Fine Sediment Management for Reducing Cyanobacterial Bloom Risks in Drinking Water Reservoirs

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Source (raw) drinking water reservoirs

- Critical for uninterrupted supply of drinking water
  - Snowpack storage serves ~2 billion people globally
  - Typically managed for quantity
  - Management for raw water quality?
- Water quality & treatability impacted by
  - Natural factors
  - Anthropogenic factors

Algal (cyanobacterial) blooms and reservoirs

- High densities of cells challenge DWTP:
  - Increase: raw water turbidity, coagulant demand, settling time
  - Clog filters, decrease filter run time
  - May interfere with disinfection
  - Produce cyanotoxins
  - Produce taste and odour compounds
- One of the biggest threats to source water quality
- Toledo, Ohio (2014)
  - Microcystin LR in finished water
  - > 500,000 customers without water
- Halifax, Nova Scotia (2021)
  - > 9,000 customers without water

Blue-green algae confirmed in Grand Lake

People are urged not to drink the water or swim in it

CBC News · Posted: Jun 15, 2021 3:26 PM AT | Last Updated: June 15

Phosphorus and algal proliferation

- Key limiting nutrient for algal growth in freshwater
- Commonly cited threshold for eutrophication: 30 µg TP L^{-1}
- TP = total dissolved P + total particulate P

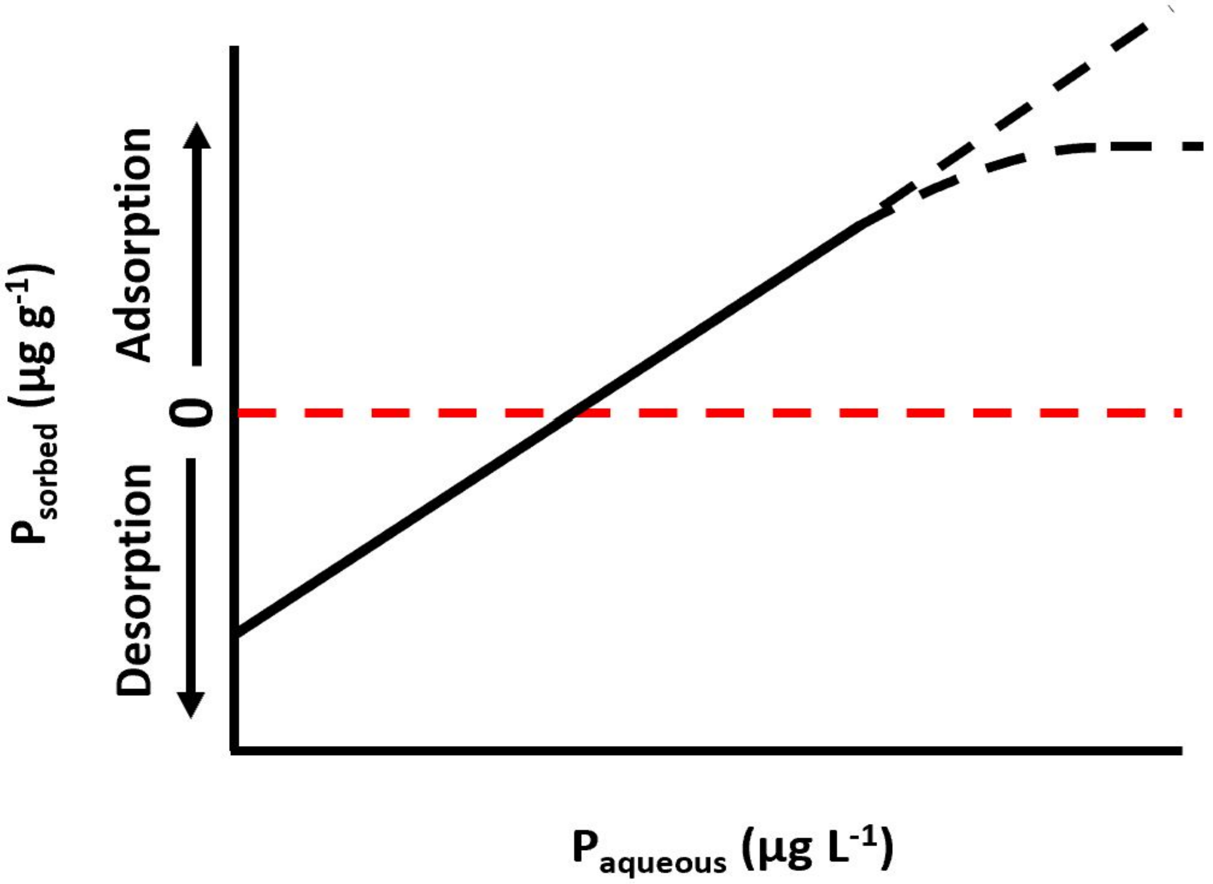
Operational Definition	Fractions	Phosphorus Type	Bioavailability
Total Dissolved Phosphorus (< 0.45 µm)	Organic	Nucleic acids	Requires processing
		Lipids	
	Inorganic	Soluble reactive phosphate (SRP)	Readily
Total Particulate Phosphorus (> 0.45 µm)	Organic	Detritus	Not-readily available
	Inorganic	Non-Apatite Phosphorus	Requires processing
		Apatite Phosphorus	Not-readily available

External loading of fine sediment

- Fine sediment: primary vector for P transport
- Landscape disturbances → sediment erosion
  - Anthropogenic (urban development, agriculture practices)
  - Natural, further exacerbated by climate change
- Watershed scale reductions attempted
  - Enhanced agricultural practices
  - Wastewater treatment plant upgrades
  - Riparian buffers
  - Wetland construction

Internal loading within the reservoir

- Suspended and deposited sediment can adsorb & desorb (sorb) P
- Primary producers can quickly utilize P desorbed from sediment
- Factors influencing phosphorus sorption:
  - Equilibrium phosphorus concentration (EPC_0)
  - Redox conditions
  - Sediment grain size
  - Sediment geochemistry
  - pH
- Decreasing EPC_0 reduces the amount of P release to the raw water column



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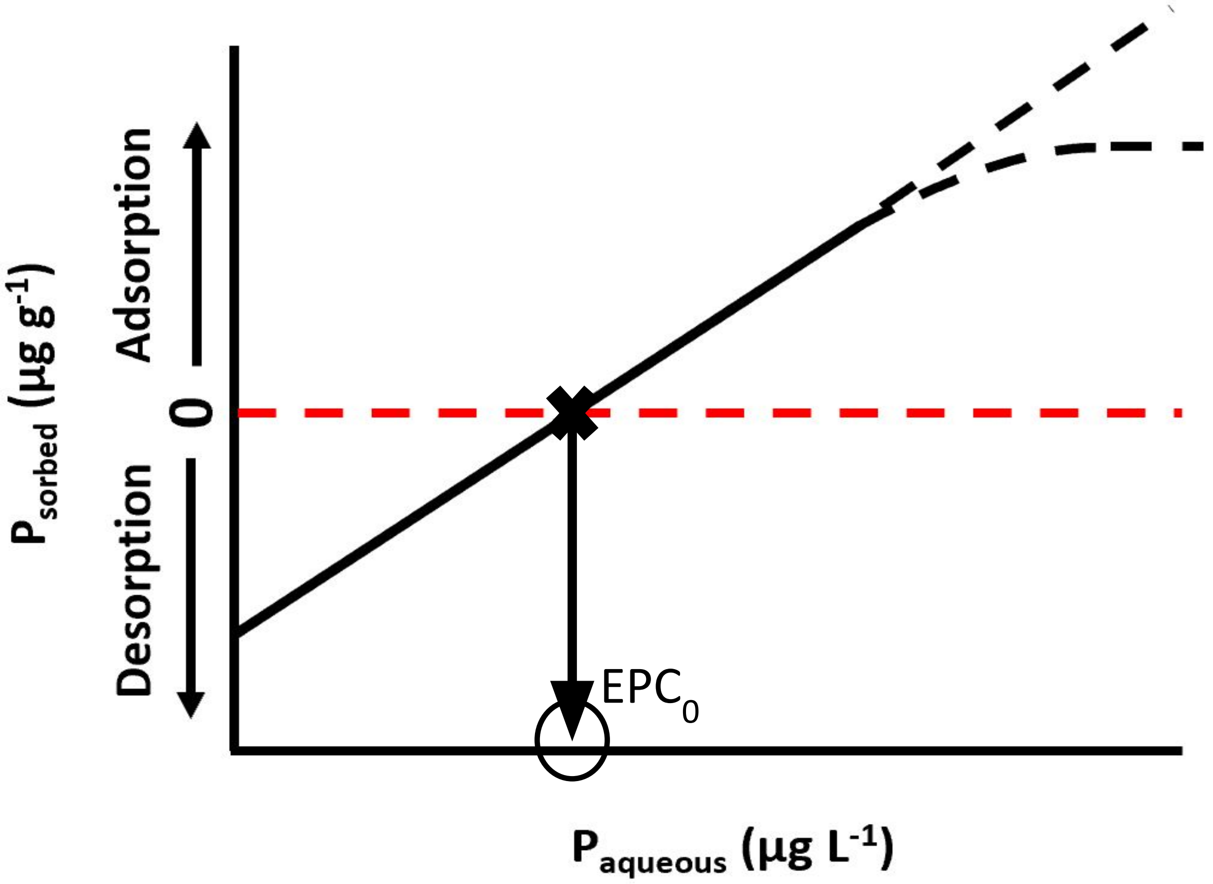

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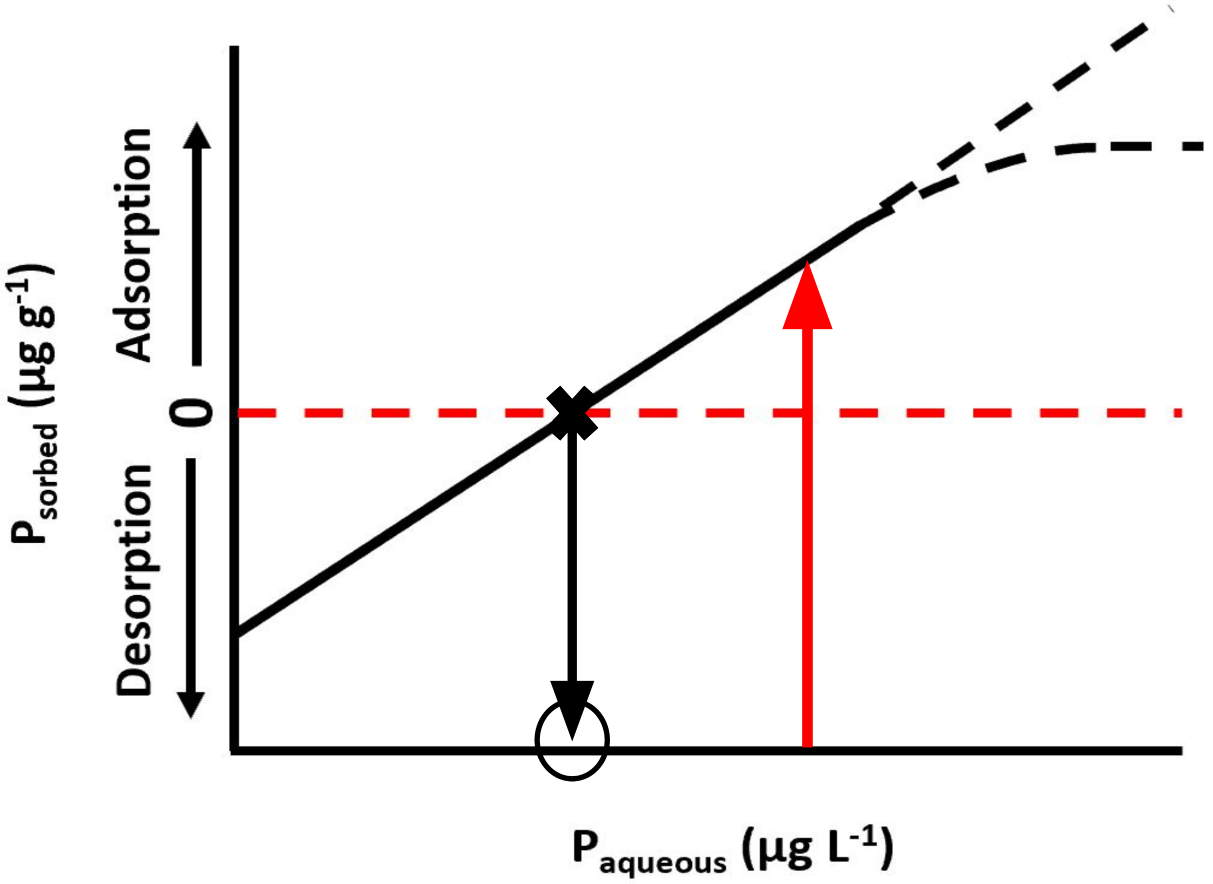

