Intensifying biological treatment through selection processes

the international water association

WEBINAR

14 December 2021 | 14:00 GMT

iwa-network.org/webinars

WEBINAR INFORMATION

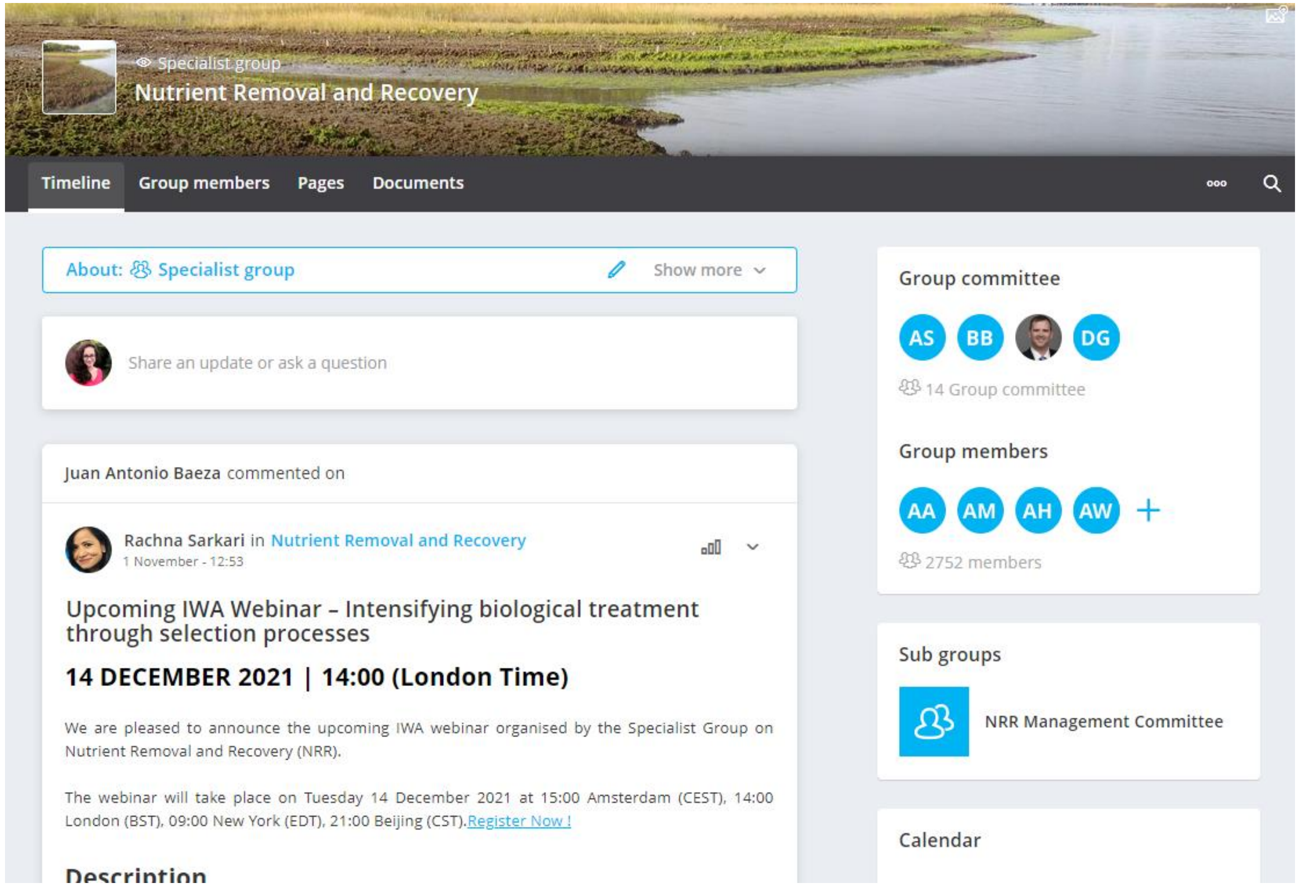
- This webinar will be **recorded and made available "on-demand"** on the IWA website.
- Following the webinar, you will be sent a **post-webinar email** with the on-demand recording, presentation slides, and other information.

- **'Chat' box**: please use this for general requests and for interactive activities.
- **'Q&A' box**: please use this to send questions to the panelists.

  (We will answer these during the discussions or in a Q&A report shared after the session)

Please Note: *Attendees' microphones are muted. We cannot respond to 'Raise Hand'.*

NUTRIENT REMOVAL AND RECOVERY SPECIALIST GROUP



The Nutrient Removal and Recovery (NRR) SG focuses on cutting edge fundamental and applied research in nutrient removal and recovery technologies, and applications of those technologies in the design, operation, and optimisation of wastewater treatment systems.

Join the NRR group on IWA Connect!

https://iwa-connect.org/group/nutrient-removal-and-recovery/timeline

AGENDA

- Welcome, housekeeping rules, introduction
  Pusker Regmi and Krishna Pagilla
- A Remembrance of Prof. David Jenkins
  JB Neethling, Paul Pitt and Sarah Jenkins Muren
- Biomass Form and Function Relationships in AS Process
  Krishna Pagilla and Andrew Schuler
- Classification of bacteria to solve foaming and separation problems
  Krishna Pagilla
- Consideration of biomass density to improve activated sludge settling
  Andrew Schuler
- *Q&A with audience*
- Biological selection of granules in continuous flow systems
  Mari Winkler
- Biological architecture for flocs and granules in continuous flow systems
  Pusker Regmi
- *Q&A with audience*
- Final remarks and conclusion
  JB Neethling

MODERATORS AND PANELISTS

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JB Neethling
HDR Wastewater Treatment and Effluent Management

Krishna Pagilla
University of Nevada

Andrew Schuler
University of New Mexico

Mari Winkler
University of Washington

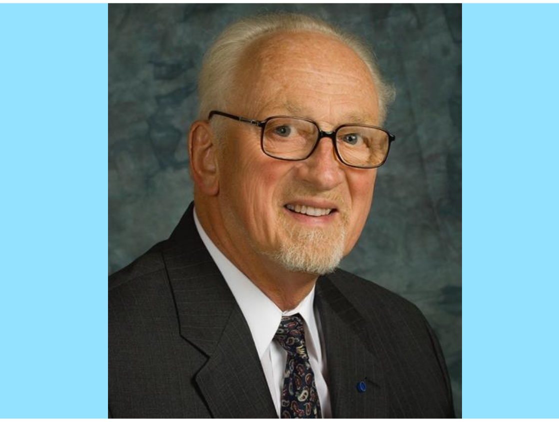
Pusker Regmi
Brown and Caldwell, Washington DC

Paul Pitt
Hazen and Sawyer

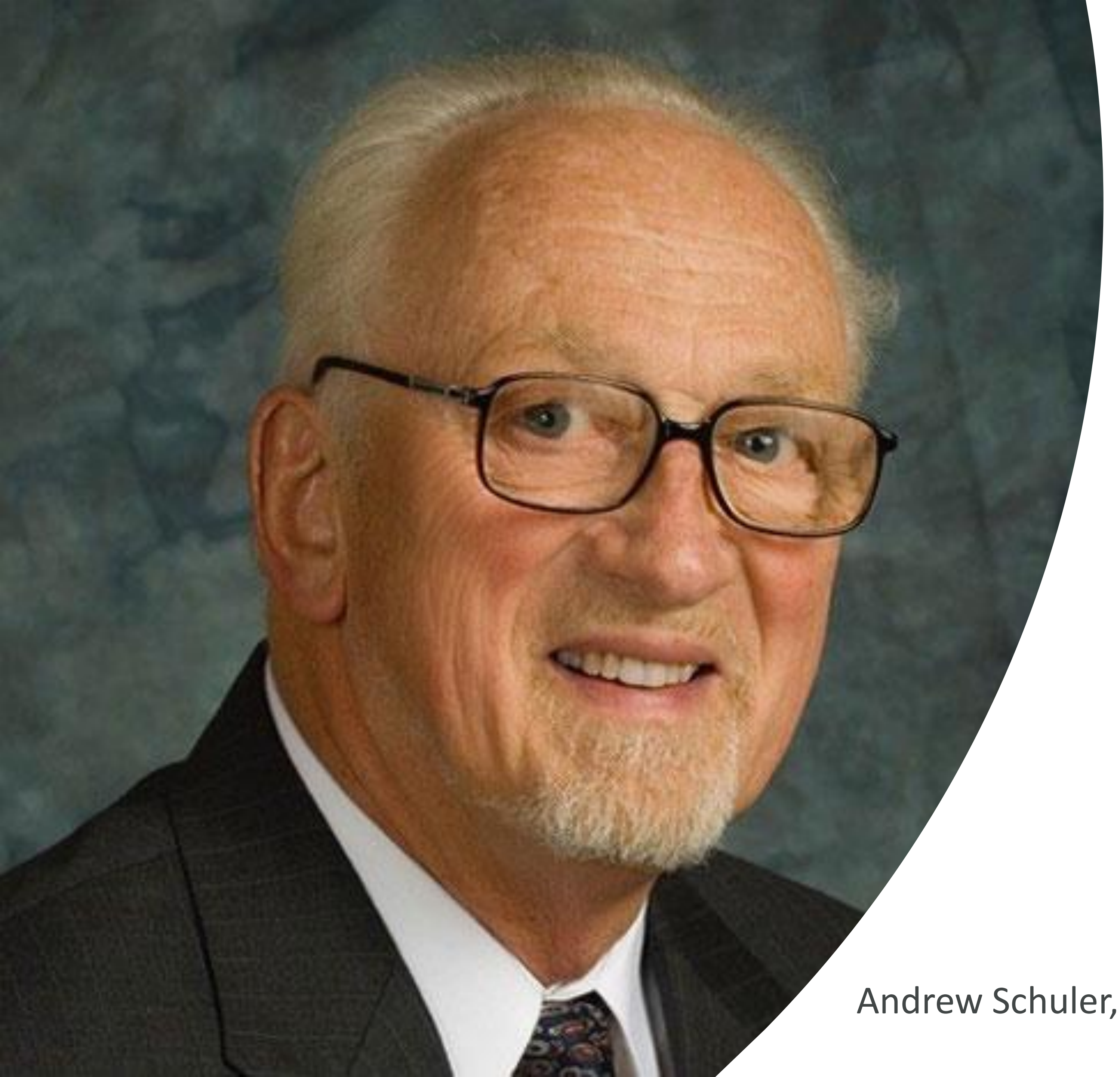
Sarah Jenkins Muren
Daughter of late Prof. David Jenkins

A Tribute to Professor David Jenkins (1935-2021)

EDUCATOR, SCIENTIST, COLLEAGUE, FRIEND



inspiring change



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David Jenkins (1935-2021)

Educator
Scientist
Colleague
Friend

Sarah Muren, JB Neethling, Paul Pitt
Andrew Schuler, James Barnard, B Narayanan, Krishna Pagilla

PROFESSIONAL HIGHLIGHTS

PhD, Kings College, 1960
Began as faculty at UC Berkeley in 1963
National Academy of Engineering
Berkeley Citation Award
Gordon Maskew Fair Medal, Water Environment Federation
George Bradley Gasgoine Medal, Water Pollution Control Federation
Simon Freeze Award and Lectureship, ASCE
Harrison Prescott Eddy Medal, Water Environment Federation (3x)
International Water Association Samuel H. Jenkins Outstanding Service Award

BORN INTO A LEGACY

David

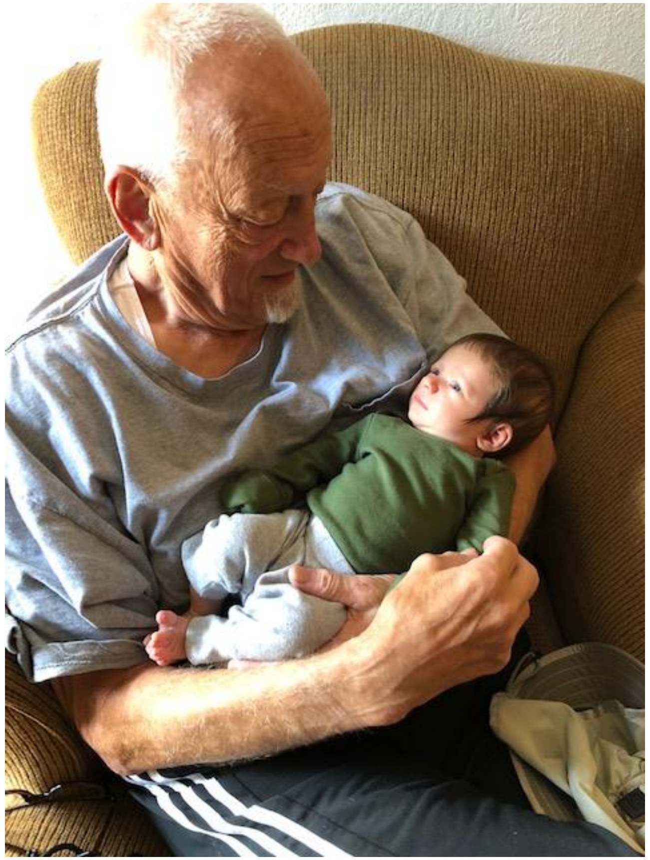
David

Samuel H. Jenkins
father

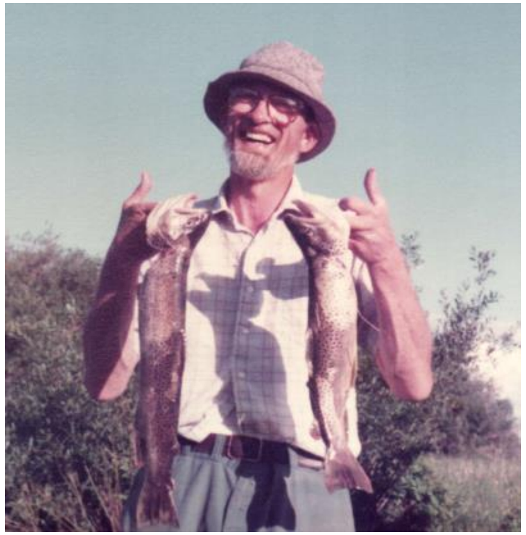
Olive Jenkins
mother

DAVID AND JOAN: A TRUE PARTNERSHIP

10



A PART OF THE FAMILY



DAVID THE EDUCATOR









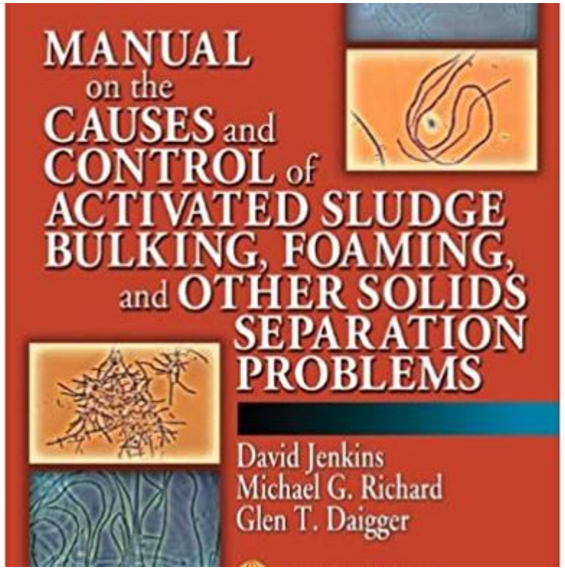


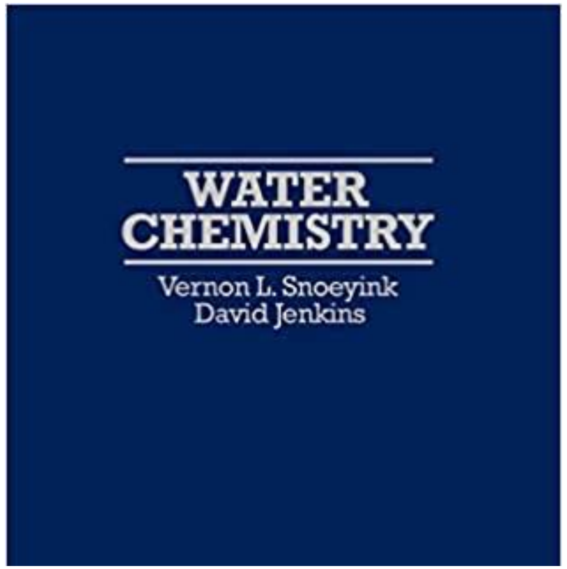







Major areas of contribution the Floc Doc

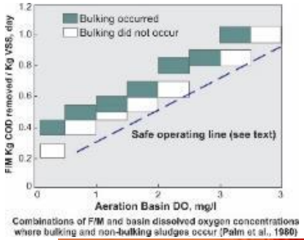


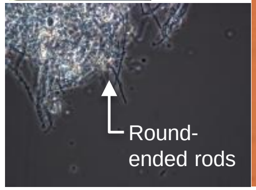


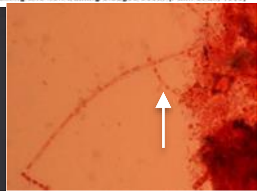
- Water chemistry
- Selectors, foaming and bulking
- Chemical P removal
- Biological nutrient removal
- Troubleshooting activated sludge problems around the world!

Newcastle University Aug 1982

1st Edition Manual 1986







Diameter < 1 um
Round end rods
Attached growth

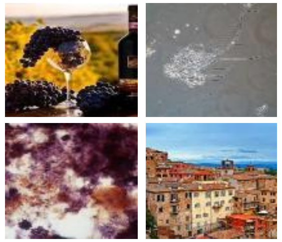
Gram stain
Gram negative

Meet the family

1988

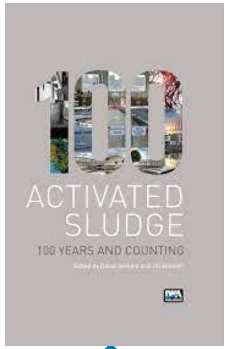
Dallas

Cal Lectures 1996



Perugia, Italy
International Specialized Course
"Operation and Control of Activated Sludge Processes Using Microbiological Analysis"

2014 Activated Sludge
100 yrs and counting



Wisdom of David Jenkins

- Look at all the data
- Read all the literature
- Go back to first principle
- Think laterally
- Keep an open mind
- Listen to everyone, but believe nobody
- Get help if you need it

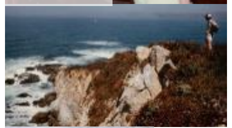
LOS ANGELES COUNTY SANITATION DISTRICTS
Converting Waste Into Resources

Meet the Extended family

SFO
June 1983

Required course

Piano

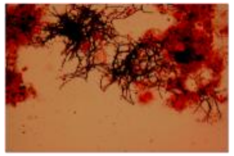


Point Reyes

Spaghetti parties

1987 SEP (+40 yrs)

Activated Sludge Foaming Research



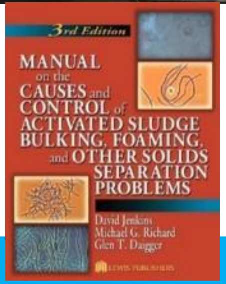
Nocardioforms

Sarah's wedding 1989

Selector Research

2004
NYC
TAC Member

David was here



Biomass Form and Function Relationships in AS Process

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UNIVERSITY OF NEW MEXICO

University of Nevada, Reno

SCHOOL OF ENGINEERING

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inspiring change

WHAT IS INTENSIFICATION?

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The term **“Intensification"** originates in chemical engineering, where we find many definitions:

“Process intensification involves design of novel reactors of increased volumetric productivity and selectivity and reduced energy use without sacrificing product quality and safety.”
P.A. Ramachandran, R.V. Chaudhari, in *Encyclopedia of Sustainable Technologies*, 2017

“Any chemical engineering development that leads to a substantially smaller, cleaner, safer, and more energy efficient technology”
Stankiewicz and Moulijn, 2000, *Chemical Engineering Progress*, Jan 2000.

- We propose: “Any engineering development that leads to a smaller system, better effluent quality, and/or improved energy efficiency.”

WHAT IS INTENSIFICATION?

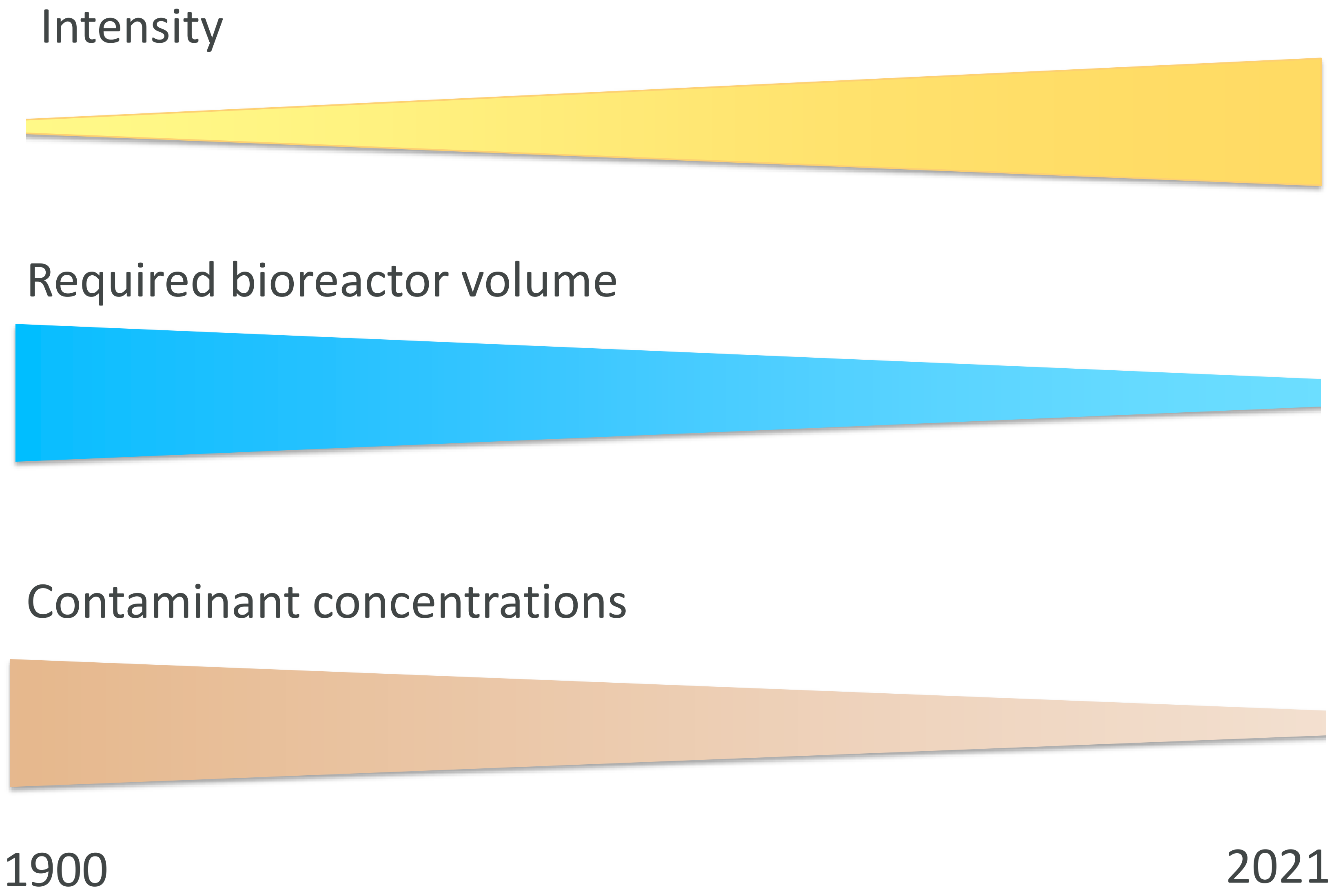
- **Intensification** typically involves increasing **volumetric rates** mass removal/(reactor volume*time).

