Effects of Bug Flows, Fall HFEs, Competition, and Water Quality on Growth Rates of Rainbow Trout in Glen Canyon

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Background

- A major objective of GCD AMP is to understand the effects Glen Canyon Dam operations on the downstream environment

- Two experimental flows, fall HFEs (5 years) and bug flows (3 years), have been implemented repeatedly over the last decade

- These flows are hypothesized to influence growth rates of rainbow trout in Glen Canyon
  - **Fall HFEs** could reduce growth during late fall/winter by scouring the prey base when subsequent recovery is expected to be slow
  - **Bug flows** could increase growth could during spring and summer by improving prey base and feeding conditions

- Changes in water quality resulting from drought are expected to have negative effects on rainbow trout growth
  - High water temperatures and low dissolved oxygen levels reduce growth due to negative metabolic effects
  - Low phosphorous concentrations are expected to reduce benthic production and hence prey availability

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Outline of Talk

Part I (Korman)

- Identify the dominant drivers of growth rates of rainbow trout in Glen Canyon
- Compare effects of experimental flows with effects of water quality
- Predict future growth and population/fishery persistence under drought-driven water quality conditions for 2022+

Part II (Deemer)

- Describe controls on phosphorus export from Lake Powell and expectations of future conditions
- Discuss potential confounding between high phosphorus and low dissolved oxygen under drought conditions

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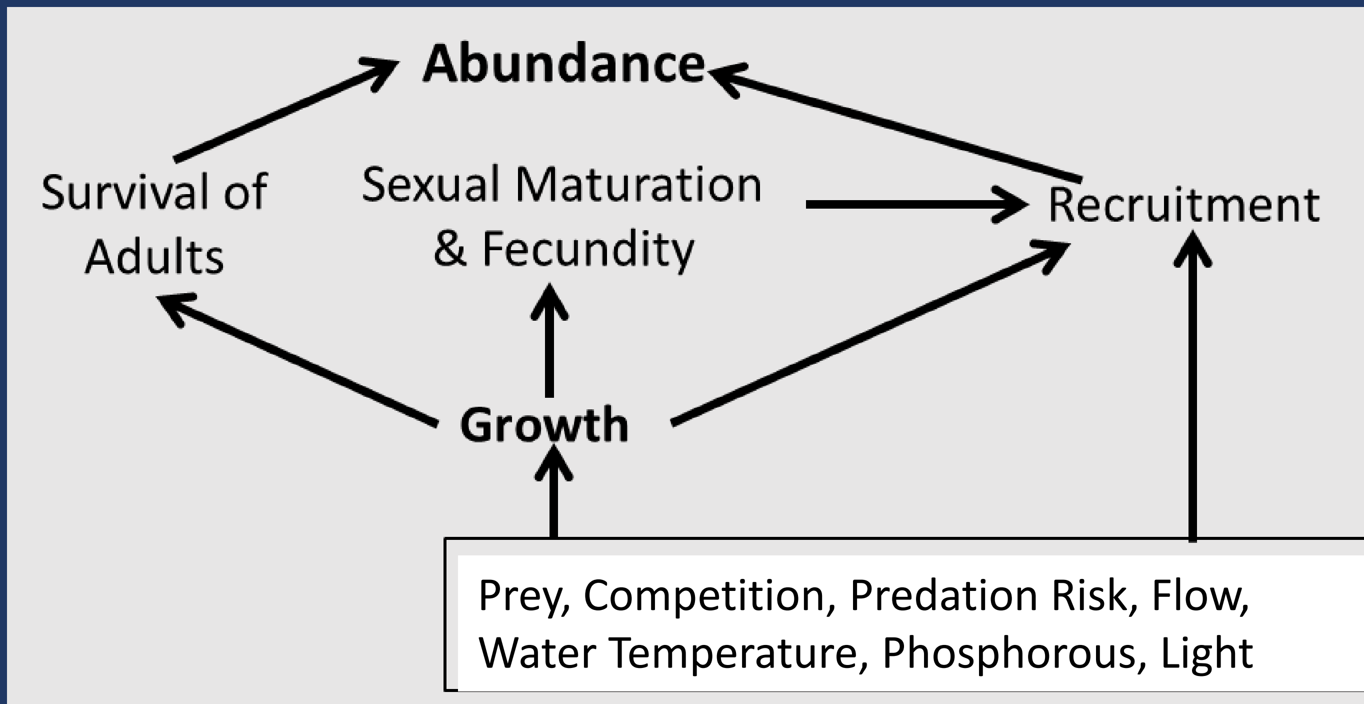
Why Study Growth?

Growth is an important determinant of rainbow trout abundance in Glen and Marble Canyons through effects on survival, maturation, and recruitment (it also effects the size of fish caught in the fishery)



Korman et al. 2021. Changes in prey, turbidity, and competition reduce somatic growth and cause the collapse of a fish population. Ecological Monographs.

Crossman et al. 2022. Population reproductive structure of rainbow trout determined by histology and advancing methods to assign sex and assess spawning capability. Transactions of the American Fisheries Society.

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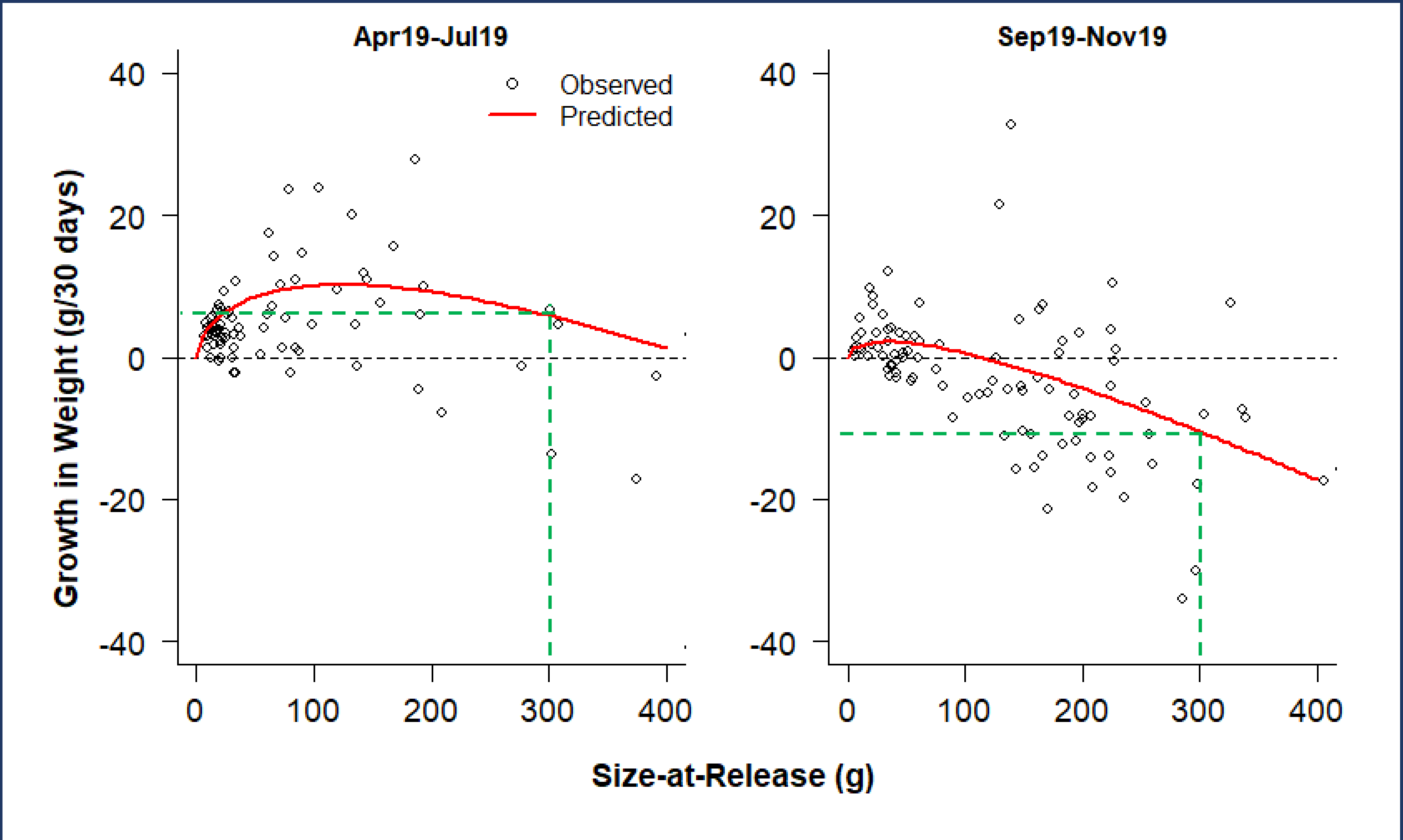
Mark-Recapture (TRGD program) Provides Direct Observations of Growth in Length and Weight

