ATP Monitoring in Drinking Water Distribution Systems

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Overview

- Biofilms
- ATP (Adenosine Triphosphate) monitoring
- Examples of ATP Monitoring in drinking water distribution systems (DWDS's)
- Future work

Water Treatment

- Disinfection does not mean sterilization
- Bacteria in the DWDS are inevitable
- Revised Total Coliform Rule:
  - Goal: Absence of Total Coliforms in 100% of samples
  - Maximum Contaminant Level: Absence of Total Coliforms in >95% of samples (for large systems)

Water Treatment

Juggling act

- Chlorine residual window (0.02-4.0 mg/L in DWDS)
- **Bacterial regrowth/biofilm formation**
- Organic content (DOC or TOC)
- DBP formation
- Corrosion control chemistry
- pH
- More…

Bacterial Regrowth

- Factors contributing to bacterial regrowth:
  - Temperature
  - pH
  - Pipe material
  - Contamination
  - Dissolved Organic Carbon (DOC): Bacteria food

Bacterial Regrowth

- Bacterial form biofilms in DWDS
- EPS Matrix: 75-90% of biomass of biofilm

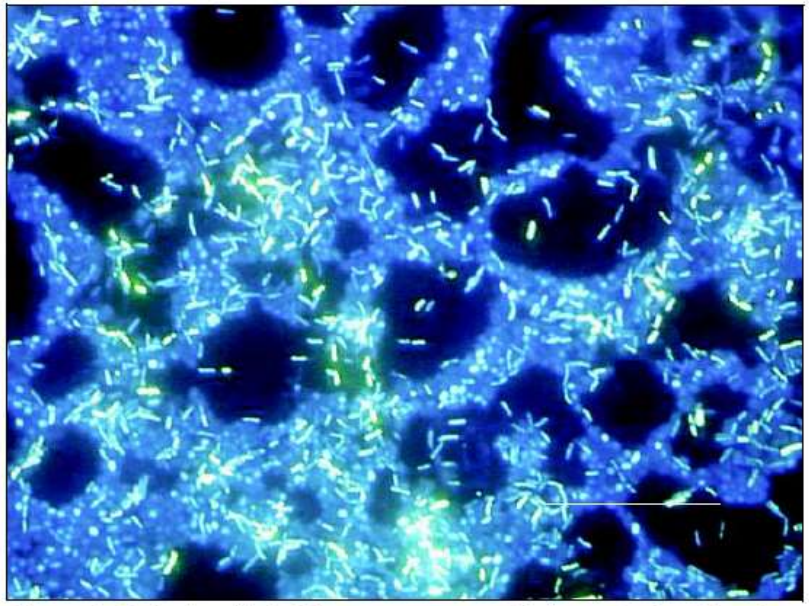


Figure 3. Polymicrobic biofilm grown on a stainless steel surface in a laboratory potable water biofilm reactor for 14 days, then stained with 4,6-diamidino-2-phenylindole (DAPI) and examined by epifluorescence microscopy. Bar, 20 µ.

Donlan, R. *Emerging Infectious Diseases* 2002, *8*, 881-890.

99.9% of all bacteria on Earth are found in biofilms!

Bacterial Regrowth

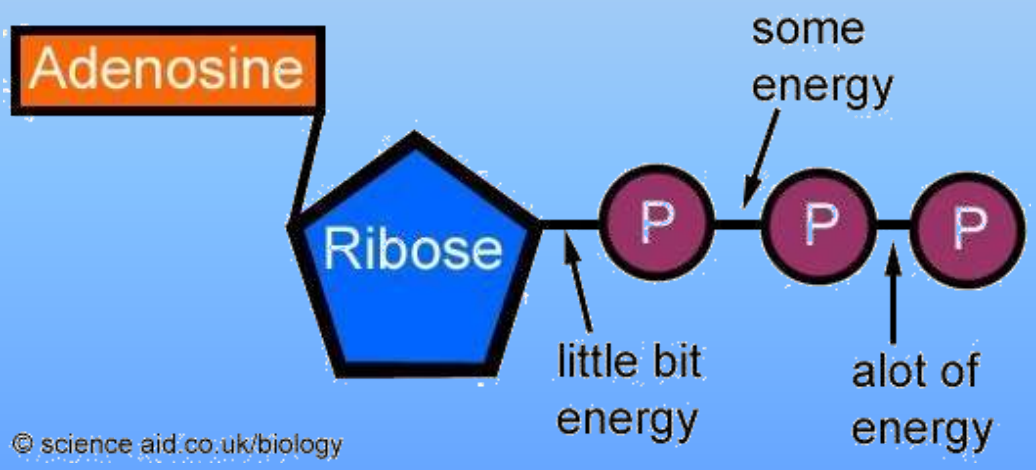
- Biofilm formation in DWDS
  - In addition to pathogenic bacteria, biofilms can harbor:
    - Viruses
    - Parasites
    - Fungi
- Biofilms can release contents which may then react with free chlorine

Bacterial Regrowth

How can we detect biofilms?

