Biogeochemical Cycling of Selenium and Mercury in Bighorn Lake, Bighorn Canyon National Recreation Area, MT and WY

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Funding provided by: *US Geological Survey and National Park Service*

PROBLEM

- Elevated Hg levels in fish tissue relative to other National Parks
- Potential for geogenic sources of Hg (Yellowstone National Park)
- Sediment mitigation actions possible in future
- Selenium inputs to reservoir via WY landscapes
- Evolving information on Hg cycling in western reservoirs
- New EPA chronic selenium criteria approved in late 2016

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OUTLINE

- Limnological and riverine controls on [Hg] and [Se]
- Hg and $Hg_{isotopes}$ in fish tissue
- Microbial community dynamics and Hg methylation
- Se and C / N isotopes in fish tissue
- Se sources to Bighorn Lake
- Comparison to other reservoirs
- Next steps

USGS

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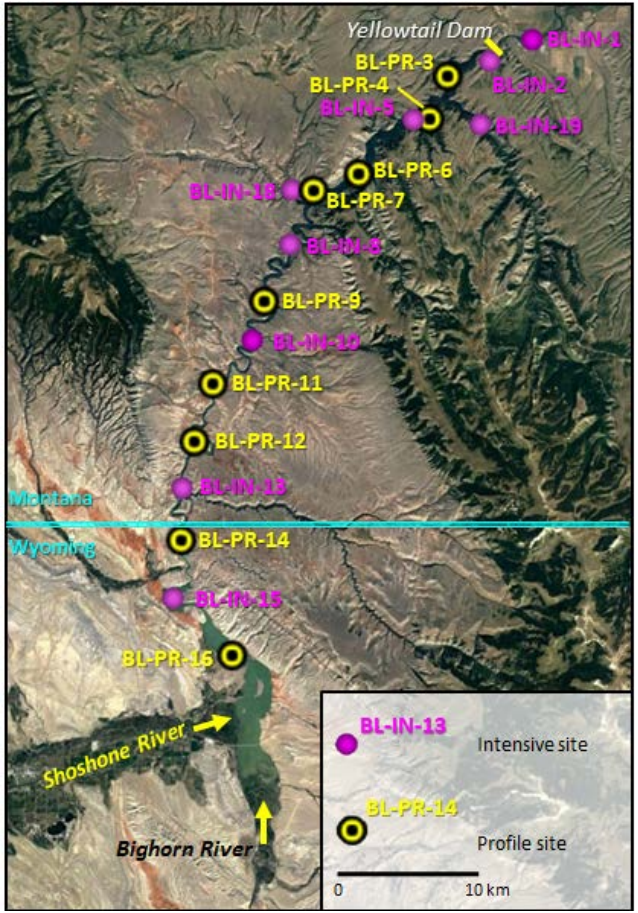
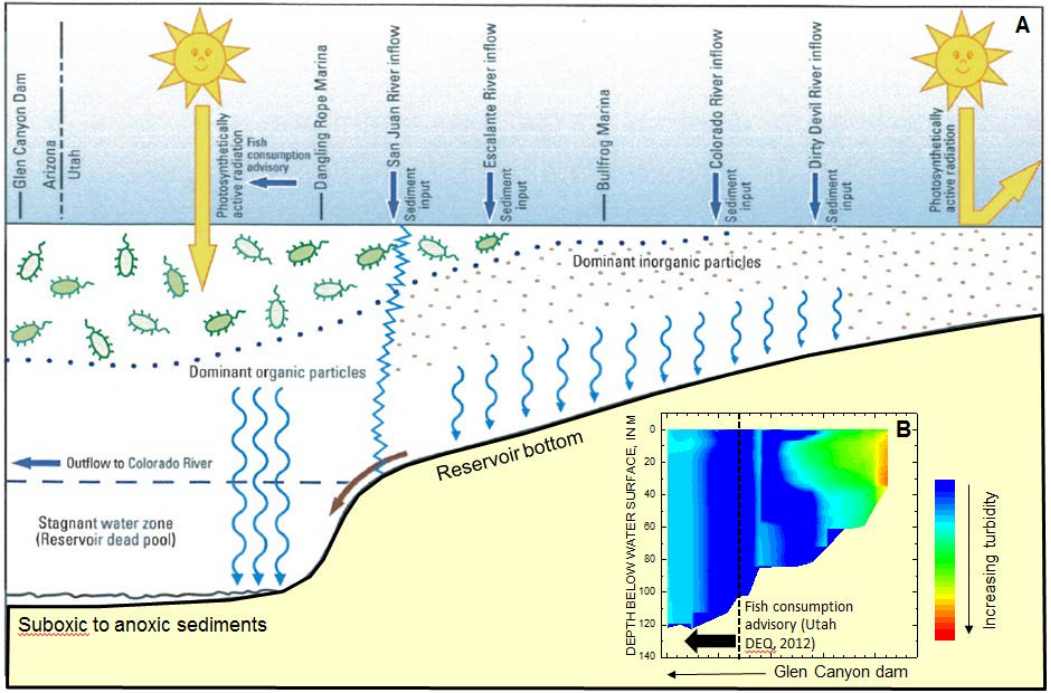
MONTANA FISH, WILDLIFE & PARKS



BACKGROUND

Hg methylation



Limnology • $[Hg]_{fish}$ • $[Se]_{fish}$ • Se sources • Other reservoirs

BACKGROUND

Bighorn Lake Hg advisories

Montana Sport Fish Consumption Guidelines

USEPA – 0.3 mg/kg (ww)

FDA – 1.0 mg/kg (ww) – "do not eat"

Location	Species	Person	Size (*Length in inches*) 6-10	10-14	14-18	18-22	22-26	26-30	30+	Contaminant
Bighorn Reservoir	Brown trout	M			6	3	5	3		Hg
		WC			2	2	2	1		Hg
	Burbot	M	9	6	7	5				Hg
		WC	3	2	3	2				Hg
	Channel catfish	M	7	8	5	5	5			Hg
		WC	3	3	2	2	2			Hg
	Sauger	M			3	3	2			Hg
		WC			1	1	[fish]			Hg
	Smallmouth bass	M		6	2					Hg
		WC		2	1					Hg
	Walleye	M		5	3	2	1			Hg
		WC		2	1	1	[fish]			Hg

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BACKGROUND

New EPA 2016 Selenium Criteria

A two-headed trout deformed by selenium pollution. Photo by U.S. Fish and Wildlife Service.

EPA United States Environmental Protection Agency

Office of Water | EPA 822-F-16-005

www.epa.gov | June 2016

Comparison of 2016 Selenium Criterion to 1999 Criteria.

	Chronic				
Criterion Version	Egg-Ovary[1] [mg/kg dw]	Whole Body[1] [mg/kg dw]	Muscle[1] [mg/kg dw]	Water Lentic[1] [µg/L]	Water Lotic[1] [µg/L]
2016 Selenium Criterion	15.1	8.5	11.3	1.5 (30 day)	3.1 (30 day)
1999 Selenium Criteria	N/A	N/A	N/A	5 (4 day)	5 (4 day)

Limnology ♦ $[Hg]_{fish}$ ♦ $[Se]_{fish}$ ♦ Se sources ♦ Other reservoirs

BACKGROUND

WY selenium issues

WYOMING DEPARTMENT OF ENVIRONMENTAL QUALITY

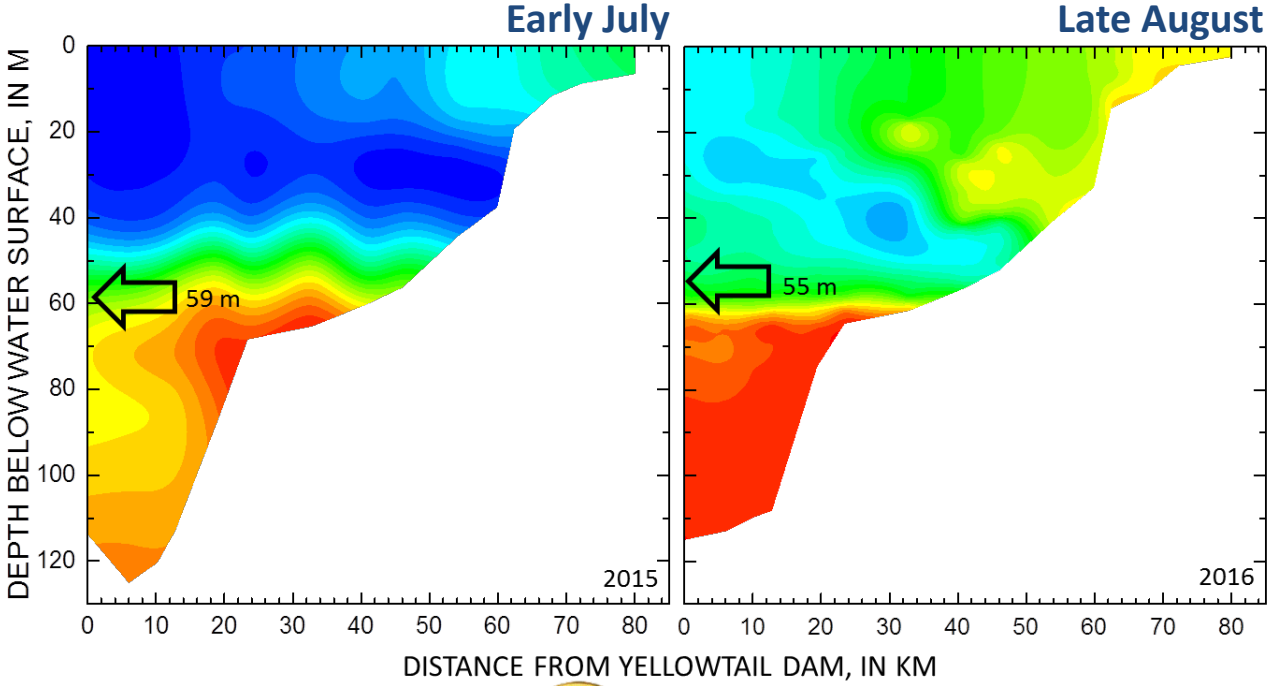
What Nonpoint source pollution problems exist in Wyo

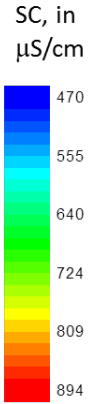
Nonpoint sources of pollution contribute to the majority of Wyoming's surface water quality impairments.

The three nonpoint source pollutants causing the majority of Wyoming's surface water quality impairments are bacterial pathogens, sediment, and selenium.

