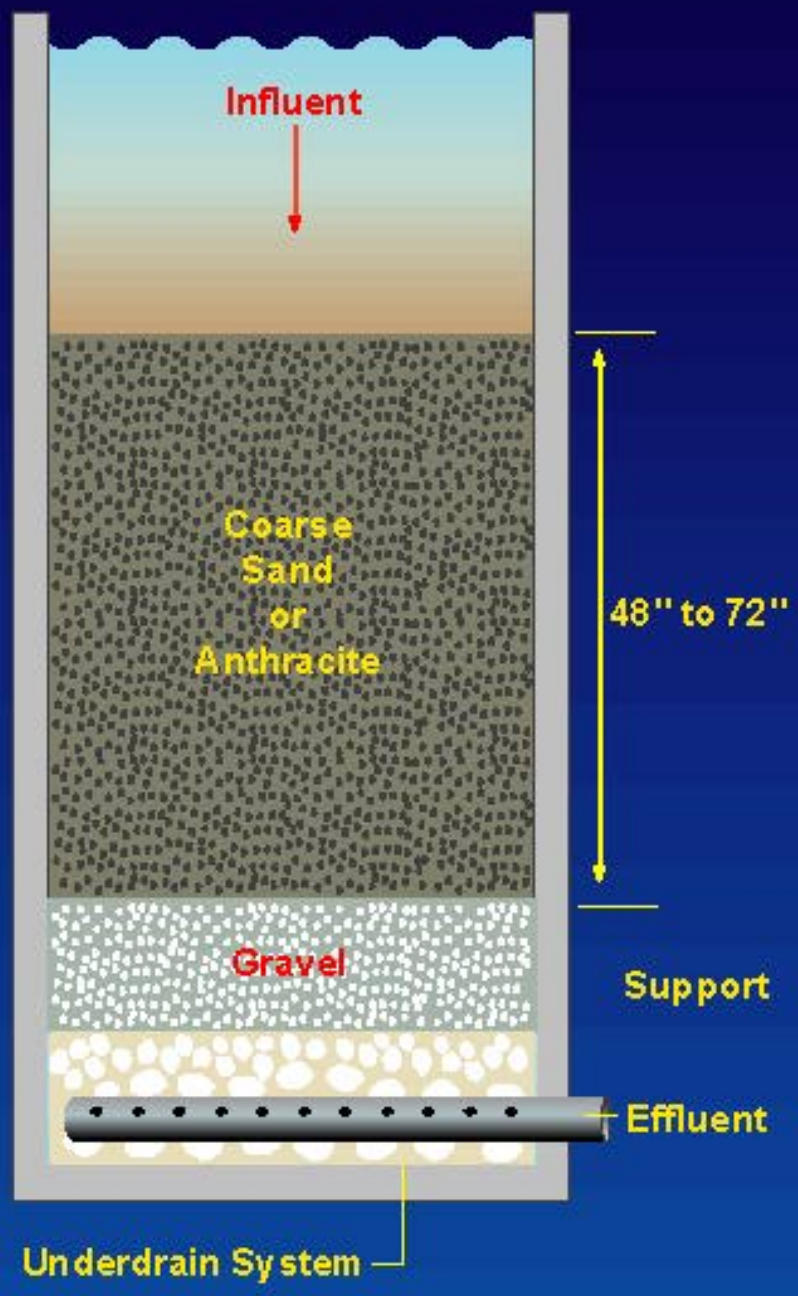
Multi Media and Deep Bed Filters





Multi Media and Deep Bed Filters





Place media samples in marked baggies

Floc Retent
Profile

Craters

Some problems may call for a more complete excavation using an excavation box

After Working on the Filter

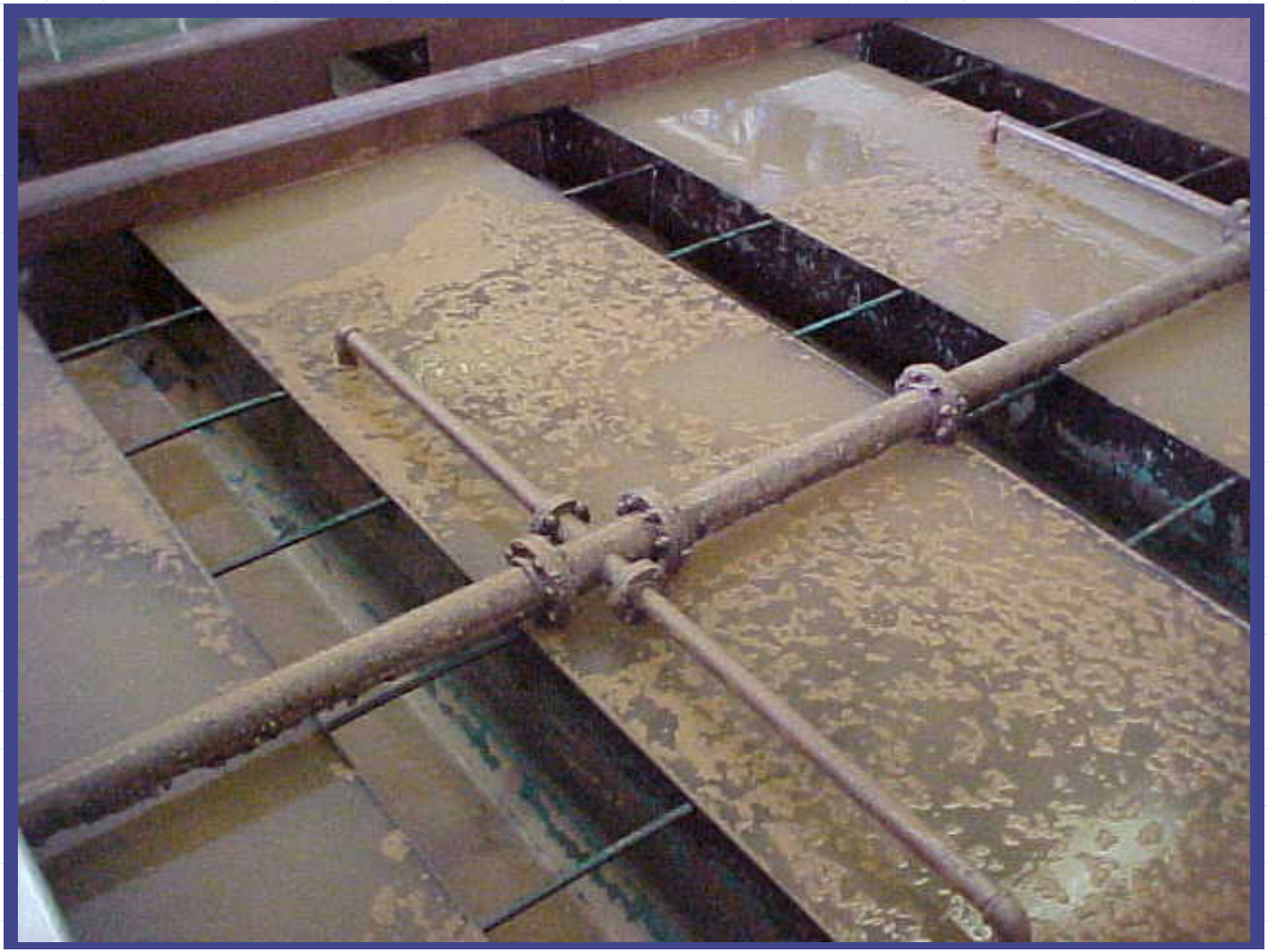
- Fill in holes
- Remove tools & ladder
- Prepare to backwash
- Evaluate backwash