Measuring ATP

- ATP is present in all living things
- Energy currency of biochemical reactions



Measuring ATP

- Results in minutes
- Surfaces, deposits, or liquid
- More ATP = more living cells

Measuring ATP

- “Firefly” ATP assay

Luciferase (enzyme)

+ Luciferin (substrate)

+ ATP (energy source)

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1 UNIT OF LIGHT @ 560 nm (what we measure)

Measuring ATP

- LuminUltra System
  - Simple 4-step system
  - Portable luminometer
  - Operate with your phone

Measuring ATP

1. Filter sample

100 mL sample size

Filtration condenses any living cells onto filter

Measuring ATP

2. Lyse cells

Wash cells stuck on filter with solution that breaks cell open and allows ATP within the cells to pass through filter

Measuring ATP

3. Mix sample with reaction mix

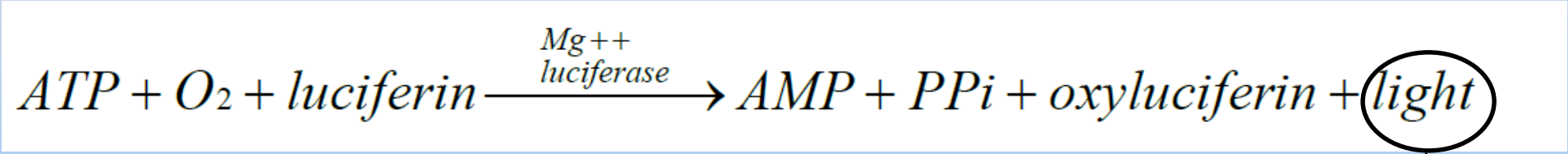


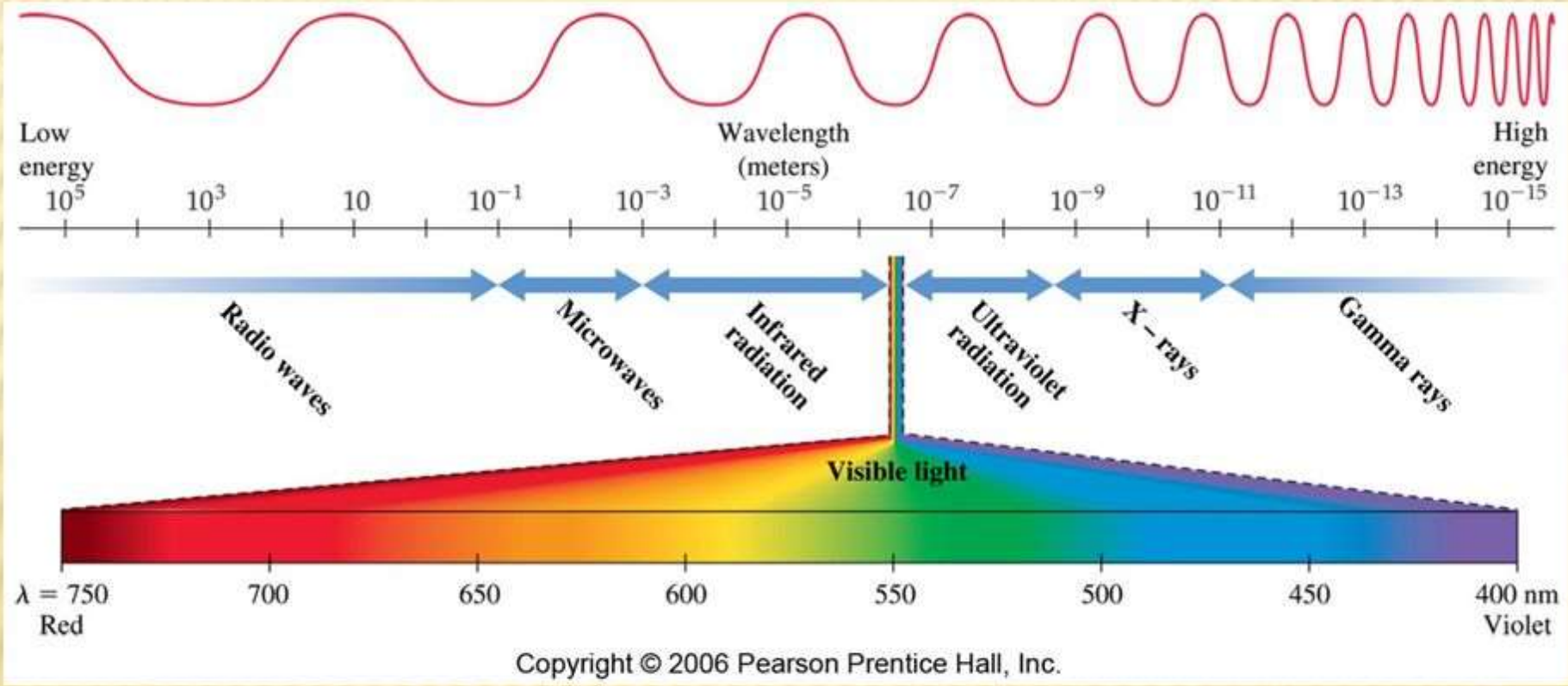
Image Credit: LuminUltra Technologies

~560 nm

Can anyone guess what color?

A) Red
B) Orange
C) Yellow
D) Green
E) Blue
F) Violet

Electromagnetic Spectrum




~560 nm

Measuring ATP

4. Measure immediately

Calibrate luminometer by first measuring a standard with a known concentration and then measuring samples.