LIMNOLOGY

Salinity gradients

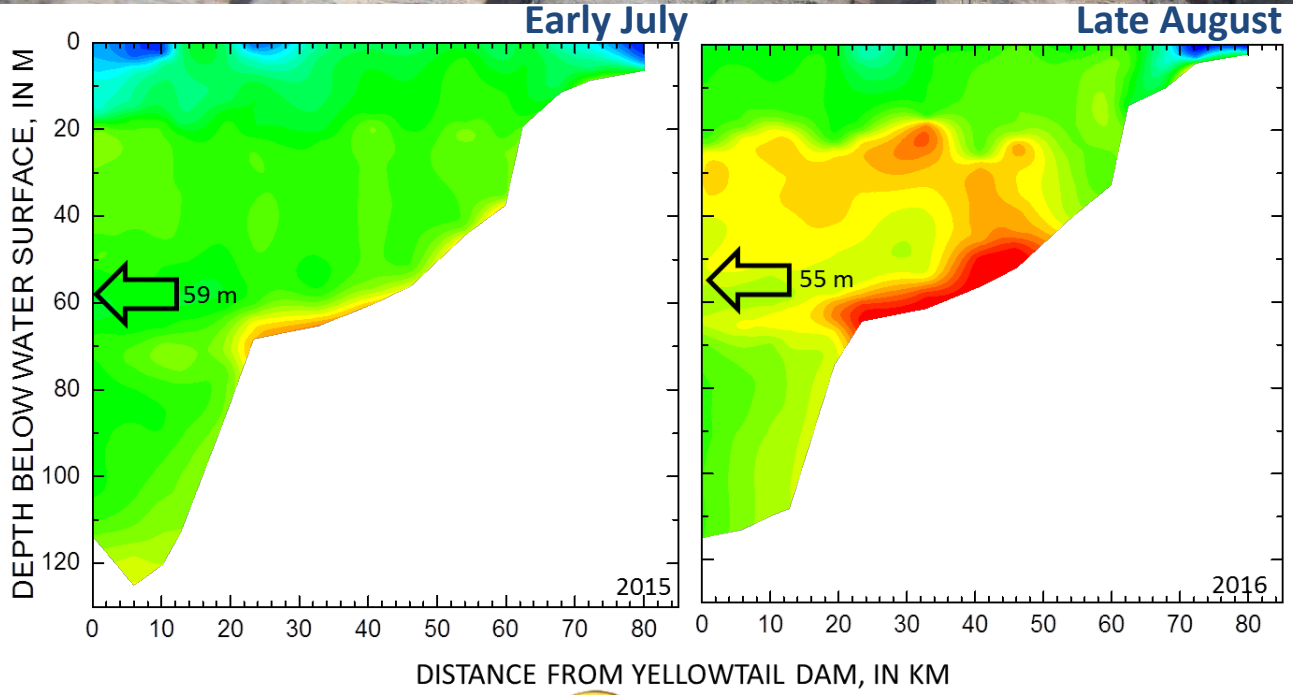




- **2015 freshet replaced by higher salinity plume**
- **2016 has higher salinity**
- **Freshwater lens below higher salinity layer**

LIMNOLOGY

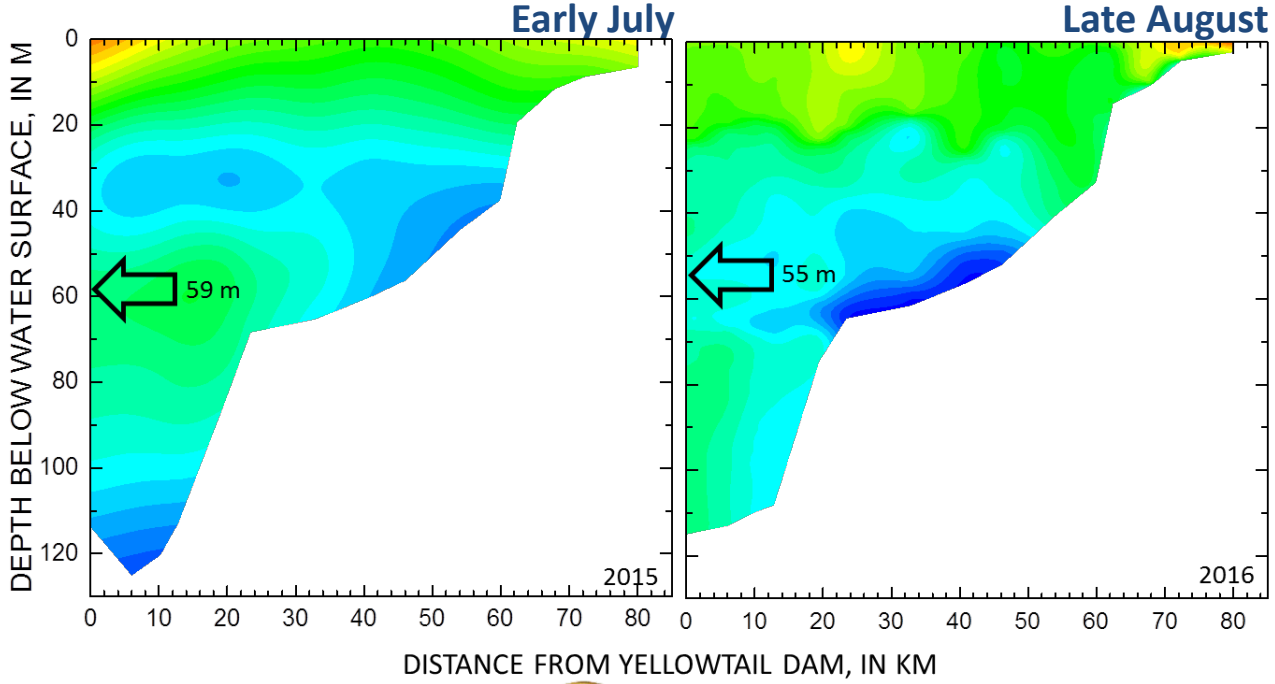
Dissolved O_2 gradients



- **2015 no inverted density gradient**
- **2016 inverted density gradient associated with low DO areas**
- **Settling POM accumulating on top of lower density freshwater lense**

LIMNOLOGY

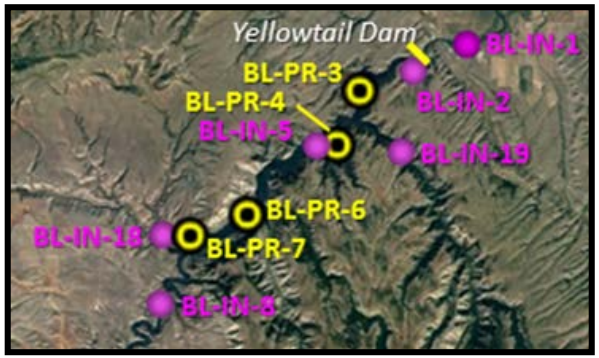
pH gradients

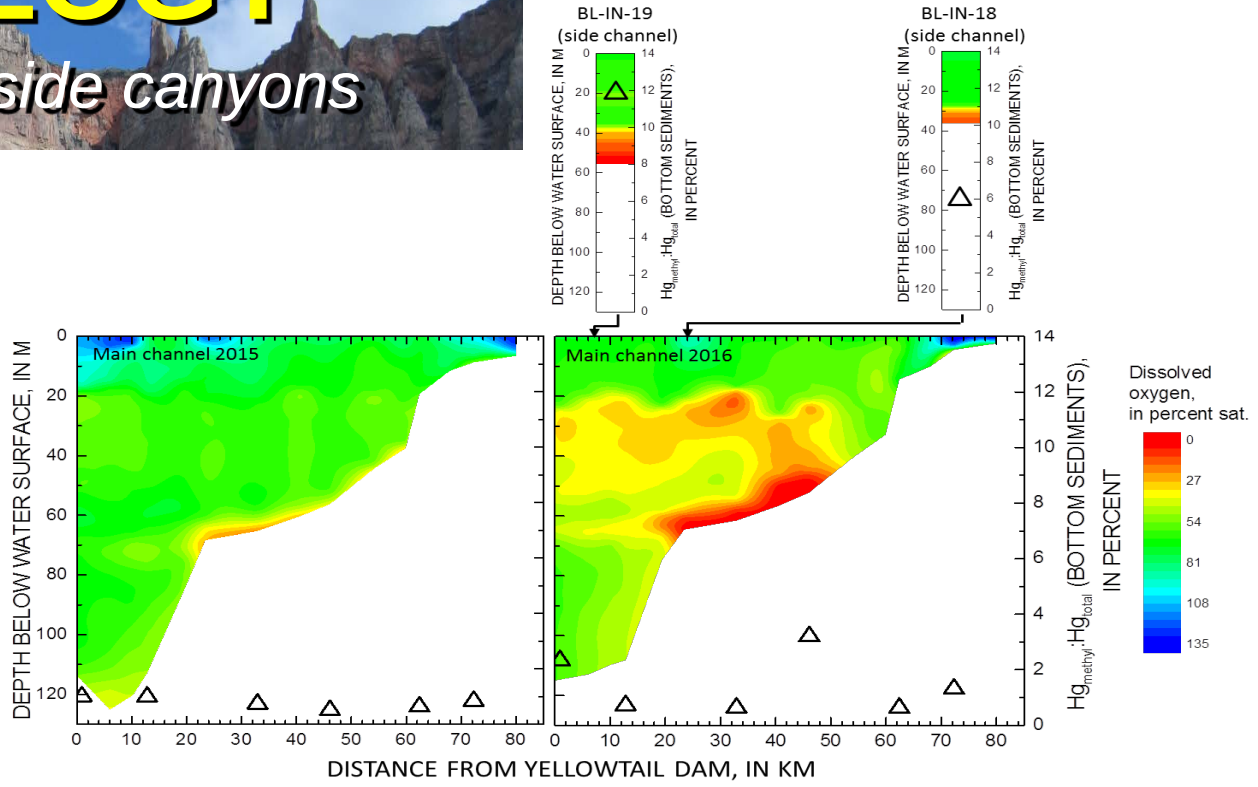


- **Low pH values in 2015 likely degradation of POM on higher salinity layer (40 m)**
- **Low pH values during 2016 support areas of POM degradation**