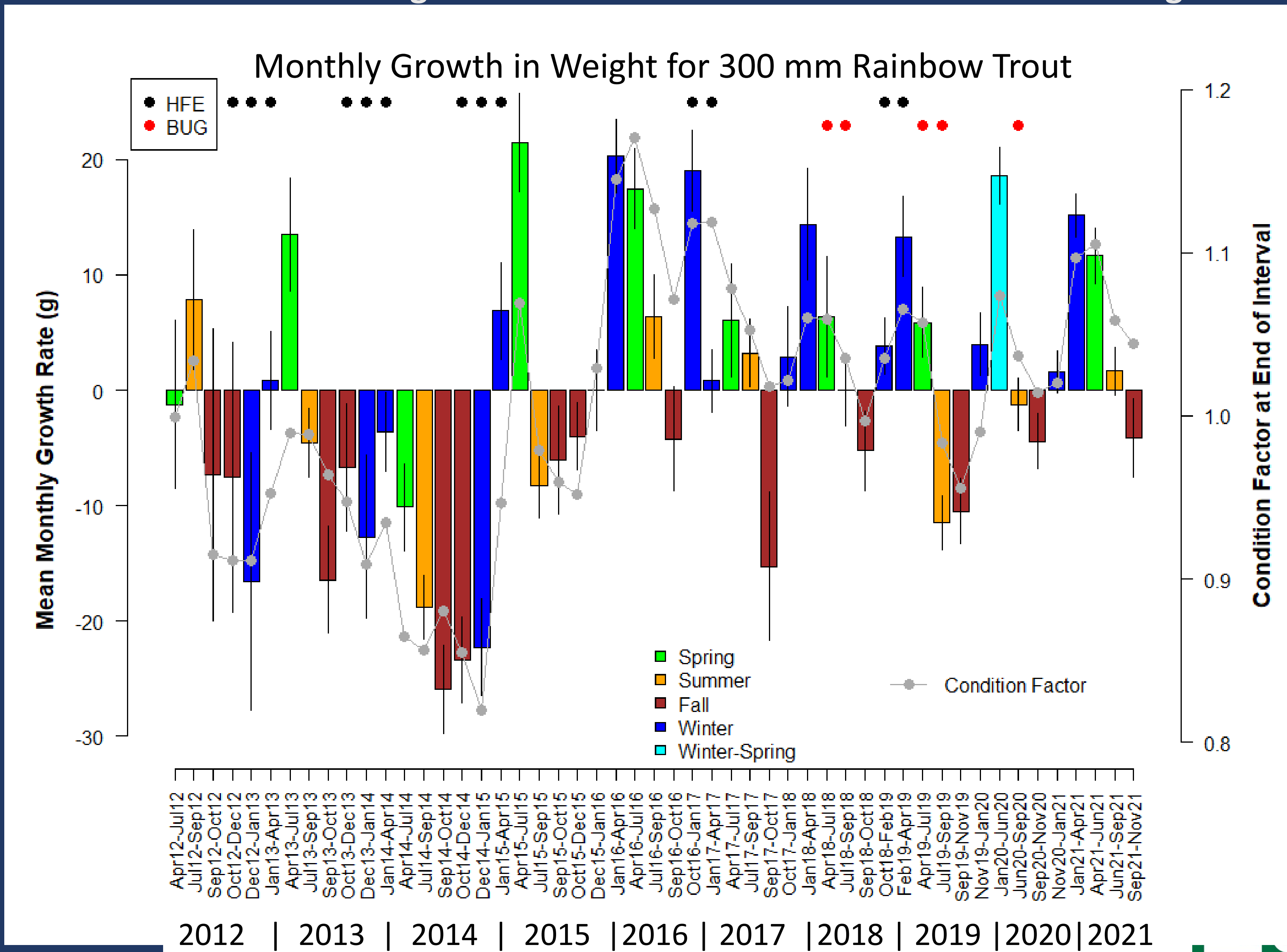


Unpublished data, subject to change, do not cite.

Model predicts variation in growth in length and weight across 51 1-3 month intervals over 10 years based on fish size, flow treatment effects (bug flows or fall HFEs), competition, average flow, water temperature, phosphorous concentration, and sunlight

Considerable Seasonal and Interannual Variation in Growth

Potential confounding of flow treatments with other factors that change over time



Preliminary Data, Do Not Cite

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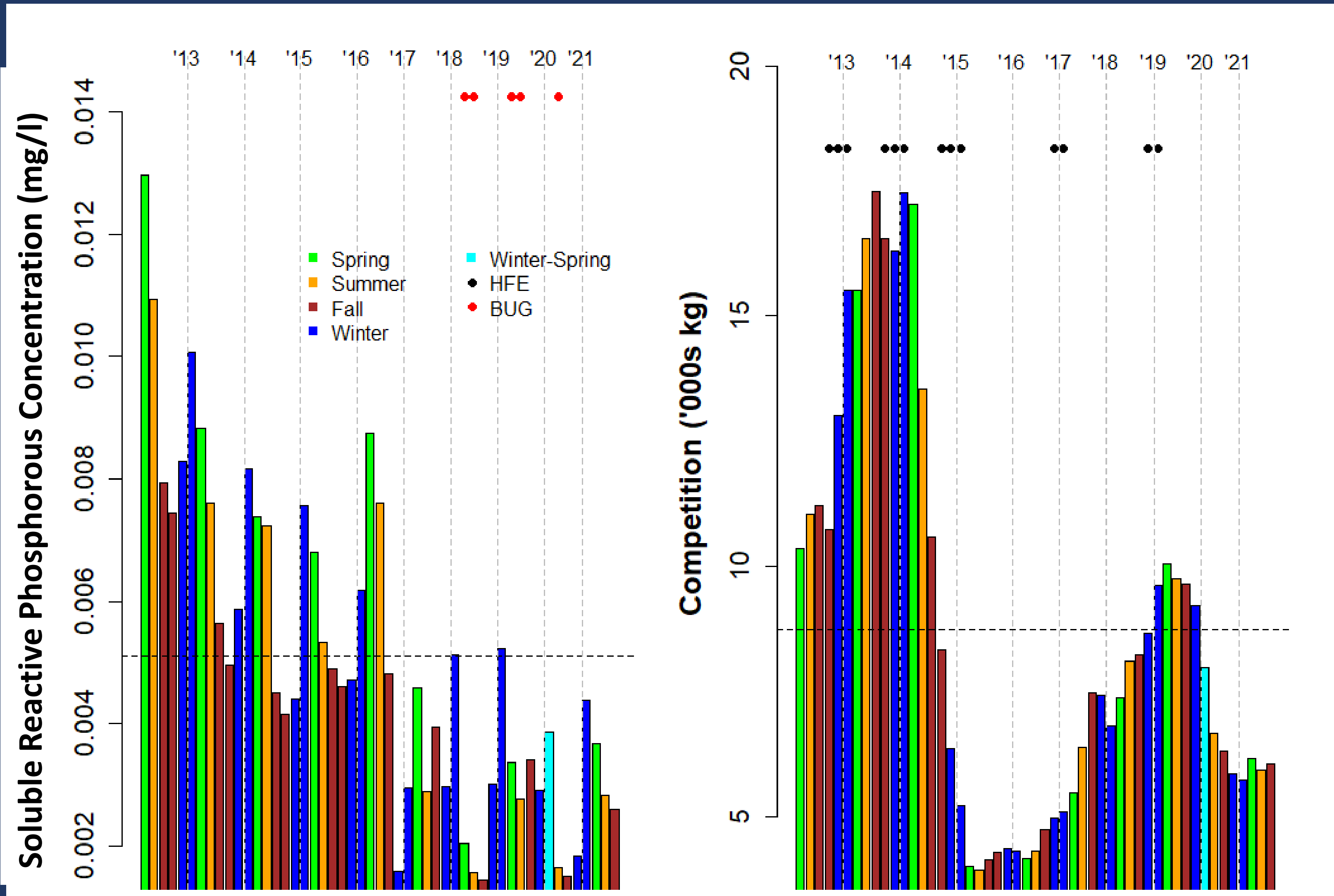
Examples of Trends in Confounding Factors



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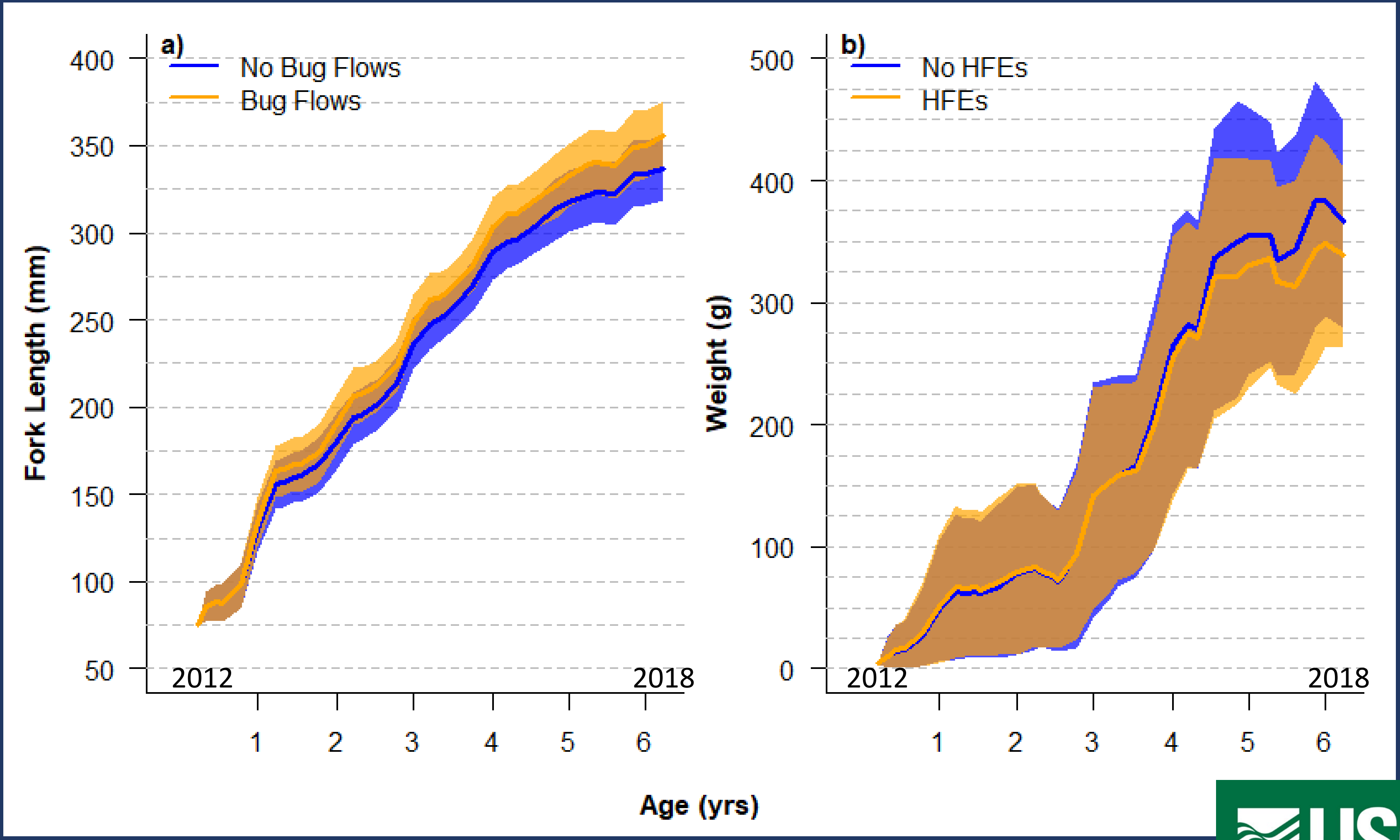
Very Limited Effects of Annual Implementation of Bug Flows or Fall HFEs on Lifetime Growth



