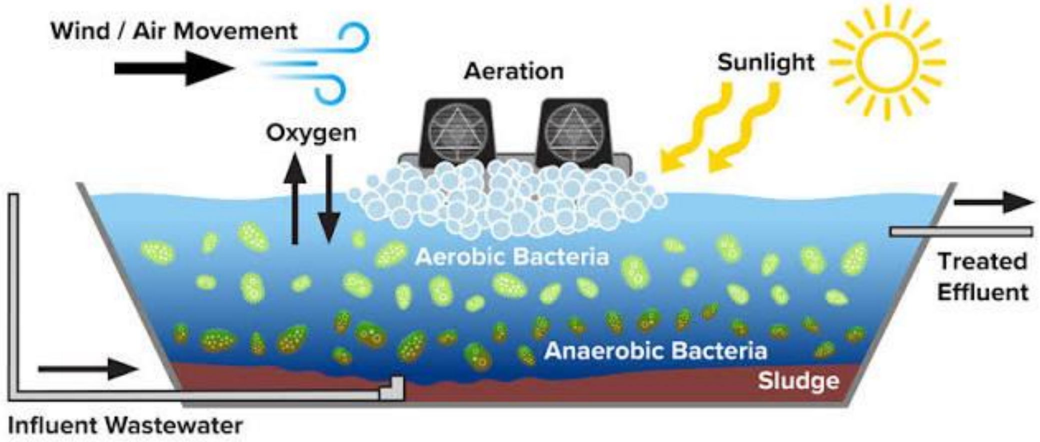
What we will cover

Biochemical Oxygen Demand (BOD)

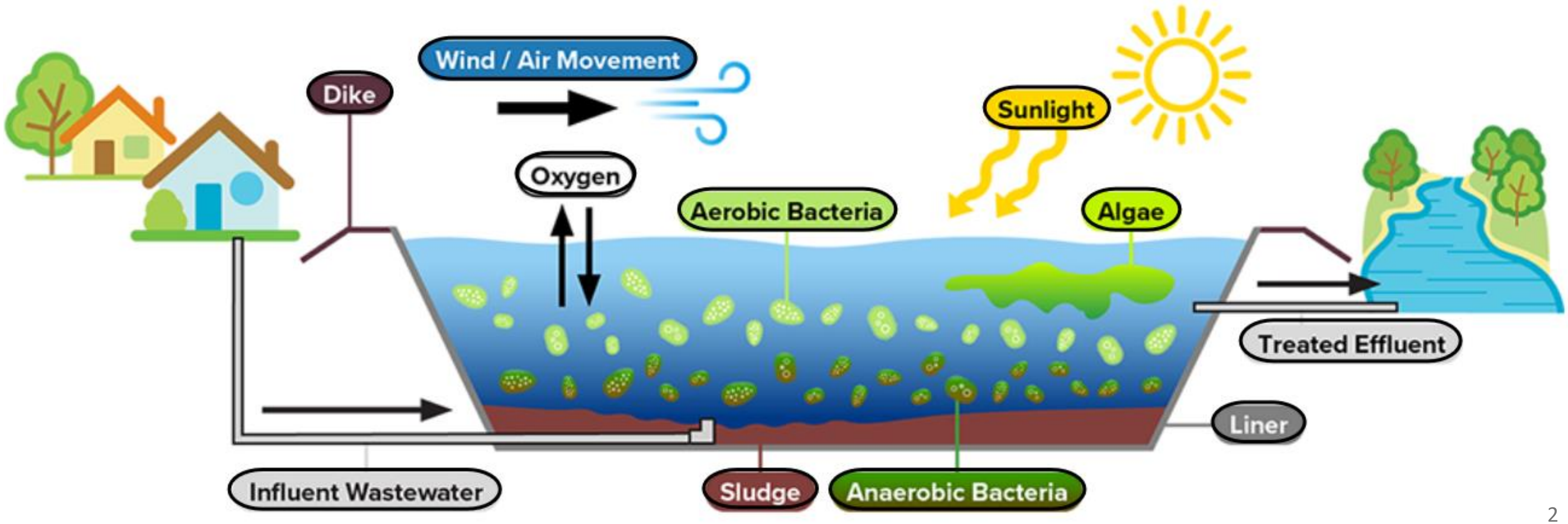
- BOD Removal Processes and Testing
- Troubleshooting common problems
- Seasonal changes in operation
- Microorganism in Lagoons



Overview of Wastewater Lagoons

Wastewater lagoons leverage natural biological processes to remove organic biodegradable wastes and solids to protect environmental and public health

- Designed to remove BOD and TSS (80% to 85% removal)
- Not specifically designed to remove nutrients (15% to 50%)

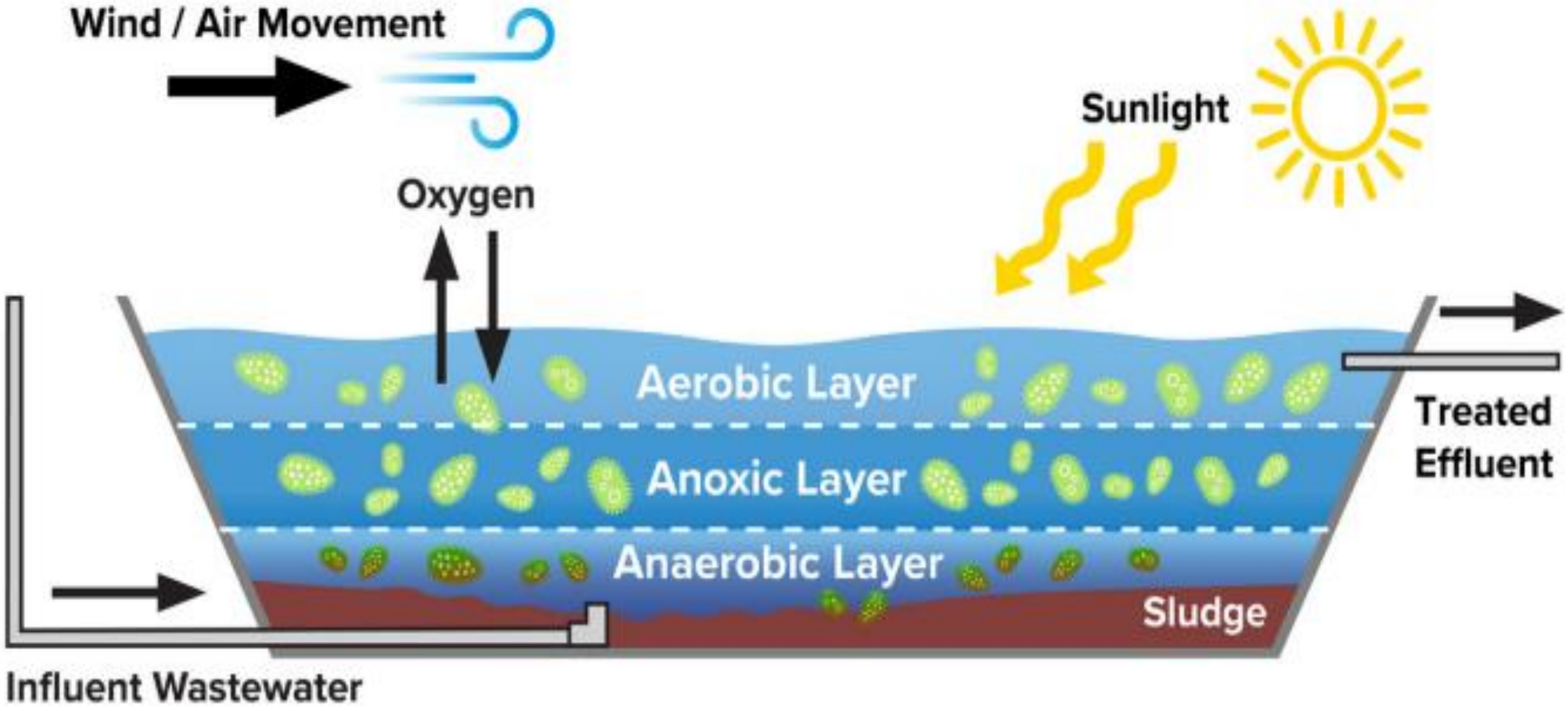


Facultative Lagoons

Aerobic Zone : Aerobic bacteria use dissolved oxygen produced by microscopic algae

Facultative Zone: Facultative bacteria can use either oxygen or nitrate as their oxygen source.

Anaerobic Zone: Anaerobic bacteria convert organic solids to gases and liquified biproducts.

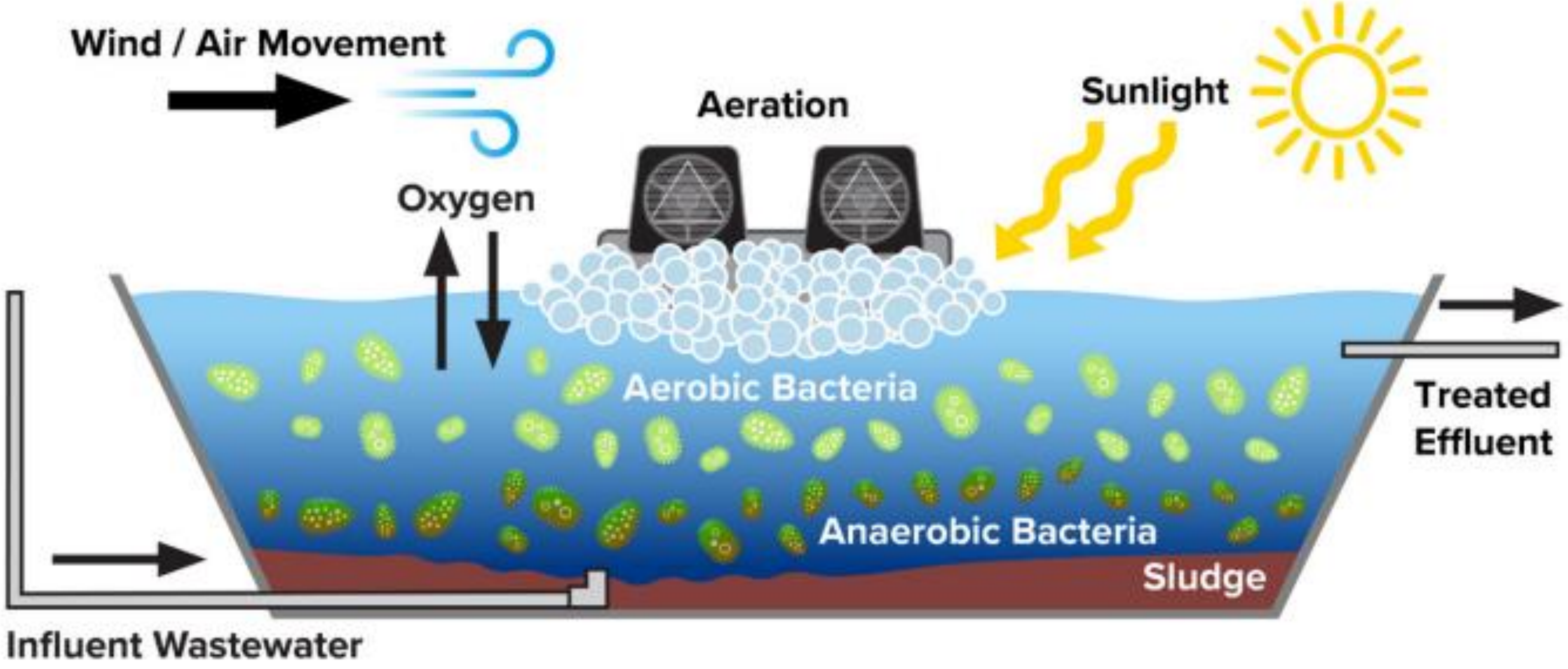


- *Depths of facultative lagoons 5ft to 6 ft typical*
- *Much larger footprint than aerated and longer retention times*
- *Stratified by temperature into three functional zones*

Aerated Lagoons (Partial mix)

Aeration:

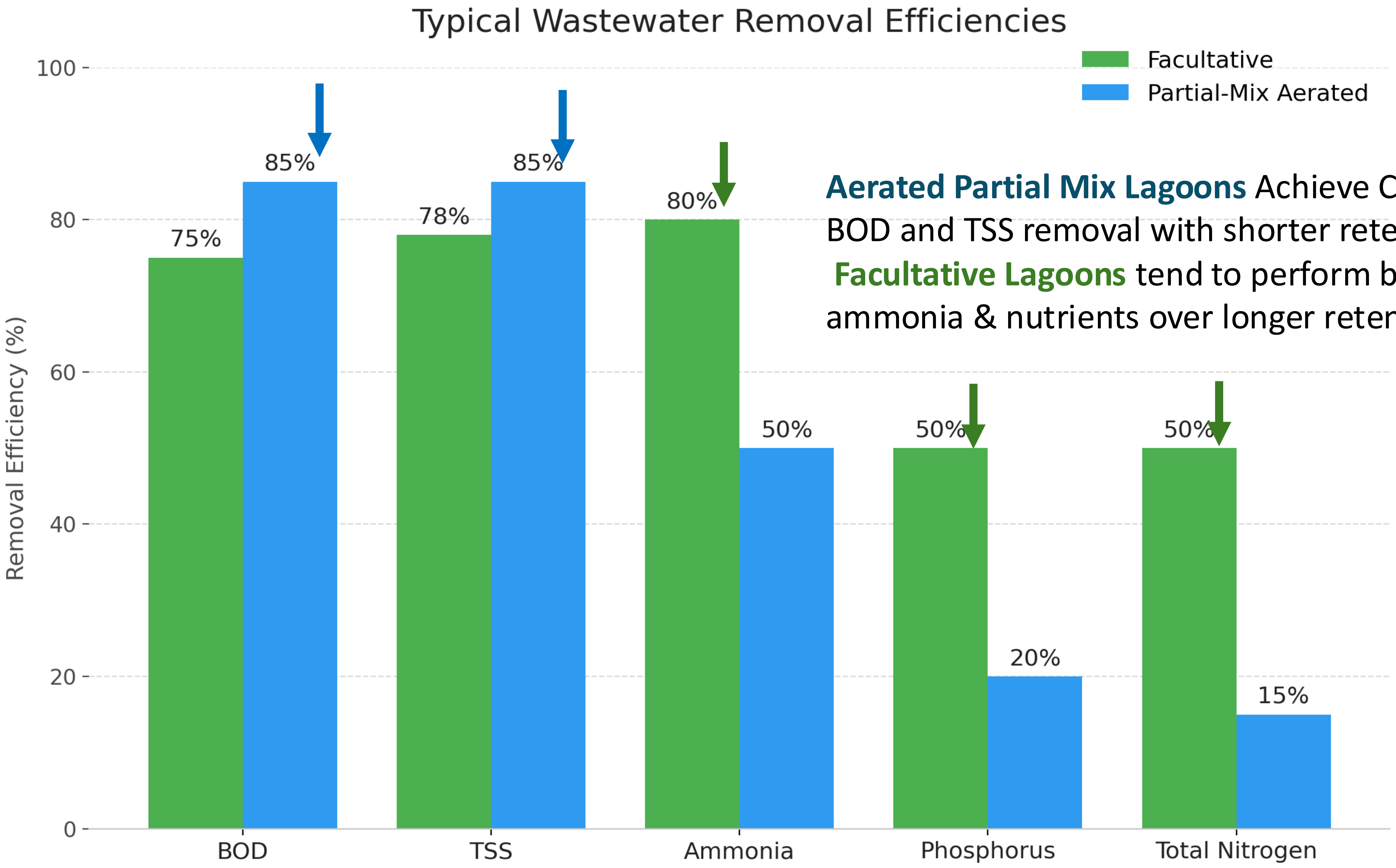
- Surface Aerators provide DO and mixing down to a depth of 5 feet.
- Provides DO necessary for BOD removal by aerobic bacteria.
- Bacterial floc capture TSS as it settles



Sludge Zone:

Sludge consists of settled bacterial floc and inorganic solids. Anaerobic bacteria consume organic solids.

Aerated Lagoons typically have a total depth of 10 to 12 feet. The greater depth helps prevent mixing of settled sludge.
Smaller footprint than facultative.

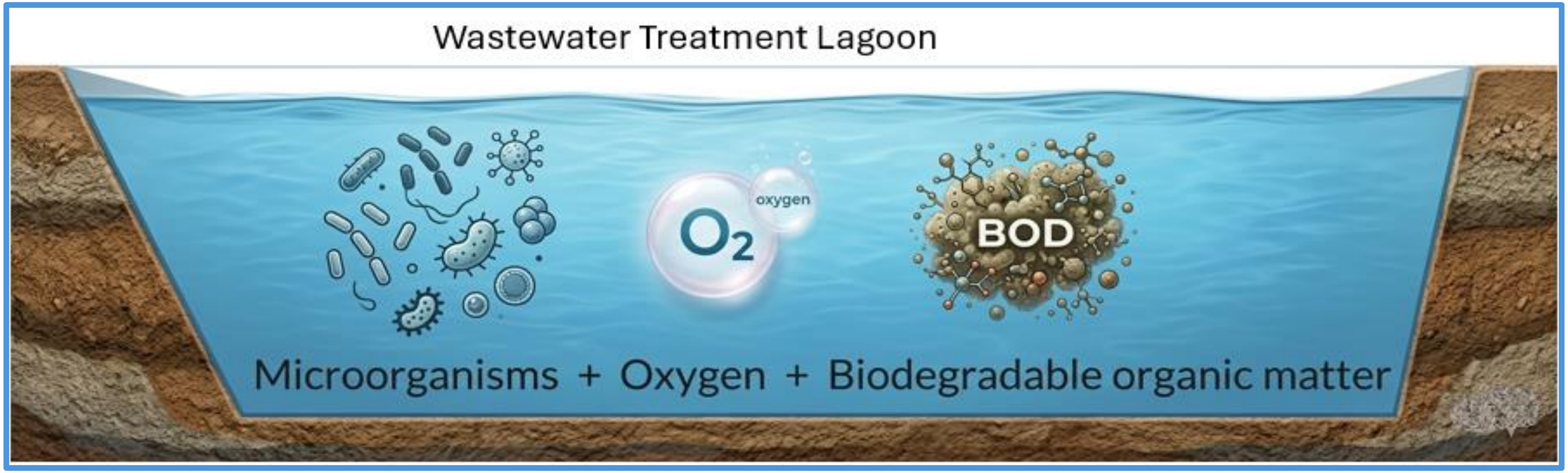


Aerated Partial Mix Lagoons Achieve Consistently high BOD and TSS removal with shorter retention times

Facultative Lagoons tend to perform better at removing ammonia & nutrients over longer retention times.

What is BOD?

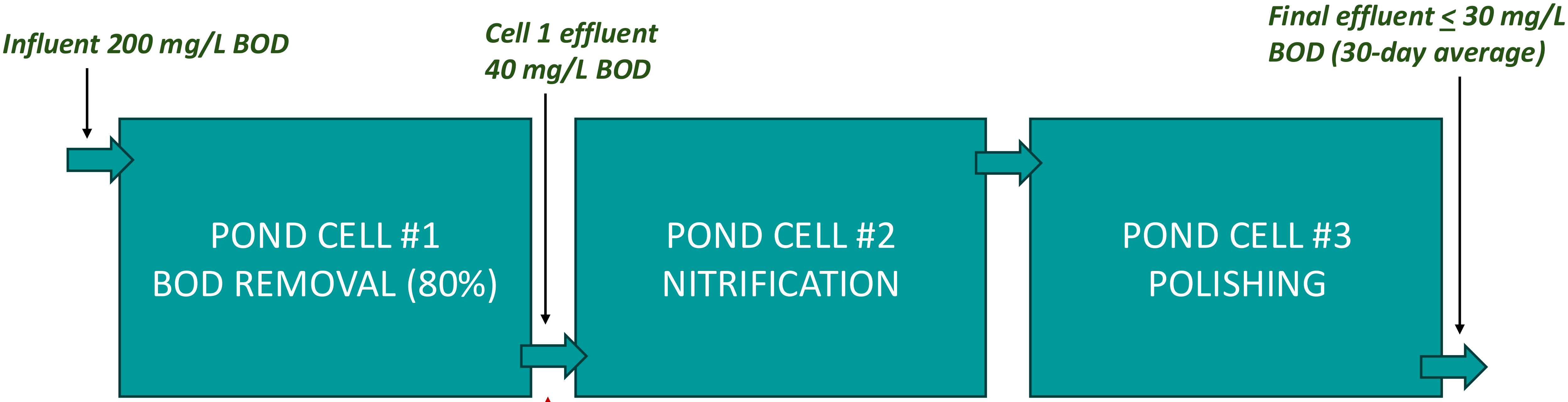
Aerobic microorganisms require oxygen to metabolize the organic wastes and convert it into Biomass (as they grow and replicate)



•Biological Oxygen Demand (BOD) is a measure of how much biodegradable organic waste is present in wastewater (based on how much oxygen is required)

•Three elements must come into contact within the lagoon for treatment to occur: aerobic microorganisms, oxygen, and BOD (food).

Typical Layout



High aeration. 80% BOD removal

Tapered aeration. Lower BOD allows nitrification

No aeration. Settling and polishing

Cell 1 effluent should show an 80% reduction in BOD. 70% for facultative lagoons.

Primary Factors:

- *Adequate Retention Time*
- *Sufficient DO*

Retention Time

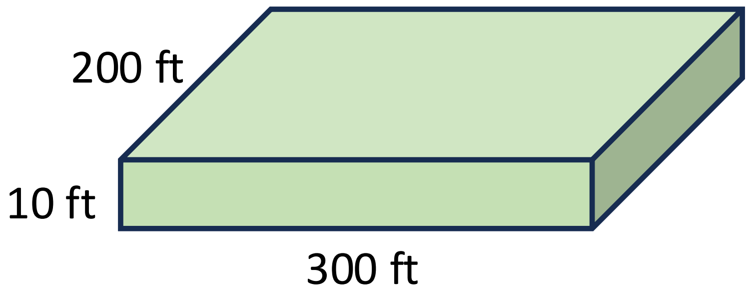
$$\textbf{Retention Time (Days)} = \frac{\text{Volume (MG)}}{\text{Flow (MGD)}}$$

A wastewater lagoon cell is 10 ft deep, 200 ft wide, and 300 ft long. The average influent wastewater flow is 0.2 MGD. What is the retention time for this cell?

Volume of lagoon:

10ft x 200ft x 300ft x 7.48 gal/cf = 4,488,000 gallons or **4.488 MG**

$$\textbf{Retention Time (Days)} = \frac{4.488\text{ (MG)}}{0.2\text{(MGD)}} = \textbf{22.4 days}$$



Retention time represents the theoretical treatment time in a lagoon.

Sizing aerated wastewater lagoon cells

The following formula is used to estimate the minimum cell size (for aerated systems).

$$t = \frac{E}{2.3 \cdot k_1 \cdot (100 - E)}$$

k_1 = 0.12/day (Standard design value for BOD metabolism rate at 68 °F / 20 °C)

E = removal efficiency (we will use 80% BOD removal as our target for cell #1)

t = time in days (this is what we are solving for).

Cell 1

Aerated
2 acres

$$t = \frac{80}{2.3 \times 0.12/\text{day} \times (100 - 80)} = \frac{80.0}{5.52/\text{day}} = \mathbf{14.5\ days}$$

Retention time is multiplied by flow to estimate minimum volume of cell 1. If flow = 0.2 MGD

14.5 days x 0.2 MGD = **2.9 MG**

Next, we would account for (a) sludge storage (2 ft.), lower winter temperatures (lower k value), and a safety factor (1.2 to 1.5). The likely final design: 10-ft-deep lagoon with an area of around 2 acres.

Sizing facultative lagoons

Facultative lagoons are sized based on BOD loading to determine the area of lagoon cells.