Volumetric rate = **specific rate** * **biomass concentration**

mg contaminant/(L*d) = mg contaminant/(mg biomass*d) * mg biomass/L

- We can therefore think of intensification as including 2 components:
  - Increasing **specific rates** (contaminant removal/(biomass*time)) [**Kinetic acceleration**]
  - Increasing **biomass concentration** (mass biomass/time) [**Densification**] (more on this later)

Progression of wastewater treatment



Intensification over the years

- Dilution is solution to pollution!
    - Discharge sewage to rivers, lakes, ponds and lagoons – natural assimilation by **suspended and attached biomass**

- Drip sewage over rocks for BOD removal by **attached biomass**
    - Early trickling filters

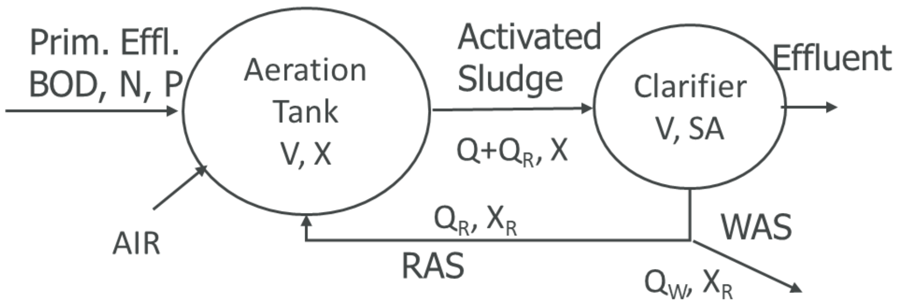
- **Aerate** sewage in tanks and **settle** the biomass
    - Ardern and Lockett Activated Sludge Process

- Introduce **clarifier or settling tank** following the aeration tank to recycle biomass
    - Classical activated sludge process and its modifications

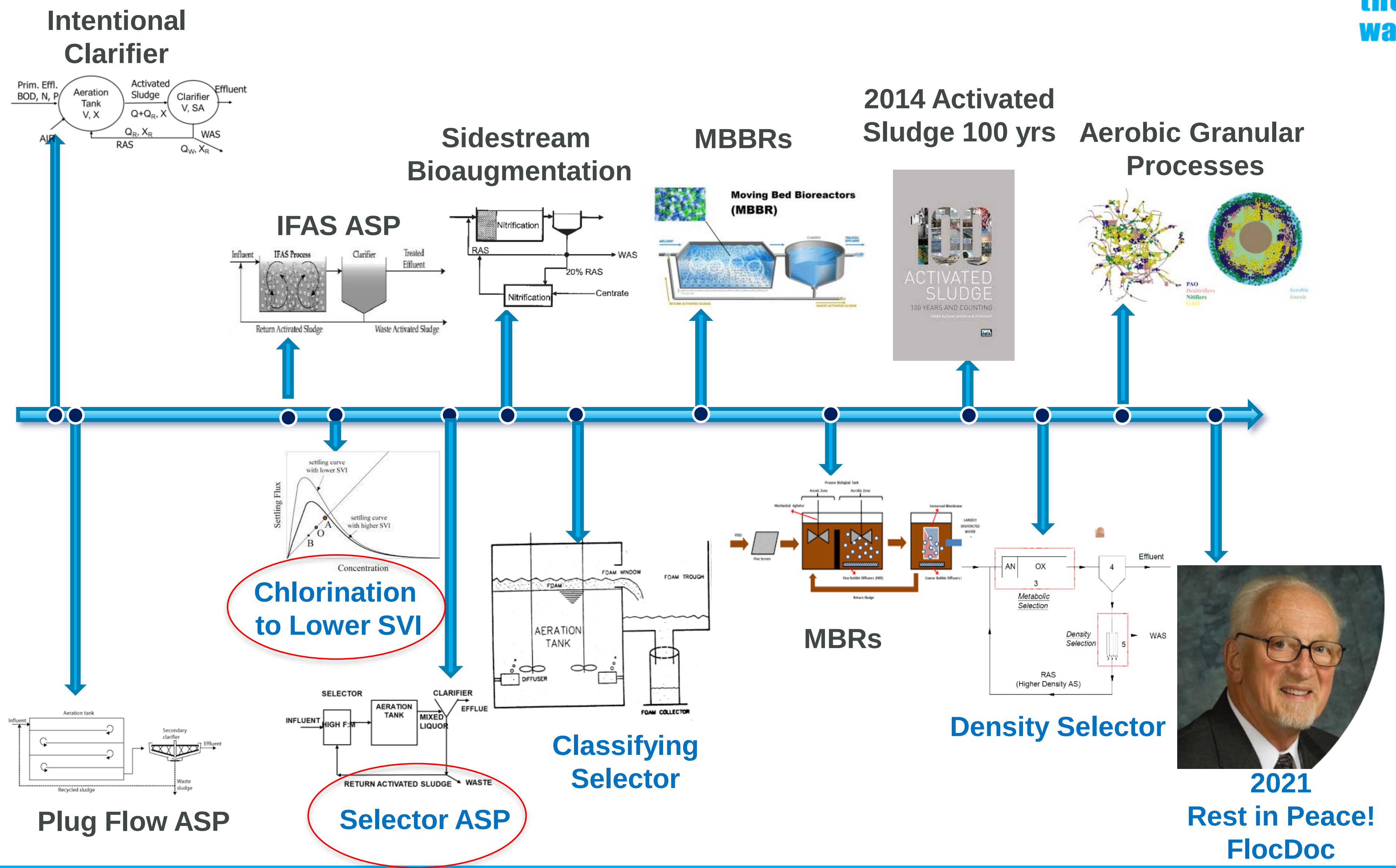
- Make it more mechanical and advanced for resource recovery
    - e.g., AGS, MBRs, MBBRs, C/N/P recovery ASPs

Intensification of Activated Sludge Process

- Add clarifier and biomass recycle
- Pure oxygen instead of air
- Plug flow versus CSTR
- High biomass conc/Flux rates
- Integrated fixed film systems
- Increase settleability of biomass
- Sidestream bioaugmentation
- Surface wasting to eliminate oaming
- Membrane bioreactors/MBBRs
- Density selection through hydrocyclones
- Granular processes



Developments in Intensification and/or Densification of Activated Sludge Process



Classifying Bacteria to Solve Foaming and Separation Problems

KRISHNA PAGILLA, PHD, PE
UNIVERSITY OF NEVADA, RENO, USA

University of Nevada, Reno

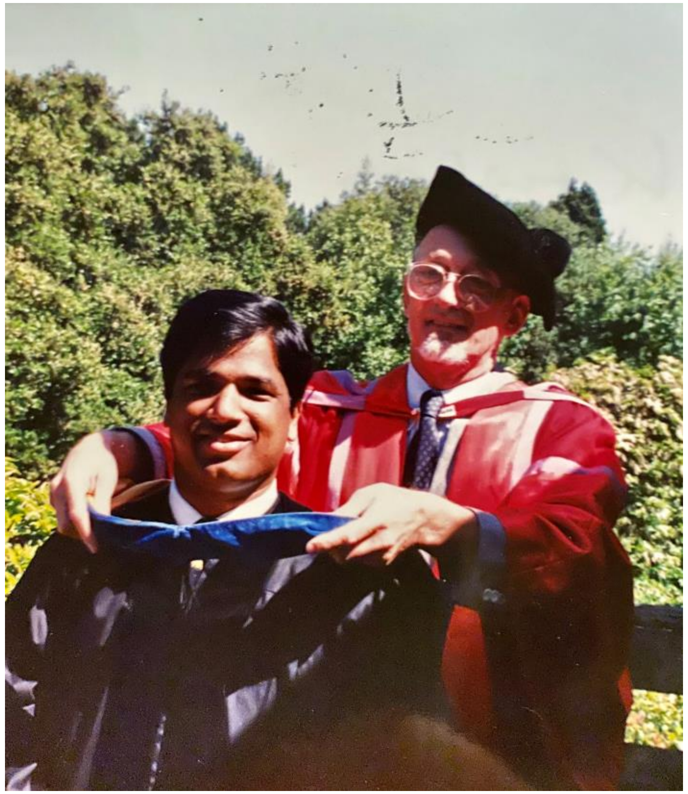
In Memory of Prof. David Jenkins

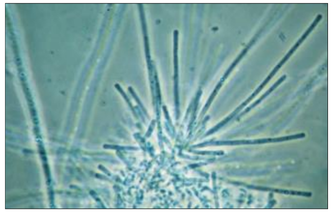
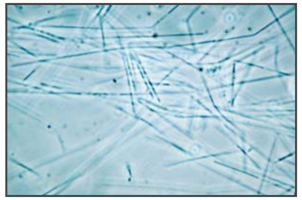
David Jenkins
1935 -2021

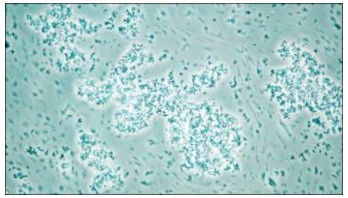
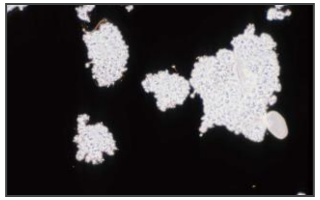
"Floc-Doc"
UC Berkeley 1962-

My time at Berkeley –
1989 – 1994

Activated Sludge,
Filaments, Flocs,
Microscopy, Selectors,
Selective Wasting,
Waste Sludge
Chlorination, EBPR,
Water Chemistry



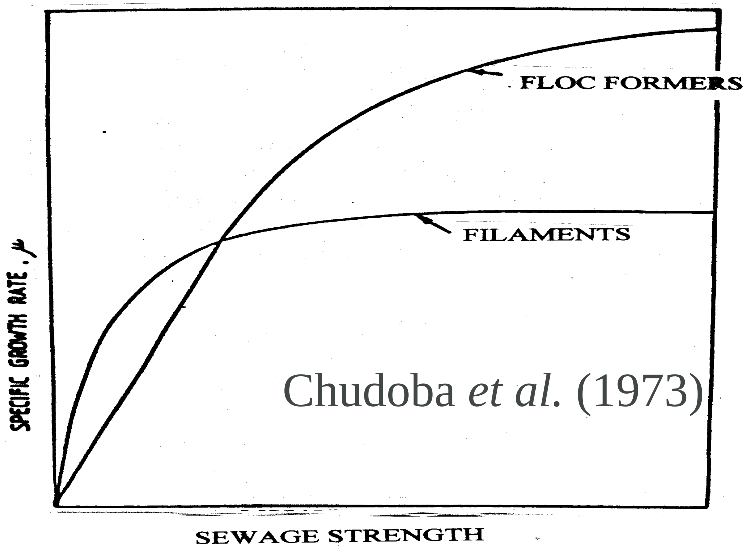



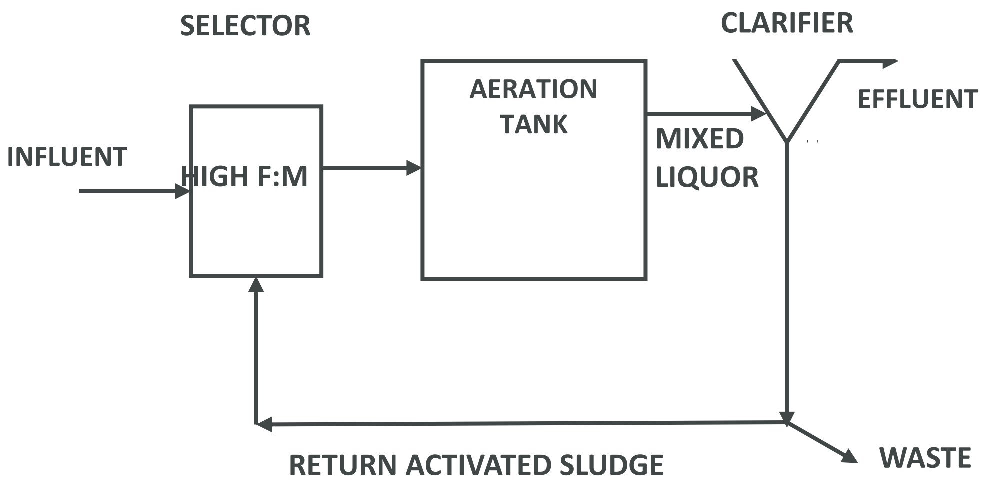
Activated Sludge Foaming and Bulking

- **BULKING**
  - TOO MANY FILAMENTS
  - HIGH SVI, CLEAR SUPERNATANT
- **PIN POINT FLOC**
  - LACK OF FILAMENTS
  - LOW SVI, TURBID EFFLUENT
- **RISING SLUDGE**
  - DENITRIFICATION PRODUCING NITROGEN GAS
  - LARGE CLUMPS OF RISING SLUDGE
  - HIGH SOLIDS INVENTORY IN CLARIFIER
- **FOAMING**
  - CHOCOLATE-COLORED STABLE FOAM
  - *GORDONA* OR *MICROTHRIX* BACTERIA
  - SMALLER FILAMENTOUS BACTERIA (<50 µm)

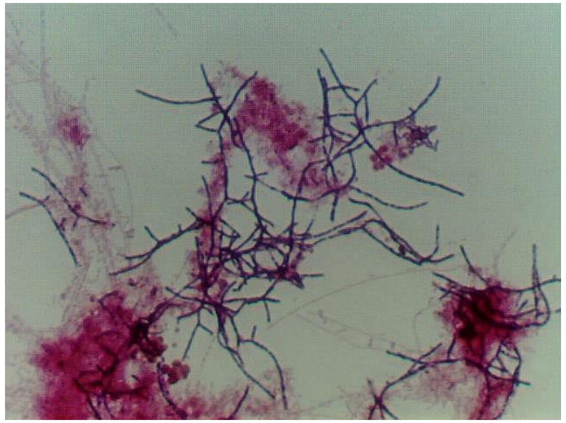
Jenkins *et al.* (1993)



Kinetic/Metabolic Selectors

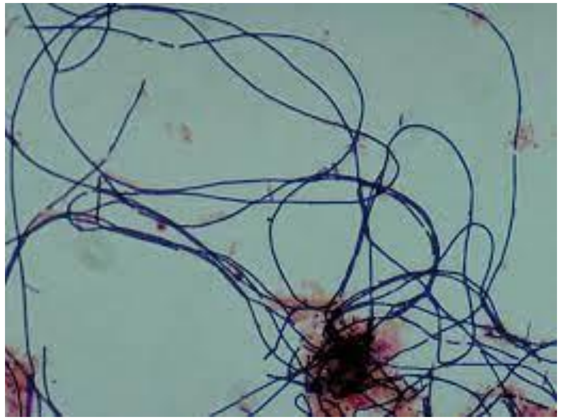


Activated Sludge Foaming and Control



Gordona amarae

Activated Sludge Foam



Microthrix parvicella

FOAMING EFFECTS

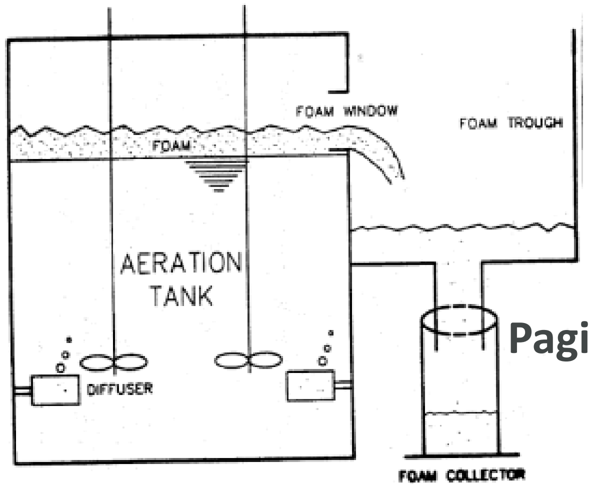
- Loss of Foam Solids – High Eff TSS
- Low MLSS in Aeration Tanks (Densification Loss)
- Foam in Aeration Tanks – Low Oxygen Transfer
- Scum/Sludge Pump Cavitation
- Anaerobic Digester Foaming
- Unsafe and Unsightly Conditions Due to Foam

BULKING VERSUS FOAMING ISSUES

- Activated Sludge Foaming - Excessive *Gordona* or *Microthrix*
- Filamentous Bulking Control Strategies Do Not Work
- *Gordona* Are Embedded in the Flocs (Not Extended Out) and Chemical Treatment Does Not Work
- Biological Selectors Do Not Work Well
- *Gordona* Foaming is Common Even Low Mean Cell Residence Time
- Foam Trapping Enables *Gordona*/*Microthrix* Persistence in AS

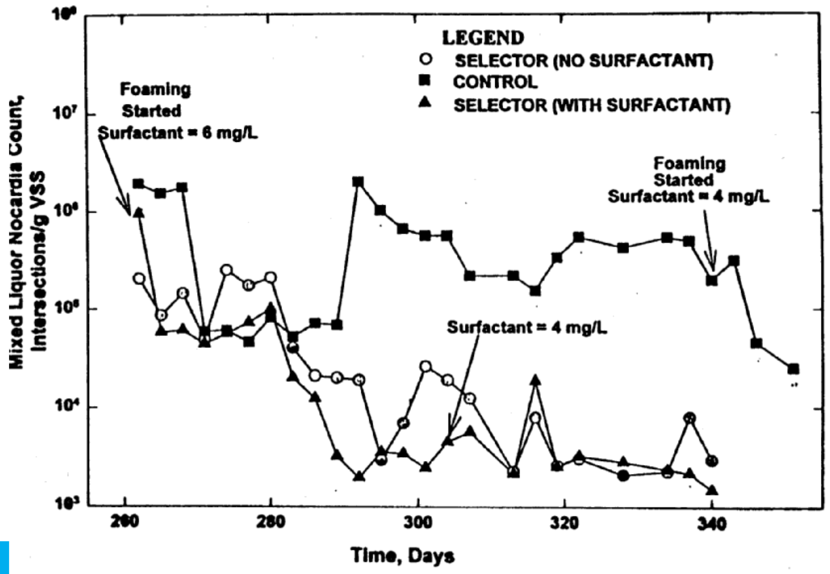
Classifying Selector for Foaming Control

- Works on the Principle of Selective Foam Wasting From the Surface of the Tank _ Selecting Out Nuisance Organisms
- Waste Foam at a Faster Rate Than Accumulation/Growth Rate
- Foam Solids SRT or MCRT is Higher than Activated Sludge SRT
- Do Not Recycle Foam to the Plant or Feed to the Digesters (Foam Trapping)
- Best to have the Classifying Selector System on RAS and Aeration Tank Mixed Liquor Channels

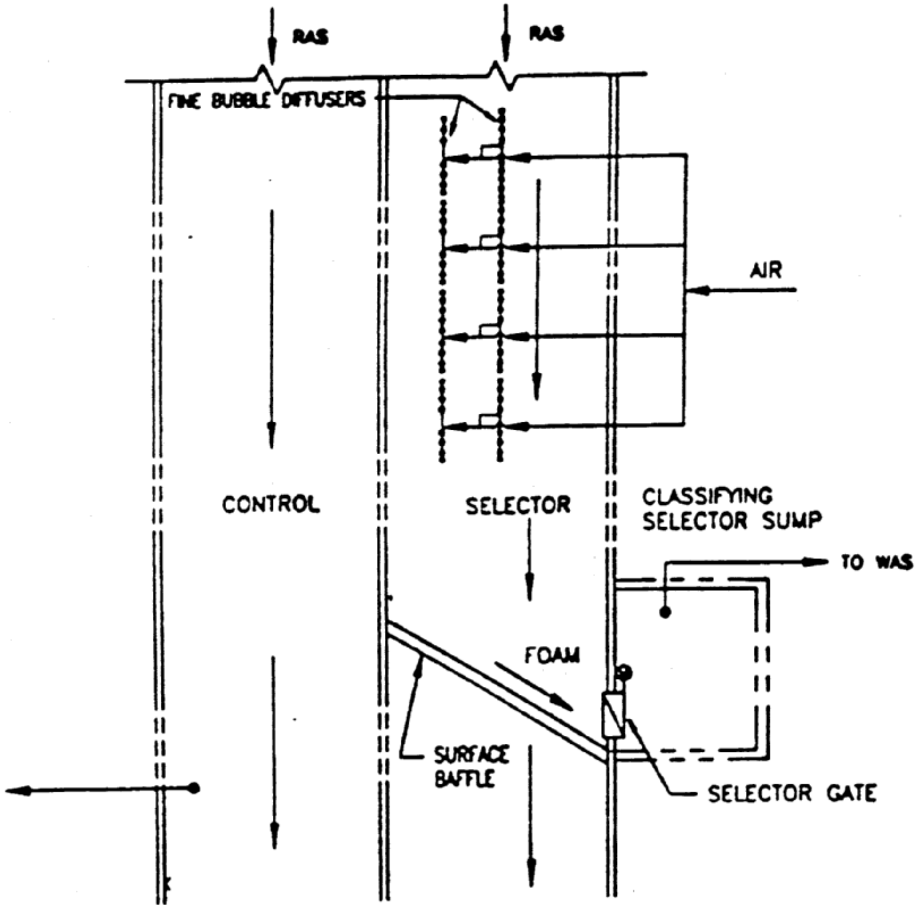


Pagilla et al., 1996, WER

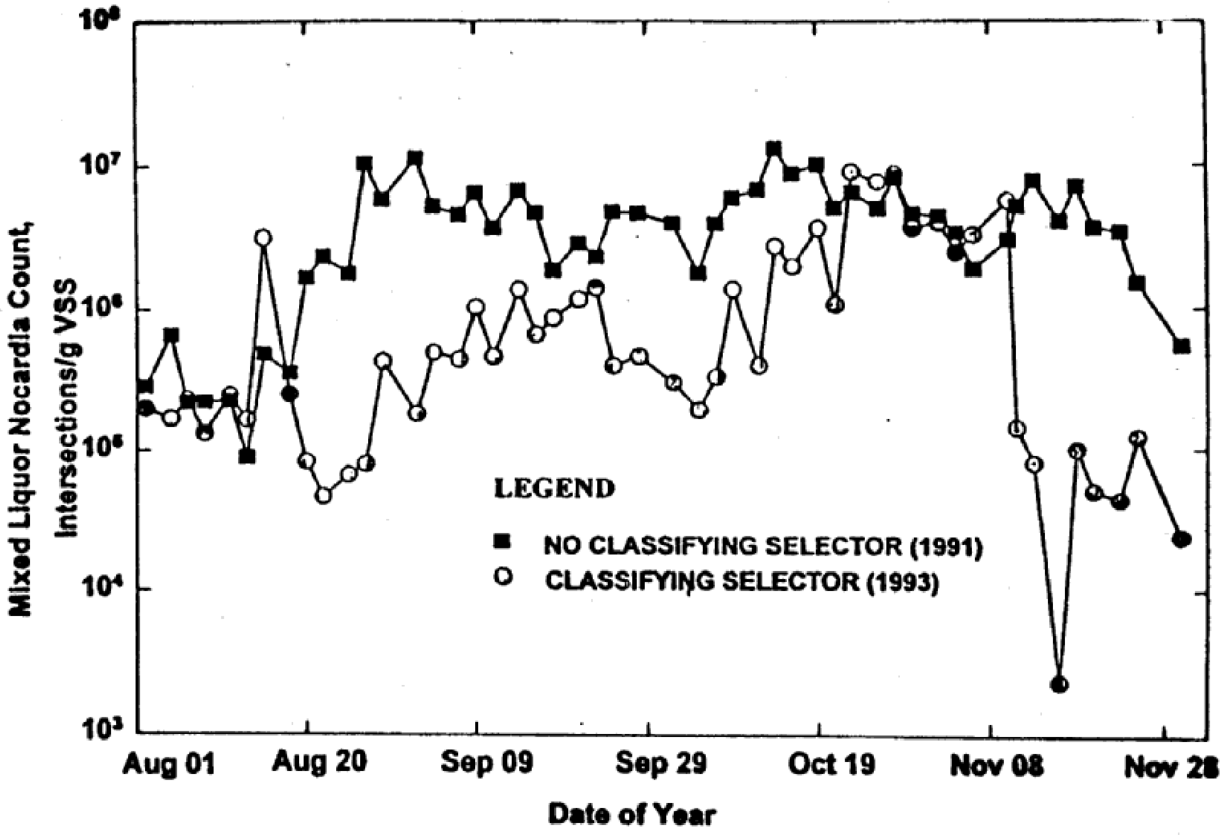
Lab Scale Classifying Selector



Full Scale Classifying Selector for Foaming Control



Full Scale Classifying Selector



Pagilla et al., 1996, WER

Density Selector for PAOs in Enhanced Biological P Removal – Classification Again!

