Introduction to Aeration and Energy for Lagoons

October 26, 2021

SEDAC
SMART ENERGY DESIGN ASSISTANCE CENTER

Providing effective energy strategies for buildings and communities

ILLINOIS ENVIRONMENTAL PROTECTION AGENCY

ILLINOIS SUSTAINABLE TECHNOLOGY CENTER
PRAIRIE RESEARCH INSTITUTE

Who We Are

We assist buildings and communities in achieving energy efficiency, saving money, and becoming more sustainable.

We are an applied research program at University of Illinois.

Our goal: Reduce the energy footprint of Illinois and beyond.

ILLINOIS ENVIRONMENTAL PROTECTION AGENCY

ILLINOIS SUSTAINABLE TECHNOLOGY CENTER
PRAIRIE RESEARCH INSTITUTE

SEDAC
SMART ENERGY DESIGN ASSISTANCE CENTER

About the IEPA PWI Energy Efficiency Program

The Illinois EPA Public Water Infrastructure Energy Assessment Program helps municipalities reduce the cost of water and wastewater treatment.

- FREE energy assessments and technical assistance
- Comprehensive report listing:
  - Cost of upgrades
  - Estimated payback period
  - Any applicable incentives or funding opportunities
- Operator continuing education

Apply at: www.sedac.org/water

Funding provided in whole or in part by the Illinois EPA Office of Energy. This program is in partnership with the U.S. Dept. of Energy Sustainable Wastewater Infrastructure of the Future (SWIFT) Accelerator for energy efficiency in wastewater treatment.

ILLINOIS ENVIRONMENTAL PROTECTION AGENCY

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

ILLINOIS SUSTAINABLE TECHNOLOGY CENTER
PRAIRIE RESEARCH INSTITUTE

SEDAC
SMART ENERGY DESIGN ASSISTANCE CENTER

Why Complete an Energy Assessment?

Older Existing System or No Previous Assessments?

Identify missed opportunities

Plan for capital improvements

Uncover what is possible

3rd party support for WWTP personnel's ideas

New or Recently Upgraded?

Always more to improve

Plan for future opportunities outside the scope of recent projects

New technologies and processes always in development

Identify opportunities for repairs or upgrades and associated funding!

ILLINOIS ENVIRONMENTAL PROTECTION AGENCY

ILLINOIS SUSTAINABLE TECHNOLOGY CENTER
PRAIRIE RESEARCH INSTITUTE

SEDAC
SMART ENERGY DESIGN ASSISTANCE CENTER

Apply for an Energy Assessment!

Step 1: Initial Application – Pre-Qualification

- Apply at www.sedac.org/water
- Be located in Illinois and be a publicly-owned plant
- Allow SEDAC/ISTC to visit site – Remote visit is an option!
- Be willing to share facility information
- Share final assessment report with Illinois EPA

Step 2: Data Collection

- Facility information –discharge reports, process flow, etc.
- 2 years of utility bills and DMRs
- We're here to assist!

Step 3: Site Visit Scheduled

ILLINOIS ENVIRONMENTAL PROTECTION AGENCY

ILLINOIS SUSTAINABLE TECHNOLOGY CENTER
PRAIRIE RESEARCH INSTITUTE

SEDAC
SMART ENERGY DESIGN ASSISTANCE CENTER

Webinar Outline

Part 1 - Why Do We Aerate?

Part 2 - How Do We Aerate?

Part 3 - How Do We Control Aeration?

ILLINOIS ENVIRONMENTAL PROTECTION AGENCY

ILLINOIS SUSTAINABLE TECHNOLOGY CENTER
PRAIRIE RESEARCH INSTITUTE

SEDAC
SMART ENERGY DESIGN ASSISTANCE CENTER

Why Do We Aerate?

ILLINOIS ENVIRONMENTAL PROTECTION AGENCY

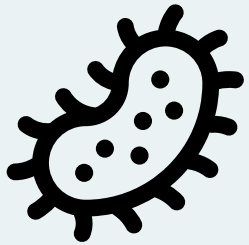
ILLINOIS SUSTAINABLE TECHNOLOGY CENTER
PRAIRIE RESEARCH INSTITUTE

SEDAC
SMART ENERGY DESIGN ASSISTANCE CENTER

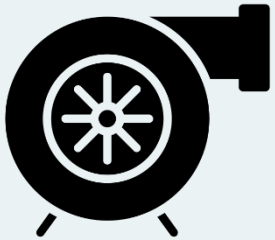
Aeration - Big Picture

Carbon and ammonia are in wastewater from **human activities**.

Biological Oxygen Demand (BOD): **microbes need oxygen** to break down contamination.



Wastewater systems **provide oxygen** to supply the required BOD.



Blower by ProSymbols from the Noun Project

ILLINOIS ENVIRONMENTAL PROTECTION AGENCY

ILLINOIS SUSTAINABLE TECHNOLOGY CENTER
PRAIRIE RESEARCH INSTITUTE

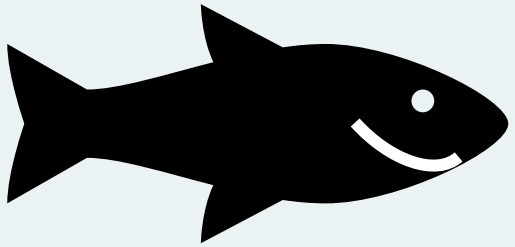
SEDAC
SMART ENERGY DESIGN ASSISTANCE CENTER

BOD_5 Big Picture

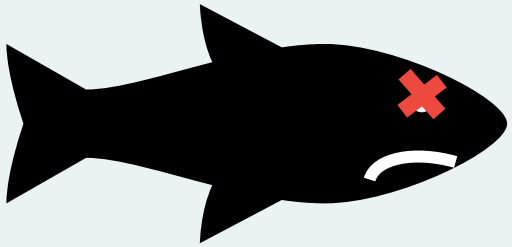
Biological Oxygen Demand (BOD) test conducted over 5 days to model natural uptake of BOD in streams.

Designed to measure typical nutrient ratios in wastewater through microbe activity

(Other tests, such as CBOD, can control for other factors)



DO = 6 mg/L



DO = 1 mg/L

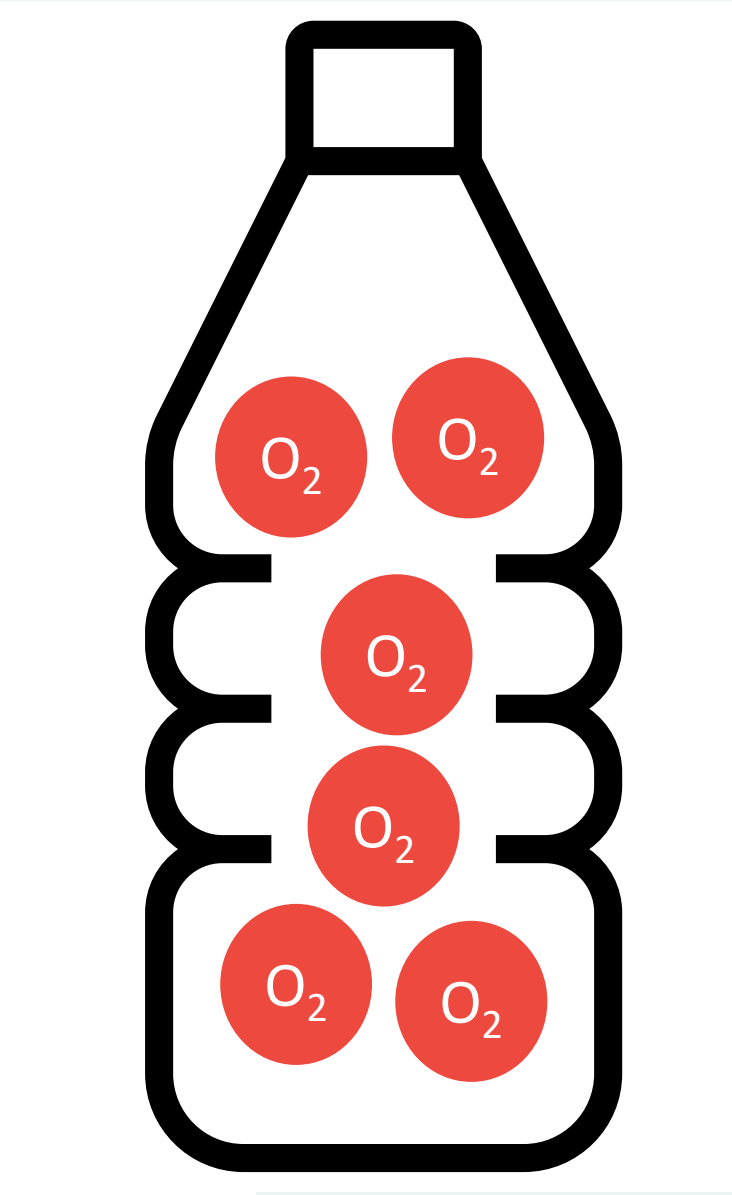
Converting Concentration to Weight:

Concentration (mg/l) x volume flow (million gallons) x 8.34 lbs/gallon = lbs of material

Dissolved Oxygen (DO)

Dissolved Oxygen (DO)

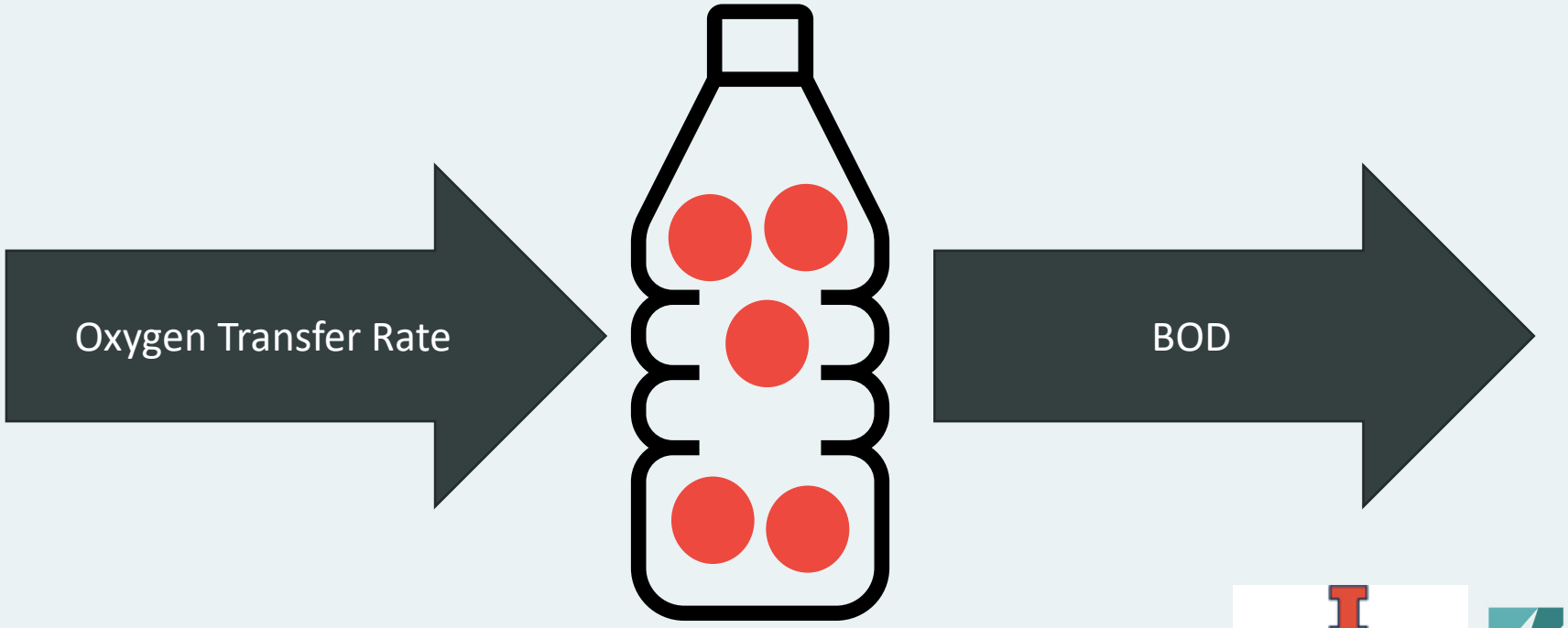
- Measured in milligrams of free oxygen molecules per liter of water
- This is a concentration at a moment in time.



Oxygen Transfer Rate (OTR)

The rate at which a system is dissolving oxygen into water.

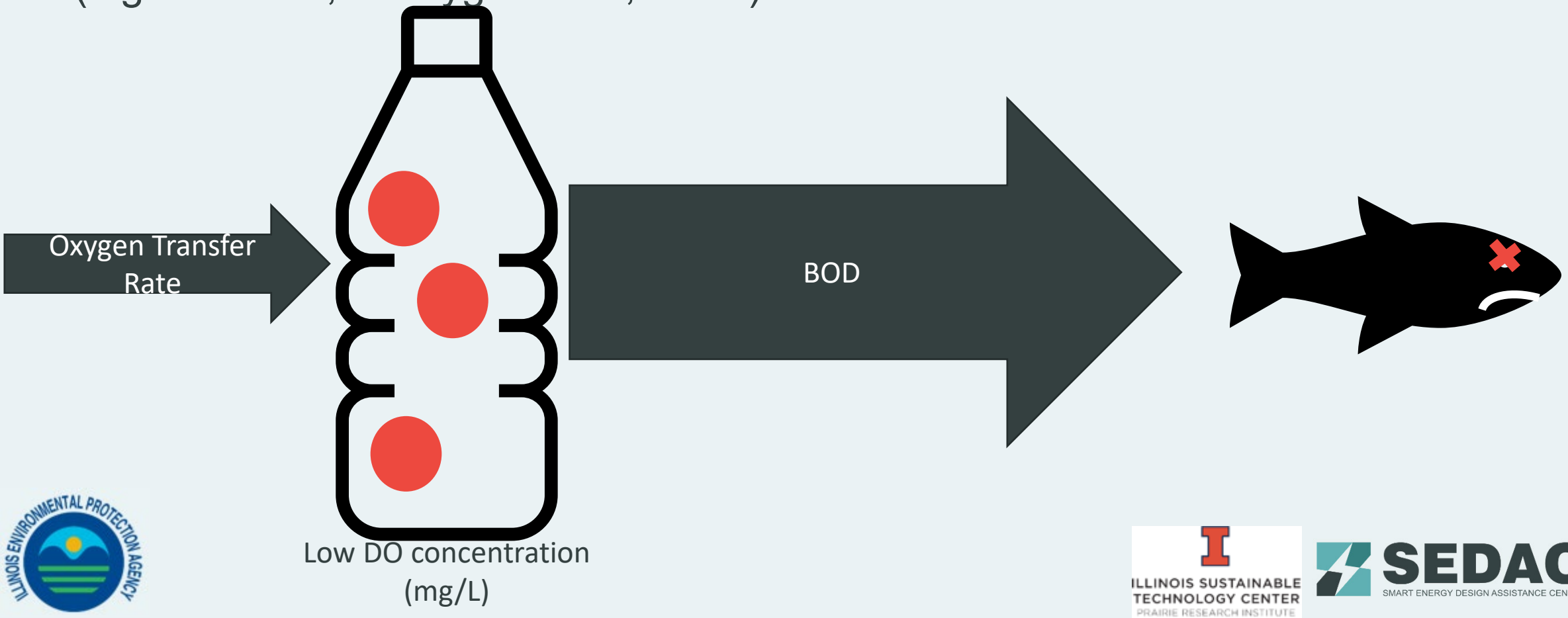
Must match the rate of removal to maintain a steady DO concentration!



