Downstream Channel Impacts of Reservoir Sediment Management

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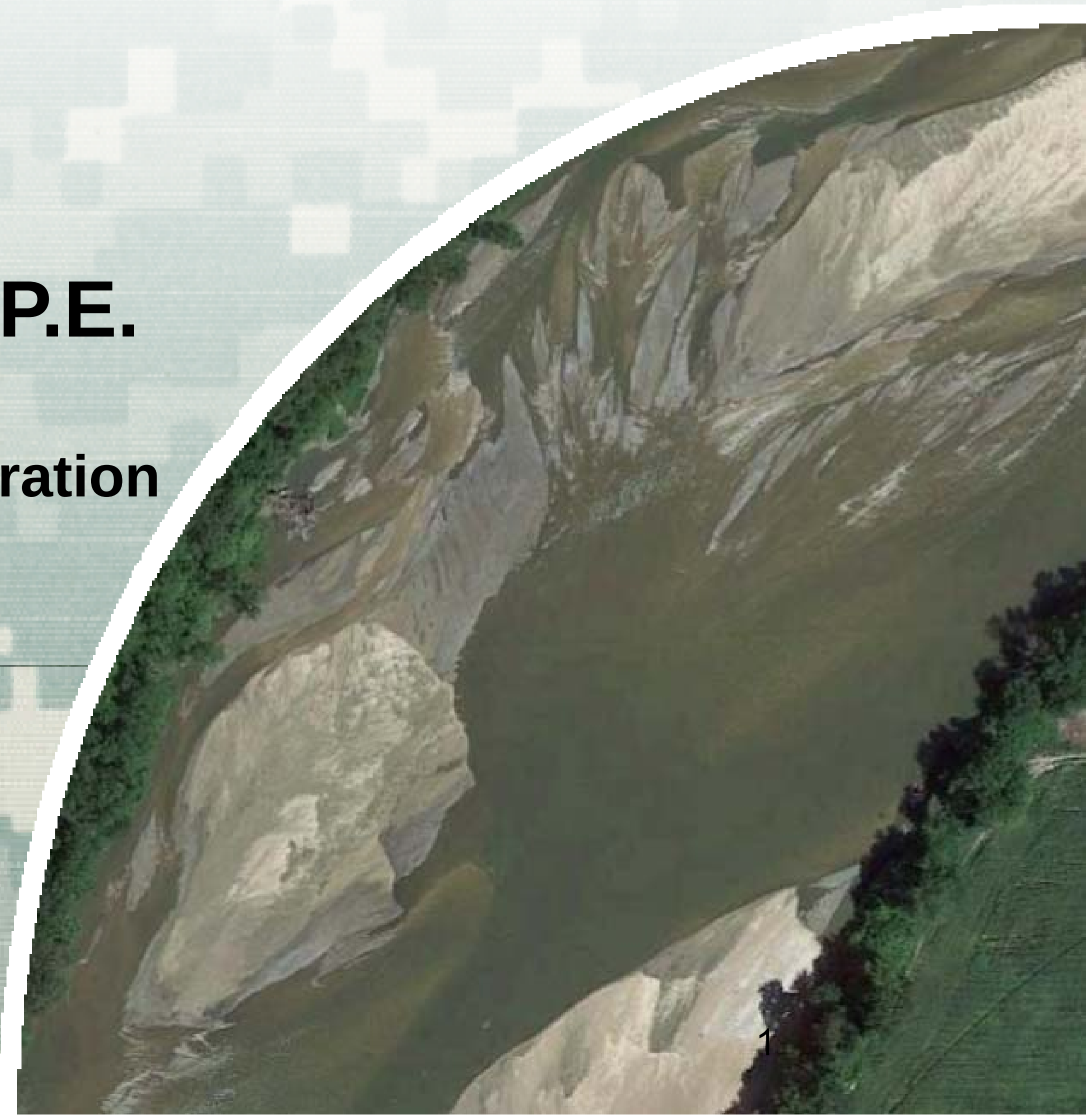


US Army Corps of Engineers
BUILDING STRONG®

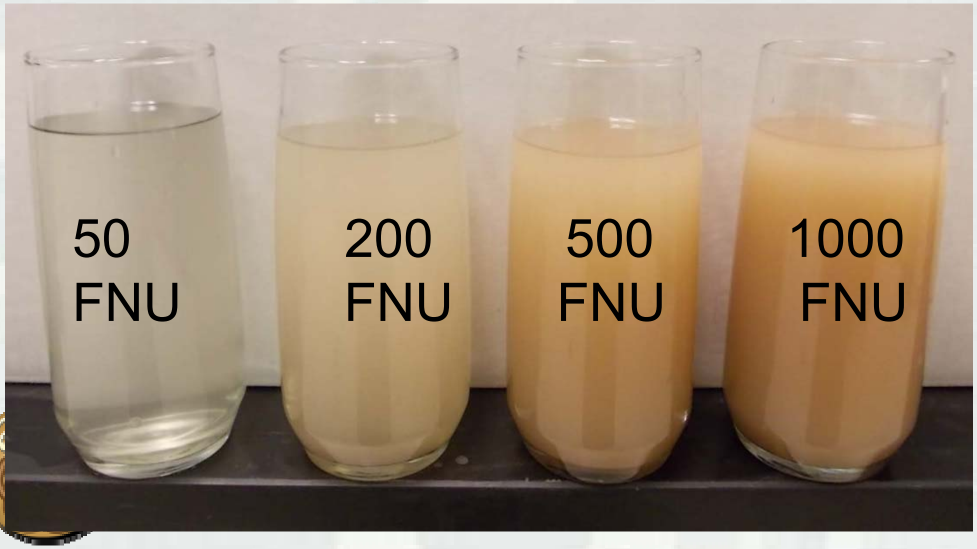
Outline

- Natural rivers
- Effects of drawdown flushing
- Effects of sediment bypass

Impacts from Lack of Turbidity: Colorado River

David Ward and Rylan Morton Starner, USGS, Grand Canyon Monitoring and Research Station

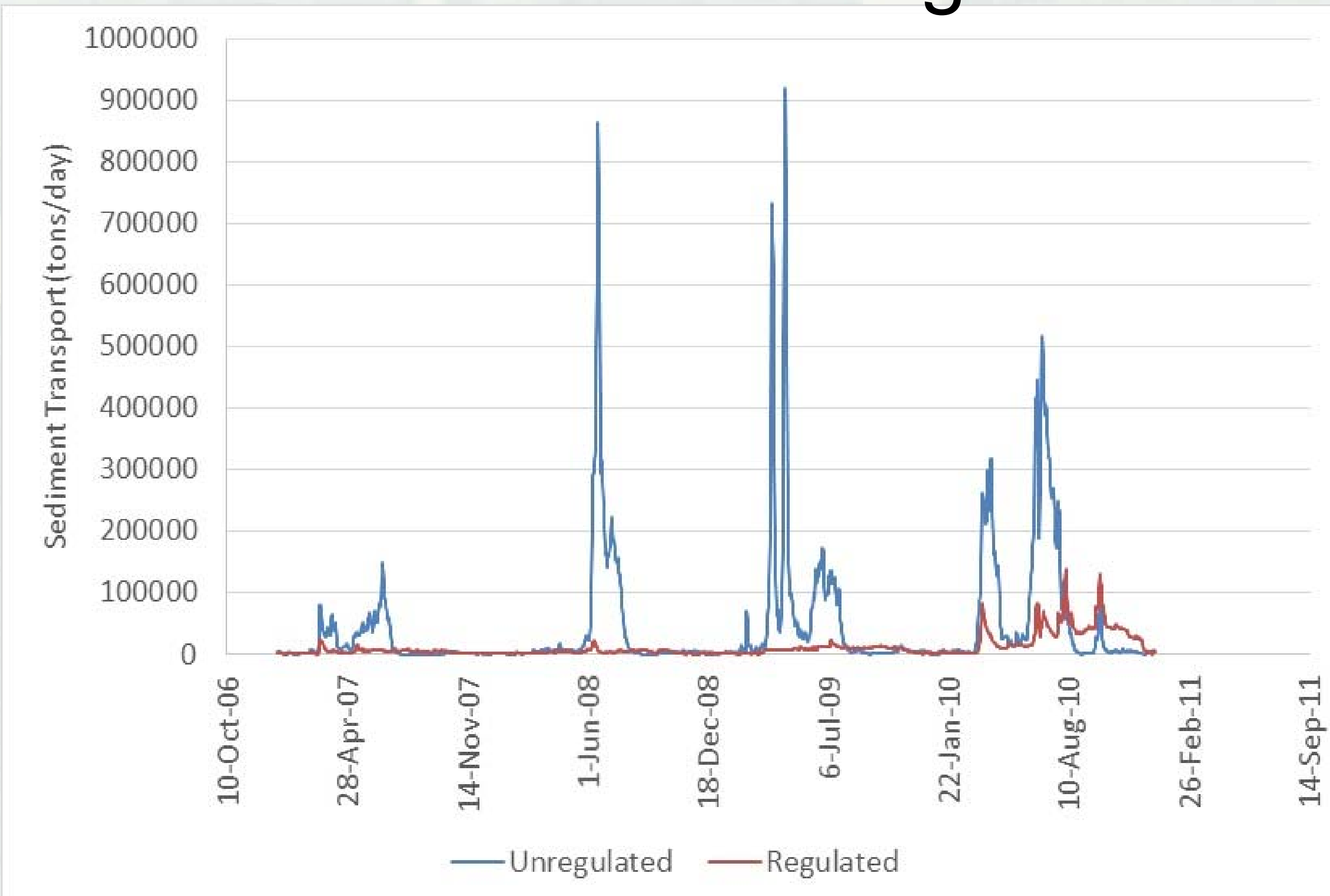
- Humpback Chub numbers have decreased substantially and they are now federally protected
- One primary reason is that the Colorado River used to be usually over 1000 FNU, but after construction of Glen Canyon Dam now is usually below 50 FNU. The small chub become easy prey for trout species in clear water.