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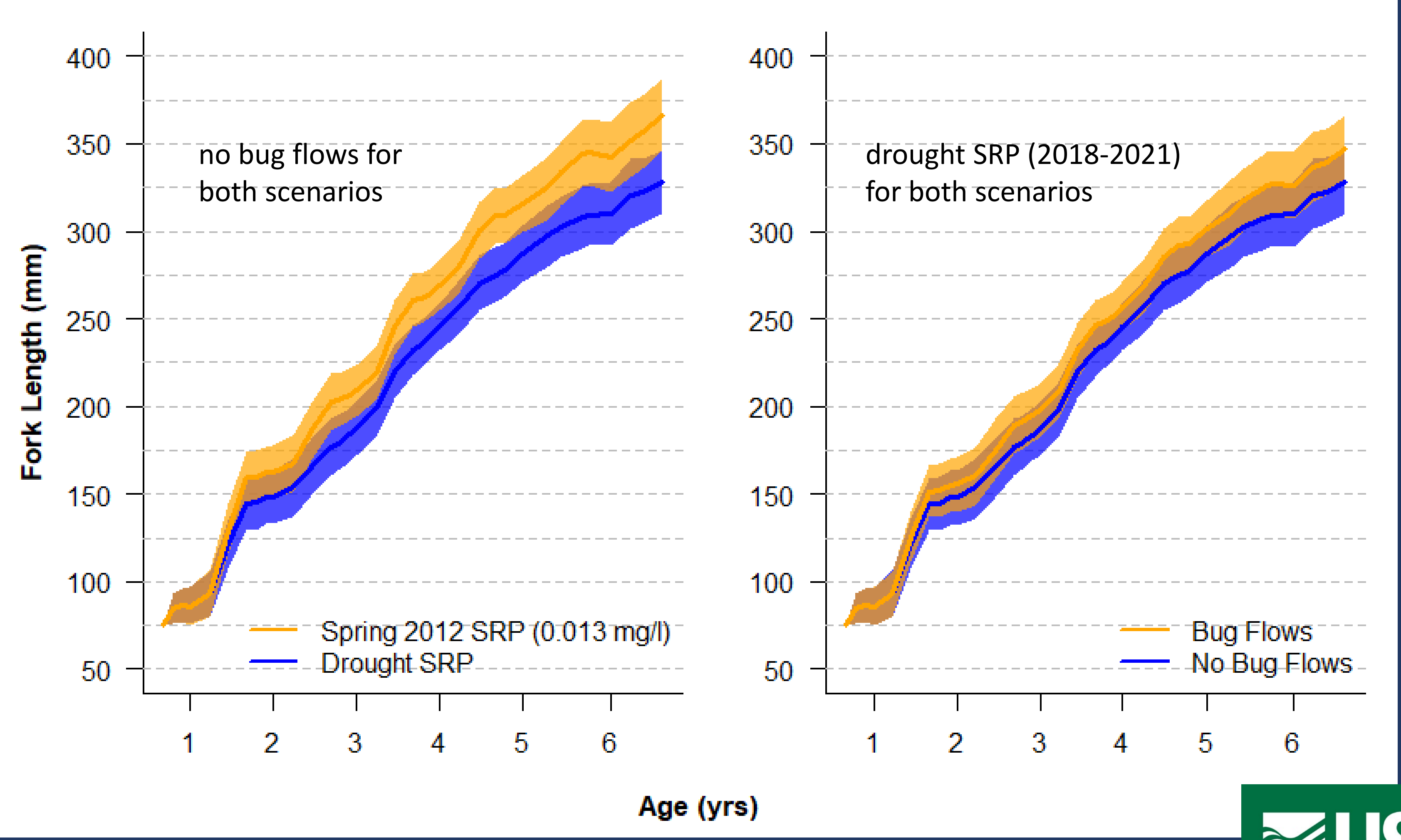
Water Quality:

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



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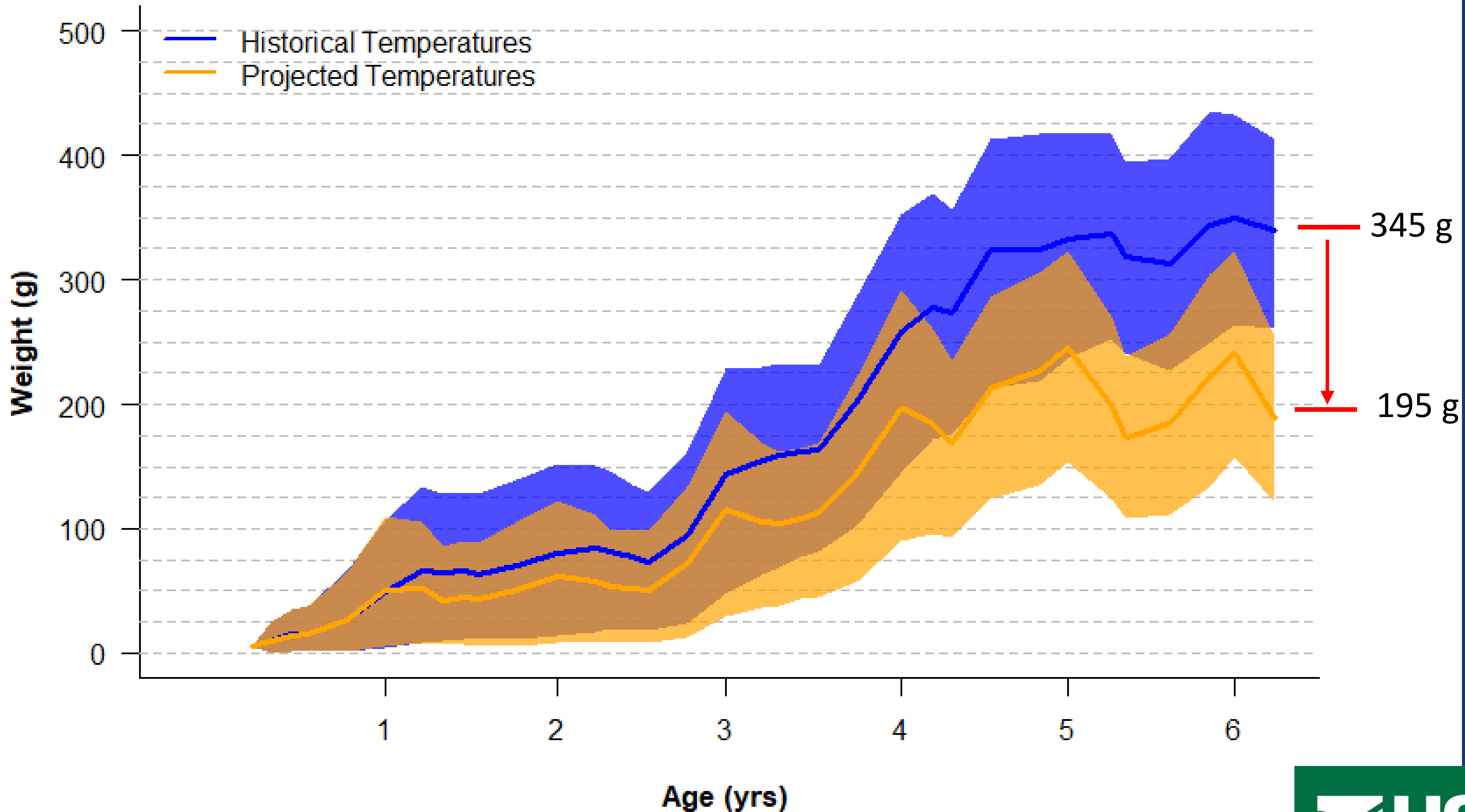
Water Quality:

Very large negative water temperature effect under drought (2022) conditions



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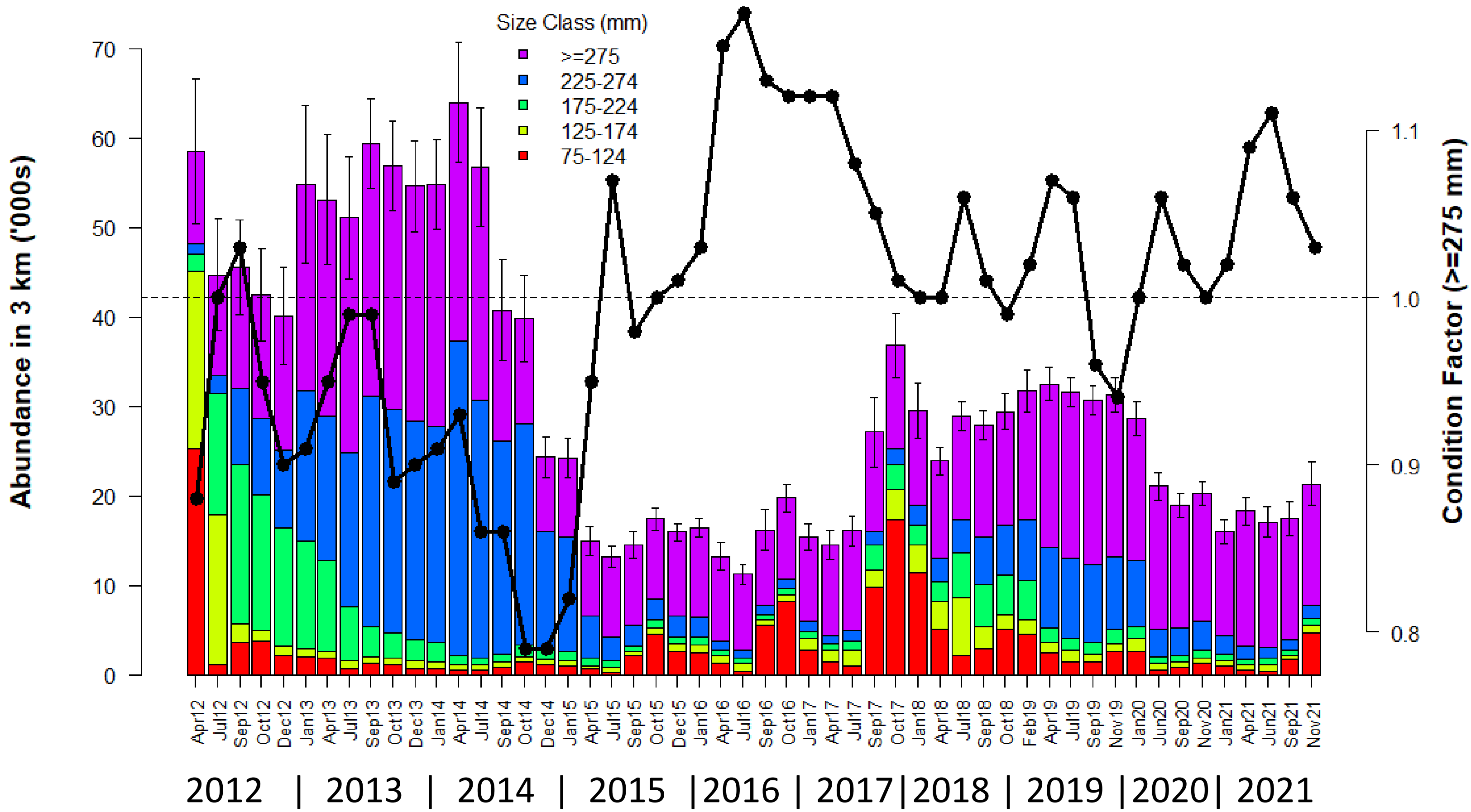
Current Rainbow Population is Dominated by Larger Fish that are More Sensitive to Temperature Increases, but their Condition is Good