Filter Backwash Evaluation

- Rise rate test
  - See manual
- Bed expansion testing
- Boils, dead spots
- Backwash water turbidity profile
- Floc retention profile

Rise Rate Test

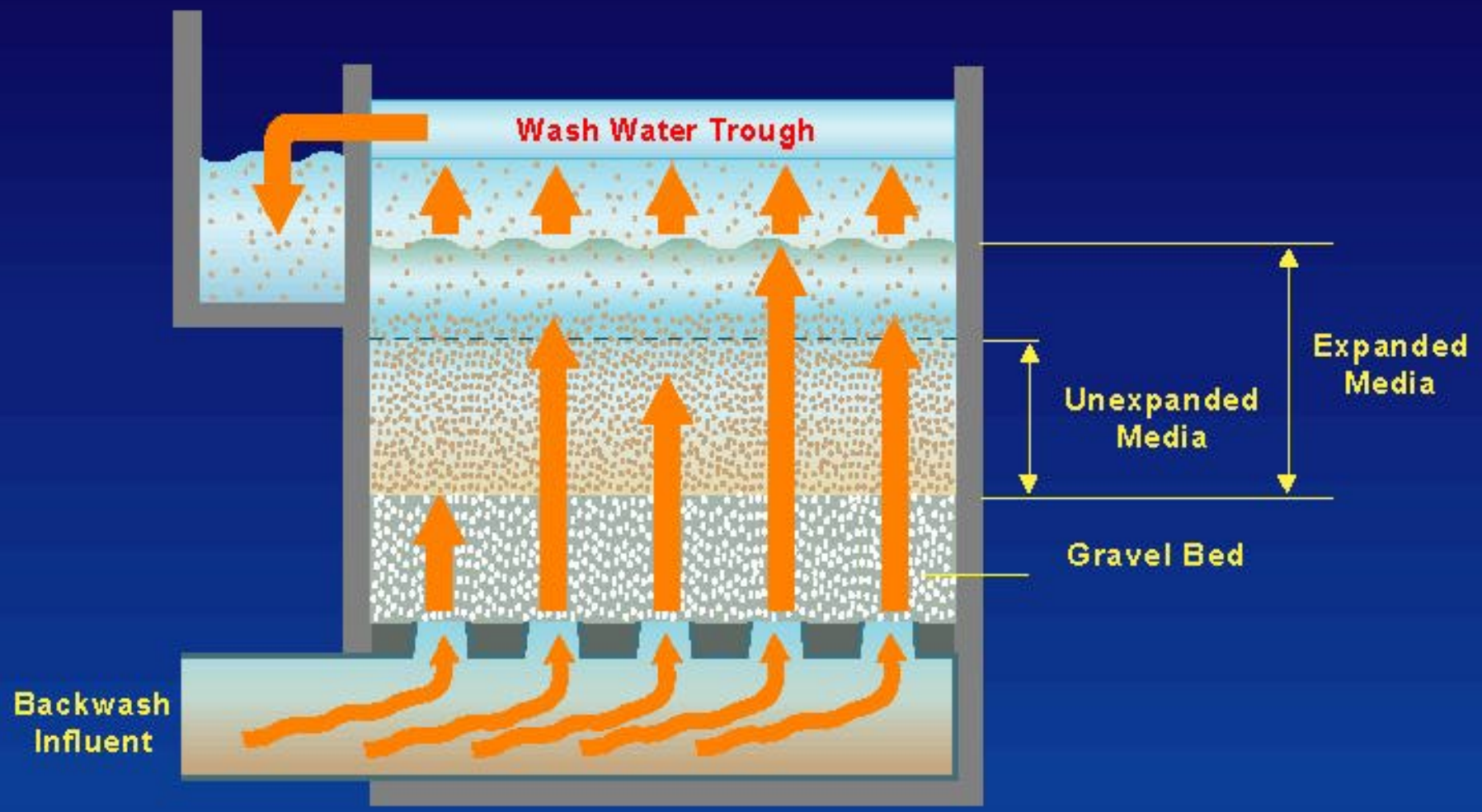
Test above or below troughs

