USGS
science for a changing world

Temperature and Nutrients as aquatic ecosystem drivers in the CRe

Charles B. Yackulic[1]

Lake Powell as a regulator of temperature

Kimberly Dibble[1]

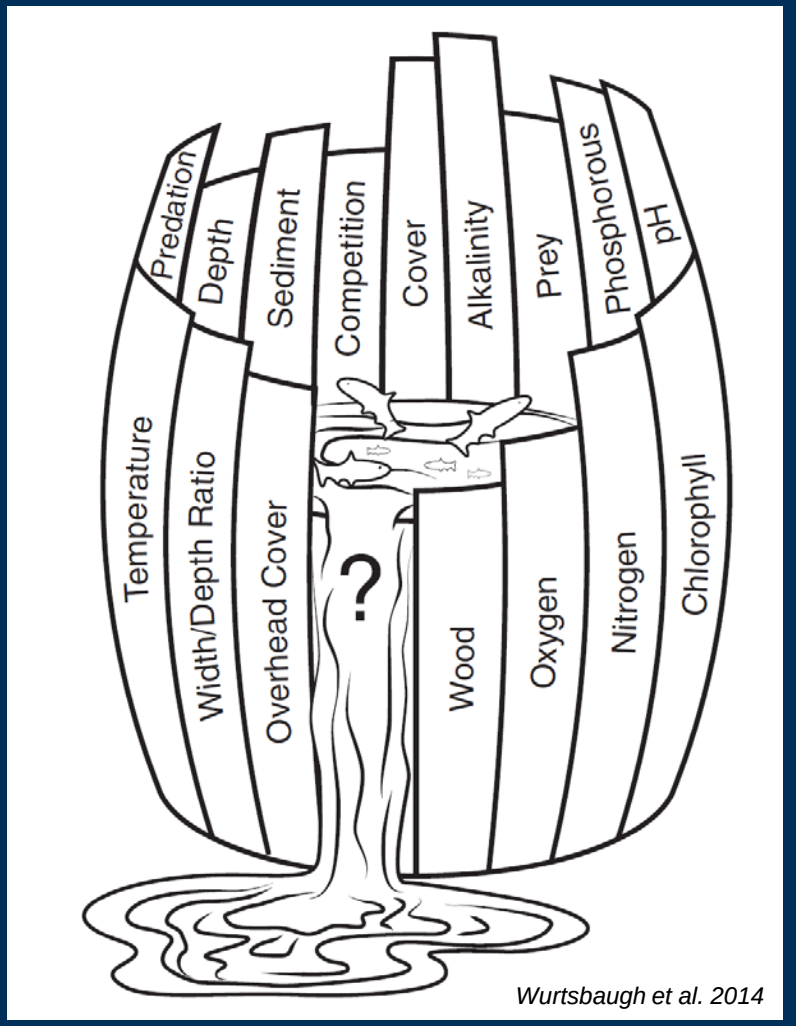
(partially funded by WaterSmart)

Lake Powell as a regulator of nutrients

Bridget Deemer[1]

(partially funded by BOR)

Annual Reporting
January 24, 2018



Wurtsbaugh et al. 2014

[1] *U.S. Geological Survey, Southwest Biological Science Center, Grand Canyon Monitoring and Research Center*

With help from Mike Yard, Ted Kennedy, Josh Korman, Bob Hall and many others

U.S. Department of the Interior
U.S. Geological Survey

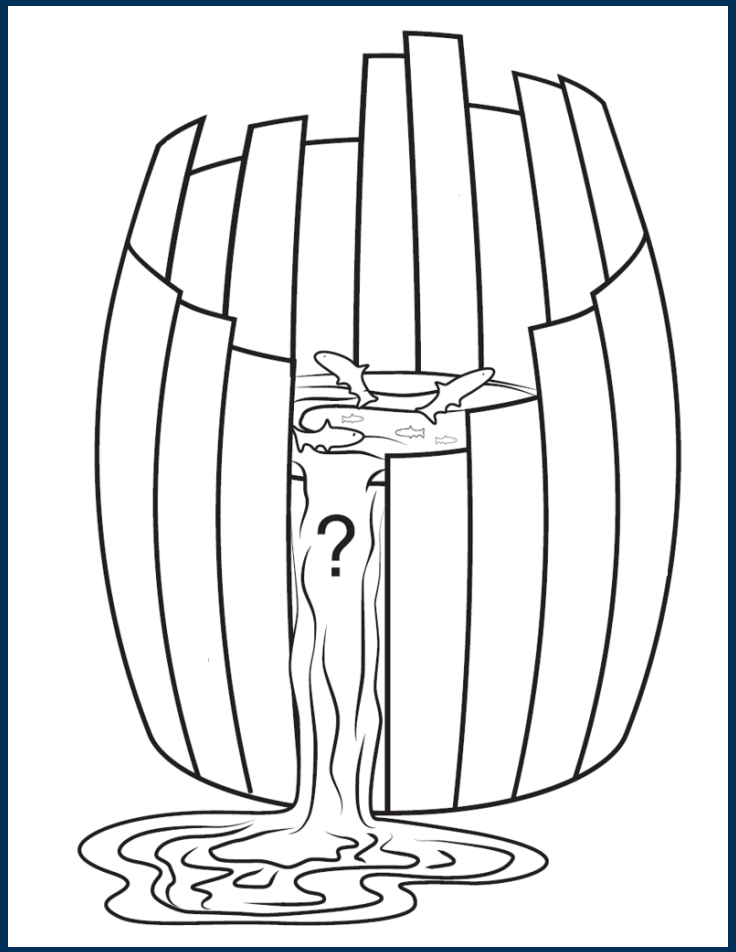
The factor(s) that limits populations can change over time



Pre-MLFF – Extreme variation in daily flows

Current – Food

Future – Temperature / Food



Wurtsbaugh et al. 2014



Pre-2000 – Water temperature

Current – LCR hydrology, Food, Temperature and RBT

Future – Smallmouth? Food? Nothing?

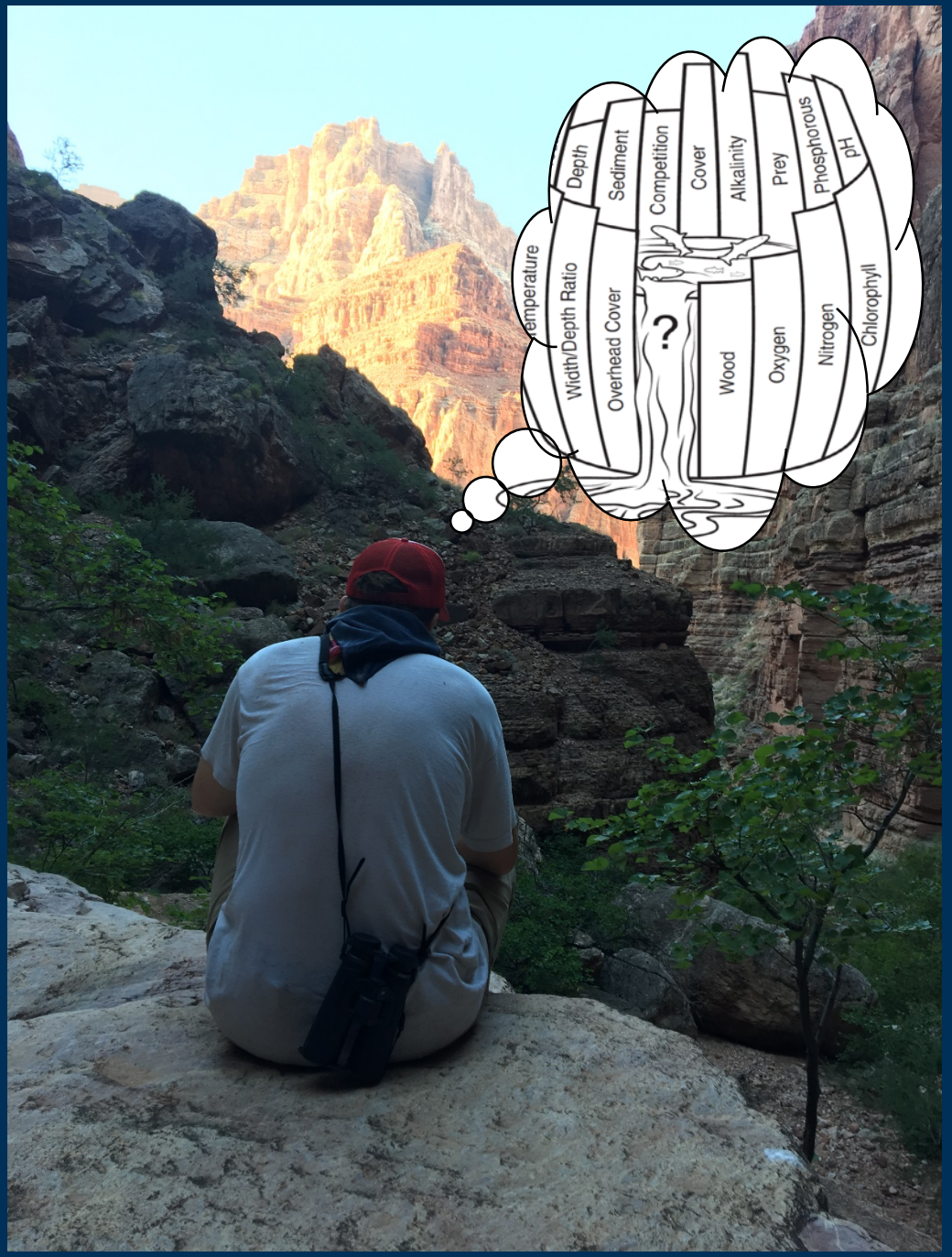
USGS

So what.

Get your head out of the clouds Yackulic!

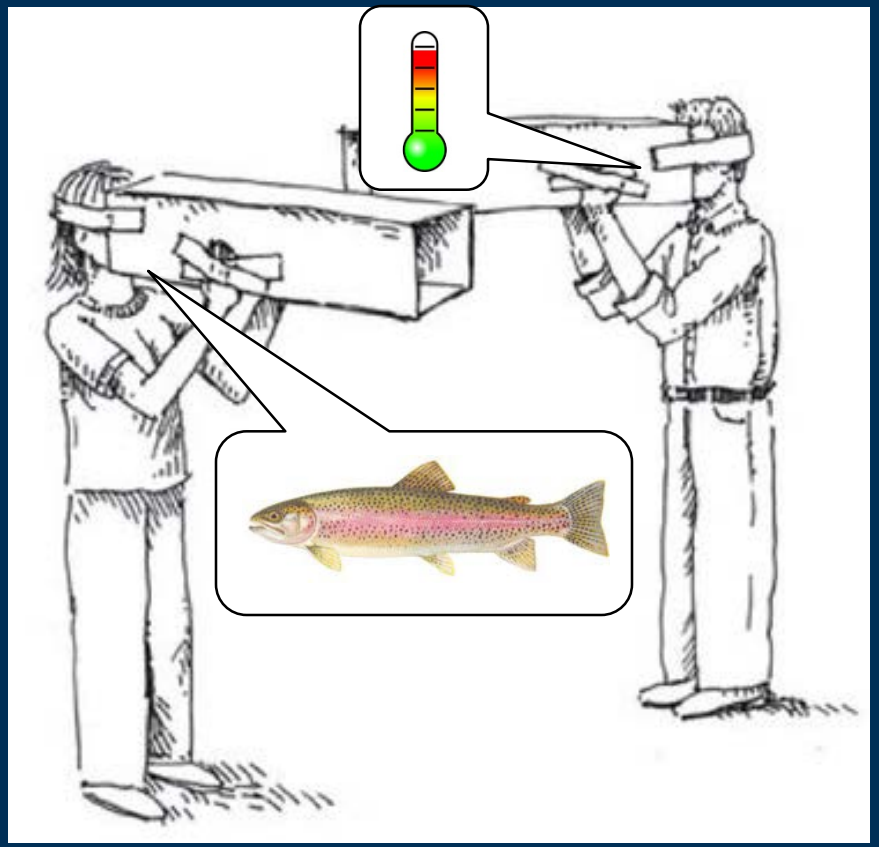
Flows and fish removals are the things we can manage.

USGS



Consequences of not thinking broadly

- Attachment to a single hypothesis
- Difficulty in recognizing confounding (especially with limited replication)
- Constrained decision space when considering management options (CONFLICT)



USGS

Discharge (m^3/s)

?

?





?



USGS

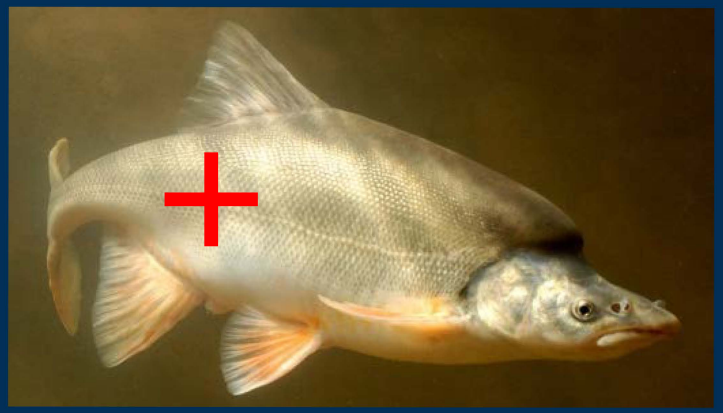
Answer the question, Yackulic!
Why study temperature and nutrients?

- **Eliminate confounding in flow and removal studies.**
- **Trigger, or improve implementation, of management.**
- **Infrastructure (e.g., retrofitting of bypass tubes) will affect both nutrients and temperature**
- The future of CRe will likely be determined by the quality of water (temperature and nutrients) exiting Lake Powell.

USGS

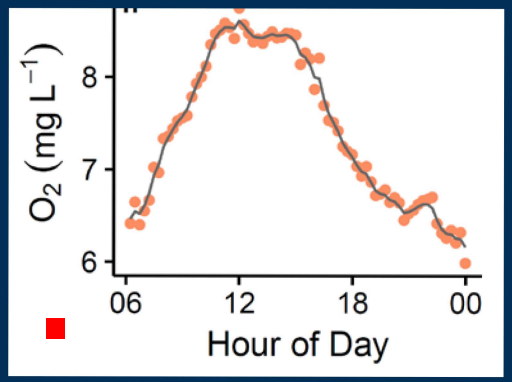
What do we know about warming water?







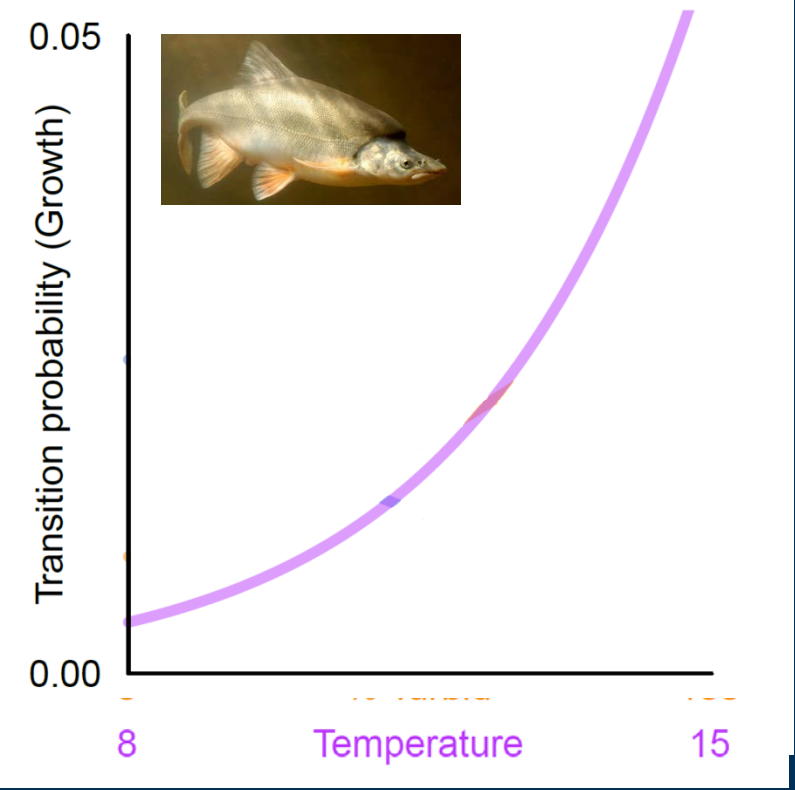




USGS

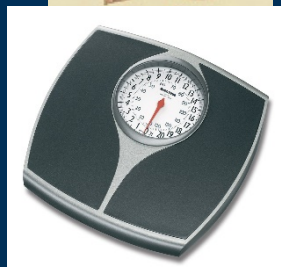
Dodrill et al., 2016
Dzul et al., 2016
Yackulic et al., 2018
Hall et al., 2016

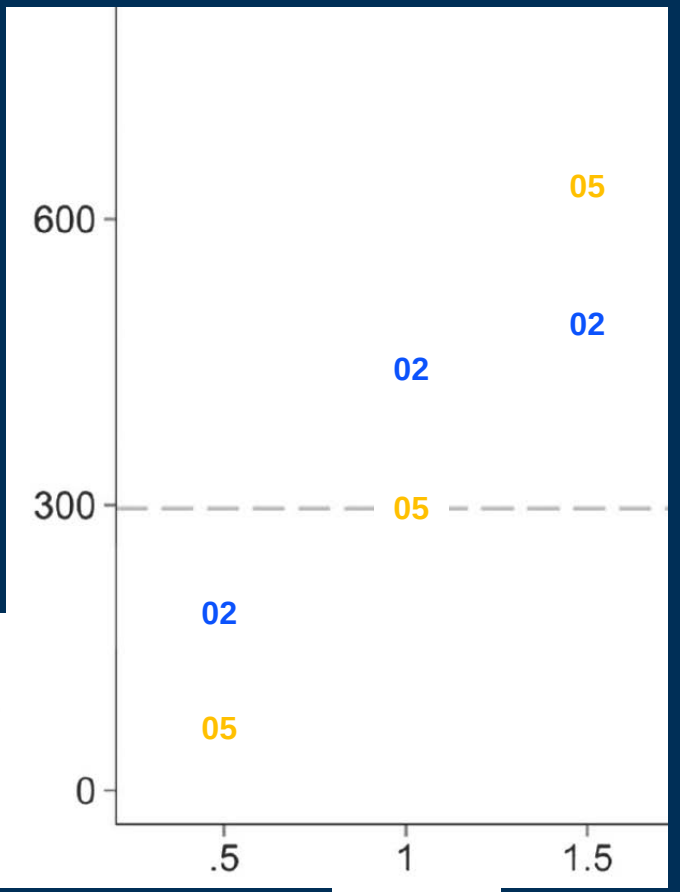
Over current range of temperatures, warm = better chub growth, more adult chub



With current foodbase and range of temperatures, warm = smaller adult rainbow trout.







