Activated Sludge Treatment

EPA Secondary Standards

- BOD_5 - monthly average
  - 30 mg/L
- TSS - monthly average
  - 30 mg/L
- Fecal coliform - monthly average
  - 500 #/100mL

Processes Used to Meet Secondary Standards

- Attached growth
  - Trickling Filters
  - Rotating Biological Contactors
- Suspended growth
  - Activated sludge processes
- Lagoon systems

What is Activated Sludge?

- The active biomass responsible for treatment

- Teeming with microlife

- Hundreds of billions of bacteria thriving

What is “Mixed Liquor”

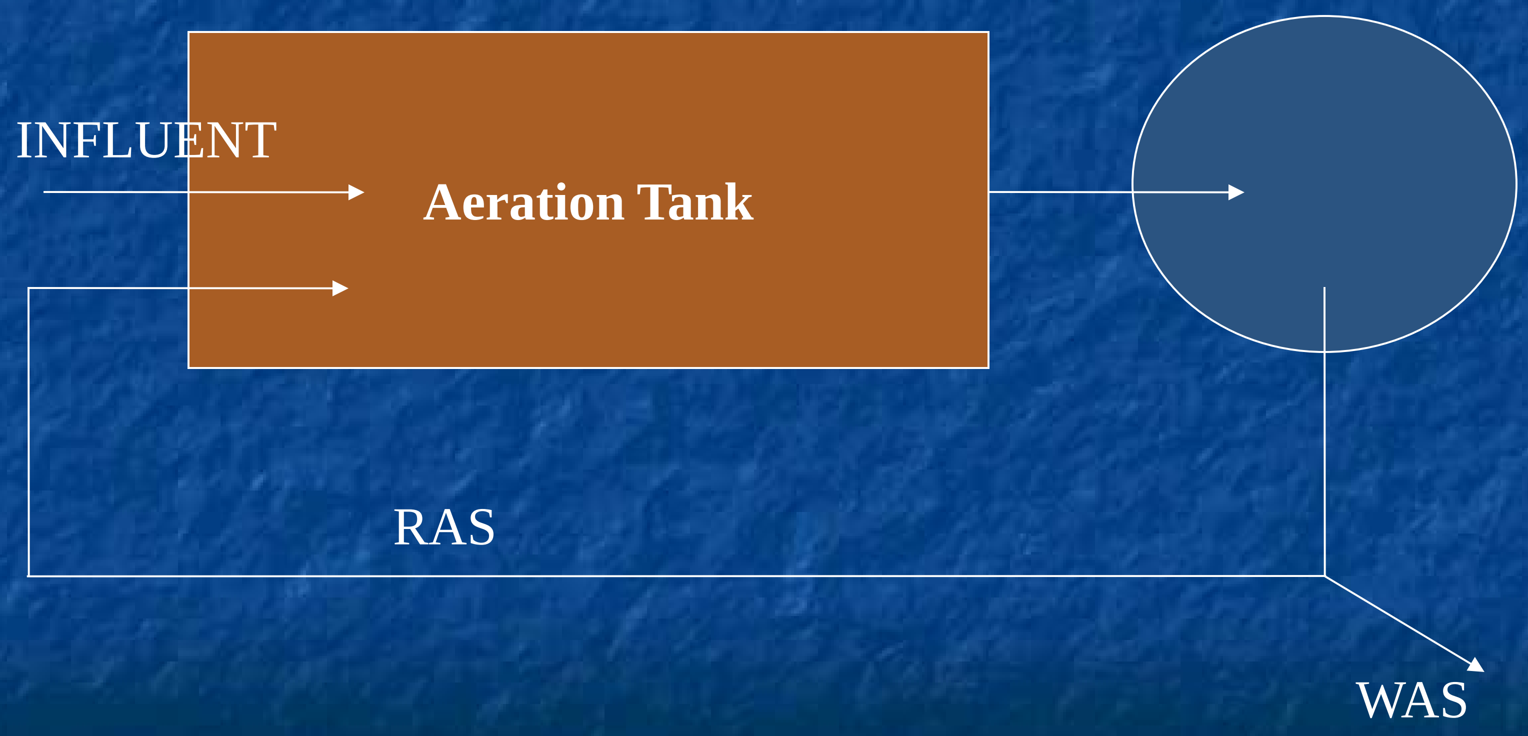
- The blend of settled activated sludge (RAS) from the bottom of a secondary clarifier
- And influent wastewater or primary effluent wastewater
- The two fluids blend together to form mixed liquor


Primary Effluent
RAS

Activated Sludge Systems

- Conventional
- Complete mix
- Step feed
- Contact stabilization
- Extended aeration
- Oxidation ditch
- Sequencing batch reactors

Conventional Activated Sludge



Conventional Activated Sludge

- Plug flow
- SRT: 5-15 days
- F/M Ratio: 0.2 -0.5 lbs BOD/lb MLVSS
- MLSS: 1500 – 3000 mg/L
- Detention time: 4-8 hrs
- RAS Flow: 15 – 75% of inf. flow

Oxygen Activated Sludge

- Usually considered a High Rate AS system
- High loading rates in a small area
- Considerable O&M of oxygen producing systems

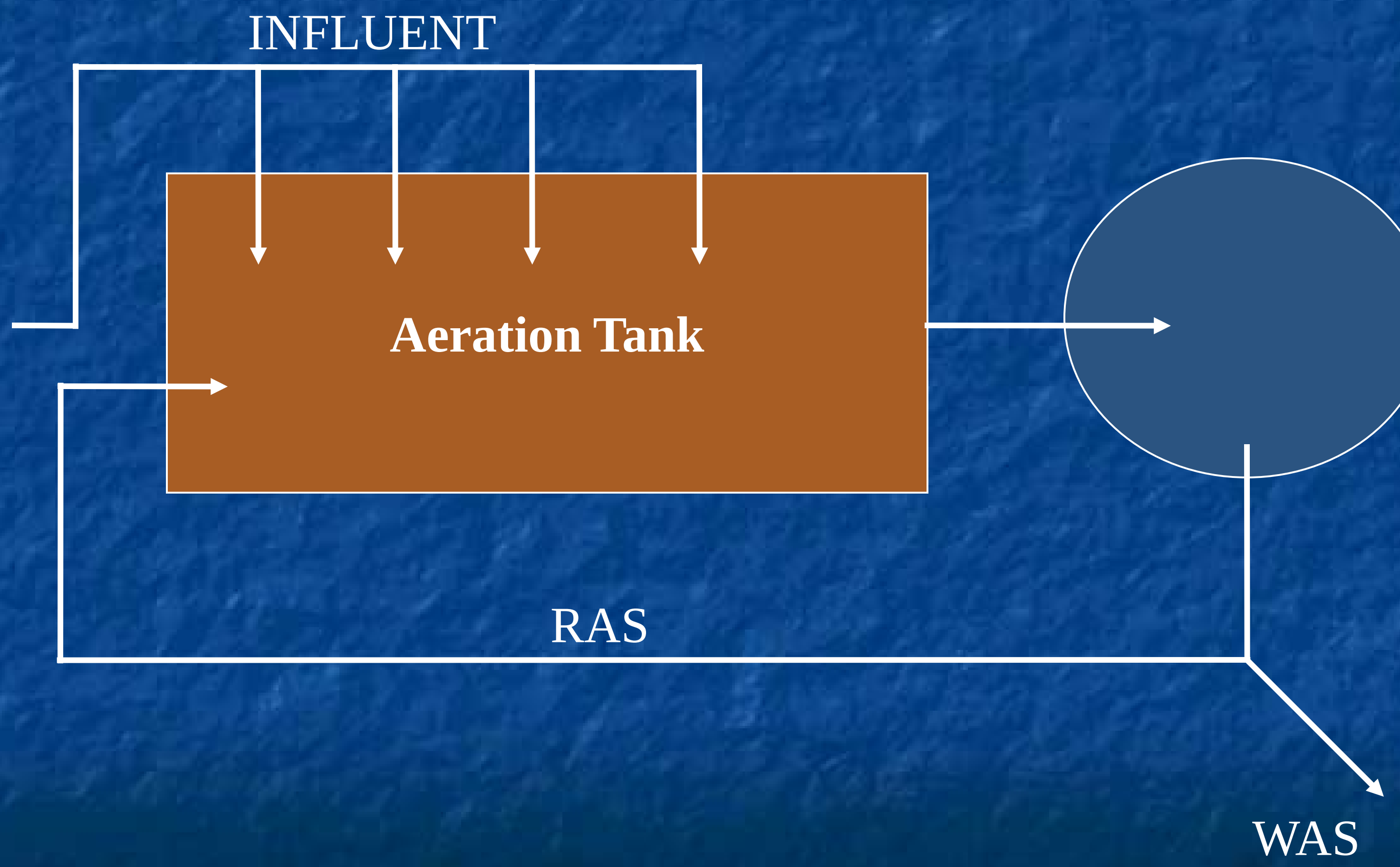

© 2007 Europa Technologies
Image © 2007 DigitalGlobe
9.63" N 75°58'22.02" W elev 3 ft
Streaming |||||||||| 100%

N
© 2007 Europa Technologies
©2007 Google
Pointer 30°24'25.04" N 87°13'24.85" W elev 7 ft Streaming |||||||||| 100%
Eye alt 663 ft


DANGER
OXYGEN IN USE
NO SMOKING
NO OPEN FLAMES
NO SPARKS
CAUTION
NOT STEP ON CONDUIT.
CONDUIT IS ALUMINUM
AND WILL BEND.
USE WALK-OVER.
-NO SMOKING-
PURE OXYGEN

0
3
0
OX
OXYGEN
REFRIGERATED
LIQUID
DANGER
OXYGEN
NO
TRESPASSING

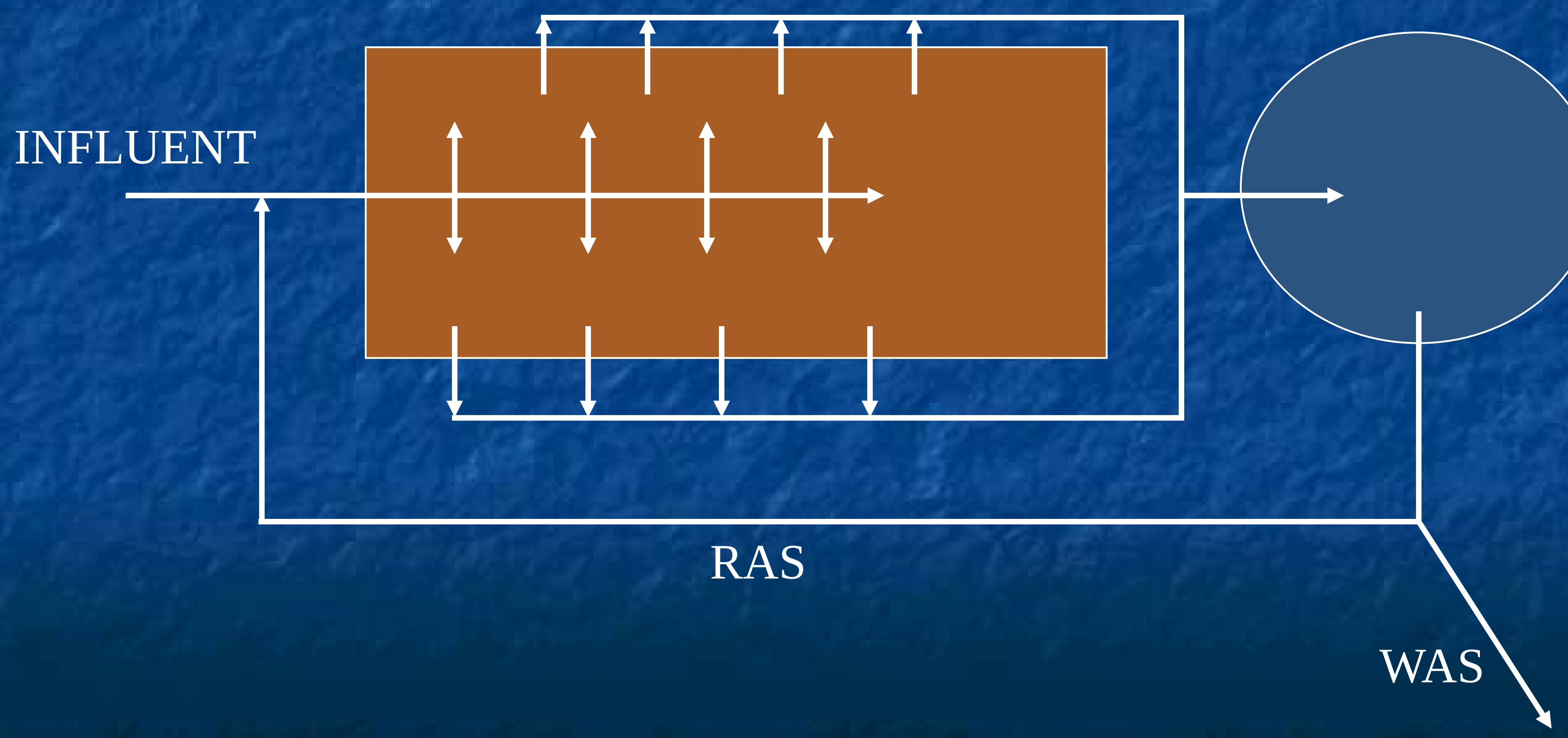
Step Feed Activated Sludge



Step Feed Activated Sludge

- SRT: 5-15 days
- F/M Ratio: 0.2 -0.5 lbs BOD/lb MLVSS
- MLSS: 2000 – 3500 mg/L
- Detention time: 3-8 hours
- RAS flow: 20-75% of inf. flow