- Warm/Southern Climates (35 lbs/acre/day)
- Cold/Northern Climates (15 lbs/acre/day)

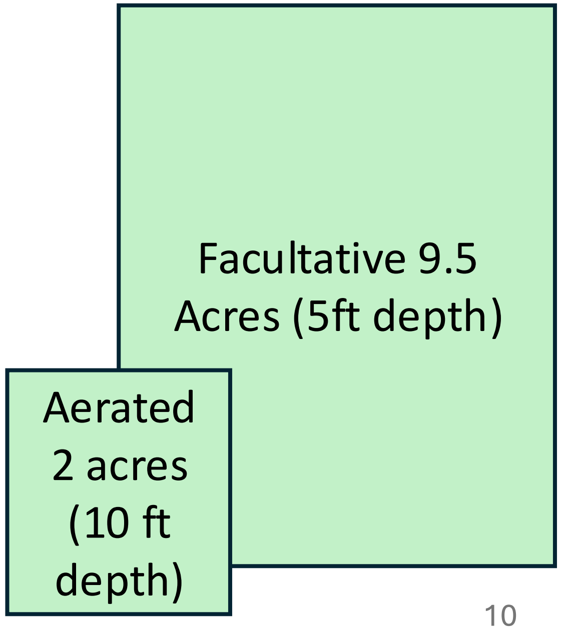
Example: **A facultative lagoon in a warm Southern climate will have a flow of 0.2 MGD and BOD of 200 mg/L. What is the minimum size of the first lagoon cell?**

Step 1: BOD in Lbs per day:

0.2 MGD x 200 mg/L x 8.34 lbs/day = **333.6 Lbs/day BOD**

Step 2: Divide by 35 lbs/acre/day

333.6 lbs/day ÷ 35 lbs/acre/day = **9.5 acres**



Even before accounting for safety factors, it is apparent that facultative lagoons are much larger than aerated lagoons.

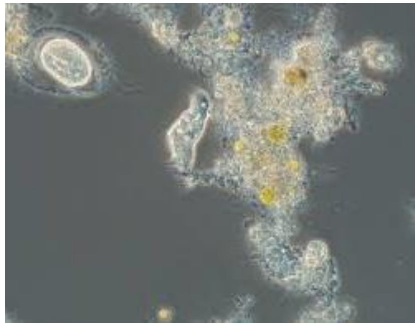
Key Microorganisms In Lagoons

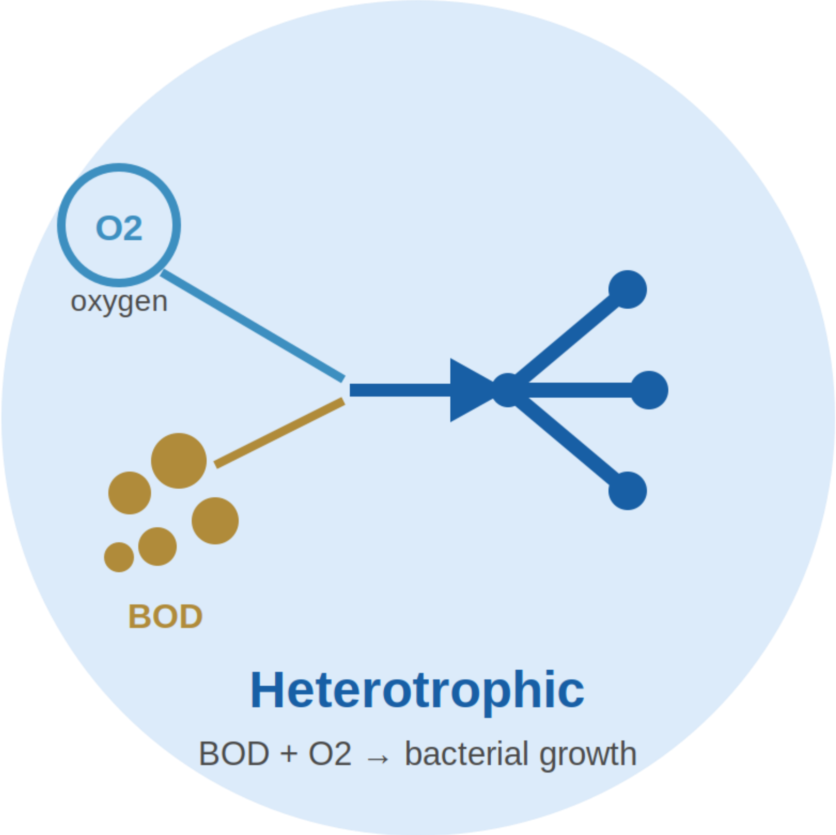
Heterotrophic Bacteria

Consume BOD in wastewater lagoons

- Requires an external carbon (food) source.
- Rapid growth from 68ºF to 95ºF and can double in 20 – 30 minutes
    - Psychrotrophic (cold-tolerant) 32 to 68°F
    - Mesophilic (warm-loving) 50°F to 104°F, dominant above 68

Bacterial floc in wastewater, consisting primarily of heterotrophic bacteria





Heterotrophic Bacteria consume BOD and Oxygen to produce biomass (replication and growth)

Key Microorganisms In Lagoons

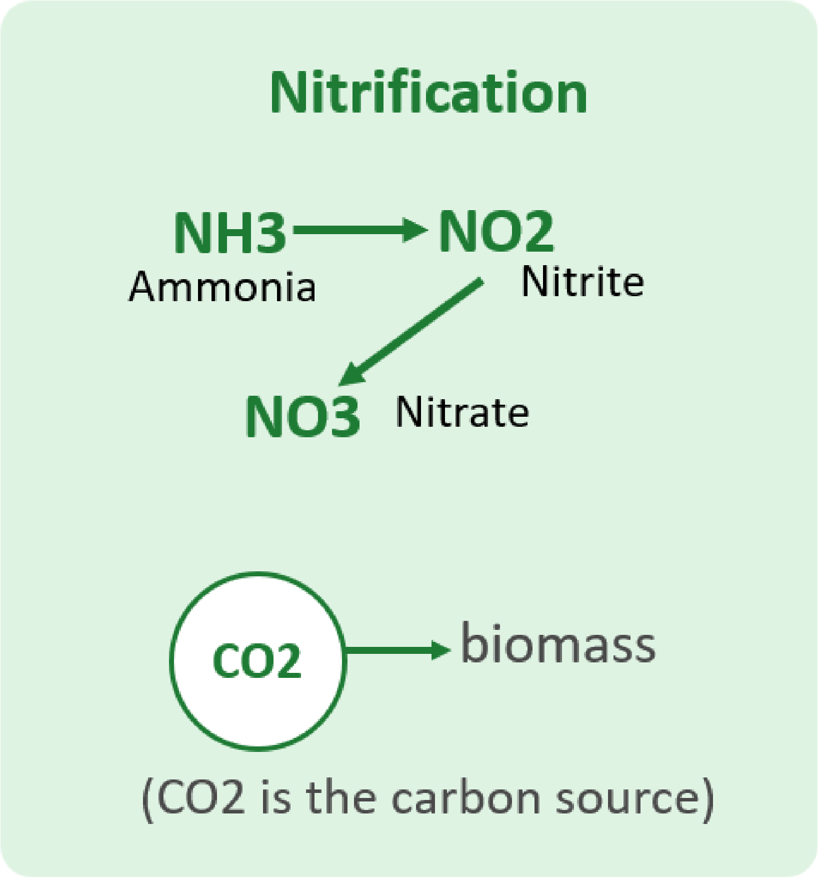
Nitrifying Bacteria: Converts Ammonia (NH3) to Nitrate.

1. Ammonia-oxidizing bacteria (Nitrosomonas) convert ammonia (NH3) to nitrite (NO2^{-}).

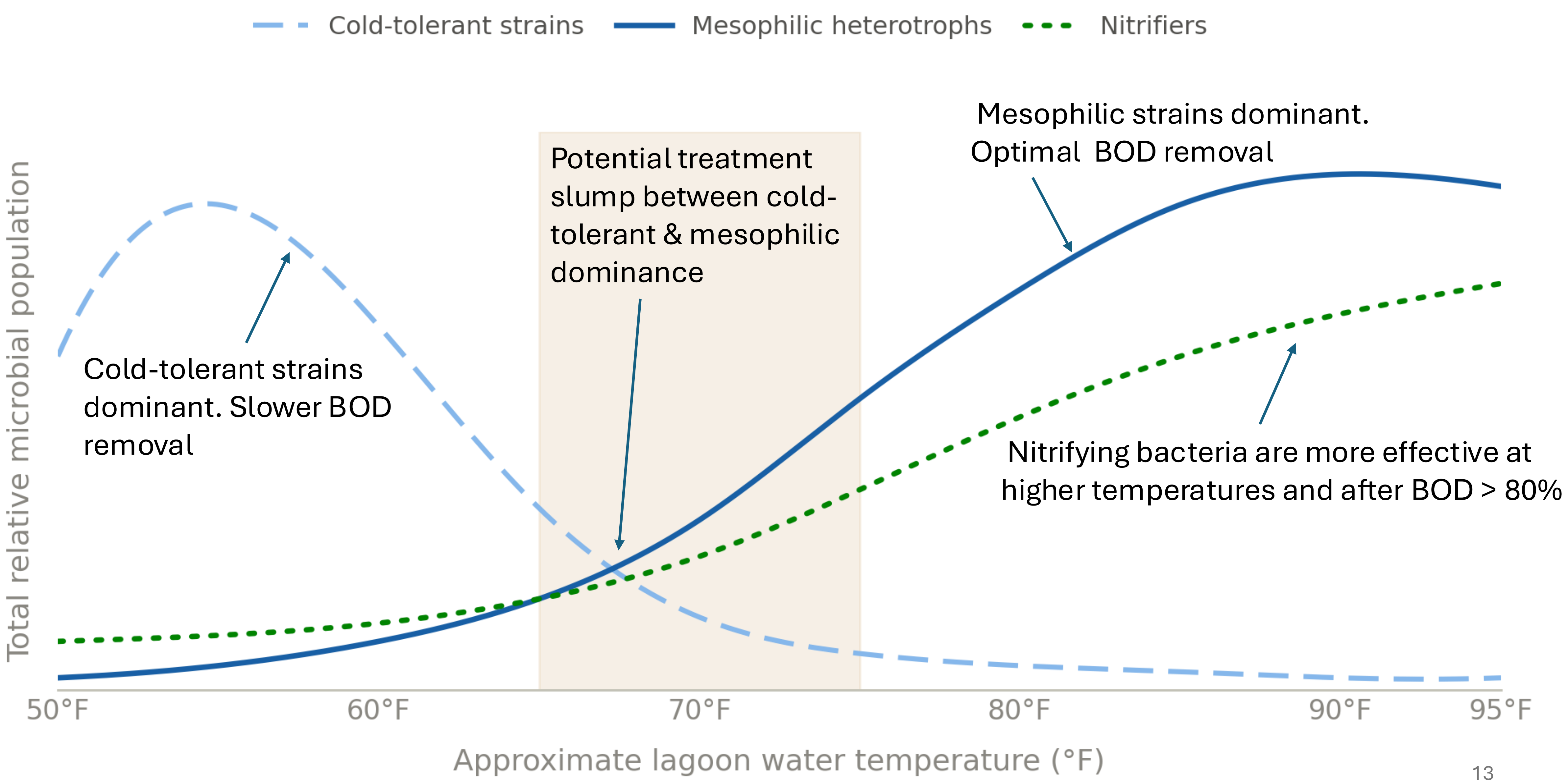
2. Nitrite-oxidizing bacteria (Nitrobacter) convert nitrite (NO2^{-}) to nitrate (NO3^{-}).