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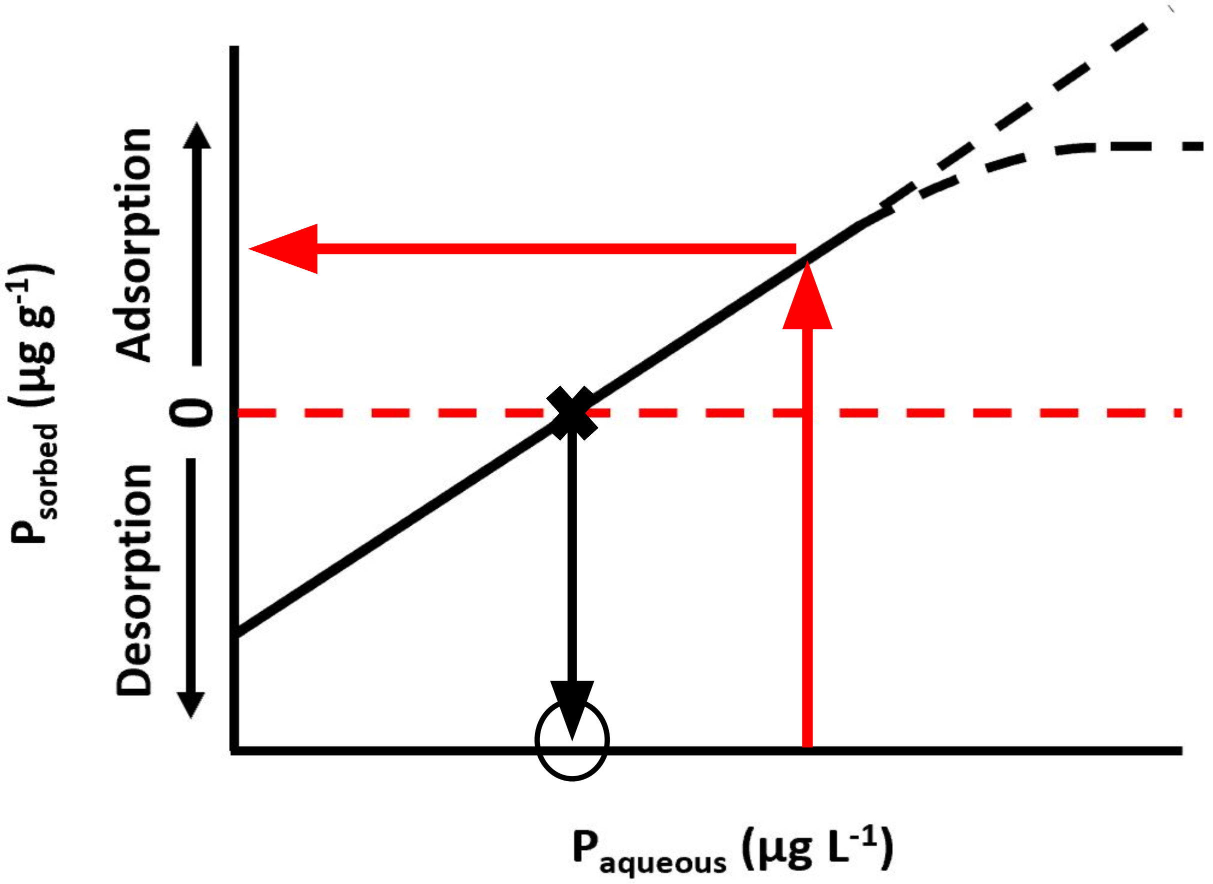

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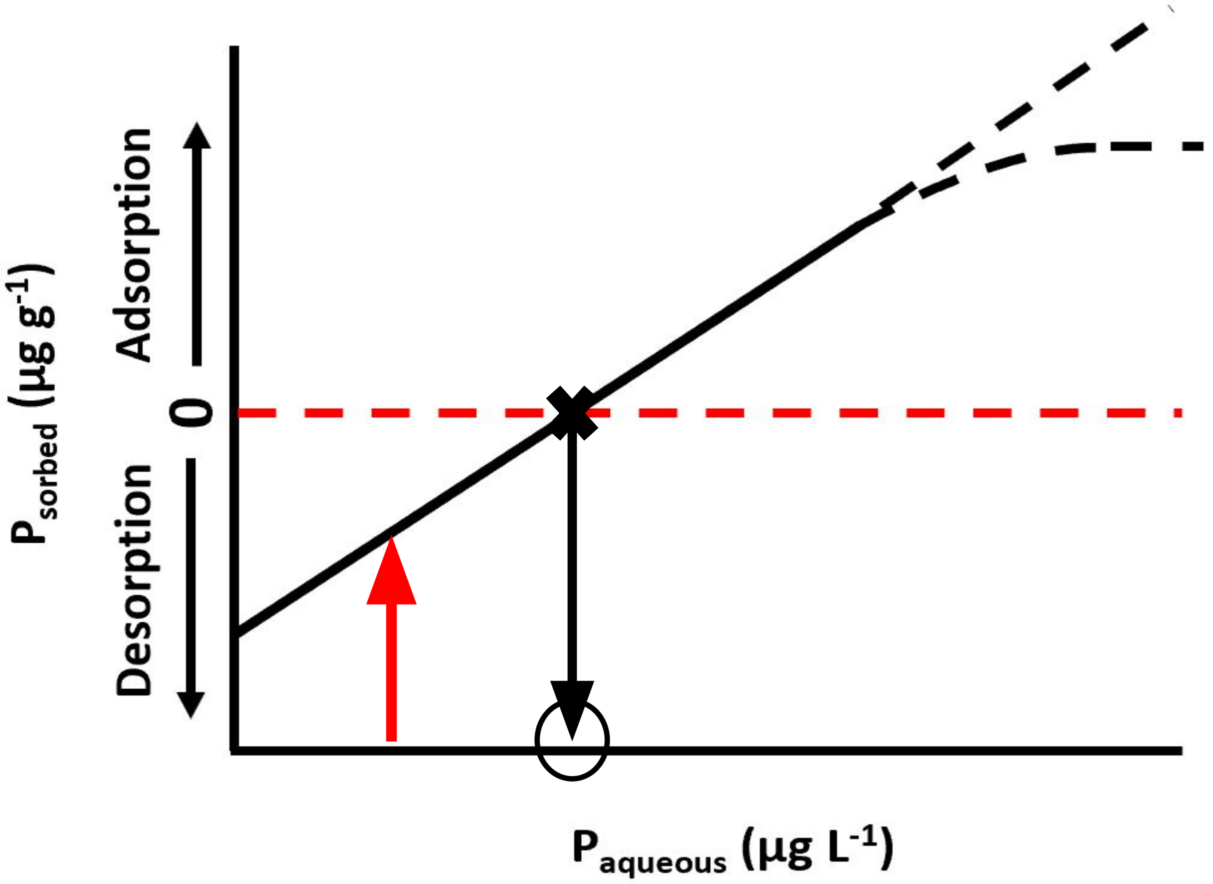

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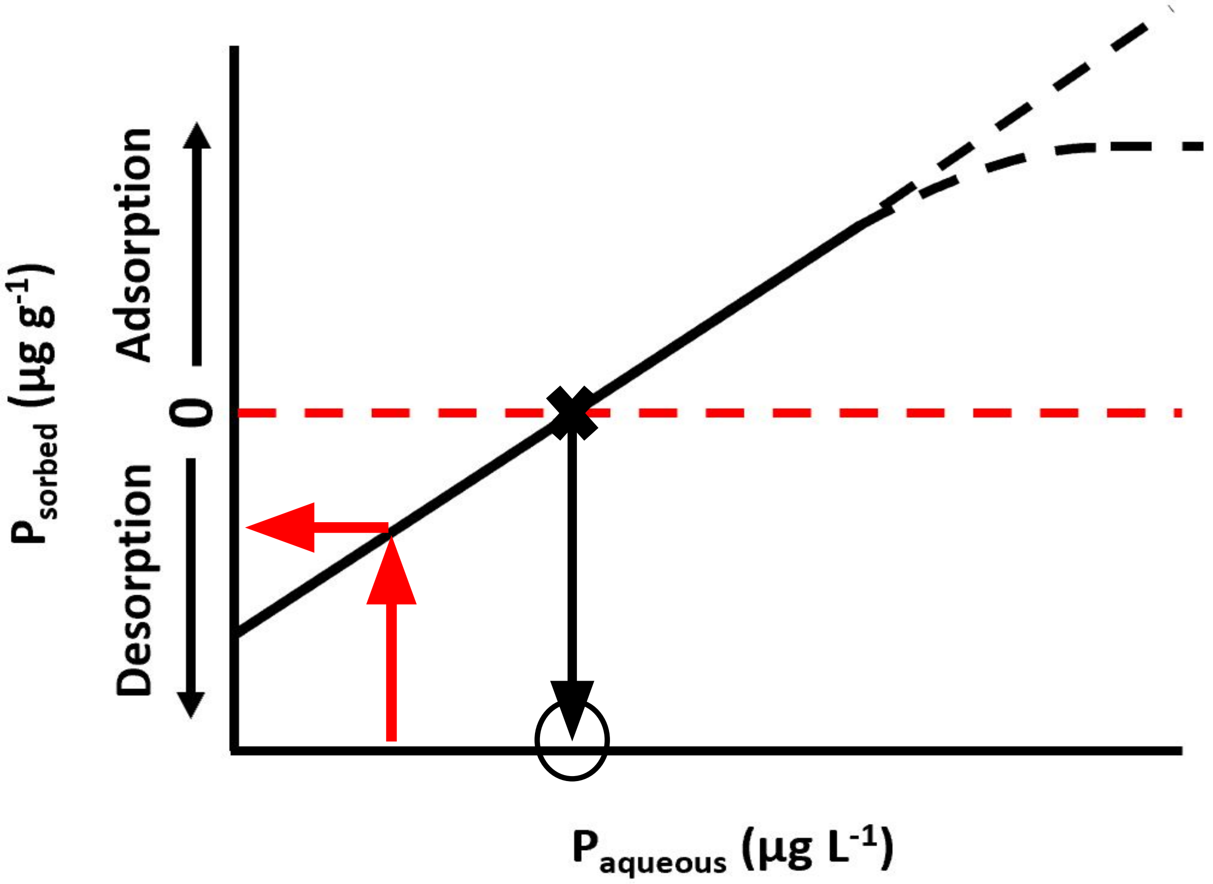


Proactive reservoir management approaches for mitigating algal threats

- Primary focus on sediment loading
- Decrease light availability
- Mechanical mixing / bubblers
- Increase sediment oxidation
- Sediment dredging
- Chemical coagulant addition
  - New York City, turbidity control

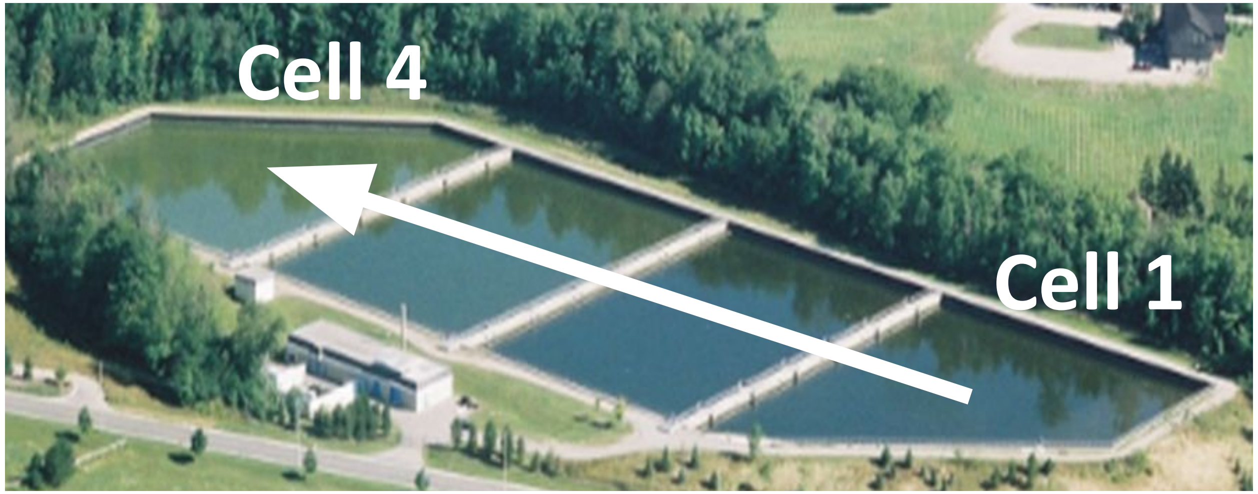
Objectives

1. Assess sediment characteristics to determine likelihood for P desorption
2. Describe P load potential to the reservoir from the fine sediment
3. Evaluate the P release potential of fine sediment
4. Evaluate possible management strategies at bench-scale for minimizing algal proliferation
   I. Chemical coagulant addition for P sequestration
   II. Combination of reservoir dredging and coagulant addition for P sequestration

Study Background

- Waterloo, Ontario
- Urban and agricultural impact
- **Sediment** physical and geochemical traits support P release

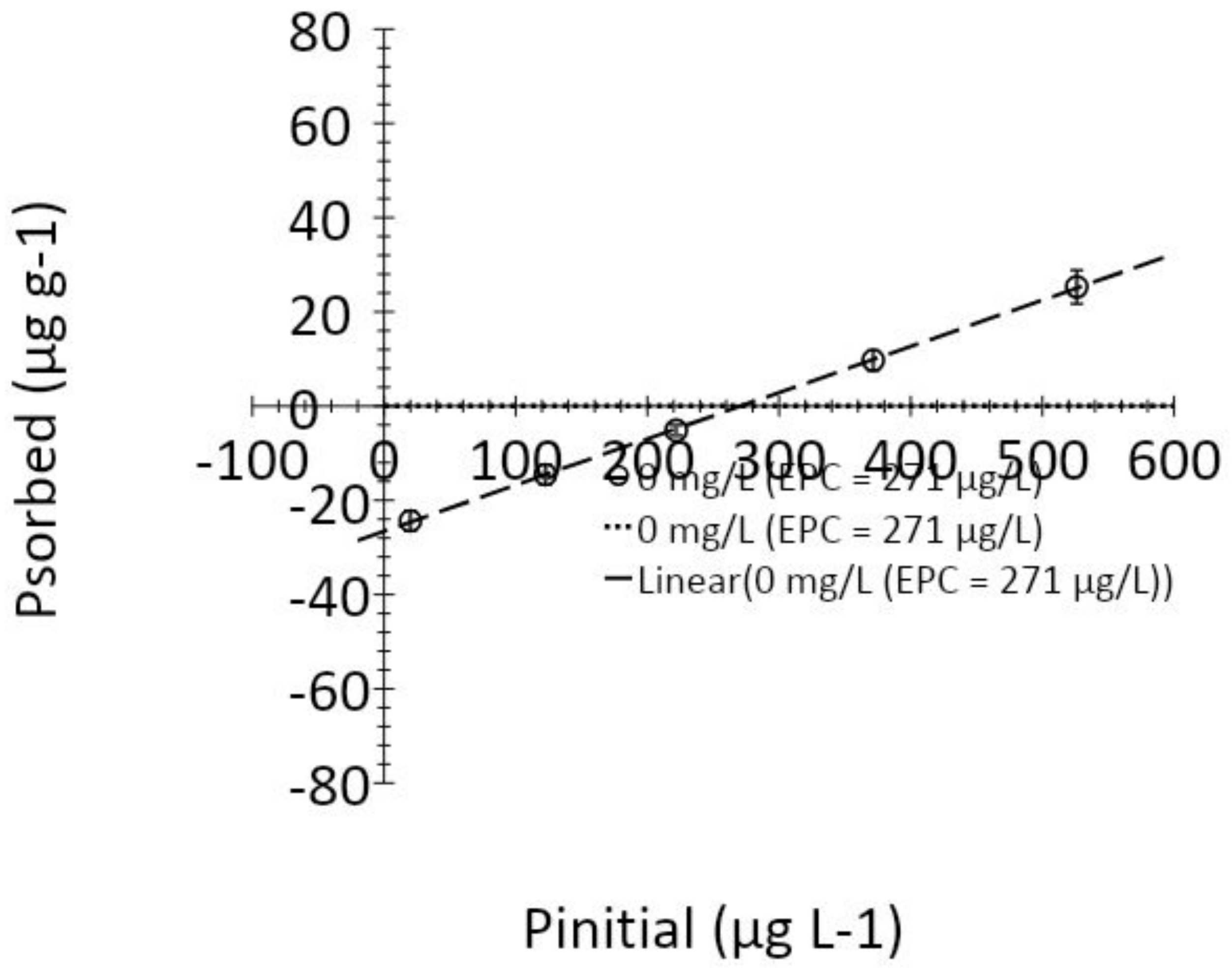
1. Sediment predominantly fine grained
   - D_{80} < 64 µm in each cell
2. Sediments with P binding metal oxide fractions higher in cells 3 and 4
   - Al, Mn, Fe, and chlorite (NAIP associated)
3. Highly anoxic sediment: confirmed by ORP analysis
4. Particulate P concentrations higher than other reported source water reservoirs