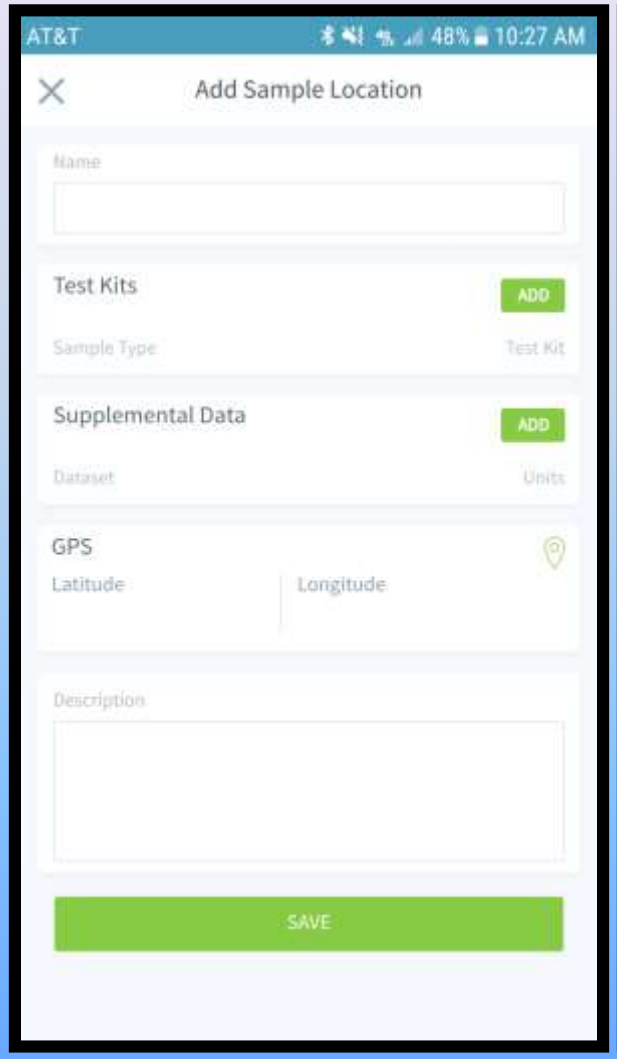
Measuring ATP

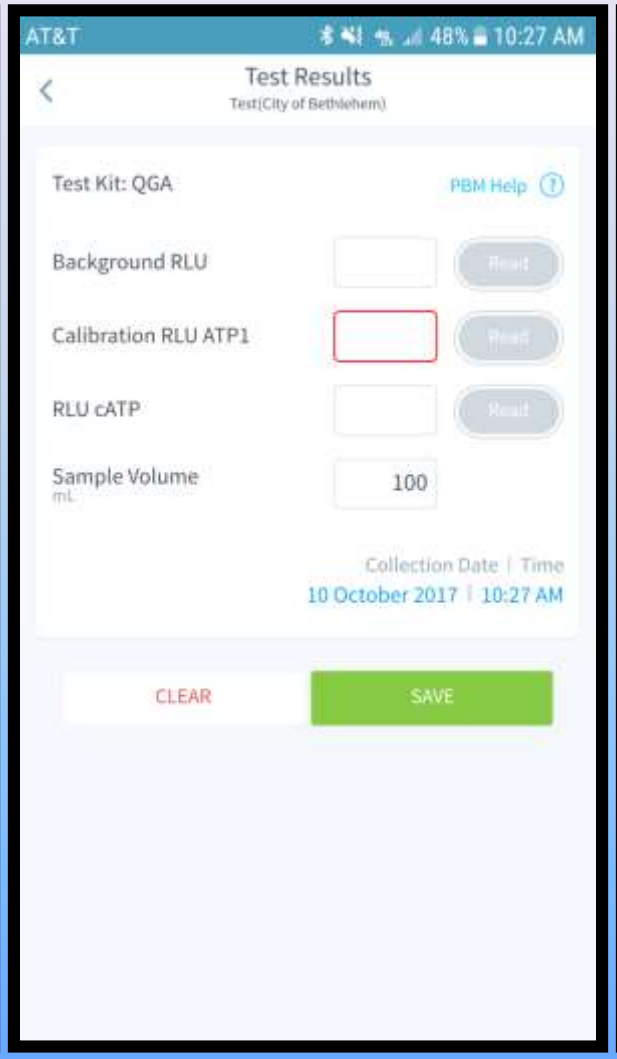
- Results are given in RLU: Relative Light Units
- Compare your unknown against a standard to determine unknown concentration
- Calculations are performed in-app
- Results are time stamped, geo-coded
- Cloud server

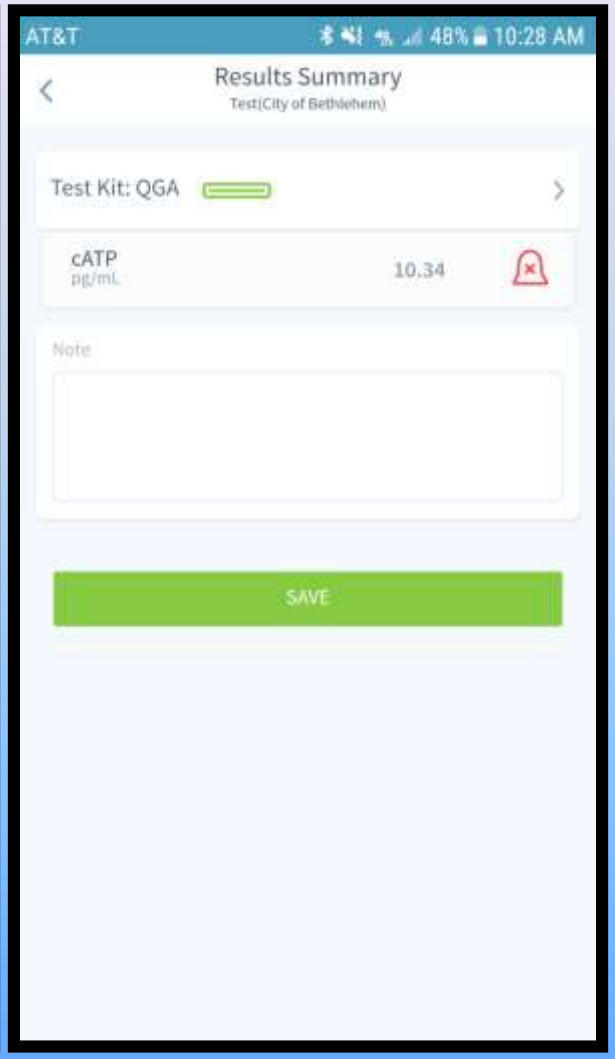
Translating Results

- Intracellular ATP only (bulk water samples)
- Direct relation to an exact number of bacteria is difficult without proper equipment
- Best translation:
  - Low (< 10 pg/mL)
  - Continued monitoring (10 pg/mL <-> Raw Water)
  - High (>Raw water)