Brown trout
mean TL = 261 mm

Humpback chub
mean TL = 56 mm

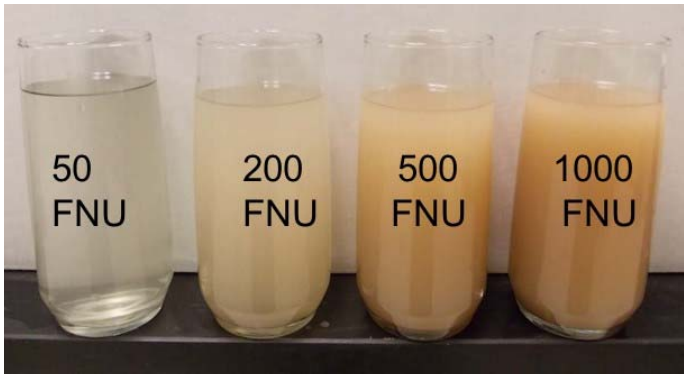
Unregulated Rivers Experience High Sediment Loads During Floods

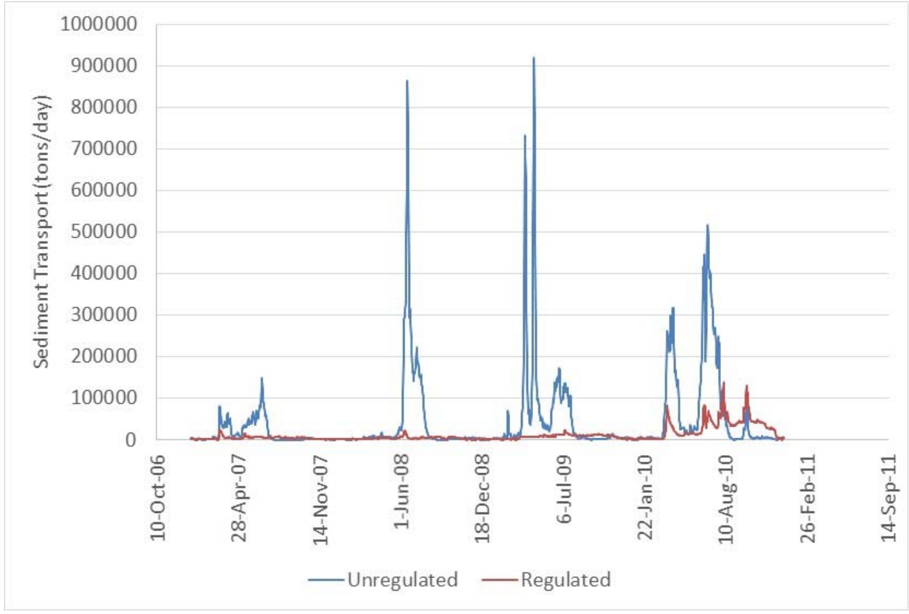


Missouri River at Sioux City, IA. Data is approximate for demonstration purposes only.

Downstream Impacts Depend On Two Major Factors

1-How closely does the management option match the natural timing, concentration, and gradation of incoming sediment load?





2-What the downstream channel is "used to"

- Historically-turbid Midwest stream vs. Historically-clear mountain stream
- When was the downstream channel infrastructure built (and for what conditions?)

Effects of Drawdown Flushing

US Examples

- Willwood
- Spencer Dam
- Fall Creek

Minimizing Downstream Channel Impacts

The Willwood Diversion Dam was built in 1924 and still contains some original equipment that could only be replaced by drawing the water behind the dam down.

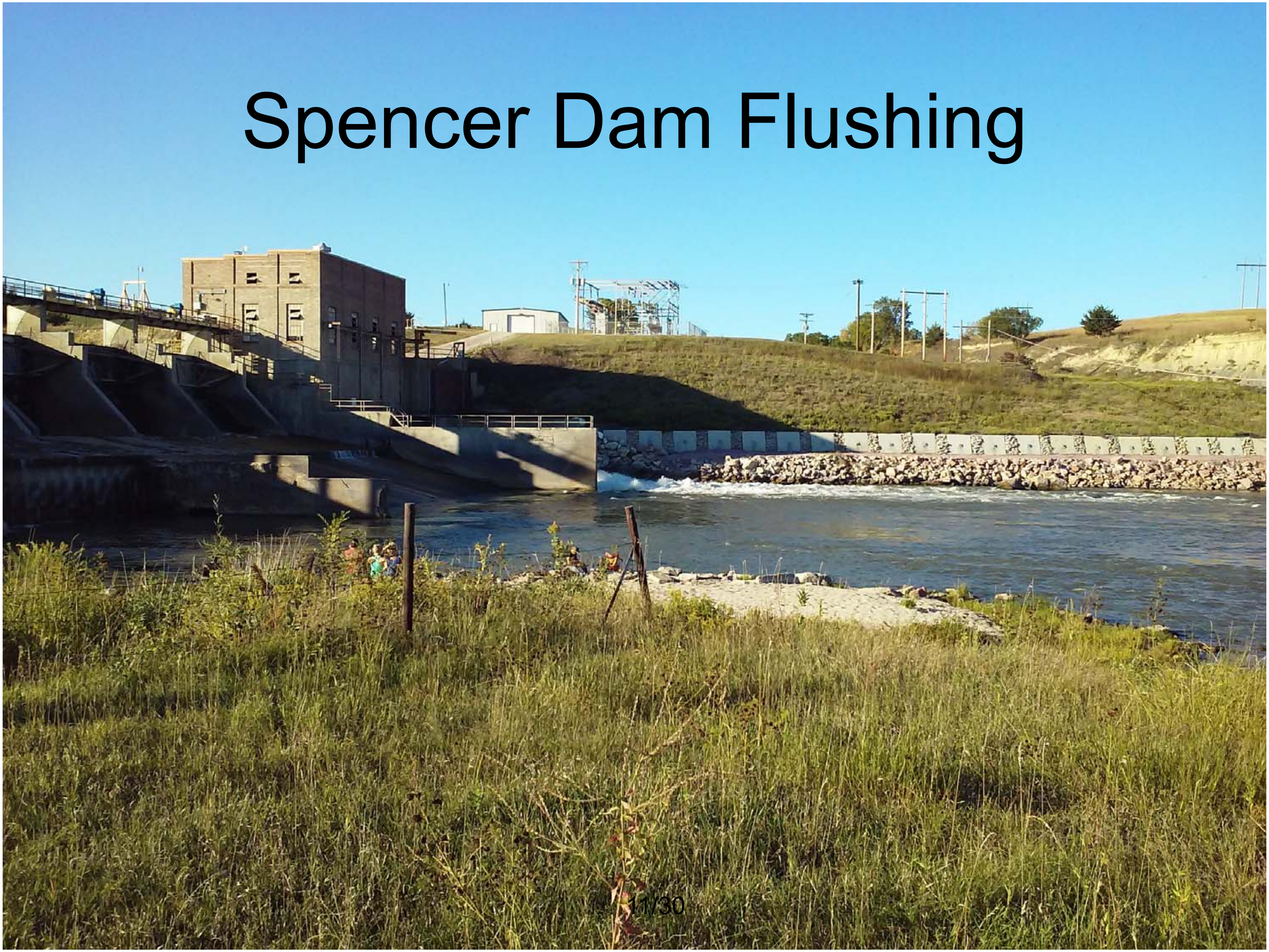
http://billingsgazette.com/lifestyles/recreation/muddy-water-suffocates-fish-in-prime-stretch-of-wyoming-s/article_94ad366d-a43b-542b-9703-b832b3900606.html

Piles of sediment have built up behind the Willwood Diversion Dam, which was built in 1924.

