Design, Operations, and Maintenance of Granular Media Filters

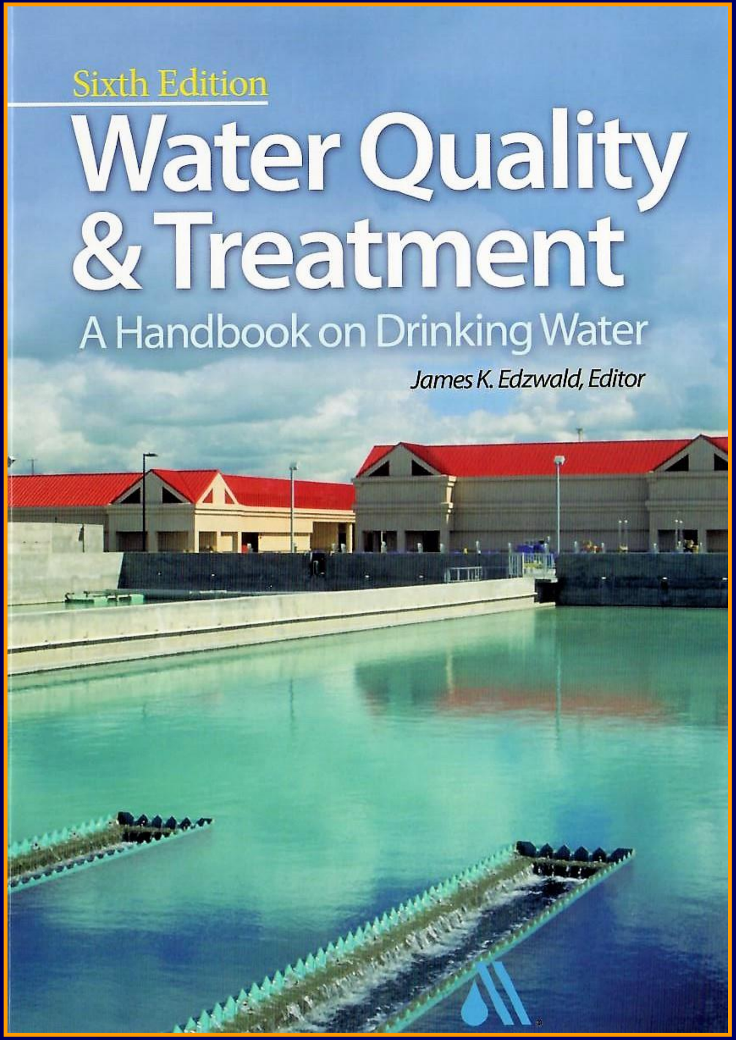
Nick Pizzi

FILTER THEORY

FILTRATION

"It can be argued that particle filtration processes are possibly the most critical component in potable water treatment facilities because of their ability to remove microorganisms, especially pathogens that cause acute health concerns"

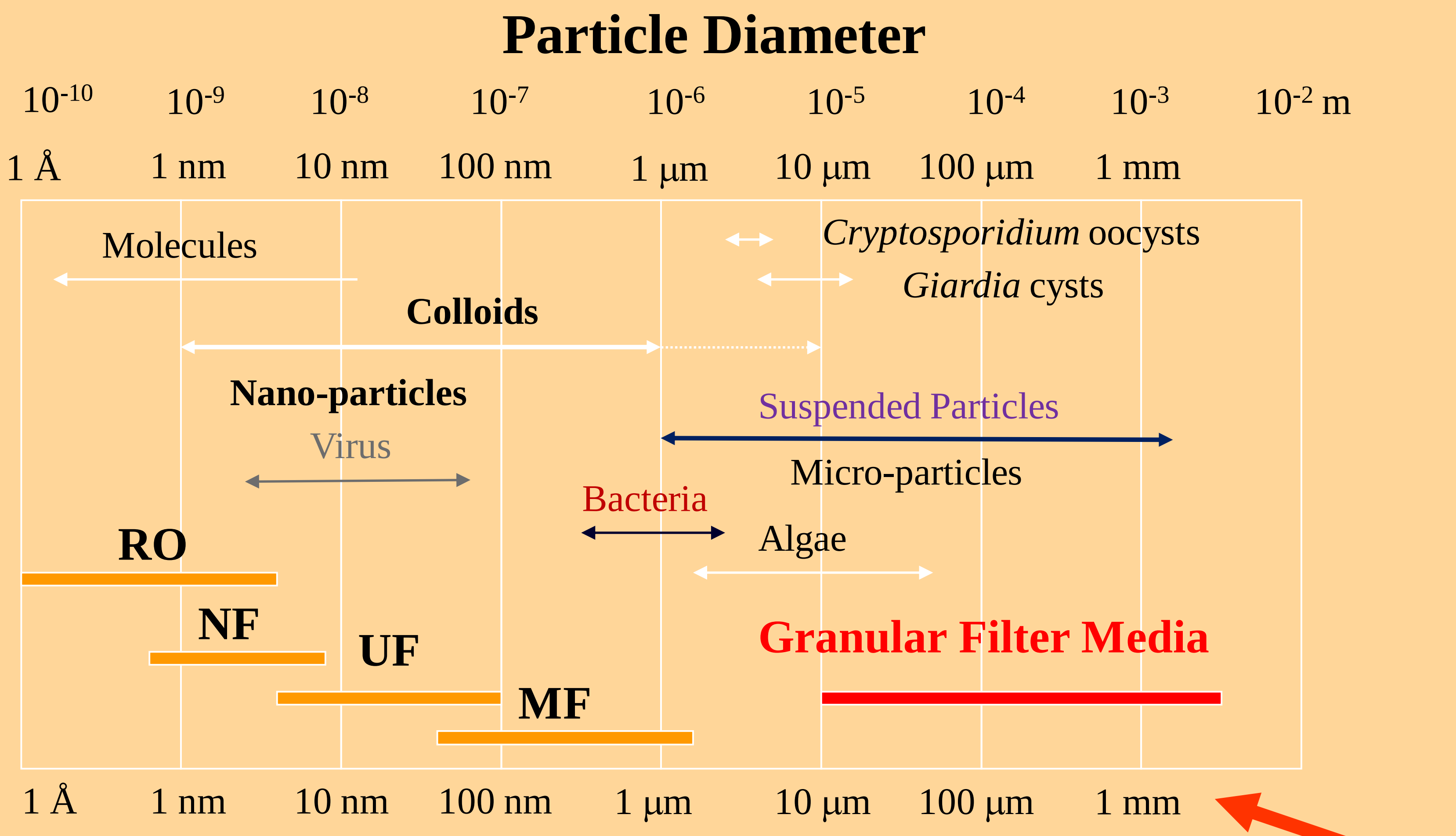
- Water Quality and Treatment, 6th Edition, page 10.4