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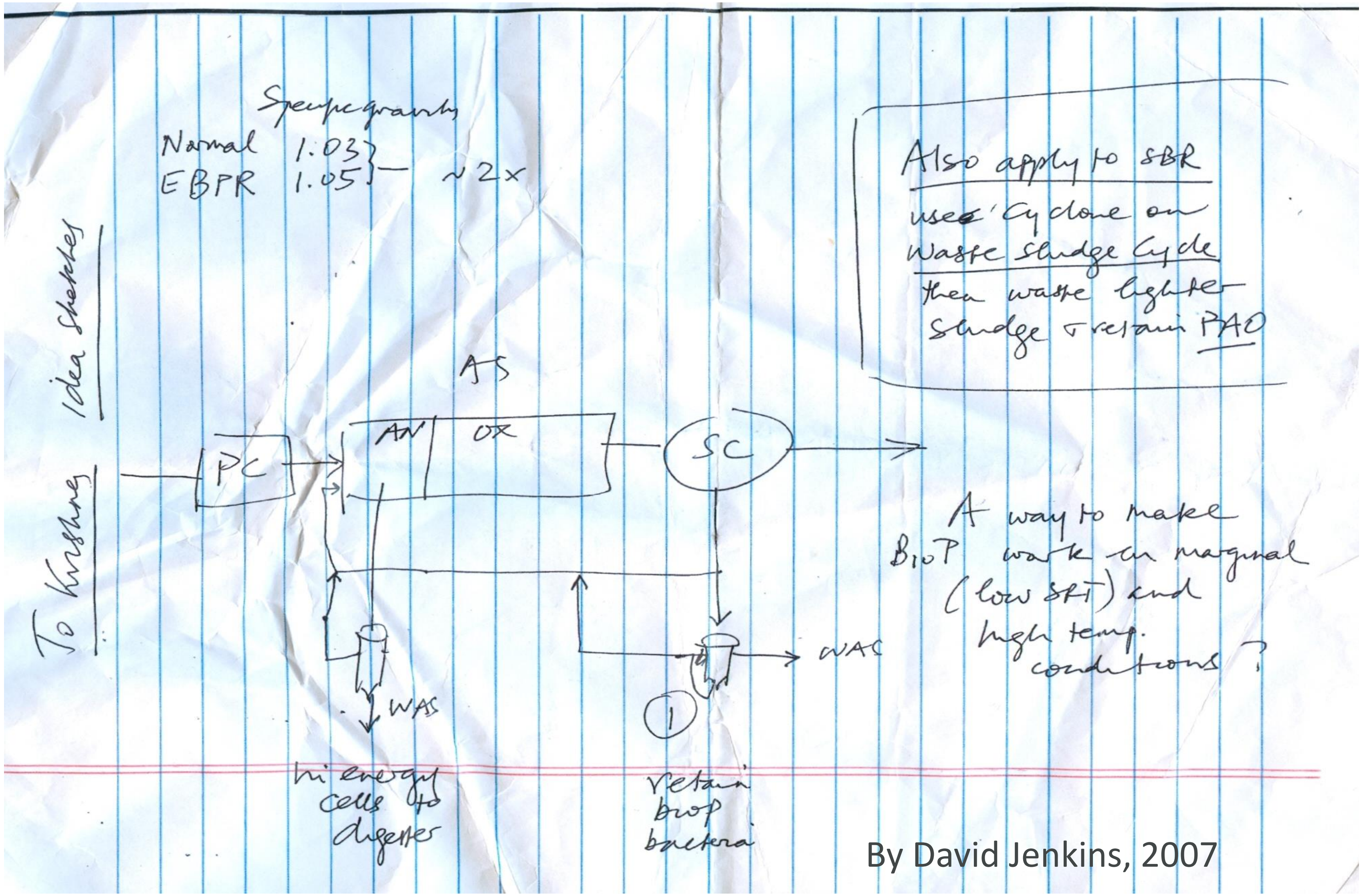
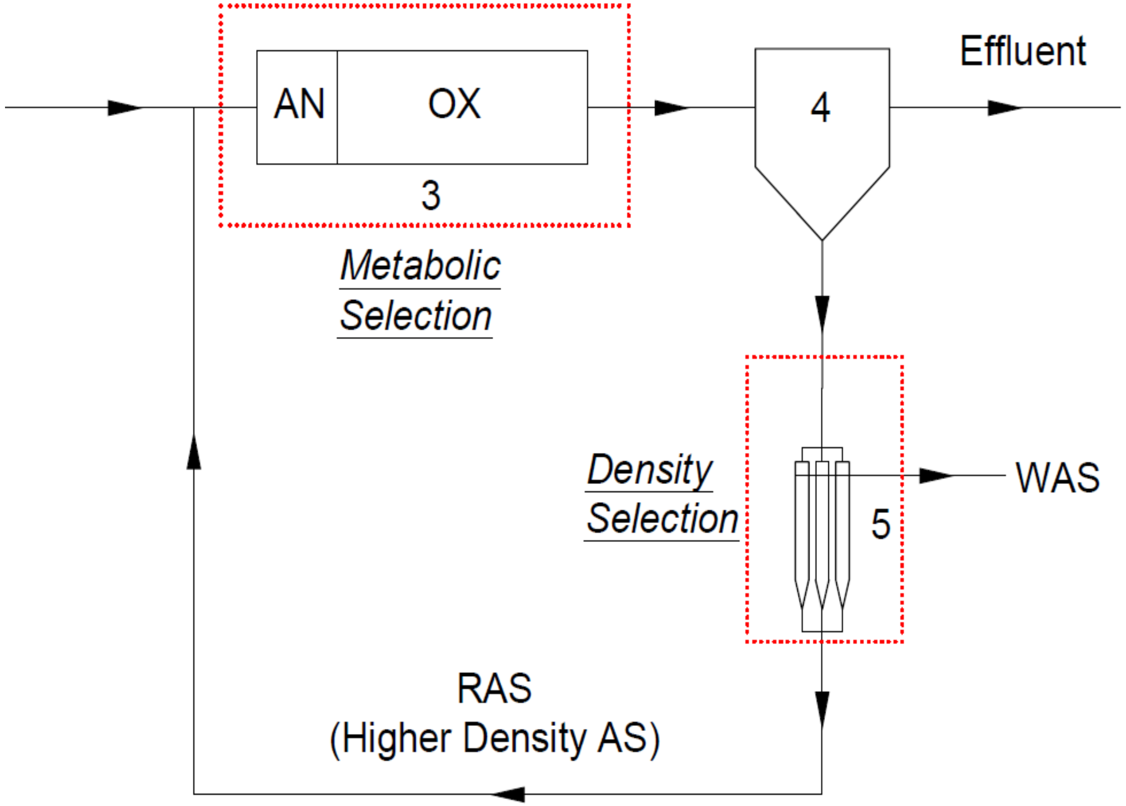
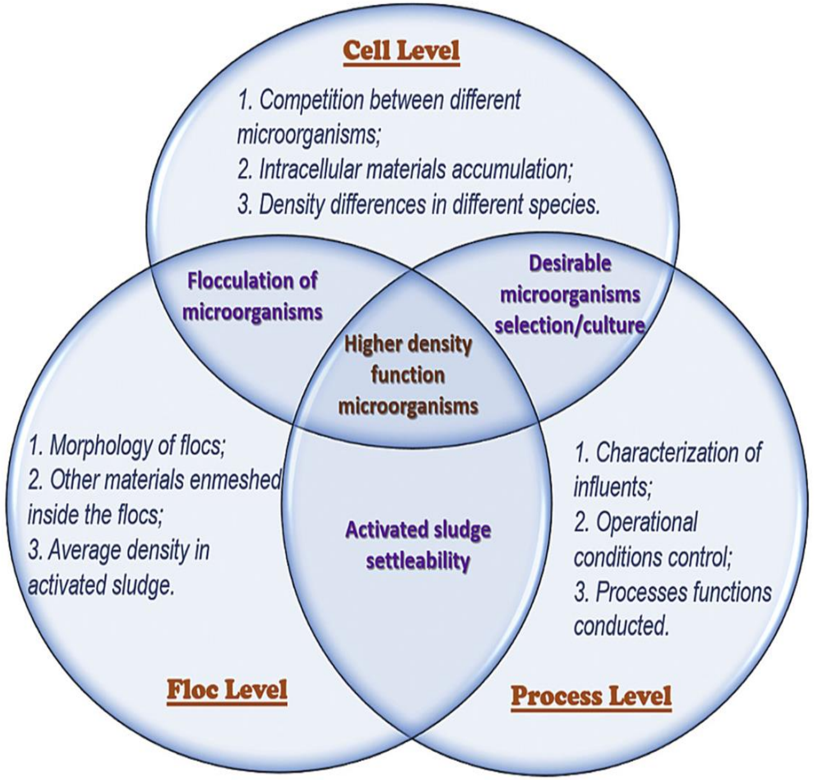


By David Jenkins, 2007

Biomass Density- Function Relationships in AS Process

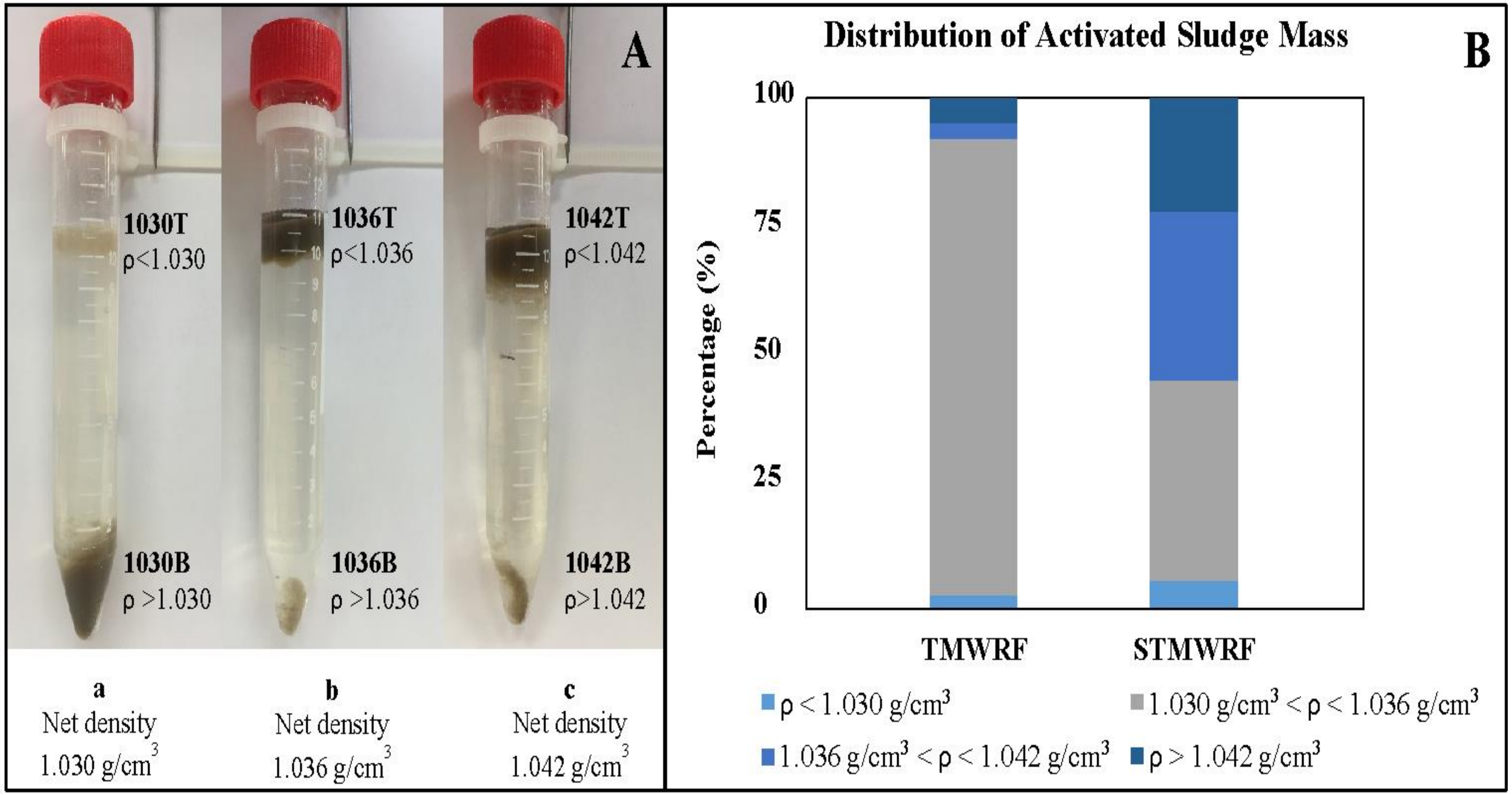


Density Selector for AS Biomass



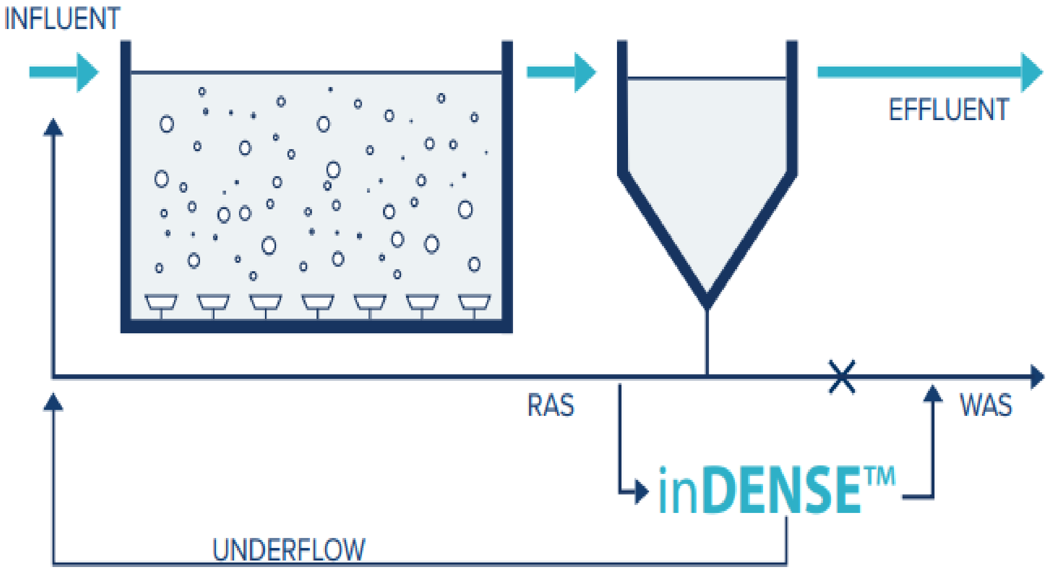
Li and Pagilla 2017, Water Res.

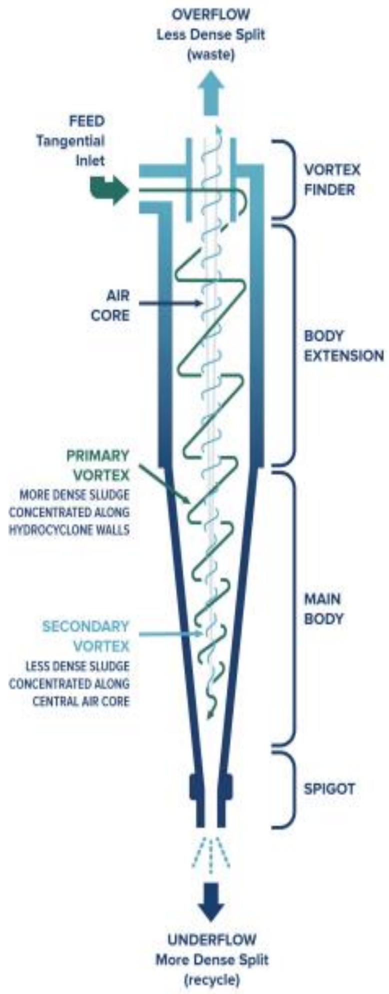
Biomass Separation by Percoll (Density) Method



Li et al., 2020, IJERPH

inDENSE Process (World Water Works)





More Possibilities for Selection

- Membranes
- Packed Bed Granular Reactor (?)
- Anaerobic Carbon Capture
- Electrochemical Systems
- What drives future developments in densification and intensification?
  - Net-zero emissions, resource recovery?

IWA-LET.ORG

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The 17th IWA Leading Edge Conference on Water and Wastewater Technologies (LET 2022)

March 27 – April 2, 2022

Nugget Resort, Reno-Sparks, Nevada, USA

University of Nevada, Reno

Co-Hosts

University of Nevada, Reno

Nevada Water Innovation Institute

International Water Association

University of Nevada, Reno

Lake Tahoe

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Consideration of biomass density to improve activated sludge settling

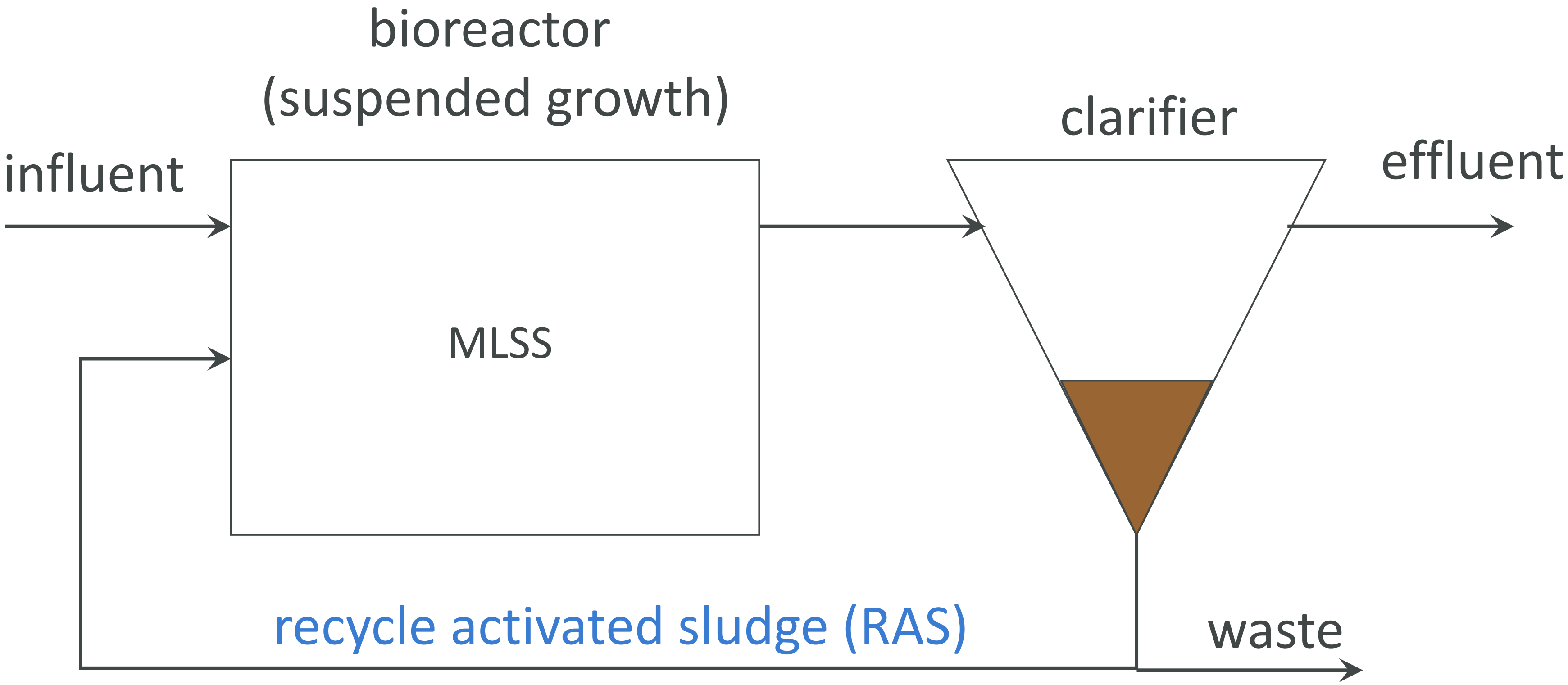
ANDREW SCHULER, PHD, PE

UNIVERSITY OF NEW MEXICO

UNM SCHOOL OF ENGINEERING

inspiring change

SETTLING AND INTENSIFICATION



Better settling → more concentrated RAS → greater clarifier capacity → increased mixed liquor suspended solids (MLSS)

"CONVENTIONAL" FACTORS KNOWN TO AFFECT SETTLING

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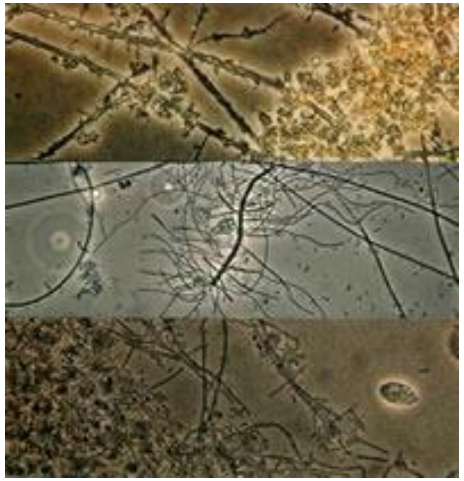
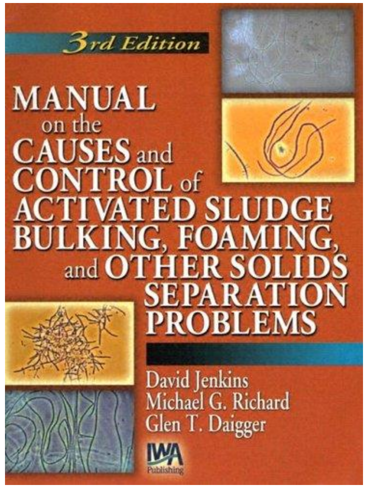
- Filaments!
- Floc shape, size
- Process parameters:
  - Dissolved oxygen, F/M ratio, pH, temperature, etc.





MOTIVATION:
CONSIDER THE FORCES ON A SETTLING FLOC

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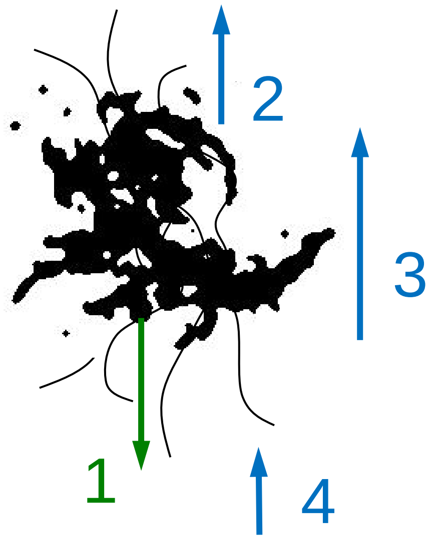
Driving force:

1. Weight of floc (density - previously neglected)

Resistance forces:

2. Weight of displaced H_2O
3. Drag forces
   (viscous, momentum)
4. Compressive resistance
   (floc deformation)

Filaments



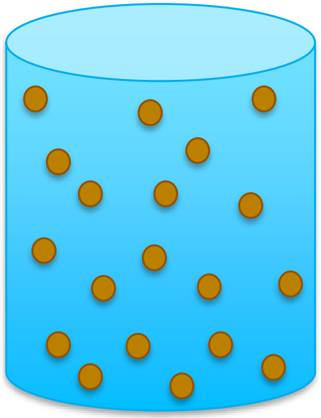
LET'S DEFINE SOME TERMS

- **Density** = mass/volume… but which volume?

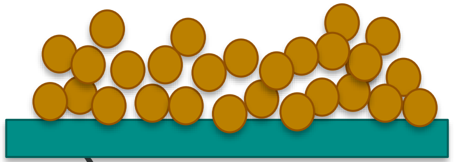
- 1. Mass per bulk volume = concentration

a dense solution

(high concentration)



a dense biofilm



(high local concentration)

- **Densification** commonly used to mean **increasing concentration** (an unfortunate term!)

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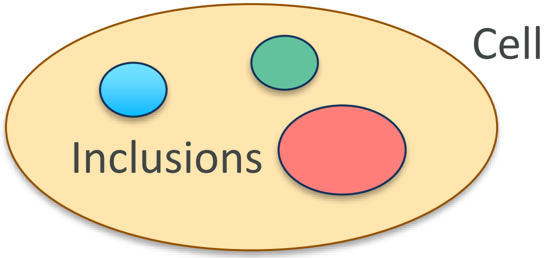
- 2. In physics, materials science etc.:

  Density (ρ) = mass/particle volume

ρ sand = 2.65 g/cm^3

- In our world: ρ = mass/cell, floc, or other biomass volume

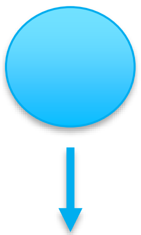


In this talk "density" means particle density

- **Densification** ≠ increasing particle density

ANOTHER TERM: BUOYANT DENSITY

- The simplest case: discrete settling velocity of a sphere (Stokes):



$$v = \frac{d^2 \boxed{(r_P - r_L)} g}{18m}$$

buoyant density =
particle density ($\boldsymbol{\rho}_p$) - liquid density ($\boldsymbol{\rho}_L$)

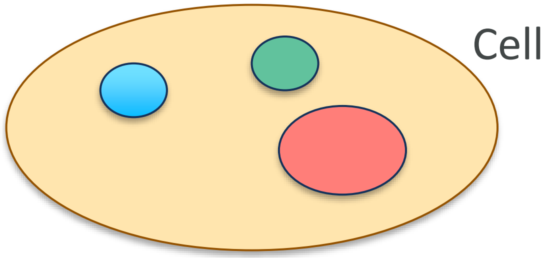
$\boldsymbol{\rho}_L$ = 1 g/mL in our case

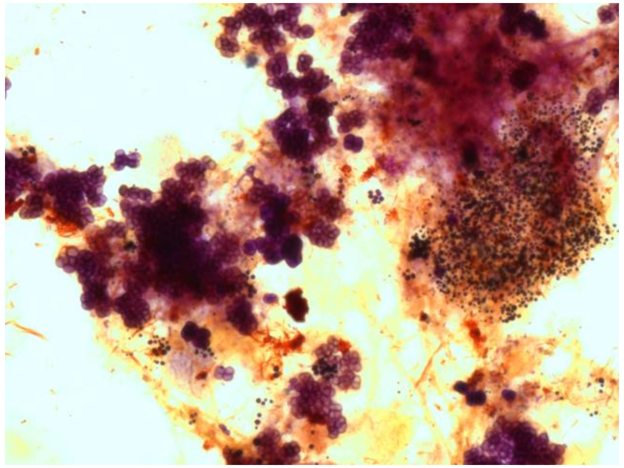
Buoyant density = net driving force of sedimentation

Linear relationship:
If you double buoyant density, you double settling velocity (true for discrete, hindered, and compression settling).