Complete Mix Activated Sludge



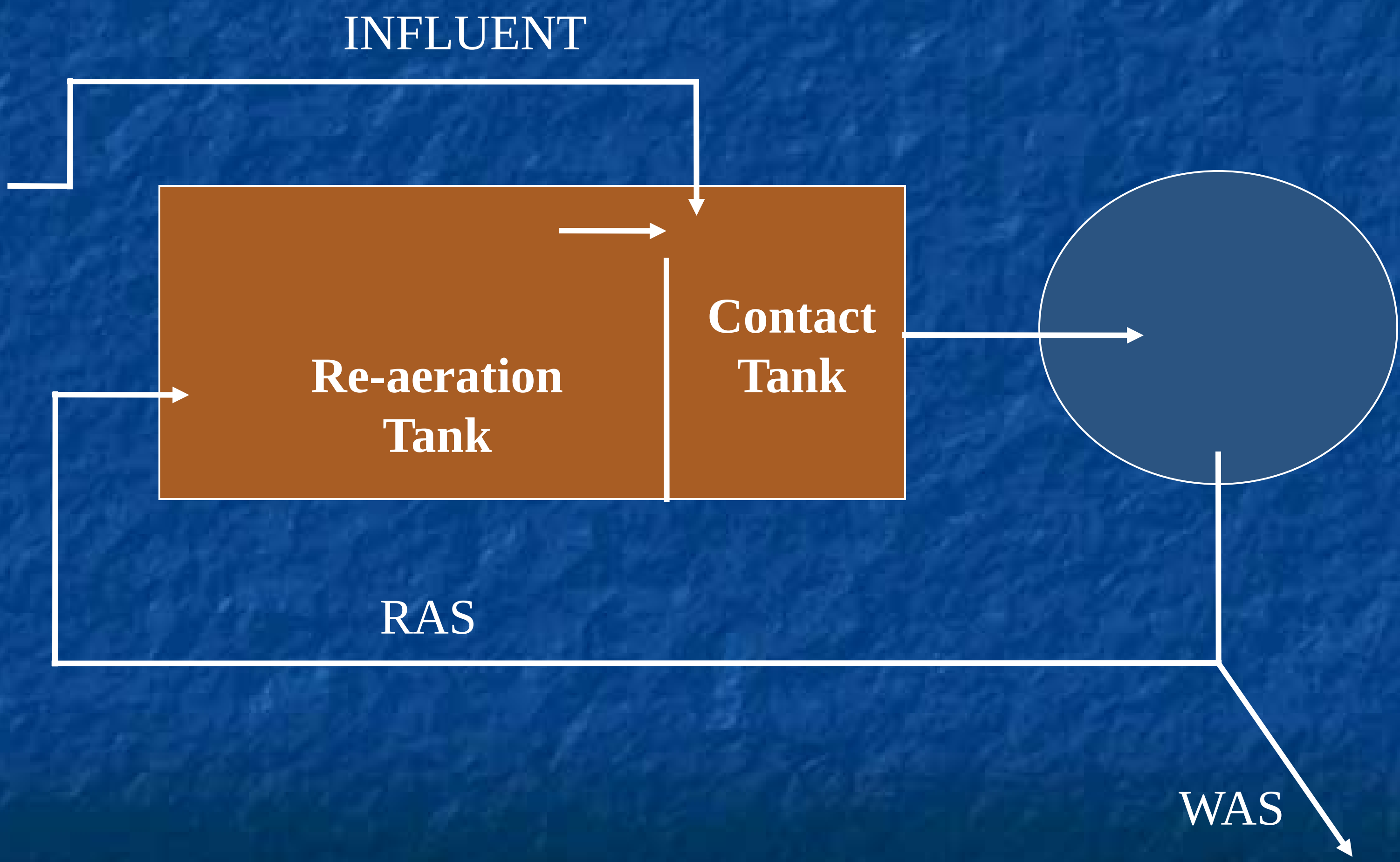

8 14 '96


26 1:26 PM

Complete Mix Activated Sludge

- Flow: completely mixed
- SRT: 5-15 days
- F/M Ratio: 0.2 -0.6 lbs BOD/lb MLVSS
- MLSS: 3000 – 6000 mg/L
- Detention time: 3-5 hours
- RAS flow: 25 – 100% of inf. flow

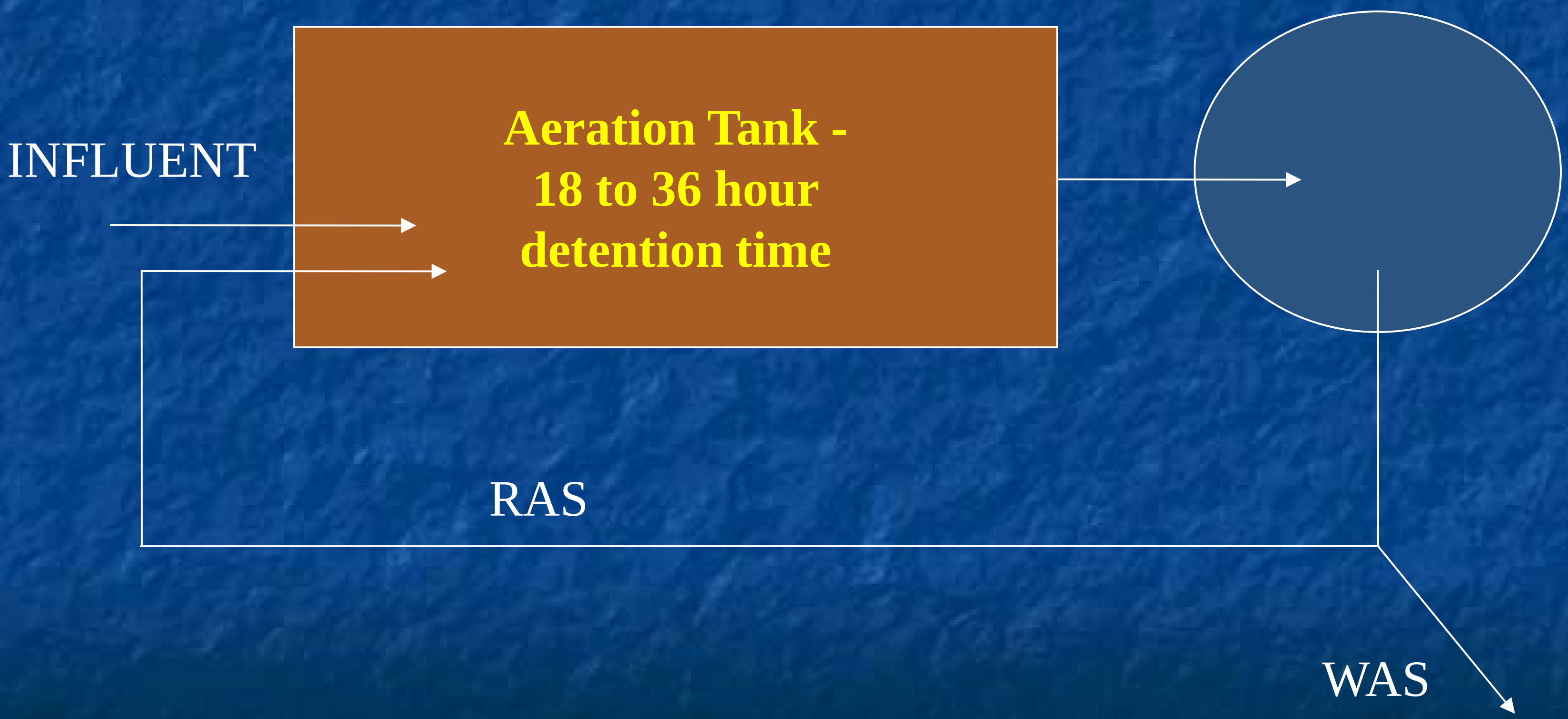
Contact Stabilization Activated Sludge



Contact Stabilization Activated Sludge

- Plug flow pattern
- SRT: 5-15 days
- F/M Ratio: 0.2 -0.6 lbs BOD/lb MLVSS
- MLSS: 1000 – 3000 mg/L Contact
  - 3000 – 10000 re-aeration tank
- Detention time: 0.5-6 hours
- RAS Flow: 50-150% of inf. flow

Extended Aeration Activated Sludge

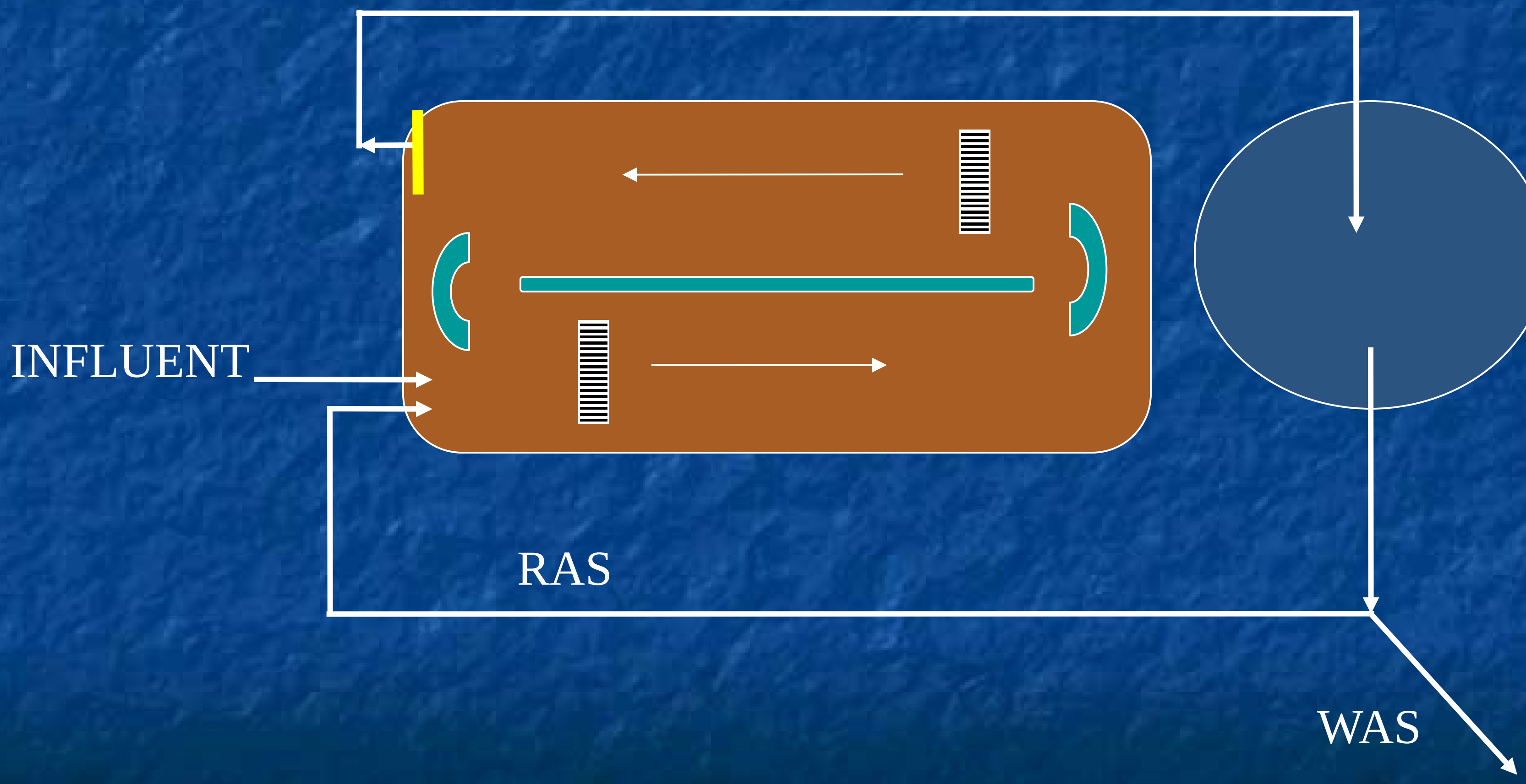


Extended Aeration Activated Sludge

- Flow pattern: completely mixed
- SRT: 20 – 30 days +
- F/M Ratio: 0.05 – 0.15 lbs BOD/lb MLVSS
- MLSS: 2000 – 6000 mg/L
- Detention time: 18-36 hours
- RAS Flow: 50 – 200% of inf. flow


DAVCO

Oxidation Ditch Activated Sludge

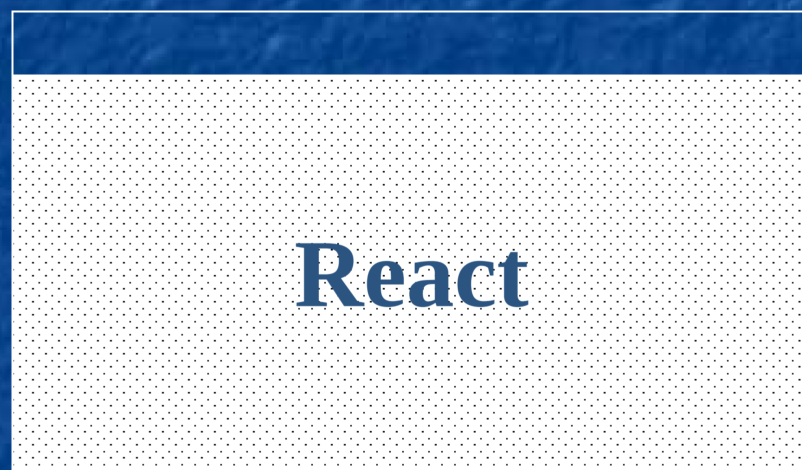




Sequencing Batch Reactor

Wastewater is added to retained biomass

Sequencing Batch Reactor

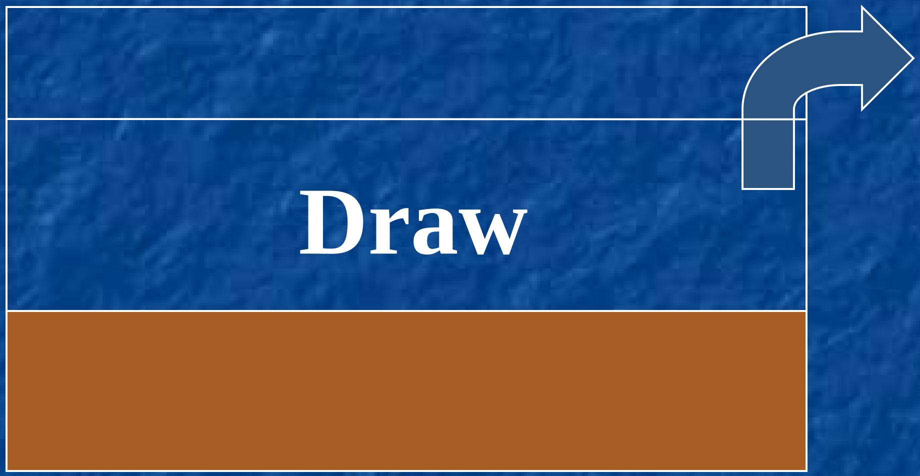


Reaction time

Sequencing Batch Reactor

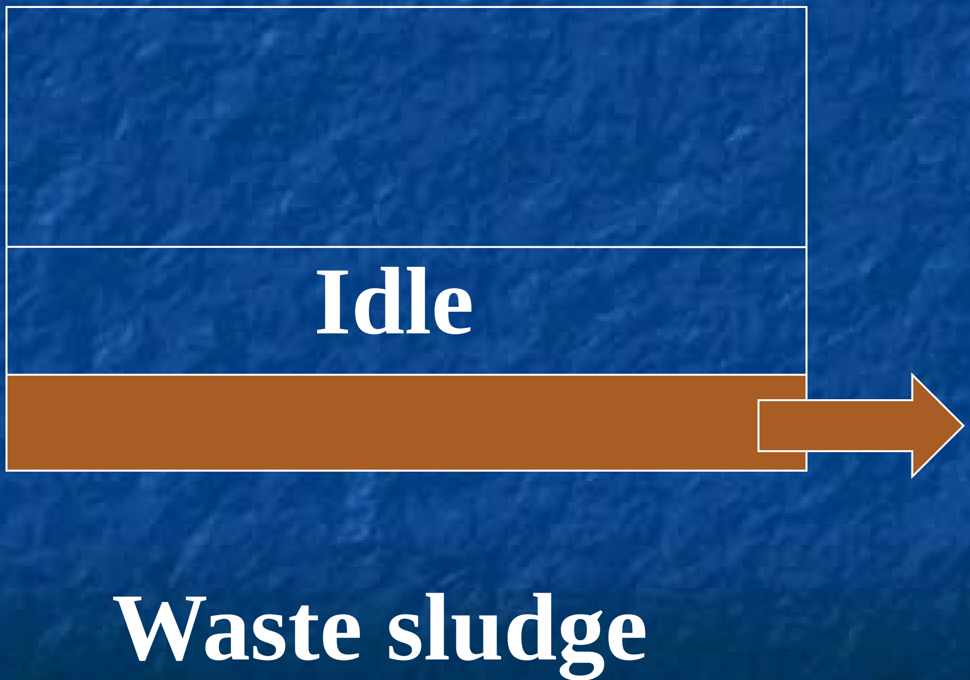
Liquid/solids separation

Sequencing Batch Reactor



Remove clarified effluent

Sequencing Batch Reactor



Sequencing Batch Reactor

- Flow pattern: completely mixed
- SRT: 5-10
- F/M Ratio: 0.2 -0.6 lbs BOD/lb MLVSS
- MLSS: 1200 – 3000 mg/L
- Batch treatment time: 2 - 4 hours
- RAS Flow: N/A

