Good Sediment, Bad Sediment:

Understanding and Managing Watershed Sediment Along the U.S. West Coast

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Santa Cruz, CA

Santa Cruz Sentinel

"... we can bring back the coho salmon and steelhead runs. But we need to deal with issues of sediment, pollution and threats to the integrity of the riparian corridors."

--Lois Robins, Oct. 23, 2013

Santa Cruz Sentinel

"Hundreds of dams on California's streams have trapped millions of cubic yards of sand that would have been carried to the shoreline under natural conditions and nourished our beaches."

--Gary Griggs, Aug. 29, 2009

Things to take home:

1. Sediment is an important part of the **natural geologic cycle**.

2. Sediment may both **enhance** and **degrade** river and coastal habitats.

3. **Humans** have disrupted U.S. West Coast sediment cycles for at least hundreds of years.

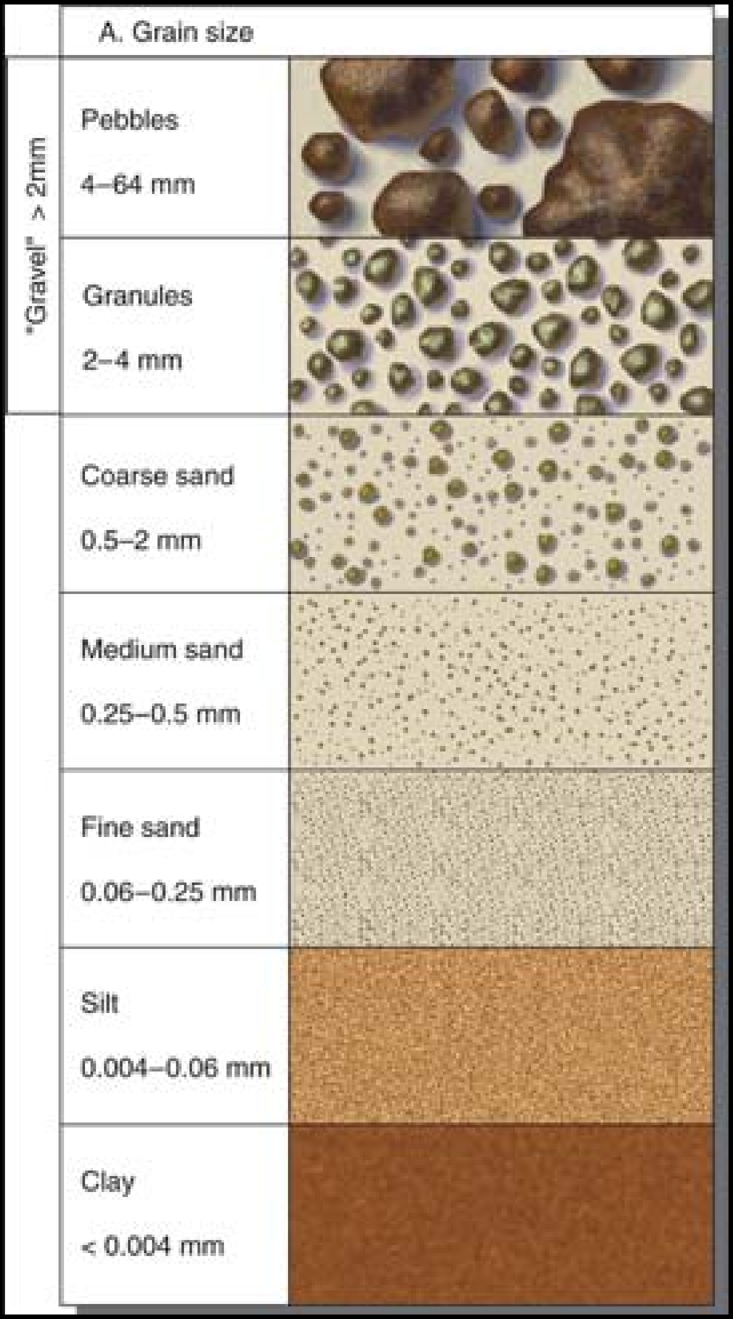
4. Sediment is being managed in **novel ways** up and down our coast.

What is "Sediment?"

Which sediment is good?!?!

Which sediment is bad?!?!

Which sediment is ugly?!?!