WHY WOULD BIOMASS DENSITY VARY?

- Microbial storage products are more dense than typical biomass
  - Typical activated sludge ~ 1.03-1.06 g/mL*
  - Polyphosphate density ~ 1.23 g/mL



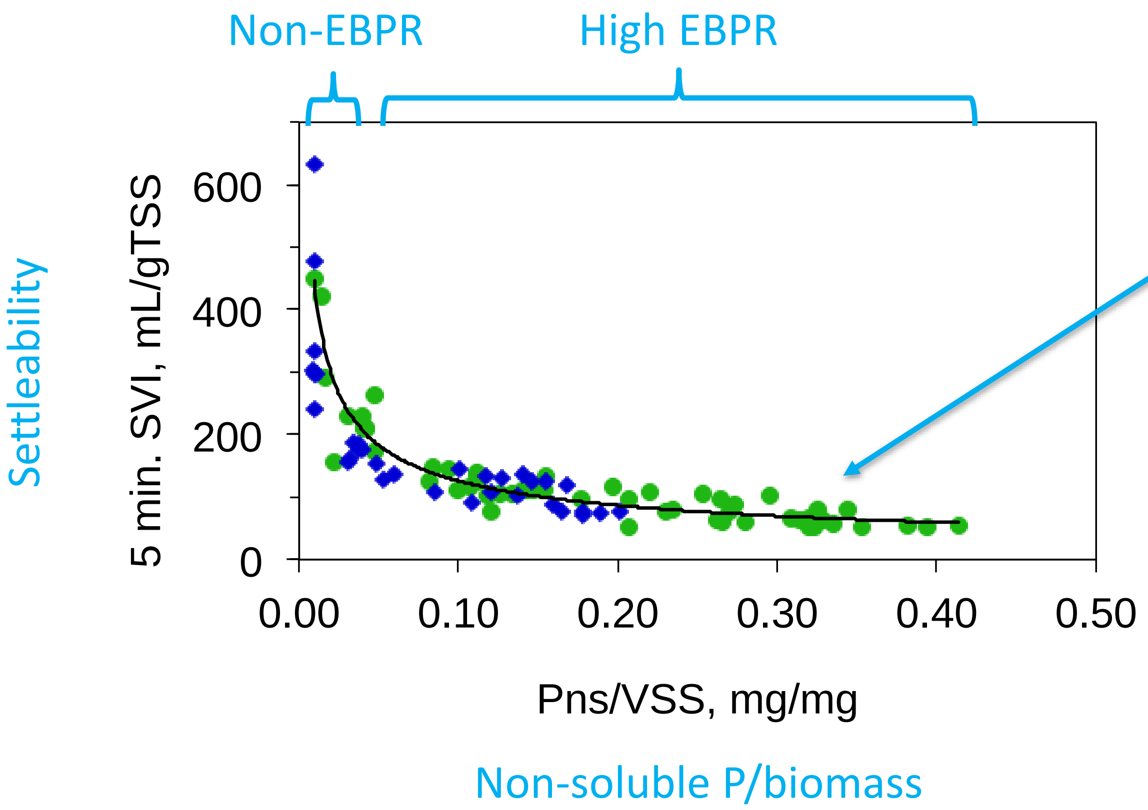


Neisser (polyphosphate) stain of activated sludge floc

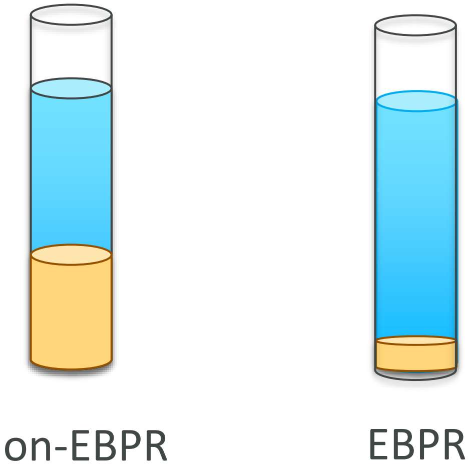
*Dammel and Shroeder, 1991, *Water Res.* 25(7) 841-845

THE BEGINNING: SERENDIPITOUS OBSERVATIONS IN PAO/GAO LAB STUDY (PHD WITH JENKINS)

the international water association



Daily manual wasting from reactors: Enhanced Biological Phosphorus Removal (EBPR) biomass settled like a rock!

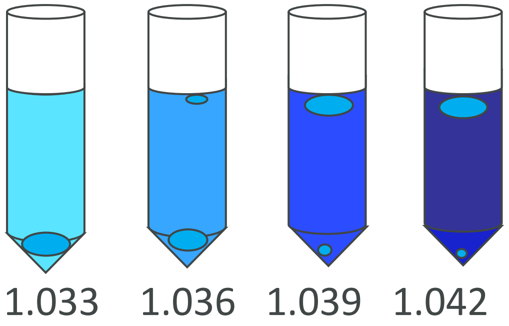


Schuler, Jenkins, and Ronen (2001) Microbial storage products, biomass density, and settling properties of enhanced biological phosphorus removal activated sludge, *Wat. Sci. Technol*. 43(1) pp 173-180.

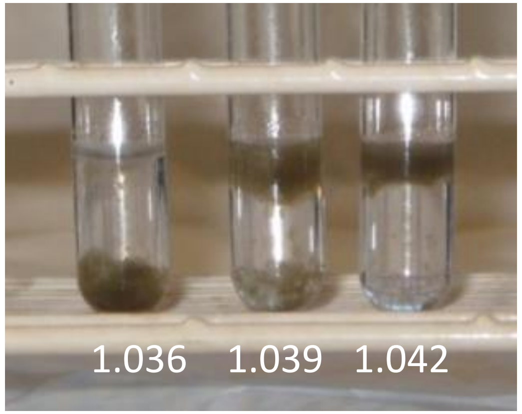
DEVELOPMENT OF DENSITY MEASUREMENT METHOD

the international water association

- Series of solutions with a range of densities (dilutions of silica particle solution Percoll), add biomass and centrifuge (improvement on gradient method).



Solution density, g/mL



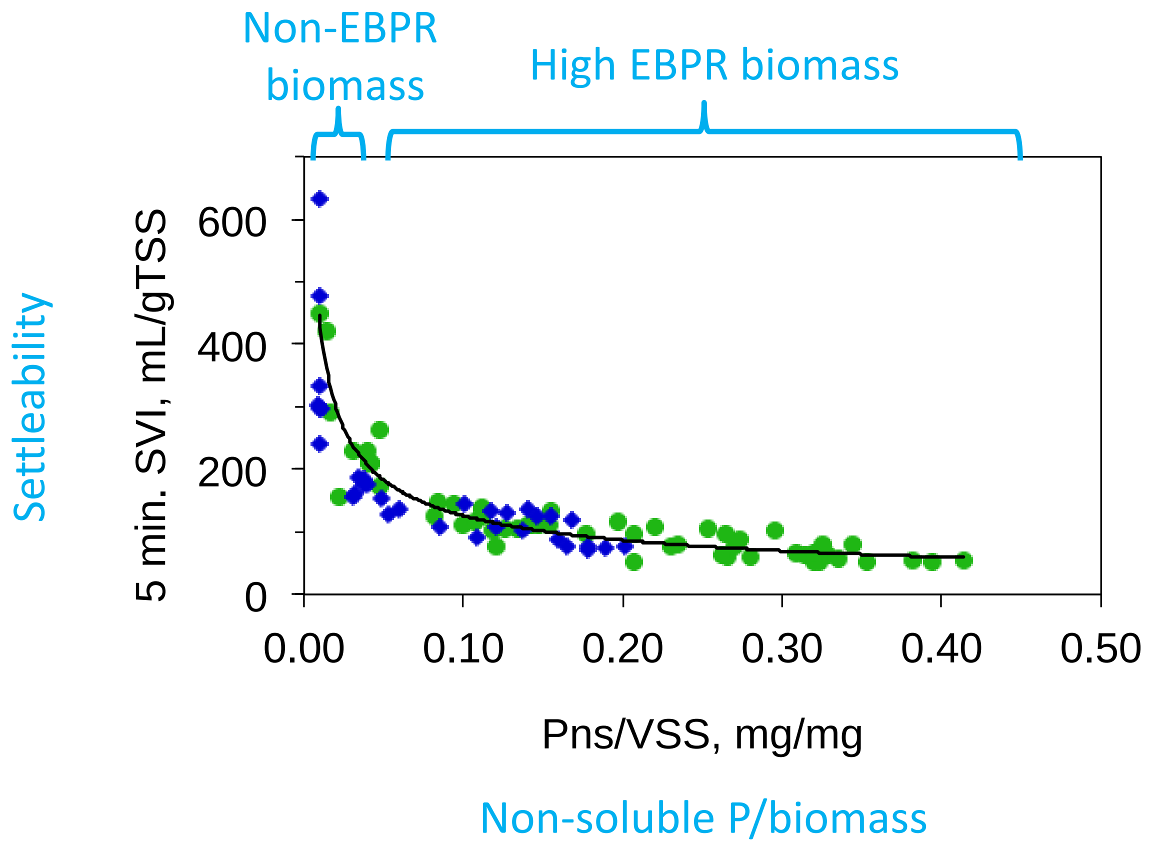
Solution density, g/mL

- Interpolate biomass density

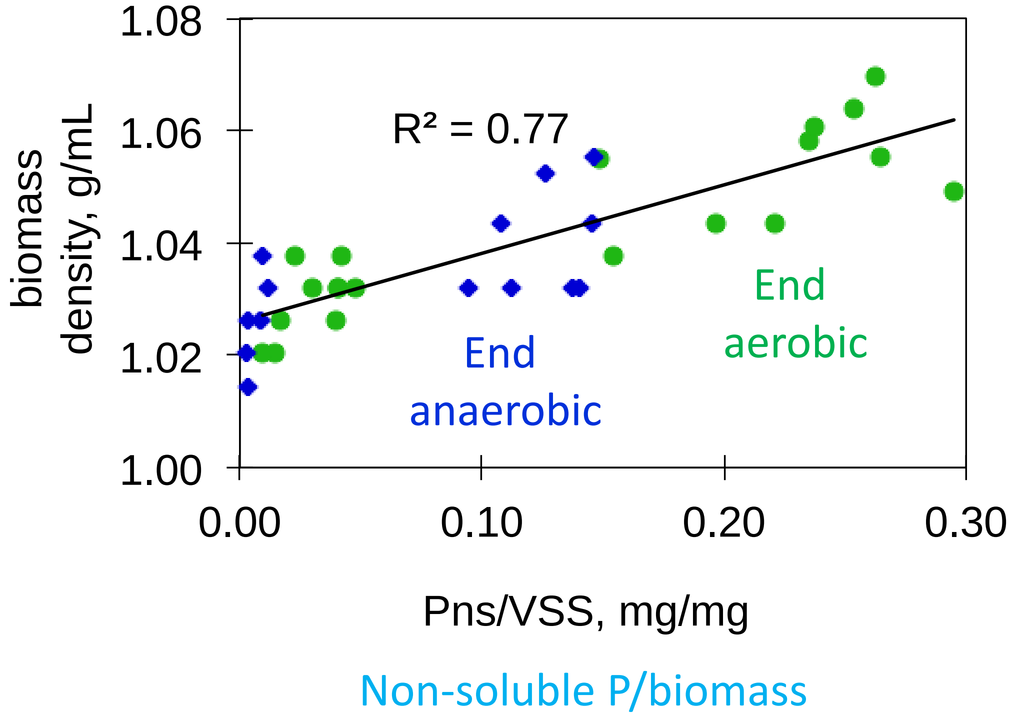
Jang, H., A.J. Schuler (2007). The case for variable density: A new perspective on activated sludge settling. *Water Environ. Res.* 79(11): 2298-2303.

THE BEGINNING: SERENDIPITOUS OBSERVATIONS IN PAO/GAO LAB STUDY (THESIS WITH JENKINS!)

the international water association



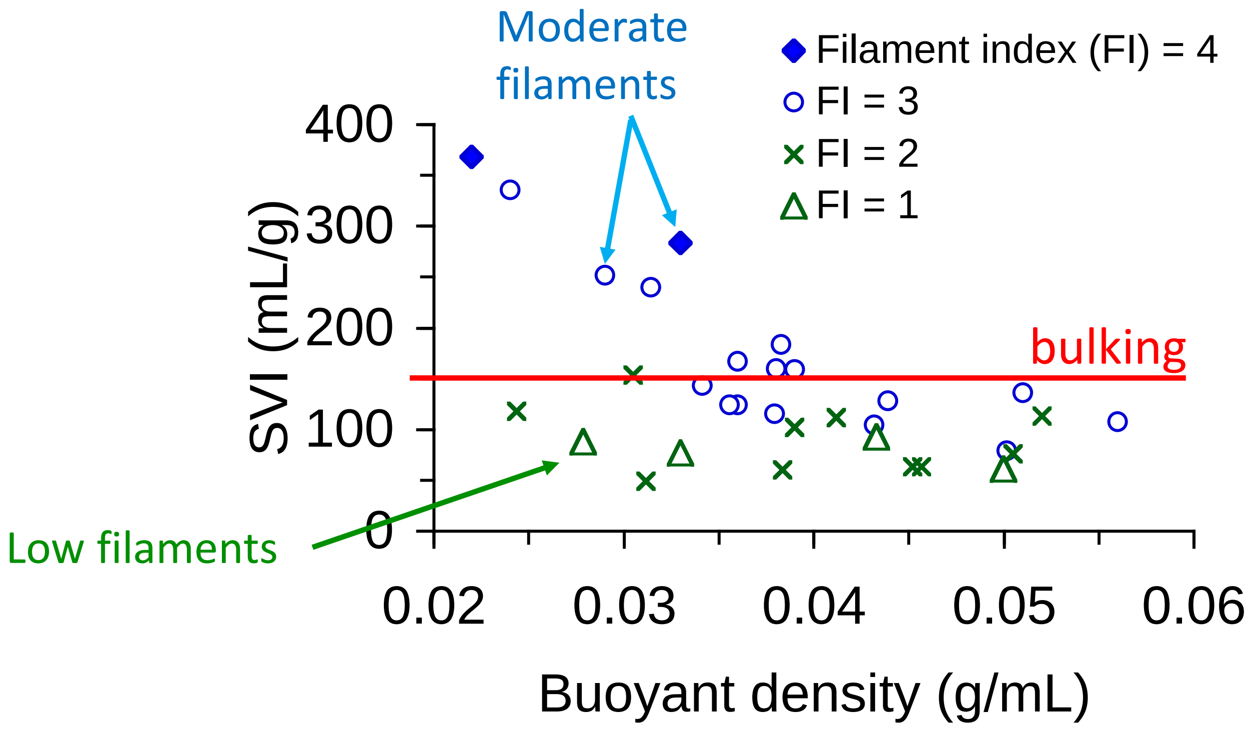
Density correlated with biomass P content (polyphosphate)



Schuler, Jenkins, and Ronen (2001) Microbial storage products, biomass density, and settling properties of enhanced biological phosphorus removal activated sludge, *Wat. Sci. Technol*. 43(1) pp 173-180.

FILAMENTS AND DENSITY ARE SYNERGISTIC
17 FULL SCALE SYSTEMS

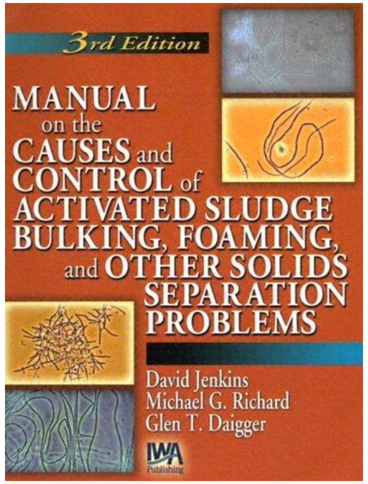
the international water association



- Low filaments: density has weak effect
- Moderate filaments (3 or 4): strong effect

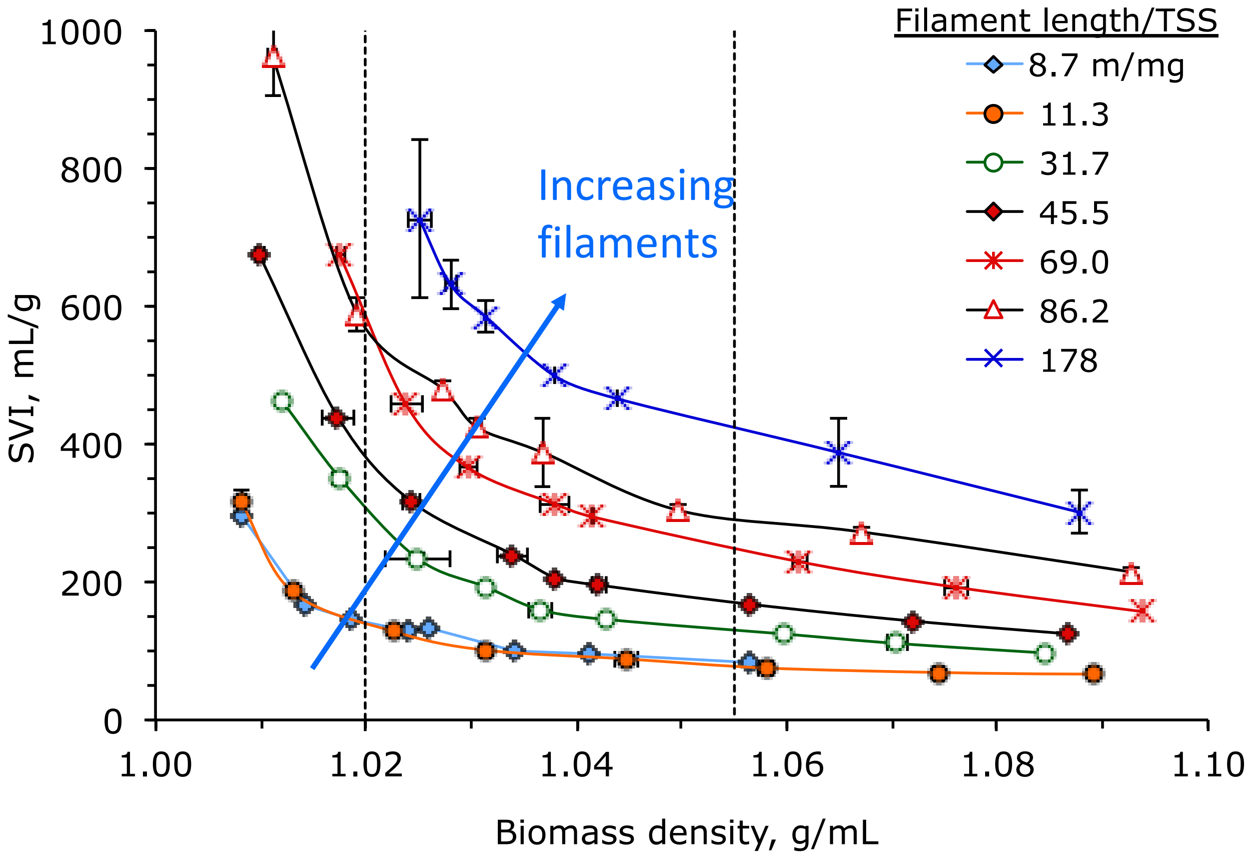
Filament Index Scale

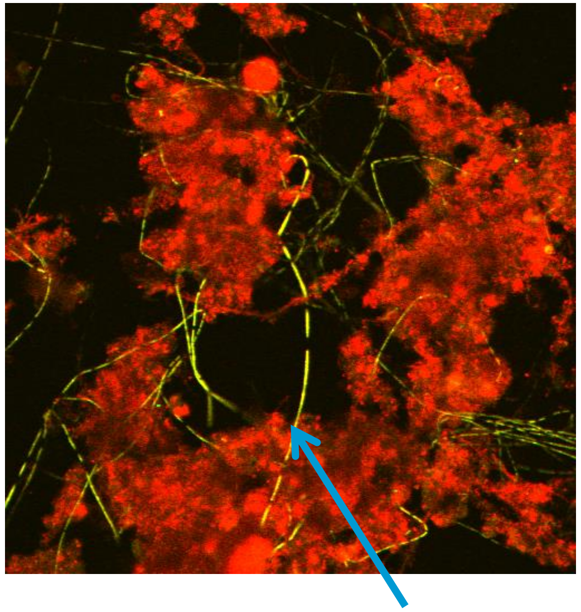
Low | Moderate
- 0: none
- 1: few
- 2: some
- 3: common
- 4: very common
- 5: abundant
- 6: excessive



Schuler and Jang (2007). Causes of variable biomass density and effects on settling in full scale biological wastewater treatment systems. *Environ. Sci. Technol.* 41(5); 1675-1681.

QUANTIFYING COMBINED FILAMENT AND DENSITY EFFECTS ON SETTLING





Lab reactors enriched for *Sphaerotilus natans*

Density varied with synthetic microspheres. Filaments measured with hemacytometer.

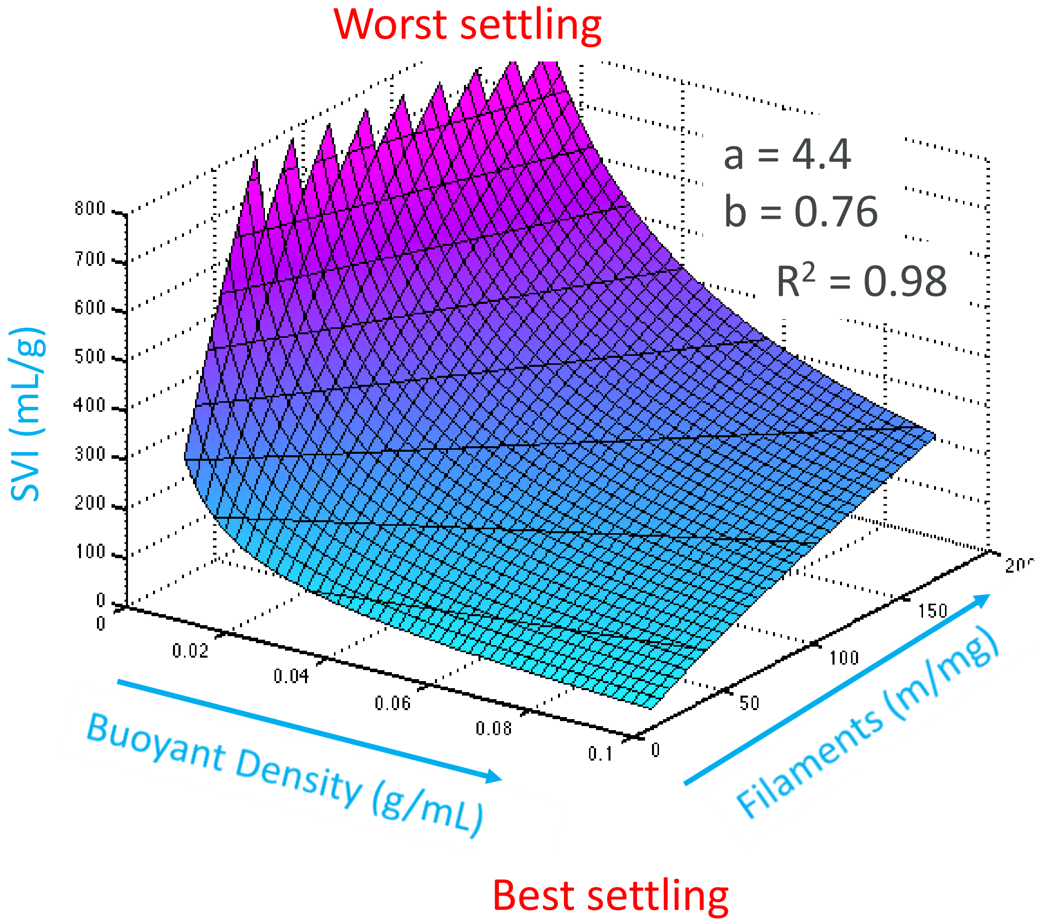
Jassby, D., Y. Xiao, A.J. Schuler (2014). Biomass density and filament length synergistically affect activated sludge settling: Systematic quantification and modeling. *Water Res*. 48:457-465.