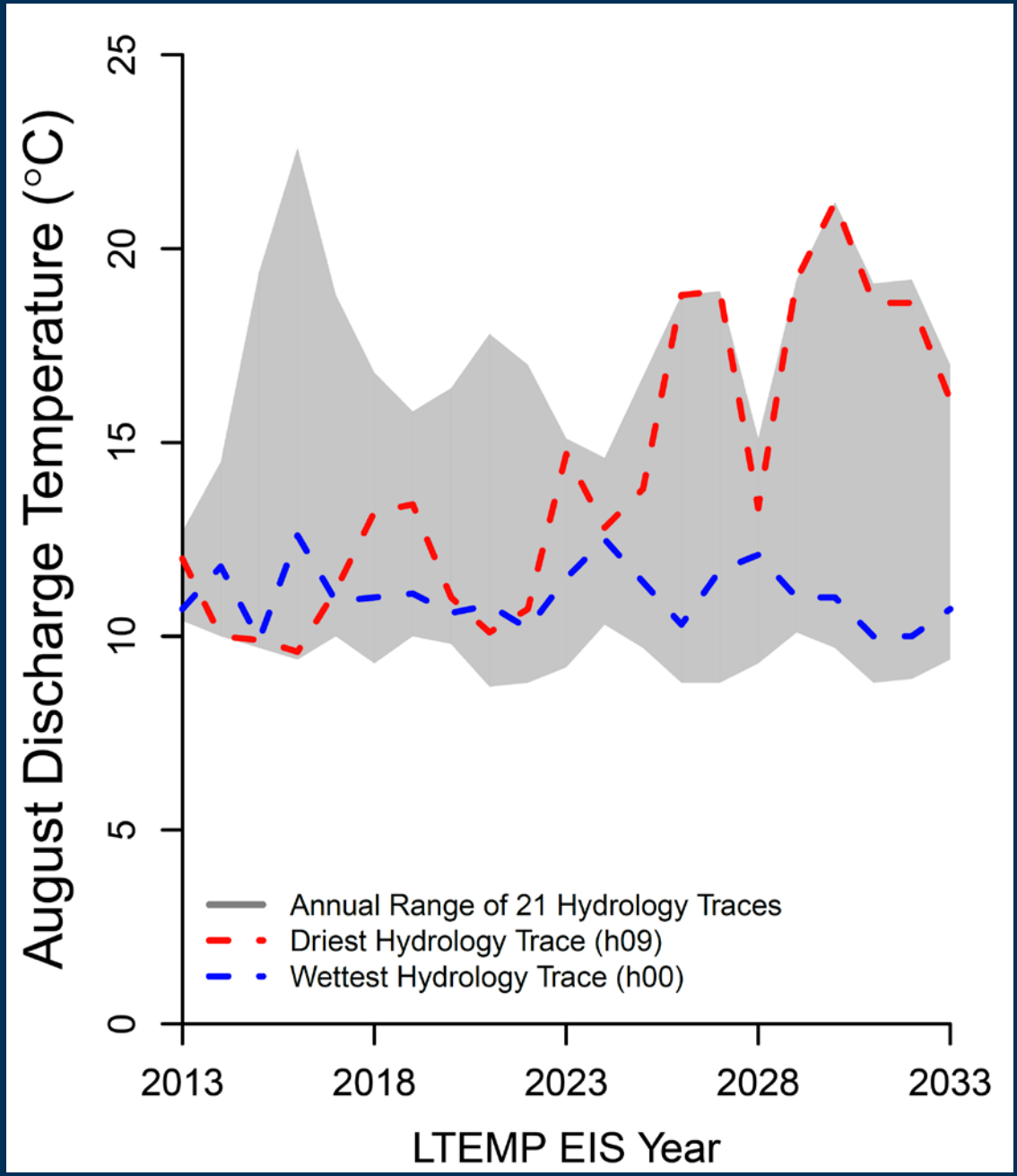
USGS

Yackulic et al. (2018) *Ecology*
Dzul et al. (2017) *CJFAS*

Dodrill et al. (2016) *CJFAS*



But what happens if / when temperatures coming out of Lake Powell are 16°C or higher for prolonged periods of time?



USGS

Preliminary Data, Do Not Cite



This is what I would expect for chub with plenty of food and without warm-water non-native species.

Chub Happiness

But things could go really bad if food doesn't keep up and/or if warm-water non-native species invade

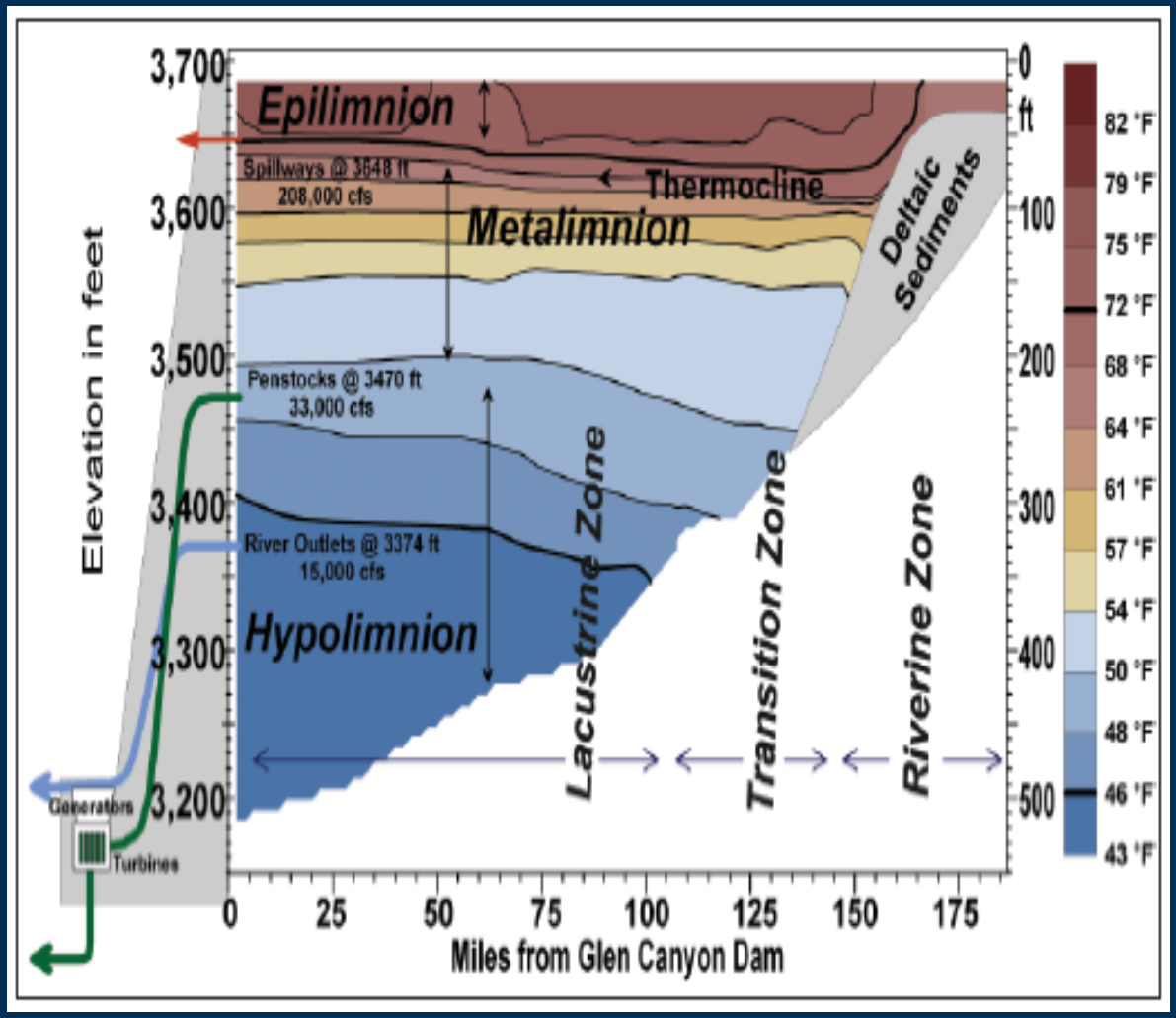


>12 12 - 16 16+

Summer water temperatures (C)

USGS

Changes in lake elevation that would drive warming above 16°C might also affect nutrient delivery to the CRe. (Pulling from closer to lake surface and changing exposure of deltaic sediments.)



USGS

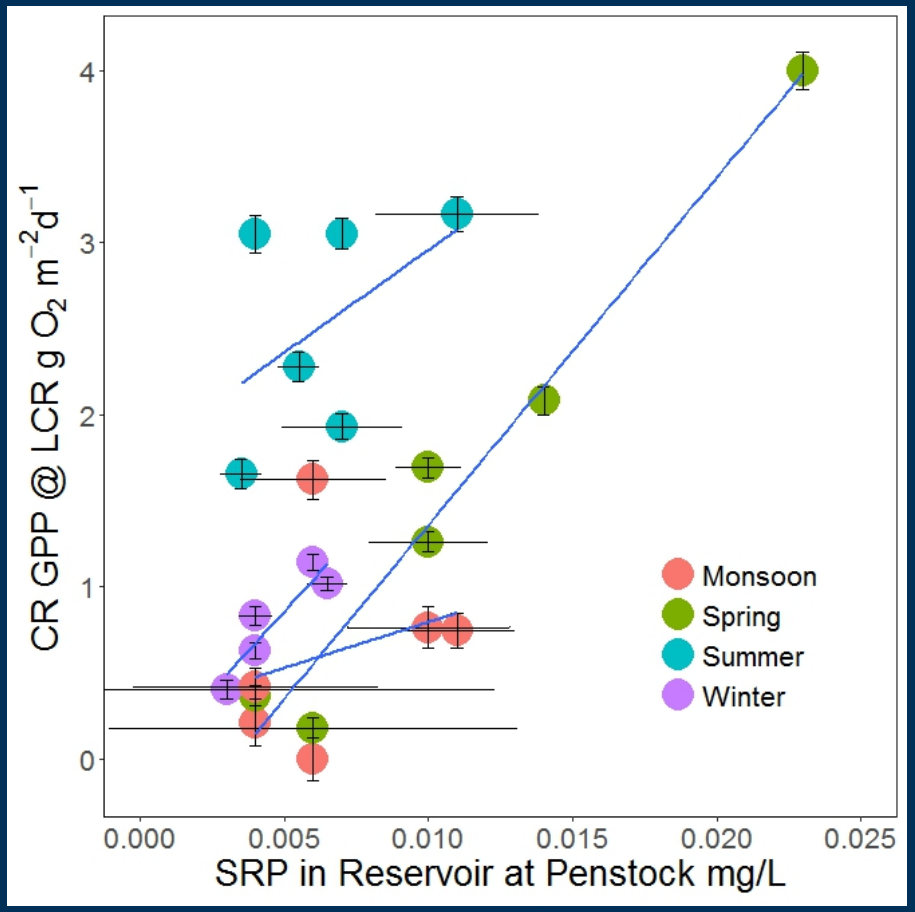
Vernieu et al. 2005

Hypothesis: Phosphorous is one of the primary drivers of the Aquatic ecosystem in the regulated portions of the Colorado River Basin.

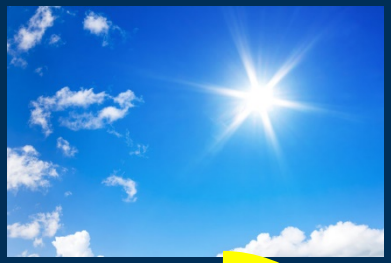
- Phosphorous limits primary production (i.e., plants) in many other ecosystems.
- In the CR Basin, most P is bound to fine clay sediments and retained in reservoirs.
- The amount of P leaving Lake Powell is always low, but varies over an order of magnitude.

USGS

Why do we care about nutrients? GPP!



Deemer and Yackulic, Preliminary Data, Do Not Cite



P



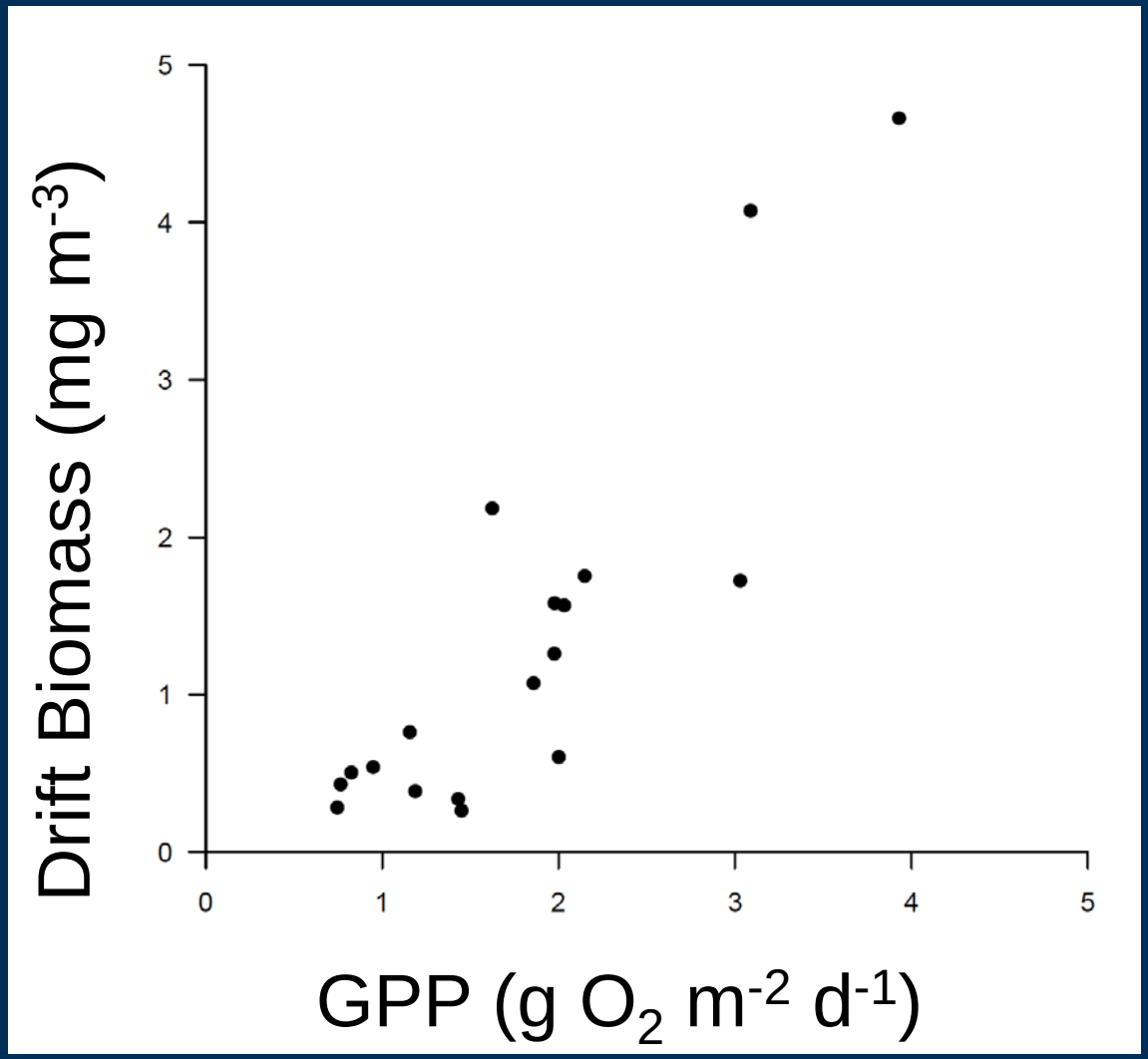


USGS

Why do we care about GPP?







USGS

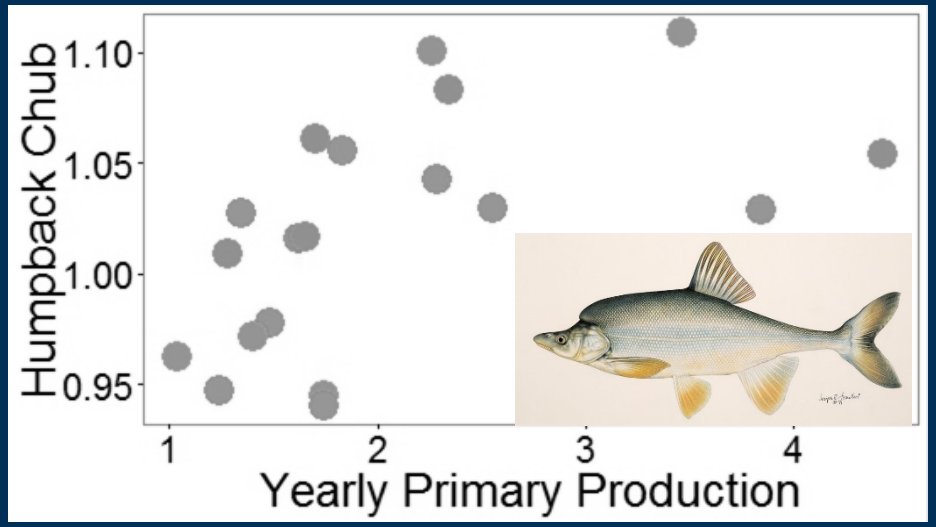
Preliminary Data, Do Not Cite







And GPP can also be linked to native fish condition (fat/skinny).



USGS

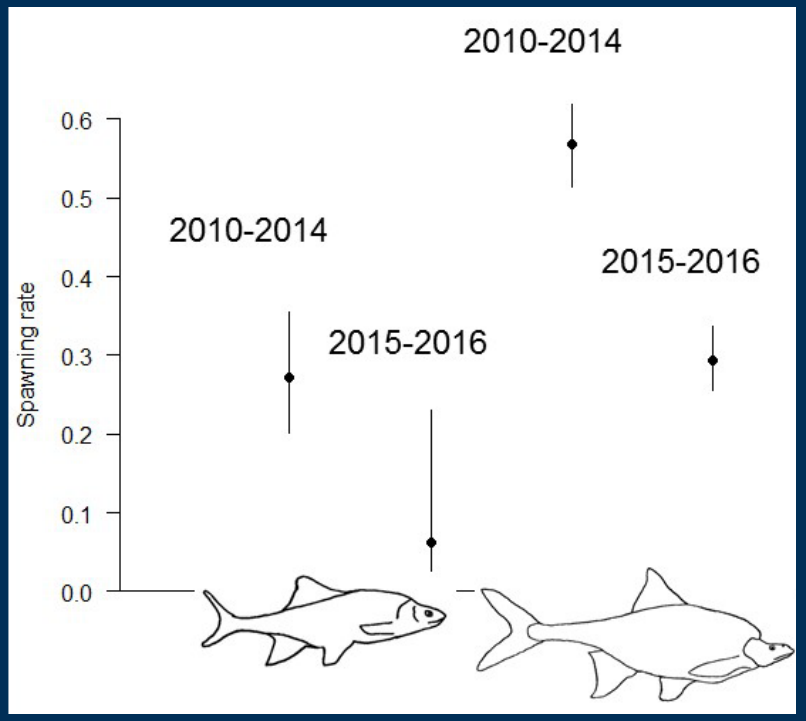
Preliminary Data, Do Not Cite

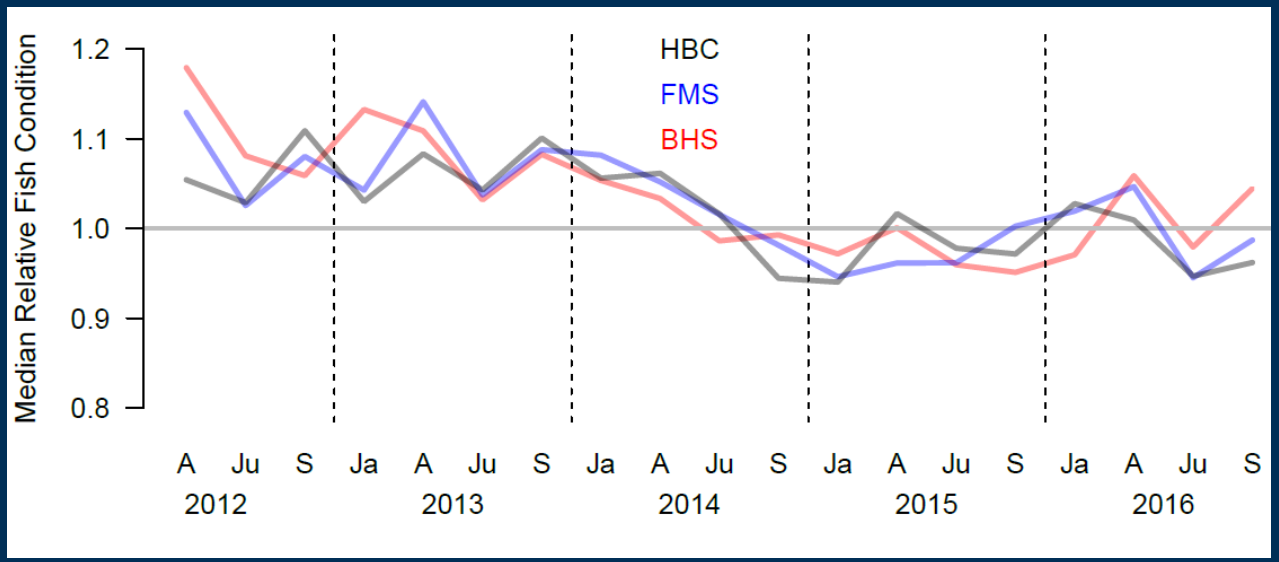
Native fish, including humpback chub, have gotten skinnier, had lowered survival and growth, and spawned less frequently.











