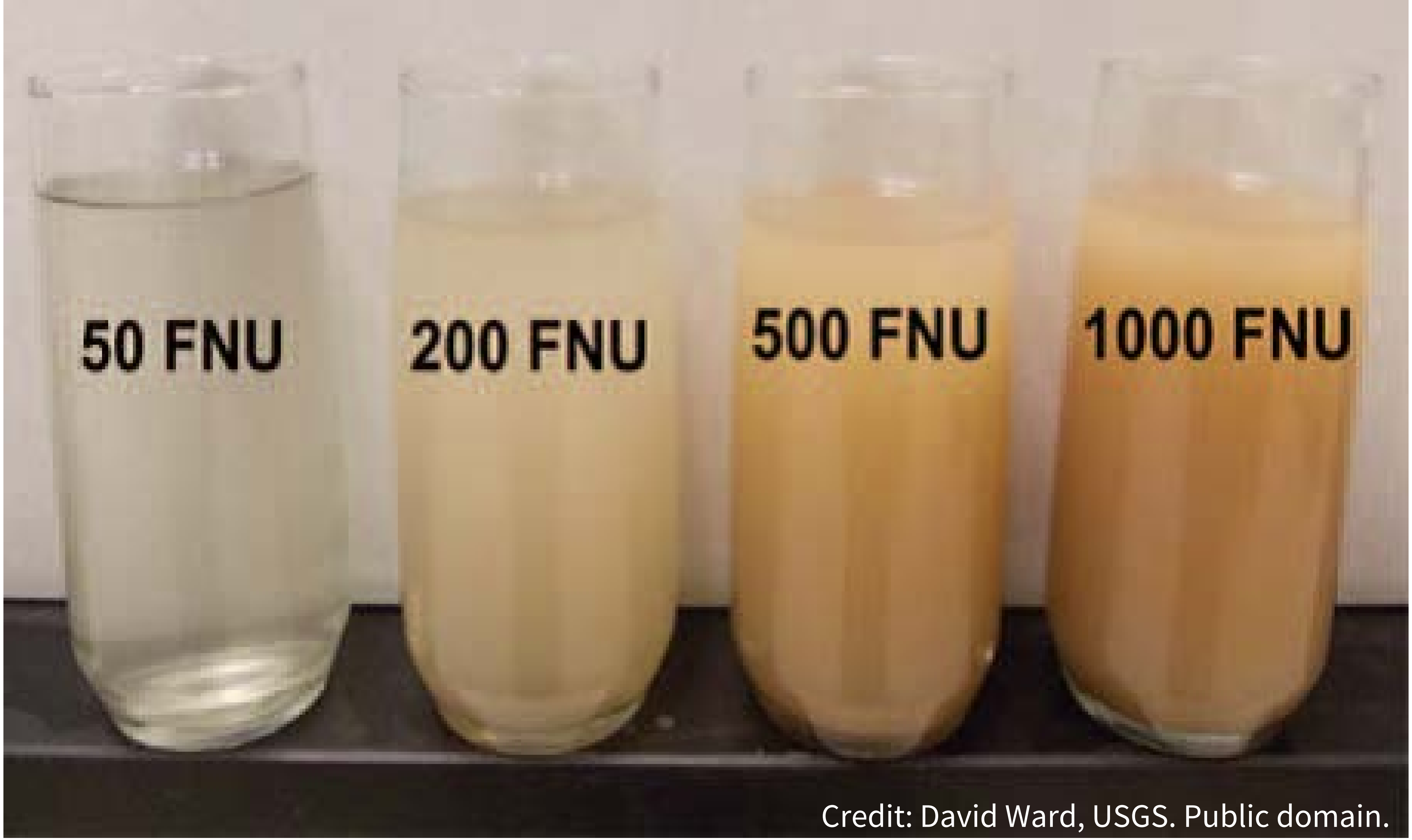
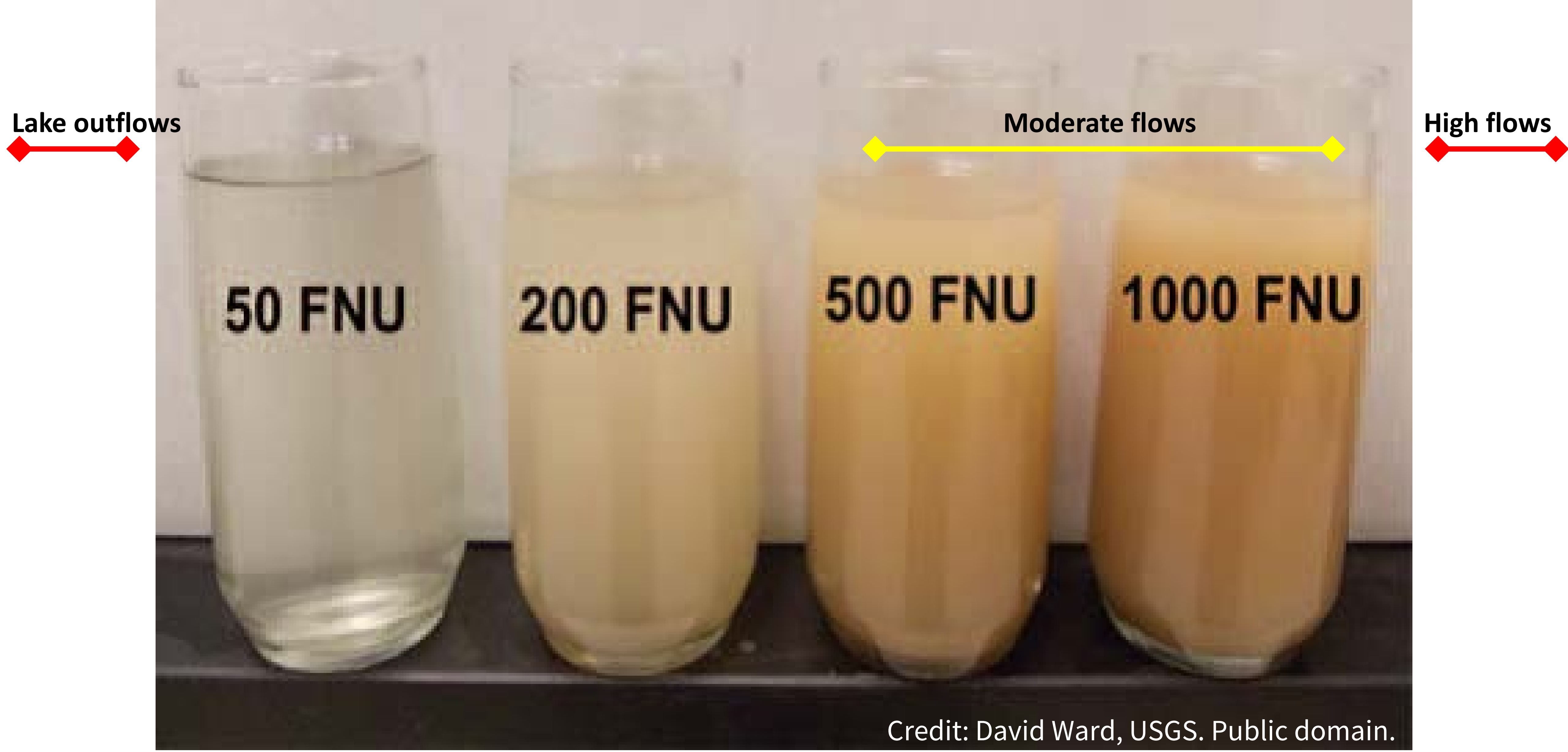
Turbidity needs and issues relating to Kansas River reservoir sediment releases

Aug 25, 2020

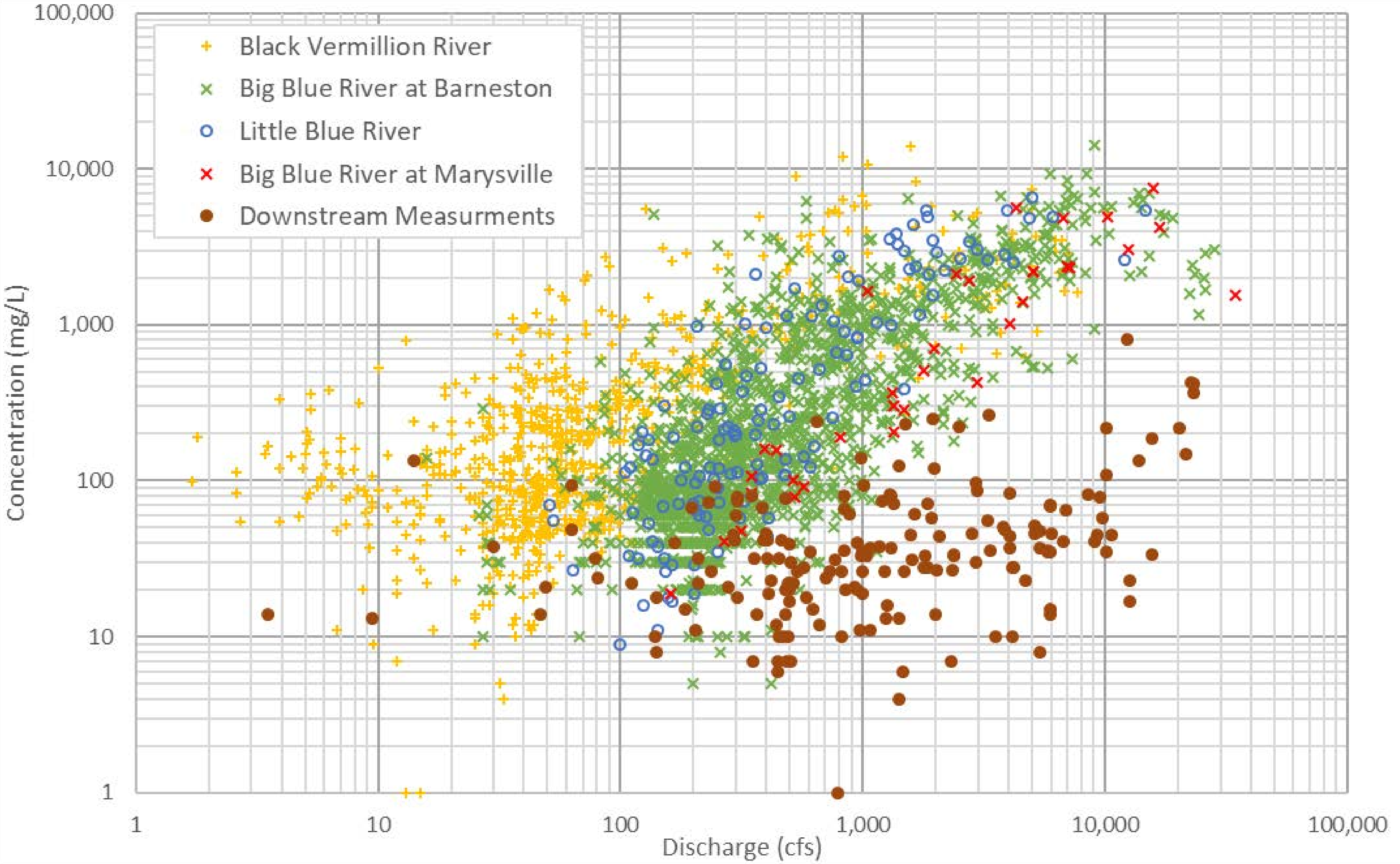
Introduction by John Shelley, Ph.D., P.E.



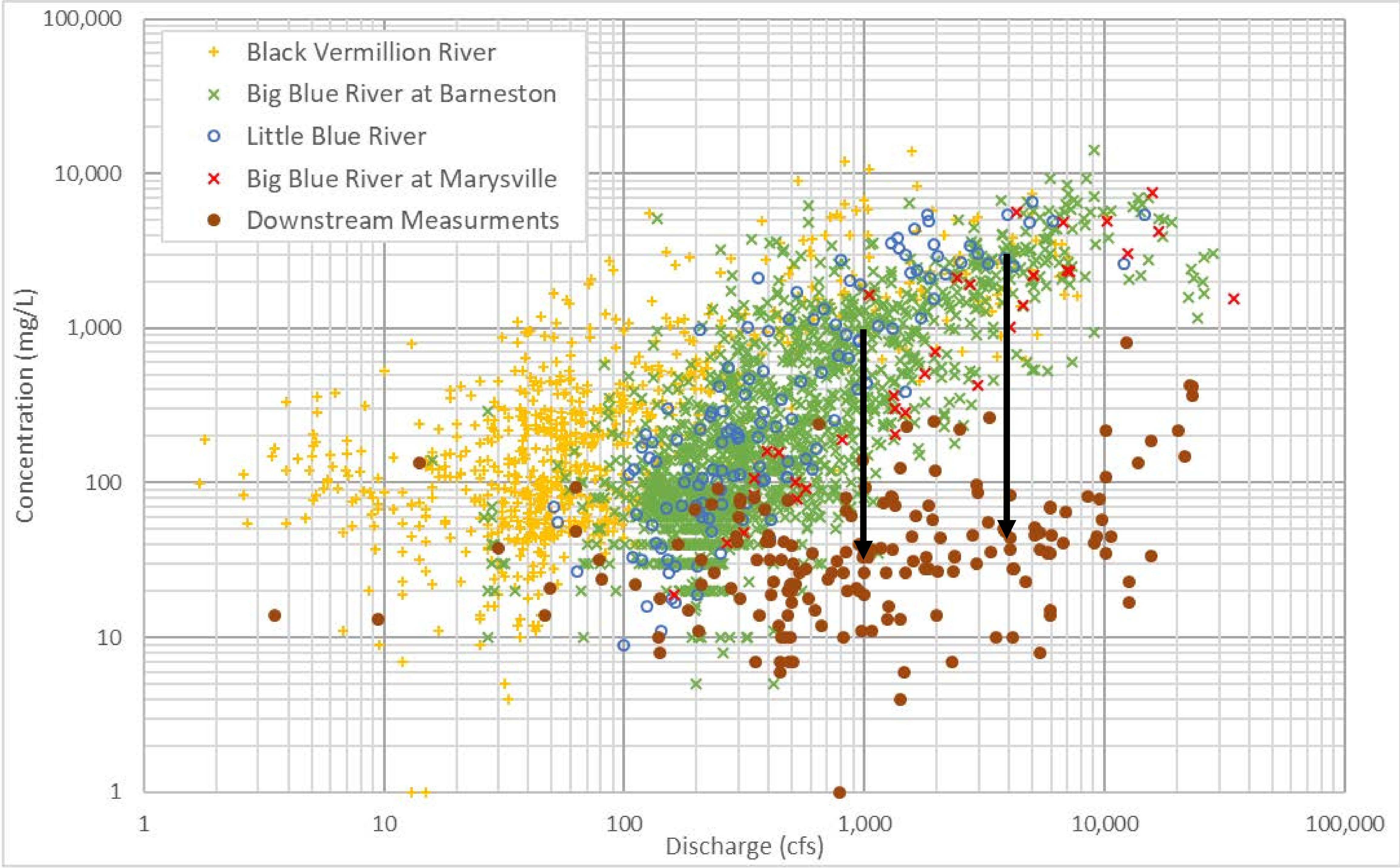
Credit: David Ward, USGS. Public domain.



Credit: David Ward, USGS. Public domain.



Black Vermillion River
Big Blue River at Barneston
Little Blue River
Big Blue River at Marysville
Downstream Measurments
Concentration (mg/L)
100,000
10,000
1,000
100
10
1
Discharge (cfs)
1
10
100
1,000
10,000
100,000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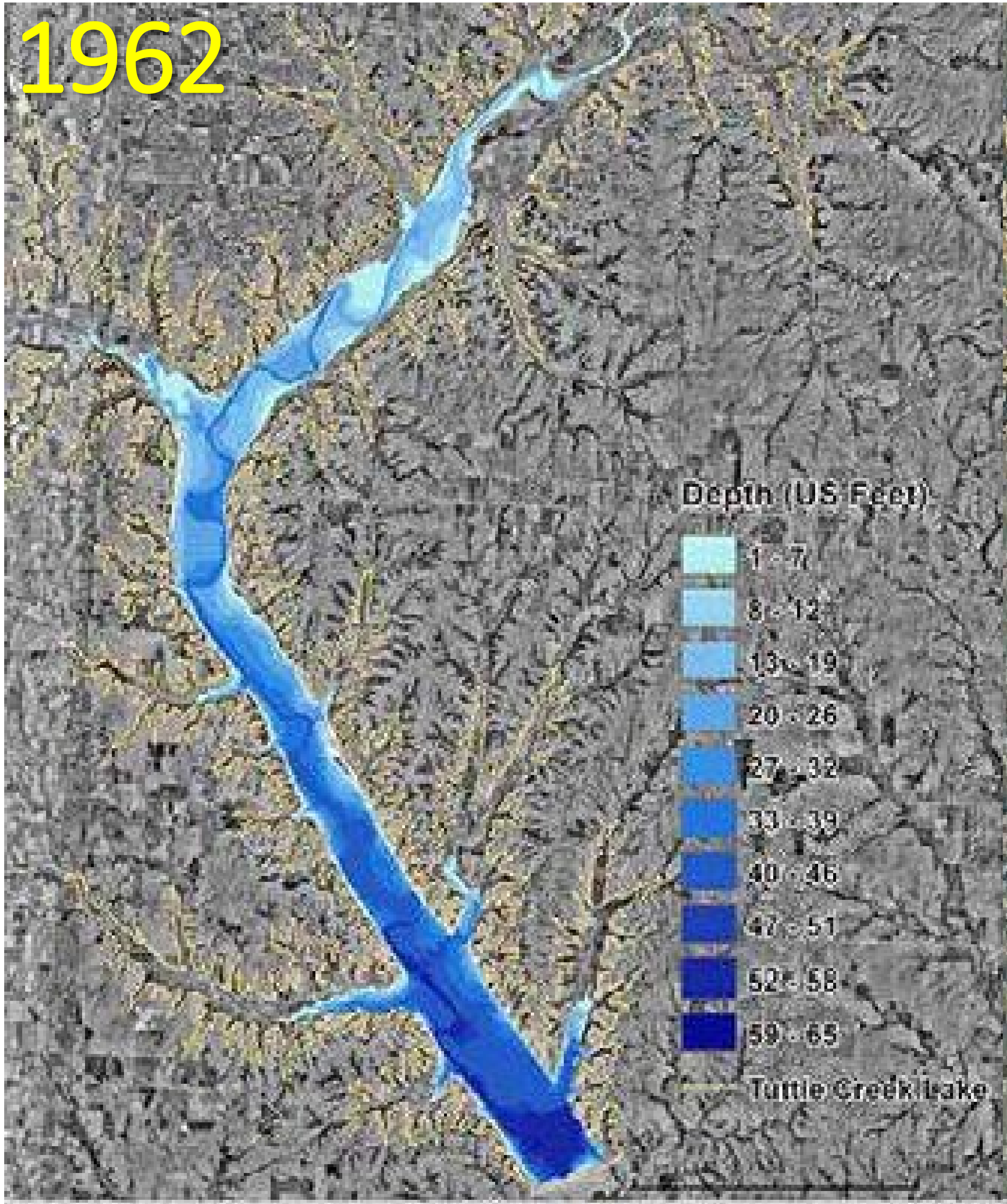
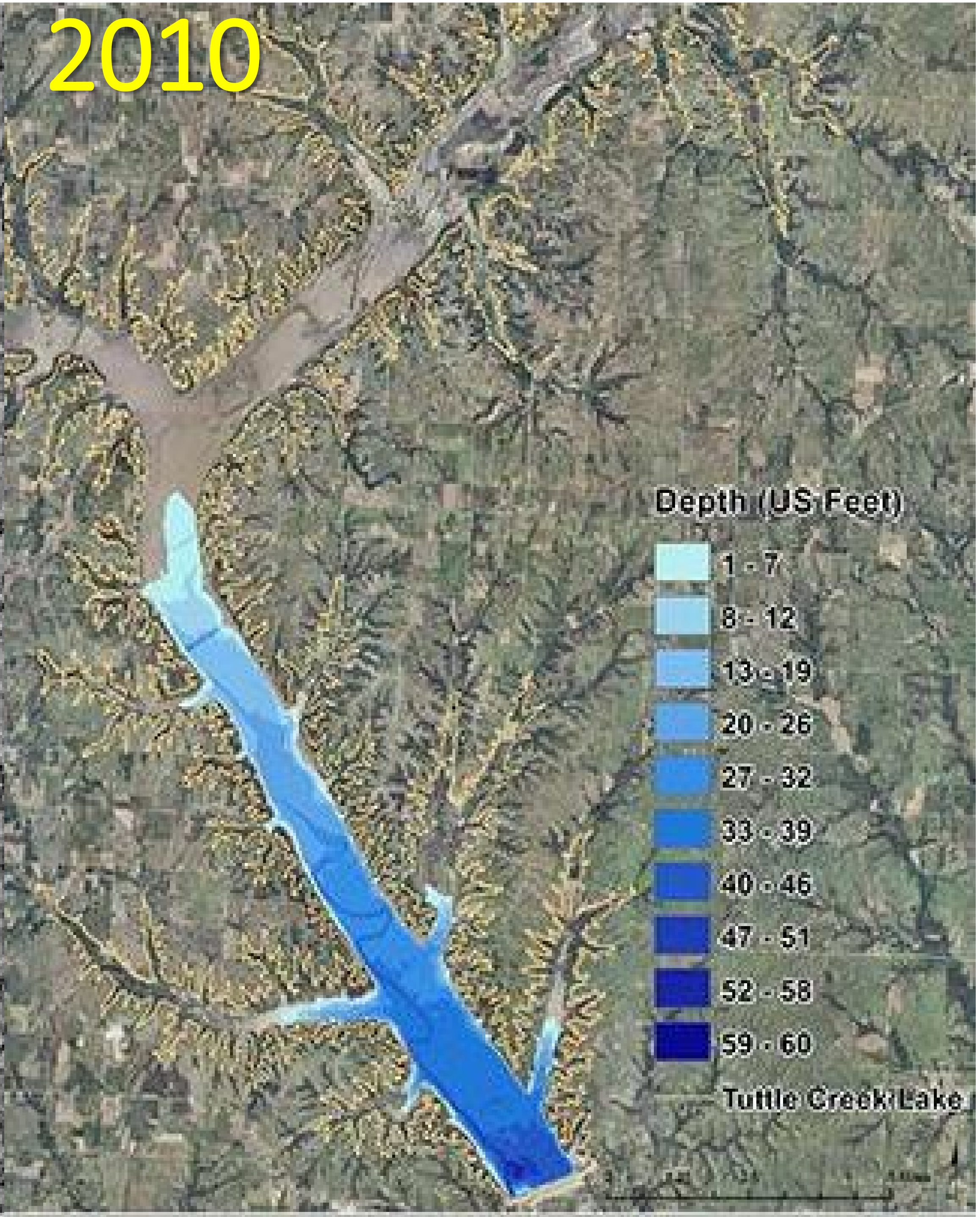
1962


Depth (US Feet)
1 - 7
8 - 12
13 - 19
20 - 26
27 - 32
33 - 39
40 - 46
47 - 51
52 - 58
59 - 65
Tuttle Creek Lake

2010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27 - 32
33 - 39
40 - 46
47 - 51
52 - 58
59 - 60
Tuttle Creek Lake

But what about the downstream channel?

Matt Kondolf, Ph.D.

- Professor at University of California at Berkley
- Internationally recognized expert
- Expertise: Fluvial geomorphology, sediment continuity, trade offs between hydropower and the environment, etc.

https://ced.berkeley.edu/ced/faculty-staff/g-mathias-kondolf

Rollin Hotchkiss, Ph.D., P.E.

- Professor at Brigham Young University
- USACE Environmental Advisory Board

- Internationally recognized expert

- Expertise: Reservoir sediment management, sediment transport, fish passage through culverts, safety at low head dams, etc.

https://scholar.google.com/scholar?hl=en&as_sdt=0%2C26&q=rollin+hotchkiss+reservoir&btnG=

Darixa Hernández-Abrams

- Research Ecologist at the USACE Engineering Research and Development Center
- Expertise: Ecological modeling for planning, restoration, and environmental impact assessments

Keith Gido, Ph.D.

- Professor at Kansas State University
- Expertise: Fish Ecology, Invasive Species Effects, Fish Assemblage Structure, etc.

https://www.k-state.edu/biology/people/tenure/gido/index.html

John Shelley, Ph.D., P.E.

- Sedimentation Engineer, Kansas City District U.S. Army Corps of Engineers

- Expertise: Reservoir sedimentation, quantitative geomorphology, sediment modeling, etc.

https://www.linkedin.com/in/john-shelley-p-e-ph-d-9a97443/

AGENDA

Dr. Matt Kondolf

Dr. Rollin Hotchkiss

Darixa Hernandez-Abrams

Dr. Keith Gido

Discussion

- What do we/don’t we know about sediment and Kansas River ecology?

- What should be monitored during a sediment release/restoration pilot project?

