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Cyanotoxin Expert Panel

Technical Session 5

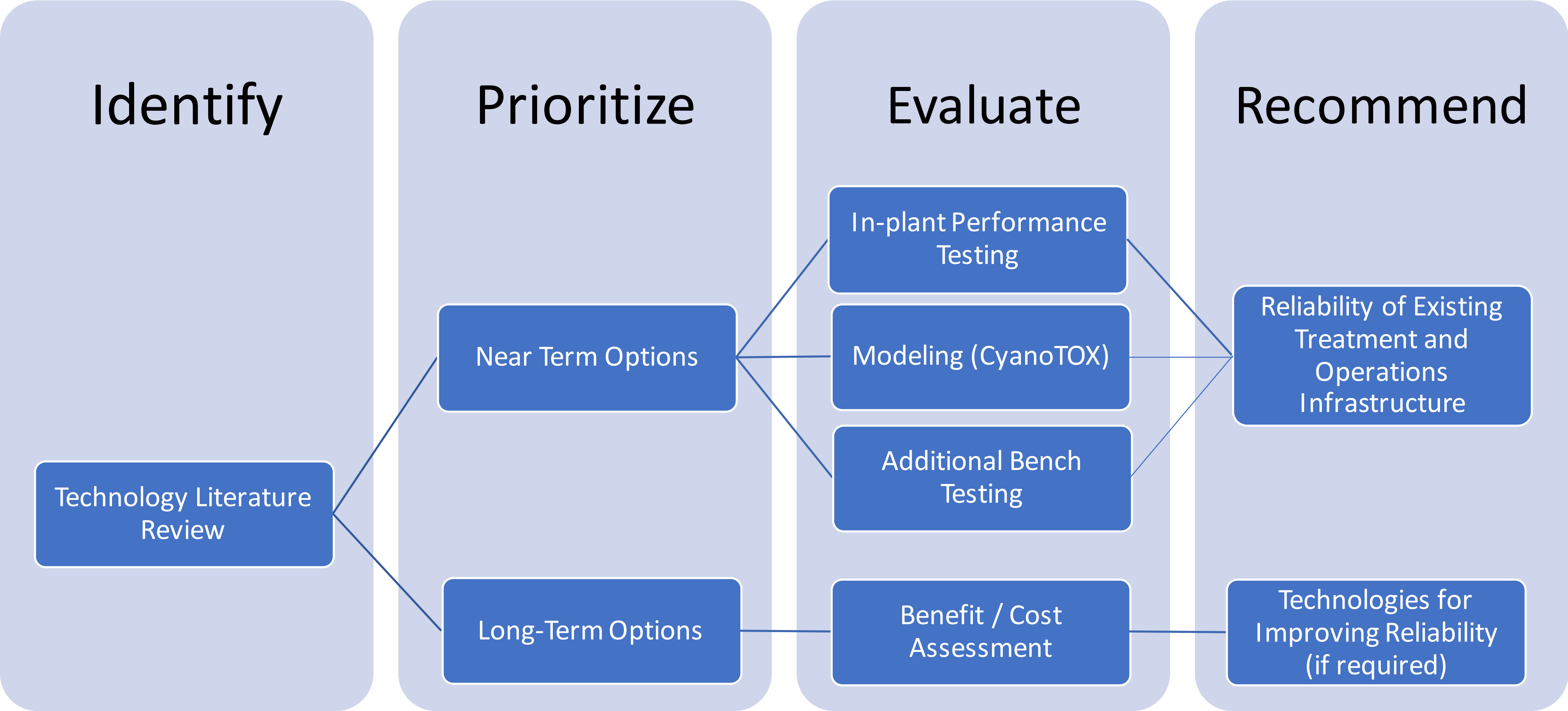
September 14, 2021 | 12:30 – 2:30 pm

Public Works Conference Room & Virtual Teams Meeting

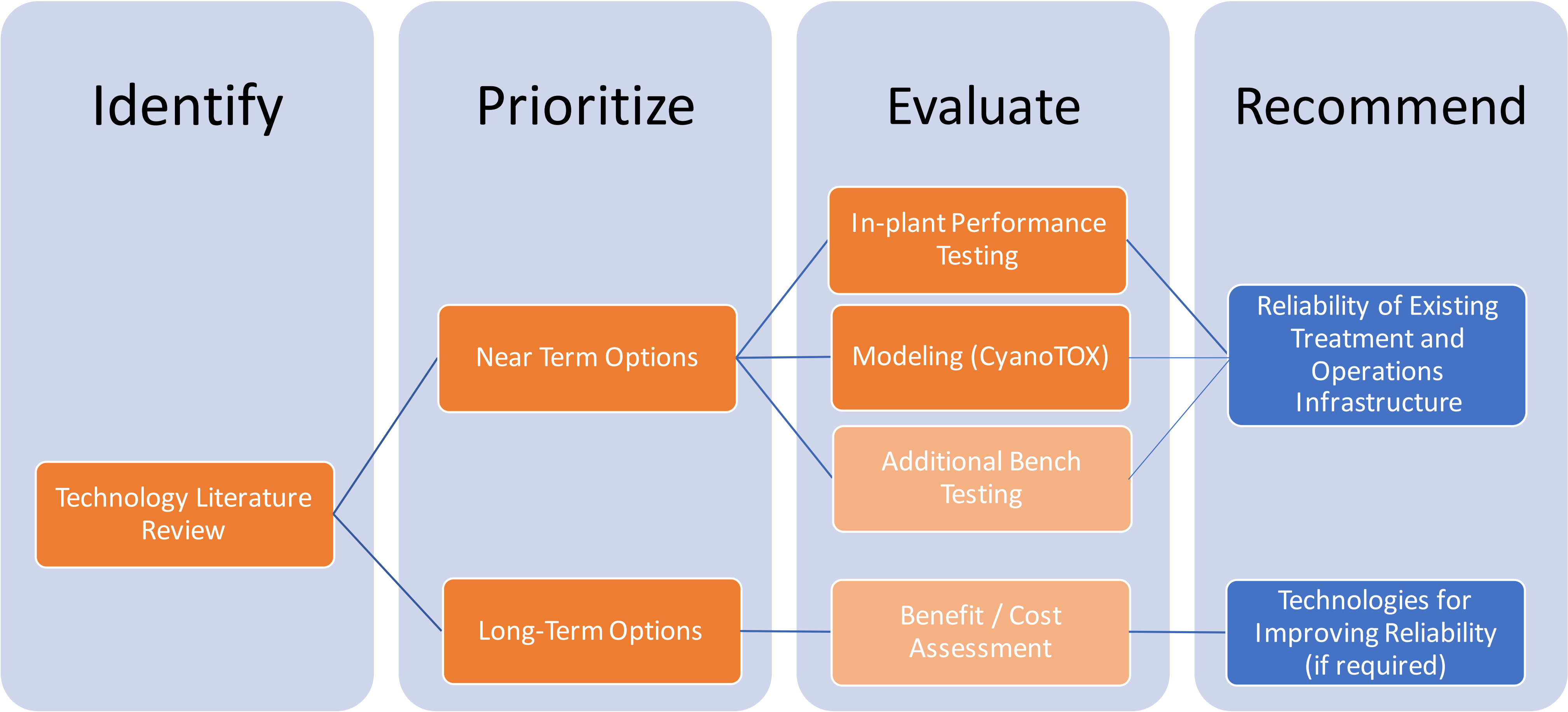
Agenda

12:30 pm	Introduction
12:35	Treatment & Operations Updates (Erik Rosenfeldt, Bill Becker)
1:35	Source Water Quality & Operations Updates (Chandra Mysore)
2:25 pm	Next Steps & Adjourn

Treatment and Ops Evaluation Strategy



Treatment and Ops Evaluation Strategy – Discussing Today



Treatment and Ops Evaluation Strategy – Literature Review

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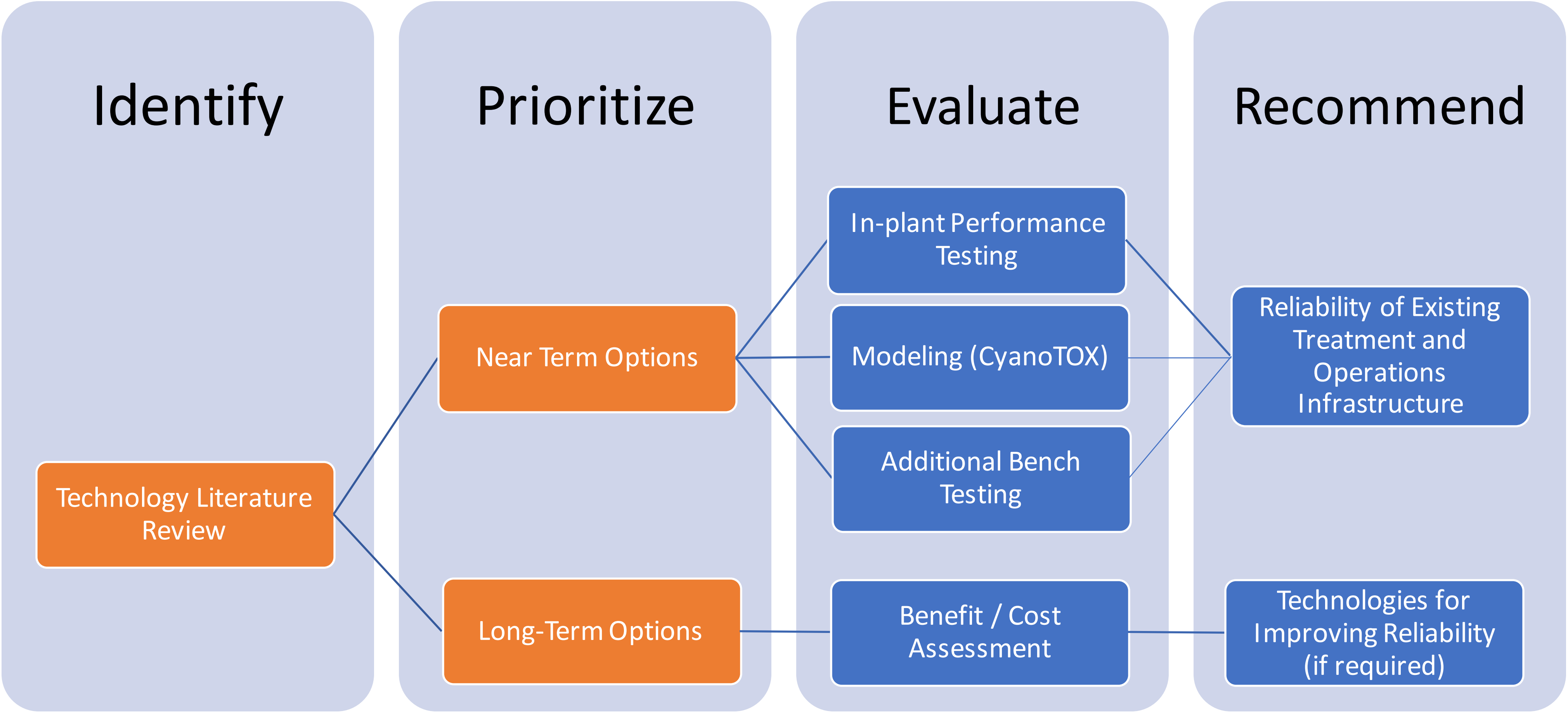

Literature Review - Effective Algal Cell and Toxin Removal Processes

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- Water Research Foundation 4692
  - Eric Wert
  - Arash Zamyadi
  - Craig Adams
  - Erik Rosenfeldt
  - Katherine Greenstein
  - Djanette Khiari

- Access the file through web or QR code
  - https://www.waterrf.org/system/files/resource/2019-08/DRPT-4692b.pdf