This view looks downstream from the dam.


billingsgazette.com

Spencer Dam Flushing



Spencer Dam Flush- The Next Morning

Spencer Dam Fish Kills- 1977-1979

Hess and Newcomb (1982) document fish kills

DO dropped to 3.1 mg/L

Species	Number
Channel catfish (*Ictalurus punctatus*)	954
Walleye (*Stizostedion vitreum*)	9
Sauger (*Stizostedion canadense*)	94
Green sunfish (*Lepomis cyanellus*)	31
Bullhead (*Ictalurus* spp.)	10
Madtom (*Noturus gyrinus*)	4
Bluegill (*Lepomis macrochirus*)	29
Gizzard shad (*Dorosoma cepedianum*)	2
Largemouth bass (*Micropterus salmoides*)	78
Drum (*Aplodinotus grunniens*)	158
Crappie (*Pomoxis* spp.)	41
Common carp (*Cyprinus carpio*)	560
Shorthead redhorse (*Moxostoma macrolepidotum*)	763
River carpsucker (*Carpiodes carpio*)	819
Stonecat (*Notorus flavus*)	58
Goldeye (*Hiodon alosoides*)	2
Northern pike (*Esox lucius*)	5
Brown trout (*Salmo trutta*)	4
Smallmouth bass (*Micropterus dolomieui*)	2
White sucker (*Catostomus commersoni*)	2
Minnow (Cyprinidae)	18,846
Total	22,471

Spencer Dam: Operational Changes since 1989

The pool is drained slowly before the flushing begins.

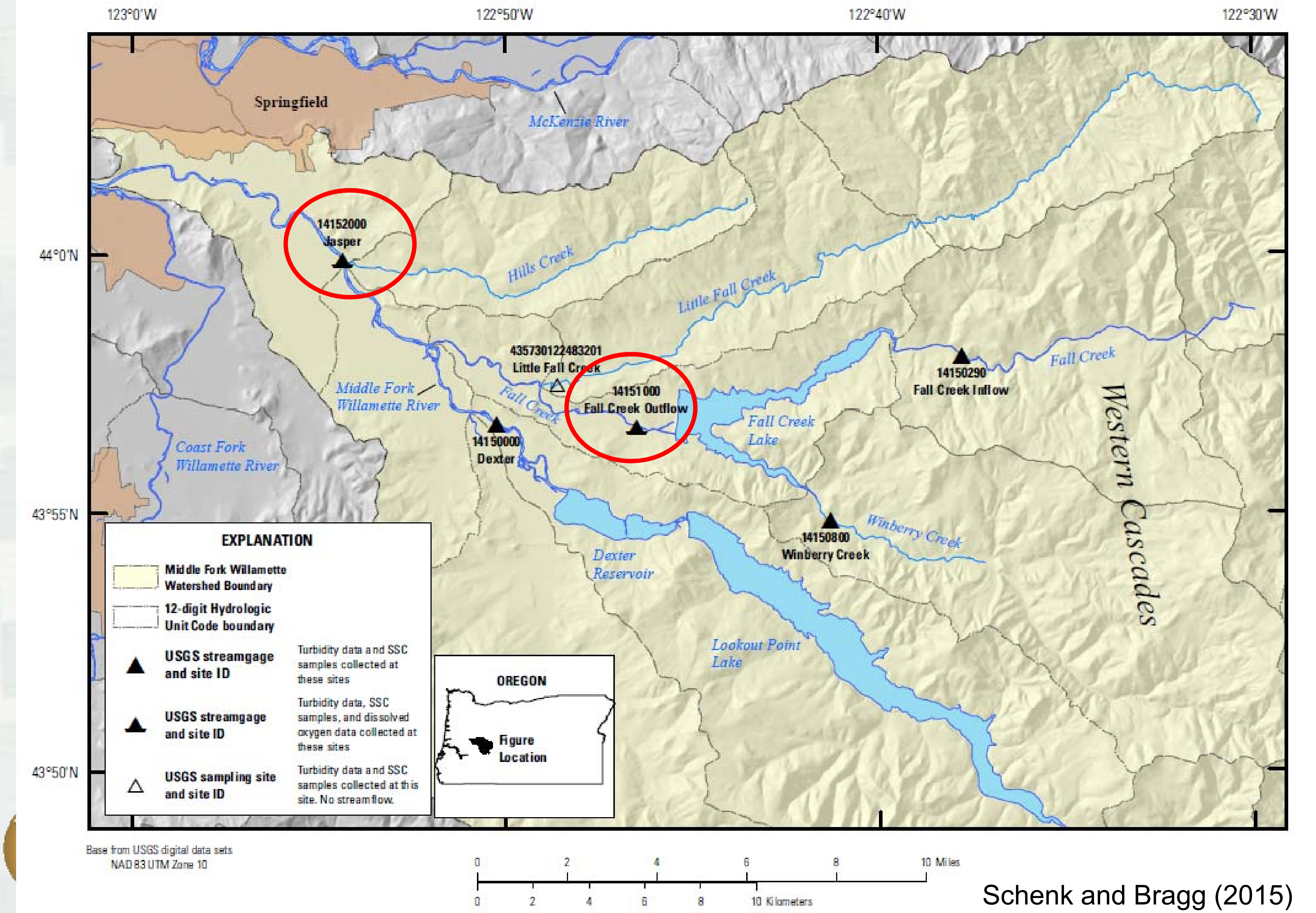
"The operational modifications of raising the gates slowly and dropping the hydro pond at a reduced rate has been successful in avoiding fish kills since 1989."

--Gutzmer, King, and Overhue 1996

"It appears that with environmentally friendly ways to pass sediment, fish below Spencer Dam survive and express resilience to conditions created by sluicing."

--Gutzmer, King, Overhue, and Chrisp 2002

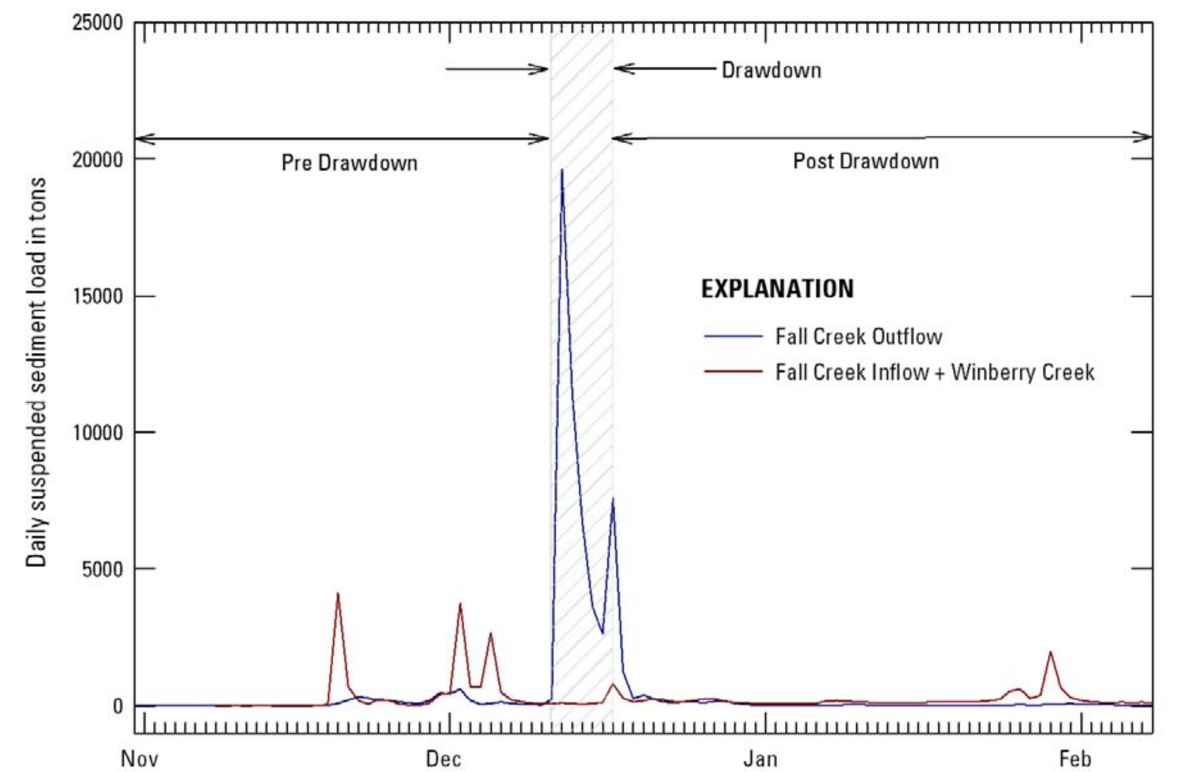
Fall Creek Lake Drawdown Flush



Schenk and Bragg (2015)

