Effects of drought-related low phosphorous concentrations on the aquatic ecosystem downstream of Glen Canyon Dam, and potential to improve productivity via nutrient fertilization

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GCD AMP management actions (water)

Experimental Flow Actions (Quantity)	Water Quality 'In-Actions' (Quality)
Spring HFE's ('96, '08)*	High water temperature*
Fall HFE's ('04, '12, '13, '14, '16, '18)	Low dissolved oxygen*
Bug Flows ('18, '19, '20, '22)	
	Low phosphorous concentrations*
Low steady summer flow ('00)*	
Fall steady flows ('09, '10, '11)	
Equalization flows ('11)*	

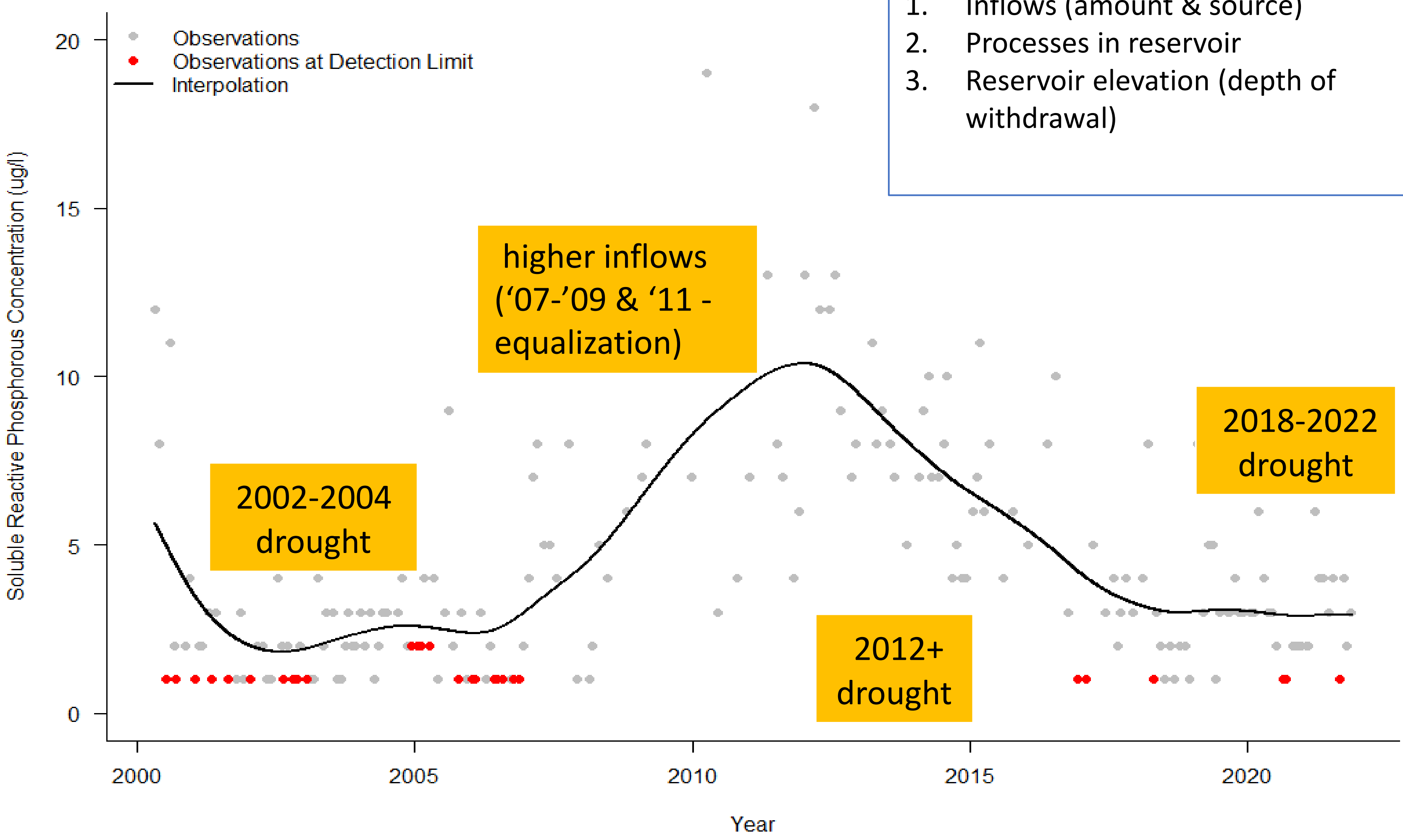
* affect on bugs or fish

	Bugs	Trout	Chub	Bass
Low steady summer flow ('00)		+	-	
Spring HFEs ('96, '08)	+	+	-	
Equalization (2011)		+ → -	-	
High water temperature		-	+/-	+
Low dissolved oxygen		-		
Low phosphorous	-	-	-(?)	

Could water quality, rather than water quantity, be the dominant influence on fish populations downstream of GCD under current and future conditions?

Or has water quality always been the dominant influence? Existing growth and survival models for Humpback chub (*Gila cypha*) in the mainstem include effects of water temperature, turbidity, and rainbow trout abundance. They do not include flow effects.

Soluble Reactive Phosphorous (SRP) concentration at Glen Canyon Dam



Factors influencing SRP in GCD Releases

1. Inflows (amount & source)
2. Processes in reservoir
3. Reservoir elevation (depth of withdrawal)

Data provided by B. Deemer, USGS

Observed effects of SRP on Colorado River aquatic ecosystem

1. Phosphorous limiting element for phytoplankton production in Lake Powell (Gloss 1977)
2. SRP positively correlated with invertebrate drift in Glen and Marble Canyons, 2012-2016 (Korman et al. 2021) and secondary production in Glen Canyon (Yard et al. 2022)
3. SRP positively correlated with rainbow trout growth in Glen Canyon, 2012-2021 (Korman et al. in review)