Literature Review - Effective Algal Cell and Toxin Removal Processes

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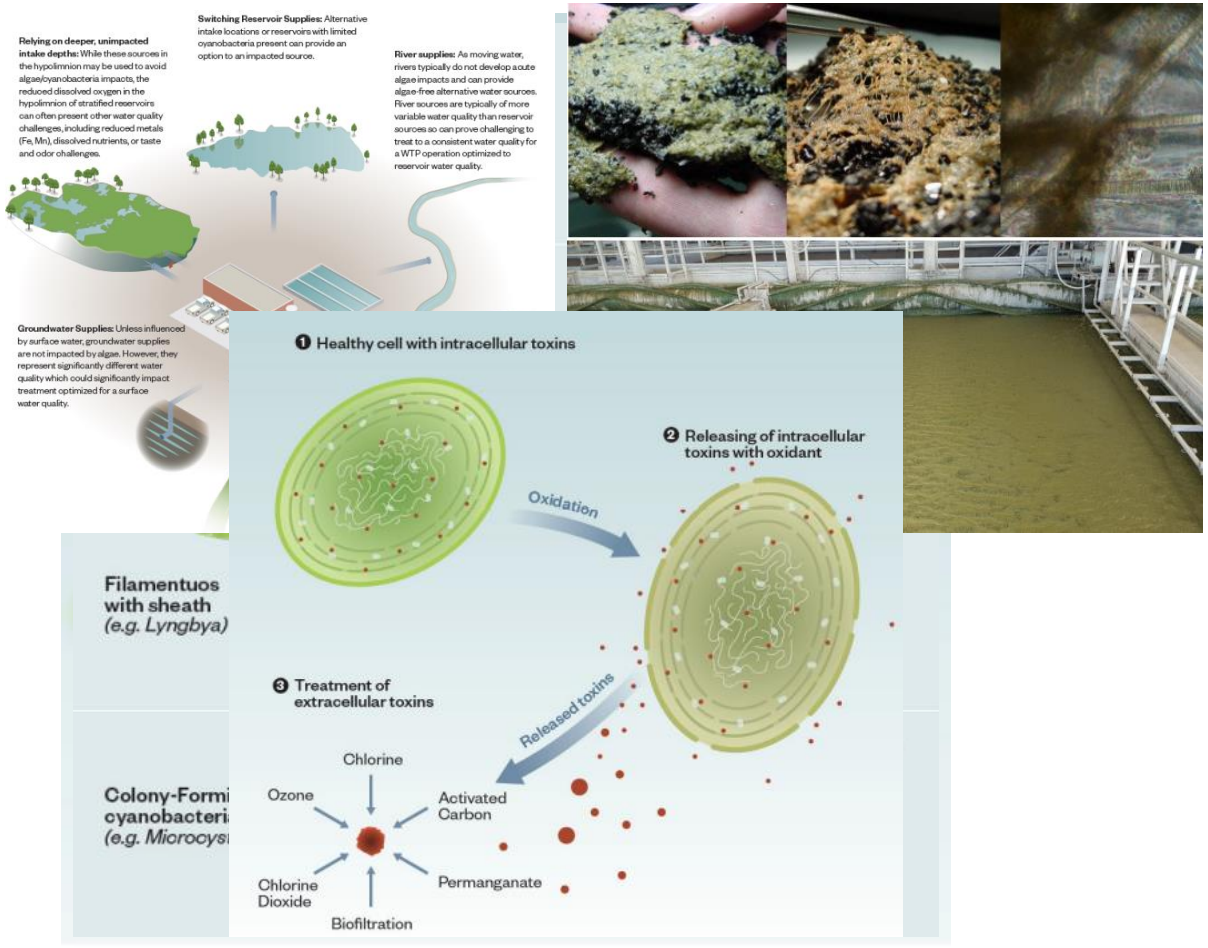
- Concepts Described include
  - Intracellular vs. Extracellular Toxins
  - Cell Morphology Impacts on Treatment
  - Strategies for Managing Cyanobacteria Cells and Intracellular Cyanotoxins
    - Manage Sources
    - Remove Cells Intact
    - “Release and Treat”



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Literature Review - Effective Algal Cell and Toxin Removal Processes

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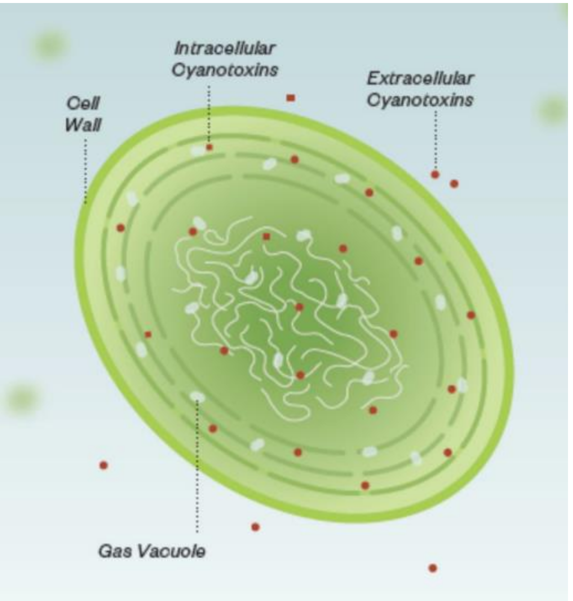
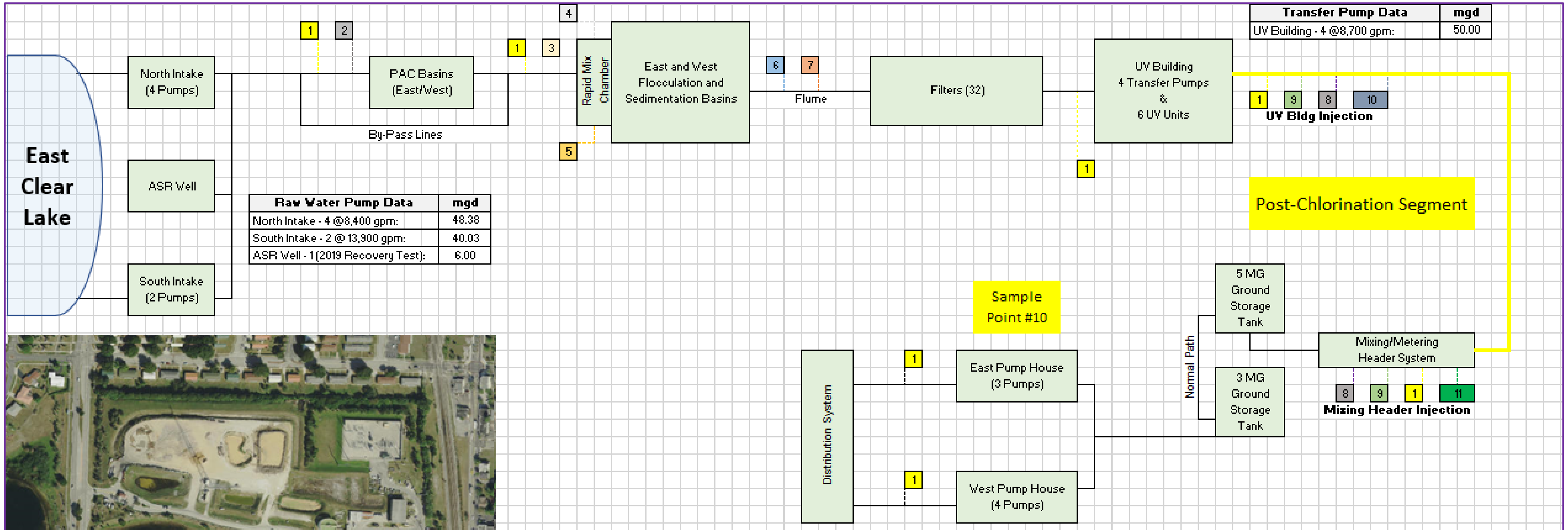


	Physicochemical Processes										
	Sedimentation		Filtration				Membranes			Sorption	
	Coag/Floc/ Sed	Coag/DAF	Direct filtration w/ coag	Direct filtration w/o coag	Bank filtration	Biofiltration	RO	NF	MF	PAC	GAC
Cyanobacteria Cell Removal	~ 90%	50 - 100%	Likely	Possible	Likely	Likely	Effective	> 97%	> 97%	No	Likely
Microcystin	Not Expected	Not Expected	Not Expected	Not Expected	Possible	Likely	Effective	Likely	No	Varied	Likely*
Cylindrospermopsin	Not Expected	Not Expected	Not Expected	Not Expected	Possible	Likely	Likely	Likely	No	Varied	Likely*
Anatoxin A	Not Expected	Not Expected	Not Expected	Not Expected	Possible	Possible	Likely	Likely	No	Varied	Likely*
Saxitoxin	Not Expected	Not Expected	Not Expected	Not Expected	Possible	N/A	Likely	Likely	No	Varied	Likely*
MIB and geosmin	Not Expected	Not Expected	Not Expected	Not Expected	Possible	Likely	Effective	Likely	No	Varied	Likely*

* Compound is well removed until carbon capacity is exhausted

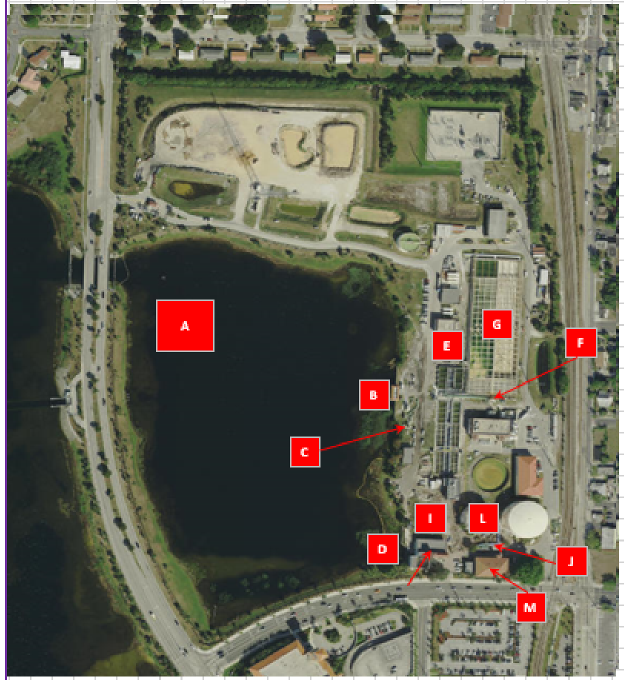
Oxidant	Microcystins	Microcystin-LA	Cylindro-spermopsin	Anatoxin A	Saxitoxins	GTX2, GTX3 and C1, C2	Nodularins	MIB and geosmin	BMAA
Free chlorine	pH		pH	Slow/no oxidation			pH		pH
Monochloramine	Slow/no oxidation					?			?
Chlorine dioxide	Slow/no oxidation					?	?		?
Permanganate						?	?	?	Slow
Ozone			pH	pH				(HO* only)	pH
Hydroxyl radical					?				pH
UV	High doses	High doses	High doses	High doses	?	?	?	High doses	High doses

West Palm Beach Process



Transfer Pump Data	mgd
UV Building - 4 @8,700 gpm:	50.00

Raw Water Pump Data	mgd
North Intake - 4 @8,400 gpm:	48.38
South Intake - 2 @ 13,900 gpm:	40.03
ASR Well - 1 (2019 Recovery Test):	6.00



Finished Water Pump Data	mgd
East Pump House (2 @ 11,100 gpm)	31.97
East Pump House (1 @ 5,700 gpm)	40.03
West Pump House (2 @ 8,000 gpm)	23.04
West Pump House (2 @ 12,000 gpm)	34.56

Facility Locations	
A	East Clear Lake
B	North Intake
C	ASR Well
D	South Intake
E	PAC Basin
F	Rapid Mix Chamber
G	Flocculation/Sedimentation Basins
H	Filters
I	UV Building
J	Mixing/Metering Header
K	5 MG Ground Storage Tank
L	3 MG Ground Storage Tank
M	East Pump House
N	West Pump House

Chemical Injection Points	
1	Hypochlorite
2	Powered Activated Carbon
3	Cationic Polymer
4	Lime (Slaked)
5	Ferric Sulfate
6	Carbon Dioxide
7	Filter Aid
8	Sodium Hydroxide
9	Ammonia
10	Fluoride
11	Orthophosphate

Locations Approximate

Literature Review - Effective Algal Cell and Toxin Removal Processes

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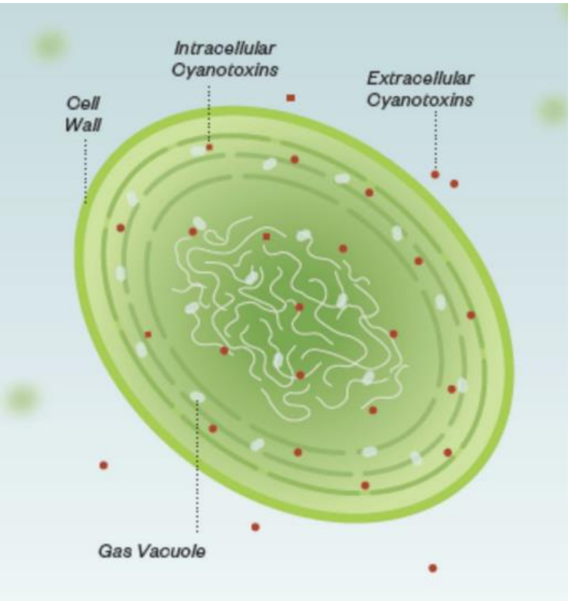

Existing Treatment Processes

Potential Future Processes

	Physicochemical Processes										
	Sedimentation		Filtration				Membranes			Sorption	
	Coag/Floc/ Sed	Coag/DAF	Direct filtration w/ coag	Direct filtration w/o coag	Bank filtration	Biofiltration	RO	NF	MF	PAC	GAC
Cyanobacteria Cell Removal	~ 90%	50 - 100%	Likely	Possible	Likely	Likely	Effective	> 97%	> 97%	No	Likely
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Anatoxin A	Not Expected	Not Expected	Not Expected	Not Expected	Possible	Possible	Likely	Likely	No	Varied	Likely*
Saxitoxin	Not Expected	Not Expected	Not Expected	Not Expected	Possible	N/A	Likely	Likely	No	Varied	Likely*
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Free chlorine	pH		pH	Slow/no oxidation			pH		pH
Monochloramine	Slow/no oxidation					?			?
Chlorine dioxide	Slow/no oxidation					?	?		?
Permanganate						?	?	?	Slow
Ozone			pH	pH				(HO* only)	pH
Hydroxyl radical					?				pH
UV	High doses	High doses	High doses	High doses	?	?	?	High doses	High doses