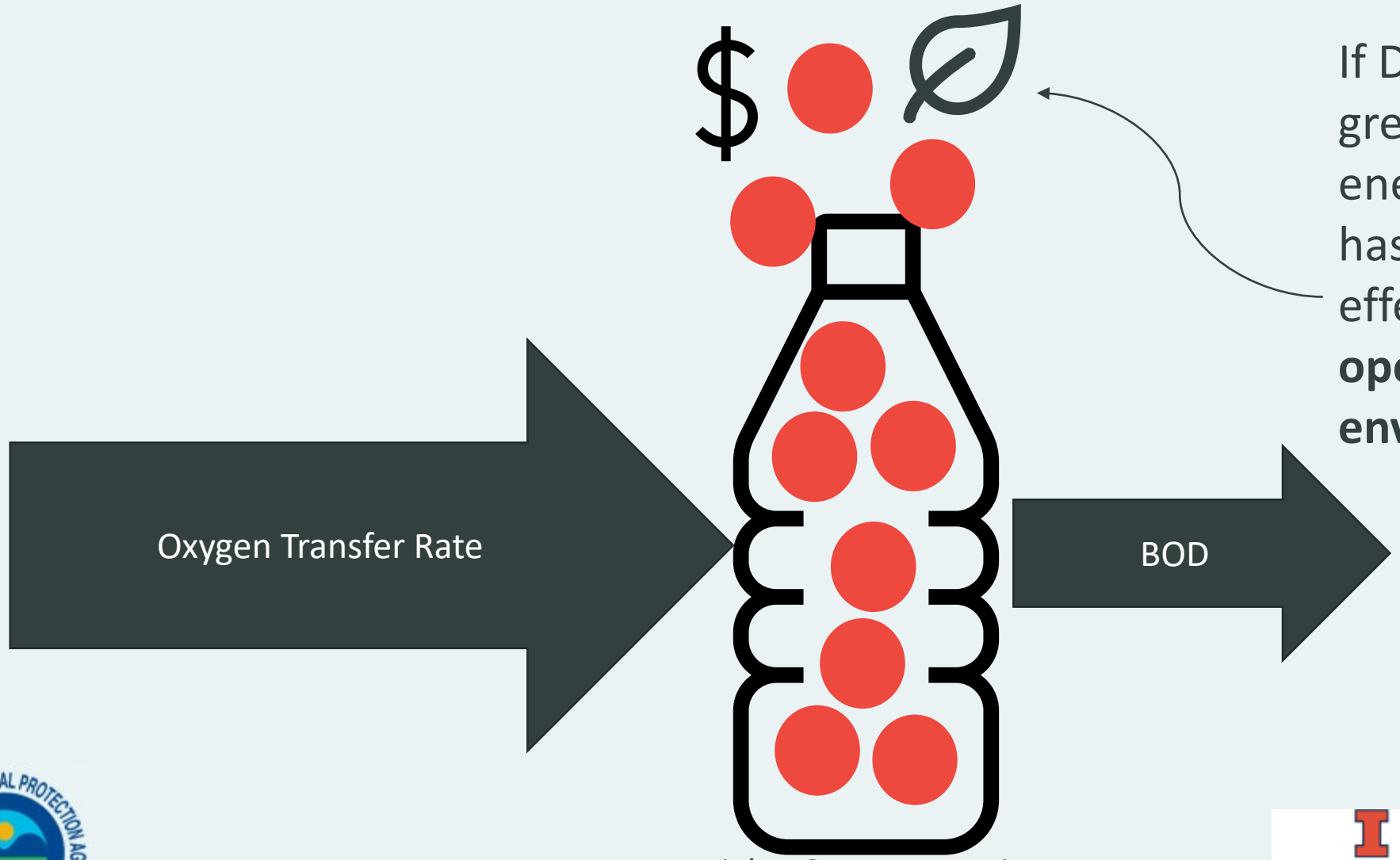
Target DO concentration (mg/L)

Oxygen Transfer Rate

If DO addition is less than BOD, the result can be downstream aquatic distress (algal blooms, deoxygenation, etc…).



Oxygen Transfer Rate

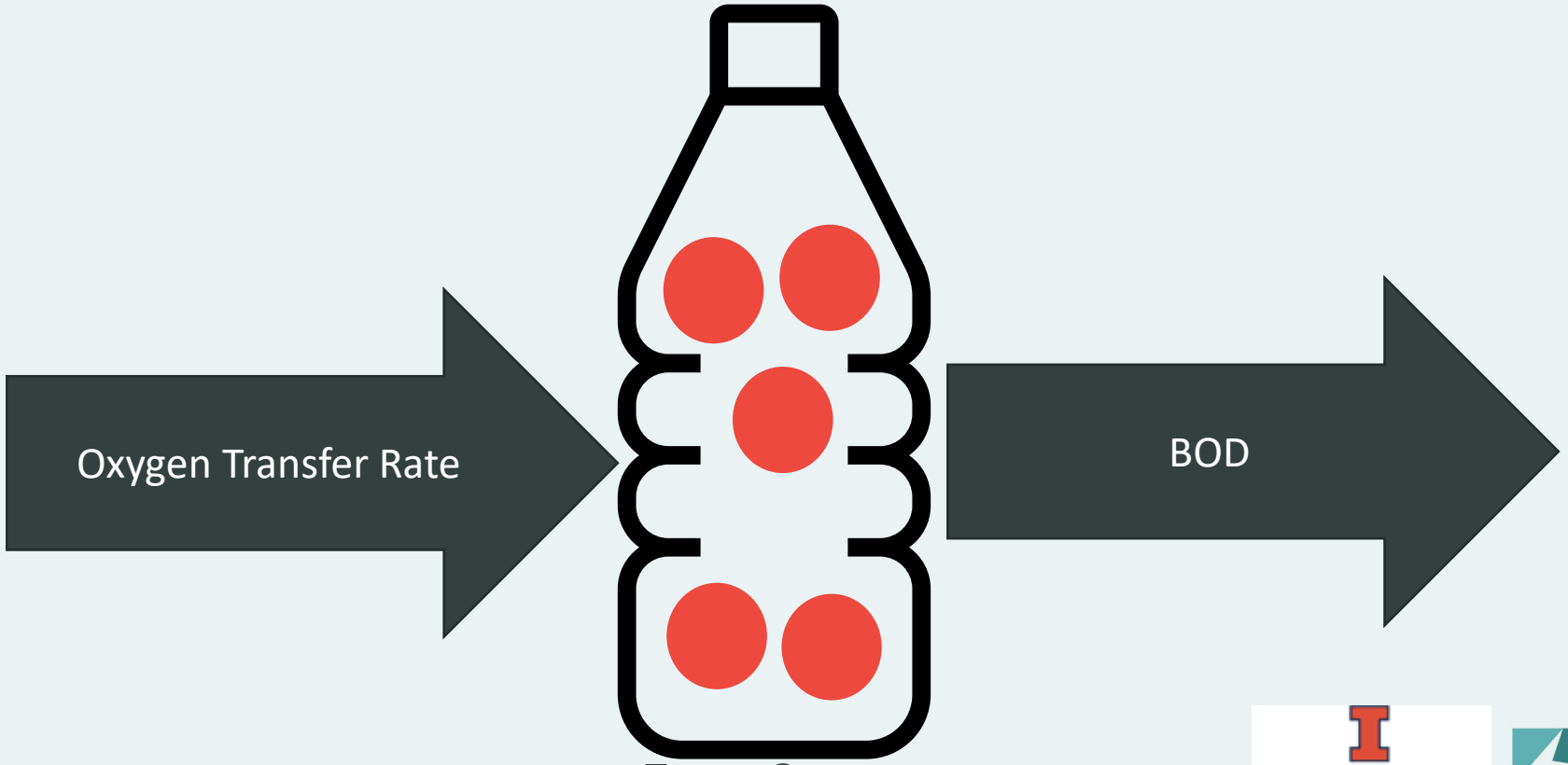


High DO concentration (mg/L)

If DO addition is greater than BOD, energy is wasted. This has a detrimental effect on the **cost of operation** and the **environment**.

Oxygen Transfer Rate

Balancing BOD and oxygen transfer rate to water is critical to minimizing facility costs while treating water effectively.