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Conclusions

- Separating effects of flow treatments (bug flows or HFEs) on growth, from other temporally varying factors, like competition and water temperature, is possible if they are jointly modelled, time series is long, and sample size is large
  - Highlights benefit of long-term monitoring of vital rates via mark-recapture
  - Simple year-by-year comparisons, which don't account for non-treatment effects, are not informative
- Effects of bug flows and fall HFEs on rainbow trout growth were small, not consistently observed in both length and weight, and may be spurious
- Effects of competition, water temperature, and phosphorous concentration on growth were larger, and competition and temperature effects were more certain and consistently observed for length and weight
- Higher water temperatures for summer and fall of 2022+ are predicted to result in substantive weight loss for larger rainbow trout, leading to poor condition and a die-off by late 2023

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Is the Dire Prediction of Severe Weight Loss for Larger Rainbow Trout in 2022/2023 Correct?

- **Most likely answer is Yes**
  - Model calibrated to ~10,000 growth observations from Glen Canyon across 51 one-three month intervals over the last 10 years (2012-2021)

- **Caveat: Model predictions are never perfect!**
  - E.g., observed growth of larger fish between Sep-Nov ‘21 (at 16 ^{0}C) was higher than predicted by the model. But this anomaly is not unusual (there is equivalent lack of fit in some other intervals)
  - Projected average water temperatures in late summer and fall of 2022 will be much higher (18-19 ^{0}C) than ever observed (predicting outside of observed range)

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What Happens if Larger Rainbow Trout Die Due to Poor Growth and Condition?

- A large proportion of population will be lost
  - Owing to limited recruitment (new births) after 2017, current population is dominated by older/larger fish which are more sensitive to high water temperatures and low dissolved oxygen
- Recovery of fishery will be slow
  - Few young and small (less temperature-sensitive) fish are present to grow into larger size classes that support the fishery
  - Recovery of catch rates in fishery from 2014 collapse took ~ four years
- Higher brown trout abundance may impede recovery
  - Rainbow trout population recovered from collapses in 2006 and 2014, but brown trout abundance was much lower

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Water Quality of GCD Releases Under Drought

Gregory Natural Bridge- March 10, 2022
Last above water in ~1969

Escalante arm of Lake Powell
Campsite for Lake Powell Quarterly trip- March 9, 2022

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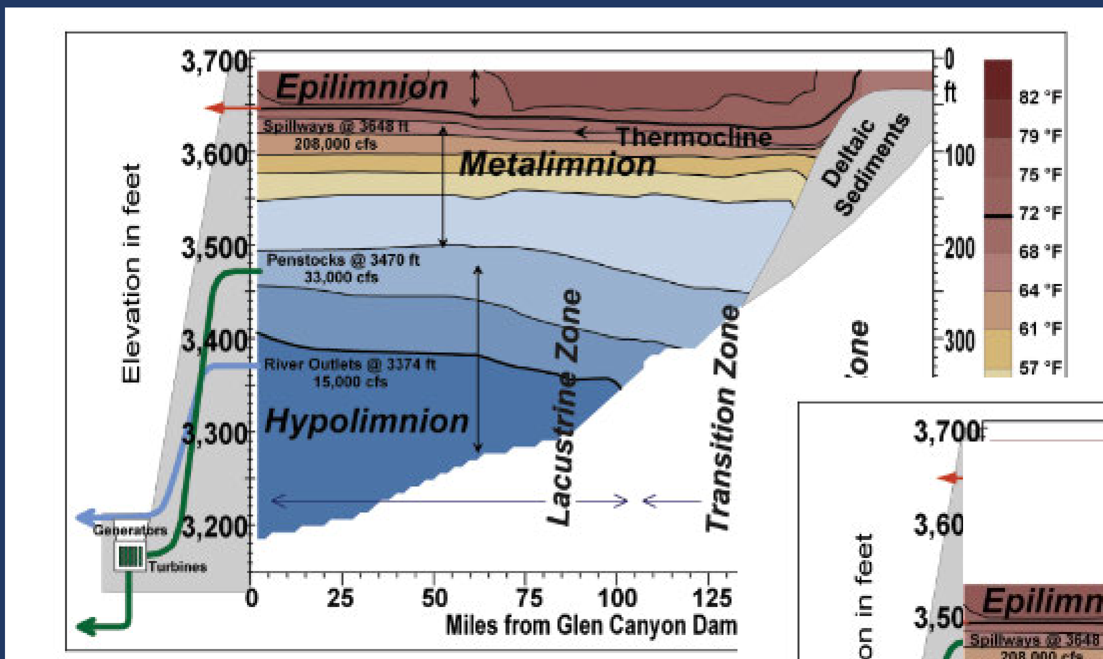
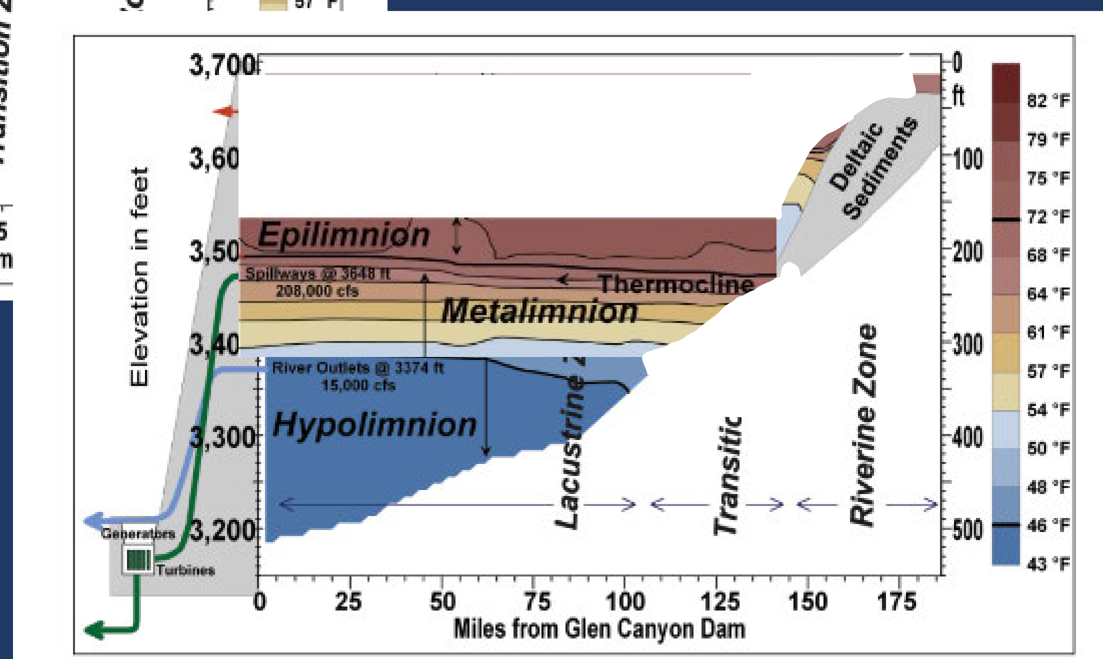
We are drawing increasingly from the reservoir surface waters





In summer:
Warmer water
Less SRP rich water
Higher pH

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

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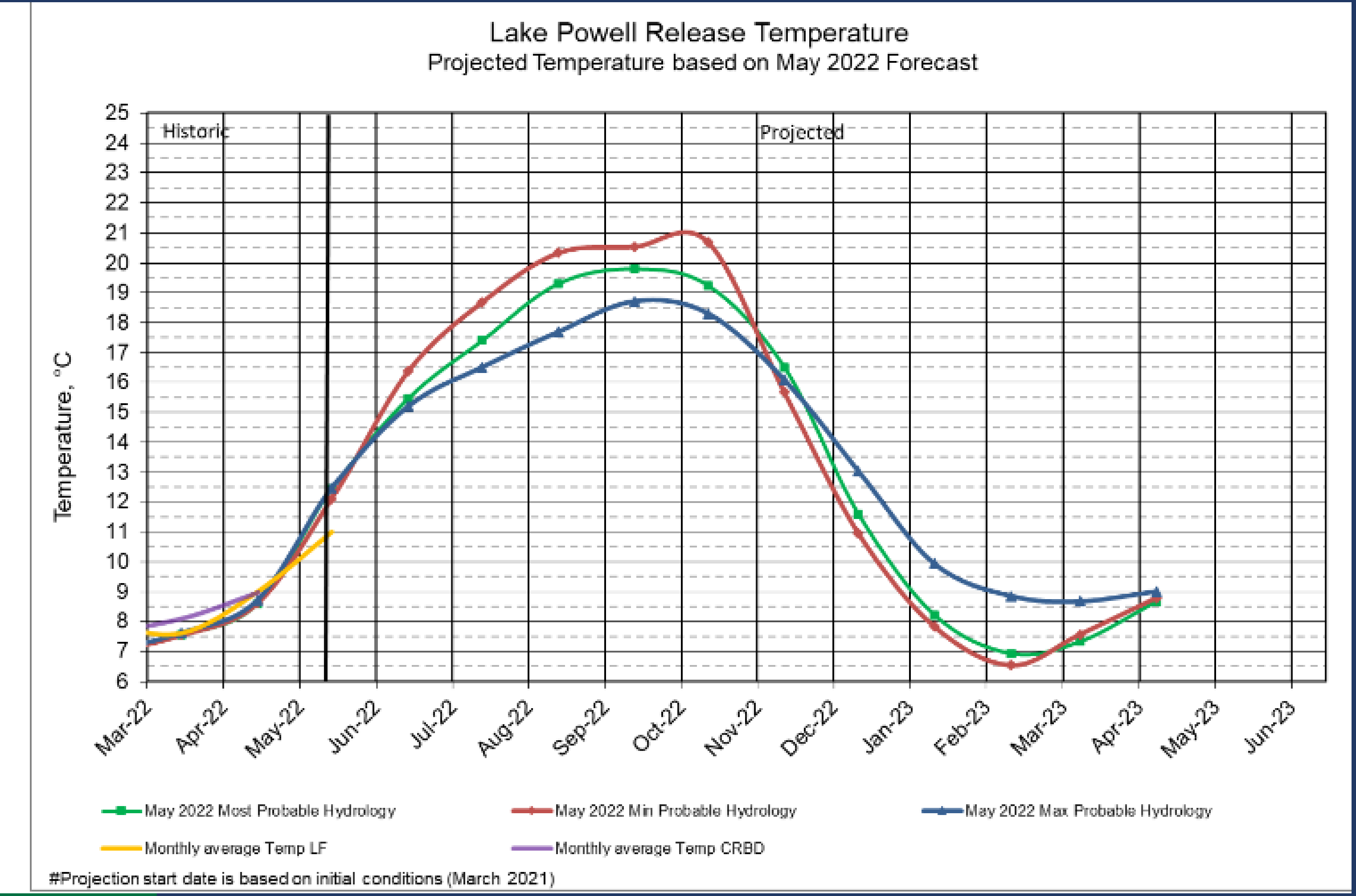
Warmer summer temps reflected in this year's WQ predictions