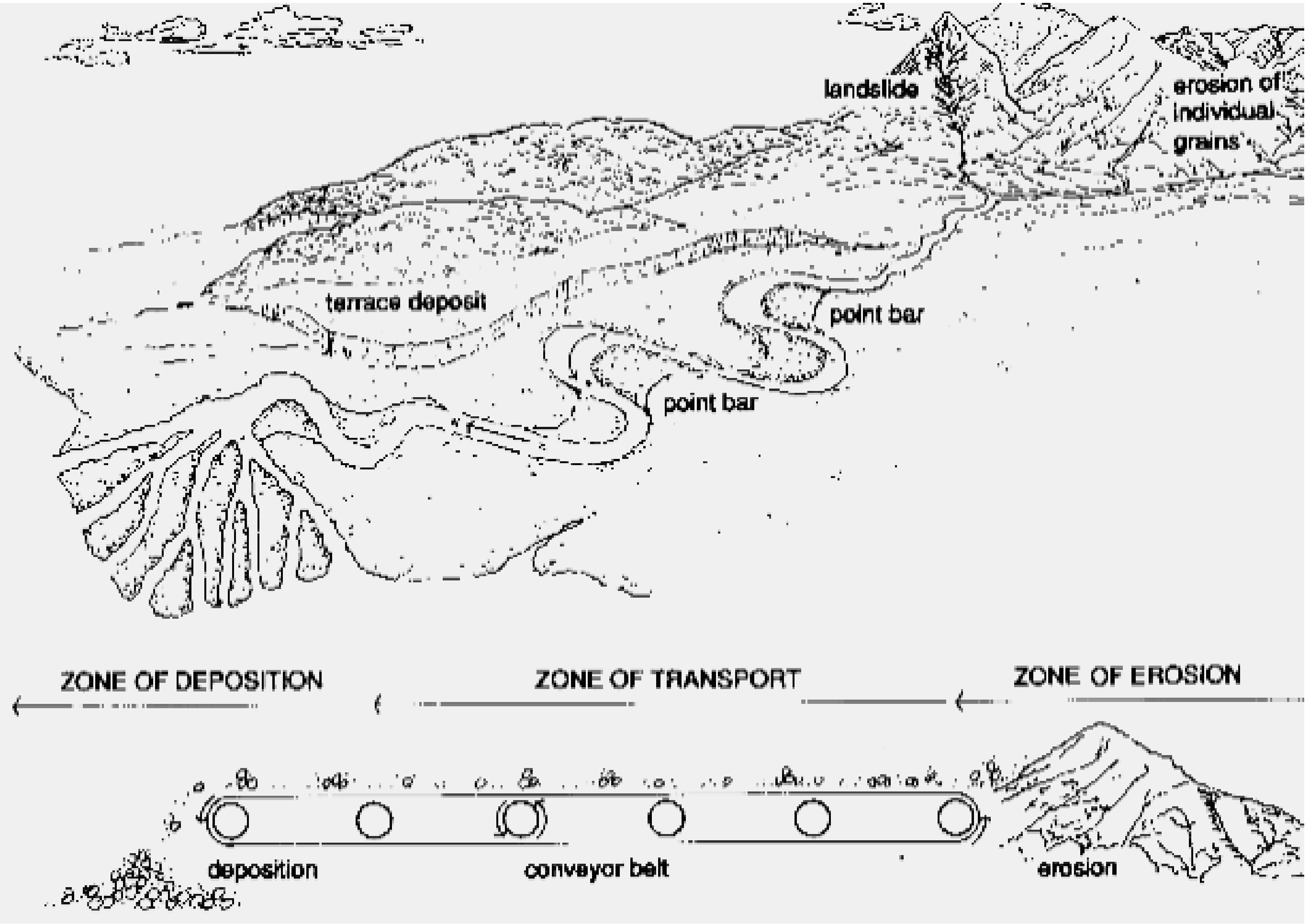
Geomorphic and Ecological Effects of Sediment Trapping by Dams and Management Strategies

G Mathias Kondolf

https://riverlab.berkeley.edu

Berkeley

Rivers carry not only water, but also sediment



Essential to maintain channel form, beaches and deltas

Transport zone = a conveyor belt

Over geologic time, sediment is in motion

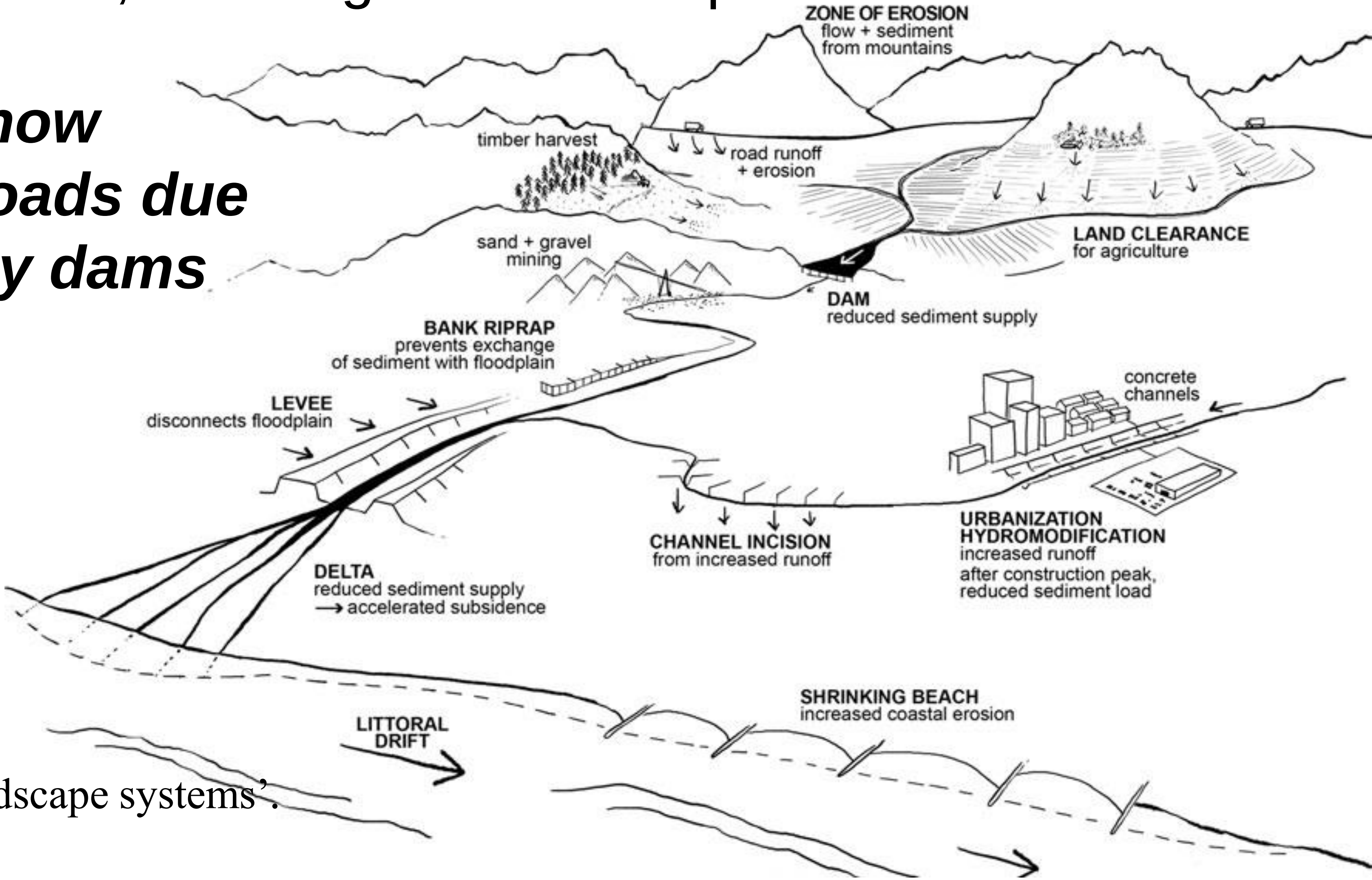
Temporary storage in bars, floodplains,

Source: Kondolf 1997 'Hungry Water', *Environmental Management*

Dams interrupt this natural continuity of sediment flux.

Many ways in which human activities alter the balance of flow (energy) and sediment load in river basins, inducing channel response.

Globally most rivers show decreasing sediment loads due to sediment trapping by dams



Kondolf and Podolak 2013.
‘Space and time scales in human-landscape systems’.
Environmental Management

Downstream Effects of Sediment-Starved (***Hungry***) Water

Excess energy leads to channel incision (downcutting), which causes:

- undermining of infrastructure
- channel widening/destabilization
- drop in water table
- loss of habitats
- coastal erosion

Sediment starvation compounded by mining sand/gravel from channels

Kondolf 1997. Hungry water: effects of dams and gravel mining on river channels *Environmental Management*

Downstream Effects of Sediment-Starved (***Hungry***) Water

Gravels transported downstream without replacement from upstream.

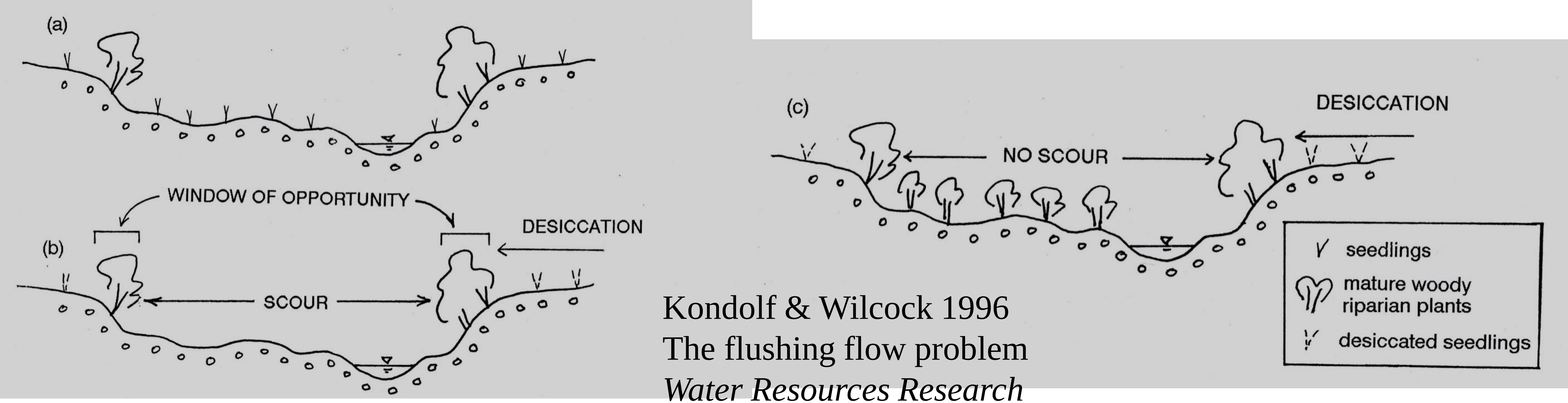
Result:

1. Channel simplification (‘bowling alley’)

Loss of gravel bars, riffles → loss of habitats.

2. Channel narrowing and fossilization by vegetation encroachment

Lack of frequent scouring floods allows trees to establish in active channel.



Kondolf & Wilcock 1996
The flushing flow problem
Water Resources Research

How to compensate for Downstream Sediment Starvation?

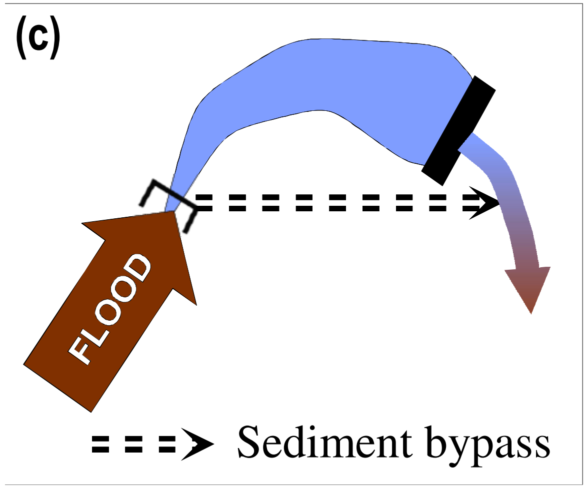
1. Pass sediment through or around dams to restore continuity of sediment transport
2. Mechanically add sediment to channel downstream of dams
3. Induce bank erosion downstream of dams (temporary solution only, benefits from increased complexity of banks from recruited trees)

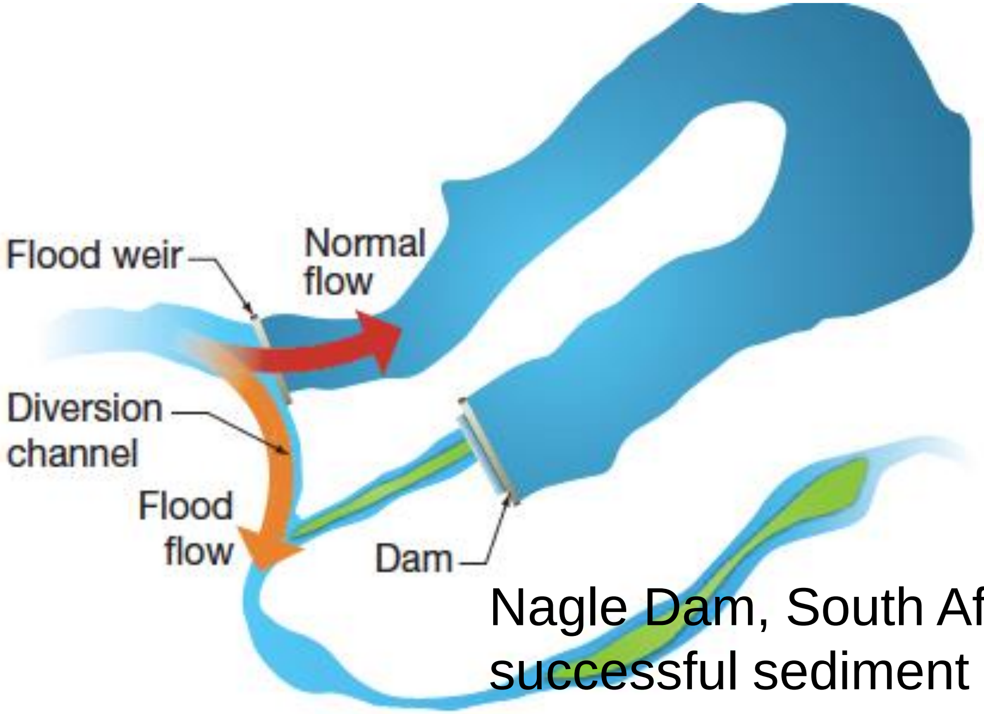
Sediment Bypassing and Diverting to Off-Channel Reservoirs

Sediment-laden waters are bypassed around the reservoir to the river downstream so they never enter the reservoir at all.

Operate only during higher flows moving sediment.

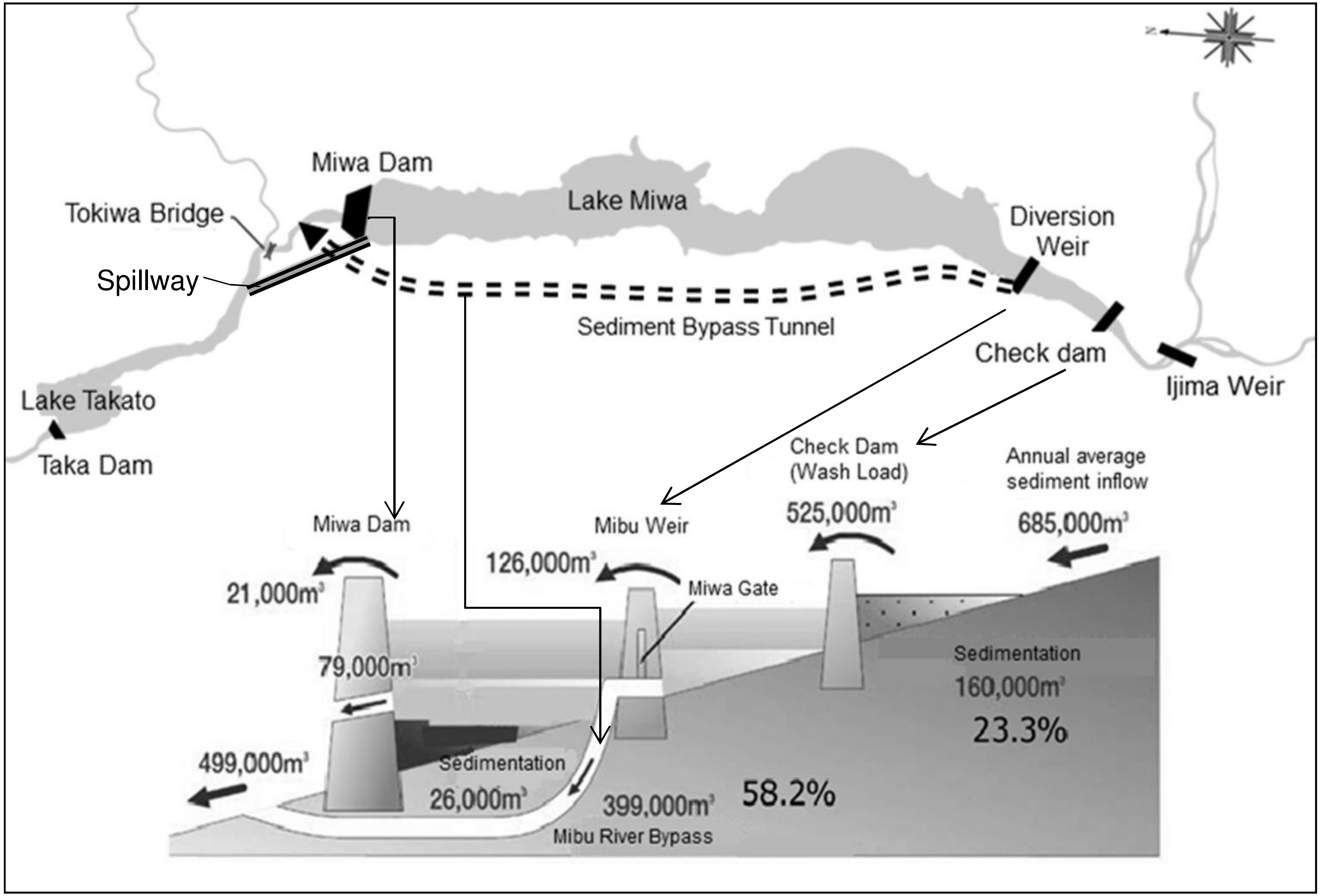
The ideal geometry: bypass as ‘shortcut’ through a river bend





Nagle Dam, South Africa: successful sediment bypass

Kondolf et al 2014 ‘Sustainable sediment management: experiences from five continents’ *Earth’s Future*

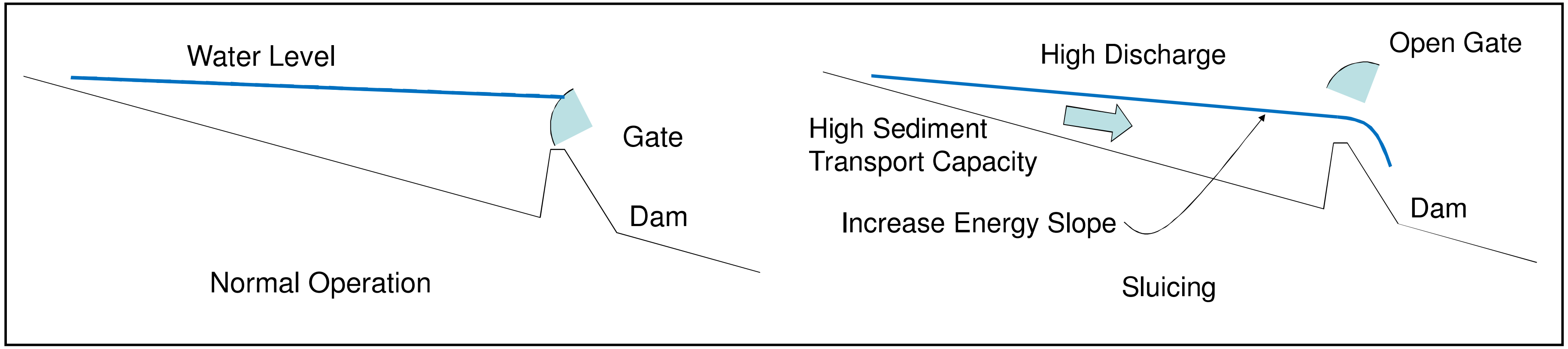


A well-documented example is the Miwa Dam, Japan.
Dam built 1959, filling with sed, so bypass tunnel built 2005.

as documented by Sumi, Kantoush and colleagues

Sediment Sluicing (aka Downstream Routing)

Discharging high flows through the dam during high inflows, to permit sediment to be transported through the reservoir and dam *without being deposited*.



“Release muddy water, store clear water” (Wang&Hu 2009)

Most effective for sand size and smaller sediments.

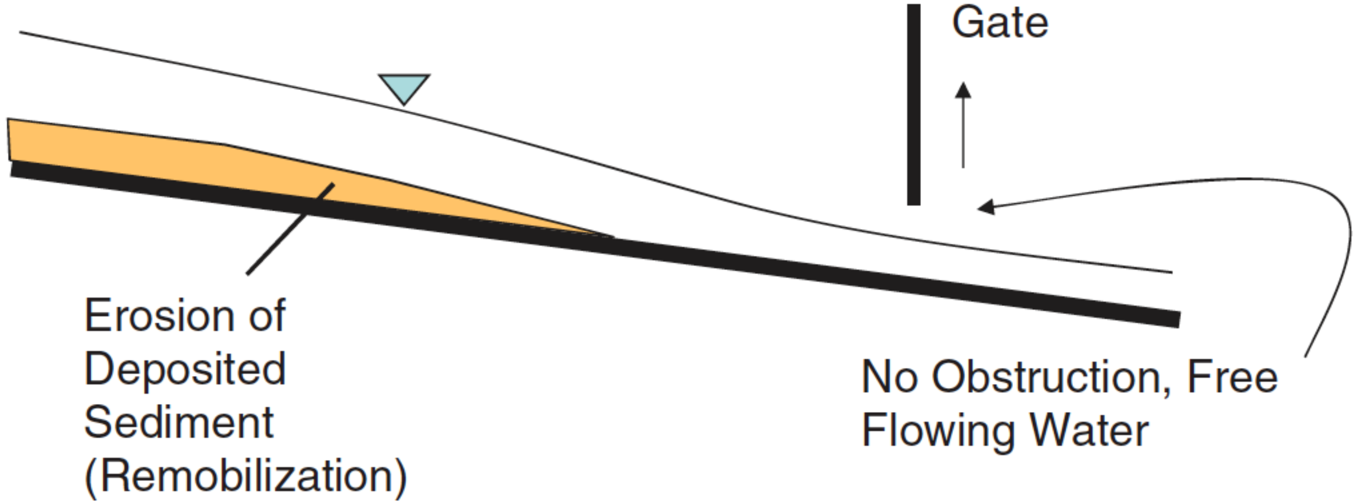
Works best in long, narrow reservoirs with steep slopes.

*-Design for **Three Gorges Reservoir**: 600km long, <1.5km wide*

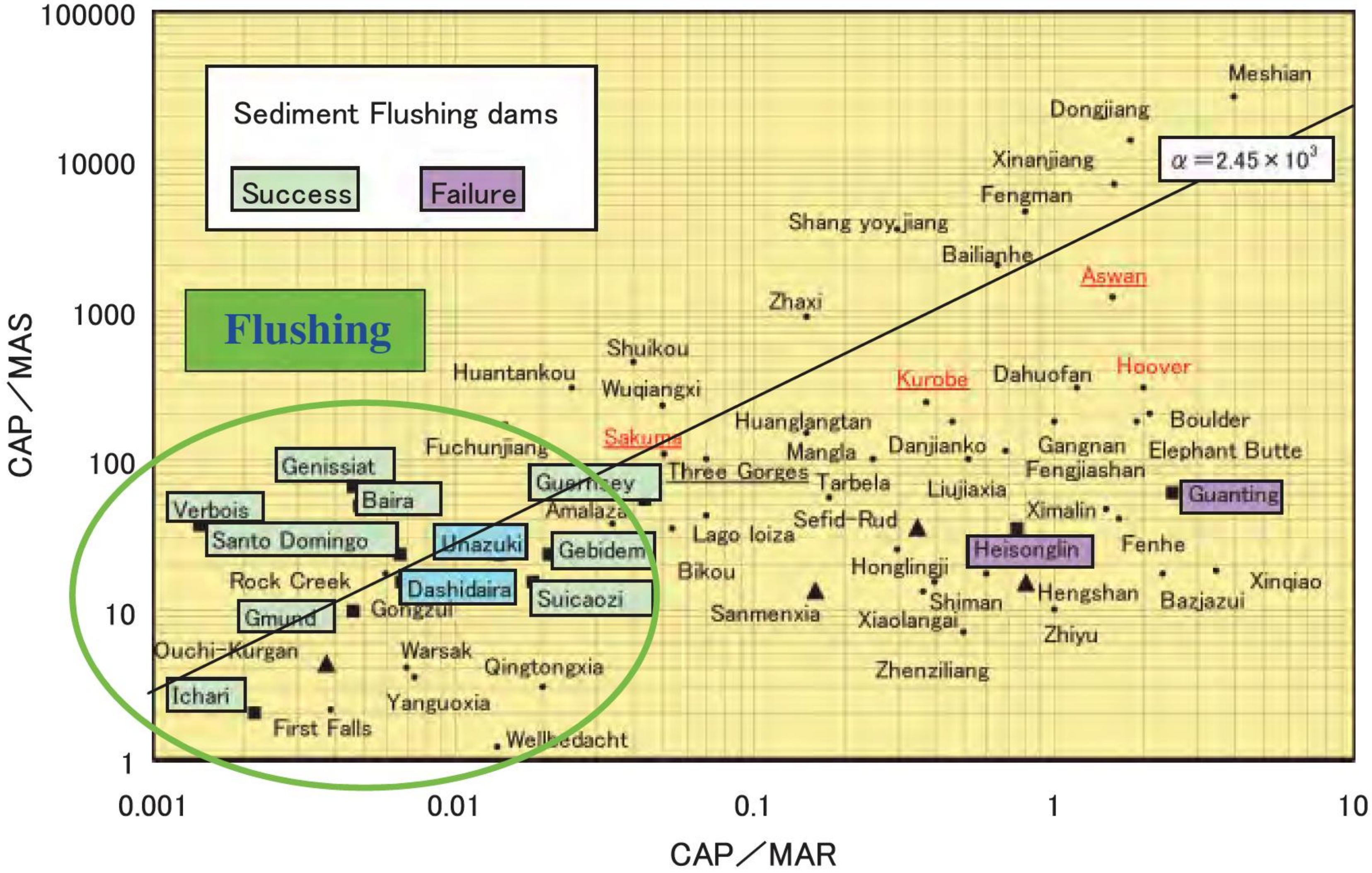
*-But also **John Redmond Reservoir**: nearly circular in plan, but minor changes in operation (reducing flood-detention time) result in decreased trap efficiency* (Lee and Foster 2013)

Drawdown Flushing

Draw down reservoir, let river flow through reservoir, entraining sediment.



If done during low-flow periods, can cause downstream impacts for deposition of sediment and anoxia from organic-rich sediments in reducing environment at bottom of reservoir.



Like sluicing, flushing works best in hydrologically small reservoirs.

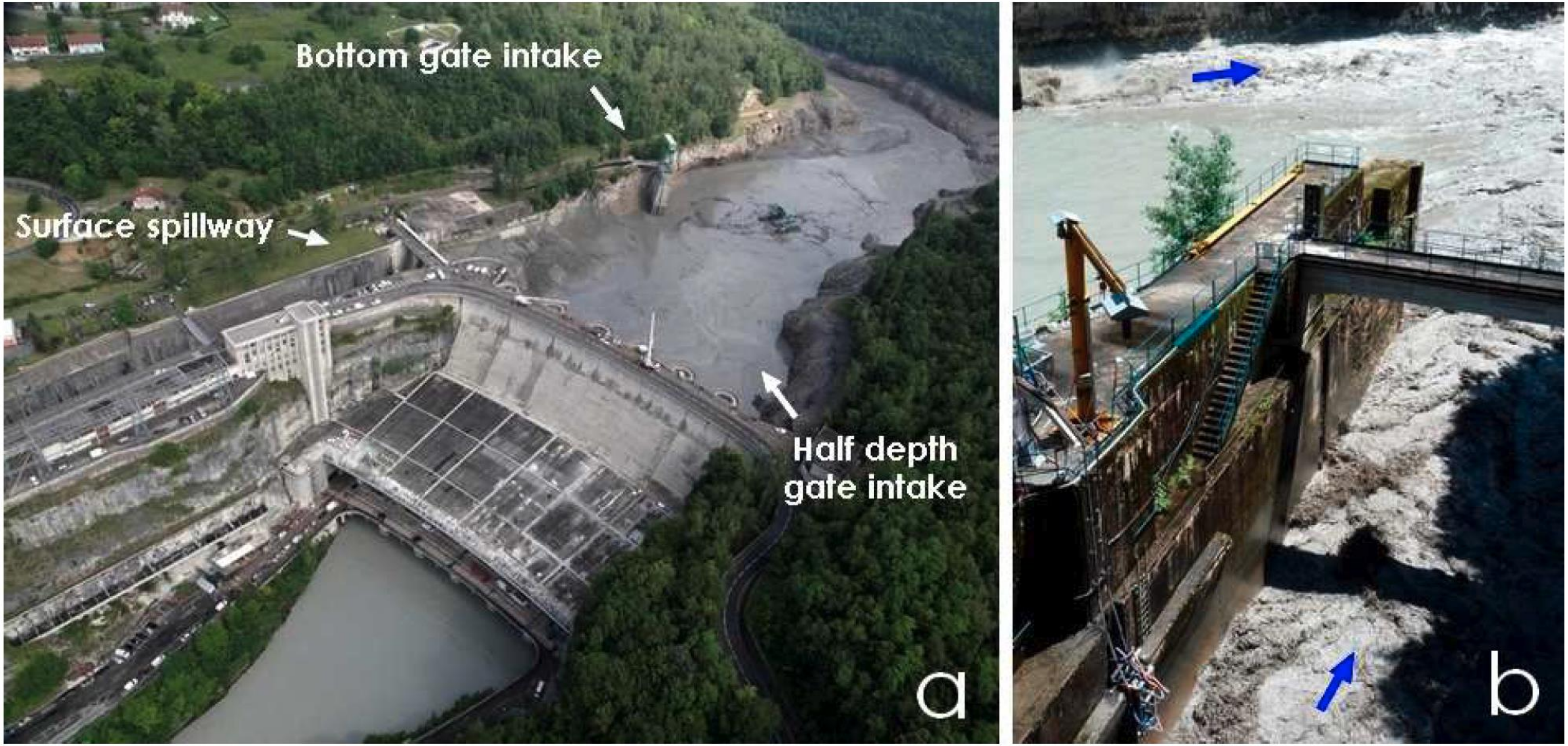
But downstream issues have been documented in many systems, including the Ebro River basin. (Batalla and Vericat 2009)

Example of flushing sediments through reservoirs in series: Génissiat Dam, Upper Rhone River, Switzerland-France

Peteuil 2012 Eco-friendly flushing downstream Génissiat Dam, Upper Rhone River, France. Proc Conf 5th Int Yellow R Forum

View upstream to confluence of Rhone (left) and Arvre (right) showing contrast in sediment concentrations.