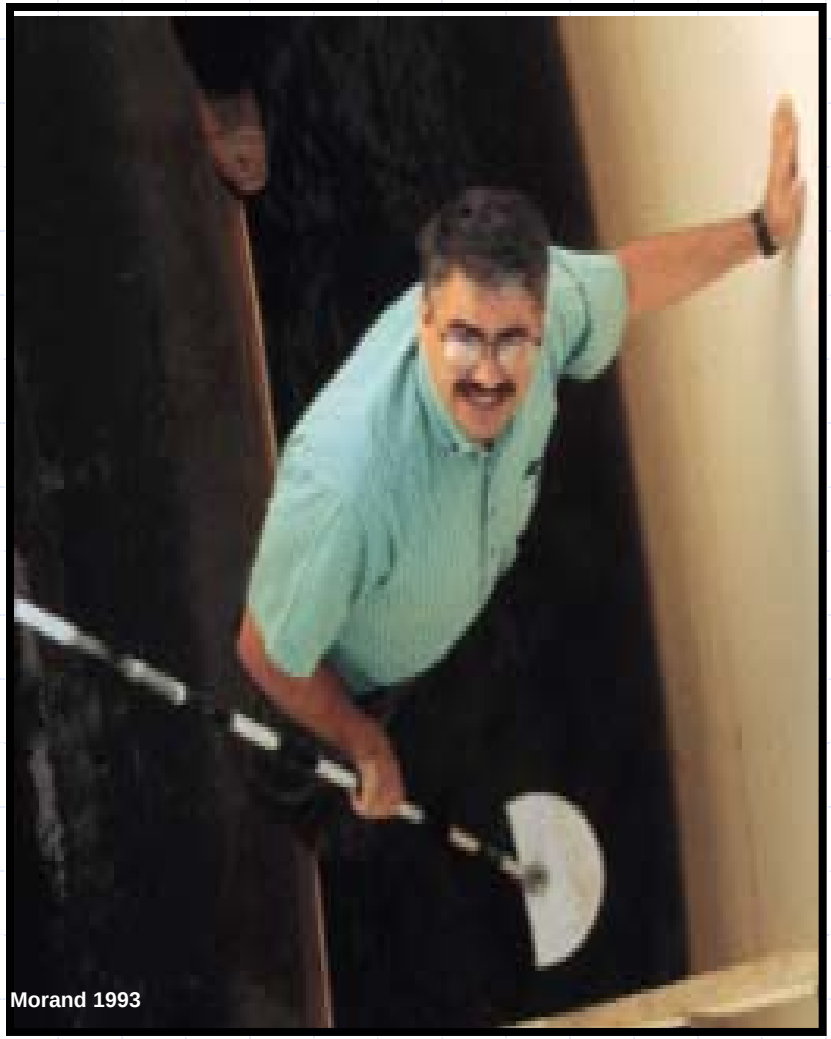


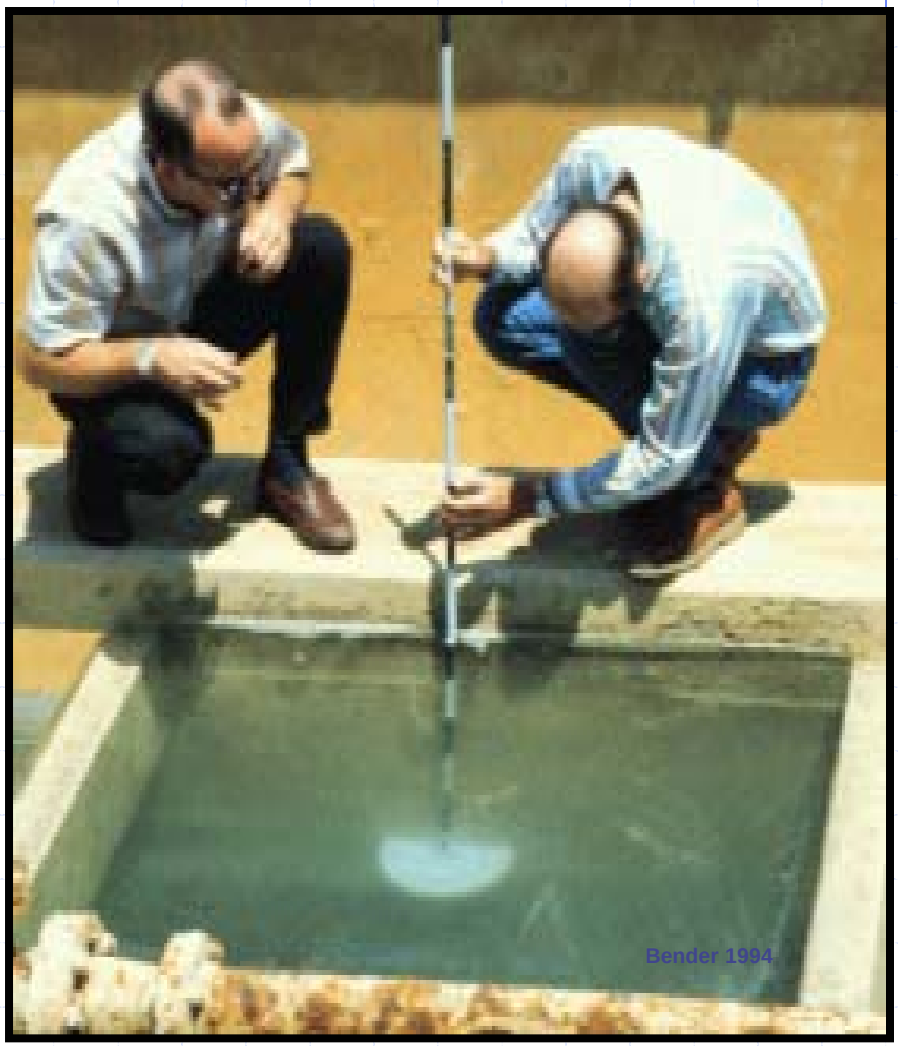
Methodology to Determine Media Expansion

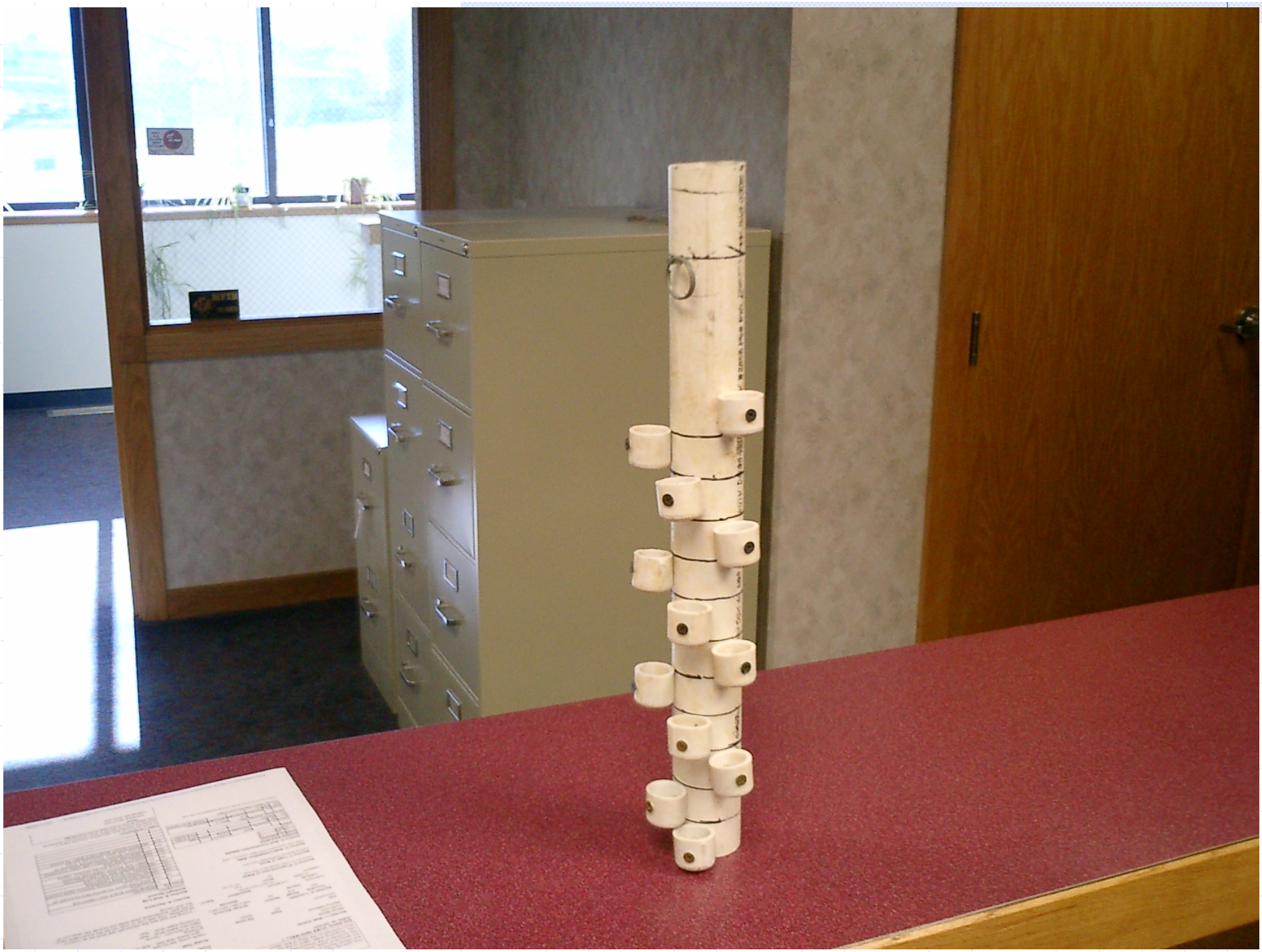
- Document entire backwash
  - Rates
  - Times
- Use Secchi disk or
- Expansion tool
  - to determine top of expanded media