LIMNOLOGY

DO gradients in side canyons



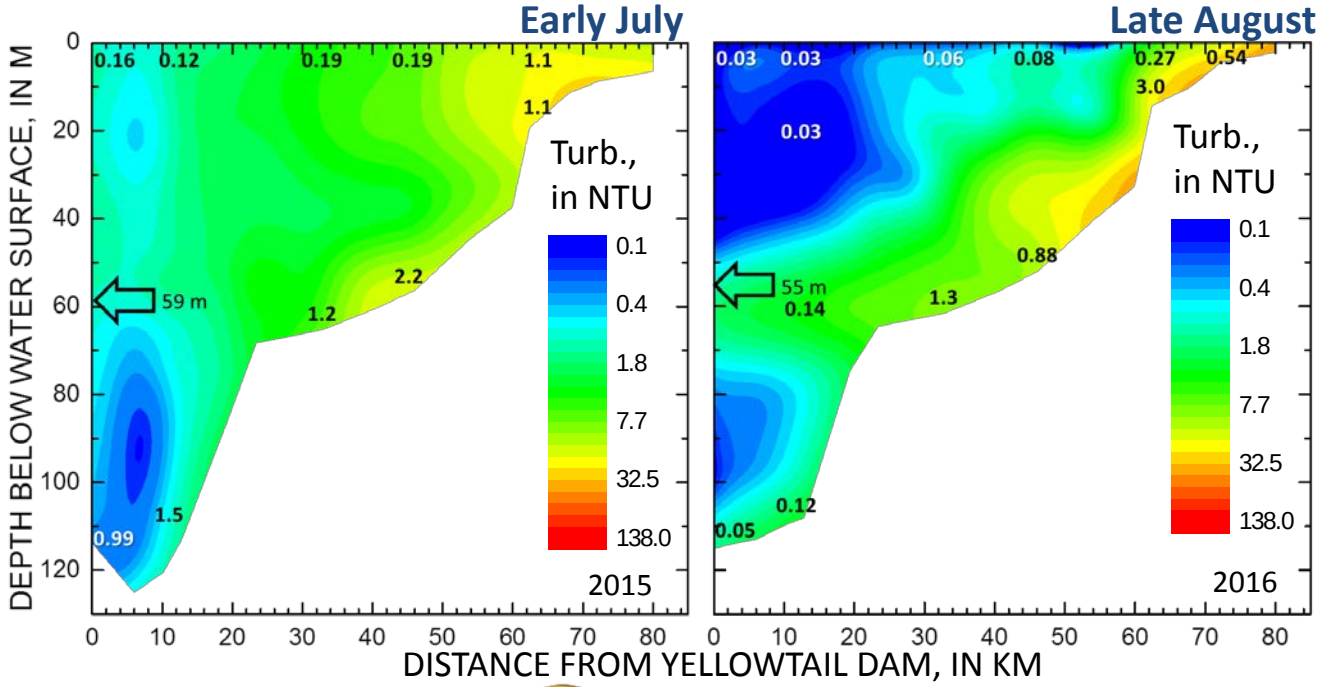


- **Restricted circulation in side canyons**
- **Elevated levels of MeHg in side canyon sediment**

Limnology ♦ $[Hg]_{fish}$ ♦ $[Se]_{fish}$ ♦ Se sources ♦ Other reservoirs

LIMNOLOGY

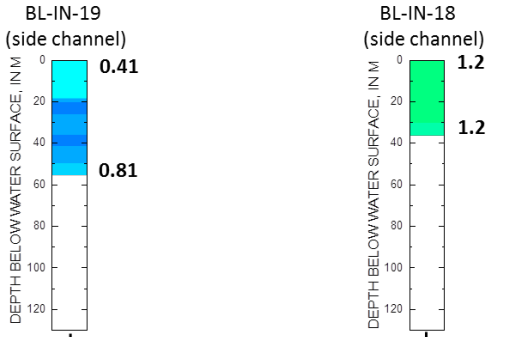
Turbidity and $THg_{suspended}$

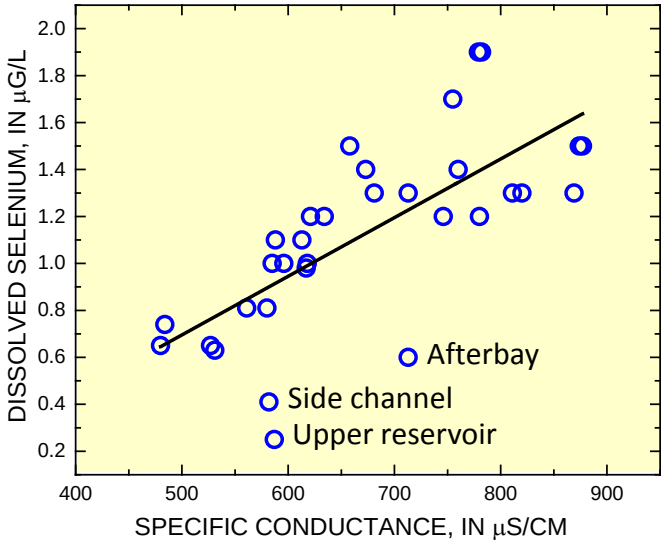


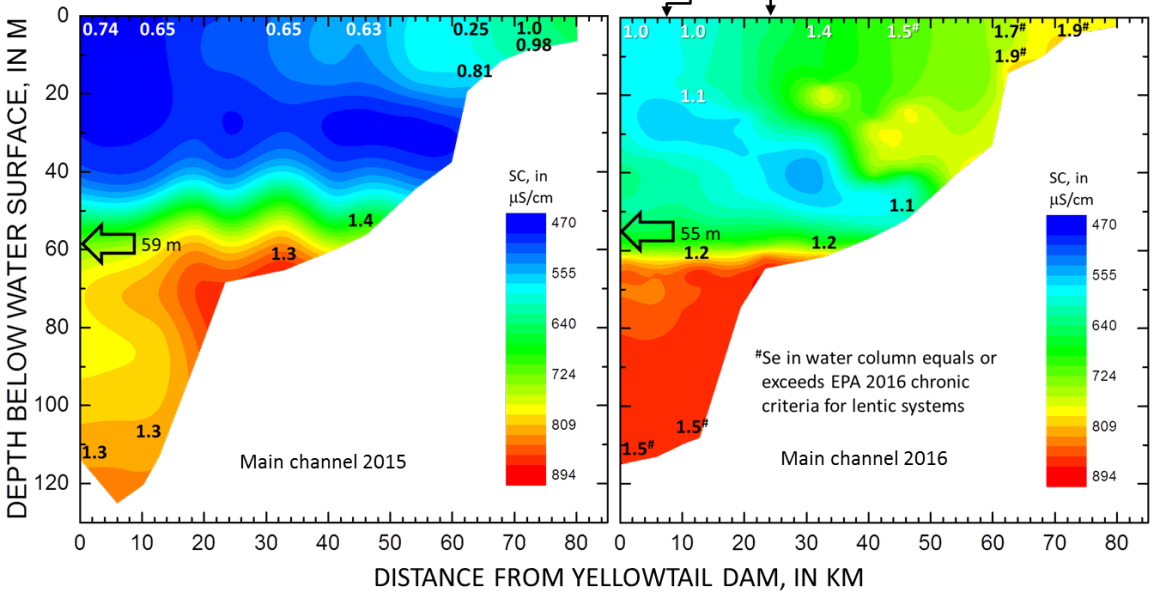
- Higher $THg_{suspended}$ during July synoptic
- Turbidity and $THg_{suspended}$ generally agree during both synoptics
- Delivery of elevated $THg_{suspended}$ to forebay

LIMNOLOGY

SC and Se gradients

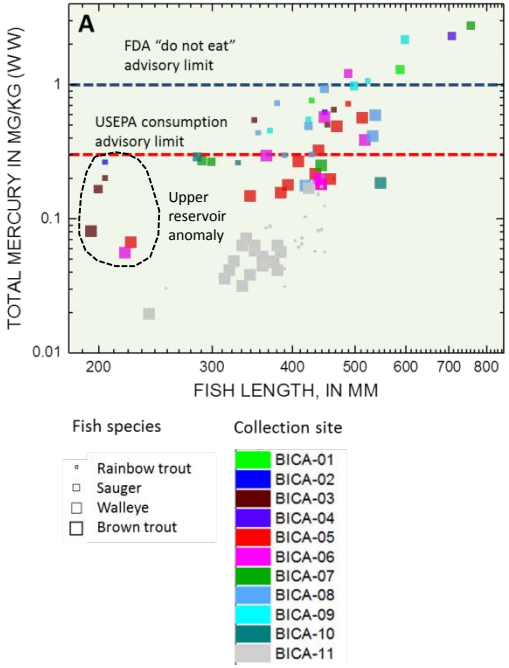


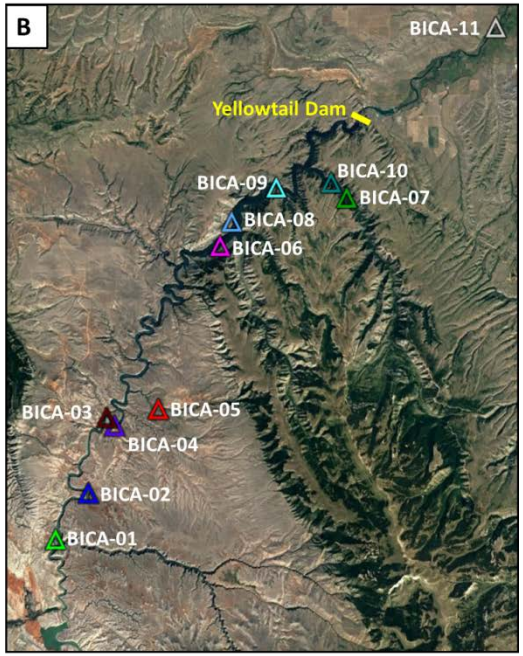




Limnology ♦ $[Hg]_{fish}$ ♦ $[Se]_{fish}$ ♦ Se sources ♦ Other reservoirs

MERCURY IN FISH TISSUE

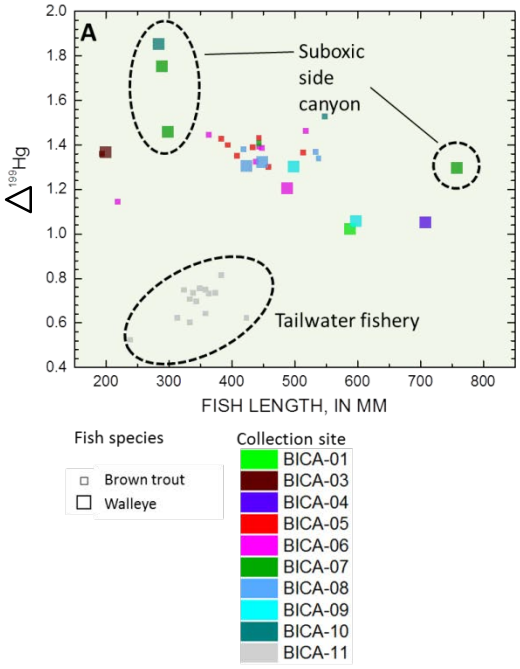


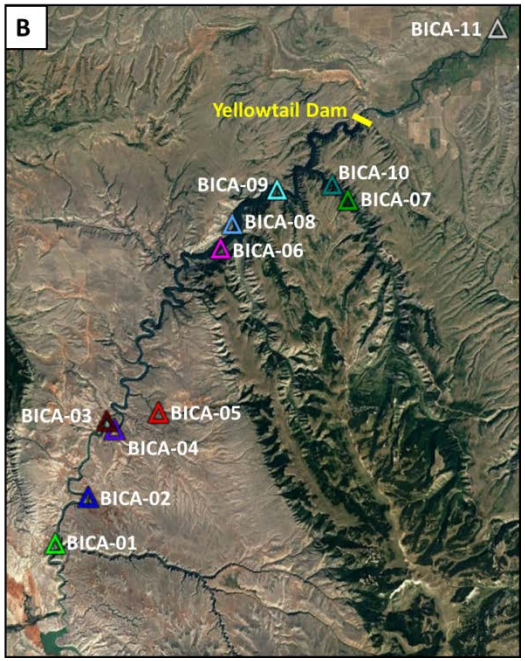


- **Increasing Hg with increasing length (common)**
- **Numerous samples exceed FDA "do not eat" advisory**
- **Anomalous fish concentrations in upper reservoir sites?**
- **Tailwater fishery shows lowest mercury concentrations**