Peteuil 2012 Eco-friendly flushing downstream Génissiat Dam, Upper Rhone River, France. Proc Conf 5th Int Yellow R Forum



Génissiat dam during the 2012 flushing operation

Peteuil 2012 Eco-friendly flushing downstream Génissiat Dam,
Upper Rhone River, France. Proc Conf 5th Int Yellow R Forum

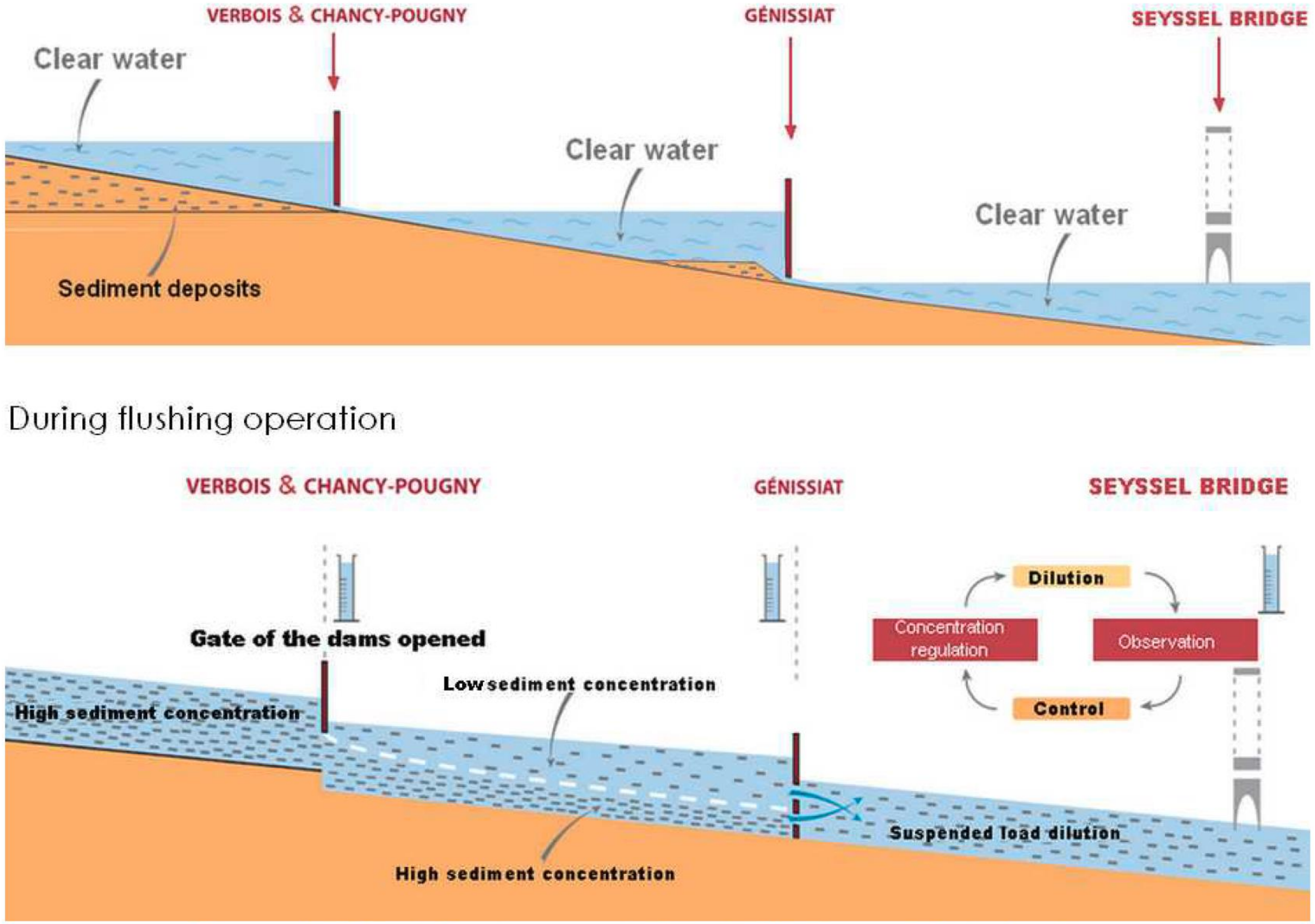
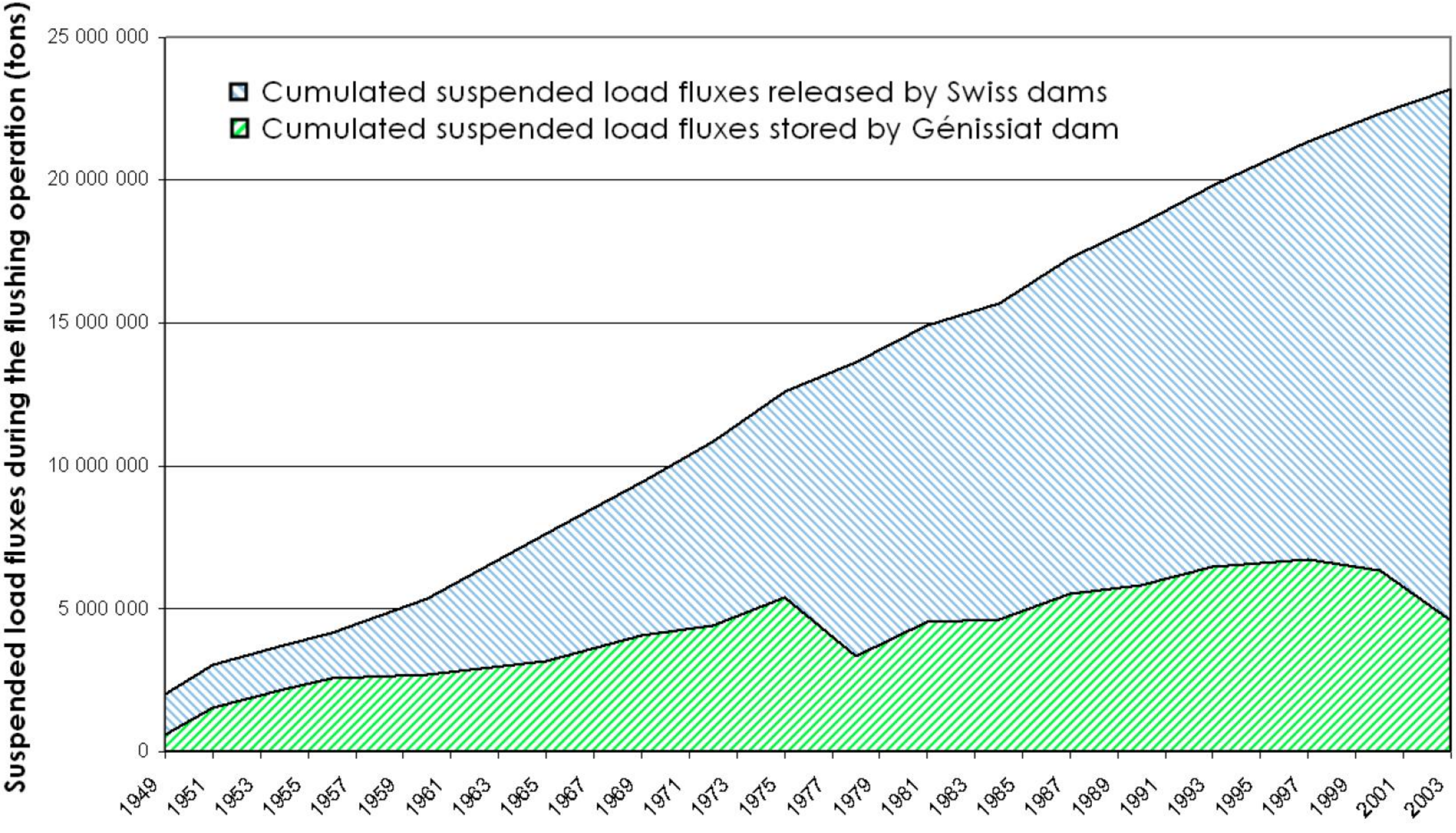

During flushing operation

Figure 4: Principle of suspended load dilution at Génissiat dam.

Maximum suspended sediment concentration permitted below Génissiat dam based on ecological standards: Average concentration during the entire operation: below 5 g/l;

Average concentration during a continuous period of 30 minutes: below 15 g/l

Peteuil 2012 Eco-friendly flushing downstream Génissiat Dam, Upper Rhone River, France. Proc Conf 5th Int Yellow R Forum



Long-term maintenance of reservoir storage capacity (and prevention of backwater flooding of Geneva) due to periodic flushing

Peteuil 2012 Eco-friendly flushing downstream Génissiat Dam, Upper Rhone River, France. Proc Conf 5th Int Yellow R Forum

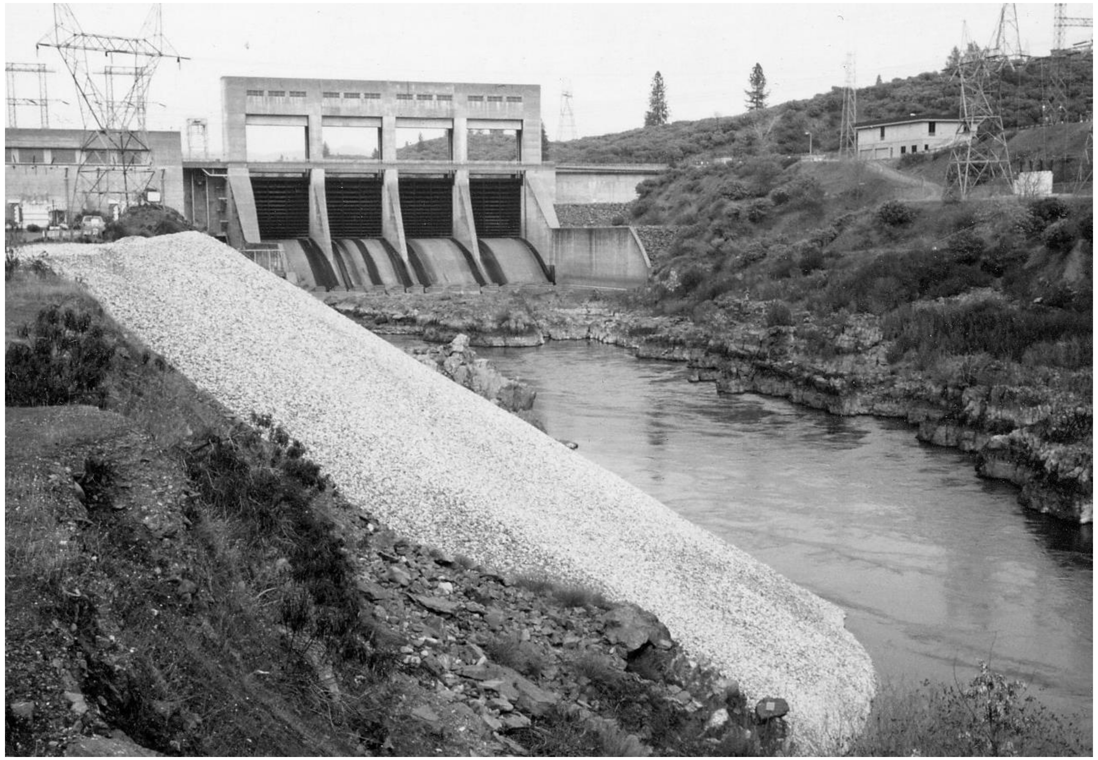
Gravel Augmentation Below Dams

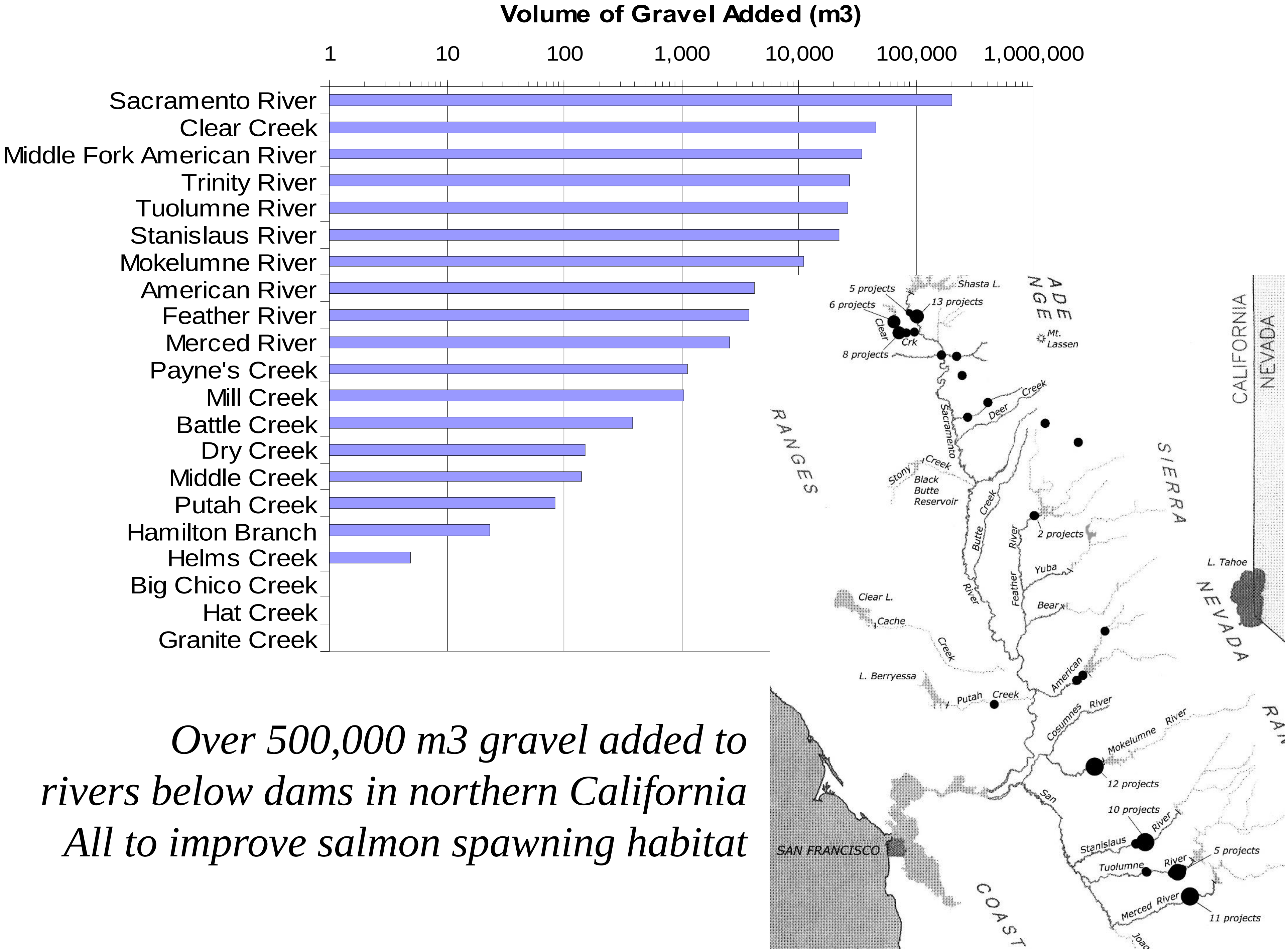
Artificially adding gravel below dams to compensate for sediment starvation

Goals: - salmonid habitat enhancement,
- protect infrastructure from incision,
- restore coarse sediment load

Two approaches:

1. Build artificial riffles (restore form)
2. inject gravel for redistribution by flows (restore process)



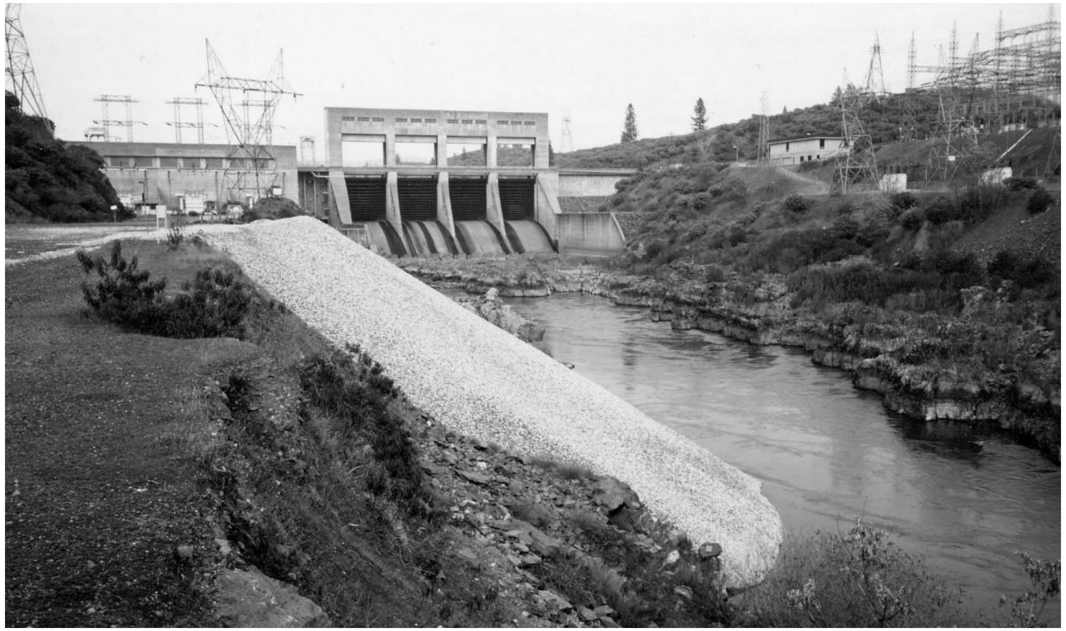


Over 500,000 m3 gravel added to rivers below dams in northern California All to improve salmon spawning habitat

Artificial riffles designed to create spawning habitat by creating the forms, Trinity River

Evolution: from early attempts to directly create fish habitat to restoring sediment supply so river can create its own complex features