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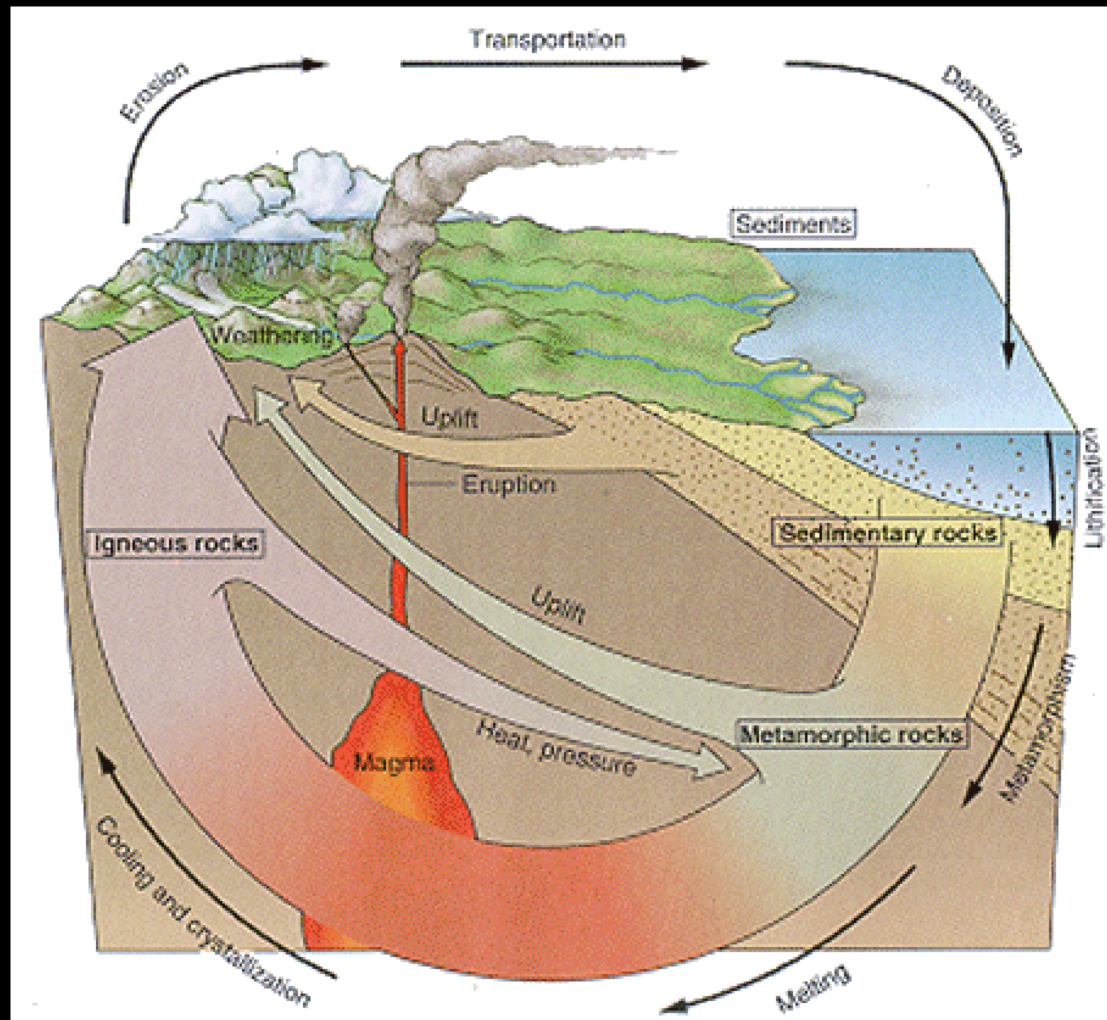