4. SRP was a better predictor of rainbow trout recruitment in Glen Canyon than flow (Yackulic, unpublished data)
5. Interannual trends in condition factor of humpback chub, flannelmouth sucker (*Catostomus latipinnis*), and bluehead sucker (*Catostomus discobolus*) in Grand Canyon were similar, and broadly correlated with the trend in phosphorous concentration (Yard and Yackulic, unpublished data)

Nutrient fertilization is a common and well-tested method for enhancing productivity in freshwater ecosystems that are nutrient-limited

- Fertilization projects have focused on addressing 2 limitations:
  - Mitigating impacts of phosphorous losses due to impoundment (dams)
  - Mitigating impacts of reduced salmon returns due to overfishing and low marine survival

- Fertilization literature survey reviewed 166 papers
  - 111 separate nutrient enhancement projects
  - 80% of projects have been conducted in North America, with most others in Europe
  - Majority of studies (58%) from British Columbia (43), Alaska (41), and Idaho (21)
  - 86% of fish species assessed were salmonids (but some chub and suckers)
  - A number of efforts conducted in large lakes and large rivers (e.g., Libby Dam on Kootenai River in Montana)

Nutrient Fertilization Studies

Ecosystem Responses

Component Measured	# of Studies	% of studies	% of positive responses
Nutrients	74	44%	72%
Algae	122	74%	58%
Macrophytes	9	5%	58%
Invertebrates	97	59%	62%
Fish	89	54%	68%

Fish Population Responses

Component	Negative	Neutral	Positive
Fish growth	3%	25%	72%
Fish abundance	10%	26%	64%

Preliminary Calculations for Glen Canyon Fertilization

- Target phosphorous concentration of 3 ug/L at release point (Glen Canyon Dam)
- March 1 – August 31 (spring-summer)
- Requires ~21,000 gallons of 10-34-0 liquid fertilizer dripped in at ratio of 70,000,000 (river flow) : 1 (liquid fertilizer)
- Cost of ~$65,000/yr at $570/metric ton
- Current cost about 2-fold higher due to war in Ukraine.