Gravel injection below Lewiston Dam, Trinity River

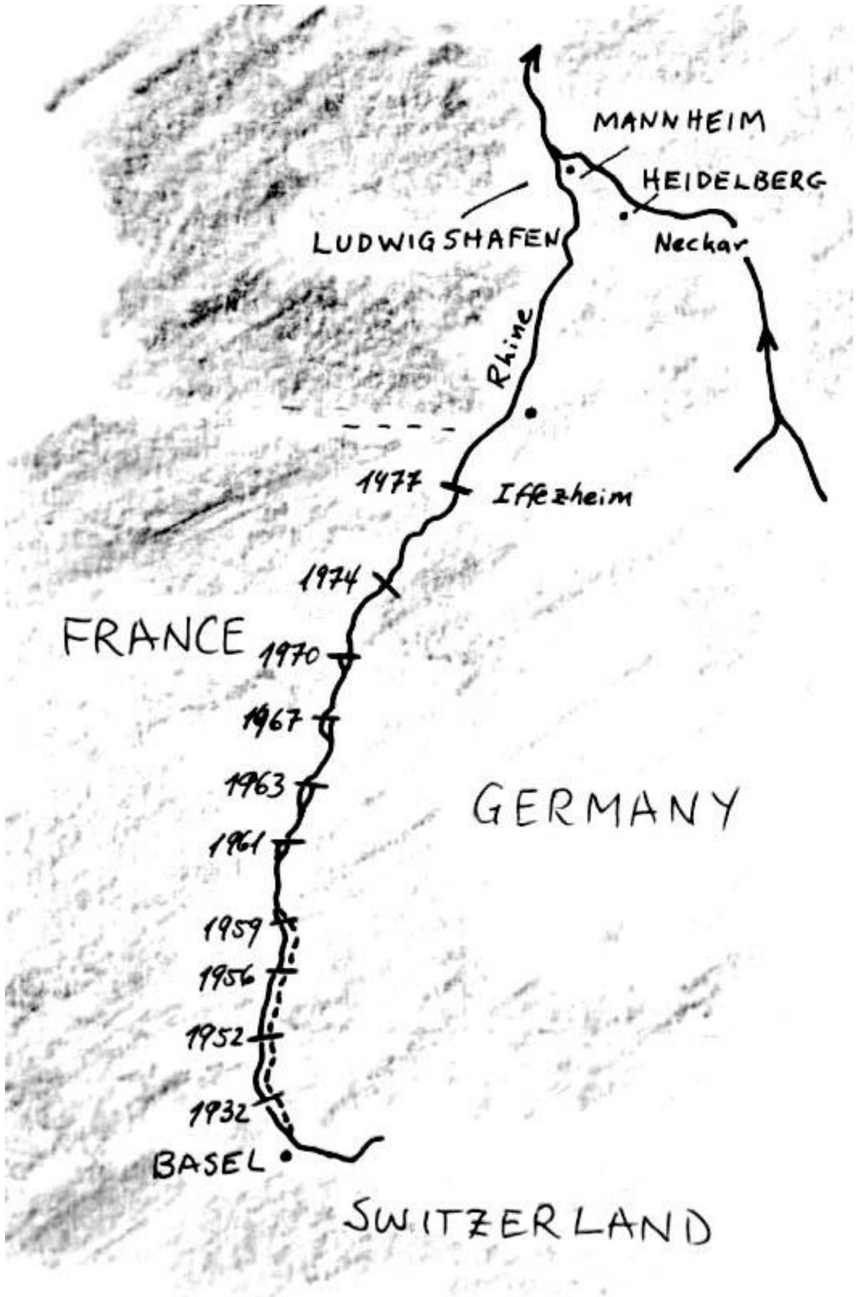


Gravel high-flow stockpile below Keswick Dam, Sacramento River

The largest gravel augmentation project is not for habitat but infrastructure on

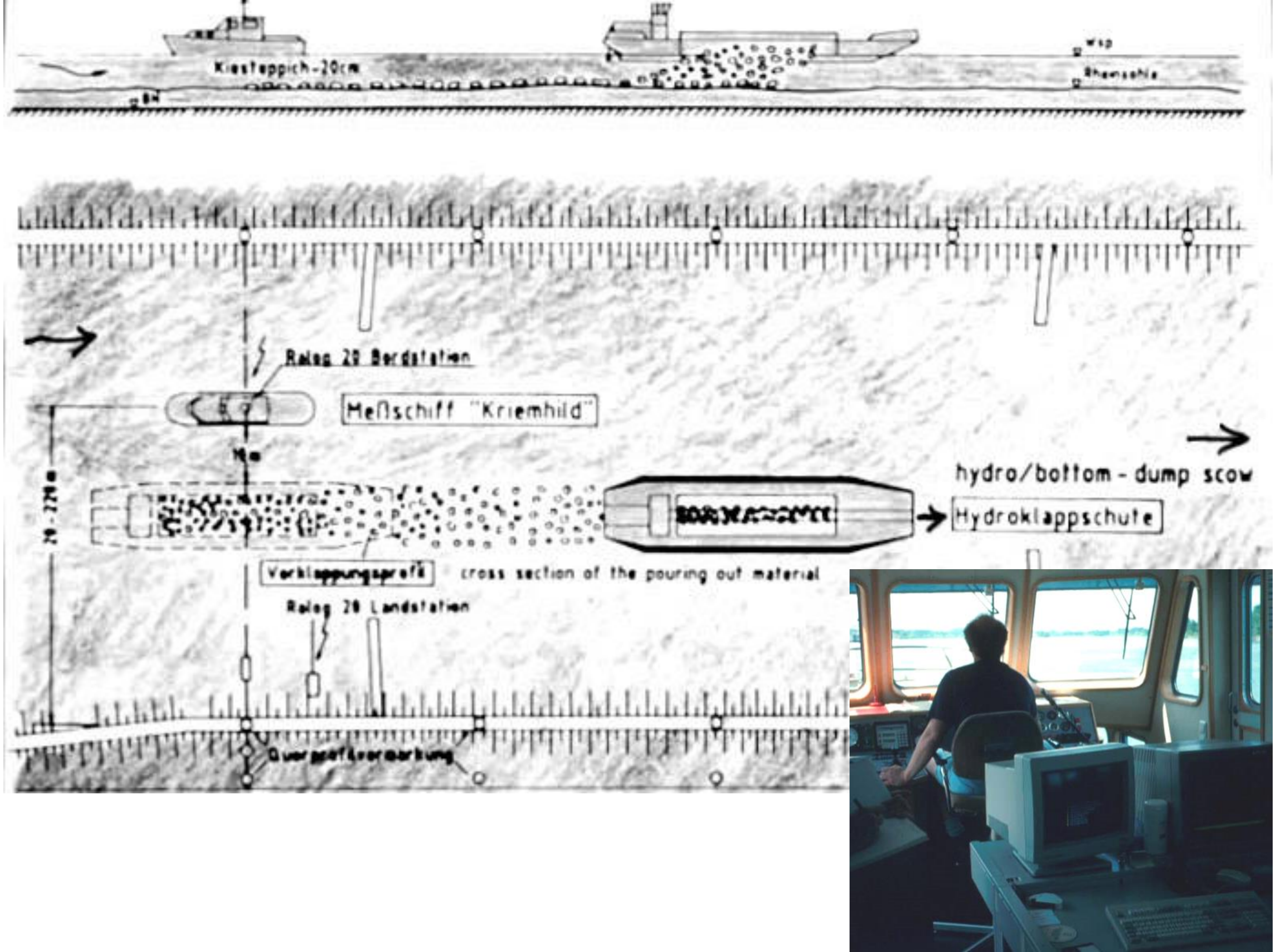
The French-German Rhine

Series of hydroelectric dams built progressing downstream

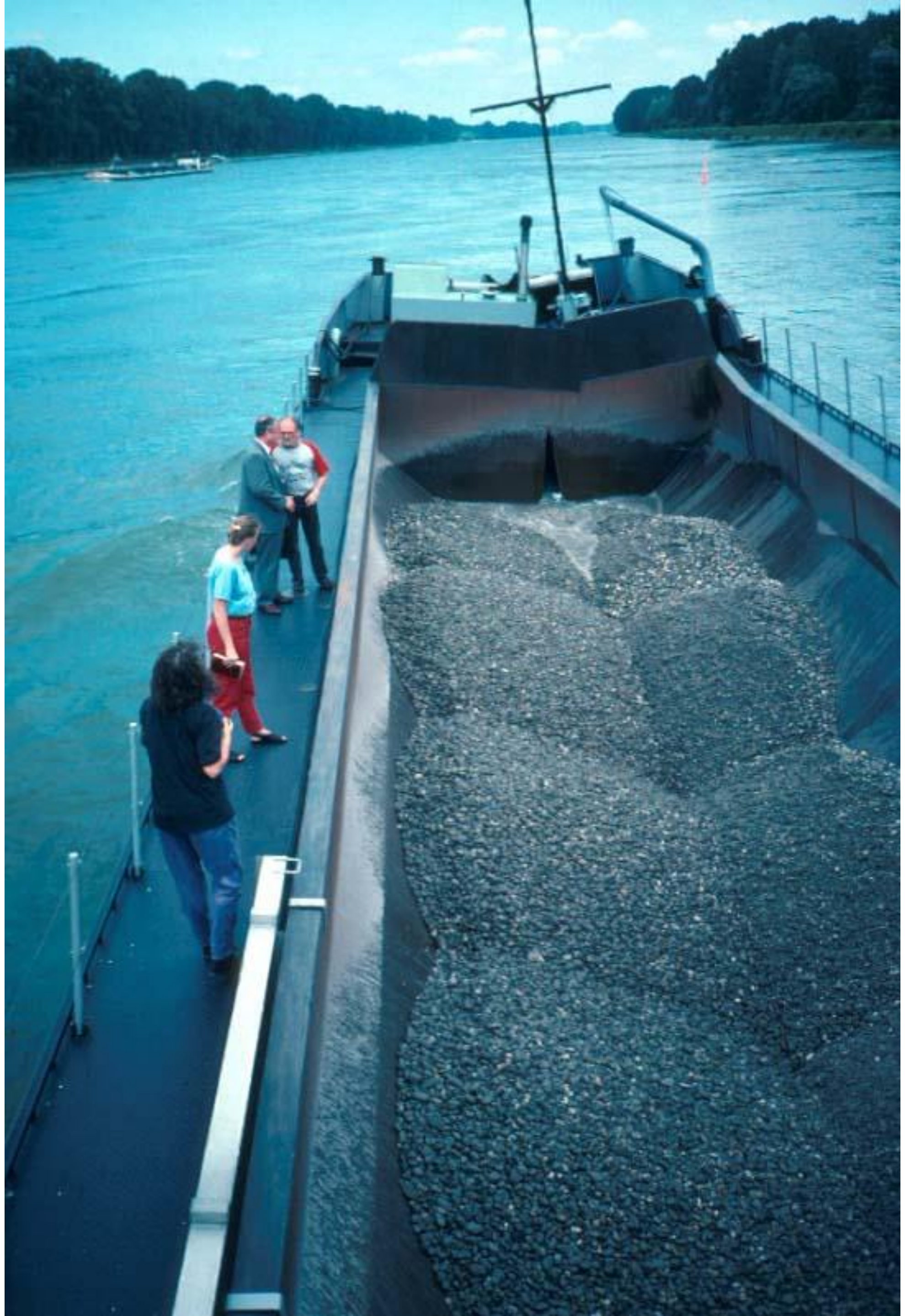


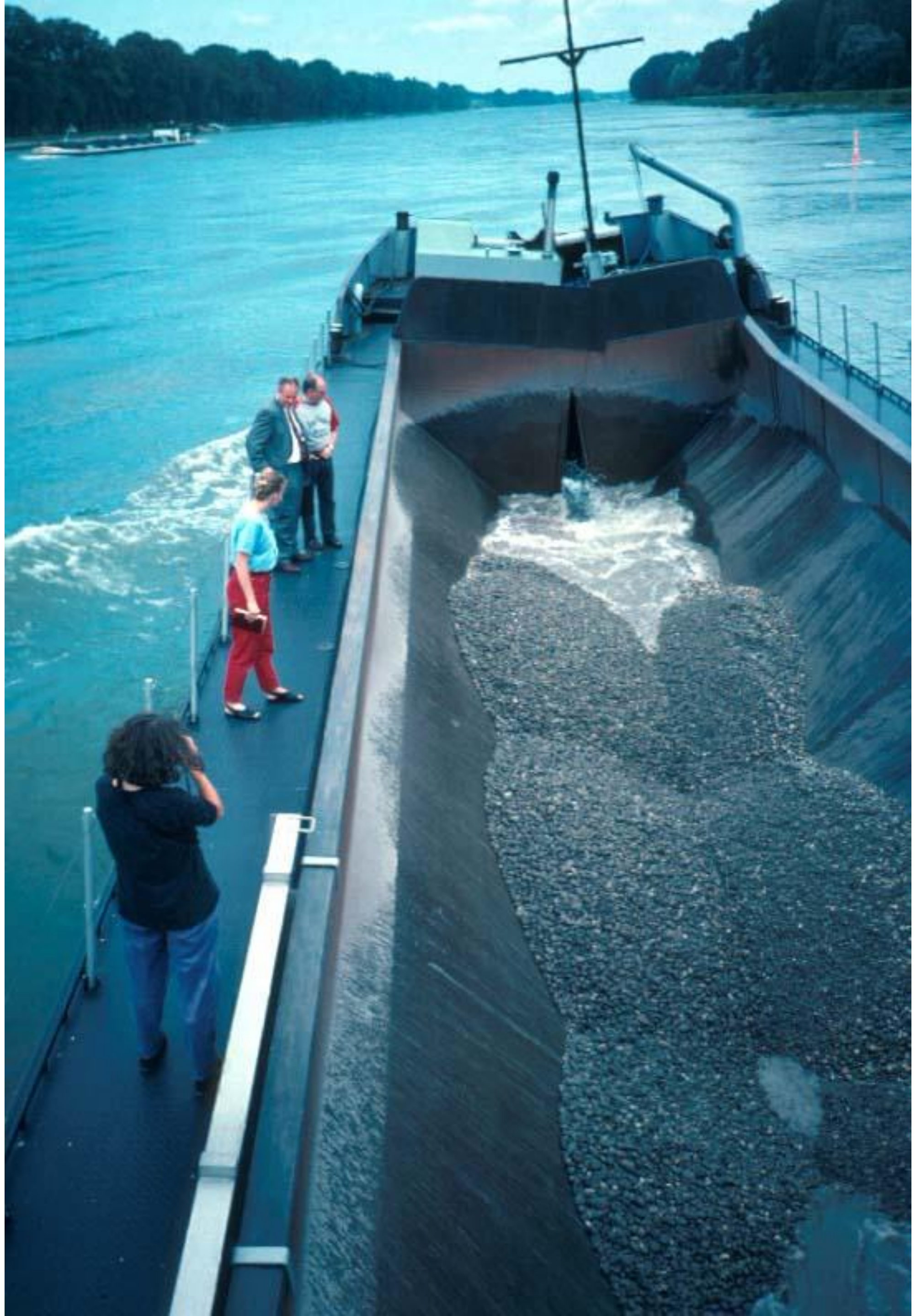
Below Iffezheim, adding gravel to compensate sediment deficit

Two barges operate 355 days/year
Add avg 170,000m3 gravel&sand, enough to meet the current sediment transport capacity of the Rhine



Kiesteppich-20cm
wsp
Rheinsohle
BH
Raleg 20 Bordstation
Meßschiff "Kriemhild"
10m
20-220m
hydro/bottom-dump scow
Hydroklappschute
Verklappungsprofil
cross section of the pouring out material
Raleg 20 Landstation
Querprofilvermarkung

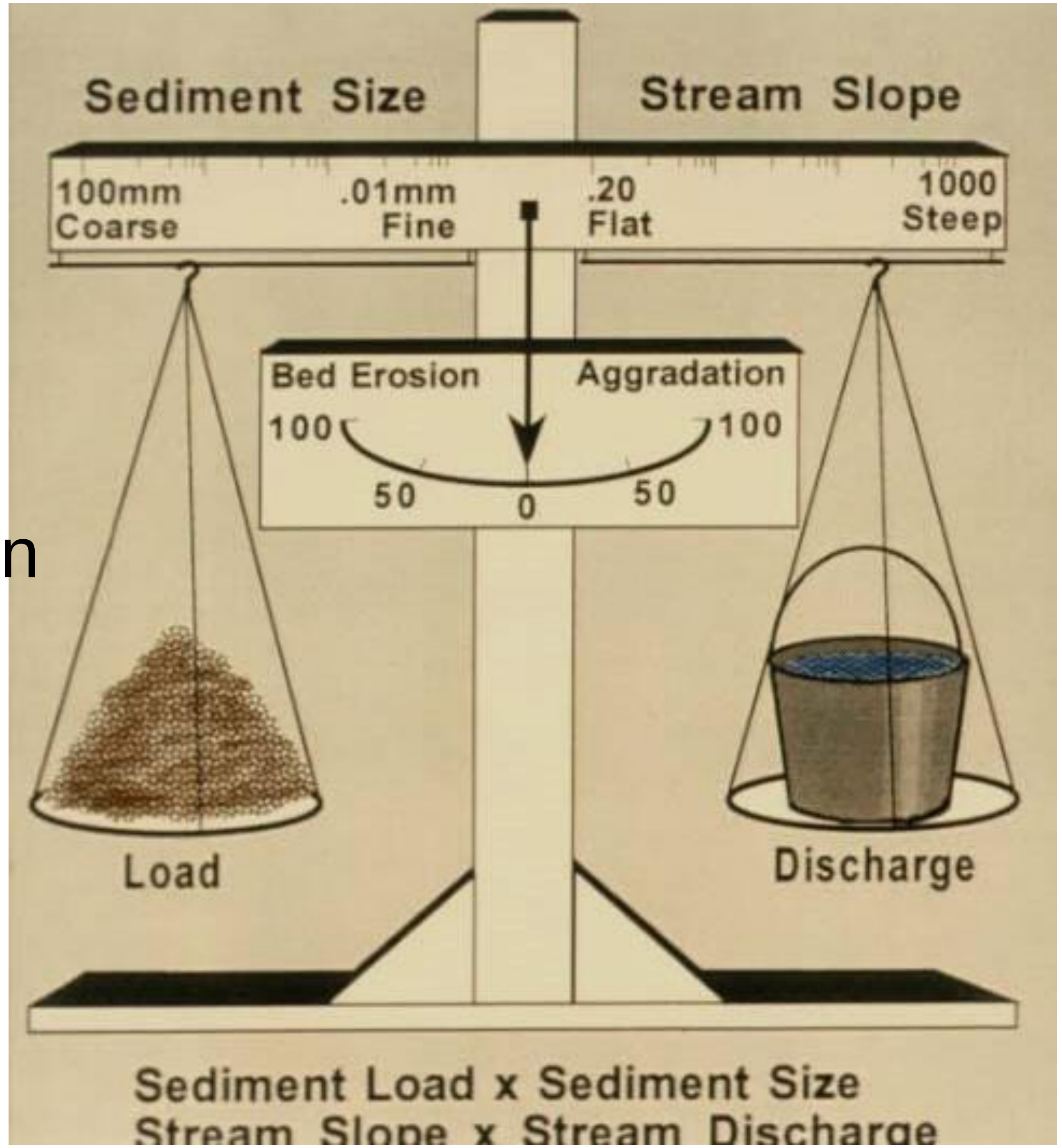


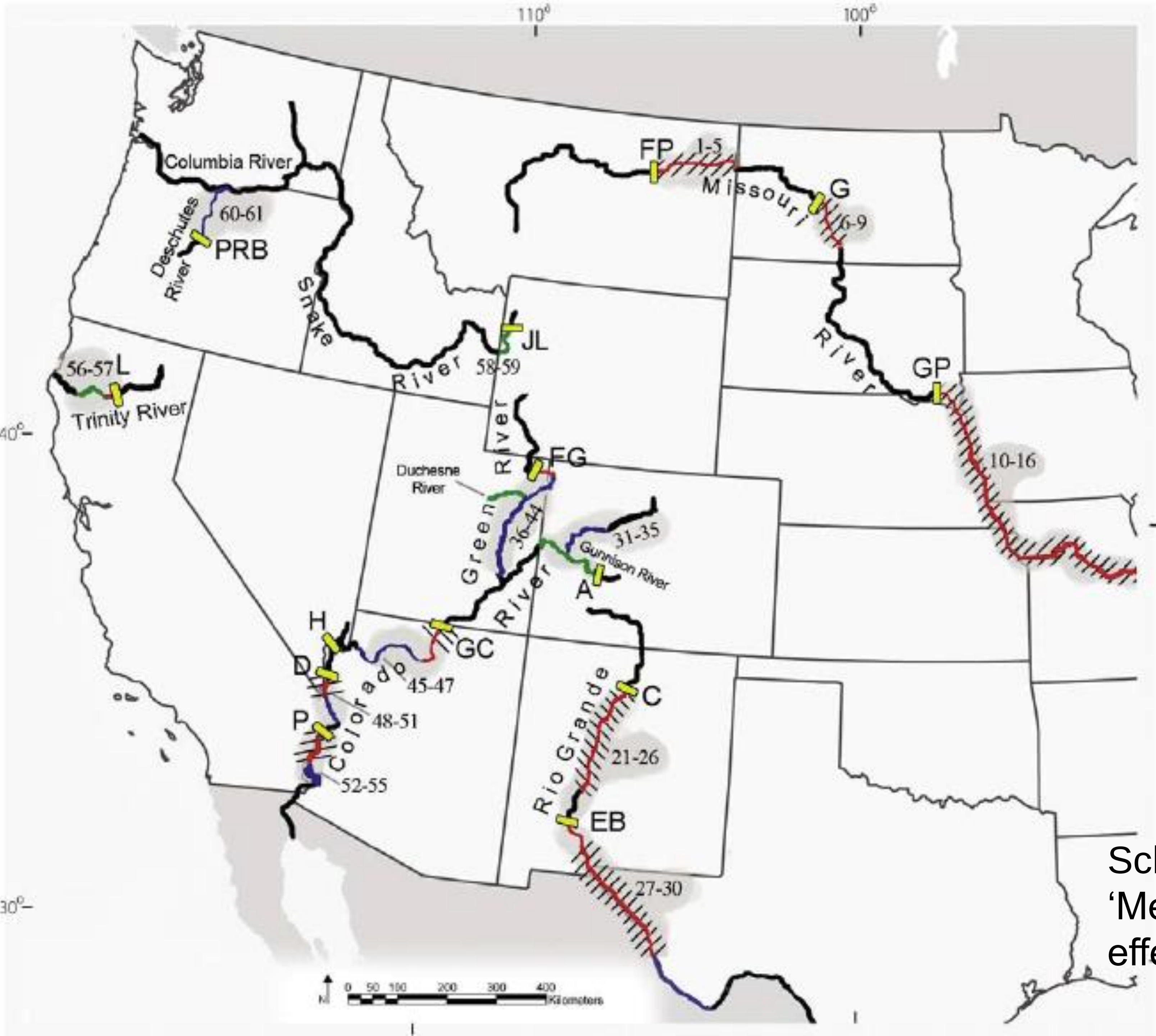


Whether *Hungry Water* occurs depends on the balance between transport energy and sediment supply for a given river reach.

If sediment supply is reduced more than transport energy: *hungry water*

If stream power is reduced more than sediment load: *sediment surplus*





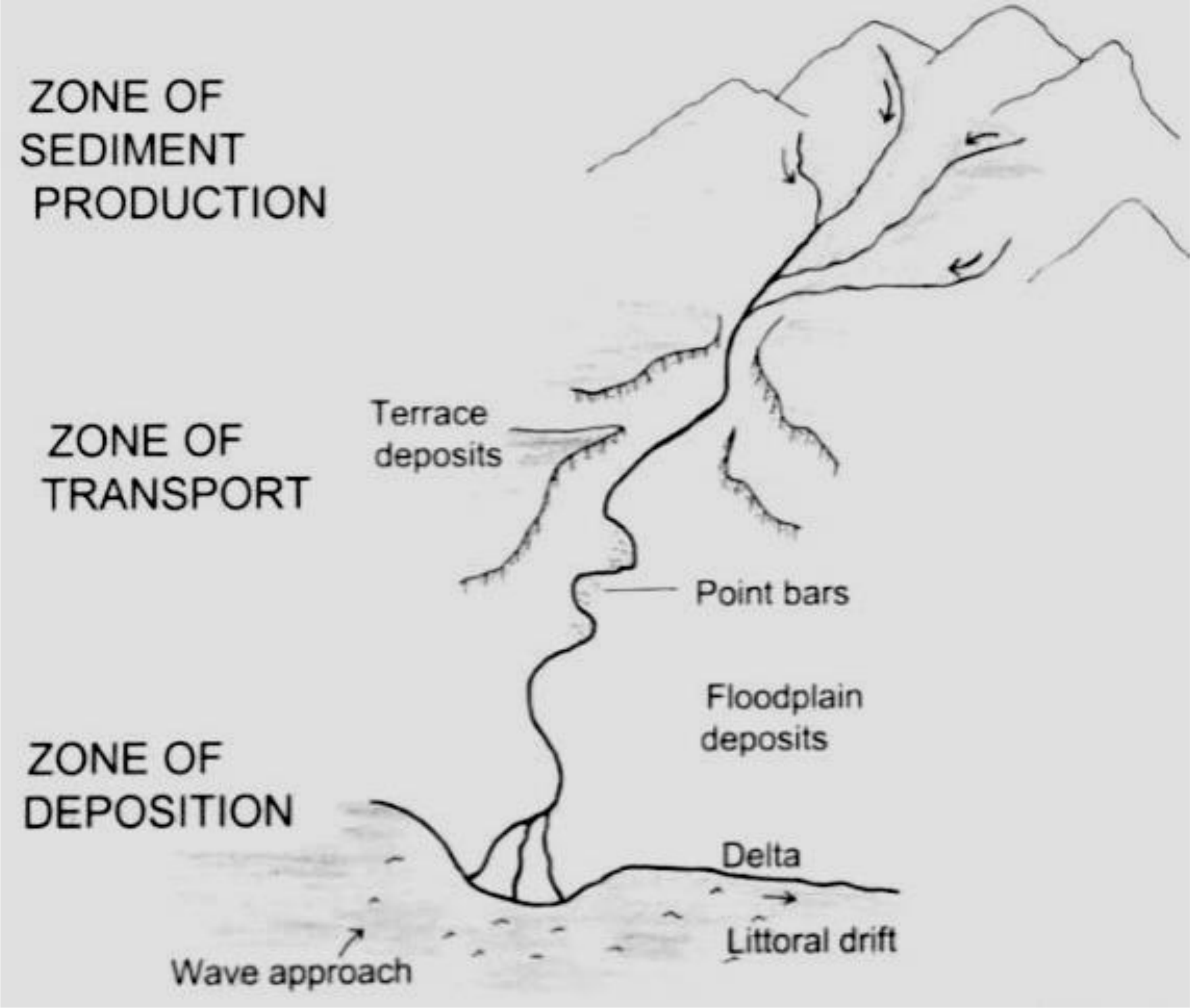
In the western US, some river reaches are in sediment surplus, but more are in sediment deficit (red)
This is also true of rivers globally.

Schmidt & Wilcock 2008
'Metrics for assessing the downstream effects of dams' *Water Resources Research*

One such reach is the
Colorado River below Glen Canyon Dam

In sediment deficit, hungry water eroding beaches needed for camping and wildlife

Proposal by US Bureau of Reclamation to dredge sand from tributary delta, add to channel below dam



At the river system scale, coastal areas depend on sediment supplied from the river basin.

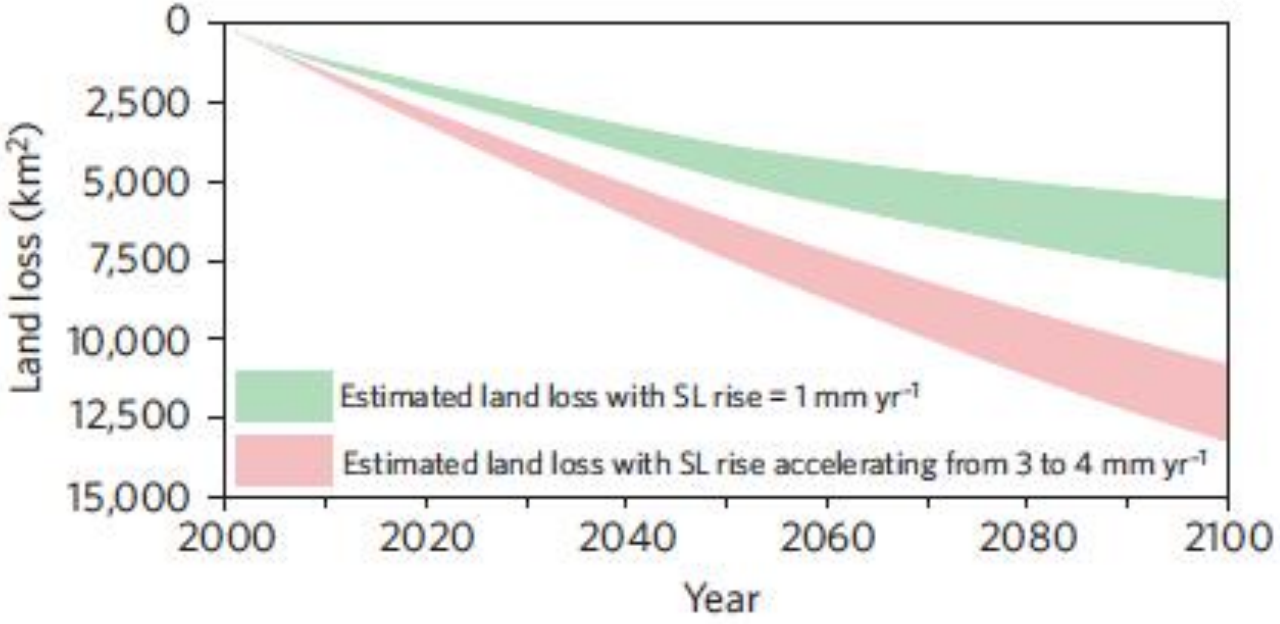
Sediment trapping by dams reduces sediment supply to maintain beaches and deltas, causing increased coastal erosion and subsidence.

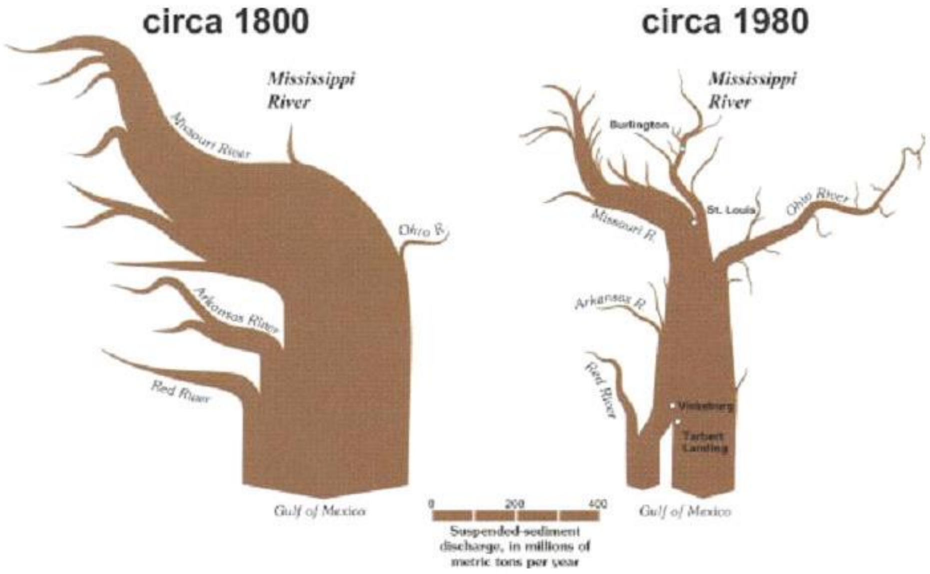
Most deltas worldwide have reduced sediment supply and had accelerated subsidence and coastal erosion.

Syvitski et al 2009. Sinking deltas due to human activity. *Nature Geoscience*

Mississippi River:
Big sediment sources (Missouri River) cut off by dams. Without sediment supply, Delta will sink below the sea.

Blum & Roberts 2009. Drowning of the Mississippi Delta due to insufficient sediment supply and global sea-level rise *Nature Geoscience*

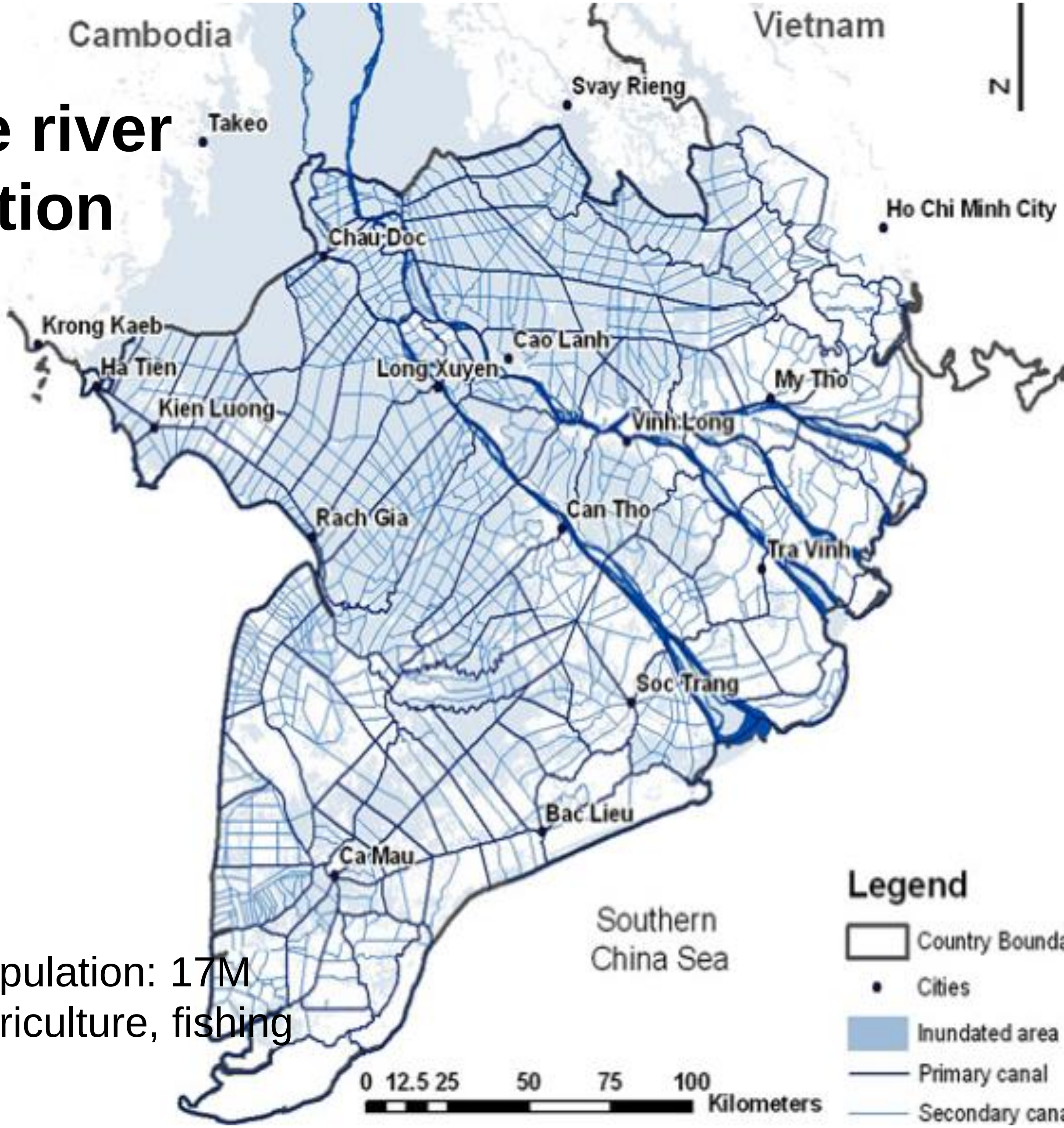




The Mekong Delta: One of many large river deltas threatened by sediment starvation

The Delta built 250 km out from Phnom Penh over the last 8000 years due to sediment supply of Mekong.