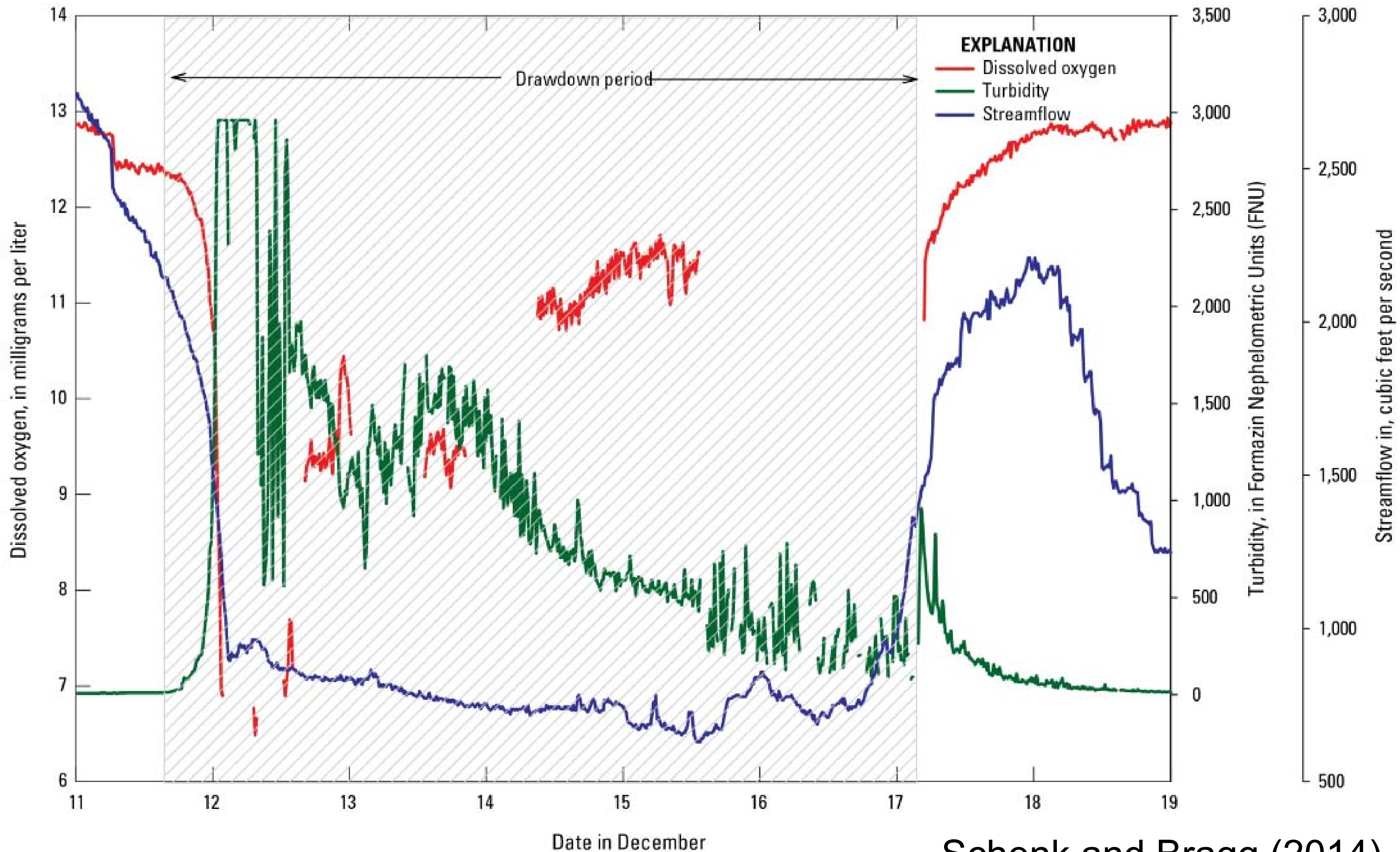

Photo Source: Greg Taylor

Suspended Sediment Loads
Fall Creek Outflow – 2012/13



Schenk and Bragg (2014)

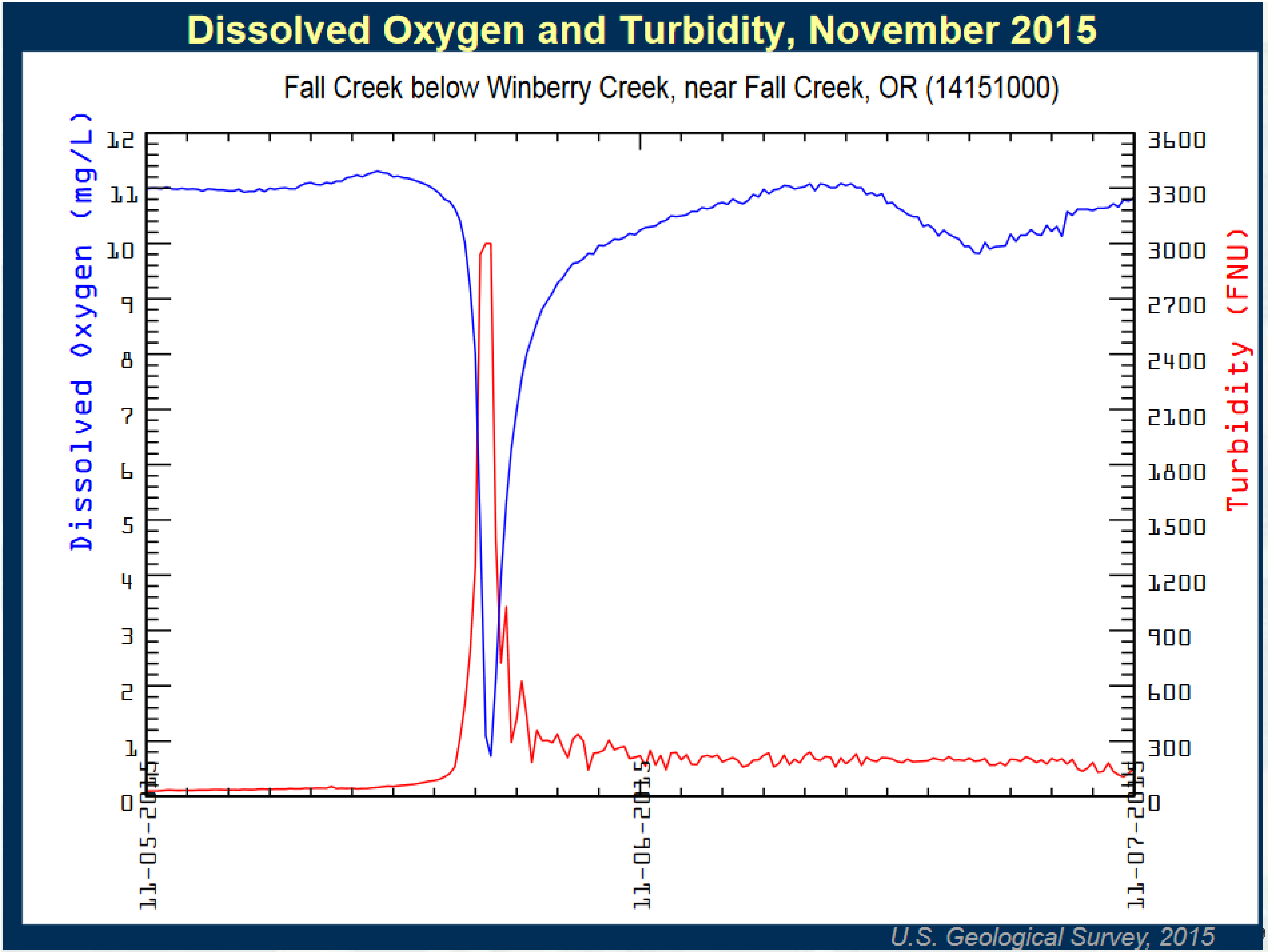
- Pre-drawdown: 4,300 tons (34 days)
- Drawdown: 51,600 tons (6 days)
- Post-drawdown: 4,030 tons (53 days)