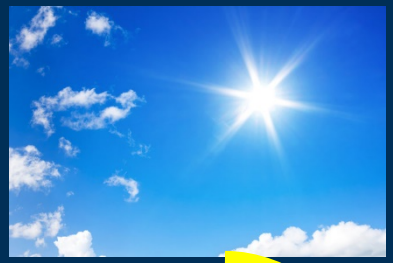
Preliminary Data, Do Not Cite

Why do we care about nutrients?









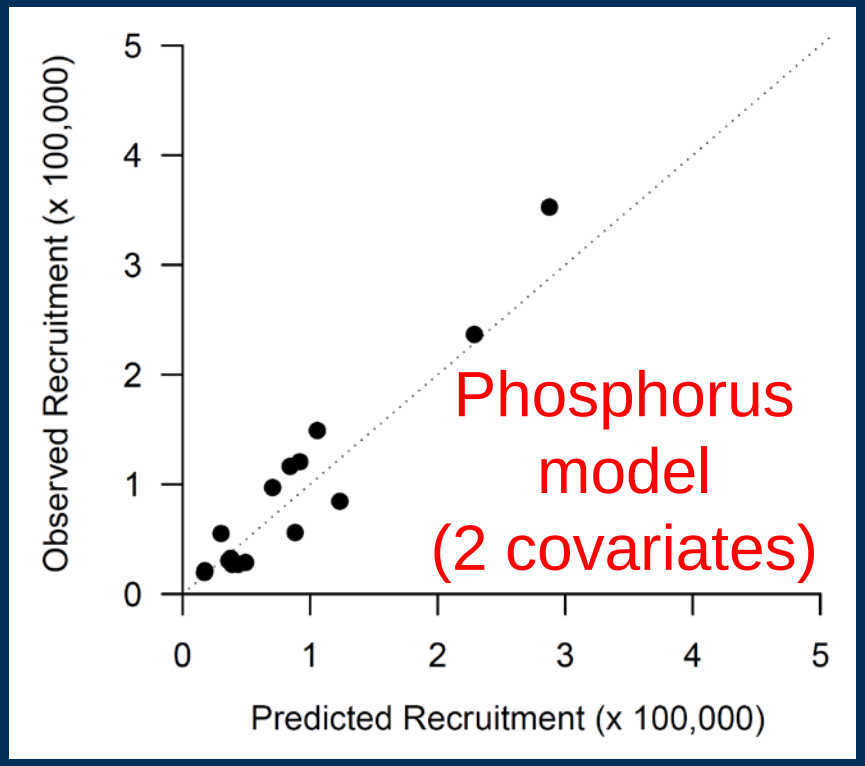
P

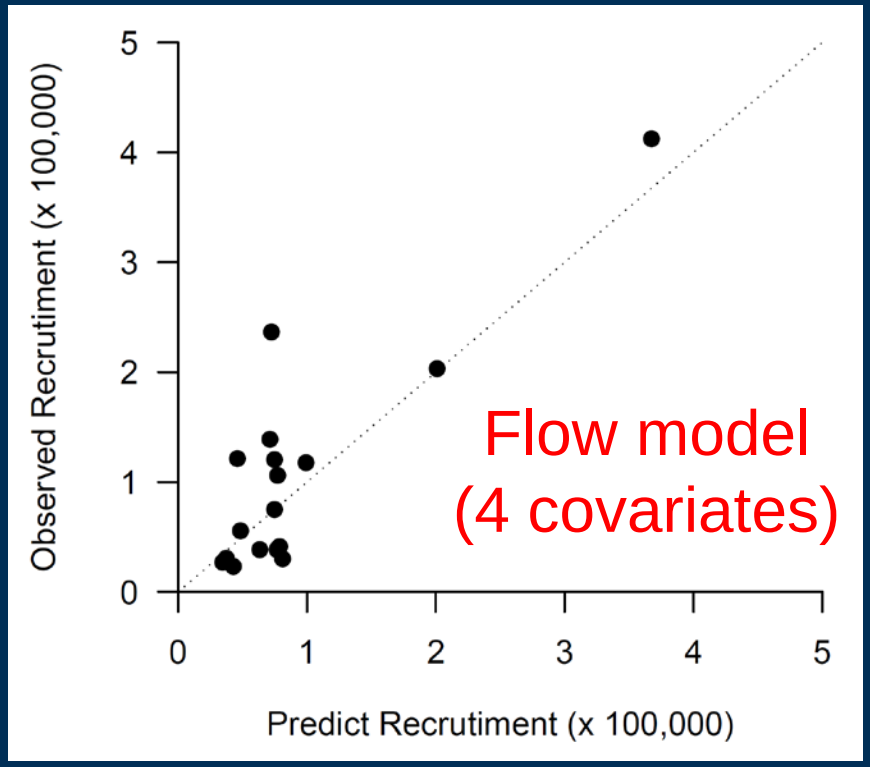




USGS

Phosphorous is more closely linked to rainbow trout recruitment than the suite of hypothesized flow based metrics (and more parsimonious).





Preliminary Data, Do Not Cite

USGS



USGS
science for a changing world

Lake Powell as a Regulator of Riverine Ecosystem Drivers-- Temperature Dynamics

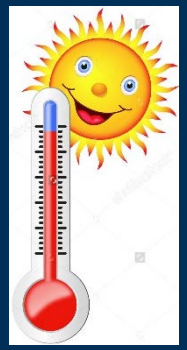
Kimberly L. Dibble[1], Charles B. Yackulic[1], and Theodore A. Kennedy[1]

[1] U.S. Geological Survey, Southwest Biological Science Center, Grand Canyon Monitoring and Research Center

Glen Canyon Dam Adaptive Management Program – 2018 Annual Reporting Meeting
Flagstaff, Arizona
March 7, 2018

U.S. Department of the Interior
U.S. Geological Survey

To what degree will changes in air temperature, discharge, and storage drive future river temperatures?



Increased air temperature (2.6ºC – 5.4ºC)

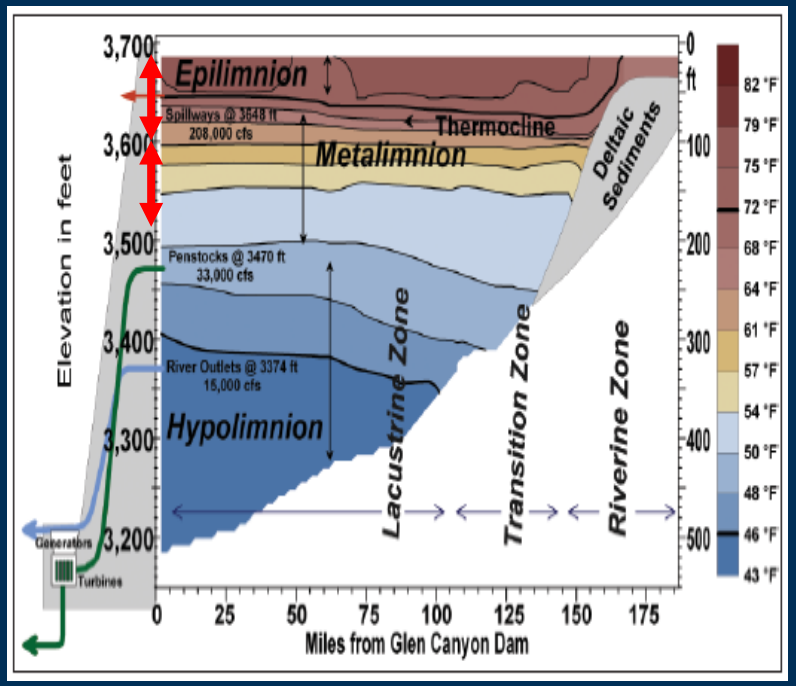


Decreased Colorado River flow (17 – 35%)

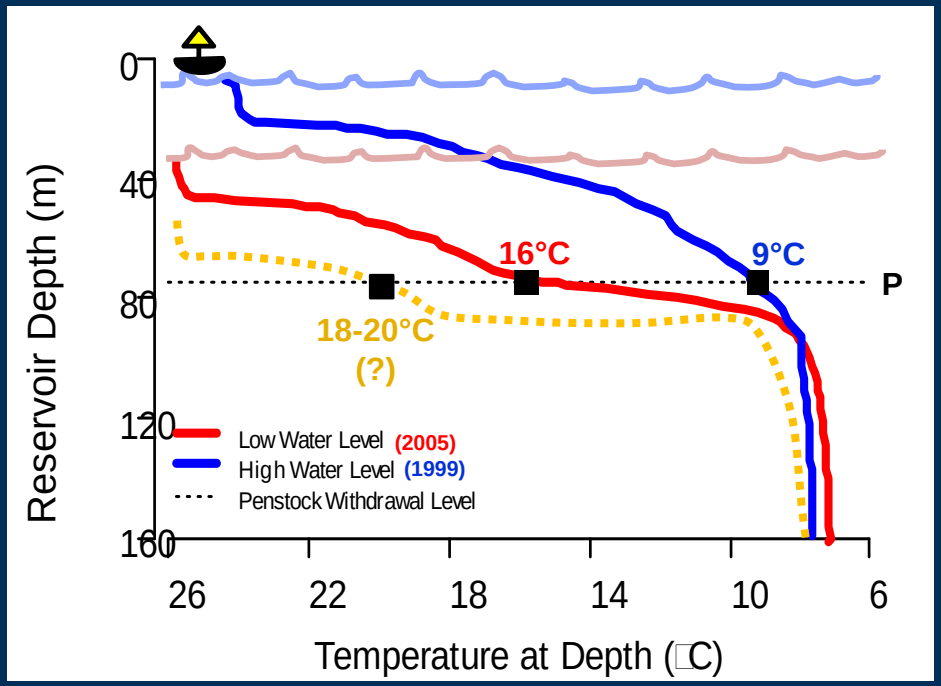


Decreased storage in Lake Powell

Lake Powell elevation as a driver of temperature



Vernieu et al. 2005

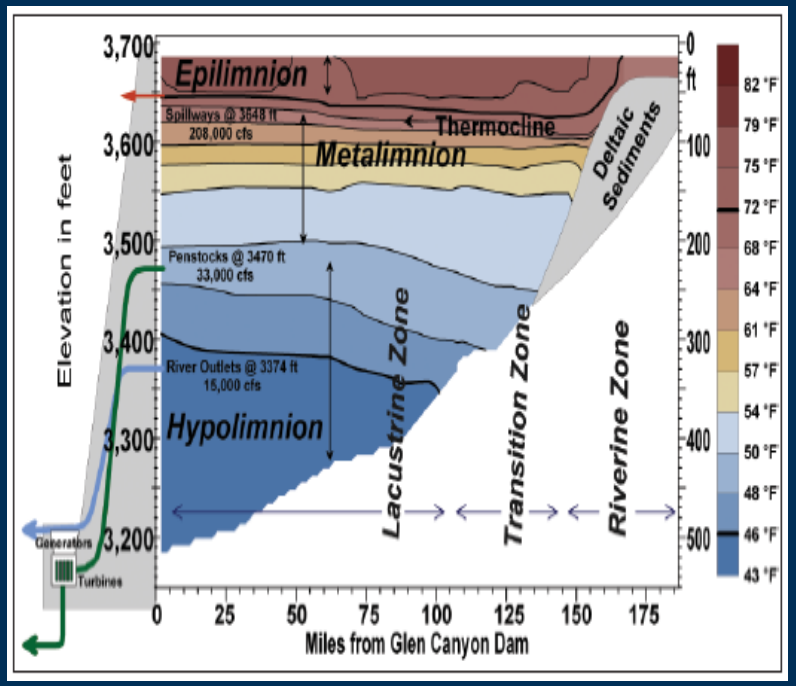


Dibble, Yackulic, and Kennedy, Preliminary Data, Do Not Cite

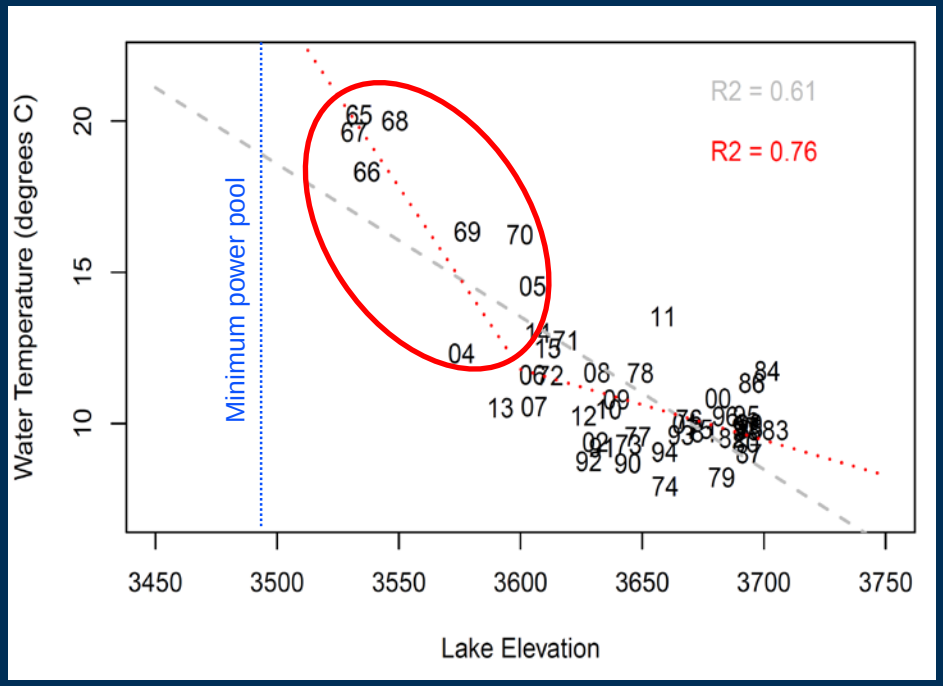
What will happen to release temperatures if Lake Powell storage declines but elevation remains above minimum power pool?

USGS

Lake Powell elevation as a driver of temperature



Vernieu et al. 2005

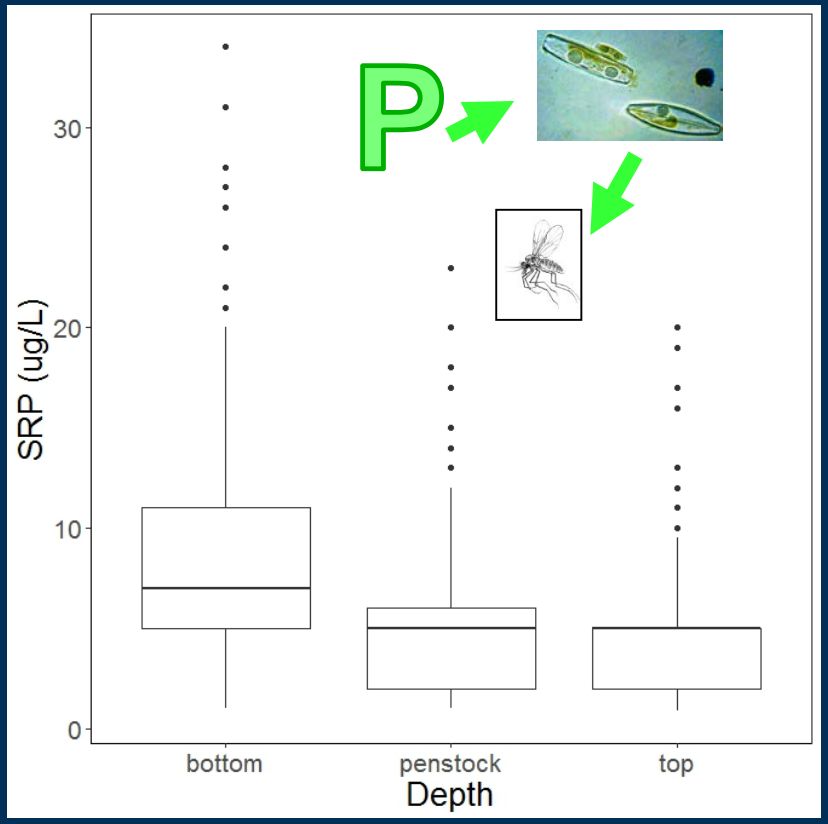


Yackulic and Deemer, Preliminary Data, Do Not Cite

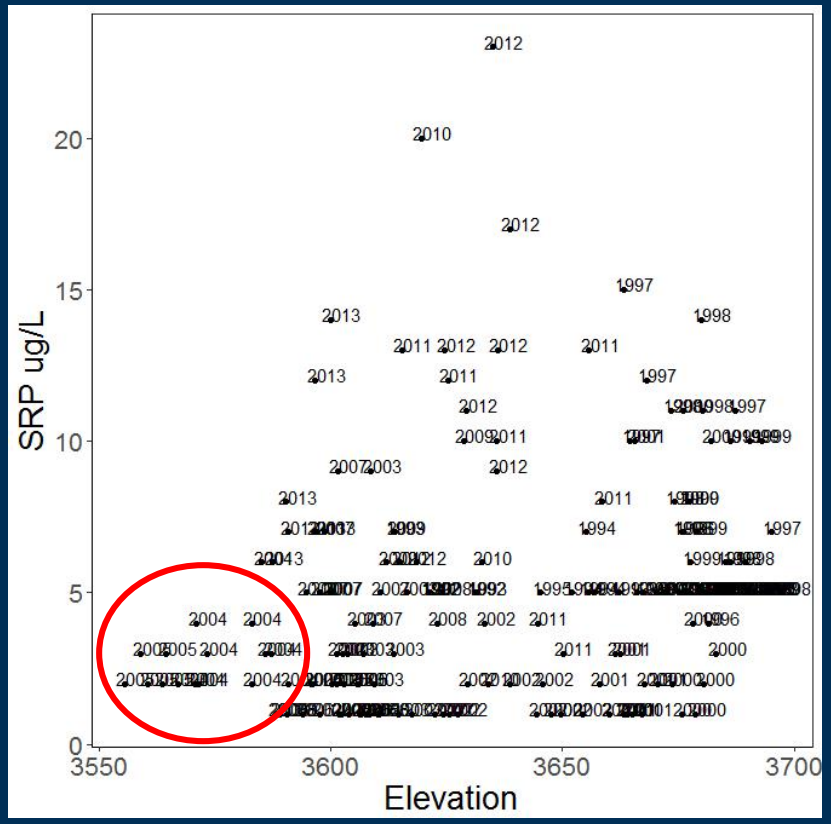
Release temperatures increase when elevation drops <3,575 feet; penstocks draw from lower epilimnion to upper metalimnion