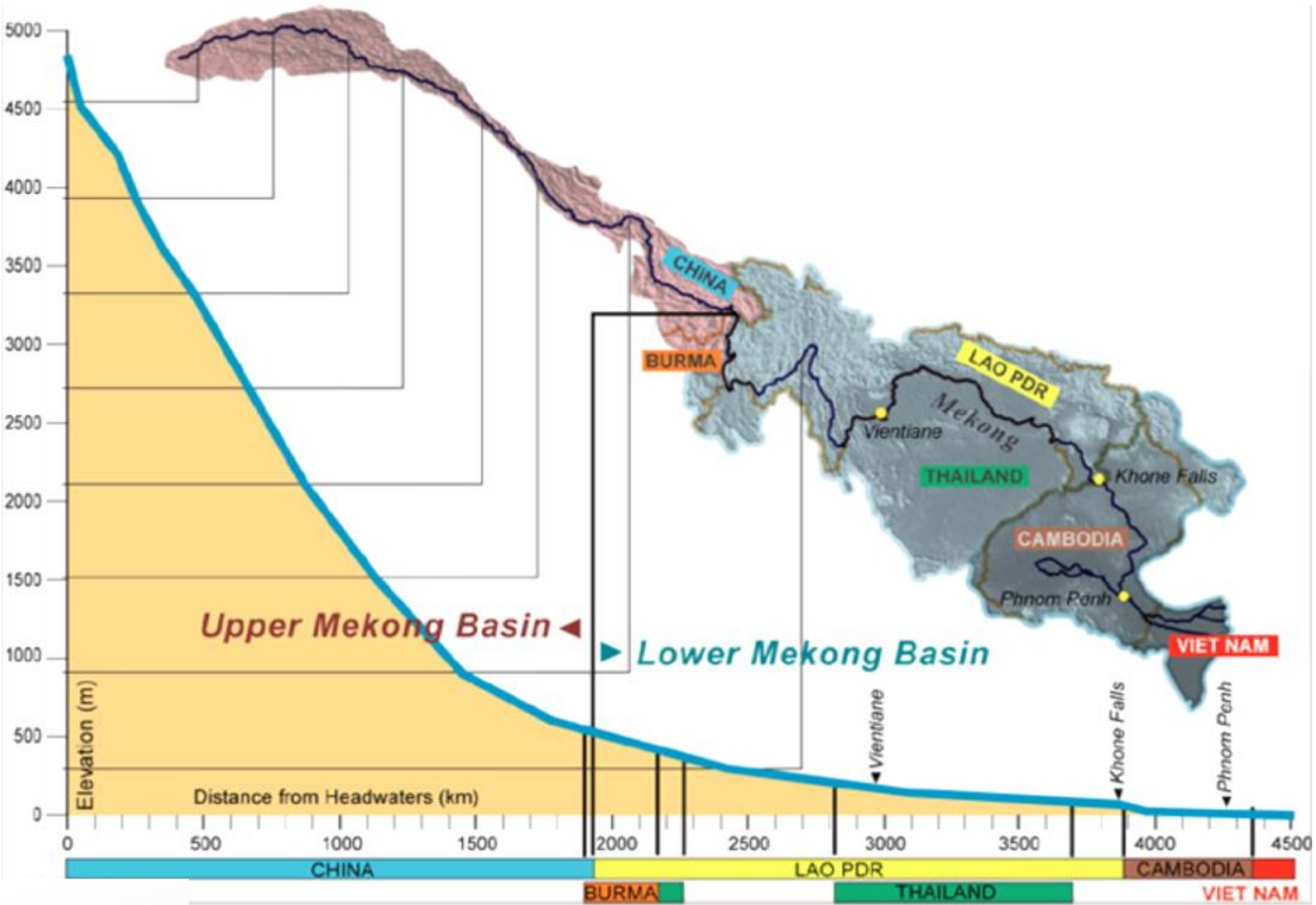
Now retreating due to reduced sediment supply and accelerated subsidence.

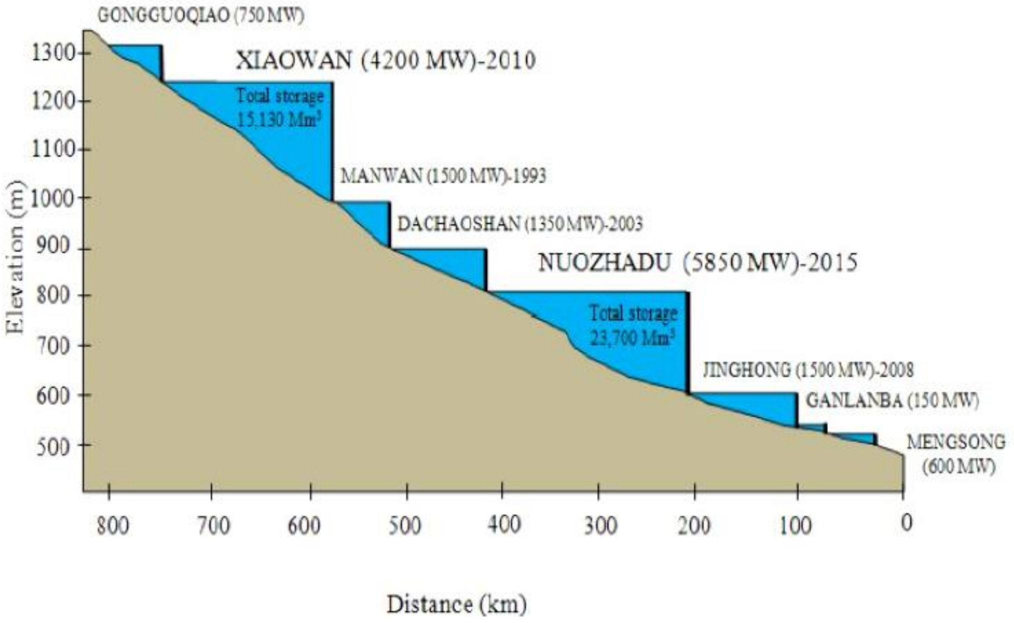


Population: 17M
Agriculture, fishing

Source: Southern Institute for Water Resources, Government of Vietnam

Dropping from the Tibetan Plateau, the Mekong has potential to generate hydroelectricity

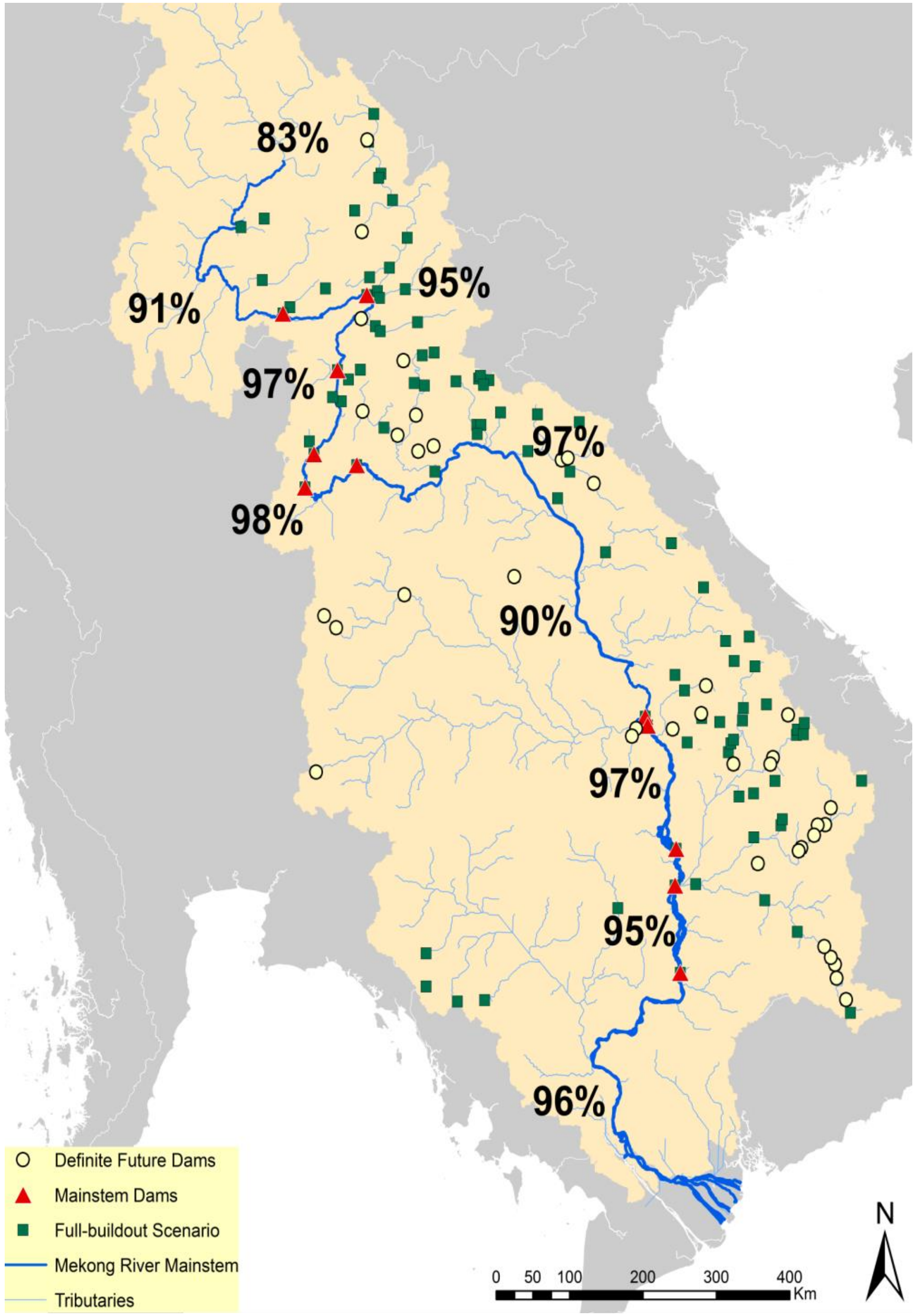




In the Chinese section of the river (upstream), 7 dams are turning the river into a series of reservoirs, cutting off sediment supply from the upper basin, which formerly supplied 50% of the river’s sediment.

Another 133 dam planned or being built on the lower Mekong River, in Laos, Cambodia, and Vietnam, 11 on the mainstem Mekong

What effect will all these dams have on channel and delta morphology?



We applied the 3W model to the 'full build' scenario of 140 dams.

Result: >90% of natural sediment load trapped along entire mainstem. Only 4% of the natural sediment load will reach the Delta.

What will be effects of extreme reduction in sediment load?

Kondolf et al 2014 'Dams on the Mekong: Cumulative Sediment Starvation' *Water Resources Research*

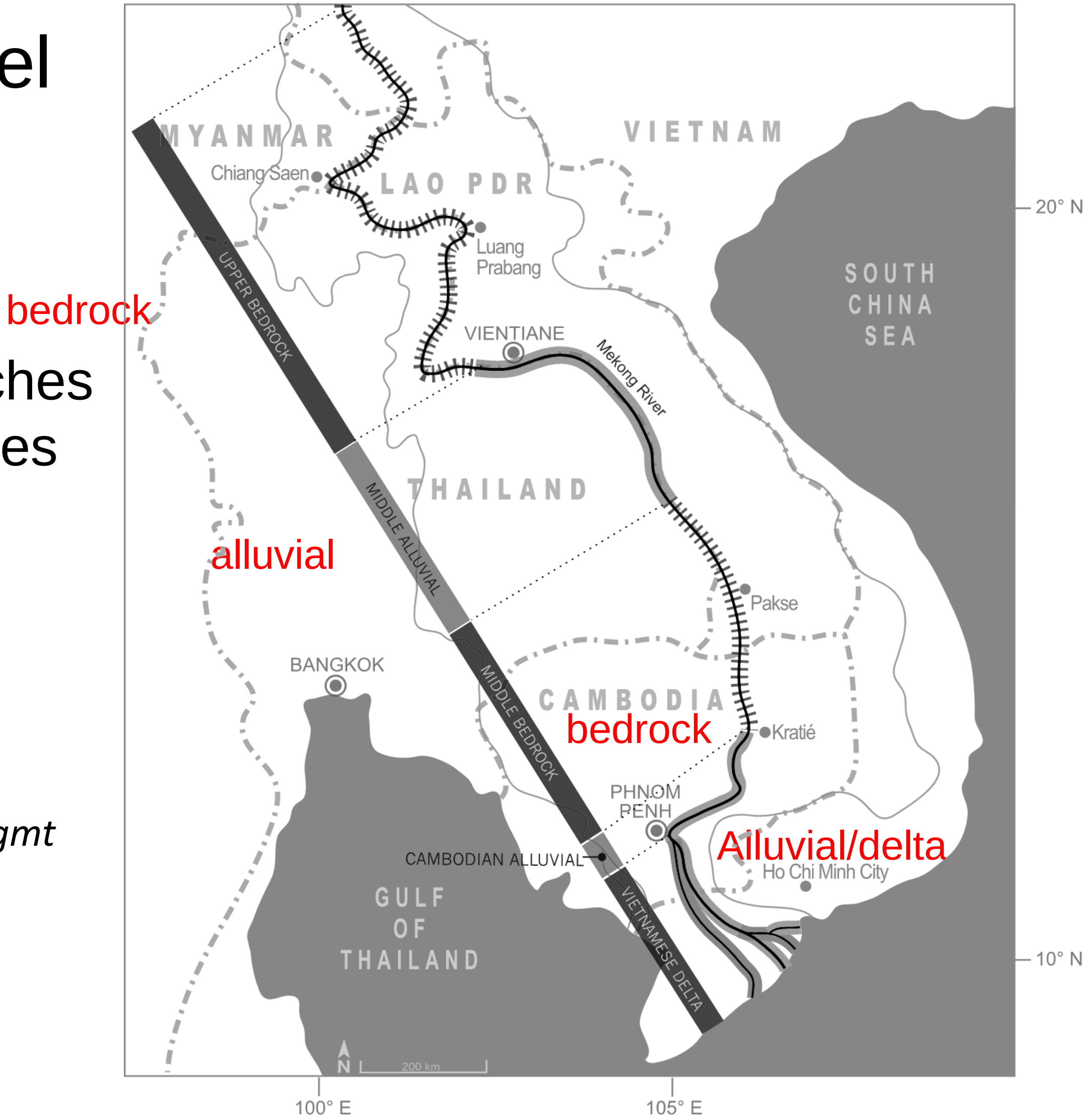
Downstream effects on channel form?

Bedrock vs alluvial reaches:

- sand deposits flush from bedrock reaches
- incision, bank erosion in alluvial reaches

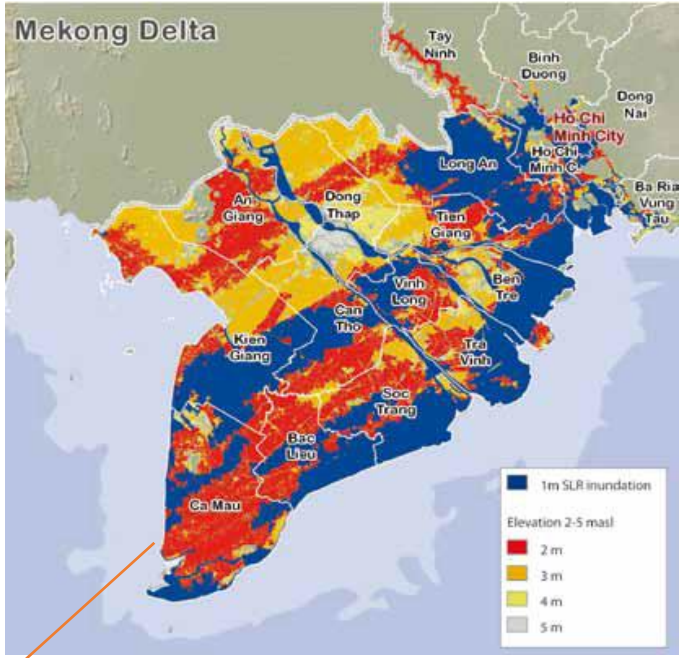
What effect on delta of 96% decrease in sediment supply?

Rubin et al., 2014 Anticipated geomorphic impacts from Mekong basin dam construction *Int Journal River Basin Mgmt*

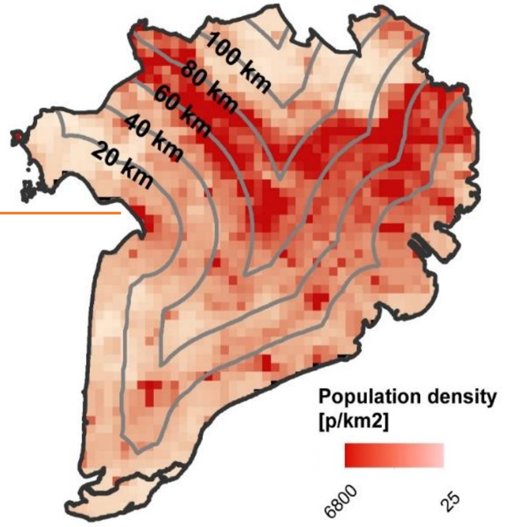


96% reduction in sediment supply means the delta landform cannot maintain itself against rising seas and coastal erosion in the long run.
But over what time scales and what other drivers?

- sand mining
- accelerated subsidence
- accelerated sea level rise
- channelizing distributaries



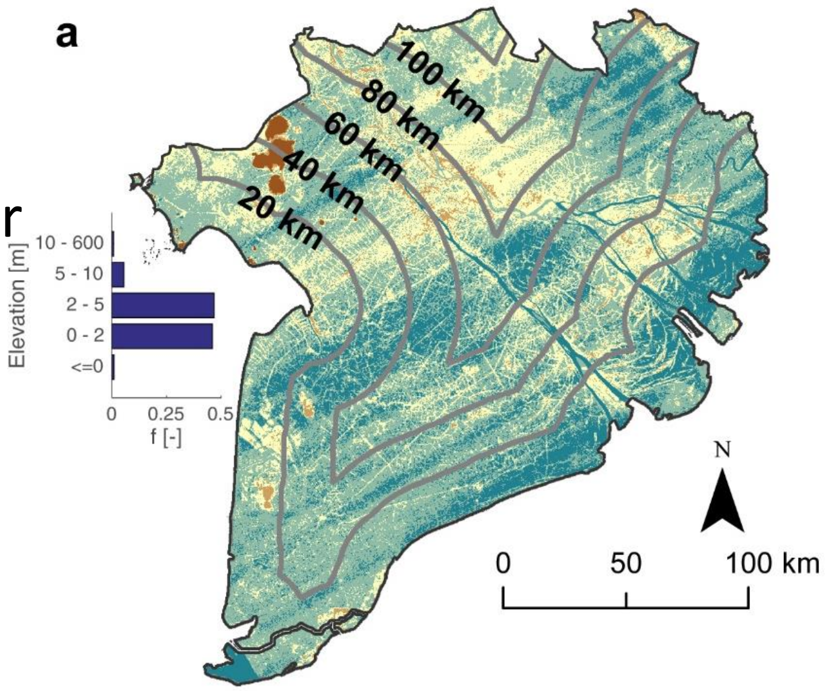
Much of the Delta is
<1m above MSL (blue) or <2m above MSL (red)
2m subsidence affects 15M population

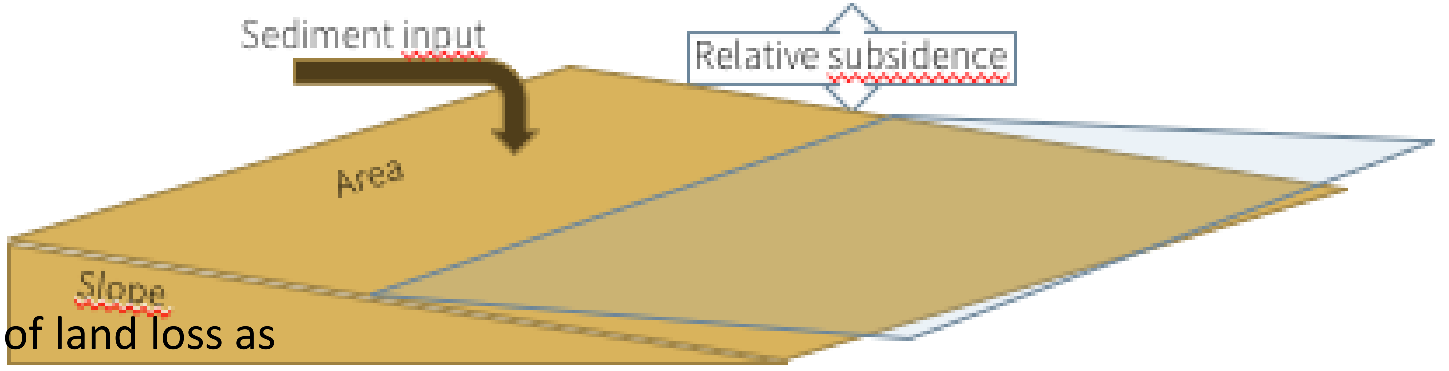


Bravard et al 2013 Geography of sand and gravel mining in the lower Mekong River, *EchoGéo*
Erban et al 2014 Groundwater extraction, land subsidence, and sea-level rise in the Mekong Delta *Environ Res Lett*

How to compile information on diverse drivers, expressed in different units?

We expressed all drivers in length scale, and our model evenly “spread out” sediment volumes over the area of the delta.
We used average slope to convert elevation change into land loss

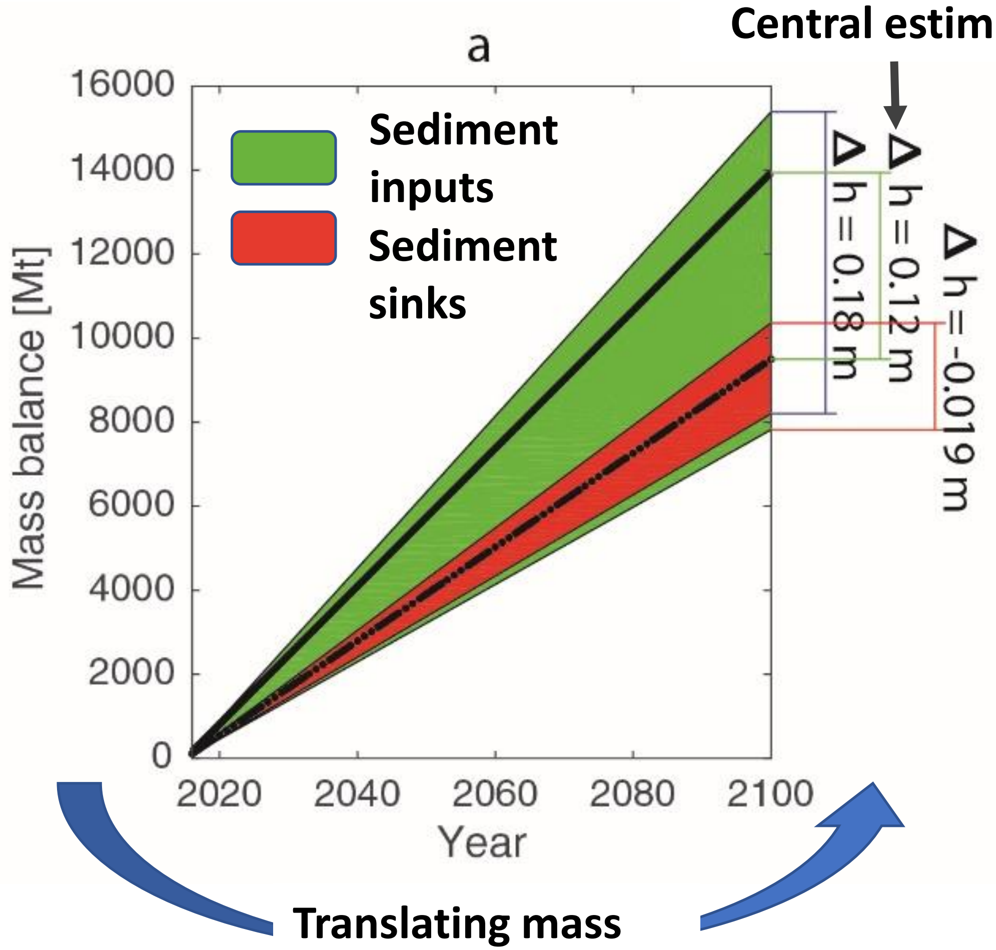




Schmitt et al 2017. Losing ground - scenarios of land loss as consequence of shifting sediment budgets in the Mekong Delta. *Geomorphology*

- Undisturbed:
- sediment inputs, compaction, and organic accumulation

- Net progradation as per holocene observations



Central estimate

Translating mass balance in a length scale

Green means sediment inputs (positive balance)
Red means sediment sinks (negative balance)

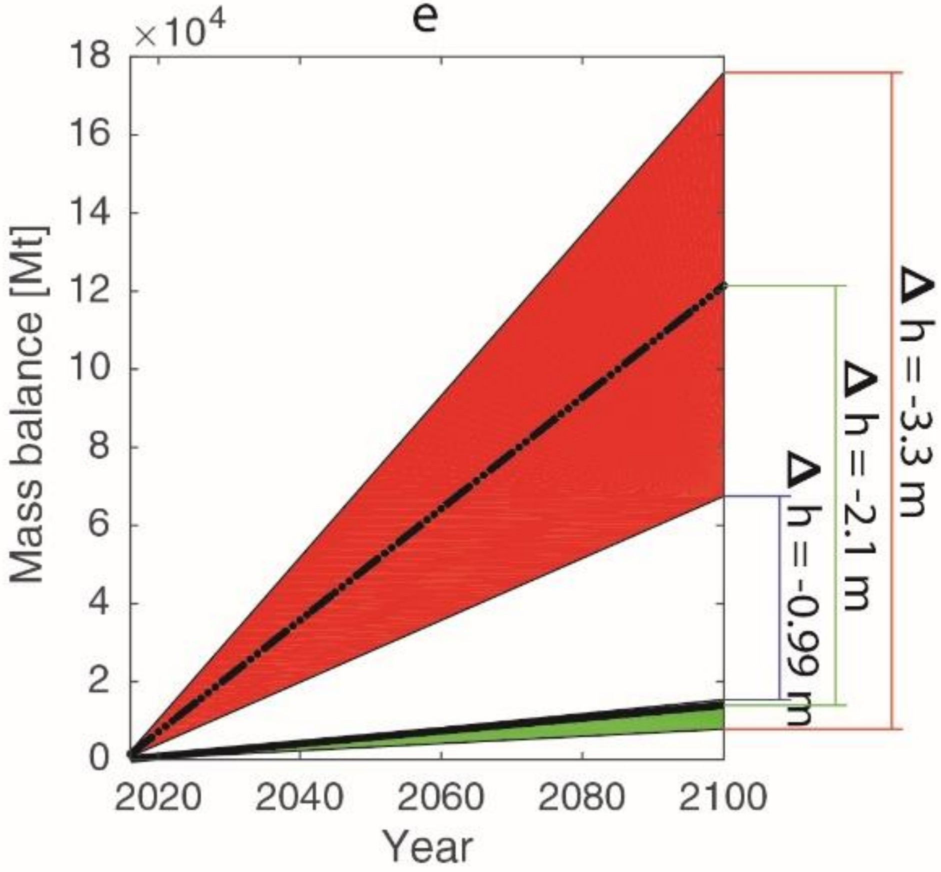
Worst Case:

Continue *'business as usual'*

- Sand mining

-Sediment trapping

-Groundwater pumping



Under worst case scenario:

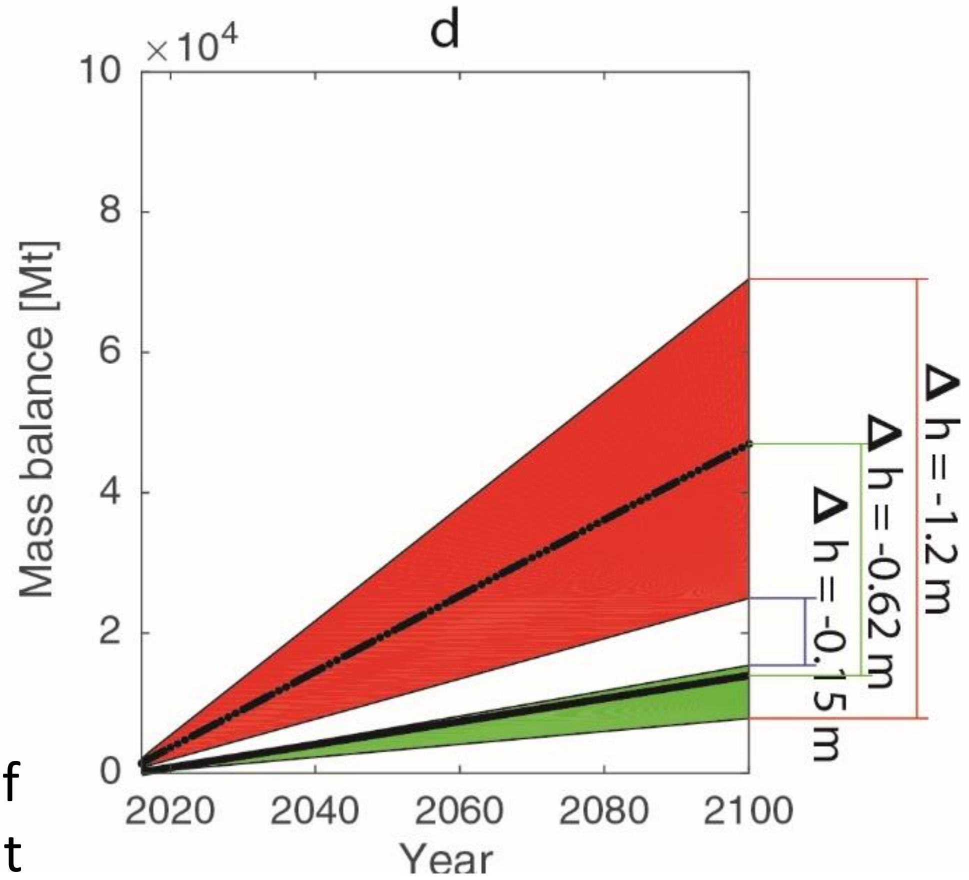
Central tendency = 2 m subsidence

Maximum = 3.3 m subsidence

However, management changes can reduce subsidence to ~ 60cm (by 2100), reduce delta loss land to only 10%

Sustainable management and strategic planning in dams
Reduce groundwater pumping,
Discontinue sand mining

Kondolf et al 2018 Changing sediment budget of the Mekong: Cumulative threats & management strategies for a large river basin. *Science of the Total Environment*



Key strategies to sustainably manage sediment in regulated rivers

-Sluice incoming sediment and/or flush accumulated sediment
 (design with large, low-level outlets, periodically draw reservoir down)
-Vent density currents (open bottom outlets to pass currents)
-Pass sediment through bypass tunnels
-Reduce sediment yield from river basin upstream of reservoir

These approaches work in many situations, but rarely implemented

Morris & Fan 1998. *Reservoir sedimentation handbook*. McGraw Hill
Annandale et al 2016. *Extending the life of reservoirs*. World Bank.
Annadale 2013. *Quenching the thirst*. Createspace
Sumi 2008. Evaluation of efficiency of reservoir sediment flushing in Kurobe River. *ICSE Proceedings*
Sumi et al 2012. Performance of Miwa Dam sediment bypass tunnel: Evaluation of upstream and downstream state and bypassing efficiency. *Proceedings 24th ICOLD Congress*
Kondolf et al 2014. Sustainable sediment management in reservoirs and regulated rivers: experiences from five continents. *Earth’s Future*

Thank you!

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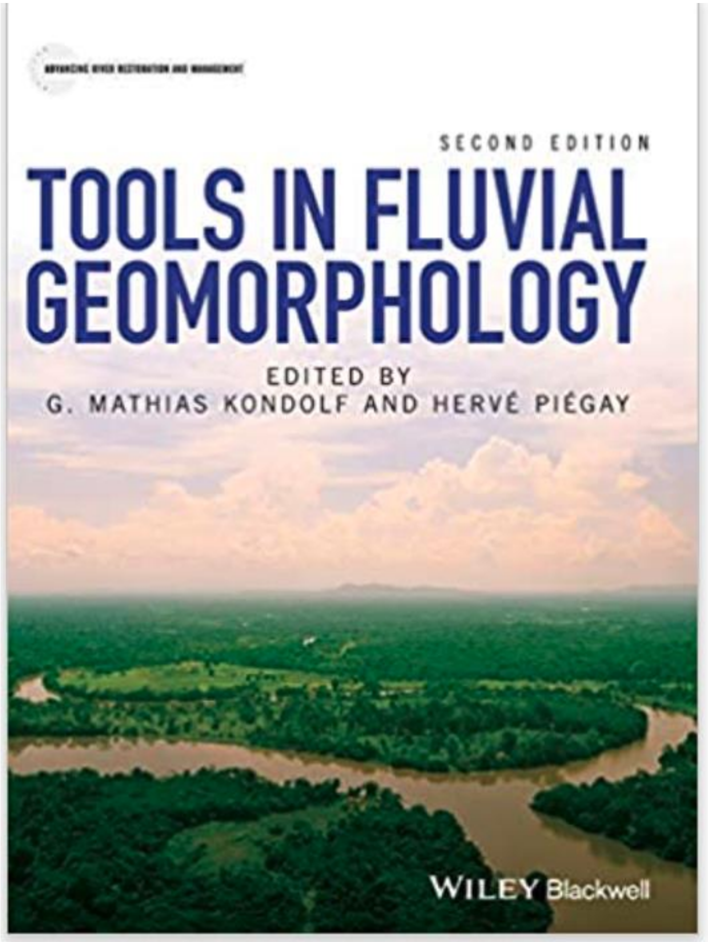
https://riverlab.berkeley.edu



SECOND EDITION

TOOLS IN FLUVIAL GEOMORPHOLOGY

EDITED BY
G. MATHIAS KONDOLF AND HERVÉ PIÉGAY

WILEY Blackwell

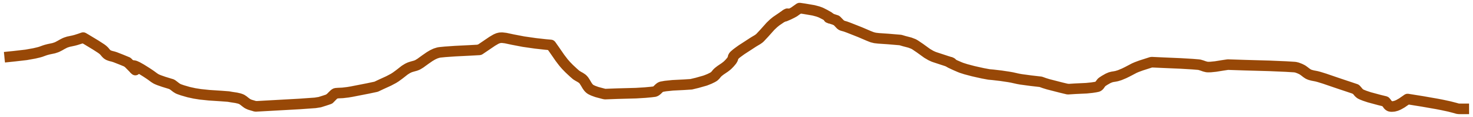
Berkeley

Moving Sediment into Ferron Creek downstream from Millsite Dam, Utah: Case Study

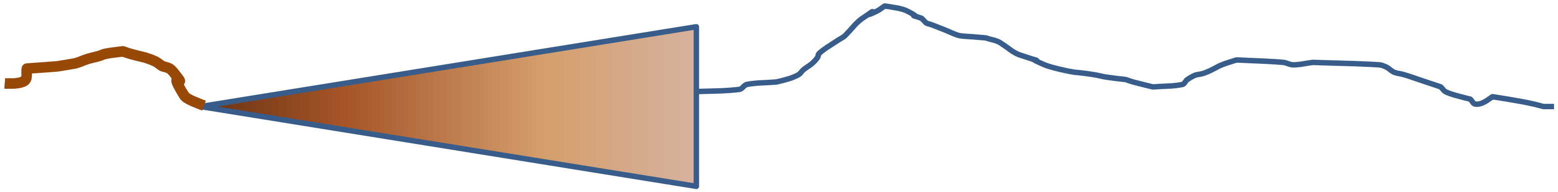
Rollin H. Hotchkiss, Ph.D., P.E., D.WRE, F.ASCE
Brigham Young University

Here’s the Problem!

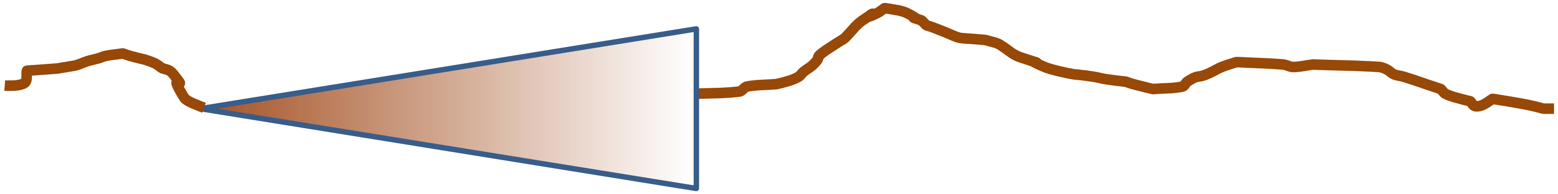
- Plan view of river before a dam



- Plan view of a river after a dam



- What we ULTIMATELY need to do:



Why?

- Try to maintain a sediment balance for
  - Geomorphic stability
  - Ecosystem health
  - Downstream needs

https://bloximages.chicago2.vip.townnews.com/yankton.net/content/tncms/assets/v3/editorial/a/ab/aab17ce6-b63b-11e8-8c68-ab440f15804a/5b98879d5dc16.image.jpg?resize=1200%2C829

https://www.e-education.psu.edu/earth107/sites/www.e-education.psu.edu.earth107/files/Unit3/Mod7/M7_640px-Happisburgh_coastal_erosion.jpeg

https://www.nps.gov/common/uploads/stories/images/nri/20150504/articles/4911CA79-FA50-B7F8-CC5E3EEDCB818DFF/4911CA79-FA50-B7F8-CC5E3EEDCB818DFF.jpg

Road Map for this Discussion

1 Context using Millsite Dam in Ferron, Utah
2 Permitting process
3 Operation
4 Results including costs
5 Related national efforts

Context: Millsite Dam in Ferron, Utah

- 1971 closure
- Small-ish facility
  - 18,000 AF storage
  - Now it's 15,400 AF
- Irrigation, water supply, recreation

Setting

- Arid
- Highly erodible soils
- More deposition in upper ½ of reservoir
- Mean annual deposition is 74 AF

Facilities

- Low-level outlet works
- May help to evacuate sediment
- But upstream from all irrigation diversions

Facilities, Continued

- Uncontrolled overflow spillway
- Passes relatively clear water
- Add dredged sediment when discharge exceeds 50 cfs

Downstream Impacts

- Increase turbidity for first part of irrigation season
- Bureau of Land Management wants more turbidity downstream
- Avoid excessive sediment deposition and loss of dissolved oxygen

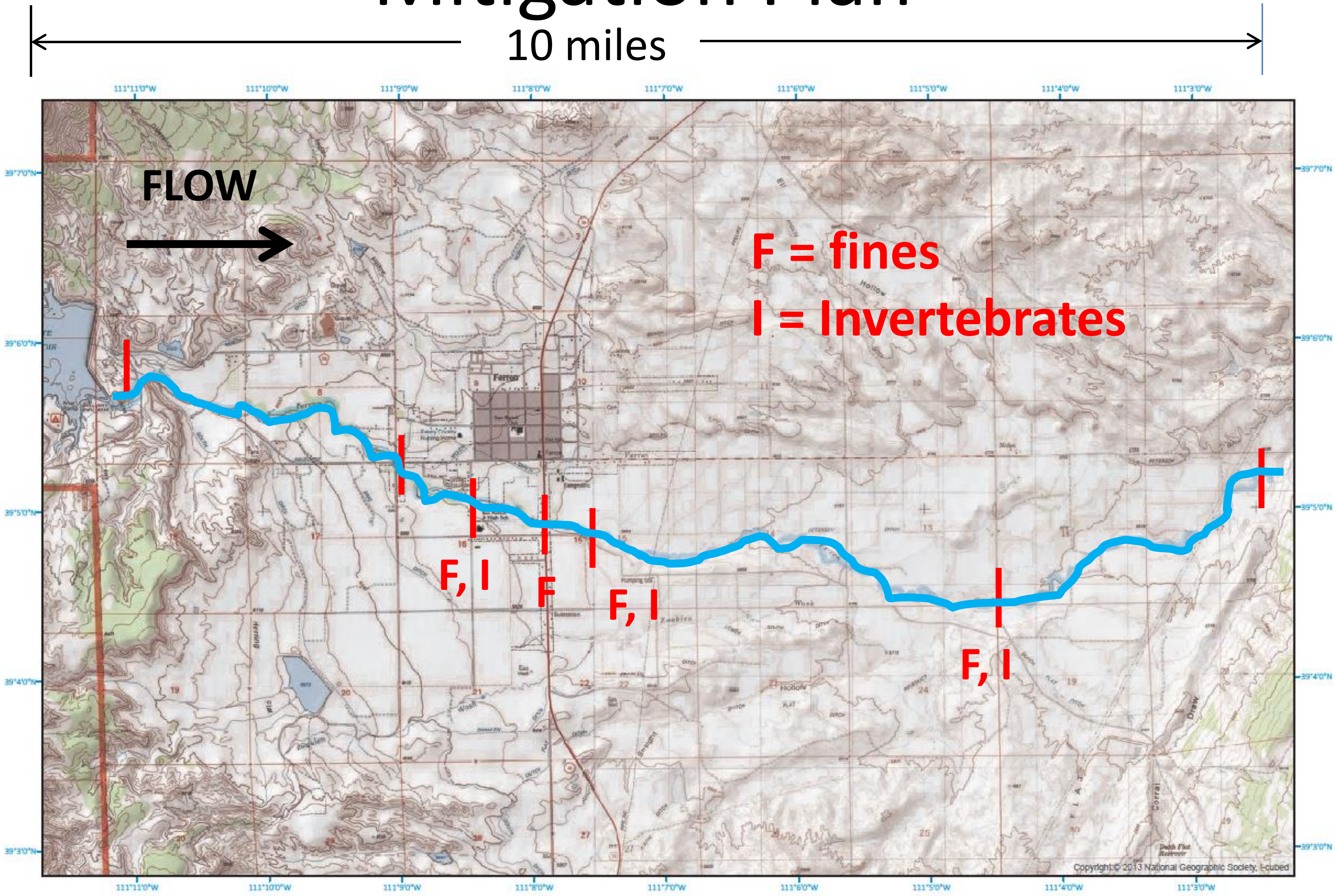
Permitting process

- Section 404 of the Clean Water Act (USACE)
- Section 401 (State of Utah)

The Process

- Submit application
- Rejected
- Modify
- Rejected
- Debate, meet at site, give and take
- Submit
- Approved with 24 conditions
- Almost 2 years required

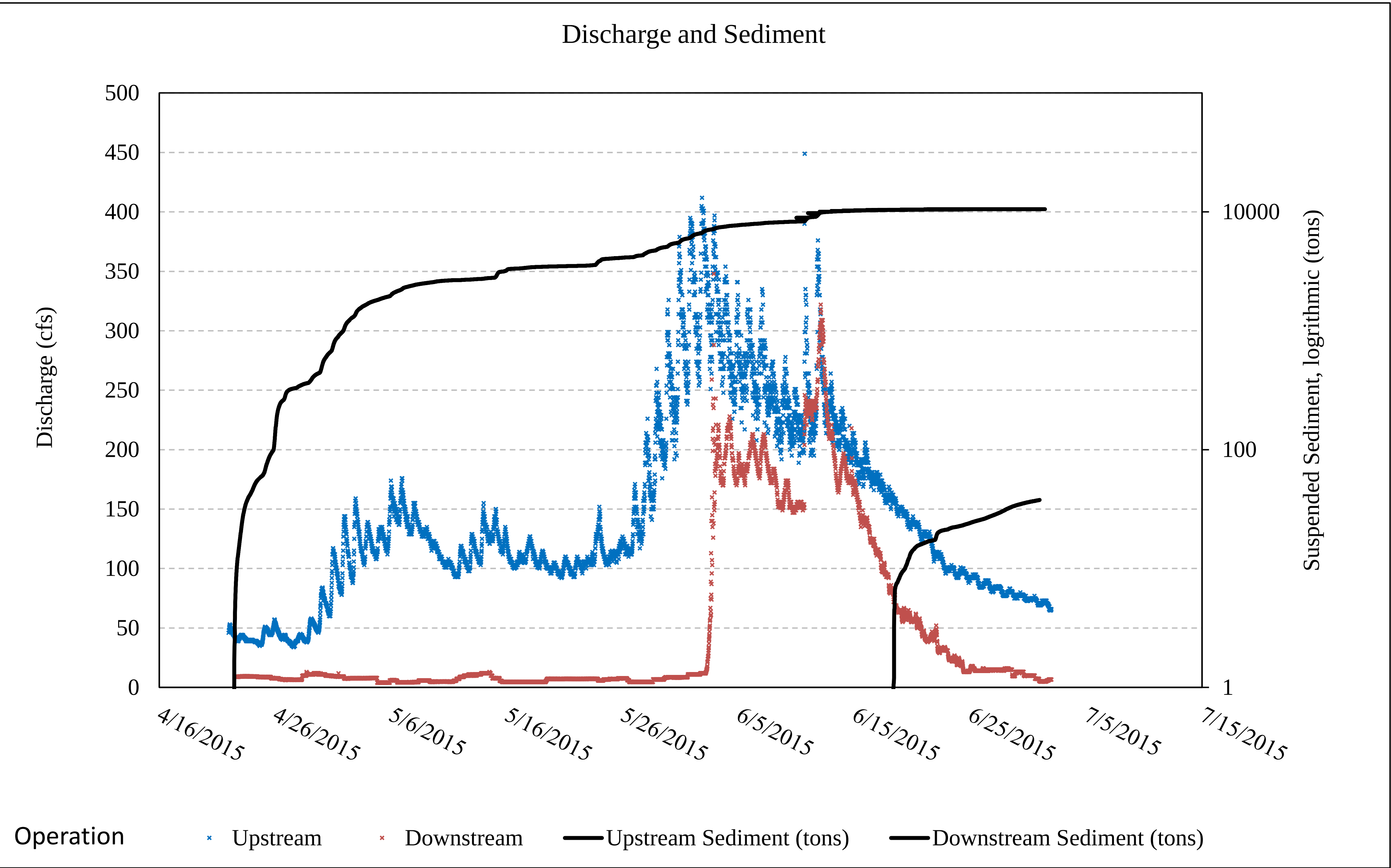
Mitigation Plan



Operation

- 401 and 404 permits approved in 2015; spillway discharge had been active for two weeks
- First year moved sediment downstream for…..two days!
- But we learned a lot

The Whole Story



Amended Operations

- Disconnect direct real time suspended load comparison: inflow C = outflow C
- Use the AVERAGE incoming sediment concentration from 50 cfs to time up to spill
- Discharge up to the AVERAGE during spill
- Stop when spillway discharges < 50 cfs

2017 Operations

- (all data were lost…trying to recover)
- 45 days of spill; dredger and crew in place
- But only dredged 18% of the time
  - Permitting fatigue decreased enthusiasm
  - Inexperienced local crew
- 31 AF entered reservoir; dredged only 2 AF
- No downstream impacts
- \$15/yd^3; potential for \$1/yd^3

Followup National Efforts

- Recommendations to Chief of USACE
  - ‘beneficial use’ of dredged sediment is to put it downstream from dams
  - economic analysis of lost storage due to sediment
  - consider impacts beyond project footprint
  - pilot projects and training for regulators
  - write a new Regulatory Guidance letter

Questions and Discussion

A conceptual framework for understanding the ecological effects of sediment regimes

Darixa Hernández-Abrams, Susan Bailey, and Kyle McKay
ERDC Environmental Laboratory

USACE Kansas City District Virtual Workshop
August 2020

Ecological Effects of Sediment Regimes

- Draw from existing conceptual models
- Review literature
    - Downstream effects of sediment
    - Fishes of Kansas
    - Related subjects on sediment and fishes (e.g., road crossing)
- Develop a conceptual model relative to Tuttle Creek and local biota

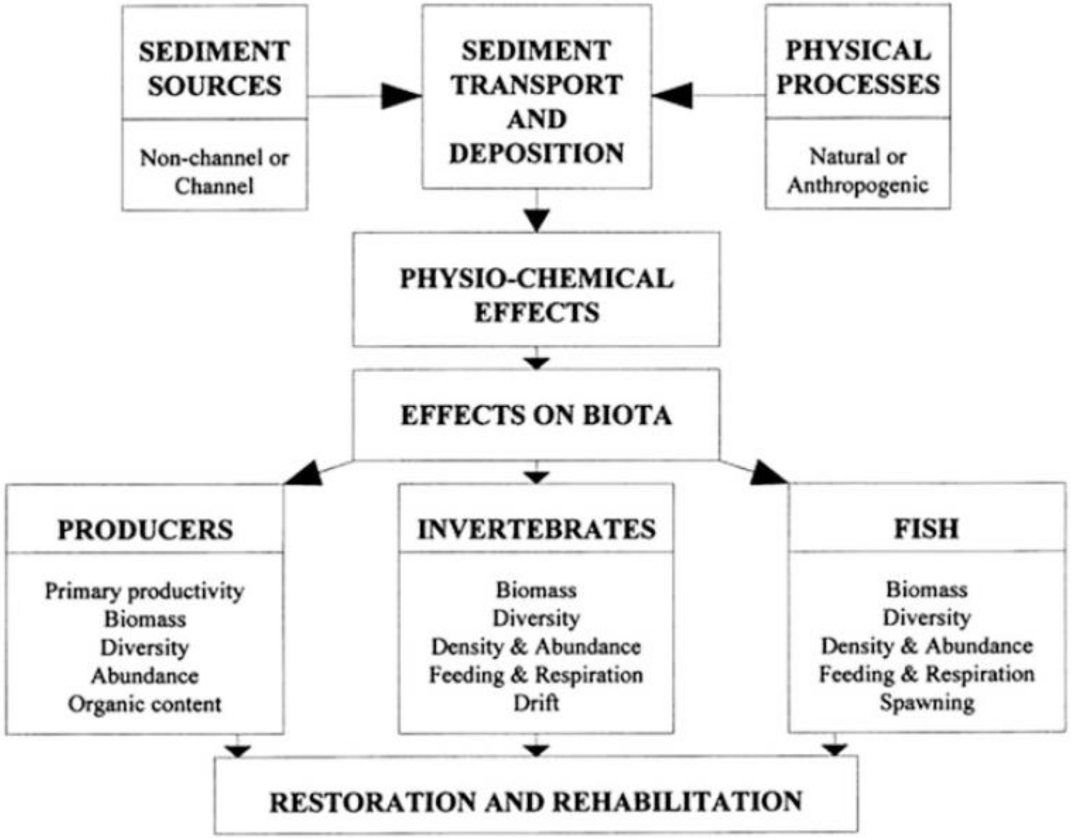
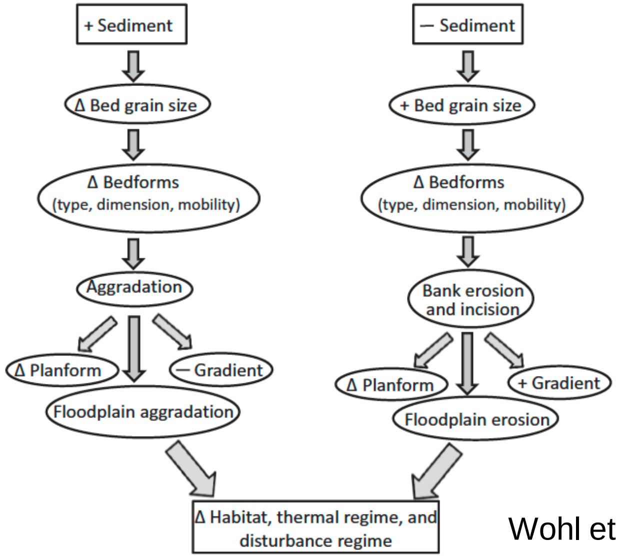


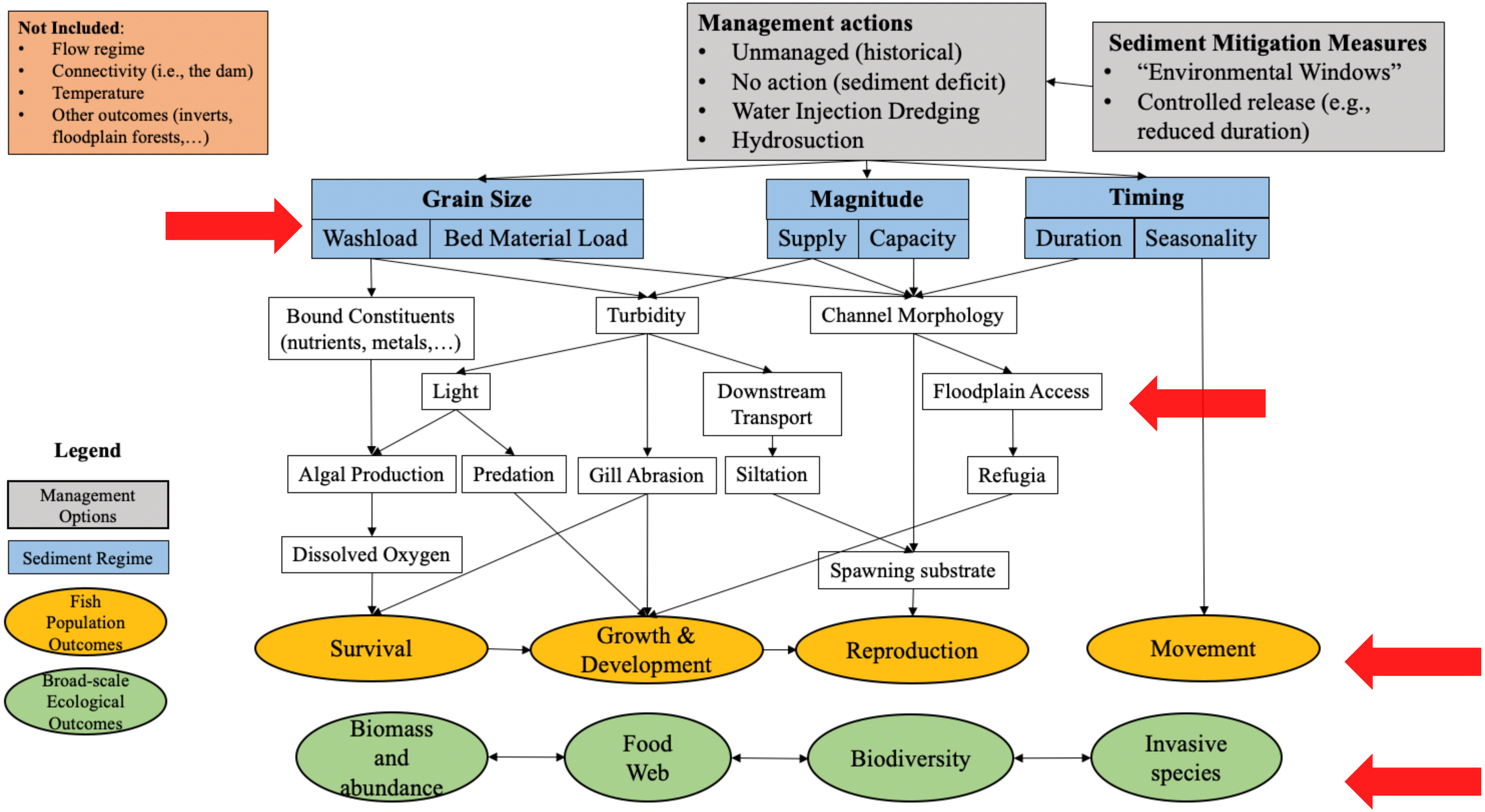
Fig. 8.3 A holistic overview of fine sediment in the lotic ecosystem, after Wood and Armitage (1997) (© Environmental management, Biological effects of fine sediment in the lotic environment, 21(2), 1997, 203–217, Wood, P. J., Armitage, P. D. With permission of Springer)