Filter Bed Expansion

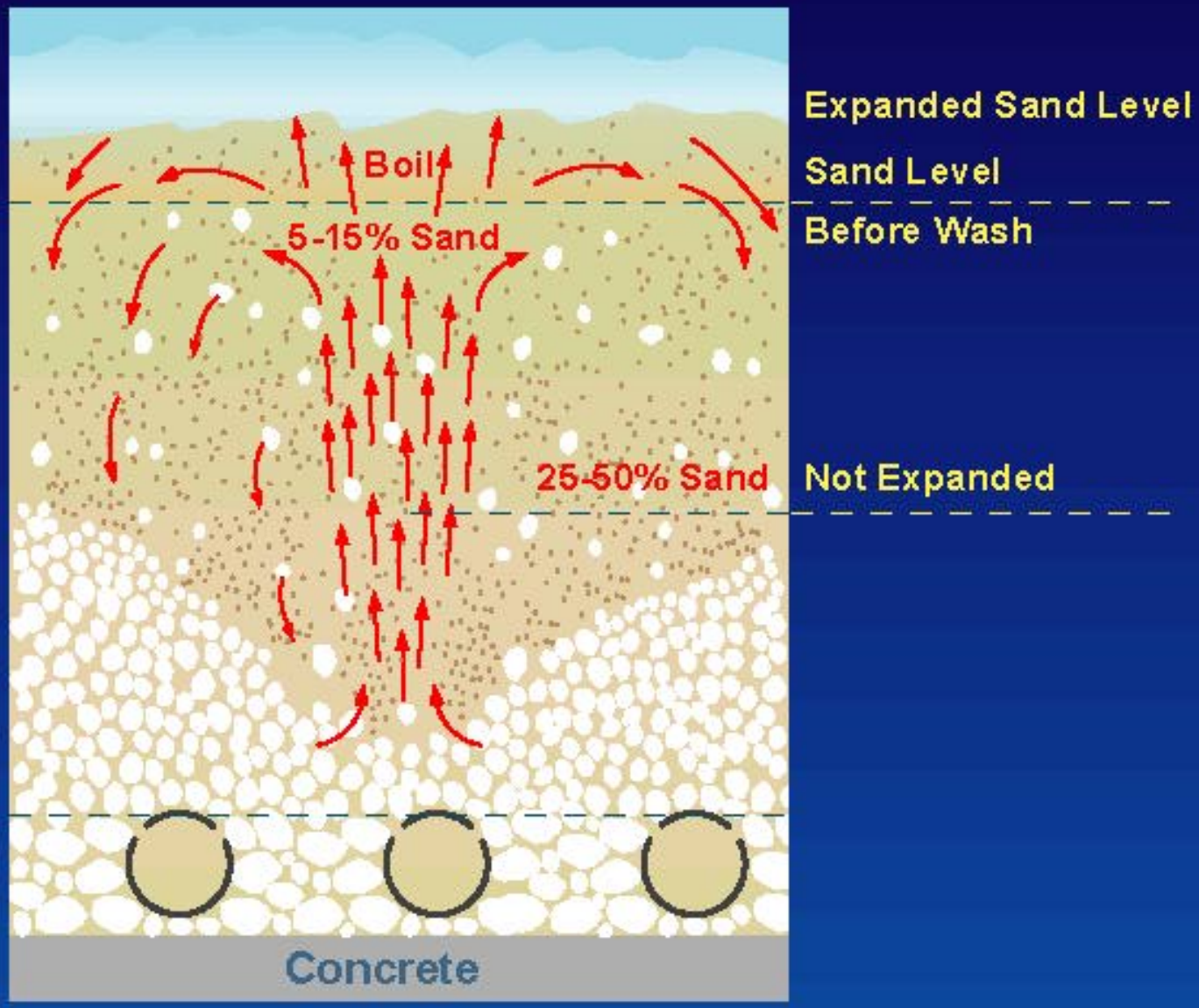



Morand 1993

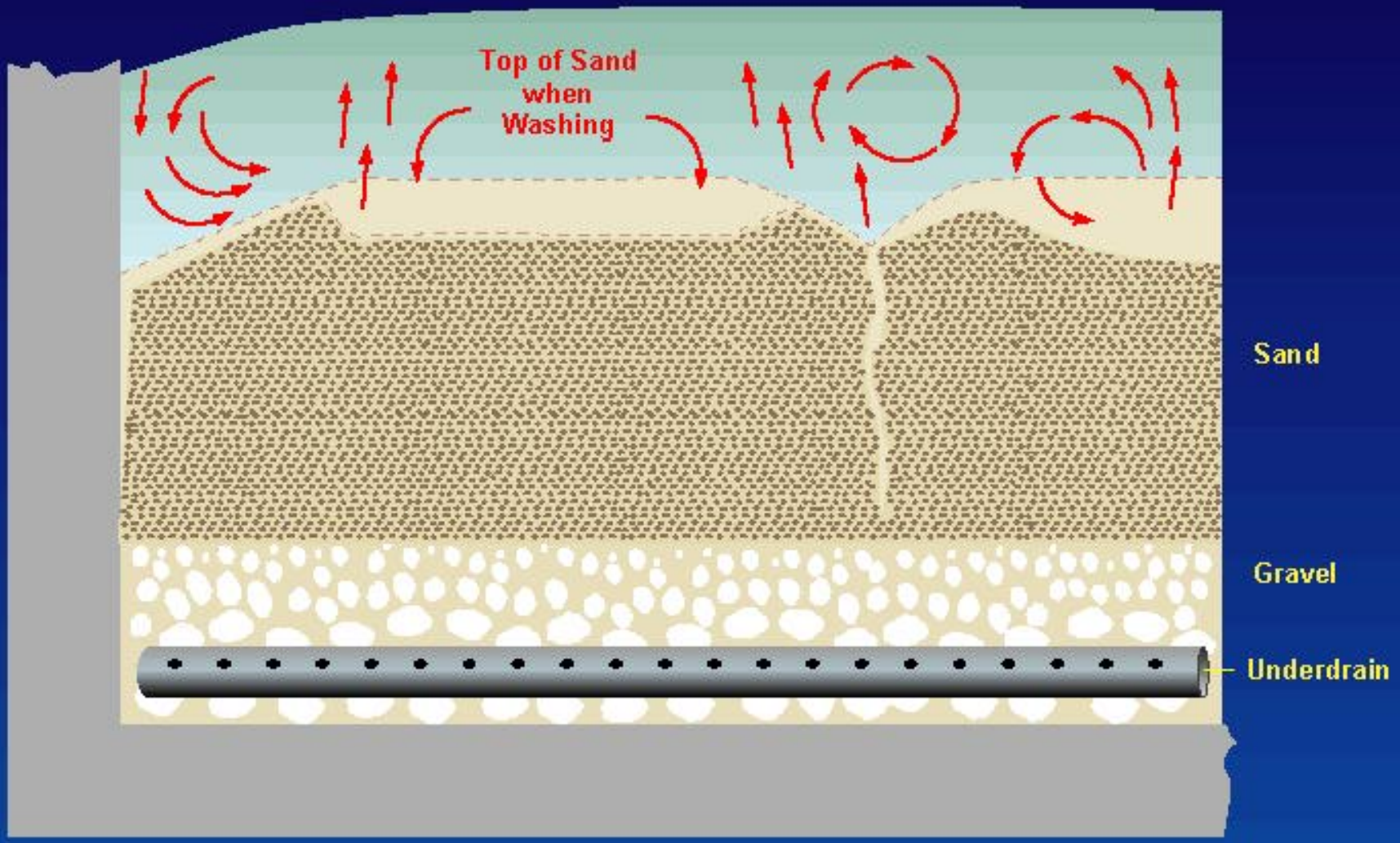

Bender 1994



Sand Boil in a Filter Bed



Clogged Filter Bed



Backwash Boils ???