Target Oxygen concentration (mg/L)

Types of BOD Loading

CBOD - Carbonaceous BOD: 0.7-1.5 #O_2 / #CBOD

NBOD - Nitrogenous BOD: 4.6 #O_2 / #NBOD

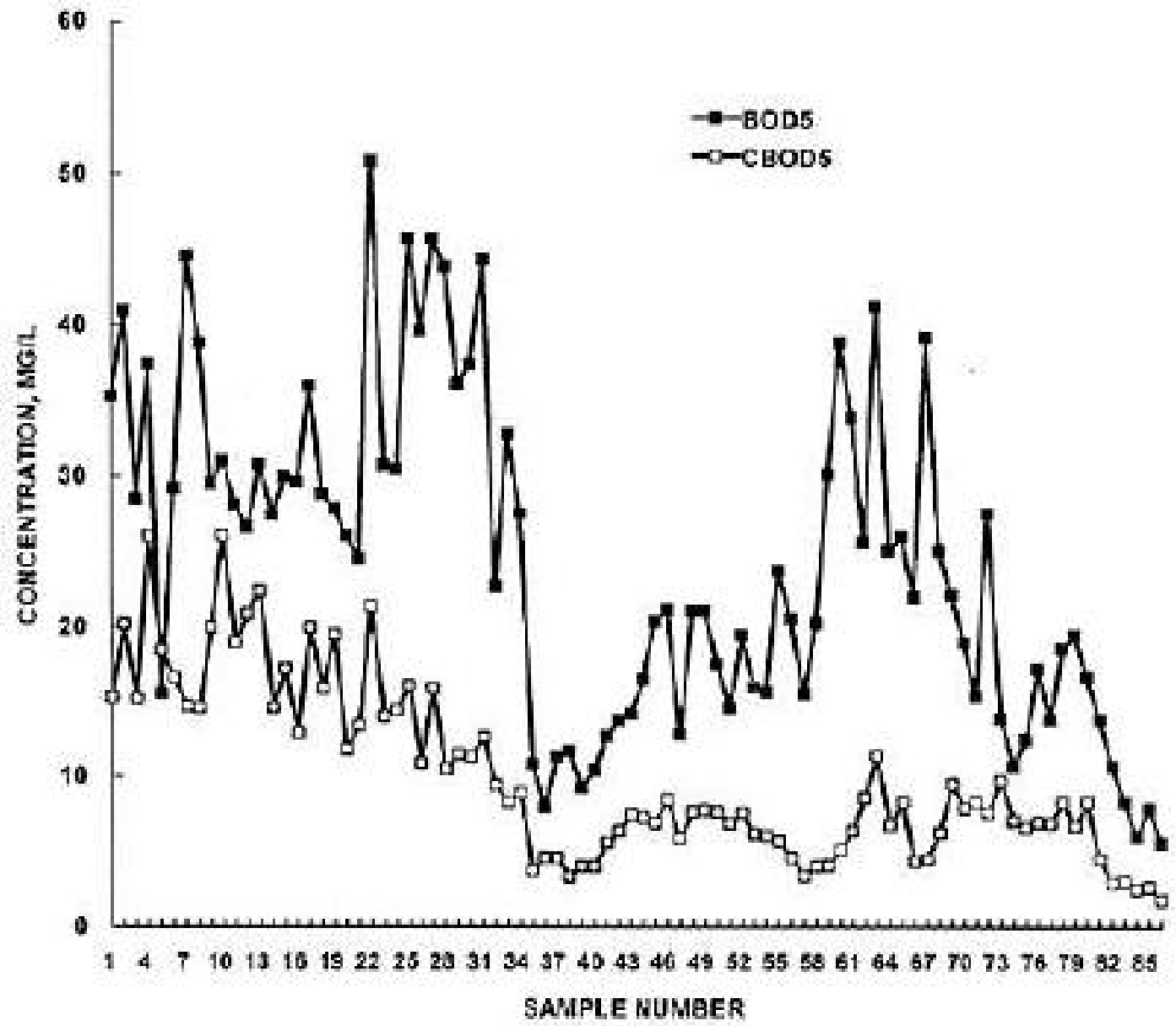
Note that in lagoons, the standard BOD5 test will capture both these values and can introduce misleading results.

ILLINOIS ENVIRONMENTAL PROTECTION AGENCY

ILLINOIS SUSTAINABLE TECHNOLOGY CENTER
PRAIRIE RESEARCH INSTITUTE

SEDAC
SMART ENERGY DESIGN ASSISTANCE CENTER

Breaking Down BOD_5



Nitrification has a large and unpredictable effect on lagoon BOD_5 test results.

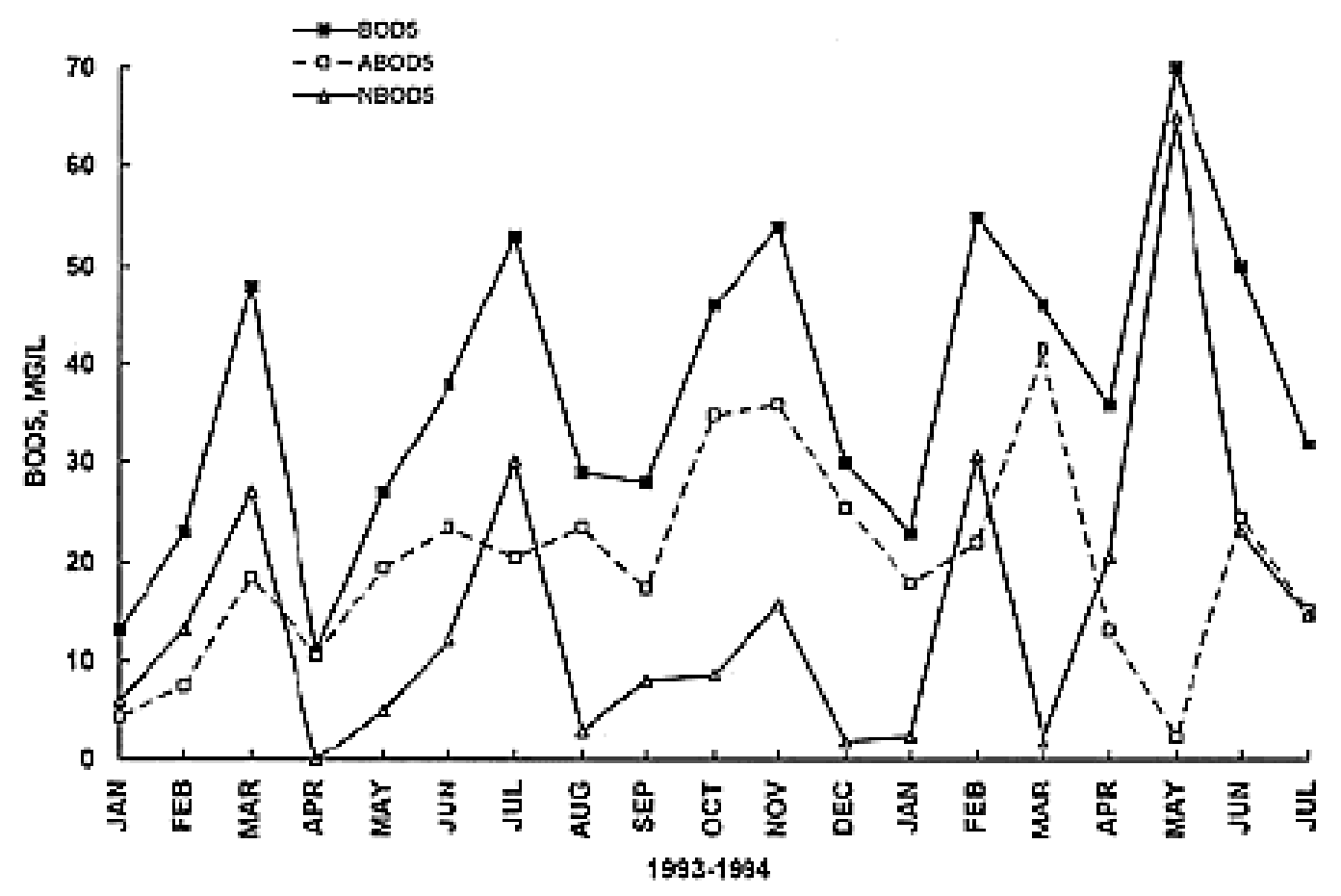
From an EPA task force study of lagoons in Maine, www.lagoonsonline.com

http://www.lagoonsonline.com/technote1.htm
https://fliphtml5.com/ruqh/uzmz/basic

ILLINOIS SUSTAINABLE TECHNOLOGY CENTER
PRAIRIE RESEARCH INSTITUTE

SEDAC
SMART ENERGY DESIGN ASSISTANCE CENTER

Breaking Down BOD_5



Algae also influences lagoon BOD_5 test results.