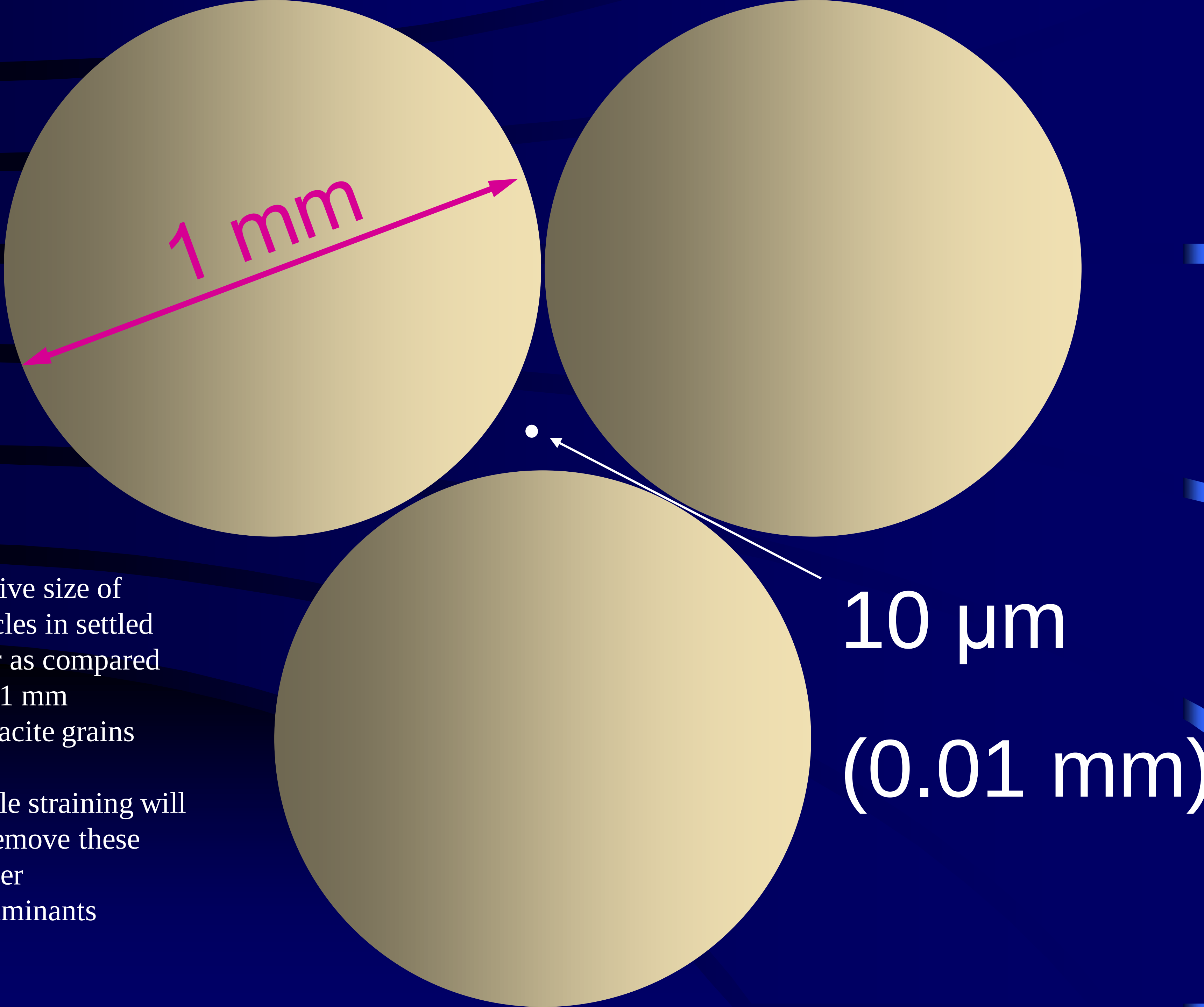
SWTR Filtration Theory

- Filtration is a solids separation process
  - Solids that have escaped the sedimentation process need to be captured
  - There are process goals associated with filtration (Regs)
    - Better to set your own more stringent goals – e.g. Partnership for Safe Water
  - Filtration must remove parasites that otherwise cannot be disinfected
    - As such, filter operations will have a direct effect on the overall health of the community you serve
- Today's topic does not include membrane filtration

Filters and Particle Size



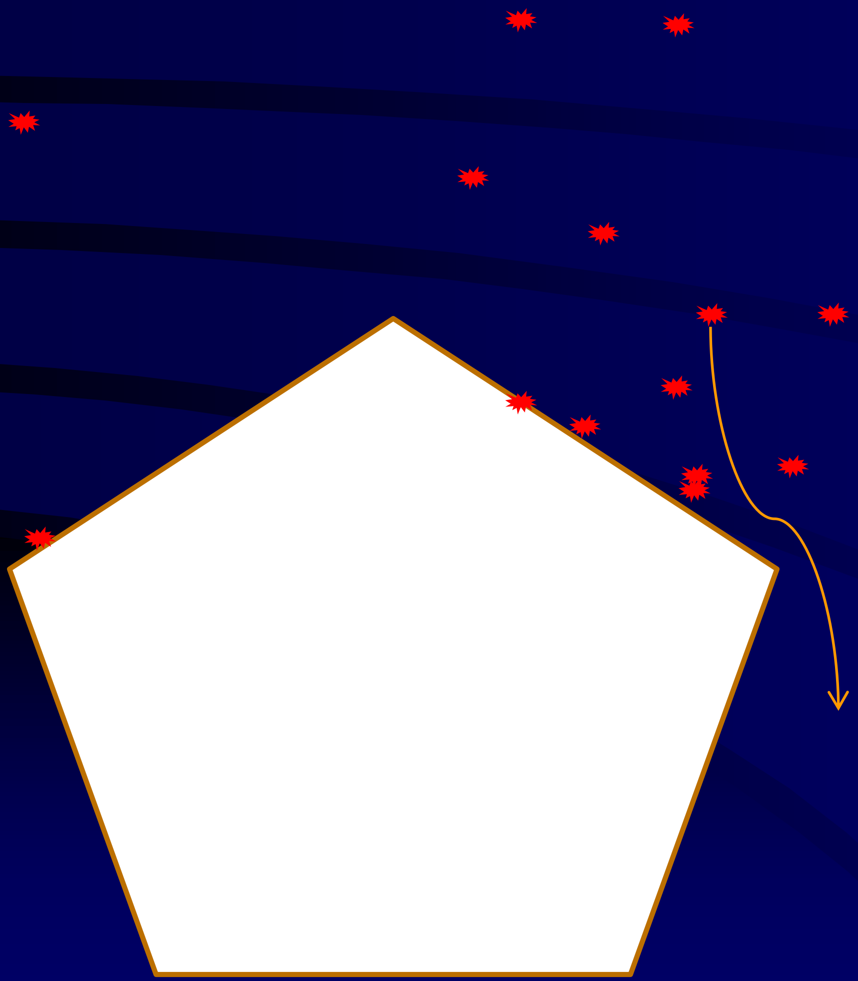
(After Stumm, ES&T, Vol. 11, p. 1066, 1977)



Relative size of particles in settled water as compared to of 1 mm anthracite grains

Simple straining will not remove these smaller contaminants

Filtration theory –transport and attachment



Filtration is "transport and attachment" of floc particles in the water

Both are necessary in order to produce low turbidity

Transporting floc particles across lines of flow is difficult but essential

Particle attachment, detachment, and re-attachment takes place many times

Transport Mechanisms in Filtration

Diagram from AWWA's "Water Quality and Treatment" text showing the basic means by which a particle is transported across streamline flows and thus brought near to the "collector".

Once a transported, the particle can be collected and attached to the filter media.