CONSIDERATION OF DENSITY ENABLED DEVELOPMENT OF MATHEMATICAL MODEL TO PREDICT SVI

Proposed model

$$SVI = \left(\frac{a + F}{BD}\right)^{b}$$

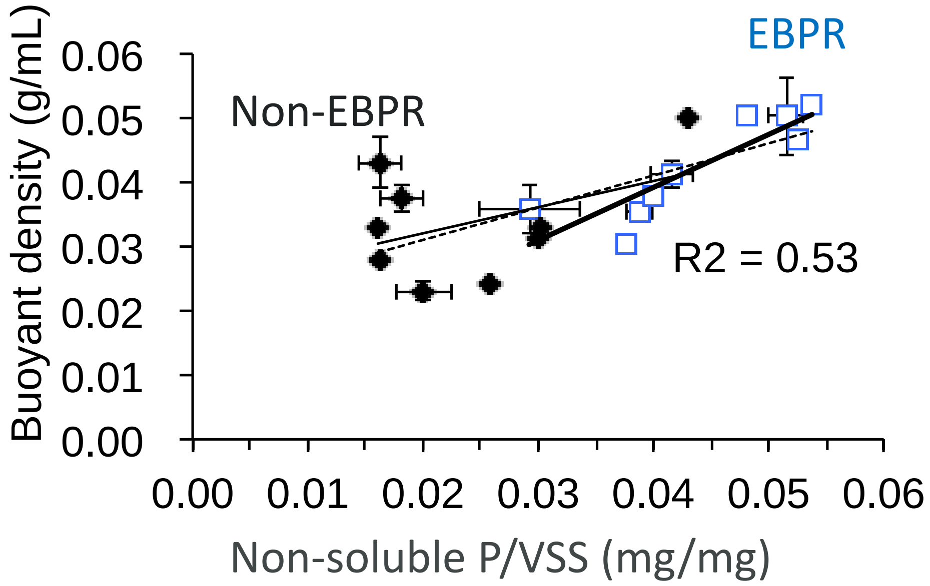
a,b – constants
F – filament content (m/mg)
BD – buoyant density (g/mL)



Jassby, D., Y. Xiao, A.J. Schuler (2014). Biomass density and filament length synergistically affect activated sludge settling: Systematic quantification and modeling. *Water Res*. 48:457-465.

WHAT DETERMINES DENSITY IN FULL SCALE SYSTEMS?

17 full scale systems

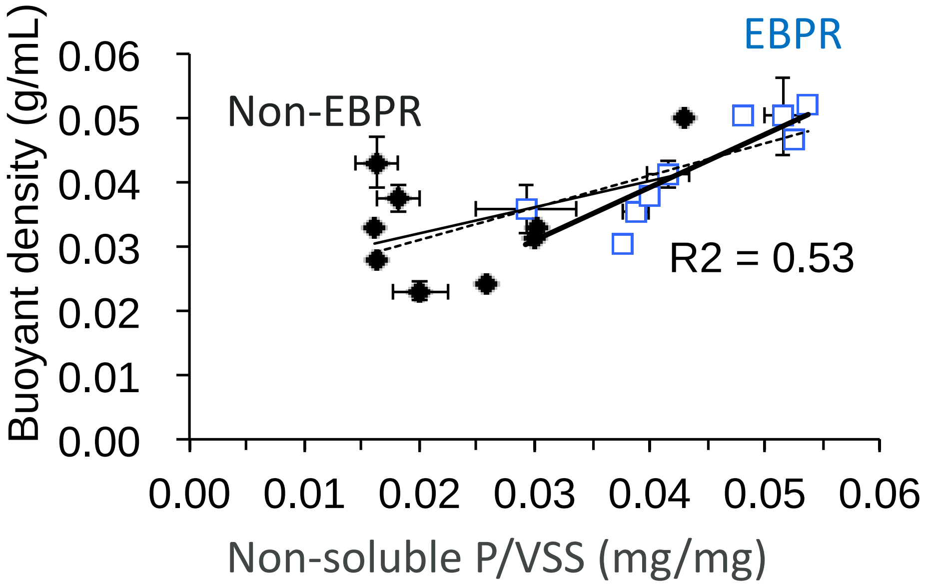


Biomass P content

Schuler and Jang (2007). Causes of variable biomass density and effects on settling in full scale biological wastewater treatment systems. Environ. Sci. Technol. 41(5); 1675-1681.

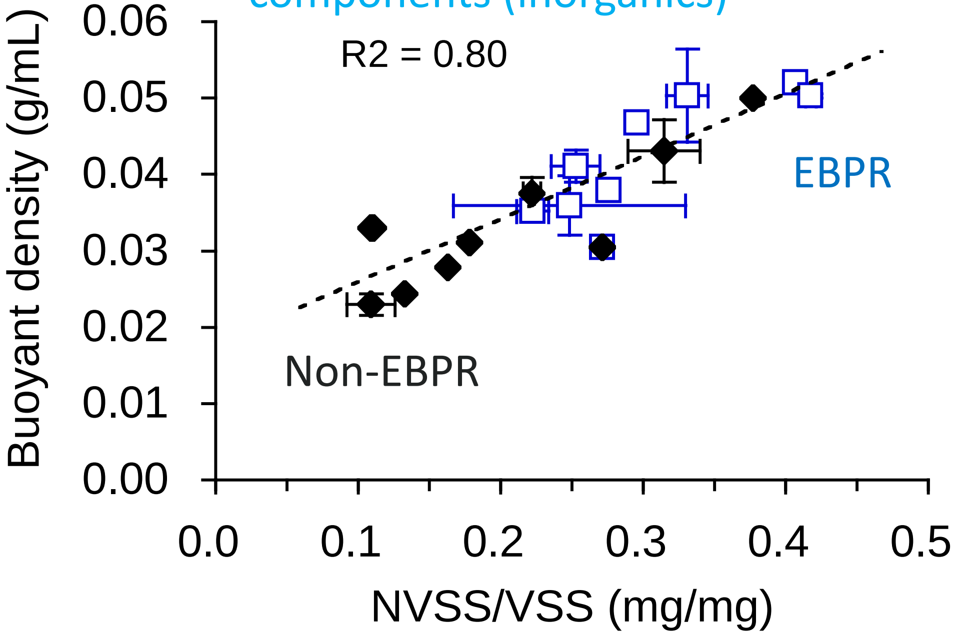
WHAT DETERMINES DENSITY IN FULL SCALE SYSTEMS?

17 full scale systems



Biomass P content

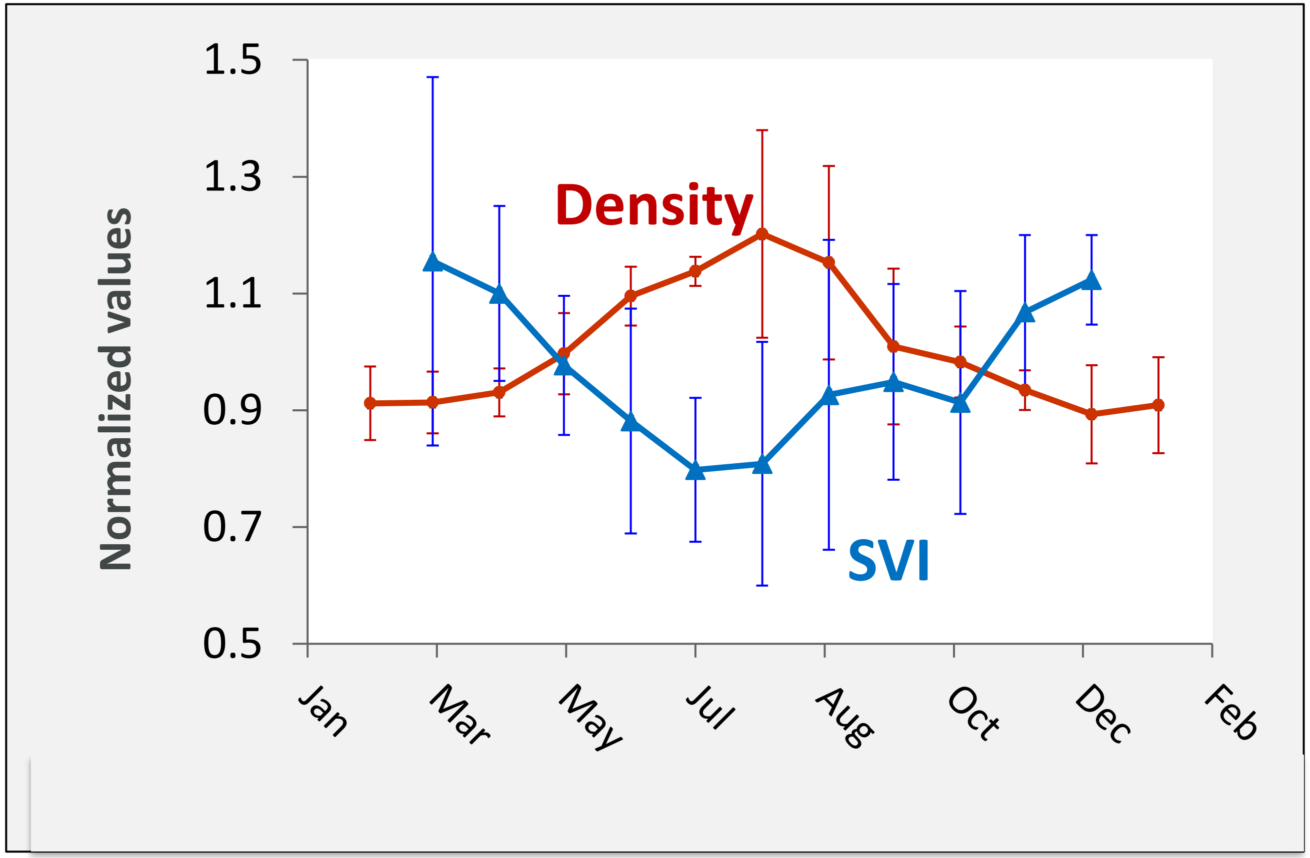
NVSS a better predictor of density than biomass P: includes other high density components (inorganics)



NVSS = non volatile SS = TSS - VSS
"inorganic" fraction of biomass
includes polyphosphate

Schuler and Jang (2007). Causes of variable biomass density and effects on settling in full scale biological wastewater treatment systems. Environ. Sci. Technol. 41(5); 1675-1681.

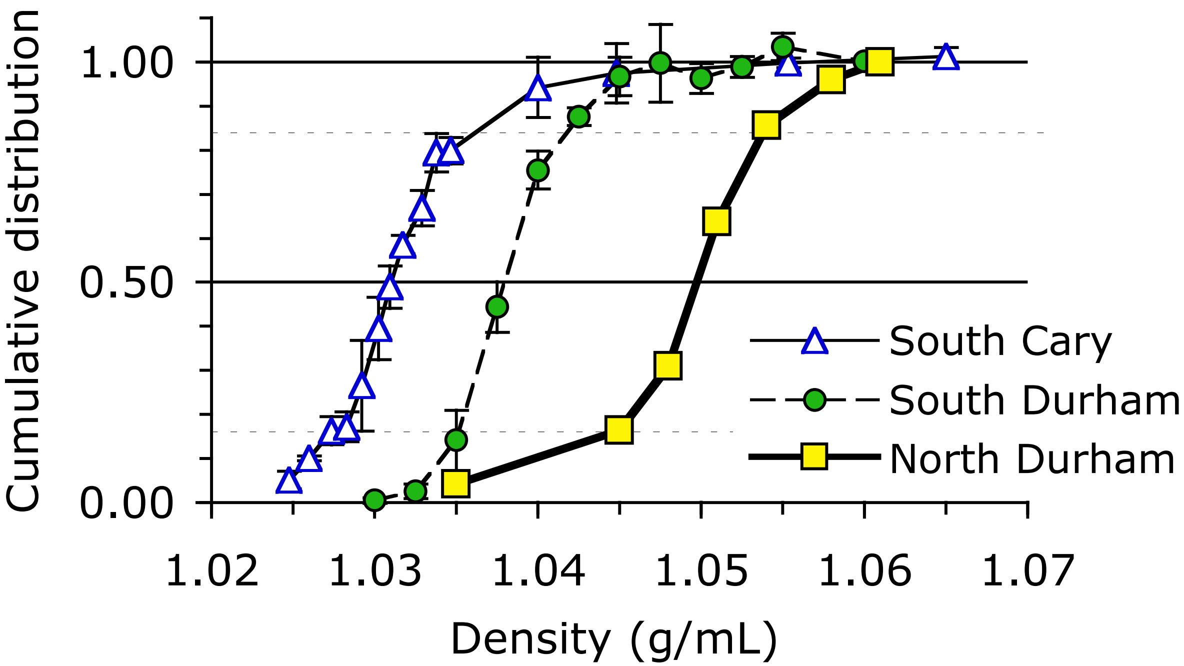
SEASONAL VARIATIONS: LOW BUOYANT DENSITY MAY EXPLAIN POORER WINTER SETTLING

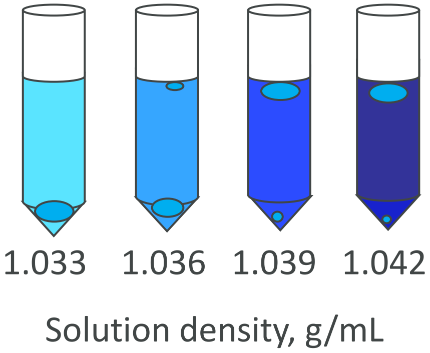


Averages of
4 full scale plants
In New Mexico

Jones, P.A., and A.J. Schuler (2012). The role of changing biomass density in process disruptions affecting biomass settling at a full scale domestic wastewater treatment plant. *ASCE J. Environ. Eng*. 138(1): 67-73.

BIOMASS DENSITY VARIES BETWEEN PLANTS, AND WITHIN SAMPLES AS WELL.



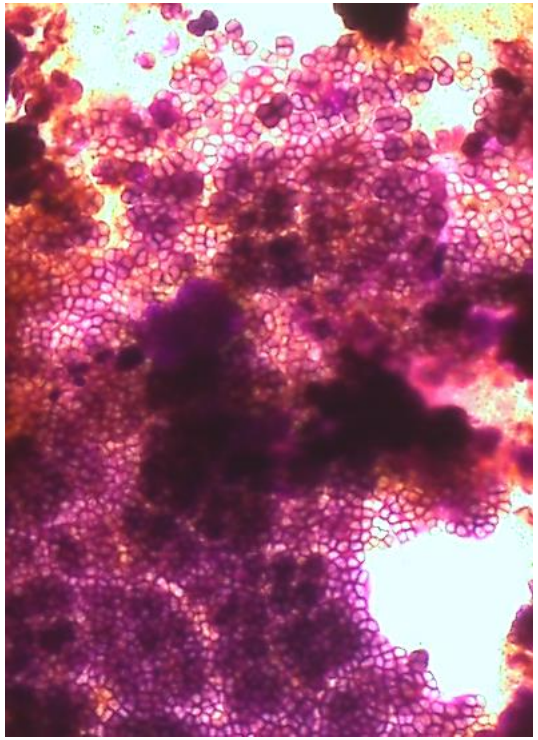


Some flocs have more PAOs than others.

Opportunity to physically select for high density fractions (cyclone).

CONCLUSIONS

- Don't confuse biomass density with concentration density.
- Biomass density works synergistically with filament content to effect settling.
- Improved settling → increase clarifier capacity → densification/intensification
- Anaerobic selectors (EBPR) not only reduce filaments, they increase density. SRT increases density in non-EBPR systems.
- Still more to learn!



Q&A Discussion

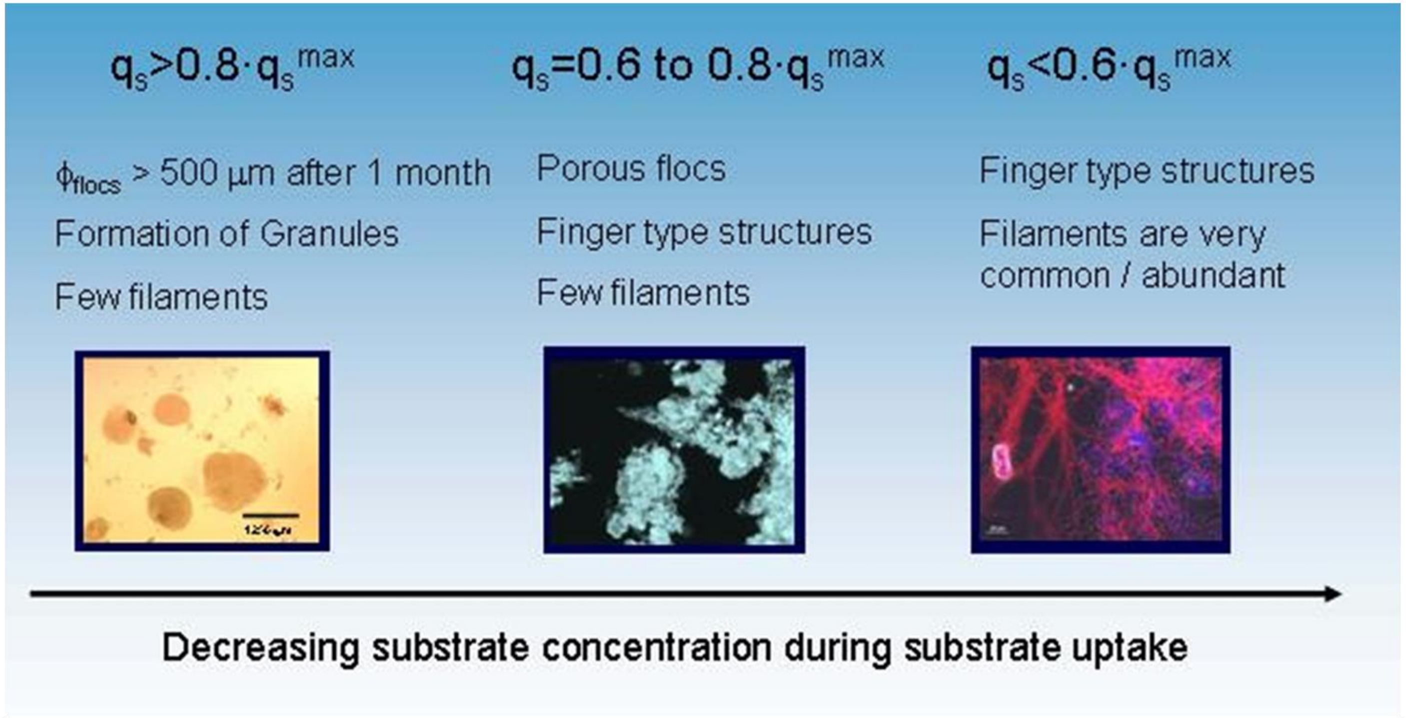
MODERATORS: PUSKER REGMI AND KRISHNA PAGILLA

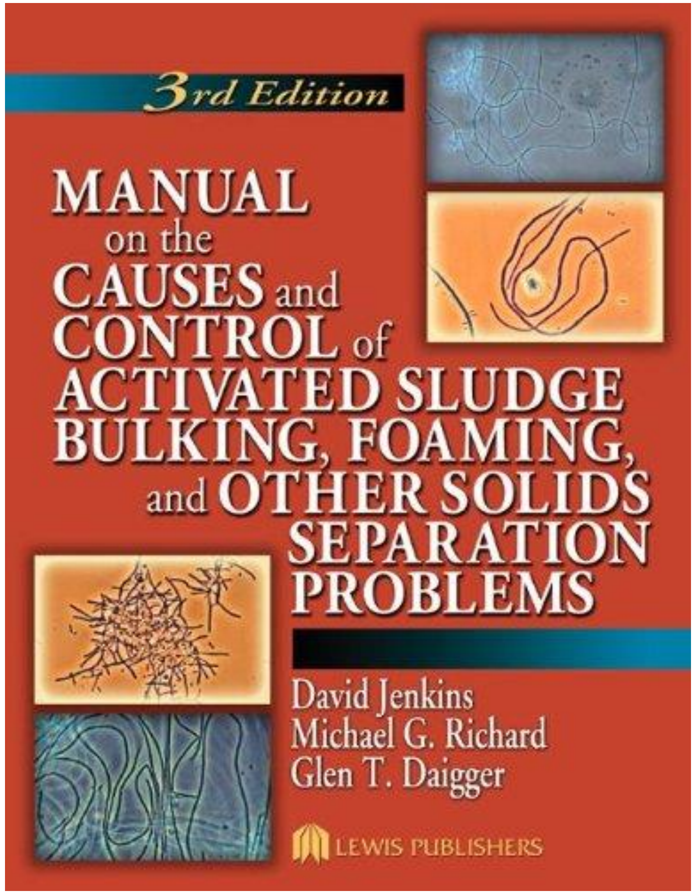
Biological selection of granules in continuous flow systems

MARI WINKLER –UNIVERSITY OF WASHINGTON

inspiring change

GRANULES, FLOCS, AND FILAMENTS





UPGRADING EXISTING WRRFS FOR NITROGEN REMOVAL – HIGH CONSTRUCTION COSTS

the international water association

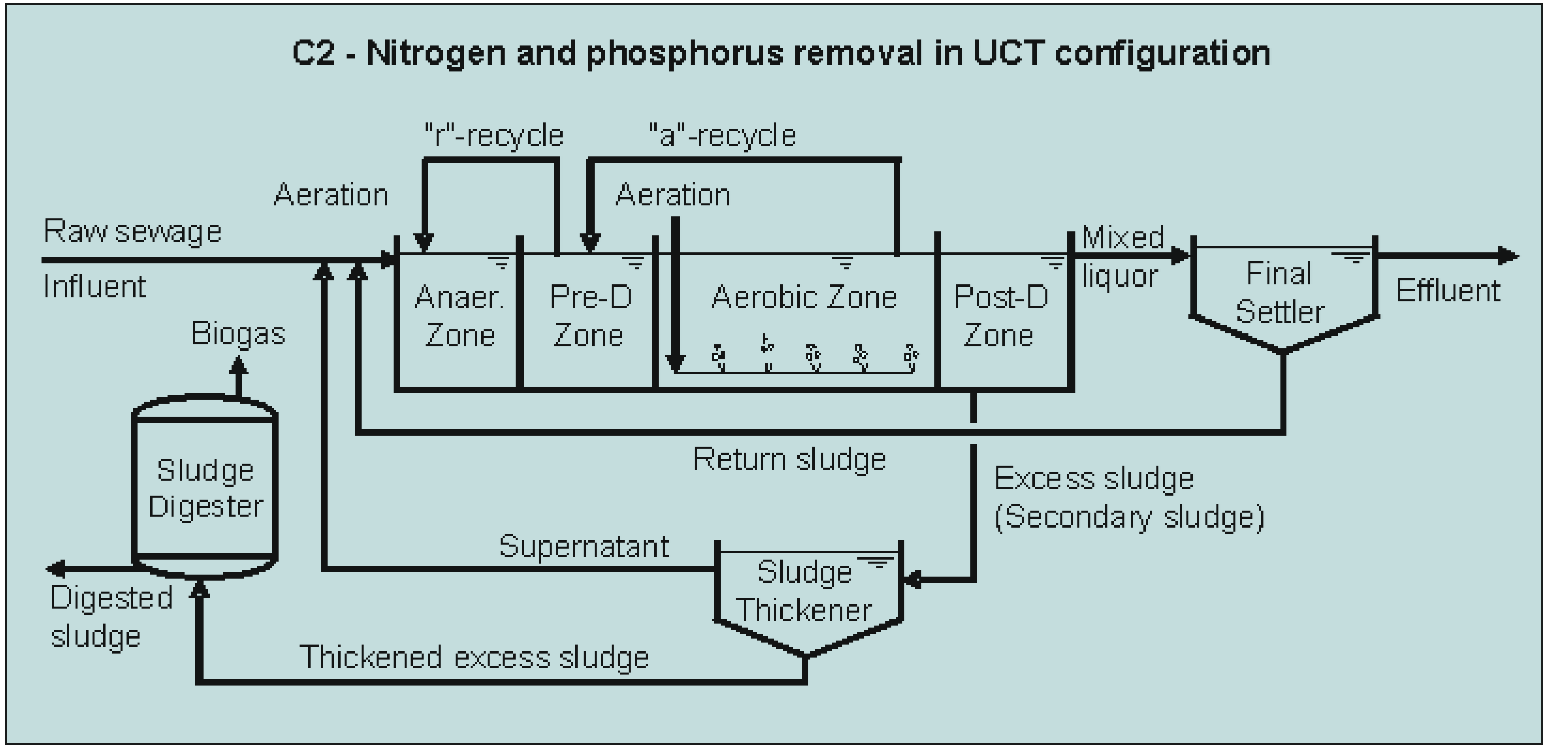
Nitrogen removal requires SRT 2-3 times that for BOD removal which requires greater tank volume

