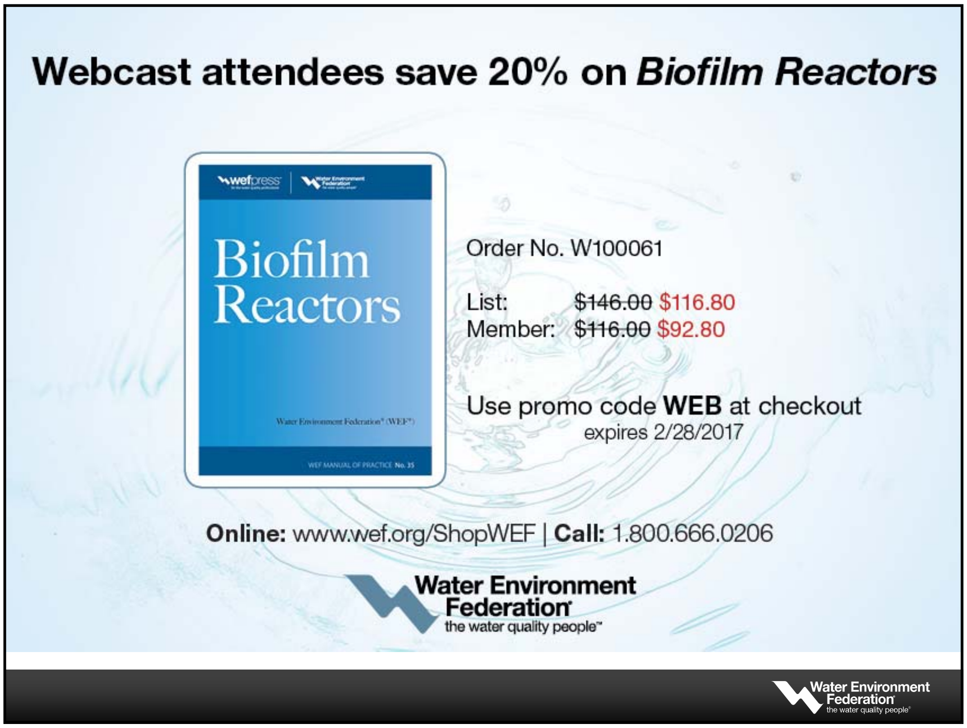

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# An MRRDC Short Course
# Biofilms: Principles and Advanced Model-Based Design

February 15th, 2017

1:00 – 3:00 PM, Eastern Standard Time

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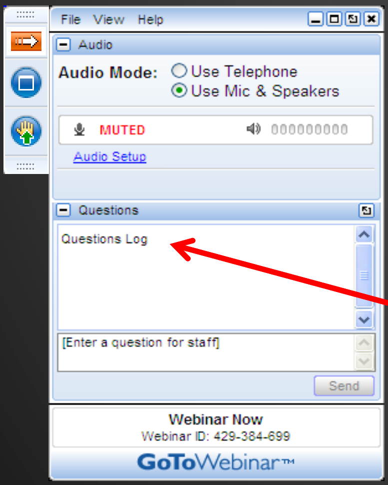

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# Today's Moderator

**John B. Copp Ph.D.**
*Primodal Inc.*
*Hamilton, Ontario*

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# Biofilms – Feb. 15, 2017

*An MRRDC Short Course*

**Biofilms: Principles and Advanced Model-Based Design**

- Topics:
  - Introduction to Critical Biofilm Concepts
  - Capturing Biofilm Concepts w Modelling
  - Biofilm Modelling Case Studies

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# Biofilms – Feb. 15, 2017

*An MRRDC Short Course*

## Biofilms: Principles and Advanced Model-Based Design

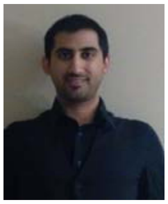
- Speakers:

Leon Downing

CH2M

Oliver Schraa

InCTRL Solutions



Tanush Wadhawan

Dynamita

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# Next Speaker

**Leon Downing, PhD, PE**
Senior Technologist
CH2M
Milwaukee, Wisconsin, USA

ch2m

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# Biofilm Reactors: What's the BIG Deal?

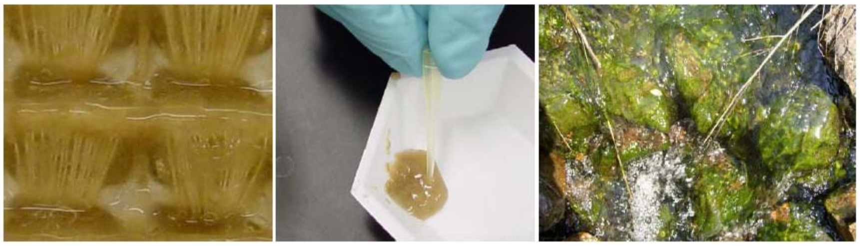
Leon Downing, PhD, PE
CH2M

## Some of the first technologies for wastewater management relied on 'slime'

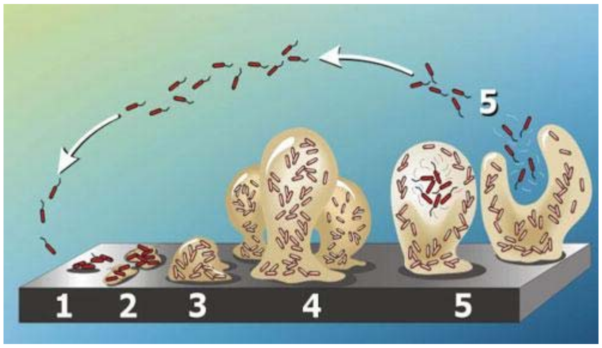
1890s
Trickle sewage over rocks
Grow slime
Cleans water

## So is it slime? Or fixed film? Or Biofilm?

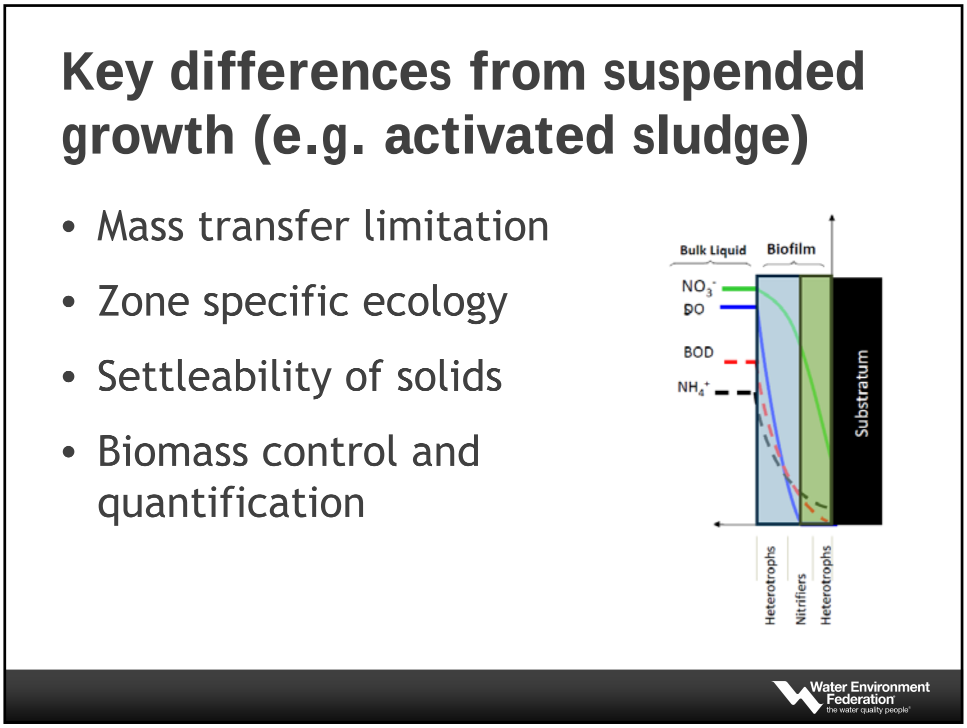
- *Biofilm* is the official terminology for WEF and the larger scientific community
- "cells immobilized at a substratum and frequently embedded in an organic polymer matrix [EPS] of microbial origin" - Characklis and Marshall 1990



## Why does this warrant an entire webcast?

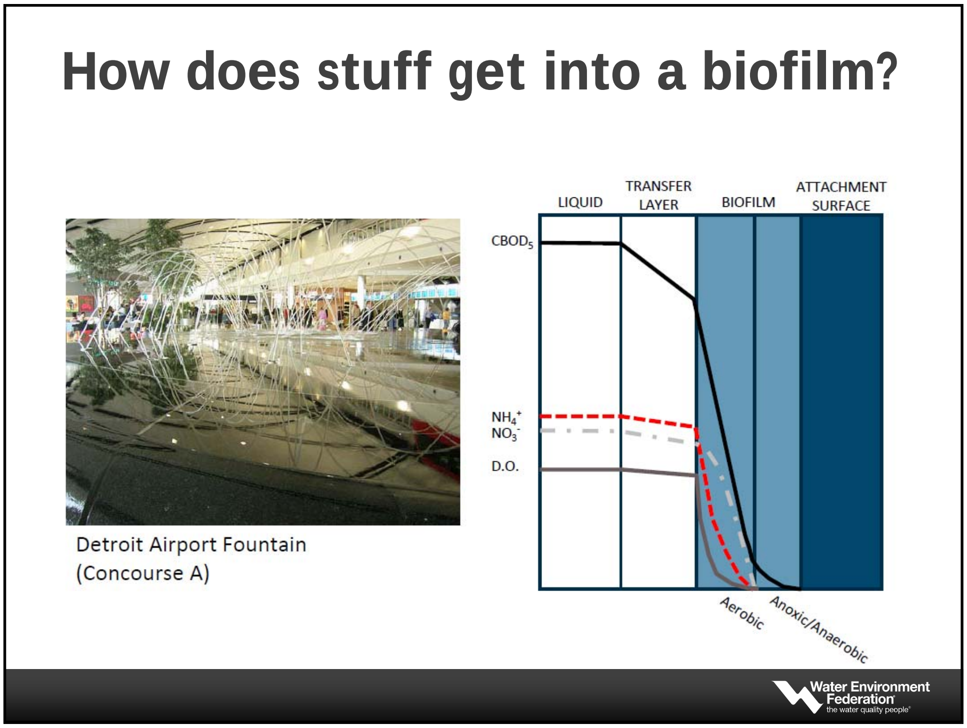


Source: Center for Biofilm Engineering at MSU-Bozeman



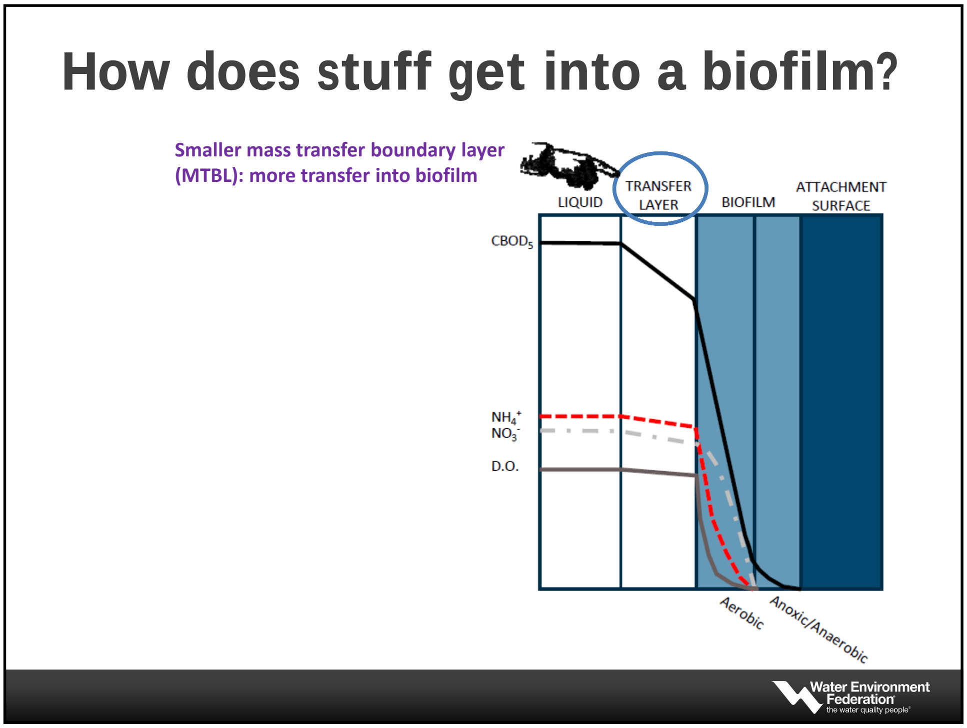
# Key differences from suspended growth (e.g. activated sludge)

- Mass transfer limitation
- Zone specific ecology
- Settleability of solids
- Biomass control and quantification



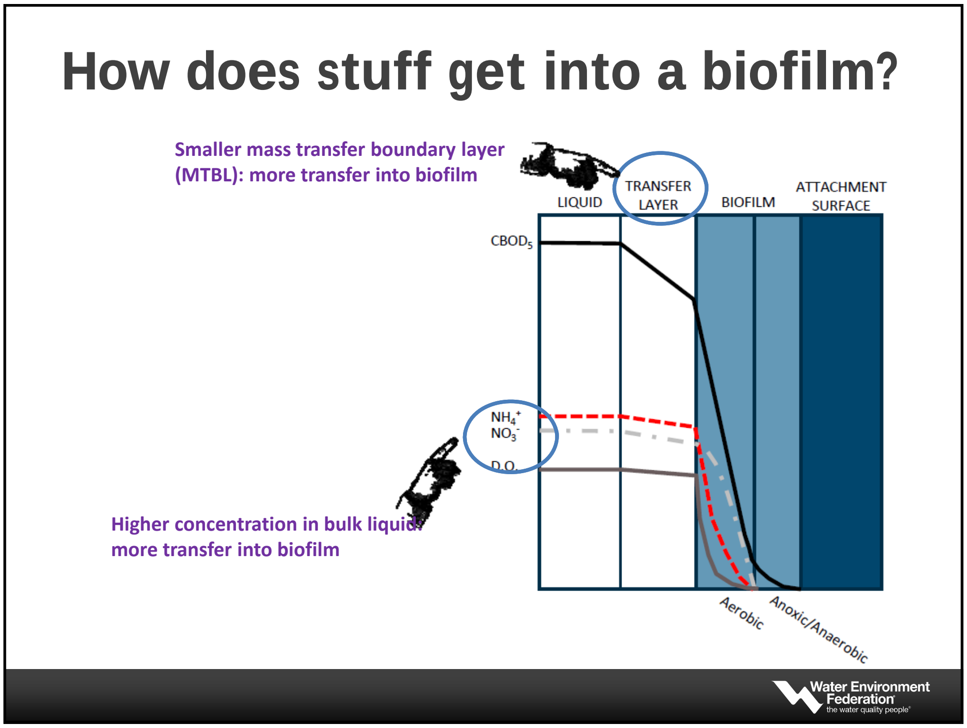
# How does stuff get into a biofilm?

Detroit Airport Fountain
(Concourse A)



# How does stuff get into a biofilm?

Smaller mass transfer boundary layer (MTBL): more transfer into biofilm



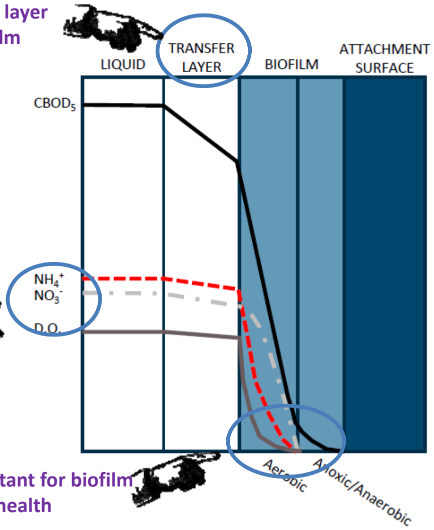
# How does stuff get into a biofilm?