Microorganism Growth Rates

High Rate activated sludge processes

- *0.75 lbs / lb BOD removed*
  - Complete mix
  - SBRs
  - Any organically overloaded wwtp

Conventional activated sludge process

- *0.55 lbs / lb BOD removed*

Extended aeration processes

- *0.15 lbs / lb BOD removed*

Nutrient Parameters Are Gradually Being Added

- Groundwater dischargers
  - NO_3 -N - 12 mg/L - maximum
- Surface water
  - TKN parameters
  - Unionized ammonia - 0.02 mg/L

AWT

- $CBOD_5$ - monthly average
  - 5 mg/L
- TSS - monthly average
  - 5 mg/L
- Total Nitrogen - monthly average
  - 3 mg/L
- Total P - monthly average
  - As low as 0.2 mg/L

Re-Use

- TSS < 5.0 mg/L
  - turbidity/TSS correlation for reject
- Normally no nutrient parameters
- Fecal coliform
  - 75th percentile of samples - no detected fecal coliform
  - 25 #/100 mL single sample maximum

Meeting More Stringent Limits Will Require

- A more thorough knowledge of our physical facilities
- A more thorough knowledge of the biology and chemistry of nutrient removal
- Facility modification, additions or new facility construction

Nutrients

- Carbon
- Nitrogen
- Phosphorus

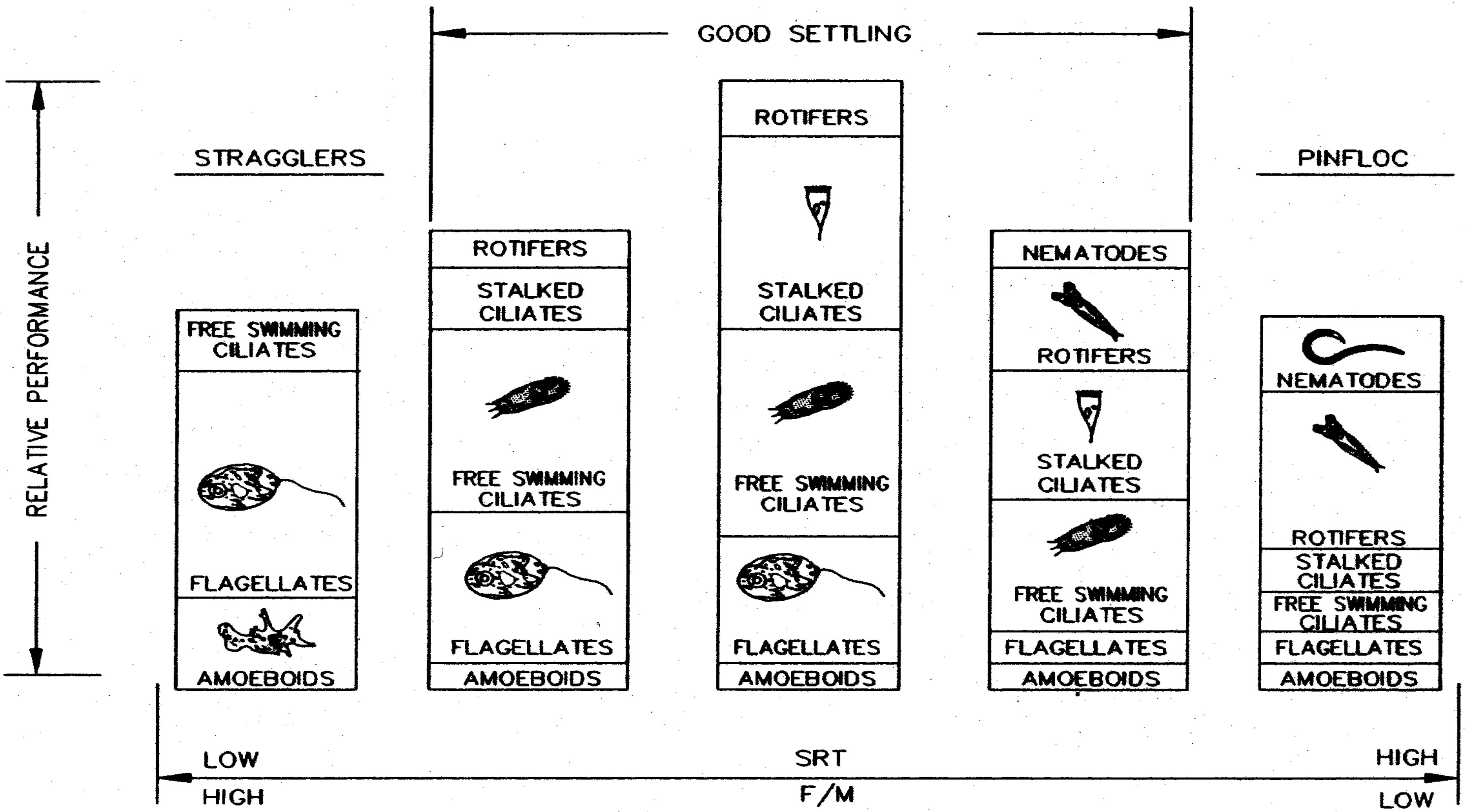
Biological Treatment

- Attached Growth
  - Trickling Filters
  - Rotating Biological Contactors
- Suspended Growth
  - Activated sludge
- Lagoons
  - Microorganisms and algae

The Basics of the Biological Process

Types of Microorganisms

- **Bacteria**
- **Protozoa**
- **Metazoa**
- **Algae**



Relative perdominance of microorganisms versus F/M and SRT

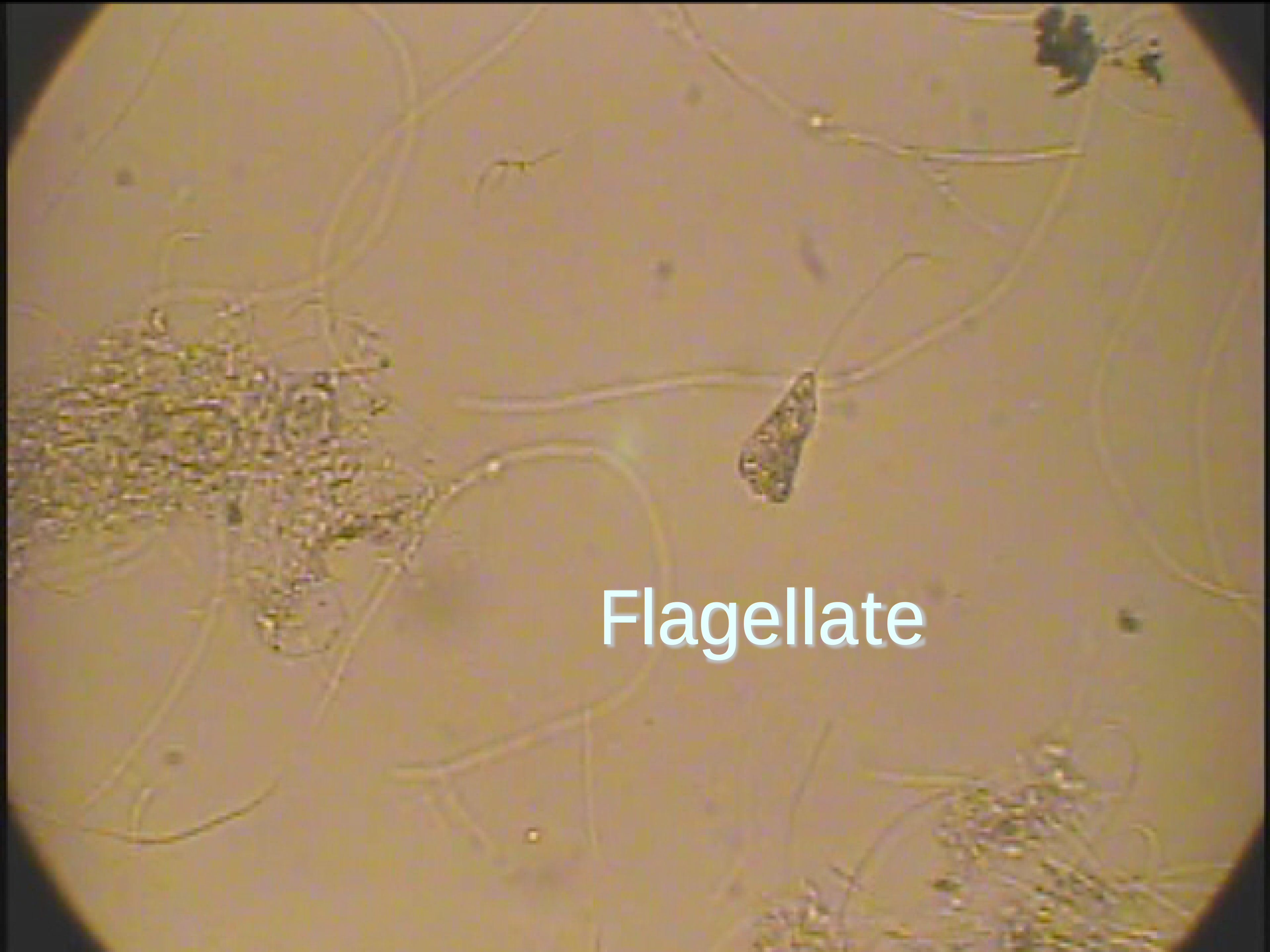
ACTIVATED SLUDGE
M.O.P. OM-9
W.P.C.F.

Indicator Organisms

Click to add text

Amoeba

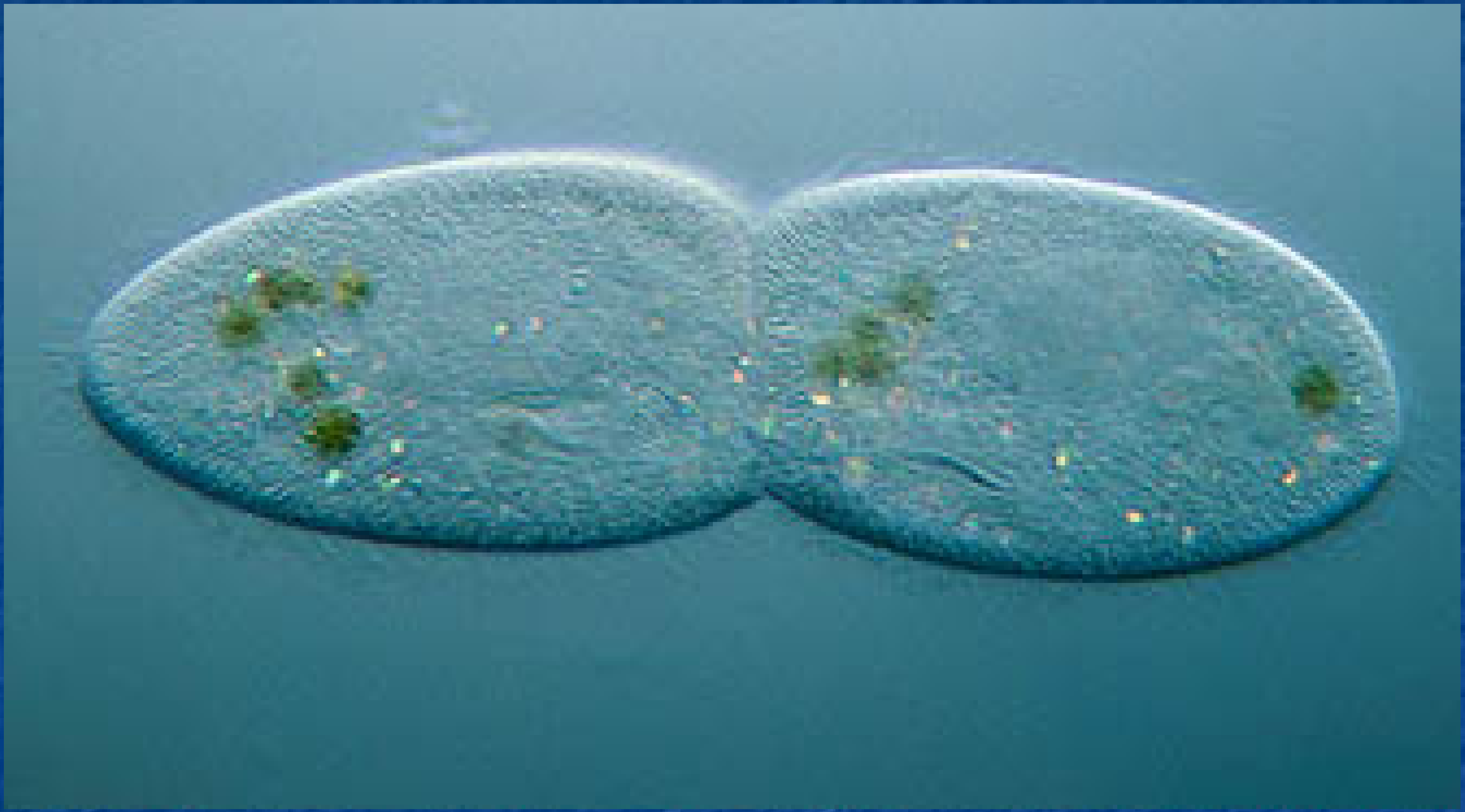
Amoeba & Zooglea bacteria


Flagellate

Free swimming ciliates

Free swimming ciliates

Free swimming ciliates



Stalked ciliates

Rotifers

Nematode

Aeolosoma (bristleworm)

