BIOLOGICAL FILTRATION: METHODS FOR MONITORING AND CONTROL

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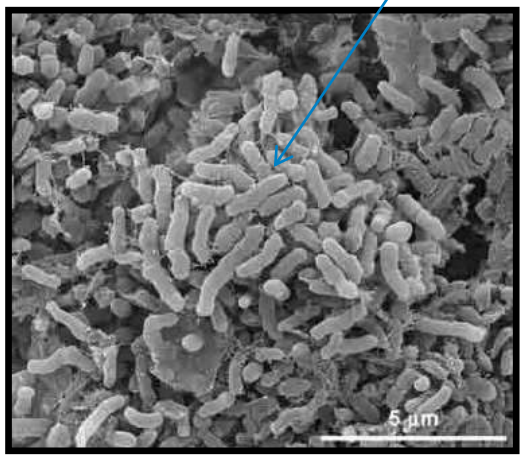
Biological Filtration

GAC Filter

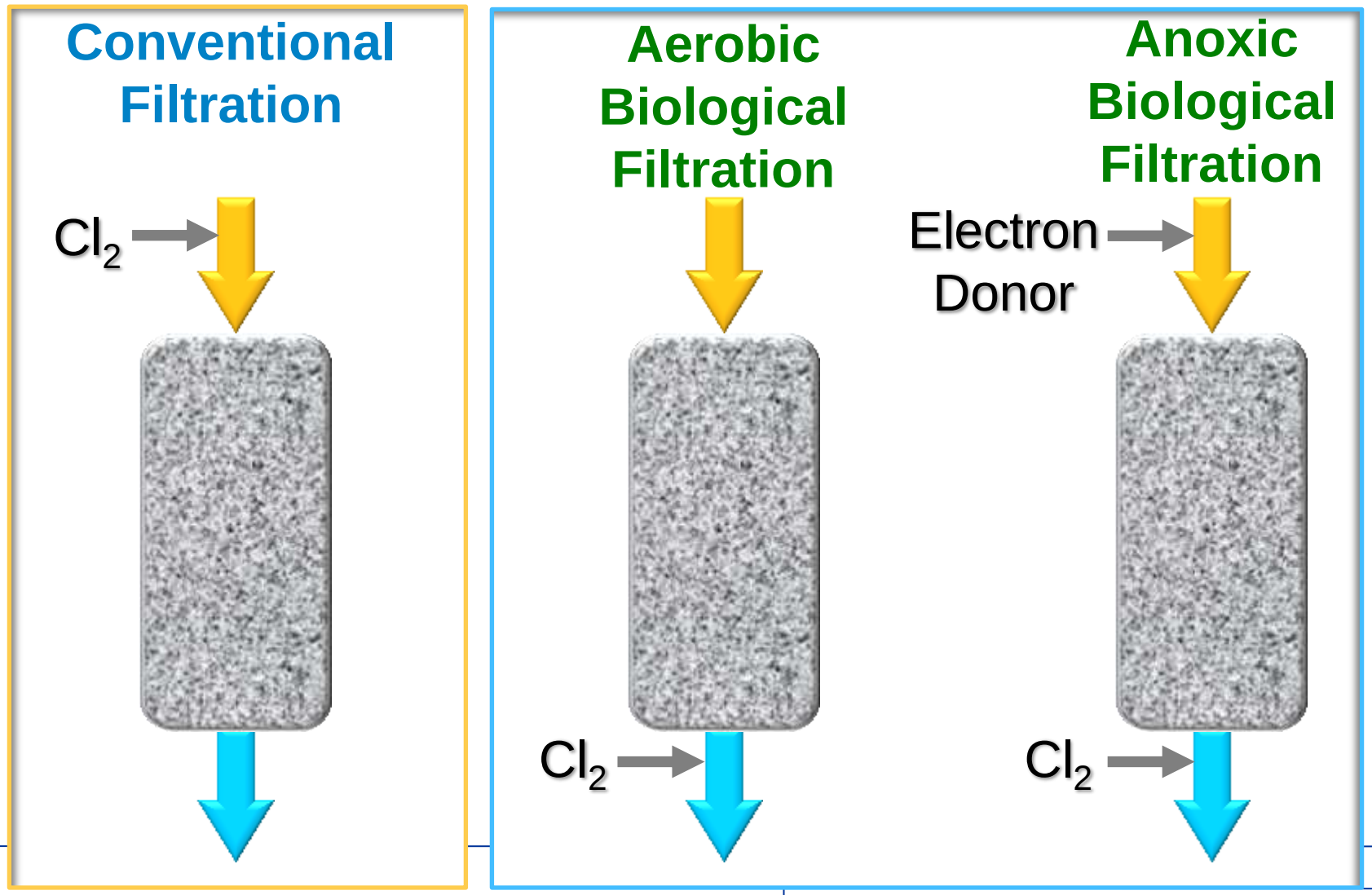
Granular media filtration operated for the dual purpose of particle removal and removal of biodegradable organic matter by biological oxidation

Filter media with biofilm

Biofilm = bacteria + extra polymeric substances



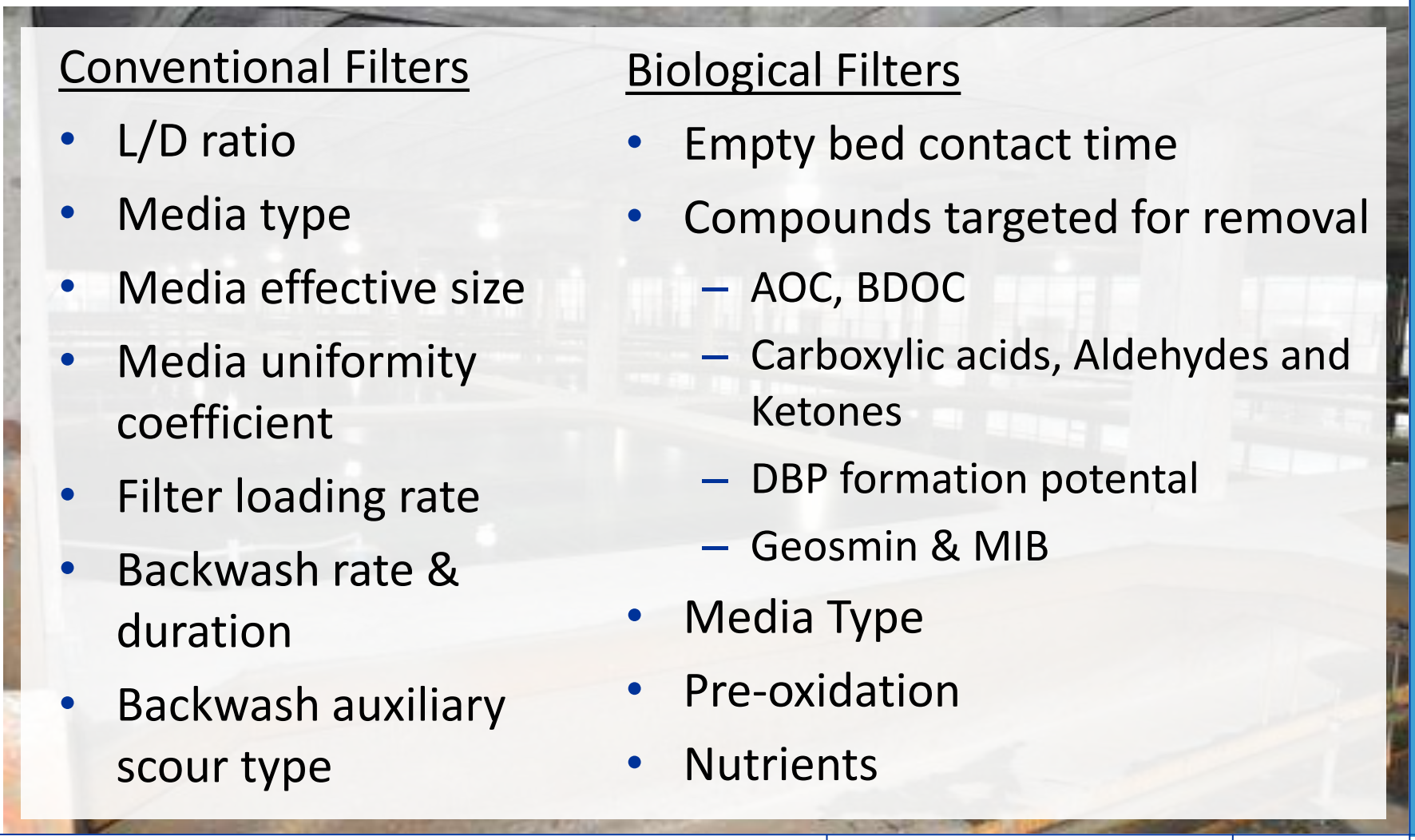
Conventional Filtration vs. Biological Filtration