Characteristics

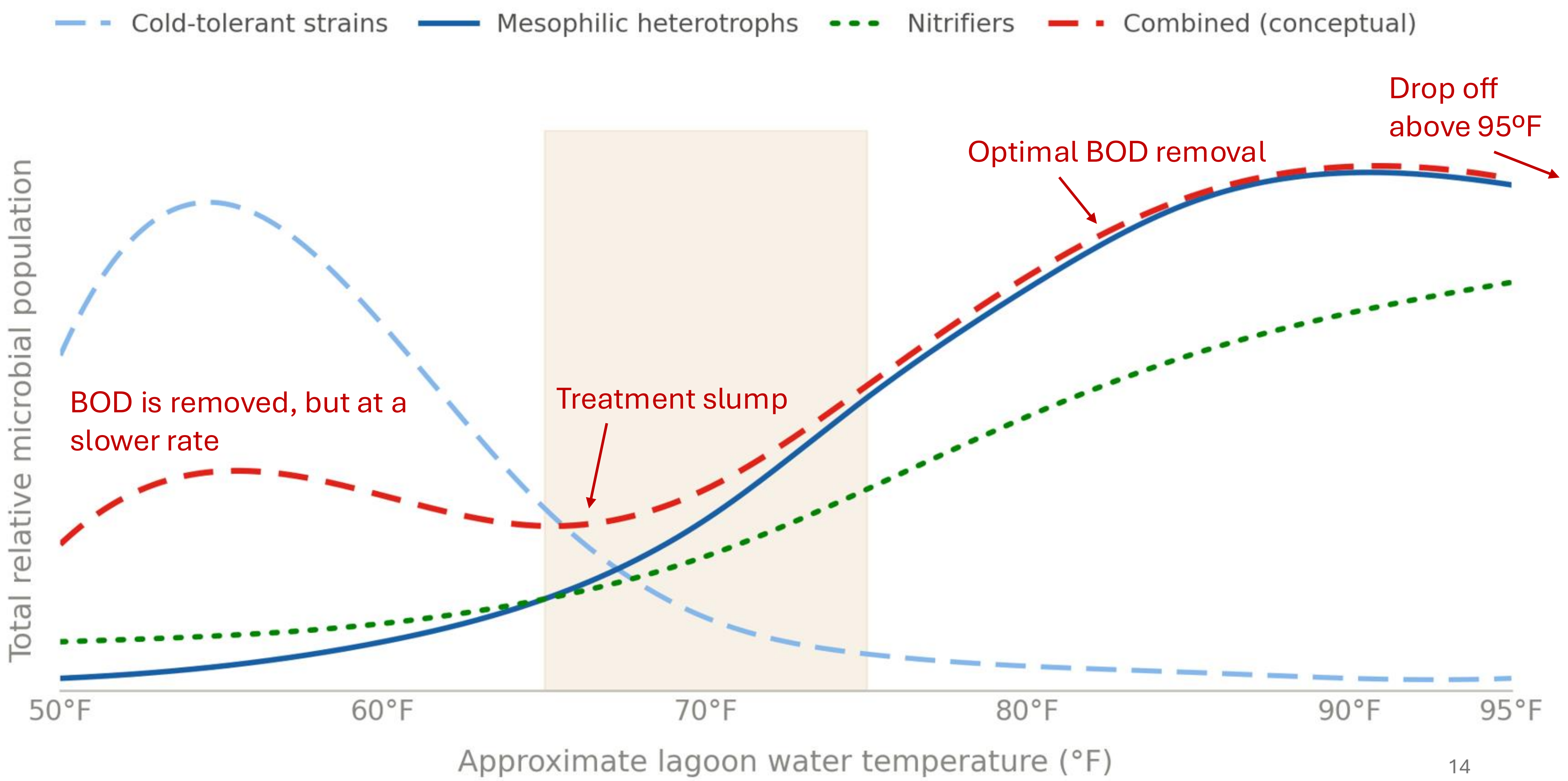
- Autotrophic - builds its own biomass from CO2
- Slow growth, doubles in 24 to 48 hours
- Temperature sensitive; ineffective below 40 ºF, optimal 85-95ºF
- BOD must be reduced to 20 to 30 mg/L (for sufficient DO)



Microbial Transition: Spring to Summer



BOD Treatment Effectiveness (Conceptual)



Dissolved Oxygen Demand

Primary Oxygen Demands

- 1.5 lbs of Oxygen is required per pound of BOD
- 4.5 lbs of Oxygen is required per pound of ammonia oxidized.

Other factors

Maintaining a minimum dissolved oxygen level helps prevent anaerobic conditions and protects against shock loads.

Recommended DO level: 2 – 3 mg/L

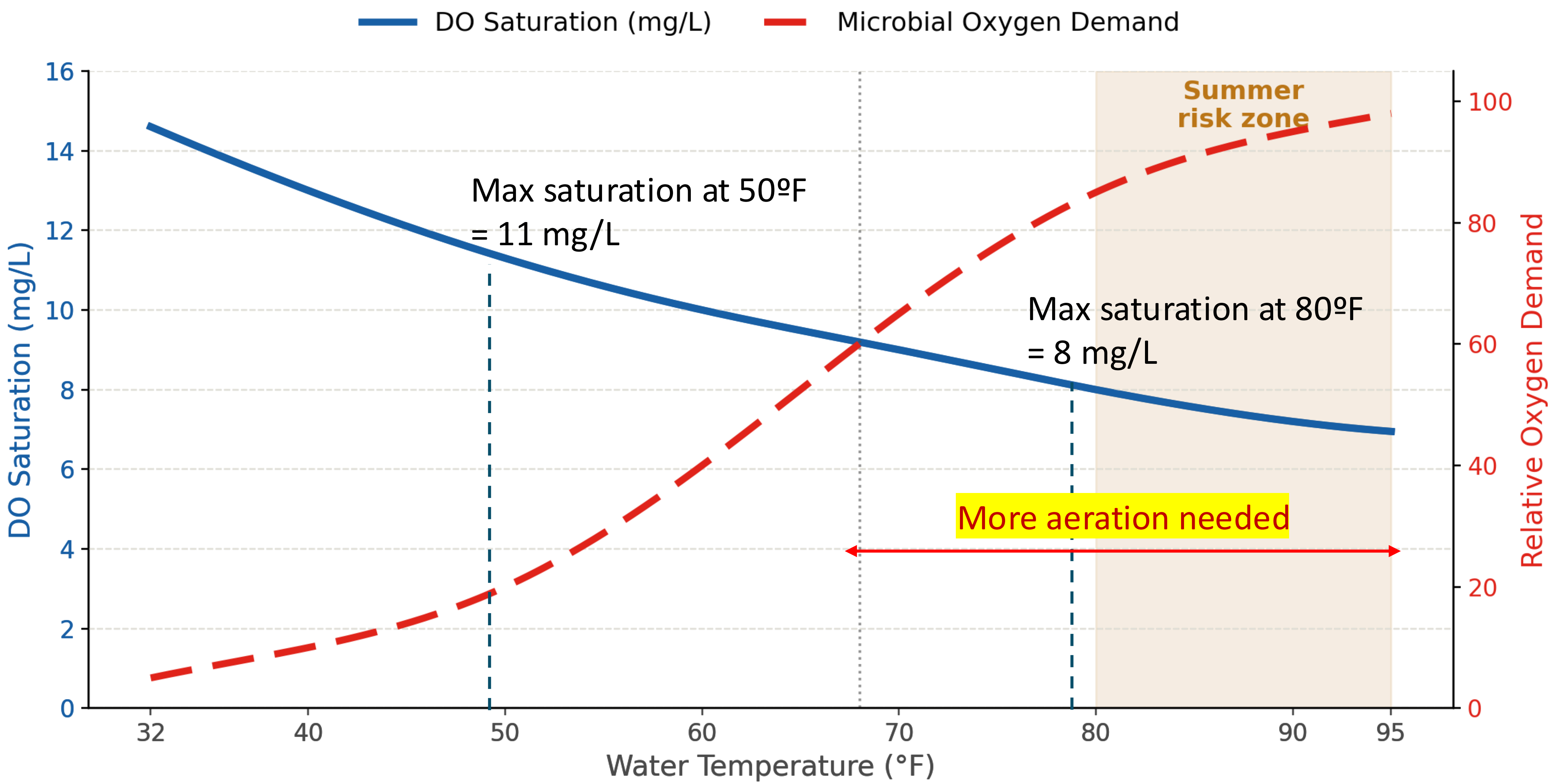
Increased Aeration

- ➢ During the summer, to support BOD metabolism
- ➢ During the transition from cold to warm
- ➢ To protect against releases from rising sludge

The impact of temperature on D.O. saturation

As water temperature rises, its physical capacity to hold dissolved oxygen drops.

(Oxygen saturation: Laboratory Conditions. **Oxygen Demand:** Conceptual

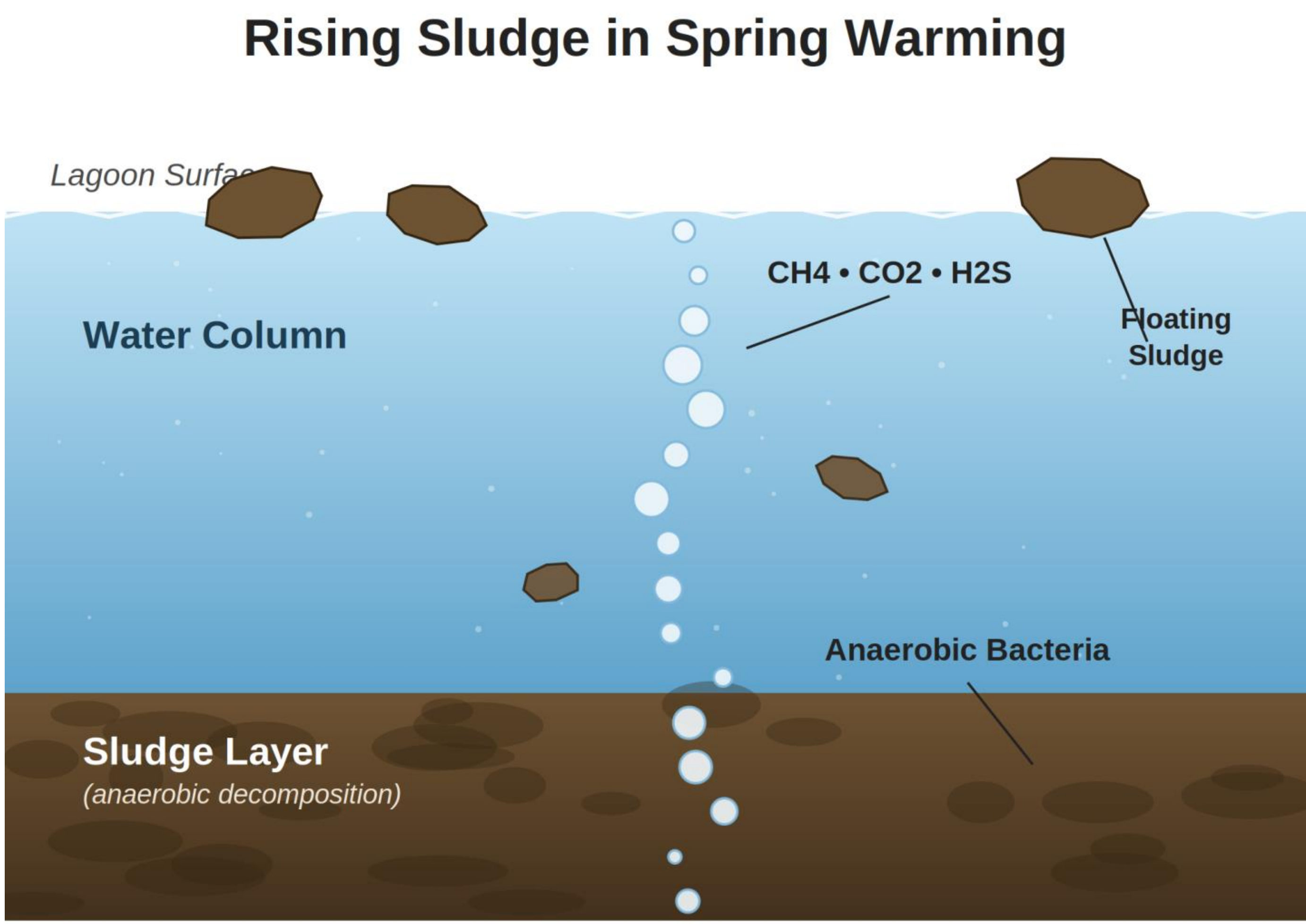


Rising sludge

- Anaerobic bacteria become active in sludge when temperatures climb into the 50s°F and begin digesting organic matter.
- Gases, including Methane (CH_4), Carbon Dioxide (CO_2), & Hydrogen Sulfide (H_2S), become trapped in the sludge, causing it to rise.
- **Warning signs**: Bubbles, drop in pH & DO

Problems Caused

- ➢ Increased Oxygen demand and odors
- ➢ Release of BOD, TSS, ammonia, and phosphorus from sludge
- ➢ Acidic pH disrupts microorganism activity



Operators can combat a rising sludge event by increasing aeration. The best prevention is to maintain sludge levels below 25% of the lagoon depth.