West Palm Beach Process

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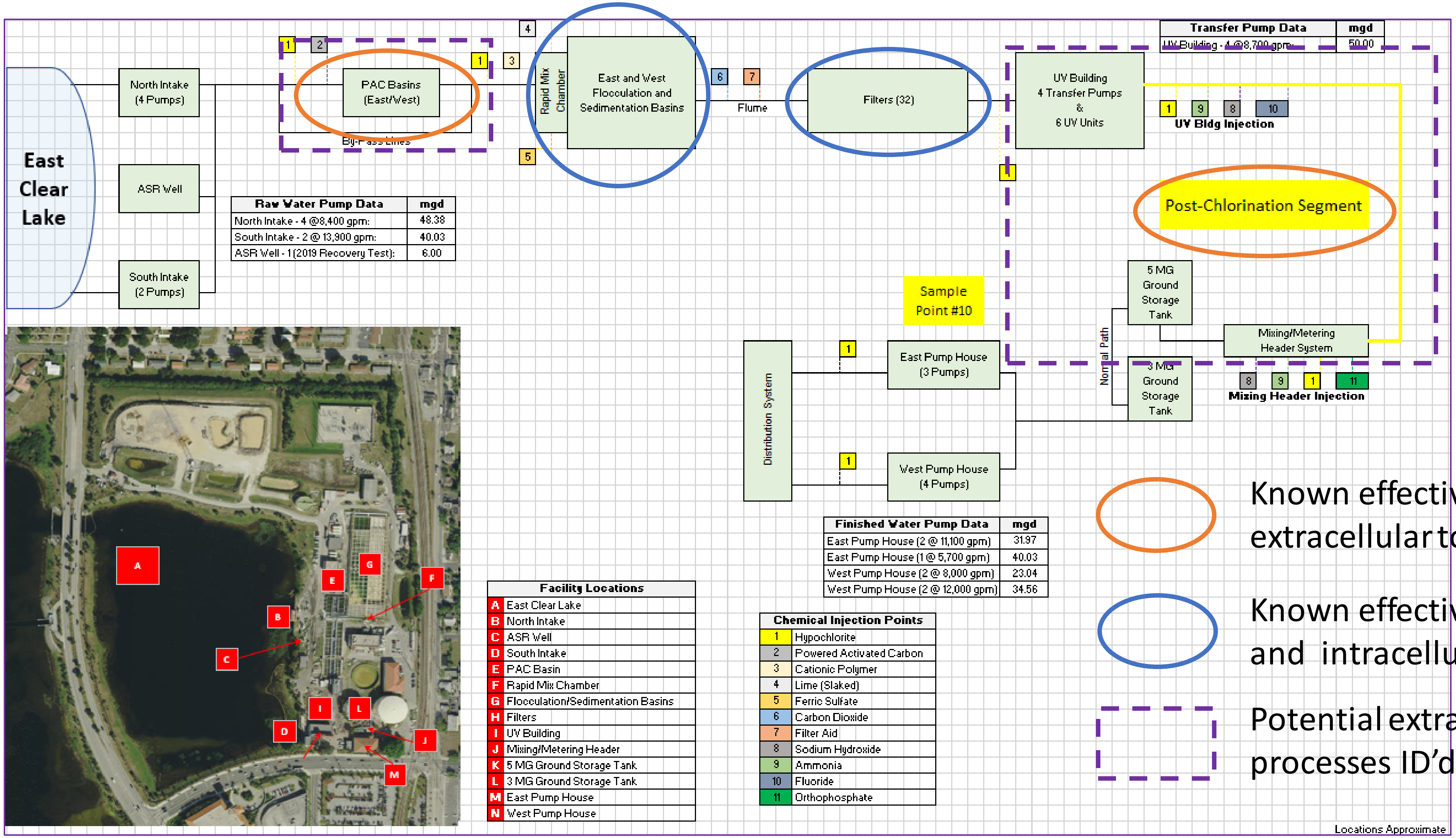

Known effective processes for extracellular toxin removal

Known effective processes for cell and intracellular toxin removal

Potential extracellular toxin removal processes ID'd for optimization

Literature Review and Prioritization Results

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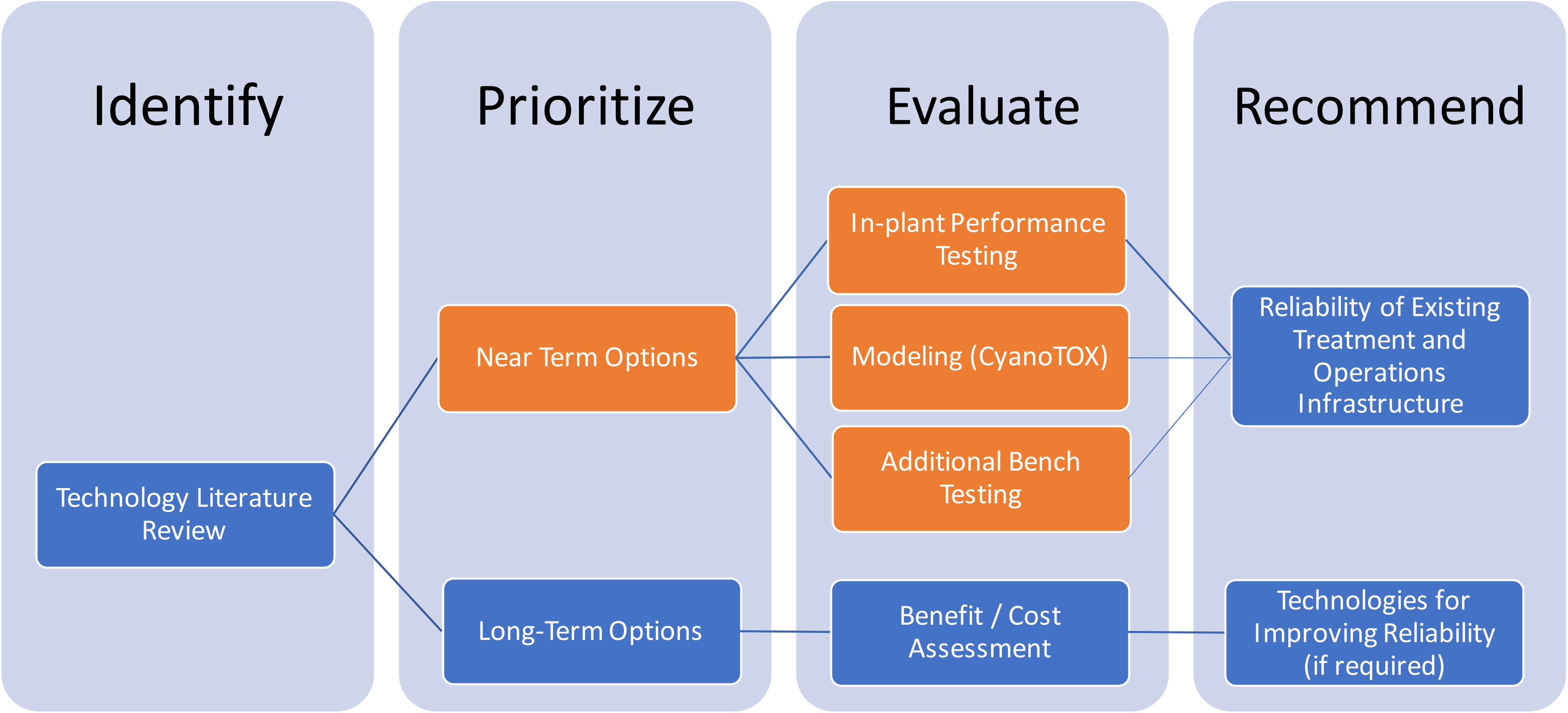
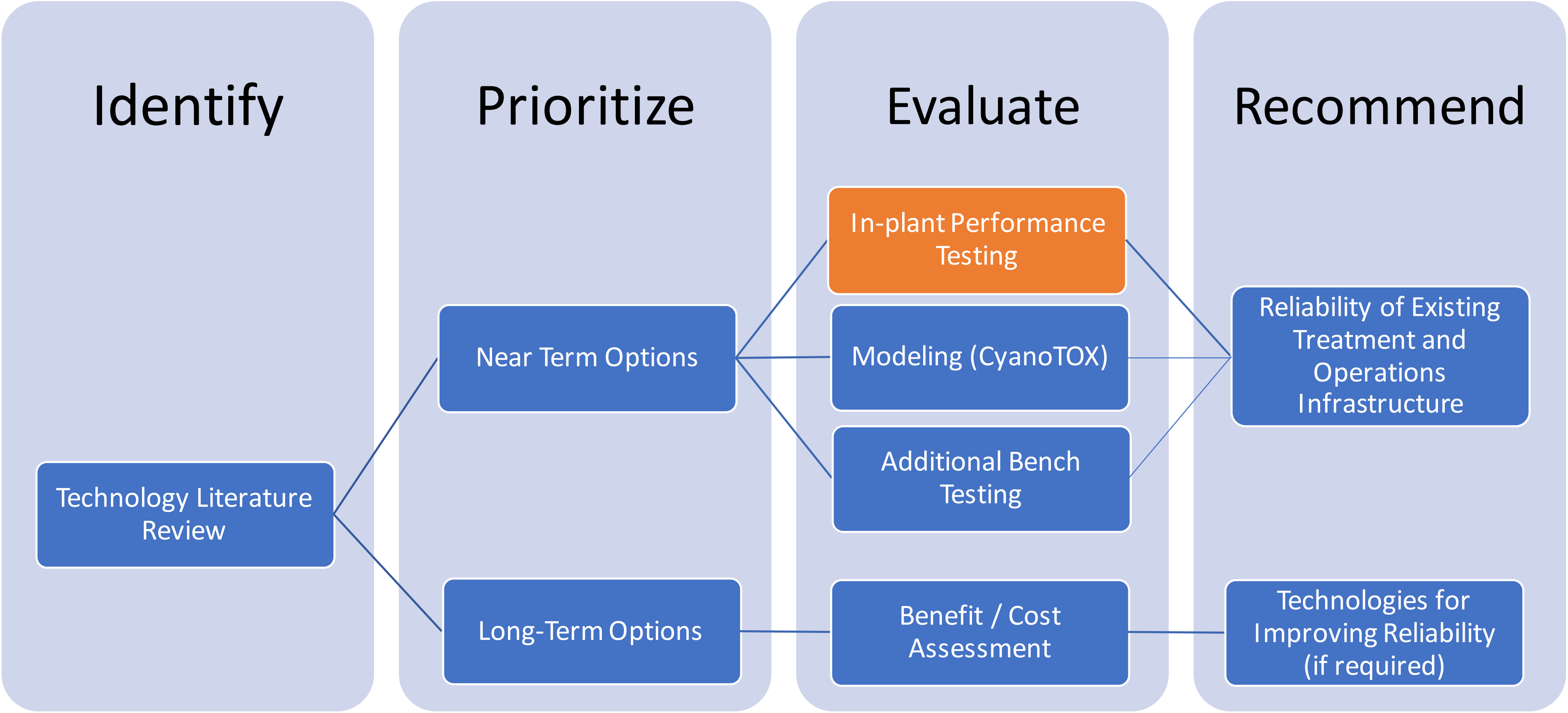
- Near-Term Options for Further Study
  - Focusing on optimizing within existing infrastructure constraints
    - **PAC, chlorine oxidation**
  - Considering both benefits and drawbacks of treatment options
  - **Modeling, in-plant testing, additional bench testing where needed**
  - Recommendations to include optimization strategies to enhance performance and definition of limits of reliable performance

- Future Long-Term Options for Consideration
  - Several advanced treatment options effective for cylindrospermopsin control
    - **Ozone, GAC, Advanced Oxidation, Reverse Osmosis / Nanofiltration Membranes**
  - Will consider feasibility, benefits, costs, and drawbacks of technologies
  - Recommendations may include technologies for further consideration