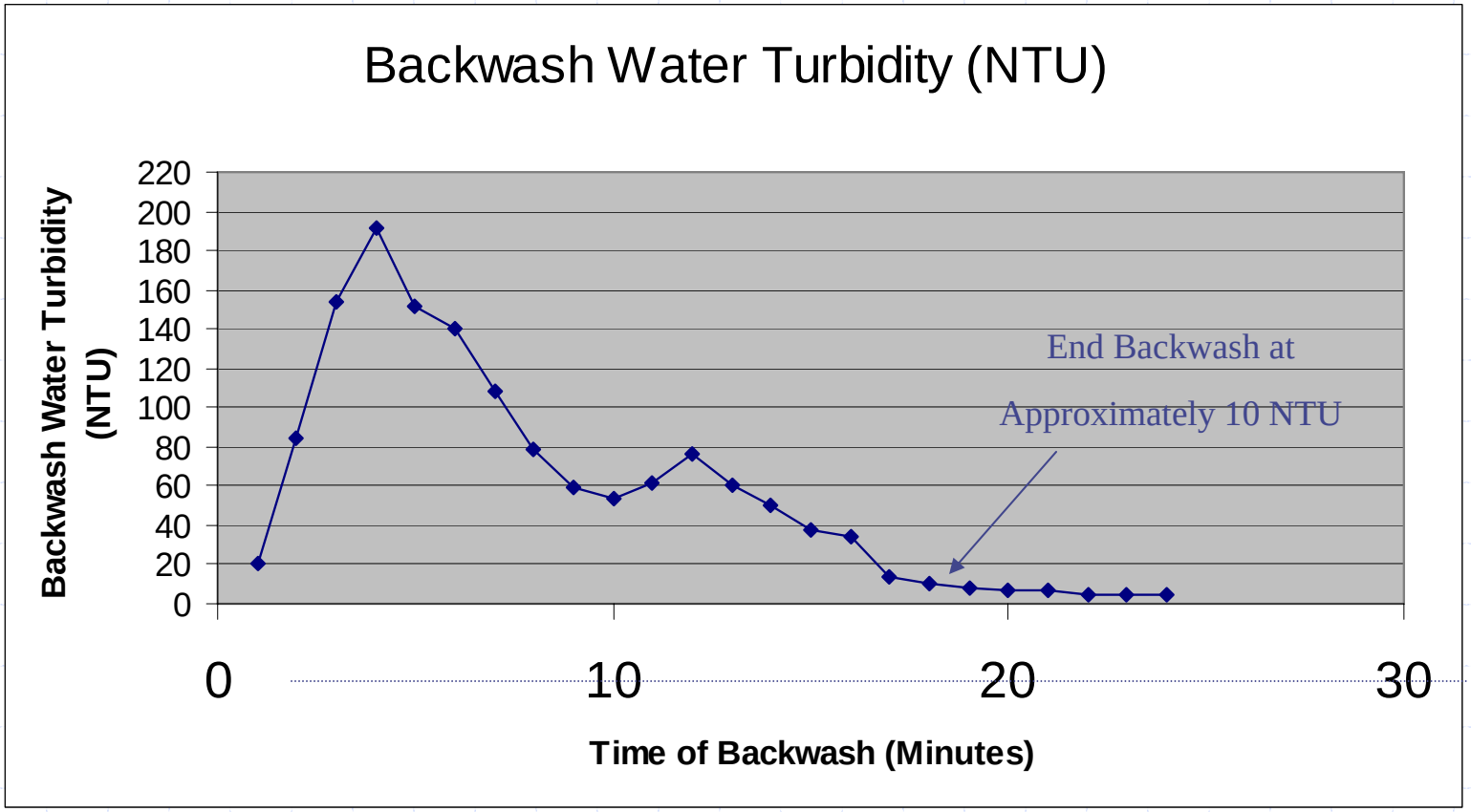
Generally seen in media after water clears up