Smaller mass transfer boundary layer (MTBL): more transfer into biofilm

Higher concentration in bulk liquid: more transfer into biofilm

# How does stuff get into a biofilm?

Smaller mass transfer boundary layer (MTBL): more transfer into biofilm



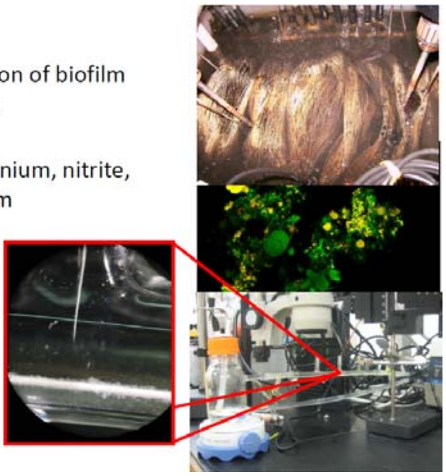
Higher concentration in bulk liquid: more transfer into biofilm

Thickness is important for biofilm performance *and* health

---

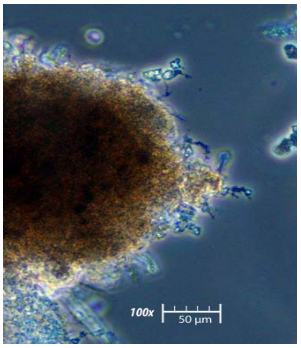
# Despite mass transfer limitation, same "bugs" are present

- Biofilm Research
  - Confirmed stratification of biofilm
    - Heterotrophs outside
    - AOB and NOB inside
  - Measured DO, ammonium, nitrite, and nitrate in a biofilm



## Mass transfer is the most critical consideration for biofilms

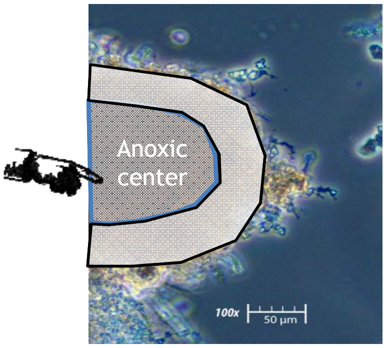
- Also important for activated sludge systems!



## Mass transfer is the most critical consideration for biofilms

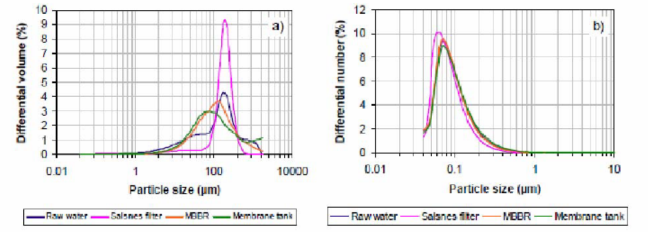
- Also important for activated sludge systems!

Mass transfer limitations in floc allows for the development of anoxic conditions in aerobic tanks, resulting in simultaneous nitrification and denitrification



# But how do the solids settle?

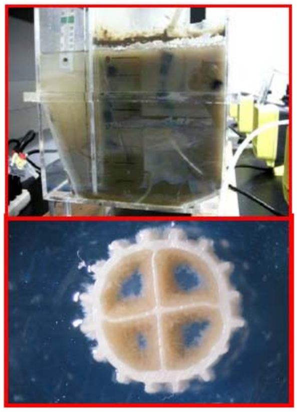
- Doesn’t settle poorly, they are just small solids



*Odegaard et al WEF/IWA Biofilm Reactor Technologies 2010*

# Controlling the biofilm is a key operational consideration

- Controlling rates
  - Decrease MTBL thickness
  - Increase bulk liquid concentrations
- Controlling biofilm thickness
  - Prevent excess thickness *and* excess sloughing
  - Not too thick, not too thin, but just right



## Given our key differences, what are the key design/modeling parameters?

- Biofilm thickness
- Mass transfer boundary layer thickness
- Biofilm growth and detachment
- Biofilm stratification and layers

## Given our key differences, what are the key design/modeling parameters?

- Biofilm thickness
- Mass transfer boundary layer thickness
- Biofilm growth and detachment
- Biofilm stratification and layers

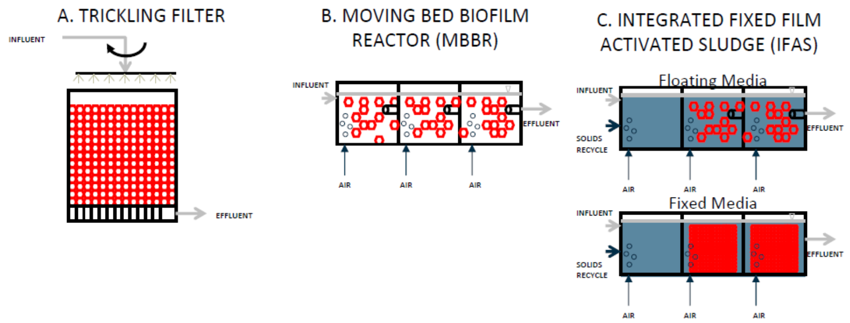
Mixing is a critical design parameters

# Mixing is a critical part of biofilm reactor design and modeling

*Flushing water/arm speed*

*Aeration and mechanical mixing*

*Aeration and mechanical mixing*



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# What are our key design parameters for biofilms?

- Activate sludge
  - <u>*SRT limited system*</u>
  - Hydraulic retention time (HRT)
  - Sludge retention time (SRT)
  - Volumetric loading rate
  - DO setpoints of less than 2 mg/L
- Biofilm reactors
  - <u>*Mass transfer limited system*</u>
  - Hydraulic retention time (HRT)
  - Biofilm thickness
  - MTBL assumptions
  - Attachment surface area
  - Media specific surface area
  - Area loading rate
  - DO setpoints of 4 to 5 mg/L

# Next Speaker

**Oliver Schraa, M.Eng.**
Chief Technical Officer
inCTRL Solutions Inc.
Oakville, Ontario, Canada

# Modeling Biofilm Reactors

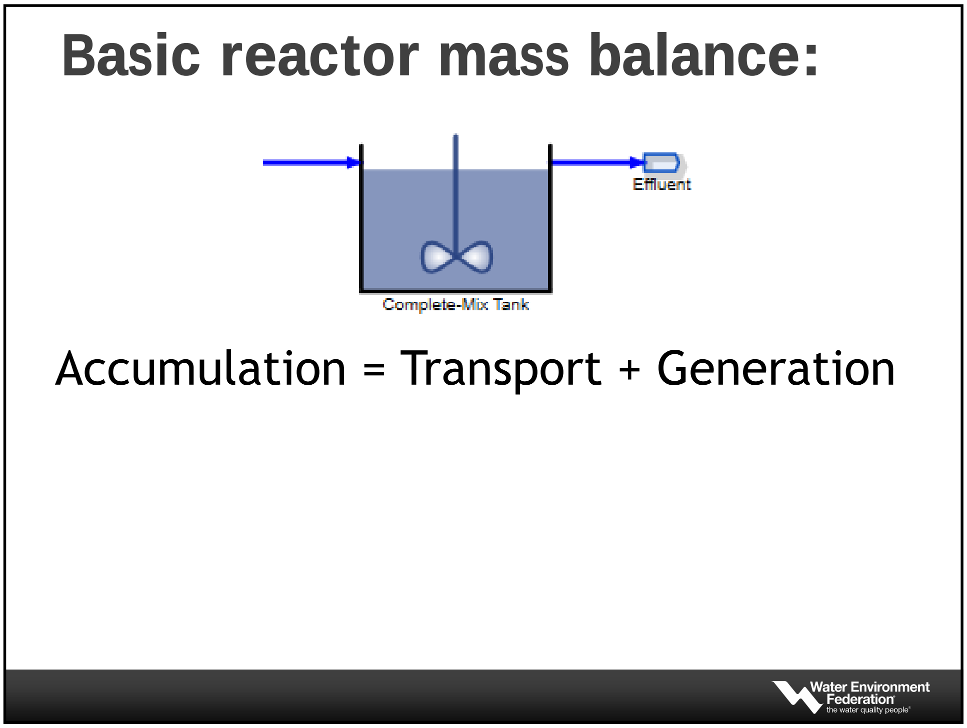
Oliver Schraa
inCTRL Solutions Inc., Oakville, Ontario

# Outline

- Introduction to activated sludge modeling
- Additional processes modeled in biofilm reactors
- Guidance on model setup and calibration
- Example
- Summary

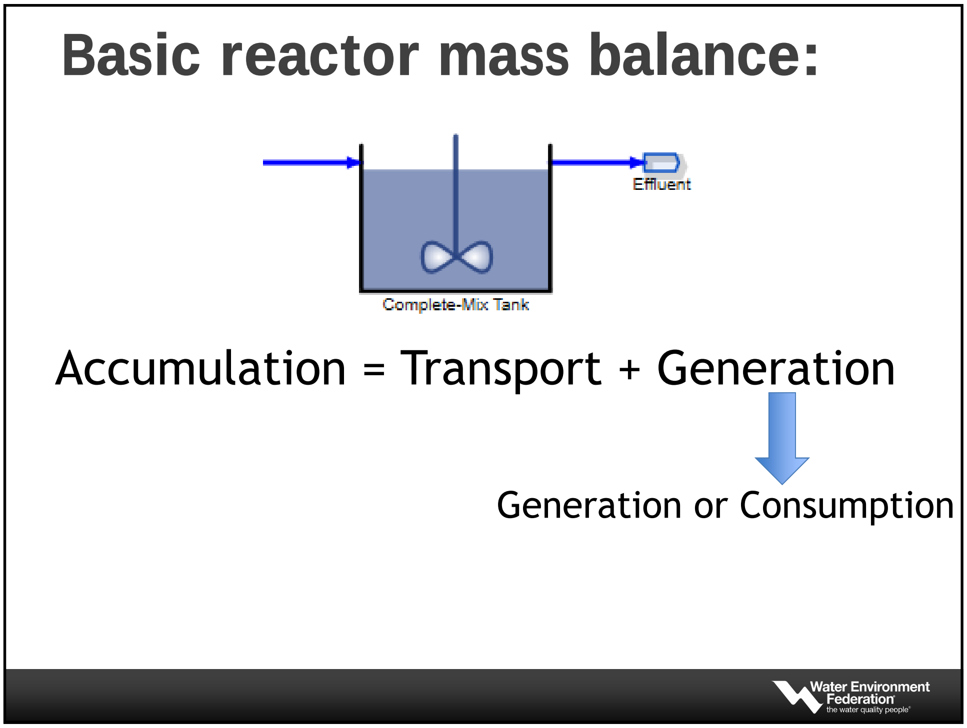
# Activated Sludge Modeling

Basic Structure of a Typical Activated Sludge Model



# Basic reactor mass balance:

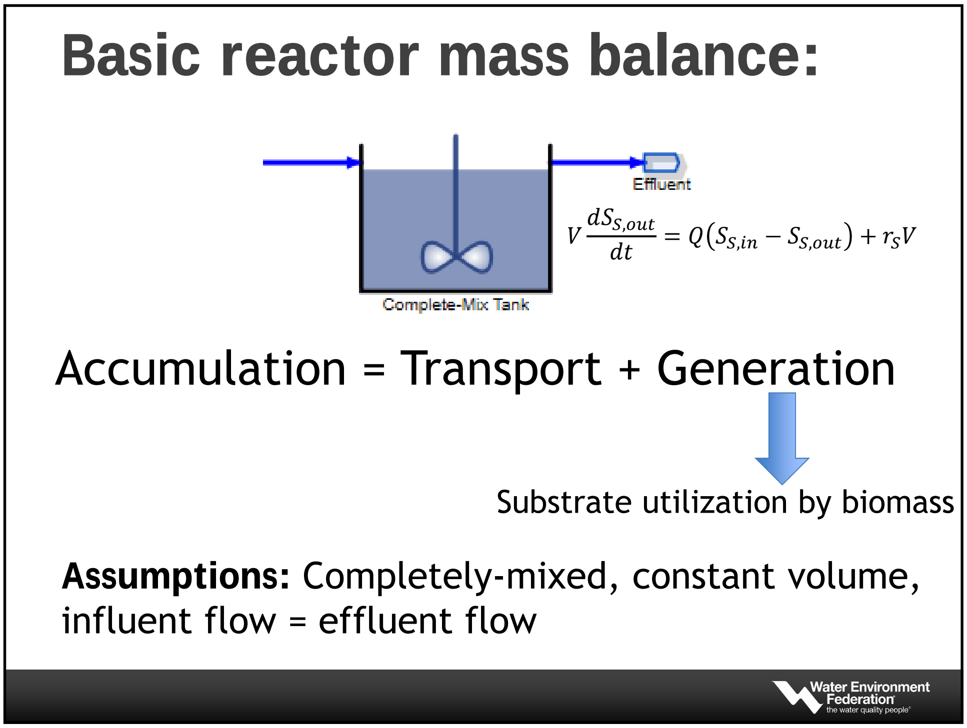
Accumulation = Transport + Generation



# Basic reactor mass balance:

Accumulation = Transport + Generation

Generation or Consumption



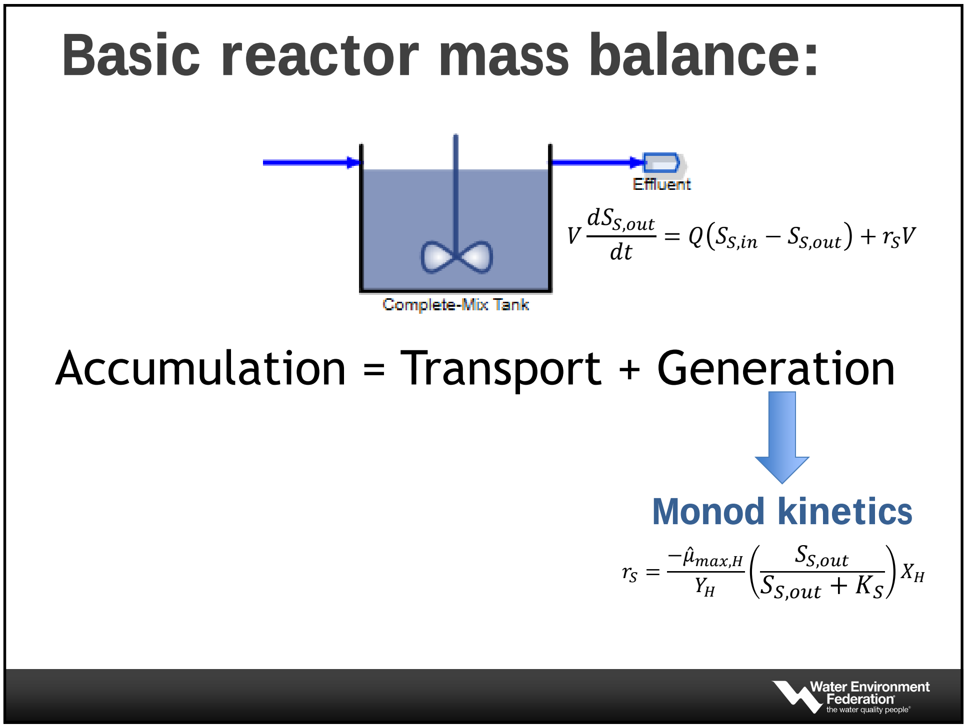
# Basic reactor mass balance:

$$V\frac{dS_{S,out}}{dt} = Q\left(S_{S,in} - S_{S,out}\right) + r_S V$$

Accumulation = Transport + Generation

Substrate utilization by biomass

**Assumptions:** Completely-mixed, constant volume, influent flow = effluent flow



# Basic reactor mass balance:

$$V\frac{dS_{S,out}}{dt} = Q\left(S_{S,in} - S_{S,out}\right) + r_S V$$

Accumulation = Transport + Generation

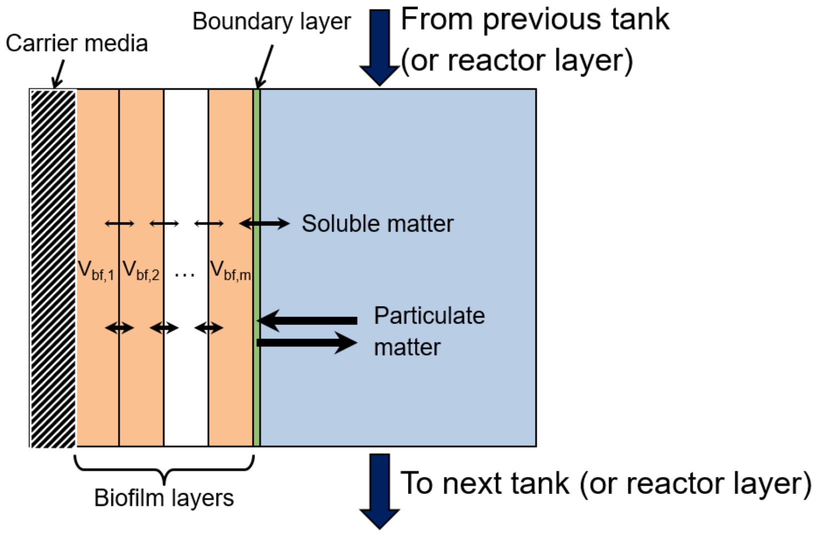
**Monod kinetics**

$$r_S = \frac{-\hat{\mu}_{max,H}}{Y_H}\left(\frac{S_{S,out}}{S_{S,out} + K_S}\right)X_H$$