Tardigrade (waterbear)

Daphnia

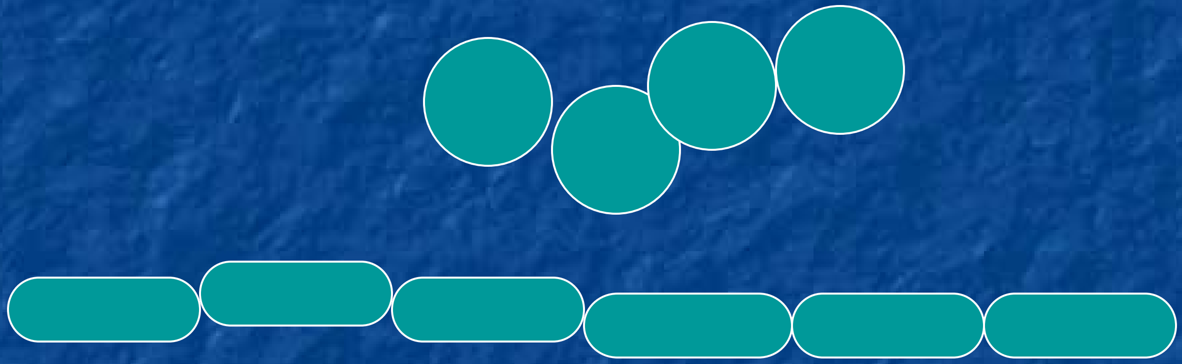
Copepod Click to ad

Bacteria

- Floc-forming
- Filamentous
- Heterotrophic
- Autotrophic
- Aerobic
- Anaerobic
- Facultative

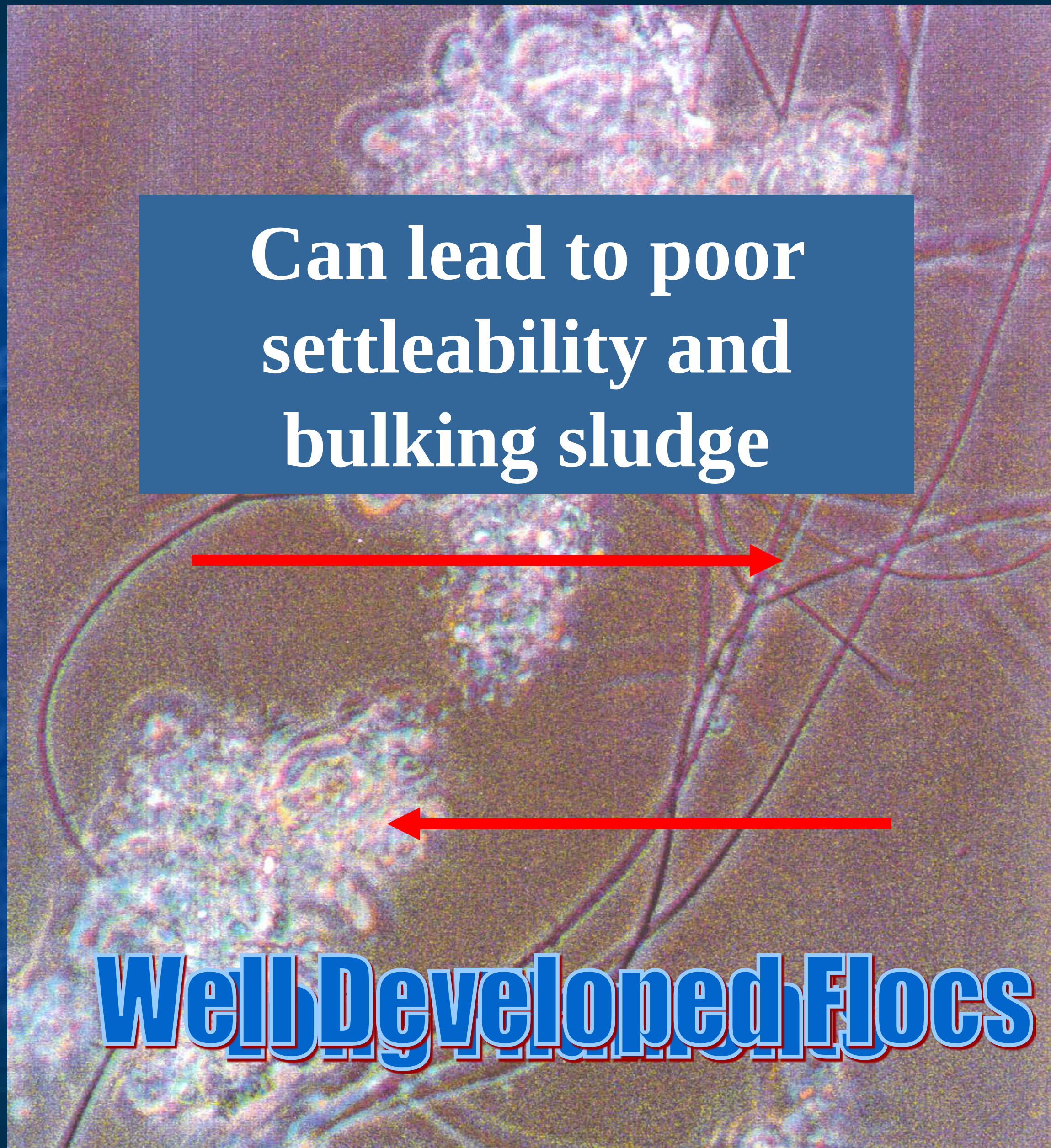
Floc-Forming

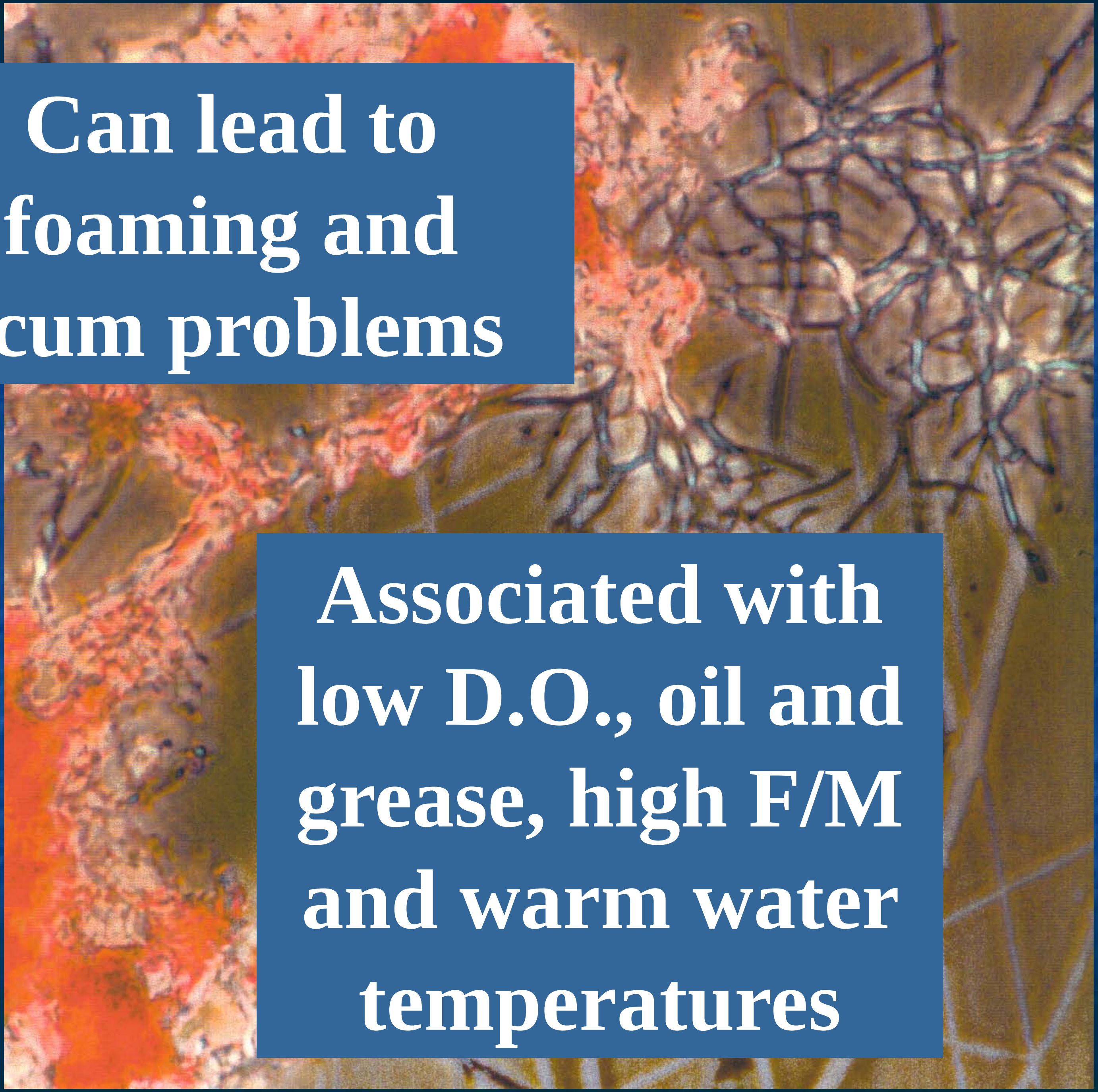
- **Non-filamentous bacteria that stick together**



Filamentous Bacteria

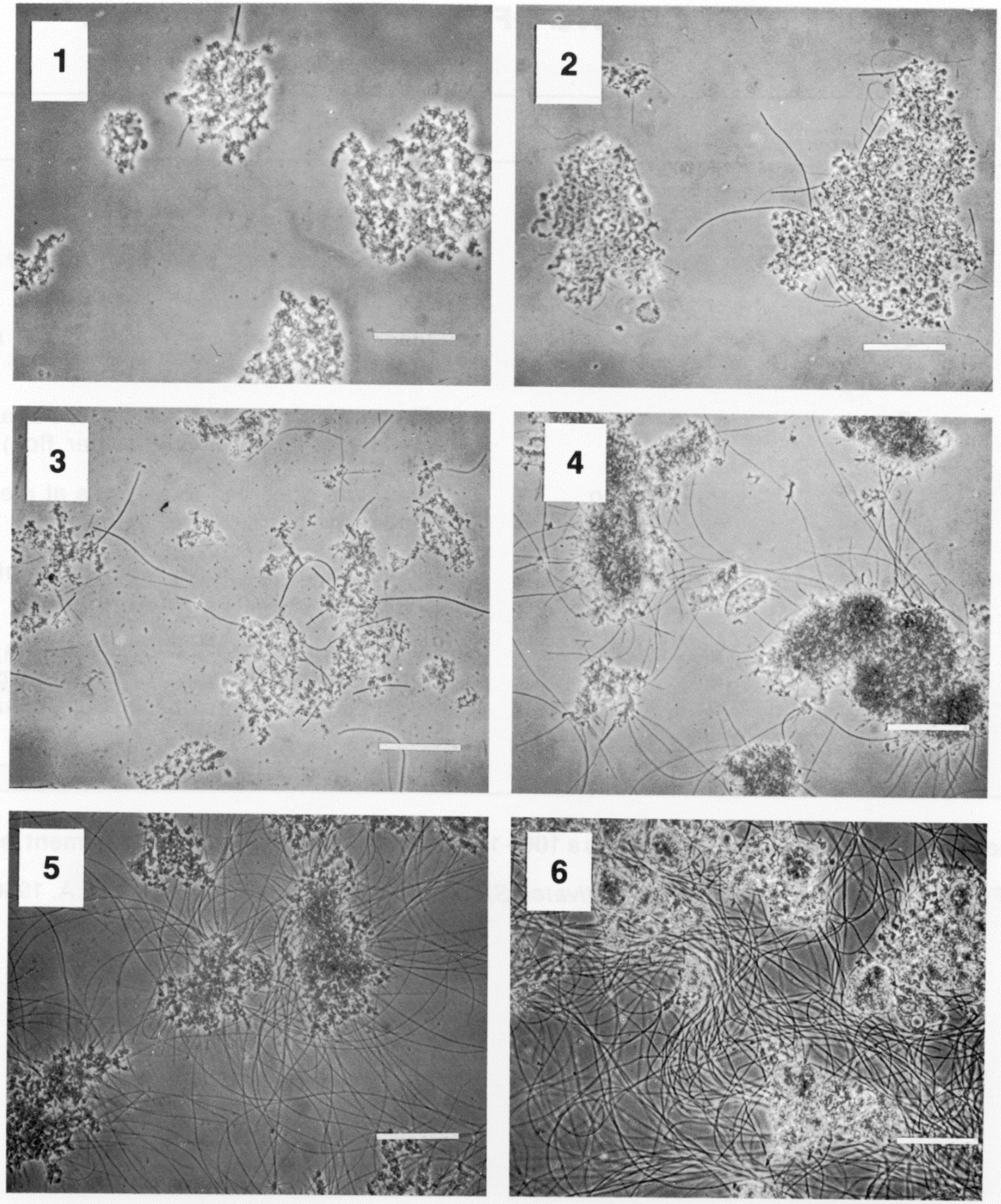
- **Form backbone of good floc**
- **Excessive filaments can cause a bulking sludge and settling problems**