- **ABOD5** - BOD5 caused by algal respiration
- **NBOD5** - BOD5 caused by nitrification in the BOD5

From an EPA task force study of lagoons in Maine, www.lagoonsonline.com

http://www.lagoonsonline.com/technote2.htm

ILLINOIS SUSTAINABLE TECHNOLOGY CENTER
PRAIRIE RESEARCH INSTITUTE

SEDAC
SMART ENERGY DESIGN ASSISTANCE CENTER

Breaking Down BOD_5

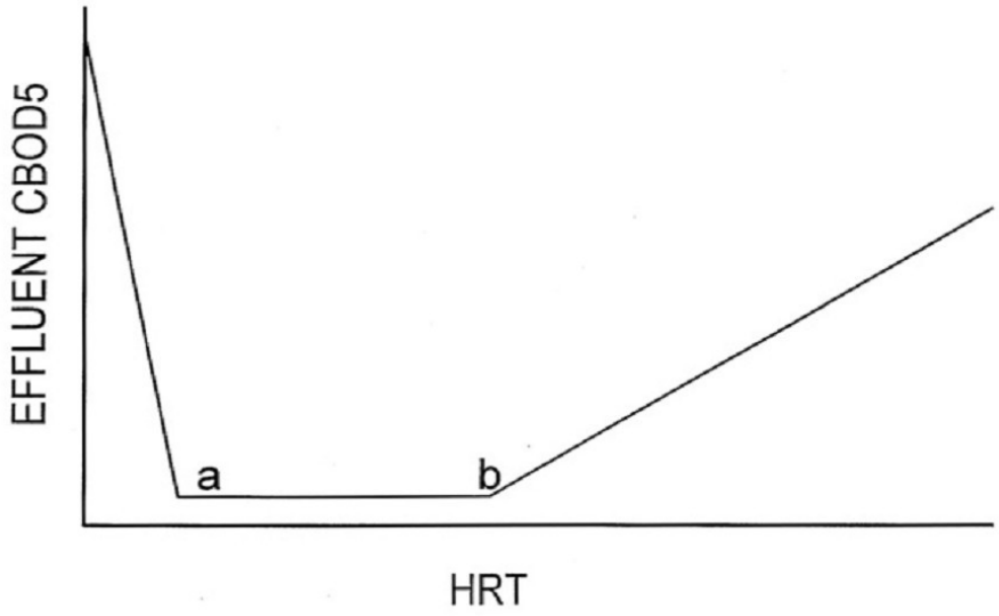


Figure 2. Conceptual sketch of influence of hydraulic retention time (HRT) on lagoon effluent $CBOD_5$

Hydraulic retention time (HRT) in cells is important factor.

- CBOD from human activity generally should be reduced quickly in the first cell
- BOD from algal respiration and nitrification increase after that

Aerated Lagoon Technology
by Linvil Rich, Clemson University

ILLINOIS ENVIRONMENTAL PROTECTION AGENCY

ILLINOIS SUSTAINABLE TECHNOLOGY CENTER
PRAIRIE RESEARCH INSTITUTE

SEDAC
SMART ENERGY DESIGN ASSISTANCE CENTER

Alternate Lagoon Tests

Test	Definition	Meaning
BOD_5	Standard 5-day BOD test.	Standard test for understanding lagoon conditions. Also required to calculate $NBOD_5$, lagoon's ability to nitrify
$SBOD_5$	A filtered BOD_5 test to remove insolubles. Measures most readily oxidizable portion of sample	Test is needed to calculate filtered $CBOD_5$
$CBOD_5$	BOD_5 test run with nitrification suppressant.	Better measure of lagoon's ability to stabilize waste
$SCBOD_5$	Soluble $CBOD_5$ test, run after filtration and addition of nitrification suppressant	Measures sludge blanket influence on feeding BOD back to the water column. Also determines algae's effect on BOD_5 test.

Steve Harris' *Wastewater Lagoon Troubleshooting, An Operator's Guide*

ILLINOIS ENVIRONMENTAL PROTECTION AGENCY

ILLINOIS SUSTAINABLE TECHNOLOGY CENTER
PRAIRIE RESEARCH INSTITUTE

SEDAC
SMART ENERGY DESIGN ASSISTANCE CENTER

Other Reasons for Aeration

- ✓ **Nitrification**: the breakdown of Ammonia into nitrates and nitrites requires oxygen.
- ✓ **Mixing**: often, aerators also provide mixing to keep solids in suspension and to ensure that microbes are in contact with nutrients of concern.

ILLINOIS ENVIRONMENTAL PROTECTION AGENCY

ILLINOIS SUSTAINABLE TECHNOLOGY CENTER
PRAIRIE RESEARCH INSTITUTE

SEDAC
SMART ENERGY DESIGN ASSISTANCE CENTER

Types of Lagoons - Aeration

Facultative relies upon natural biological treatment. Aerobic surface water and anerobic sludge decomposition at bottom.

Partial Mix Aerated uses mechanical aeration and/or mixers but does not maintain all particles in suspension and does not necessarily achieve a uniform water column.

Fully Mixed is rarer. High loading and short detention time. More like an activated sludge process.

ILLINOIS ENVIRONMENTAL PROTECTION AGENCY

ILLINOIS SUSTAINABLE TECHNOLOGY CENTER
PRAIRIE RESEARCH INSTITUTE

SEDAC
SMART ENERGY DESIGN ASSISTANCE CENTER

Types of Lagoons - Loading

6-acre Facultative:

15-35 # BOD/acre/day
* 6 acres =
90-210 # BOD/day
which is about
450-1,050 people

States often estimate 0.2 # BOD per person for permitting.

6-acre Aerated:

50 -100 # BOD/acre/day
* 6 acres =
300-600 # BOD/day
Up to about 3,000 people

Data source: https://www.doh.wa.gov/portals/1/Documents/Pubs/337-103.pdf
Image source: https://www.waterworld.com/home/article/16192273/introduction-to-wastewater-treatment-ponds

ILLINOIS SUSTAINABLE TECHNOLOGY CENTER
PRAIRIE RESEARCH INSTITUTE

SEDAC
SMART ENERGY DESIGN ASSISTANCE CENTER

Types of Lagoons – Detention Time

Example:

6-acre Pond

10’ deep => ~15 MG

200 gallons/ppl/day

1,000 people

.2 MGD

Theoretical Detention Time:

75 days

Guidelines:

Facultative:

120 days

Aerated:

30-60 days

$$\textbf{Detention Time} = \frac{\textbf{Pond Volume (gallons)}}{\textbf{Influent Rate (gal/day}}$$