Translating Results





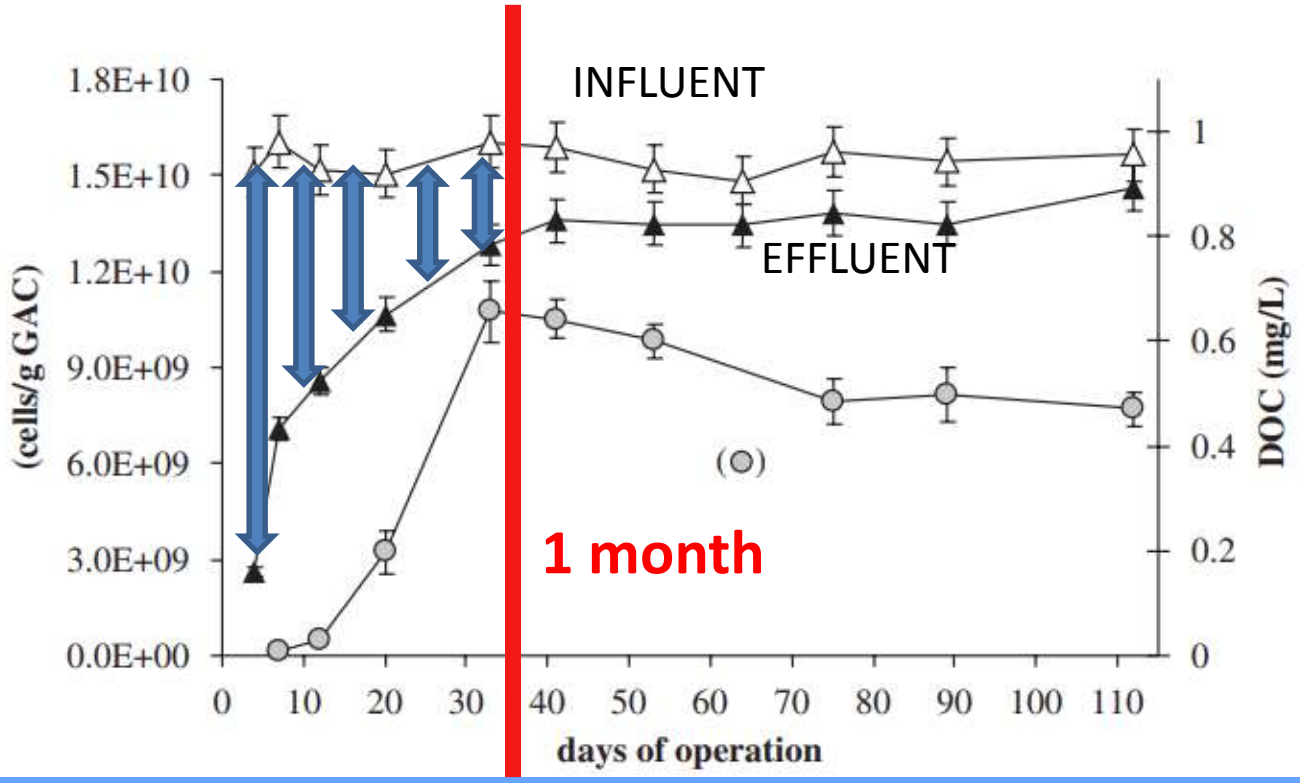


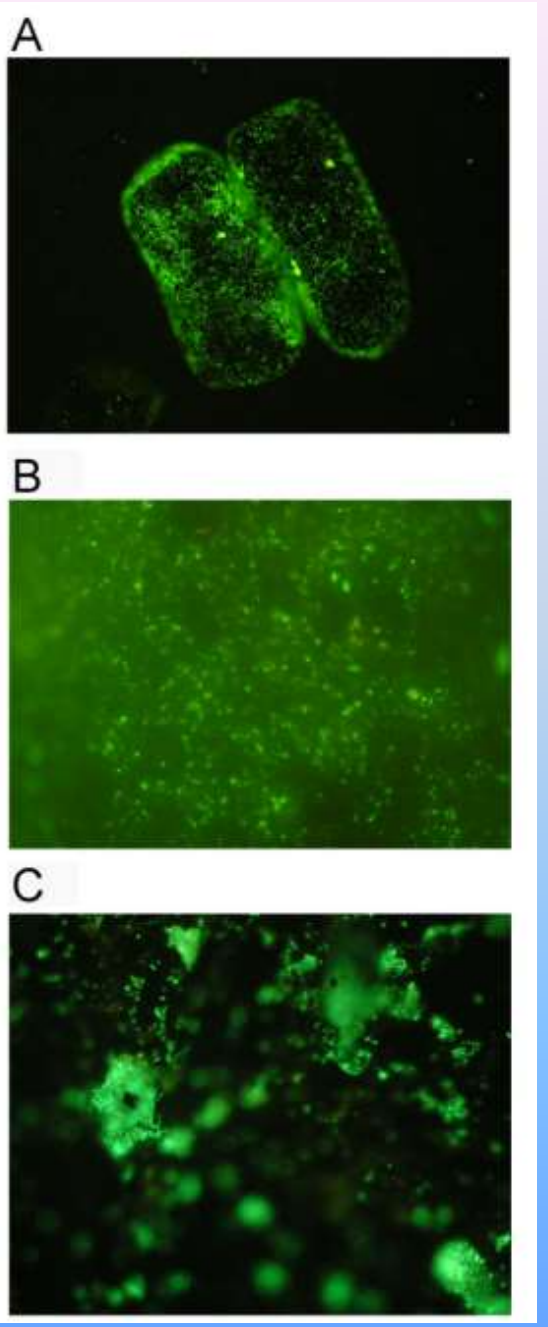
Bacterial Regrowth Areas of Concern

- Areas of high water age
- Finished water storage tanks
- Dead ends
- Interconnects with other DWDS's
- Filter beds/Sides of filter bed walls
- More…