Spent Backwash Turbidity Profile

- Collect samples of backwash water
  - Every minute

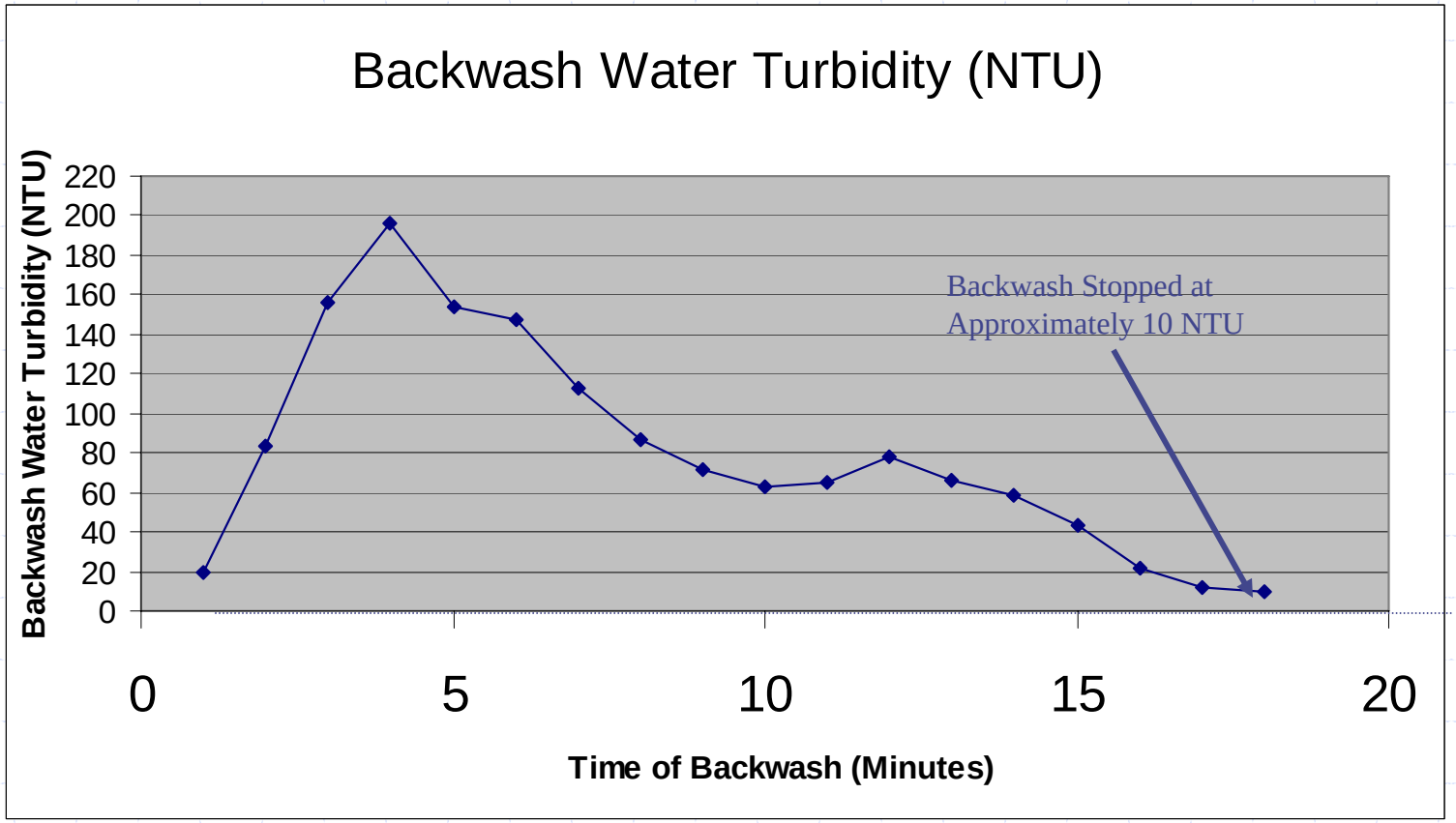
See Form 6

Spent Backwash Turbidity Profile for an Excessive Filter Wash



At About 24 - 25 Minutes

Spent Backwash Turbidity Profile for Acceptable Filter Wash



At About 18 Minutes

At the End of Backwash

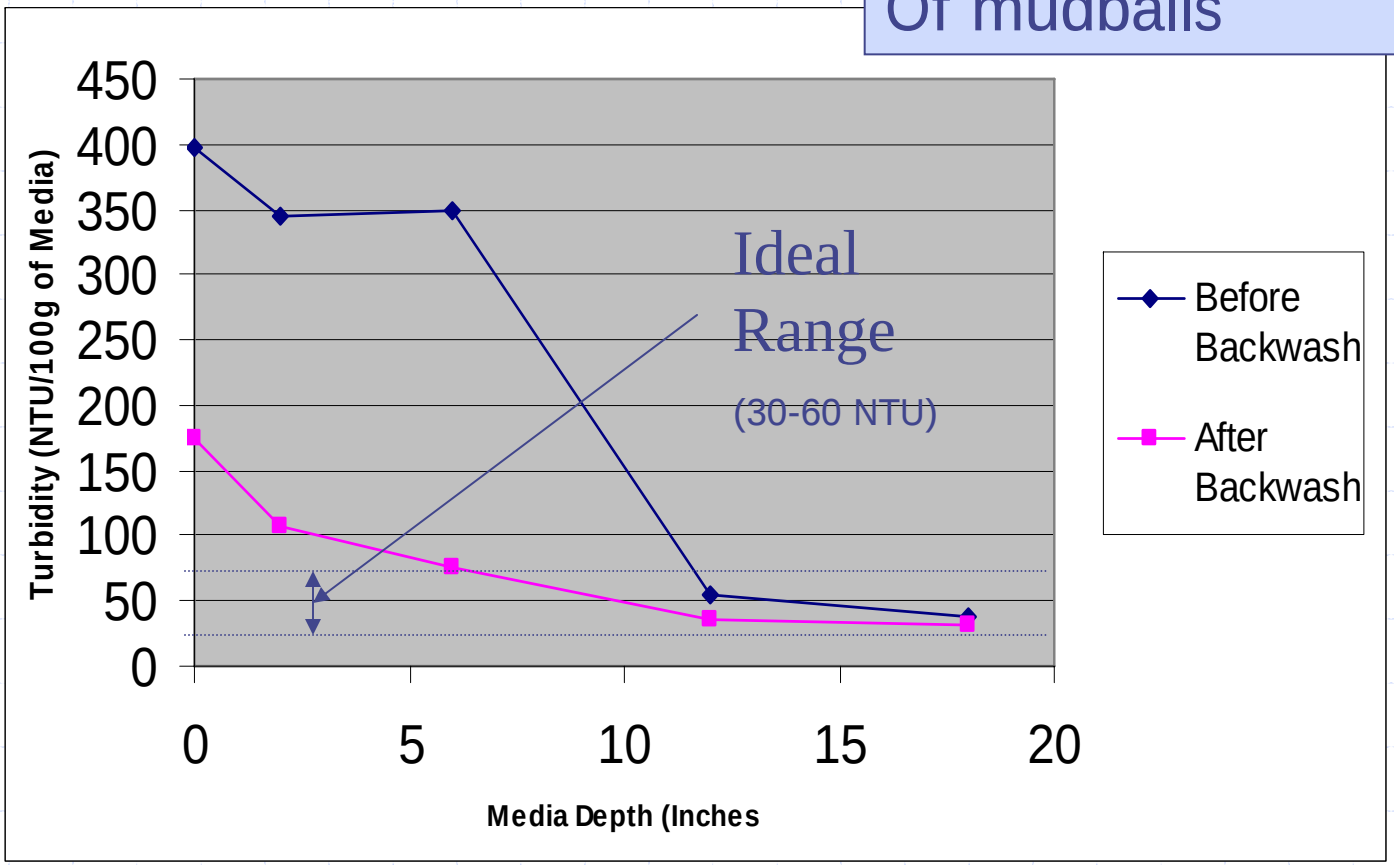
- Drain filter
- Observe condition of filter surface
- Core filter at same locations for part 2 of sludge retention profile
- Collect media for sieve analysis
- Backwash filter again and put into service

Steps of Floc Retention Analysis

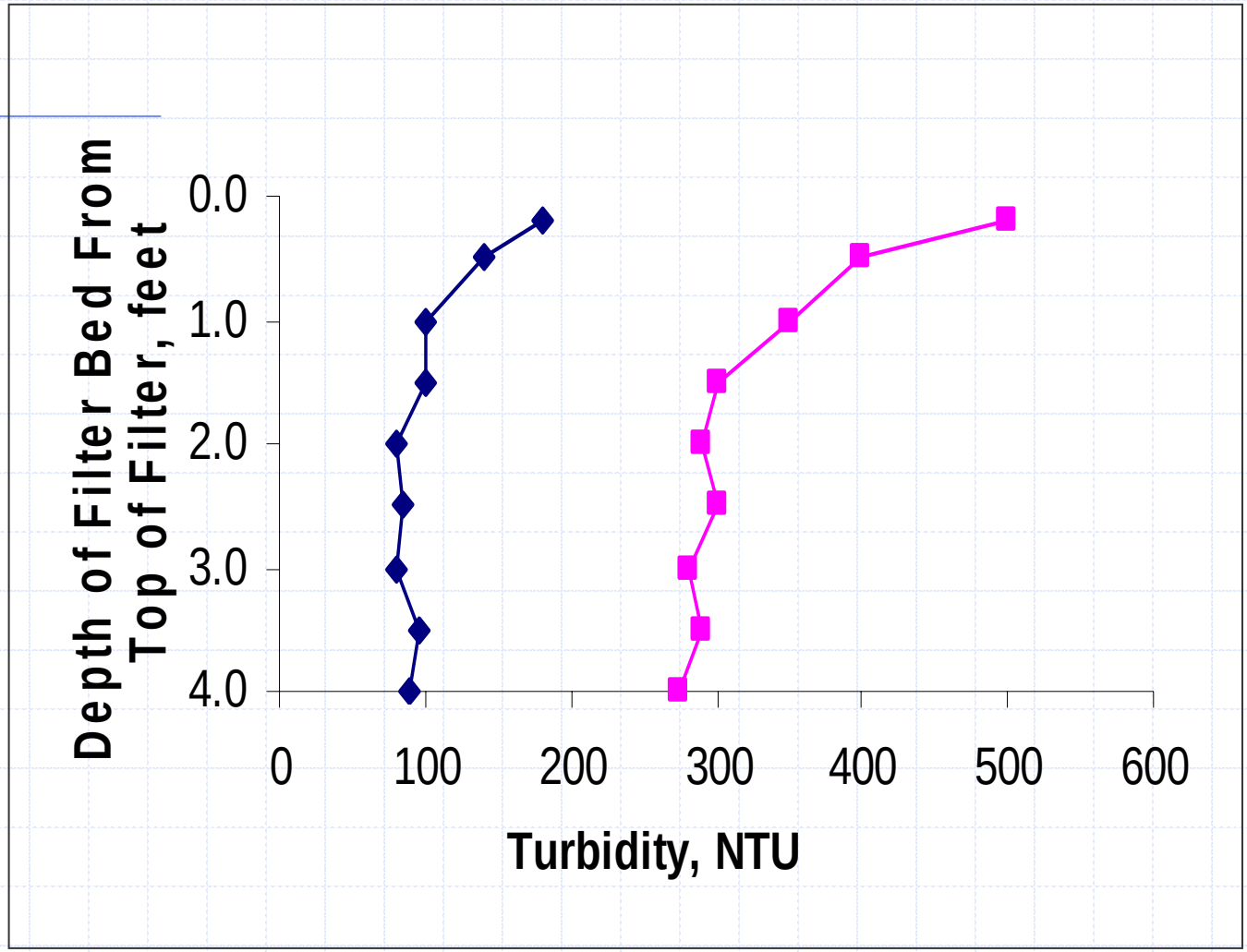
1. Prepare a 50 mL test sample from each bag
2. Place media sample in wide-mouth 500 mL flask
3. Add 100 mL of tap water and shake for 30 seconds
4. Drain water into a 1-L beaker
5. Repeat washing procedure 4 more times
6. Measure and record turbidity of wash water
7. Multiply results by 2
   i. Turbidity for 100 mL media sample
8. Plot the results