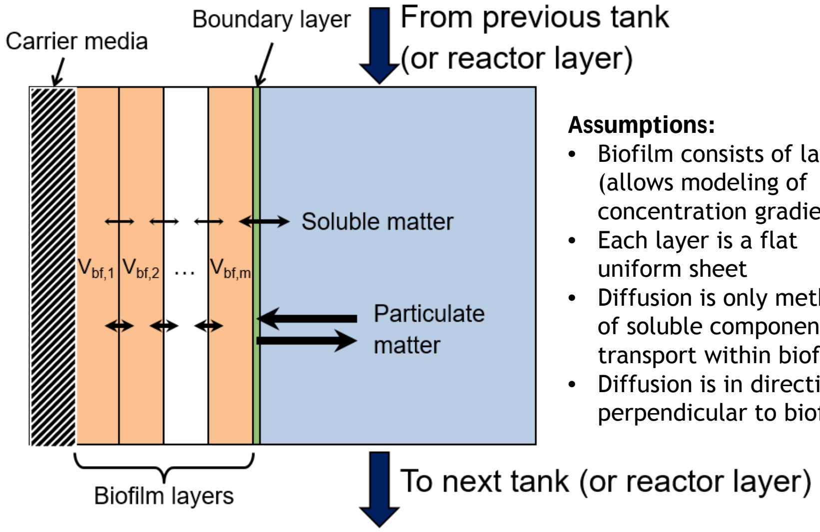
# Additional Processes Modeled in Biofilm Reactors

- **Diffusion** of soluble components into and within biofilm
- **Varying biofilm thickness** due to growth and decay, attachment of particles, and detachment of particles
- **Stratification of biofilm** into regions with different organisms and redox conditions

# Conceptual biofilm structure for model development



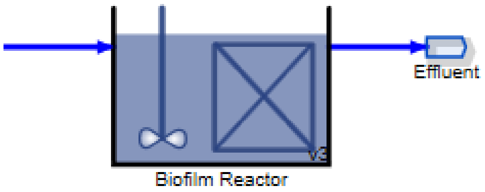
## Conceptual biofilm structure for model development



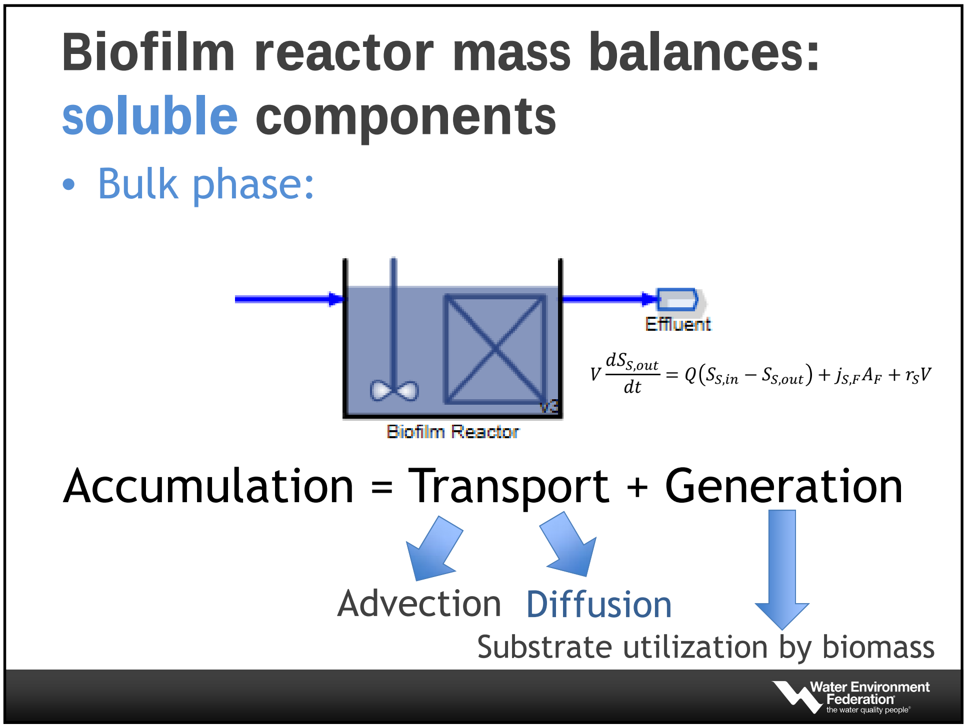
**Assumptions:**
- Biofilm consists of layers (allows modeling of concentration gradients)
- Each layer is a flat uniform sheet
- Diffusion is only method of soluble component transport within biofilm
- Diffusion is in direction perpendicular to biofilm

## Biofilm reactor mass balances: soluble components

- Bulk phase:



Accumulation = Transport + Generation



## Biofilm reactor mass balances: soluble components

- Bulk phase:

$$V\frac{dS_{S,out}}{dt} = Q(S_{S,in} - S_{S,out}) + j_{S,F}A_F + r_S V$$

Accumulation = Transport + Generation

Advection Diffusion

Substrate utilization by biomass

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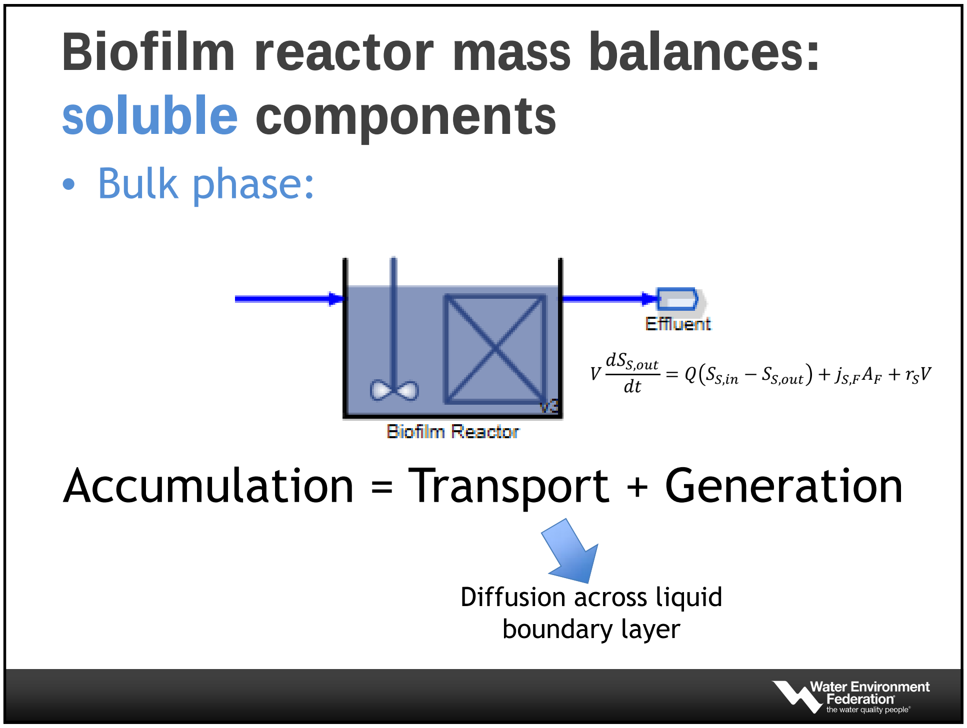

## Biofilm reactor mass balances: soluble components

- Bulk phase:

$$V\frac{dS_{S,out}}{dt} = Q(S_{S,in} - S_{S,out}) + j_{S,F}A_F + r_S V$$

Accumulation = Transport + Generation

Diffusion across liquid
boundary layer

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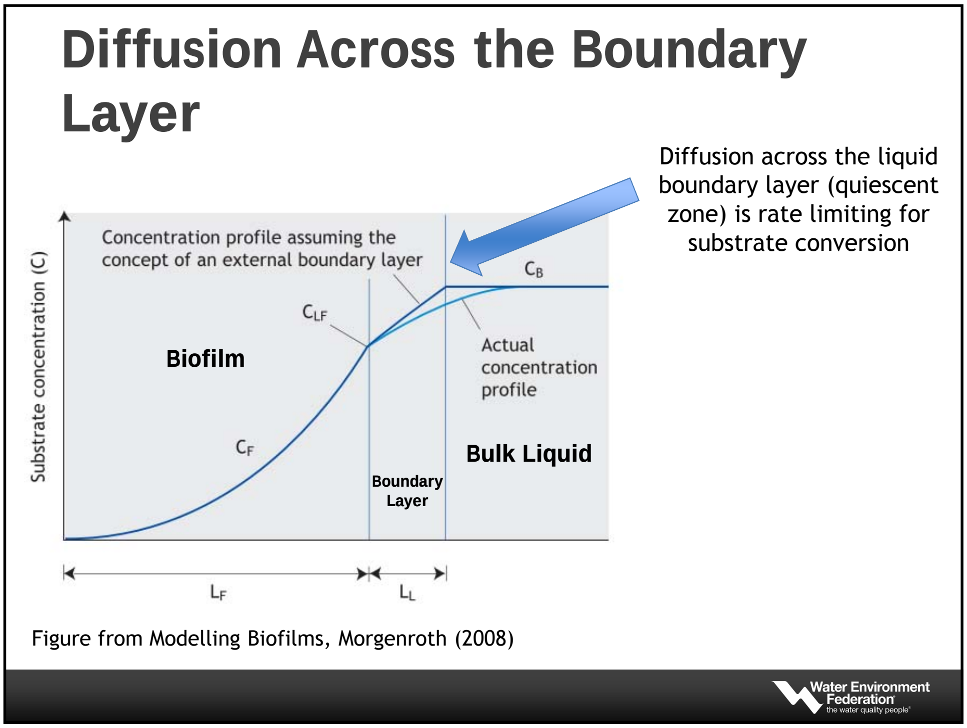
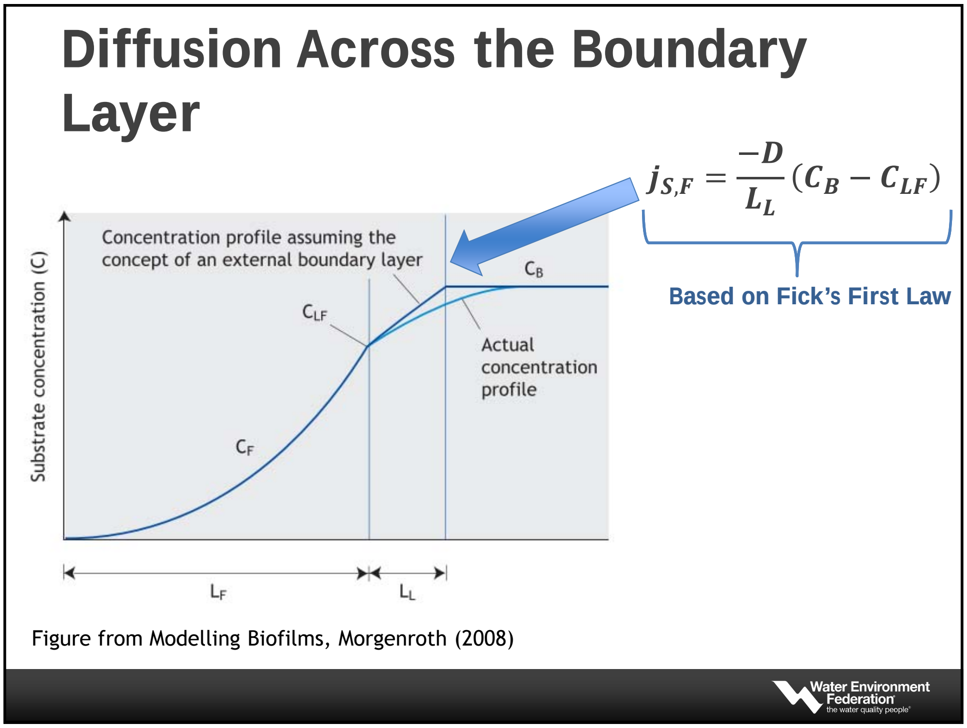


# Diffusion Across the Boundary Layer

Diffusion across the liquid boundary layer (quiescent zone) is rate limiting for substrate conversion

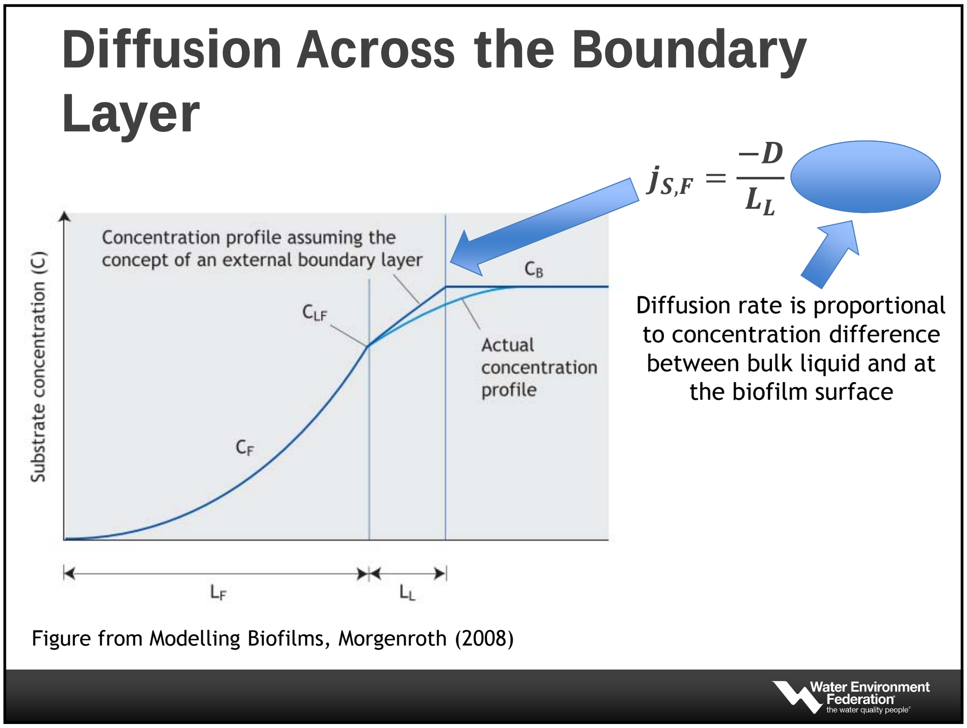
Figure from Modelling Biofilms, Morgenroth (2008)



# Diffusion Across the Boundary Layer

$$\underbrace{j_{S,F} = \frac{-D}{L_L}(C_B - C_{LF})}_{\text{Based on Fick's First Law}}$$

Figure from Modelling Biofilms, Morgenroth (2008)