Can lead to poor settleability and bulking sludge
Well Developed Flocs

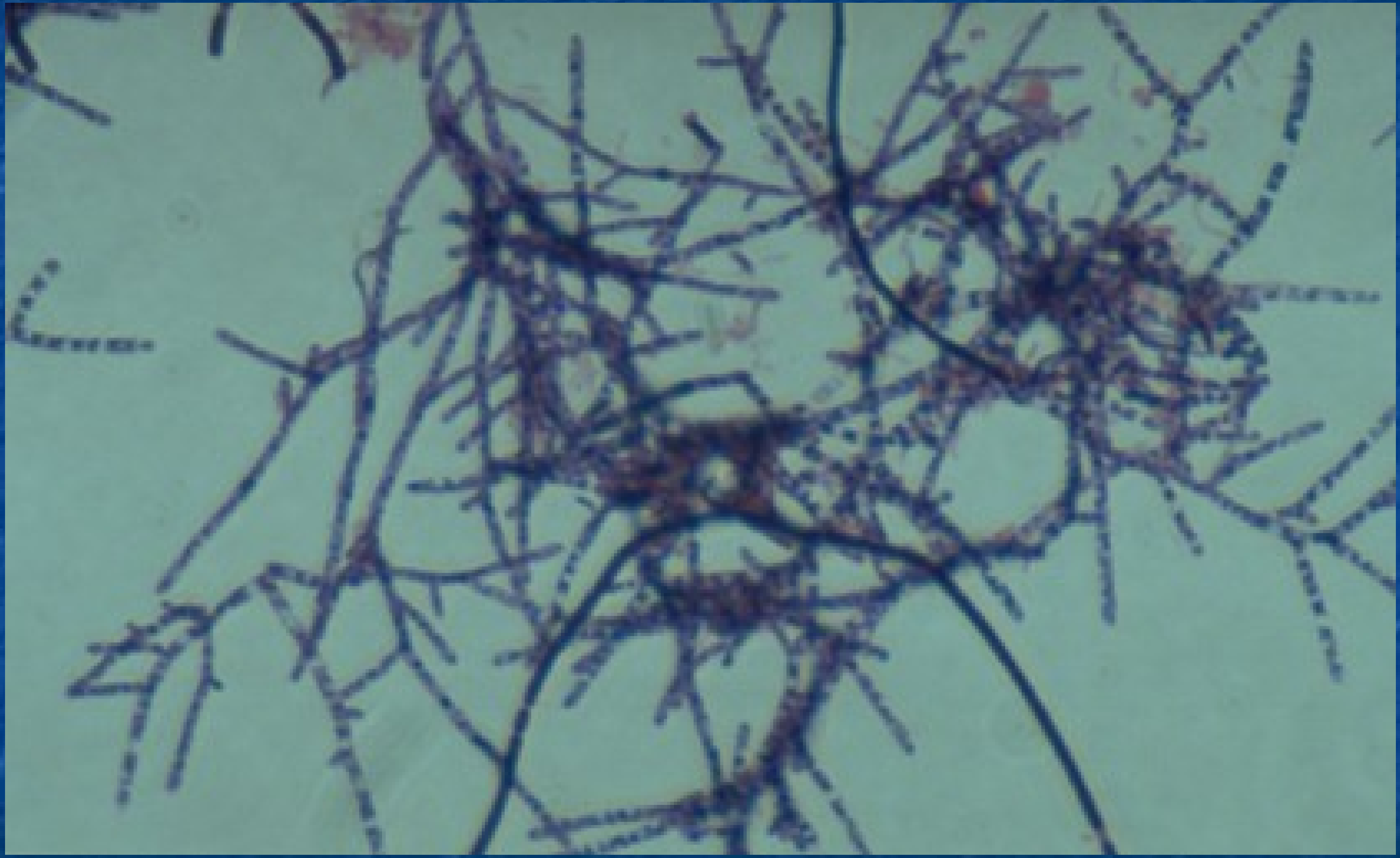


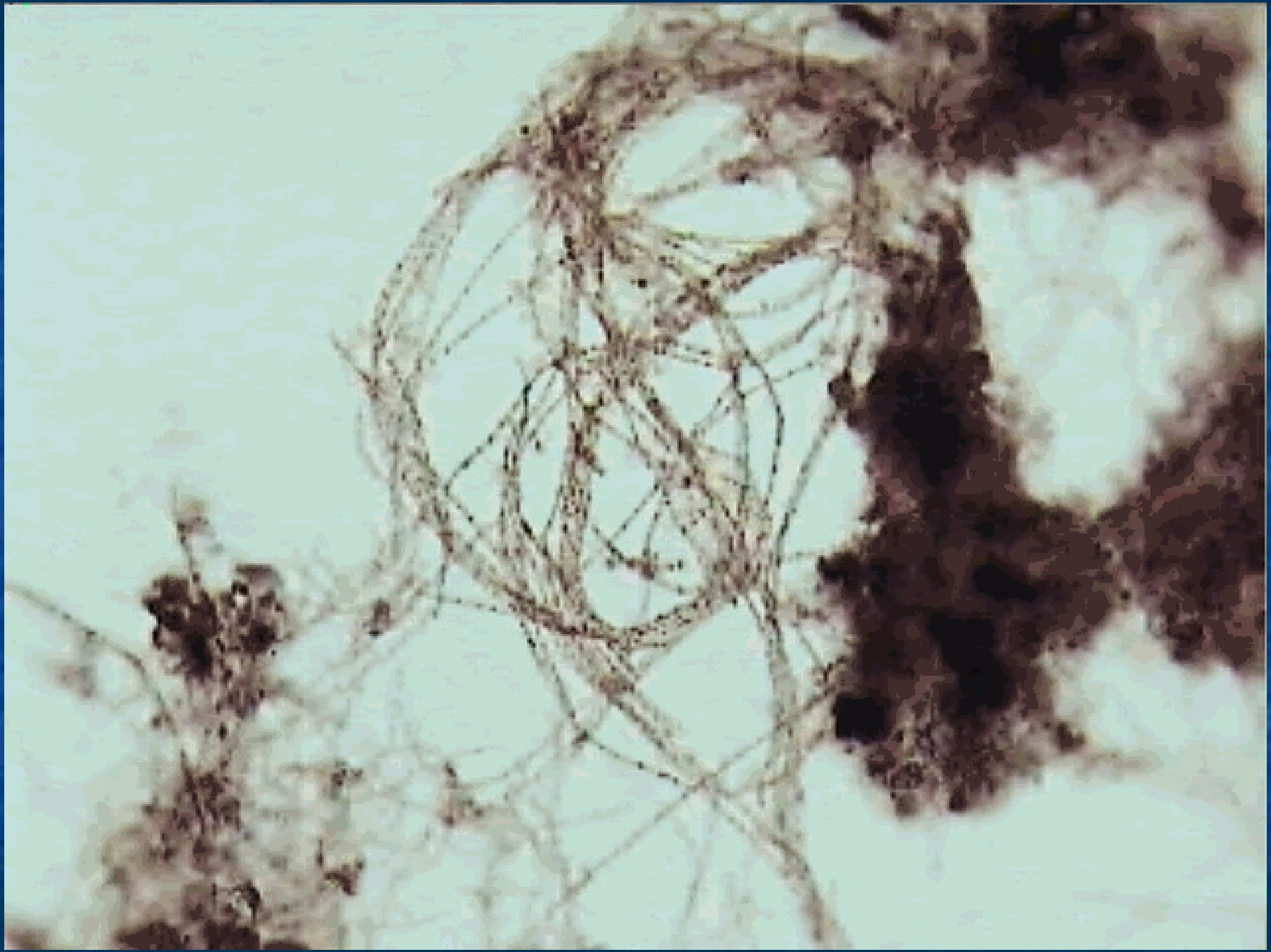
Can lead to foaming and scum problems

Associated with low D.O., oil and grease, high F/M and warm water temperatures



Filament abundance categories using subjective scoring system:
1. few; 2. some; 3. common; 4. very common; 5. abundant; and 6.
excessive (all 100X phase contrast; bar = 100 um).





Bacteria

- The workhorses of biological treatment
- Convert suspended, dissolved and colloidal solids into bacterial biomass (cells)
- Cells flocculate (form flocs) which are slightly heavier than water
- Biological flocs will settle out given the right conditions (clarification)

Bacteria

- One cubic inch of mixed liquor can contain up to 9,000,000,000,000 bacteria
- 1 mL contains over 60,000,000 bacteria
- Generation times
  - E. coli has a generation time of approximately 12.5 minutes
  - Methanobacterium sp. has a generation time of between 3 and 50 days

Successful Operation Requires Meeting the Environmental Needs of the Bacteria

- Temperature
- pH
- Nutrients
- Time to reproduce (SRT)
- Proper respiratory conditions

Temperature

- Ideal range is between 25 and 35 degrees Celsius
- Below 15 degrees Celsius is inhibitory
- Above 40 degrees Celsius is terminal to some forms of bacteria

pH

- Ideal pH is between 7.0 and 8.5
- pH below 6.5 is inhibitory
- pH below 6.0 is terminal

Nutrients

- Microorganisms require carbon, nitrogen, phosphorus, iron and trace minerals for cellular reproduction

- Minimum of 100:5:1:0.5 ratio
  - For every 100 parts of BOD
  - 5 parts of N
  - 1 part of P
  - ½ part Fe

Respiratory Conditions

- Aerobic or Oxic
- Anoxic
- Anaerobic

Aerobic or Oxic Conditions

- Free dissolved oxygen present
- Normally 1 - 2 mg/L D.O.

$$\textbf{Organics + Oxygen} \xrightarrow{\textit{Aerobic bacteria}} \textbf{Carbon dioxide + Water + Energy}$$


HQ30d
flexi
0.29 mg/L
YSI
556 MPS
17.55 °C
376.6 ORP
0.550
3.5 DO%
0.33
7.55 pH
7/19/2006 11:31:05
Esc

Anoxic Conditions

- No free dissolved oxygen present
- Nitrate - N or NO_3-N is present
- Normally a temporary state

Anaerobic Conditions

- No free dissolved oxygen present
- No nitrate - N present
- Sulfate and carbon dioxide may be present

Aerobes

- Strictly aerobic organisms
- Examples
  - Sphaerotilus natans - Nuisance Filament
  - Nitrobacter sp. - Nitrifier
  - Zoogloea ramigera - Floc former

Facultative

- Can operate under aerobic, anoxic or anaerobic conditions
- Requires a change in enzyme system
- Example
  - Escherichia coli - Degrades CBOD
  - Pseudomonas sp. - Denitrifier and phosphorus luxury uptake

Anaerobes

- Strict anaerobic bacteria
- Example
  - Desulfovibrio sp. - Sulfate reducer $SO4^{-2}$ to H_2S - Somewhat oxygen tolerant
  - Methanobacterium sp. - Methane former - Completely oxygen intolerant

Bacteria

Where do they get their food and energy?

- Heterotrophic
- Autotrophic

Heterotrophic Bacteria

- Carbon source is organic matter
- Energy source is organic matter

"one stop shopping"

Autotrophic Bacteria

- Carbon source is bicarbonate alkalinity or carbon dioxide
- Energy source is inorganic compounds such as ammonia

Multi-store shopping trip…

An Inventory of Microorganisms

- Approximately 95 % facultative heterotrophs
- Approximately 5 % aerobic autotrophs

Which group is easy to maintain?

What Effect Does This Have on Treatment

- Carbon removal will occur under aerobic, anoxic and/or anaerobic conditions
- Nitrogen and phosphorus removal will require different environments at different times

Biological Nutrient Removal

Nutrients

- Carbon (BOD)
- Nitrogen
- Phosphorus

Types of BOD

- Non-Particulate BOD
  - Soluble BOD
    - Simplistic - Methanol or Acetic acid
    - Complex - Glucose
  - Colloidal BOD
    - Proteins and lipids

Types of BOD

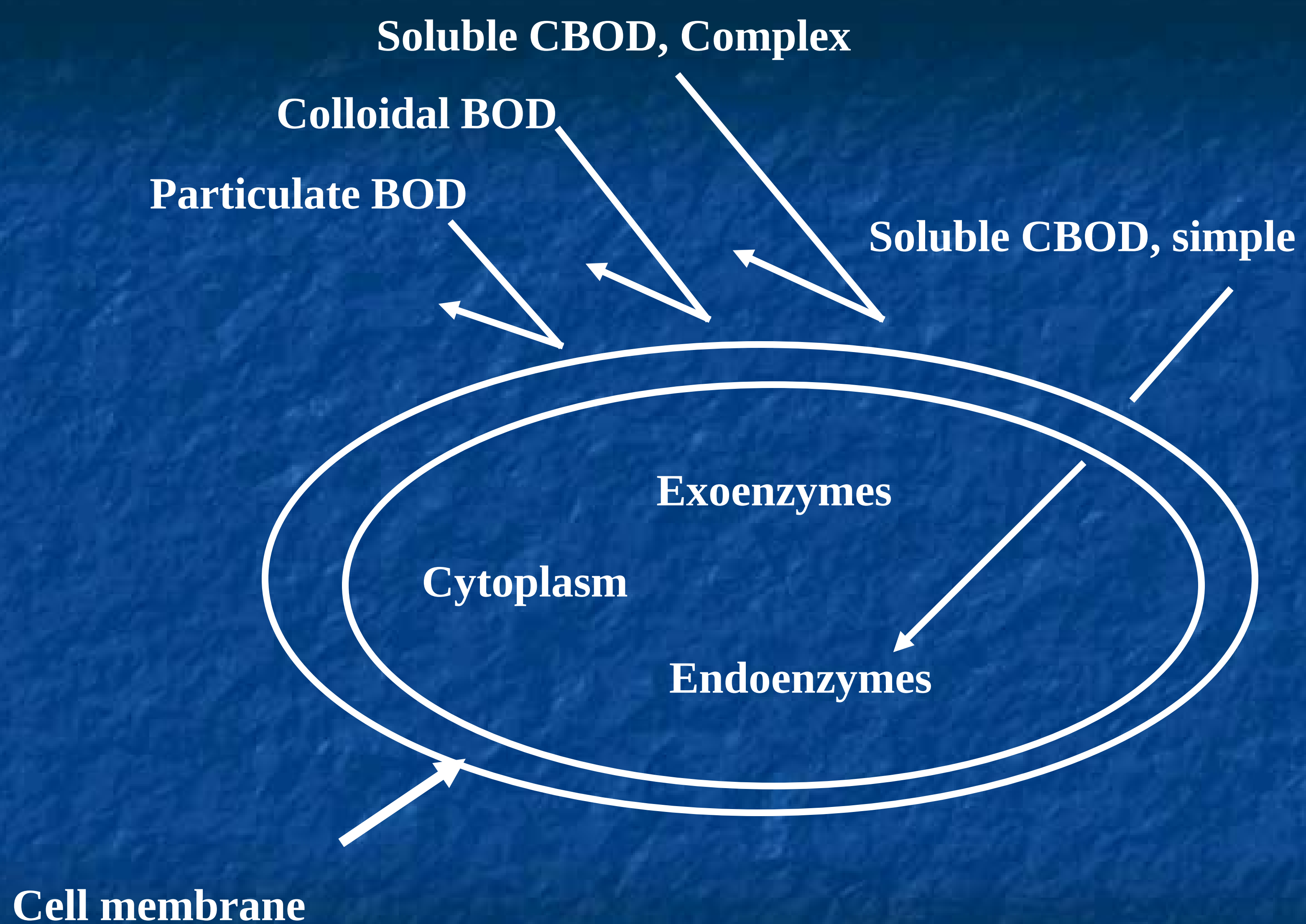
- Particulate BOD
  - If sufficient detention time, it will be converted to non-particulate BOD
  - If not, it will settle with the sludge either attached or unattached to microorganisms

Soluble BOD

- Carbonaceous BOD (CBOD)
- Nitrogenous BOD (NBOD)
  - NH_3 and NO_2

How do Bacteria Eat?