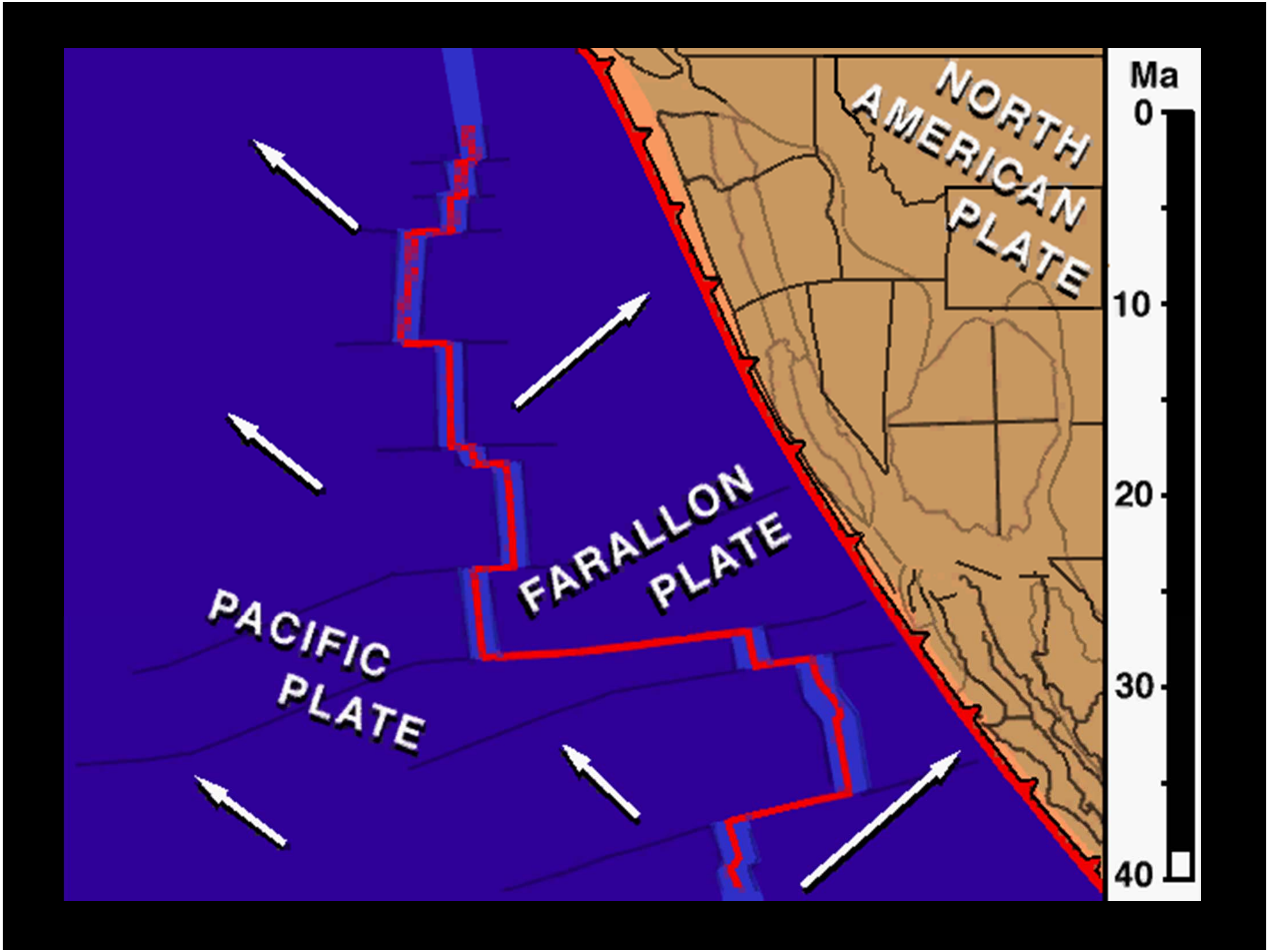
The geologic cycle...