West Point Treatment Plant

South Treatment Plant

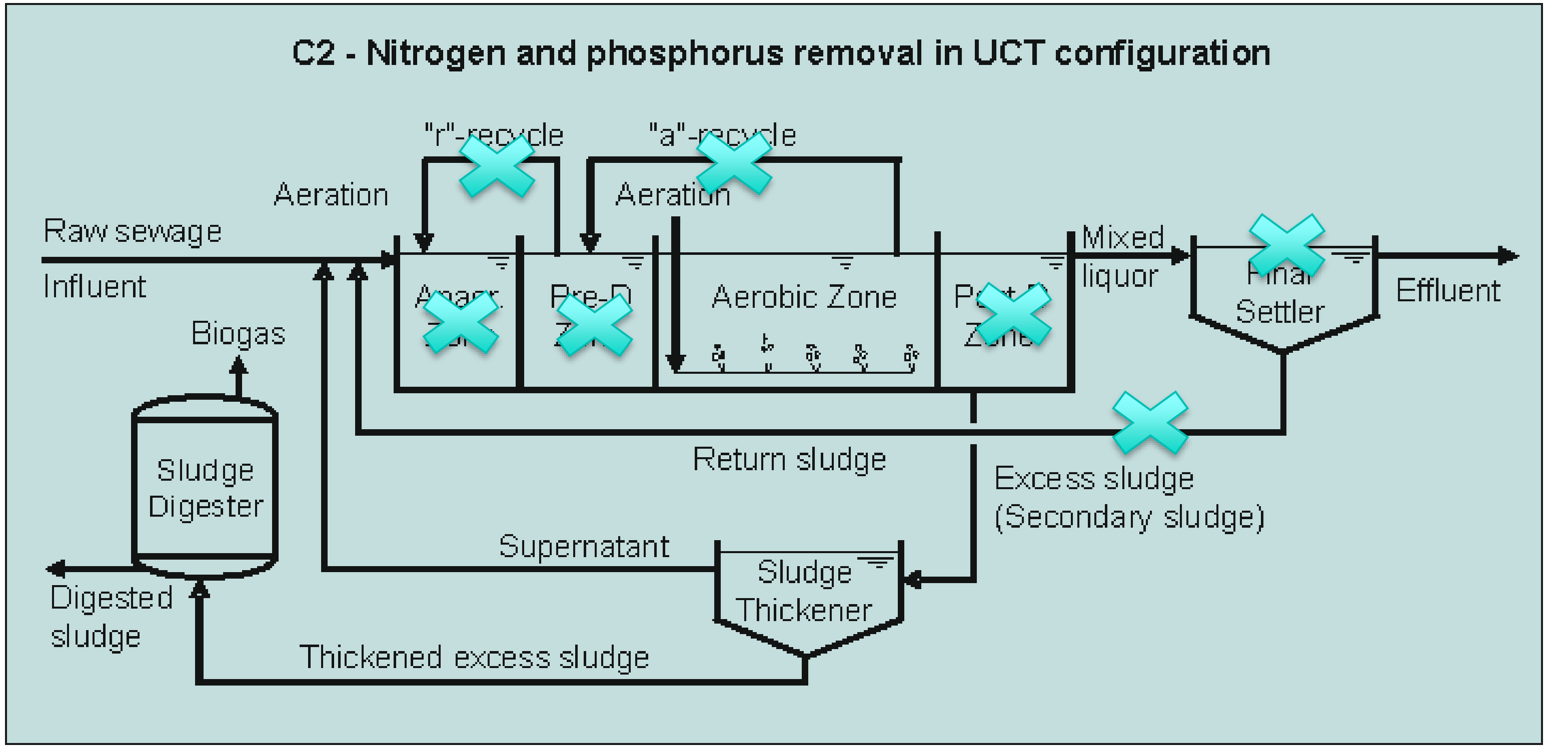
CONVENTIONAL WASTEWATER TREATMENT

Biological nutrient removal in activated sludge requires many compartments and circulation flows



NEREDA® COMPARED WITH CONVENTIONAL TREATMENT

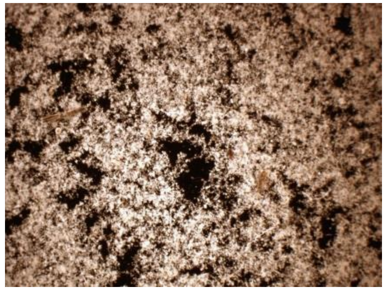
75% reduction in space, simulators N,C,P removal, less energy due to less recycling, more efficient aeration



GRANULE SELECTION CRITERIA

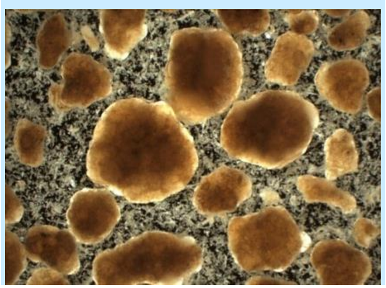
Encourage change in biomass structure

activated sludge



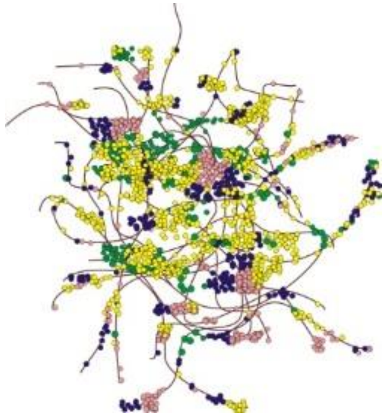
transformation

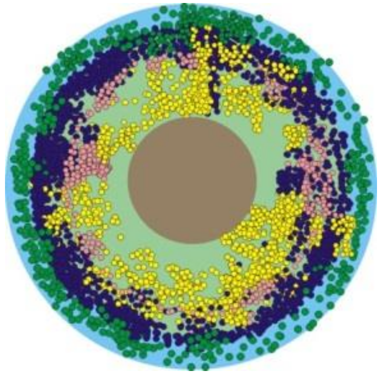
aerobic granules



Main selection principles

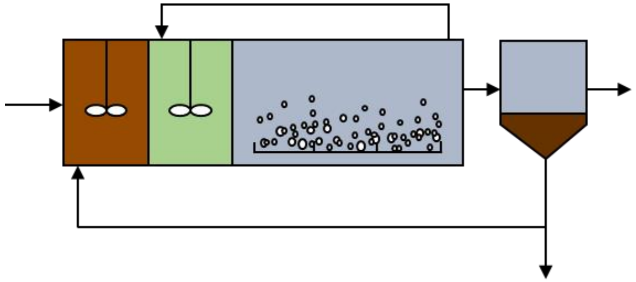
- Short settling time
- Anaerobic period promotes slow growers
  - P removal possible
- High shear
  - smooth granules
- Low DO-> more anoxic volume fraction
  - Good denitrification

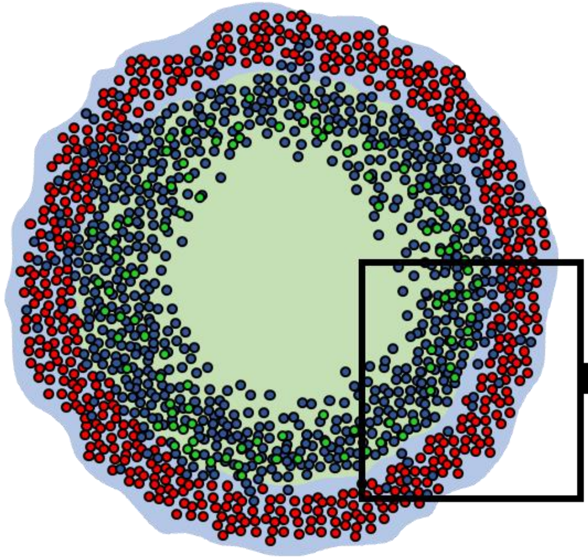


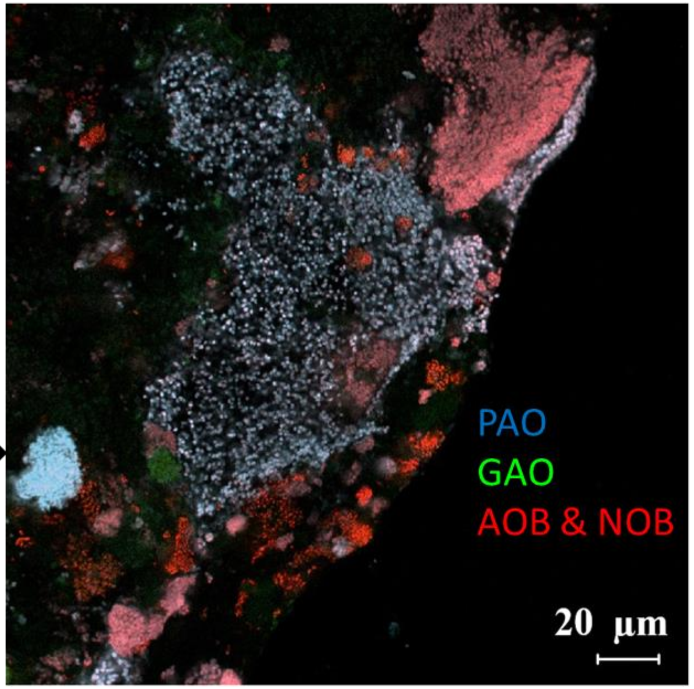


AEROBIC GRANULAR SLUDGE

PAO = Polyphosphate accumulating organisms
GAO = Glycogen accumulating organisms
AOB = Ammonia oxidizing bacteria
NOB = Nitrite oxidizing bacteria



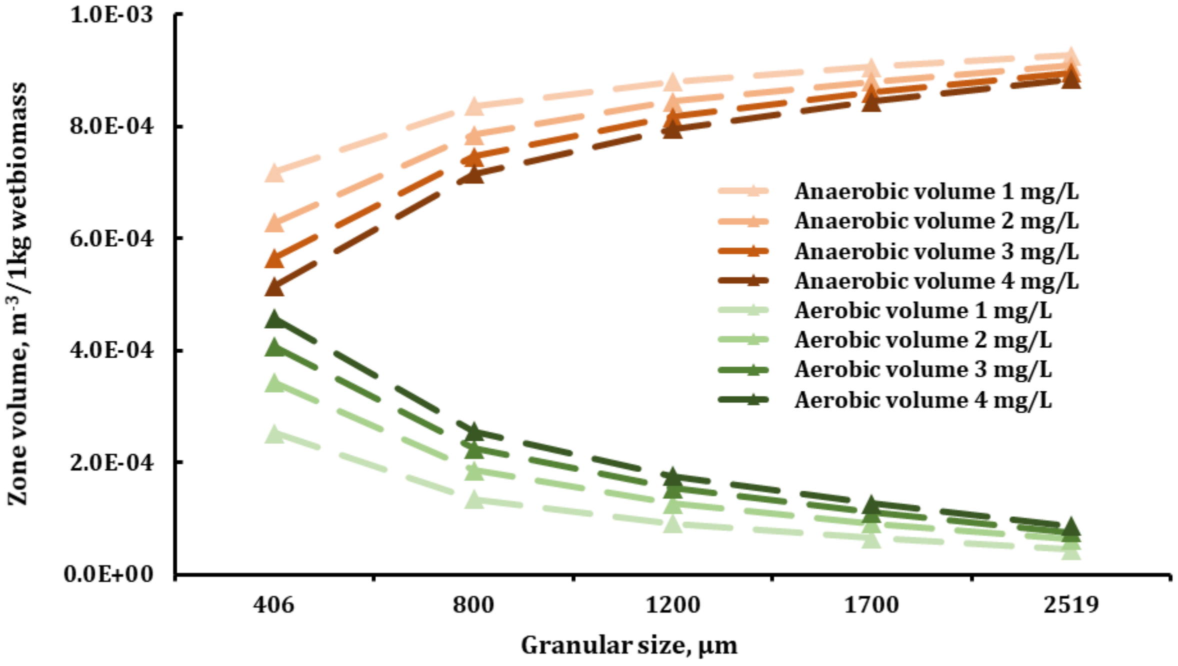


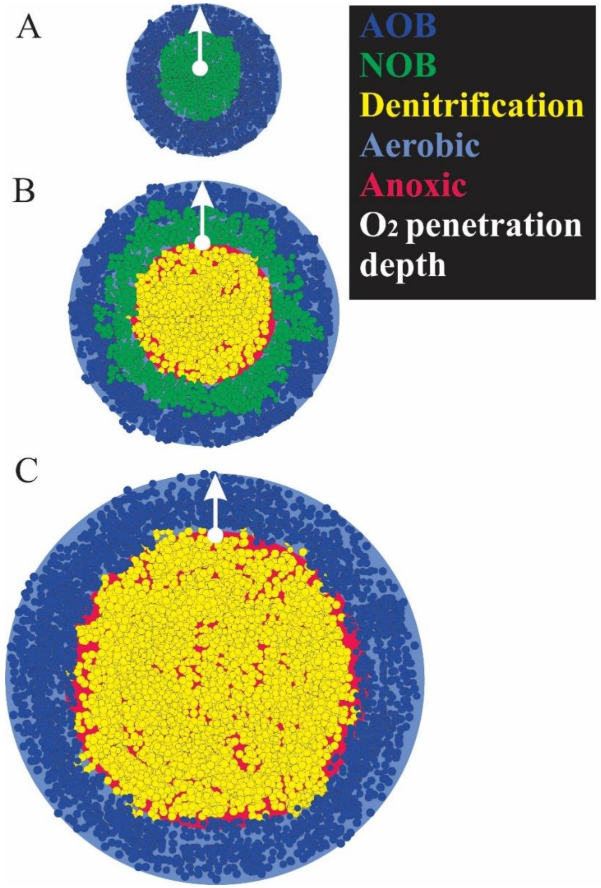


Aerobic
Anoxic
Anaerobic

Different redox zones exist within one granule

MICROBIAL COMMUNITY COMPOSITION IN SMALL AND BIG GRANULES





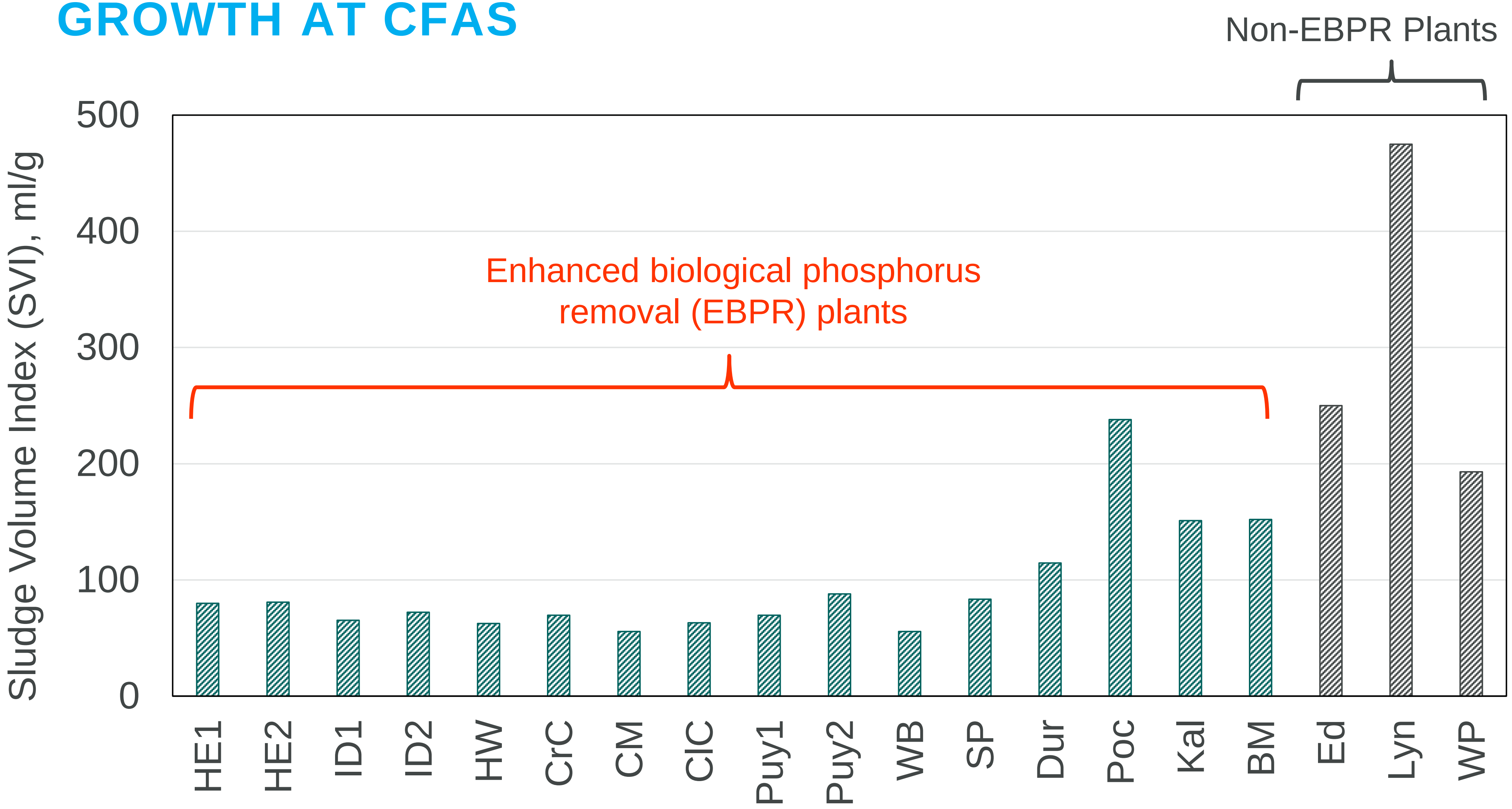
Nguyen Quoc, B., Armenta, M., Carter, J.A., Bucher, R., Sukapanpotharam, P., Bryson, S.J., Stahl, D.A., Stensel, H.D. and Winkler, M.K.H., 2021. An investigation into the optimal granular sludge size for simultaneous nitrogen and phosphate removal. Water Research, 198, p.117119

Implementation of Aerobic Granular Sludge in Continuous Flow Activated Sludge (CFAS) Plants

Aerobic granular sludge SBRs
- Sequencing batch operations
- High anaerobic F/M Ratio
- Short settling time

Conventional activated sludge
- Continuous flow
- Can have high anaerobic F/M with selector
- No settling selection

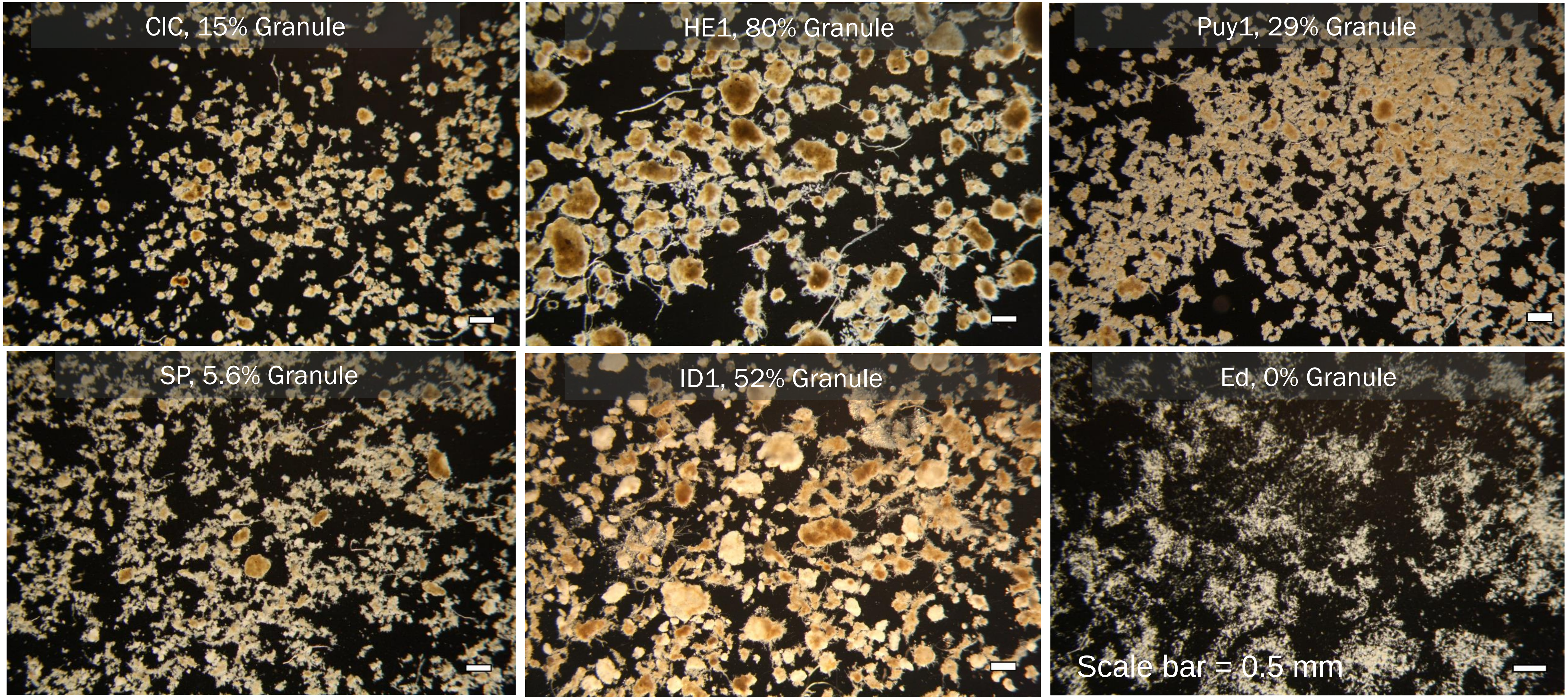
SELECTION FACTORS LEADING TO GRANULE GROWTH AT CFAS



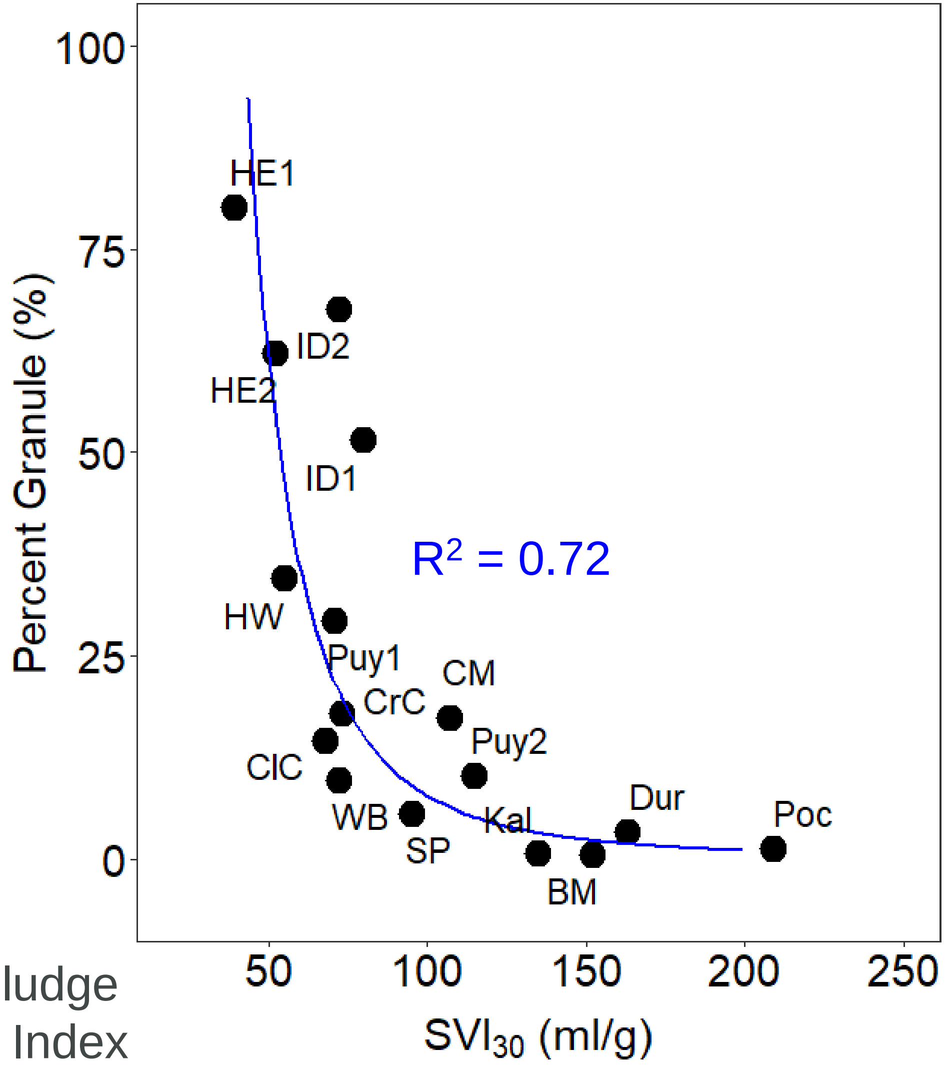
Wei, S. P., Stensel, H. D., Nguyen Quoc, B., Stahl, D. A., Huang, X., Lee, P.-H., Winkler, M-K.H., 2020. Flocs in disguise? High granule abundance found in continuous-flow activated sludge treatment plants. Water Research