- Adsorption
  - Particulate BOD
  - Colloidal BOD
  - Complex soluble BOD
- Exocellular digestion by exoenzymes
- Absorption
  - Direct - non-Particulate simple soluble BOD
  - After excocellular digestion for particulate, colloidal and complex soluble BOD



BOD must be taken inside the bacterial cell

Removal of Carbon

- Cellular respiration
- Fermentation

$CBOD_5$ Removal

$CBOD_5 + O_2 \longrightarrow CO_2 + MLSS$ (0.6 lb)

$CBOD_5 + NO_2/NO_3 \longrightarrow CO_2 + N_2 + MLSS$ (0.4 lb)

$CBOD_5 + SO4^{-2} \longrightarrow CO_2 + H_2S + MLSS$ (0.3 lb)

$CBOD_5 \longrightarrow CO_2$ + acids/alcohols + malodorous gases +MLSS (0.04 lb)

$CBOD_5 \longrightarrow CH_4 + MLSS$ (0.02 lb)

Removal of Nitrogen

- What form is it in?
- How much of it do we have?
- Is my current treatment process capable of removing the type and the amount?

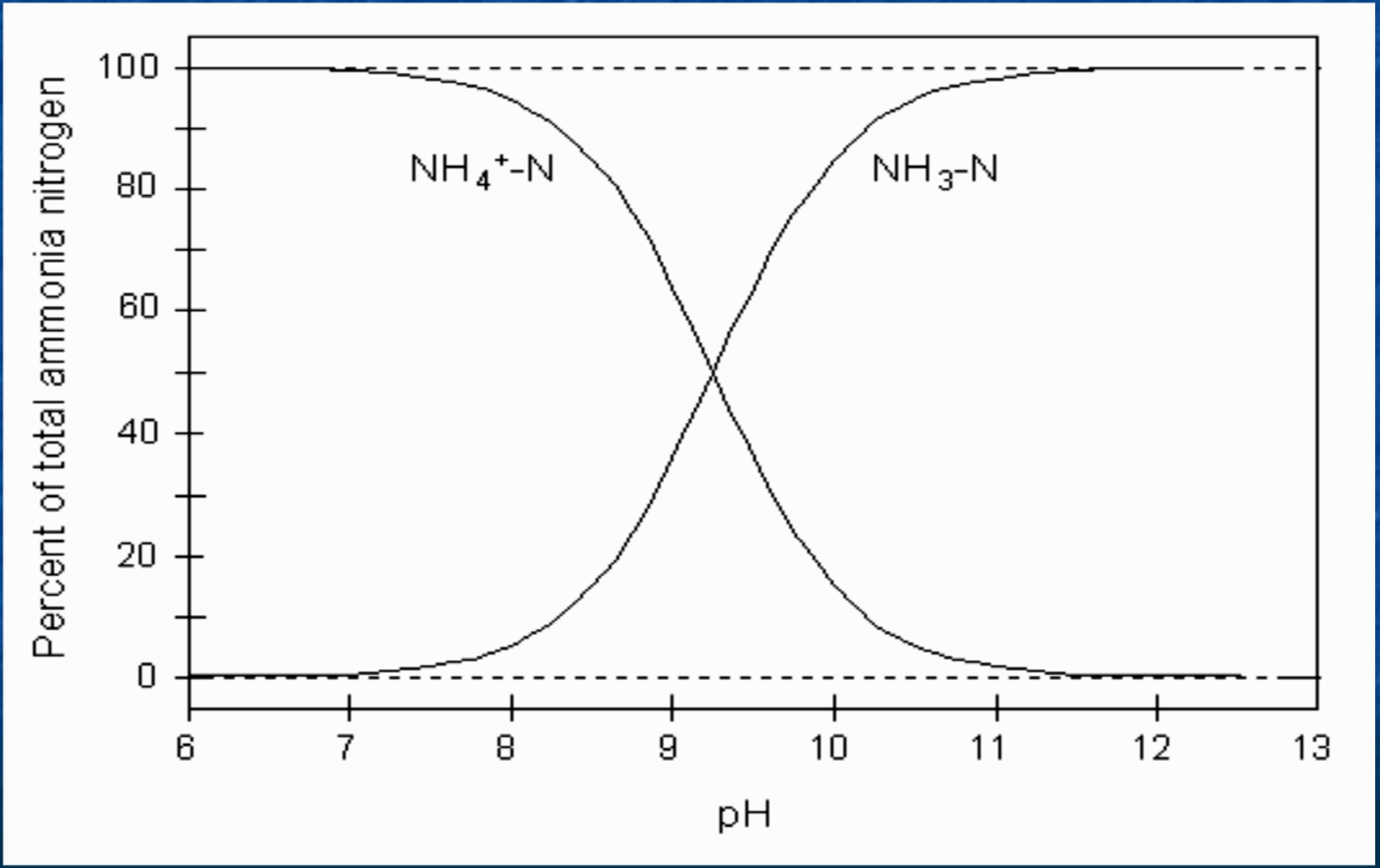
Why Do We Remove Nitrogen?

- **Ammonia, nitrate and nitrite can be toxic**
- **Ammonia exerts an oxygen demand**
- **Ammonia and nitrate stimulate the growth of algae and aquatic plants**
- **Ammonia, nitrate and nitrite can cause plant operational problems**

Forms of Nitrogen in Wastewater

- **Ammonia and ammonium**
- **Organic nitrogen**
- **Nitrate and nitrite**
- **Nitrogenous gasses**

pH and Ammonia



What is Total Kjeldahl Nitrogen (TKN)

- **The sum of ammonia-N and organic-N**

What is Total - N?

The sum of TKN and nitrate and nitrite

Plant Operational Problems

Plant Operational Problems

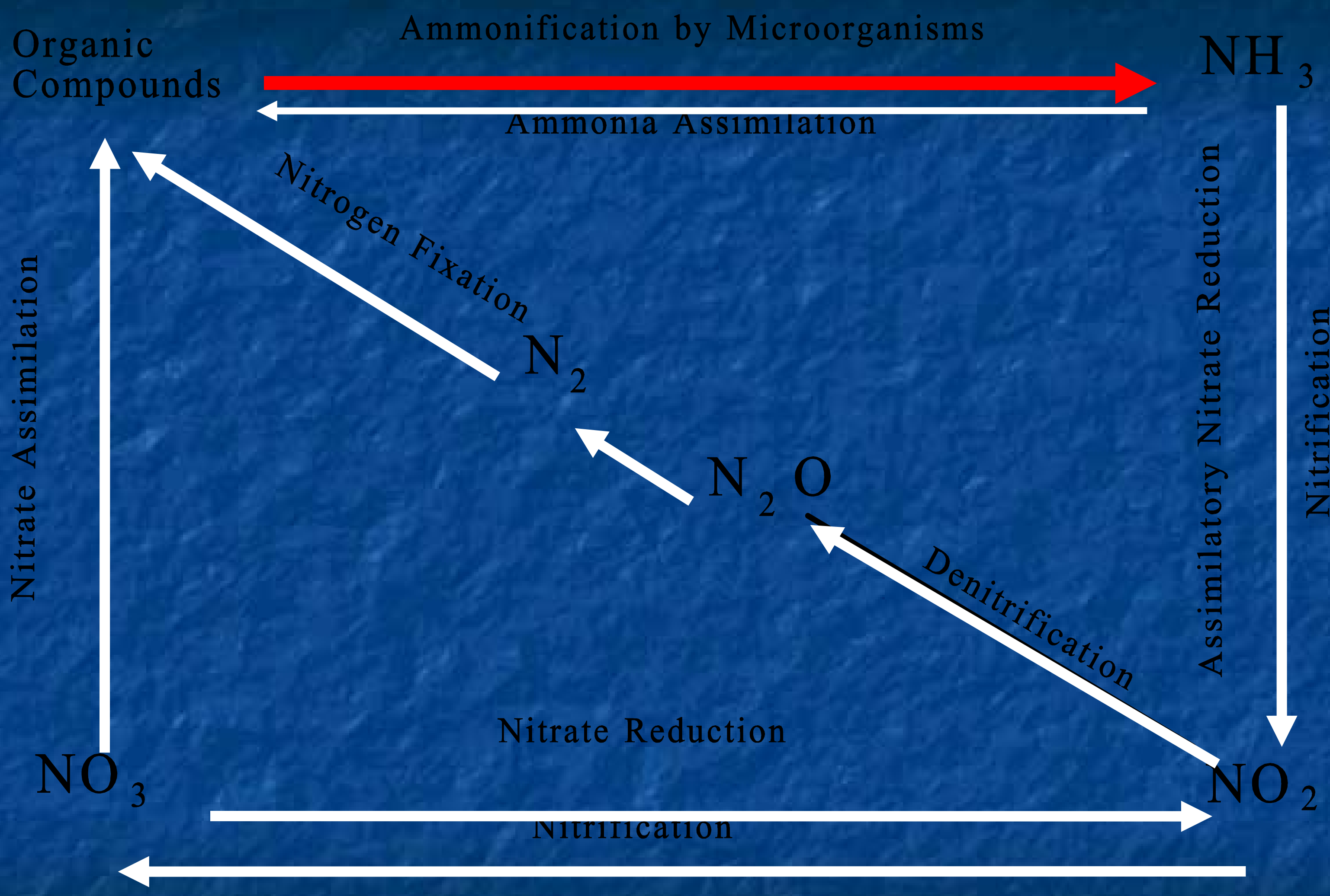
- Pop ups in clarifier or SBR
- Rising sludge blanket in clarifier or SBR
- Low dissolved oxygen levels in aeration tanks
- Cloudy effluent
- High chlorine demand
- Poor fecal coliform kills
- Effluent toxicity

Influent Nitrogen

- 99% is in the form of TKN
  - 40% organic nitrogen
  - 59% ammonia/ammonium
  - This ratio is dependent on pH, temperature and detention time in the collection system
- Less than 1% nitrate and nitrite

Do We Actually Remove Nitrogen?

- Ammonification
- Nitrification
- De-nitrification


Organic Compounds
Ammonification by Microorganisms
NH_3
Ammonia Assimilation
Nitrogen Fixation
Nitrate Assimilation
Assimilatory Nitrate Reduction
Nitrification
N_2
N_2O
Denitrification
Nitrate Reduction
NO_3
NO_2
Nitrification

Ammonification

Conversion of organic-N to ammonia by decomposition and hydrolysis

Nitrogen cycle

Ammonification by microorganisms

Click to add text

Organic Compounds $\longrightarrow$ **NH_3**

Ammonification

- Some hard-to-break-down substances containing nitrogen may pass through the process
- There may be 1 to 2 mg/L of organic -N left after treatment
- This is a part of the Total -N value
- May cause problems with disinfection

Nitrification

Conversion of ammonia-N to nitrate-N

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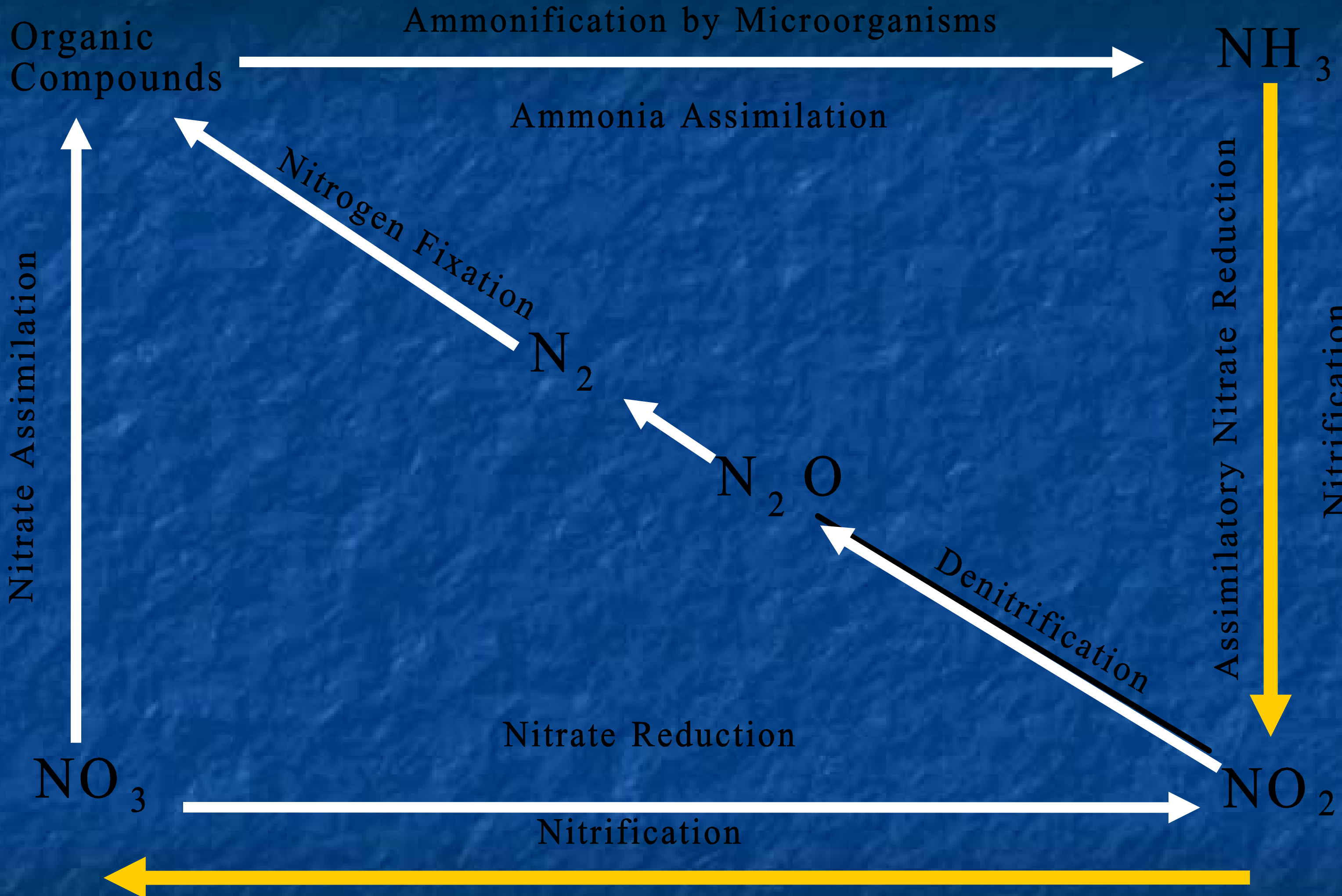
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N_2
N_2O
Nitrate Assimilation
Assimilatory Nitrate Reduction
Nitrification
Denitrification
Nitrate Reduction
NO_3
NO_2
Nitrification

$$\text{Ammonia} + \text{Oxygen} \xRightarrow{\textit{Nitrosomonas}} \text{Nitrite} + \text{Acid} + \text{More } \textit{Nitrosomonas}$$

$$\text{Nitrite} + \text{More Oxygen} \xRightarrow{\textit{Nitrobacter}} \text{Nitrate} + \text{More } \textit{Nitrobacter}$$

Factors Affecting Nitrification

- Process temperature
- Concentration of ammonia-N
- Dissolved oxygen
- Influent and process pH
- Influent and process alkalinity
- Oxic sludge retention time
- F/M ratio
- No Toxic wastewater!