Turnover

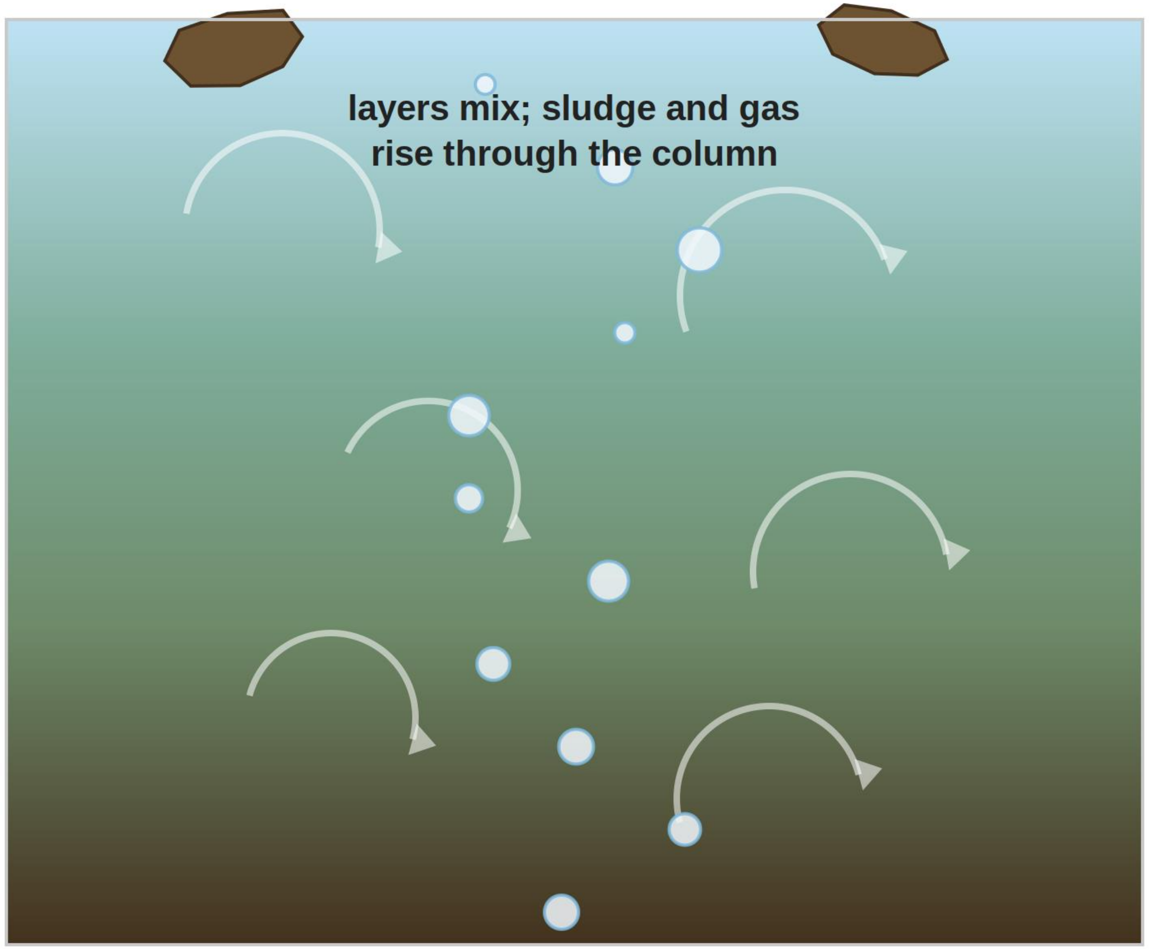
Facultative lagoons depend on three functional layers stratified by temperature (denser, colder water on the bottom).

When the upper layer cools, it can become denser and sink, leading to mixing of sludge throughout the lagoon.

Solutions

- Monitor the lagoon's temperature at different depths during seasonal temperature changes.
- The use of hydraulic mixers is recommended to prevent turnover when temperatures indicate it could occur.

Destratification (Spring Turnover)



Once the gradient narrows enough, wind-driven mixing overcomes it.

Mixing

Floating mixers move large volumes of water to circulate DO and prevent stratification. Mixing can be horizontal or vertical

How is BOD measured? BOD testing

DO is measured at the start and end of a 5-day testing period.

A wastewater sample is added to oxygen saturated water that contains essential minerals and a pH buffer.

Incubated at 20°C (68°F) for 5 days (no light source)

2 mL to 20 mL sample of wastewater

Essential minerals and neutral pH buffer.

Oxygenated distilled or deionized water (280mL to 298 mL)

300 mL BOD sample bottle

Calculating BOD from test results

In a 300 mL BOD influent sample, the wastewater portion was 5.0 mL. Starting DO was 8.3 mg/L. Final DO was 4.8 mg/L. Find the concentration of BOD in mg/L

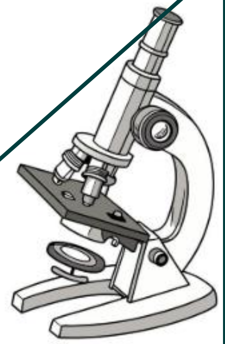
$$\textbf{BOD mg/L} = \frac{\textbf{Start DO – Final DO}}{\textbf{P Value}}$$

Step 1: Find P (dilution proportion)

$$P = \frac{\text{wastewater sample volume}}{\text{total sample volume}} = \frac{5.0\text{ mL}}{300\text{mL}} = \mathbf{0.0167}$$

Step 2: Calculate BOD concentration in mg/L

$$\frac{8.3\text{ mg/L} - 4.8\text{ mg/L}}{0.0167} = \mathbf{209.6\text{ mg/L}}$$



5 mL WW portion
Start DO: 8.3 mg/L
End DO: 4.8 mg/L

Range for Measuring BOD of Cell 1 and Final Effluent

Cell 1 Effluent Range

Cell 1 Effluent Range	
Wastewater Volume Used	Dilution Factor
100 mL	3x
50 mL	6x
20 mL	15x
10 mL	30x
Blank (0 mL)	0x

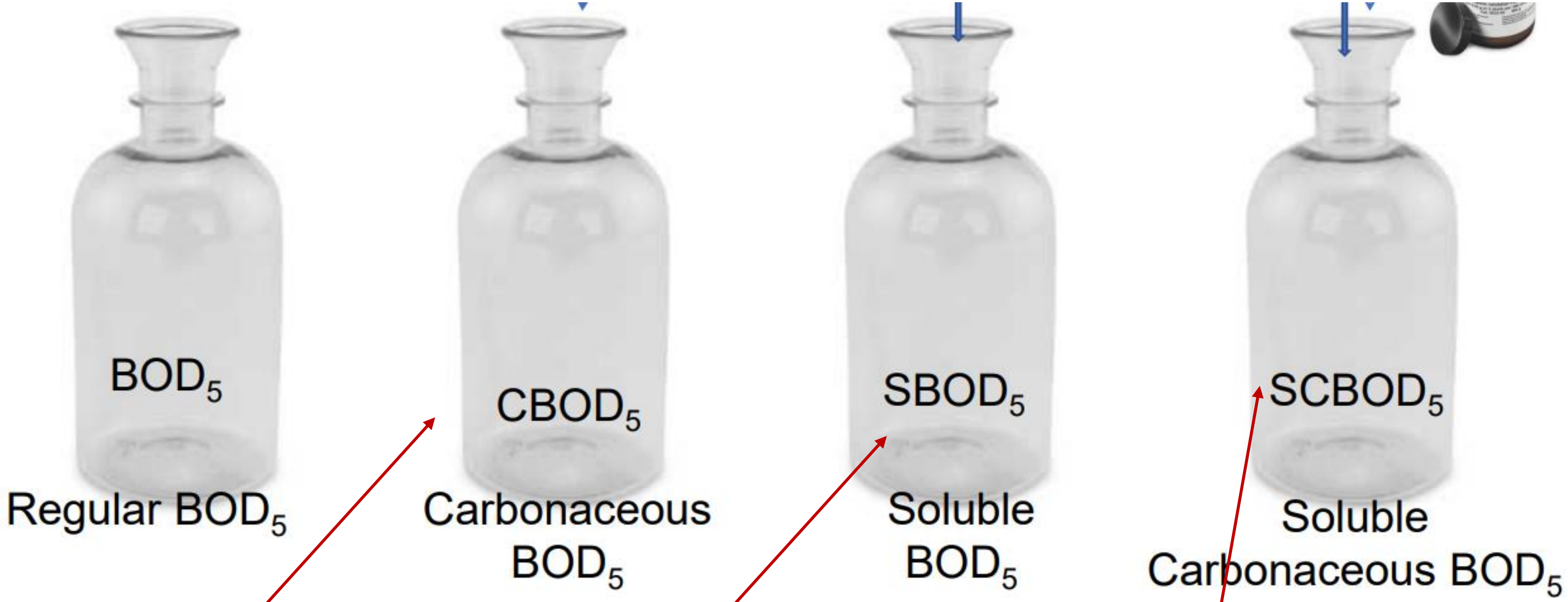
Cell 1 is expected to remove from 60 to 80% of BOD (Typical BOD from 30 to 90 mg/L)

Final Effluent Range

Final Effluent Range	
Wastewater Volume Used	Dilution Factor
300 mL (Straight)	1x (No Dilution)
200 mL	1.5x
100 mL	3x
50 mL	6x
Blank (0 mL)	*Control*

Final Effluent BOD is expected to be very low (5 to 20 mg/L)