Study Background

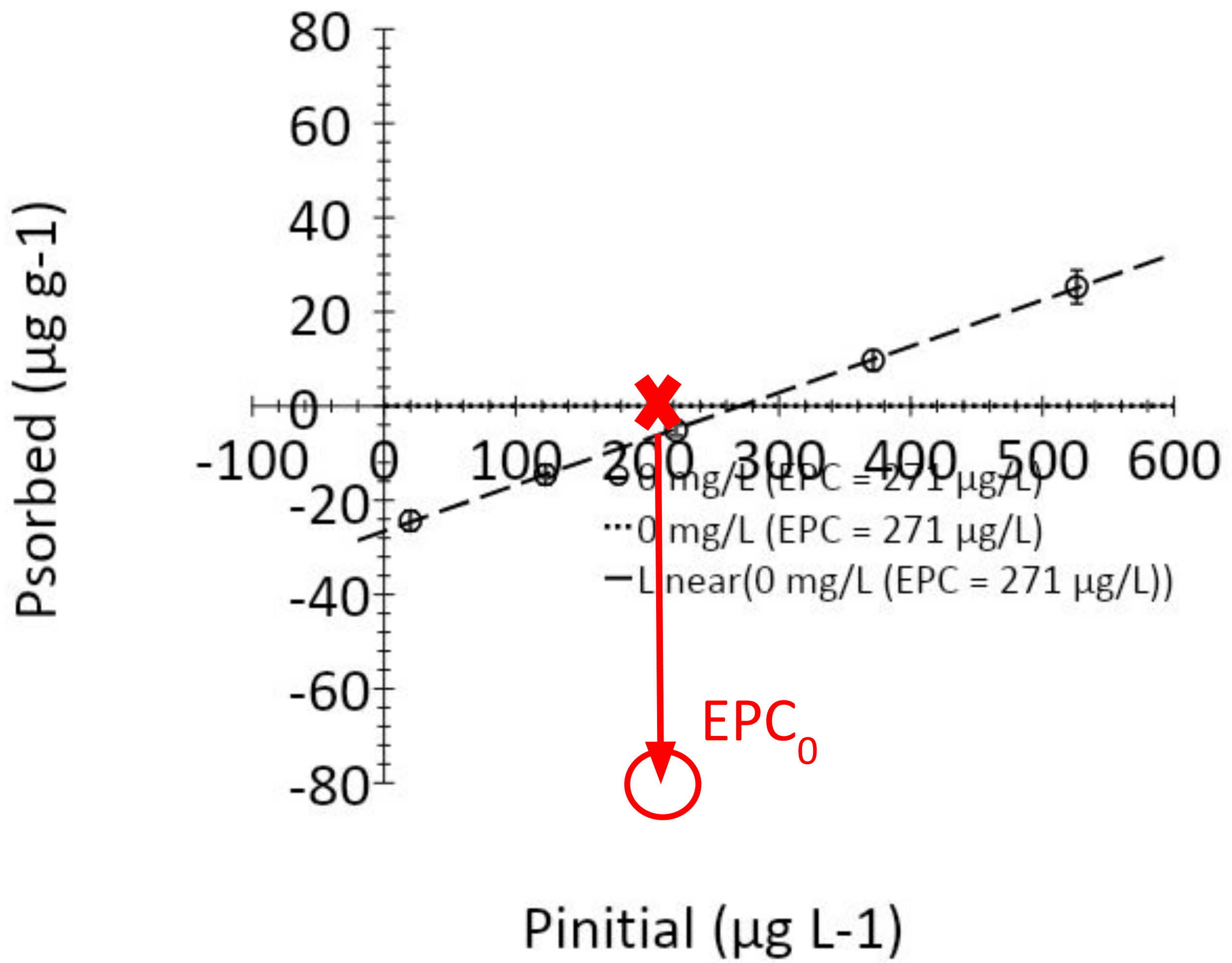
- Commonly cited threshold for eutrophication
  30 µg TP L^{-1}
- **Raw Water** historical data supports P release
  - Historical TP intake data ranges from
    20 – 200 µg P L^{-1}
- Factors underscore the need for fine **sediment** and **water** quality management

Cell #1: P desorption from fine sediment



Cell #1: P desorption from fine sediment

- EPC_0 = 271 µg P L^{-1}



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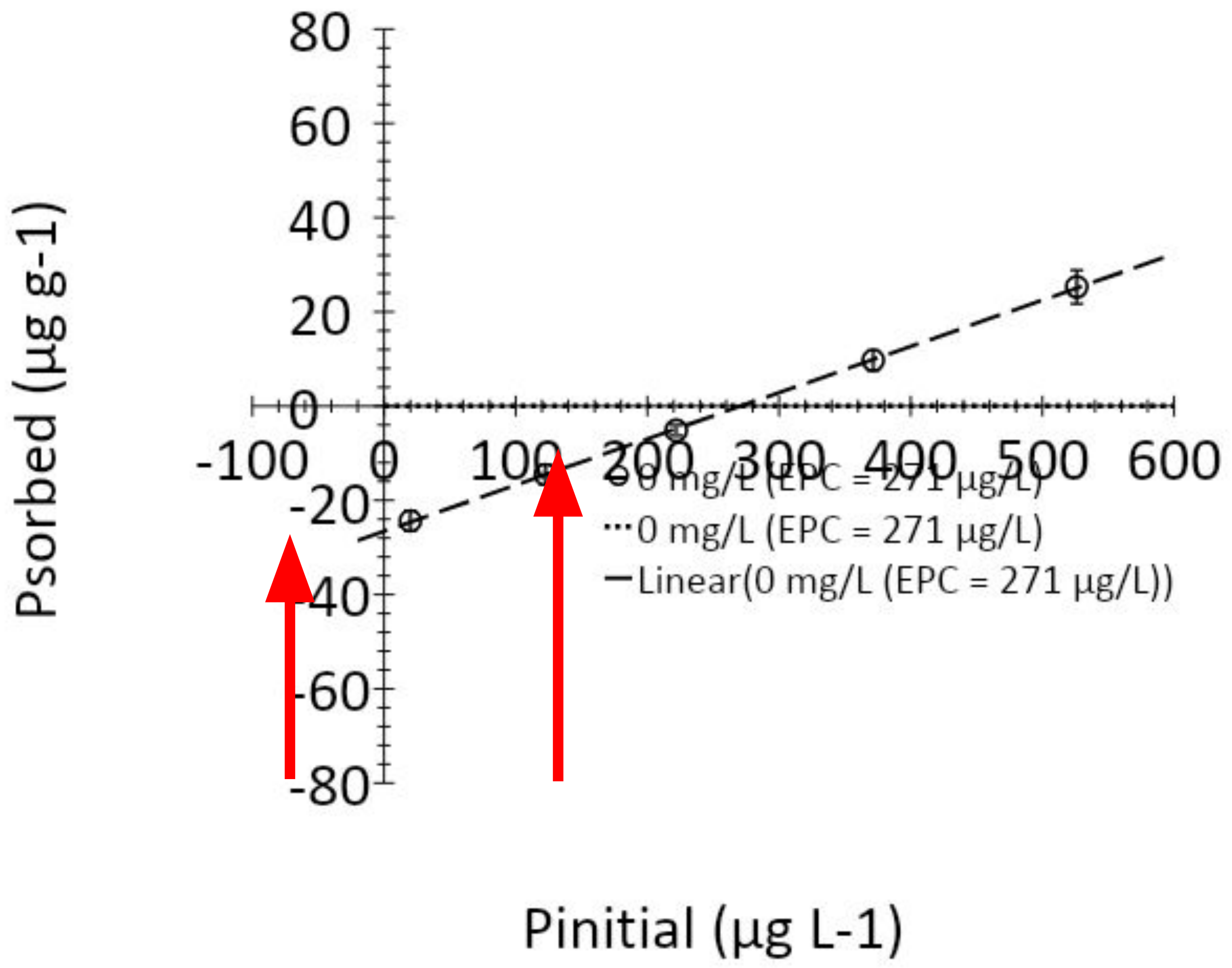

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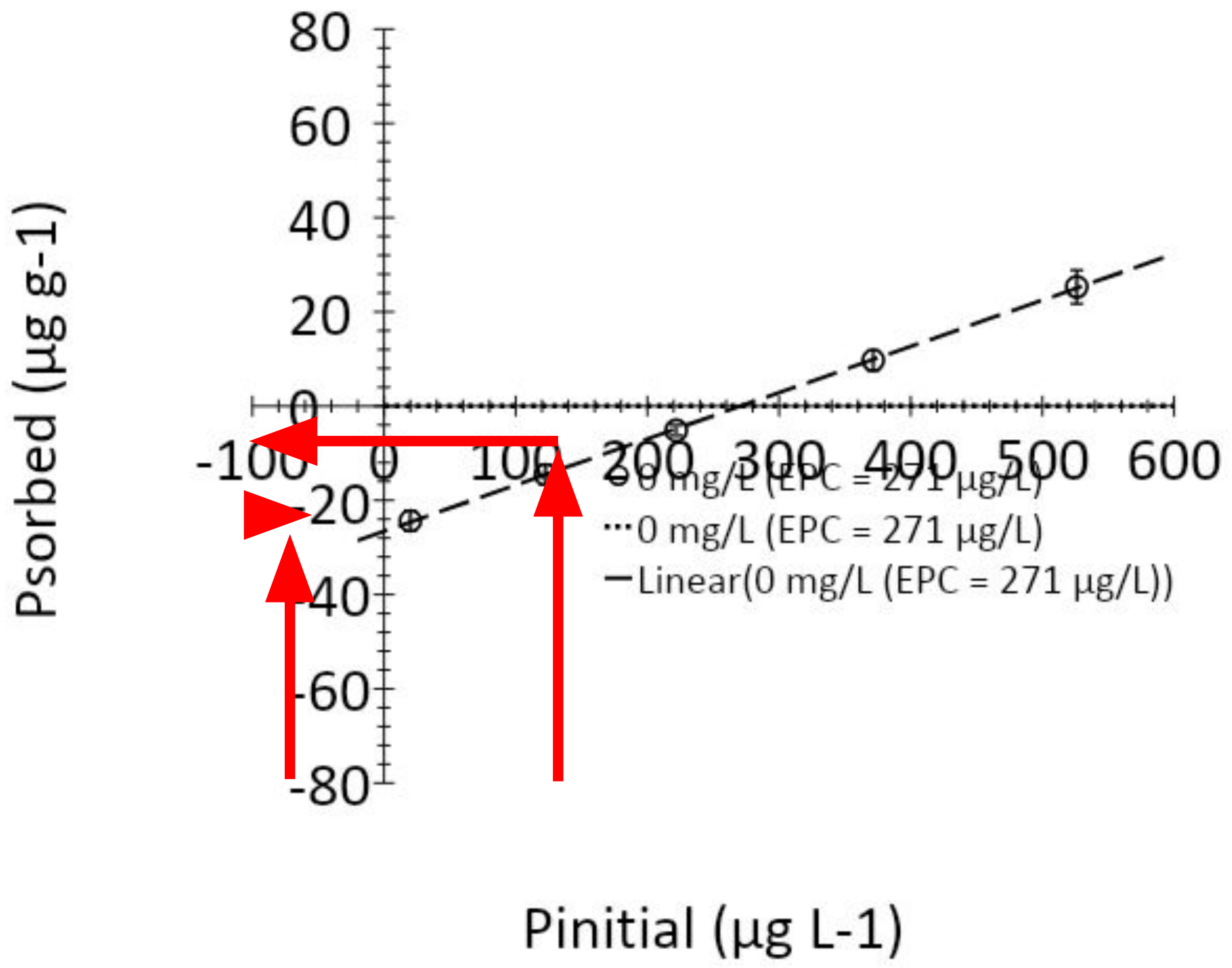
- EPC_0 = 271 µg P L^{-1}
- Raw water [TP] range 20 – 200 µg P L^{-1}
- Sediment desorbs 5 – 25 µg P $g_{sediment}^{-1}$