USGS

Warmer Lake Powell releases contain less nutrients



Deemer and Yackulic, Preliminary Data, Do Not Cite

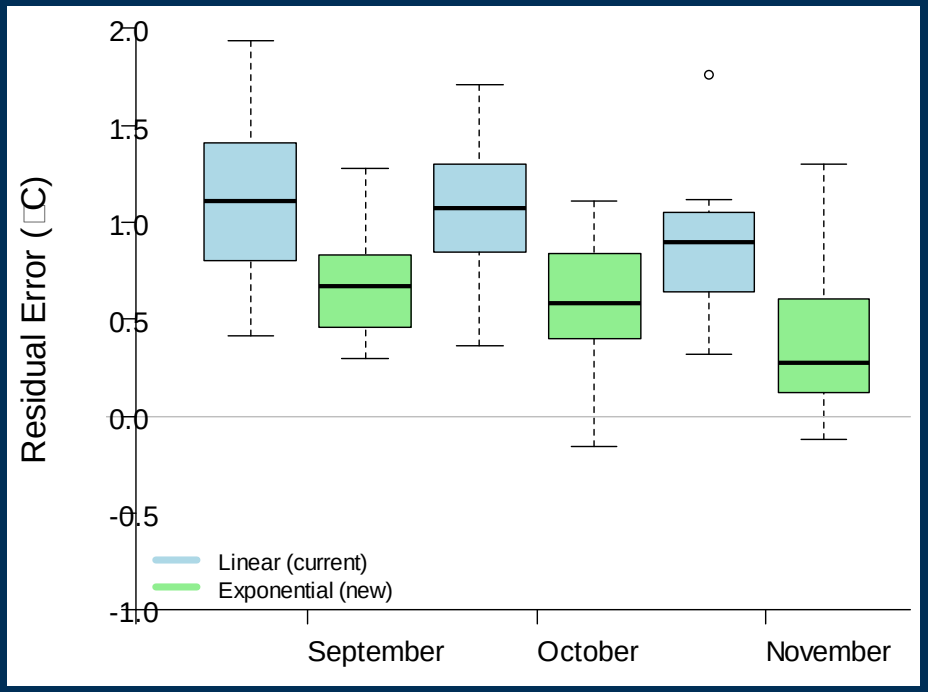


Deemer and Yackulic, Preliminary Data, Do Not Cite

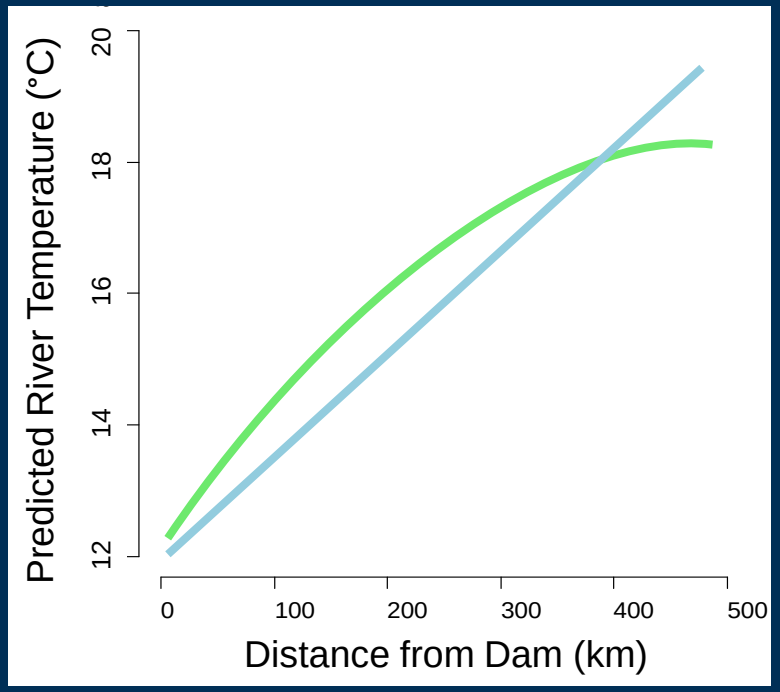
Phosphorus concentrations are elevated in bottom water

Warmer withdrawals may decrease nutrient availability → fish

To model future river temperatures, we modified the current CR temperature model

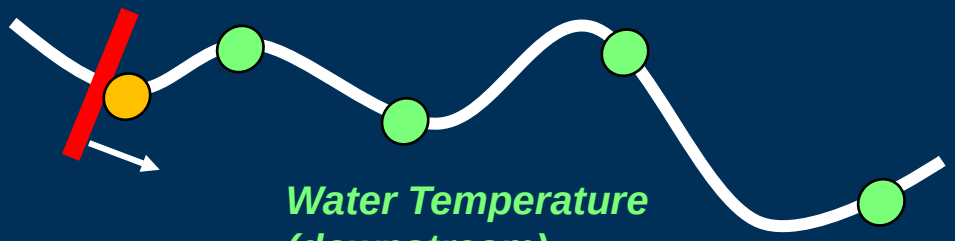


Dibble, Yackulic, and Kennedy, Preliminary Data, Do Not Cite



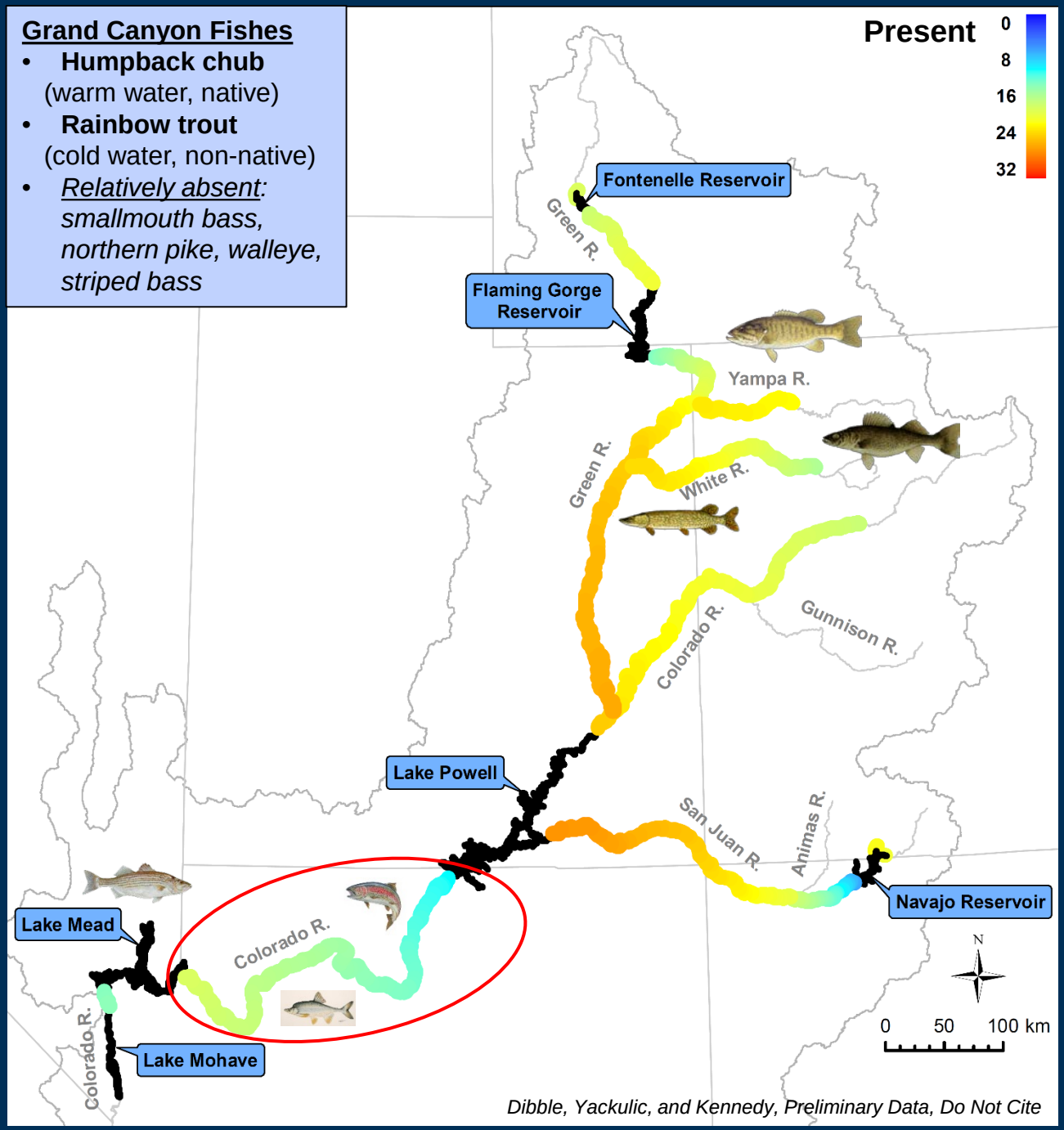
Dibble, Yackulic, and Kennedy, Preliminary Data, Do Not Cite

Release Temperature
Air Temperature
Discharge at dam



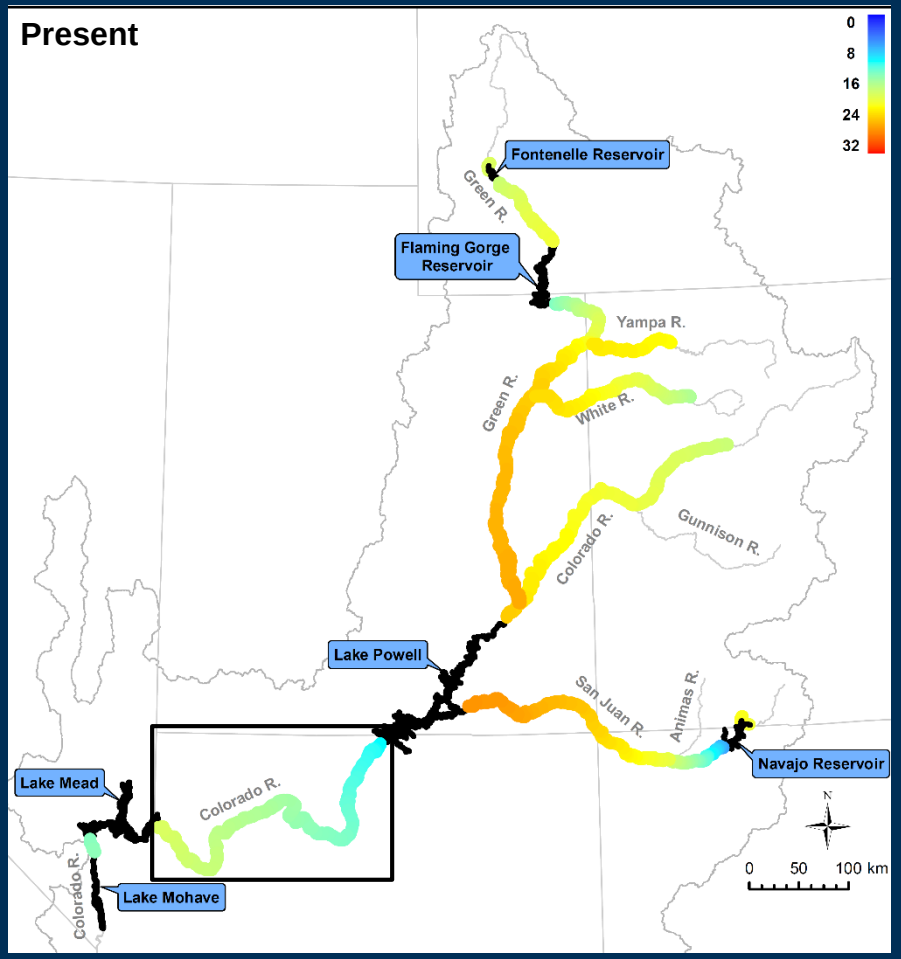
Water Temperature (downstream)

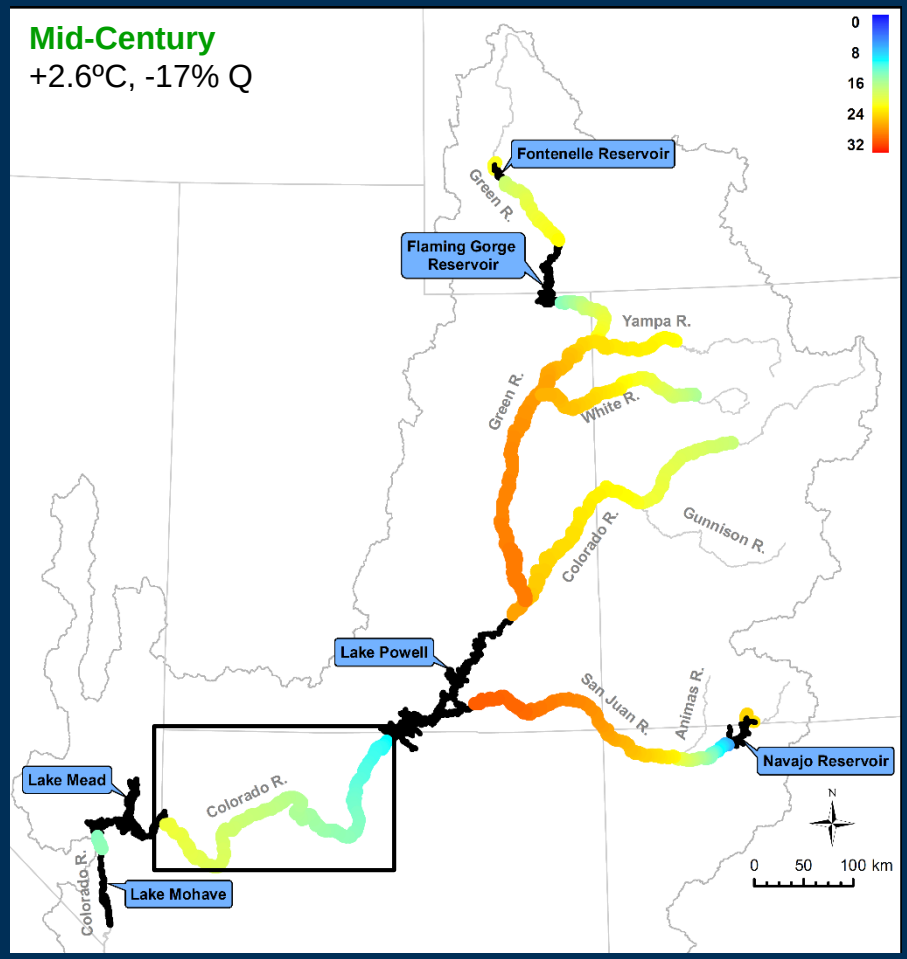
USGS


Grand Canyon Fishes
• Humpback chub (warm water, native)
• Rainbow trout (cold water, non-native)
• Relatively absent: smallmouth bass, northern pike, walleye, striped bass
Present
0
8
16
24
32
Fontenelle Reservoir
Green R.
Flaming Gorge Reservoir
Yampa R.
Green R.
White R.
Colorado R.
Gunnison R.
Lake Powell
San Juan R.
Animas R.
Navajo Reservoir
Lake Mead
Colorado R.
Lake Mohave
Colorado R.
N
0 50 100 km
Dibble, Yackulic, and Kennedy, Preliminary Data, Do Not Cite

USGS

Changes to future water temperature from increased air temperature and decreased flow



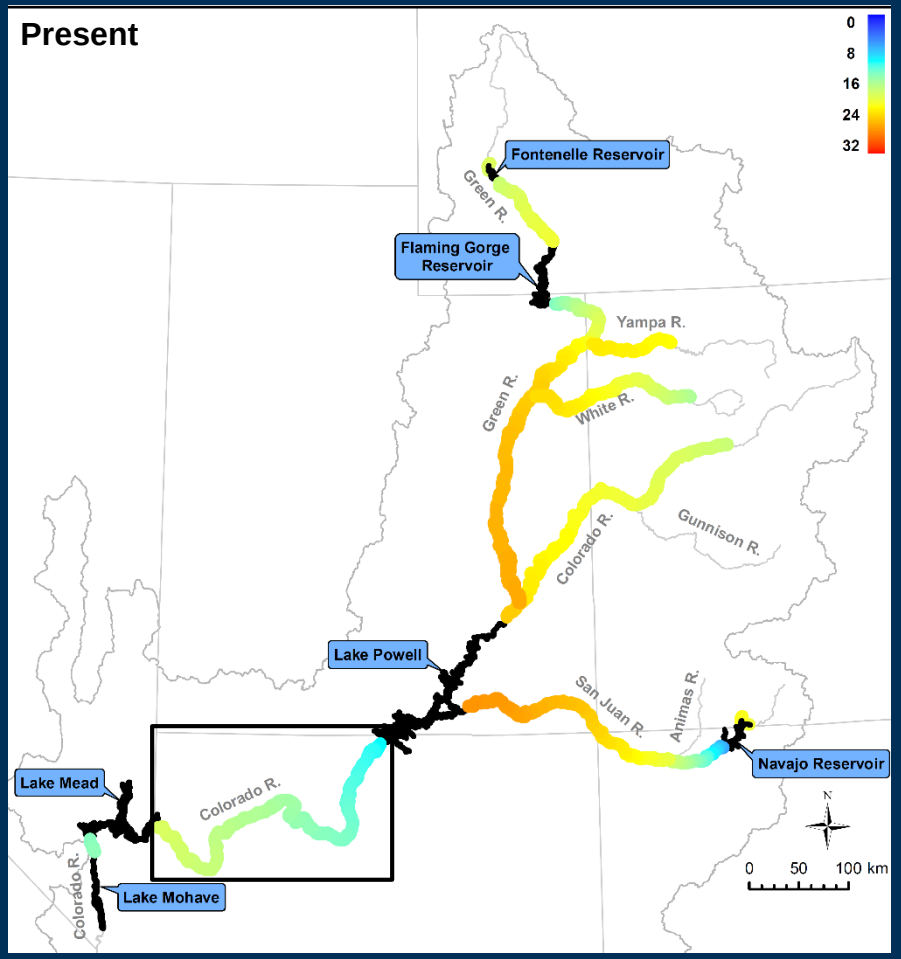


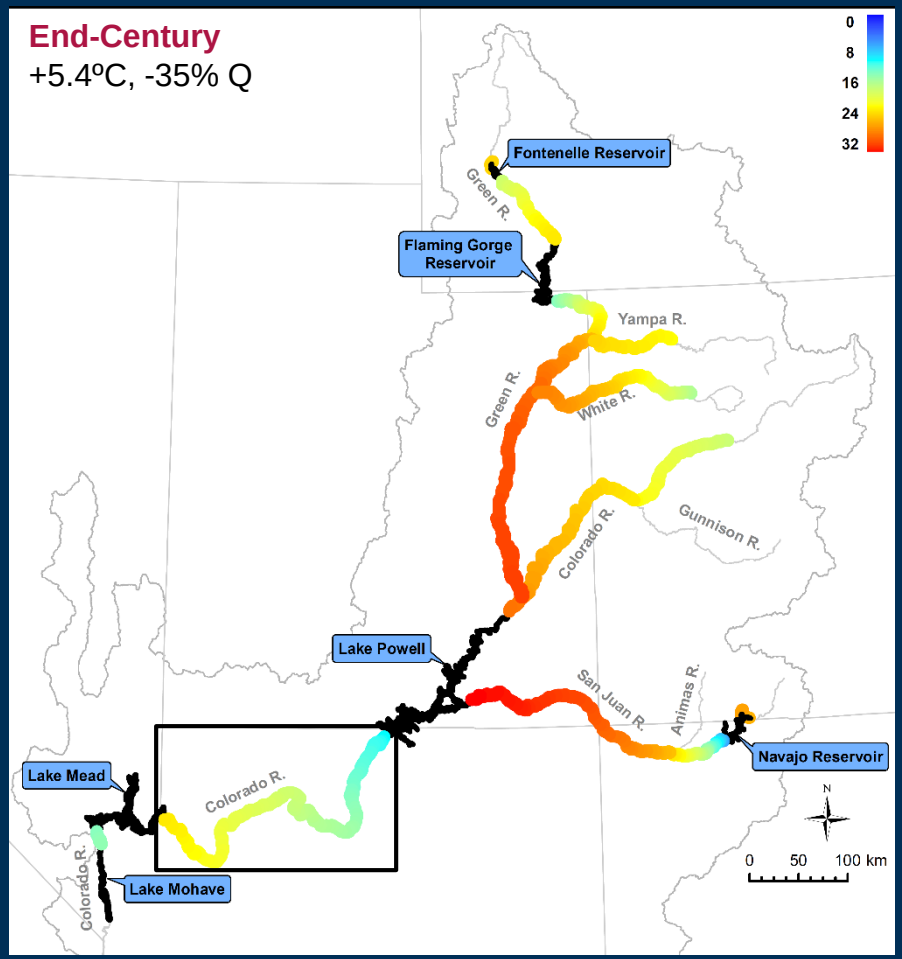
Dibble, Yackulic, and Kennedy, Preliminary Data, Do Not Cite