"Active tectonic margins" are hot spots of mountain building and erosion

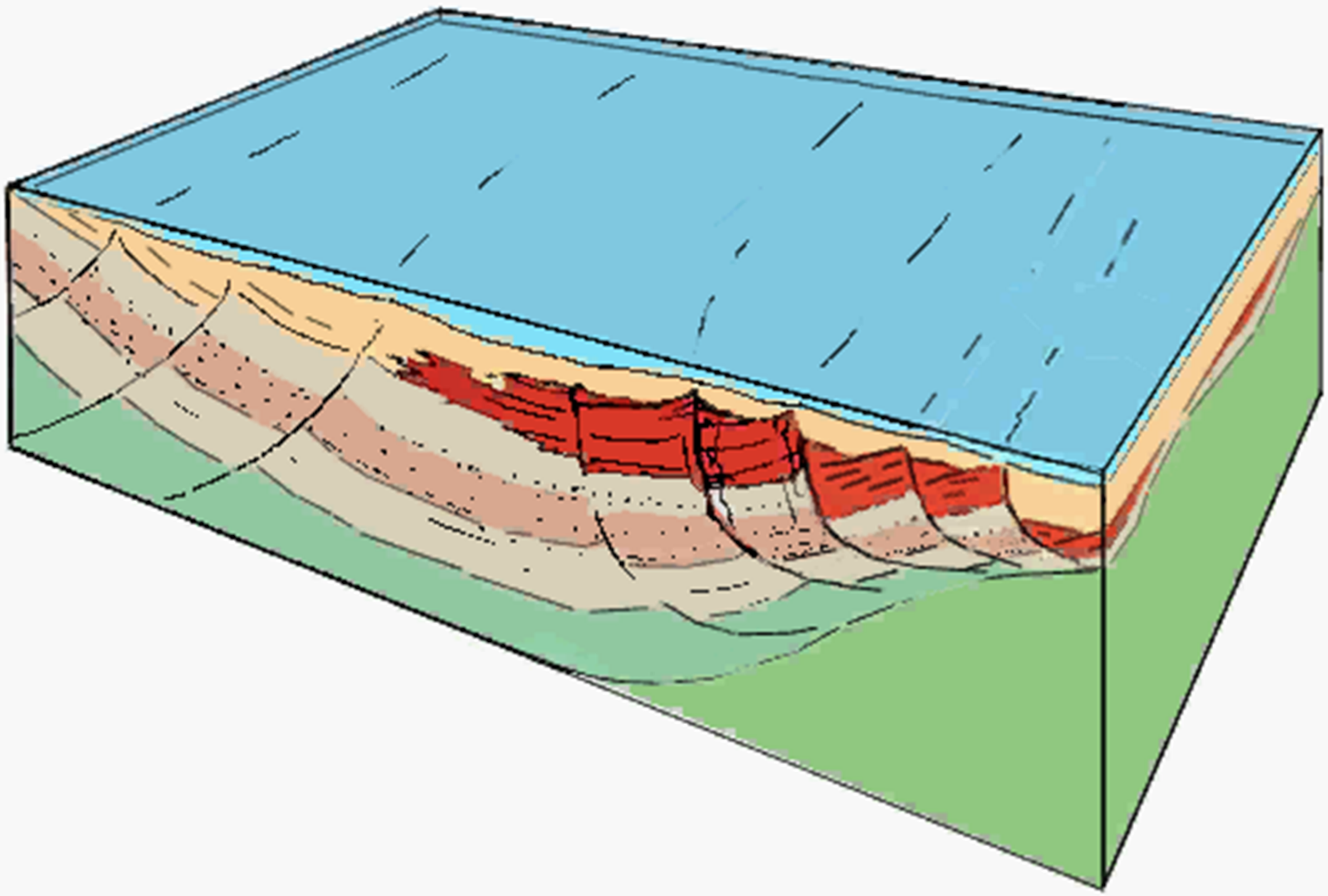
Milliman and Farnsworth (2012)




NORTH AMERICAN PLATE
FARALLON PLATE
PACIFIC PLATE
Ma
0
10
20
30
40

Plio-Pleistocene

Oblique Shortening against the "Big Bend"



Drawn and animated by Tanya Atwater (UCSB)

Deposition of River Sediment in the Sea…

Moore (1969)

