# Fluidized-Sand Biofilters

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## Benefits of FSB

- Treat dissolved wastes.
- Cost effective for large recycle systems:
  - ✓filter sand is relatively inexpensive,
    - cost for surface area is low ($0.02-0.001/m$^2$)
  - ✓biofilters scale to treat large flows
    - 1.5 – 15 m$^3$/min
    - 400 to 4000 gal/min



## FSB Can Be More Cost Effective

- FSB are about 5 times less expensive than comparable trickling filters

| (Summerfelt & Wade, 1998, *Recirc Today*) | *Fluidized-sand biofilter #1* | *Fluidized-sand biofilter #2* | *Plastic media trickling filter* |
|---|---|---|---|
| Flow capacity, L/min | 1,520 | 2,280 | 2,000 |
| Design feed load[d], kg/day | 58 | 64 | 59 |
| Media specific surface area, m$^2$/m$^3$ | 11,300 | 11,300 | 180 |
| Design TAN removal rate, g/d/m$^2$ | 0.06 | 0.06 | 0.2 |
| Media volume, m$^3$ | 2.5 | 2.7 | 49.0 |
| Cost of media, $ | 380 | 415 | 20,600 |
| **Total biofilter cost, $** | **$6,000** | **$5,500** | **$28,000** |



## FSB Can Be More Cost Effective at Large Scales

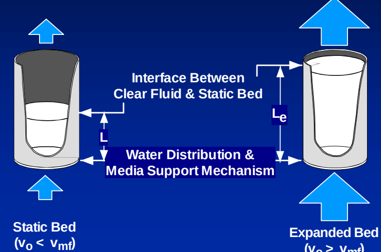
- Capital cost estimates associated with biofilter choice for a 1 million lb/yr tilapia farm.

| (Timmons et al., 2000) | *Farm Cost* | *Cost, $/lb/yr* |
|---|---|---|
| RBC | $668,000 | $0.68 |
| Trickling Biofilter | $620,000 | $0.62 |
| Pressurized Bead Filter | $296,000 | $0.30 |
| Conventional FSB | $124,000 | $0.12 |
| Cyclo Bio™ | $76,000 | $0.08 |



## Fluidization Fundamentals

- Buoyant force of rising water lifts sand bed when velocity exceeds minimum fluidization velocity ($v_{mf}$).



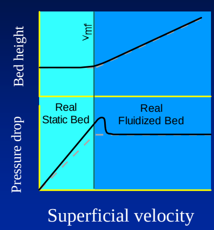



## Fluidization Fundamentals

- Bed expansion terminology:
  - ✓50% expansion , e.g., 1 m of static sand depth expands to 1.5 m
  - ✓100% expansion , e.g., 1 m of static sand depth expands to 2.0 m
  - ✓200% expansion , e.g., 1 m of static sand depth expands to 3.0 m

# Fluidization Fundamentals

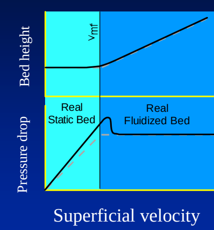
- Pressure drop across a sand bed
  - ✓ increases according to Ergun's equation until bed begins to expand.
  - ✓ remains constant at all water velocities after the expansion begins.
  - ✓ remains constant for all sand sizes,
    - 1 m of static sand requires about 1 m of water head to expand.
- see Summerfelt and Cleasby (1996)





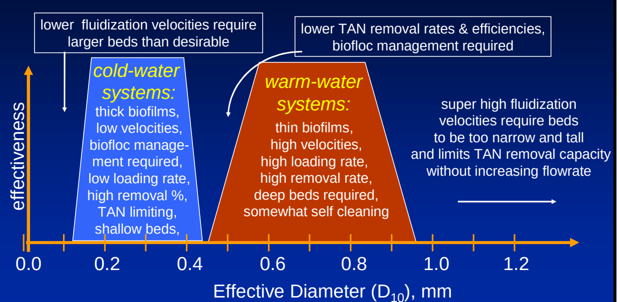

# Fluidization Fundamentals

- Estimate bed expansion for a given sand as a function of water velocity, using:
  - ✓ water viscosity and density
  - ✓ sand size, sphericity
  - ✓ void space of the static bed
- see Summerfelt and Cleasby (1996)