Design Guidelines for Biological Filters

- There are **no industry-standard guidelines** for designing biological filters
- Ten States Standards does not contain recommendations for design of biological filters
- Ten States Standards states that biological filters may be considered based on pilot studies pre-approved by the reviewing authority

Biological Filter Design and Management



Conventional Filters

- L/D ratio
- Media type
- Media effective size
- Media uniformity coefficient
- Filter loading rate
- Backwash rate & duration
- Backwash auxiliary scour type

Biological Filters

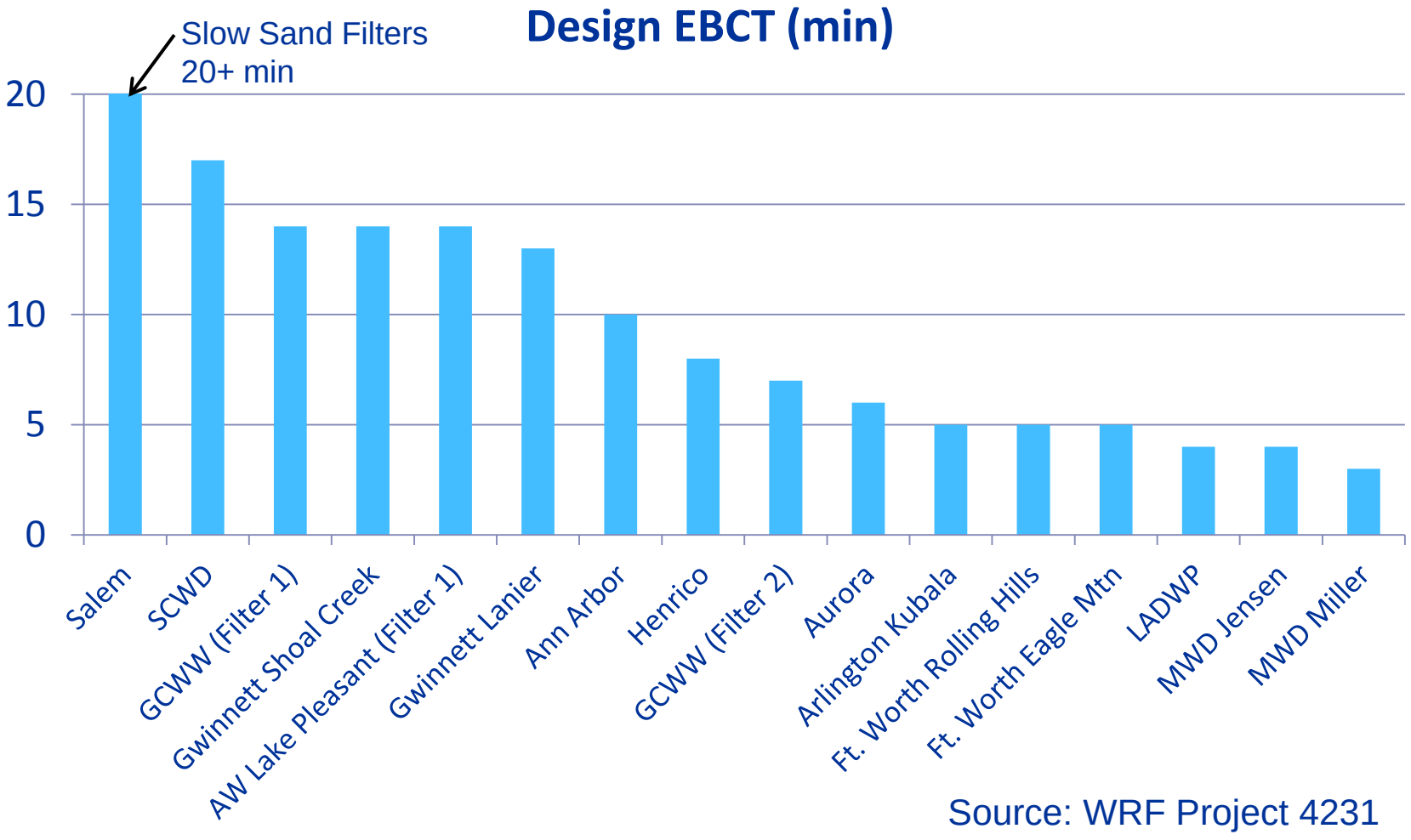
- Empty bed contact time
- Compounds targeted for removal
  - AOC, BDOC
  - Carboxylic acids, Aldehydes and Ketones
  - DBP formation potental
  - Geosmin & MIB
- Media Type
- Pre-oxidation
- Nutrients

Level of control over parameters influencing biological filtration

	Degree of Control (✓) or Effect (♦)			
Parameter	**None**	**Low**	**Moderate**	**High**
Media Type			♦	✓
Chlorination			✓	♦
Filtration rate (EBCT)			✓♦	
Backwashing method			♦	✓
BOM loading		✓	♦	
Temperature	✓			♦
Time since startup	✓			♦

Source: Huck et al. 2000 (AwwaRF Report 90793)