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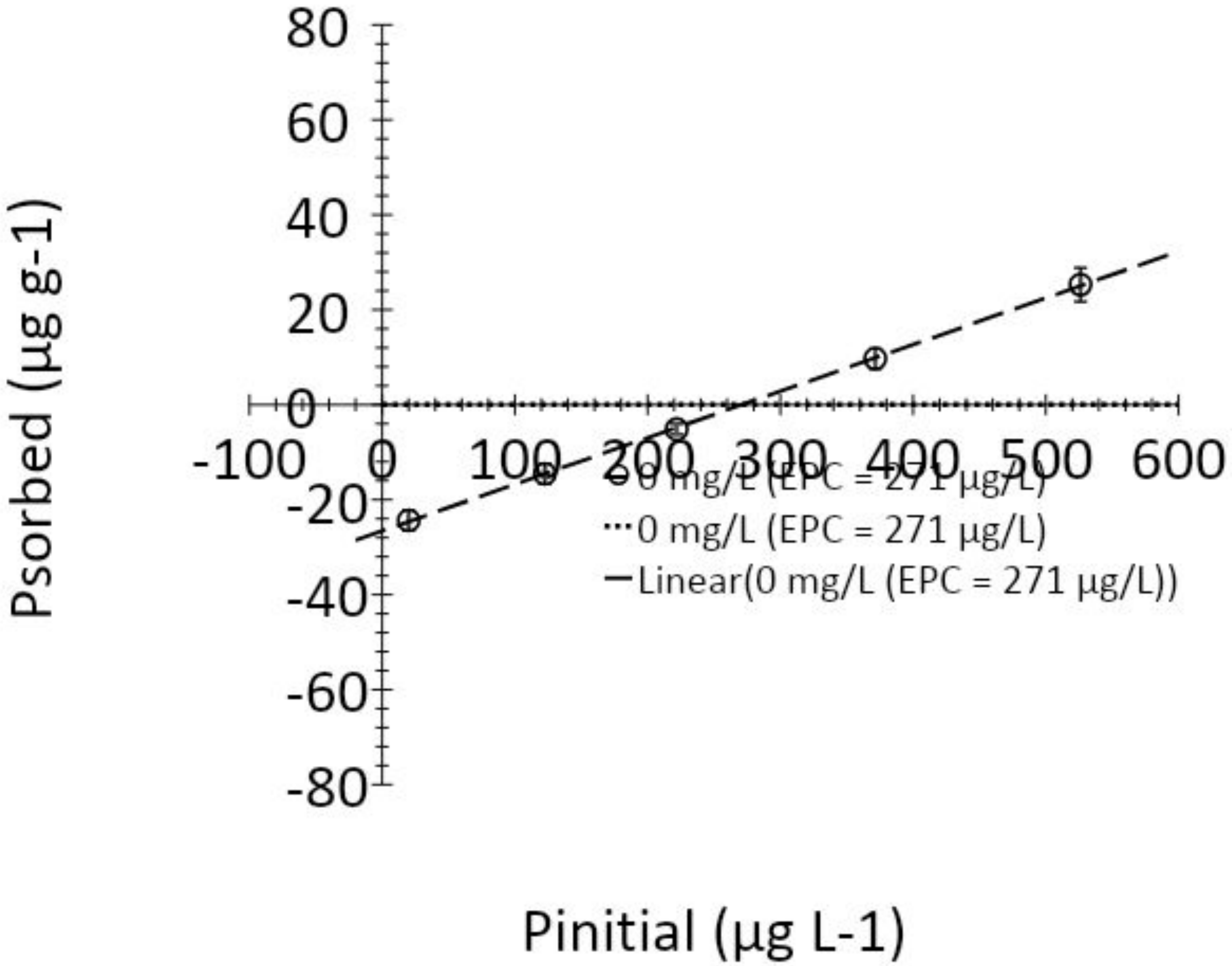
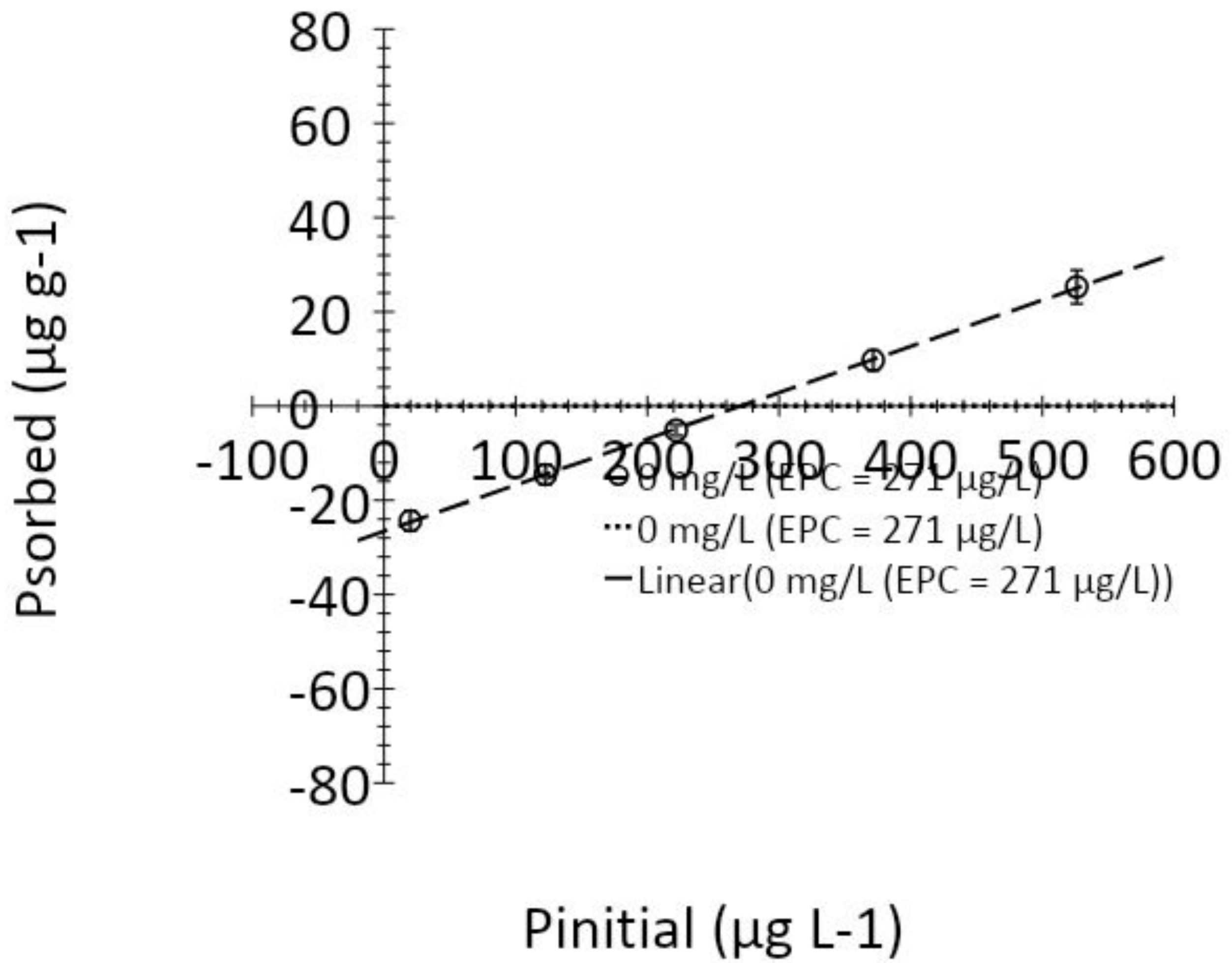
- $EPC_0 = 271$ µg P L^{-1}
- Raw water [TP] range 20 – 200 µg P L^{-1}
- Sediment desorbs 5 – 25 µg P $g_{sediment}^{-1}$
- P availability for primary producers
- Reservoir sediment & water quality management should be considered



P sequestered with common chemical coagulants

- Alum, PACl, and $FeCl_3$ coagulants added to reduce EPC_0



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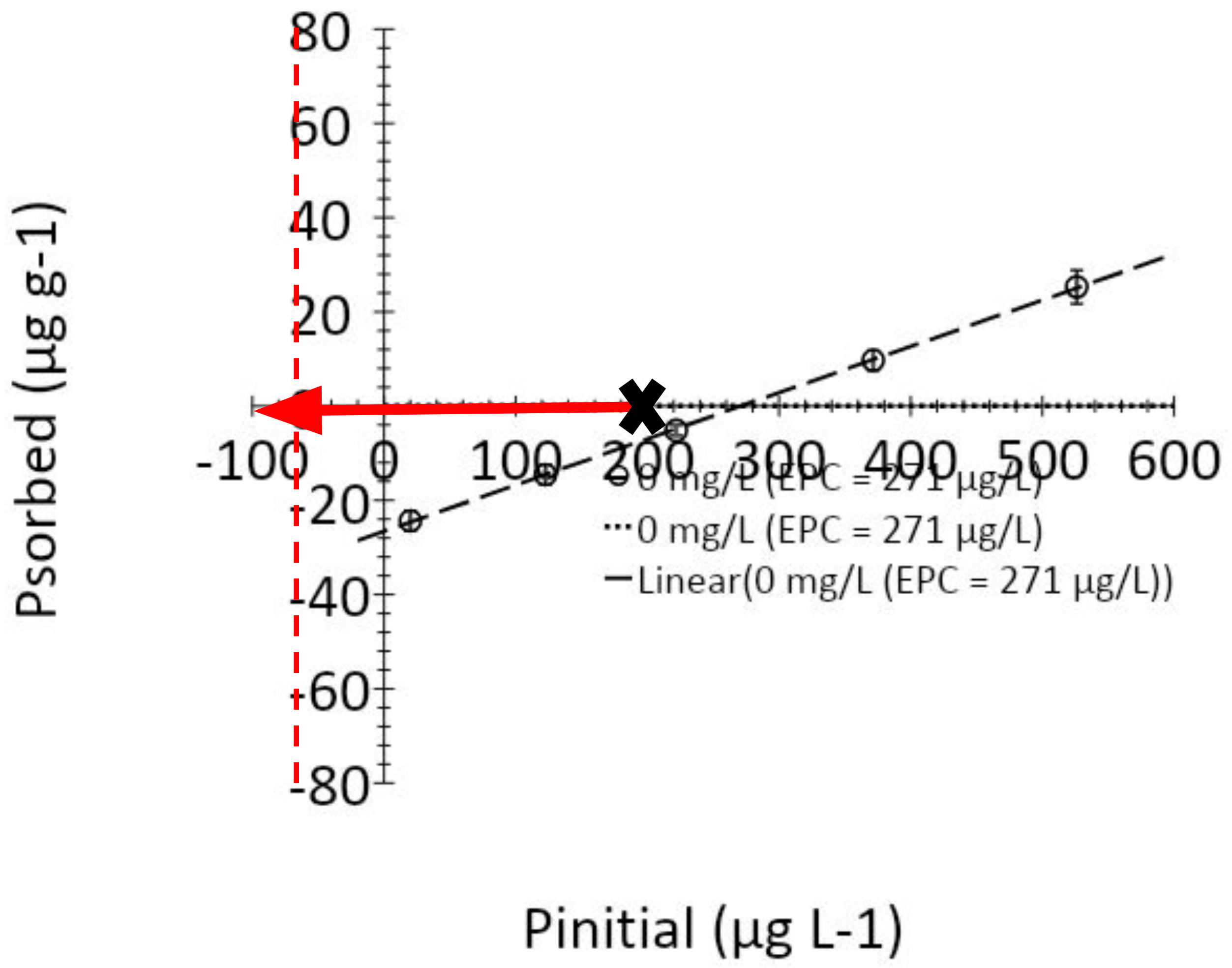

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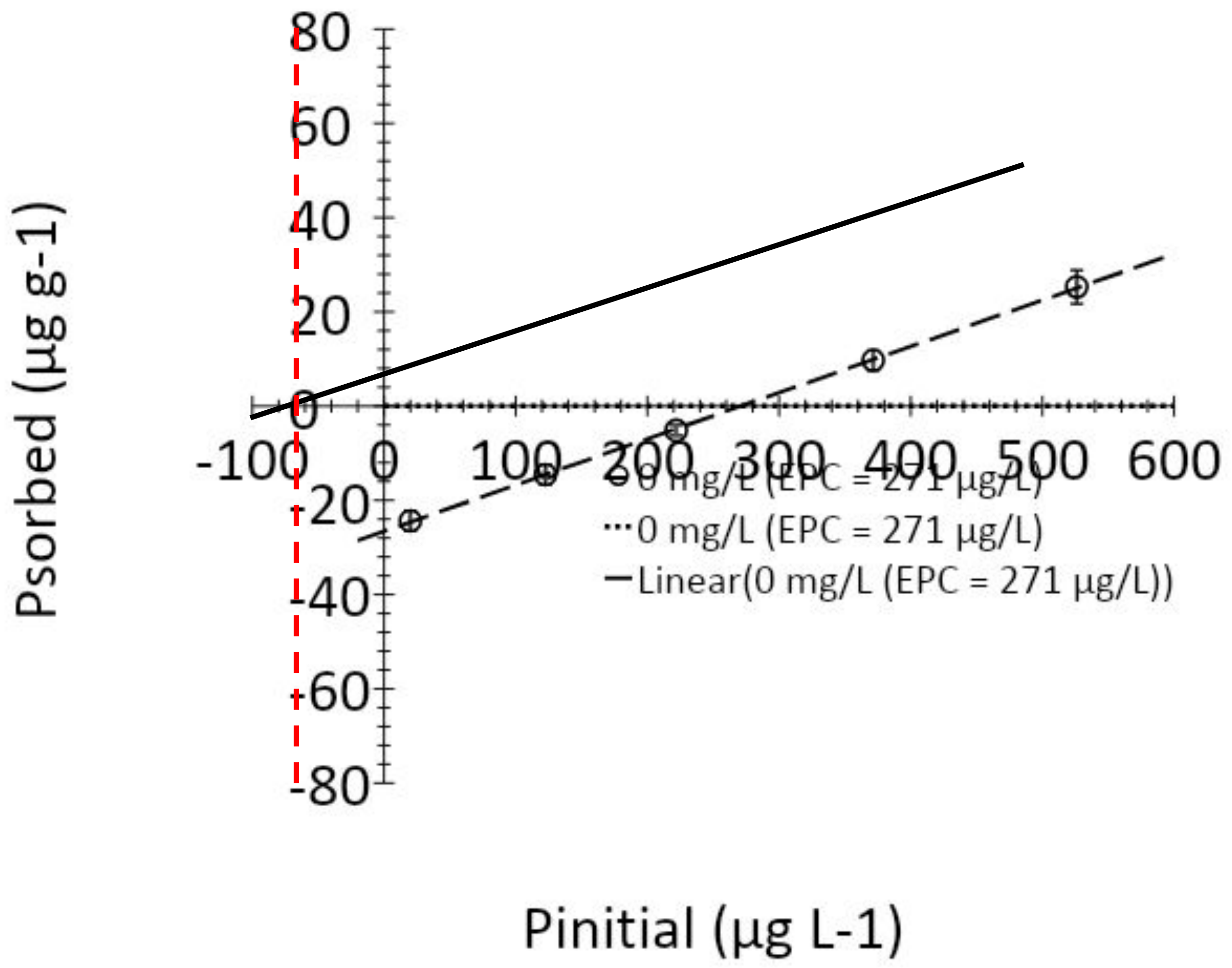