## Applications: Coldwater vs. Warmwater




(See Timmons & Summerfelt, 1998)



# Nitrification Rates

- Warm-water & cold-water applications:

| | g TAN removed per day | | TAN Removal Efficiency |
|---|---|---|---|
| | per $m^2$ surface area | per $m^3$ static sand vol. | |
| COLD-WATER BIOFILTER fine sand, ~11,500 $m^2/m^3$ $D_{10}$ = 0.17-0.25 mm | 0.06 | 700 | 70-90% |
| WARM-WATER BIOFILTER coarse sand, ~5,000 $m^2/m^3$ $D_{10}$ = 0.6-0.8 mm | 0.2 | 1000 | 10-30% |

(summarized by Timmons & Summerfelt, 1998)



# Coldwater Applications

- Fine sands ($D_{10}$ = 0.20-0.25 mm) are used:
  - ✓ provide high specific surface areas
    - 11,000 $m^2/m^3$
  - ✓ require low water velocities
    - 0.7-1.0 cm/s
  - ✓ provide longer hydraulic retention times across bed
    - 1-3 min

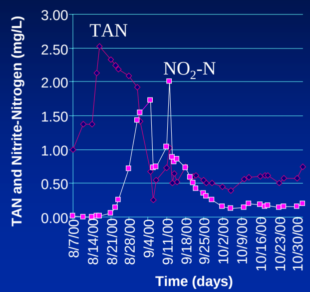


# Coldwater Applications

- Fine sands ($D_{10}$ = 0.20-0.25 mm) are used:
  - ✓ produce higher TAN removal efficiencies
    - 80-95% TAN removal each pass
  - ✓ provide excess nitrification capacity
    - 200% excess can be achieved
  - ✓ controls nitrite-nitrogen at very low levels
    - generally < 0.1-0.2 mg/L

# FSB Start-up in Coldwater

- Start-up period at FI took 7-8 week at 14ºC.



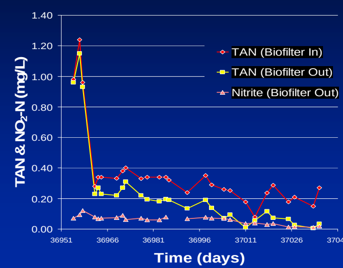

Note 1. Step changes in make-up water flows were used to increase or decrease dilution when nitrite spiked.

Note 2. Feeding reached 79 kg/day by 11/2/00 and TAN removal efficiency was > 50%.



# FSB Performance in Coldwater

- FSB first started up on ammonium chloride.



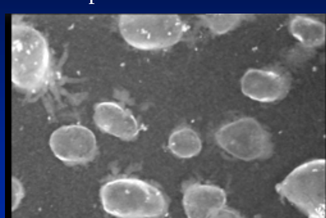

Note 1. At stocking the fish density was 15 kg/m$^3$ (mean fish weight = 150 g).

Note 2. Last measured fish density was 33.5 kg/m$^3$ (mean fish weight = 320 grams).



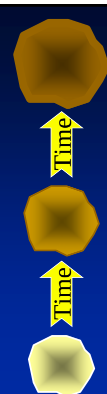
# Biofilm Development

- Biofilms develop around individual sand grains;



Suggested reading: Nam et al. 2000. Aquacultural Engineering, 22: 213-224.

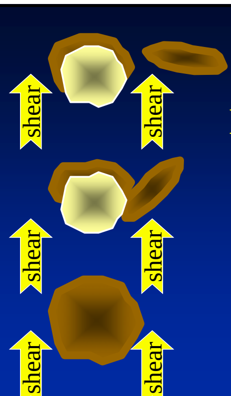





# Biofilm Development in Fine Sand Biofilters

- biofilms thicken with time:
  - ✓decreasing particle density,
  - ✓increasing bed expansion,
  - ✓migrating to top of bed.