GAC ATP Monitoring

Granular Activated Carbon filters:
DOC removal with help of biofilms

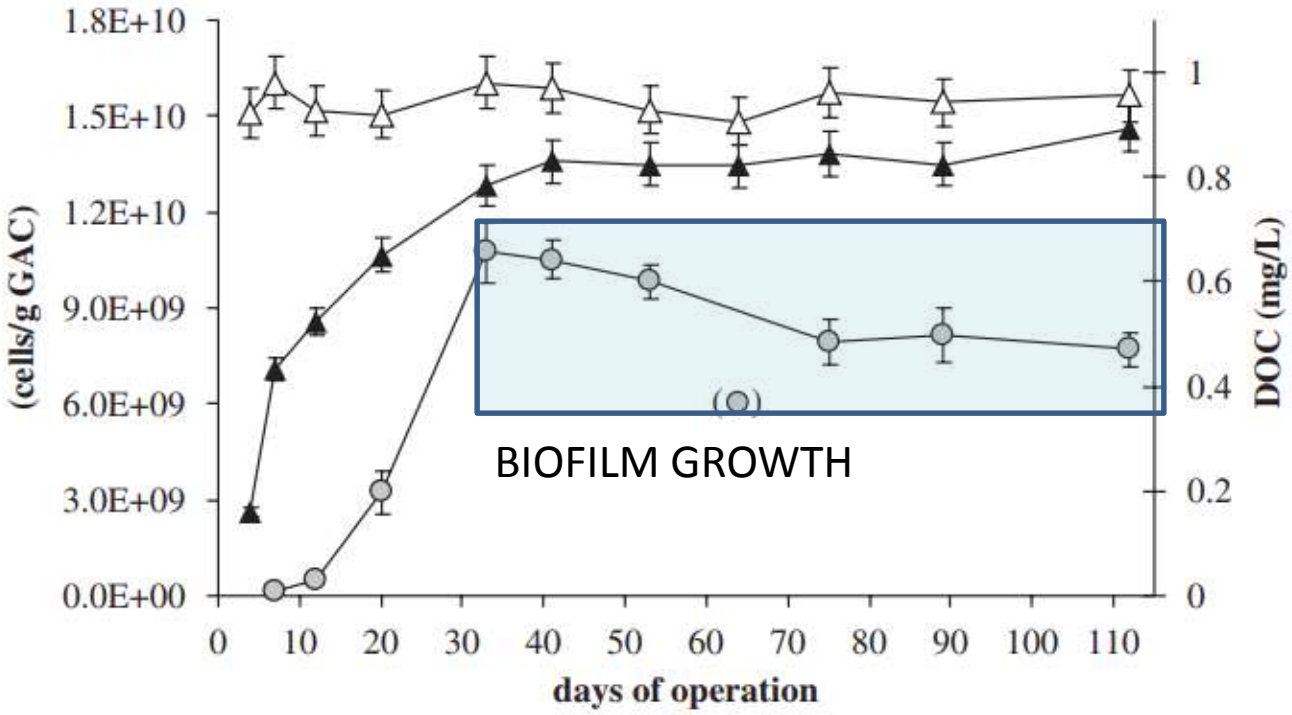


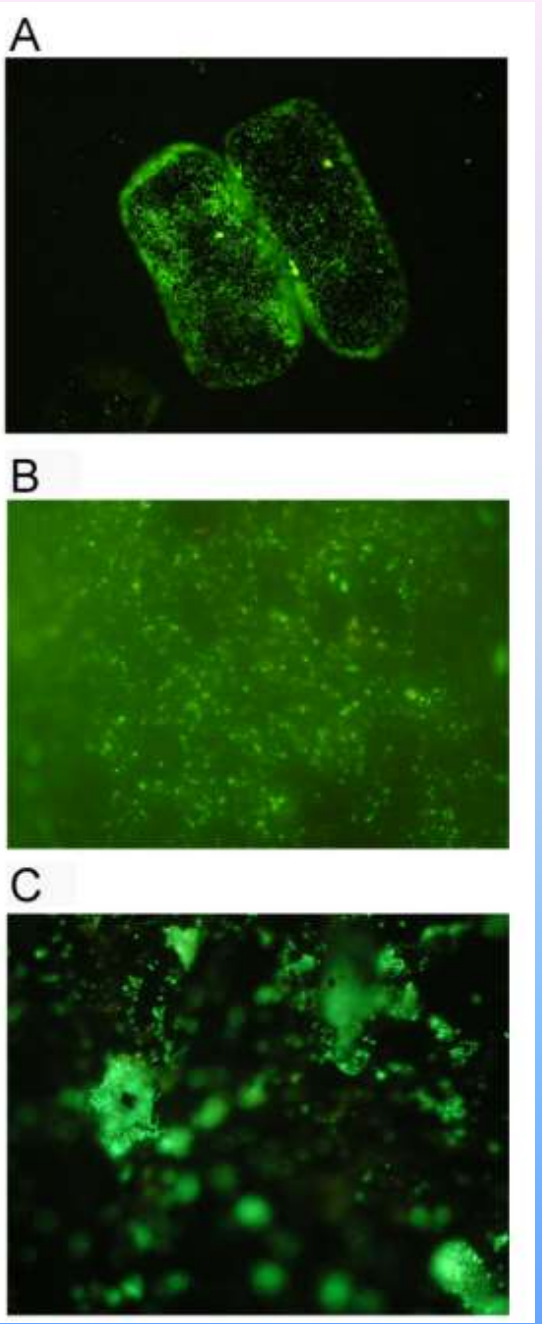


Velten, S. et al. (2007) Water Research, 41, 1973–83.