Influent Alkalinity

- Nitrification reaction produce acid which react with approximately 7.1 lbs of alkalinity for every 1.0 lb of ammonia-N oxidized
- Influent alkalinity can be a process limiting factor
- Low influent alkalinity may require chemical addition

Nessler Reagent
HACH
250 mL
200
150
100
NALGENE®
1201-0250

Chemical Addition to Supplement Alkalinity

- **Sodium hydroxide**
- **Soda ash**
- **Lime**

Summary of Factors Effecting Nitrification

- Process Temperature
- Optimum 30 -35 °C
- Concentration of ammonia-N
- Affects nitrifier growth rate - Last 0.5 mg/L is hardest to remove
- Dissolved Oxygen
- Minimum of 1 mg/L, average of 2 mg/L,
- 4.6 lbs O_2 required to oxidize 1 lb NH_3

Summary of Factors Effecting Nitrification

- **Influent and process pH**
- **Optimum range is 7 .5 to 9.0 SU**
- **Influent and Process Alkalinity**
- **7.1 lbs of alkalinity is destroyed for every 1.0 lb of ammonia-N oxidized**
- **Oxic SRT**
- **Dependent on D.O., pH, temperature and target removal rate**

Summary of Factors Effecting Nitrification

- **Toxicants**
  - **Heavy metals, cyanide and some organic chemicals can inhibit nitrification rate**
- **F/M Ratio**
- **Higher D.O.s are required at lower F/M and high SRTs**

What Form of Nitrogen is left after Nitrification?

A. Nitrogen gas
B. Nitrite
C. Nitrate
D. Organic nitrogen

C. Nitrate

Process Control Testing to Evaluate Nitrification Efficiency

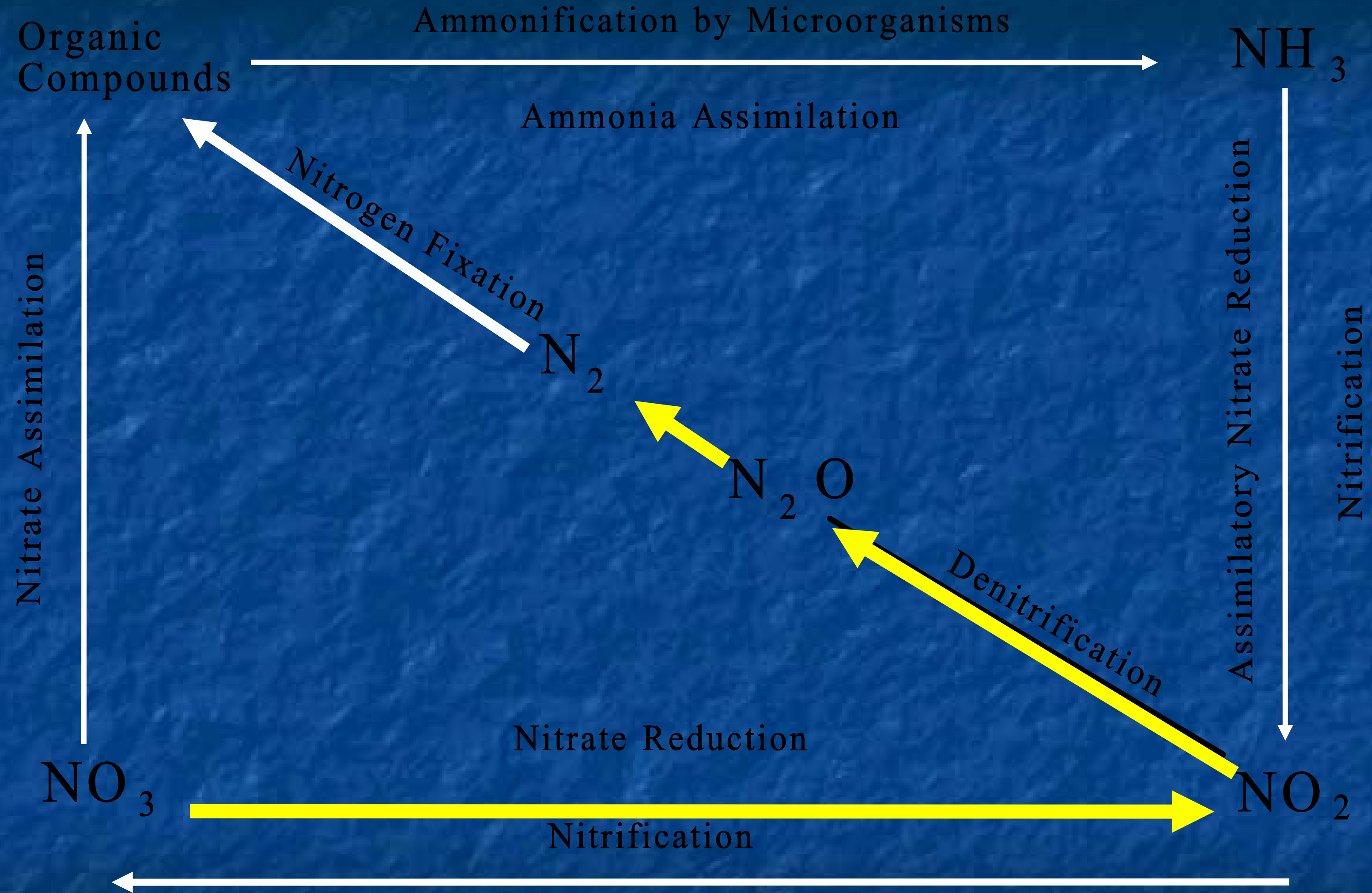
- Effluent Ammonia - N analysis
  - colorimetric or electrometric
- Dissolved Oxygen
  - Sufficient DO
  - Excessive DO - Toxicity
- pH and alkalinity
- Oxic MCRT or Sludge age - gravimetric or volumetric

De-nitrification

Conversion of nitrate-N to nitrogenous gasses

Click to add text

$$\textbf{Nitrate + Organics} \xrightarrow{\textit{Facultative Anaerobic Bacteria}} \textbf{Carbon dioxide} + N_2 + \textbf{Water + Energy}$$



Organic Compounds
Ammonification by Microorganisms
NH_3
Ammonia Assimilation
Nitrogen Fixation
Assimilatory Nitrate Reduction
Nitrification
Nitrate Assimilation
N_2
N_2O
Denitrification
Nitrate Reduction
NO_3
NO_2
Nitrification

Conditions Required for De-nitrification

- **Anoxic environment**
- **Carbon source**
- **Proper range for other environmental factors (pH, temperature, SRT)**

Anoxic Environment

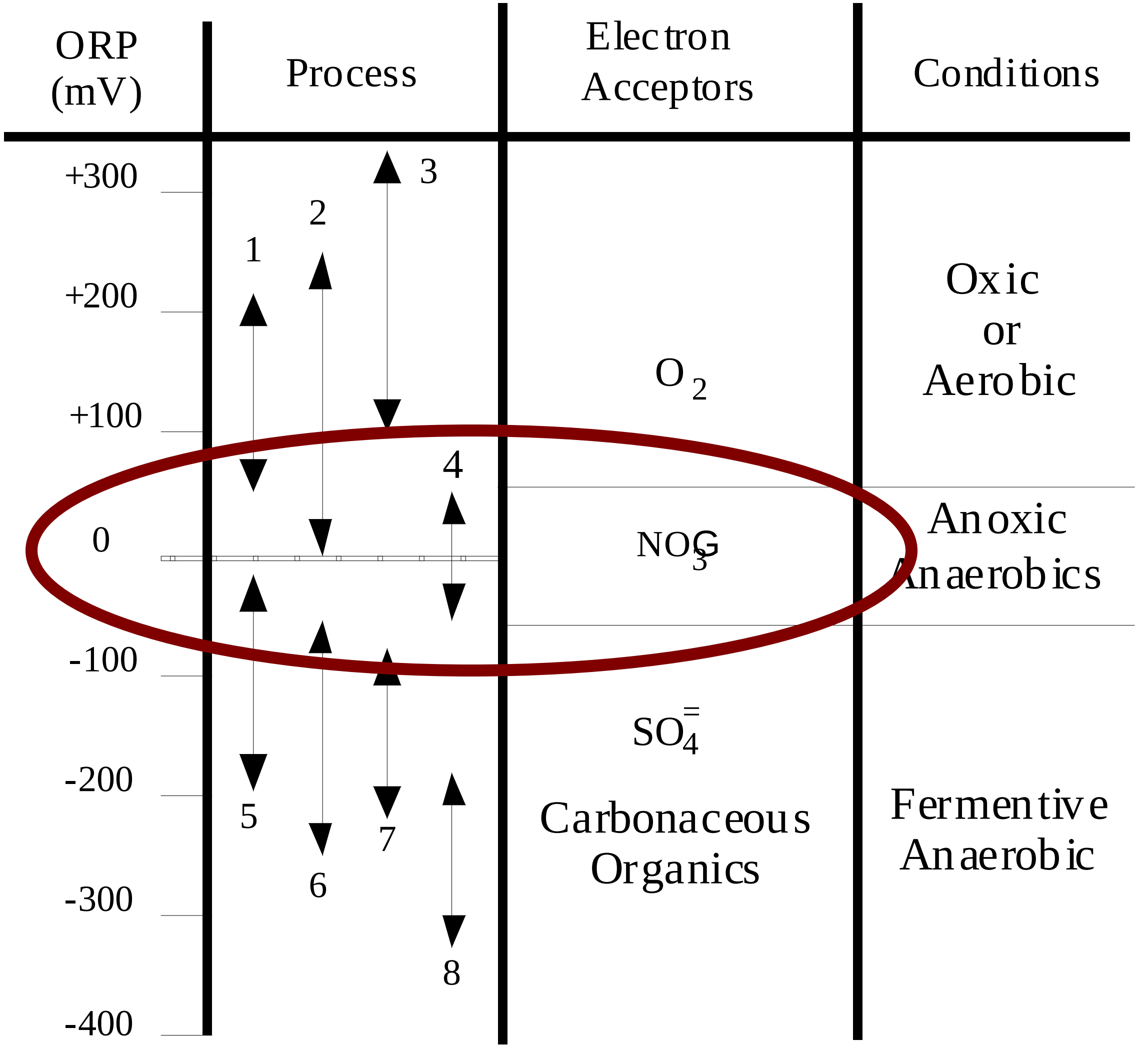
- No free dissolved oxygen present
- NO_3 -N present
- Facultative bacteria utilize oxygen in the following order
  - O_2
  - NO_3
  - SO_4
  - CO_2

Anoxic Environment

- Dissolved oxygen level below 0.2 mg/L
- Nitrates must be present
- Oxidation Reduction Potential (ORP) of between + 50 and - 50
- Mixing is important
- Watch dissolved oxygen in return streams


Anoxic
Zone


Dissolved Oxygen



1- Organic Carbon Oxidation
2- Polyphosphate Development
3- Nitrification
4- Denitrification
5- Polyphosphate Breakdown
6- Sulfide Formation
7- Acid Formation
8- Methane Formation

Figure 3-6: ORP & Metabolic Processes


Mixing

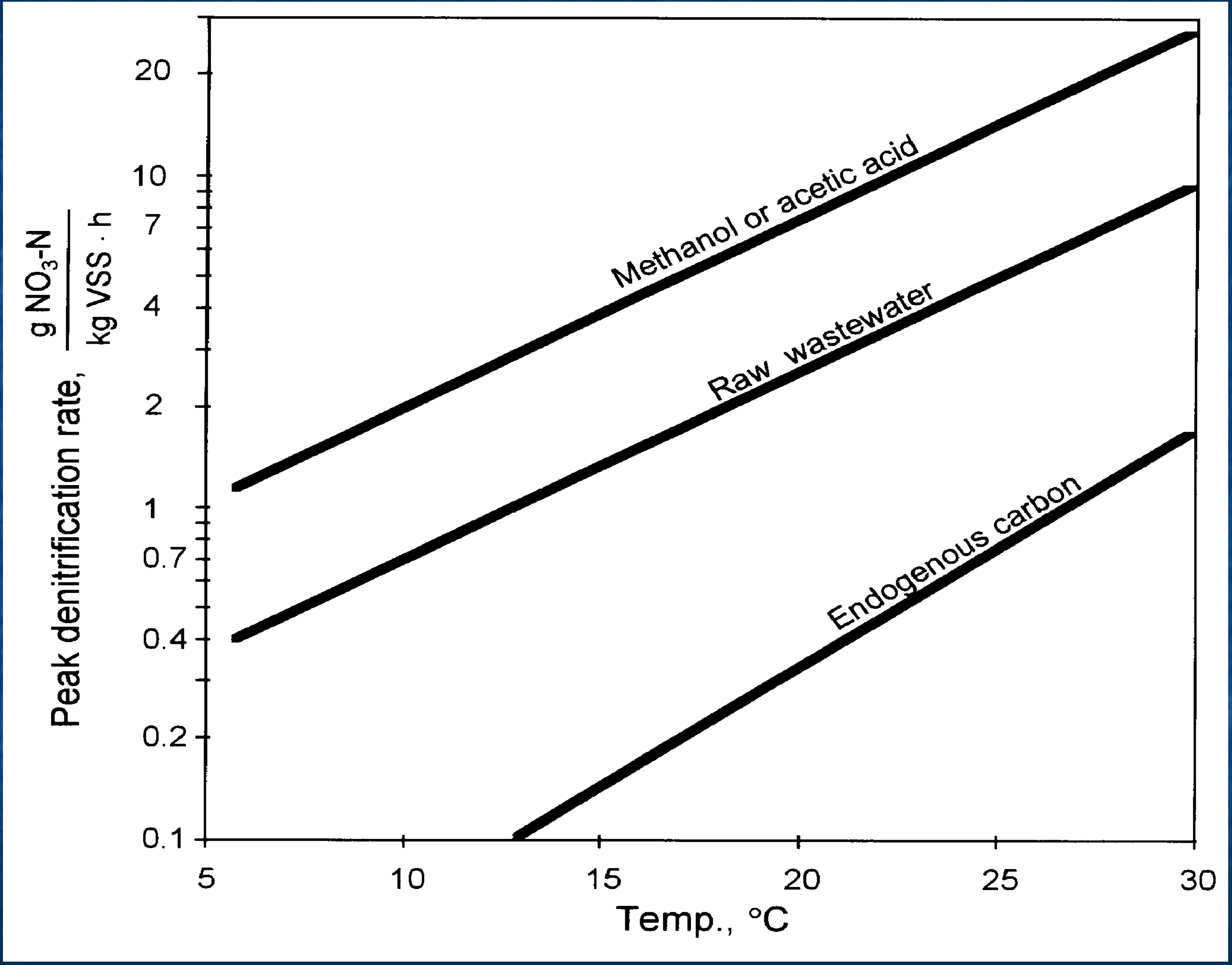
Mixing

- Put the food and microorganisms in intimate contact
- Allow for adsorption and absorption