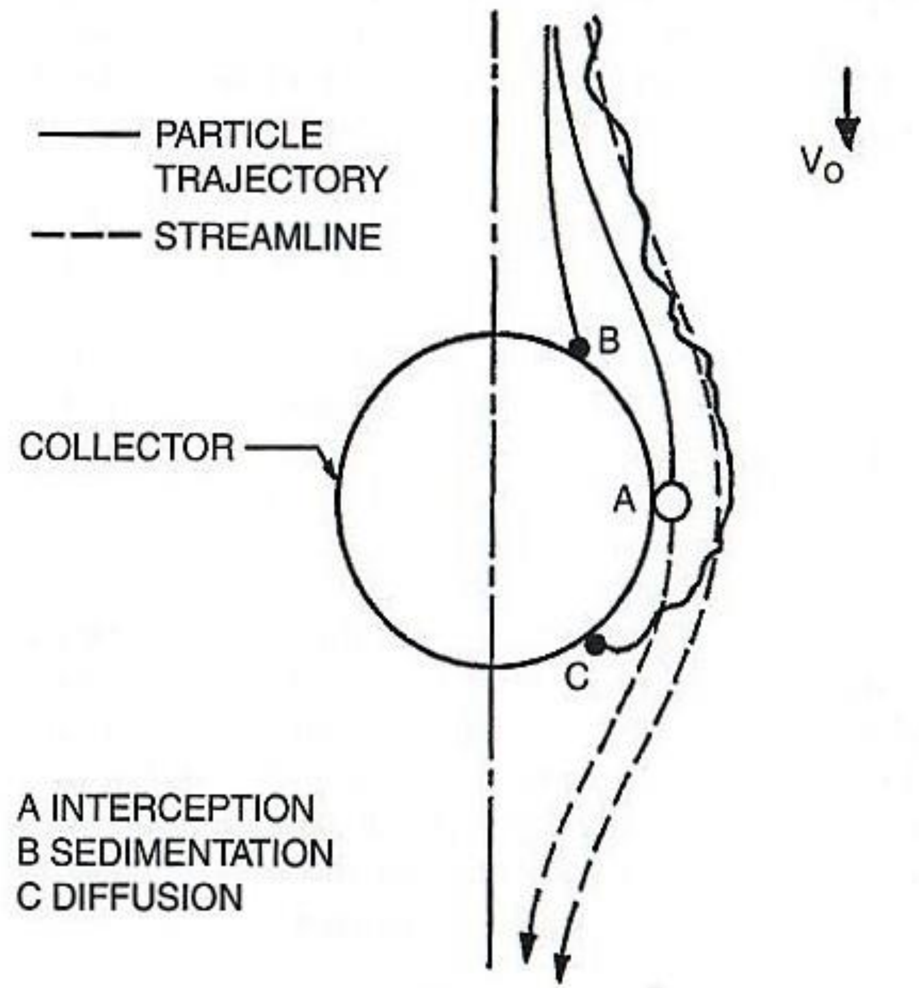
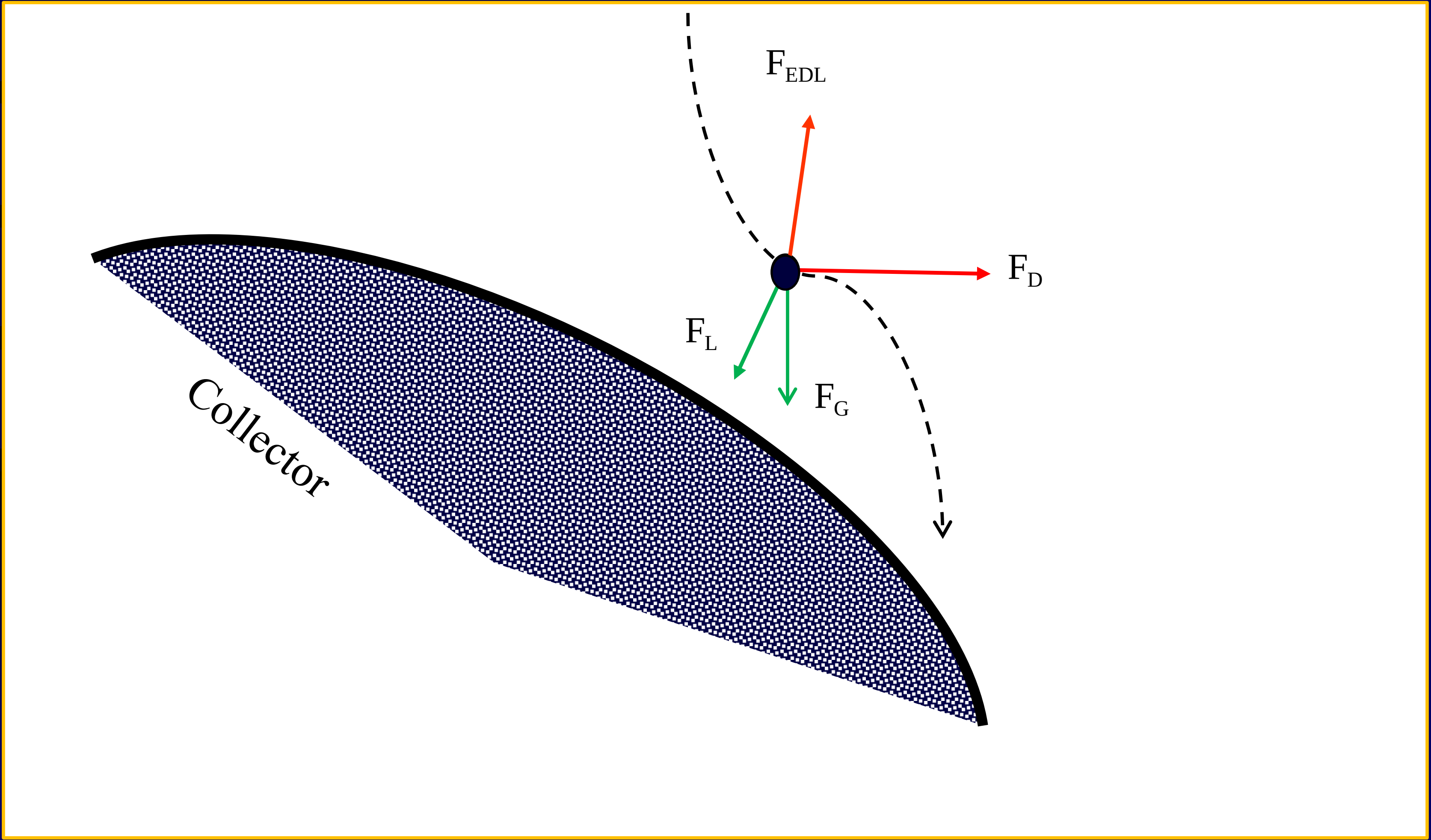


FIGURE 10-10 Basic transport mechanisms in water filtration. (*Source: Reprinted with permission from Yao et al., 1971.*)

Particle Transport and Attachment in Filters



Some Operational Filter Theory

- Think of a filter as a particle storage device – not a particle removal device
- Modern filters are often designed as dual-media units - this provides deeper bed filtration and longer runs
- Good filtration depends on good pretreatment – poorly treated water won't filter well at typical filtration rates
  - Learn to recognize and interpret increases in filter effluent turbidity
  - Your water is only as good as your worst filter online

FILTER REGULATIONS

FOR SURFACE WATER PLANTS

IESWTR Regulations for Filtration

Basis for Regulations:

- The Interim Enhanced Surface Water Treatment Rule (IESWTR) governs the quality of filtered water
- The regulations are written as a means of protecting the consumer against pathogen passage through the filters and on to the customer
- Filters must remove what disinfection cannot destroy
- Pretreatment and filtration for turbidity removal has a Treatment Technique that serves as a surrogate for the removal of pathogens

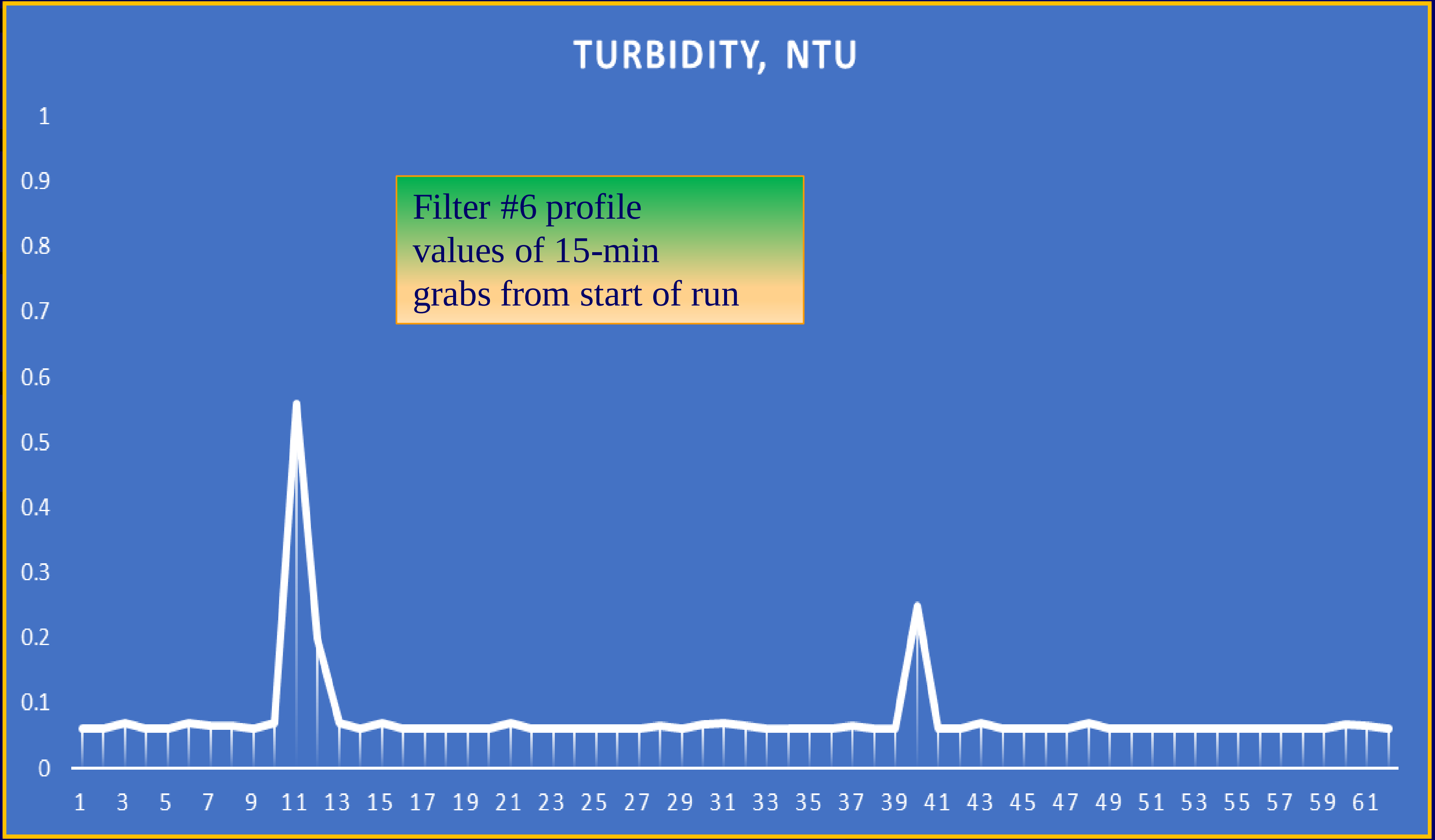
- IESWTR requires that the WTPs meet specific turbidity goals
  - Each filter online must be monitored for turbidity continuously, and turbidity must be recorded at intervals no more than 15 mins apart
    - Individual filter effluent (IFE) turbidity must be less than 1.0 ntu in first 4 hours of run, then less than 0.5 ntu for remainder*
  - The combined filter effluent (CFE) must be less than 0.3 ntu 95% of time, and never over one ntu