Empty Bed Contact Time for Various Plants with GAC Biological Filters



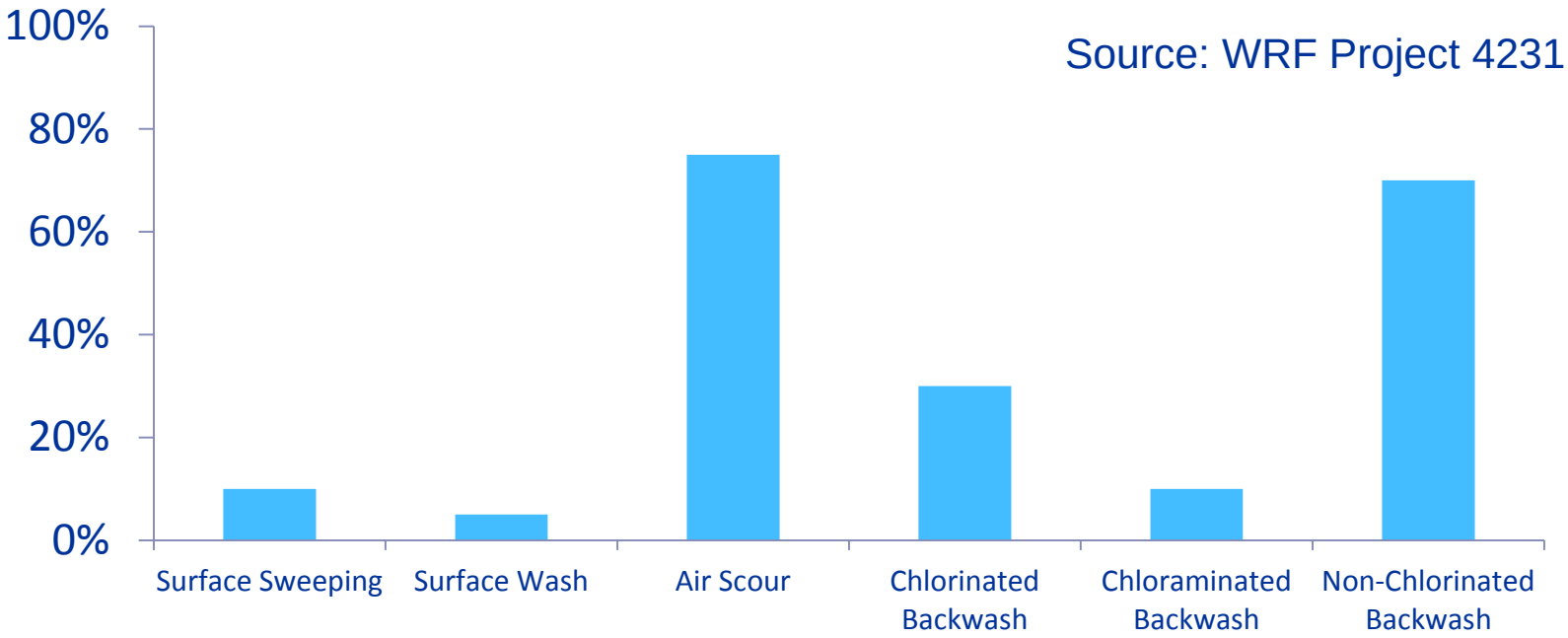
Source: WRF Project 4231

Backwashing Options for Biological Filters

- Probable backwashing intervals at 24 hours
- Simultaneous air and water (collapsed pulsing condition), followed by a standard water fluidization; not found to be detrimental to AOC reduction (many utilities)
- Non-chlorinated backwash water (most common)
- Chlorinated backwash (some still use)
  - Chlorine does decrease biomass
  - BOM removal much less affected
  - Chlorine in air/water improves initial turbidity spike, improves headloss
- Monitor effluent microbial activity

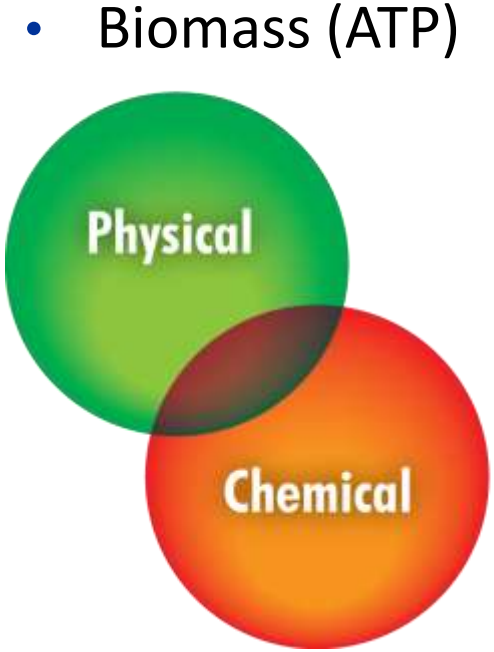
Data from Huck et al. WQTC 1998

Backwashing Strategies by 21 Utilities with Biological Filters



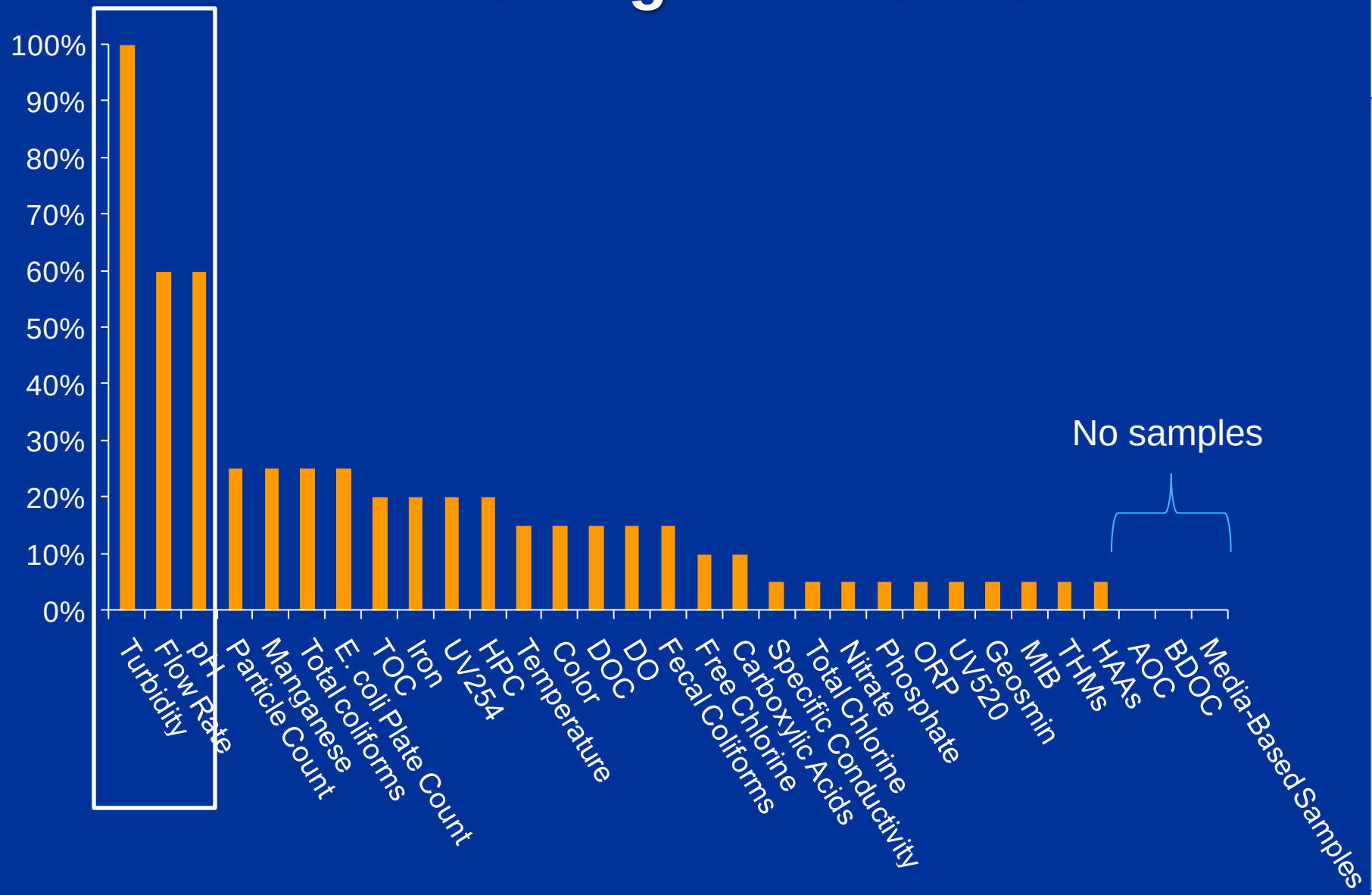
How Do We Monitor & Control Biological Filters Today?