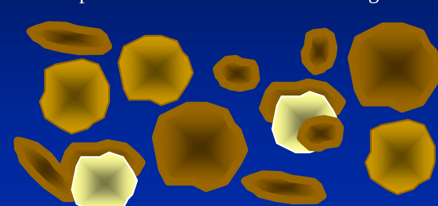

# Biofilm Development in Fine Sand Biofilters

- Shear forces tear biofilm pieces from the sand,



# Biofilm in Fine Sand Biofilters

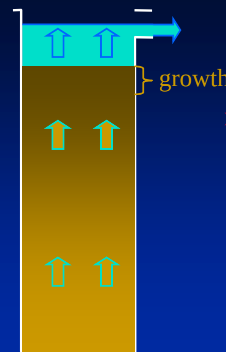
- Water velocities (0.7-1.4 cm/s) do not flush larger sheared pieces from the bed;
  - ✓such pieces accumulate & continue to grow.



## Biofilm in Fine Sand Biofilters

- biofilms grow on the expanded sand

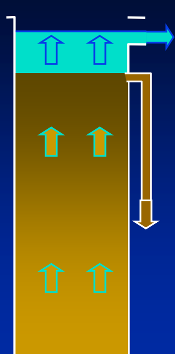





## Fine Sand Biofilters

- Biofilter bed depth increases with time (about 8 cm/wk @ FI):
  - ✓bio-particles accumulate;
  - ✓bed expansion increases,
    - as thickening biofilm reduces particle densities.

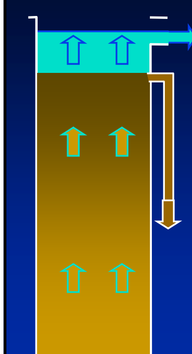




## Managing Bed Depth

- Siphon biosolids from the bed:
  - ✓maintain a maximum bed depth;
  - ✓remove biosolids from the top,
    - removes thickest and oldest biofilm;
  - ✓also remove some sand,
    - lost sand must be replaced on occasion.





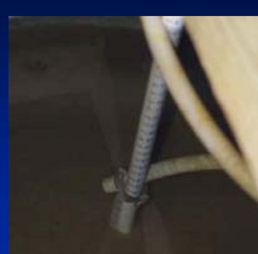
## Managing Bed Depth

- Intermittent biosolids siphoning,
  - ✓remove top 15-30 cm of bed,
  - ✓only when bed reaches a max depth,
  - ✓technique used in past.
- Continuous biosolids siphoning:
  - ✓4-20 L/min (1-5 gpm) siphon rate,
  - ✓0.2 - 1% of total biofilter flow,
  - ✓current tecchnique in FI's growout system.



## Managing Bed Depth

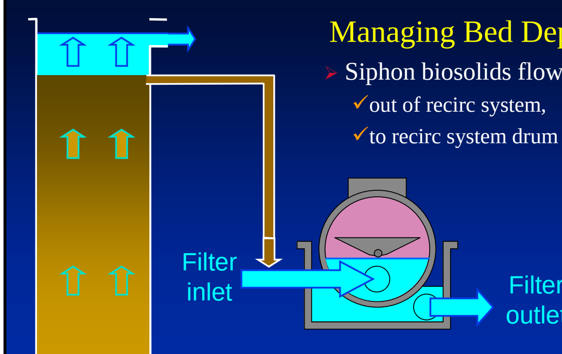
- Siphoning biosolids from a biofilter in the Freshwater Institute's old research system.





## Managing Bed Depth

- Siphon biosolids flow:
  - ✓out of recirc system,
  - ✓to recirc system drum filter.