GAC Monitoring

Biofilm monitoring via ATP shows Biofilm stabilizes after 30 days…





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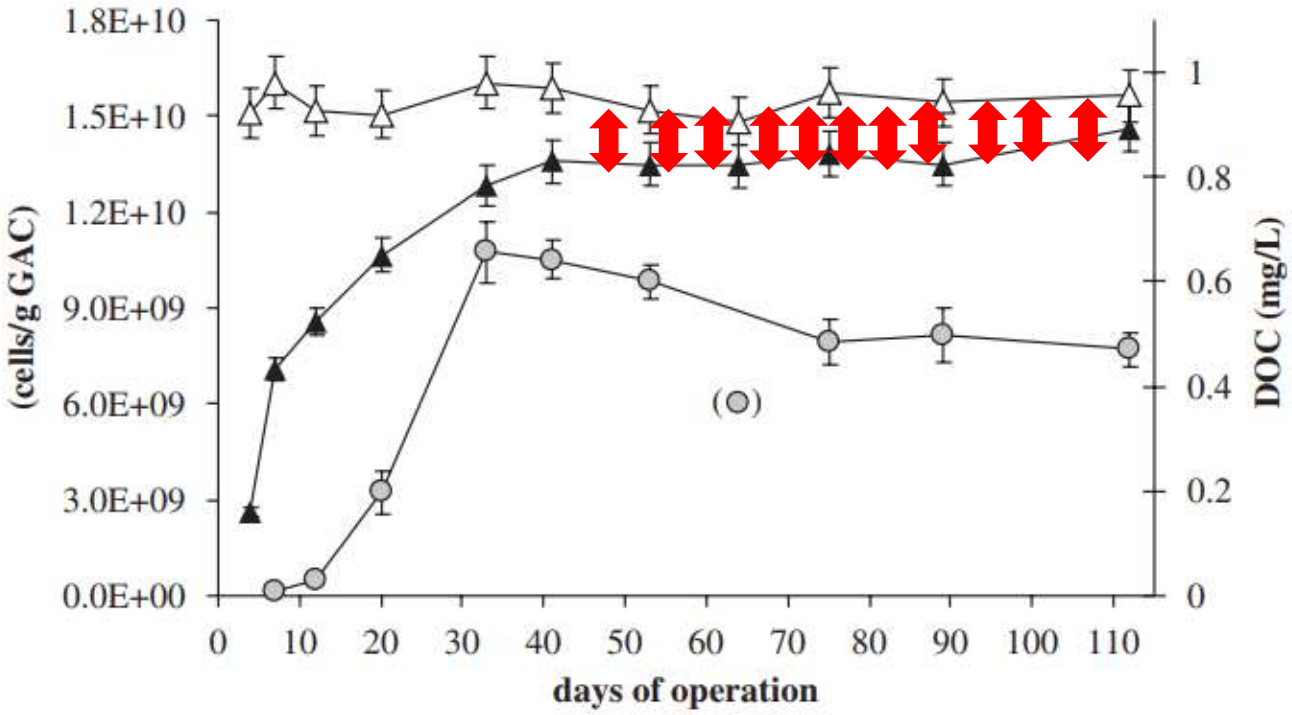
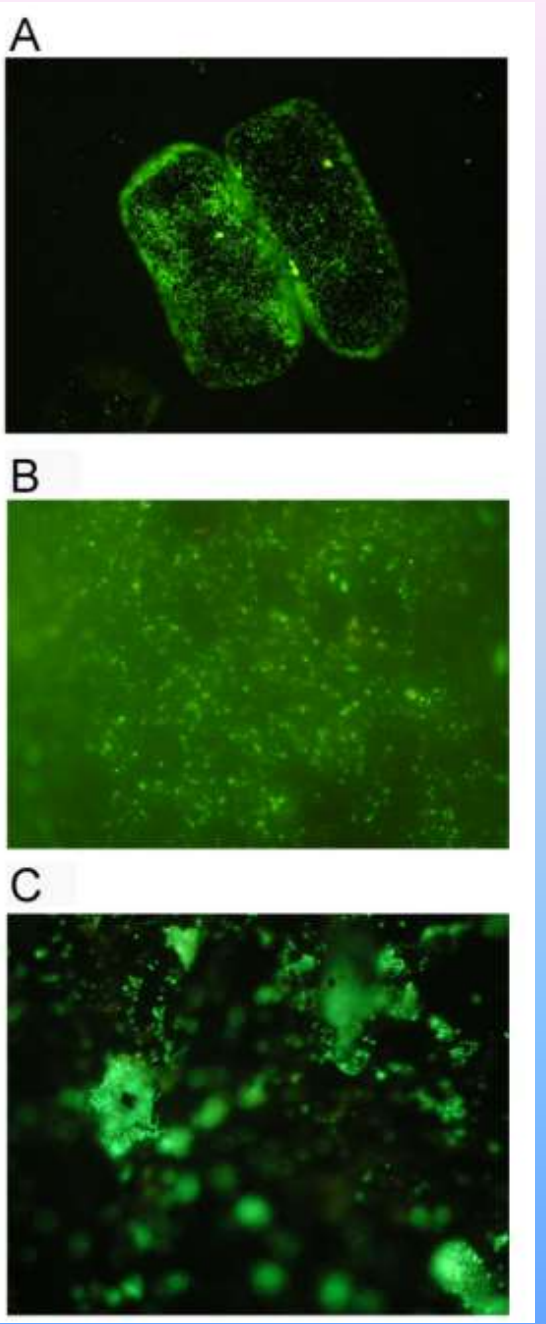
GAC Monitoring