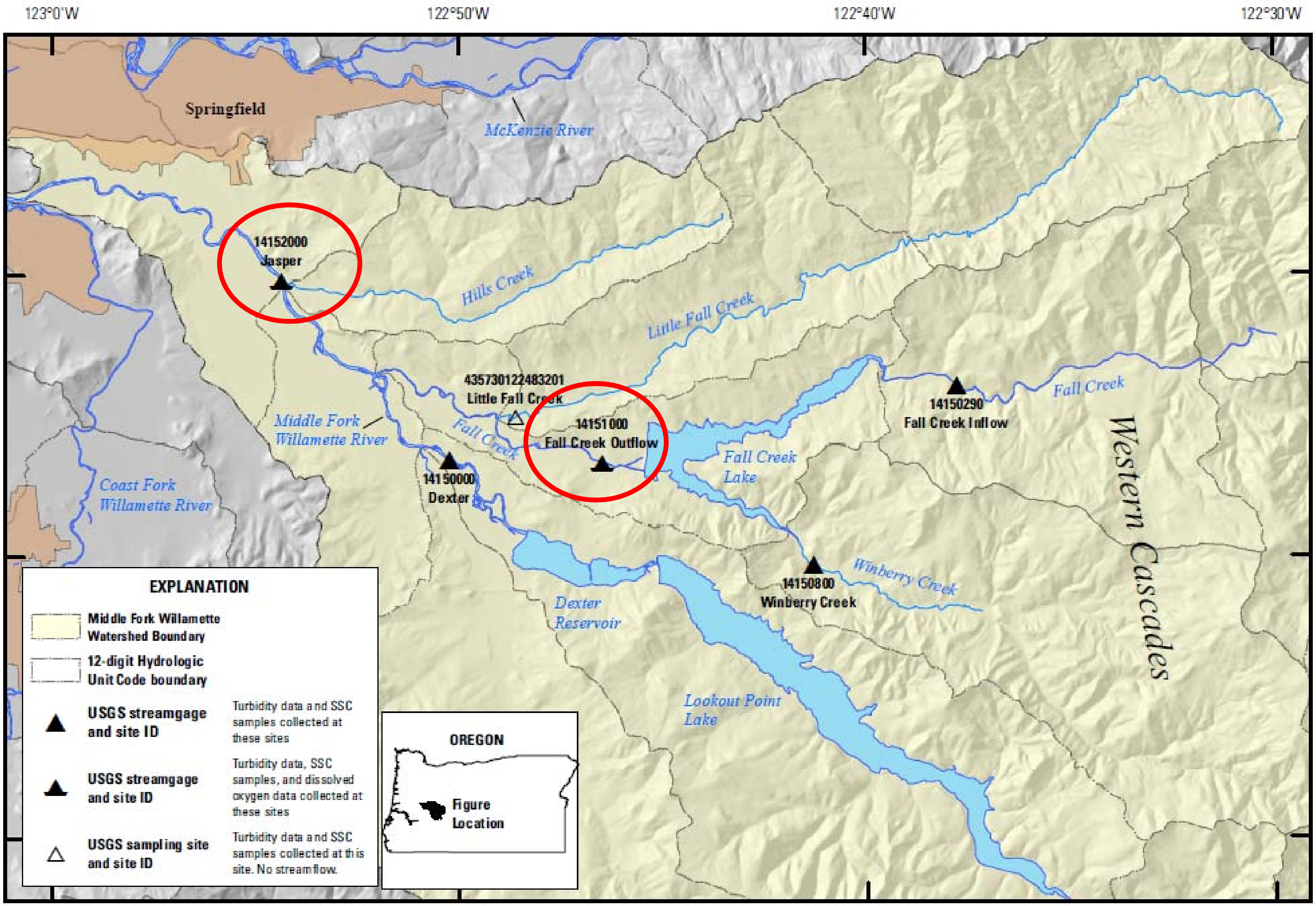


Schenk and Bragg (2014)

Figure 9. Dissolved oxygen, turbidity, and streamflow during the drawdown at *Fall Creek Outflow*, Middle Fork Willamette River Basin, Oregon, December 2012.

“During the drawdown, DO data at Fall Creek Outflow decreased rapidly at the onset of the large sediment release from approximately 13 mg/L to a minimum value of 6.50 mg/L”


Dissolved Oxygen and Turbidity, November 2015
Fall Creek below Winberry Creek, near Fall Creek, OR (14151000)
Dissolved Oxygen (mg/L)
Turbidity (FNU)
12
11
10
9
8
7
6
5
4
3
2
1
0
3600
3300
3000
2700
2400
2100
1800
1500
1200
900
600
300
0
11-05-2015
11-06-2015
11-07-2015
U.S. Geological Survey, 2015



"DO at Jasper decreased slightly during the drawdown to a minimum value of 11.63 mg/L, suggesting that although a small effect is possible, the sediment release from Fall Creek Lake did not cause a rapid decrease in DO approximately 10 river miles downstream of the dam." --Schenk and Bragg (2014)

Fall Creek Sediment Flushing

- Ten-fold increase in the adult salmon that later return to Fall Creek
- No observed fish kills
- In-reservoir: Removal of invasive species, significant increase in natural populations

Effects of Drawdown Flushing

US Examples

- Spencer Dam
- Fall Creek
- Willwood

Minimizing Downstream Channel Impacts

Minimizing Downstream Impacts

- Mimic natural conditions
  - ► Max SSC = flood SSC
  - ► Time of year = natural flooding time of year

- Minimize fish impacts
  - ► Assess with Severity Index
  - ► Dilute sediment discharges
  - ► Alternate clear water and sediment laden discharges

Newcomb and Jenson (1996) Meta Analysis

- 80 studies
- Six simple, empirical equations relating severity of ill effects on fish to
  - SSC in mg/l
  - Duration in hours

SEV	Description of effect
	Nil effect
0	No behavioral effects
	Behavioral effects
1	Alarm reaction
2	Abandonment of cover
3	Avoidance response
	Sublethal effects
4	Short-term reduction in feeding rates; short-term reduction in feeding success
5	Minor physiological stress; increase in rate of coughing; increased respiration rate
6	Moderate physiological stress
7	Moderate habitat degradation; impaired homing
8	Indications of major physiological stress; long-term reduction in feeding rate; long-term reduction in feeding success; poor condition
	Lethal and paralethal effects
9	Reduced growth rate; delayed hatching; reduced fish density
10	0–20% mortality; increased predation; moderate to severe habitat degradation
11	>20–40% mortality
12	>40–60% mortality
13	>60–80% mortality
14	>80–100% mortality

Juvenile and Adult Salmonids

Duration of exposure to SS ($\log_e$ hours)

(A) Average severity-of-ill-effect scores (empirical)

Concentration (mg SS/L)	0	1	2	3	4	5	6	7	8	9	10	($\log_e$ mg SS/L)
162755	14	-	-	14	-	-	-	-	-	-	-	12
59874	-	-	12	10	14	12	-	-	-	-	-	11
22026	-	-	-	-	-	11	-	-	-	-	-	10
8103	3	-	-	10	12	10	-	11	-	14	-	9
2981	6	-	-	9	11	8	9	13	-	-	-	8
1097	4	-	-	-	10	9	11	8	-	14	8	7
403	4	5	8	-	-	8	10	9	10	-	-	6
148	4	-	6	9	-	8	9	9	-	-	-	5
55	2	4	5	-	-	7	10	9	10	-	-	4
20	3	4	-	4	-	-	-	10	-	9	-	3
7	-	-	-	-	-	3	-	9	-	9	-	2
3	-	-	-	-	-	5	-	-	-	-	-	1
1	3	-	-	-	-	-	-	-	-	-	-	0
	1	3	7	1	2	6	2	7	4	11	30	
	Hours			Days			Weeks		Months			

Adult Freshwater Nonsalmonids

Duration of exposure to SS ($\log_e$ hours)

(A) Average severity-of-ill-effect scores (empirical)

Concentration (mg SS/L)	0	1	2	3	4	5	6	7	8	9	10	($\log_e$ mg SS/L)
162755	10	-	-	-	-	-	10	-	-	-	-	12
59874	-	-	-	-	-	-	-	-	-	-	-	11
22026	-	-	-	-	-	-	10	-	-	-	-	10
8103	5	-	-	-	-	-	-	-	-	-	-	9
2981	-	-	-	-	-	-	-	-	-	13	-	8
1097	-	-	-	-	-	-	-	12	-	-	-	7
403	4	-	-	-	10	-	-	-	-	-	-	6
148	-	-	-	-	-	-	10	11	-	-	-	5
55	-	-	-	-	-	-	-	9	-	-	-	4
20	4	-	-	-	-	-	-	-	-	12	-	3
7	-	-	-	-	-	-	-	-	-	-	-	2
3	-	-	-	-	-	-	-	-	-	-	-	1
1	-	-	-	-	-	-	-	-	-	-	-	0
	1	3	7	1	2	6	2	7	4	11	30	
	Hours			Days			Weeks		Months			