*failure here triggers exceptions reporting to your local regulatory agency

IESWTR Exceptions Reporting

- Exceptions Reporting for problem filters…
  - If an individual filter has turbidity levels > 1.0 NTU at any time in each of three consecutive months, the PWS shall conduct a filter self-assessment
  - If an individual filter has turbidity levels > 2.0 NTU at any time in each of two consecutive months, the PWS shall arrange a CPE
  - Filter profile should be created from the data to observe "spiking" – keep for three years
    - Frequency, magnitude, and duration are key

Example Filter Profile



Comprehensive Performance Evaluation (CPE)

- If an exception is noted, a thorough review and analysis of a filter's performance based capabilities may be required
- Can include an assessment of the hydraulic loading conditions, condition and placement of media, description of backwash practices, inspection of support media, and an assessment of the rate-of-flow controllers and valves.
- *All this may be required if you have filter exceptions*

FILTER DESIGN

A Word About Design

- There has been a lot of newer technology developed for filtration systems in the past 15 years or so
  - If it is time that your plant renews its filters, don't settle for the old technology
- As operators, we should expect our design engineers to provide us with the right type and correct construction of our filters
- Once done though, we operators must understand that any unacceptable filter turbidities are our fault

Dual Media Filtration Terms

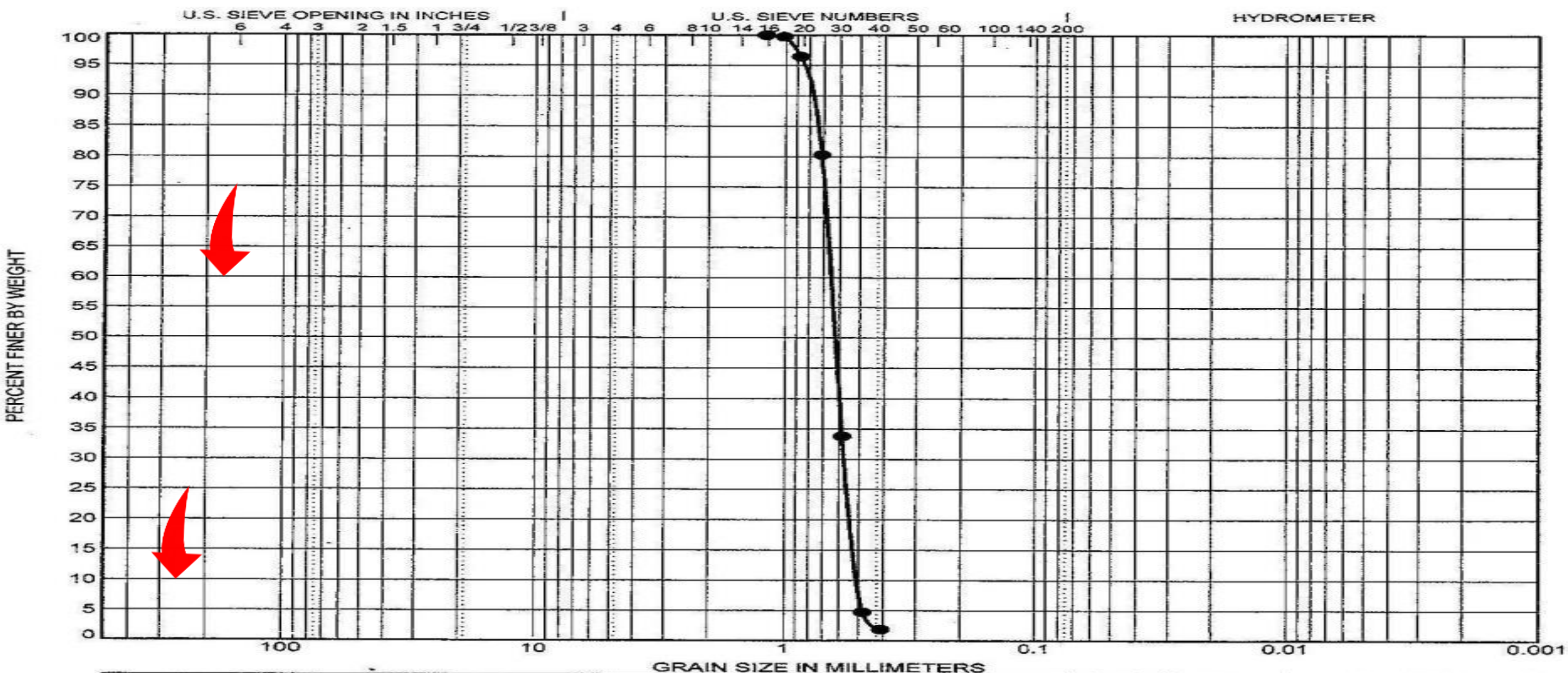
- Effective Size or ES
  - The 10% size - this is what sits at top of each layer in the filter
- Uniformity Coefficient or UC – preferably not >1.3
  - This is what characterizes the types of filtering holes you get (60% size ÷ ES)
- Intermix ratio
  - The D_{90} coal size divided by the D_{10} sand size – usually around 3
- L/D_e ratio
  - Depth of bed (L) divided by the ES (D_{10}) – should be greater than 1,000
- Bed expansion
  - Happens when backwashing - This is what determines how well the bed gets cleaned
- Solids Retention
  - The amount of material left in the bed - offers proof that backwashing is working well or not
- Unit Filter Run Volume (UFRV)
  - Total number of gallons filtered divided by the square foot area of the filter – usually needs to be >5,000

Sieve Analysis

- ES, UC, and other sizes are determined by Sieve Analysis
- Each of these stacked pans has a sieve of decreasing size from top to bottom