Wohl et al. (2015, *Bioscience*)

Hauer et al. (2018, *Riv Eco Mngmt*)

Conceptual Model



Not Included:
- Flow regime
- Connectivity (i.e., the dam)
- Temperature
- Other outcomes (inverts, floodplain forests,…)

Management actions
- Unmanaged (historical)
- No action (sediment deficit)
- Water Injection Dredging
- Hydrosuction

Sediment Mitigation Measures
- "Environmental Windows"
- Controlled release (e.g., reduced duration)

Grain Size: Washload | Bed Material Load

Magnitude: Supply | Capacity

Timing: Duration | Seasonality

Bound Constituents (nutrients, metals,…)

Turbidity

Channel Morphology

Light

Downstream Transport

Floodplain Access

Algal Production

Predation

Gill Abrasion

Siltation

Refugia

Dissolved Oxygen

Spawning substrate

Survival

Growth & Development

Reproduction

Movement

Biomass and abundance

Food Web

Biodiversity

Invasive species

Legend

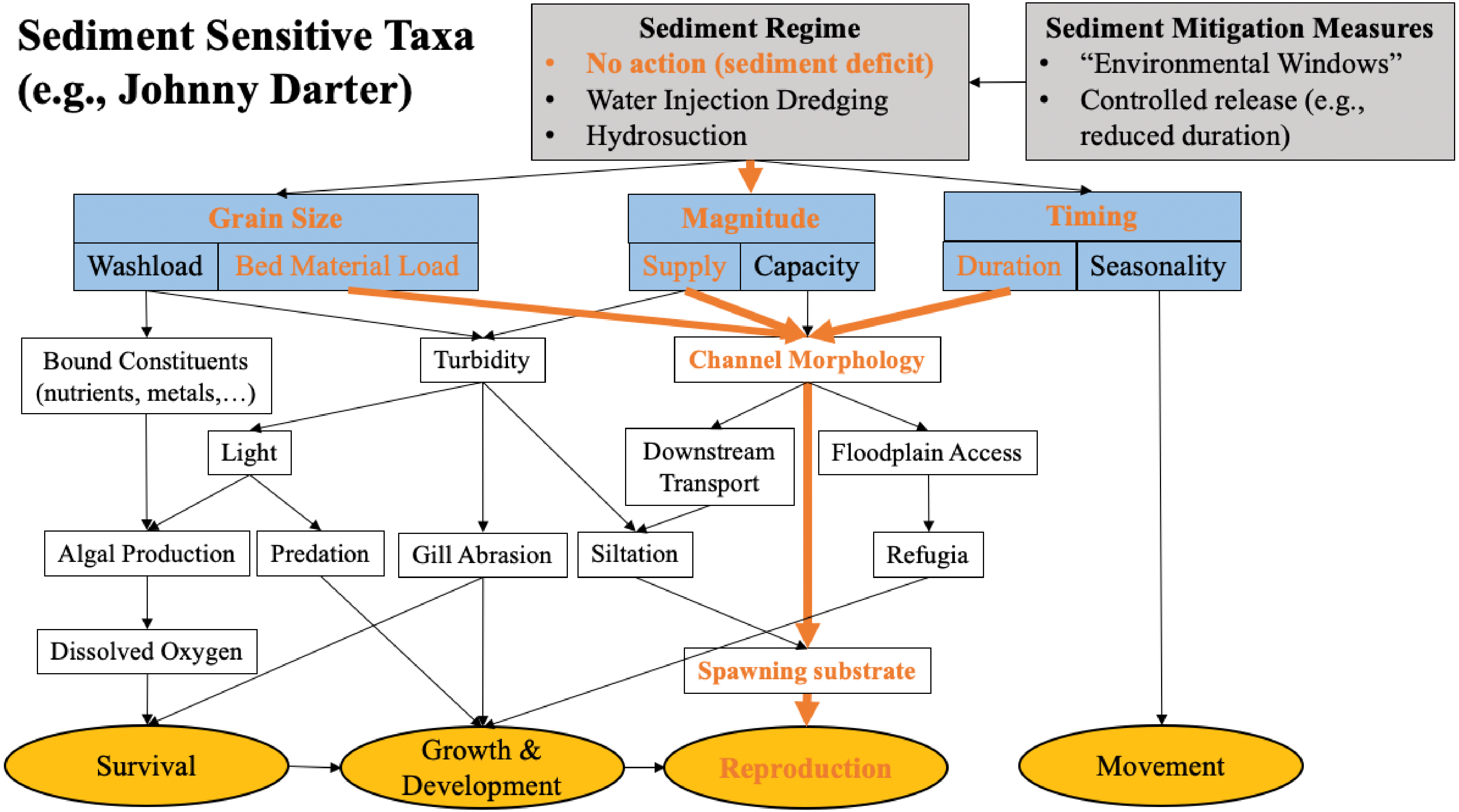
Management Options

Sediment Regime

Fish Population Outcomes

Broad-scale Ecological Outcomes

Example Application #1

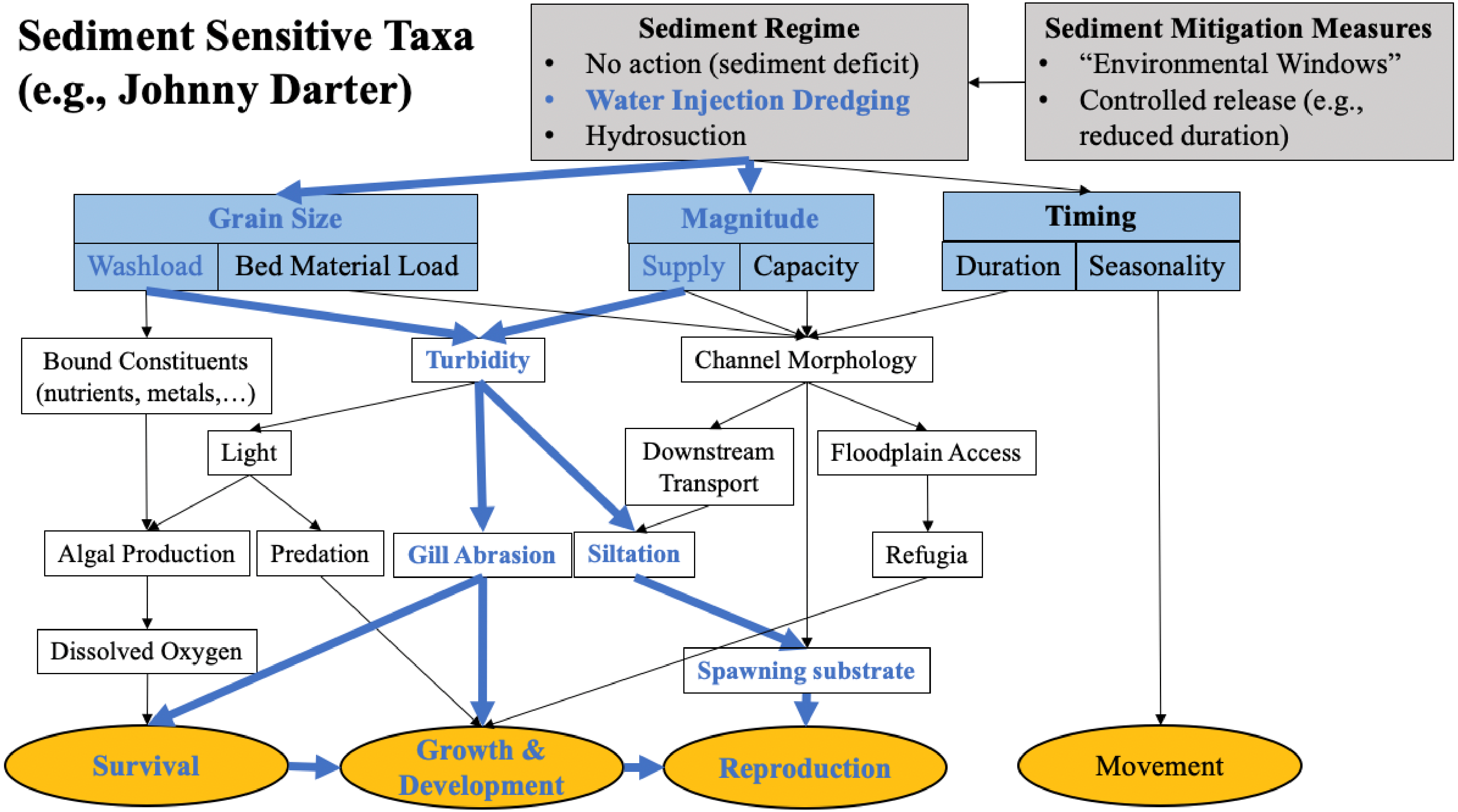


Sediment Sensitive Taxa
(e.g., Johnny Darter)

Sediment Regime
- No action (sediment deficit)
- Water Injection Dredging
- Hydrosuction

Sediment Mitigation Measures
- "Environmental Windows"
- Controlled release (e.g., reduced duration)

Example Application #2



Sediment Sensitive Taxa (e.g., Johnny Darter)

Sediment Regime

- No action (sediment deficit)
- **Water Injection Dredging**
- Hydrosuction

Sediment Mitigation Measures

- "Environmental Windows"
- Controlled release (e.g., reduced duration)

Grain Size: Washload | Bed Material Load

Magnitude: Supply | Capacity

Timing: Duration | Seasonality

Bound Constituents (nutrients, metals,…)

Turbidity

Channel Morphology

Light

Downstream Transport

Floodplain Access

Algal Production

Predation

Gill Abrasion

Siltation

Refugia

Dissolved Oxygen

Spawning substrate

Survival

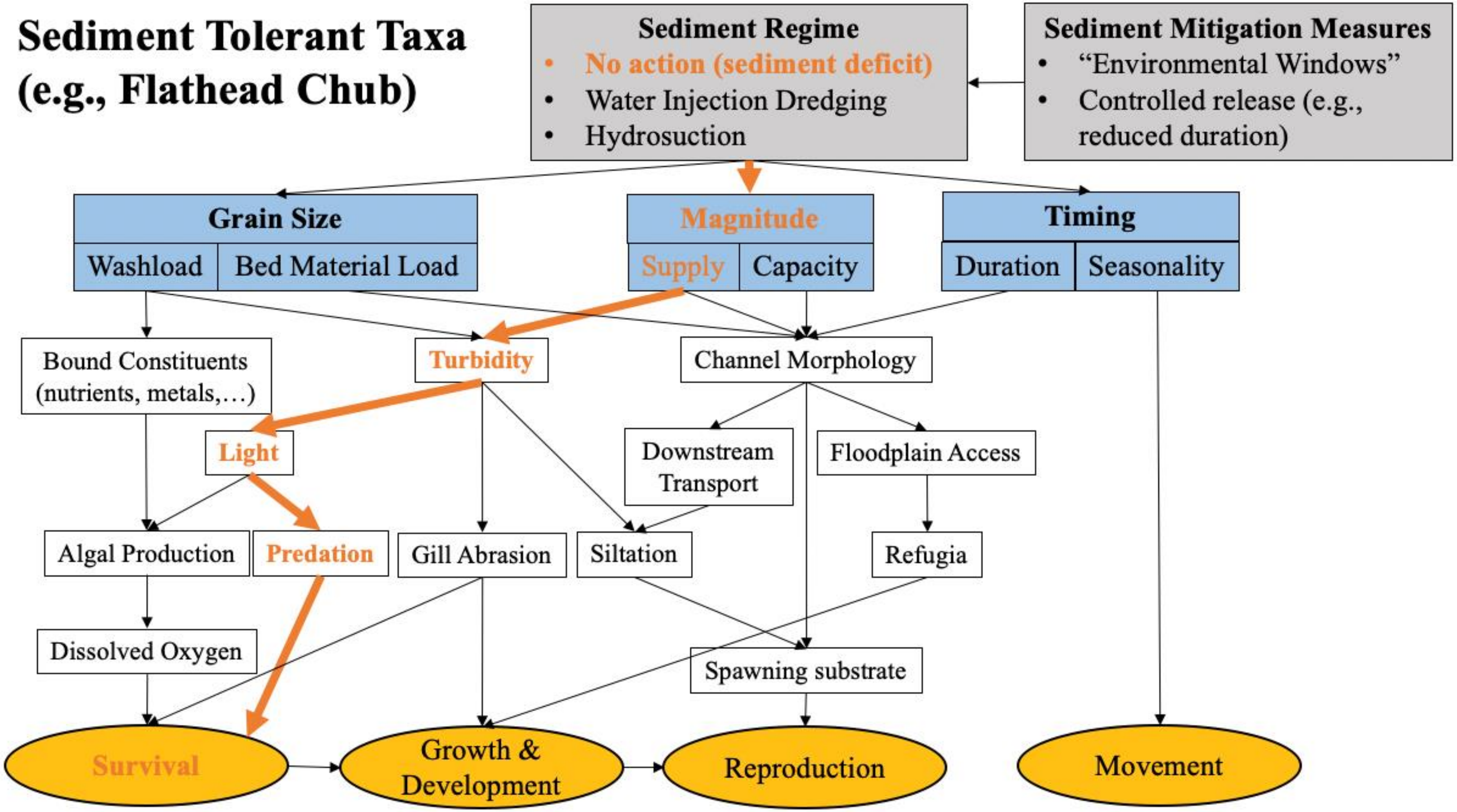
Growth & Development

Reproduction

Movement

Example Application #3

Sediment Tolerant Taxa
(e.g., Flathead Chub)



Sediment Regime
- No action (sediment deficit)
- Water Injection Dredging
- Hydrosuction

Sediment Mitigation Measures
- "Environmental Windows"
- Controlled release (e.g., reduced duration)

Grain Size
- Washload
- Bed Material Load

Magnitude
- Supply
- Capacity

Timing
- Duration
- Seasonality

Bound Constituents (nutrients, metals,…)

Turbidity

Channel Morphology

Light

Downstream Transport

Floodplain Access

Algal Production

Predation

Gill Abrasion

Siltation

Refugia

Dissolved Oxygen

Spawning substrate

Survival

Growth & Development

Reproduction

Movement

Thank you for your time!

Take-home messages

- Conceptual models help structure thinking about complex, ecological processes
- Some taxa may benefit from sediment release while others may not
- Turbidity effects may be short-term relative to geomorphic change
- Next steps…
  - Proposed project examining the issues of sediment starvation/release nationally
  - Trait-based guilding based on sediment sensitivity or tolerance

Acknowledgements

- John Shelley for his insights and engaging us in an interesting challenge
- Initial feedback from: Seth Wenger, Mary Freeman, and Shishir Rao at the UGA River Basin Center
- Funding from: USACE Sustainable Rivers Program and the USACE Ecosystem Management and Restoration Research Program (EMRRP)

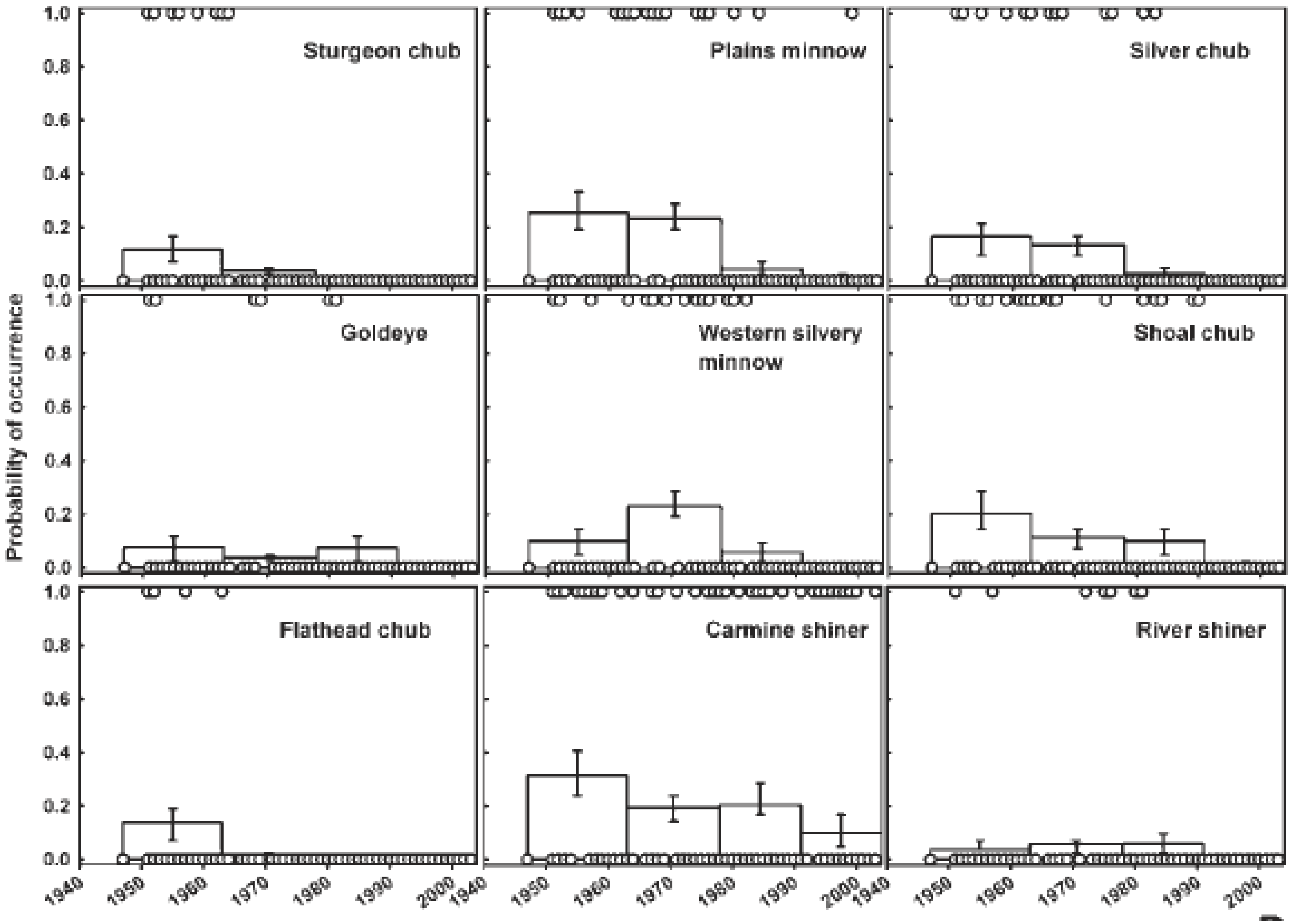
- Contact information:

Darixa Hernández-Abrams
Darixa.D.Hernandez-Abrams@erdc.dren.mil

What do we/don't we know about sediment, the effect of sediment trapping or releases, and Kansas River ecology?

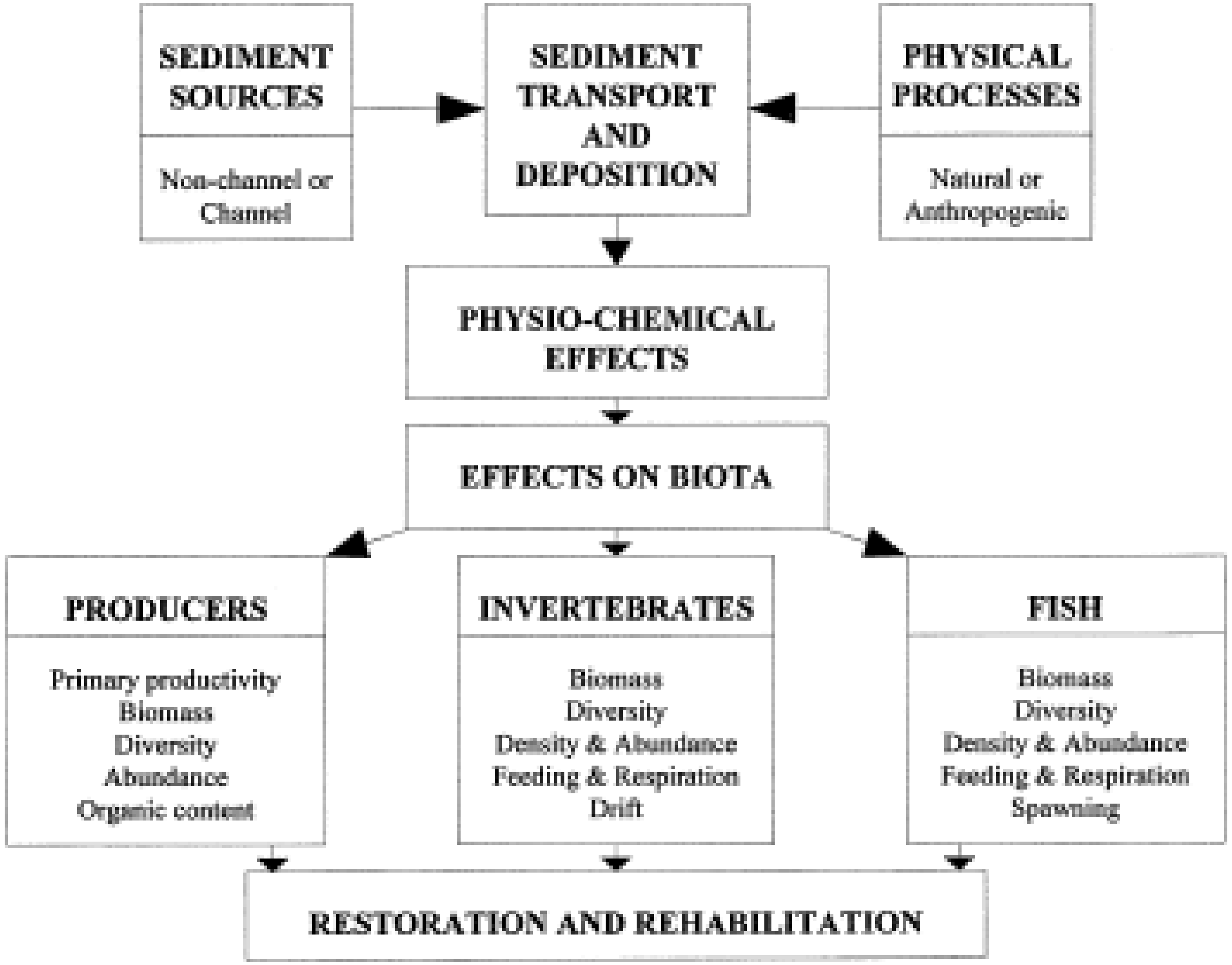
Background: Long term changes in fishes in the Kansas River Basin

- Declines in fishes coincide with reservoir construction, urbanization, invasive species



Gido et al. 2010

Effects of fine sediments are well studied in salmonid streams



SEDIMENT SOURCES

Non-channel or Channel

SEDIMENT TRANSPORT AND DEPOSITION

PHYSICAL PROCESSES

Natural or Anthropogenic

PHYSIO-CHEMICAL EFFECTS

EFFECTS ON BIOTA

PRODUCERS

Primary productivity
Biomass
Diversity
Abundance
Organic content

INVERTEBRATES

Biomass
Diversity
Density & Abundance
Feeding & Respiration
Drift

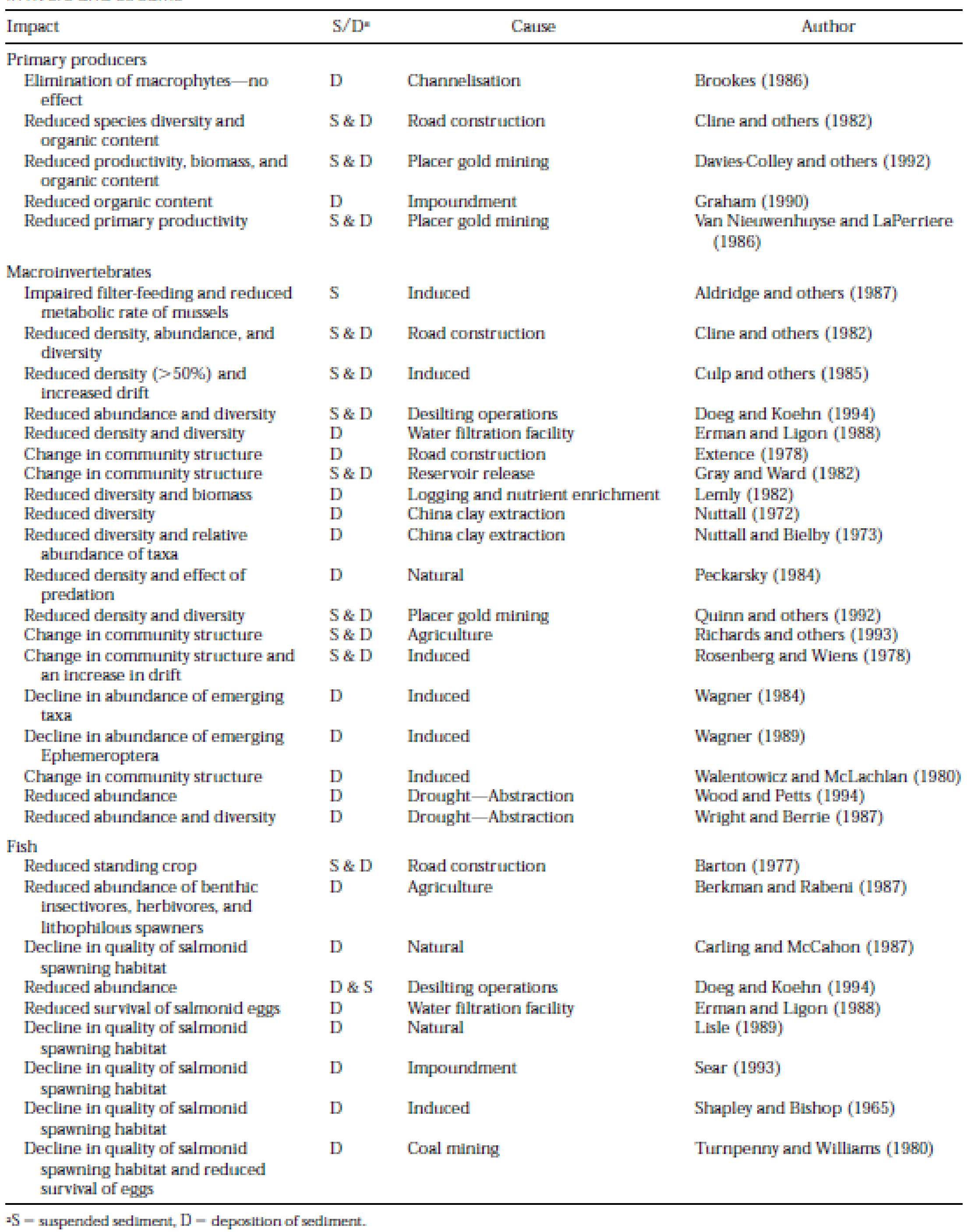
FISH

Biomass
Diversity
Density & Abundance
Feeding & Respiration
Spawning

RESTORATION AND REHABILITATION

Wood and Armitag 1997

Ecological impact of fine sediments on ecology of river systems



Impact	S/D[a]	Cause	Author
Primary producers			
Elimination of macrophytes—no effect	D	Channelisation	Brookes (1986)
Reduced species diversity and organic content	S & D	Road construction	Cline and others (1982)
Reduced productivity, biomass, and organic content	S & D	Placer gold mining	Davies-Colley and others (1992)
Reduced organic content	D	Impoundment	Graham (1990)
Reduced primary productivity	S & D	Placer gold mining	Van Nieuwenhuyse and LaPerriere (1986)
Macroinvertebrates			
Impaired filter-feeding and reduced metabolic rate of mussels	S	Induced	Aldridge and others (1987)
Reduced density, abundance, and diversity	S & D	Road construction	Cline and others (1982)
Reduced density (>50%) and increased drift	S & D	Induced	Culp and others (1985)
Reduced abundance and diversity	S & D	Desilting operations	Doeg and Koehn (1994)
Reduced density and diversity	D	Water filtration facility	Erman and Ligon (1988)
Change in community structure	D	Road construction	Extence (1978)
Change in community structure	S & D	Reservoir release	Gray and Ward (1982)
Reduced diversity and biomass	D	Logging and nutrient enrichment	Lemly (1982)
Reduced diversity	D	China clay extraction	Nuttall (1972)
Reduced diversity and relative abundance of taxa	D	China clay extraction	Nuttall and Bielby (1973)
Reduced density and effect of predation	D	Natural	Peckarsky (1984)
Reduced density and diversity	S & D	Placer gold mining	Quinn and others (1992)
Change in community structure	S & D	Agriculture	Richards and others (1993)
Change in community structure and an increase in drift	S & D	Induced	Rosenberg and Wiens (1978)
Decline in abundance of emerging taxa	D	Induced	Wagner (1984)
Decline in abundance of emerging Ephemeroptera	D	Induced	Wagner (1989)
Change in community structure	D	Induced	Walentowicz and McLachlan (1980)
Reduced abundance	D	Drought—Abstraction	Wood and Petts (1994)
Reduced abundance and diversity	D	Drought—Abstraction	Wright and Berrie (1987)
Fish			
Reduced standing crop	S & D	Road construction	Barton (1977)
Reduced abundance of benthic insectivores, herbivores, and lithophilous spawners	D	Agriculture	Berkman and Rabeni (1987)
Decline in quality of salmonid spawning habitat	D	Natural	Carling and McCahon (1987)
Reduced abundance	D & S	Desilting operations	Doeg and Koehn (1994)
Reduced survival of salmonid eggs	D	Water filtration facility	Erman and Ligon (1988)
Decline in quality of salmonid spawning habitat	D	Natural	Lisle (1989)
Decline in quality of salmonid spawning habitat	D	Impoundment	Sear (1993)
Decline in quality of salmonid spawning habitat	D	Induced	Shapley and Bishop (1965)
Decline in quality of salmonid spawning habitat and reduced survival of eggs	D	Coal mining	Turnpenny and Williams (1980)

[a] S = suspended sediment, D = deposition of sediment.