…and yields a stable ~15-40% Reduction in DOC over long term due to biofilm metabolism of DOC





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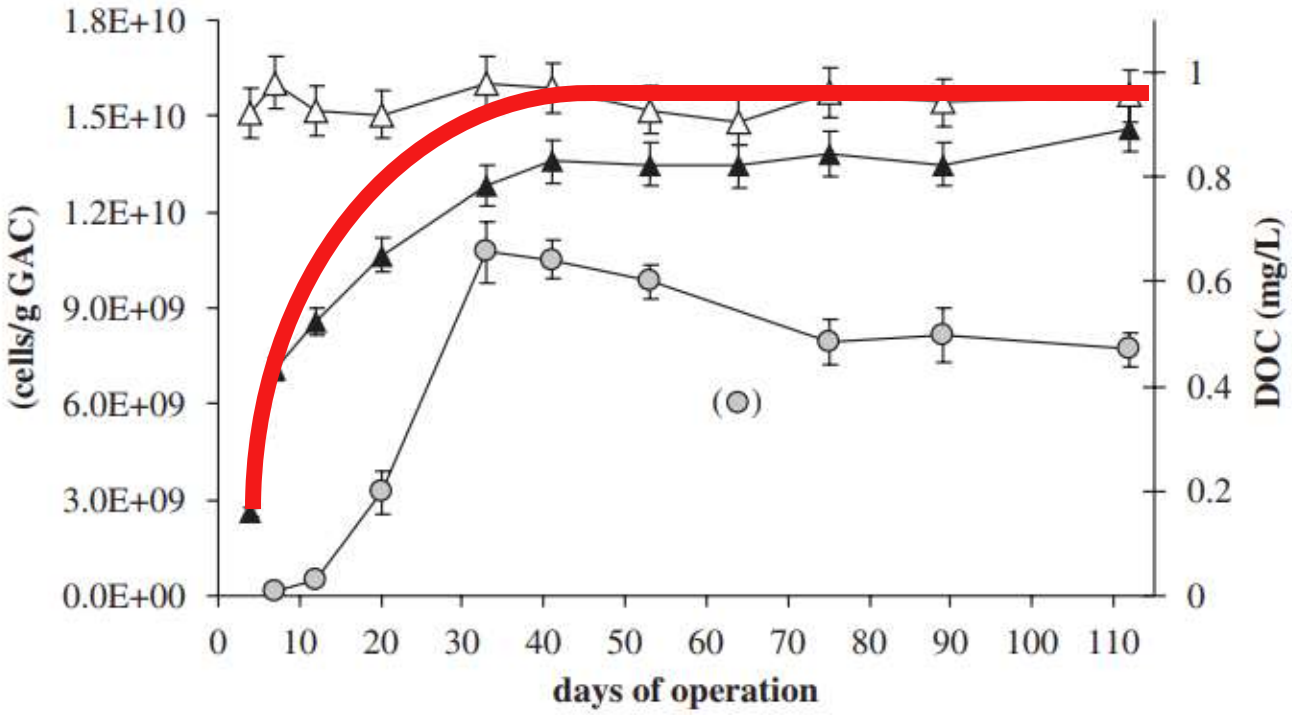
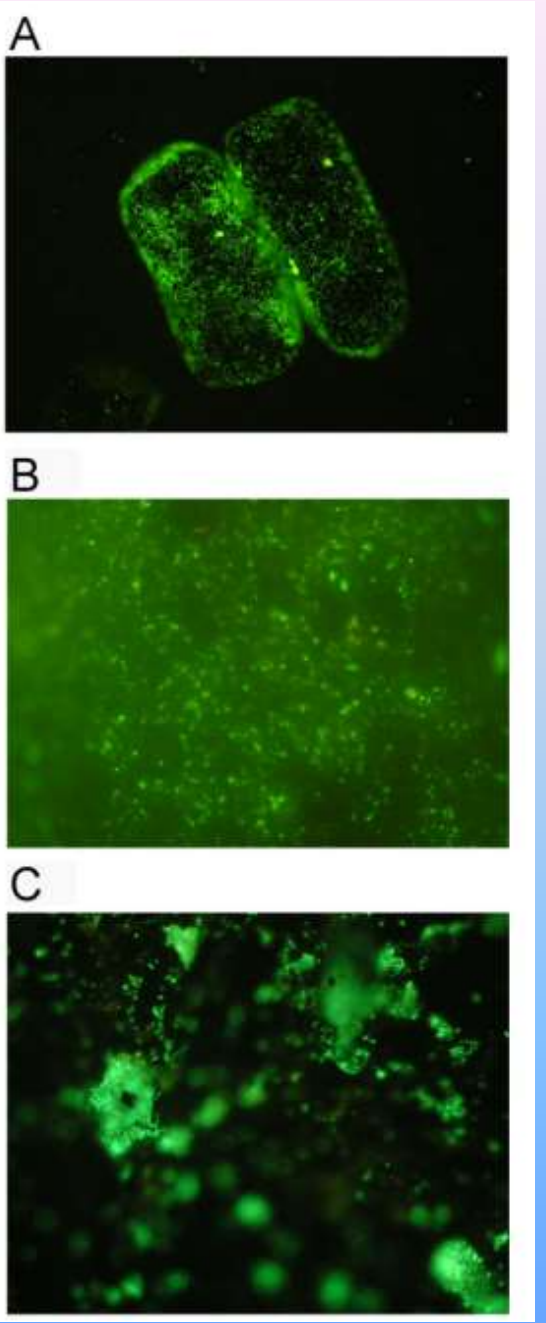
GAC Monitoring