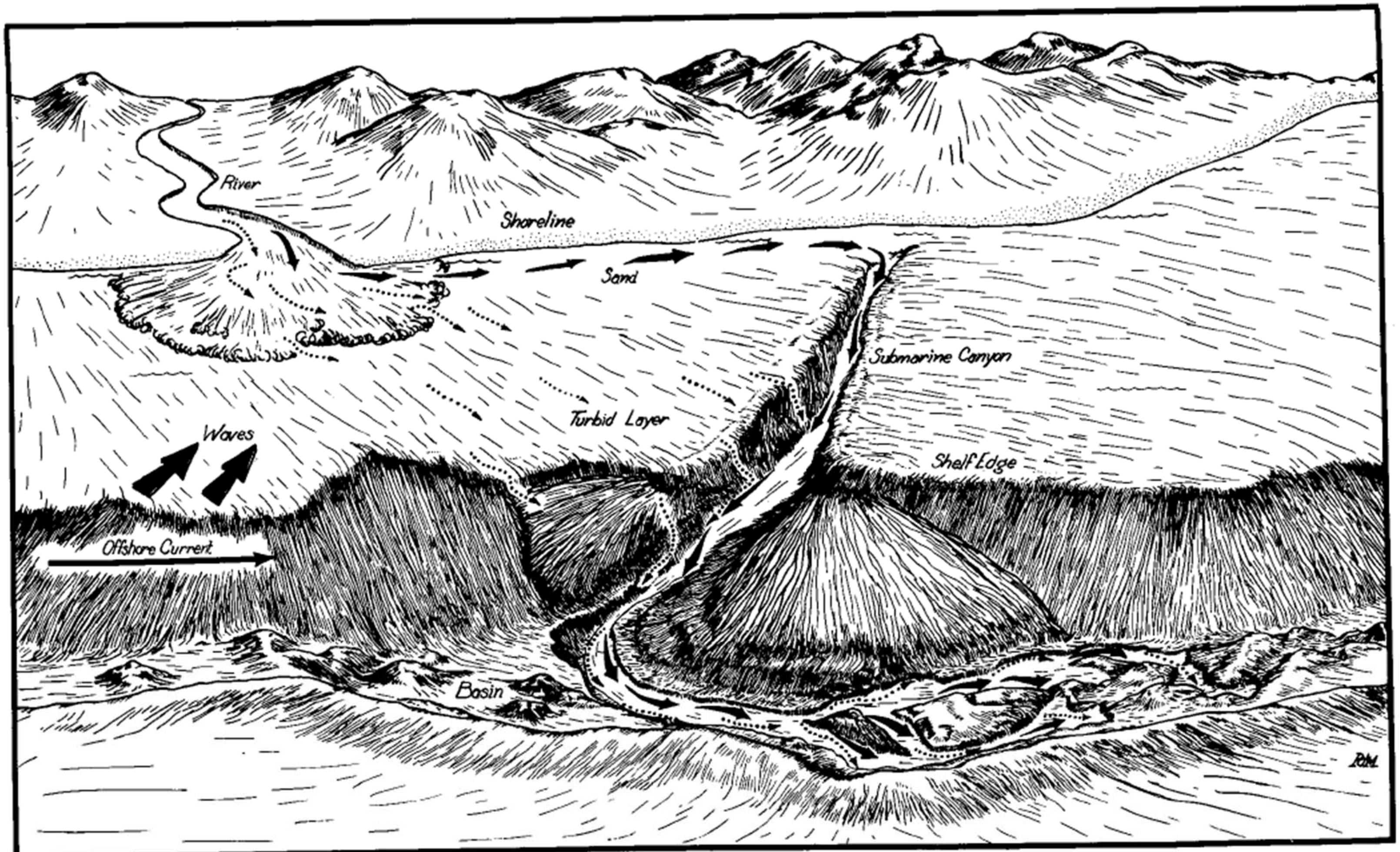
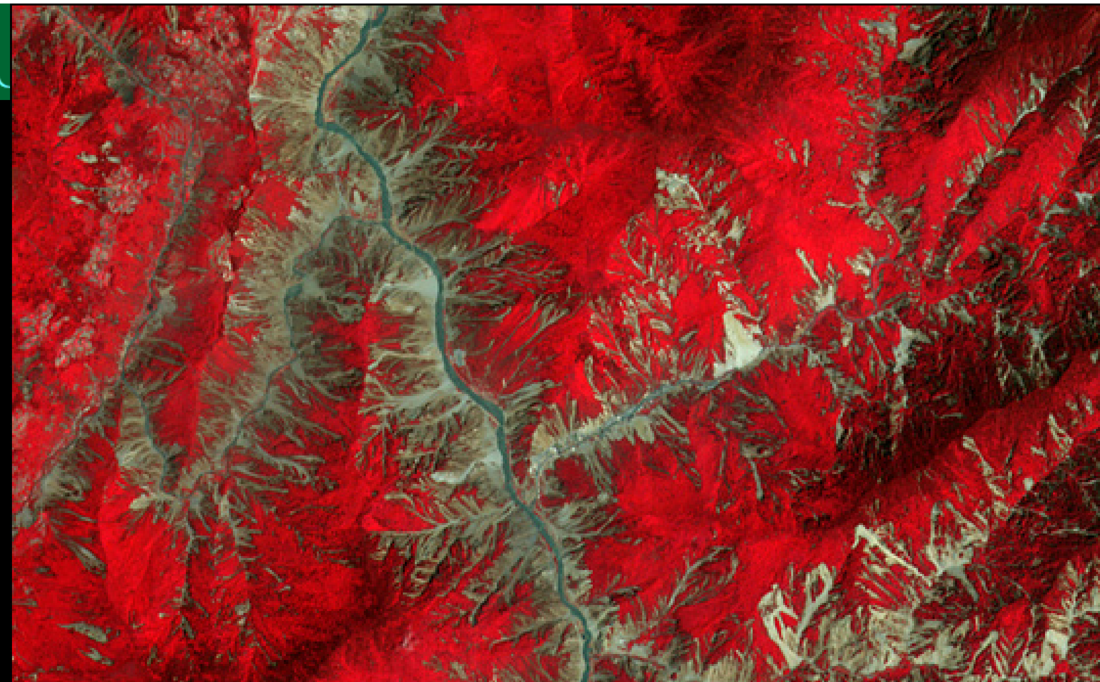


Figure 22. Schematic diagram of routes of transportation of sand (solid arrows) and finer-sized detritus (dotted arrows) from river mouth to basin floor.