Treatment and Ops Evaluation Strategy – Evaluate Near-Term Options



Treatment and Ops Evaluation Strategy – In-plant Testing



In-Plant Performance Testing

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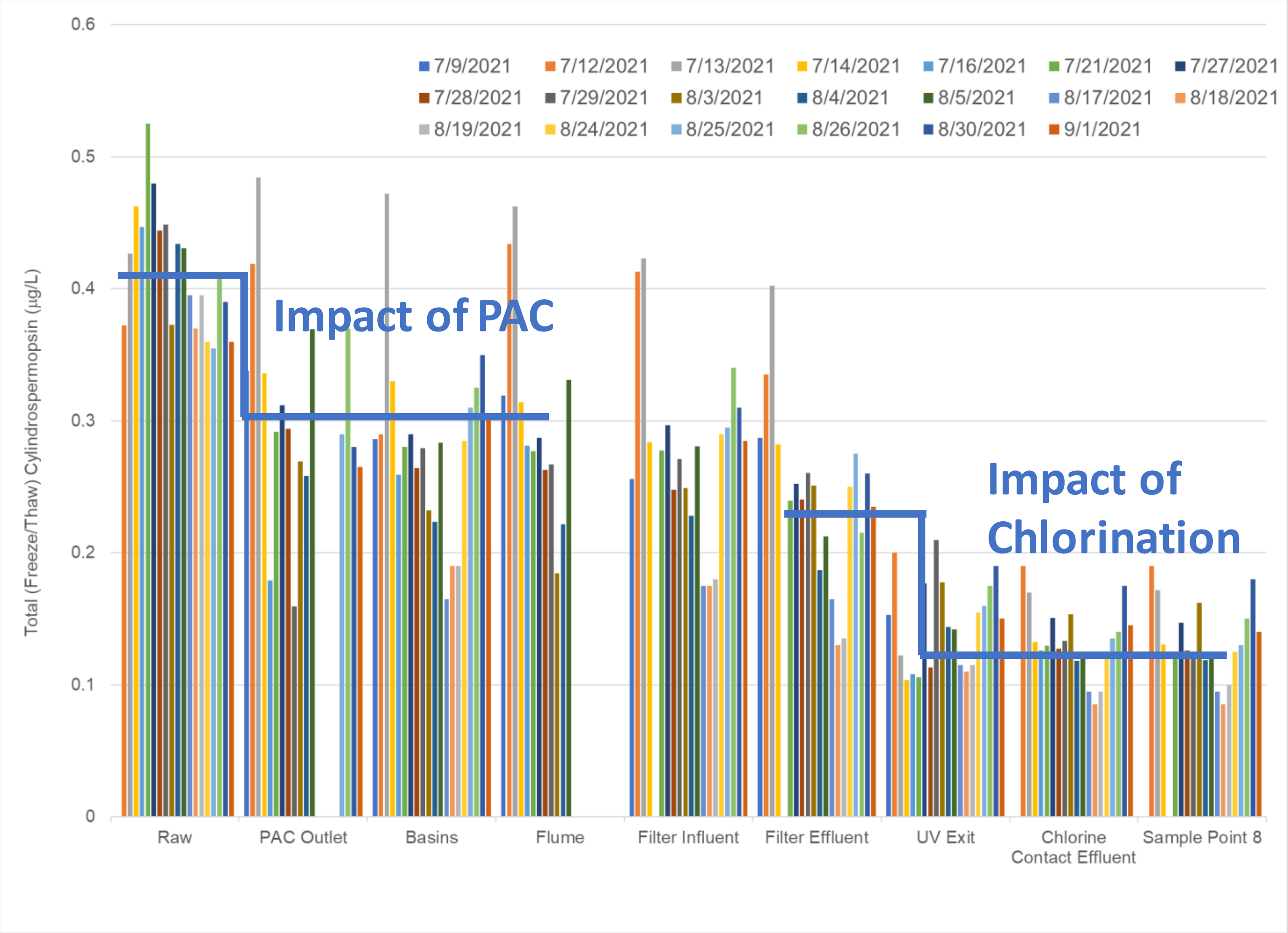
Key Takeaways

- PAC Generally Effective
  - Data after 7/14 considered
- Biological Filters are not showing much removal
- "UV" chlorination strategy is working well
- Chlorine Contact is not removing much if anything?



In-Plant Performance Testing Summary of Removal

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Process	Average	Min	Max
PAC → Sed Basins[1]	35%	13%	60%
Biofilters[2]	14%	-4%	39%
Post-Filter Chlorine[3]	39%	15%	53%

Limited and variable effectiveness → Biofilters

Workhorse Processes → PAC → Sed Basins; Post-Filter Chlorine

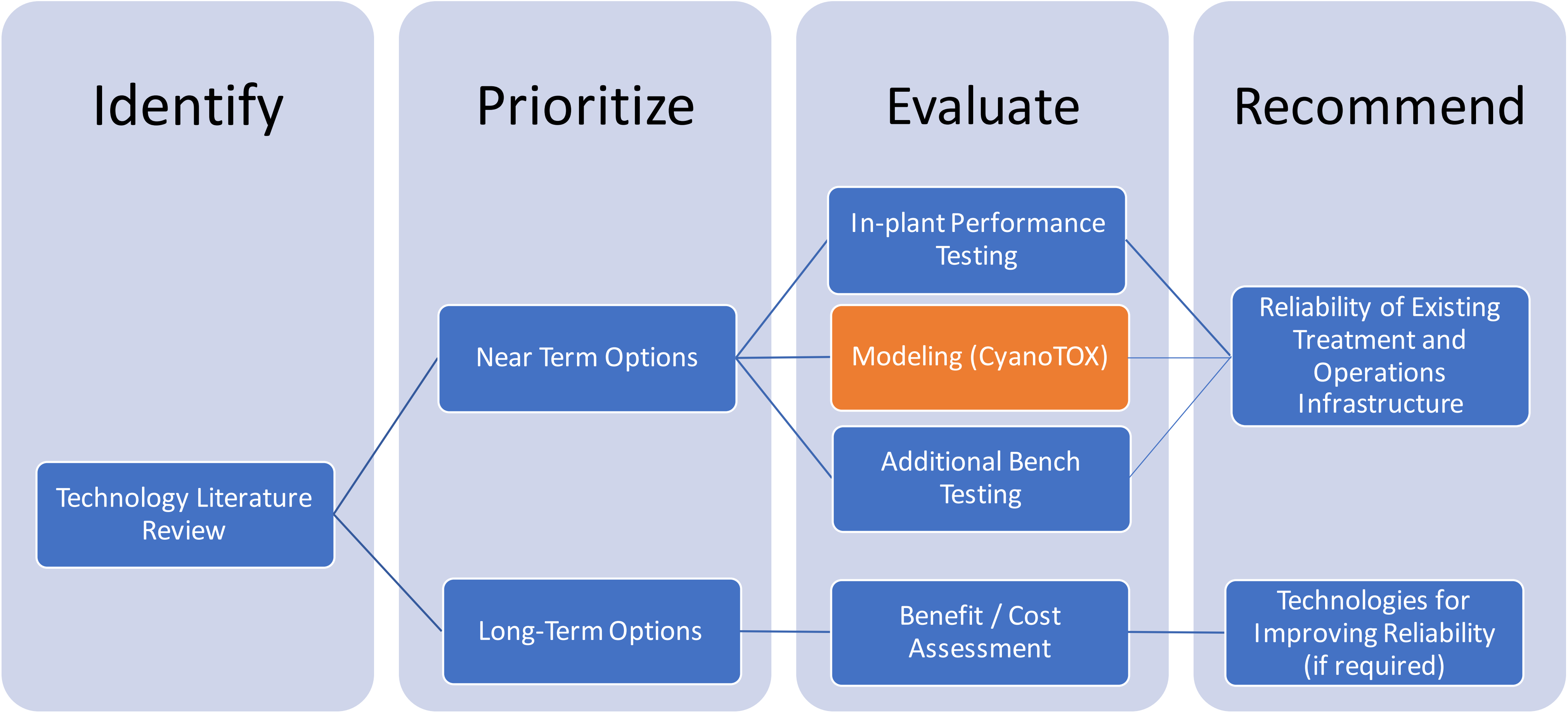
Notes about performance:

[1] Trends show this is primarily PAC removal

[2] A different biofilter sampled every day

[3] Includes "UV Building" chlorine segment and CT Segment

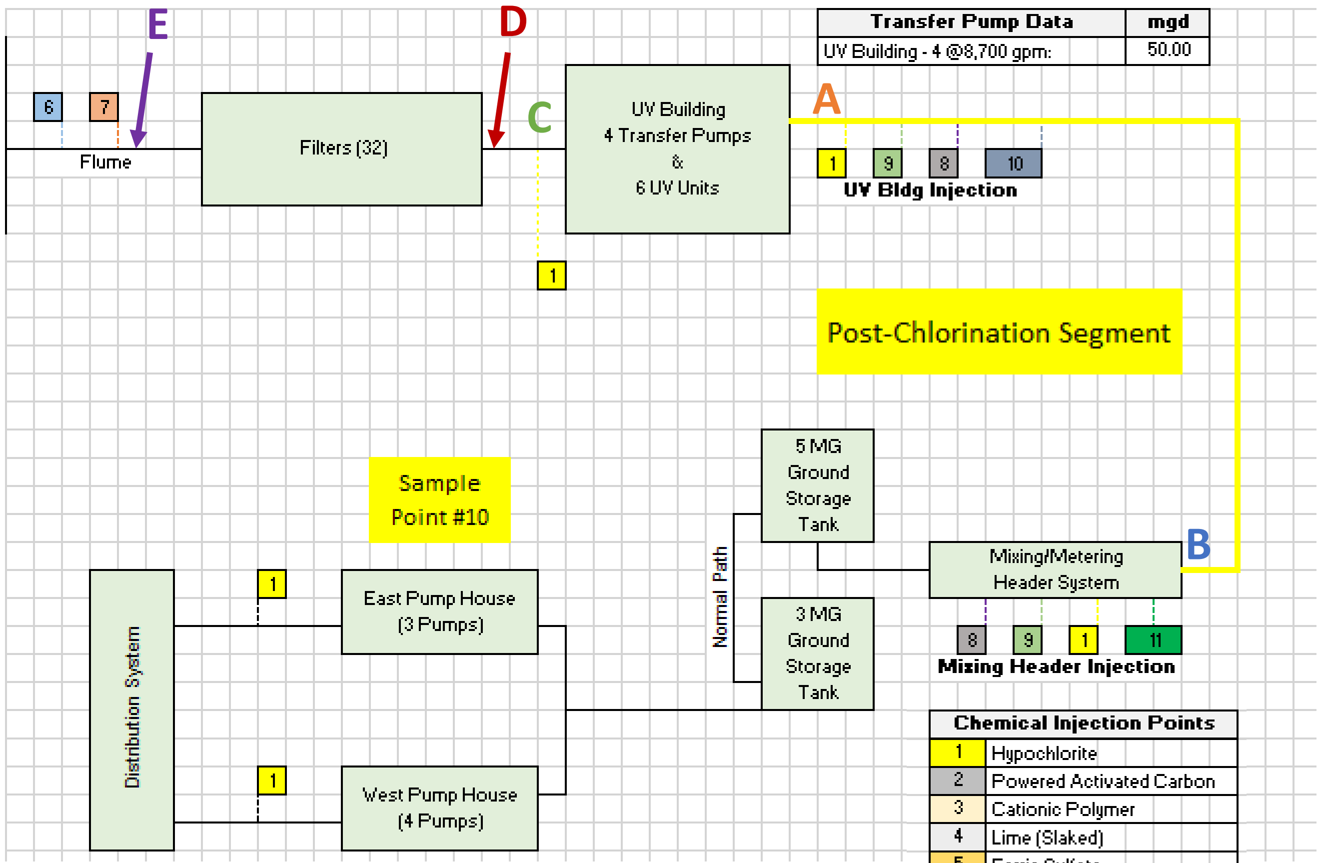
Treatment and Ops Evaluation Strategy – Modeling



Modeling - Operational changes in post-filter chlorination

- Potential Operations Practices:
  1. Increase A to achieve < 5ppm Cl_2 at B (in CYL emergency)[1]
  2. Add Cl_2 at C to take advantage of contact time across UV Building (already in practice)
  3. Place new Cl_2 feed point at D to utilize post-filter chlorine contact[2]
     - 50' of 60" ID pipe = 7,500 gals
  4. Add Cl_2 in flume at E (after pH adjustment) for emergency oxidation

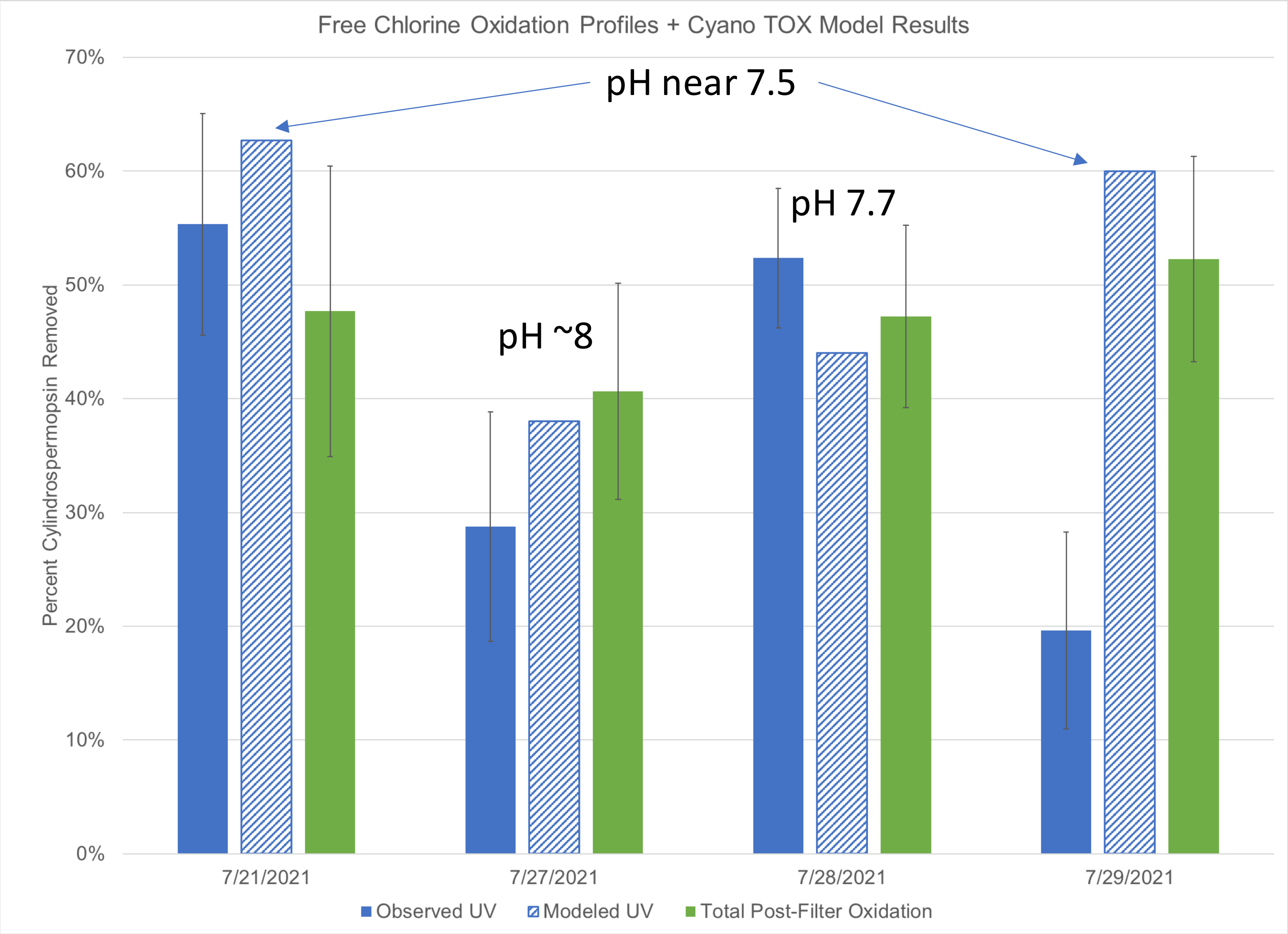
Note: All Oxidation performance tests to end at B, just prior to ammonia feed.