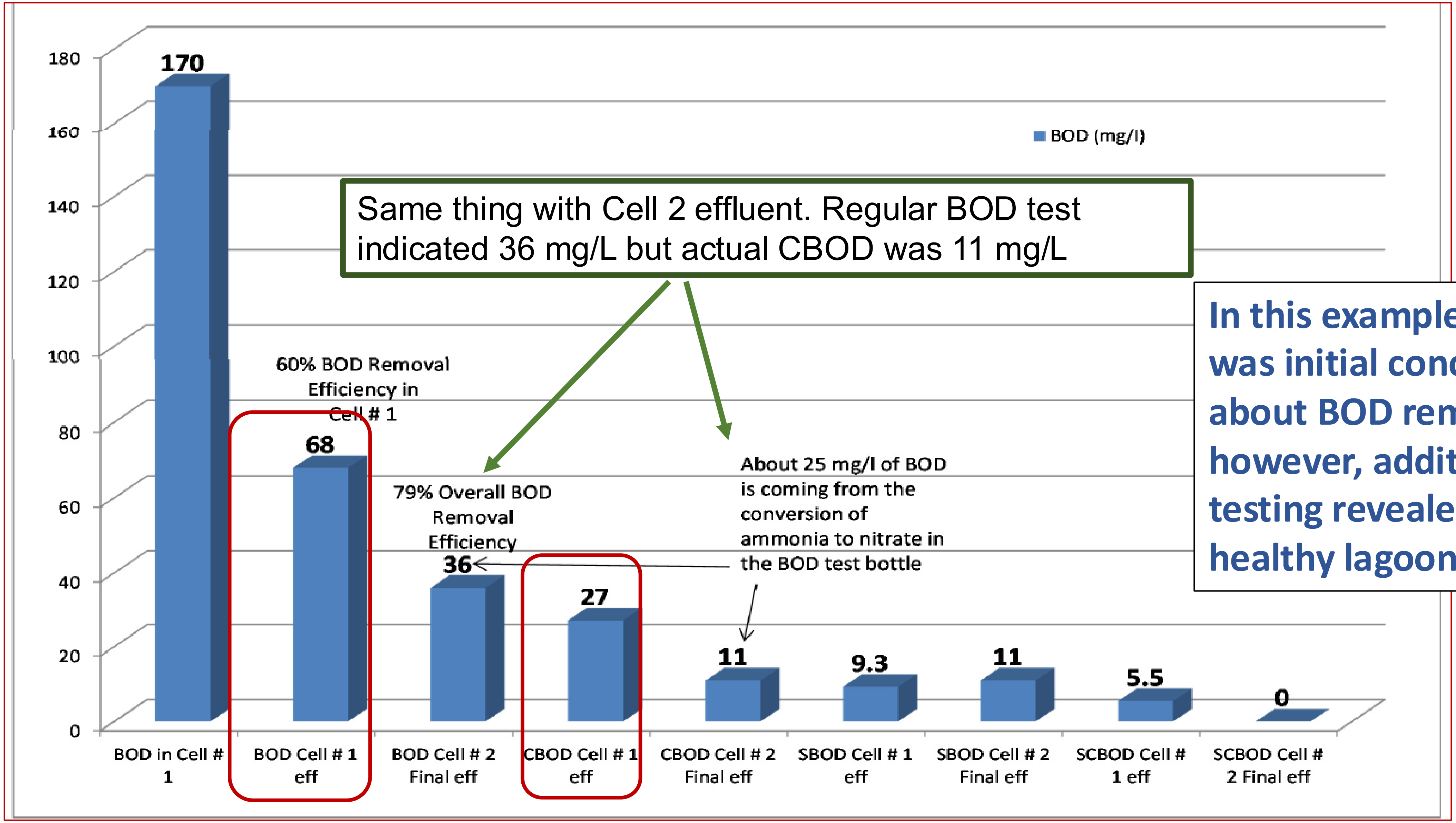
Types of BOD Tests (diagnostic)



Eliminates the effects of nitrification in the BOD test bottle (nitrification inhibitor added)

Eliminates the effects of algae particles by filtering

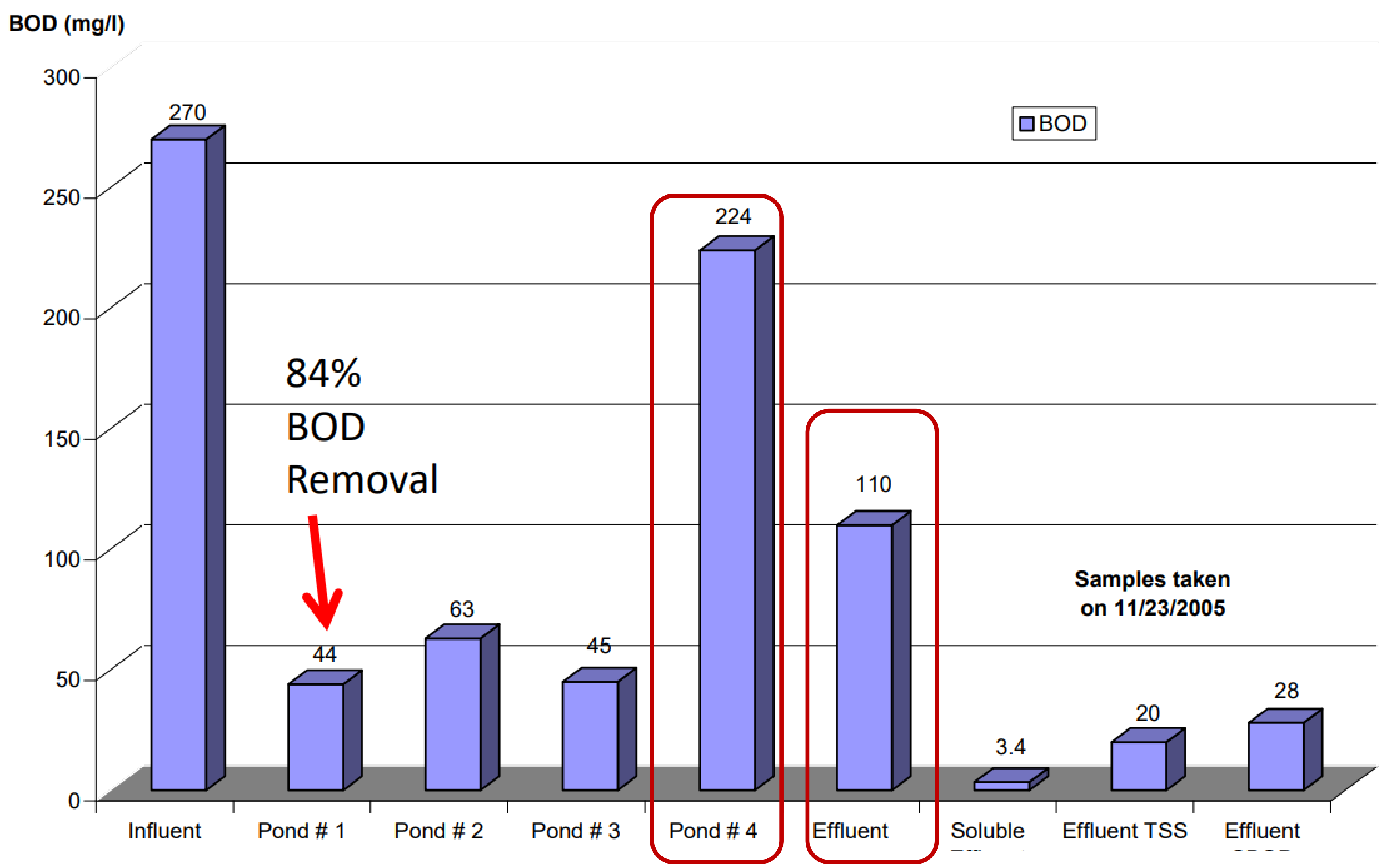
Eliminates the effects of sludge feedback by filtering and nitrification inhibitor



In this example, there was initial concern about BOD removal; however, additional testing revealed a healthy lagoon system

The regular BOD test showed the Cell 1 effluent at 68 mg/L. But CBOD eliminated nitrification occurring in the bottle and revealed BOD had been reduced to 27 mg/L

Operators can request that compliance be based on CBOD



In this example, effluent BOD was very high at 110 mg/L. Further investigation revealed that pond cell 1 had an 84% removal rate and that BOD was spiking in cell 4. A soluble (SBOD) test indicated algae was the problem.

Problems from Algae blooms

Increases BOD and TSS: Each mg of algal TSS results in about 0.5 mg of BOD. Most effluent TSS and BOD is caused by algae

Low DO: Algal die-offs deplete oxygen, leading to low dissolved oxygen (DO) conditions.

Nutrient feedback: Algae take up ammonia and phosphorus into their cells and then release it back into the water column as they die off.

Increased Sludge: As algal blooms die off, they sink to the bottom and accumulate as sludge.

Natural Solutions for Algae Problems

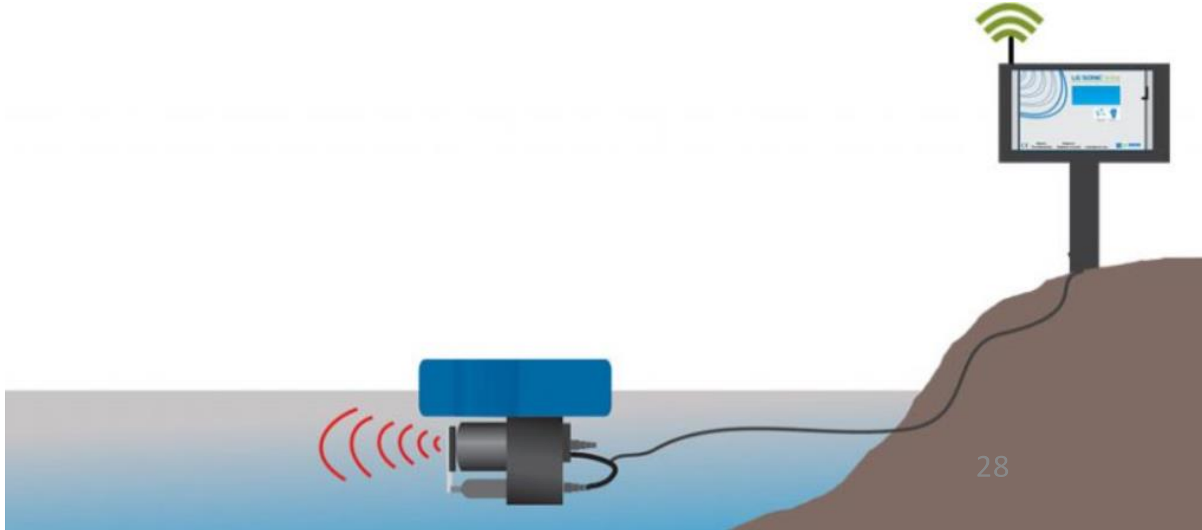
Floating mats of Barley straw inhibit algae growth.

Shading blocks sunlight and prevents photosynthesis and eliminates algae

Installing baffles improves mixing and eliminates stagnant water, reducing algae growth

Ultrasonic Algae Control

- High-frequency sound waves disrupt the buoyancy of algal cells and inhibit growth
- Reduces algal concentrations by 70% to 90% in wastewater lagoons and improves effluent BOD and TSS



Duckweed

Duckweed identification: individual petals that separate.

Duckweed Problems

- When it dies off, it can release nutrients that trigger algae blooms.
- Contributes to additional BOD and sludge accumulation.

Physical removal

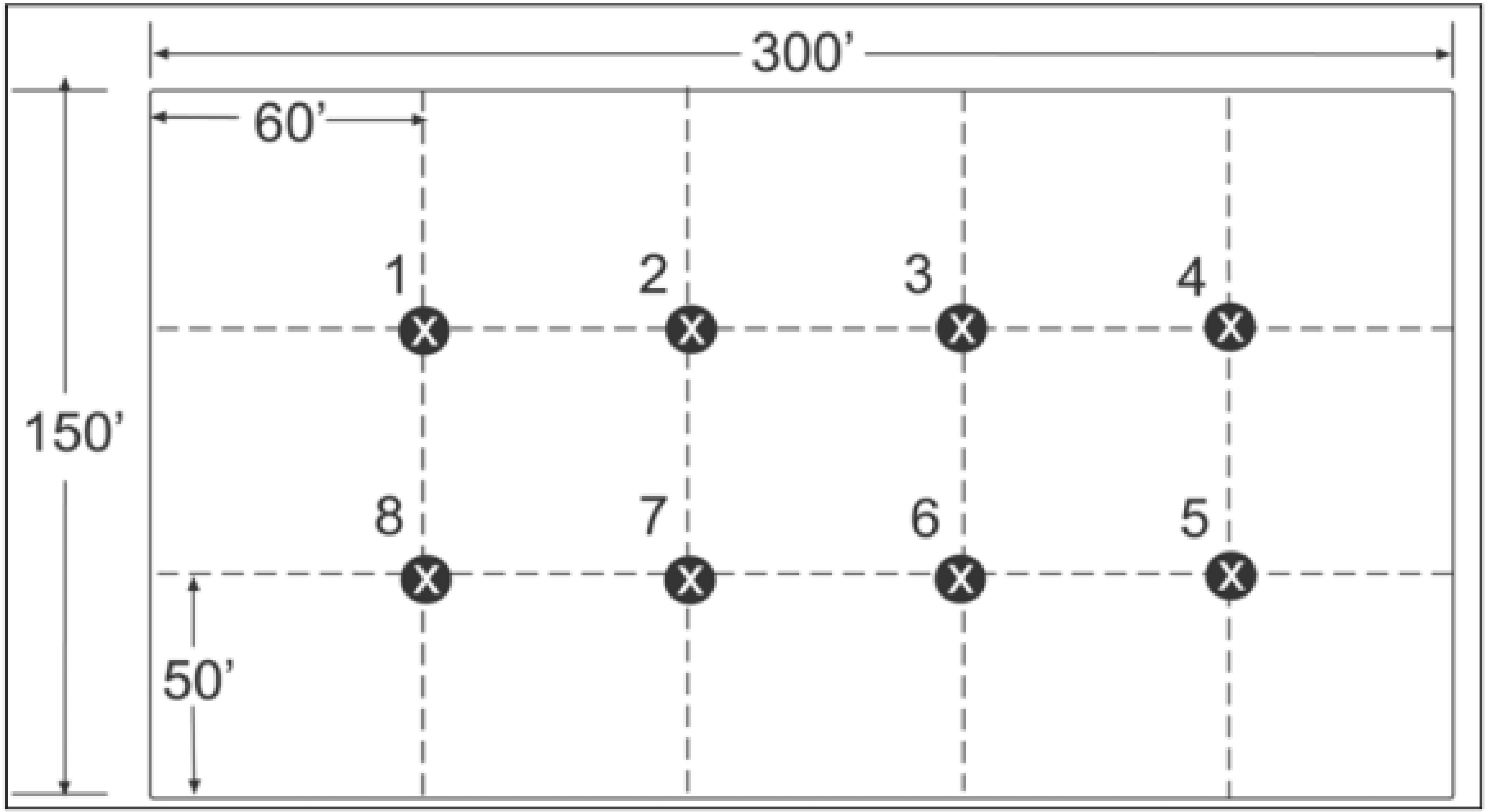
Water pump with a surface skimmer fitting or manual removal with a pool skimmer when the wind drives it to the pond edge.