Limnology ♦ $[Hg]_{fish}$ ♦ $[Se]_{fish}$ ♦ Se sources ♦ Other reservoirs

△^{199}Hg IN FISH TISSUE

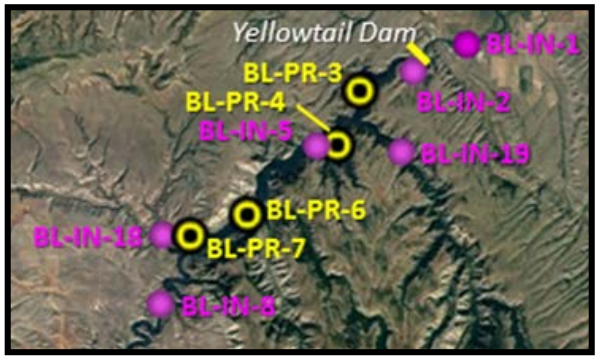




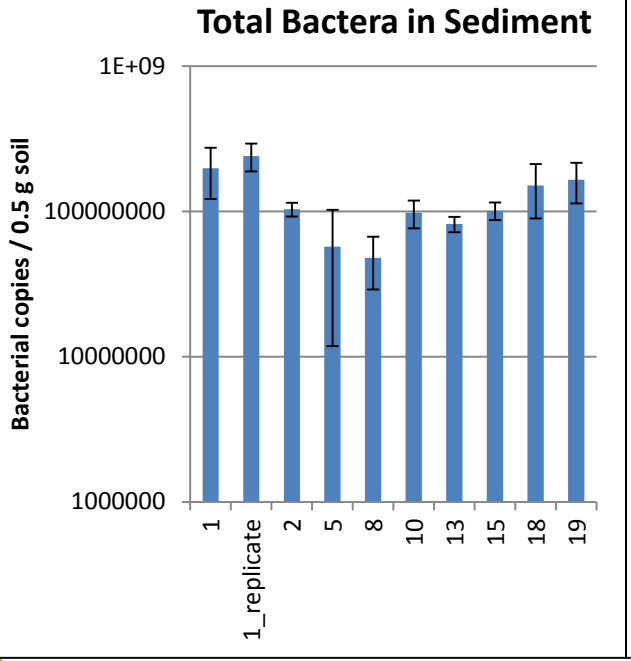
- △^{199}Hg = ^{199}Hg(permil) / ^{198}Hg(permil)
- Low △^{199}Hg in tailwater fishery reflects less photochemical processing of the Hg
- Water released from Yellowtail dam (> 50 m in depth) less opportunity for photochemical processing

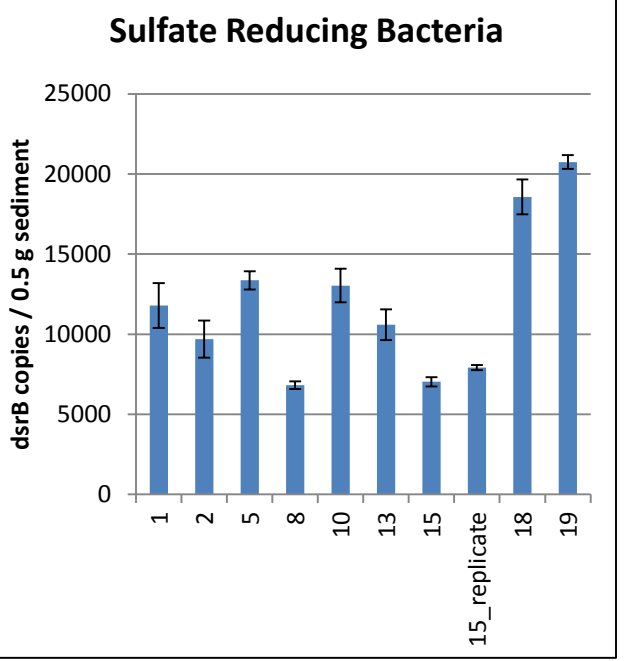
SRBs in Sediment Samples

DO gradients in side canyons



- **Known Hg Methylators**
- **Elevated levels of MeHg in side canyon sediment**





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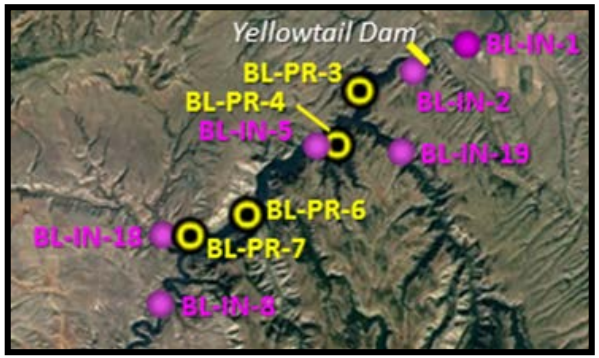
Limnology ♦ $[Hg]_{fish}$ ♦ $[Se]_{fish}$ ♦ Se sources ♦ Other reservoirs

SRBs in Water Samples

DO gradients in side canyons



- **Known Hg Methylators**
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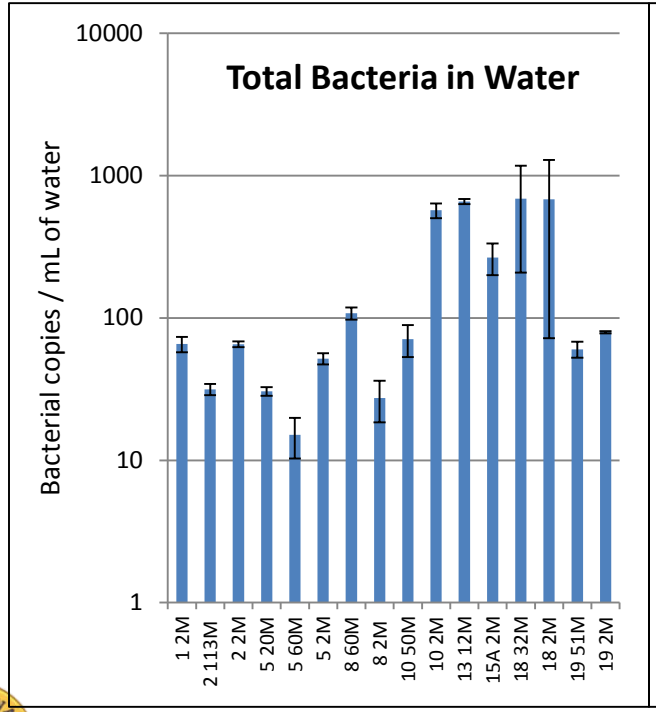

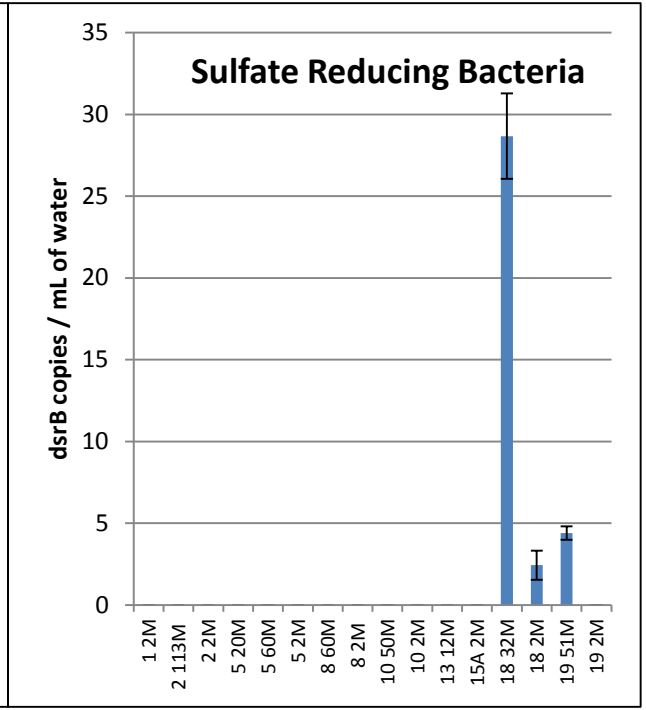

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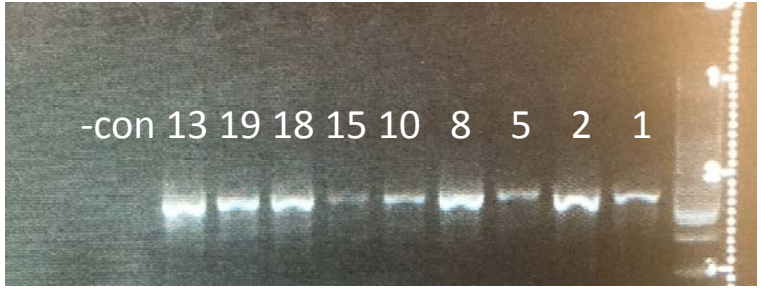
Limnology ♦ $[Hg]_{fish}$ ♦ $[Se]_{fish}$ ♦ Se sources ♦ Other reservoirs