Adult Freshwater Nonsalmonids

Duration of exposure to SS ($\log_e$ hours)

(B) Average severity-of-ill-effect scores (calculated)

Concentration (mg SS/L)	0	1	2	3	4	5	6	7	8	9	10	($\log_e$ mg SS/L)
162755	7	8	9	10	10	11	12	12	13	14	-	12
59874	7	8	9	9	10	11	11	12	13	14	14	11
22026	7	8	8	9	10	10	11	12	13	13	14	10
8103	7	7	8	9	9	10	11	12	12	13	14	9
2981	6	7	8	8	9	10	11	11	12	13	13	8
1097	6	7	7	8	9	10	10	11	12	12	13	7
403	6	6	7	8	9	9	10	11	11	12	13	6
148	5	6	7	8	8	9	10	10	11	12	13	5
55	5	6	7	7	8	9	9	10	11	12	12	4
20	5	6	6	7	8	8	9	10	11	11	12	3
7	5	5	6	7	7	8	9	10	10	11	12	2
3	4	5	6	7	7	8	9	9	10	11	11	1
1	4	5	6	6	7	8	8	9	10	10	11	0
	1	3	7	1	2	6	2	7	4	11	30	
	Hours			Days			Weeks		Months			

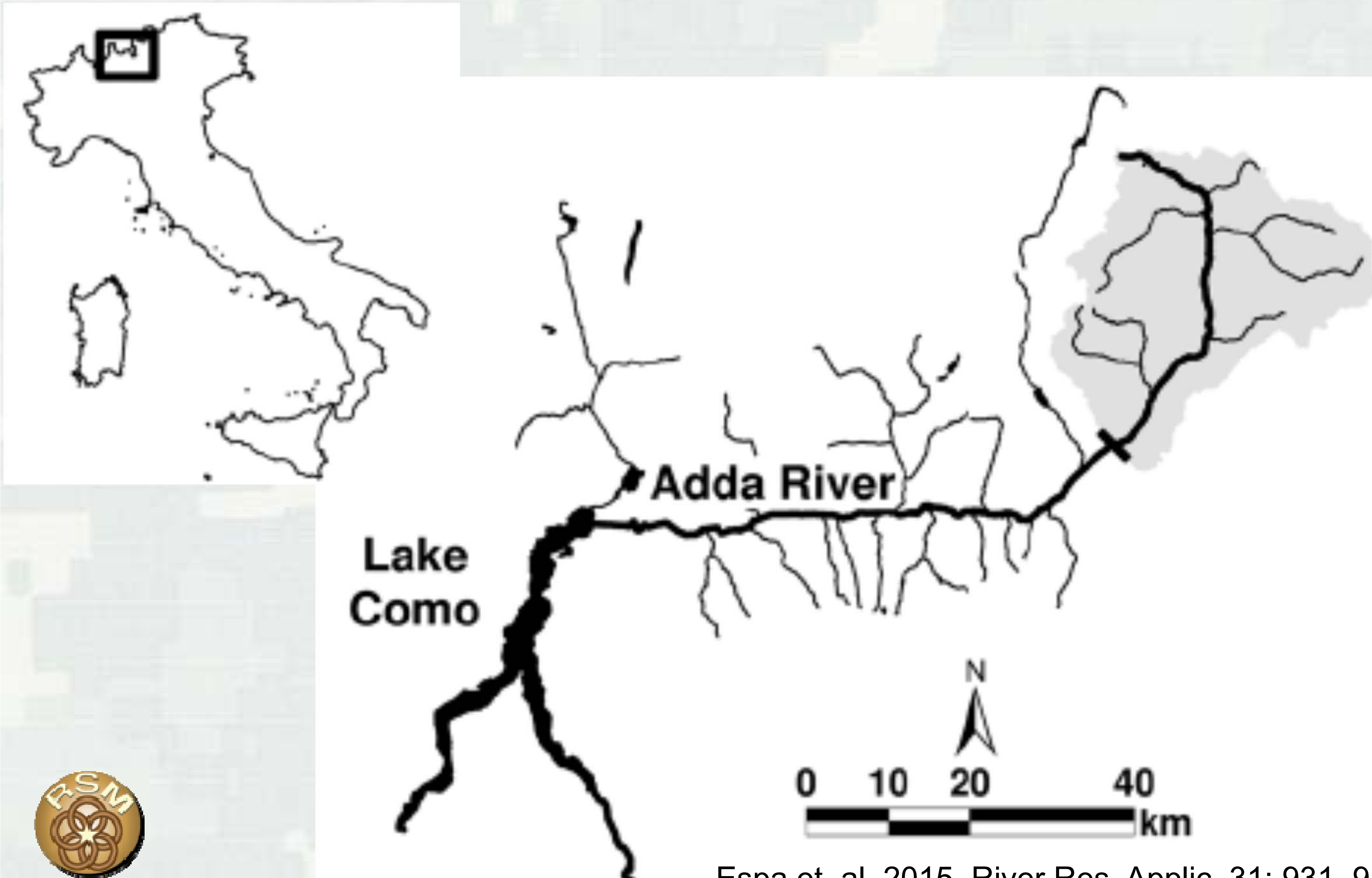
For more information:

Newcombe, C. and Jensen, J. 1996.

"Channel Suspended Sediment and Fisheries: A Synthesis for Quantitative Assessment of Risk and Impact"

North American Journal of Fisheries Management, Volume 16, November 1996, Number 4.

Lake Como (Italy)



Espa et. al, 2015. River Res. Applic. 31: 931–942

Lake Como (Italy)

- Non-consecutive days
  - ►2009: 16 days from 23 May to 10 July
  - ►2010: 6 days from 8 July to 20 July
  - ►2011: No flush

- SSC Thresholds:
  - ►1,500 mg/L daily average
  - ►3,000 mg/L alert value to adjust ongoing activity

Espa et. al, 2015. River Res. Applic. 31: 931–942

Lake Como (Italy)

- Total sediment removed:
  - ► 2009: 75,000 tons in 16 days
  - ► 2010: 24,000 tons in 6 days
  - ► 2011: No flush

- 44% fines
- 54% sand

Results

- Macroinvertebrates
  - ►Seasonal changes, no change during flush years vs. non flush year
- Bullhead (EU protected)
  - ►Increase in density
- Brown trout
  - ►No impact

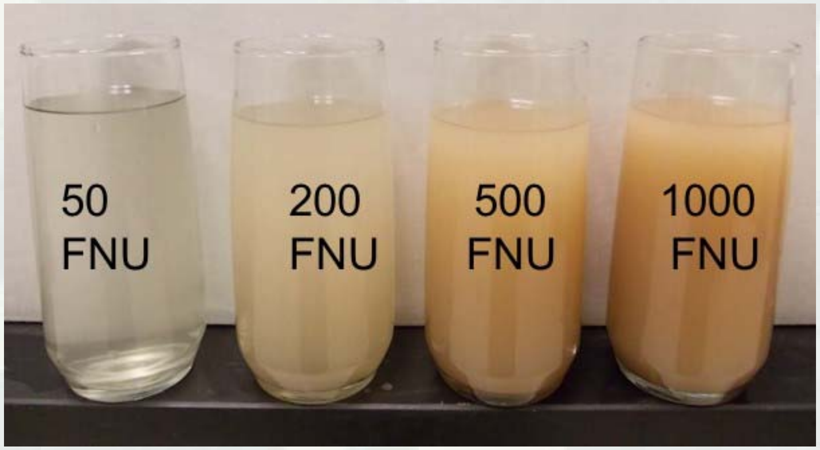
Outline

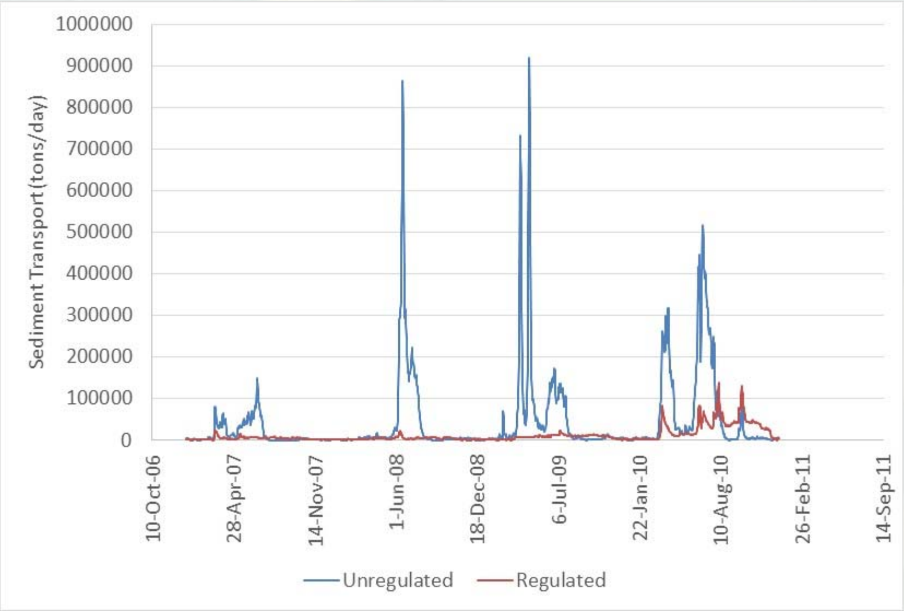
√ ▪ Natural rivers

√ ▪ Effects of drawdown flushing

▪ Effects of sediment bypass

Two types of bypass (as far as the downstream channel is concerned)