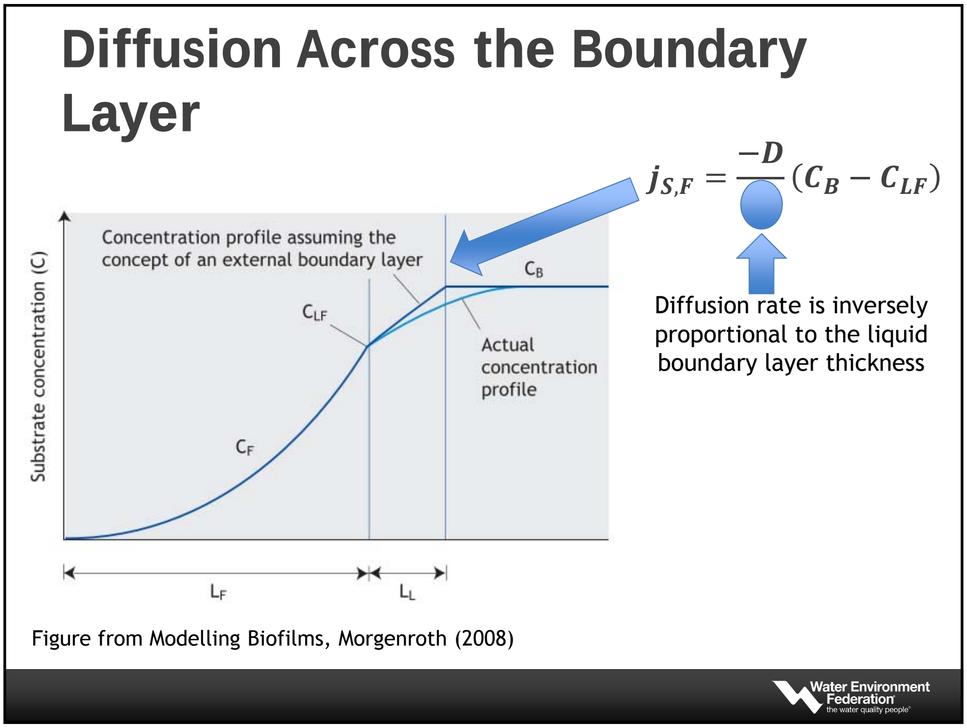


## Diffusion Across the Boundary Layer

$$j_{S,F} = \frac{-D}{L_L}$$

Diffusion rate is proportional to concentration difference between bulk liquid and at the biofilm surface

Figure from Modelling Biofilms, Morgenroth (2008)



## Diffusion Across the Boundary Layer

$$j_{S,F} = \frac{-D}{\quad}(C_B - C_{LF})$$

Diffusion rate is inversely proportional to the liquid boundary layer thickness

Figure from Modelling Biofilms, Morgenroth (2008)

## Biofilm reactor mass balances: soluble components

- **Within biofilm:**

Accumulation = Transport + Generation

---

## Biofilm reactor mass balances: soluble components

- **Within biofilm:**

Accumulation = Transport + Generation

↓

Diffusion that varies with biofilm depth

**Fick's first law of diffusion used to describe diffusion**

$$j_z = -D_{S,F}\frac{\partial S_{S,F}}{\partial z}$$

## Biofilm reactor mass balances: soluble components

- **Within biofilm:**

$$\underbrace{\text{Accumulation = Transport + Generation}}_{\text{Becomes a partial differential equation}}$$

$$\frac{\partial S_{S,F}}{\partial t} = -D_{S,F}\frac{\partial^2 S_{S,F}}{\partial z^2} + r_{S,F}$$

---

## Biofilm reactor mass balances: soluble components

- **Within biofilm:**

Accumulation = Transport + Generation

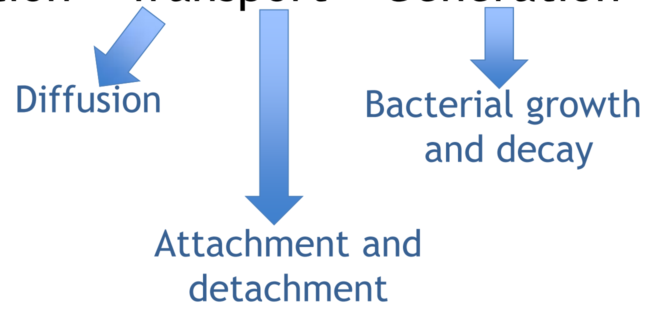
↓

Diffusion term discretized in space by
splitting biofilm into layers

## Biofilm reactor mass balances: particulate components

- **Within biofilm:**

Accumulation = Transport + Generation



Diffusion

Bacterial growth and decay

Attachment and detachment

---

## Biofilm reactor mass balances: particulate components

- **Within biofilm:**

$$\underbrace{\text{Accumulation} = \text{Transport} + \text{Generation}}_{\text{Becomes a partial differential equation}}$$

$$\frac{\partial X_{S,M}}{\partial t} = -\frac{\partial\left(u_F X_{S,M}\right)}{\partial z} + r_{X_{S,M}}$$

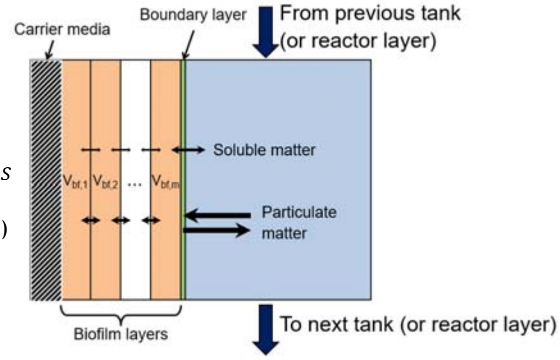
From Wanner et al. (2006)

# Balance on biofilm thickness

Change in thickness = Velocity of expansion or contraction due to
biomass growth or decay +
Attachment velocity –
Detachment velocity

$$\frac{dL}{dt} = u_f + u_{a,S} - u_{d,S}$$

From Wanner et al. (2006)



# Model Solution

- Solve system of partial differential equations (discretized into ordinary differential equations)
- Solve model using numerical integration (dynamic) or nonlinear algebraic solver (steady-state)
- Difficult system to solve numerically because of competing slow and fast processes
  - e.g. biomass growth versus diffusion rate
  - Specially designed solvers can help but biofilm reactor simulations are typically very time-consuming

# Model Calibration

General Steps with Any Activated Sludge Model

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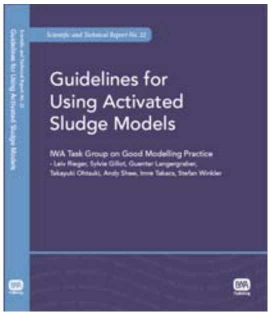
# The GMP Unified Protocol

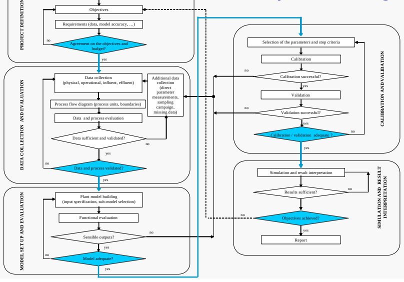
1. Project Definition
2. Data Collection & Reconciliation
3. Plant Model Set-Up
4. **Calibration/Validation**
5. Simulation & Results Interpretation


Scientific and Technical Report No. 22

Guidelines for Using Activated Sludge Models

IWA Task Group on Good Modelling Practice
– Leiv Rieger, Sylvie Gillot, Guenter Langergraber, Takayuki Ohtsuki, Andy Shaw, Imre Takacs, Stefan Winkler

https://iwa-gmp-tg.irstea.fr



## Step 4: Calibration and Validation

- **BNR Calibration Procedure**
  - Hydraulic model (tanks in series, flow splits)
  - Influent characterization
  - Sludge production (first COD and then TSS)
  - Nitrification
  - Denitrification
  - Phosphorus removal

**Iterative procedure!**

# Model Setup and Calibration

Additional Steps with Biofilm Models

# Model Setup and Calibration

- Key Additional Steps for Biofilm Reactors
  - Reactor physical parameters:
    - Carrier surface area and reactor fill fraction
    - Density of biofilm
    - Number of biofilm layers
  - Calibration parameters:
    - Liquid boundary layer thickness
    - Biofilm detachment rate
    - Diffusion reduction in biofilm

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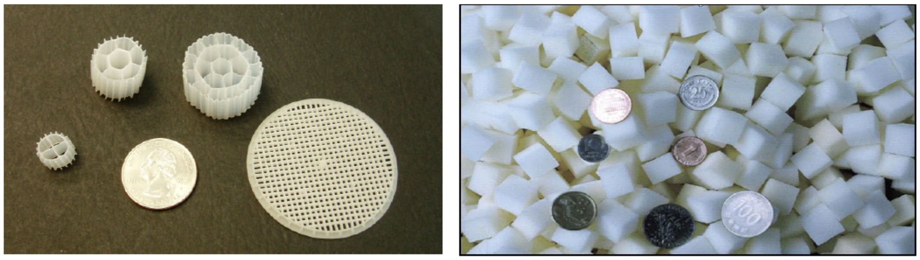
# Model Setup

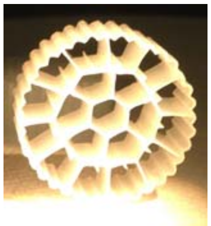
- **Specify details of media**



From Wallis-Lage et al. (2006)

# Model Setup

- **Specific carrier surface area:**
  - Surface area per volume of media
  - Ranges from 50 to 4,000 $m^2/m^3$ (Morgenroth, 2008)
    - Reported range for MBBR media is 400 to 1,200 $m^2/m^3$ (Weiss et al., 2005)
  - Data provided by manufacturers



# Model Setup

- **Fraction of reactor volume filled by media:**
  - Depends on technology
  - 30 to 60% is typical for MBBRs and IFAS
  - Also need water volume displaced by media

# Model Setup

- **Specify details of biofilm**

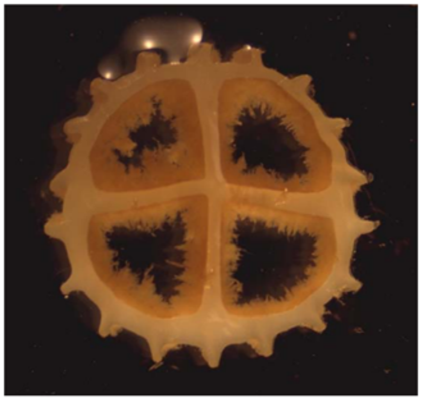


Photo from Ødegaard (1999)

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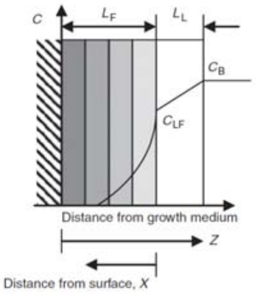
# Model Setup

- **Density of biofilm:**
  - Specify water content and dry density
  - Biofilm is typically between 3 and 7% dry solids
  - Density of dry solids ranges from 10 to 100 g/L (Melo, 2005)

# Model Setup

- **Number of biofilm layers**
  - Affects soluble profile through biofilm
  - 3 to 5 layers typical in most simulators
  - Fewer layers = faster simulations but less accurate profiles



Lewandowski Z and Boltz JP (2011) Biofilms in Water and Wastewater Treatment. In: Peter Wilderer (ed.) Treatise on Water Science, vol. 4, pp. 529–570 Oxford: Academic Press.

# Model Calibration

- **Estimation of liquid boundary layer**

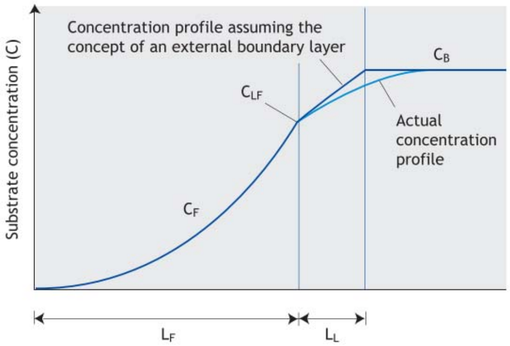


Figure from Modelling Biofilms, Morgenroth (2008)

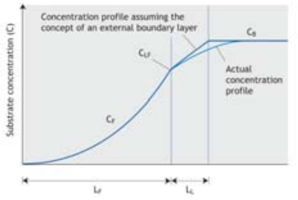
# Model Calibration

- **Liquid boundary layer**
    - Affects rate of diffusion into biofilm
    - Diffusion across biofilm is usually the rate limiting step
    - Thickness directly related to hydrodynamic conditions
        - Higher wastewater and air flowrates and more intense mixing lead to thinner boundary layers

---

# Model Calibration

- **Liquid boundary layer**
    - Ranges between 20 and 1,500 μm (Morgenroth, 2008)
    - **For exisiting systems:** calibrate using soluble concentrations in reactors, or estimate with empirical correlations
    - **For design:** calibrate to manufacturer or pilot data



# Model Calibration

- **Biofilm detachment rate**
  - Impacts biofilm thickness and SRT
  - Typical expression used:
    - $Detachment\ Rate = k_d$ Wanner and Gujer (1986)

Detachment rate is proportional to biofilm density and square of biofilm thickness

---

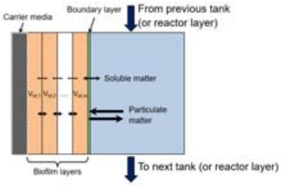
# Model Calibration

- **Diffusion rates**
  - Default model values taken from chemical engineering literature

- **Reduction in biofilm:**
  - Diffusion reduced in biofilm due to interactions with particulates
  - Ratio of diffusion in biofilm to diffusion in liquid phase is typically between 0.3 and 0.8
  - Typically leave at default value

# What are the most important biofilm-specific model inputs?

- Physical chacteristics of media:
    - Carrier surface area, water displaced by media, and reactor fill fraction
    - Density of biofilm
    - Number of biofilm layers
- Parameter requiring calibration:
    - Liquid boundary layer thickness



# Important concepts for design and modeling of biofilm reactors

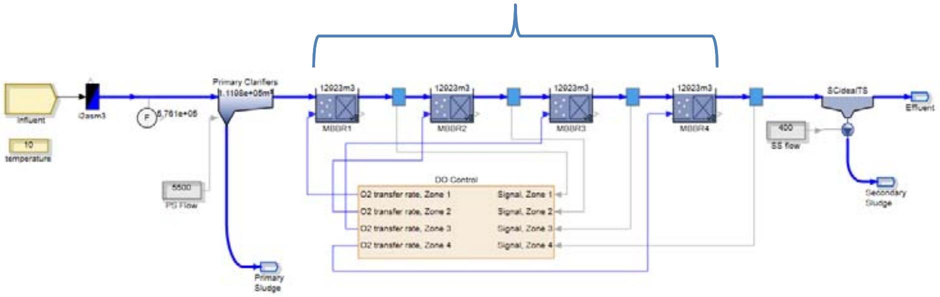
- Mass transfer is typically the rate-limiting step
- Identity of the limiting substrate changes over length of a biofilm reactor
- Can have different redox conditions within different regions of a biofilm
- Can have stratifcation of organisms within different regions of a biofilm

# Example

- Using a model to study impact of mass transfer resistance

**MBBR Plant for BOD removal and nitrification**

**Four MBBR's in series**



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the water quality people

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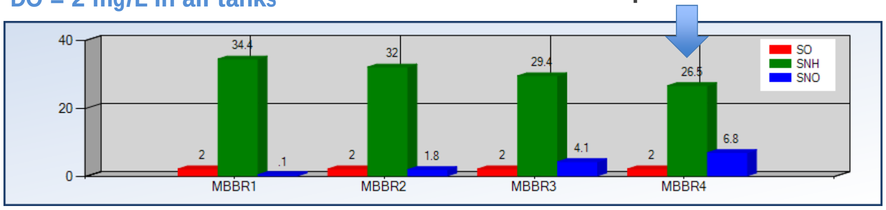
# Example

- Using a model to study impact of mass transfer resistance

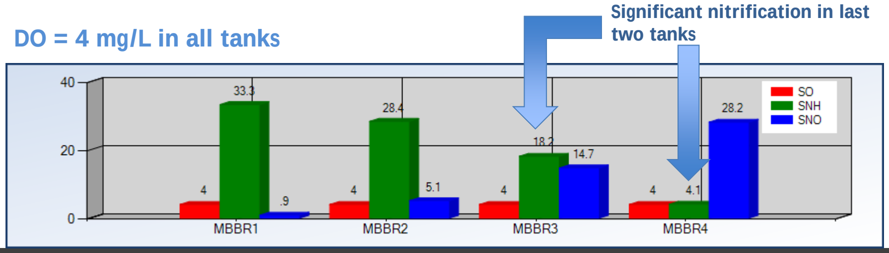
**DO = 2 mg/L in all tanks**

**Little nitrification: heterotrophs dominate in all tanks**



**DO = 4 mg/L in all tanks**

**Significant nitrification in last two tanks**



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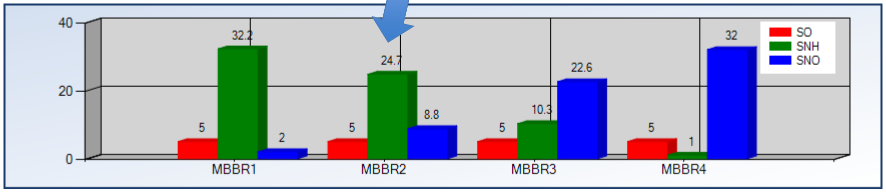
# Example

**Significant nitrification in second tank:**
**Nitrification becomes significant once oxygen penetrates far enough into biofilm and COD is low enough**

**DO = 5 mg/L in all tanks**



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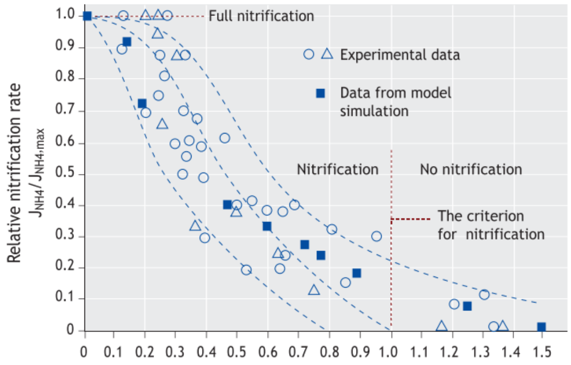
# Example

**Simulation agrees with experimental data:**
Nitrification rate is higher when organic substrate penetratation into biofilm is low relative to oxygen penetration



Ratio of organic substrate penetration to $O_2$ penetration

Adapted by Morgenroth (2008) from Henze et al. (2002)

## Summary

- Biofilm reactor modeling is similar to suspended growth modeling but more information is required for model setup
- Biofilm reactors are mass transfer limited and models are useful in studying how this impacts reactor design and control
- The key input parameters are:
    - Carrier surface area, water displaced by media, and reactor fill fraction
    - Density of biofilm
    - Number of biofilm layers
    - Liquid boundary layer thickness

## What is Next?

Using Biofilm Reactor Models as Part of Plant Design and Optimization

# Presenter Contact Information

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# References

Henze,M., Harremoës,P., Jansen,J.l.C. and Arvin,E. (2002). *Wastewater Treatment*. 3rd edition. Springer, Berlin.