Newly Identified Mercury Methylation Genes

Sediment

- All sediment sites amplified



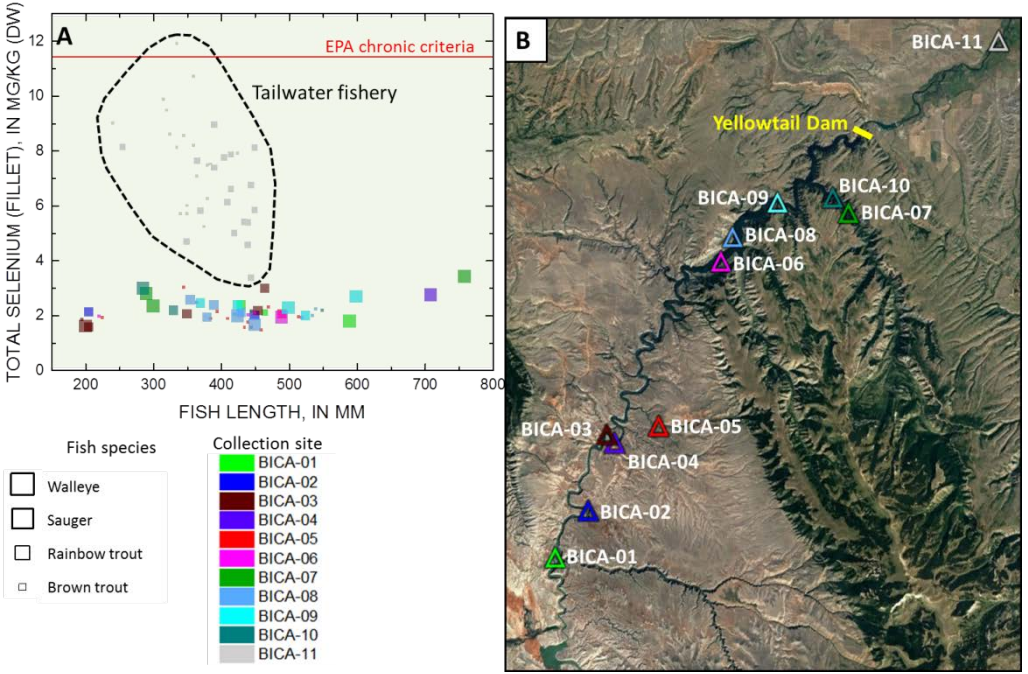
- Only 18B from the water samples amplified

Water Samples

Limnology ♦ $[Hg]_{fish}$ ♦ $[Se]_{fish}$ ♦ Se sources ♦ Other reservoirs

FISH TISSUE SELENIUM

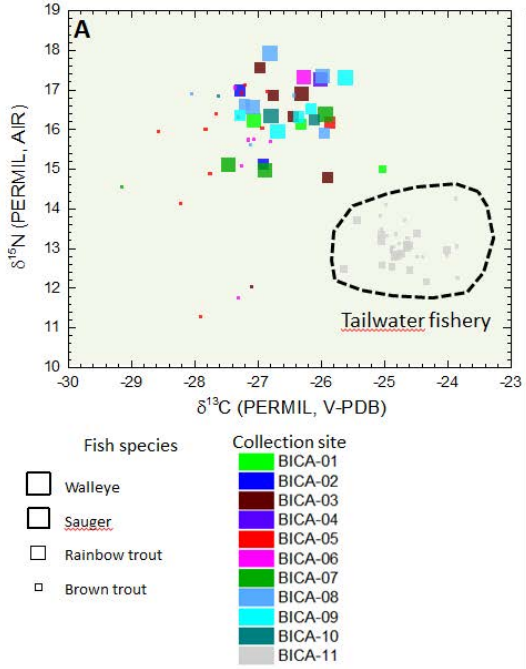
Tailwater fishery is anomalous

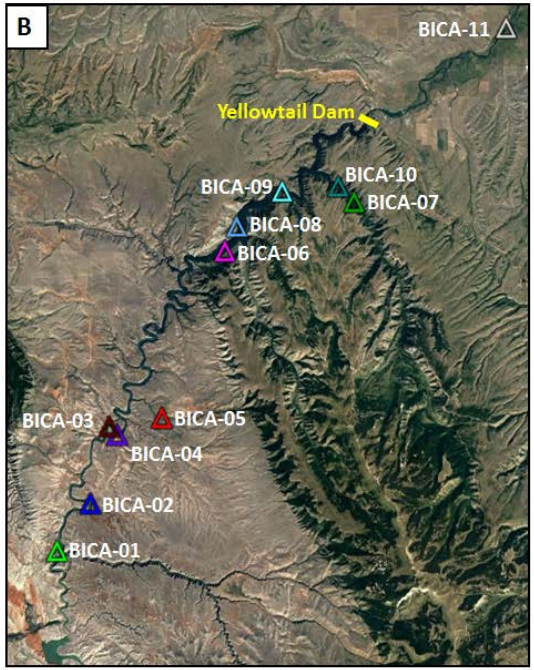


- **Higher [Se] at depth in reservoir is reflected in tailwater fishery**
- **Some tissue samples in tailwater exceed/approach 2016 EPA chronic criteria of 11.3 mg/kg (dw)**
- **High K_ds in dam release may influence Se uptake in lower trophic levels and smaller fish in tailwater?**

FISH TISSUE C and N ISOTOPES

You are what you eat





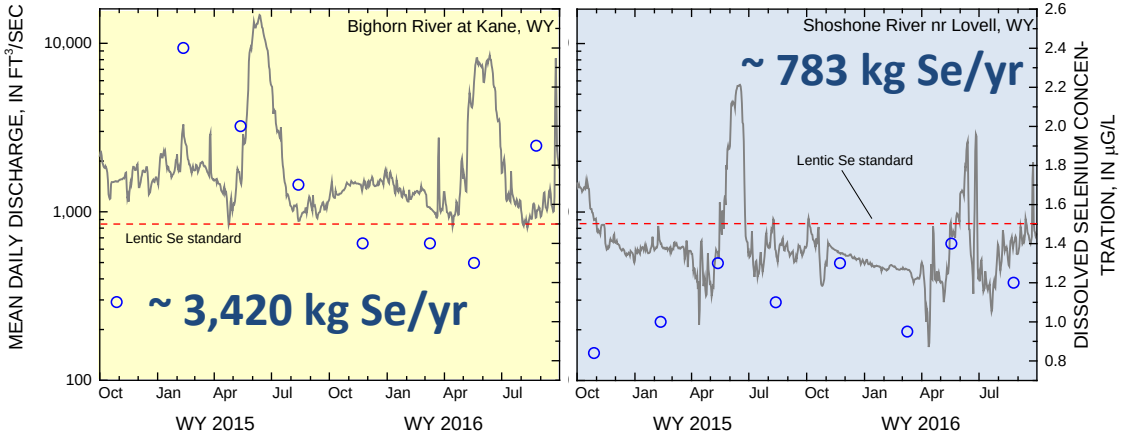
- **Tailwater brown trout are a full trophic level lower than reservoir population**
- **Is the tailwater food web influenced by organic detritus released from the reservoir chemocline?**
- **Is the high insect biomass in the tailwater influenced by selenium- and organic-rich detritus from the reservoir?**

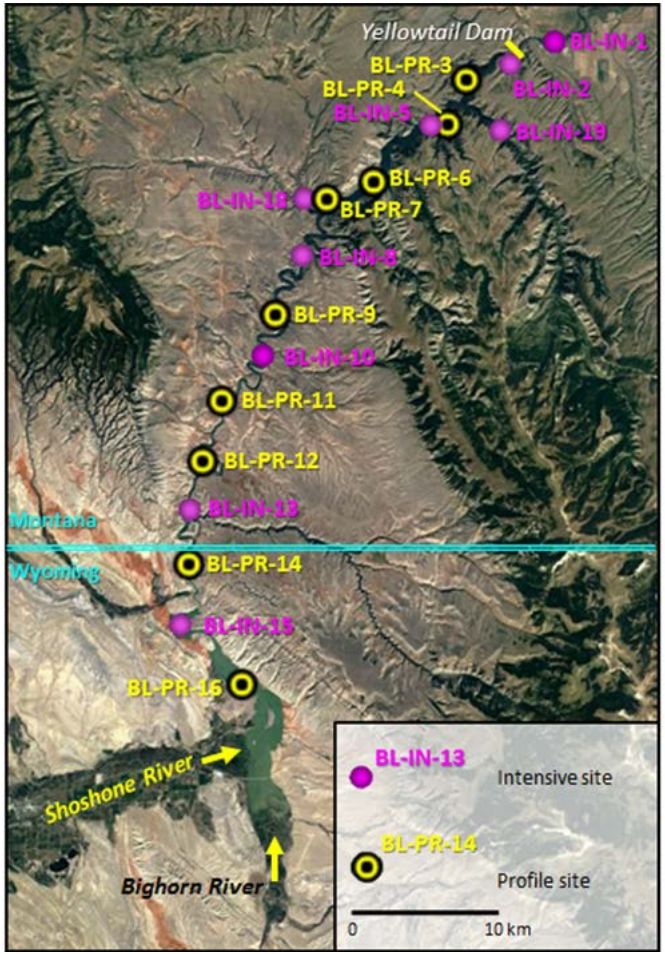
Limnology ♦ $[Hg]_{fish}$ ♦ $[Se]_{fish}$ ♦ Se sources ♦ Other reservoirs