Typical grain size distribution report from sieve analysis

GRAIN SIZE DISTRIBUTION TEST REPORT



% +3"	%Gravel	%Sand	%Silt	%Clay
0.0	0.0			

LL	PI	D90	D60	D50	D30	D15	D10	Cc	Cu
		0.806	0.654	0.627	0.571	0.517	0.5	0.99	1.31

REMARKS	USCS	AASHTO

PROJECT NUMBER A11216

PROJECT NAME LAKE COUNTY WATER TREATMENT PLANT

LOCATION Tank #4

DATE 12/13/11

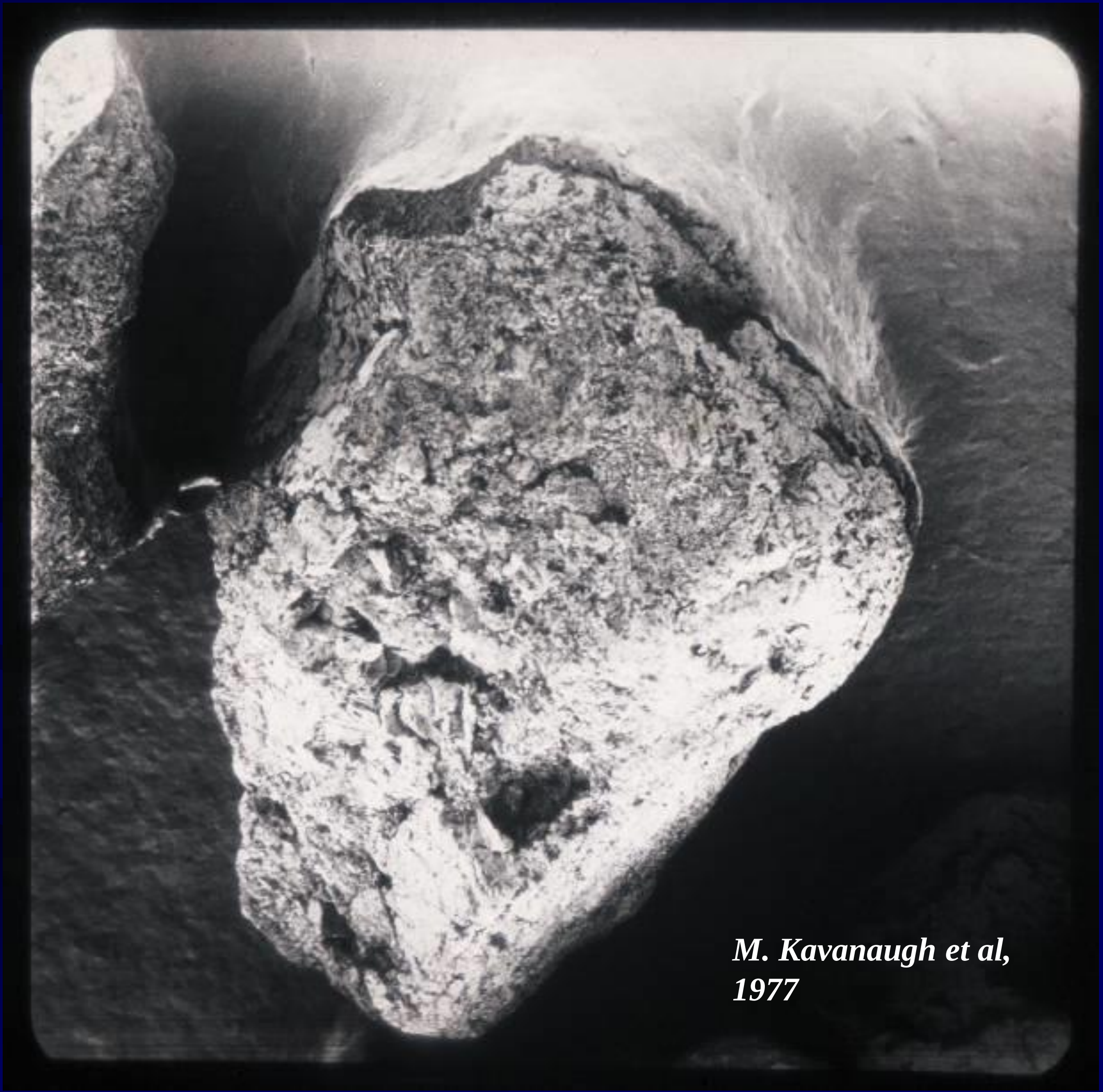
MATERIAL DESCRIPTION

Filter Sand

Solar Testing Laboratories, Inc.
1125 Valley Belt Road
Brooklyn Heights, Ohio 44131
Telephone: 216-741-7007
Fax. 216-741-7011

CURVE # _____

Scanning Electron Micrograph Silica Sand 0.5 mm



Scanning Electron Micrograph Anthracite Filter Media, 1 mm

M. Kavanaugh et al, 1977

CASE STUDY OF PILOTING AND DESIGN

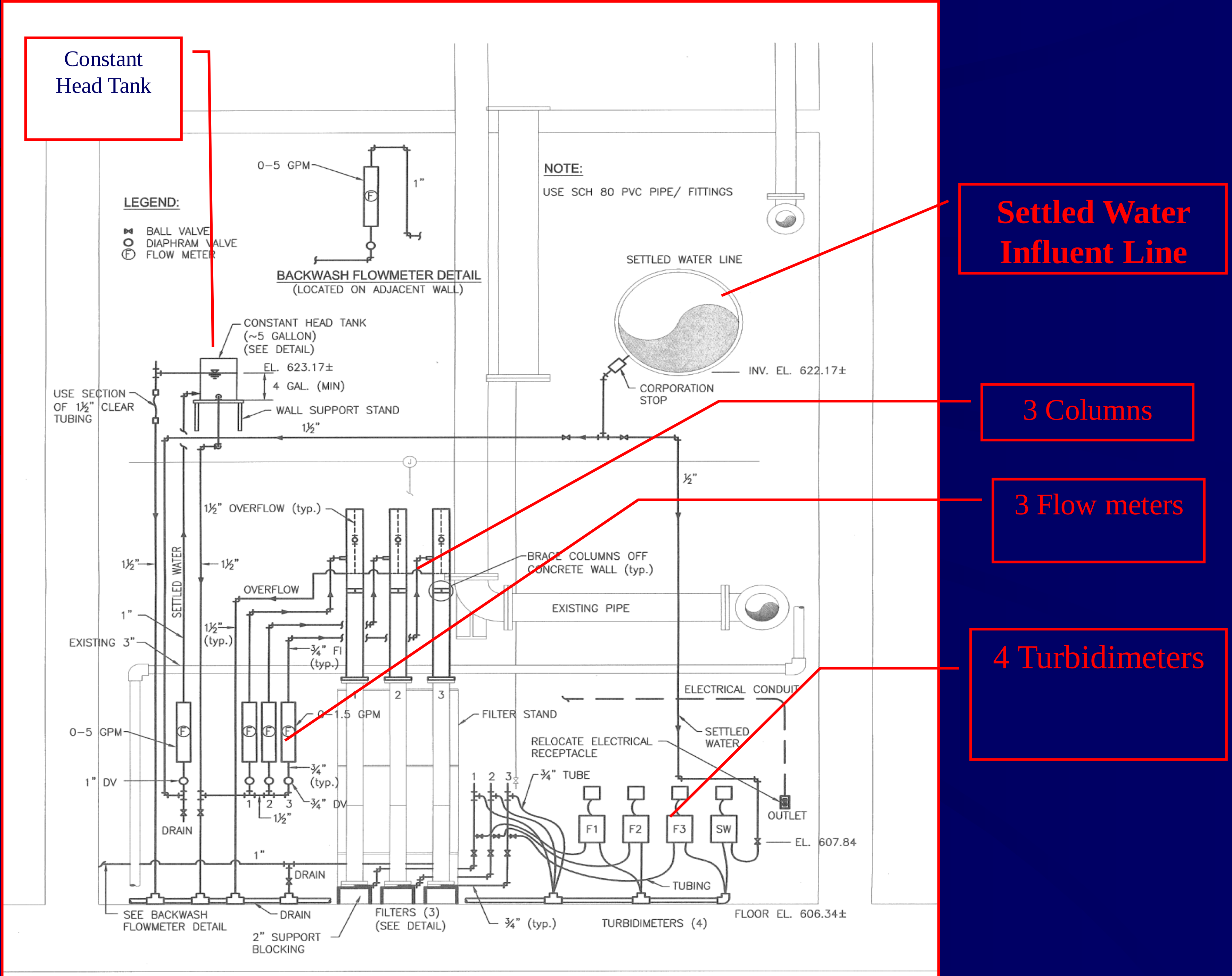
Case study - A brief graphical review of a pilot facility leading to design

By reviewing this process, we can follow the way that design engineers use pilot filters to achieve regulatory approval

This pilot project provided data that was subsequently used to design and install filters at several Lake Erie WTPs

Filter reconfiguration considerations

- Lake County, Ohio Utilities asked Ohio EPA to approve new configuration for Aquarius WTP
  - The old filter system theoretically had enough capacity, but …
  - The design was 30 year old technology
    - They didn't want to simply repair old design
      - Lots of available improvements on the market since then
  - The existing filters had lost media
  - More head space was needed
- Lake County had already successfully piloted the new configuration