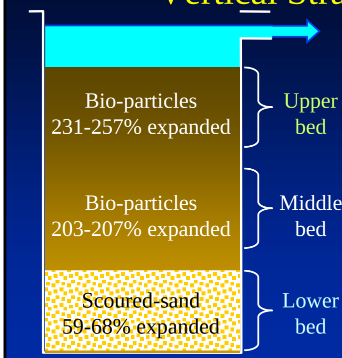


## Vertical Stratification

- The beds are vertically stratified in:
  - ✓sand size
  - ✓bed expansion
  - ✓biofilm thickness and biofloc size
  - ✓nitrification rate



## Vertical Stratification




*Particle Size*

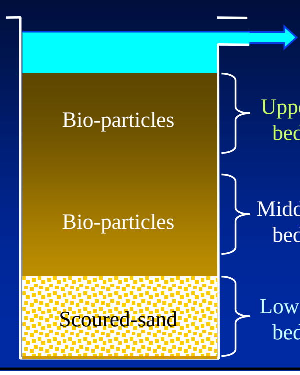
Upper bed: 0.320 to 0.341 mm sand, 4-15 µm biofilm, 0.9-1.1 mm biofloc

Middle bed: 0.343 to 0.358 mm sand, 7-20 µm biofilm, 0.9-1.7 mm biofloc

Lower bed: 0.421 to 0.434 mm sand, no visible biofilm, no biofloc



## Vertical Stratification




*Regional TAN Removal Rates ($g/d/m^2$ sand surface)*

Upper bed: 0.116 - 0.150

Middle bed: 0.099 - 0.172

Lower bed: 0.031 - 0.048



## Flow Distribution Mechanisms

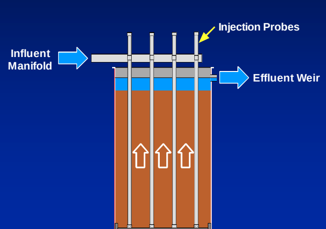
- Flow distribution methods vary, but are all important!


orifices distributed across false-floor (controlling ΔP) | orifices distributed across pipe-manifold (controlling ΔP) | slotted inlet about circumference (NO controlling ΔP)



## Distribution by Vertical Probes

- In 1989, Dallas Weaver (Scientific Hatcheries) sold FI a FSB that used vertical injection probes.




Freshwater Institute's 'old system'



## Distribution by Vertical Probes

- Peterson Fish Farm (MN)

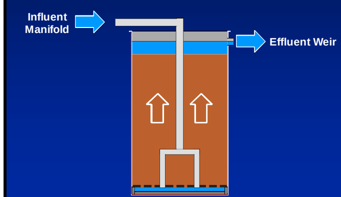
(Designed by Dallas Weaver)

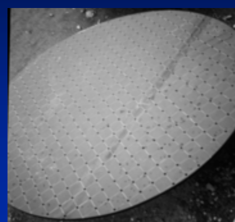
- Sierra Aquafarm (CA)

(Designed by Dallas Weaver)

## Distribution Through False Floor

- Eric Swanson reported (Aqua Expo, 1992) flow injection underneath a false floor.



false-floor distribution plate



## Distribution Through False Floor

- Buckmans Creek Hatchery (NB)


(Swanson-type design)



## Distribution Through False Floor

- Formerly *Penobscot Smolt Hatchery* (Franklin, ME)
- Currently *Center for Cooperative Aquaculture Research*

(Designed by Eric Swanson)



## Distribution Through False Floor

- Oak Bay Hatchery, Cooke Aquaculture (NB)

(Swanson-type design)



## Distribution Through False Floor

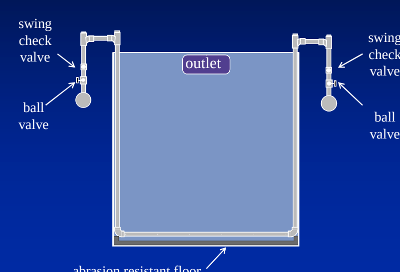
- Atlantic Silver Hatchery (NB)

(Designed by Eric Swanson)



## Pipe-Lateral Distribution

- Freshwater Institute adopted a modified pipe-lateral distribution manifold.



# Pipe-Lateral Distribution

- Modified pipe-lateral distribution manifold at Freshwater Institute's old facility.