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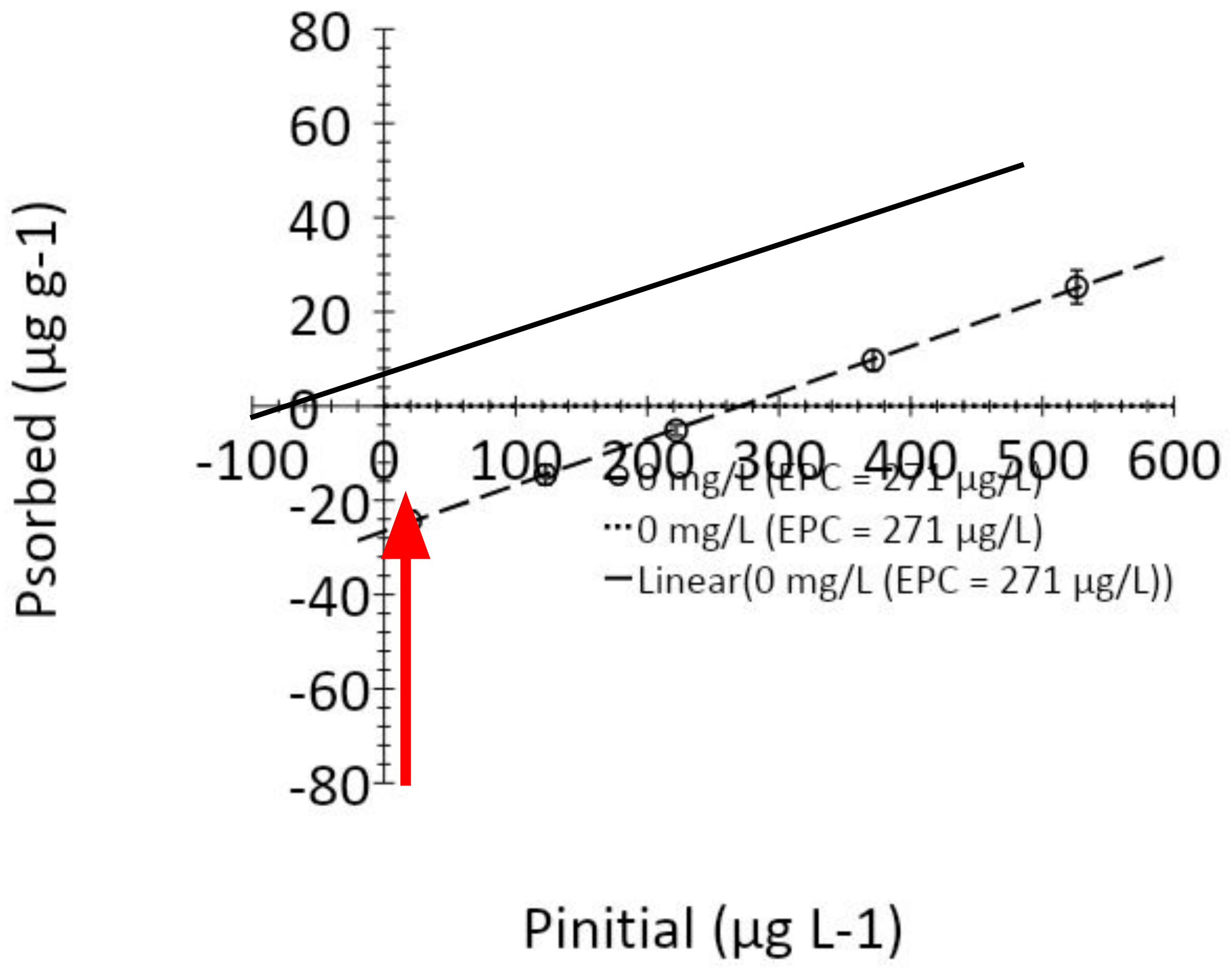

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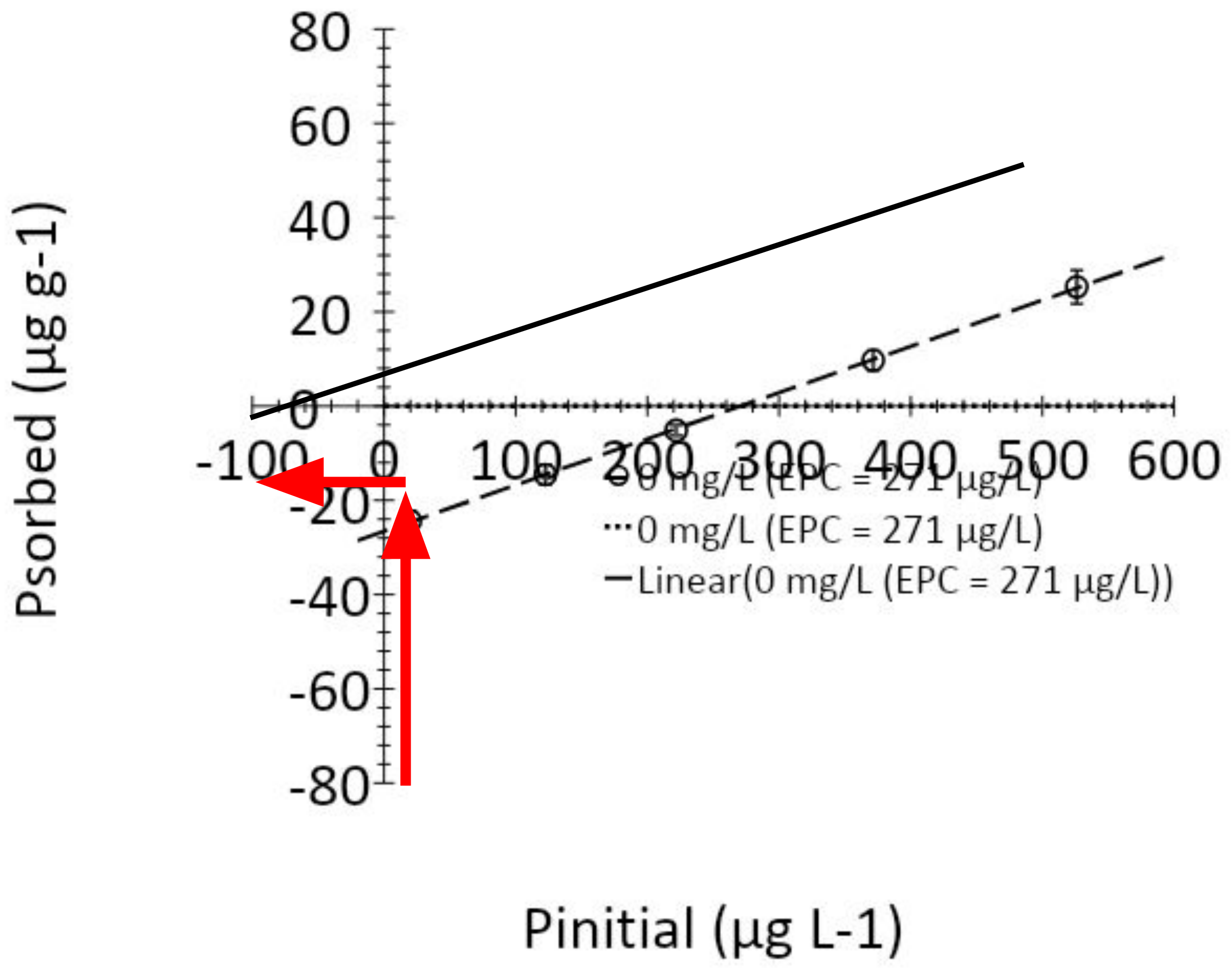

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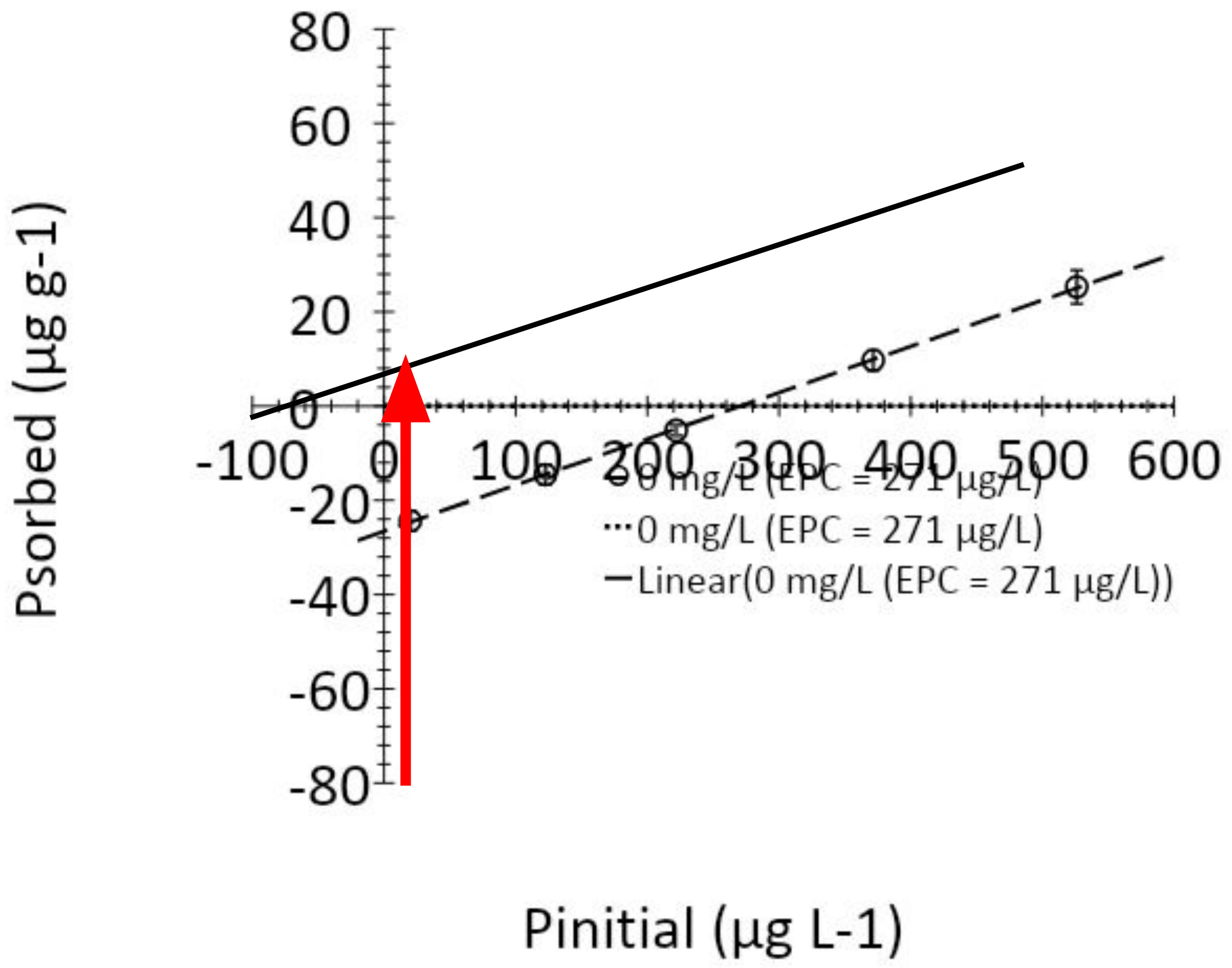

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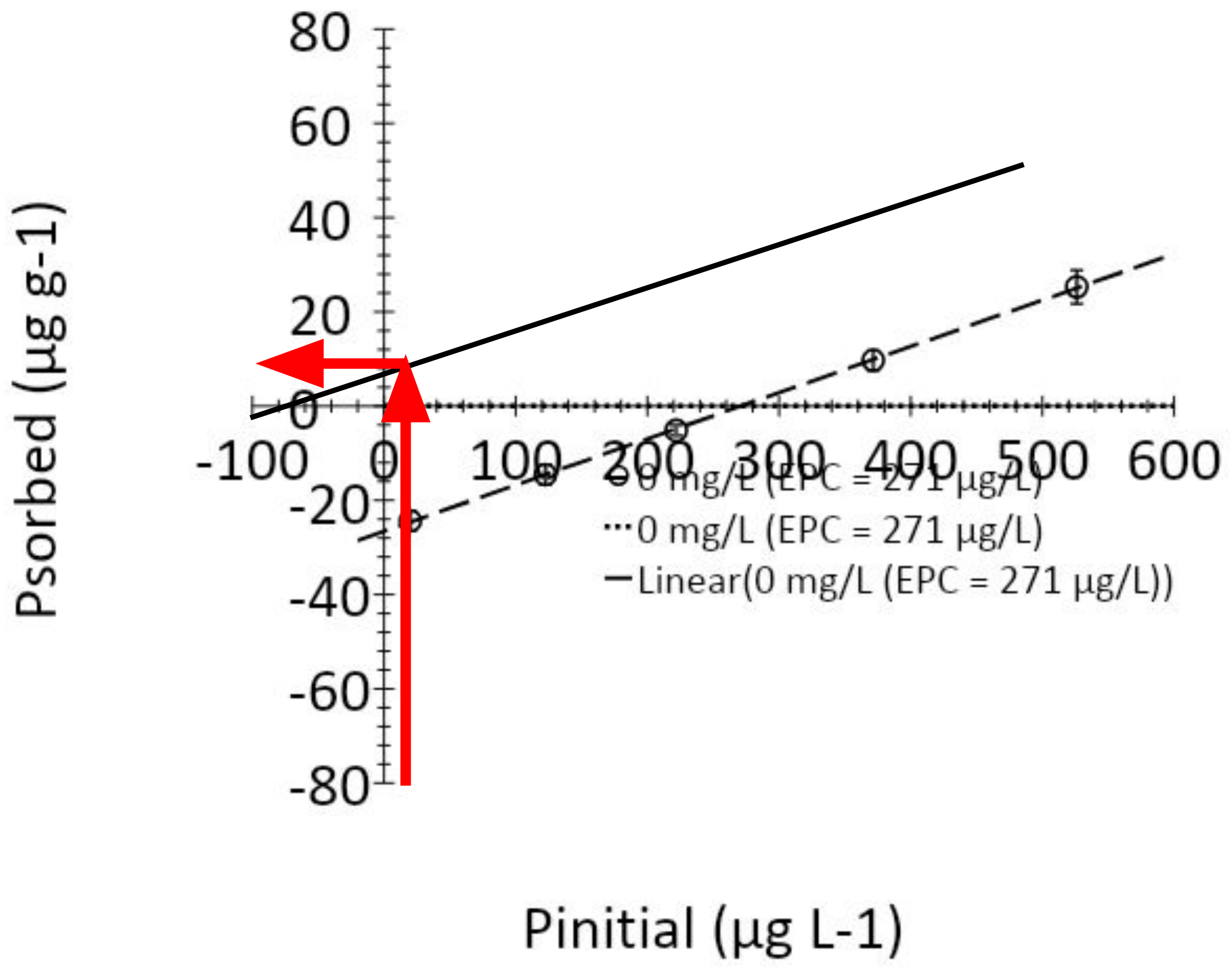