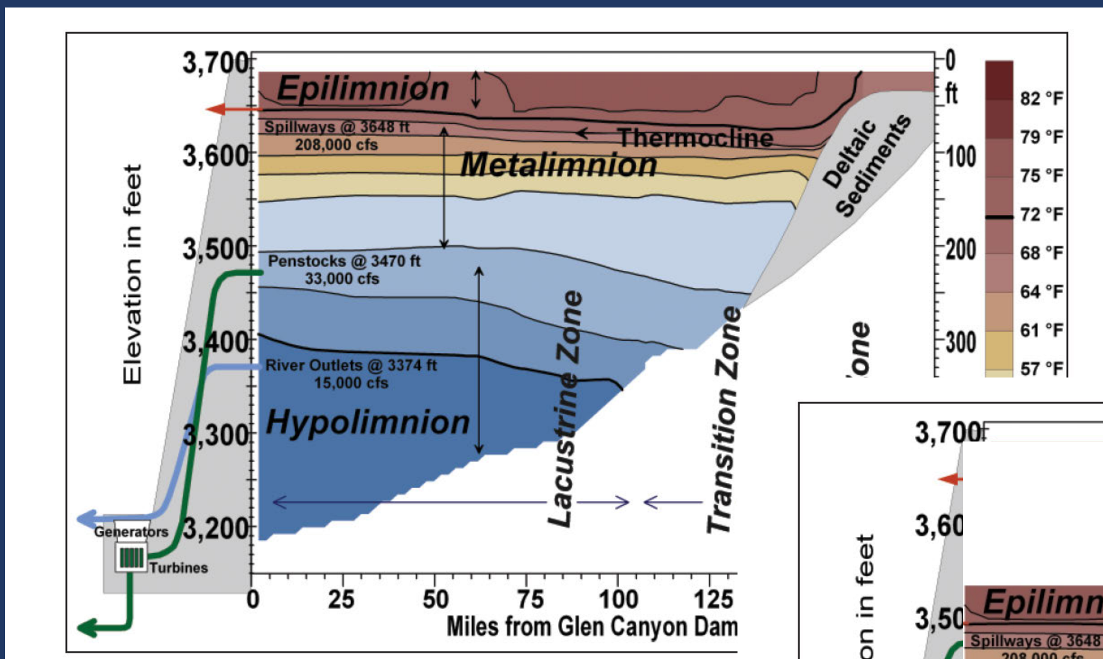
Is phosphorous fertilization a viable GCD AMP action to mitigate effects of drought and impoundment?

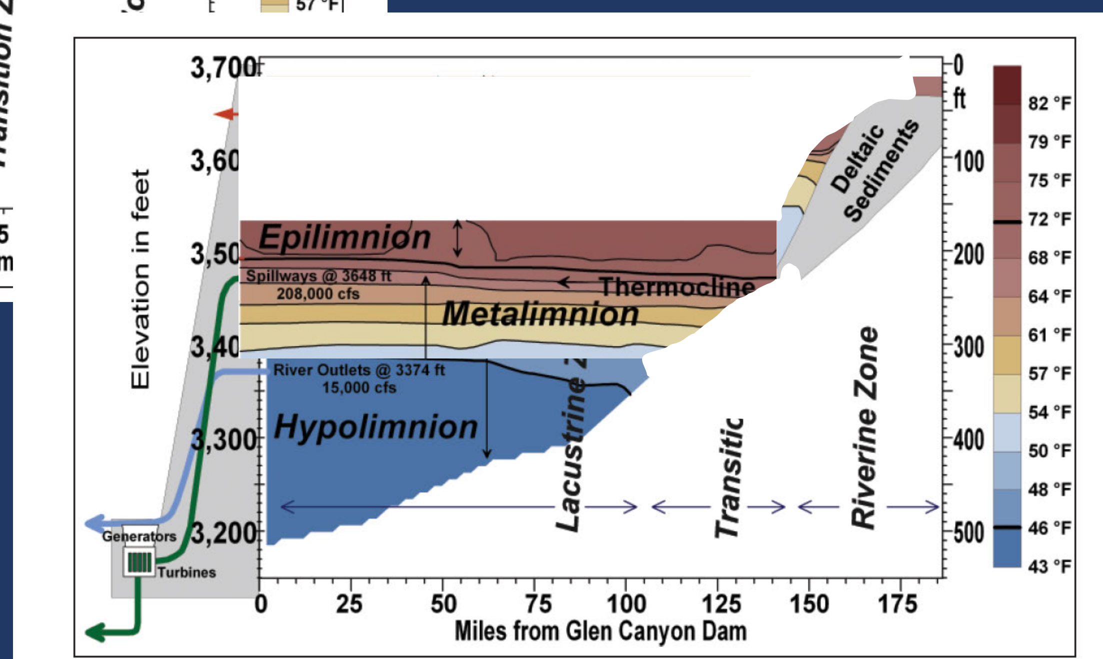
- Does not require water ✓
- Does not impair hydropower ✓
- Relatively low cost ✓
- Makin' life, not takin' life ✓
- Extensive support in literature that it can be effective ✓
- Indications in GCD AMP data it could be effective ✓
- Relatively easy to manipulate/study ✓