- Differential Pressure
- Turbidity
- Particle counts
- Biomass (ATP)



- Surface Loading Rate
- Pre-Oxidant Concentration
- Coagulant Concentration
- Backwash Duration
- Post-Backwash Rest Duration
- Backwash Disinfectant

Monitoring Parameters



Water Research Foundation Project 4213:
Assessing and Enhancing Biological Filtration

Monitoring and Control Tool Box

Monitoring Tools

Biological

- **DO**
- **ATP**
- Enzyme Activity
- HPC
- EPS
- PLFA
- Electron Transport System Activity
- TRFLP

Organic Carbon

- TOC
- **DOC**
- **BDOC**
- AOC
- **Carboxylic Acids**
- UV254
- UV/VIS Spectra
- SUVA
- Fluorescence Spectroscopy

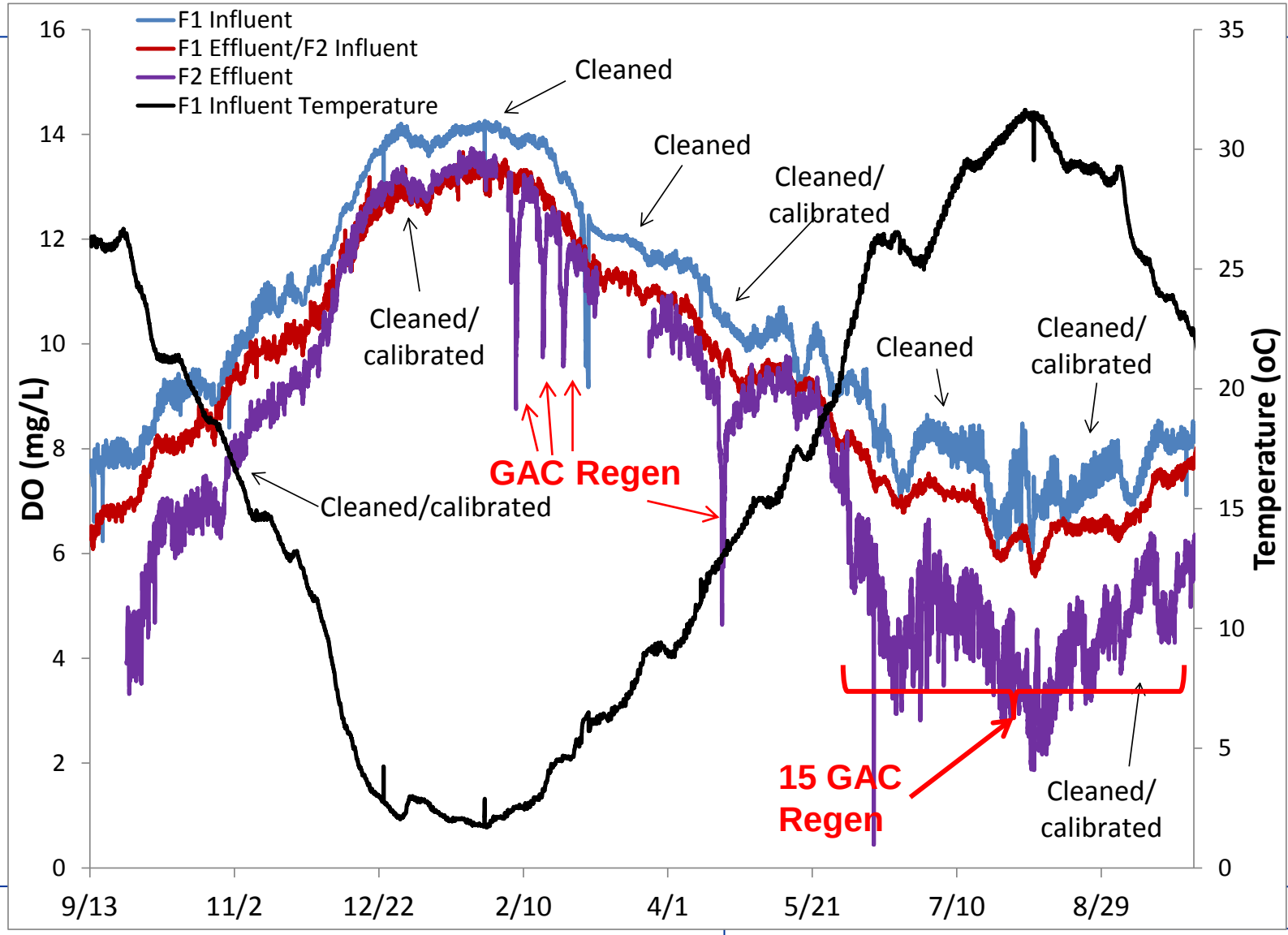
Water Quality

- **Temperature**
- pH
- Turbidity
- **Nutrients (N & P)**
- DBP Formation Potential
- Trace Chemical Constituents