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- Alum, PACl, and $FeCl_3$ coagulants added to reduce EPC_0
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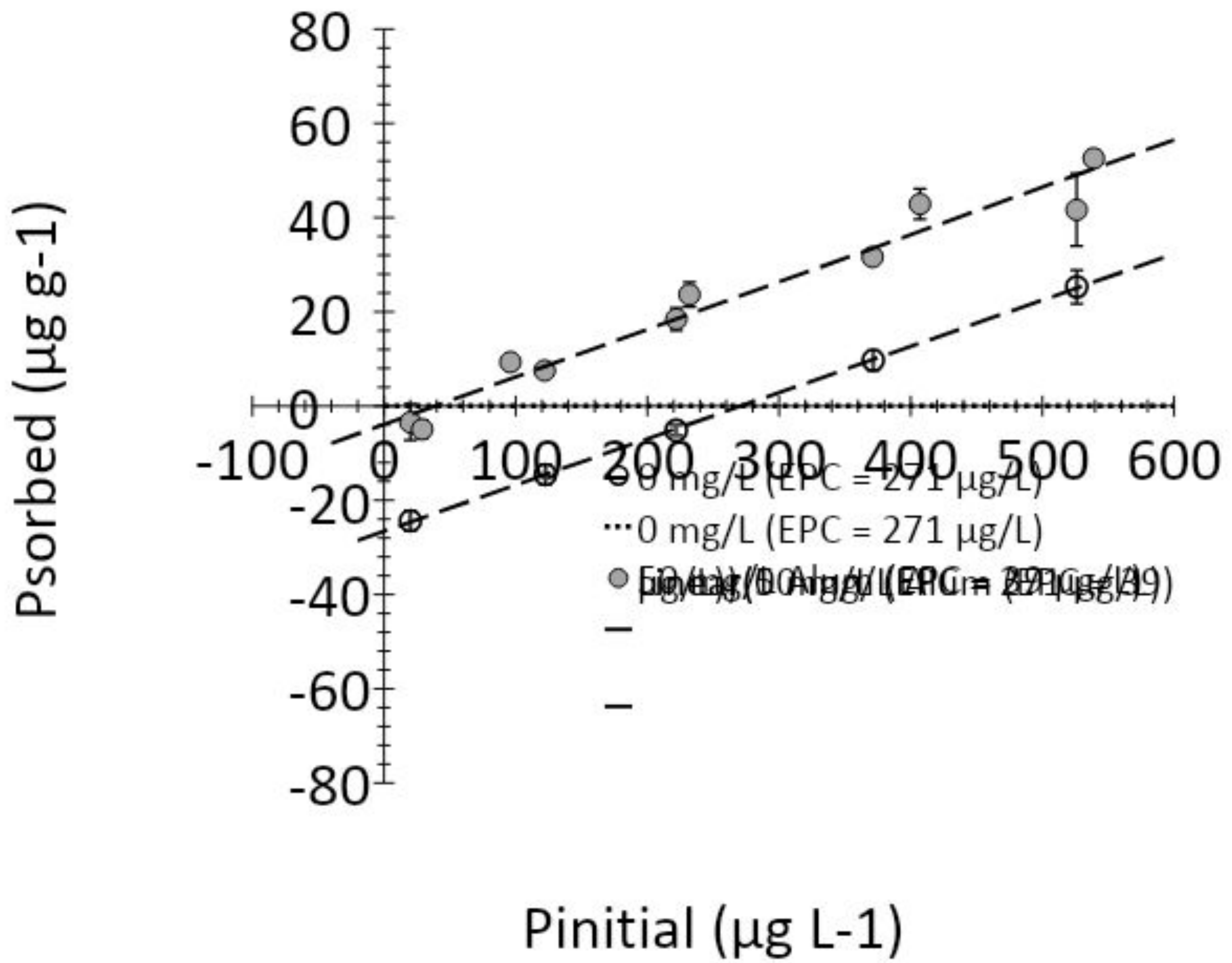

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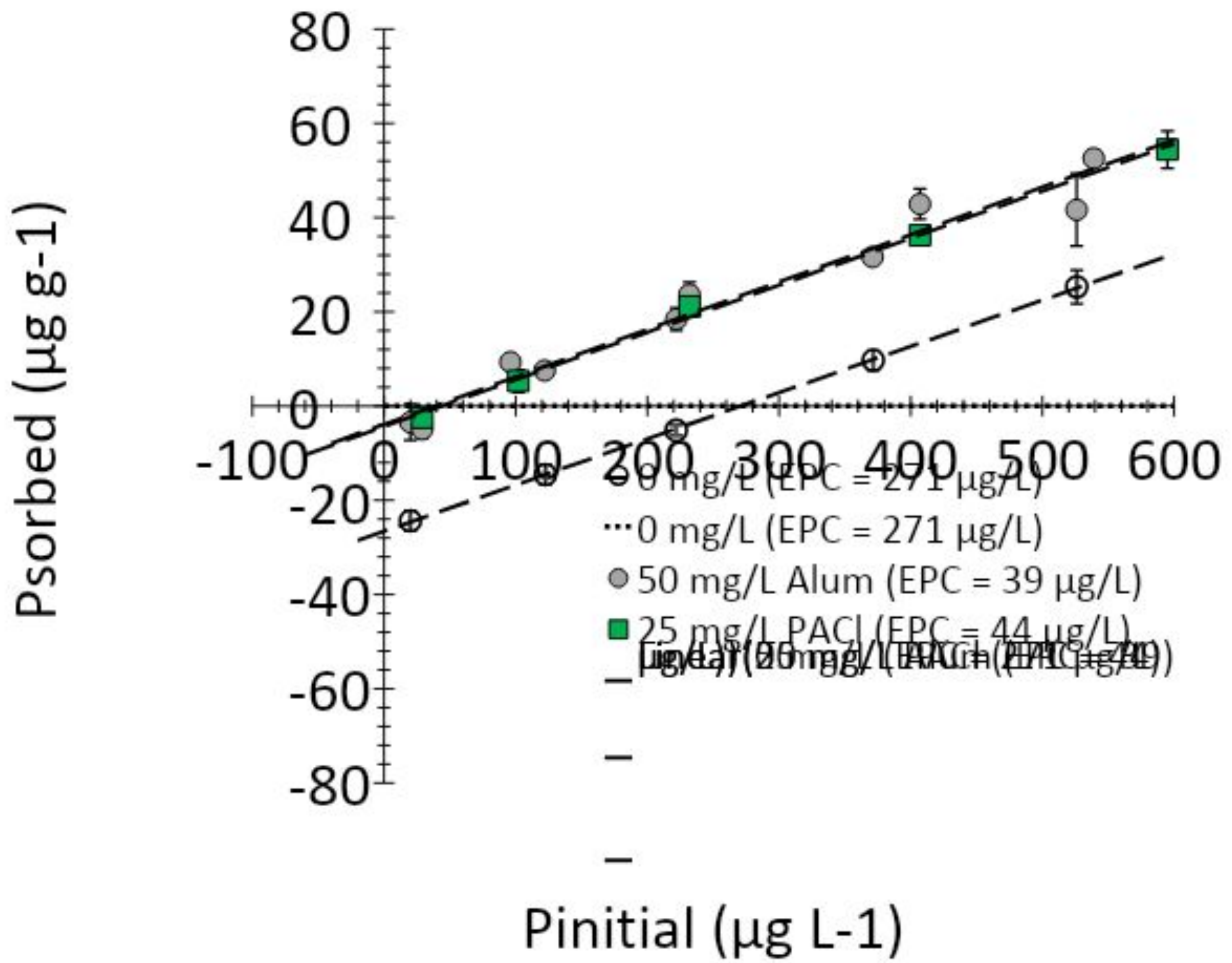

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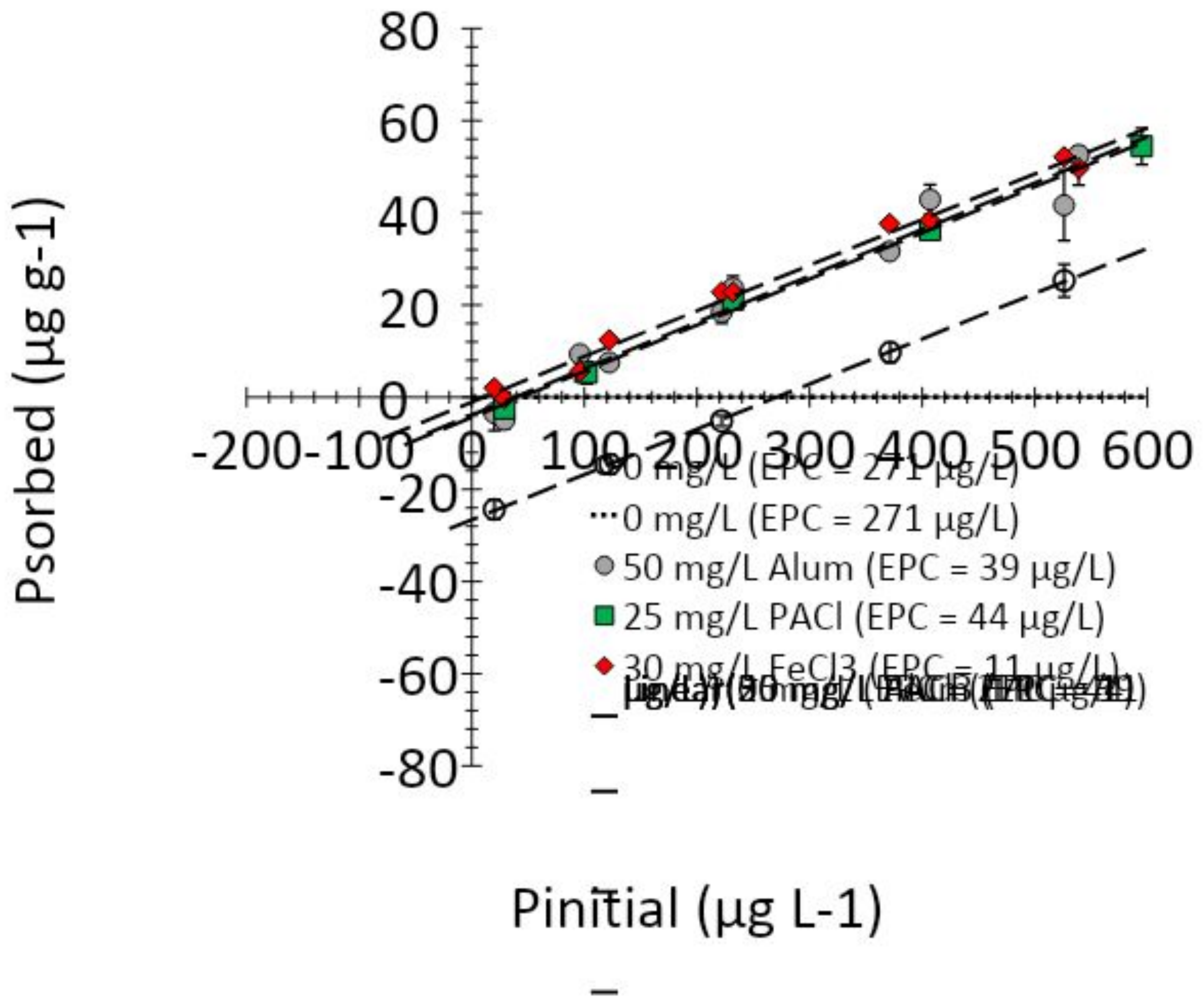
- $FeCl_3$ (30 mg L^{-1}) rapidly reduced EPC_0 from 271 µg P L^{-1} to 11 µg P L^{-1}
  - Low dose $FeCl_3$ (10 mg L^{-1}) achieved target threshold reduction 25 µg P L^{-1}