Earthquakes and erosion...

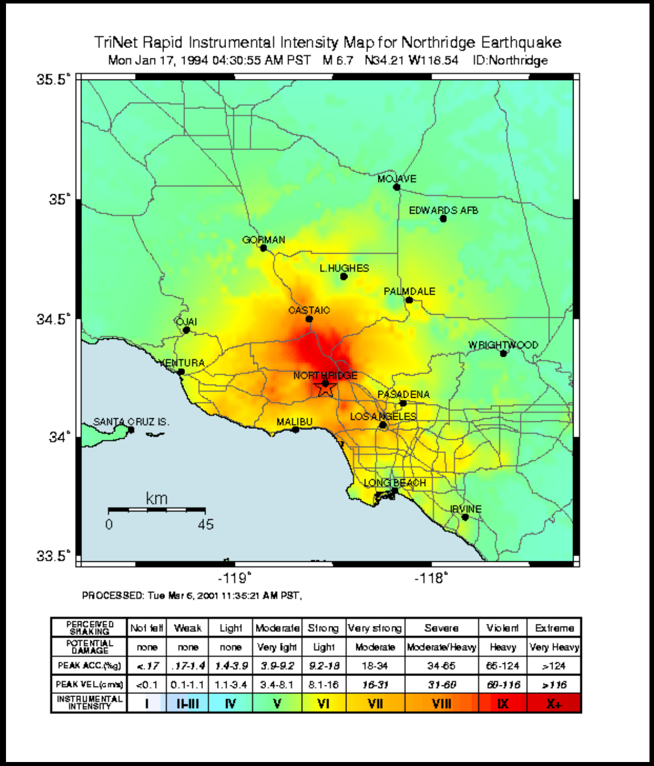
2008 Sichuan Earthquake
(M = 8.0)



May 23, 2008

February 19, 2003

Earthquakes and erosion...



1994 Northridge Earthquake
(M = 6.7)

USGS (1995)