Chemical Injection Points	
1	Hypochlorite
2	Powered Activated Carbon
3	Cationic Polymer
4	Lime (Slaked)
5	Ferric Sulfate
6	Carbon Dioxide
7	Filter Aid
8	Sodium Hydroxide
9	Ammonia
10	Fluoride
11	Orthophosphate

[1] Temporary exceedance of D/DBP Rule MRDL for total chlorine of < 4.0 mg/L allowed per DOH
[2] Limited by chlorine compatibility concerns for UV reactor components

Calibrating "CyanoTOX"



CyanoTOX models the UV and/or post-filter chlorination scenarios well

CT segment could not be accurately modeled because of low CYL at this location

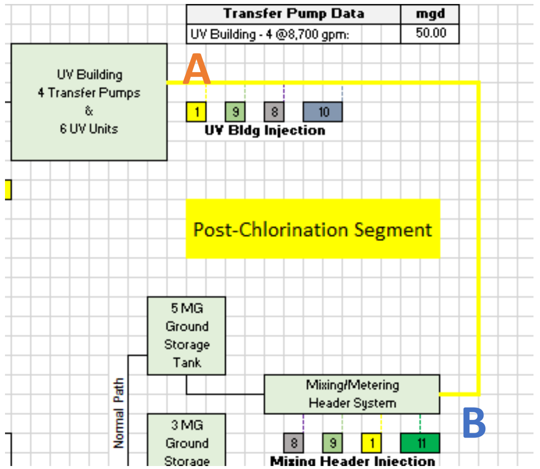
- Detection limit challenges

Observations from the testing

- High dependence on pH
- UV segment providing excellent removal
- When UV segment does not "remove", CT segment is an effective second barrier

CyanoTOX Model – Historical Performance

- Model Chlorine Contact Segment **A** → **B**
  - pH = 7.5 - 8
  - T = 30°C
  - Baffling Factor = 0.7 (pipe)
  - $Cl_{2,Final}$ = 1 – 4 mg/L
  - Target Final C-toxin of 0.3 ppb



Max Raw Cyl for 0.3ppb = 300 ppb

% CYL Oxidation at pH = 7.5

Flow Rate (mgd)	Detention Time (min)	Cl_2 = 1ppm	Cl_2 = 3ppm	Cl_2 = 4 ppm
20	2.2	83.1%	99.5%	99.9%
25	1.7	74.7%	98.4%	99.6%
30	1.4	67.8%	96.7%	98.9%
35	1.2	62.1%	94.6%	97.9%
40	1.1	58.9%	93.1%	97.2%
45	1.0	55.5%	91.2%	96.1%

Max Raw Cyl for 0.3 ppb = 0.7 ppb

% CYL Oxidation at pH = 8.0

Flow Rate (mgd)	Detention Time (min)	Cl_2 = 1ppm	Cl_2 = 3ppm	Cl_2 = 4 ppm
20	2.2	59.5%	93.3%	97.3%
25	1.7	50.2%	87.7%	93.9%
30	1.4	43.7%	82.2%	90.0%
35	1.2	38.9%	77.2%	86.1%
40	1.1	36.3%	74.2%	83.6%
45	1.0	33.7%	70.8%	80.6%

Max Raw Cyl for 0.3ppb = 0.45ppb

CyanoTOX Model – Summary of Past Performance

Maximum Concentrations of Post-filtered Cylindrospermopsin that the Cl_2 segment could handle to achieve 0.3 ppb

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pH 7.5

Flow Rate (mgd)	Cl_2 = 1ppm	Cl_2 = 3ppm	Cl_2 = 4 ppm
20	1.8	60	300
25	1.2	19	75
30	0.9	9.1	27
35	0.8	5.6	14
40	0.7	4.3	11
45	0.7	3.4	7.7

pH 8

Flow Rate (mgd)	Cl_2 = 1ppm	Cl_2 = 3ppm	Cl_2 = 4 ppm
20	0.7	4.5	11
25	0.6	2.4	4.9
30	0.5	1.7	3.0
35	0.5	1.3	2.2
40	0.5	1.2	1.8
45	0.5	1.0	1.5

- Green = > 25ppb (low risk)
- Yellow = 10 – 25ppb (moderate risk)
- Red = < 10ppb (higher risk)

Takeaways

- Higher risk at pH 8 than pH 7.5
- Significant Risk of exceeding 0.3ppb with 1ppm Cl_2, at pH 7.5 or 8
- Risk somewhat reduced with higher Cl_2 (> 3ppm), particularly at pH 7.5
- Need to balance with DBP formation

CyanoTOX Model – Impact of UV chlorination section (0.2 – 0.5ppm)

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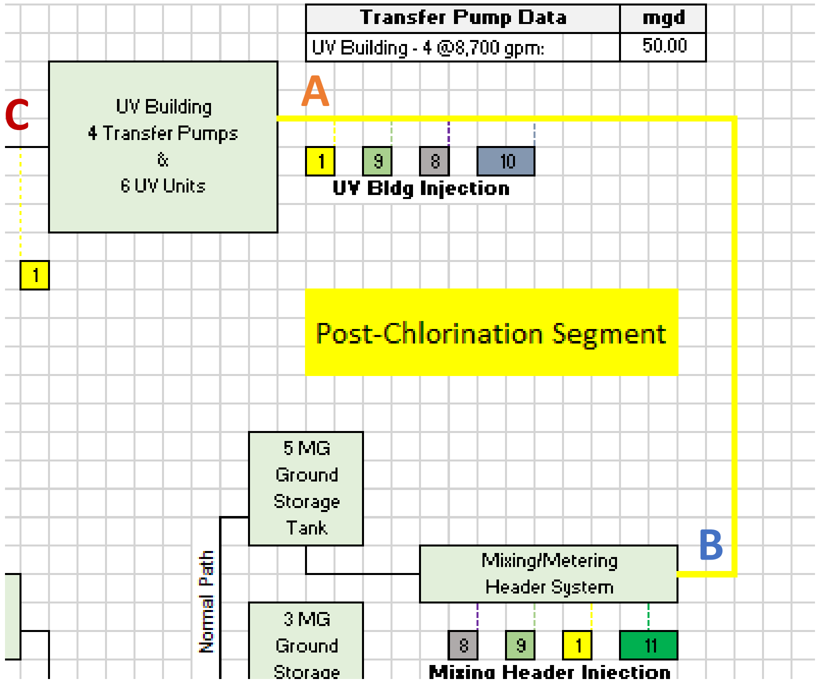
- Model Chlorine Contact Segment C → A
  - pH = 7.5 - 8
  - T = 30°C
  - Baffling Factor = 0.3 (C→A)
  - $Cl_{2,Final}$ (C→A) = 0.2 – 0.5 mg/L (Limited by UV)
- Model Chlorine Contact Segment A → B
  - pH = 7.5 - 8
  - T = 30°C
  - Baffling Factor = 0.7 (pipe)
  - $Cl_{2,Final}$ = 3 – 4 mg/L



CyanoTOX Model – Summary of Current Performance

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Maximum Concentrations of Post-filtered Cylindrospermopsin that the Cl_2 segment + UV segment could handle to achieve 0.3 ppb

pH 7.5

Flow Rate (mgd)	$Cl_{2\,(segment)}$ = 1ppm		$Cl_{2\,(segment)}$ = 3ppm		$Cl_{2\,(segment)}$ = 4ppm	
	$Cl_{2,UV}$ = 0.2ppm	$Cl_{2,UV}$ = 0.5ppm	$Cl_{2,UV}$ = 0.2ppm	$Cl_{2,UV}$ = 0.5ppm	$Cl_{2,UV}$ = 0.2ppm	$Cl_{2,UV}$ = 0.5ppm
20	12	>1000	399	>1000	1996	>1000
25	5.3	>500	85	>600	338	>800
30	3.2	172	31	1679	94	5036
35	2.3	74	16	523	41	1344
40	1.8	36	11	214	27	528
45	1.5	21	7.6	106	17	238

pH 8

Flow Rate (mgd)	$Cl_{2\,(segment)}$ = 1ppm		$Cl_{2\,(segment)}$ = 3ppm		$Cl_{2\,(segment)}$ = 4ppm	
	$Cl_{2,UV}$ = 0.2ppm	$Cl_{2,UV}$ = 0.5ppm	$Cl_{2,UV}$ = 0.2ppm	$Cl_{2,UV}$ = 0.5ppm	$Cl_{2,UV}$ = 0.2ppm	$Cl_{2,UV}$ = 0.5ppm
20	1.8	8.7	11	53	28	131
25	1.2	4.3	5.1	17	10	35
30	0.9	2.6	2.8	8.4	5.0	15
35	0.8	1.9	2.2	5.1	3.6	8.4
40	0.7	1.5	1.8	3.8	2.9	5.9
45	0.7	1.3	1.5	2.9	2.3	4.3

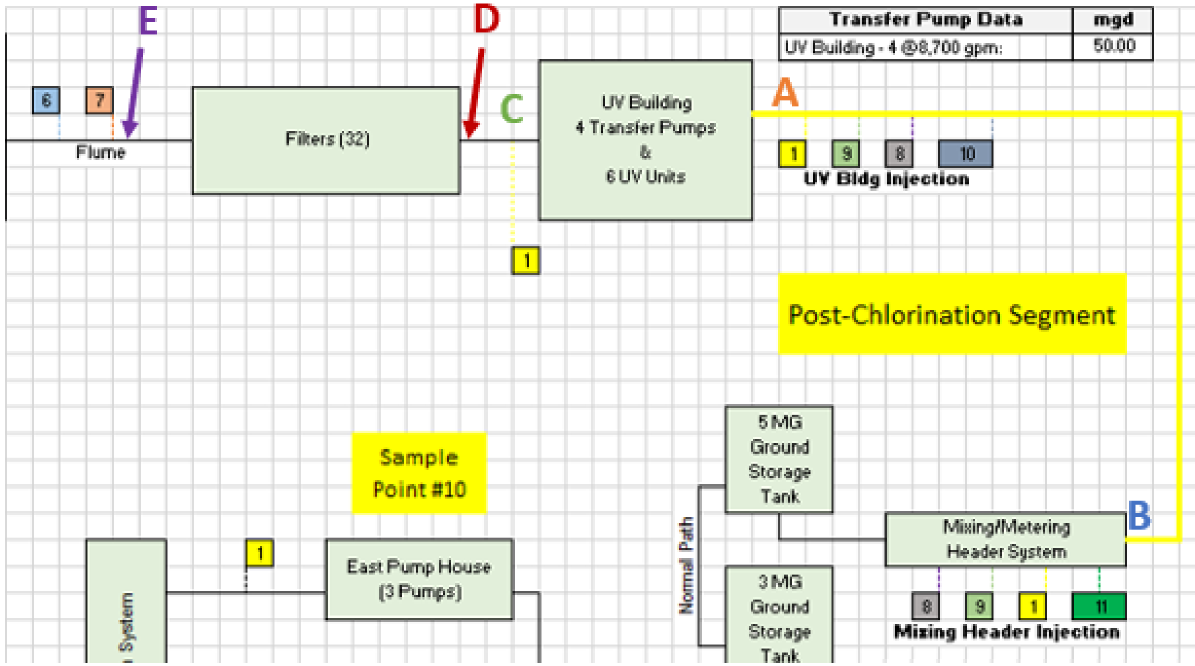
- Green = > 25ppb (low risk)
- Yellow = 10 – 25ppb (moderate risk)
- Red = < 10ppb (higher risk)

Takeaways

- Risk significantly reduced, especially at:
  - $Cl_{2,UV}$ of 0.5ppm
  - Cl_2,segment > 3ppm
  - pH 7.5
- Still risk at pH 8

CyanoTOX Model – Extended (0.2 ppm added pre-filter)

- Model Chlorine Contact Segment E → Filters
  - pH = 7.5 - 8
  - T = 30°C
  - Baffling Factor = 0.5 (E→Filters)
  - $Cl_{2,Final\ (C\rightarrow A)}$ = 0.2 mg/L (Limited by Filters)
- Model Chlorine Contact Segment C → A
  - pH = 7.5 - 8
  - T = 30°C
  - Baffling Factor = 0.3 (C→A)
  - $Cl_{2,Final\ (C\rightarrow A)}$ = 0.2 – 0.5 mg/L (Limited by UV)
- Model Chlorine Contact Segment A → B
  - pH = 7.5 - 8
  - T = 30°C
  - Baffling Factor = 0.7 (pipe)
  - $Cl_{2,Final}$ = 3 – 4 mg/L