# Pipe-Lateral Distribution

- To create uniform flow distribution:
  - ✓ Pressure drop ($\Delta P$) across orifice should be ≥ headloss through the sand bed (i.e., ≥ depth of static sand):

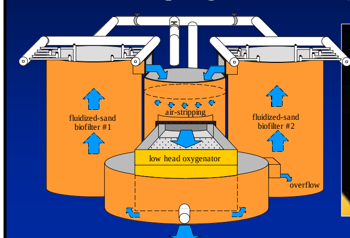
$$\Delta P_{orif} = \left[\frac{Q_{orif}}{C \cdot A_{orif}}\right]^2 \cdot \frac{1}{2 \cdot g}$$

$Q_{orif}$ = flowrate in $ft^3/s$
$A_{orif}$ = orifice area in $ft^2$
$C = 0.6$ and $g = 32.2\ ft/s^2$



# Pipe-Lateral Distribution

- Glacier Springs Fish Farm (Manitoba)

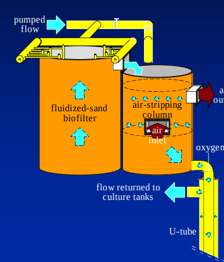



(system designed by FI)



# Pipe-Lateral Distribution

- Integrated Aquaculture Systems (PA)



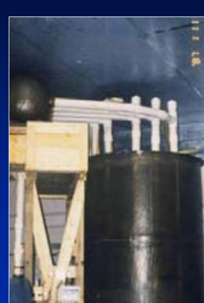

(system designed by FI)



# Pipe-Lateral Distribution

- Fingerlakes Aquaculture (NY)

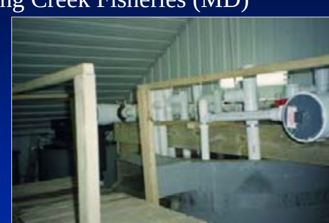
(farm designed by Mike Timmons)





# Pipe-Lateral Distribution

- Hunting Creek Fisheries (MD)



(system designed by FI)

# Pipe-Lateral Distribution

- Bingham Hatchery (Maine)

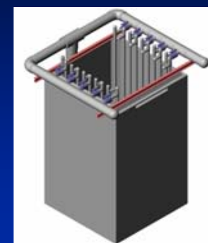
(system designed by PRAqua Tech.)



# Pipe-Lateral Distribution

- Target Marine Hatchery (BC)

(systemdesigned by PRAqua Tech.)



Courtesy of PRAqua Technologies (BC)



# Pipe-Lateral Distribution

- Target Marine Hatcheries(BC)

(system designed by PRAqua Tech.)



# Pipe-Lateral Distribution

- Three salmon smolt systems at Nutreco's Big Tree Creek Hatchery (BC)

(system designed by PRAqua Tech.)



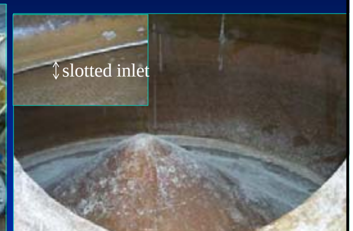
# Cyclo Biofilter™

- Patent protected technology from Marine Biotech Inc. (Beverly, MA)



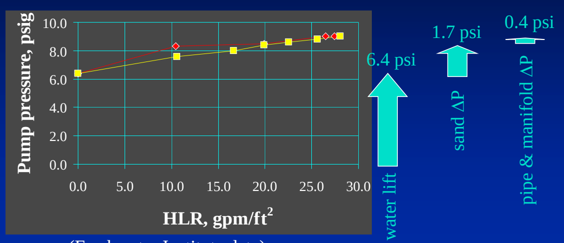

# Cyclo Biofilter™

- Water injected tangentially into circular plenum and through 1.9 cm (3/4") slotted inlet about its base.