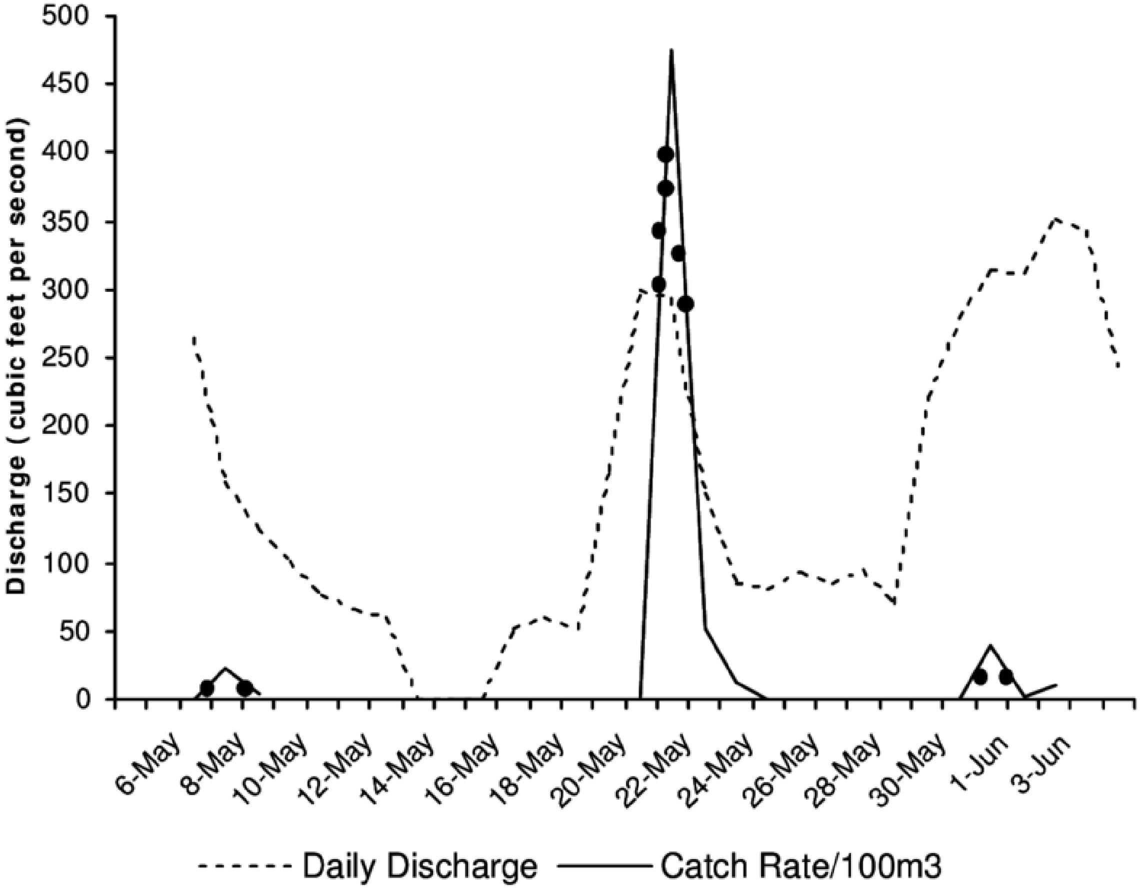
Wood and Armitag 1997

What are impacts of sediment trapping by impoundments on sand-bottom streams?

- Physico-chemical effects
  - Flow reductions
  - Sediment compaction
  - Deposition/erosion of sediment in main and off channel habitats
- Biotic effects

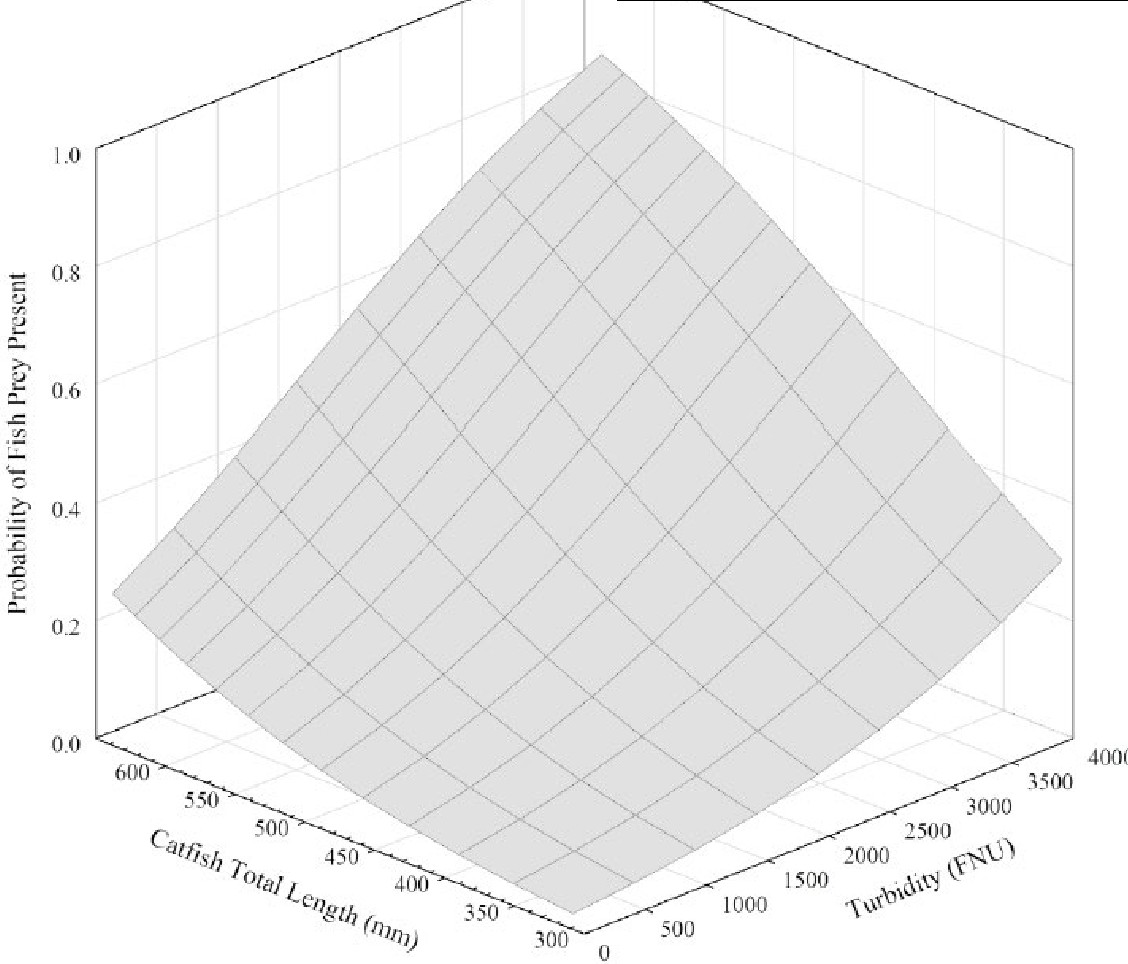
Dr. Frank Cross, University of Kansas

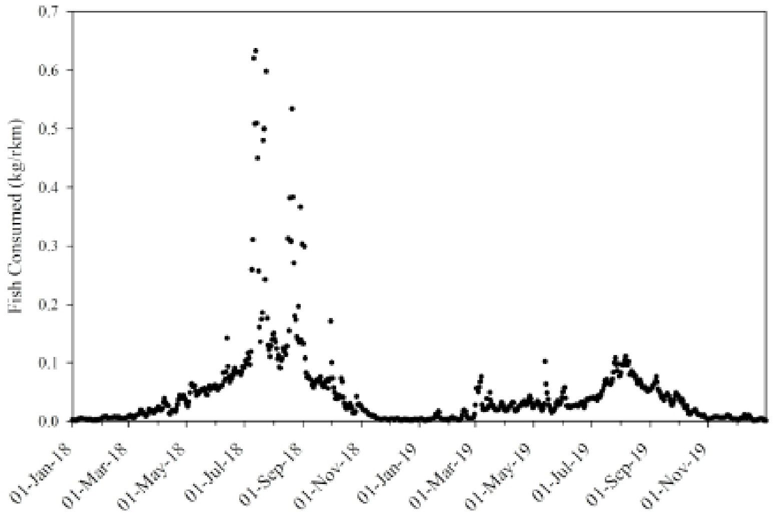
Turbidity flow pulses associated with spawning

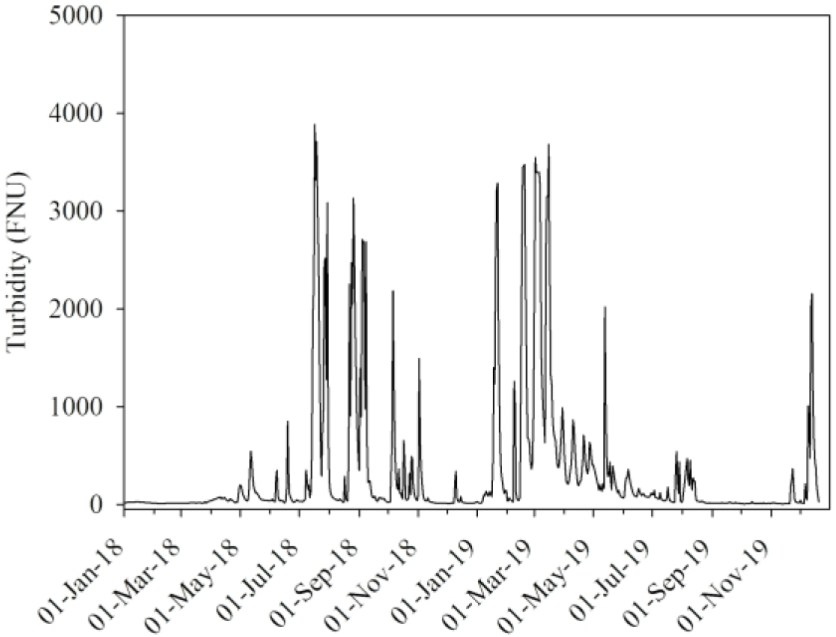


Rio Grande Silvery Minnow

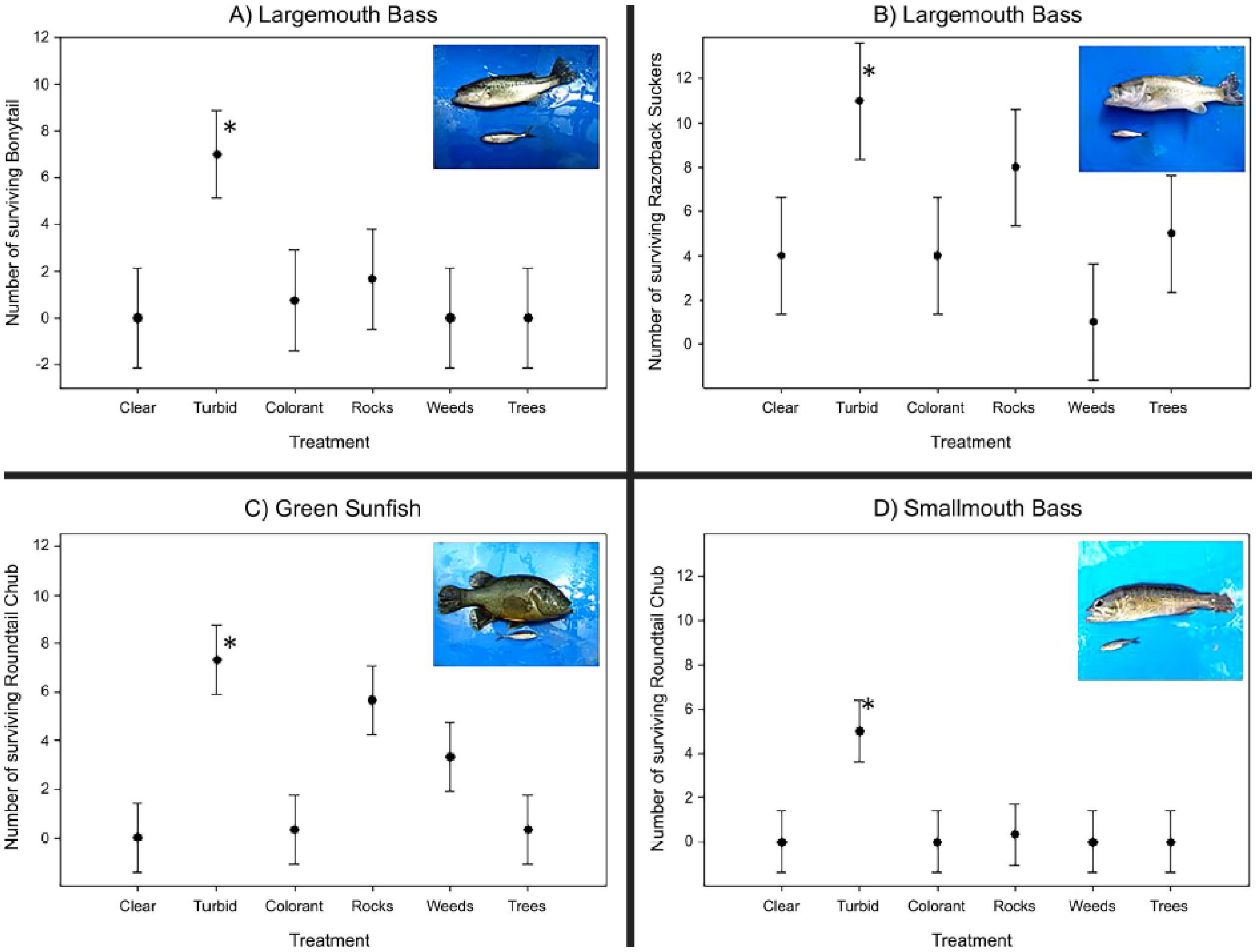
Turbid flow pulses influence feeding activity



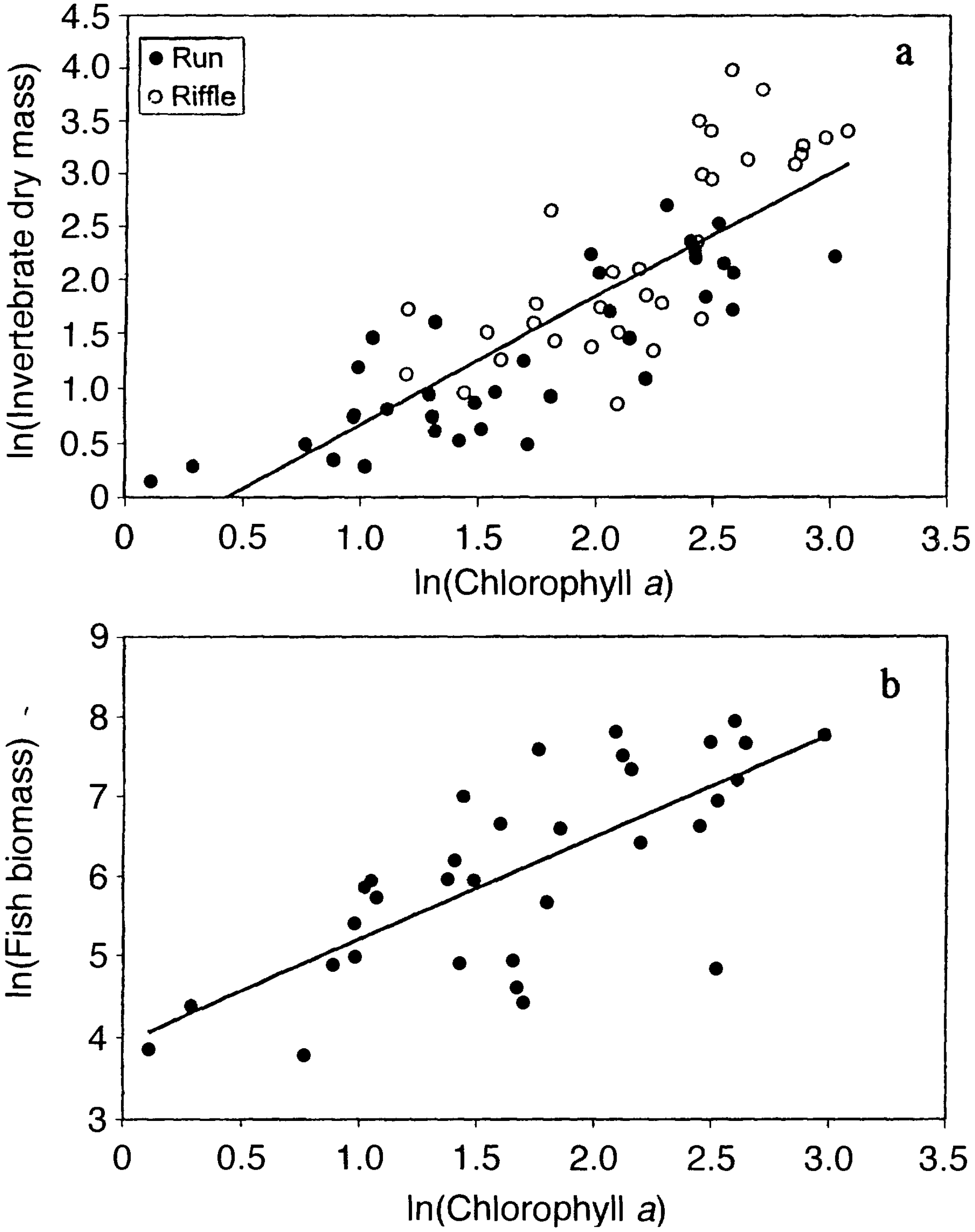




Turbidity effects predator-prey dynamics



Ward and Vaage 2019



FLOW–SEDIMENT–BIOTA RELATIONS: IMPLICATIONS FOR RIVER REGULATION EFFECTS ON NATIVE FISH ABUNDANCE

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[2] *Department of Rangeland Resources, Utah State University, Logan, Utah 84341-5230 USA*
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[4] *Department of Geography, University of Colorado, Box 260, Boulder, Colorado 80309-0260 USA*

Abstract. Alteration of natural flow regimes by river regulation affects fish distribution and assemblage structure, but causative pathways are not always direct and may go unrecognized. The Colorado River population of the endangered Colorado pikeminnow, *Ptychocheilus lucius*, suffers from low rates of recruitment and reduced carrying capacity. We hypothesized that availability of prey fish for this large-bodied native piscivore may, in part, be limited by reduced standing crops of periphyton and macroinvertebrates resulting from accumulation of fine sediment in the riverbed. We stratified the 373-km-long study area into 11 strata and sampled various physical and biological parameters in runs and riffles of three randomly selected 1- to 3-km-long study reaches in each stratum during base flows of spring and fall 1994–1995. Significant correlations were found between biomass of both chlorophyll *a* and macroinvertebrates and various physical metrics that described the degree of fine sediment accumulation in gravel–cobble substrates. Riffles were relatively free of fine sediment throughout the study area, but substrates of runs contained progressively more fine sediments with distance downstream. There was a corresponding longitudinal change in biota along the river continuum with greatest biomass of fish, invertebrates, and periphyton upstream. Adult pikeminnow were concentrated in upstream strata where potential prey fishes were most abundant. We suggest that fine-sediment effects on biota have increased in recent years as a result of river regulation. Historically, spring snowmelt frequently produced flows with magnitudes sufficient to mobilize the bed and winnow silt and sand from coarse substrates. Following regulation, the mean recurrence interval of such flows lengthened from 1.3–2.7 yr (depending on the stratum) to 2.7–13.5 yr, extending the duration of fine sediment accumulation and potentially depressing biotic production. Our results describe and help explain the spatial distribution of the Colorado River fish community and establish a link between flow, sediment, and the riverine food web supporting the community's top predator. To maintain intact native fish communities in this and other river basins, managers need to identify functional aspects of the natural hydrograph and incorporate these findings into river restoration efforts.

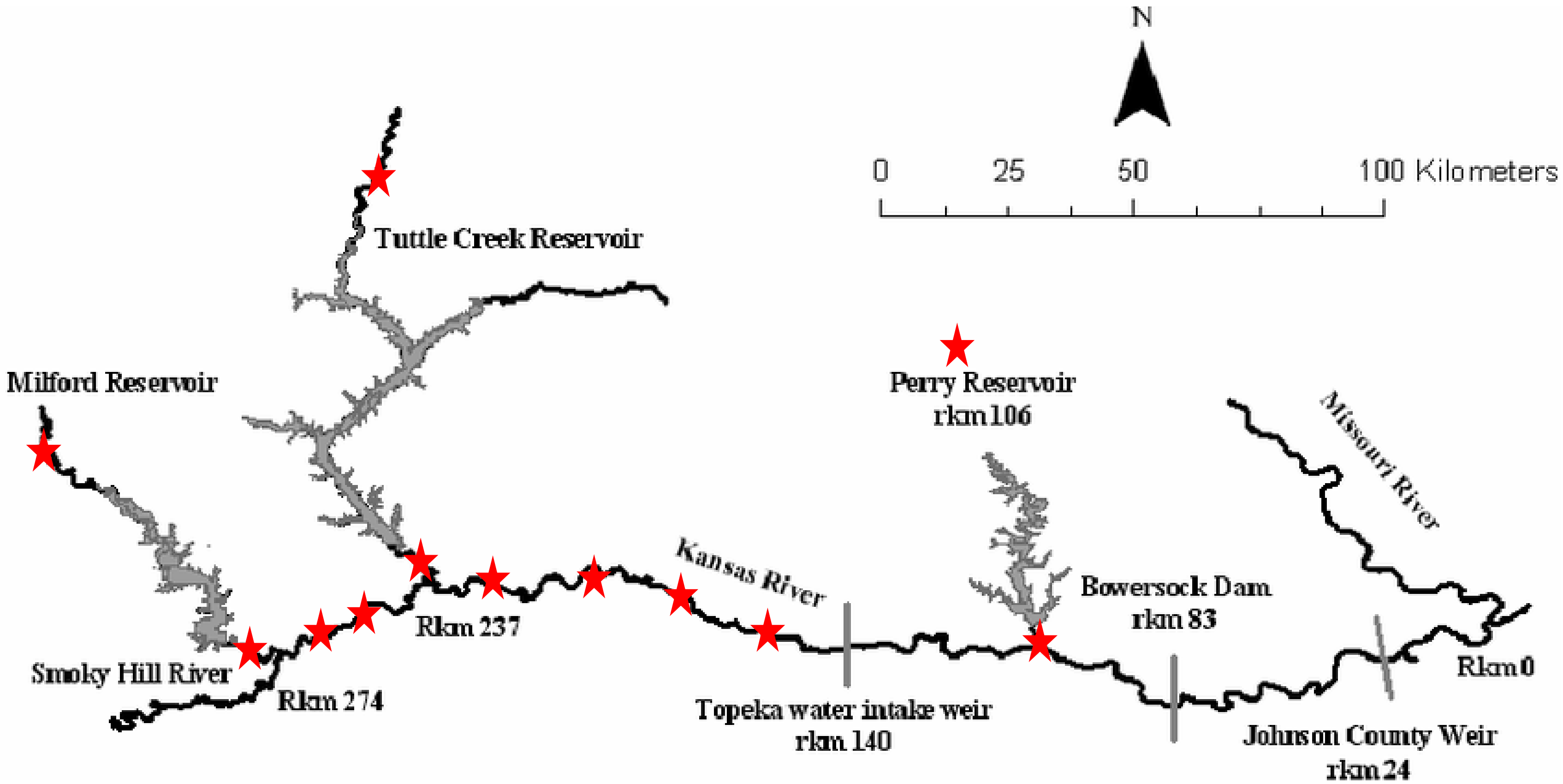
Key words: benthic macroinvertebrates; Colorado pikeminnow; Colorado River; fish distribution; flow regime; foodweb; interdisciplinary research; natural-flow-regime paradigm; Ptychocheilus lucius; *river regulation; river restoration; sediment.*

What should be monitored during a sediment release/restoration pilot project?

- Water quality
  - Nutrients, DO, etc.
- Food web
  - Primary production, secondary production
- Community structure
  - Species composition
- Recruitment and growth
  - Juvenile abundance, age and size structure of populations
- Movement and habitat associations
  - Telemetry
- Experimental design
  - BACI – treatment and control sites
  - Season of treatment

Experimental Design

- Before After Control Impact (BACI)
- Reference sites
  - Above and below reservoir
  - Upstream of confluence
  - Downstream gradient



Questions and Discussion