ILLINOIS SUSTAINABLE TECHNOLOGY CENTER
PRAIRIE RESEARCH INSTITUTE

SEDAC
SMART ENERGY DESIGN ASSISTANCE CENTER

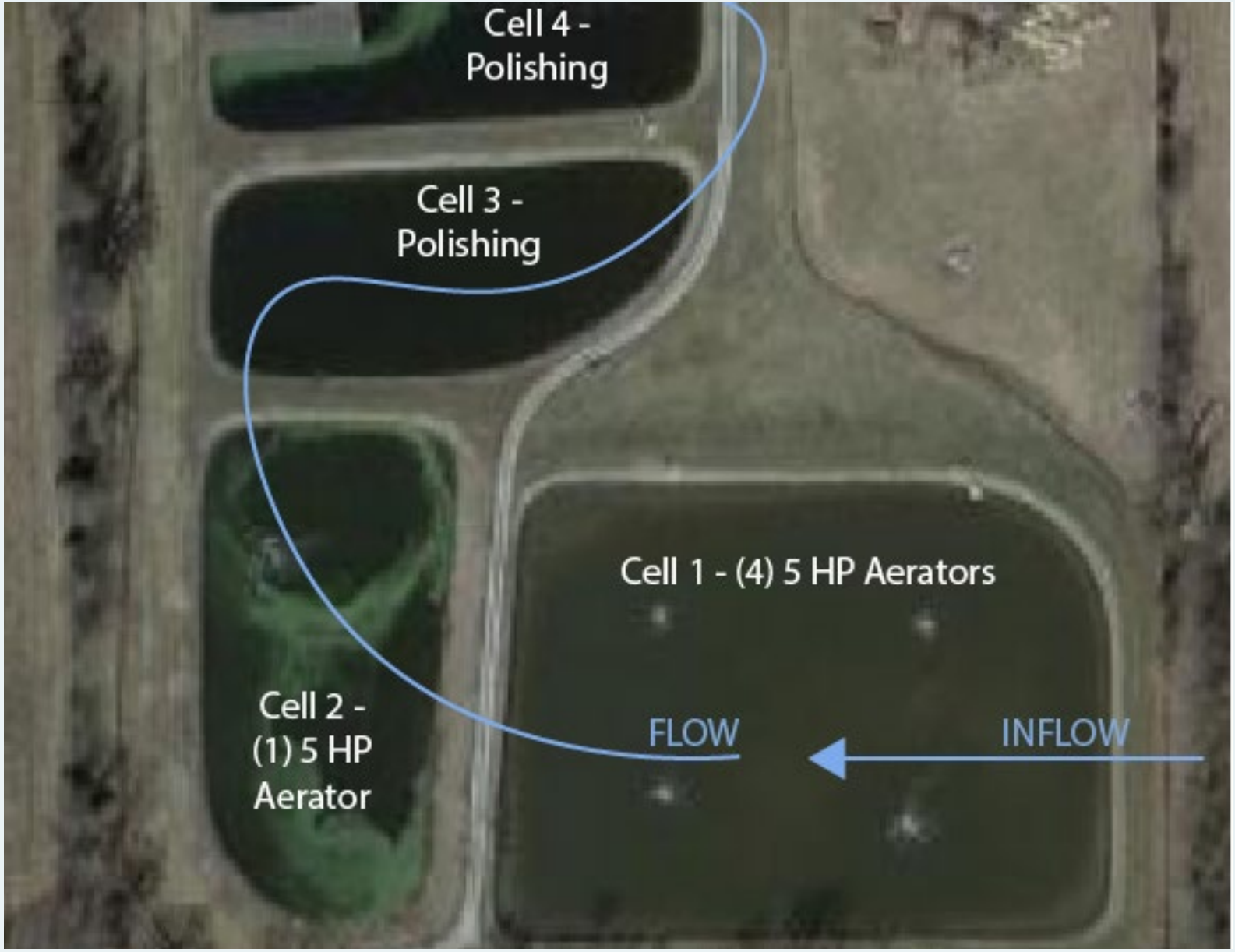
Types of Lagoons – Cells

Most lagoons vary the amount of aeration per cell

Primary Cell (Cell 1) – most aeration

Secondary Cell (Cell 2)– some aeration

Settling Cell (Cell 3&4)– often facultative



How Do We Aerate?

ILLINOIS ENVIRONMENTAL PROTECTION AGENCY

ILLINOIS SUSTAINABLE TECHNOLOGY CENTER
PRAIRIE RESEARCH INSTITUTE

SEDAC
SMART ENERGY DESIGN ASSISTANCE CENTER

Natural Oxygen Production & Use

- ✓ **Algae**:
  - ✓ During the day, algae produces oxygen through photosynthesis.
  - ✓ At night, algae switch to respiration using oxygen and producing carbon dioxide.
  - ✓ Eventually, algae dies off and the breakdown of organic matter oxygen.

ILLINOIS ENVIRONMENTAL PROTECTION AGENCY

ILLINOIS SUSTAINABLE TECHNOLOGY CENTER
PRAIRIE RESEARCH INSTITUTE

SEDAC
SMART ENERGY DESIGN ASSISTANCE CENTER

Natural Oxygen Production & Use

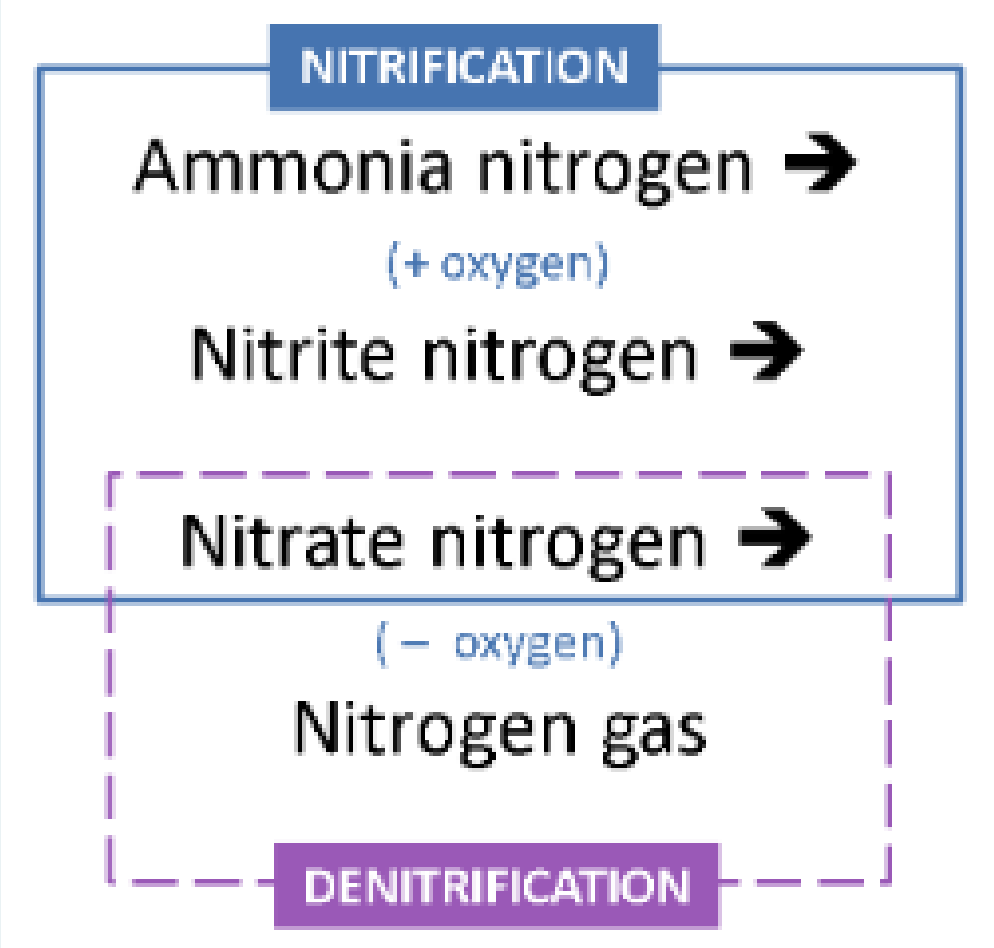
- ✓ **Surface Area**: the volume of water exposed to the air absorbs oxygen directly.
  - ✓ Larger lagoons absorb more oxygen from air contact
  - ✓ Mechanical splashers put more water in contact with air

ILLINOIS ENVIRONMENTAL PROTECTION AGENCY

ILLINOIS SUSTAINABLE TECHNOLOGY CENTER
PRAIRIE RESEARCH INSTITUTE

SEDAC
SMART ENERGY DESIGN ASSISTANCE CENTER

Natural Oxygen Production & Use



- ✓ **Bound Oxygen:** If the right conditions exist, bacteria will use bound oxygen.

For example, nitrite and nitrate (NO_2 and NO_3) provide oxygen for denitrifying bacteria in anoxic conditions.

This will improve water quality by breaking down nitrates into harmless nitrogen gas.

https://www.pca.state.mn.us/sites/default/files/wq-wwtp8-21.pdf

Oxygen Transfer Efficiency

Temperature

Easier in cold weather when air is more dense.
Colder water also hold more dissolved gases, thus more oxygen.