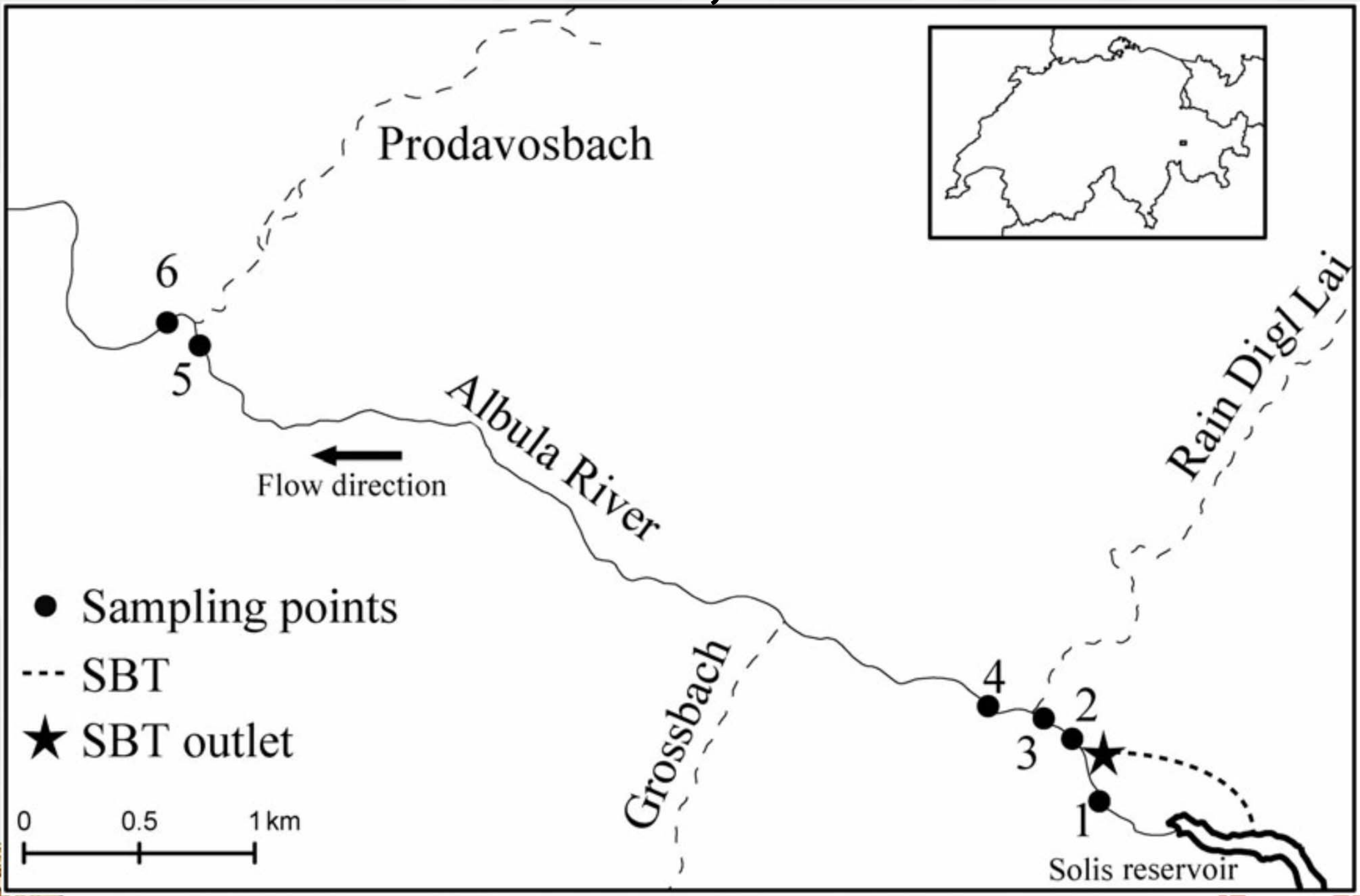


1-Options that raise the base-level SSC

2-Options that raise the flood-related SSC

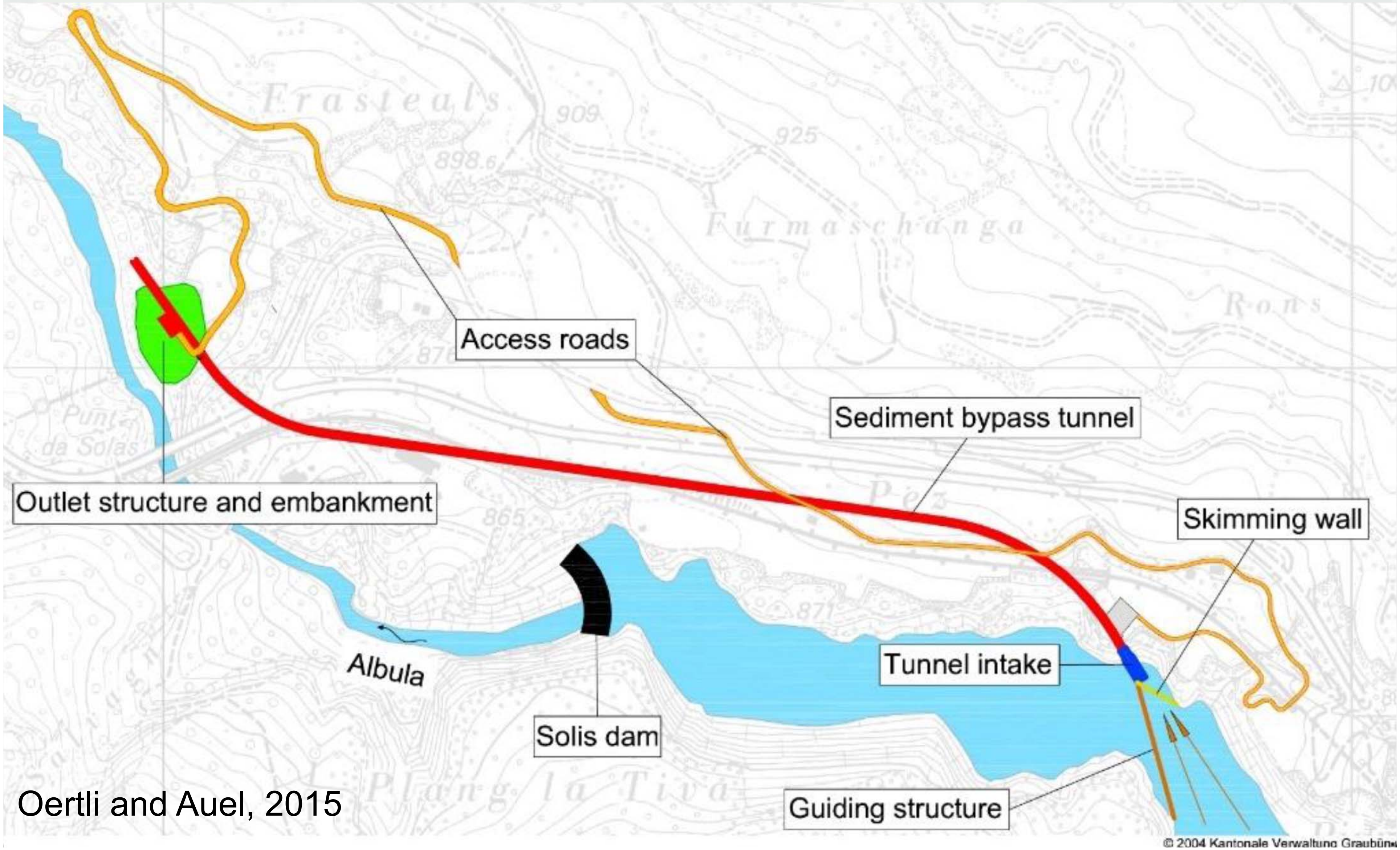
If “raise” = “restore” the effect is generally positive from an ecological perspective, though there could still be infrastructure concerns.