Potential next steps

- WAPA will distribute fertilization literature review to AMP
- GCMRC could include a fertilization component in their upcoming 3-year workplan
- Baby step: nutrient-algae bioassays to better evaluate P limitation
- Big-boy step: experimental fertilization in Glen Canyon
    - Simpler logistics/lower costs
    - Extensive baseline of drift, trout growth and recruitment
    - Might help offset current impacts of high temperature and low oxygen on rainbow trout
    - Could be implemented at downstream locations for native fish (near LCR)

At lower reservoir elevations we are drawing increasingly from the reservoir surface waters





In summer:
Lower dissolved oxygen
warmer water
less SRP rich water

Figure from Vernieu et al. 2005 (second version manually modified)

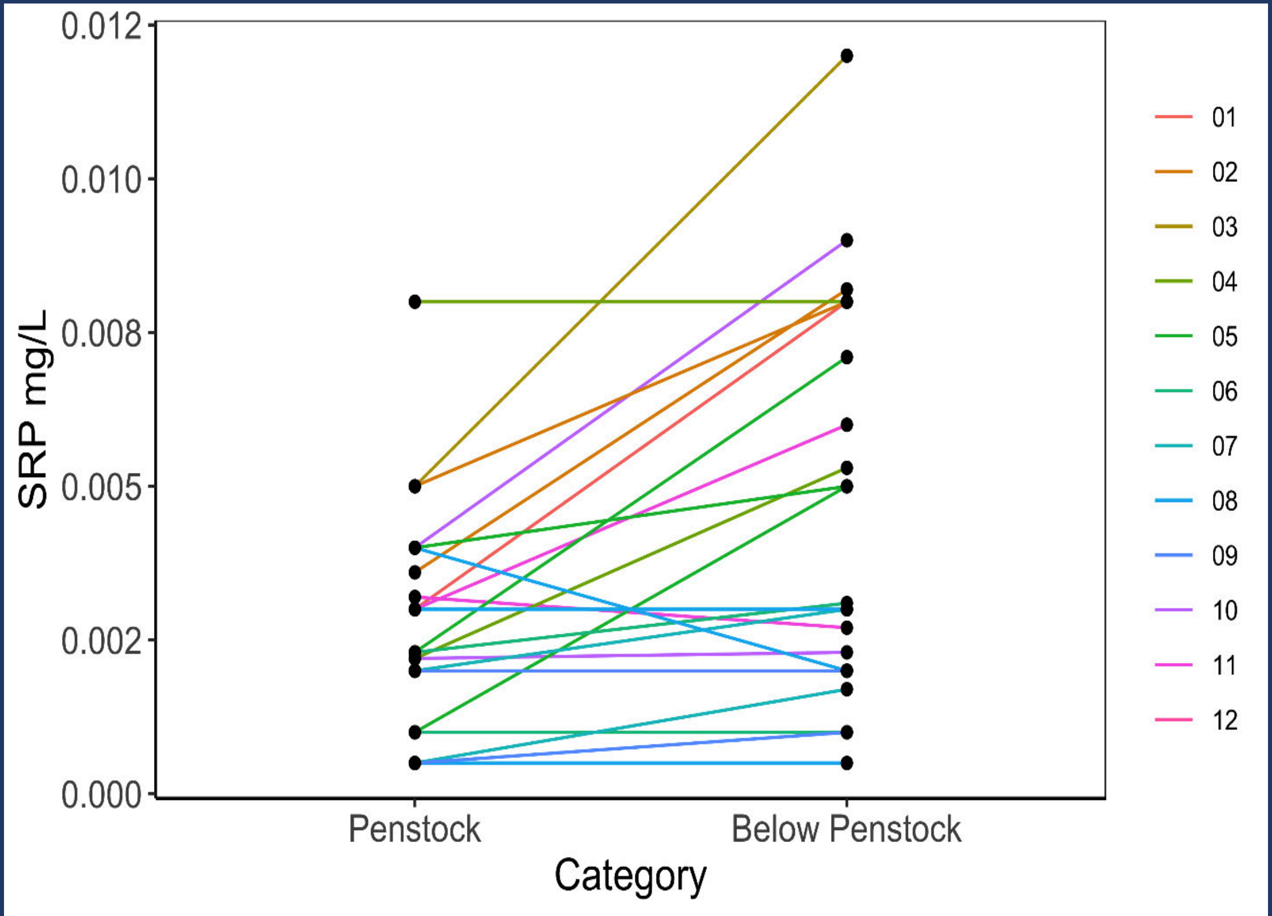
Lower water levels (and warmer temperatures) will generally mean less SRP