Se INPUTS

Bighorn vs. Shoshone Rivers

Bighorn River **Shoshone River**

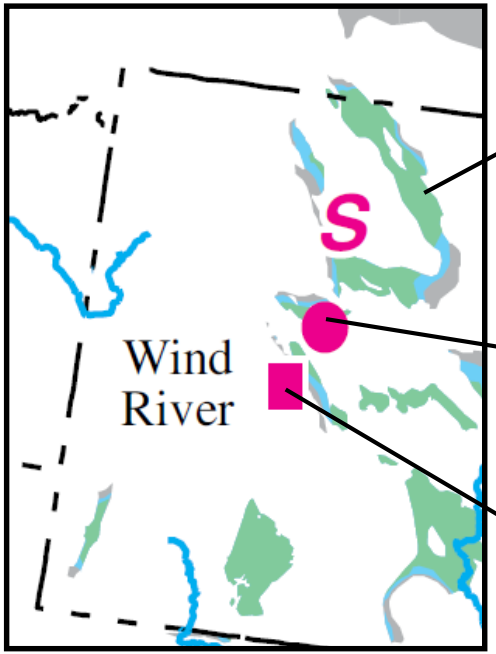




Limnology ♦ $[Hg]_{fish}$ ♦ $[Se]_{fish}$ ♦ Se sources ♦ Other reservoirs

Se INPUTS

Areas susceptible to Se contamination

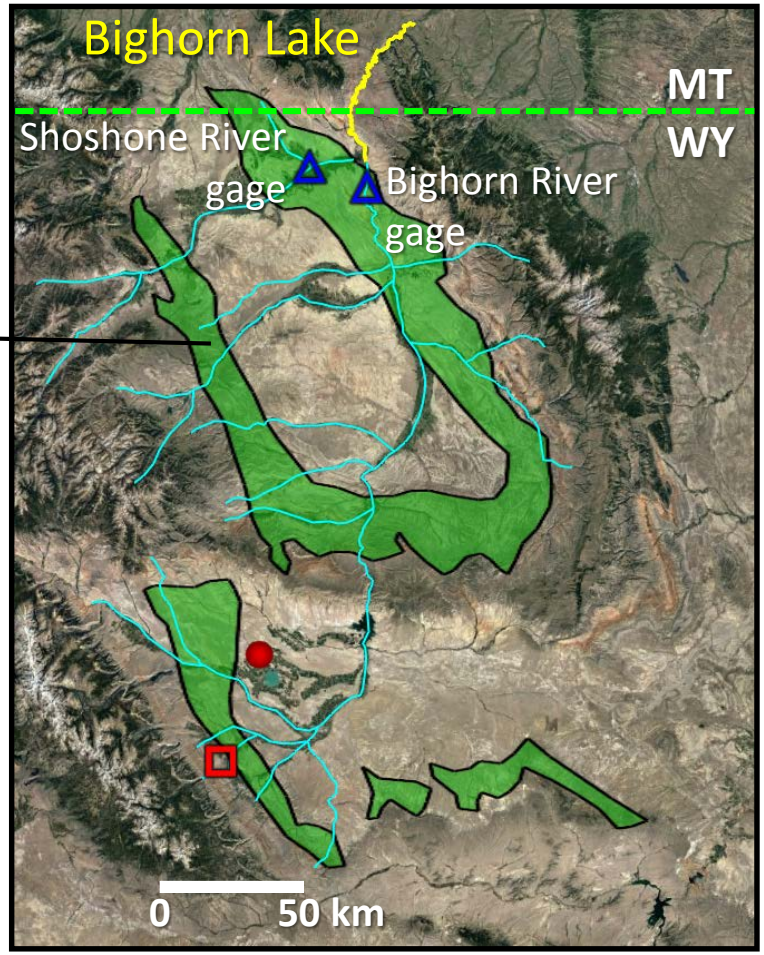


Seiler et al., 2003

"Areas susceptible to irrigation-induced Se contamination of water and biota"

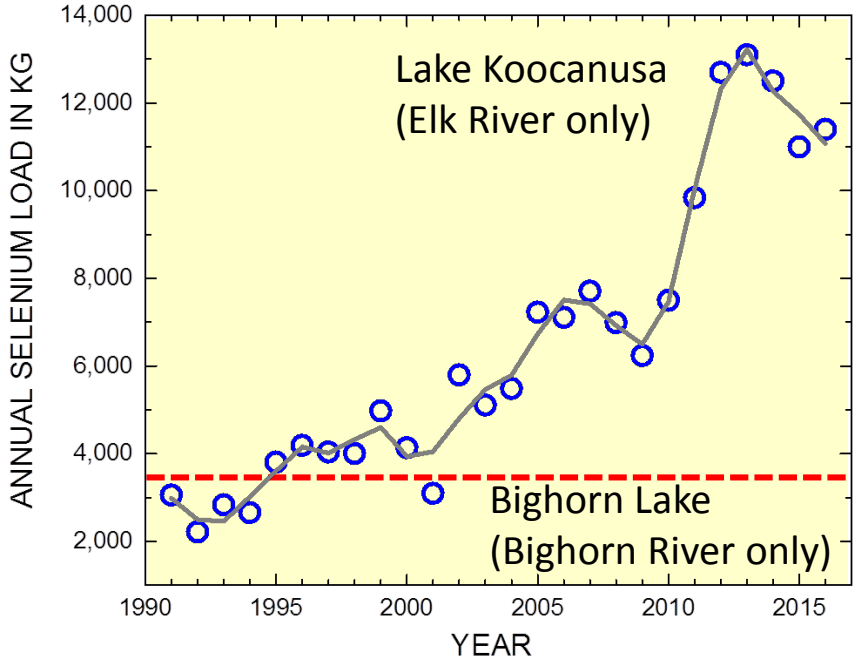
"Area where some bird eggs contain embryotoxic concentrations of selenium"

"Area or site where surface water is selenium contaminated"



Se INPUTS

Comparison to Lake Koocanusa

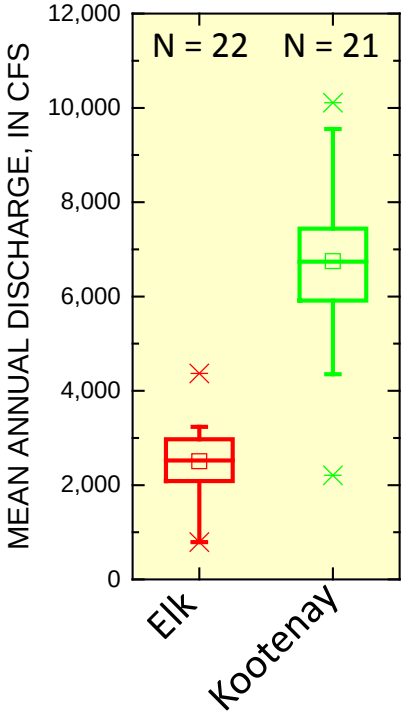


- **Lake Koocanusa volume = 7 km^3**
- **Bighorn Lake volume = 1.7 km^3**
- **Elk River = High Se and minor flow contributor**
- **Bighorn River = High Se and major flow contributor**