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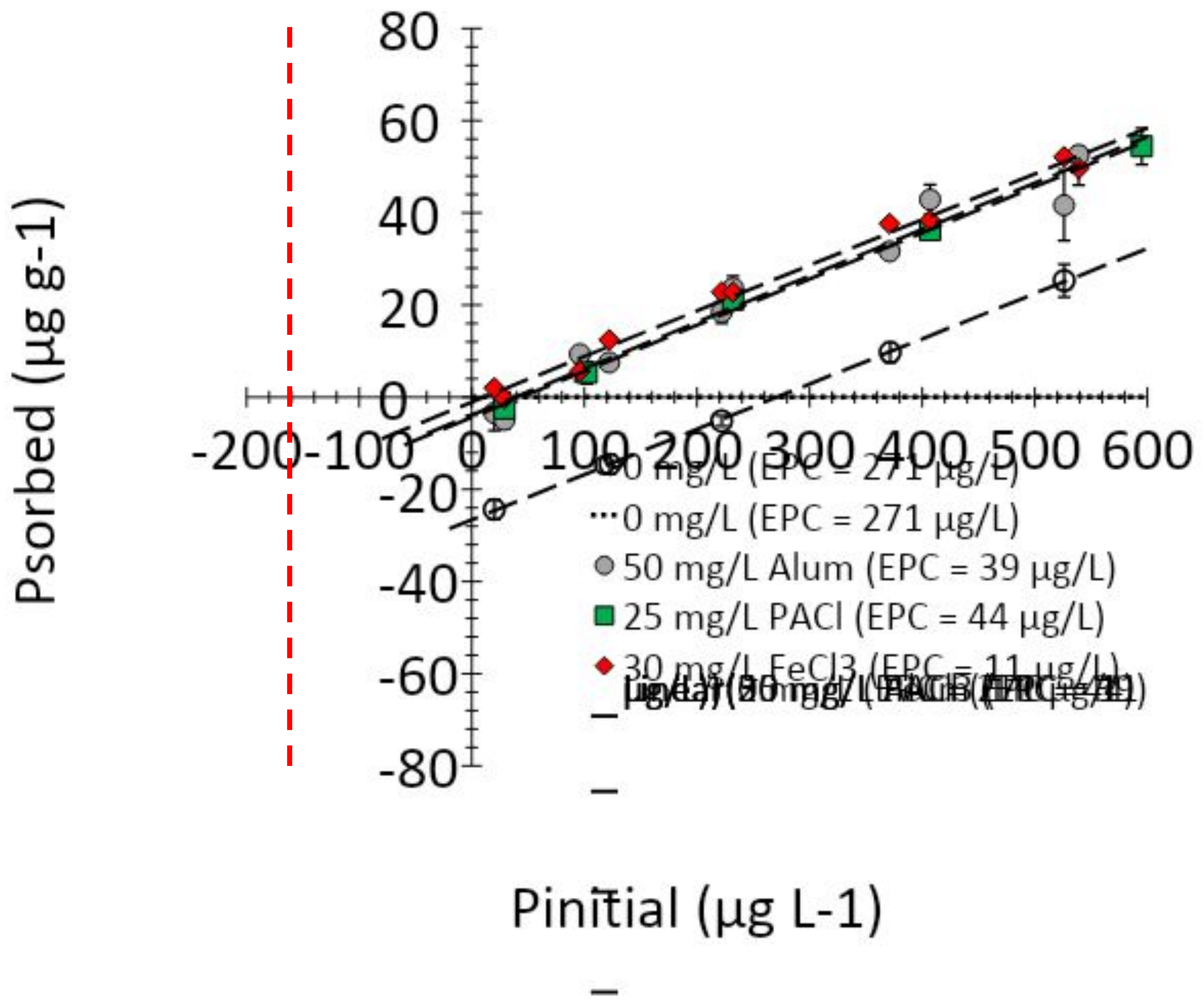
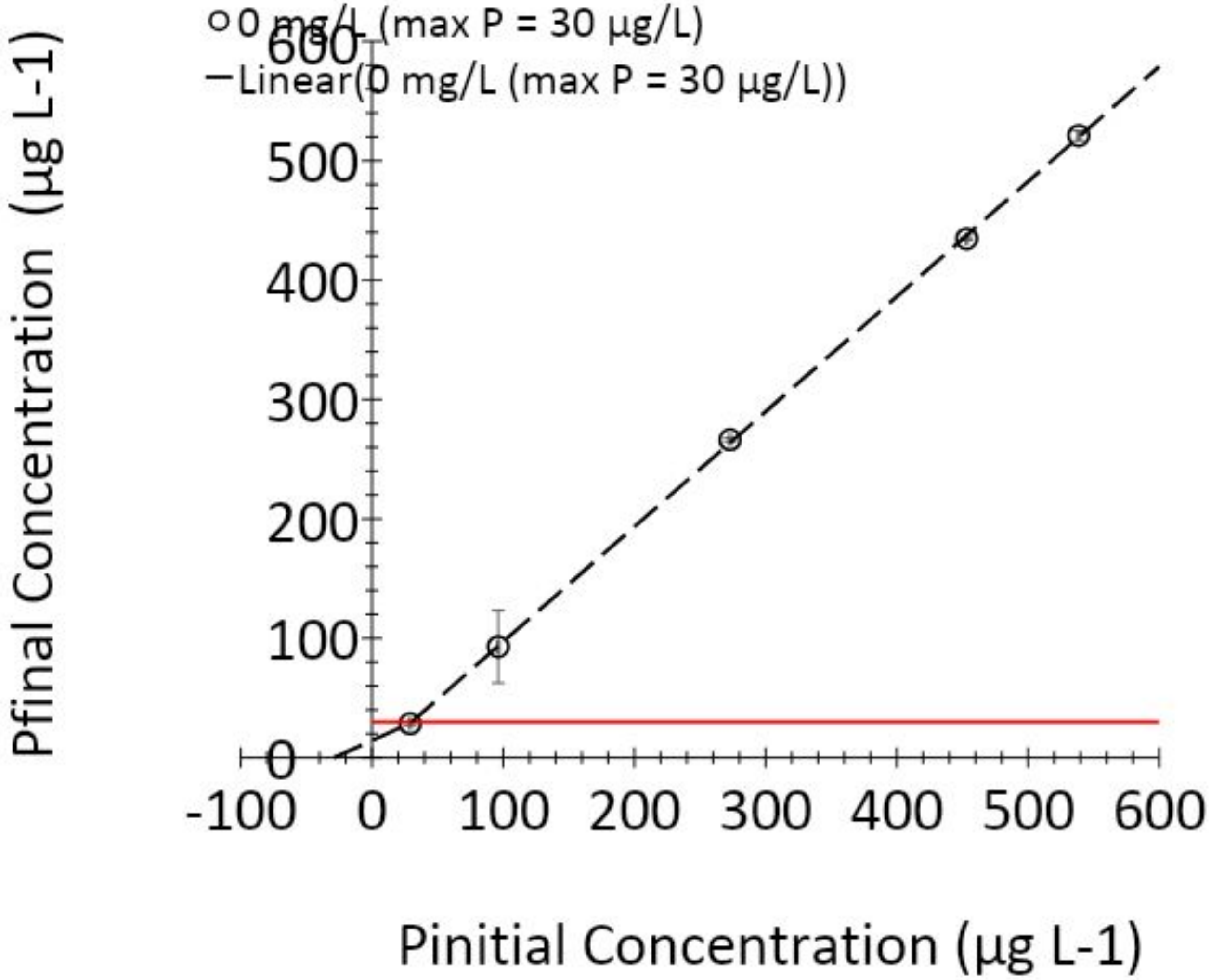


Dredging & coagulant addition enhance P removal

- Sediment removed before Alum, PACl, and $FeCl_3$ coagulants added to minimize P



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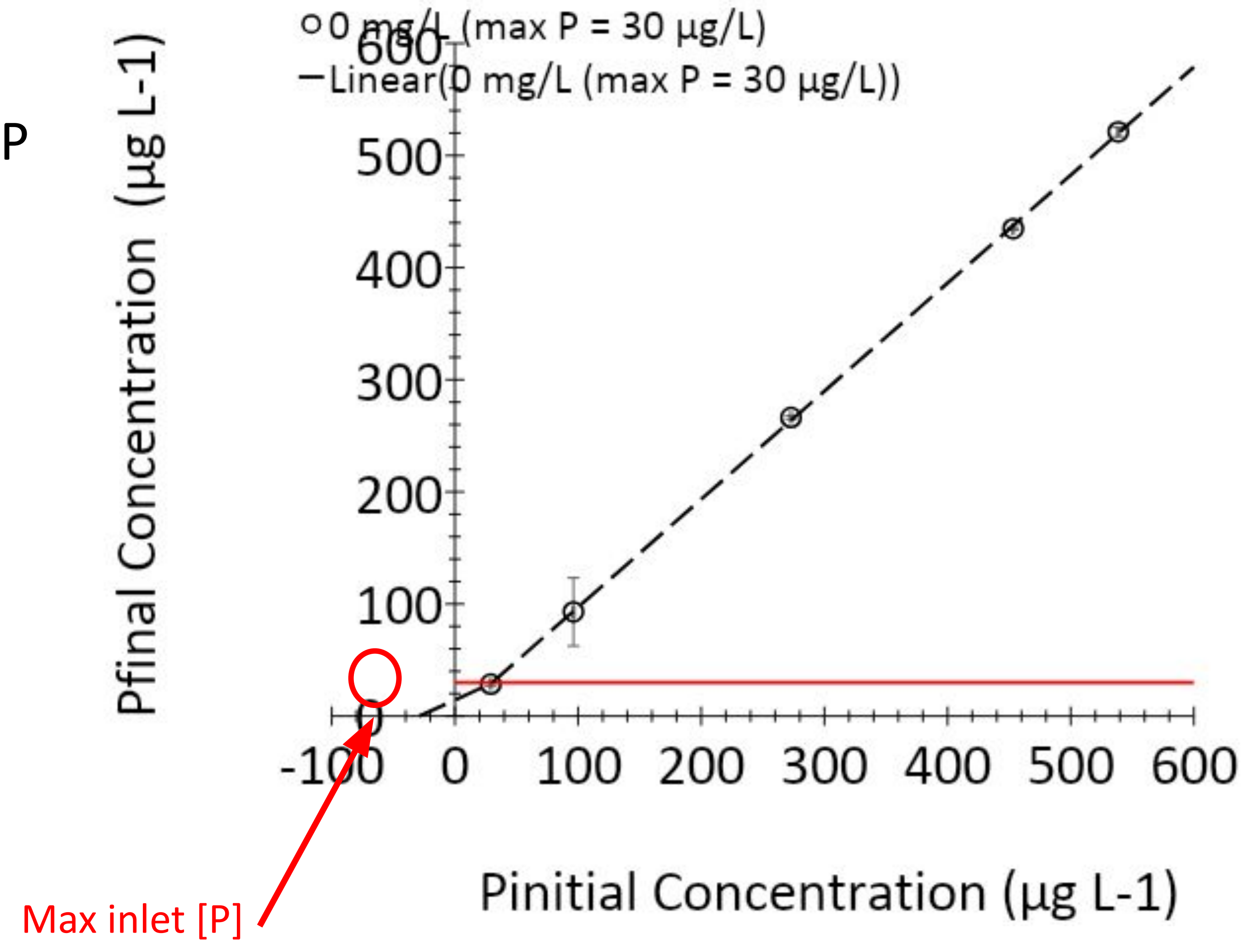

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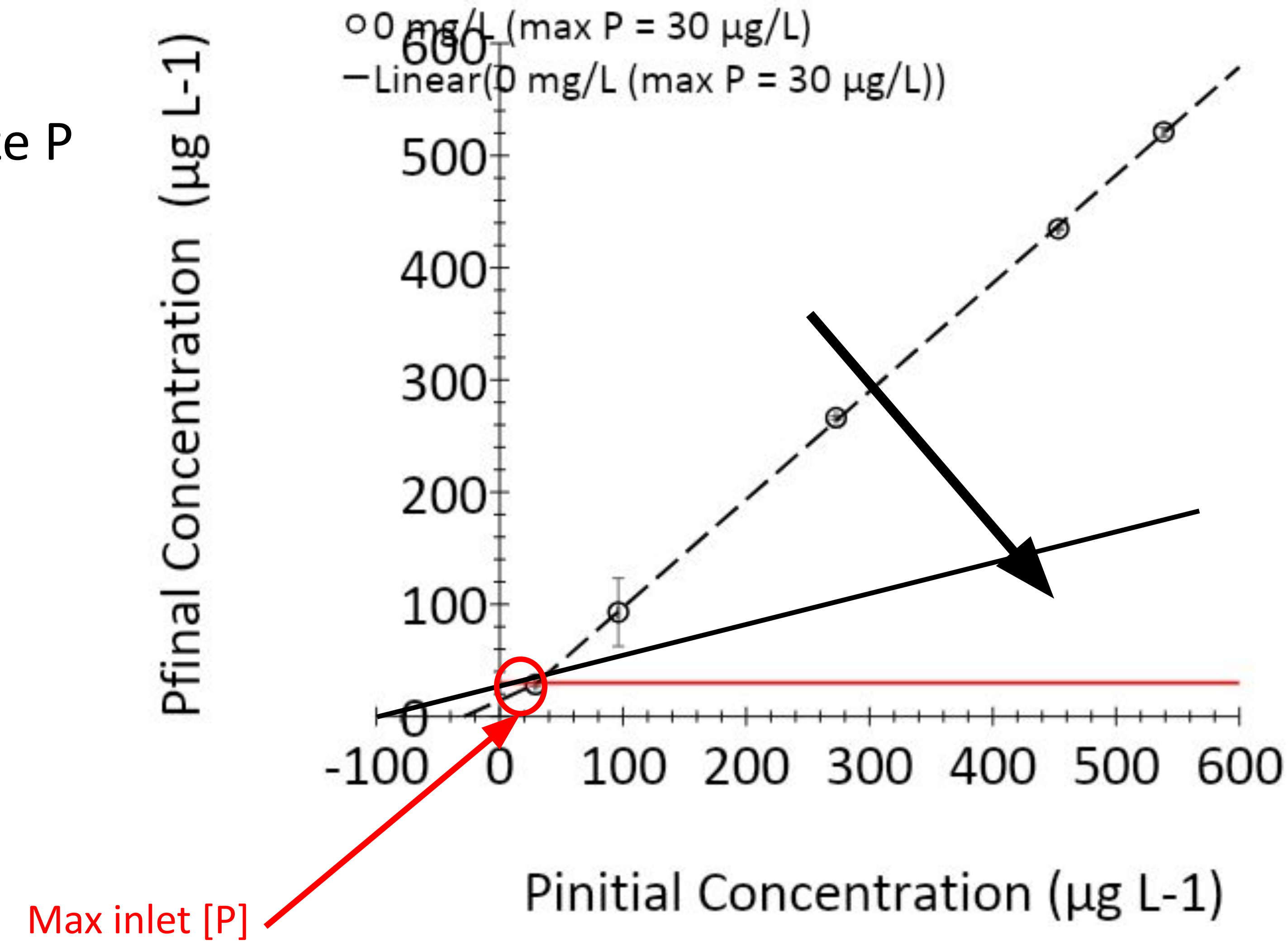