DO Concentration

Easier to add oxygen when the concentration is lower.

ILLINOIS ENVIRONMENTAL PROTECTION AGENCY

ILLINOIS SUSTAINABLE TECHNOLOGY CENTER
PRAIRIE RESEARCH INSTITUTE

SEDAC
SMART ENERGY DESIGN ASSISTANCE CENTER

Surface Aerators

Horizontal Jet

1.5 to 2.1 kg O_2/kW-hour

(2.5 to 3.5 lbs O_2/hp-hour)

EPA Aerated, Partially Mixed Lagoons Tech Sheet
https://www3.epa.gov/npdes/pubs/apartlag.pdf

Horizontal Aspirator

Vertical Splash

By the numbers, we'd expect to run **7-20 HP** 24 hours for a plant with ~300 # BOD/day

Images courtesy Triplepoint™

Sub-Surface Aerators

Fine Bubble

Coarse Bubble

Images courtesy of Water Online and Cole-Parmer

3.7 to 4 kg O2/kW-hour

(6 to 6.5 lbs O2/hp-hour)

EPA Aerated, Partially Mixed Lagoons Tech Sheet
https://www3.epa.gov/npdes/pubs/apartlag.pdf

At standard conditions, we'd expect to run only **~5-8 HP** 24 hours for a plant with ~300 # BOD/day

Sub-Surface Aerators

Fine Bubble

Better O_2 Transfer

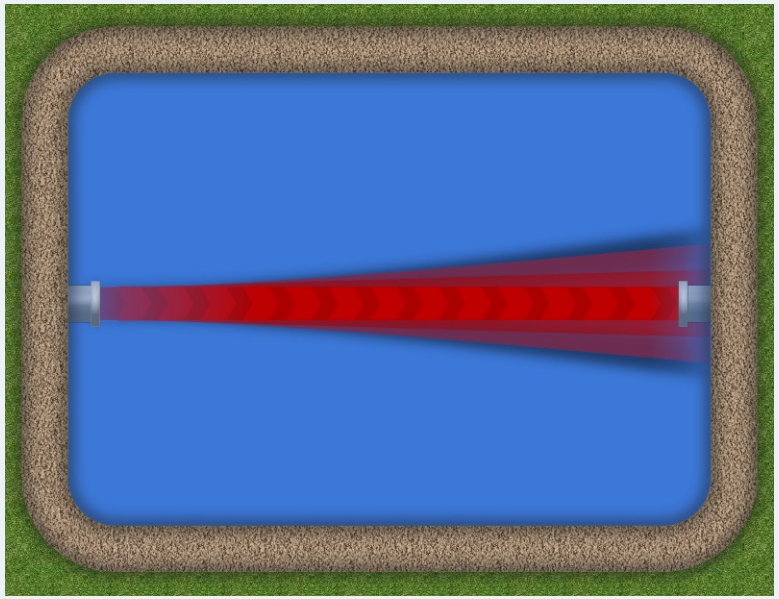
Coarse Bubble

Better Mixing

Images courtesy of Water Online and Cole-Parmer

Aerator Locations

- Dependent on lagoon influent and effluent pipes, wind direction, sludge accumulation, and aerator locations.
- Surface aerators can be used to disrupt short circuit flows, increasing retention time and improving treatment.
- Possible, but more difficult to do with subsurface aerators.



Short Circuiting Reduces Treatment Time and Quality

Image Sources:
Short circuit: www.lagoons.com/blog/industrial-wastewater/causes-of-lagoon-short-circuit/
Good Detention Time: https://www.wwdmag.com/operations-maintenance/what-process-short-circuiting-water-how-combat-it

Good Flow Ensures Full Detention Time and Treatment

ILLINOIS ENVIRONMENTAL PROTECTION AGENCY

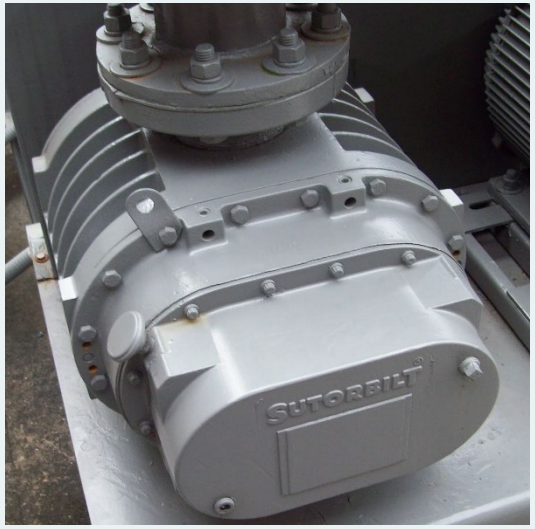
ILLINOIS SUSTAINABLE TECHNOLOGY CENTER
PRAIRIE RESEARCH INSTITUTE

SEDAC
SMART ENERGY DESIGN ASSISTANCE CENTER

Positive Displacement Blowers

Rotary lobe blowers

- 3 lobe common now, reduces vibrations
- 2 lobe higher vibration
- 45-70% efficiency, ~50% turndown



Positive Displacement Blowers

Other Positive Displacement Types

- **Piston/Reciprocating blowers** – high noise/vibration level, high heat generation, 70-85% efficiency, nearly infinite turndown

- **Rotary screw blowers** – lowest vibration for PD systems, 65-75% efficiency, ~50-60% turndown

ILLINOIS ENVIRONMENTAL PROTECTION AGENCY

ILLINOIS SUSTAINABLE TECHNOLOGY CENTER
PRAIRIE RESEARCH INSTITUTE

SEDAC
SMART ENERGY DESIGN ASSISTANCE CENTER

Centrifugal Blowers

Centrifugal blowers: can be single or multi-stage. High efficiency (70-85%), lower noise and heat, but limited turndown 30-50%. cccc

Turbo blowers: High efficiency (75-85%), again,
~55% maximum turn-down for magnetic bearing
~45-50% turn-down for air bearing
Rare that lagoon can justify expense or have capacity requirement for turbo

Blower Efficiency

Types of blowers impact aeration efficiency

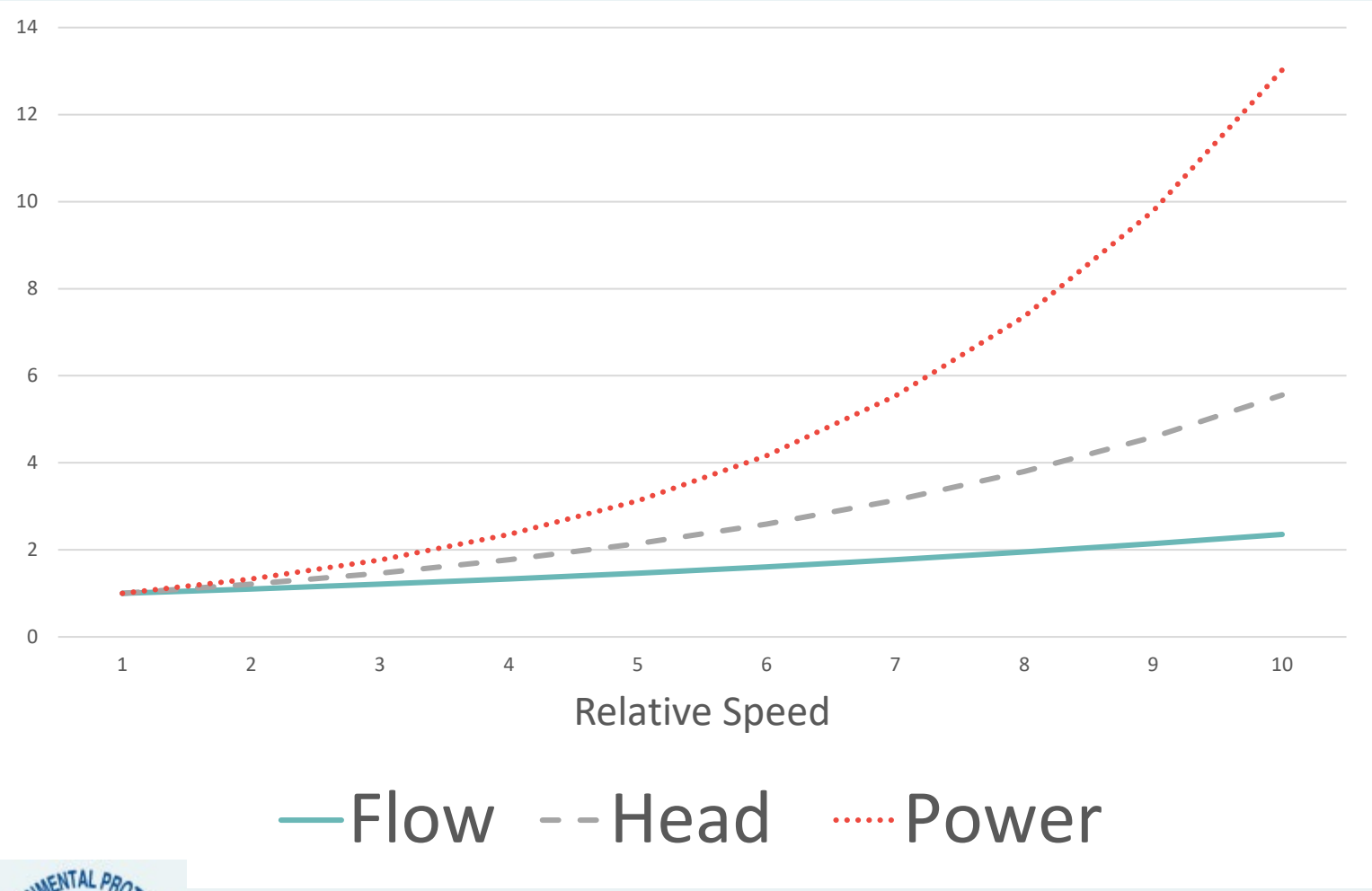
- Positive displacement – lower efficiency but higher turn-down capacity
  - Reciprocating
  - Rotary Lobe
  - Screw
- Centrifugal blowers – Higher efficiency, but less turn-down capacity
  - Multi-stage centrifugal
  - Turbo blowers