CyanoTOX Model – Summary of pre-Filter Cl_2

Percent Removal if the pre-filter flume can be used with chlorination

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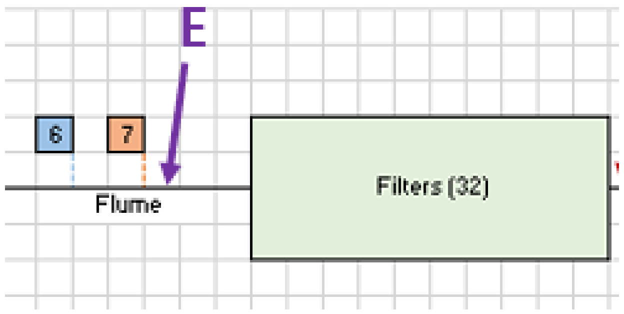
% CYL Oxidation at 0.2ppm pre-filter Cl_2

Flow Rate (mgd)	Detention Time (min)	pH 7.5	pH 8	pH 8.5
20	21	91%	71%	38%
25	17	86%	63%	32%
30	14	80%	56%	27%
35	12	75%	51%	24%
40	11	72%	48%	22%
45	9	65%	41%	18%



Takeaways

- Significant oxidation can be achieved at pH 7.5.
- Effectiveness reduces significantly at pH 8 and pH 8.5
- Potentially viable but need to understand DBPs

CyanoTOX Model – Summary of Potential Pre-Filter Cl_2

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Maximum Concentrations of Post-filtered Cylindrospermopsin that the Cl_2 segment + UV segment + pre-filter flume could handle to achieve 0.3 ppb

pH 7.5

Flow Rate (mgd)	$Cl_{2\,(segment)}$ = 3ppm		$Cl_{2\,(segment)}$ = 4ppm	
	$Cl_{2,UV}$ = 0.2ppm, $Cl_{2,pre\text{-}filt}$ = 0.2ppm	$Cl_{2,UV}$ = 0.5ppm, $Cl_{2,pre\text{-}filt}$ = 0.2ppm	$Cl_{2,UV}$ = 0.2ppm, $Cl_{2,pre\text{-}filt}$ = 0.2ppm	$Cl_{2,UV}$ = 0.5ppm, $Cl_{2,pre\text{-}filt}$ = 0.2ppm
20	>5000	>5000	>5000	>5000
25	721	>5000	2883	>5000
30	182	>5000	546	>5000
35	72	2957	185	>5000
40	43	1059	106	2609
45	24	410	54	925

pH 8

Flow Rate (mgd)	$Cl_{2\,(segment)}$ = 3ppm		$Cl_{2\,(segment)}$ = 4ppm	
	$Cl_{2,UV}$ = 0.2ppm, $Cl_{2,pre\text{-}filt}$ = 0.2ppm	$Cl_{2,UV}$ = 0.5ppm, $Cl_{2,pre\text{-}filt}$ = 0.2ppm	$Cl_{2,UV}$ = 0.2ppm, $Cl_{2,pre\text{-}filt}$ = 0.2ppm	$Cl_{2,UV}$ = 0.5ppm, $Cl_{2,pre\text{-}filt}$ = 0.2ppm
20	43	231	106	574
25	15	59	30	118
30	7	23	12	40
35	5	12	8	20
40	4	8	6	13
45	3	6	4	8

- Green = > 25ppb (low risk)
- Yellow = 10 – 25ppb (moderate risk)
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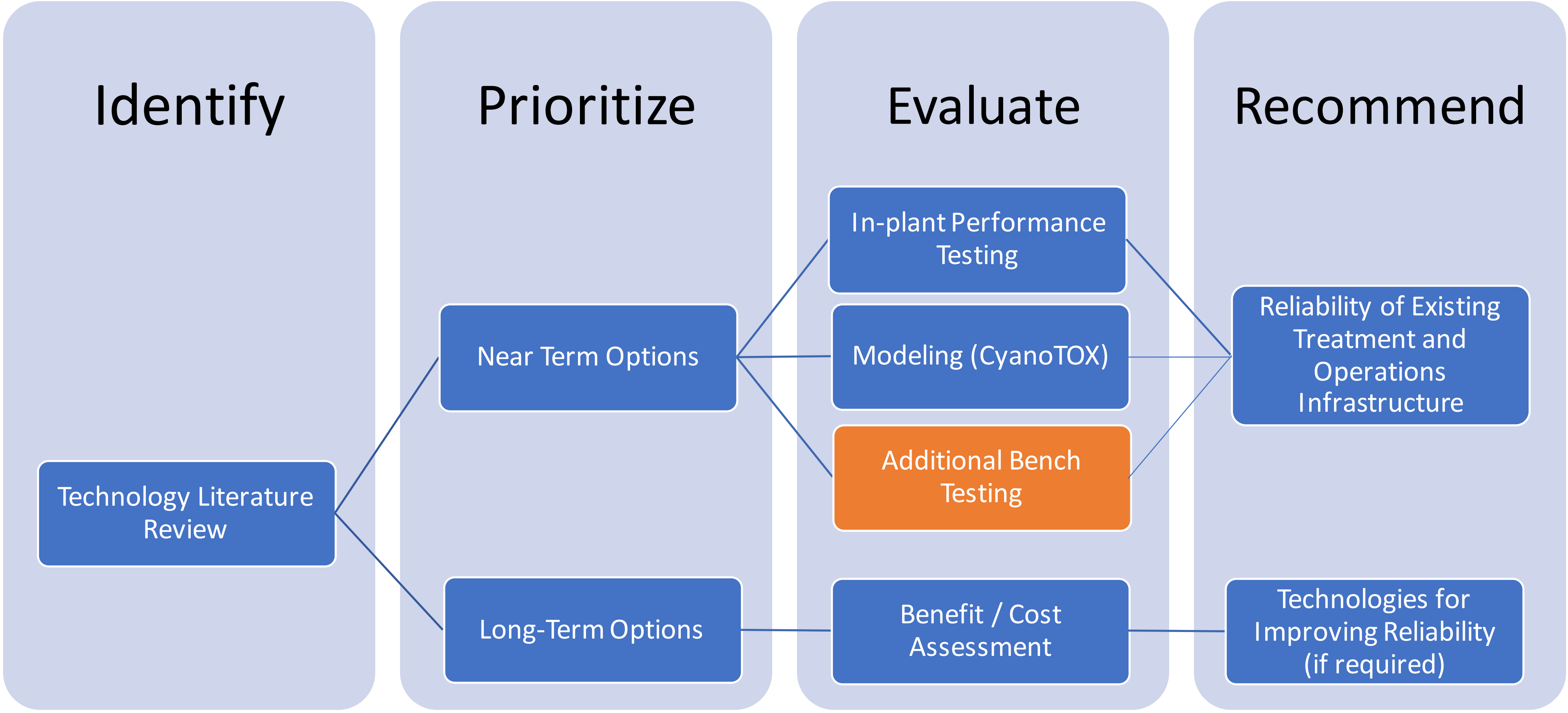
Takeaways

- Very effective at pH 7.5
- Allows for 0.2ppm Cl_2 at UV
- Expands effectiveness at pH 8.0, but
- Still important to adjust pH to 7.5
- DBPs will be of concern

Treatment and Ops Evaluation Strategy – Bench Testing



Questions raised during testing and modeling

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- PAC Performance
  - Impact of contact time
  - Impact of PAC dose
  - Impact of PAC product

- Chlorine Performance
  - Impact of location
    - “CT segment”, “UV Building”, and “Pre-filter”
  - Impact of pH
  - Performance *and* constraints
    - Disinfection Byproduct formation

Bench Testing Contract

Hazen and Sawyer contracted to perform bench testing

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- Collect water from 3 locations in the plant and perform jar testing

1. PAC removal of Cylindrospermopsin
    - Raw water treatment
    - 3 PACs, 3 doses, 3 reaction times,
        - Measure treated temperature, cylindrospermopsin, TOC
2. Chlorine Demand/Decay
    - 3 water sources, 4 “locations”
        - Softened (pre-filter flume), Filtered (UV bldg. and CT segment), Post-UV (CT segment)
    - 2 pH (7.5, 8.0), One temperature (20^{o}C)
    - Decay Curves for 2 doses per water (1, 3, 5, 10 depending on water)
    - 2 Finished chloramine decay curves (CT segment only and CT + UV segments)
        - Measure pH, temp, fCl2, tCl2, mCl2 and fNH3.
3. Chlorine Oxidation of Cylindrospermopsin
    - 3 Water sources, 4 locations
        - Softened (pre-filter flume), Filtered (UV bldg. and CT segment), Post-UV (CT segment)
    - Oxidation “validation” tests
        - Softened: 2 pH, 1 dose and decay time combinations for each pH
        - Filtered, UV bldg; 2pH, 1 dose and decay combination for each pH
        - Filtered (CT segment), 2 pH, 1 dose and decay combination for each pH
        - Post-UV (CT segment), 2 pH, 1 dose and decay combination for each pH
        - Post-UV chloramine, 1 pH, 1 dose, instantaneous and 24 hours later).

Near-term Summary

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- ***In-plant testing*** indicates PAC and Cl_2 treatment appear effective for controlling Cylindrospermopsin
- ***Modeling*** indicating chlorination practices can provide effective oxidation of cylindrospermopsin
  - Reliance on CT segment only is risky
  - Addition of UV chlorination segment greatly reduces risk (at 0.5ppm residual Cl_2), but needs to be coupled with pH control to ~ 7.5
  - Addition of a pre-filter chlorination segment (flume) could further assist
    - Allows for reduced UV segment chlorination (0.2ppm)
    - Maintaining pH at ~ 7.5 is still critically important
- ***Ongoing bench testing*** to further understand benefits and limits of treatment
  - PAC and Cl_2 oxidation of CYL performance testing
  - PAC testing to include multiple products, doses, contact times
  - Cl_2 demand testing to understand background matrix effects
    - 3 segments (pre-filter flume, UV building, Cl_2 contact chamber)
    - ***Understanding impacts on DBP formation is critical***

Treatment and Ops Evaluation Strategy – Long-term Options

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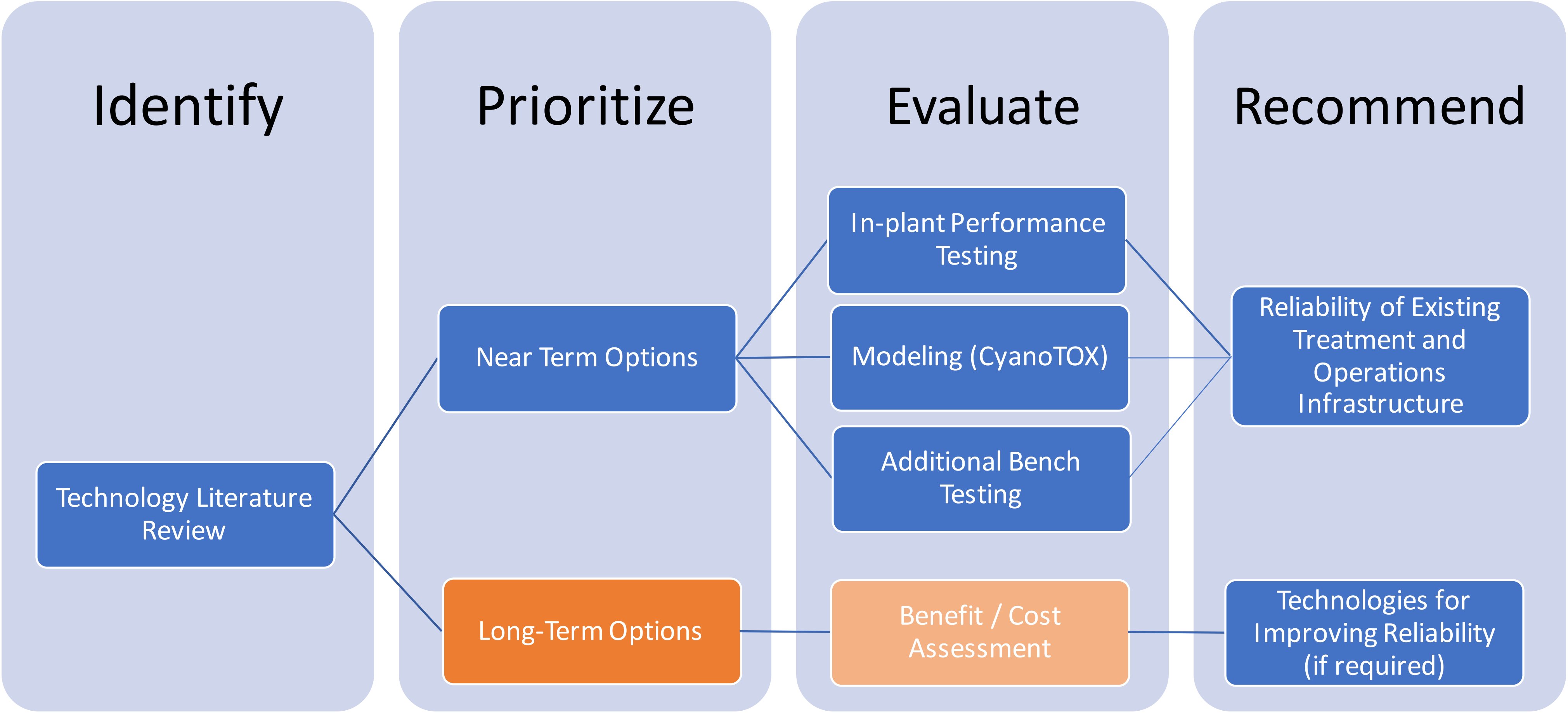
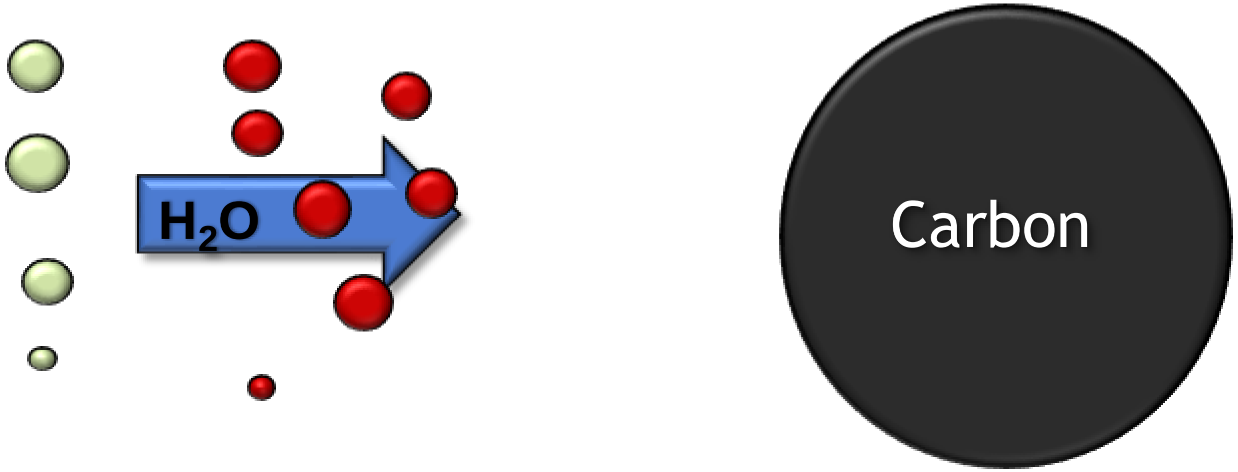