USGS

Increased air temperature and decreased discharge will not have a large influence on future river temperatures in Grand Canyon

Changes to future water temperature from increased air temperature and decreased flow





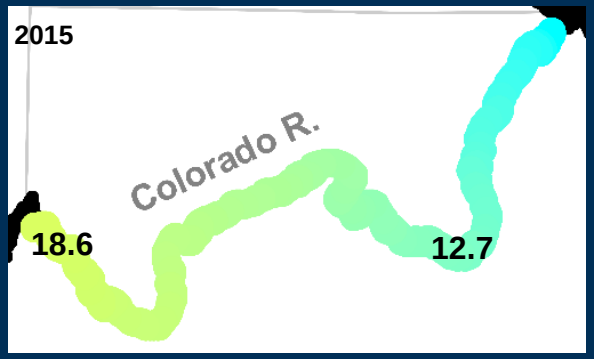
Dibble, Yackulic, and Kennedy, Preliminary Data, Do Not Cite

USGS

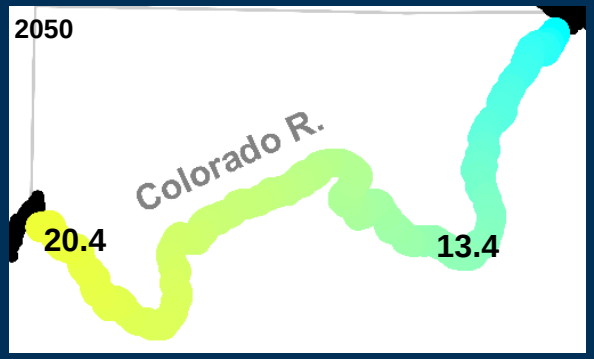
Increased air temperature and decreased discharge will not have a large influence on future river temperatures in Grand Canyon

Water temperature predictions in Grand Canyon

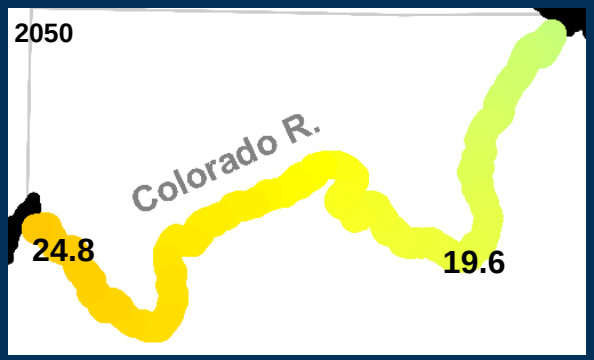
Present



Increased air temperature (+2.6 ºC)
Decreased discharge (-17%)



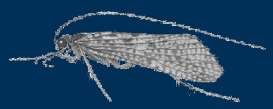
Increased air temperature (+2.6 ºC)
Decreased discharge (-17%)
Decreased reservoir storage (+7 ºC)



Dibble, Yackulic, and Kennedy, Preliminary Data, Do Not Cite

Potential ecological outcomes of 18-20°C releases

Invertebrate taxa abundance/diversity; better food base



Caddisflies



Midges

Mainstem spawning of native fish species



Humpback Chub



Razorback Sucker

Nutrients decline (warmer, epilimnetic), food base tanks

P

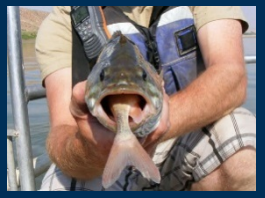


Diatoms



Midges

Rainbow trout decline, replaced by piscivorous non-native fish

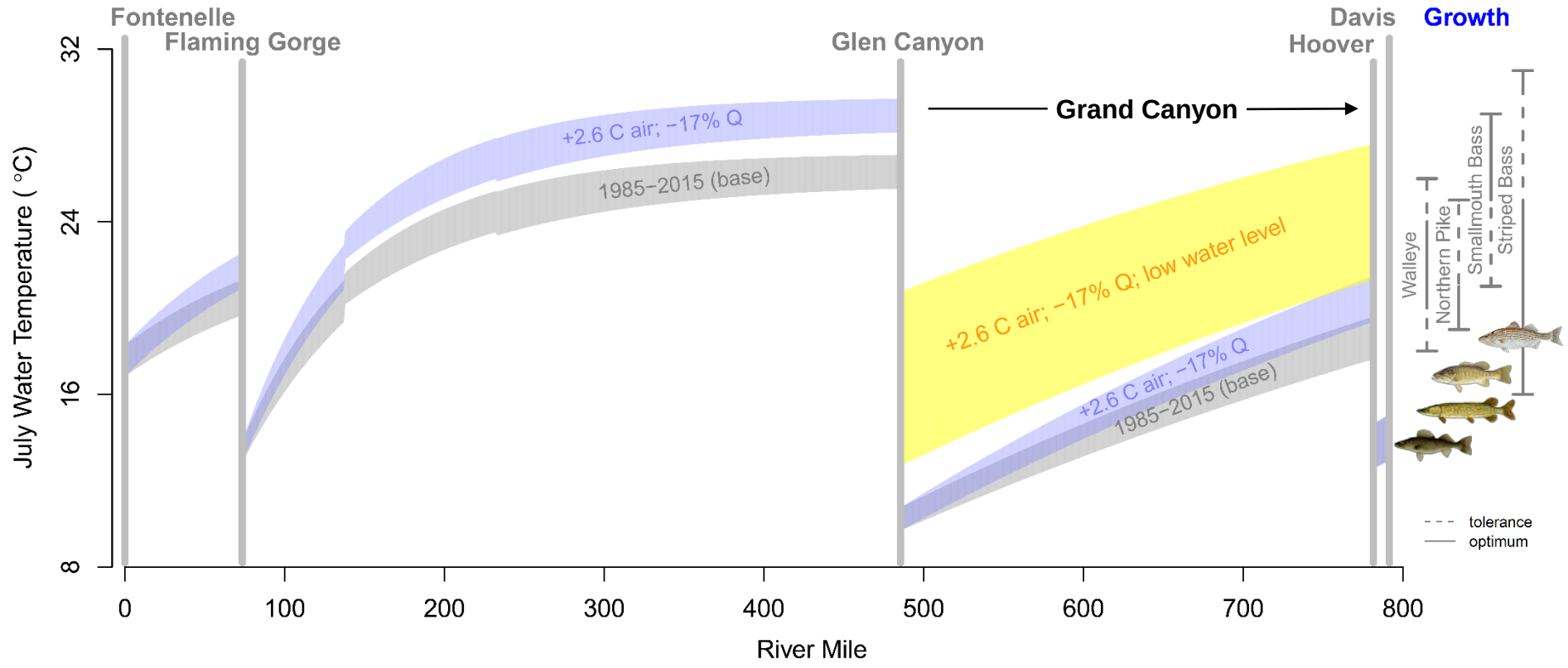


Smallmouth Bass



Northern Pike

Low storage could facilitate piscivorous fish invasion



Dibble, Yackulic, and Kennedy, Preliminary Data, Do Not Cite

USGS

Upper Basin non-native fish removal efforts



Mechanical removal

Chemical treatment

Reservoir net barriers

Sterilization

Angling tournaments

Liberalized harvest

Environmental flows

Take Home Messages

- Lake Powell storage will be a bigger driver of river temperatures than air temperature or discharge

- Response of Colorado River ecosystem to warmer temperatures is uncertain (out-of-box conditions)
  - Nutrients, food base, physiological responses of fish
  - Potential invasion of warm water non-native species

- Research in FY18-20 work plan includes use of artificial stream experiments to test hypotheses on temperature and nutrients

USGS

Acknowledgements

Funding

- USBR Glen Canyon Dam Adaptive Management Program
- USGS WaterSMART Program

Data

- Colorado Division of Water Resources
- U.S. Army Corps of Engineers
- U.S. Bureau of Reclamation, Hydromet
- USDA NRCS National Water and Climate Center
- Upper Colorado River Endangered Fish Recovery Program
- USFWS San Juan River Basin Recovery Implementation Program
- USGS BioData and WaterWatch
- Tom Gushue, GCMRC, GIS Support

USGS

Lake Powell as a Regulator of Riverine Ecosystem Drivers– Nutrient Dynamics



GCDAMP Annual Reporting Meeting

March 7, 2018

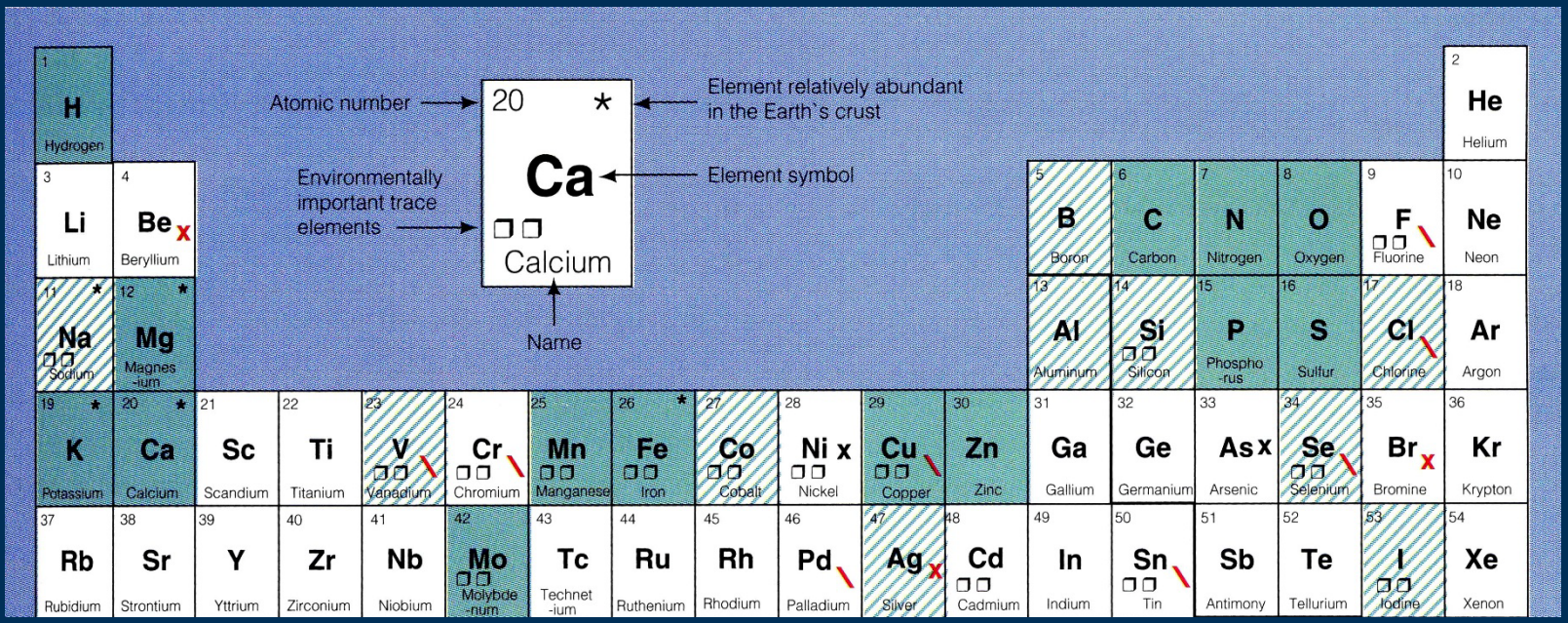
Bridget Deemer[1], Charles Yackulic[1], and Ted Stets[2]

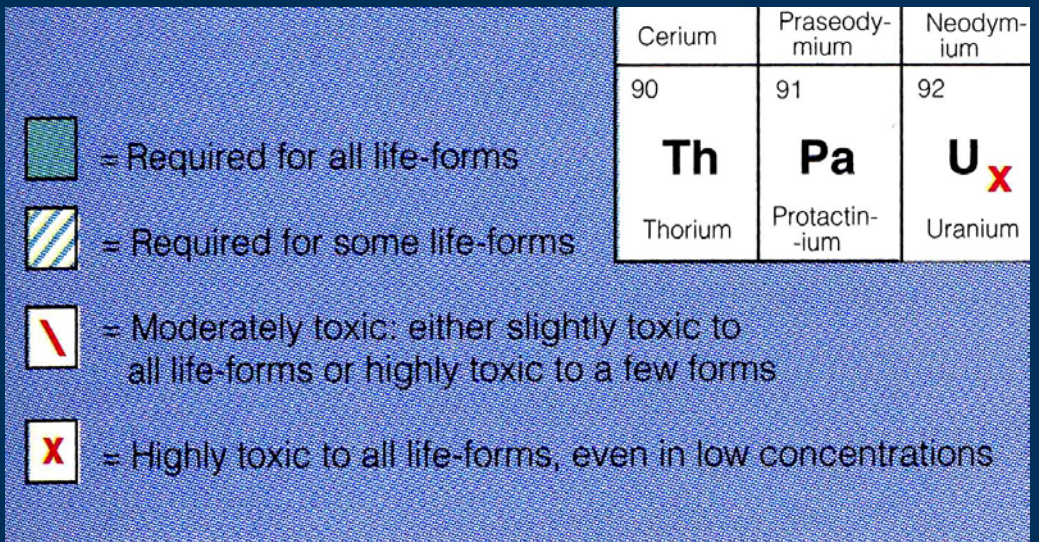
U.S. Department of the Interior
U.S. Geological Survey

[1] U.S. Geological Survey, Southwest Biological Science Center, Grand Canyon Monitoring and Research Center

[2] U.S. Geological Survey, Water Resources Mission Area, National Research Program

Nutrients– Building Blocks of Life





About 26 chemical elements comprise all of life.

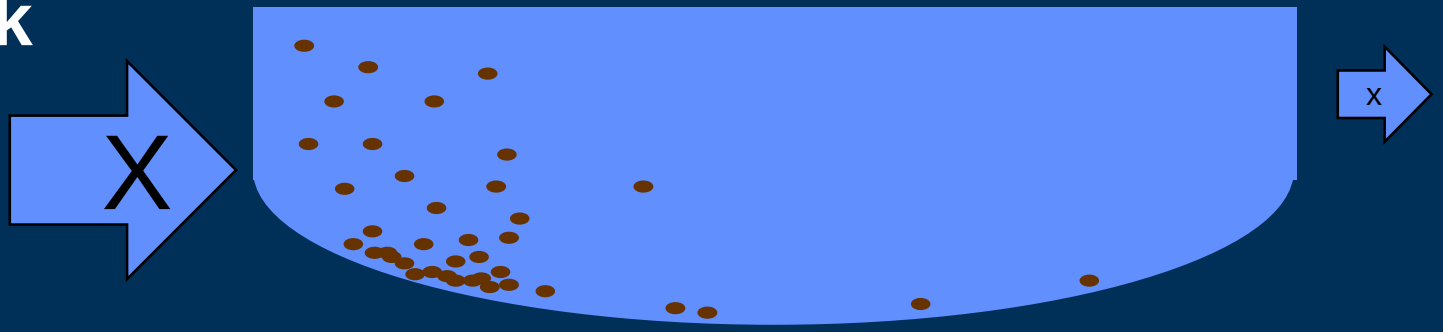
Talk Outline

- Lake Powell as a Biogeochemical Reactor
- Phosphorus Dynamics in Lake Powell
- Nutrient Footprint Below Lake Powell