ILLINOIS ENVIRONMENTAL PROTECTION AGENCY

ILLINOIS SUSTAINABLE TECHNOLOGY CENTER
PRAIRIE RESEARCH INSTITUTE

SEDAC
SMART ENERGY DESIGN ASSISTANCE CENTER

Centrifugal Blowers and Affinity Laws



Volume Flow Capacity

$$q_1 / q_2 = (n_1 / n_2)$$

Head or Pressure

$$dp_1 / dp_2 = (n_1 / n_2)^2$$

Power

$$P_1 / P_2 = (n_1 / n_2)^3$$

ILLINOIS ENVIRONMENTAL PROTECTION AGENCY

ILLINOIS SUSTAINABLE TECHNOLOGY CENTER
PRAIRIE RESEARCH INSTITUTE

SEDAC
SMART ENERGY DESIGN ASSISTANCE CENTER

How Do We Measure and Control Aeration?

ILLINOIS ENVIRONMENTAL PROTECTION AGENCY

ILLINOIS SUSTAINABLE TECHNOLOGY CENTER
PRAIRIE RESEARCH INSTITUTE

SEDAC
SMART ENERGY DESIGN ASSISTANCE CENTER

Blower Controls

What inputs should control blower output?

- ✓ DO (or ORP)
- ✓ Temperature
- ✓ Time of Day
- ✓ Season
- ✓ Flow

ILLINOIS ENVIRONMENTAL PROTECTION AGENCY

ILLINOIS SUSTAINABLE TECHNOLOGY CENTER
PRAIRIE RESEARCH INSTITUTE

SEDAC
SMART ENERGY DESIGN ASSISTANCE CENTER

Time Clocks

Time clocks are an affordable and simple way to control aeration energy input where blowers are easily turned on and off.

ILLINOIS ENVIRONMENTAL PROTECTION AGENCY

ILLINOIS SUSTAINABLE TECHNOLOGY CENTER
PRAIRIE RESEARCH INSTITUTE

SEDAC
SMART ENERGY DESIGN ASSISTANCE CENTER

Variable Frequency Drives (VFDs)

Variable Frequency Drives (VFDs) save energy by slowing motors, drawing less power.

ILLINOIS ENVIRONMENTAL PROTECTION AGENCY

ILLINOIS SUSTAINABLE TECHNOLOGY CENTER
PRAIRIE RESEARCH INSTITUTE

SEDAC
SMART ENERGY DESIGN ASSISTANCE CENTER

Variable Frequency Drives (VFDs)

But how does the VFD know how fast to run the equipment?

It varies.

ILLINOIS ENVIRONMENTAL PROTECTION AGENCY

ILLINOIS SUSTAINABLE TECHNOLOGY CENTER
PRAIRIE RESEARCH INSTITUTE

SEDAC
SMART ENERGY DESIGN ASSISTANCE CENTER

Sensing Aeration Demand

Dissolved Oxygen sensors

2 types for wastewater applications:

- Electrochemical – galvanic reaction with oxygen in water induces current changes that measure DO. Requires flow over meter.
- Optical – light of specific wavelength shines on fluorescing material. Dimming of light used to measure DO. Does not require flow.

Images courtesy https://sensorex.com/dissolved-oxygen/

Takeaways

ILLINOIS ENVIRONMENTAL PROTECTION AGENCY

ILLINOIS SUSTAINABLE TECHNOLOGY CENTER
PRAIRIE RESEARCH INSTITUTE

SEDAC
SMART ENERGY DESIGN ASSISTANCE CENTER

Air Distribution

- Shallow lagoons benefit best from surface aerators
- Deep lagoons benefit from subsurface aeration
- Graduated aeration improves nutrient removal and minimizes energy consumption
- Beware of placement that can cause short circuits!

ILLINOIS ENVIRONMENTAL PROTECTION AGENCY

ILLINOIS SUSTAINABLE TECHNOLOGY CENTER
PRAIRIE RESEARCH INSTITUTE

SEDAC
SMART ENERGY DESIGN ASSISTANCE CENTER

Control Devices

- Timers usually very cost effective for lagoon systems
  - Small size and reduced initial energy consumption usually makes VFDs harder to justify
- VFDs on PD blowers can be cost effective without impacting lagoon mixing ability
  - Centrifugal blower for largest lagoons may also benefit from VFD
  - Be wary of loss of pressure from slowing centrifugal blowers

ILLINOIS ENVIRONMENTAL PROTECTION AGENCY

ILLINOIS SUSTAINABLE TECHNOLOGY CENTER
PRAIRIE RESEARCH INSTITUTE

SEDAC
SMART ENERGY DESIGN ASSISTANCE CENTER

Blower Efficiency

- Maximize efficiency of blower system to improve overall aeration efficiency.
- Turndown of 8:1, or intermittent operation, based on lagoon oxygen levels.
- Use peak blower performance for given load – may required multiple blowers and blower types to optimize.

ILLINOIS ENVIRONMENTAL PROTECTION AGENCY

ILLINOIS SUSTAINABLE TECHNOLOGY CENTER
PRAIRIE RESEARCH INSTITUTE

SEDAC
SMART ENERGY DESIGN ASSISTANCE CENTER

“Homework”

- ✓ Calculate how many hours per day or speed your aeration need to run just to satisfy BOD from carbon and for nitrification of ammonia.
- ✓ Check the DO in various parts of your system – not just the discharge. If possible, same for BOD.
- ✓ Check DO in the morning and the evening to observe the effect of algal respiration on overnight DO levels

ILLINOIS ENVIRONMENTAL PROTECTION AGENCY

ILLINOIS SUSTAINABLE TECHNOLOGY CENTER
PRAIRIE RESEARCH INSTITUTE

SEDAC
SMART ENERGY DESIGN ASSISTANCE CENTER

Questions?

info@sedac.org
800-214-7954

www.sedac.org/water

ILLINOIS ENVIRONMENTAL PROTECTION AGENCY

ILLINOIS SUSTAINABLE TECHNOLOGY CENTER
PRAIRIE RESEARCH INSTITUTE

SEDAC
SMART ENERGY DESIGN ASSISTANCE CENTER