Preventing regrowth

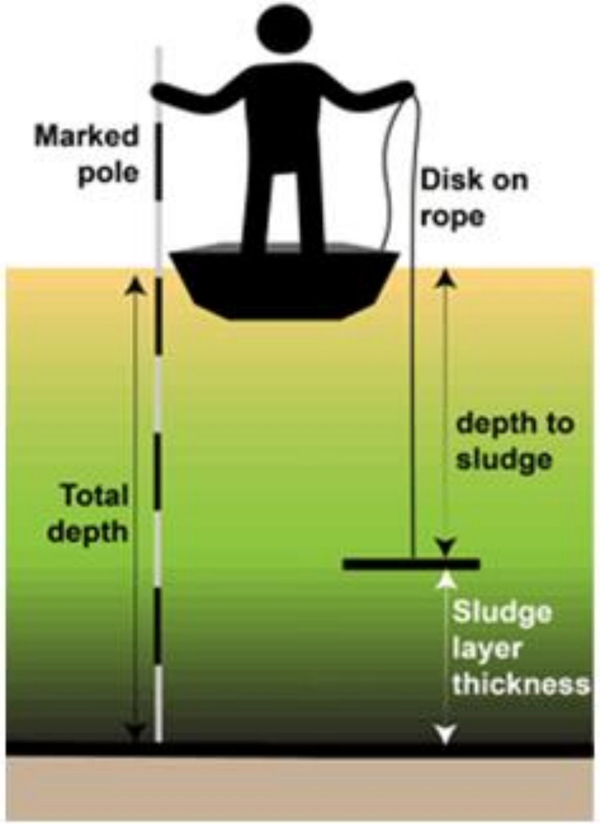
- Increased mixing and aeration
- Shading

Conducting a Sludge Survey

Sludge can build up over time as a natural result of settling. Excessive sludge, however, can result from organic overloading, algae, and incomplete treatment due to low DO, short-circuiting, and inadequate mixing.



Sample layout grid for a 150 ft x 300 ft lagoon that identifies sample points where sludge depth will be measured.



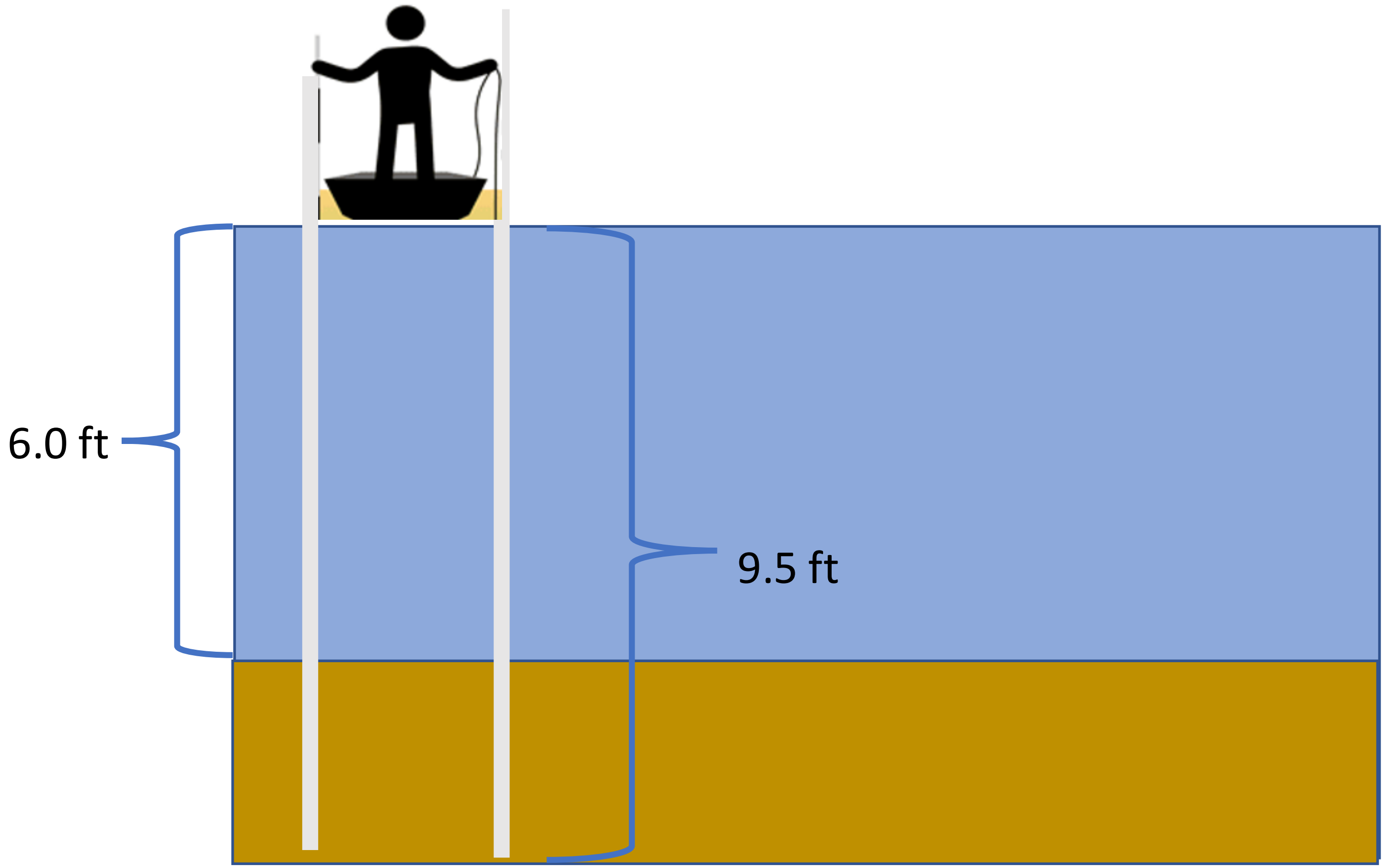
Depth to sludge is subtracted from total depth

Evaluating Sludge Depth

- The depth to sludge is subtracted from the total depth.
- The maximum allowable sludge layer is 25% of the total lagoon depth

Problems
- Rising sludge
- Short-circuiting
- Loss of Retention Time
- Release of BOD and nutrients

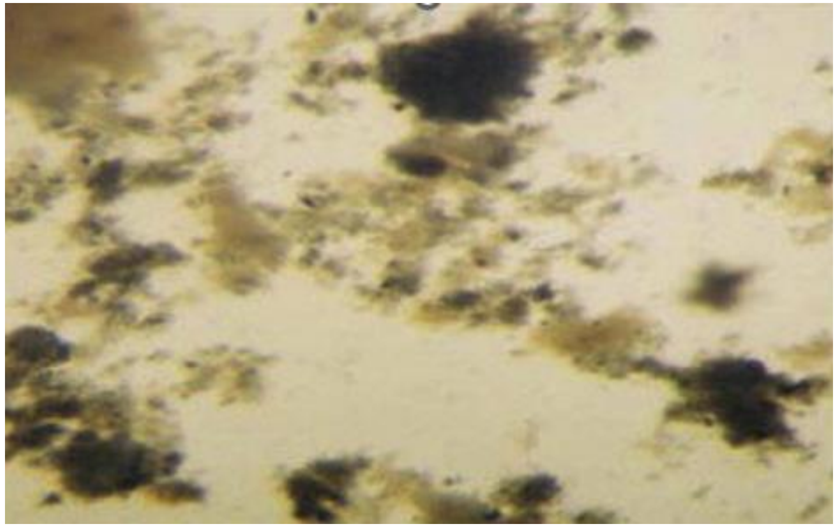
Solutions:
- Mechanical Dredging
- Gentle mixing to reduce through biological treatment



Sludge depth = 9.5 ft – 6.0 ft = **3.5 feet**

$\frac{3.5}{9.5}$ x 100% = **36.8%**

Effects of sludge accumulation



Old sludge and bacterial floc in the final effluent indicate potential high sludge levels and organic overloading

Filamentous bacteria indicate low DO or septicity, likely associated with excess sludge.

High sludge levels impair BOD removal in multiple ways

- reduces retention time
- Adds BOD and nutrients
- Creates additional oxygen demand.

TSS to BOD Ratio in Final Effluent

Easily found from lab effluent testing results. Normal proportion is 1.5.

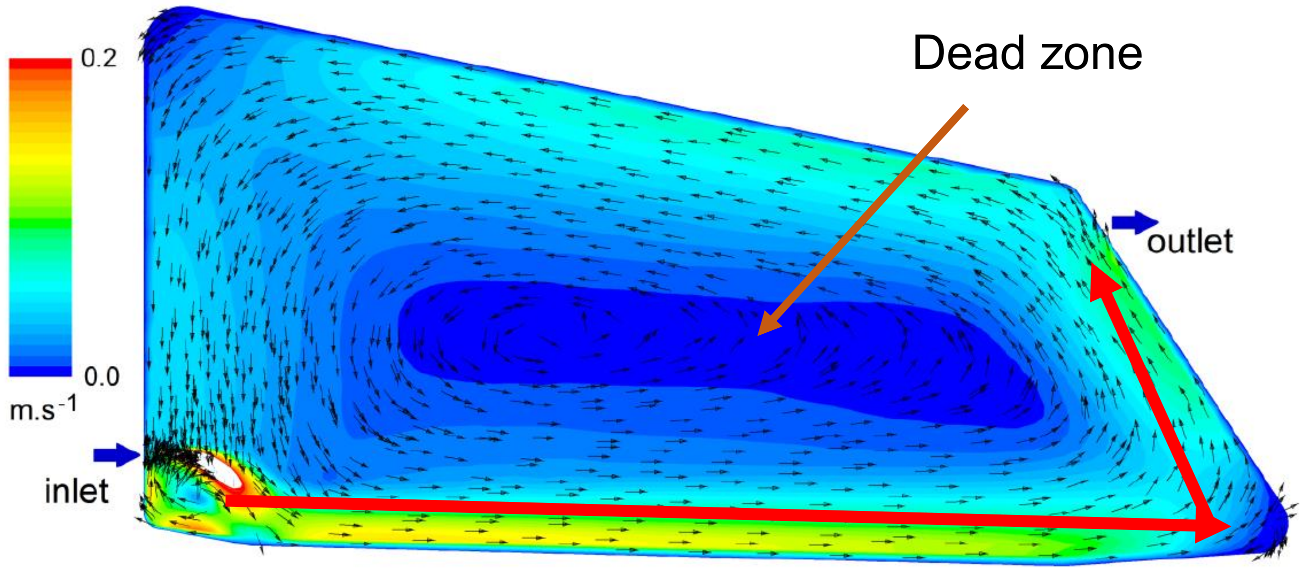
Example: If TSS is 30 mg/L and BOD is 20 mg/L, then $\frac{TSS}{BOD} = \frac{30}{20} = \mathbf{1.5}$

	TSS: BOD Ratio	Cause	Possible Solutions
Extra BOD released from sludge	Less than 1.0	**Old sludge releasing soluble BOD.**	Sludge mixing to reduce VSS content of sludge.
Lack of retention time to treat BOD	Equal to 1.0	Incomplete treatment due to **short-circuiting**	Baffling to decrease short circuiting. Reduce excess sludge.
	1.5	**Normal** lagoon treatment	
Extra TSS from algae blooms	2.0 to 3.0	**Algal overgrowth**	Aeration and mixing.