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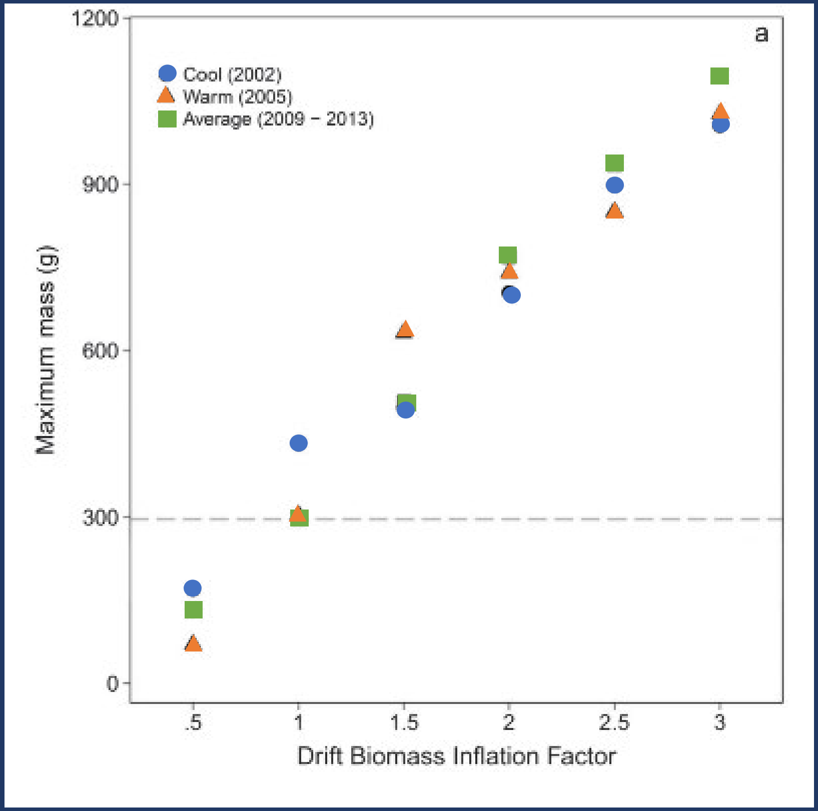
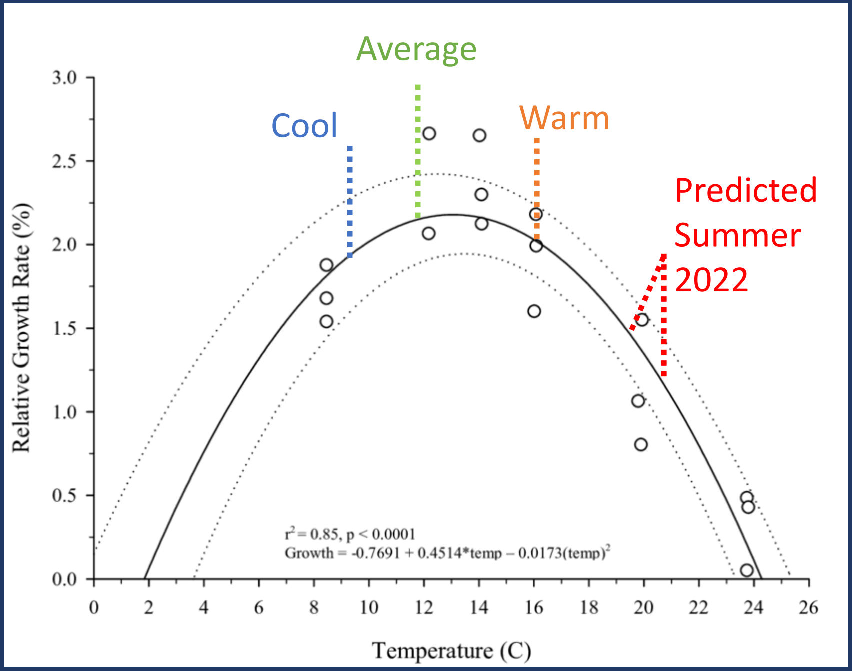
From BOR- Glen Canyon Monthly Operations Call– Basin Hydrology and Operations. May 25, 2022

How Do Warm Temperatures Overlay with Other Water Quality Conditions?



Modified from Dodrill et al. 2016



Modified from Bear et al. 2005

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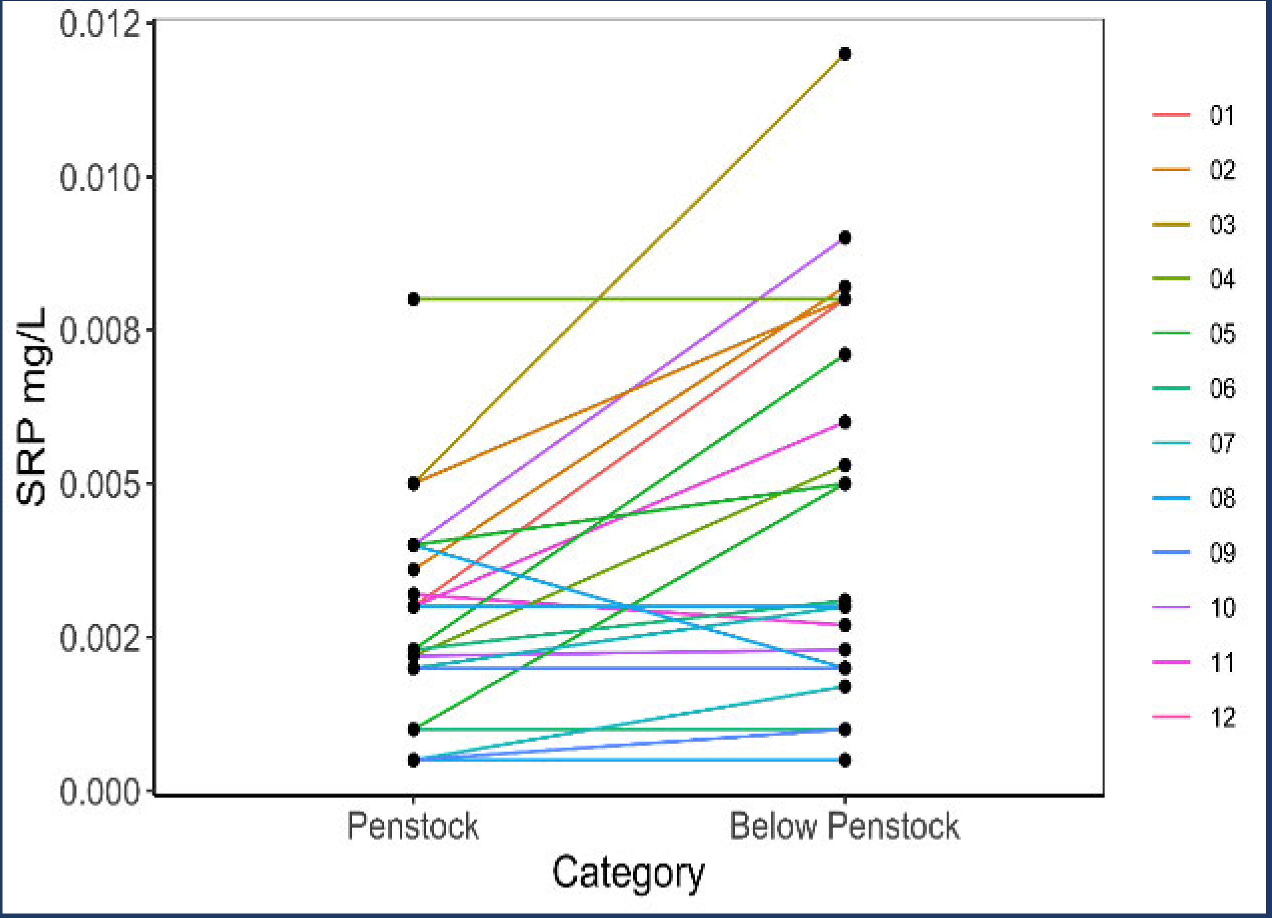
Lower water levels (and warmer temperatures) will generally mean less SRP

Average SRP gradient of 2 $\mu g\ L^{-1}$ 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