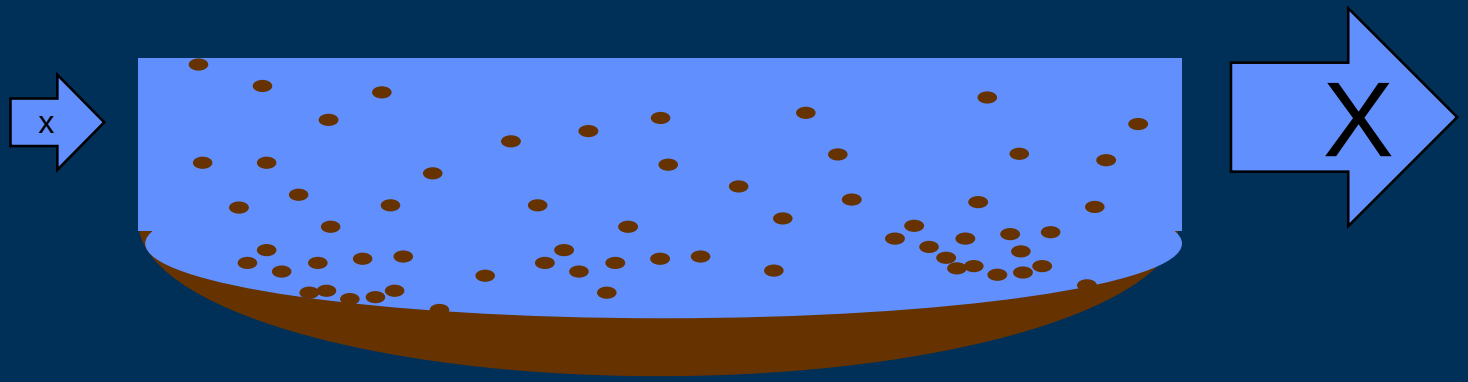
USGS

Reservoirs as a Chemical Sink versus a Source

- Sink

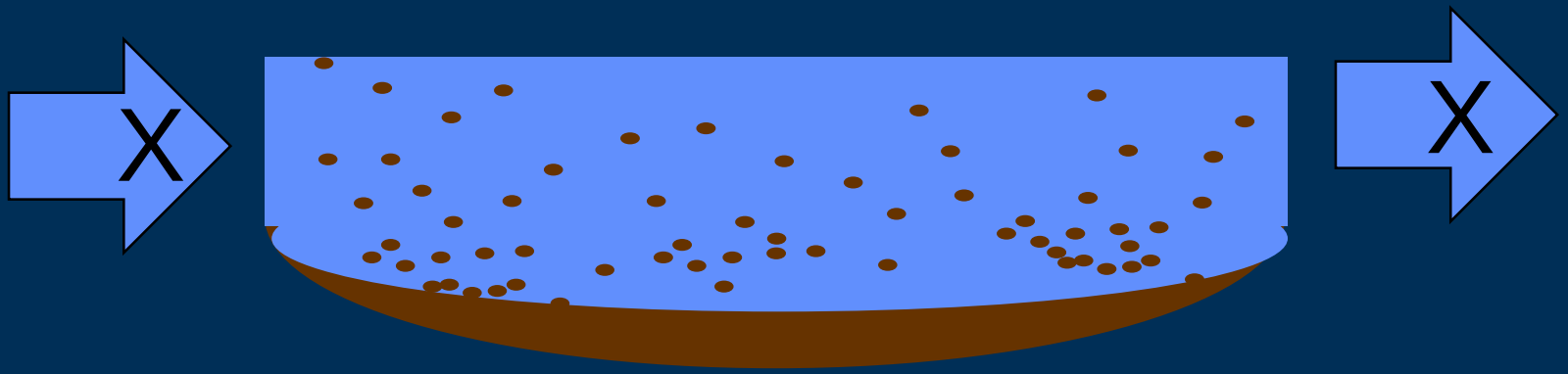


- Source



USGS

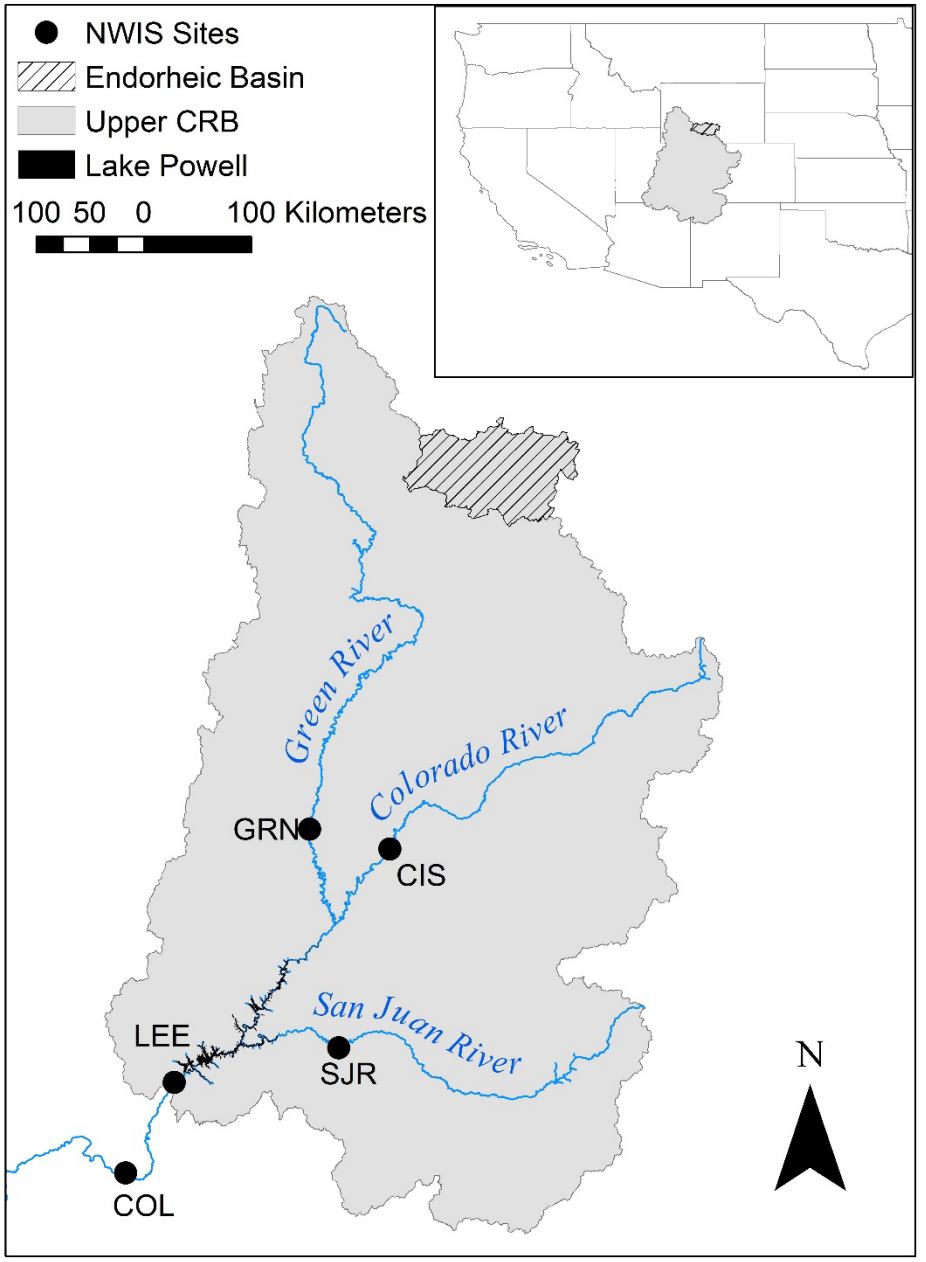
Reservoirs as a Chemical Sink versus a Source



USGS

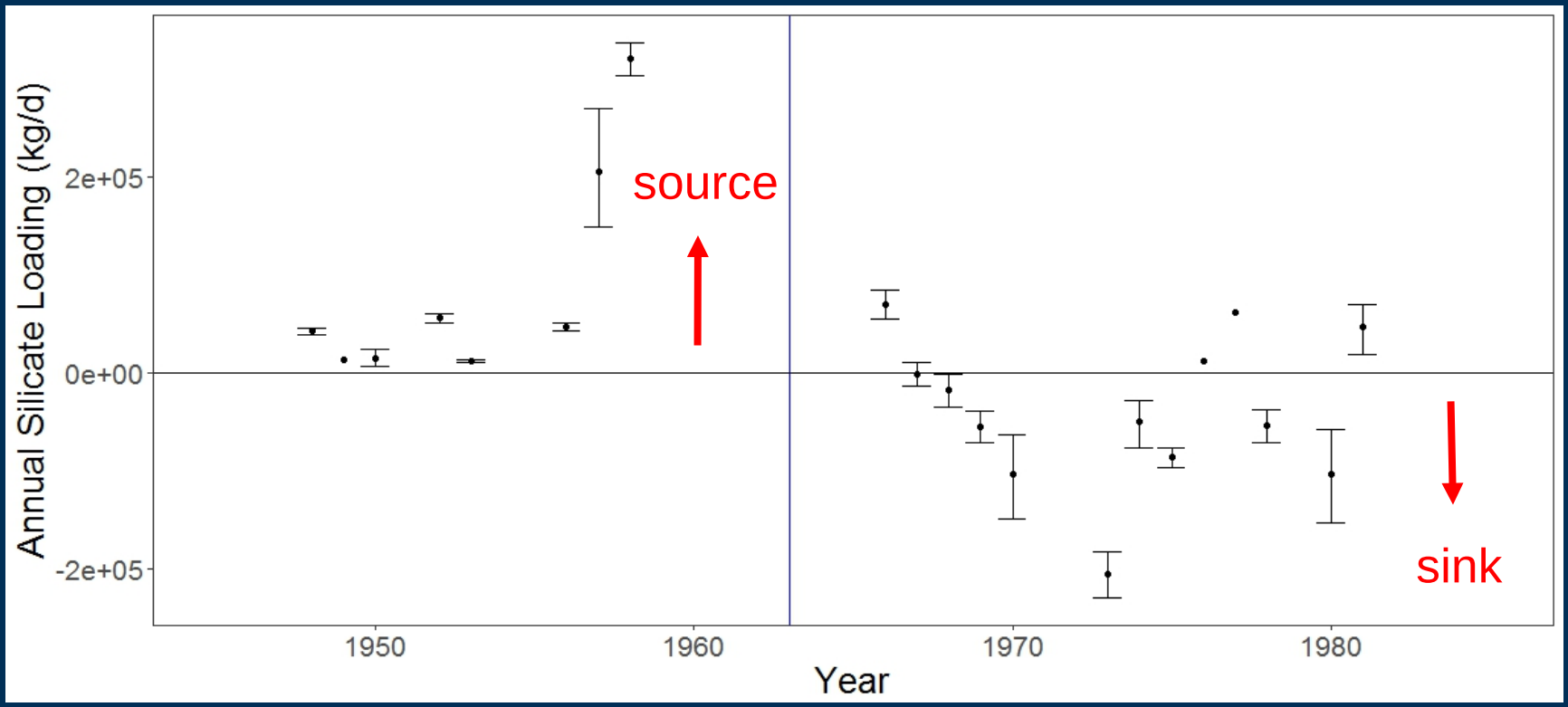
Lake Powell as a Biogeochemical Reactor

- Long term chemical record for 5 solutes at inflows and outflow
- Mass Balance estimates show when reservoir is functioning to retain or supply nutrients



USGS

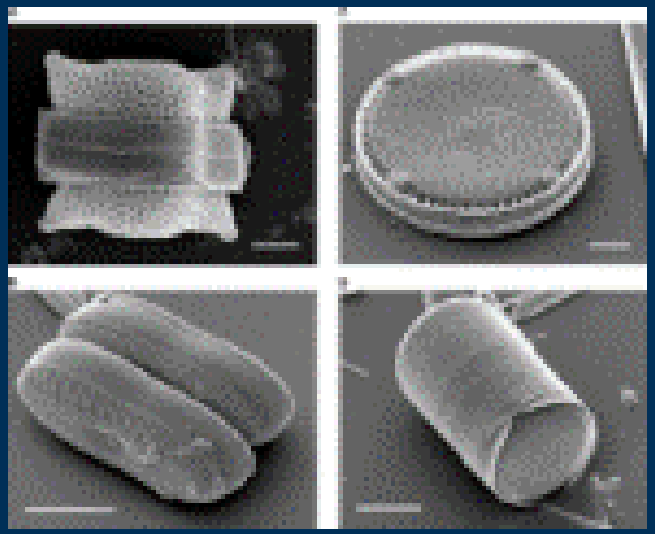
Dam reduces downstream transport of silicate



Preliminary Data, Do Not Cite

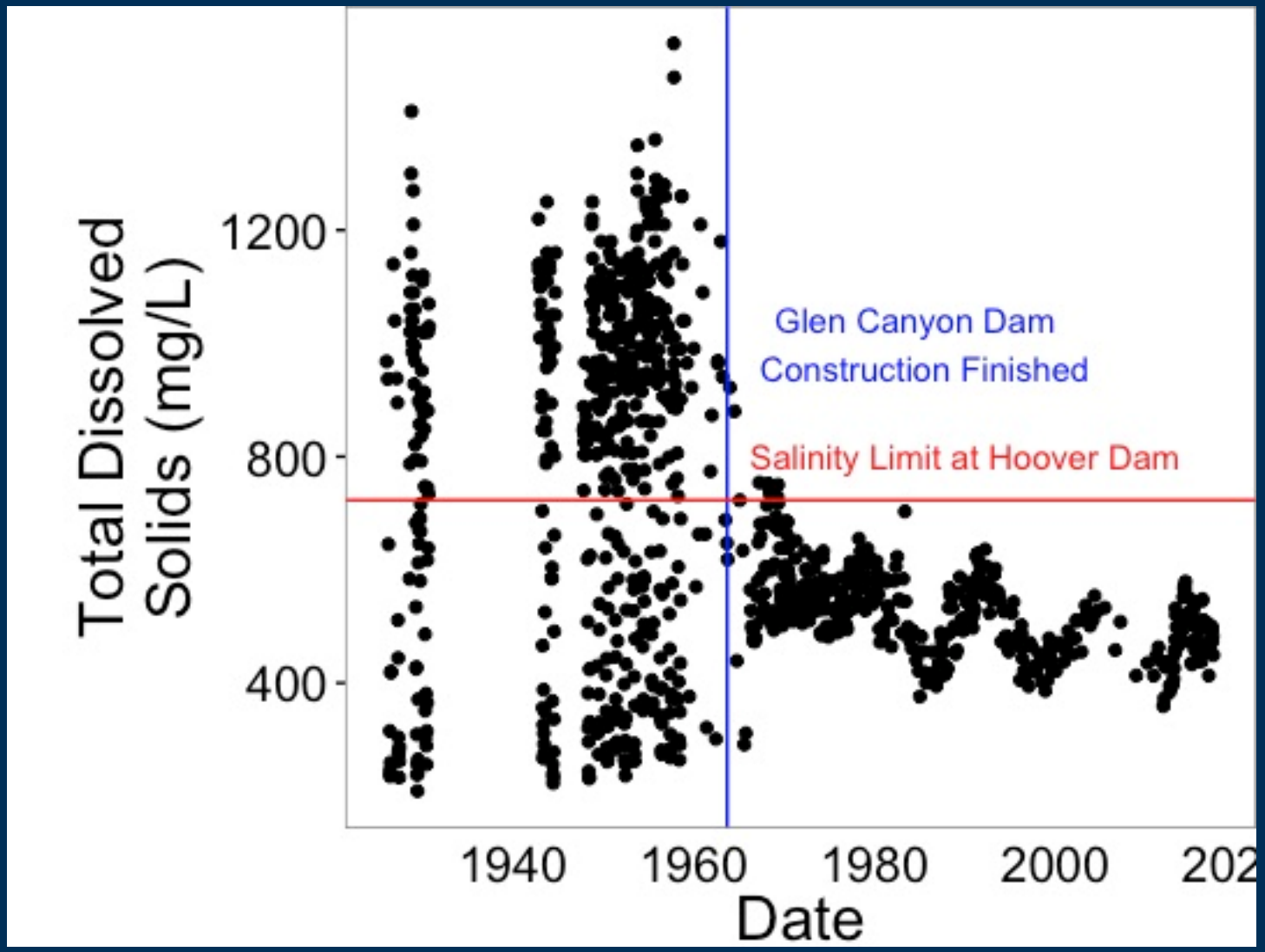
Silica is key for the formation of diatom frustules

USGS



Diatoms are a high quality food source

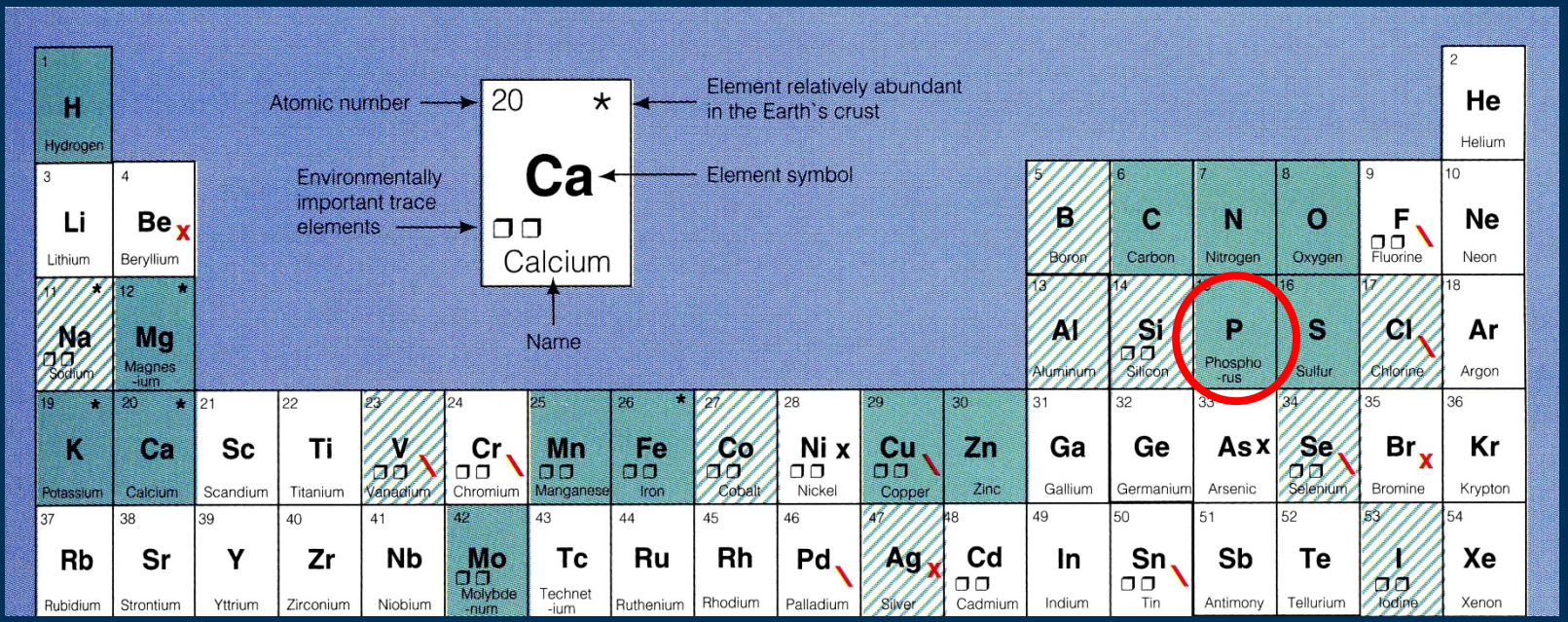
Dam also reduces downstream transport and concentration of salts