SELECTION FACTORS LEADING TO GRANULE GROWTH AT CFAS

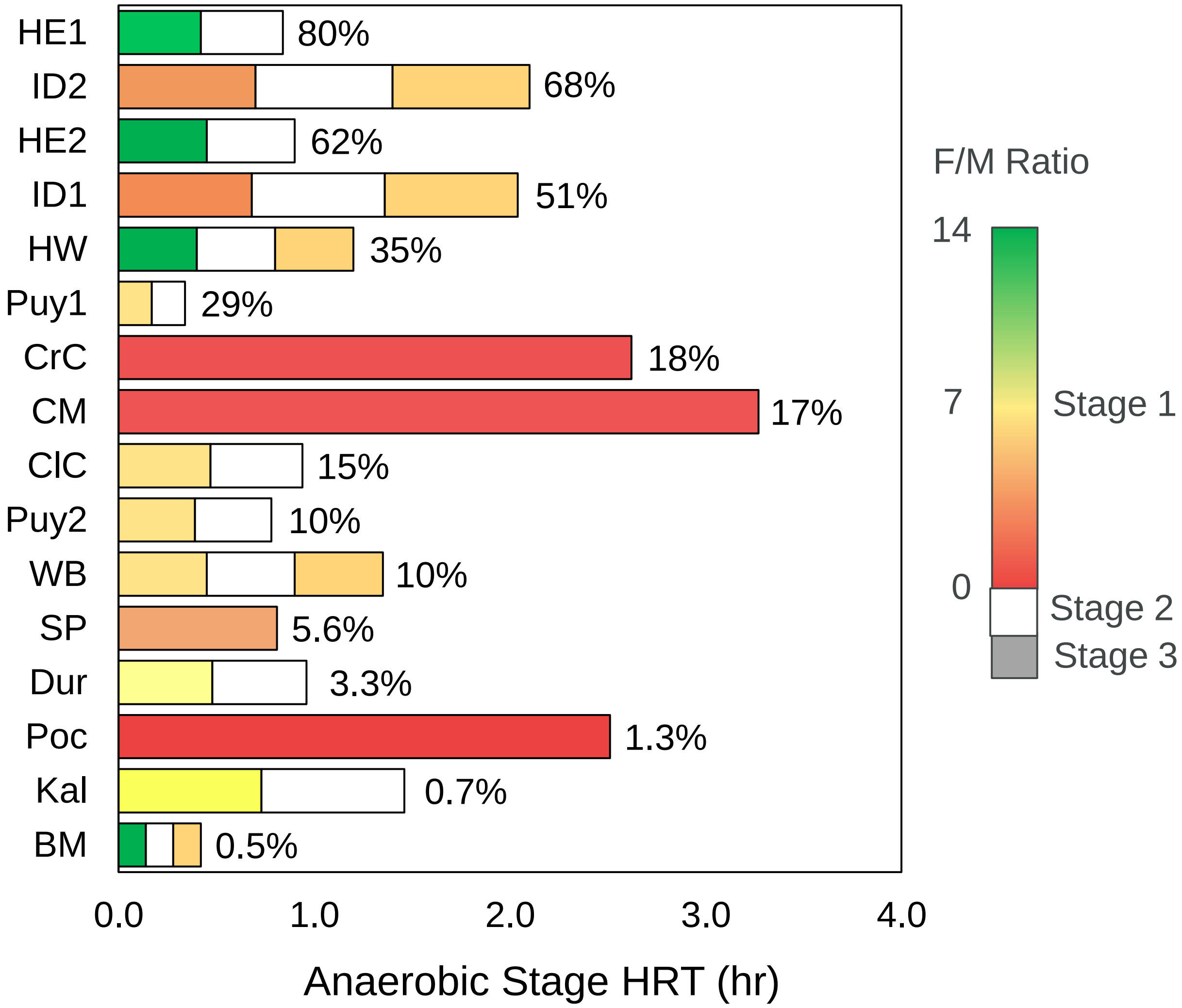
the international water association



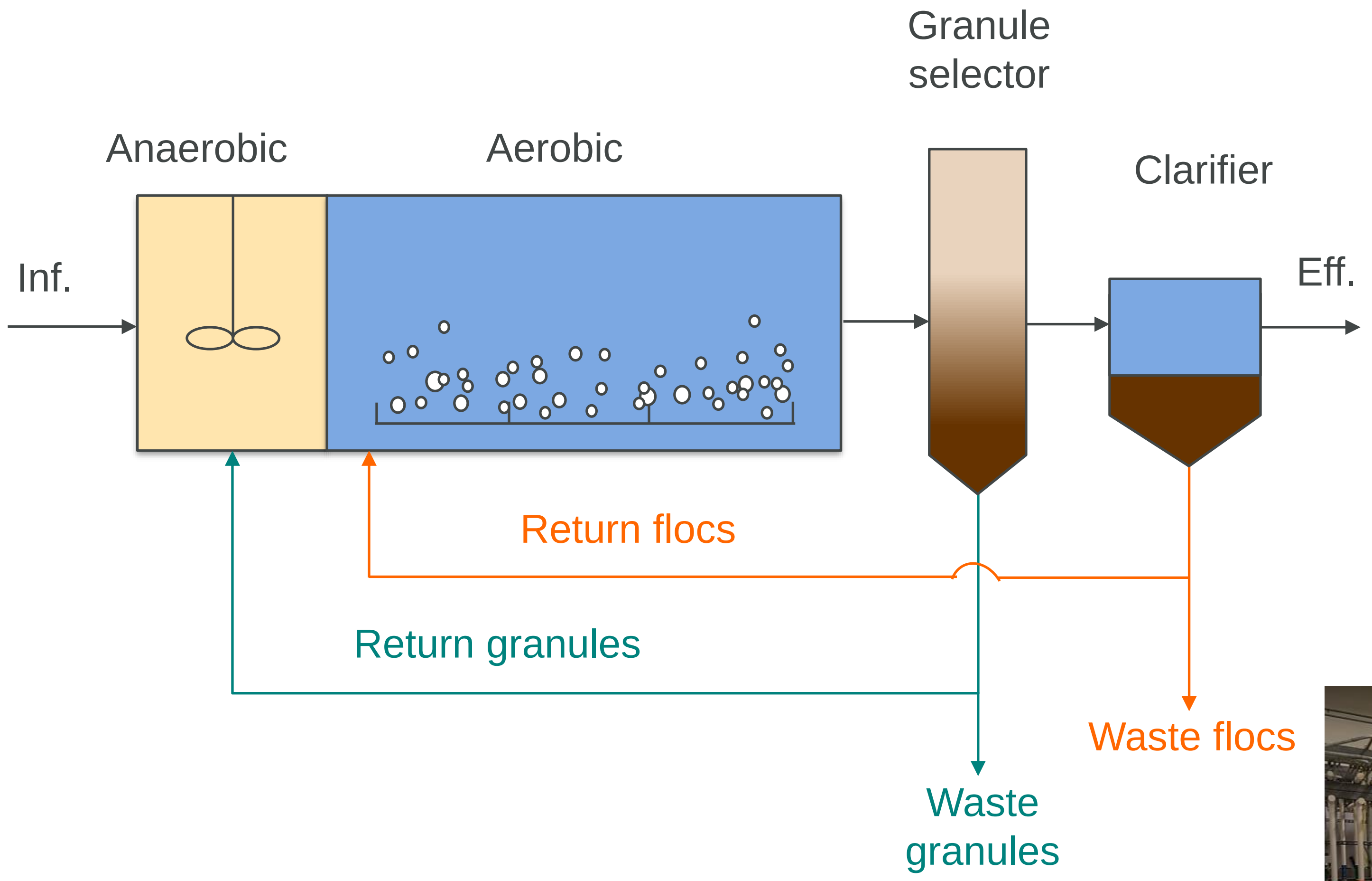
SELECTION FACTORS LEADING TO GRANULE GROWTH AT CFAS



SVI = Sludge Volume Index



CONCEPTUAL SCHEME FOR INTEGRATING AGS IN CFAS SYSTEM



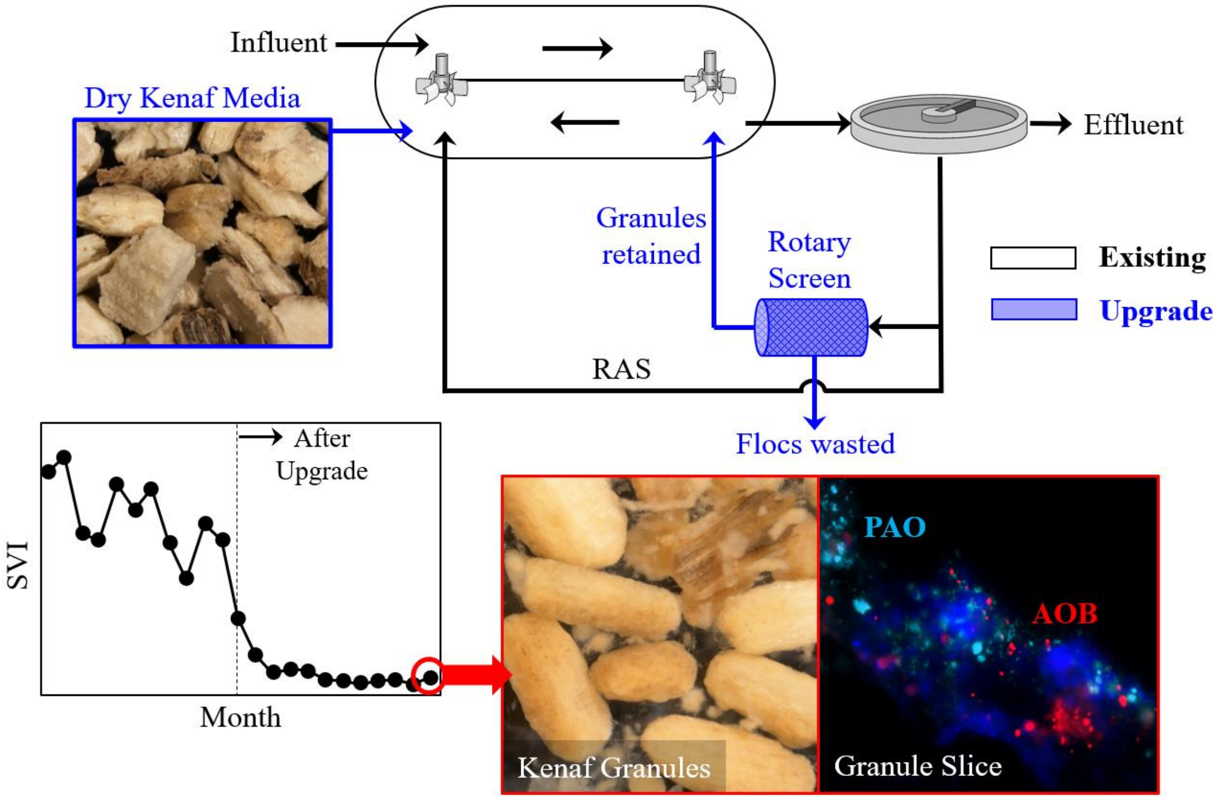
Options for granule / floc separation

- Hydrocodone
- Surface wasting
- Hydraulic separator
- Rotating drum
- Sieve / grit
- Maybe magnets?

David Stensel

KENAF MOBILE ORGANIC CARRIER

Moorefield Advanced Nutrient WWTP



Edmonds, Snohomish County, WA

Benefits

- Up to 75% lower footprint
- Adds N/P removal with only a few retrofits
- Lower chemical usage due to alkalinity gain through denitrification

Wei, S. P., Winkler M-K. H. et al. "Application of Aerobic Kenaf Granules for Biological Nutrient Removal in a Full-scale Continuous Flow Activated Sludge System.“ Chemosphere

THANK YOU!

BIOLOGICAL ARCHITECTURE FOR FLOCS AND GRANULES IN CONTINUOUS FLOW SYSTEMS

PUSKER REGMI, PHD, PE, BCEE
BROWN AND CALDWELL, UNITED STATES

inspiring change

"

If you want to discourage filamentous organism growth, you have to change the nature of the floc-forming microorganisms

- David Jenkins

What is this nature? Granules or a hybrid of filaments-flocs-granules

?

AGENDA

- How should we design and operate brownfield continuous flow BNR facilities for densification?
- How do learnings from Dr. Jenkins make us rethink BNR applications?

CONSIDERATIONS FOR BROWNFIELD APPLICATIONS

the international water association

1. Higher settlings rates

Can a reliable and consistent settling characteristics be achieved?

2. SRT safety factor

Can slower-growing organisms (e.g., nitrifiers) be retained longer?

3.Favorable BNR Kinetics

Is low DO BNR compatible with densification and high kinetic rates?

4.Bioflocculation

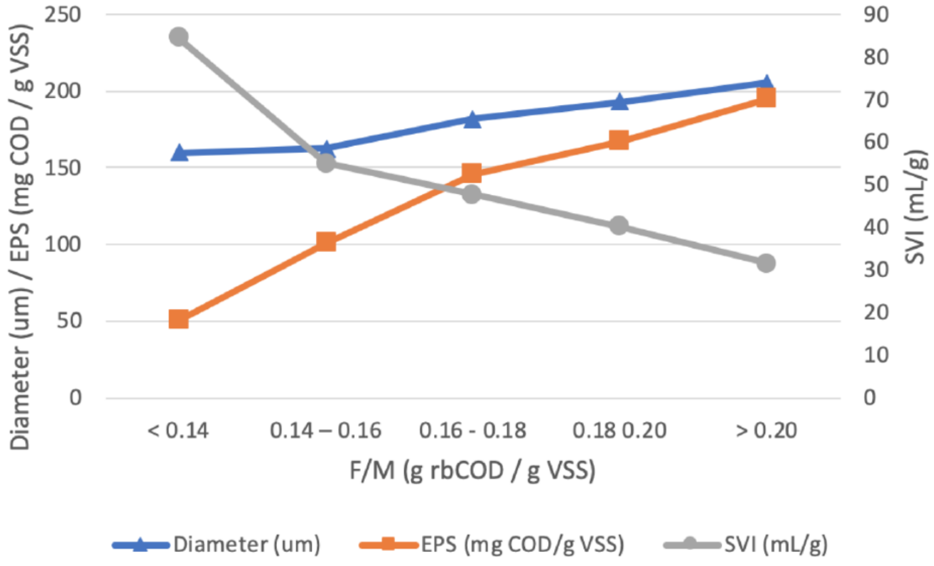
Can we reliably maintain low effluent TSS/turbidity?

BIOLOGICAL SELECTION FOR SLUDGE DENSIFICATION

the international water association

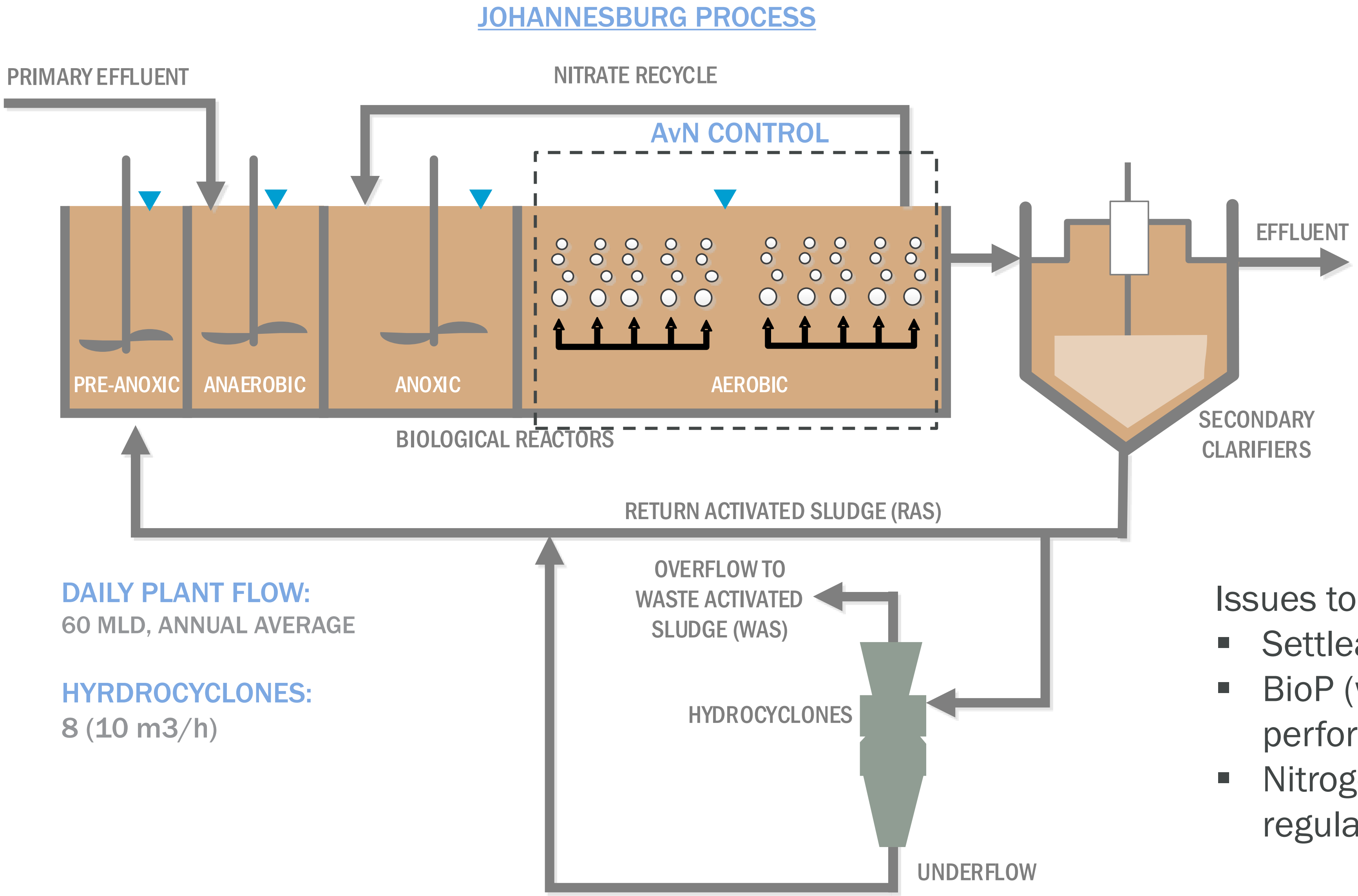
- Complete uptake of rbCOD in selector zone
- Selector F/M ratio of ~0.2g rbCOD/g VSS-d (WERF UR1R4) **(Feast)**
- Extended famine conditions that encourage bacteria for storing energy compounds **(Famine)**
- In many conventional BNR systems:

Selector size and conditions are more or less fixed, resulting in a non-ideal environment for sludge densification



Source: Sturm et al. (2019)

AVN CONTROL + HYDROCYCLONE (PUEBLO, CO)



DAILY PLANT FLOW:
60 MLD, ANNUAL AVERAGE

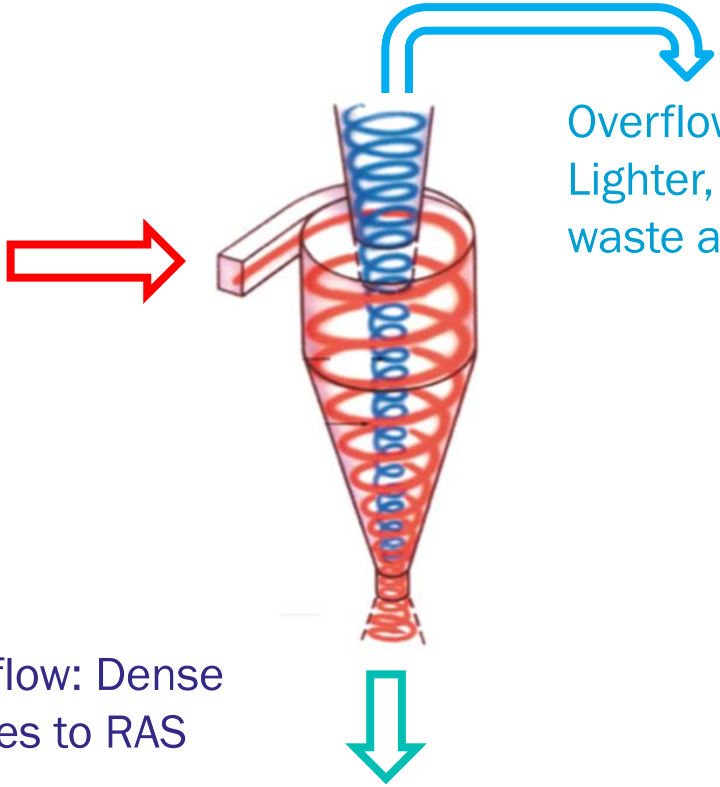
HYRDROCYCLONES:
8 (10 m3/h)

Issues to be addressed:

- Settleability
- BioP (winter performance)
- Nitrogen removal (new regulation)

EXTERNAL (PHYSICAL) SELECTOR - HYDROCYCLONE

Feed: Return Activated Sludge (RAS/WAS)

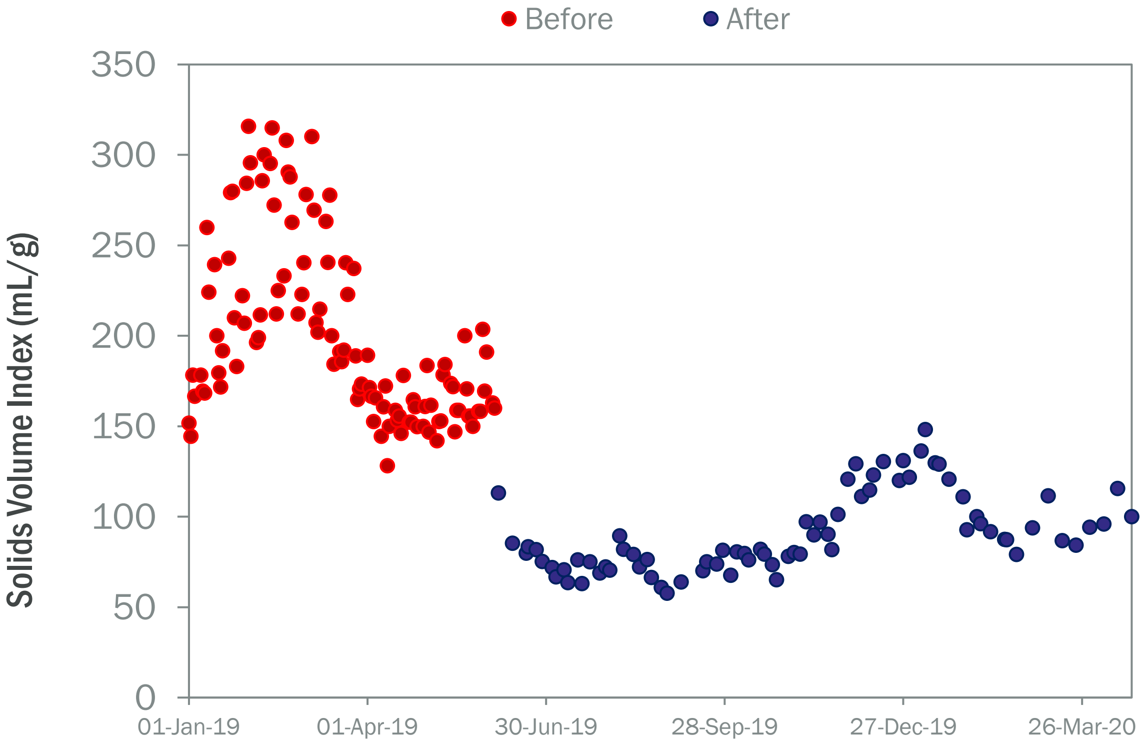


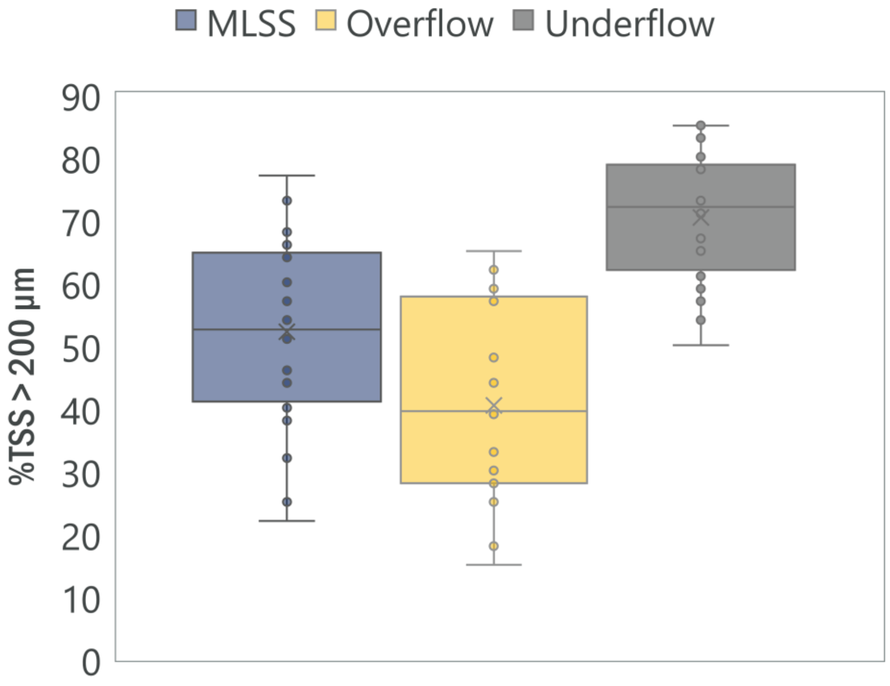
Overflow:
Lighter, poorer-settling solids to waste activated sludge (WAS)