Floc Retention Profile

- >102 NTU is dirty
- >300 NTU is indicative Of mudballs



4’ Deep Bed Mono Media Filter



Form 8 - Sludge Retention Profile Evaluation Form

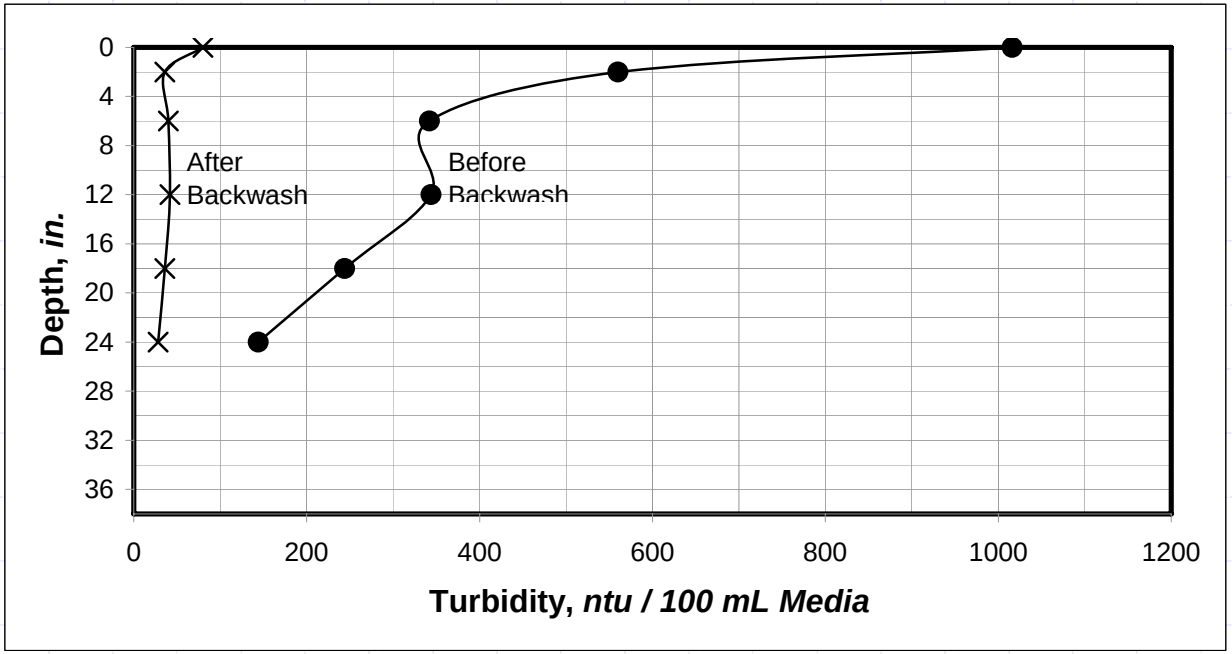
Date: _____ Filter I.D.: _____

Evaluator: _____ Evaluator: _____

Before Backwash		
Level	**ntu**	**ntu x 2**
0-2 in.		1016
2-6 in.		560
6-12 in.		342
12-18 in.		344
18-24 in.		244
24-26.5 in.		144

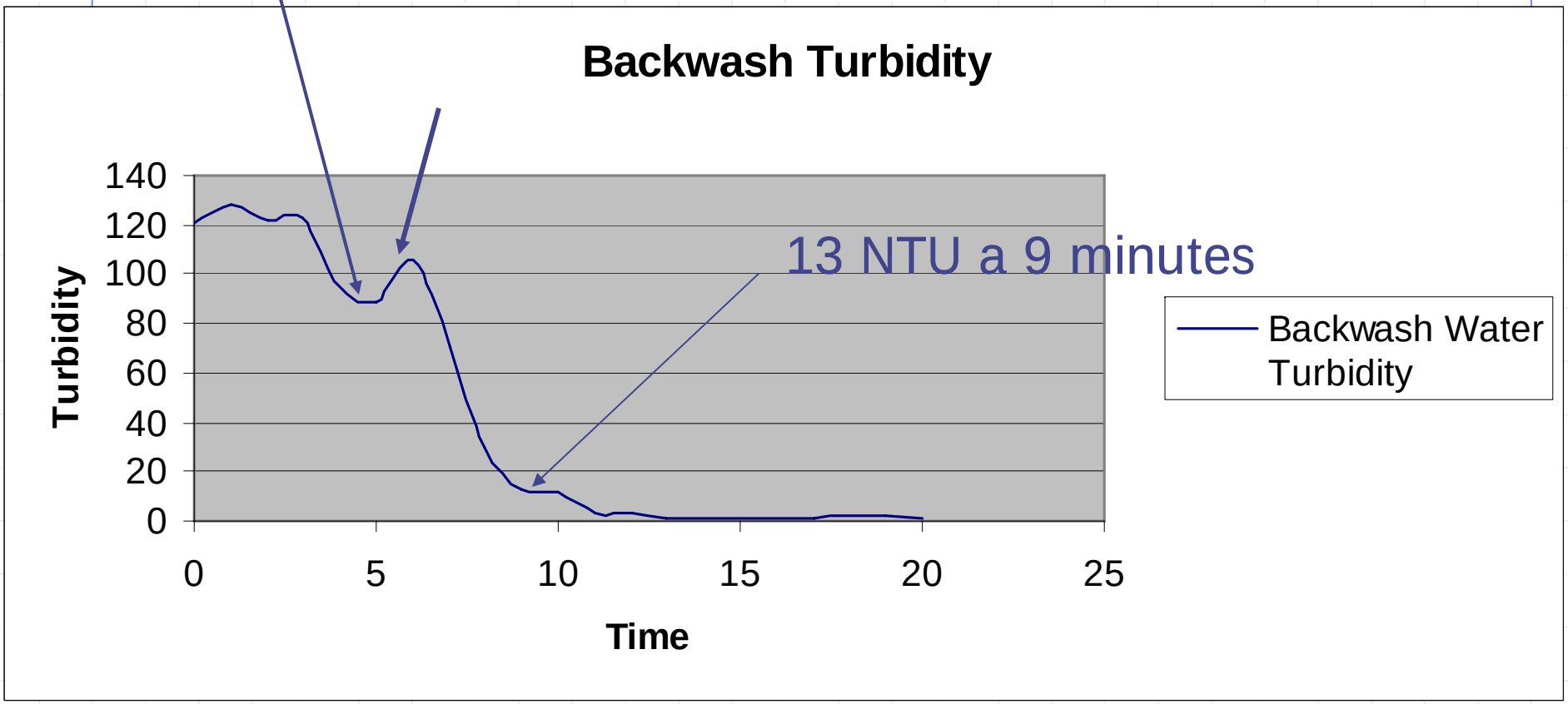
After Backwash		
Level	**ntu**	**ntu x 2**
0-2 in.		80
2-6 in.		36
6-12 in.		40
12-18 in.		42
18-24 in.		36
24-26.5 in.		28