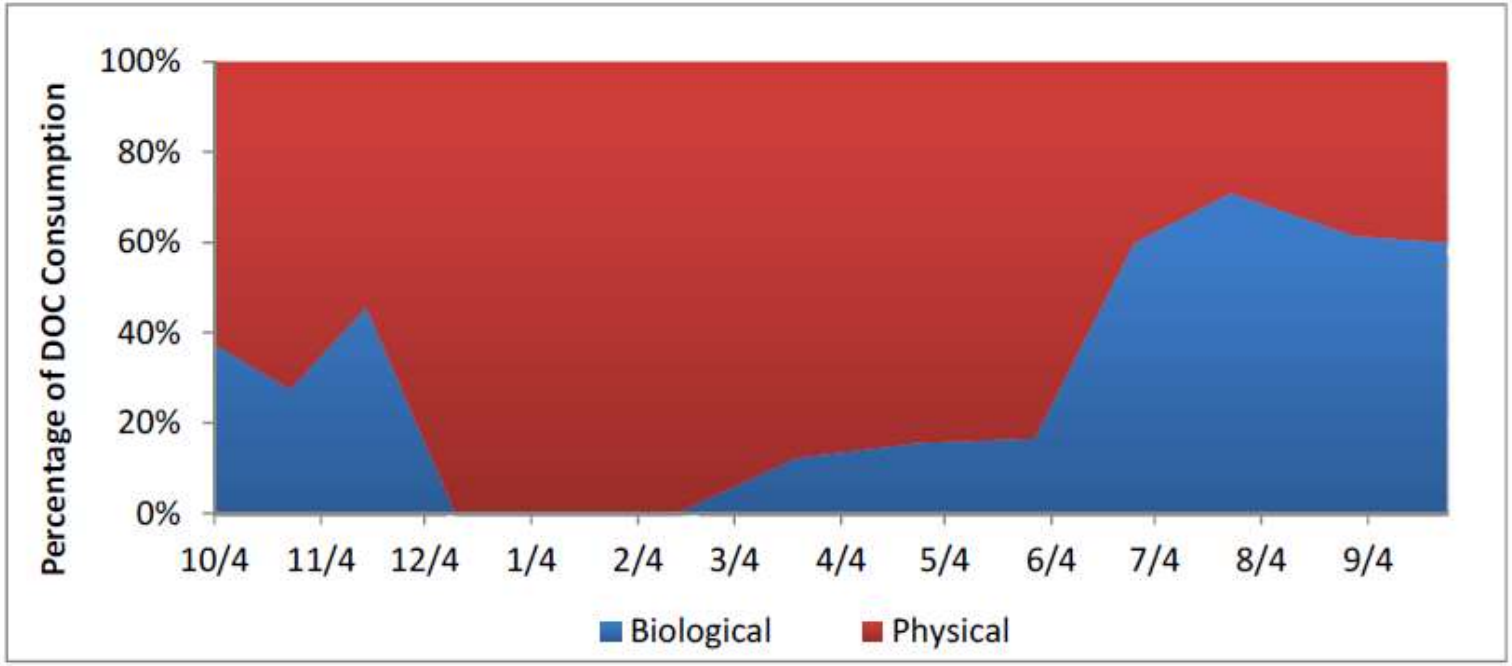
Dissolved Oxygen

- Calculate respirometric potential across filter (DO consumption) as indicator of biological activity
- Grab Samples
  - SM 4500-O
    - Iodometric/Titrimetric
    - Membrane Electrode
- Online Probes
  - Membrane Electrode
  - **Luminescent Dissolved Oxygen Probe** - EPA Method 360.3
    - account for elevation during set-up
    - perform on-site calibration
    - account for percent saturation

Dissolved Oxygen Probes at Utility 14-OH



Biological Organic Carbon Removal on GAC

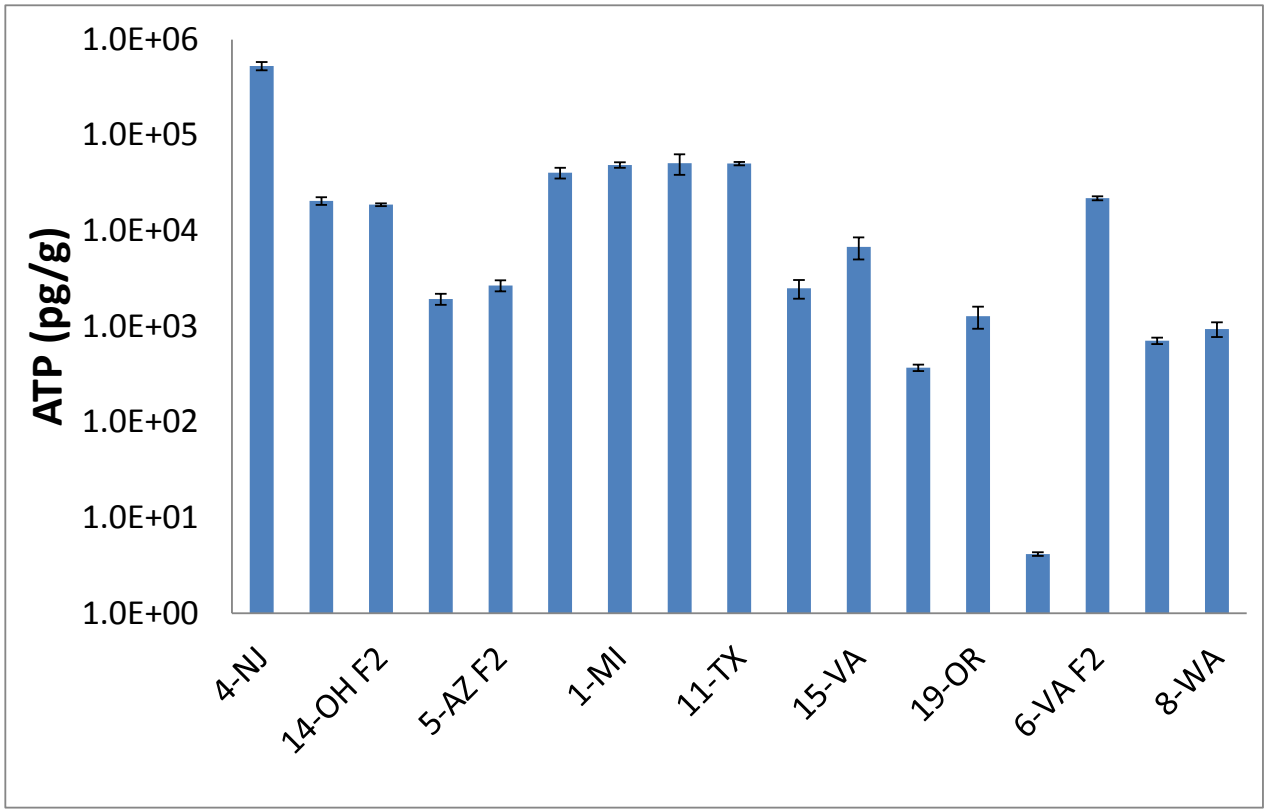


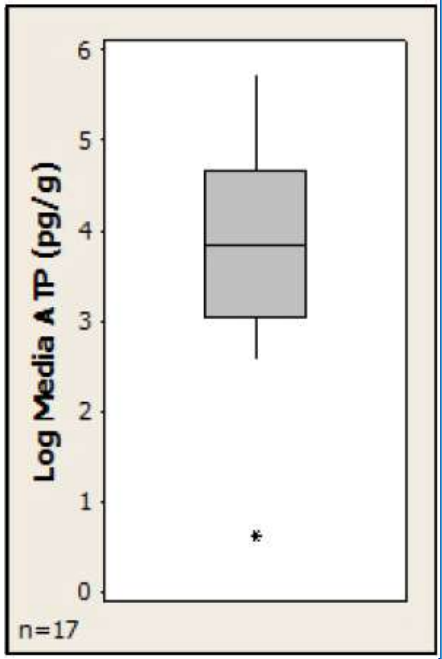
Linked DO consumption to theoretical biological carbon utilization for cellular respiration