Average SRP gradient of 2 µg L^{-1} per 10 m drop below the penstock

Mechanisms:

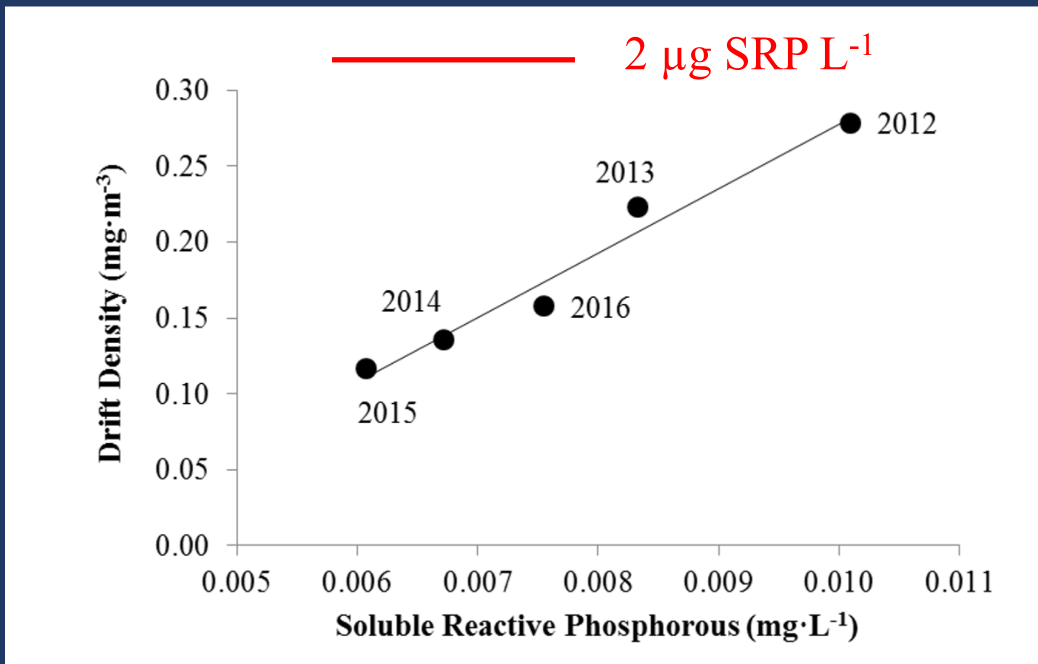
Plankton in surface water take up phosphorus so less is available

Surface waters have higher pH/temp so free SRP is bound to calcite



Preliminary Data, Do Not Cite

Depth-related differences in SRP are biologically meaningful



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Changes in prey, turbidity, and competition reduce somatic growth and cause the collapse of a fish population