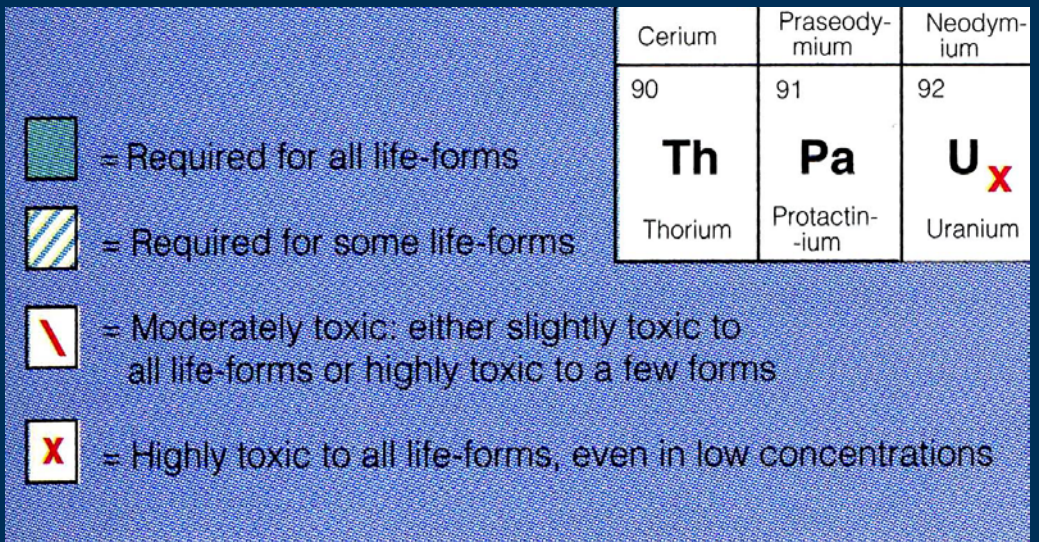


USGS

Preliminary Data, Do Not Cite

Phosphorus Dynamics in Lake Powell





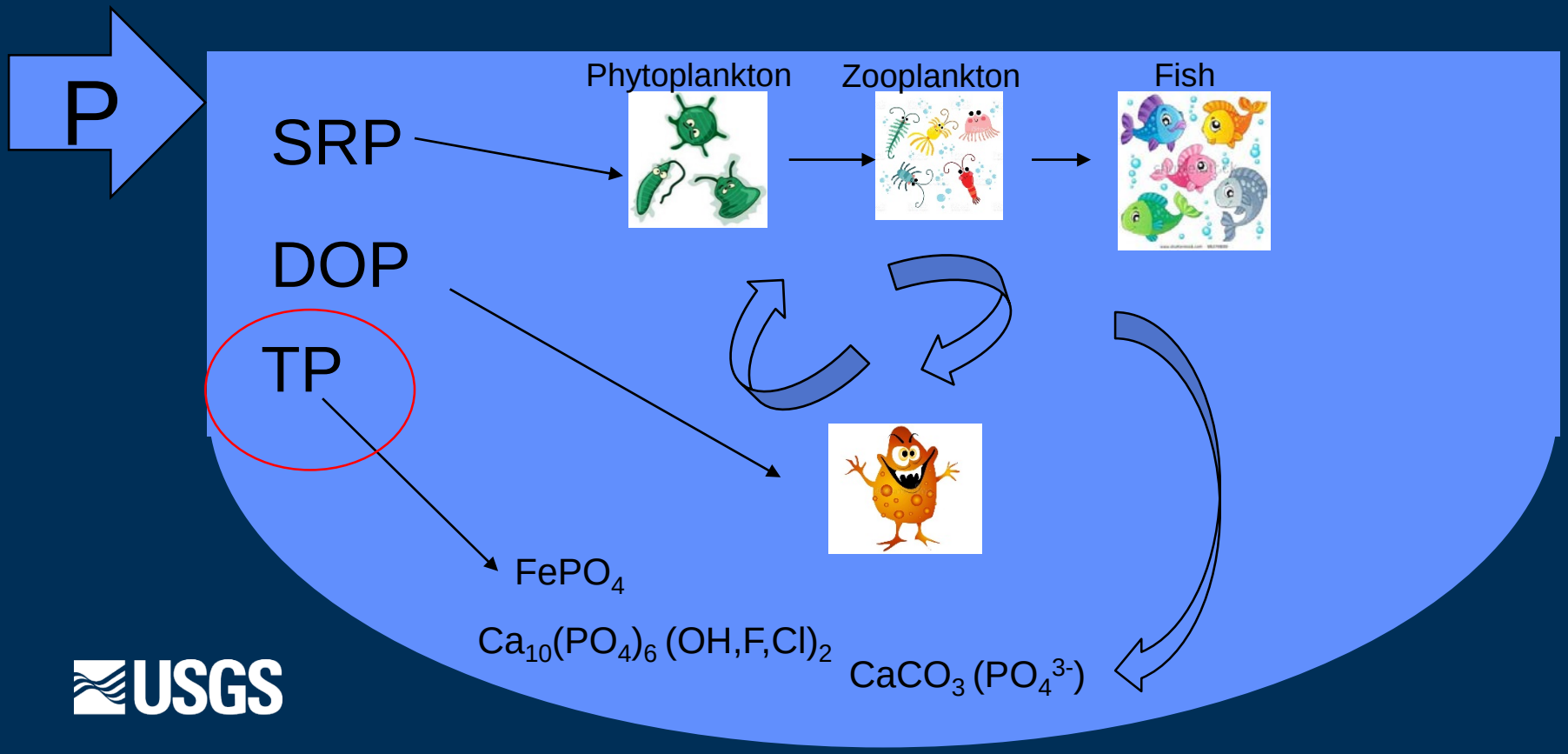
About 26 chemical elements comprise all of life.

Talk Outline

- Lake Powell as a Biogeochemical Reactor
- Phosphorus Dynamics in Lake Powell
- Nutrient Footprint Below Lake Powell

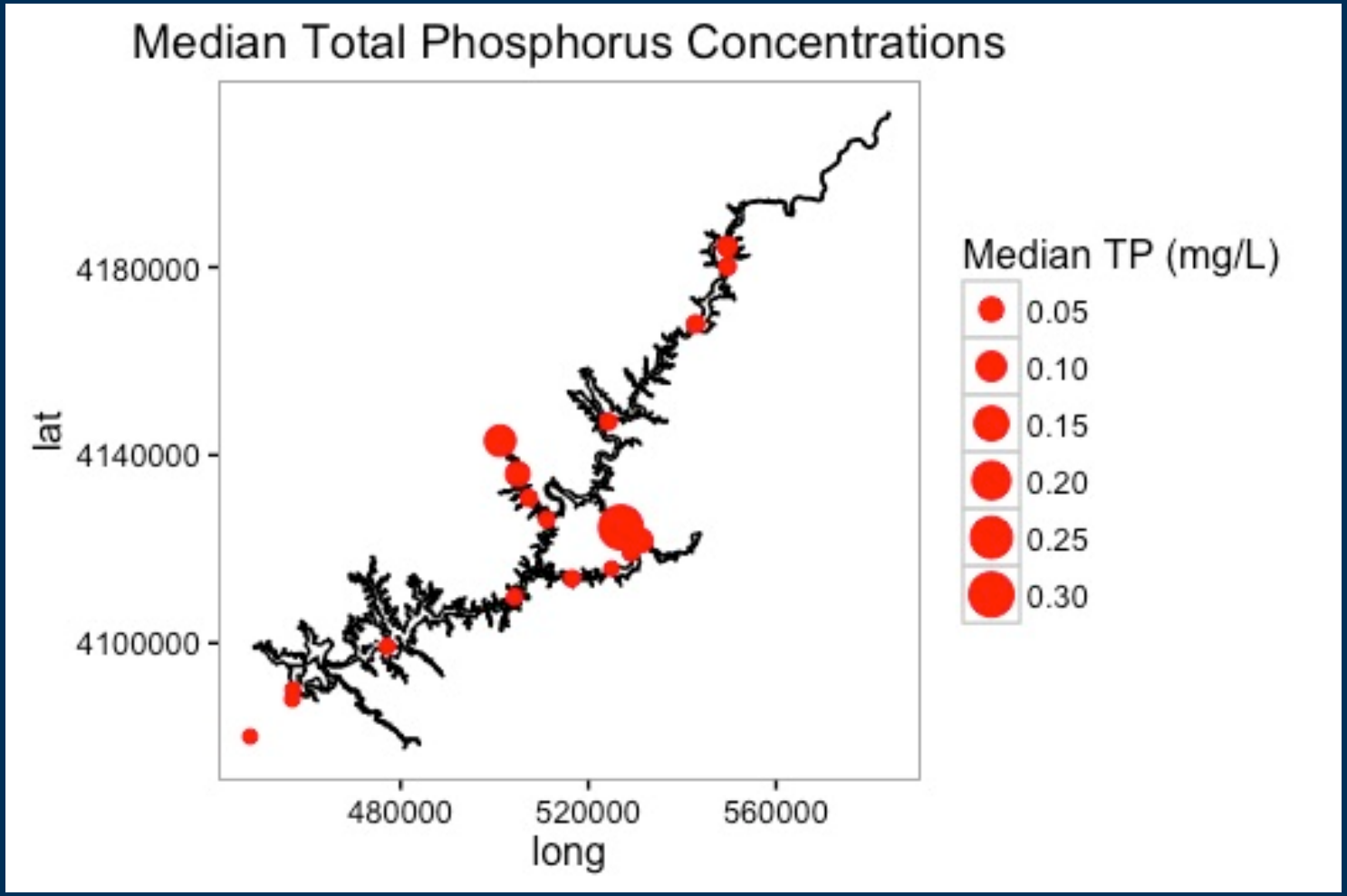
USGS

Aquatic P Cycling



USGS

P Limitation in Lake Powell



USGS

Preliminary Data, Do Not Cite

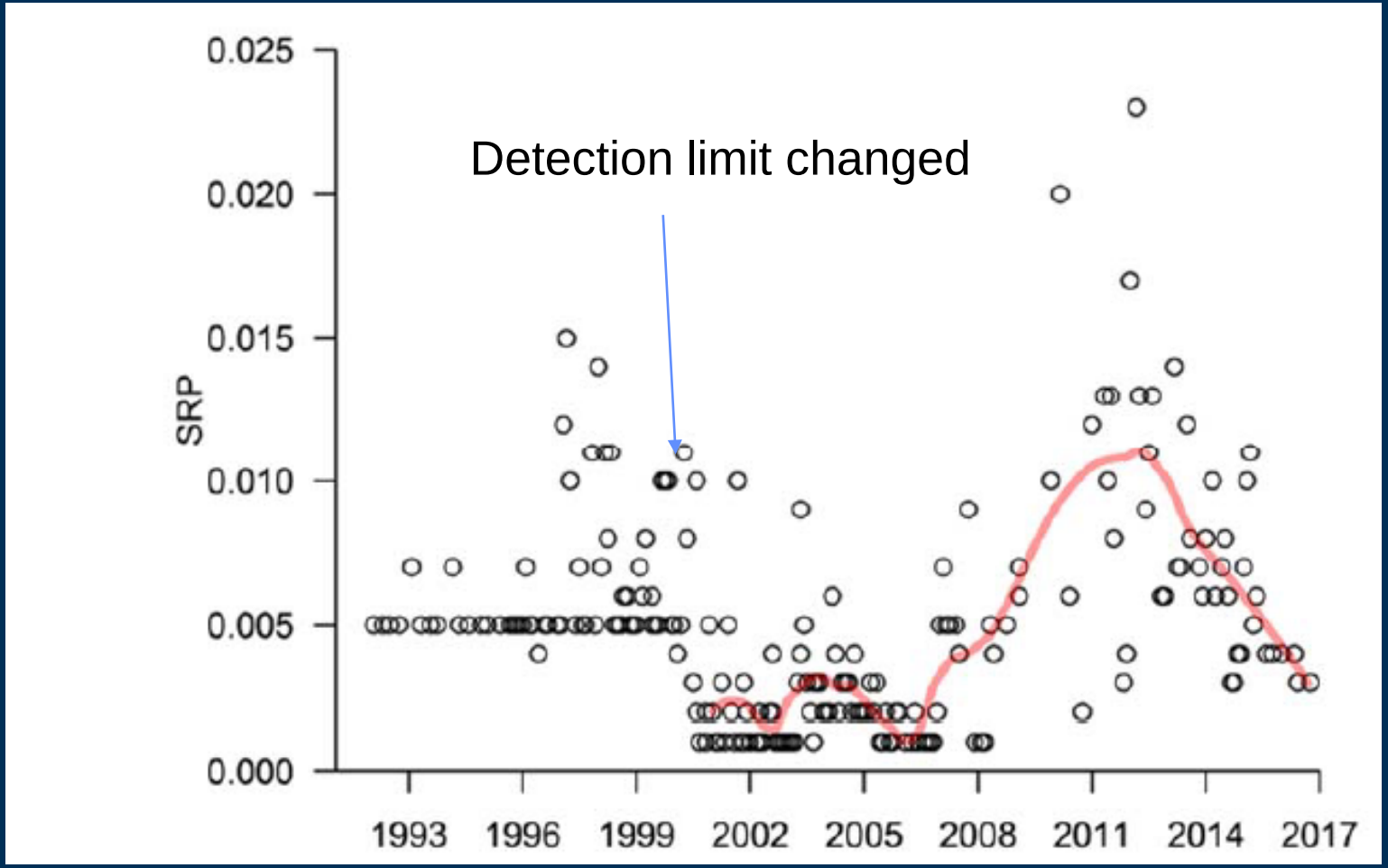
P Limitation in Lake Powell

- High P retention
- SRP is Low (5 ug/L)
- Algal growth P limited



USGS

P Dynamics in Lake Powell



Preliminary Data, Do Not Cite

~Order of magnitude variation in SRP concentrations at the dam

P

SRP

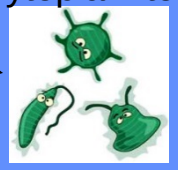
DOP

TP

Phytoplankton

Zooplankton

Fish









$FePO_4$

$Ca_{10}(PO_4)_6(OH,F,Cl)_2$

$CaCO_3$ (PO_4^{3-})





USGS

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

P

SRP

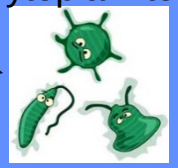
DOP

TP

Phytoplankton

Zooplankton

Fish









$FePO_4$

$Ca_{10}(PO_4)_6(OH,F,Cl)_2$

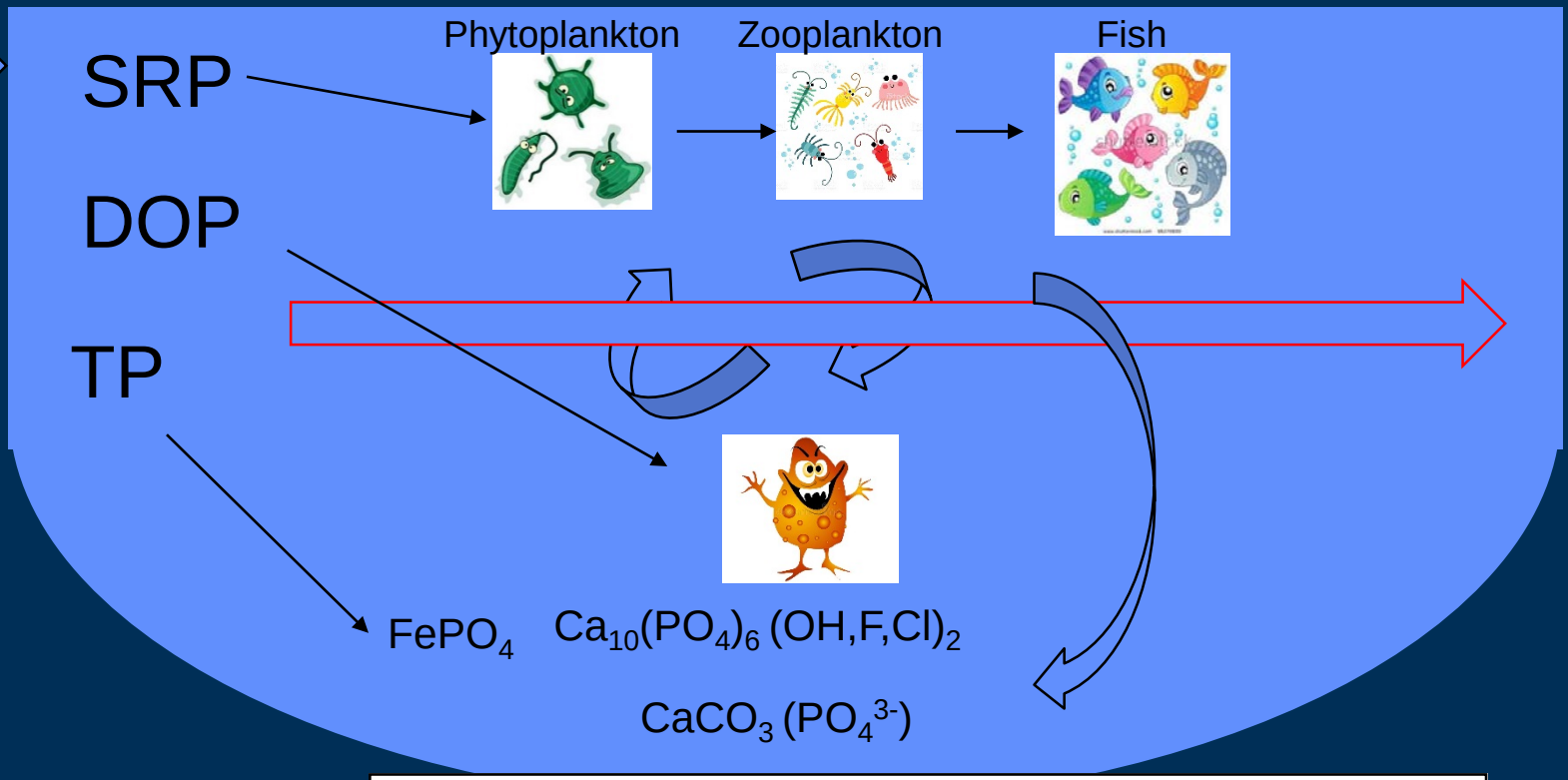
$CaCO_3$ (PO_4^{3-})

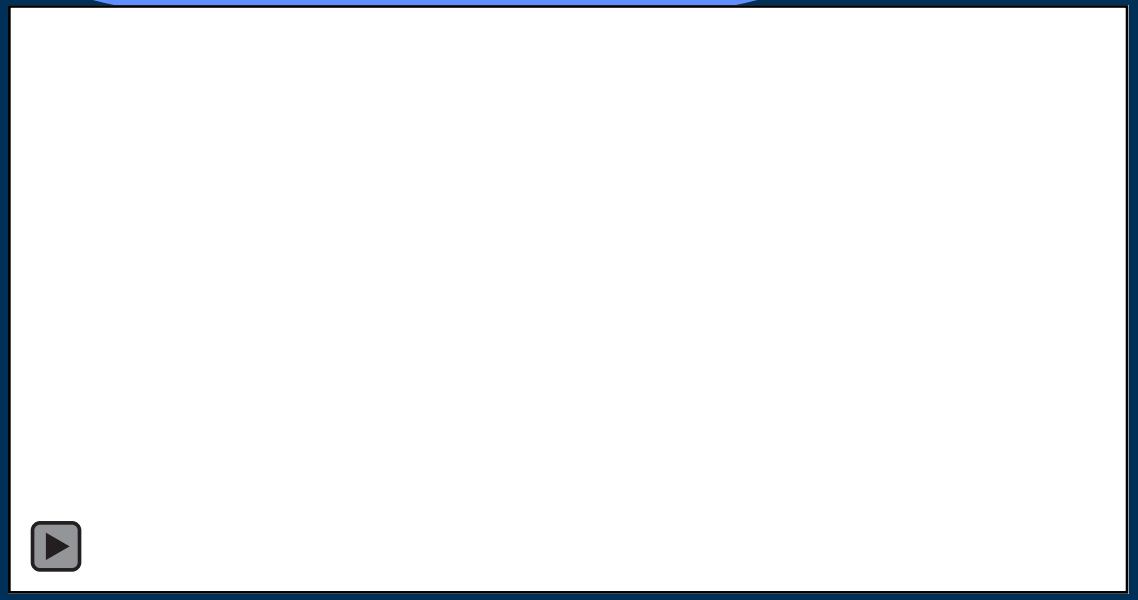




Lake Powell waters appear “milky” during times of calcite precipitation- Photos from Robert Radtke