Carbon Source

Carbon or Food Sources

- Raw Wastewater
- Endogenous carbon
- Methanol
- Acetic acid
- Dog food



Peak denitrification rate, $\frac{g\ NO_3\text{-}N}{kg\ VSS \cdot h}$
20
10
7
4
2
1
0.7
0.4
0.2
0.1
5
10
15
20
25
30
Temp., °C
Methanol or acetic acid
Raw wastewater
Endogenous carbon

Environmental Factors

- pH
- Temperature
- Retention time
- Toxicity

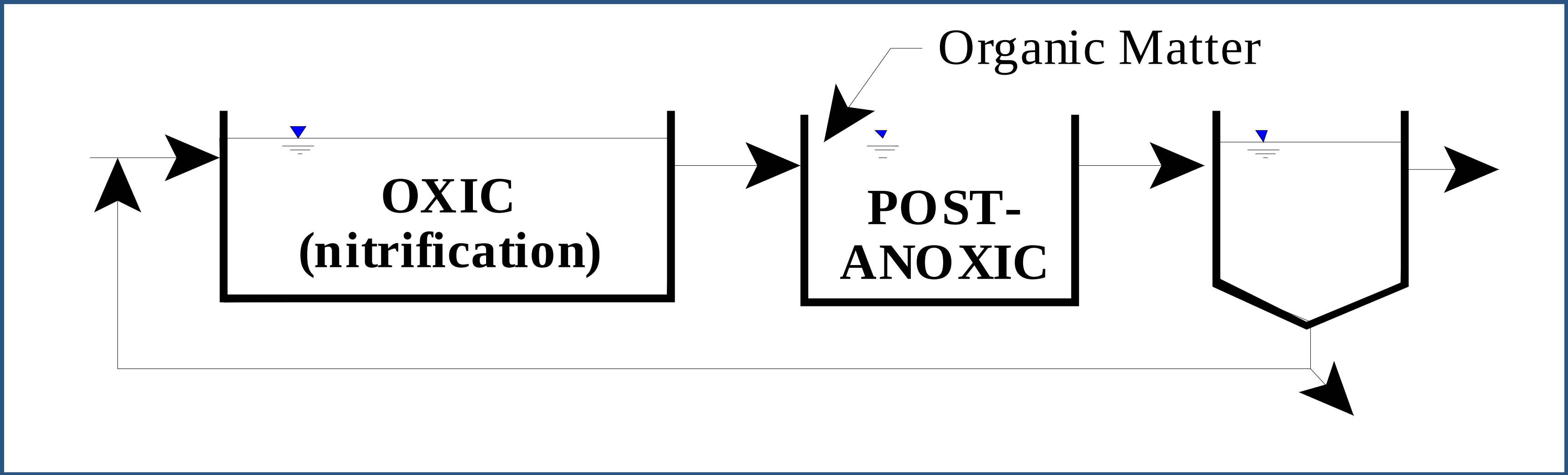
Factors Effecting De-nitrification

- **pH**
- **7.5 - 9.0 SU**
- **Temperature and SRT**
- **Longer SRT and higher MLSS during periods of low temperature**
- **Anoxic conditions**
- **D.O. less than 0.2 mg/L or ORP in +50 to -50 mV**

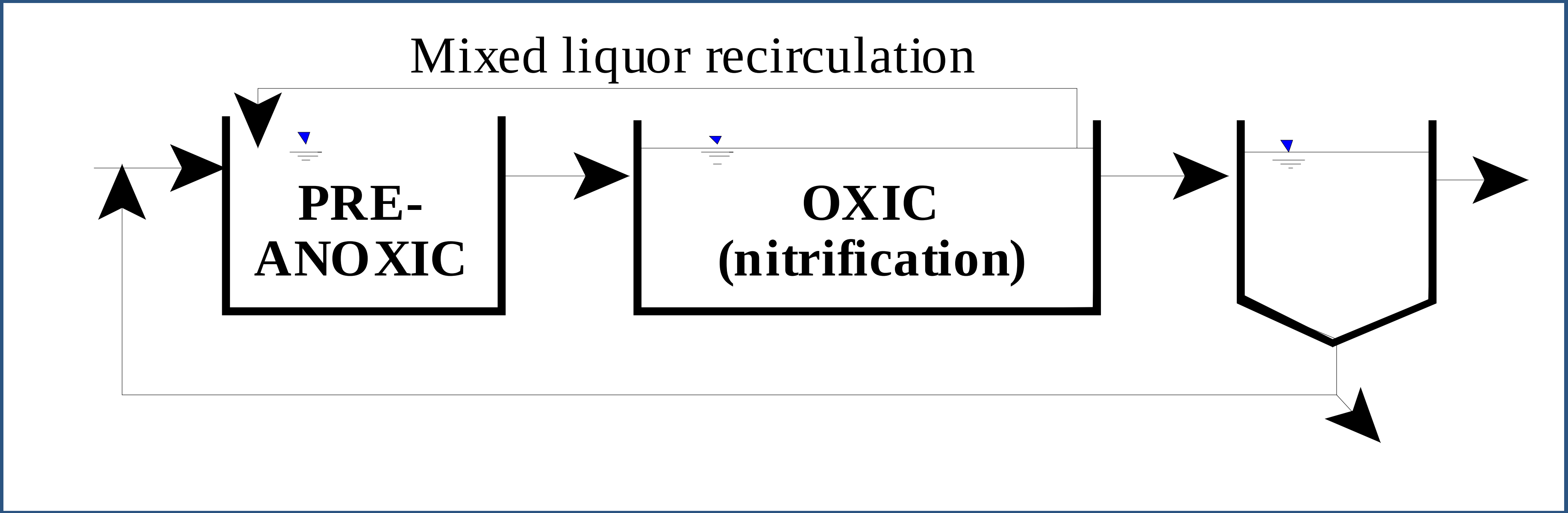
Factors Effecting De-nitrification

- **Carbon Source**
- **Relative to process temperature**
- **Endogenous carbon may not be enough during periods of low temperature**
- **Quality and quantity of carbon available strongly influences denitrification rate**

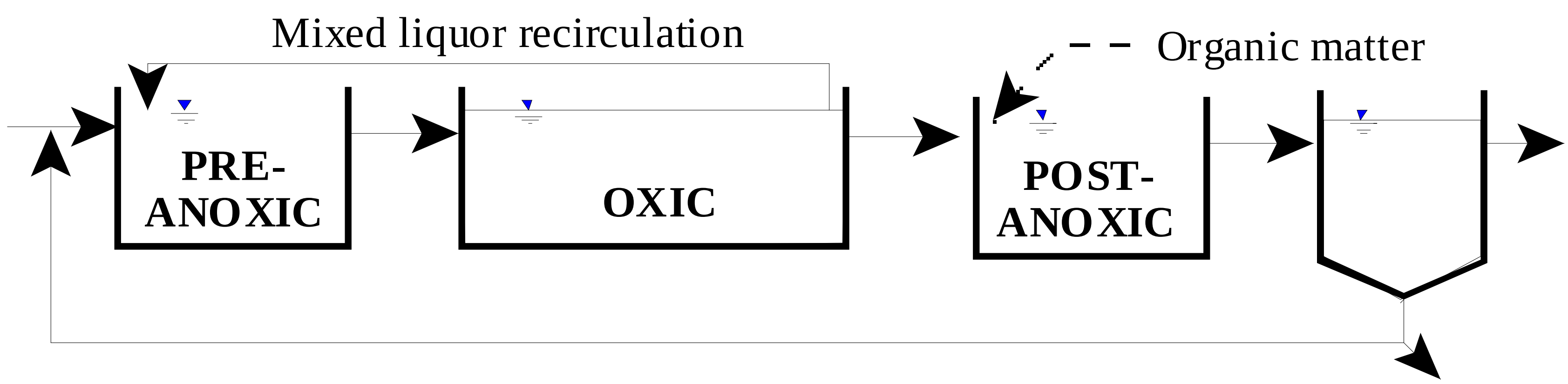
Post-denitrification-Wuhrman Process



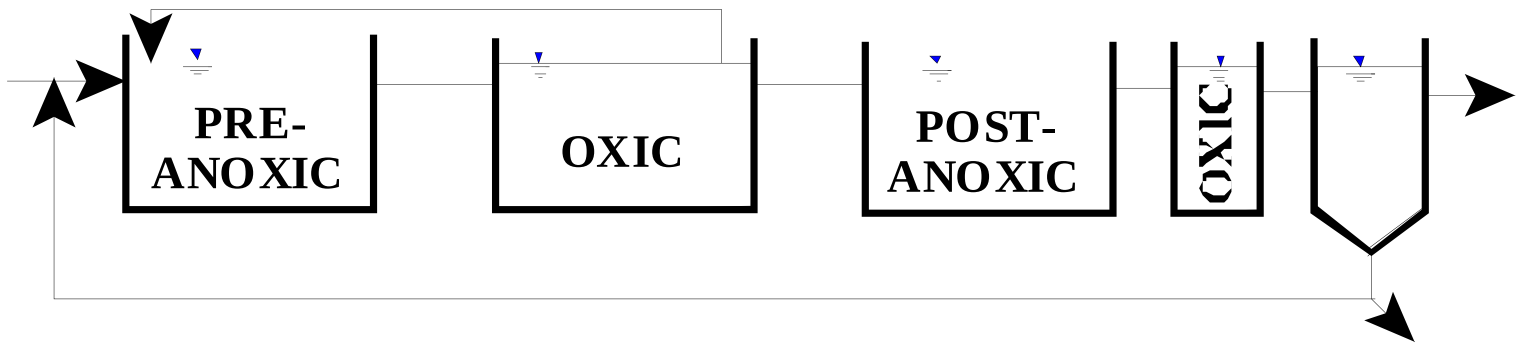
Pre-denitrification-Modified Ludzak Ettinger Process



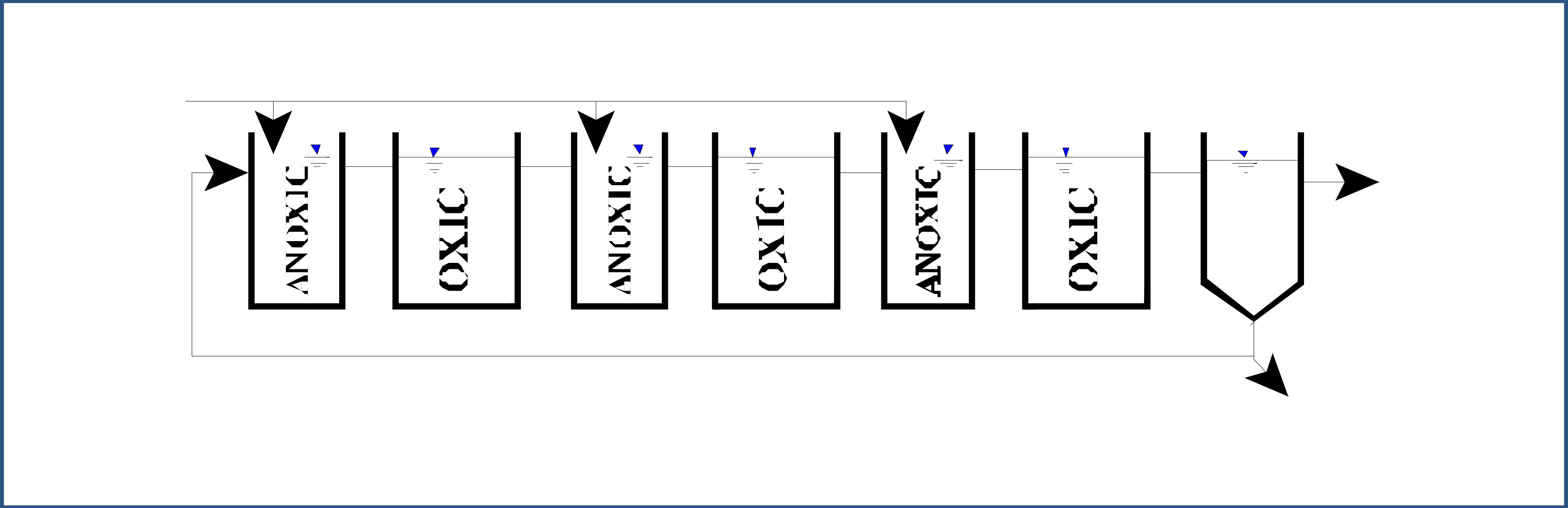
Dual Anoxic Zones



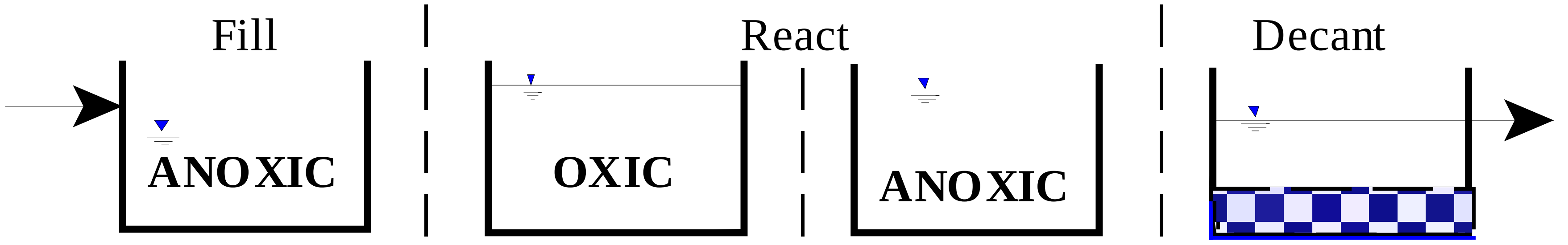
Four-Stage Bardenpho Process



Anoxic-Oxic Step Feed Process



Sequencing Batch Reactor



Process Control Testing for Denitrification

- Dissolved oxygen
- ORP
- NO_3 - N - colorimetric or electrometric
- pH and alkalinity
- COD or TOC
- SRT

Questions?