Constant Head Tank
Settled Water Influent Line
3 Columns
3 Flow meters
4 Turbidimeters
0-5 GPM
1"
LEGEND:
BALL VALVE
DIAPHRAM VALVE
FLOW METER
BACKWASH FLOWMETER DETAIL
(LOCATED ON ADJACENT WALL)
NOTE:
USE SCH 80 PVC PIPE/ FITTINGS
SETTLED WATER LINE
INV. EL. 622.17±
CORPORATION STOP
CONSTANT HEAD TANK (~5 GALLON) (SEE DETAIL)
EL. 623.17±
4 GAL. (MIN)
WALL SUPPORT STAND
USE SECTION OF 1½" CLEAR TUBING
1½"
½"
1½" OVERFLOW (typ.)
BRACE COLUMNS OFF CONCRETE WALL (typ.)
EXISTING PIPE
SETTLED WATER
OVERFLOW
1½" (typ.)
¾" FI (typ.)
EXISTING 3"
0-1.5 GPM
FILTER STAND
ELECTRICAL CONDUIT
RELOCATE ELECTRICAL RECEPTACLE
SETTLED WATER
¾" TUBE
¾" (typ.)
¾" DV
1" DV
DRAIN
OUTLET
F1
F2
F3
SW
EL. 607.84
TUBING
SEE BACKWASH FLOWMETER DETAIL
2" SUPPORT BLOCKING
FILTERS (3) (SEE DETAIL)
¾" (typ.)
TURBIDIMETERS (4)
FLOOR EL. 606.34±

Regulatory Approval Criteria

- Requirements:
  - Ohio EPA wanted to see the filter design that could best produce
    - At least 5,000 UFRV
    - Could meet the IFE requirements of the IESWTR
    - Could operate at acceptable head loss
  - Design Engineer wanted to have:
    - L/De ratio greater than 1,000, and Intermix ratio of about 3
    - Low UC and the capability to operate at 5.7 gpm/ft^2
  - Design chosen and subsequently approved:
    - 24 inches of 1.1 mm anthracite, UC of 1.3
    - 12 inches of 0.5 mm sand, UC of 1.3
    - Low profile filter bottoms (IMS caps)

Wide range of densities of old filter media at Aquarius

- **Anthracite - 1.4**
- **Silica sand - 2.6**
- **Ilmenite - 4.72**

Aquarius Filter reconfiguration

- Old filters

- 24 inches 1 mm ES anthracite
  - UC – 1.5
- 12 inches 0.5 mm ES sand
  - UC = 1.5
- 3 inches 0.35 mm ES ilmenite
- 6 inches gravel on top of 12 inch Leopold Clay Tile underdrains
- Head space for washing: 31 inches
- Ohio EPA loading rate : 3 gpm/ft^2

- New filters

- 24 inches of 1.1 mm ES anthracite
  - UC = 1.24
- 12 inches 0.5 mm ES sand
  - UC = 1.3
- 8 inch IMS cap underdrains
- Ohio EPA loading rate: 5.7 gpm/ft^2
  - Depth filtration
- More head space for washing
  - 44 inches
  - Helps with media loss issues

Total space taken by media and support system :

57 inches **44 inches**

Assembled dual arm sweeps

prior to media placement

- Upper washer arm located about an inch above the anthracite
- Lower wash arm located in the middle of the interface
- Must fluidize bed before starting washer for both arms to work
- Top arm will rotate prior to bottom arm starts to rotate

Filter media characteristics

new filter installation at Aquarius

Sand

- l/D_e ratio*
  - (12 inches of sand X 25.4 mm/inch) ÷ 0.5 mm
    - ≈ 610

Anthracite

- l/D_e ratio*
  - (24 inches of anthracite X 25.4 mm/inch) ÷ 1.1 mm
    - ≈ 554

Total l/D_e ratio = 610 + 554 = 1,164

*l/D_e ratio = depth of the bed in mm ÷ ES

Values are additive, and > 1,000 total is desirable

Intermix Ratio

D_{90} coal size to D_{10} sand size =

1.669 / 0.514 = 3.24

Note: it was specified as 3 to 3.5

FILTER O&M AND INSPECTION

The Key to Good Filter Operational Techniques

- Filter startup
  - Bring filter rate up slowly
  - Don’t start a dirty filter
- Filter run
  - Load the filter effectively
  - Avoid or minimize hydraulic shock
  - Minimize length of run
  - Use filter aid if applied water is poor
- Filter backwash
  - Choose a temperature dependent wash rate
  - Avoid washes that are too short or long
  - Rest the filter before returning to service

Rate of Flow Control

- The ability to control the flow rate through a filter is important
  - Headloss buildup can allow unequal loading of filters
  - This can cause excessive filter rates in some of the filters, and unacceptably low rates in others
- A mechanism to control the rate is usually employed (rate of flow control valve)
  - Older designs that allowed “declining rate” filtration have built-in problems as stated above

Filter run length/times

- Resist the urge to run your filters for long periods
- The filter run time – or length – should be based on scientific and reproducible goals that are set by the plant staff and agreed upon by all operations staff
  - It should be based on water quality considerations, and then on equipment limitations, and then on operator convenience or accommodations
  - How much risk are you willing to take on?
  - An example goal might be:
    - The filter will be operated until the effluent turbidity reaches 0.1 ntu in two consecutive five-minute readings, or
    - Head loss reaches 4 feet or 48 inches, or
    - The filter has produced at least 7,500 UFRV's

Using Filter Aid Polymer

Filter aid can be added to the settled water on the way to filtration

When using a filter aid polymer:

- Dilute neat polymer to make a 1% solution
- Limit the feed time
- When finished, run some clean water through the feed pump otherwise the polymer will gum it up
- Don't try to store diluted polymer as it will break down

Flow rate of water to be treated, gpm	Feed rate of 1% polymer, mLs/min
1,400	26.6
1,600	30.4
1,800	34.2
2,000	38.0
2,200	41.8
2,400	45.6
2,600	49.4

Table shows the amount of 1% polymer needed to achieve a dosage of 0.05 mg/L in the flow of water going over to the filters

Filter Backwashing

- Filters cannot produce good water indefinitely
  - They will experience increased head-loss as they get dirtier
  - Floc particles will begin to shear from the collectors and find their way into the clear well
- Filters must be taken off-line and backwashed
  - Previously stored particles must be washed away in order to get the bed clean enough for production
  - Backwashing requires a "bed expansion rate" which allows the collectors to scrub themselves clean
    - Is calculated as percent expansion of the entire bed
    - It is important to achieve this percent expansion by using a temperature-dependent flow rate
  - Each of the two layers are cleaned separately, so two rates should be achieved

Backwash Rate Temp Correction

- Assume a % expansion is correct for you – then determine the seasonal rate which achieves that %
- Bed Expansion Measurement Rate Requirement

Temp (Deg C)	Multiply 25 Deg value by
30	1.09
25	1.00
20	0.91
15	0.83
10	0.75
5	0.68