# Cyclo Biofilter™

- Pressure drop across the piping, sand, & cyclo bio




(Freshwater Institute data)



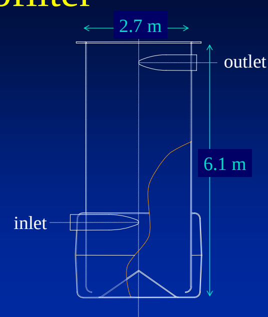
# Cyclo Biofilter™ Advantage

- Cyclo Bio requires less pressure to operate.
  - ✓0.1-0.3 bar (2-4 psig) less pressure was required to operate a cyclo bio compared to a modified-pipe manifold FSB.
    - assuming a similar fluidized-sand biofilter height.
  - ✓cyclo bio's reduce ΔP of piping and inlet orifice



# Cyclo Biofilter™

- Cyclo Bio™ at Freshwater Institute
  - ✓Dimensions:
    - 2.7 m (9 ft) dia
    - 6.1 m (20 ft) tall
  - ✓Static sand capacity:
    - 1.5 m (5 ft) depth
    - 8.5 $m^3$ (300 $ft^3$) volume
    - 15 TON
    - assimilates TAN from ~200 kg feed/day
      - e.g., 0.7 kg TAN/$m^3$/day
    - Treats 1250 gal/min flow




(courtesy of Marine Biotech Inc.)



# Cyclo Biofilter™

- Effluent collection launder

To stripping column



# Cyclo Biofilter™

- Cyclonic bed rotation observed @ HLR > 25 gpm/$ft^2$



# Cyclo Bio™ at Freshwater Inst.

# Cyclo Bio™ at WV Aqua

- Three 9 ft dia Cyclo Bio's installed at char farm


(system designed by PRAqua Tech.)



# Cyclo Bio's™ at Fingerlakes Aqua

- Four 11 ft dia Cyclo Bio's (Groton, NY)


(farm designed by Mike Timmons)



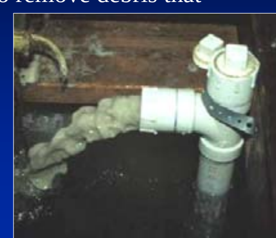
# Practical Considerations: Sand Blasting

- Installation of an abrasion resistant floor is critical.




# Practical Considerations: Clean Outs

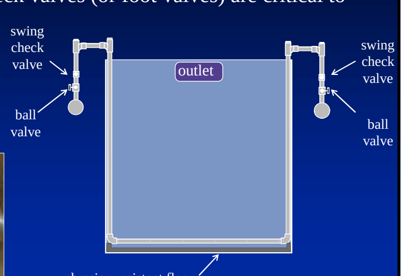
- Clean-out caps on all distribution pipes provides a method to remove debris that could plug laterals.





# Practical Considerations: Check Valves

- Reliable swing check valves (or foot valves) are critical to prevent backflow!




swing-flex foot valves @ FI



# Practical Considerations: Biosolids Removal

- Siphon biosolids bed regularly to prevent them from overtopping biofilter.

## Practical Considerations: Viewing Bed

- Select a clear FRP vessel to provide a visual of expanded bed.



## Practical Considerations: Air Bubbles

- Prevent bubbles from being pumped into fluidized-sand biofilters. Bubbles washout sand!



## Purchasing Filter Sand

- Sand suppliers usually report the effective size and uniformity coefficient of their sand.



## Characterizing Sand: $D_{10}$

- The "*effective size*" ($D_{10}$) is defined as the opening size which will pass only the smallest 10%, by weight, of the granular sample. The $D_{10}$ provides an estimate of the smallest sand in the sample and is the size used to estimate the maximum expansion at a given superficial velocity.



## Characterizing Sand: UC

- The "*uniformity coefficient*" (UC) is a quantitative measure of the variation in particle size of a given media and is defined as the ratio of $D_{60}$ to $D_{10}$.