Activated Carbon Adsorption

- If substances "don't like" being in water (hydrophobic) they will prefer to interact with a hydrophobic, solid material
- We can take advantage of this to remove many organics



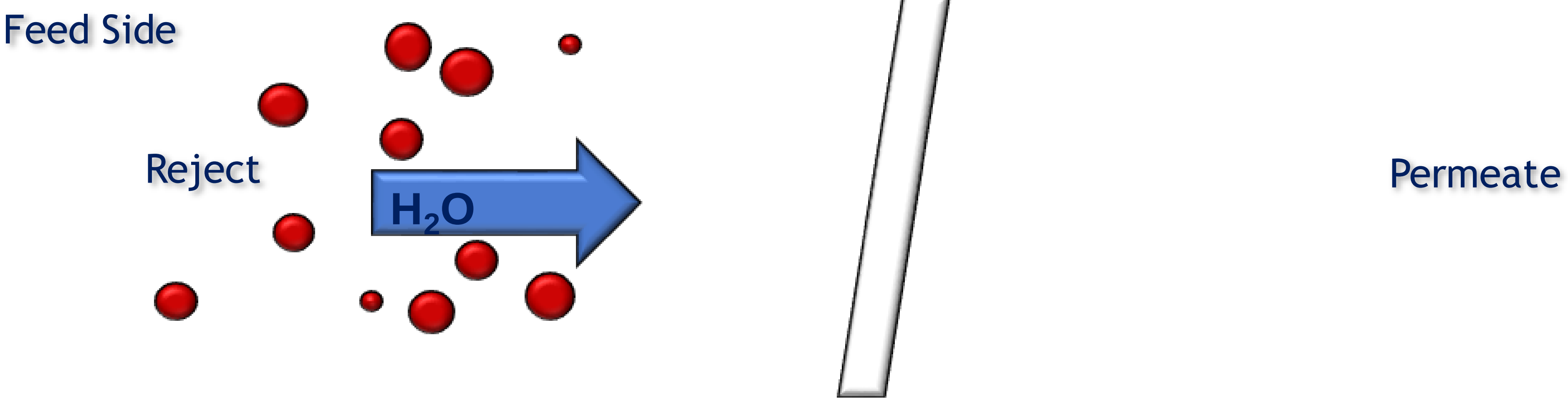
Membrane Separations

- Thin barrier to constituents in water
- What gets through depends on size
  - Microfiltration (MF)
  - Ultrafiltration (UF)
  - Nanofiltration (NF)
  - Reverse Osmosis (RO)

Particle Removal (MF, UF)

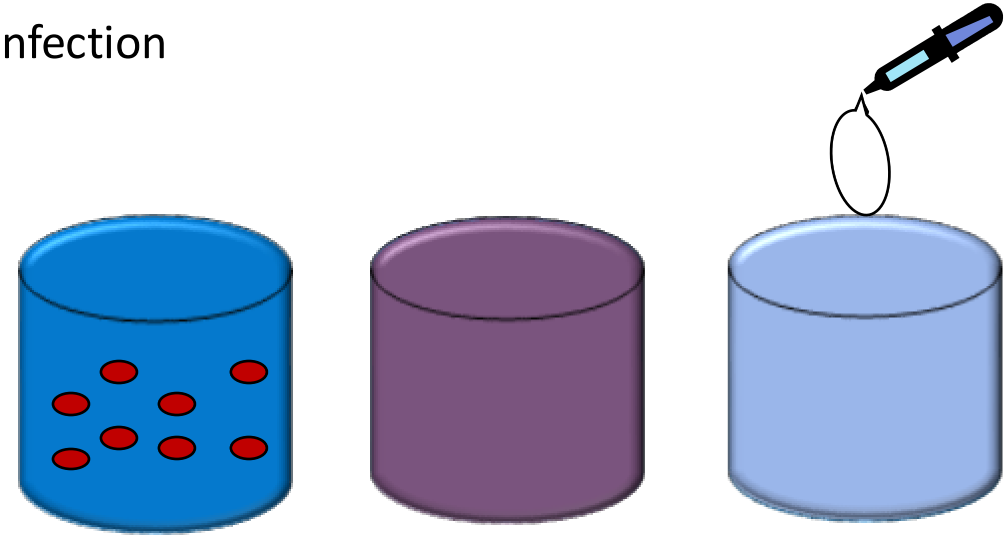
Molecule Removal (NF, RO)

- Molecule removal requires much more energy

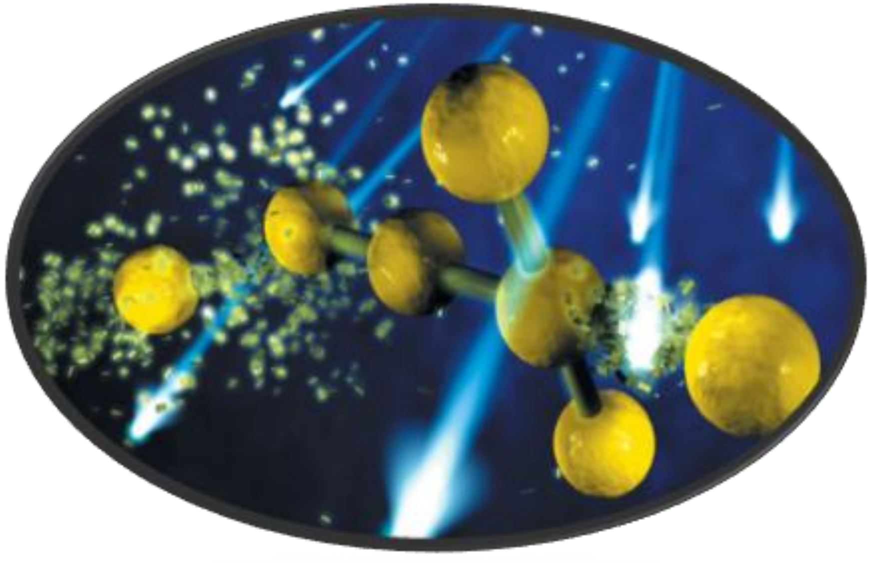


UV Advanced Oxidation

- UV is high energy and can provide effective contaminant transformation if:
  - UV energy is absorbed by contaminant
  - Bonds are amenable to breaking
- Two (or 3) "types" of UV treatment
  - Disinfection – effective and low energy barrier for organisms
  - Photolysis / Oxidation – UV absorbed by a chemical causing a reaction
- Oxidation typically requires 100 – 1,000x more energy than disinfection

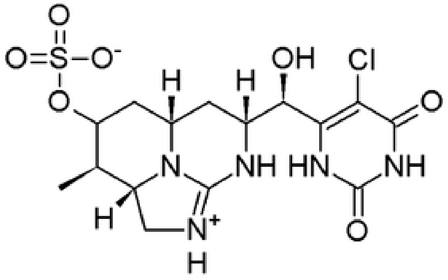


Disinfection **Photolysis** **Advanced Oxidation (H_2O_2 or HOCl)**

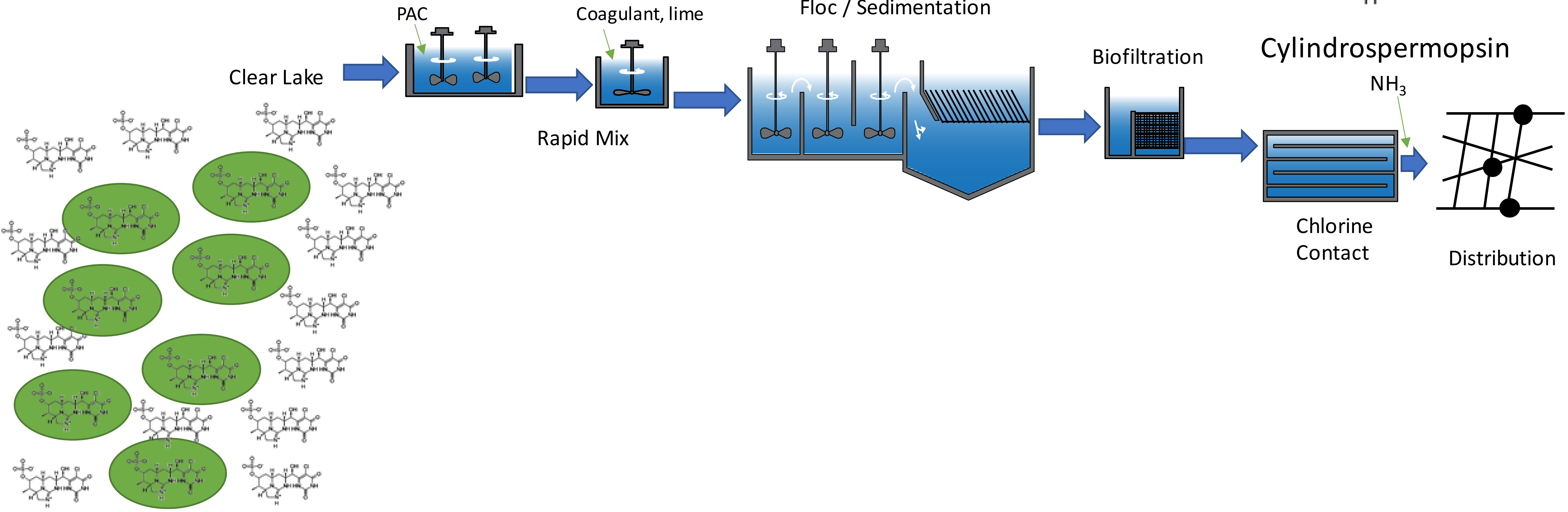


Biofiltration

- Biological Filtration (BAF) provides an opportunity for microorganisms to degrade contaminants