ATP

- Luciferase enzyme isolated from firefly
- Consumes ATP and Luciferin to produce light
- Promega test kit
  - GloMax® luminometer
  - BacTiter-Glo™ reagents
- LuminUltra test kit
  - Kikkoman Lumitester
  - Quench-Gone Aqueous® reagents

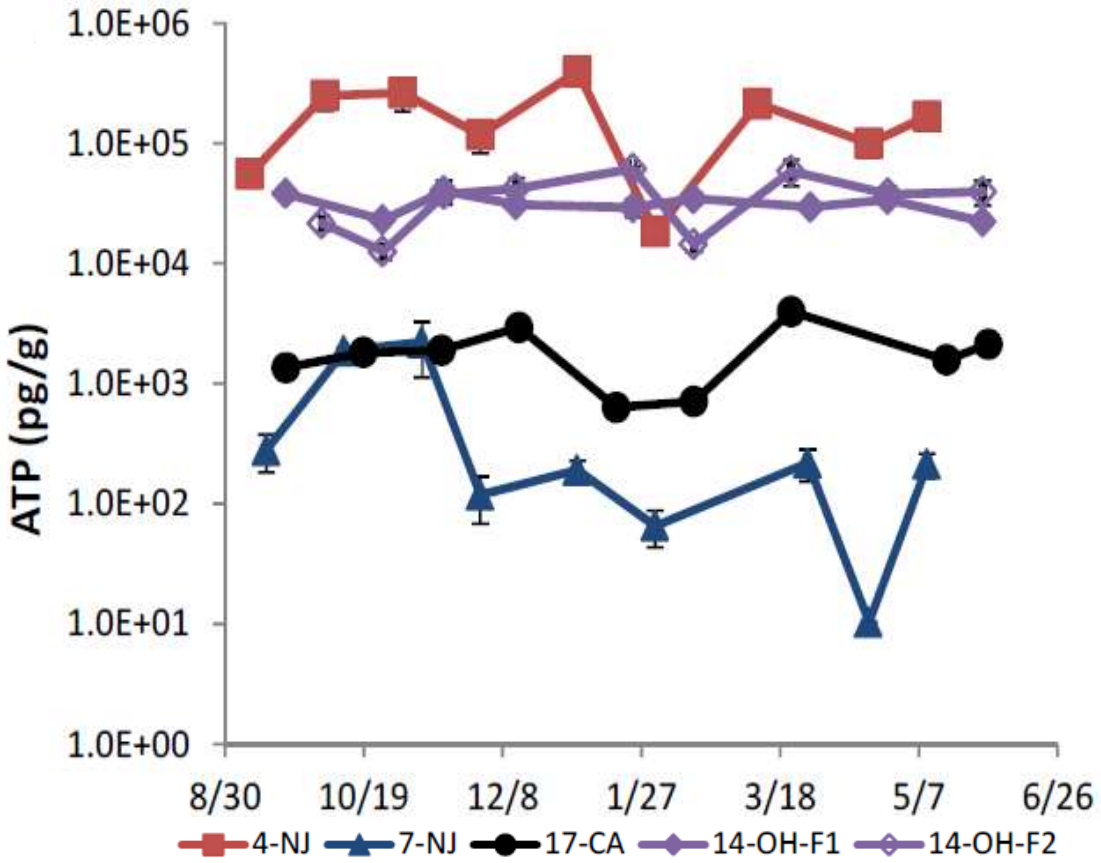
ATP Ranges in Values





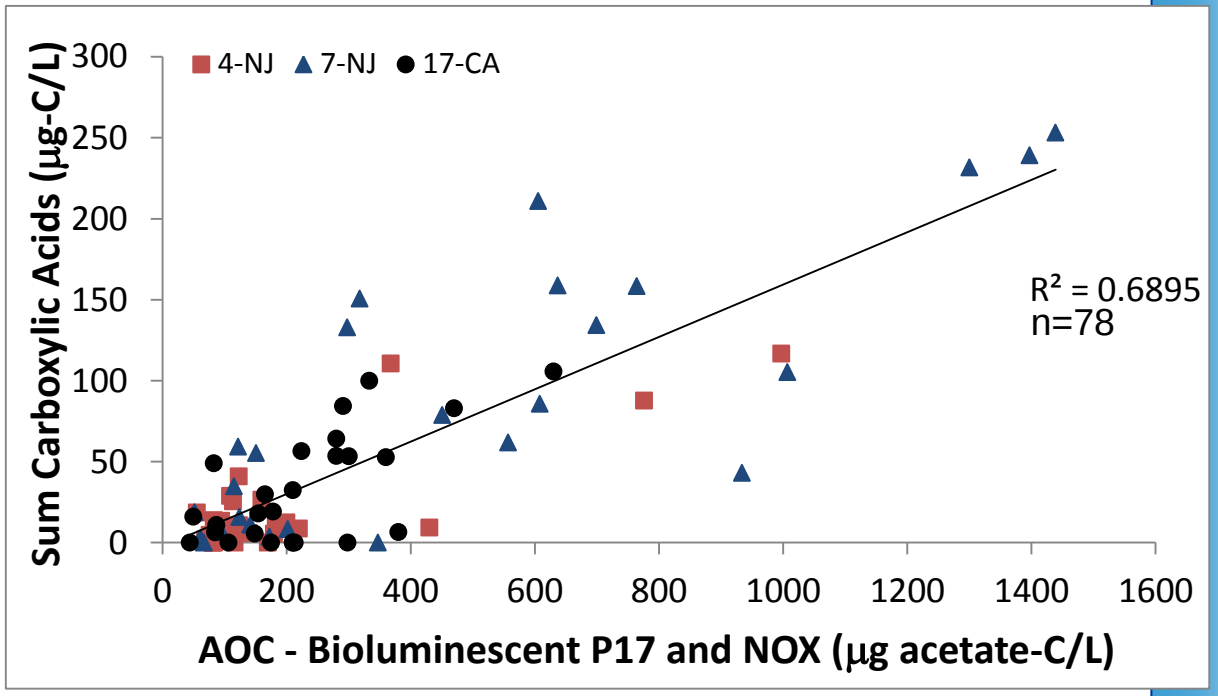
ATP Temporal Variations

Relatively consistent over time



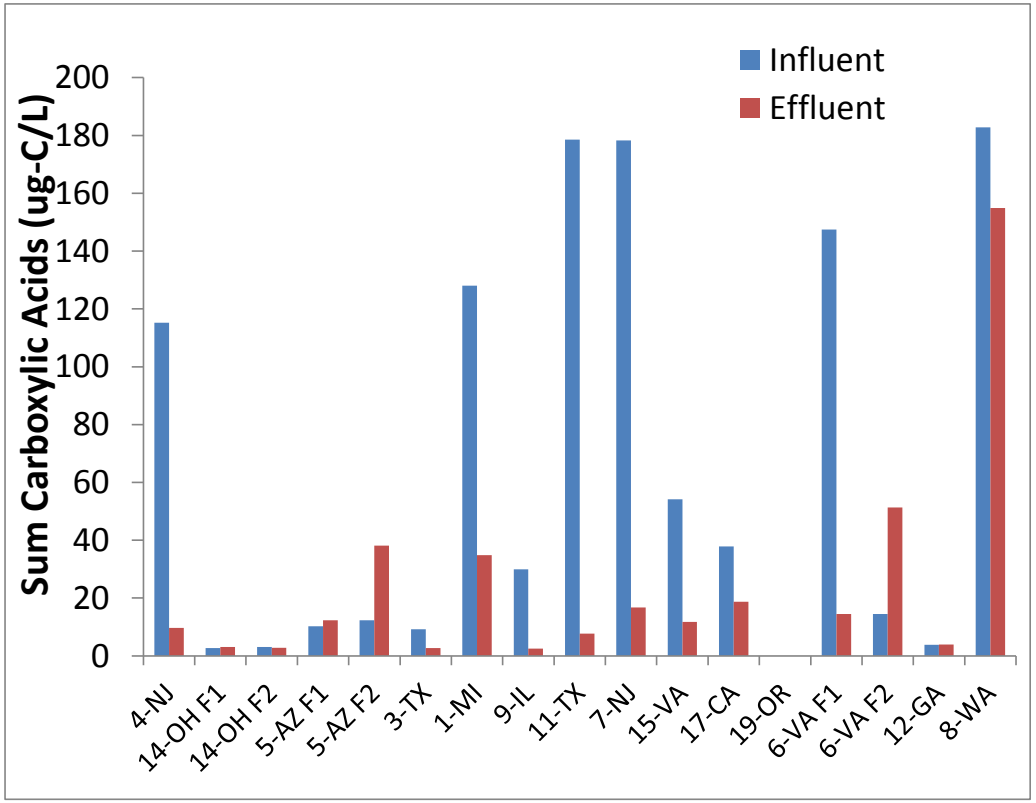
Carboxylic Acids

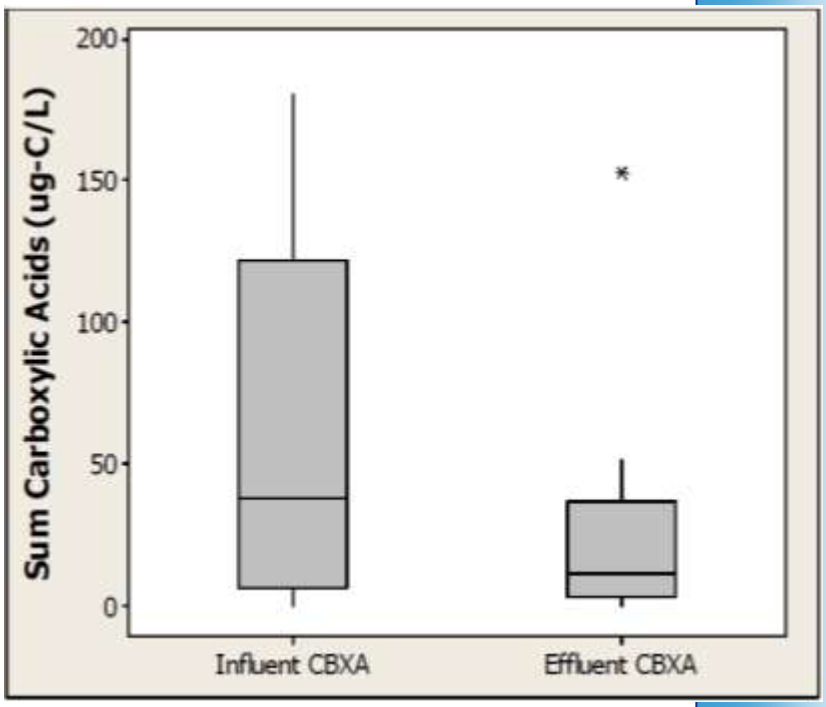
- Most are formed during pre-oxidation
- Low concentrations
  - µg/L or µg/L as C
- Typical acids
  - Acetate
  - Formate
  - Oxalate
  - Pyruvate



- May be used as a proxy for AOC measurements if higher concentrations are present

Carboxylic Acids Range in Values





Tools Recommended for Use

Biological
- ΔDO
- ATP
- EPS

Organic Carbon
- TOC/DOC
- AOC
- Carboxylic Acids
- UV254
- UV spectroscopy
- SUVA

Water Quality
- Temperature
- pH
- Turbidity
- Nutrients (N & P)
- DBP Formation Potential