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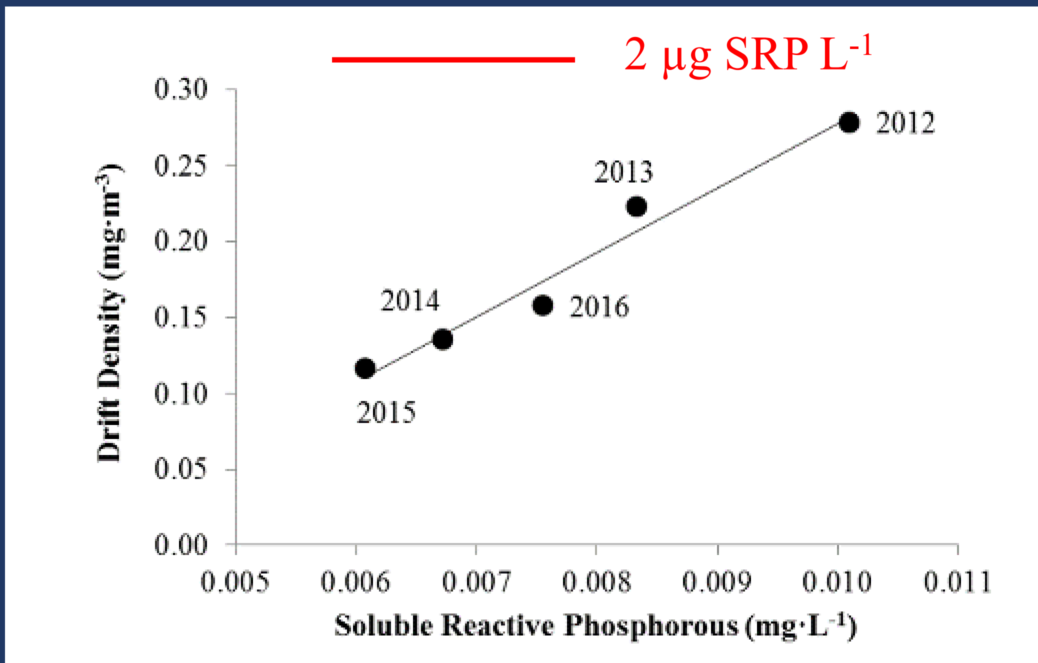
Depth-related differences in SRP are biologically meaningful



Ecological Monographs, 91(1), 2021, e01427

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

Josh Korman,[1,3] Michael D. Yard,[2] Maria C. Dzul,[2] Charles B. Yackulic,[2] Michael J. Dodrill,[2,4] Bridget R. Deemer,[2] and Theodore A. Kennedy[2]

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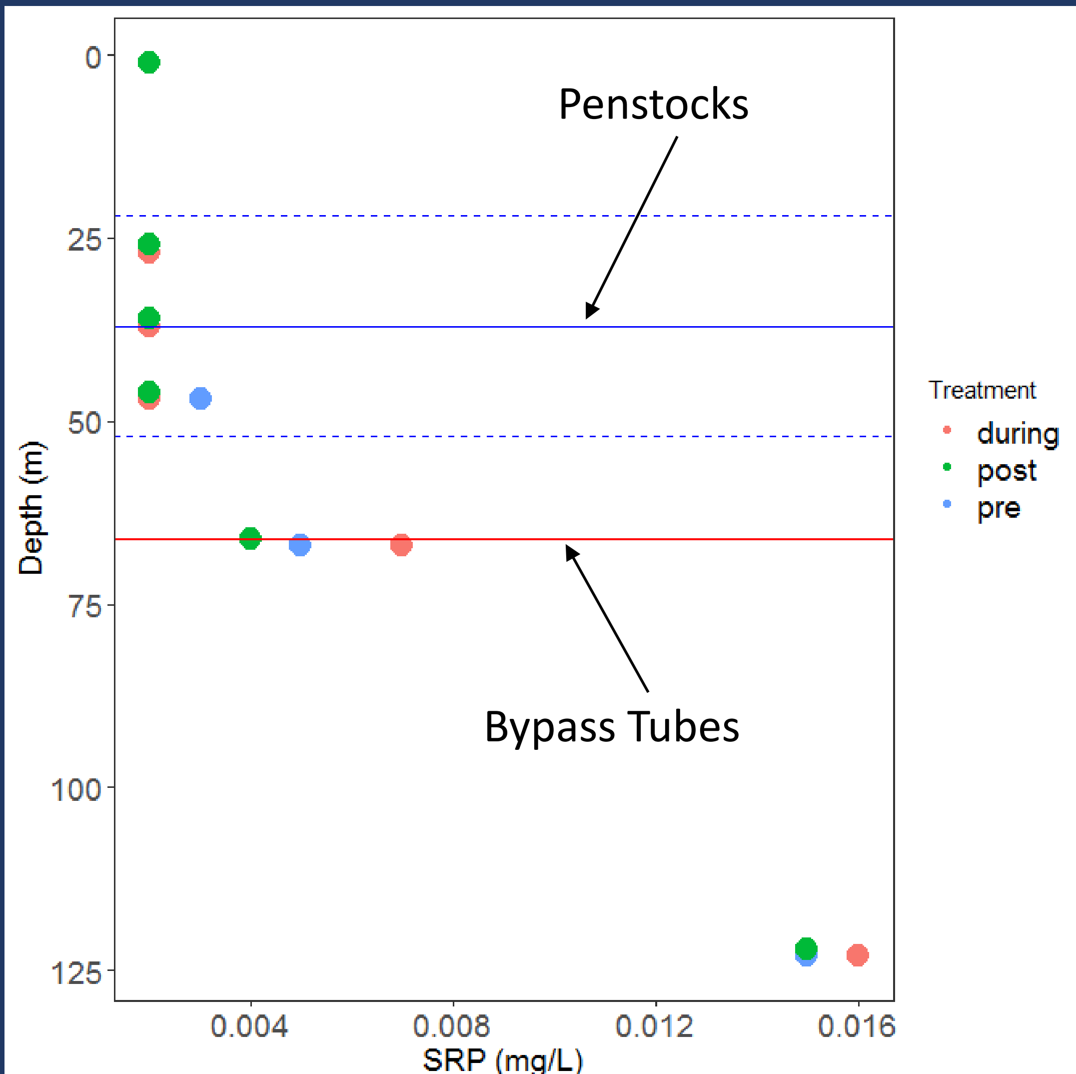
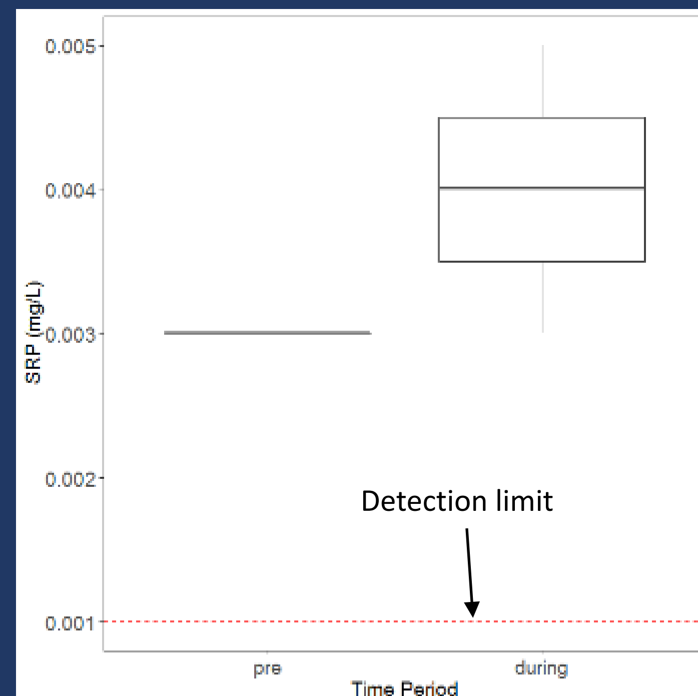
Bypass release will most-always lead to higher SRP availability in Glen Canyon



- Elevated SRP in Glen Canyon due to bypass releases during 2018 Fall HFE



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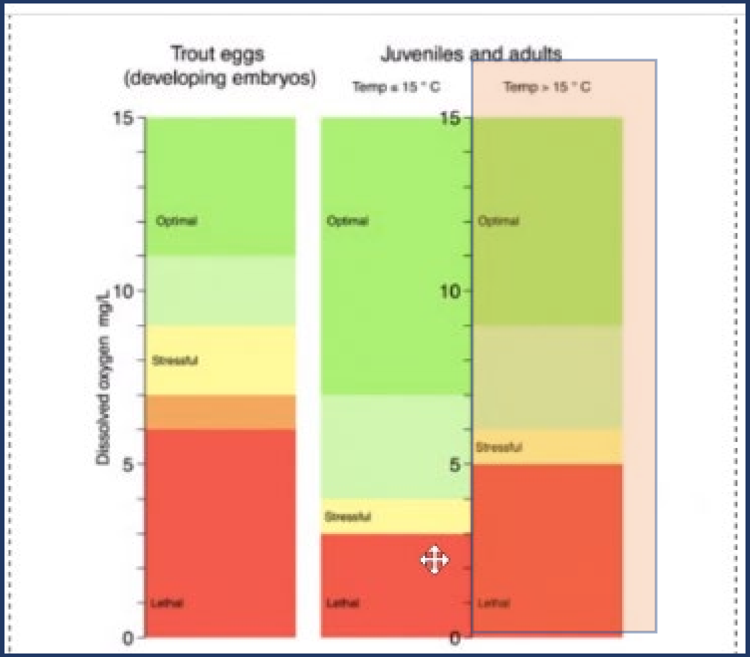
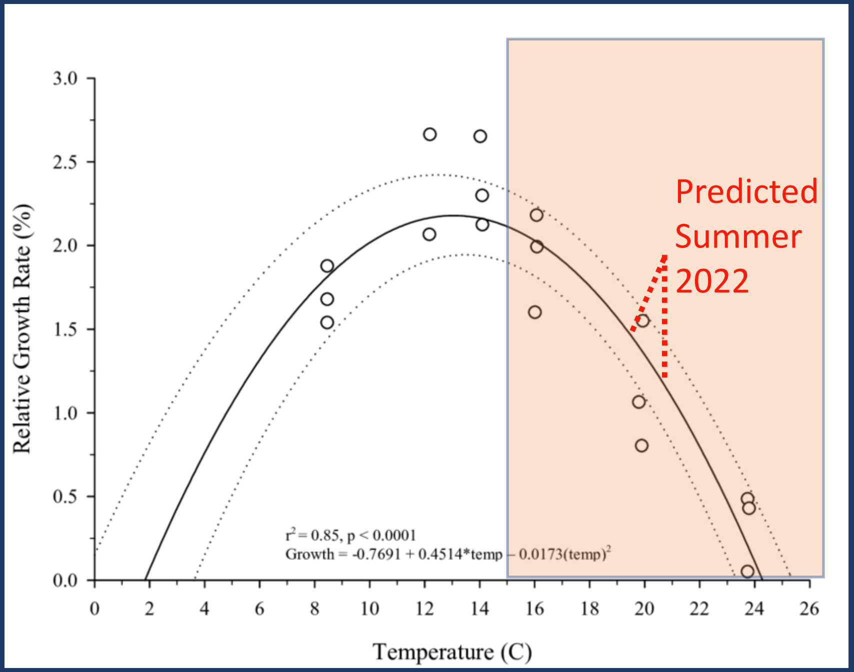


Graphic created by Three Rivers Ranch
Based on values in Chapman 1966, Raleigh et al. 1964, and Raleigh et al. 1966