Solis Reservoir, Switzerland

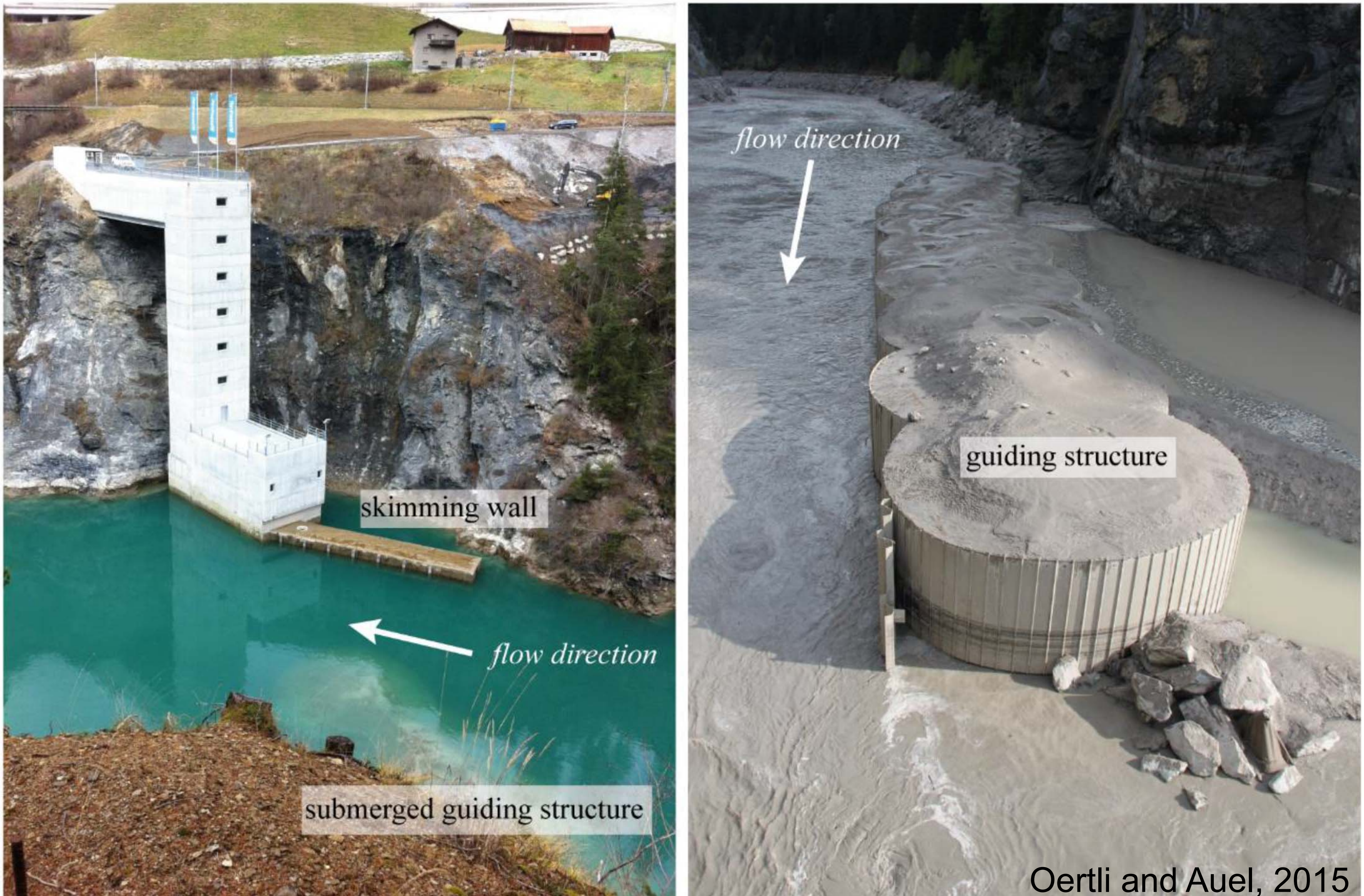


 Martin, Doering, and Robinson, 2017

Solis Reservoir, Switzerland



Oertli and Auel, 2015



Oertli and Auel, 2015

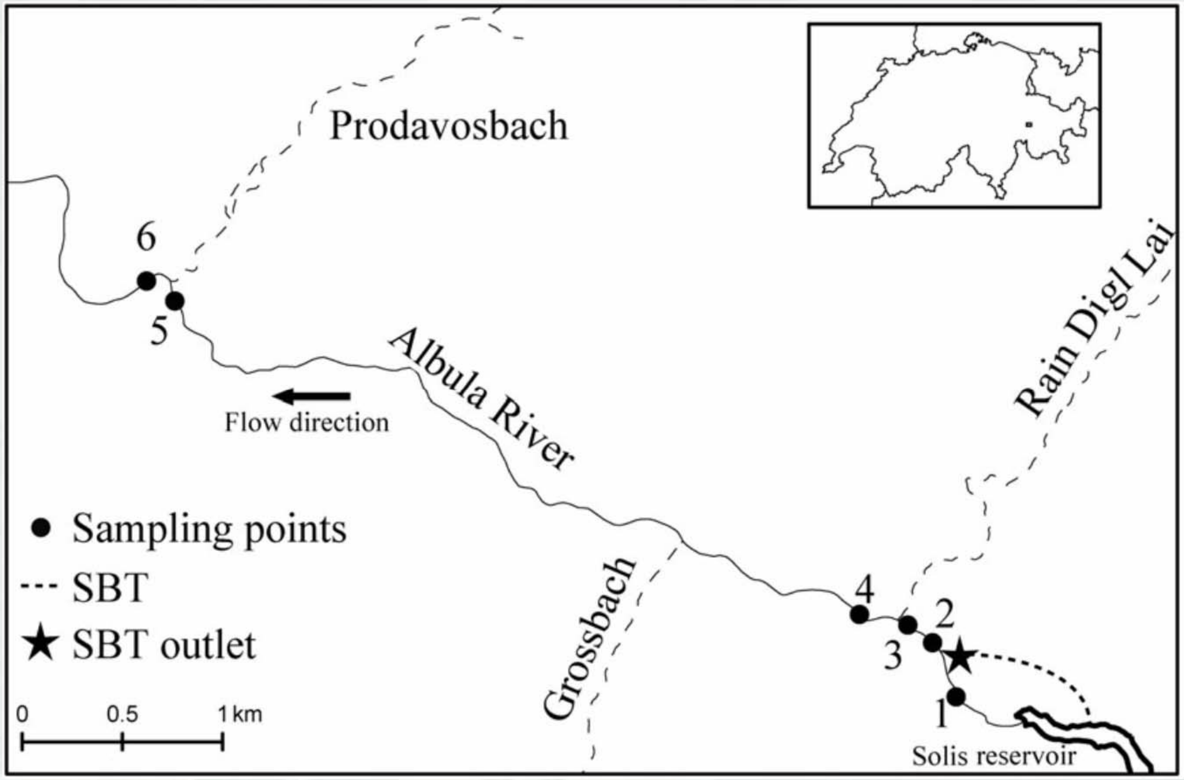
Downstream Discharge

Oertli and Auel, 2015

Solis Reservoir, Switzerland

Measured

- Chemical properties
- Sediment respiration
- Benthic organic matter
- Sediment size distribution
- Periphyton and macroinvertebrates



5x/year for two years

 Martin, Doering, and Robinson, 2017

Solis Reservoir, Switzerland: Conclusions

- Sediment Bypass Tunnel (SBT) discharges induced effects in the downstream channel typical of natural flooding.
- "In the short term, SBT operations can increase the flow/sediment variability that is often lost in flow-regulated rivers."
- "A permanent positive change in the system would take several years of adaptive management operations, similar to experimental floods."
- "In conclusion, we found that SBTs, if ecologically implemented (i.e. having the operational characteristics similar to the natural flood features of a system), can improve the longitudinal connectivity of sediments of rivers impounded by dams. Indeed, SBT events can be used as environmental flows to simulate more natural flow/sediment regimes of receiving waters."

Martin, Doering, and Robinson, 2017

Conclusion

- √ ▪ Natural rivers
  - ► How closely does the sediment discharge match the natural, no-dam conditions?
- √ ▪ Effects of drawdown flushing
  - ► How can the sediment concentrations be limited to acceptable severity levels?
- √ ▪ Effects of sediment bypass