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Wanner,O., Eberl,H.J., Morgenroth,E., Noguera,D.R., Picioreanu,C., Rittmann,B.E. and van Loosdrecht,M.C.M. (2006). *Mathematical Modeling of Biofilms,* IWA Publishing, London, UK. Series: Scientific and Technical Report Series Report No. 18.

# Next Speaker

**Tanush Wadhawan, Ph.D.**
Dynamita,
Toronto, Ontario, Canada

dynamita
PROCESS MODELING

sumo

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# Modeling applications for biofilm design and operations

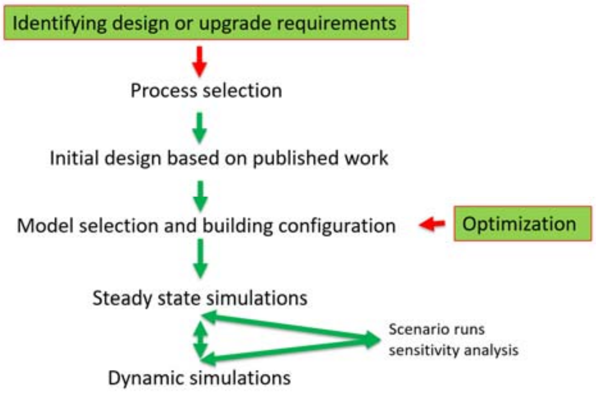
Tanush Wadhawan, PhD
Dynamita

# Key outline points

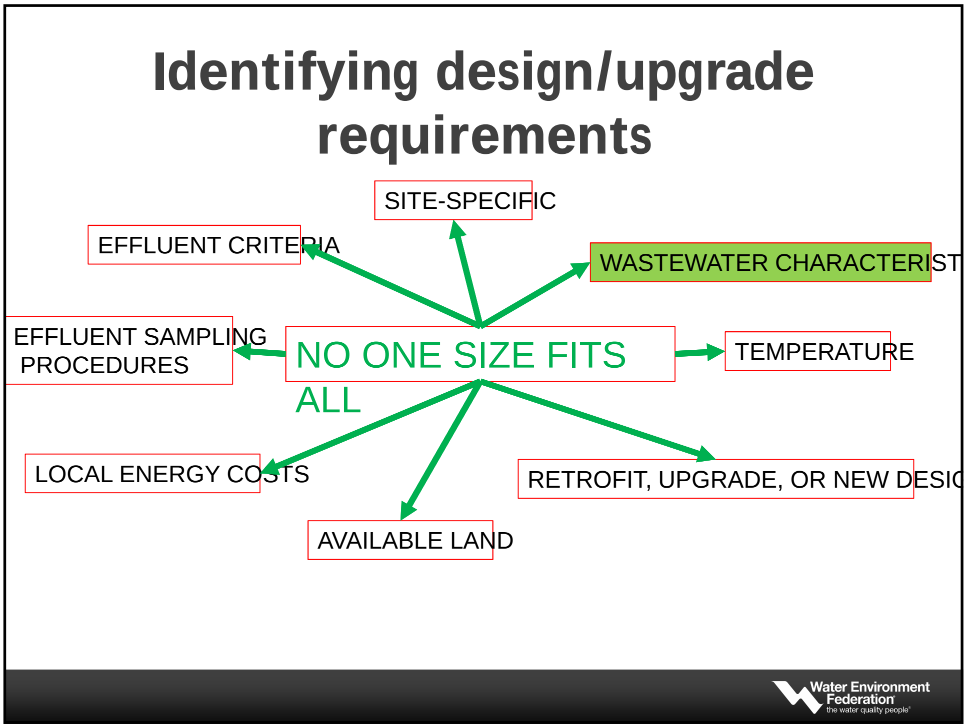
- Introduction to model applications
- Basic model/design requirements
- MBBR case study/applications
- Summary

# Modeling applications and guidelines

- Design
- Upgrade
- Optimization



Modified from https://iwa-gmp-tg.irstea.f



## Identifying design/upgrade requirements

SITE-SPECIFIC

EFFLUENT CRITERIA

WASTEWATER CHARACTERIST

EFFLUENT SAMPLING
PROCEDURES

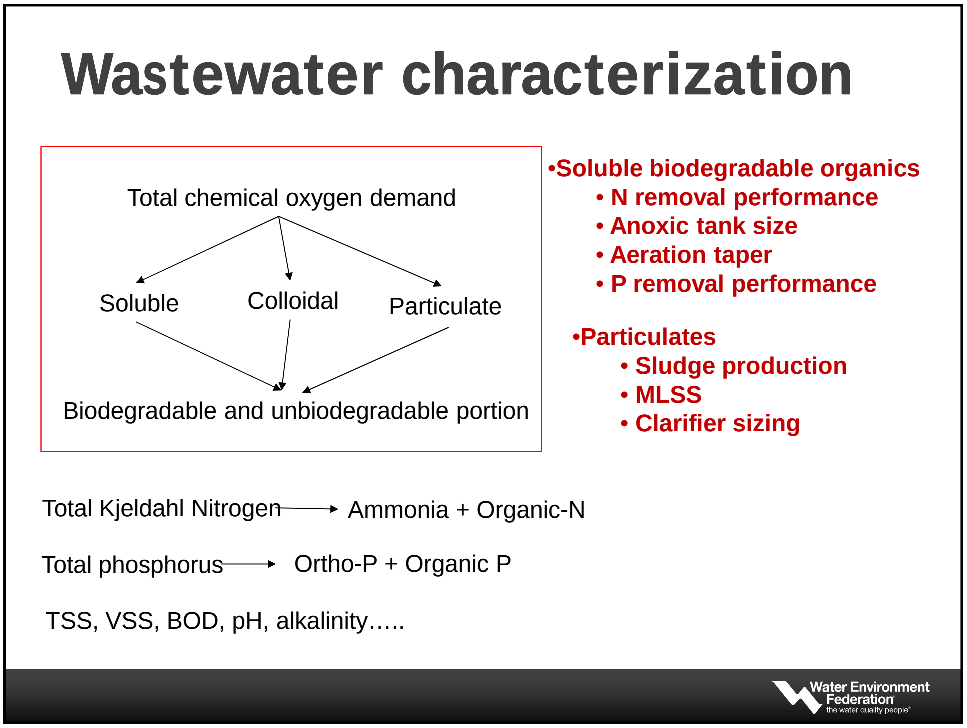
NO ONE SIZE FITS ALL

TEMPERATURE

LOCAL ENERGY COSTS

RETROFIT, UPGRADE, OR NEW DESI

AVAILABLE LAND



## Wastewater characterization

Total chemical oxygen demand

Soluble

Colloidal

Particulate

Biodegradable and unbiodegradable portion

- **Soluble biodegradable organics**
  - **N removal performance**
  - **Anoxic tank size**
  - **Aeration taper**
  - **P removal performance**
- **Particulates**
  - **Sludge production**
  - **MLSS**
  - **Clarifier sizing**

Total Kjeldahl Nitrogen → Ammonia + Organic-N

Total phosphorus → Ortho-P + Organic P

TSS, VSS, BOD, pH, alkalinity…..

# Basic design requirements

- Pre-screening of inert material
- Length-to-width ratio of 0.5:1 - 1.5:1
- Carrier fill - 25 to 67%
- Coarse bubble aeration system
- Sieve to retain media
- Mechanical mixing
- Solids separation

http://www.worldwaterworks.com

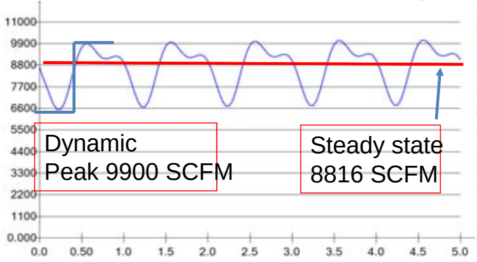
# Steady state simulations

- Long term averaged performance
  - Average annual and average monthly
  - Average weekly – Caution! (facility might not be at steady state)
- Good for initial process design and sizing
- Facilities are inherently dynamic (especially nutrient removal processes)
  - Use peaking factors in design procedure
  - Using dynamic modeling

# Dynamic simulations

- Anticipating peak loading conditions
- Refining the design

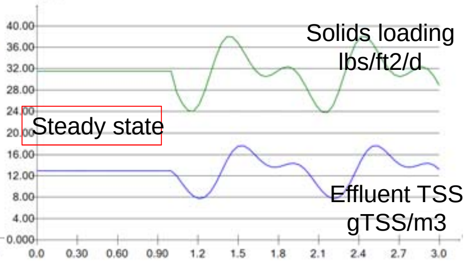
**Aeration/blower design**



Dynamic
Peak 9900 SCFM

Steady state
8816 SCFM

**Clarifier design**



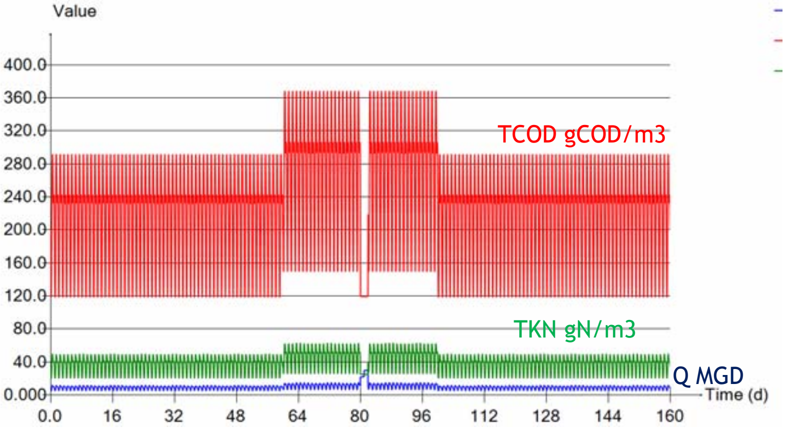
Solids loading
lbs/ft2/d

Steady state

Effluent TSS
gTSS/m3

---

# Dynamic simulations



- Diurnal
- Weekly, monthly, and seasonal modelling
- Maximum Month “Birthday Cake” analysis
- Dynamic response to storm water event

# Modeling MBBR applications

A. Case studies
1. Broomfield WWTP, Colorado, USA
2. James river treatment plant, VA, USA

B. Other applications
1. Volumetric loading verses surface area loading
2. Comparing footprint of an MBBR versus and activated sludge process
3. Evaluating robustness of an MBBR process versus and activated sludge process
4. Improving capacity of an MBBR system

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the water quality people

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# Broomfield WWTP, Colorado

Water Environment Federation
the water quality people

# Broomfield wastewater treatment plant (BWWTP)

Biofilm reactors, Chapter 11, WEF MOP No. 35.

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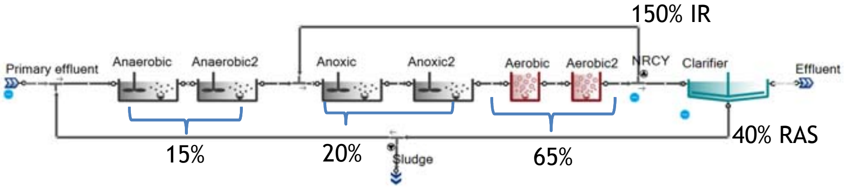
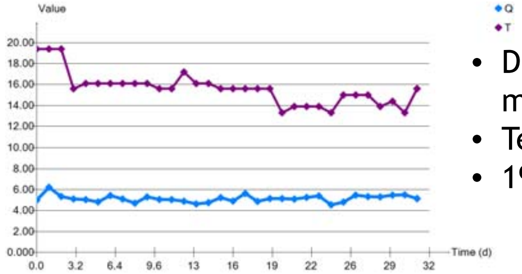
# BWWTP configuration



Total volume 1.853 MG

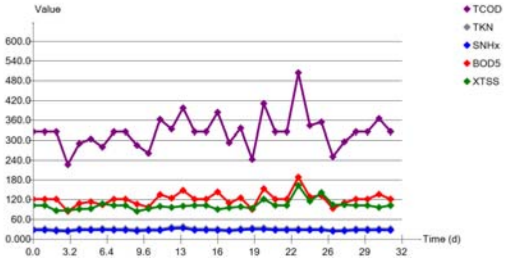
- IFAS plant operated as A2O configuration
- Kaldnes K1 media with 30% fill
- Biofilm surface area 500 m2/m3
    - Effective surface area 150 m2/m3
- Total SRT 5 days, aerobic SRT 3.25 days

# Primary effluent



- Daily flow and temperature measurements
- Temperature change is crucial
- 19 C to 13 C during December

- BOD, TSS, NHx-N, NOx-N weekly
- COD/BOD ratio once a month (2.7)



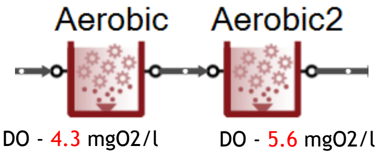
# Operational data collection

- Media is dried, weighed and compared to bare media for biofilm growth
- Biofilm thickness should be measured occasionally (at least visual inspection)
- The biofilm is thinner in the winter than in the summer
- First aerobic reactor has thicker (1 ± 0.2 mm) biofilm that second aerobic reactor (0.6 ± 0.2 mm)

# MBBR operational data

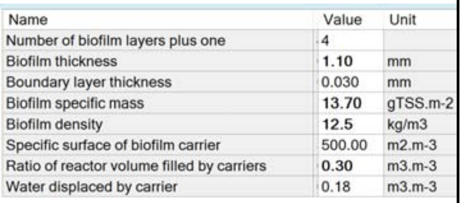
| | Values | Units | Comments |
|---|---|---|---|
| **Suspended biomass, MLSS** | 1630 | g/m3 | Measured data |
| **Aerobic 1 fixed biomass** | 2050 | g/m3 | |
| **Aerobic 2 fixed biomass** | 1104 | g/m3 | |
| **Volume per cell** | 2271 | m3 | Design |
| | | | |
| **Effective surface area** | 150 | m2/m3 | Manufacturer's data |
| **Total surface area per cell** | 340650 | m2 | Calculated |
| | | | |
| **Biomass Aerobic 1 per surface area** | 13.7 | kg/1000 m2 | Calculated |
| **Biomass Aerobic 2 per surface area** | 7.4 | kg/1000 m2 | |
| | | | |
| **Biofilm thickness Aerobic 1** | 1.1 | mm | Calculated from density 12.5 kg/m3 |
| **Biofilm thickness Aerobic 2** | 0.6 | mm | |