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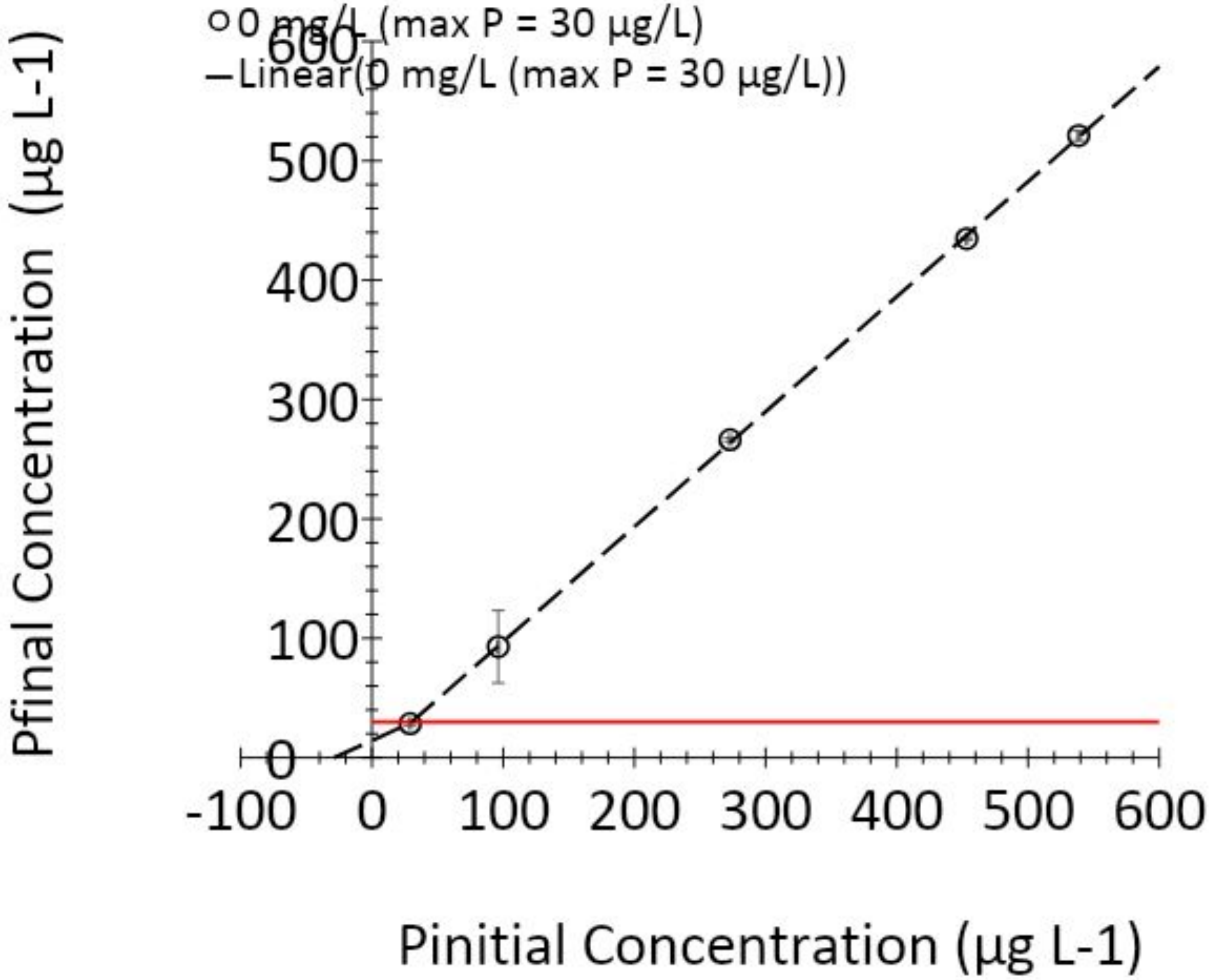

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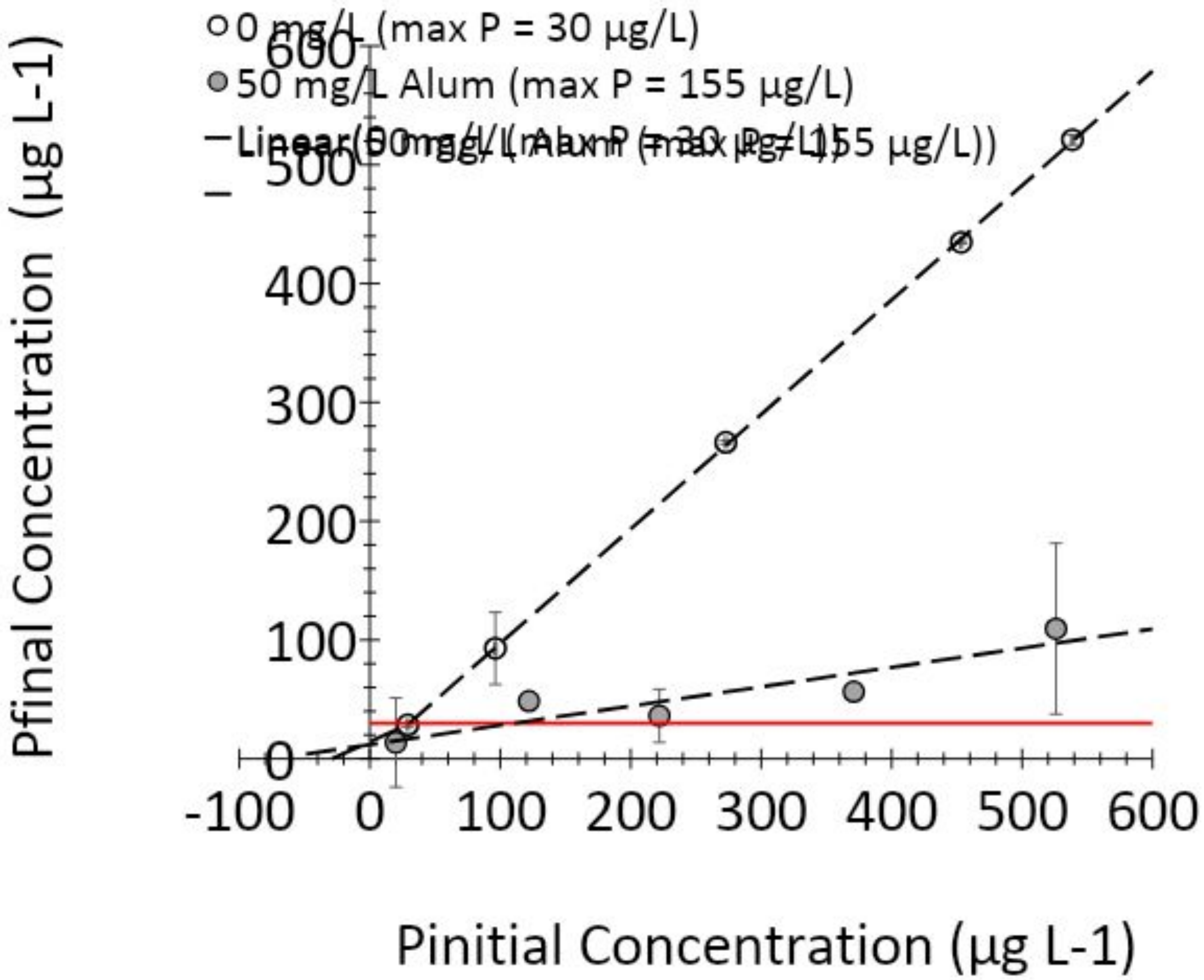

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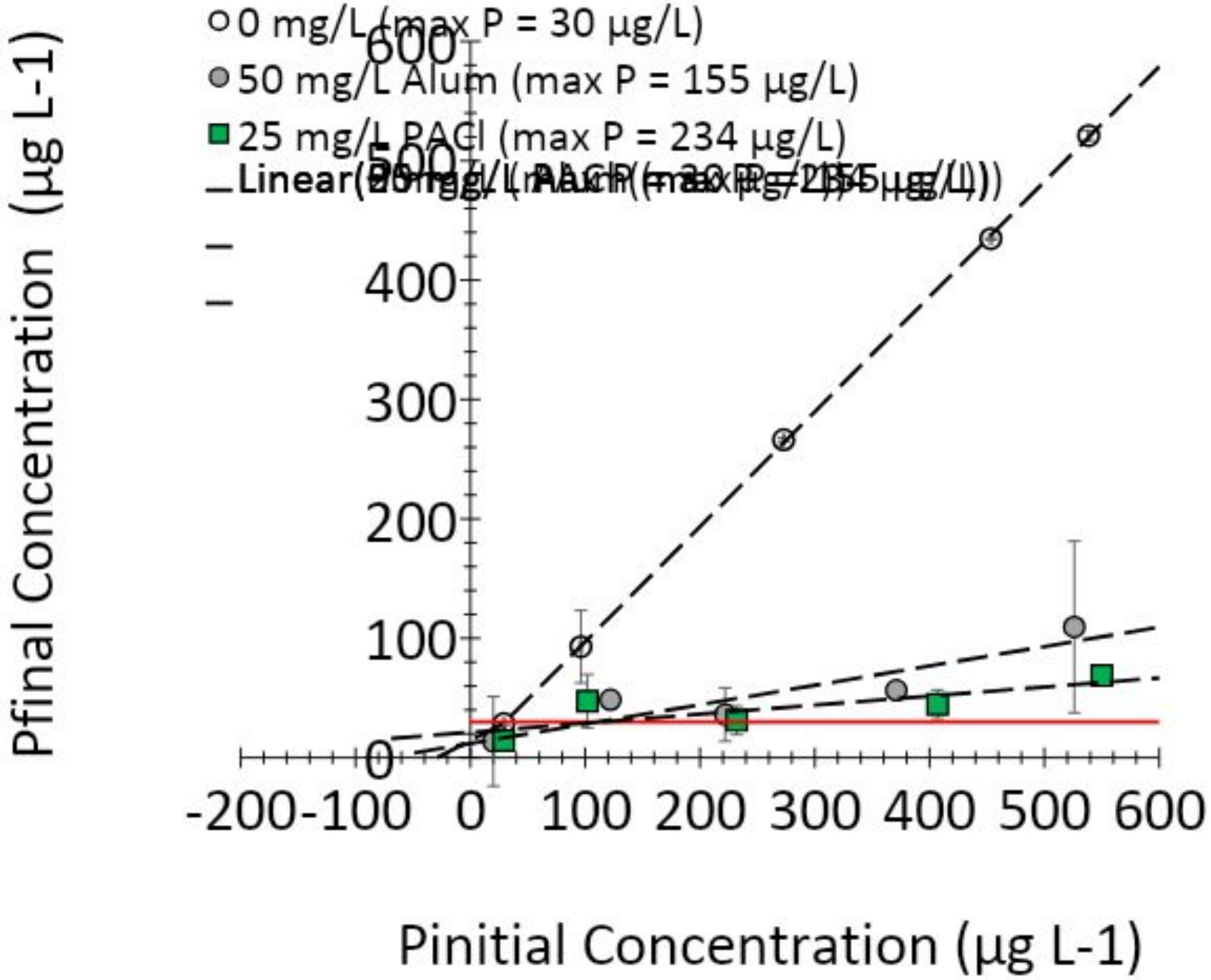

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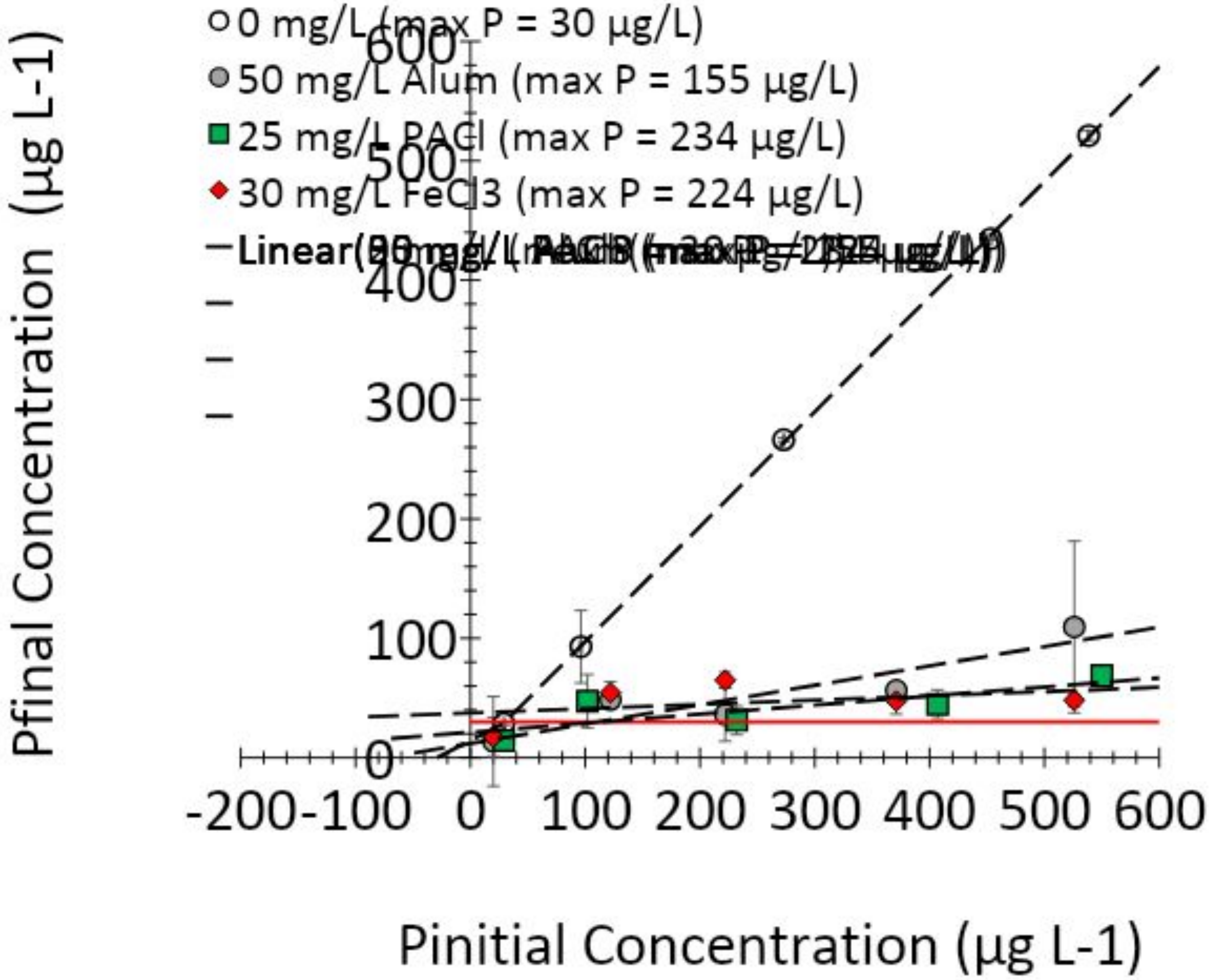
- $FeCl_3$ (30 mg L^{-1}) reduced inlet [P] < 224 µg P L^{-1} to below threshold
  - Low dose $FeCl_3$ (10 mg L^{-1}) reduced inlet [P] < 125 µg P L^{-1} to below threshold



Conclusions

1. Sediment geochemical properties suggest potential for P desorption

2. Historical P intake data suggest significant potential for algae proliferation

3. Chemical coagulant addition to raw (untreated) water storage reservoir inflows can sequester P and reduce bioavailability

4. Coagulant addition following reservoir dredging can reasonably sequester P

5. Engineering controls can provide viable options for managing reservoir water quality and algae proliferation potential

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Thank you

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