Without biofilm, DOC of effluent might look like this:





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Filter Bed Spray Cleaners

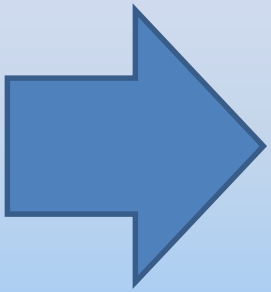
Filter Bed Spray Cleaners

Filter Bed Spray Cleaners

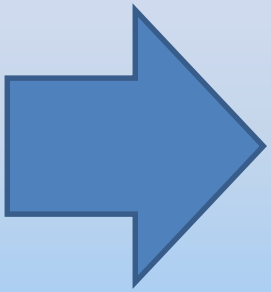
Sample ID or QC Action	Result (RLU)	Result	Result Units	% Reduction
Coated Surface	102	10	pg/cm^2	73.5%
Coated: cleaned	27	2.6	pg/cm^2	
Uncoated	1017	99	pg/cm^2	95.7%
Uncoated: cleaned	44	4.3	pg/cm^2	
Trough	154	15	pg/cm^2	85.1%
Trough: Cleaned	23	2.2	pg/cm^2	
Anthracite	11594	33500	pg/g	96.0%
Anthracite: Cleaned	468	1400	pg/g	
Sand	1225	3500	pg/g	84.8%
Sand: Cleaned	186	540	pg/g	
Biofilm	228959	660000	pg/g	

Future Work

If we measure ATP….

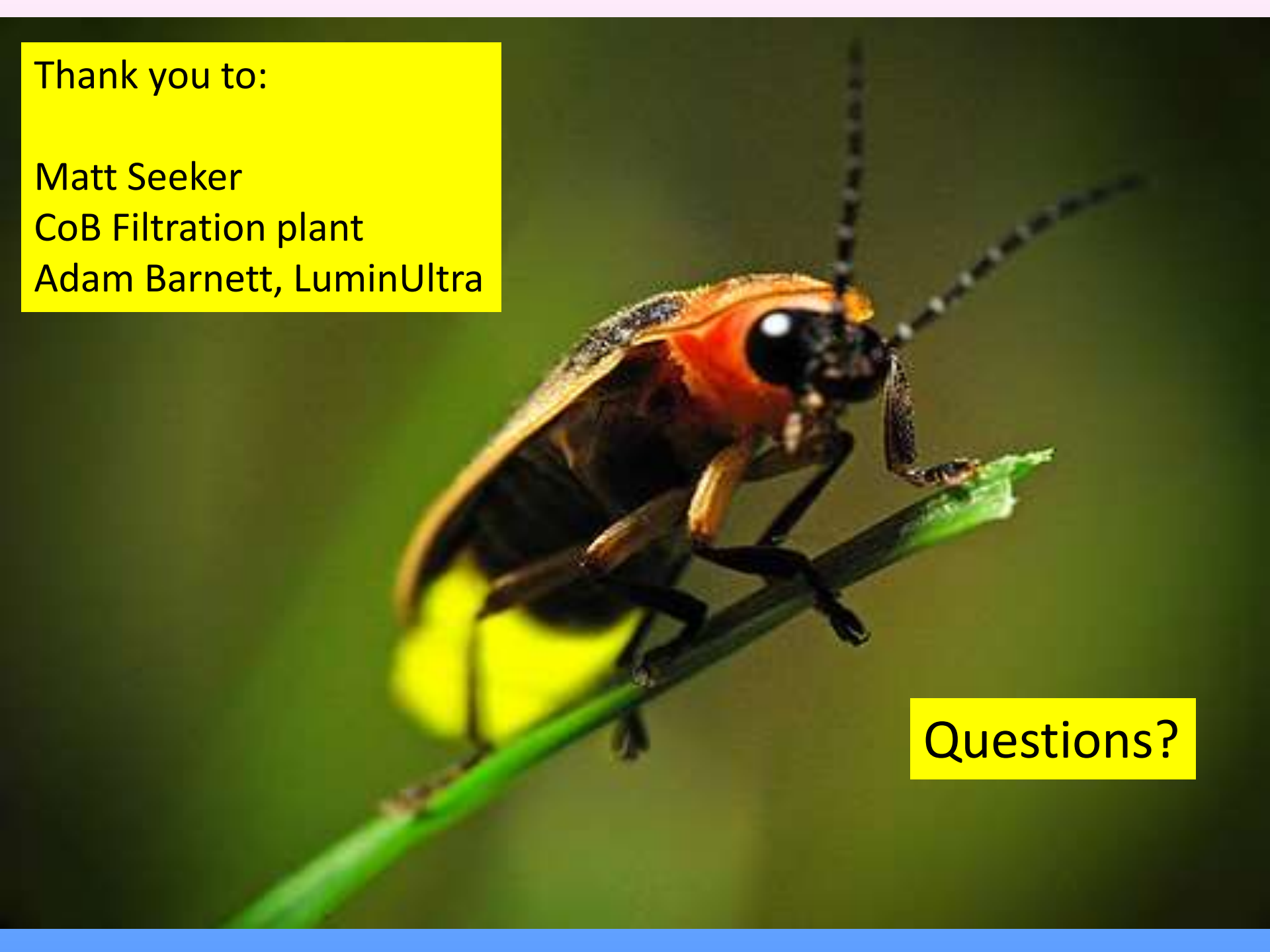


We detect elevated biomass…



Does this correlate with anything else?

- DBPs
- Incidences of diseases
- More…


Thank you to:
Matt Seeker
CoB Filtration plant
Adam Barnett, LuminUltra
Questions?