Red are model inputs



DO - 4.3 mgO2/l

DO - 5.6 mgO2/l

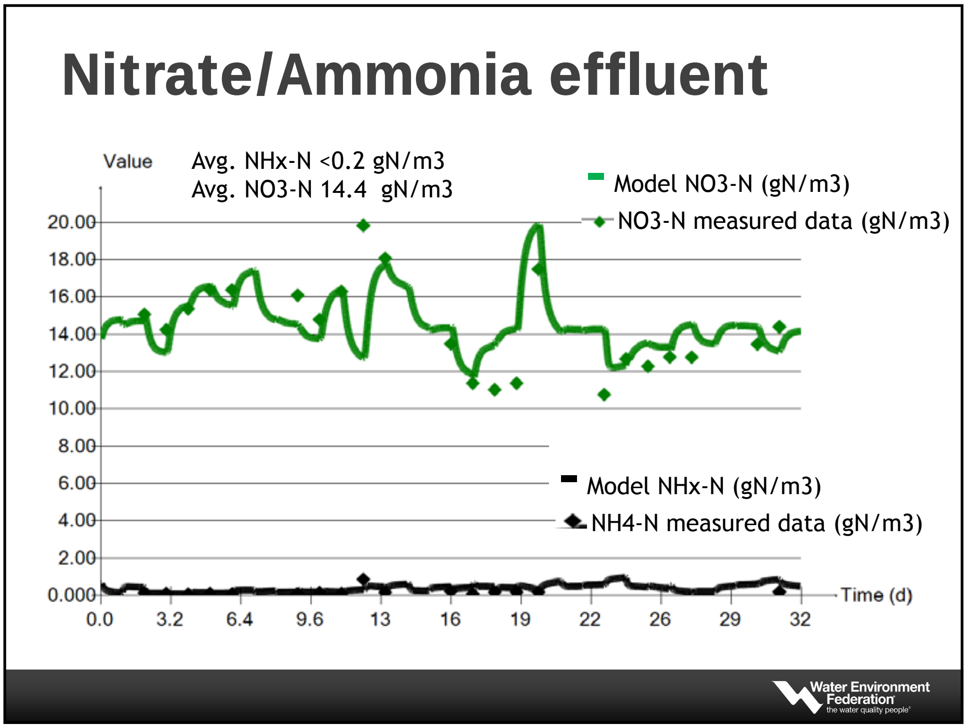


| Name | Value | Unit |
|---|---|---|
| Number of biofilm layers plus one | 4 | |
| Biofilm thickness | 1.10 | mm |
| Boundary layer thickness | 0.030 | mm |
| Biofilm specific mass | 13.70 | gTSS.m-2 |
| Biofilm density | 12.5 | kg/m3 |
| Specific surface of biofilm carrier | 500.00 | m2.m-3 |
| Ratio of reactor volume filled by carriers | 0.30 | m3.m-3 |
| Water displaced by carrier | 0.18 | m3.m-3 |

---

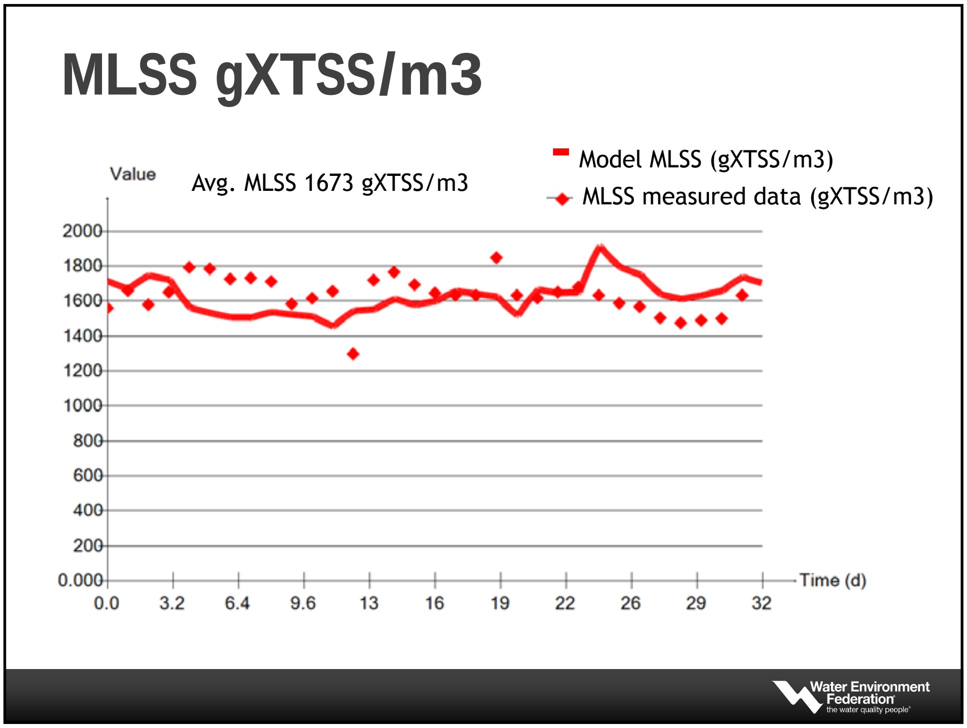
# Calibration process

- Garbage “In” = Garbage “Out”
  - Very important to get the influent characterization correct
  - Temperature is quite important
    - Nitrification rates (every 10 C increase rates double)
    - Models use Arrhenius equation
  - Estimating biofilm input parameters from data or manufacture’s data
- Using default setting of the models will simulate reasonably



# Nitrate/Ammonia effluent

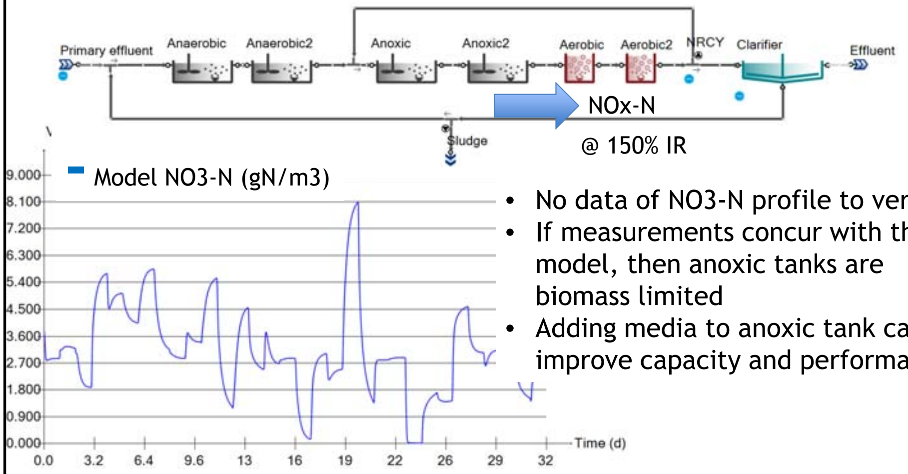
Avg. NHx-N <0.2 gN/m3
Avg. NO3-N 14.4 gN/m3



# MLSS gXTSS/m3

Avg. MLSS 1673 gXTSS/m3

# Identifying limitations



- No data of NO3-N profile to verify
- If measurements concur with the model, then anoxic tanks are biomass limited
- Adding media to anoxic tank can improve capacity and performance

This is an example of a significant finding from a simulation study that can help improve design and operation of a plant.

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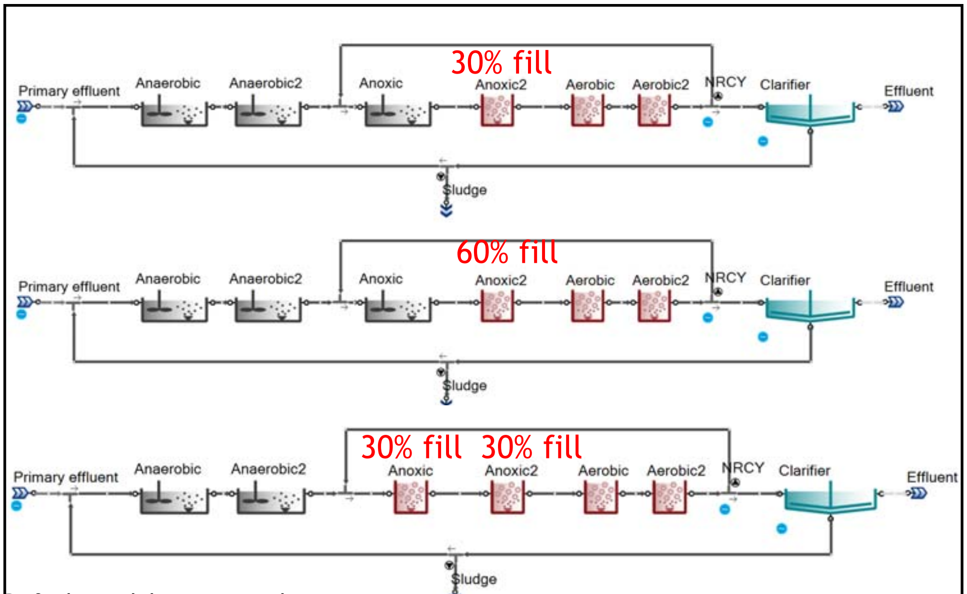
# Summary from BWWTP case study

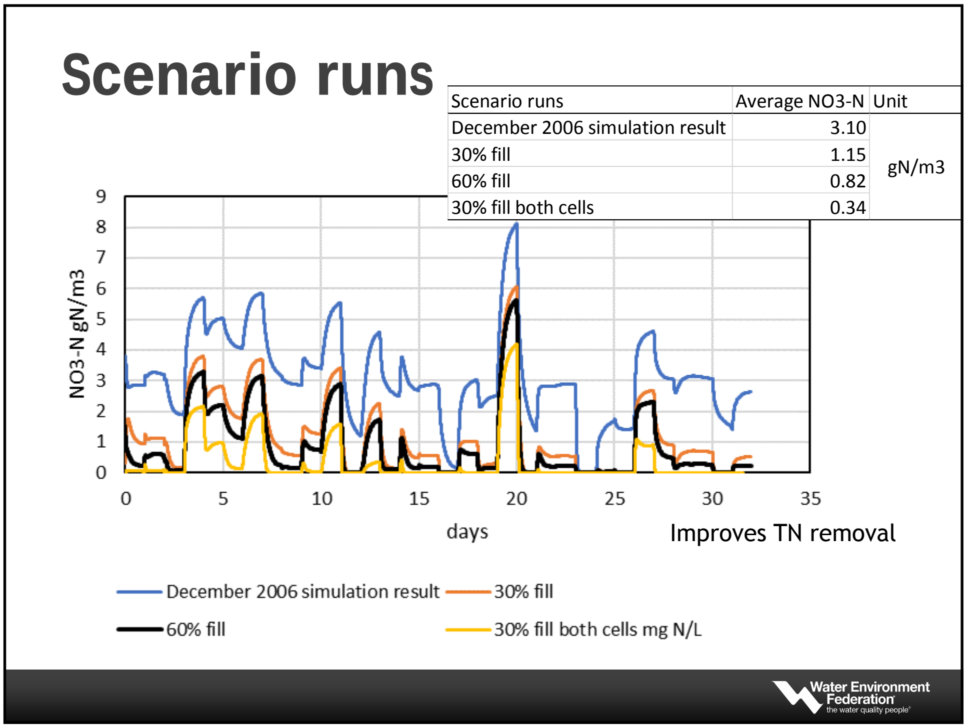
- Influent and operational data
  - Biofilm specific mass
  - Biofilm thickness
  - Specific surface area
- As long as most of the inputs are correct, models will give reliable outputs
- The modeling study helped identify design limitations and areas for operational improvement

# Lets try to upgrade!

- When a model is well calibrated to existing operation then scenario runs are quite beneficial
    - Upgraded Anoxic2 from activated sludge to IFAS by 30% K1 media
    - Increased media to 60%
    - Upgraded both anoxic cells with 30% K1 media



Default model inputs used
For more accurate representation get information from published work or manufacturers



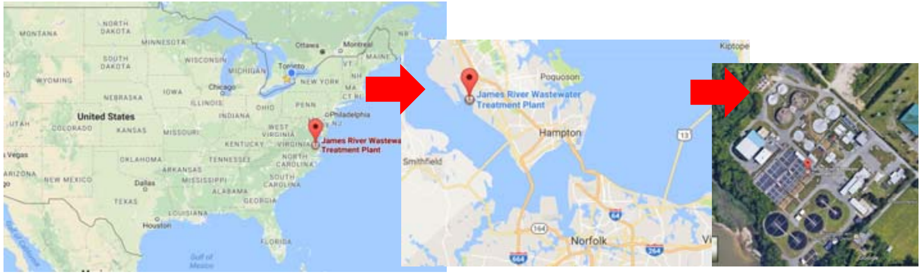
# Scenario runs

| Scenario runs | Average NO3-N | Unit |
|---|---|---|
| December 2006 simulation result | 3.10 | gN/m3 |
| 30% fill | 1.15 | |
| 60% fill | 0.82 | |
| 30% fill both cells | 0.34 | |

Improves TN removal

# James river WWTP, VA, USA

# James river treatment plant (JRTP)



- One of nine major treatment plants operated by the Hampton Roads Sanitation District (HRSD) in southeast Virginia

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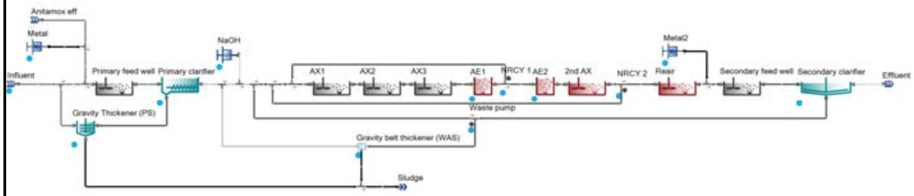
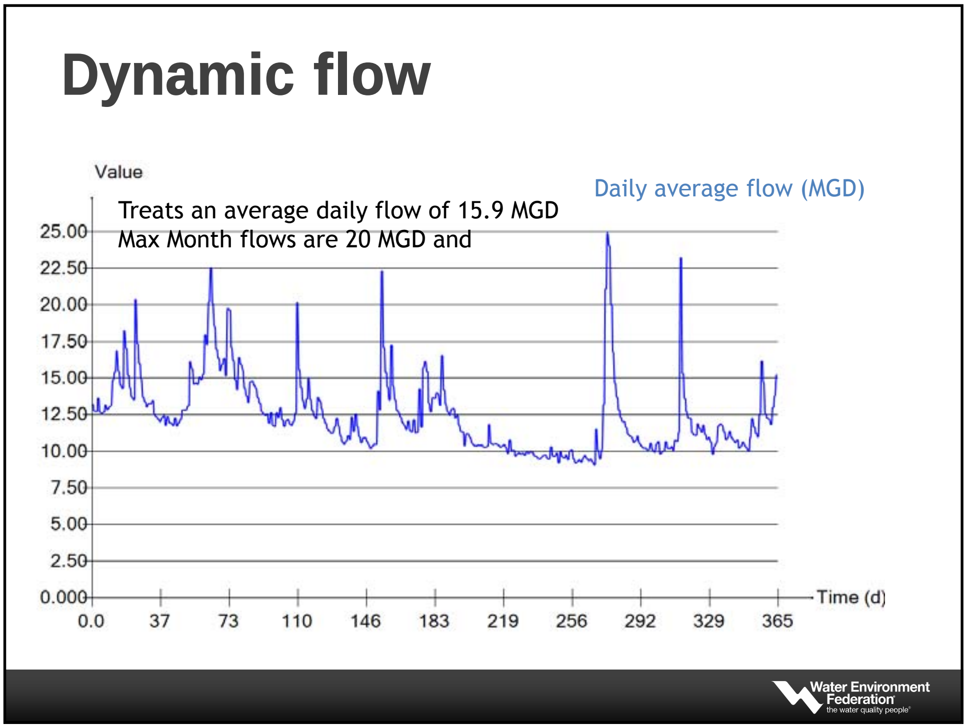
# JRTP configuration