Cylindrospermopsin



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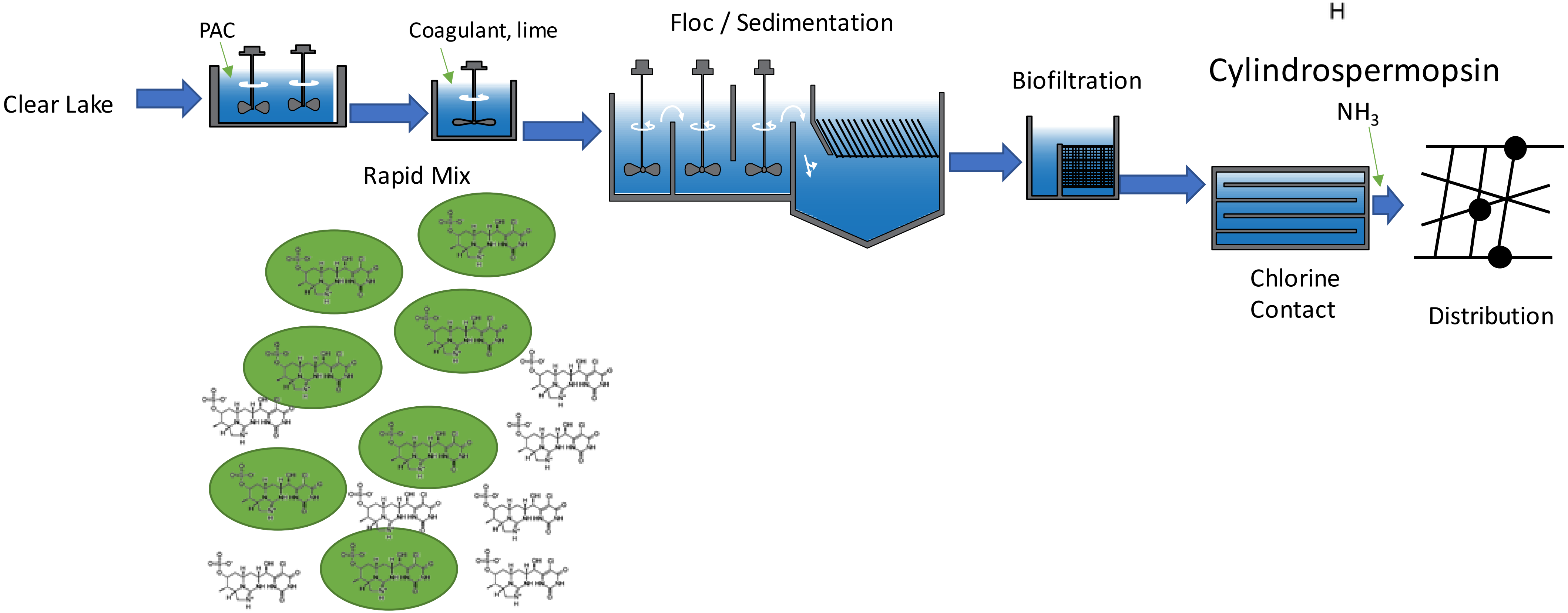
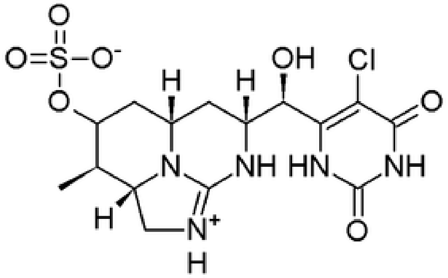
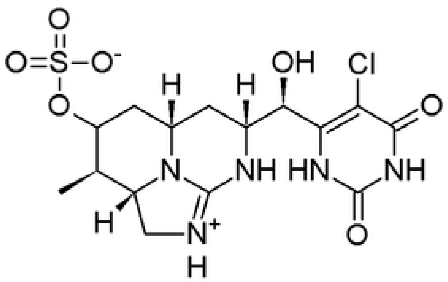




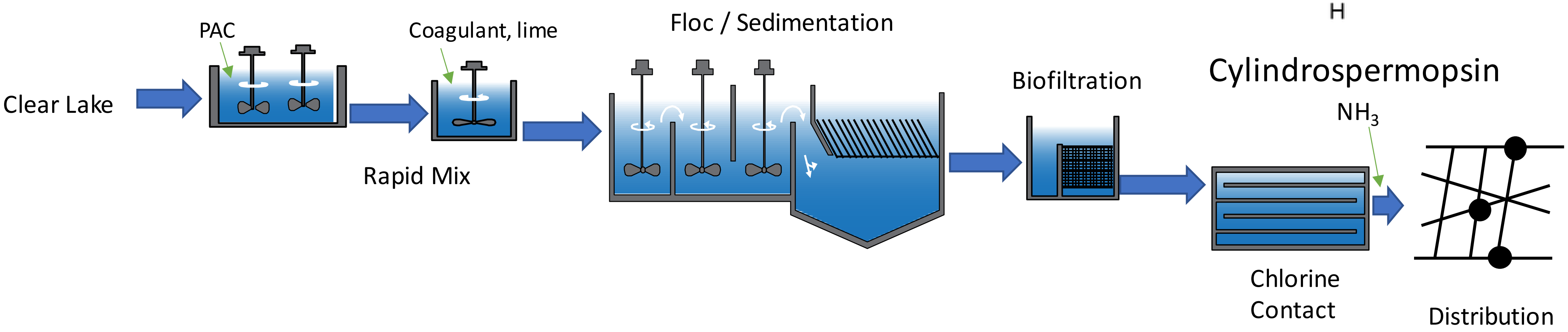
Cylindrospermopsin

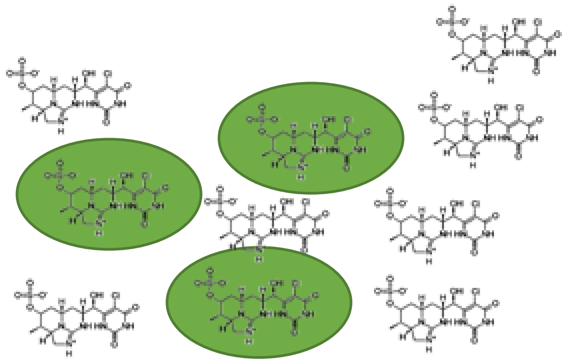
Biofiltration

- Biological Filtration (BAF) provides an opportunity for microorganisms to degrade contaminants



Cylindrospermopsin





Ozone

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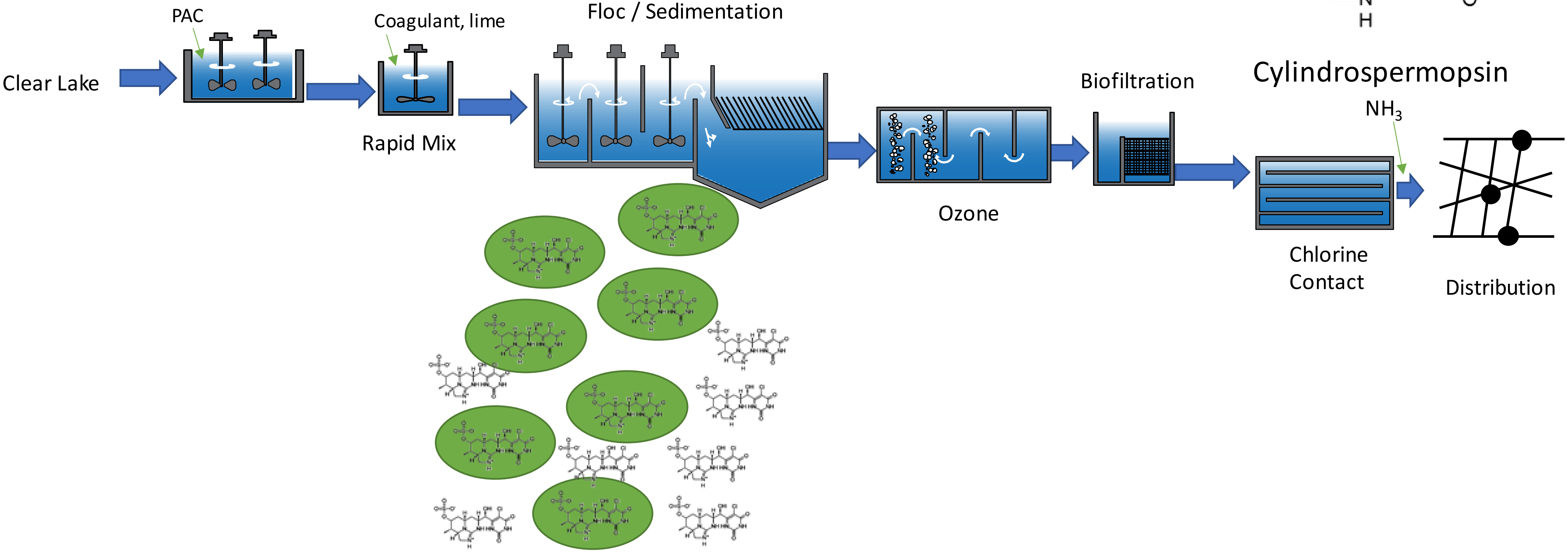
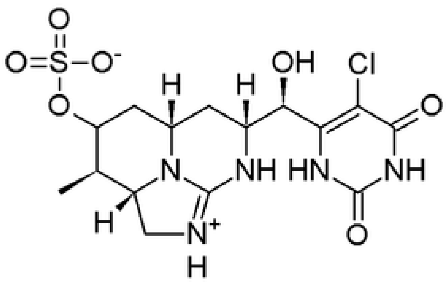
- Ozone is very reactive towards CYL





Cylindrospermopsin

Benefits of effective technologies

Technology	Removes T&O	Effective for Cylindrospermopsin	Emerging Contaminants	Effective Disinfection	"As Needed" Operations
Cl_2		pH dependent		✓	✓
PAC	Variable	Variable	Variable		✓
GAC*	✓	✓	✓		
Ozone	✓	✓	✓	✓	
Ozone/BAC	✓	✓	✓	✓	
UV AOP	✓	✓	✓	✓	✓
RO / NF	✓	✓	✓	✓	

*GAC describing long-EBCT post-filter contactor

Drawbacks of Technologies

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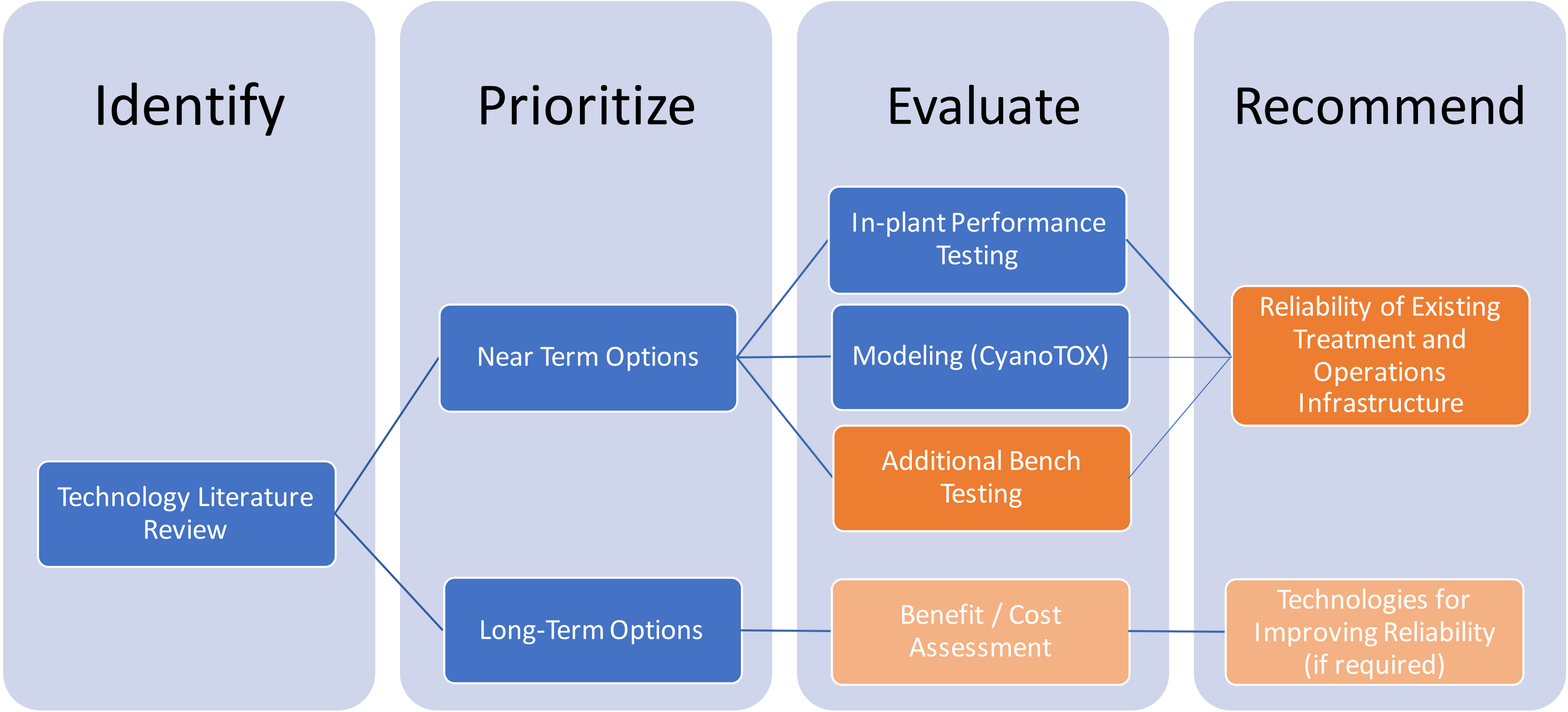
Technology	Energy Intensive	Expensive	Regulated Byproducts	Impacts Treatment	Efficiency Impacted by Background WQ
Cl_2		pH dependent	✓ (DBPs)		
PAC		$ existing infrastructure		✓ (Turbidity)	✓
GAC*	✓	$$$$			✓
Ozone	✓	$$$	✓ (Bromate)	✓ (DS Stability)	✓
Ozone/BAC	✓	$$$	✓ (Bromate)		✓
UV AOP	✓	$$$$	✓ (Bromate?)		✓
Ozone AOP	✓	$$$	✓ (Bromate?)		✓

*GAC describing long-EBCT post-filter contactor

Treatment and Ops Evaluation Strategy – Next Steps



Treatment & Operations:
Preliminary Alternatives

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- Optimize Near-term PAC and chlorine treatment processes
  - Define performance, identify challenges to performance, evaluate performance-limiting factors (ie DBPs)
  - Define extent of reliable performance – is “more” treatment needed?
- Evaluate feasibility, benefits, cost, and limitations of effective advanced treatment processes for enhanced removal
  - Ozone, GAC, UV AOP, RO/NF Membranes

Looking Forward

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- Continue Near-term Actions
- Monthly Technical Work Sessions through February
- Focus on source water management, treatment, distribution water quality, and monitoring strategies

Thank you!