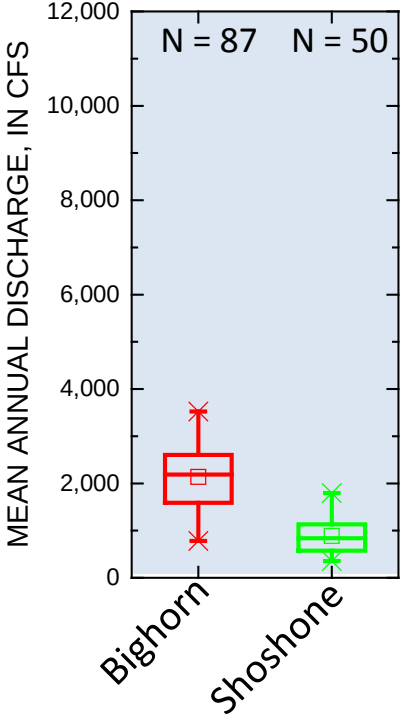
INFLOW RATIOS

Lake Koocanusa and Bighorn Lake

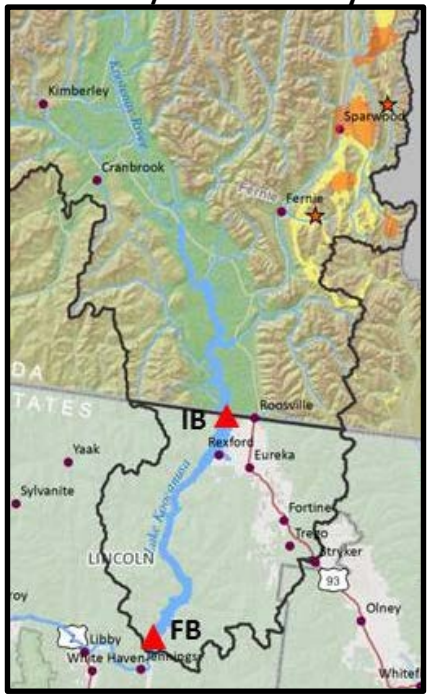
Elk:Kootenay
0.37



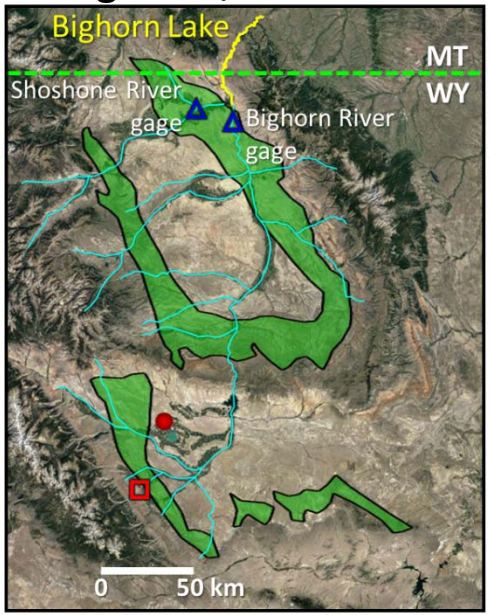
Bighorn: Shoshone
2.42



Elk / Kootenay



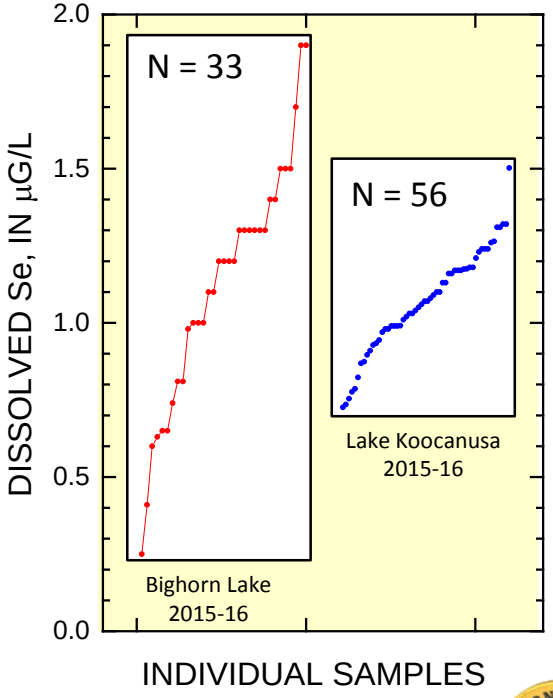
Bighorn / Shoshone



Limnology ♦ $[Hg]_{fish}$ ♦ $[Se]_{fish}$ ♦ Se sources ♦ Other reservoirs

Se IN WATER

Comparison to Lake Koocanusa

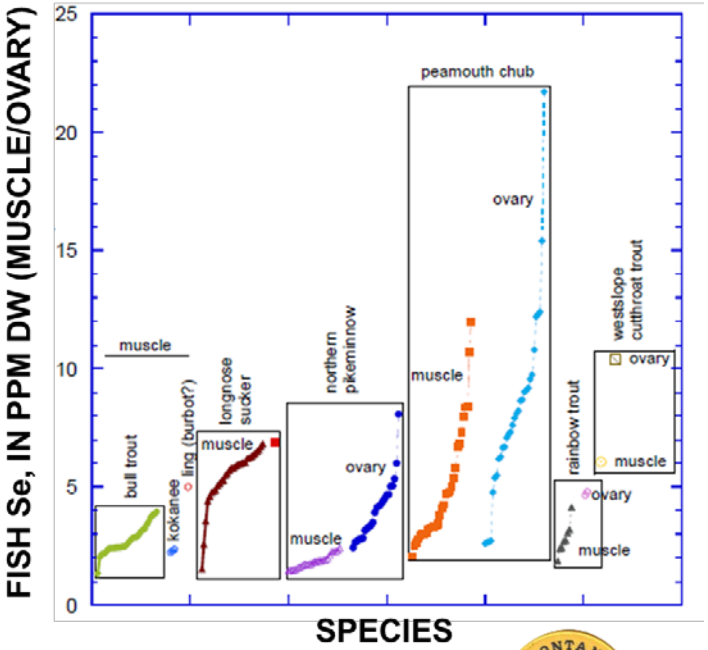


Limnology ♦ $[Hg]_{fish}$ ♦ $[Se]_{fish}$ ♦ Se sources ♦ Other reservoirs

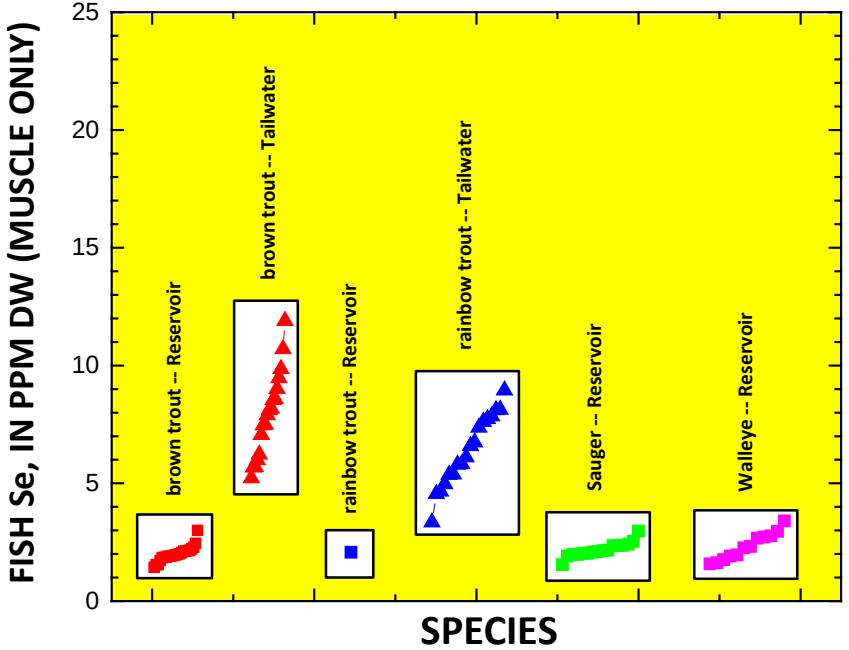
Se IN FISH TISSUE

Comparison to Lake Koocanusa

Lake Koocanusa (*MT FWP*)



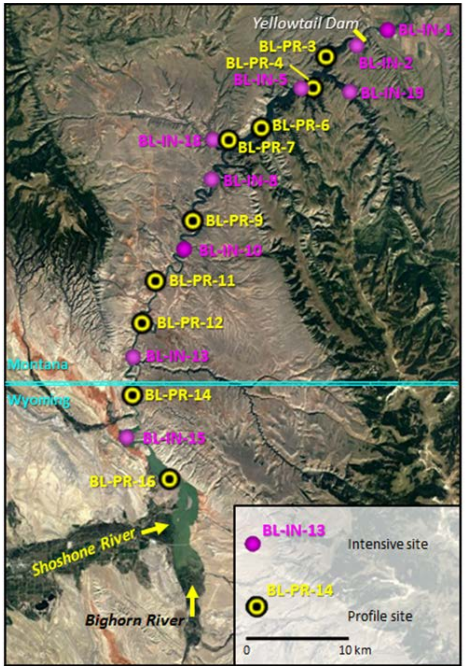
Bighorn Lake and tailwater (USGS / MT FWP**)**



Limnology ♦ $[Hg]_{fish}$ ♦ $[Se]_{fish}$ ♦ Se sources ♦ Other reservoirs

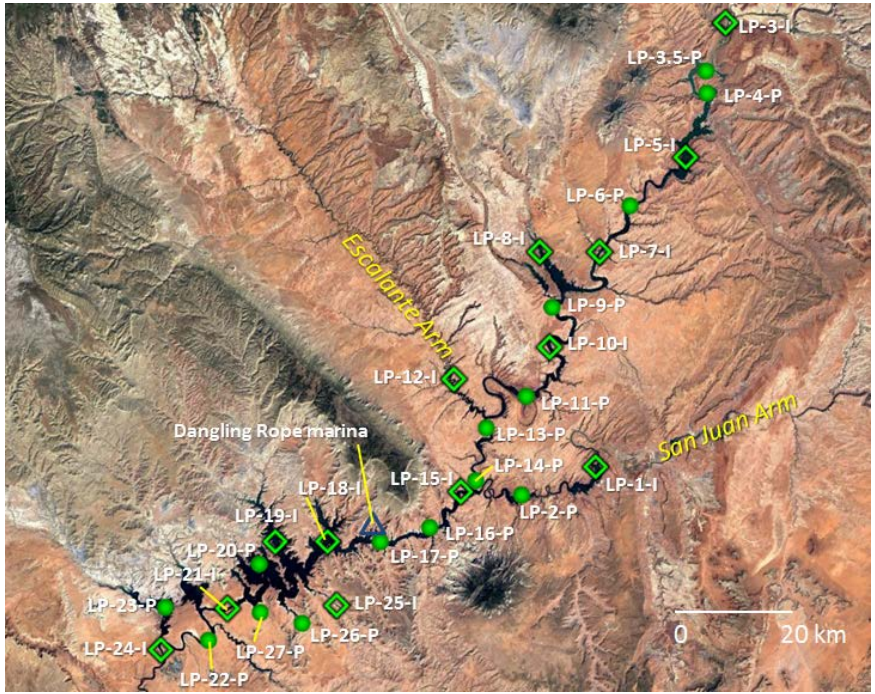
LAKE POWELL COMPARISON

Similar reservoir morphology



Bighorn Lake, MT/WY ←

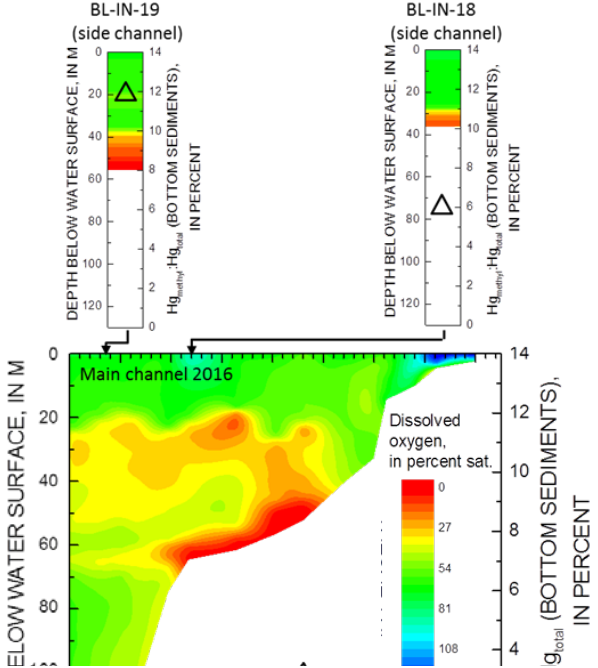
Lake Powell, AZ/UT →

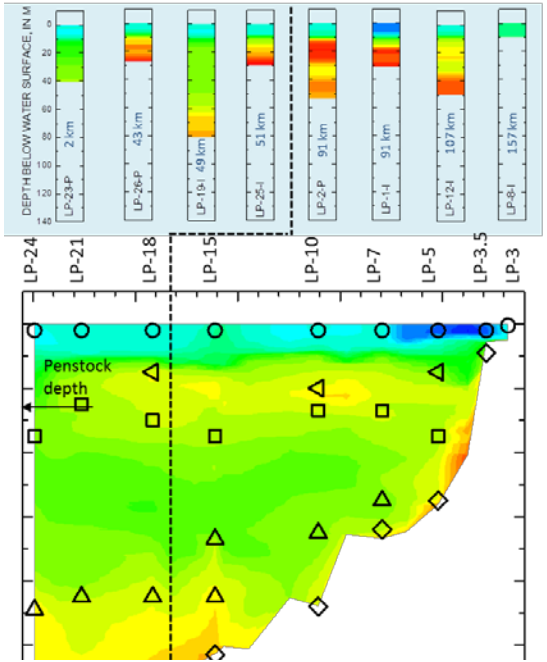


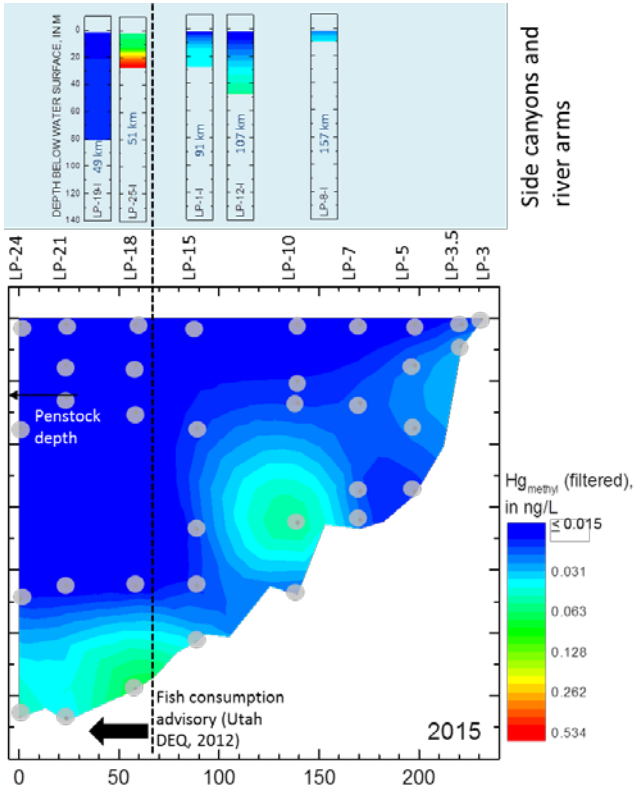
Limnology ♦ $[Hg]_{fish}$ ♦ $[Se]_{fish}$ ♦ Se sources ♦ Other reservoirs

SIDE CANYON ANOXIA

Bighorn Lake DO/Hg *Lake Powell DO* *Lake Powell MeHg*







LAKE KOOCANUSA

- Se sourced from British Columbia
- Two major river inflows (high Se + low flow)
- Modeled Se loads up to 13,000 kg/yr
- [Se] in reservoir ranges from 0.7 to 1.2 µg/L
- Listed under Section 303 (d) as threatened by Se

BIGHORN LAKE

- Se sourced from Wyoming
- Two major river inflows (high selenium + high flow)
- Estimated Se loads ~ 4,200 kg/yr
- [Se] in reservoir ranges from 0.25 to 1.9 µg/L
- No 303 (d) listing for Se
- Tailwater impacts?