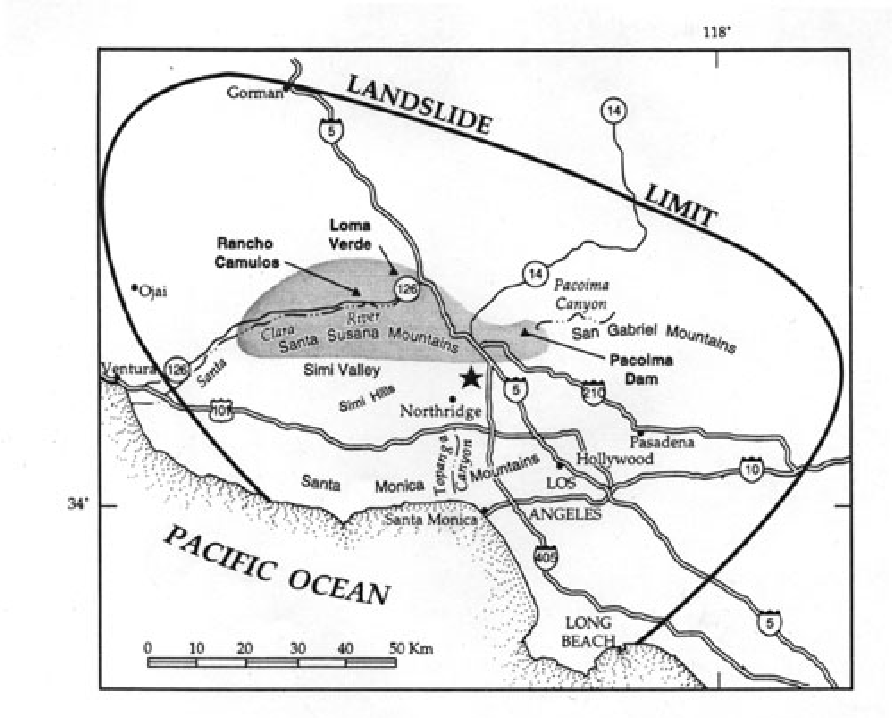
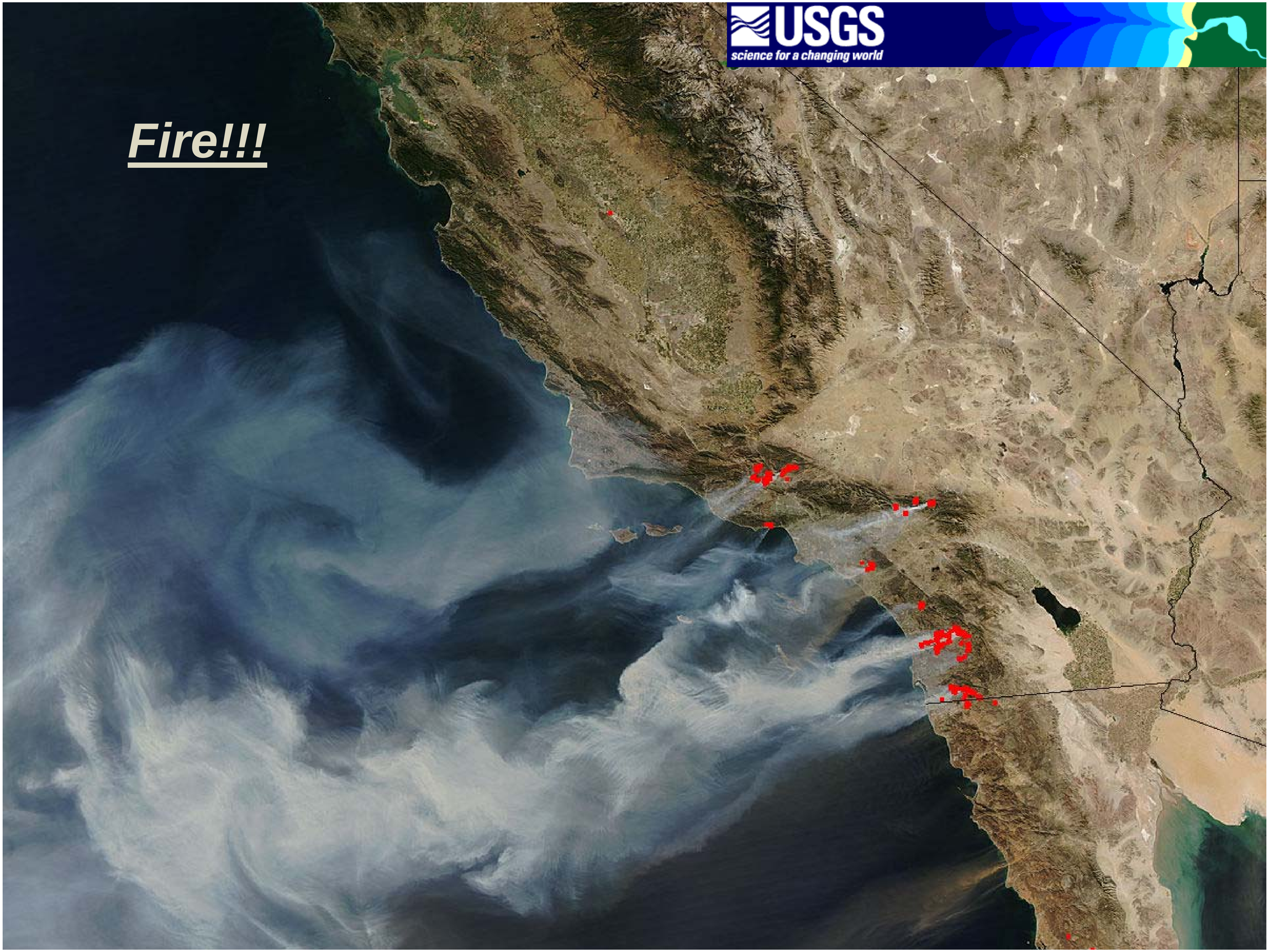


Figure 1. Map showing epicenter of Northridge earthquake (star), limit of landslides triggered by the earthquake (heavy, solid line), and area of greatest landslide concentration (shaded).

Fire!!!



Fire can dramatically increase sediment production from Coastal California hillslopes.