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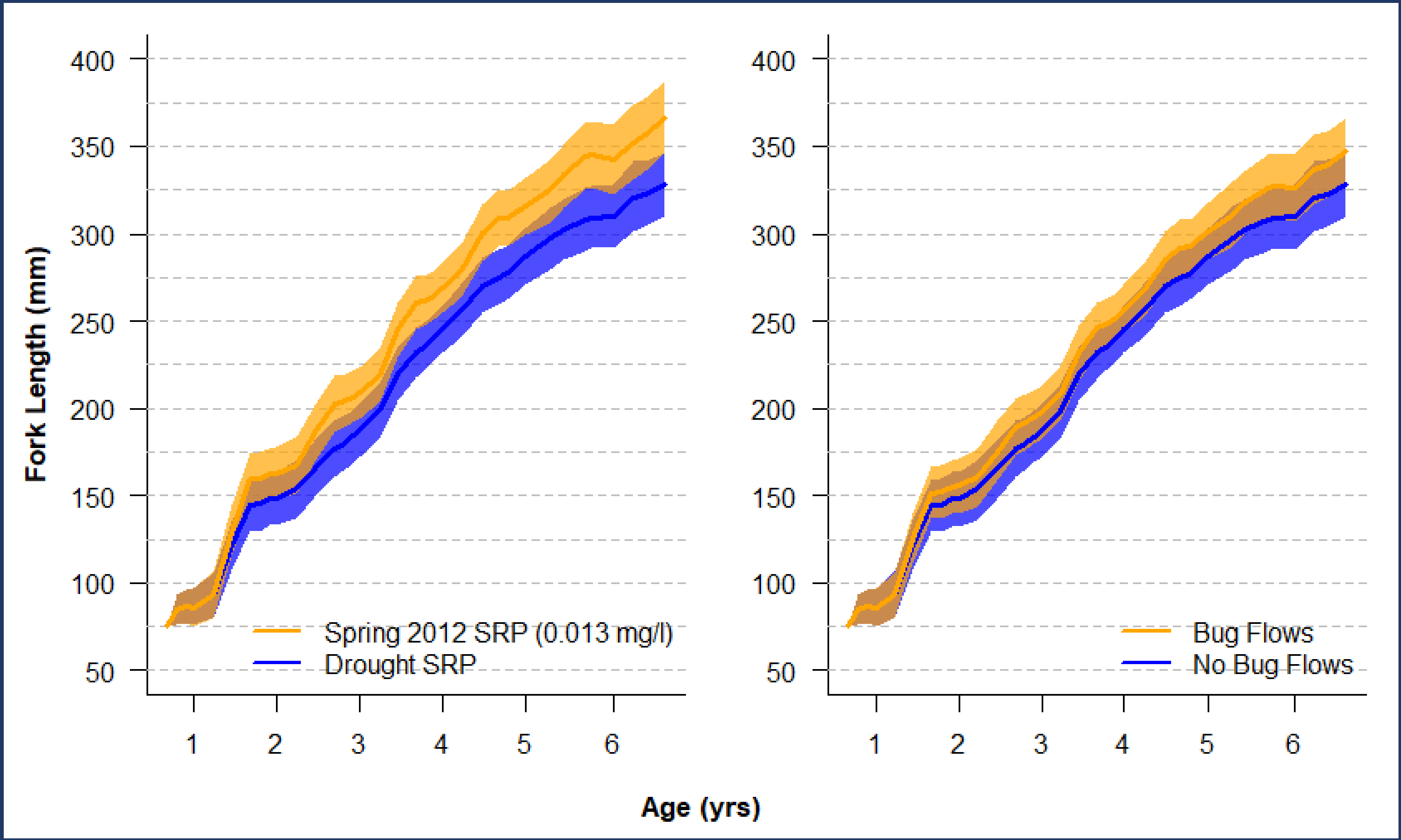
Phosphorous (P) additions produce twice the growth benefit for rainbow trout relative to bug flows if baseline P is low (drought)



Potential Impediments for Experimental Implementation of Phosphorous Fertilization

- Historically, GCD AMP actions have focused on changes in flow or mechanical removal
  - fertilization is an unfamiliar action
  - Does not fit in with natural flow paradigm
- Administrative concerns
  - phosphorous can be a pollutant (but in systems with too much phosphorous)
- May produce benefits to rainbow trout population in Glen Canyon
  - Reduce probability of collapse due to high temperature and low oxygen
  - But high temperature and low oxygen may be overwhelming
- Uncertain response for Colorado River Ecosystem, as some of its characteristics are rare in fertilization studies
  - Abundant macrophytes (Glen)
  - Sandy river bottom and periods of high turbidity (Marble, Little Colorado River inflow reach)