LAKE POWELL

- Long, narrow reservoir with numerous side canyons
- Low levels of Hg_{water} in main channel
- Seasonal anoxia in narrow side canyons
- Elevated levels of $MeHg_{water}$ in side canyons
- Hg fish advisory for lower reservoir

BIGHORN LAKE

- Long, narrow reservoir with some side canyons
- Low levels of Hg_{water} in main channel
- Seasonal anoxia in side canyons
- Higher proportion of $MeHg_{sediment}$ and $SRB_{sediment}$ in side canyons
- Hg fish advisory for entire reservoir

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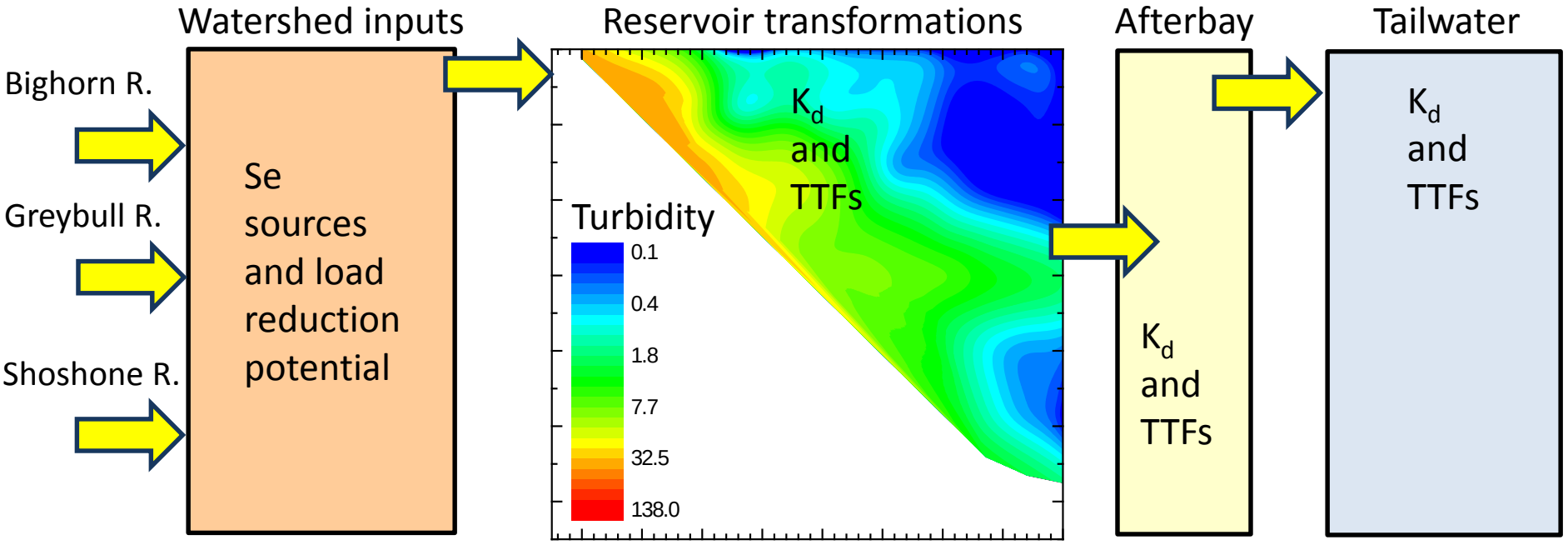
Limnology ♦ $[Hg]_{fish}$ ♦ $[Se]_{fish}$ ♦ Se sources ♦ Other reservoirs

Se CONCEPTUAL MODEL



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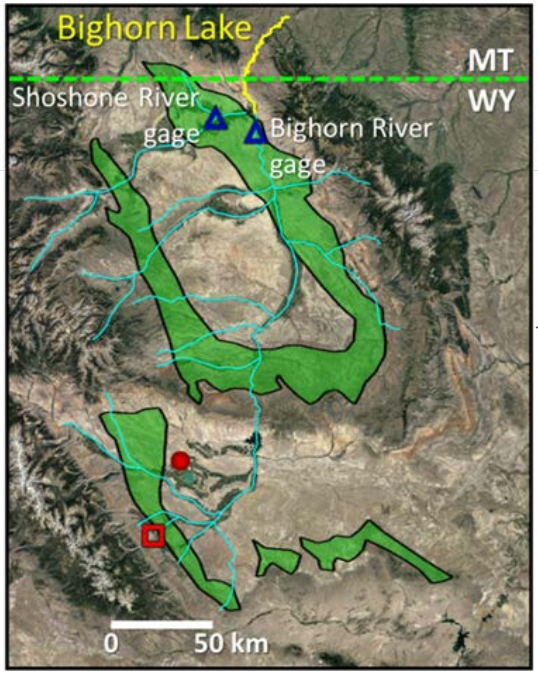
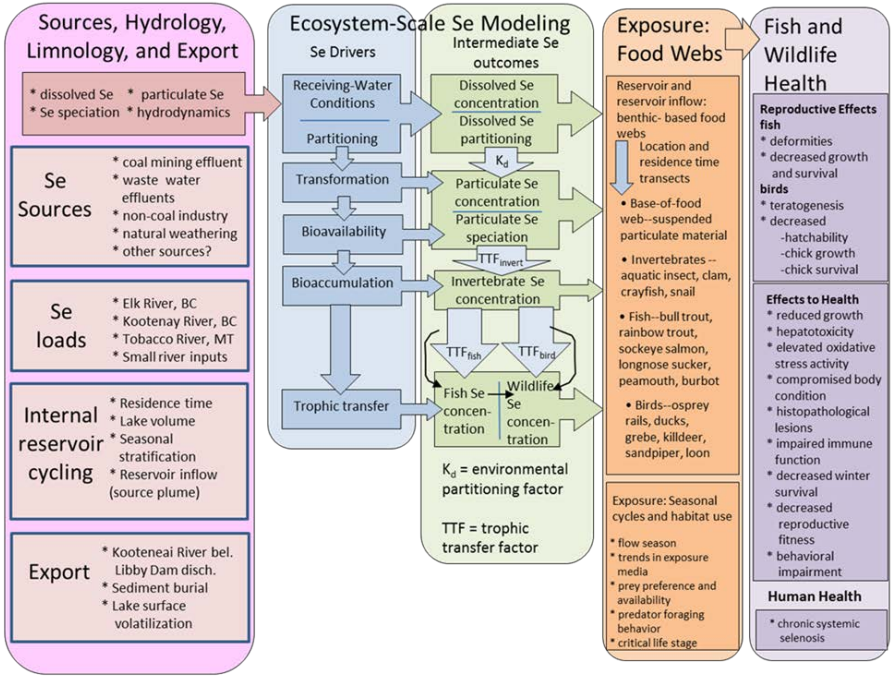
BIGHORN LAKE FUTURE NEEDS



SPARROW model (*Preston et al., 2009*) for Bighorn, Greybull, and Shoshone watersheds

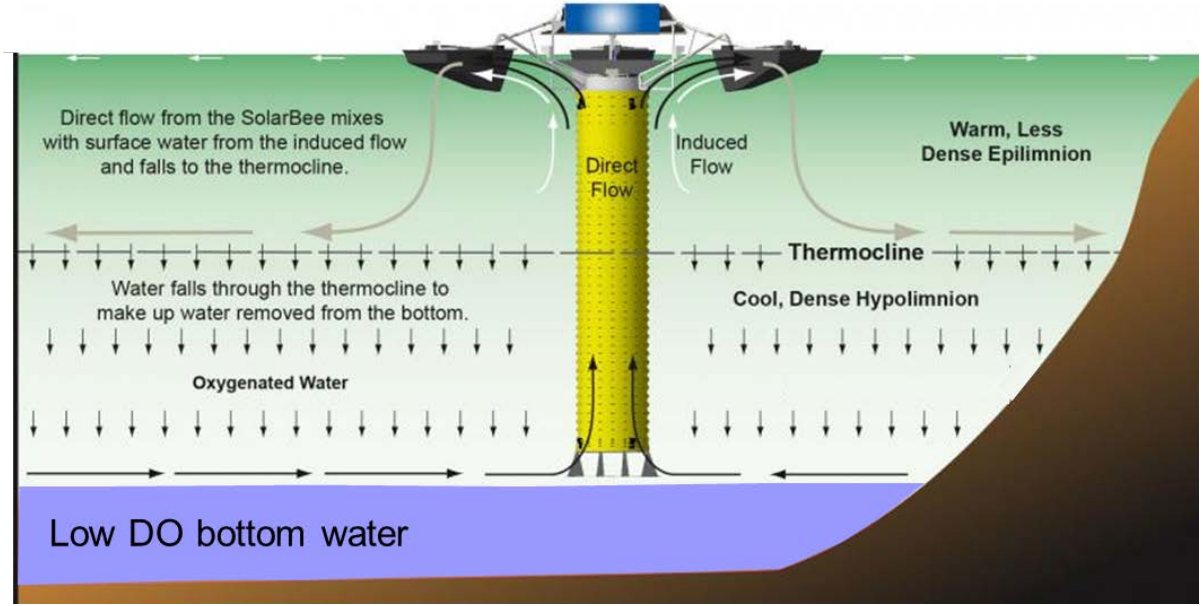
Ecosystem-scale model (*Presser and Luoma, 2010*) for Bighorn Lake



Bighorn Lake Study Team

MANAGEMENT OPTIONS

Thermocline manipulation in side canyons



Solar pump operating at Newcastle Reservoir, Utah

- **Oxygenate bottom water and near-surface sediments**
- **Photodegrade MeHg?**

SUMMARY

- Low DO in side canyons and microbial populations support Hg methylation
- High Hg levels in larger reservoir fish
- Elevated Se levels in reservoir water and tailwater fish tissue
- Se loads to BICA from Bighorn River watershed
- Similar Hg processes in Bighorn Lake and Lake Powell
- Se model for BICA would be useful as an adaptive management tool