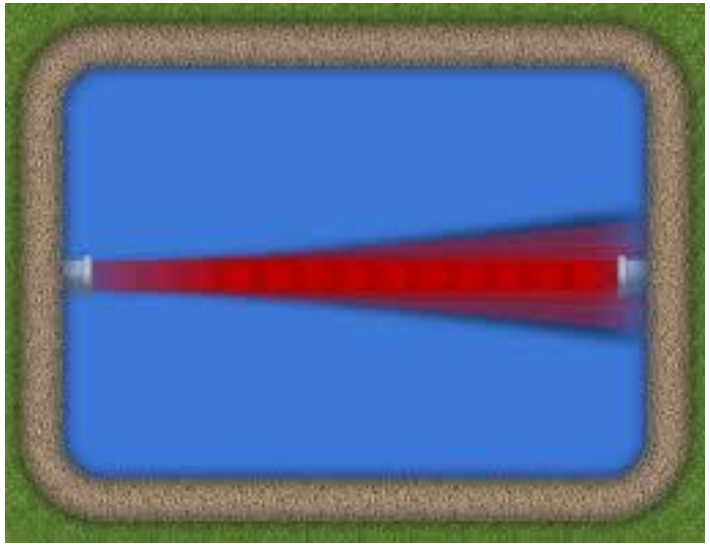
Short circuiting

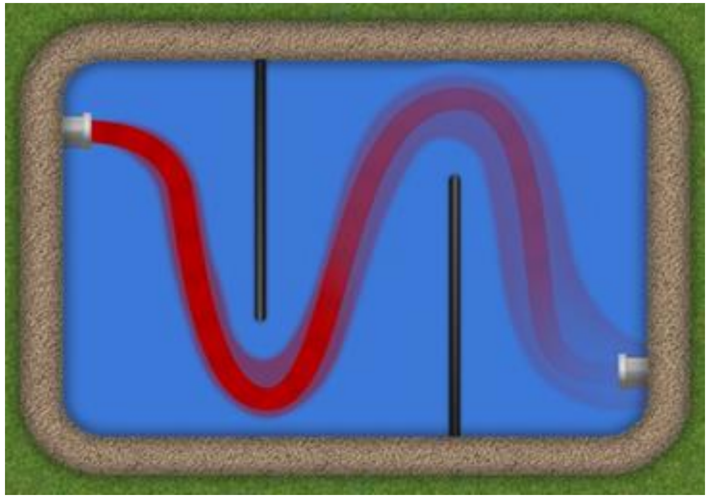
A portion of the wastewater flow passes through the lagoon too quickly without adequate treatment.

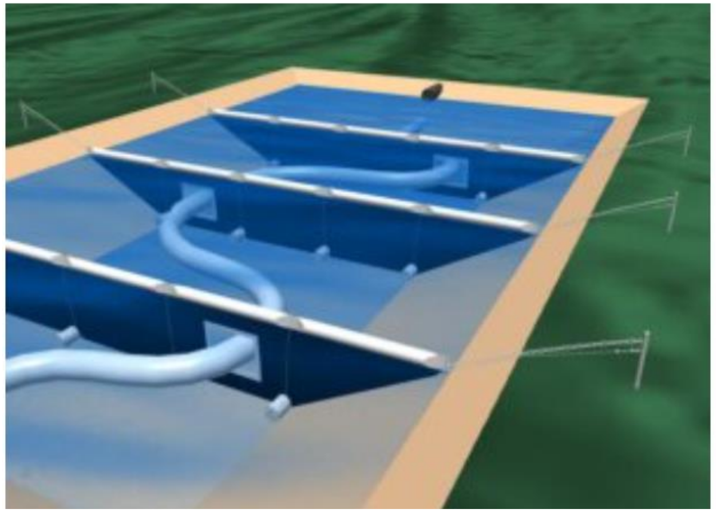
- Lack of mixing or baffling to direct flow
- Channels formed from sludge accumulations
- High velocity water vectors

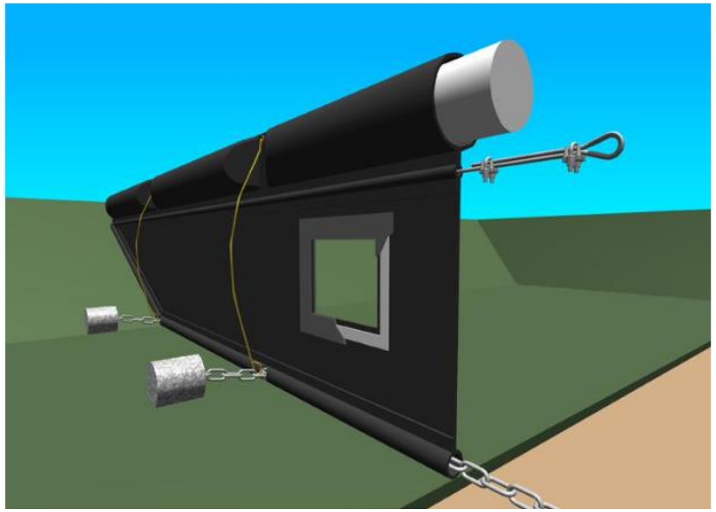


Model of flow velocity in a lagoon

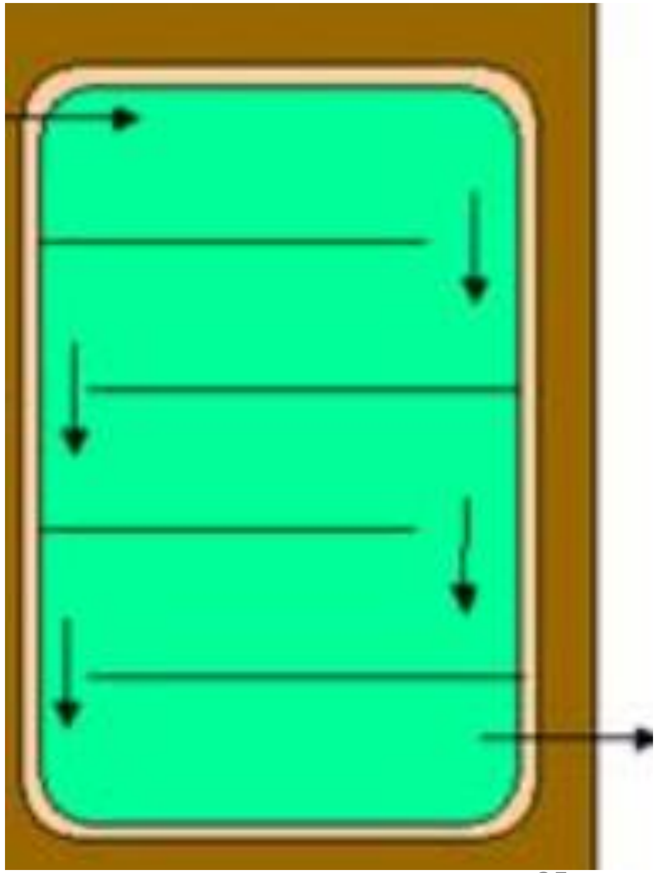








Curtain baffles can be installed to eliminate short-circuiting by directing flow in a serpentine fashion



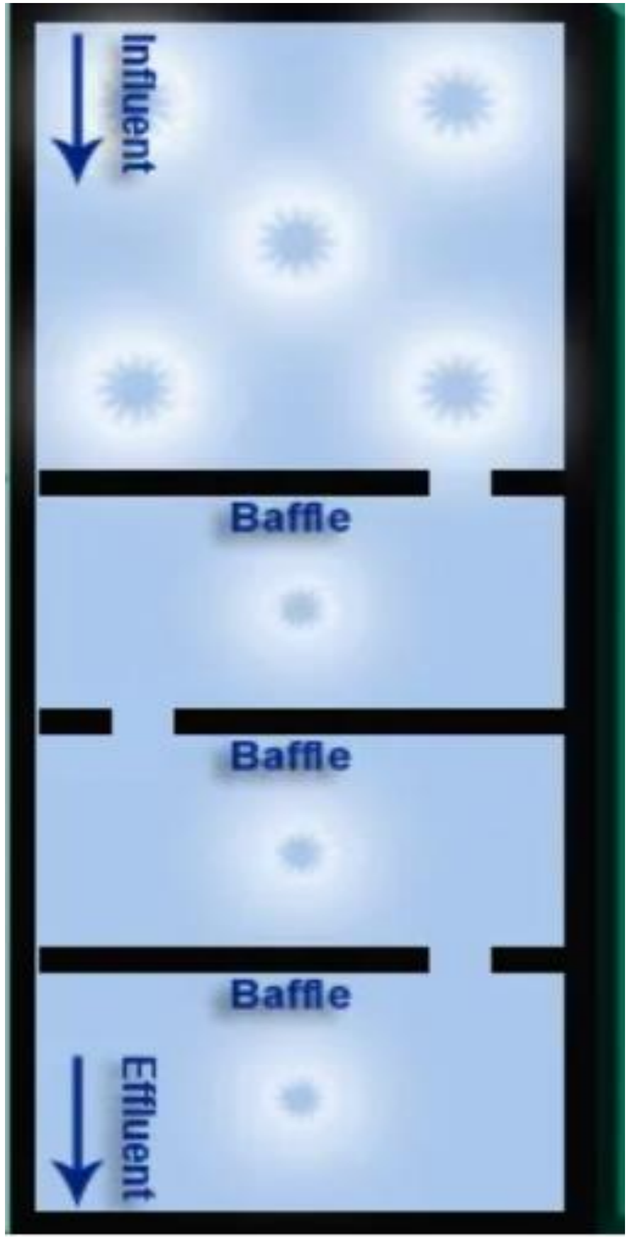
Key Take-aways

Optimize BOD removal

- Eliminate short circuiting (add baffling)
- Ensure optimal DO levels (2 – 3 mg/L)
- Maintain sludge levels below 25% of depth

Evaluate Performance

- BOD tests between cells
- Analyze effluent TSS to BOD ratios



Essential Resources to Learn More

USEPA (2011) Principles of Design and Operation of Wastewater Treatment Pond Systems for Plant Operators, Engineers, and Managers. https://www.epa.gov/sites/default/files/2014-09/documents/lagoon-pond-treatment-2011.pdf

Harris, S. (2020). Aerated Wastewater Lagoon Troubleshooting (slides). https://www.epa.gov/sites/default/files/2020-09/documents/aeratedwwwebinar-slides.pdf

USEPA (2022). Compliance Tips for Small Wastewater Treatment Lagoons with Clean Water Act Discharge Permits. https://www.epa.gov/system/files/documents/2022-03/lagoon-complianceadvisory.pdf

USEPA (2026). Lagoon Wastewater Treatment Systems (official Lagoonspage). https://www.epa.gov/small-and-rural-wastewater-systems/lagoon-wastewater-treatment-systems

USEPA (2024). Troubleshooting Manual for Small, Facultative, Partial-Mix Aerated, and Complete-Mix Aerated Wastewater Lagoons. https://www.epa.gov/system/files/documents/2024-02/lagoon-troubleshooting-manual.pdf

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Mississippi Water Resources Research Institute

Website: https://www.wrri.msstate.edu/

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Environmental Finance Center Network

Website: https://efcnetwork.org/

- Request Technical Assistance
- Funding tables, tools
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EFCN environmental finance center network