Source: Opflow – Sanks, R.L., quoted by MacPhee and Becker

FILTER INSPECTIONS

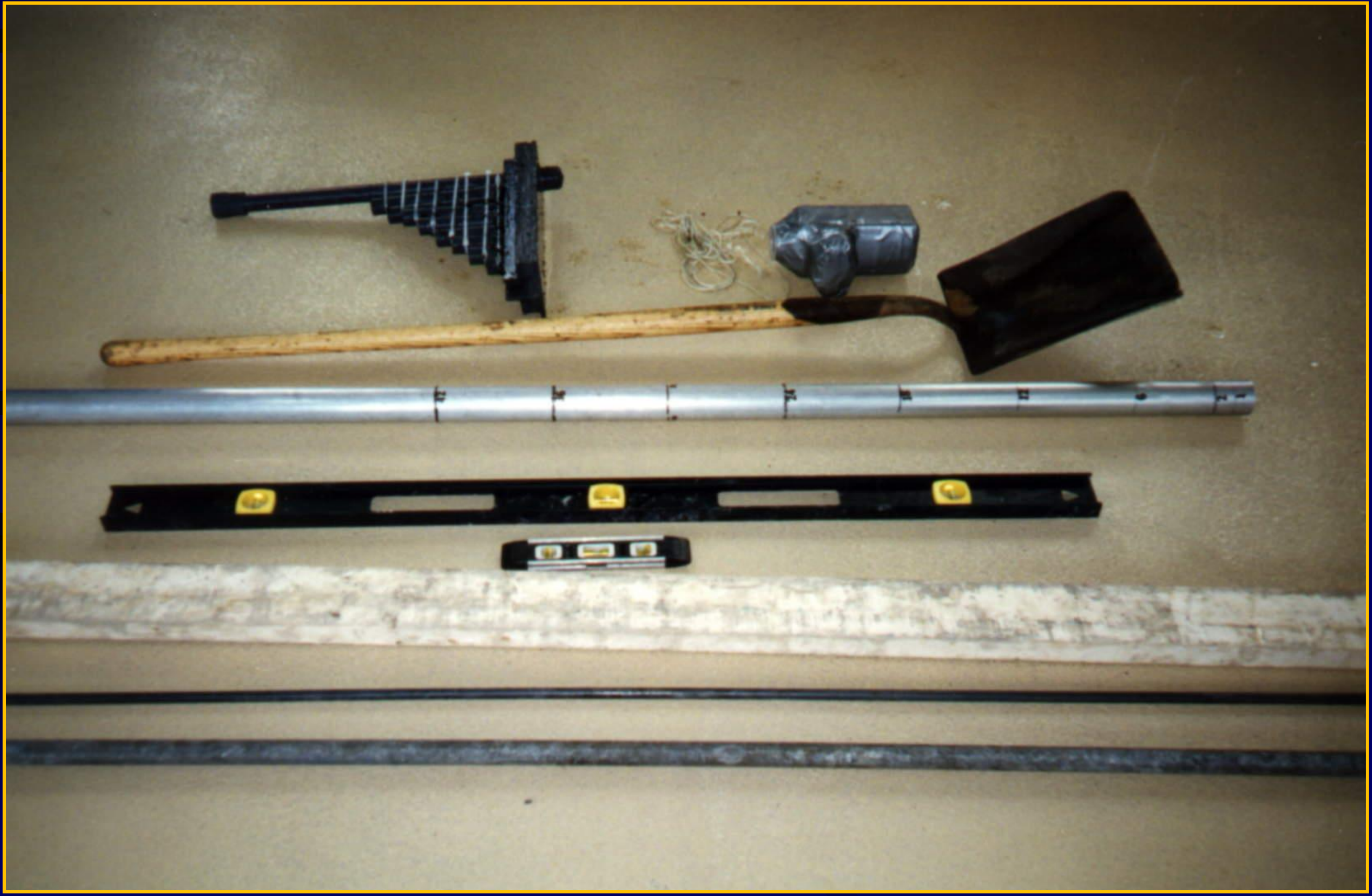
Filter Inspections

- Filter inspections should be done at least yearly (keep records), and whenever there is suspicion that the bed has been disturbed in any way
  - Inspections should include:
    - Measurement of bed depth and visuals
    - Measurement of the amount of solids retained in the bed both B4 and after backwash (solids retention)
    - Calculation of D_{90}/D_{10} ratio
    - Measurement of % bed expansion
    - Measurement of the spent filter backwash water turbidity

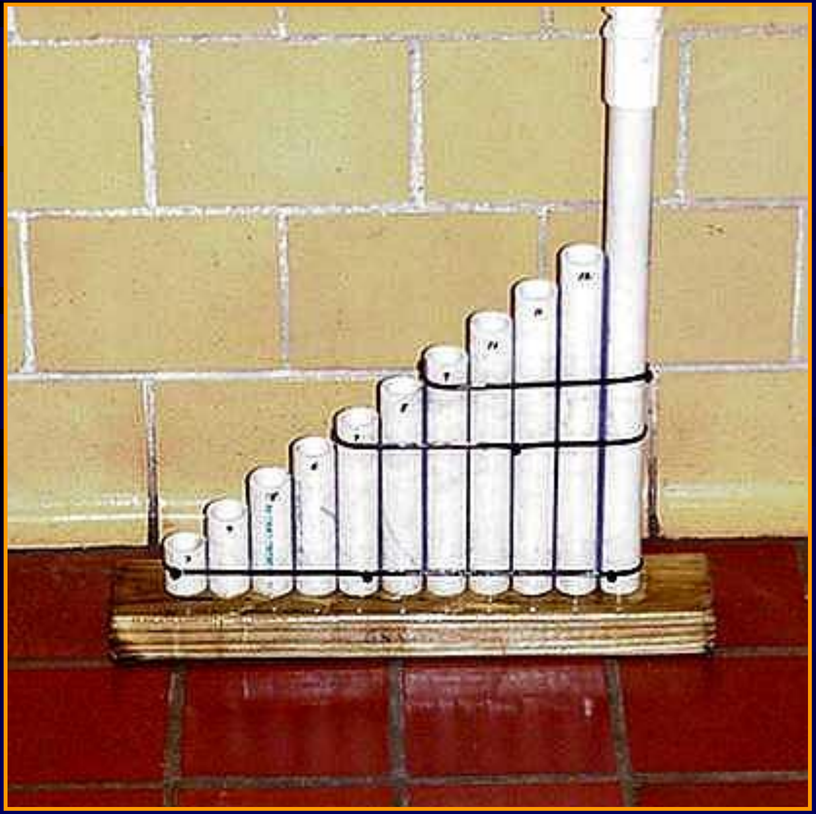
Tools and Techniques for Inspection

- Measurement Tools
  - Shovel, spoon, level, 3/8 inch steel rod or all thread, tape measure
- Coring Tool
  - 1 ½ inch electrical conduit (beveled ends), 5 foot length, baggies
- Expansion Tool
  - one inch interval tubes or cups
- Laboratory Instruments and Tests
  - Sample bottle with string or rod attached, turbidimeter, glassware, balance, sample bottles, particle counters, plywood, cable ties, sieve analysis contractor

Filter Inspection Tools



Example Bed Expansion Tool



Sample Bed Expansion Tool

Make the expansion tool out of good heavy materials so it holds up under repeated use

Ten pound hand weight to show scale

Lab Setup for Core Samples

- Turbidimeter
- Pan Balance
- Baggies – B4 and After
- Glassware
- Lab Water
- Weigh boats or other plastic cups

Tools and Techniques for Inspection

- Bed Depth Measurement (Drained Bed)
  - Know original specs - Effective size - Uniformity Coefficient - Depth - L/D ratio - D_{90} coal / D_{10} sand
  - Use a 3/8 inch steel rod to poke into media, or dig into it to measure depth
    - If filter is dual or mixed bed, note depth of each strata, and depth of mixed interface
  - Check to see if troughs are level, then measure distance from trough to bed - check for mounding
  - Calculate L/D_e ratio - should be >1100 for low NTU production