Bear et al. 2005

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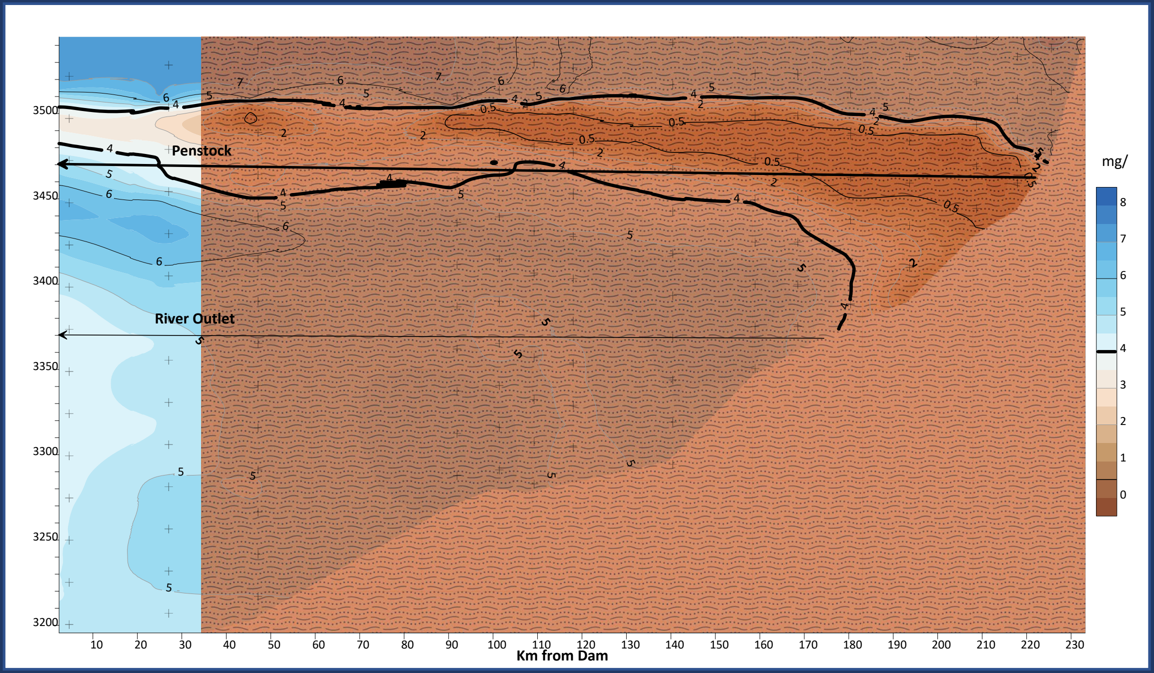
Deltaic Sediment Remobilization: low DO events

- Resuspension events generally occur during spring inflows (May and June)
- More recently low DO plumes developed due to large monsoon



Plot courtesy of Robert Radtke, Preliminary Data Do Not Cite

View from Highway 95 Near Hite Marina March 2002 (left) and March 2003 (right). Photos by John Dohrenwend

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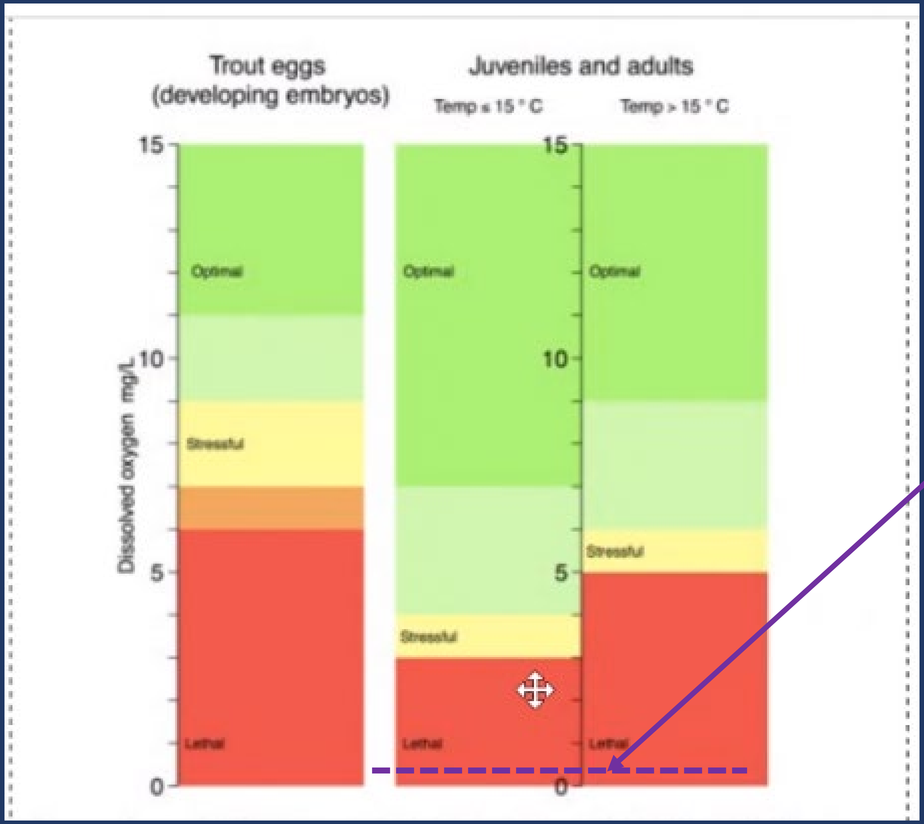

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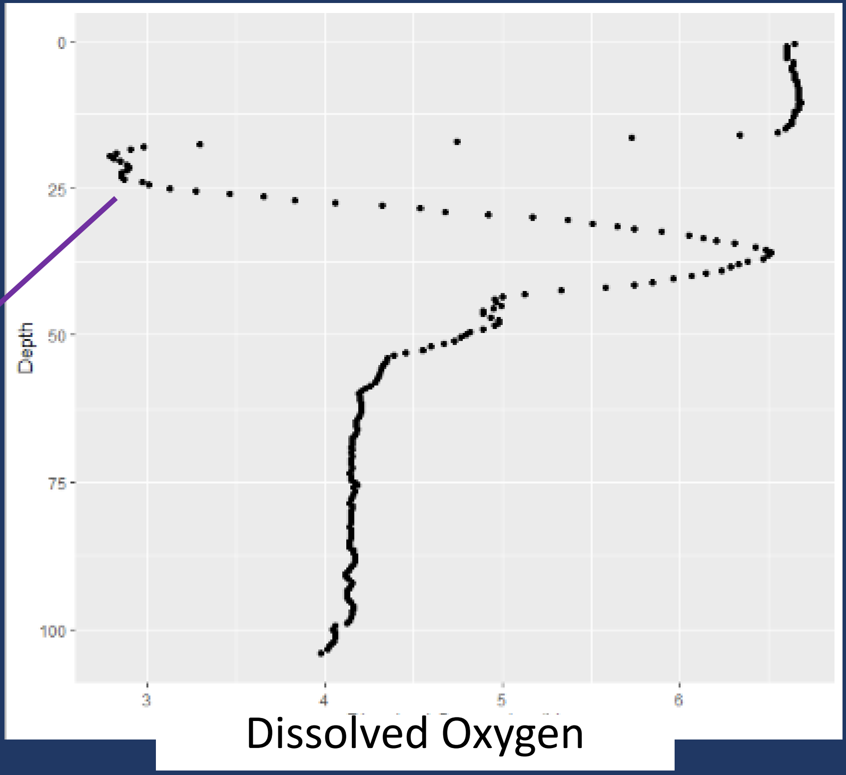
Wahweap Profile from 10/20/21



Unpublished data, subject to change, do not cite.

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Improving our modeling capabilities for dissolved oxygen in Lake Powell

- Sediment incubations this summer will quantify chemical and biological dissolved oxygen demand and phosphorus availability under
  - 3 different temperature treatments
  - 3 different elevations of Colorado inflow deposits

Bryce Mihalevich will be joining USGS to help update the Lake Powell CE-QUAL model

Anna Fatta measures dissolved oxygen and pH in a closed bottle incubation.

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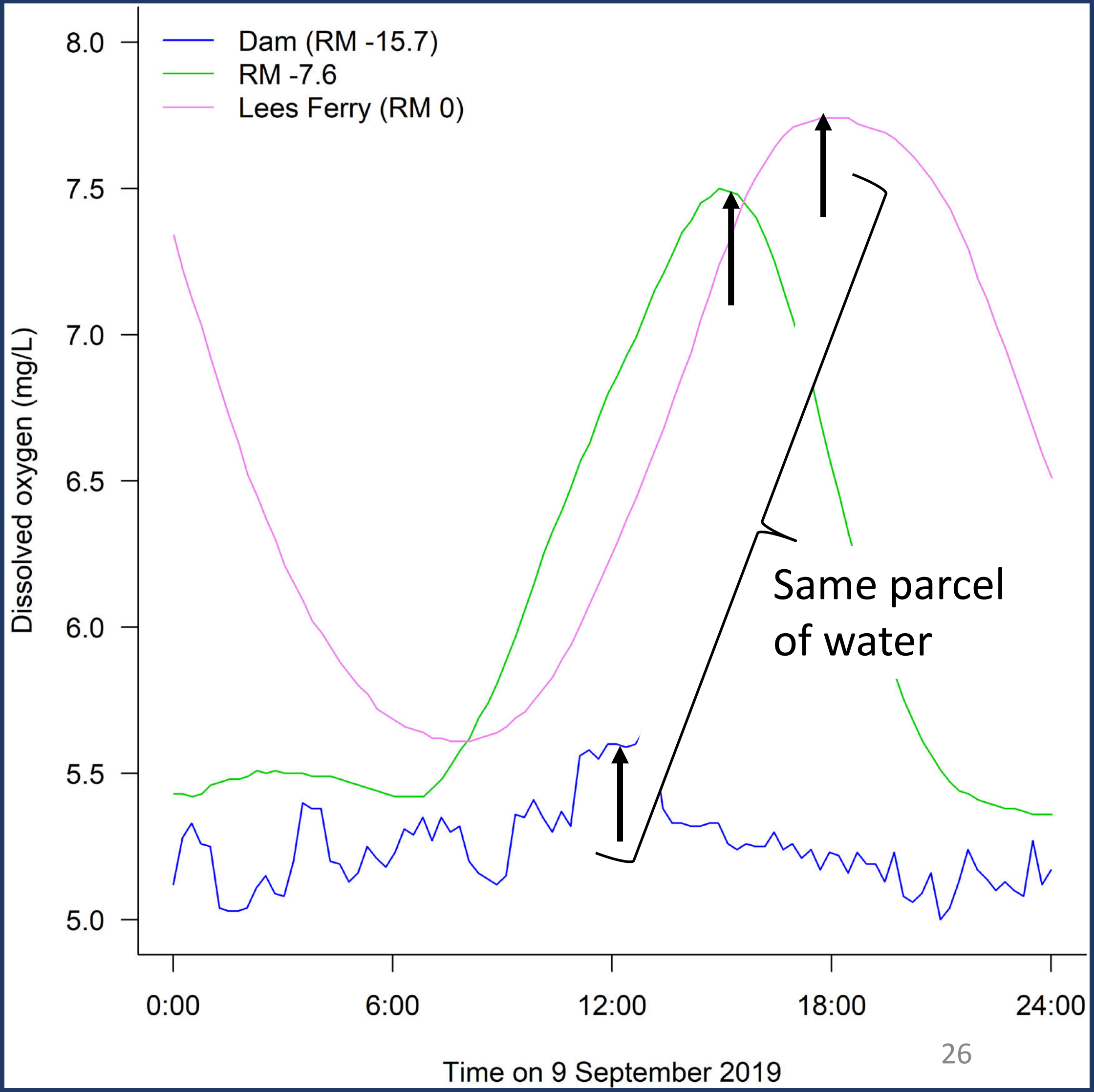
Low Dissolved Oxygen Will Have Largest Impact on Trout Near Dam