Sludge Retention Graph

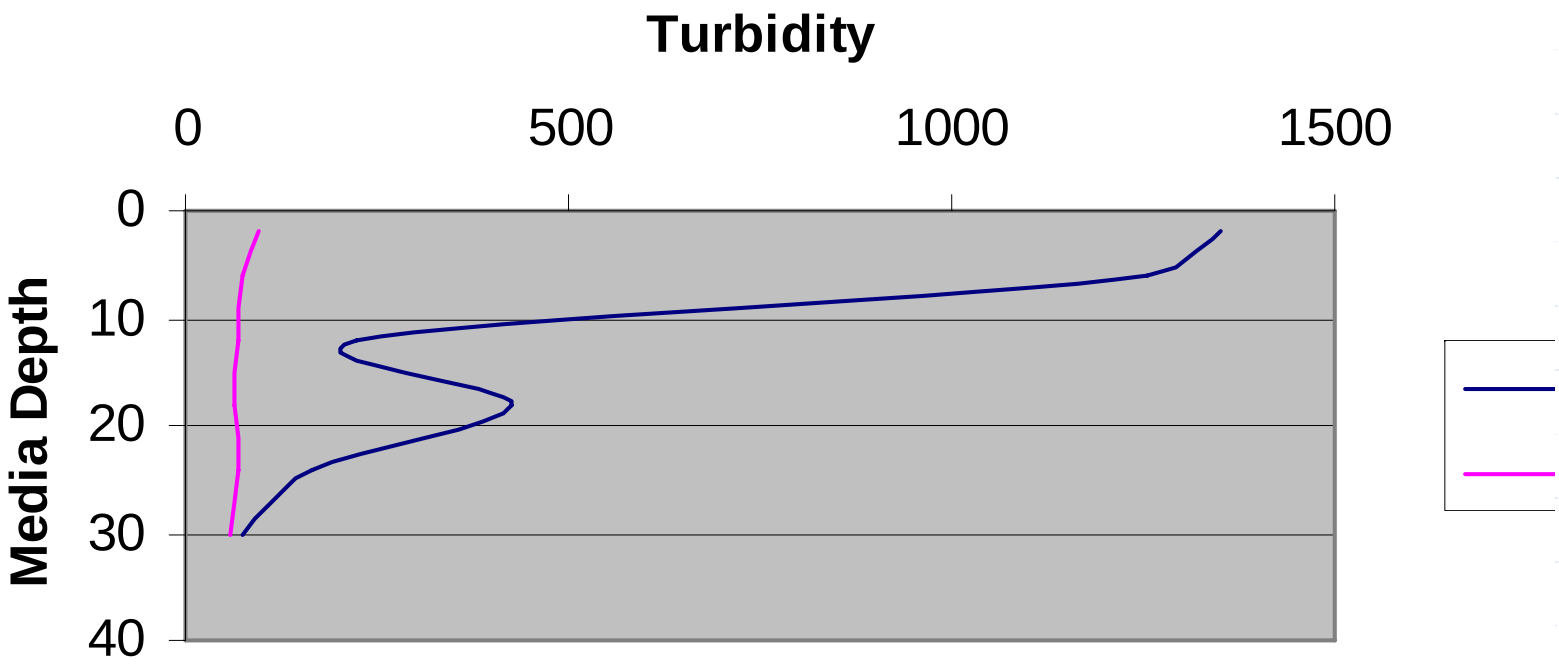


Surface wash at
Low rate until 4.5 min.

High rate at 5.5 minutes;
Normally shuts down at 14 min.
Shuts down at 16 min. this time



Sludge Retention Profile



Sampling Media for Sieve Testing

Sieve Testing

- Representative sample
- Slowly reduce backwash rate (ideally over several minutes)
- Obtain a vertical core
- Separate media
  - Visual separation?
  - Sucrose solution that will float the coal

Kawamura, 2000 Page 655-6

- Three features of media size should be evaluated
  - The upper 2-inches
  - The size profile across the entire depth
  - The interface zone of dual and mixed media filters

Kawamura, 2000

The effective size of the grains in the top 2 inches of the filter should be no smaller than 90% of the effective size for that type of media. If it is < 80% of the E. S. specified, the top 2-inches should be scraped off in order to maintain a reasonable filter run.

e.g. if E.S. of coal = 1.0 mm and measured E.S. of top 2-inches of coal is <0.8 mm

Kawamura, 2000

The size and U.C. of the upper 6-inches of the bed should be nearly equal to that of the lowest 6-inches[1].

If the size of the medium becomes progressively larger toward the bottom of the bed, the chance of early breakthrough is increased

This problem can be minimized by specifying a U.C. of <1.5, preferably 1.4.

1. Paraphrased from Kawamura

Kawamura, 2000

An interface zone over 6-inches will have a smaller void ratio and, therefore, promote floc accumulation in the interface. This problem can be minimized by specifying media with complementary characteristics and providing an auxiliary scouring system.

Slow closing of the backwash valve after fluidization can also help.

Kawamura, 2000

- L/d Ratio
  - L = depth of bed in mm
  - d = E.S. of medium
- Should be:
  - >1,000 for rapid sand and dual media
  - >1,250 for mixed media
  - > 1,250-1,500 for coarse mono media
    - 1.5-2.0 mm E.S.

Additive for each layer of media.

Filtration Checklist

- Conformance with original specifications
- Review backwash procedures
- Observe and analyze initial filter profile
- Minimize hydraulic changes

Filtration Checklist
(Cont.)

- Think of filters as particle storage
- Do annual inspections
- Look for non-performers when multiple filters

Re-starting Dirty Filters

- Resulting shear forces wash out particles
  - Carrollton, GA, 1990
    - Blending masked the problem
- More risky with higher headlosses
  - Colder water

Don't Re-start Dirty Filters!!

Potential Ways to Reduce Risk of Restarting Filters

- Continuous monitoring of IFE at <1 minute intervals
- Filter to waste
- Use headloss as an indicator
  - >50% terminal HL filters <u>should</u> not be re-started
  - >75% <u>MUST</u> not be restarted

Variable Raw Water Turbidity

- Coagulation control strategy
- Change intake level
- Fill treated water reservoirs and shut down
- Buy water and shut down
- Monitor upstream and plan ahead

Variable Raw Water pH

- Adjust pH
- Change coagulants
  - Use one effective over a broader range of pHs

Taste and Odor

- Use
  - PAC, $KMnO_4$, chlorine dioxide or prechlorination
  - Use combinations of the above
  - Cap filters with GAC

High Color/TOC

- Change intake level
- Use enhanced coagulation
  - Lower pH
- Use ozone
- Increase $KMnO_4$
- Use Powdered Activated Carbon

Cold Water

- Impacts coagulation reactions
  - Especially with alum
- More viscous
  - Creates higher headlosses through filters
    - Higher initially and
    - Increases more rapidly
  - Higher shear forces
  - Changes bed expansion during backwash

Cold Water Solutions

- Change from alum to
  - Ferric
  - PACl
- When using alum,
    - Coagulate at higher pH
  - Speed up flocculators
  - Avoid overfeeding
- Check bed expansion during backwash

Iron/Manganese

- Use preoxidation
  - Try potassium permanganate with Mn
- Increase monitoring
  - Raw
  - Finished

Algae

- Change intake depth
- Use copper sulfate
- Change coagulant dose
- Consider lowering pH of coagulation
- Watershed/reservoir control