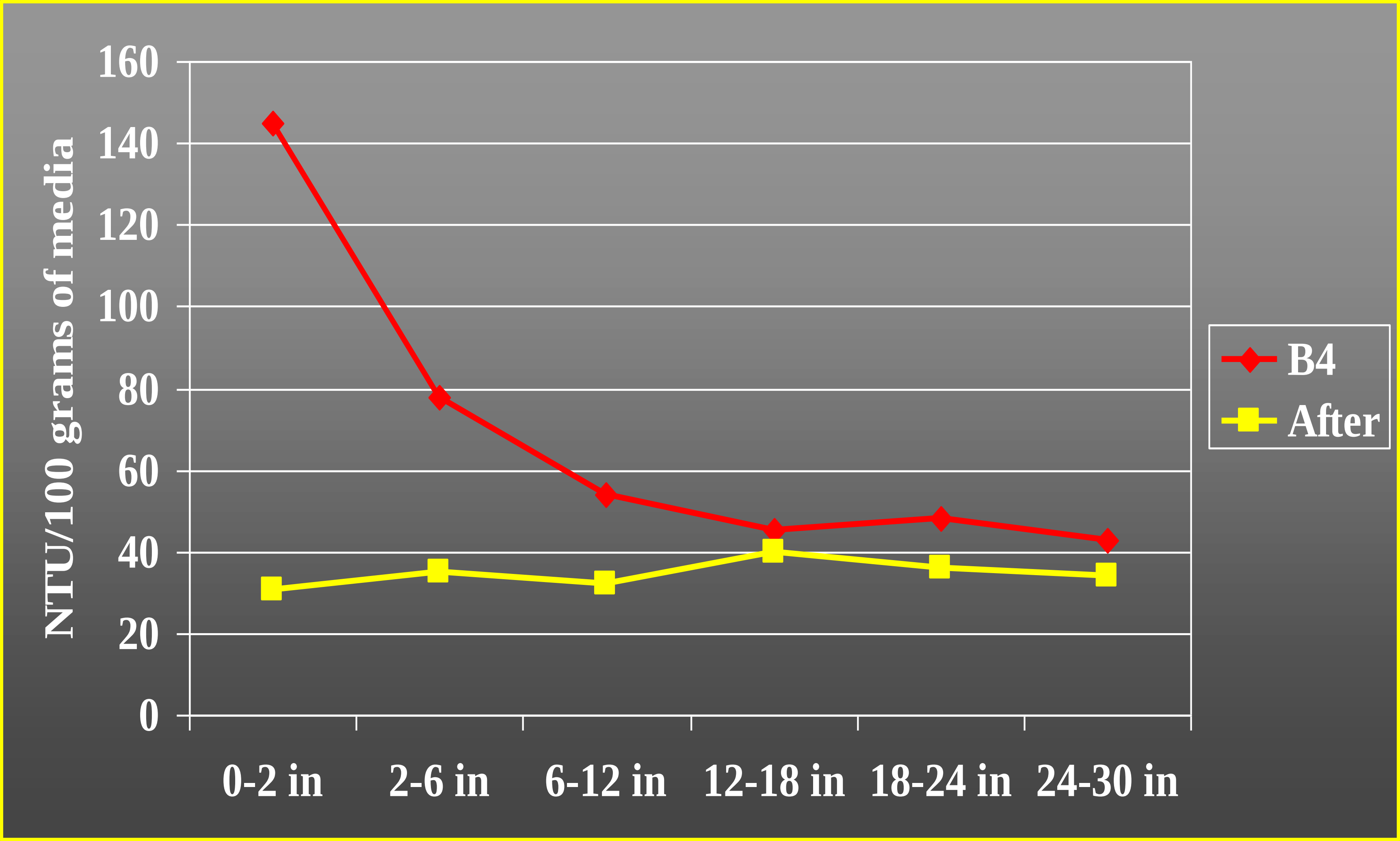
Tools and Techniques for Inspection

- Example Bed Depth Measurement
  - Dual Media - originally 36 inches 1 mm anthracite and 6 inches 0.5 mm sand - L/D_e = 1,066
  - Measurement shows only 32 inches of anthracite left, and the 6 inches of sand = 38 total inches
  - Rough L/D_e calculation (send media for analysis)
    - (32 in X 25.4)/1mm ≅ 813
    - 6 in X 25.4)/0.5mm ≅ 152
    - Therefore L/D_e = 965

Tools and Techniques for Inspection

- Example Core Sampling for Solids Retention
  - use core sampling tool (1 ½ inch elec. conduit) and baggies to obtain samples of the filter strata
    - take samples at 0-2 inches, 2-6, 6-12, 12-18, 18-24, etc., until all bed strata are sampled
    - sample before and after washing the bed
    - wash 50 grams of each sample with successive 100 mL washes of lab water
    - measure turbidity of each X 2- plot on graph as NTU/100 grams media

Solids Retention Profile



Solids Retention Guidelines*

- < 30 NTU - Bed is too clean - examine wash rate and length - this bed will not ripen quickly
- 30 - 60 NTU - Well cleaned and ripened bed - no need for action
- 60 - 120 NTU - Slightly dirty bed - re-schedule retention analysis soon
- > 120 NTU - Dirty bed - re-evaluate filter wash system and procedures
- > 300 NTU - mudball problem - rehab bed

*Kawamura - *Integrated Design of Water Treatment Facilities*

D_{90}/D_{10} ratio calculation

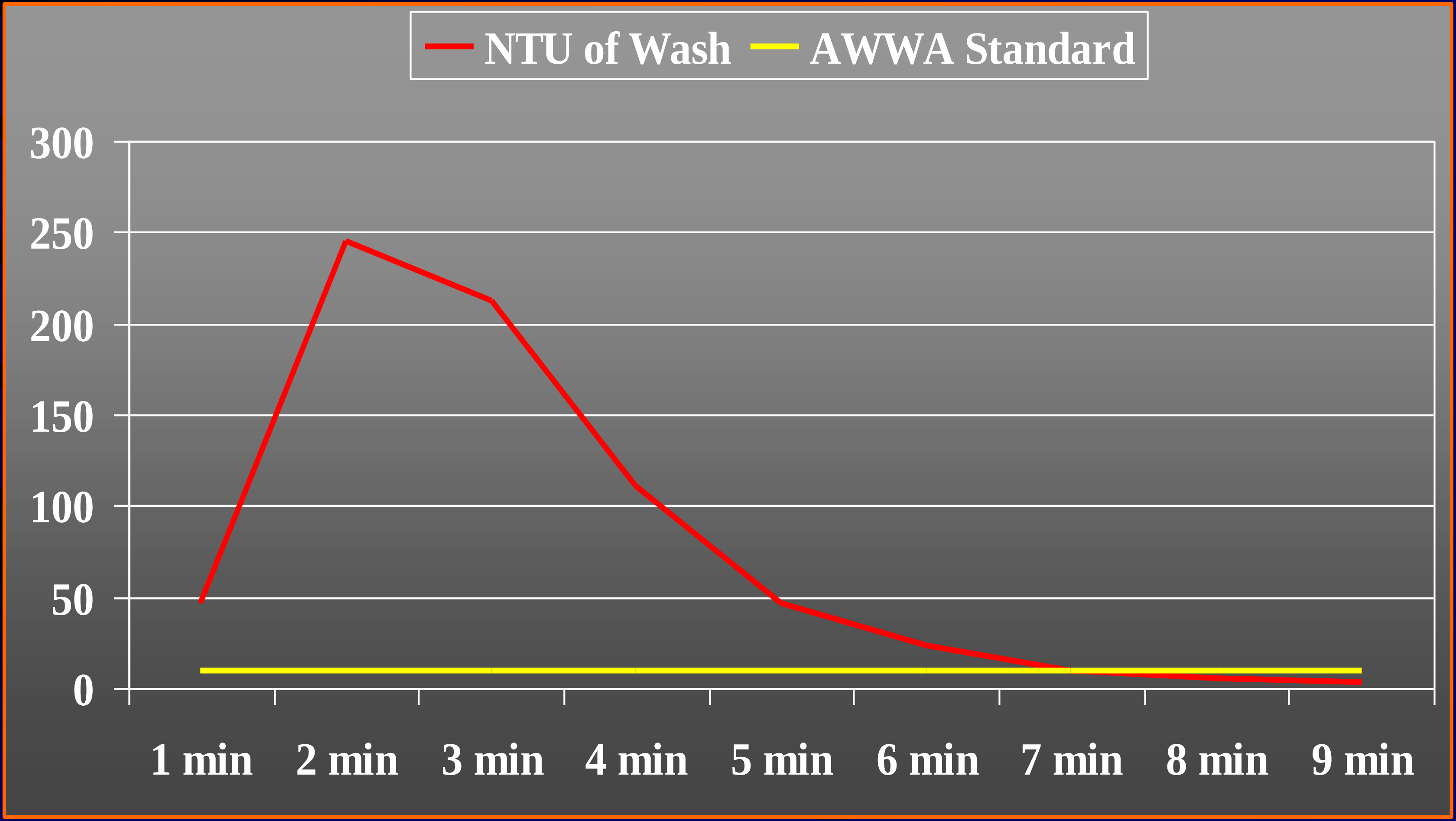
- Typical Lab Analysis of Media (sieve analysis) for this Filter
  - anthracite sample
    - D_{90} size = 1.6
  - sand sample
    - D_{10} size = 0.517
  - D_{90}/D_{10} ratio, (intermix ratio) $\cong 3$

Tools and Techniques for Inspection

- Washwater Analysis
  - After the first coring, and before the bed expansion measurement and second coring, the washwater turbidity should be measured for the length of the wash
  - Sample at 1 minute intervals, and graph results as NTU vs. time
  - Note amount used, rates, ramping intervals, operator habits, flow irregularities, "hot spots"

Bottles Ready for Backwash NTU Sampling

Washwater Turbidity Plot



Tools and Techniques for Inspection

- Bed Expansion Measurement with Expansion Tool
  - choose a target wash rate (seasonally adjusted) that will achieve a 0.7 porosity – approx. 30%
  - position and tie down the expansion tool so that it rests on top of the bed
  - wash bed under normal conditions and observe amount of expansion
    - Don’t operate surface washer with device installed

Example Bed Expansion Calculation

- Bed Expansion Measurement with Expansion Tool (Example for 36 inch bed)
  - Place the expansion tool on the bed and secure it – then backwash the filter (no SW)
  - observe expansion tool
    - count all the tubes that are filled with media, not the partially filled tube
    - Say 9 tubes are filled, and the base is 2 inches
    - 11 inches ÷ 36 inches ≈ 30%

- more informative than "rate of rise measurement"