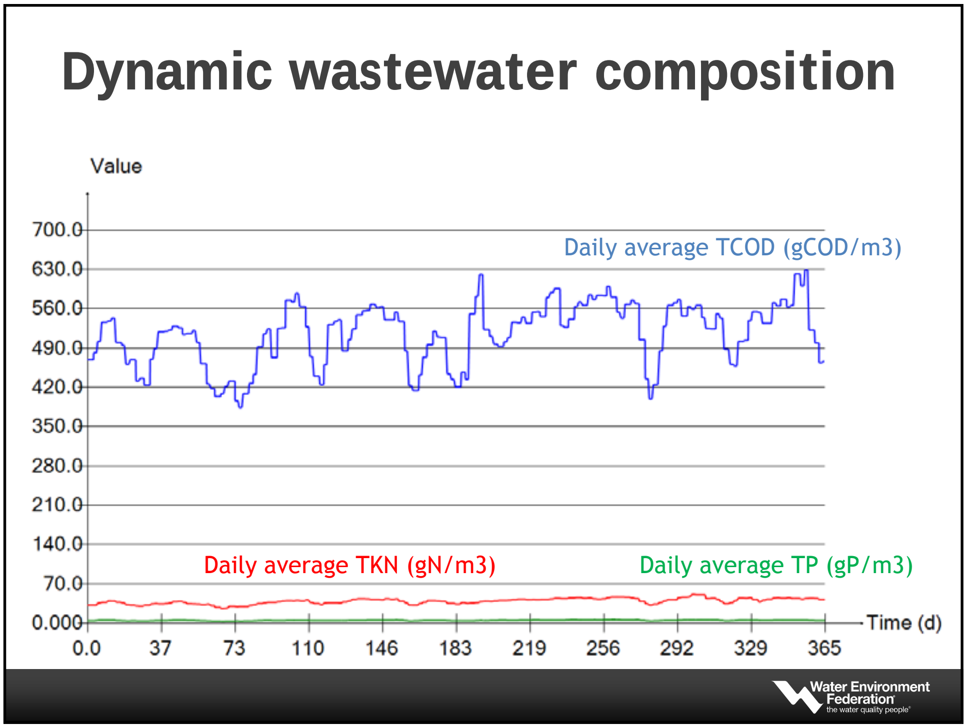


- Initial design activated sludge
- Upgraded to pre-anoxic zones + IFAS (MLSS + media)
- The plastic media is retained by cylindrical screens



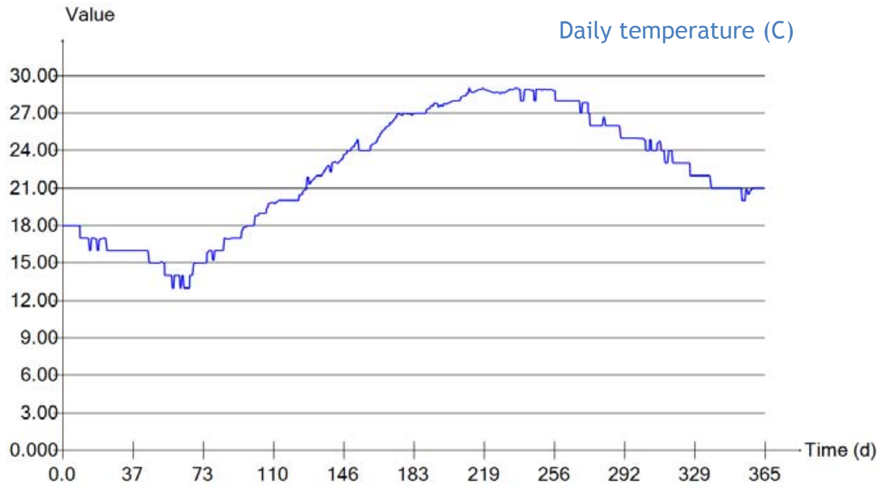
## Dynamic flow

Treats an average daily flow of 15.9 MGD
Max Month flows are 20 MGD and

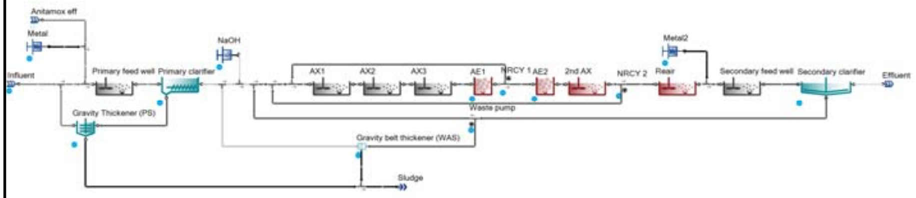


## Dynamic wastewater composition

# Dynamic temperature

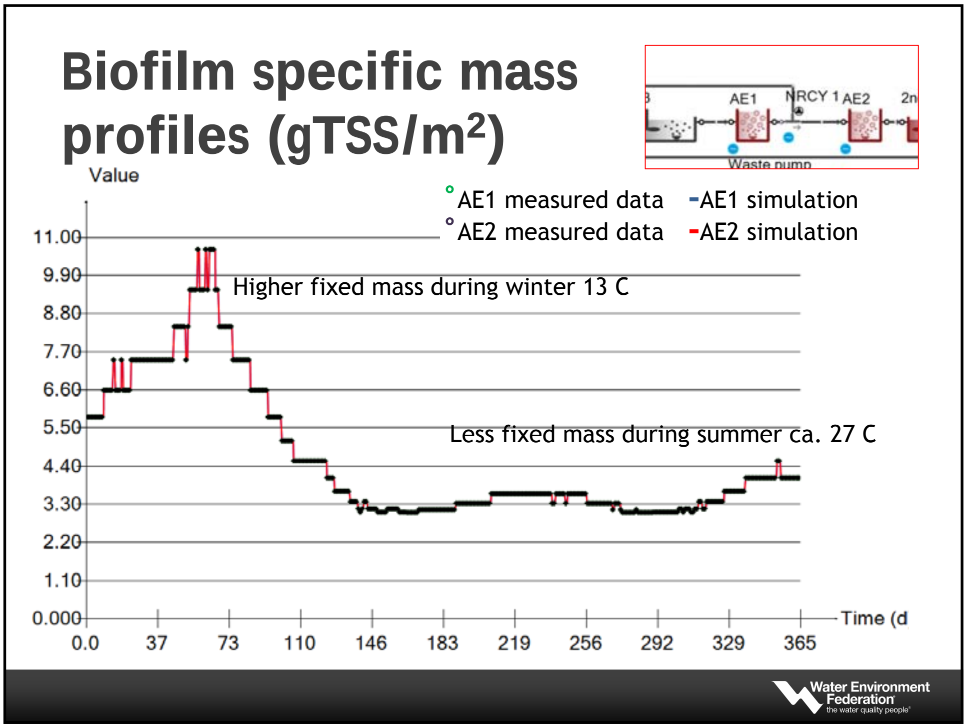


# JRTP configuration



| Name | AE1 | AE2 | Unit |
|---|---|---|---|
| Number of biofilm layers plus one | 4.0 | 4.0 | Unitless |
| Biofilm thickness | 0.70 | 0.70 | mm |
| Boundary layer thickness | 0.030 | 0.030 | mm |
| Biofilm specific mass | 4.1 | 4.1 | gTSS.m-2 |
| Biofilm density | 1020 | 1020 | kg/m3 |
| Specific surface of biofilm carrier | 500 | 500 | m2.m-3 |
| Ratio of reactor volume filled by carriers | 0.45 | 0.45 | m3.m-3 |
| Water displaced by carrier | 0.13 | 0.13 | m3.m-3 |

Specific mass changes seasonally
Previous example was only for December

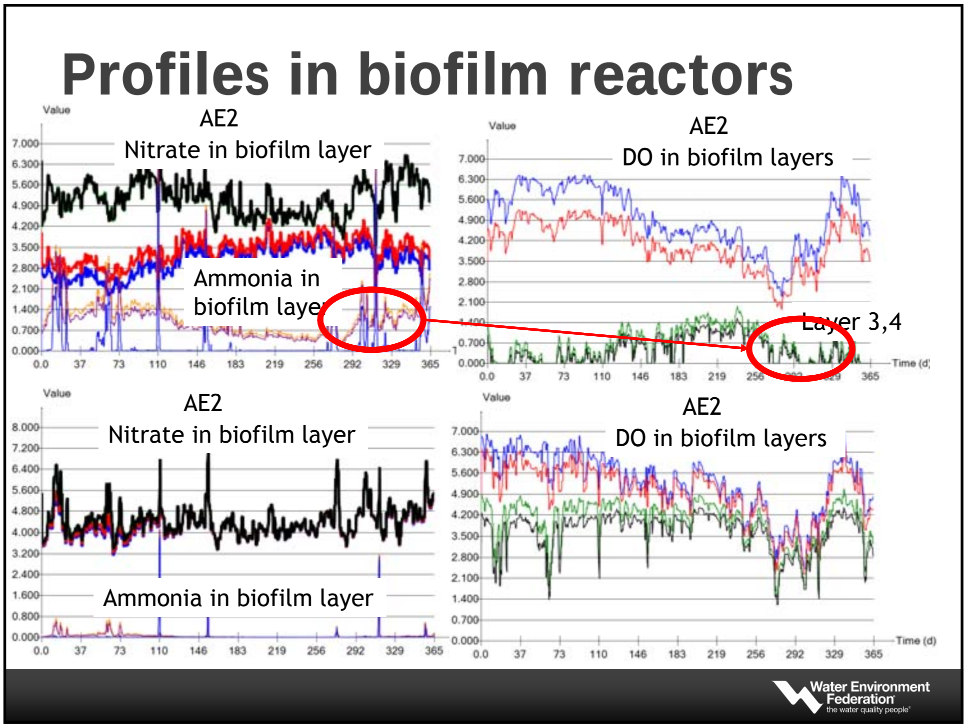


# Biofilm specific mass profiles (gTSS/m$^2$)

° AE1 measured data
° AE2 measured data
- AE1 simulation
- AE2 simulation

Higher fixed mass during winter 13 C

Less fixed mass during summer ca. 27 C



# Profiles in biofilm reactors

AE2
Nitrate in biofilm layer

Ammonia in biofilm layer

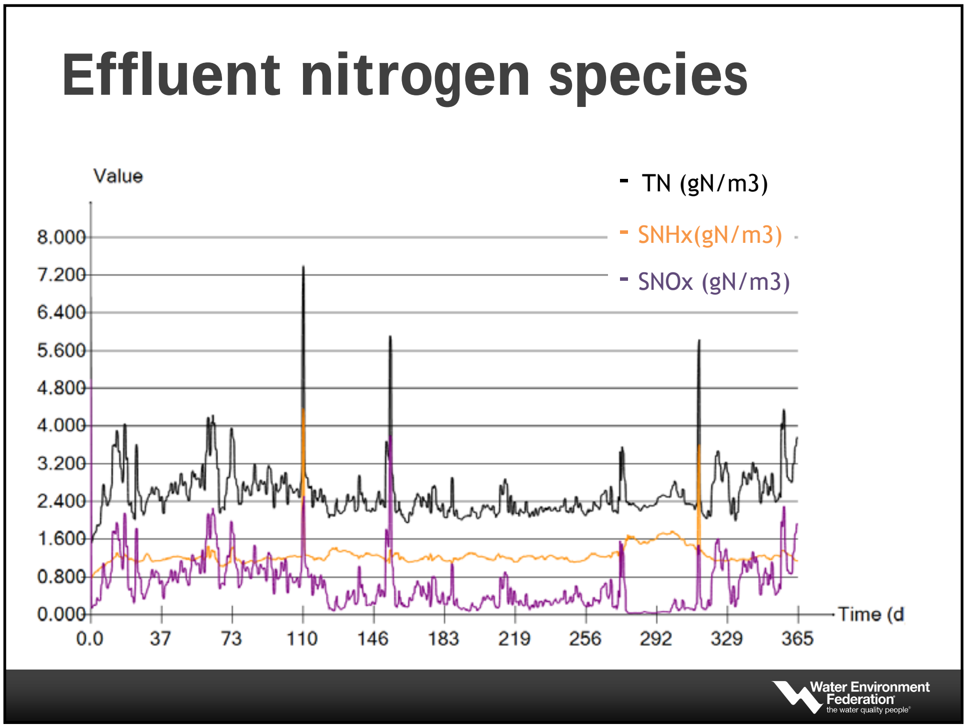
AE2
DO in biofilm layers

Layer 3,4

AE2
Nitrate in biofilm layer

Ammonia in biofilm layer

AE2
DO in biofilm layers

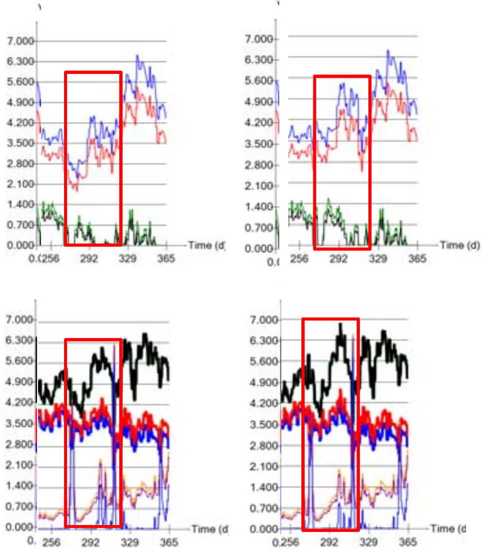


# Effluent nitrogen species

# Summary from JRTP case study

- IFAS upgrade increased biomass in the tank
- Able to achieve more treatment in the same volume and meet low TN limits
- Calibrated models can help understand the limiting conditions for nitrification

# Increasing DO when limiting



- DO gets limiting in the biofilm layers
- Limiting nitrification
- Increased the bulk DO concentration during the 269-309 days by 1 gO2/m3
- Increased NO3-N by 1 gN/m3

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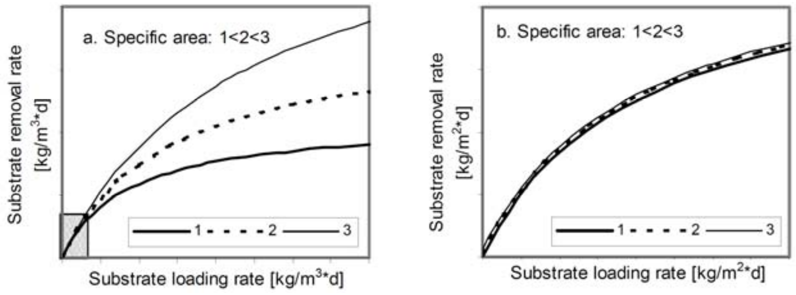
# Other applications

Evaluating biofilm applications using simulation

# Volumetric loading verses surface area loading

Size and surface area of the media does not matter as long as surface loading rates are the same.