- **Increase in maximum DO owing to algae production**

Site	Max. DO (mg/L)
Dam (RM-16)	5.65
RM -7.6	7.50
Lees Ferry (RM 0)	7.74

Slide courtesy of Ted Kennedy
Unpublished data, subject to change, do not cite.



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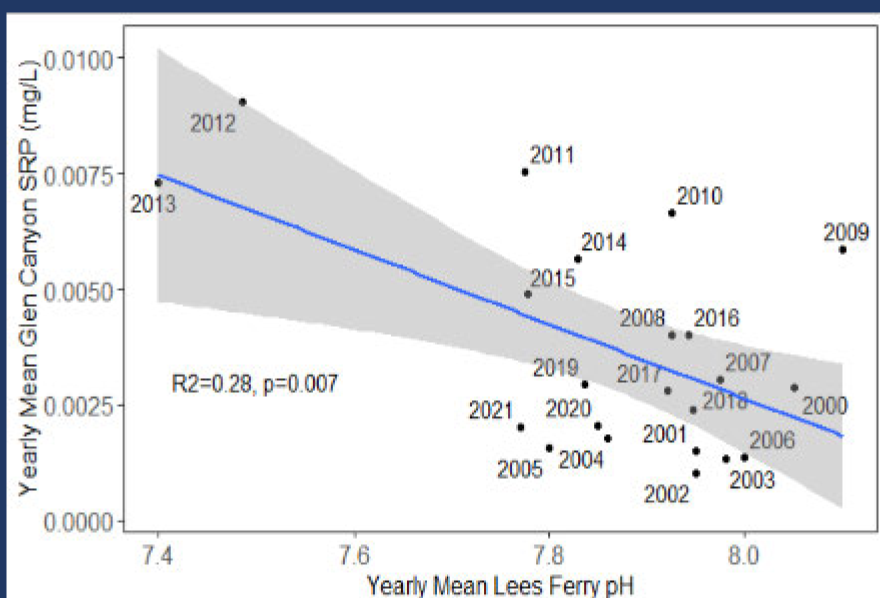
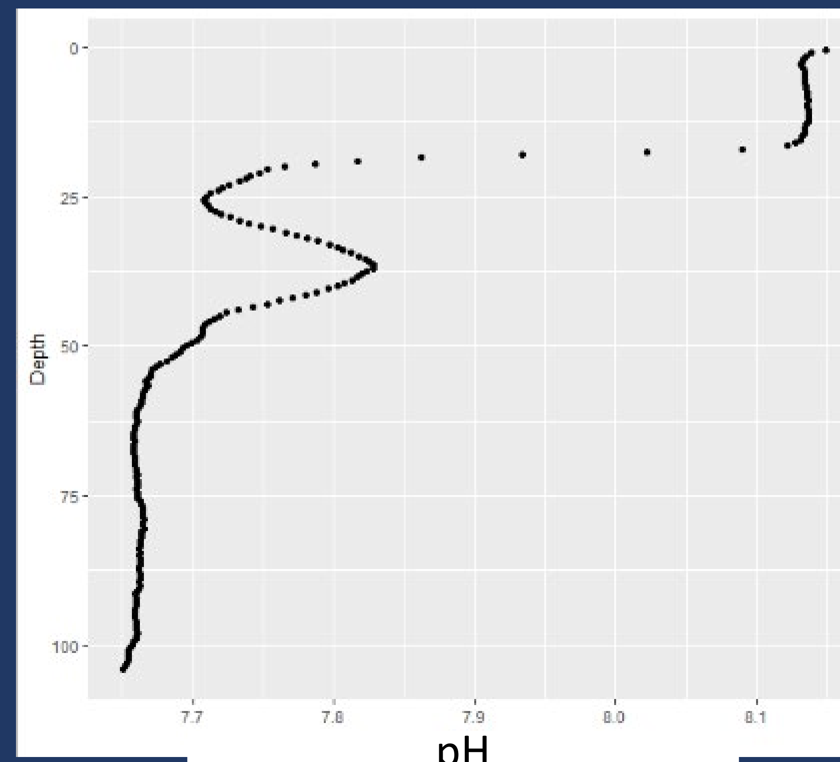
Deltaic Sediment Remobilization: another source of SRP?

- Lower pH in plume may also elevate SRP
- Associated low dissolved oxygen might trump any benefit to trout



Wahweap Profile from 10/20/21



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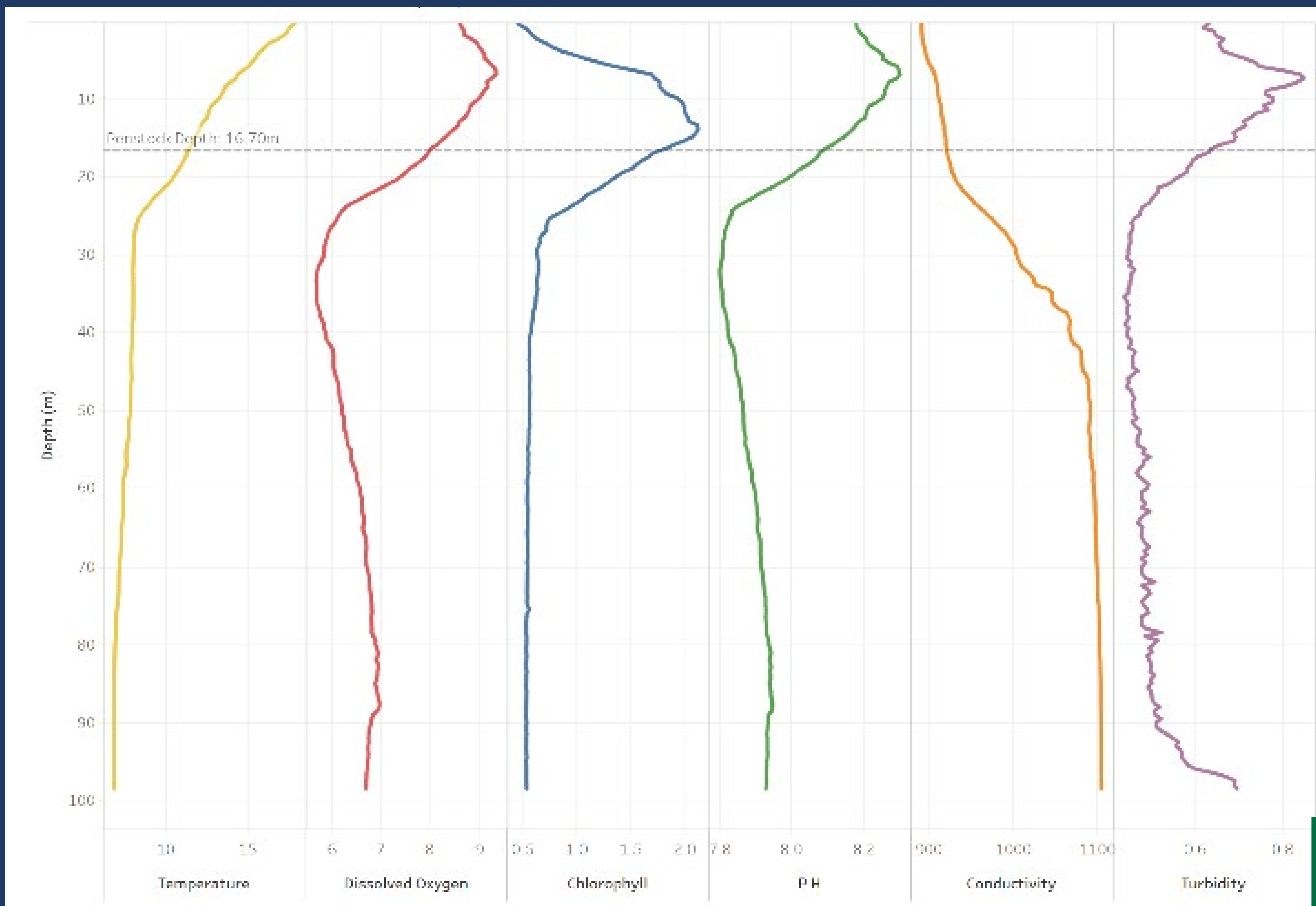
New Era for Water Quality May 16, 2022 Profile at Wahweap



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Actions to Avoid Population Collapse Due to Drought Conditions

- Lower temperature and increase oxygen in GCD outflows
  - Release some water through jet tubes (which would also elevate SRP)
  - Oxygenate water immediately upstream of dam

- Increase prey supply
  - Nutrient supplementation
  - Implement a spring HFE (uses water, less certain)

- Purpose of these actions would be to avoid **'catastrophic failure of the trout population'**
  - Objective 4 of Lees Ferry fisheries management plan (AGF-Rogers 2015)
  - Under current circumstances these are not 'enhancement' actions

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Questions?

Gregory Natural Bridge- March 10, 2022
Last above water in ~1969

Escalante arm of Lake Powell
Campsite for Lake Powell Quarterly trip- March 9, 2022

Acknowledgements

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- Field work: Thanks to the many boatmen, biologists, and technicians!

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