Underflow: Dense granules to RAS

inDENSE skid from World Water Works

1. HIGHER SETTLING RATES





Before:
50^{th} Percentile = 184 mL/g
90^{th} Percentile = 284 mL/g

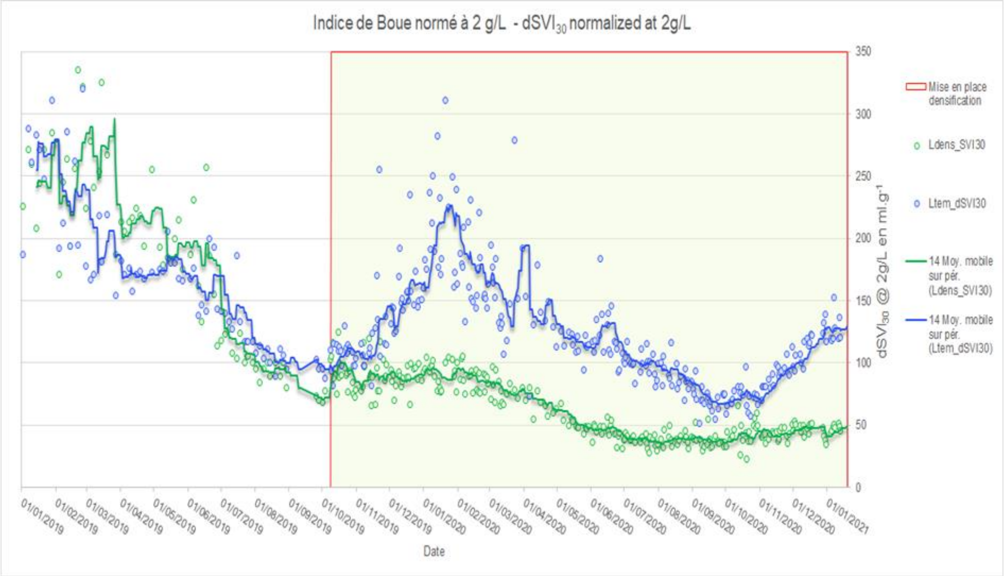
After:
50^{th} Percentile = 90 mL/g
90^{th} Percentile = 130 mL/g

Regmi et al. (2021) in revision Water Research

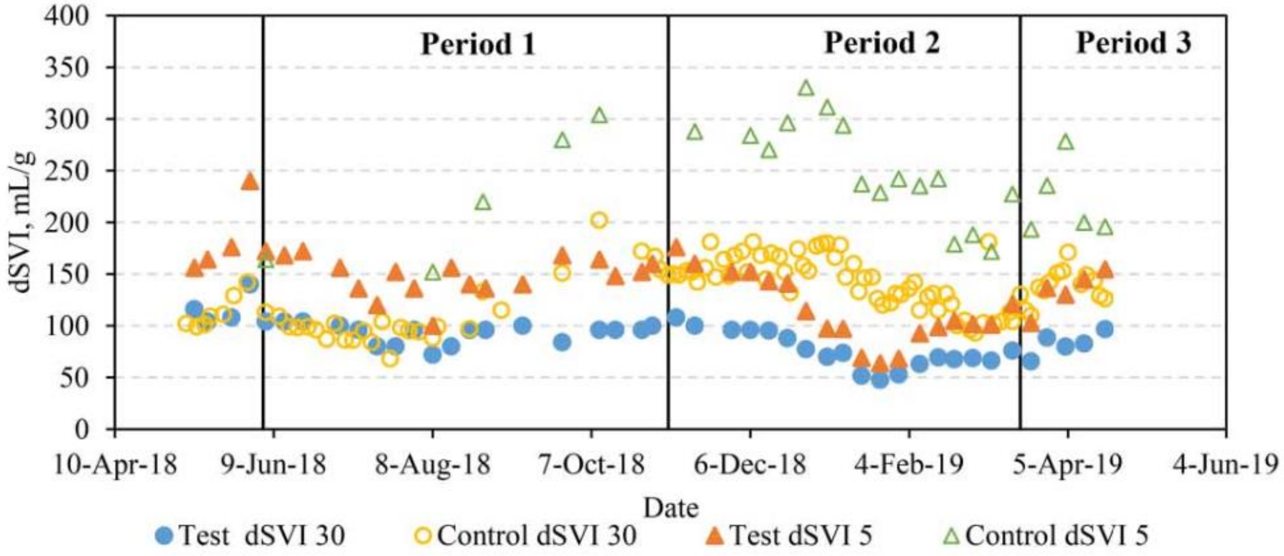
FROM OTHER FACILITIES

Dijon, France

Denver, CO, USA

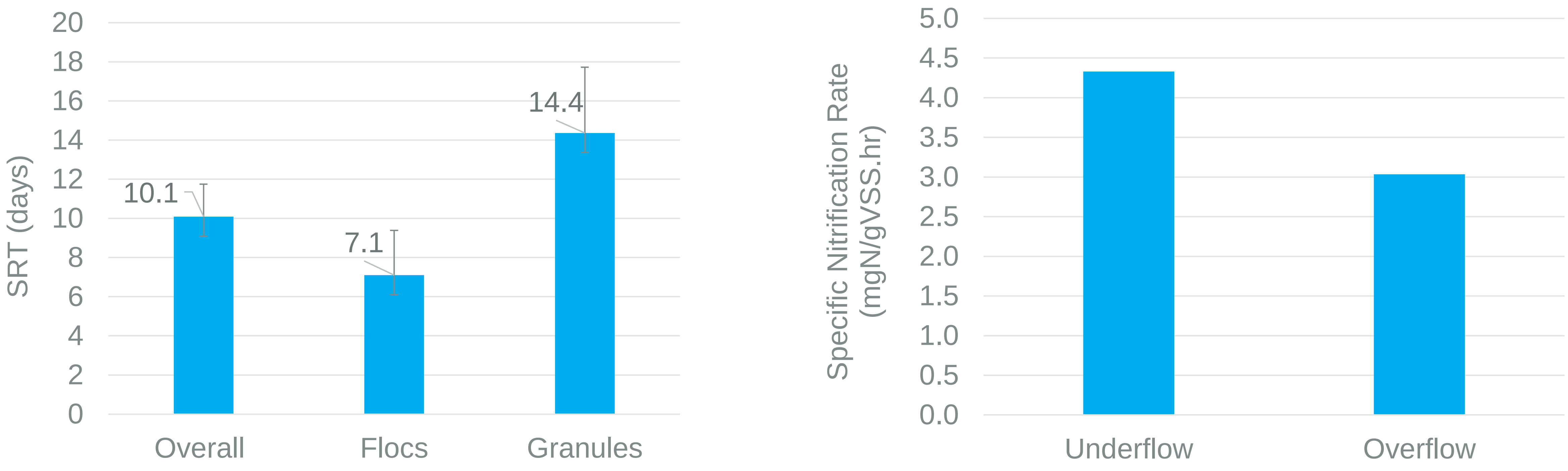


Roche et al. (2021)



Avila et al. (2020)

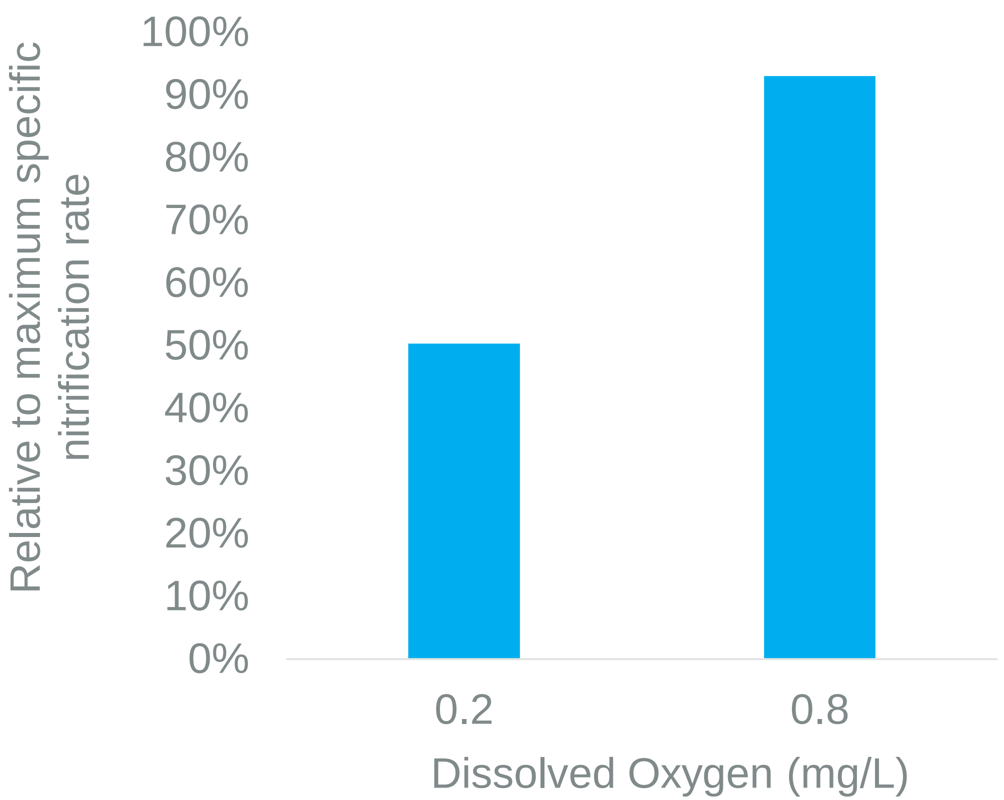
2. SRT SAFETY FACTOR

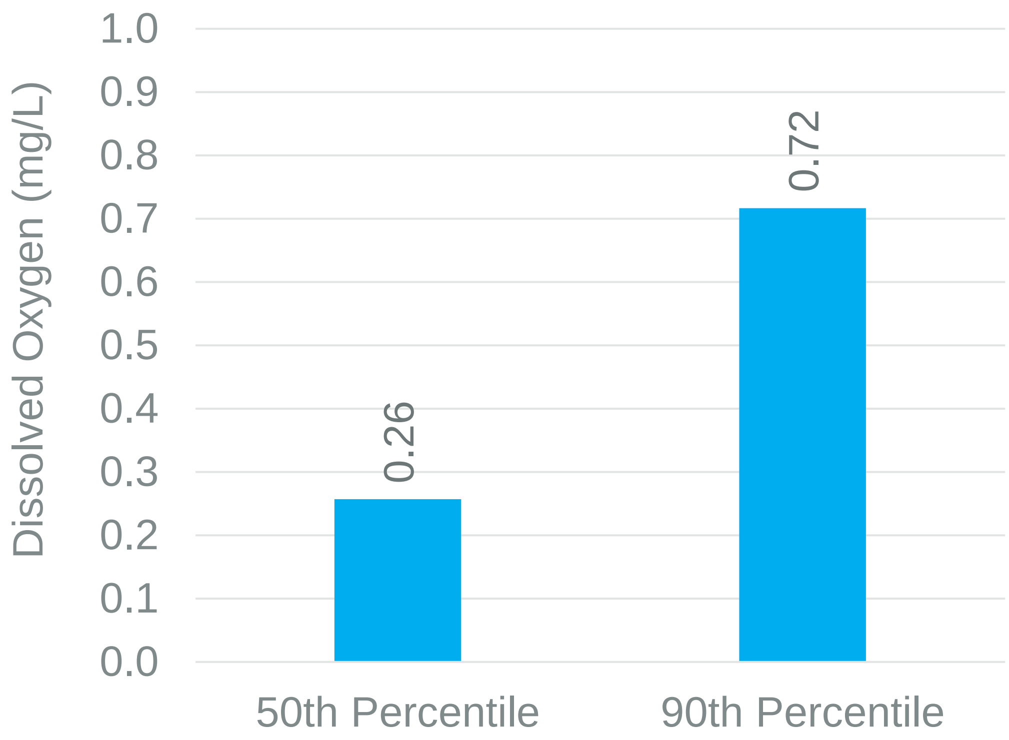


Nitrifiers in the granules experience longer SRT, leading to enrichment?

Regmi et al. (2021) in revision Water Research

3. FAVORABLE BNR KINETICS

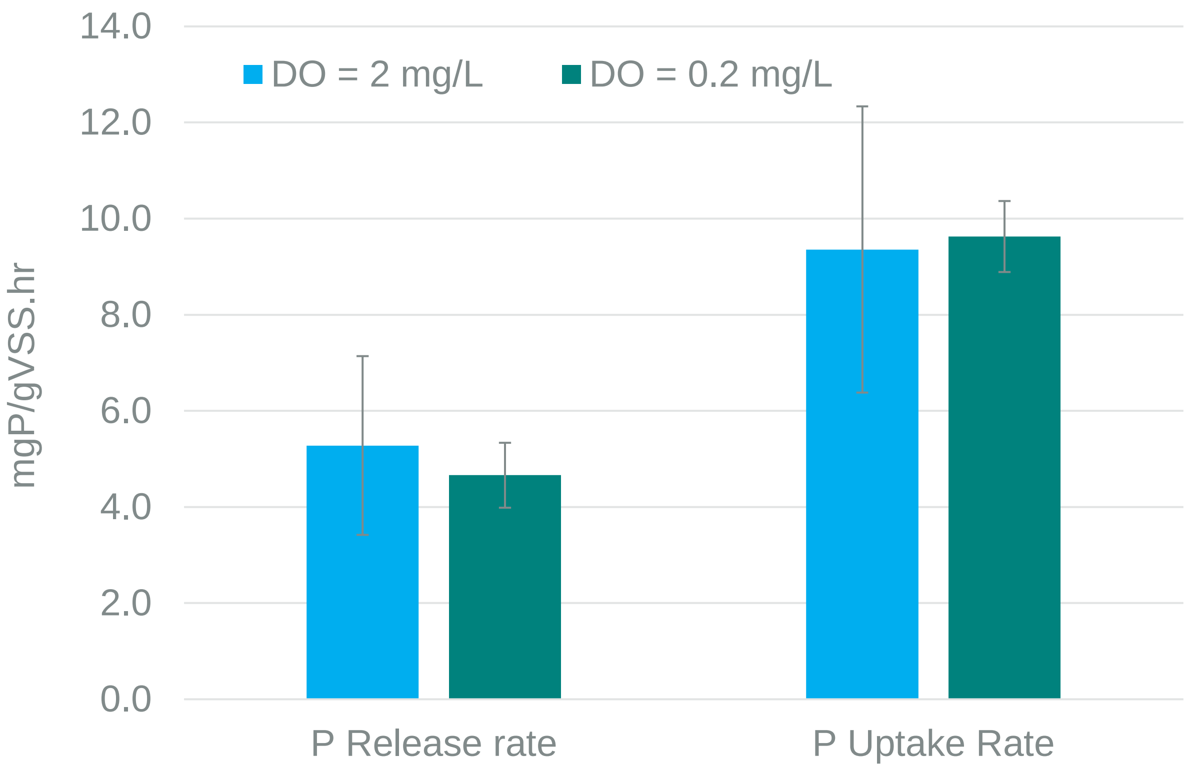




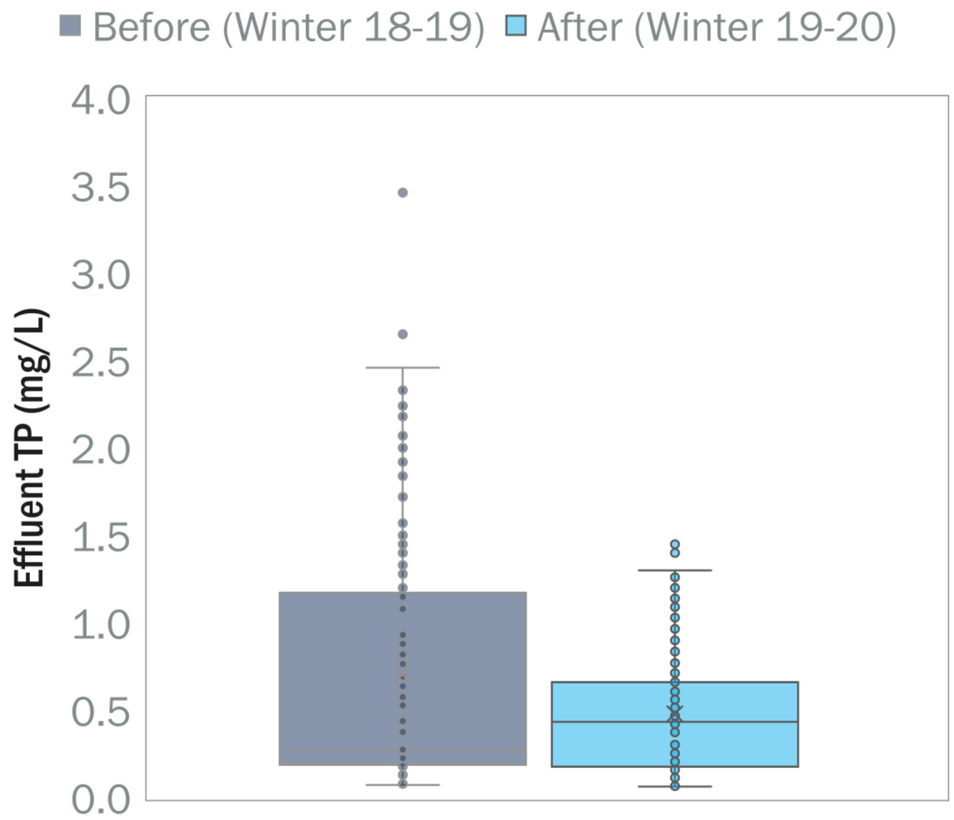
- High nitrifier oxygen affinity resulted in low DO operation
- >30% aeration energy savings was realized compared to conventional high DO operation (AvN control was used)

Regmi et al. (2021) in revision Water Research

Low DO P uptake and more stable bioP



Low DO didn't hinder P uptake



Better bioP in winter

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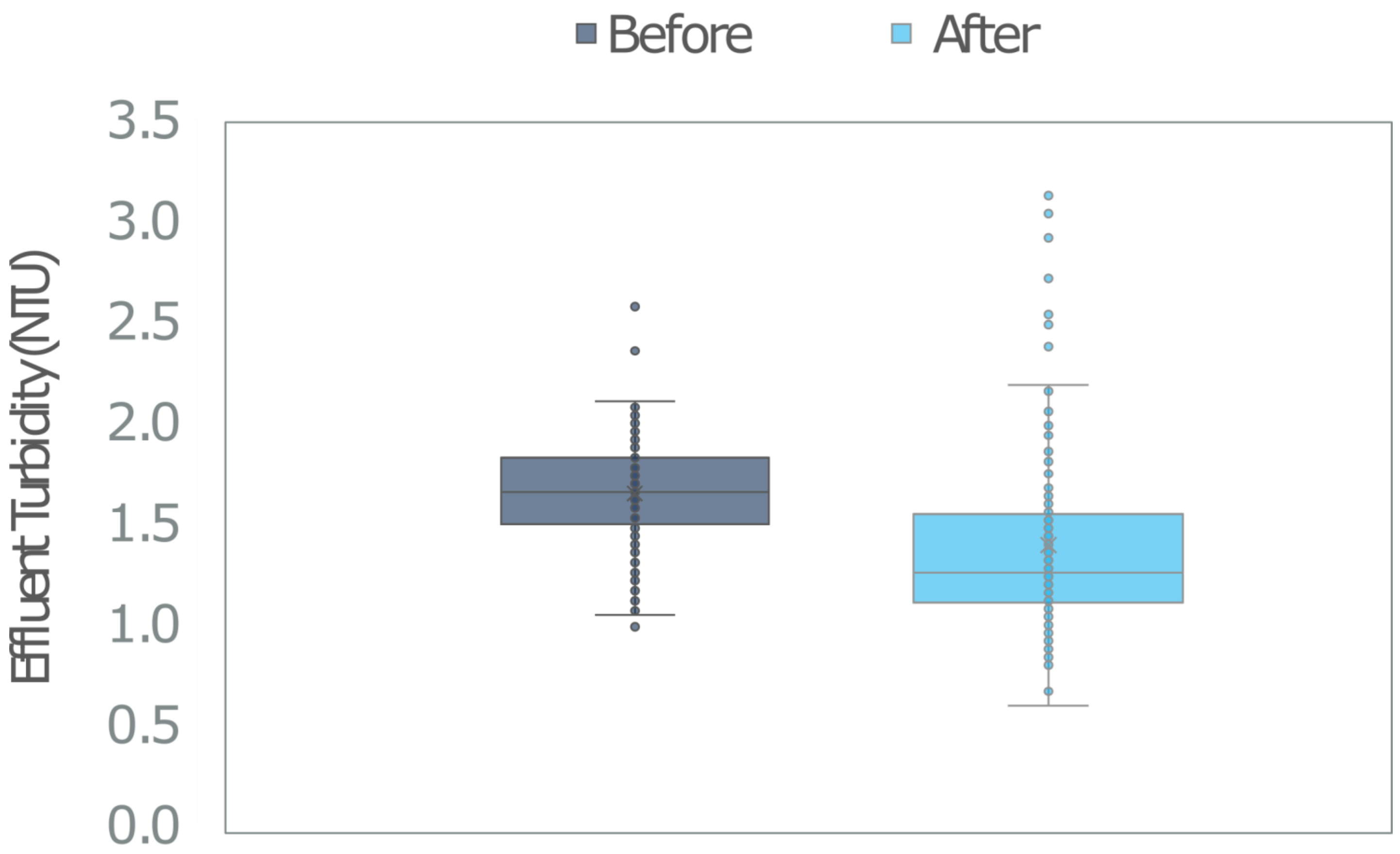
4. GOOD BIOFLOCCULATION

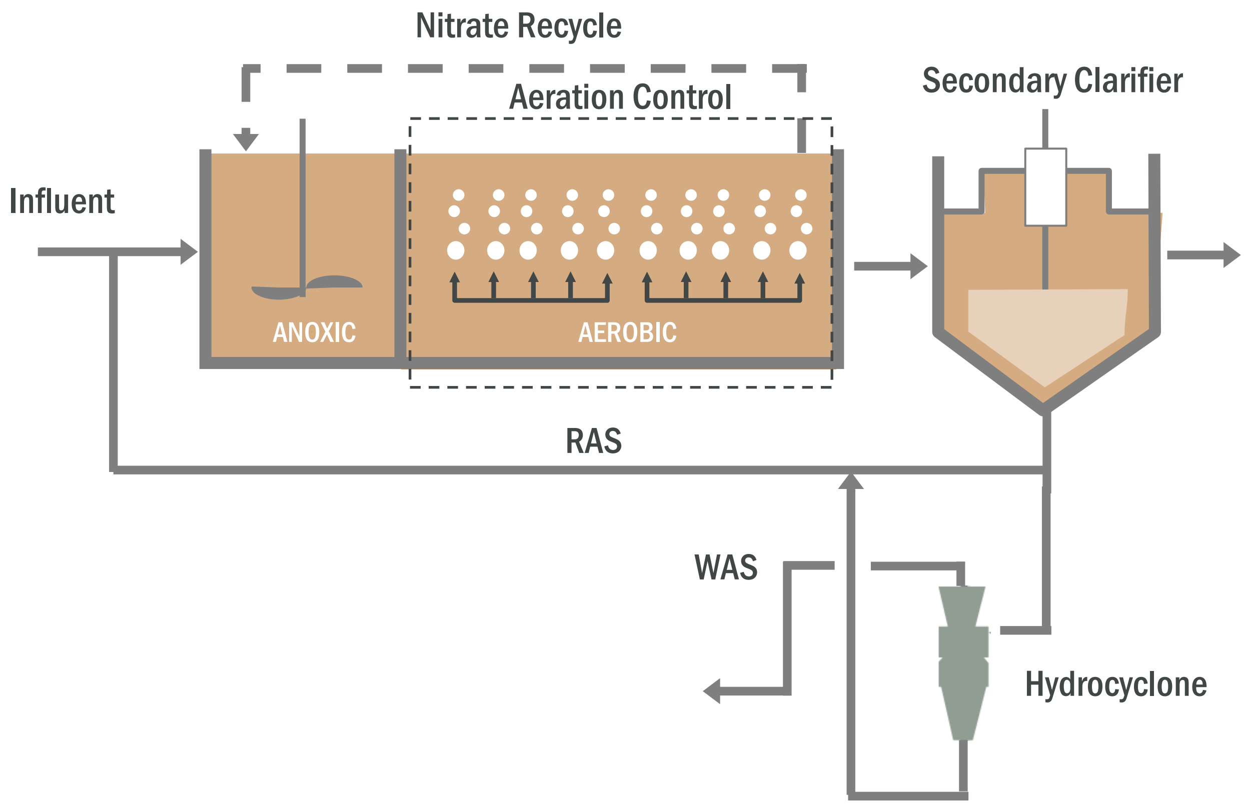


- Densification didn't increase the effluent solids
- Hybrid filament-floc-granule matrix was able to trap smaller fines from escaping

Regmi et al. (2021) in revision Water Research

KEEPING IT SIMPLE!

A|SND + Physical selector



Aeration control
-SND
-Lowers O_2 and NO_3 back to the pre-anoxic zone

Physical selector
-Retain beneficial functional group

Nitrate recycle control
-Control the electron acceptor in the anoxic zone to favor storage

REMEMBERING FLOC DOC

The picture was taken after the CWEA workshop at Berkley, CA in February of 2018

Q&A Discussion

MODERATORS: PUSKER REGMI AND KRISHNA PAGILLA

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