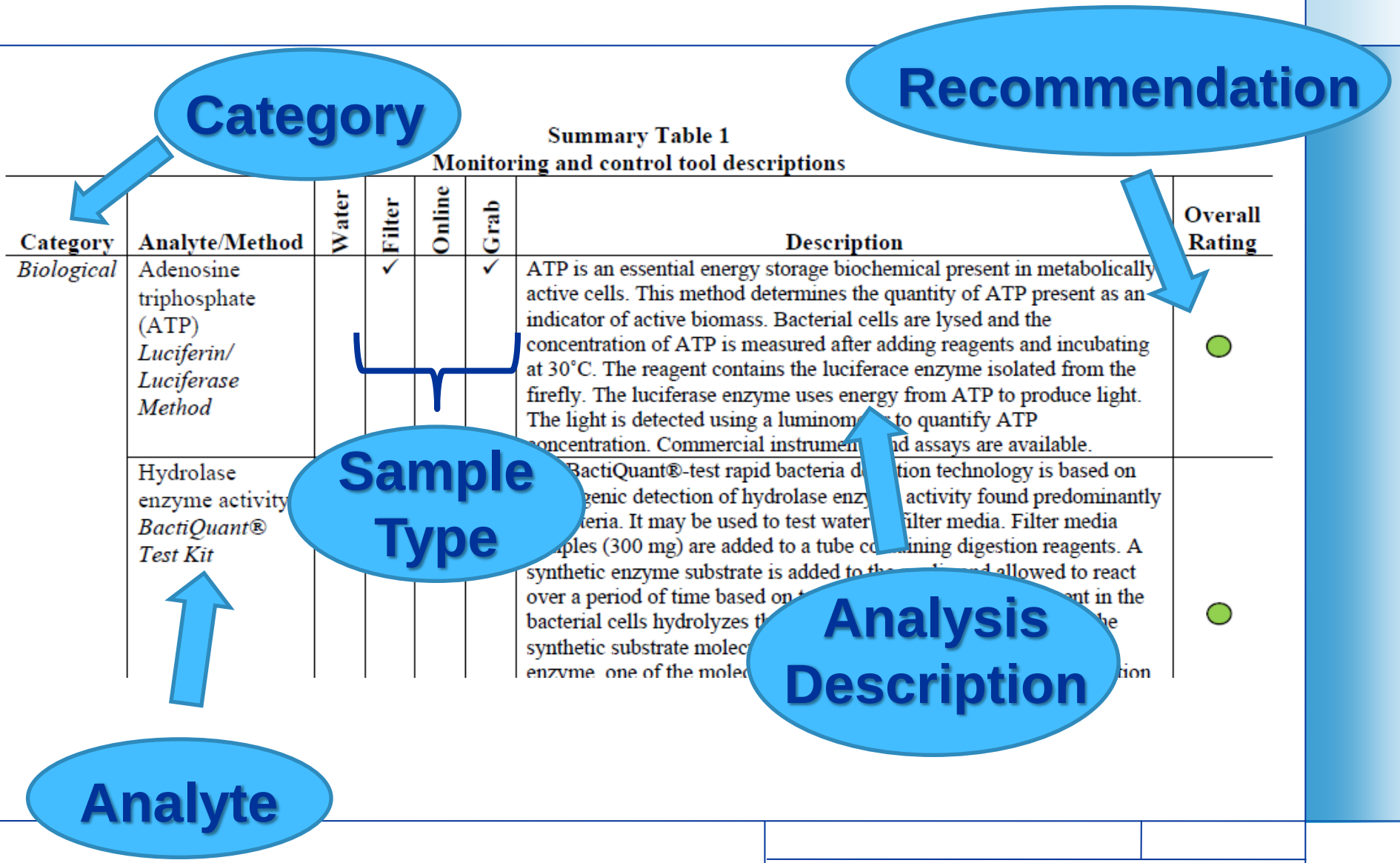
Operational
- Head Loss
- Oxidant Residual

Control
- Oxidant Dose
- Nutrient Dose (phosphate)
- Flow rate/contact time

Monitoring Integration

- Step 1 – Develop Treatment Objectives
- Step 2 – Select Tools
  - Minimum of one tool from each category
- Step 3 – Develop a Baseline
  - Include 1 year of monitoring to benchmark data and assess temporal variability
- Step 4 – Develop a Filter Management Plan
  - Integrate monitoring and control tools for process control
  - Develop benchmarks and set points for treatment objectives
- Step 5 – Revise Management Plan as needed

Biological Filtration Monitoring and Control Toolbox Guidance Manual



Summary Table 1
Monitoring and control tool descriptions

Category	Analyte/Method	Water	Filter	Online	Grab	Description	Overall Rating
Biological	Adenosine triphosphate (ATP) *Luciferin/ Luciferase Method*		✓		✓	ATP is an essential energy storage biochemical present in metabolically active cells. This method determines the quantity of ATP present as an indicator of active biomass. Bacterial cells are lysed and the concentration of ATP is measured after adding reagents and incubating at 30°C. The reagent contains the luciferace enzyme isolated from the firefly. The luciferase enzyme uses energy from ATP to produce light. The light is detected using a luminom[illegible] to quantify ATP [illegible]oncentration. Commercial instrumen[illegible]d assays are available.	
	Hydrolase enzyme activity *BactiQuant® Test Kit*					[illegible]BactiQuant®-test rapid bacteria d[illegible]tion technology is based on [illegible]genic detection of hydrolase enzy[illegible] activity found predominantly [illegible]teria. It may be used to test water[illegible]ilter media. Filter media [illegible]ples (300 mg) are added to a tube co[illegible]ining digestion reagents. A synthetic enzyme substrate is added to th[illegible]d allowed to react over a period of time based on t[illegible]nt in the bacterial cells hydrolyzes th[illegible]he synthetic substrate molec[illegible] enzyme, one of the molec[illegible]tion	

Monitoring and Control Toolbox Guidance Manual

Evaluation Criteria

Category

Summary Table 2
Monitoring tool evaluation results

			Usefulness				Data Quality					Implementability					Cost		
Category	**Analyte**	**Method**	**Metrics for evaluation**	**Correlations to treatment objectives**	**Ability to control**	**Response/turnaround time**	**Precision**	**Accuracy**	**Span**	**Representativeness**	**Selectivity/specificity**	**Technology maturity**	**Training requirements**	**Ease of use**	**Data acquisition requirements**	**Applicability to small utilities**	**Capital**	**Operating and maintenance**	**Overall Rating**
Biological	Adenosine triphosphate (ATP)	Luciferin/Luciferase[1,2]	3	2	2	4	4	5	5	5	5	3	3	3	3	3	4	4	
	[illegible]olase [illegible]yme activity	BactiQuant®	3	2	2	4	5	5	3	4	5	3	3	4	3	3	4	5	
	[illegible]erotrophic [illegible]e count (HPC)	SM 9215 C[G]	3	2	1	2	5	5	5	2	4	5	2	2	2	5		5	

Analyte

Method

Overall Rating

Biological Filtration Monitoring and Control Toolbox Guidance Manual

Biological
Adenosine triphosphate (ATP)
Luciferin/luciferase test kits

Criterion		Rating	Explanation
Usefulness	Metrics for evaluation	3	Ranges in values at 14 full-scale utilities were between 4 and $5x10^5$ picograms (pg) of ATP per gram (g) filter media. Order of magnitude changes over time are considered significant[4].
	Correlations to treatment objectives	2	Biological activity can impact performance but is typically not a limiting factor.
	Ability to control	2	Concentrations are reduced when an oxidant residual is present at the filter influent[4].
	Response/turnaround time	4	Analysis time requires five minutes for the luminescence reading, and 3 hours are needed for kits requiring a media-based calibration curve.
Data Quality	Precision	4	Relative percent difference for field duplicates was on average 43 percent (n=4)[4]. Other assays have shown

- Ratings by category
- Recommendations
- Method Description
- Applicable Treatment Objectives
- Typical ranges
- Interferences
- Implementation Requirements
- Procurement
- References

Conclusions

- Biological filtration is used today for production of high quality water BUT is often treated like a black box
- Innovative tools have recently been developed for practical monitoring and control
- Online tools can be used to monitor biological activity and performance real time, such as ΔDO and UV
- Biological activity can be assessed through various techniques including ATP and ΔDO
- Use these tools in combination with process knowledge and SCADA data
- These tools will facilitate optimization and enhancement of biological filtration

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- 21 Utilities

Report and **Guidance Document** are **FREE** and available for download!

http://www.waterrf.org/Pages/Projects.aspx?PID=4231

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