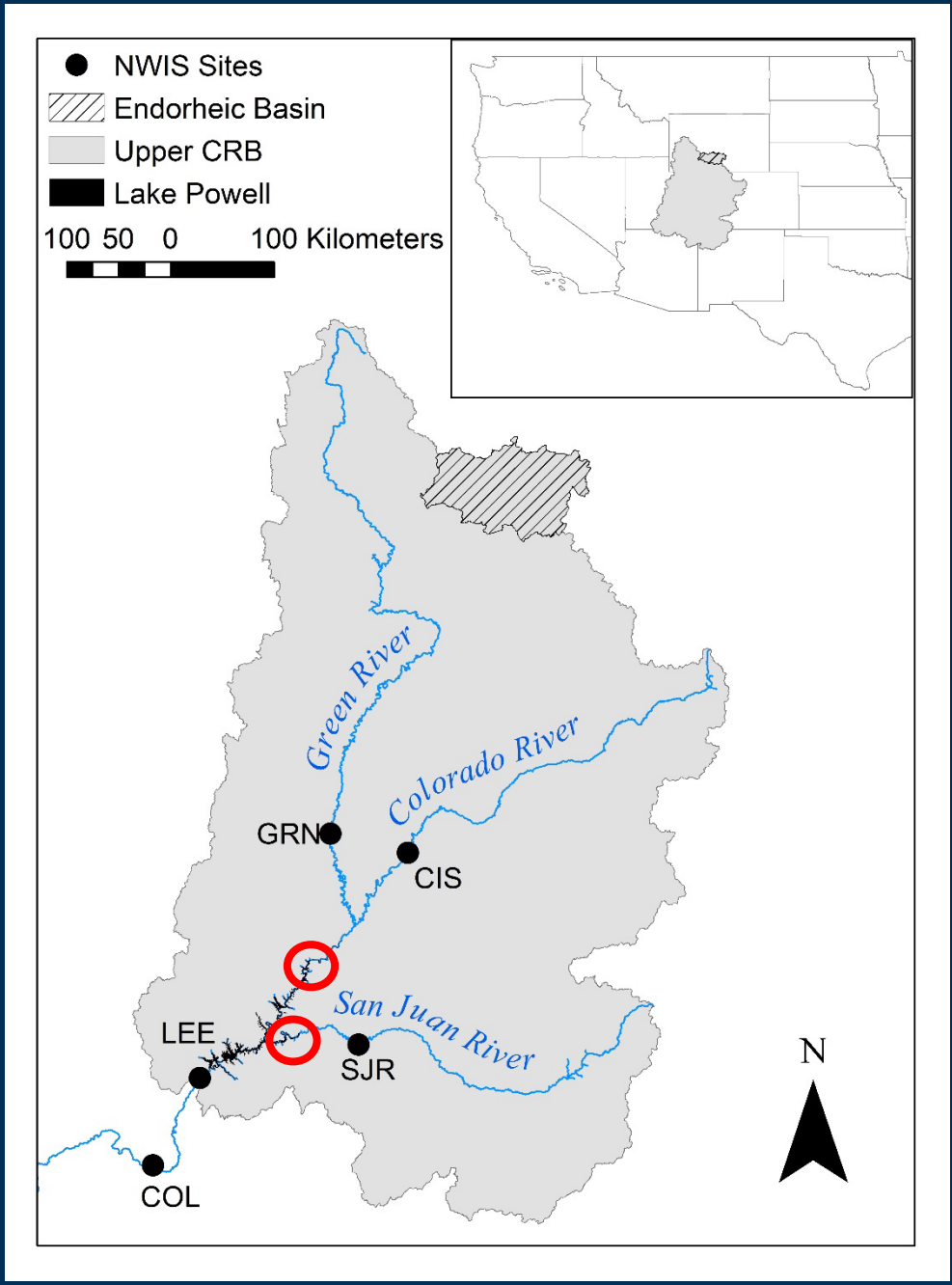
P


Phytoplankton
Zooplankton
Fish
SRP
DOP
TP
$FePO_4$
$Ca_{10}(PO_4)_6(OH,F,Cl)_2$
$CaCO_3$ (PO_4^{3-})



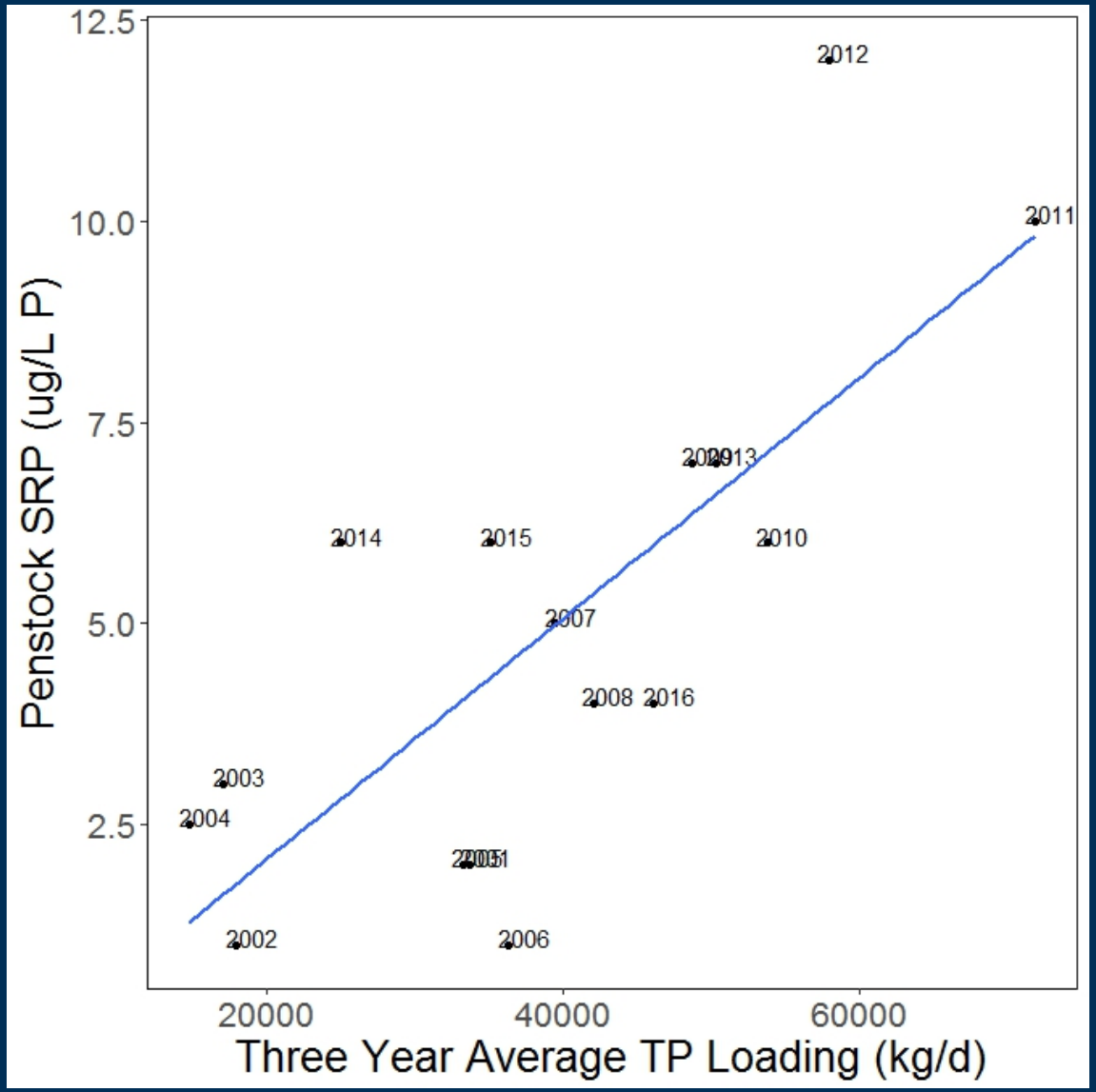
USGS

In lieu of phosphorus data from gauged stations, we used variable inflow stations to model loading



TP Loading is a Strong Predictor of P availability at Dam

Total phosphorus loading explains ~55% of the variance in penstock SRP availability



USGS

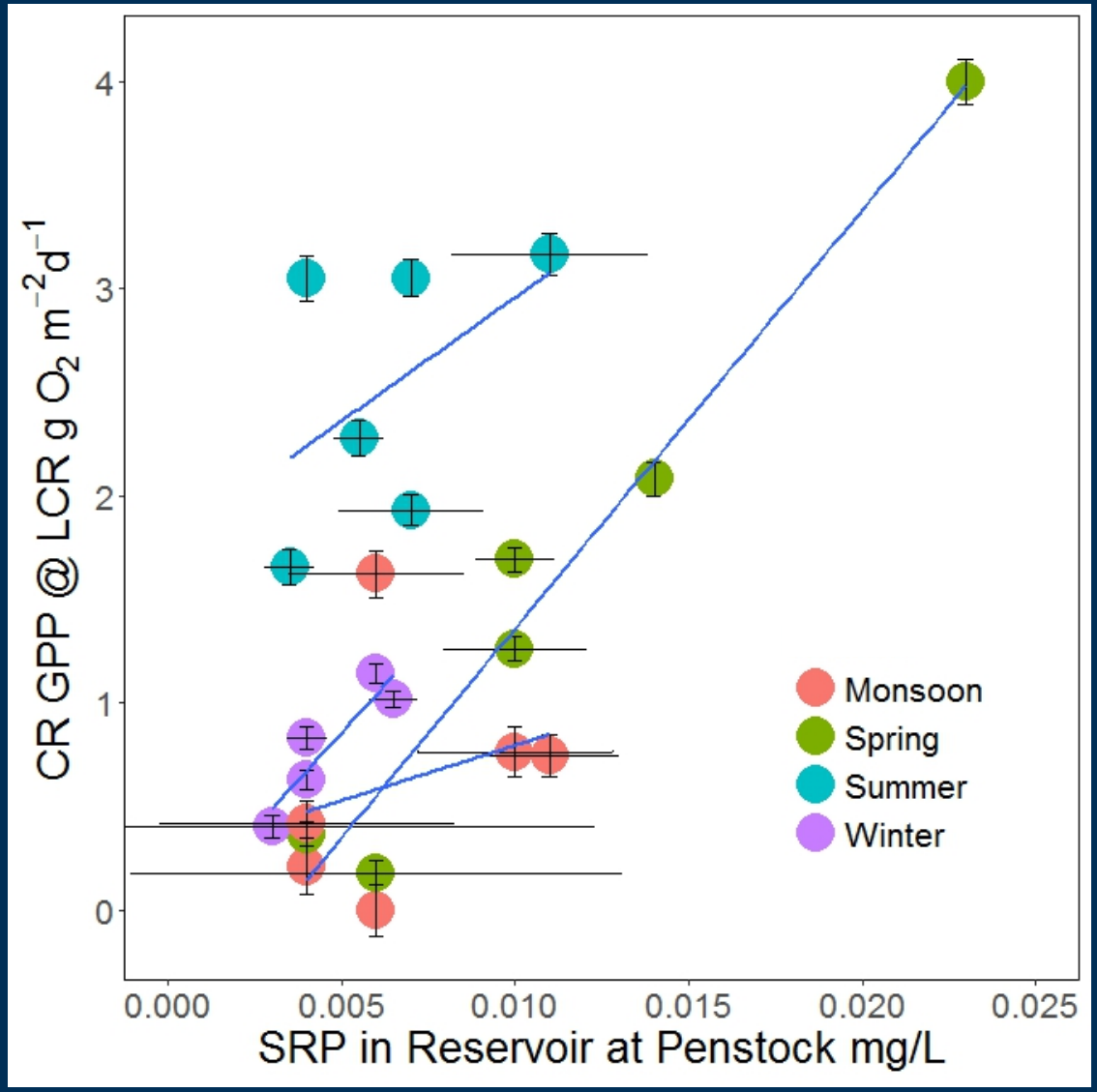
Preliminary Data, Do Not Cite

Talk Outline

- Lake Powell as a Biogeochemical Reactor
- Phosphorus Dynamics in Lake Powell
- Nutrient Footprint Below Lake Powell

USGS

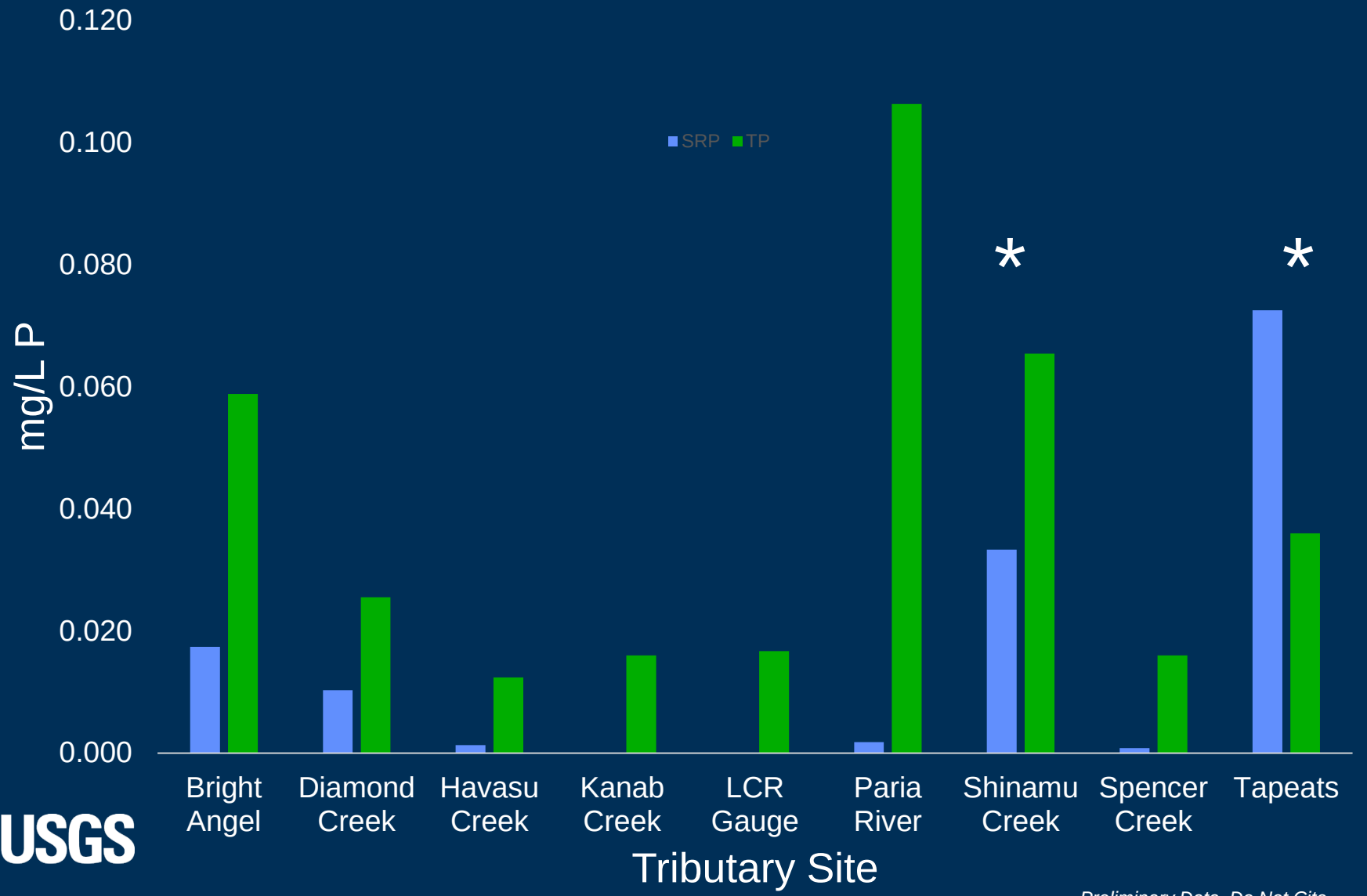
SRP from Lake Powell Correlates with GPP 120 km Downstream During Most Seasons



USGS

Preliminary Data, Do Not Cite

Role of Tributaries



USGS

Preliminary Data, Do Not Cite

Downstream Phosphorus Dynamics

-Role of storm inputs from Paria River
-Spatio-temporal differences in GPP



USGS

Conclusions

- Lake Powell functions as a sink for silicate, salt, and phosphorus.
- There is variability in the strength of this sink.
- For phosphorus, catchment loading is an important determinant of P availability in reservoir outflows.
- Future work will aim to characterize other controls on the reservoir sink & to characterize the spatial and temporal nutrient “footprint” of Lake Powell .

USGS

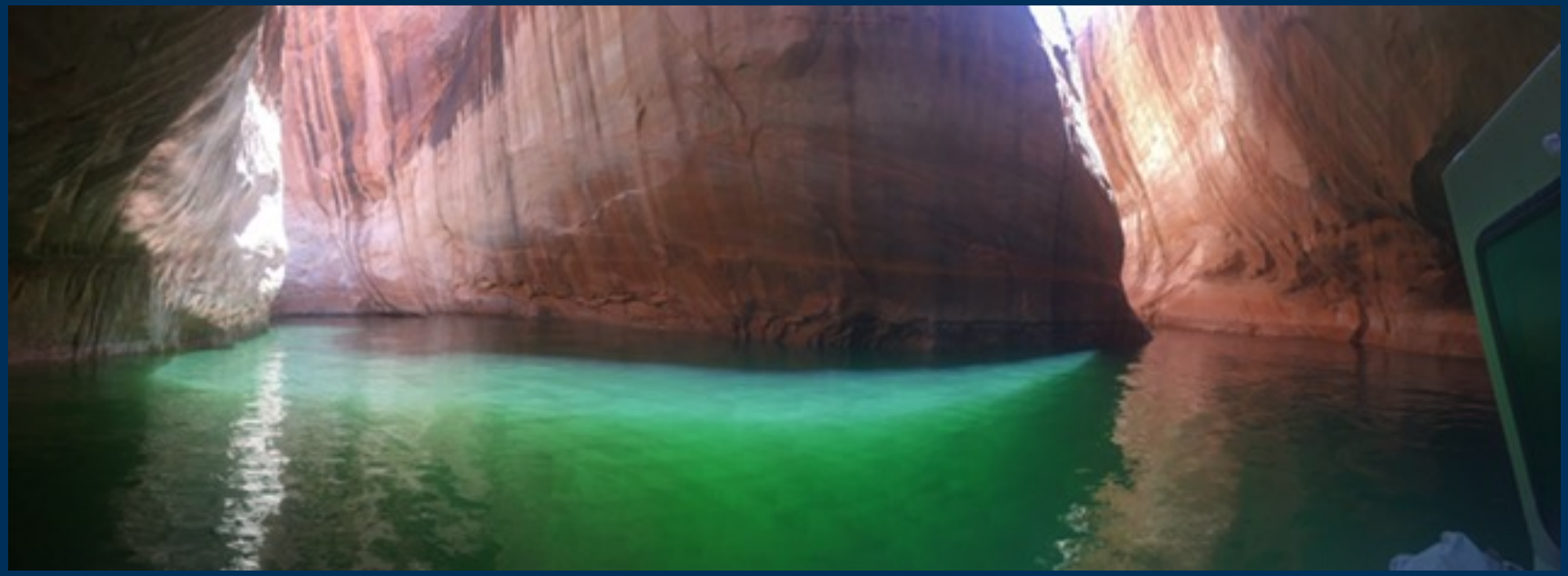
Acknowledgements

- Lake Powell Monitoring Group: Nick Voichick, Robert Radtke, Mark Anderson, and Keri Stout
- River Metabolism: Charles Yackulic, Ted Kennedy, Bob Hall, Glenn Bennett
- Lake Powell P Biogeochemistry: Sasha Reed, Robin Reibold
- Logistics & Lab Support: Carol Fritzinger, Dave Foster, and Seth Felder, Amy Stephenson
- Lake Powell PEP Panel: Steve Hamilton, Chris Holdren, Todd Tietjan, Ted Stets, Kristin Strock



USGS

Questions



USGS