Ødegaard, 2000

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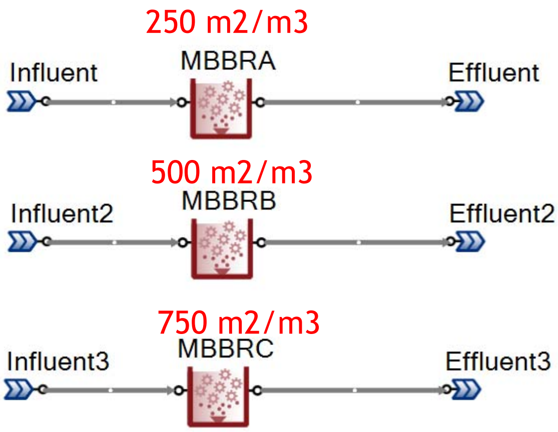
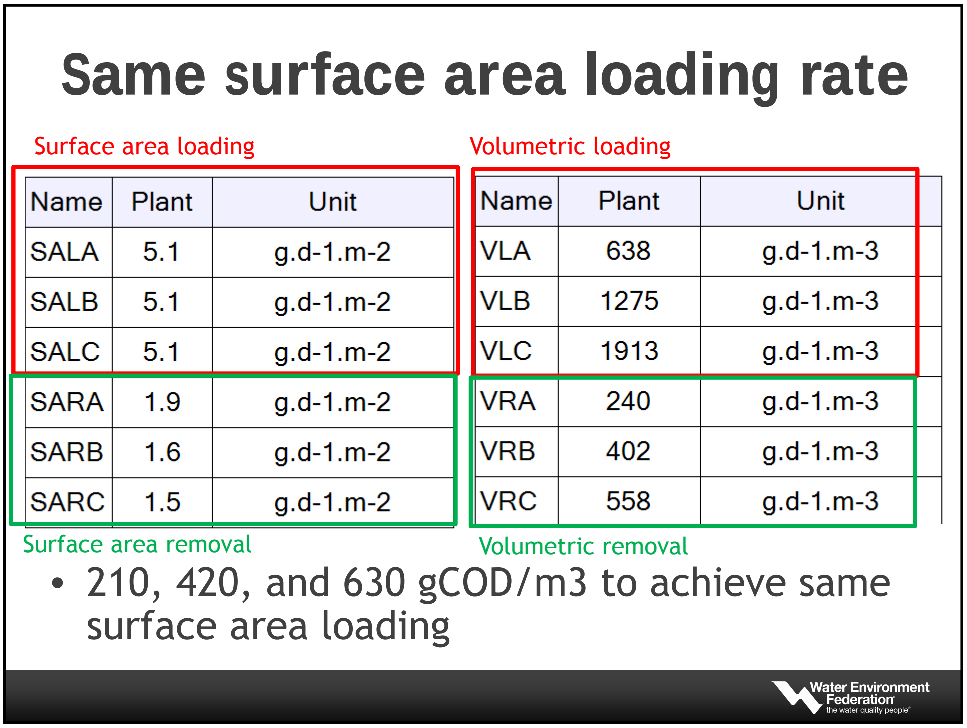
# Model evaluation


250 m2/m3

500 m2/m3

750 m2/m3

- Same influent and default MBBR parameters



# Same surface area loading rate

Surface area loading

| Name | Plant | Unit |
|---|---|---|
| SALA | 5.1 | g.d-1.m-2 |
| SALB | 5.1 | g.d-1.m-2 |
| SALC | 5.1 | g.d-1.m-2 |
| SARA | 1.9 | g.d-1.m-2 |
| SARB | 1.6 | g.d-1.m-2 |
| SARC | 1.5 | g.d-1.m-2 |

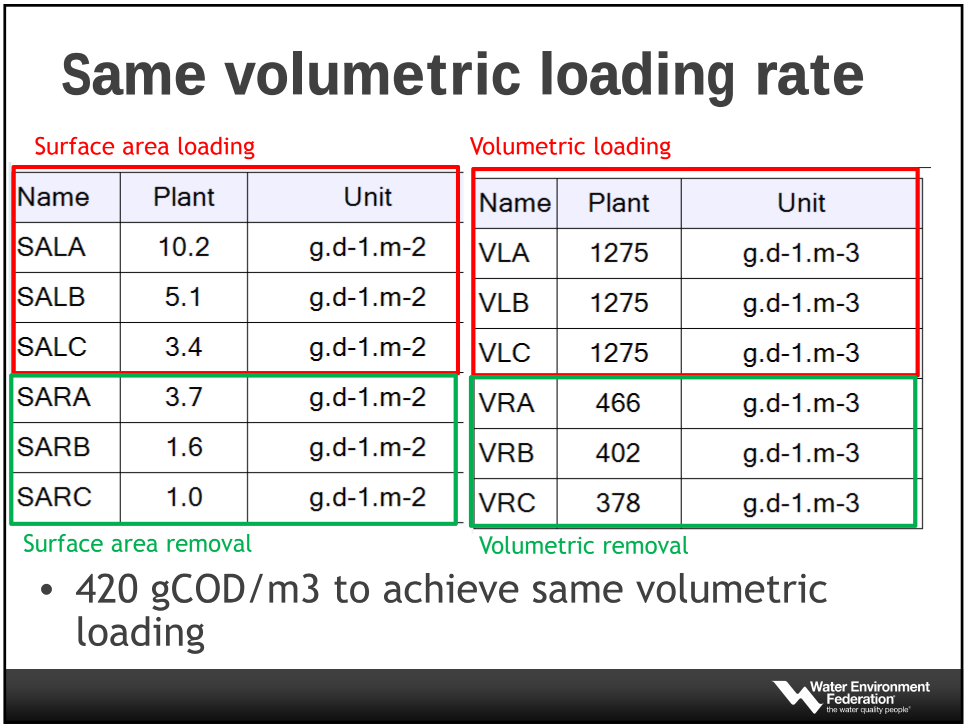
Surface area removal

Volumetric loading

| Name | Plant | Unit |
|---|---|---|
| VLA | 638 | g.d-1.m-3 |
| VLB | 1275 | g.d-1.m-3 |
| VLC | 1913 | g.d-1.m-3 |
| VRA | 240 | g.d-1.m-3 |
| VRB | 402 | g.d-1.m-3 |
| VRC | 558 | g.d-1.m-3 |

Volumetric removal

- 210, 420, and 630 gCOD/m3 to achieve same surface area loading



# Same volumetric loading rate

Surface area loading

| Name | Plant | Unit |
|---|---|---|
| SALA | 10.2 | g.d-1.m-2 |
| SALB | 5.1 | g.d-1.m-2 |
| SALC | 3.4 | g.d-1.m-2 |
| SARA | 3.7 | g.d-1.m-2 |
| SARB | 1.6 | g.d-1.m-2 |
| SARC | 1.0 | g.d-1.m-2 |

Surface area removal

Volumetric loading

| Name | Plant | Unit |
|---|---|---|
| VLA | 1275 | g.d-1.m-3 |
| VLB | 1275 | g.d-1.m-3 |
| VLC | 1275 | g.d-1.m-3 |
| VRA | 466 | g.d-1.m-3 |
| VRB | 402 | g.d-1.m-3 |
| VRC | 378 | g.d-1.m-3 |

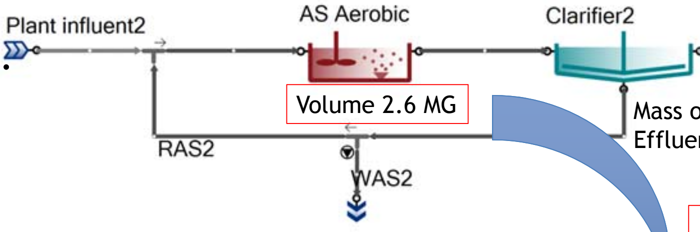
Volumetric removal

- 420 gCOD/m3 to achieve same volumetric loading

# Comparing footprint

Temp 20 C, fully nitrifying, SRT 5 days Activated sludge plant

1.



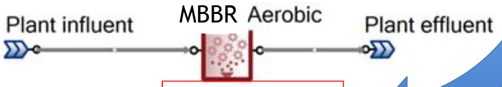
Volume 2.6 MG

Mass of TSS 47,264 lbs
Effluent nitrate 22 gN/m3

19% reduction

Temp 20 C, fully nitrifying, 50% fill MBBR plant

2.

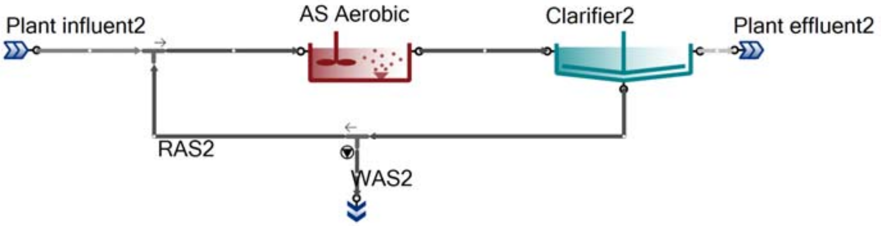


Volume 2.1 MG

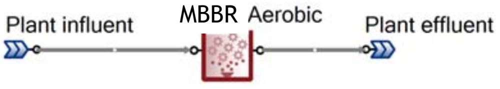
Mass of TSS 47,263 lbs
Effluent nitrate 21 gN/m3

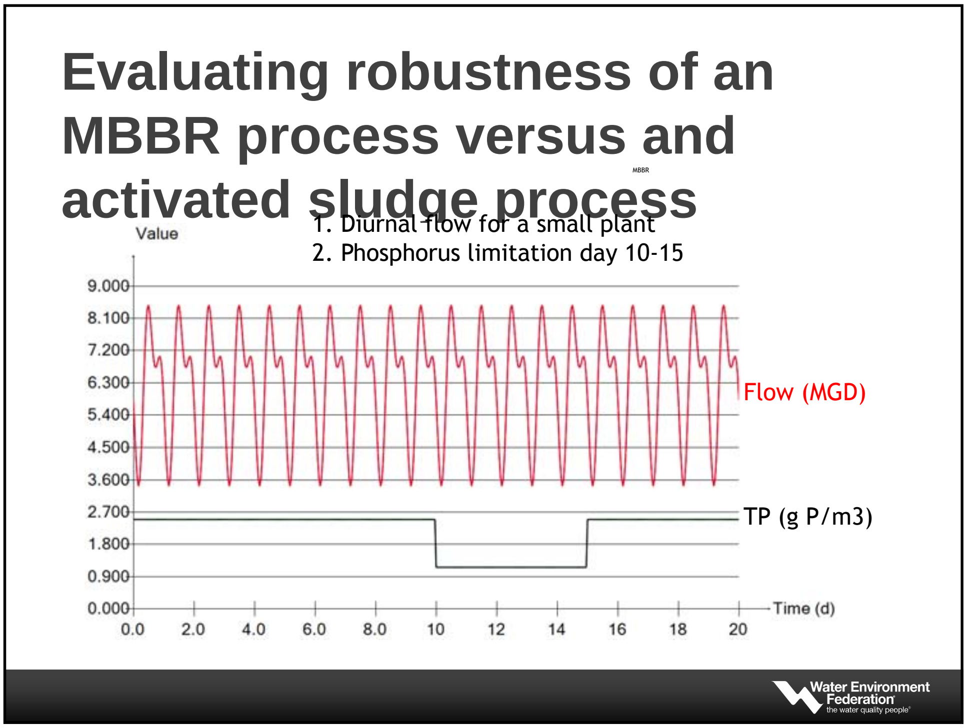
# Evaluating robustness of an MBBR process versus and activated sludge process

MBBR



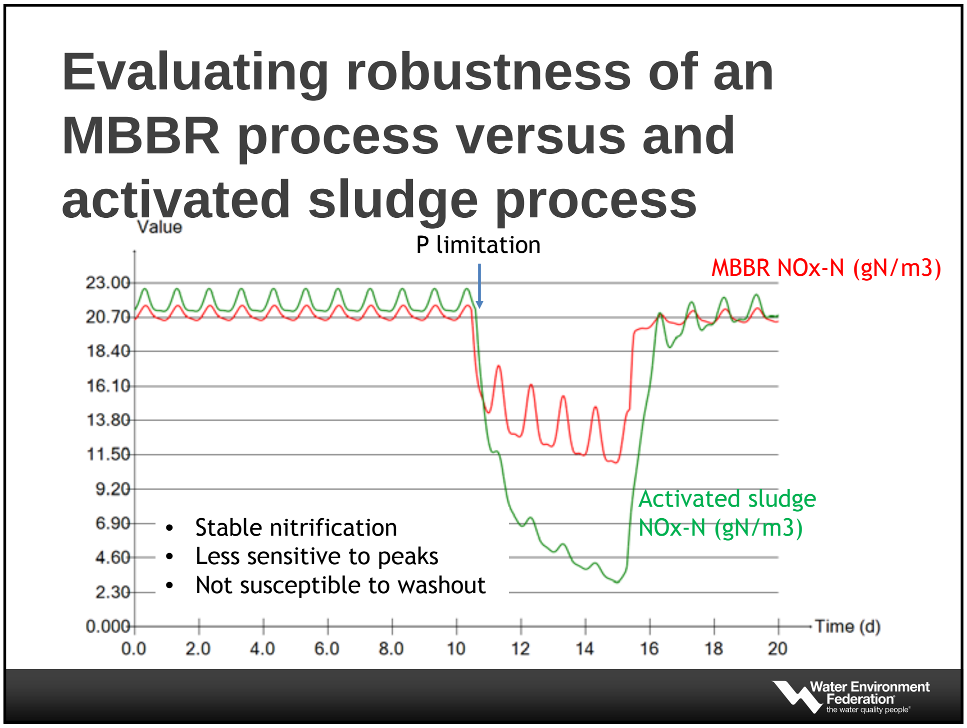
Temp 20 C, fully nitrifying, 50% fill MBBR plant





## Evaluating robustness of an MBBR process versus and activated sludge process

1. Diurnal flow for a small plant
2. Phosphorus limitation day 10-15

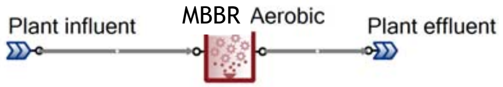


## Evaluating robustness of an MBBR process versus and activated sludge process

- Stable nitrification
- Less sensitive to peaks
- Not susceptible to washout

# Improving capacity

Temp 20 C, fully nitrifying, 50% fill MBBR plant



- Diurnal flow
- Increased nitrogen load by 16%
- Identify desired carrier fill

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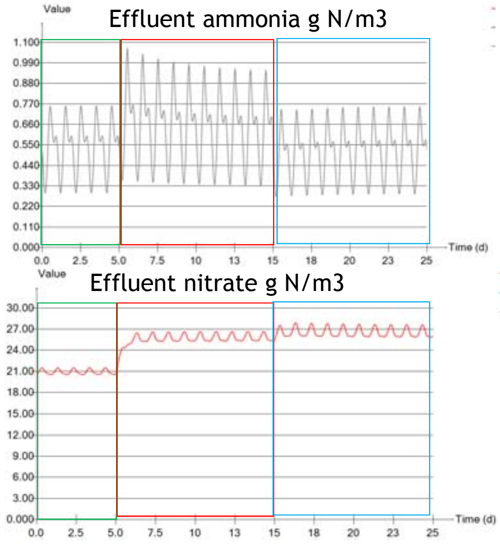
# Improving capacity of an MBBR



**Meeting effluent ammonia target < 1 gN/m3**

- 0-5 days
    - Fill percentage 50%
    - TN load 985-2432 lbsN/d
- 5-15 days
    - Fill percentage 50%
    - TN load 1146-2828 lbsN/d
- 15-25 days
    - Fill percentage 65%
    - TN load 1146-2828 lbsN/d

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## By the power vested in me by the MODELS I pronounce you designed/upgraded/optimized!

### Quite a powerful tool

- Substrate profiles
- Biomass competition
- Desired bulk DO concentration
- Peak AOTR demand
- Desired fill percentage

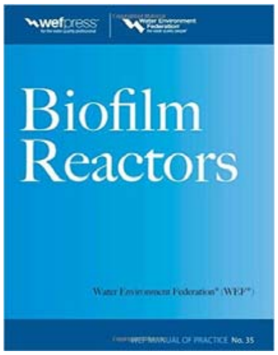
---

## Summary

- Existing models follow a variety of design guidelines and match experimental data including full-scale plant operation
- Garbage “In” means garbage “Out”
- Identifying process limitation
- Well calibrated models help useful scenario runs for design and operation improvements
- Other applications
  - Smaller footprint
  - Robust performance
  - Increase capacity
- These applications can be used on a single plant to uograde for nutrient removal

# Good reads!

Ødegraard, H, Gisvold, B, Strickland, J. (2000). The influence of carrier size and shape in the moving bed biofilm process. Water Science & Technology, 41(4-5), 383-342.



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# Thank you!

Questions?

Tanush@dynamita.com

# Biofilms – Feb. 15, 2017

*An MRRDC Short Course*

## Biofilms: Principles and Advanced Model-Based Design

- Final Q & A:

| | | |
|---|---|---|
| Biofilms → | Leon Downing | CH2M |
| Modeling → | Oliver Schraa | InCTRL Solutions |
| Application → | Tanush Wadhawan | Dynamita |

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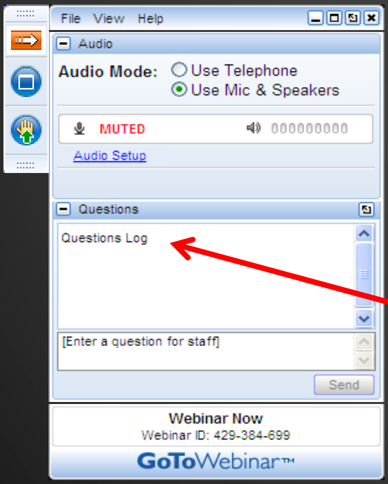
# How to Participate Today



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