$$UC = \frac{D_{60}}{D_{10}}$$



## Characterizing Sand: $D_{90}$

- The "*largest size*" ($D_{90}$) is the sieve size for which 90% of the grains by weight are smaller.
- The $D_{90}$ provides an estimate of the largest sand in the sample and is the size to estimate the minimum expansion at a given velocity. The $D_{90}$ can be estimated from the $D_{10}$ and the UC:

$$D_{90} = D_{10} \cdot \left(10^{1.67 \cdot \log(UC)}\right)$$

## Characterizing Sand: $D_{50}$

- The "*mean size*" ($D_{50}$) is the sieve size for which approximately 50% of the grains by weight are smaller. The $D_{50}$ provides an estimate of the average size of the sand in the sample and is the value used during design to estimate the average bed expansion at a given superficial velocity:

$$D_{50} = D_{10} \cdot \left(10^{0.83 \cdot \log(UC)}\right)$$



## Characterizing Sand: $S_b$

- The "*bed specific surface area*" is the specific surface area available per unit of bed volume ($S_b$); this can can be estimated using estimates for the static bed void fraction ($\varepsilon \approx 0.45$) and sand sphericity ($\Psi \approx 0.75$):

$$S_b = \frac{6 \cdot (1-\varepsilon)}{\Psi \cdot D_{50}}$$

  - ✓ Recognize the limits of guesstimates.



## Purchasing Filter Sand

- Some filter sand suppliers listed in the Northeast:
  - ✓ Ricci Brothers Sand and Gravel (NJ)
    - 609-785-0166 ph
  - ✓ Unimin Corporation
    - 800-243-9004 ph
  - ✓ U.S. Silica (WV)
    - 800-243-7500 ph
  - ✓ Unifilt Corporation (PA)
    - 412-758-3833 ph
  - ✓ F. B. Leopold Company, Inc. (PA
    - 412-452-6300 ph;
  - ✓ Lang Filter Media Co. (PA)
    - 412-779-3990 ph
  - ✓ American Materials Corp. (WI)
    - 800 -238-9139 ph
  - ✓ Morie Company, Inc. (NJ)
    - 800-257-7034 ph
  - ✓ R.W. Sidley, Inc. (OH)
    - 800-536-9343 ph

•*as published in the 1998 AWWA Sourcebook and 1996 AWWA Buyers Guide



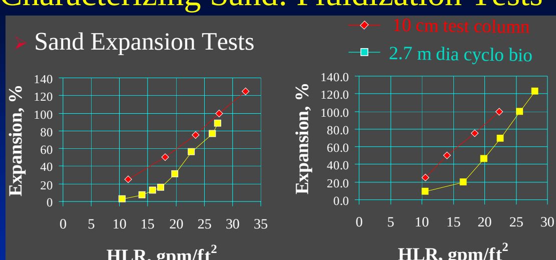
## Characterizing Sand: Sieve Analysis

- Typical mean % retained at a given screen size.

| USA STD Sieve Size | | Typical Mean % Retained | |
|---|---|---|---|
| mesh | mm opening | *US Silica #1 Q-ROK* | *Parry Company 35/42 silica sand* |
| **20** | **0.84** | **0** | **0** |
| **30** | **0.60** | **8** | **0** |
| **40** | **0.42** | **52** | **9** |
| **50** | **0.30** | **32** | **45** |
| **70** | **0.21** | **7** | **40** |
| **100** | **0.15** | **1** | **6** |
| **140** | **0.11** | **0** | **0** |



## Characterizing Sand: Fluidization Tests




US Silica sand
$D_{10} = 0.275$ mm

Parry Company sand
$D_{10} = 0.23$ mm



## Purchasing Filter Sand

- Freshwater Institute recently purchased filter sands from:
  - ✓ *US Silica Company* (Berkeley Springs, WV)
    - $D_{10} = 0.275$ mm, UC =1.7
    - $1300 for 15 tons delivered in 100 lb bags on pallets
  - ✓ *The Parry Company* (Richmond Dale, OH)
    - $D_{10} = 0.23$ mm, UC =1.5
    - $1800 for 15 tons delivered by pneumatic truck

## Installing Filter Sand

- *US Silica Sand*: 300 bags (100 lb/bag) hand loaded into cyclo bio.



## Installing Filter Sand

- *Parry Company sand*: 15 tons of sand were pneumatically transferred from a tank truck.



## Installing Filter Sand

- Wash fine clay found in new sand out of system before recirculating water to fish.



## Questions?

- Contact Steven Summerfelt
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