LACFCD (1959)
Scott and Williams (1978)
Griffin (1978)
Davis (1980)
Fall (1981)
Wells (1981)
Hecht (1981)
Florsheim et al. (1991)
Keller et al. (1997)
Gabet and Dunne (2003)
Lavé and Burbank (2004)
Warrick and Rubin (2007)
Hunsinger et al. (2008)
Warrick et al. (2012)

On burned watersheds debris production during floods increases dramatically. In La Crescenda a mudflow from Shields Canyon on March 4, 1978, carried cars along with large boulders down a street into this house; just the roof is showing. (See the paper by Daniel Davis in Section 4 of the full proceedings.)

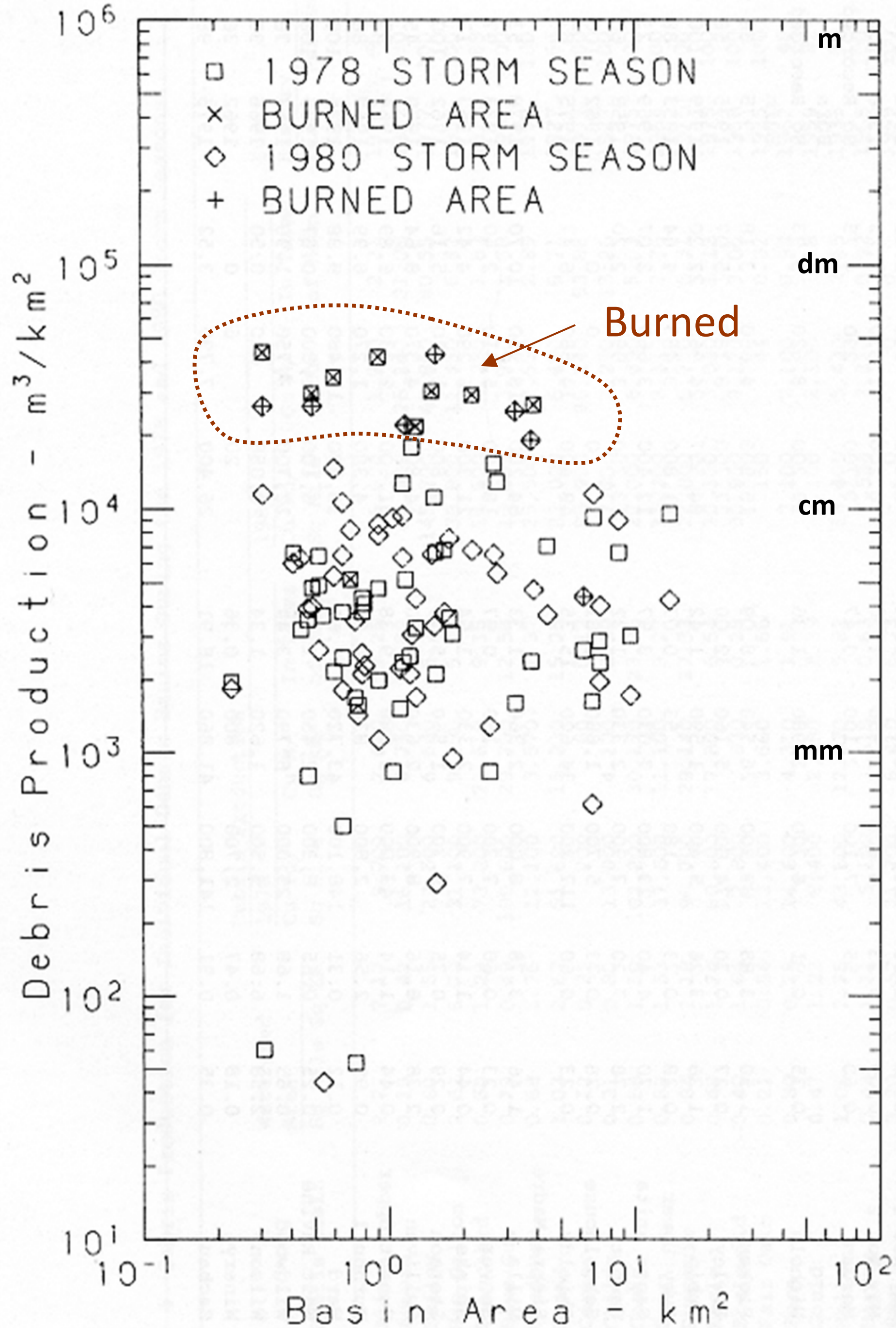


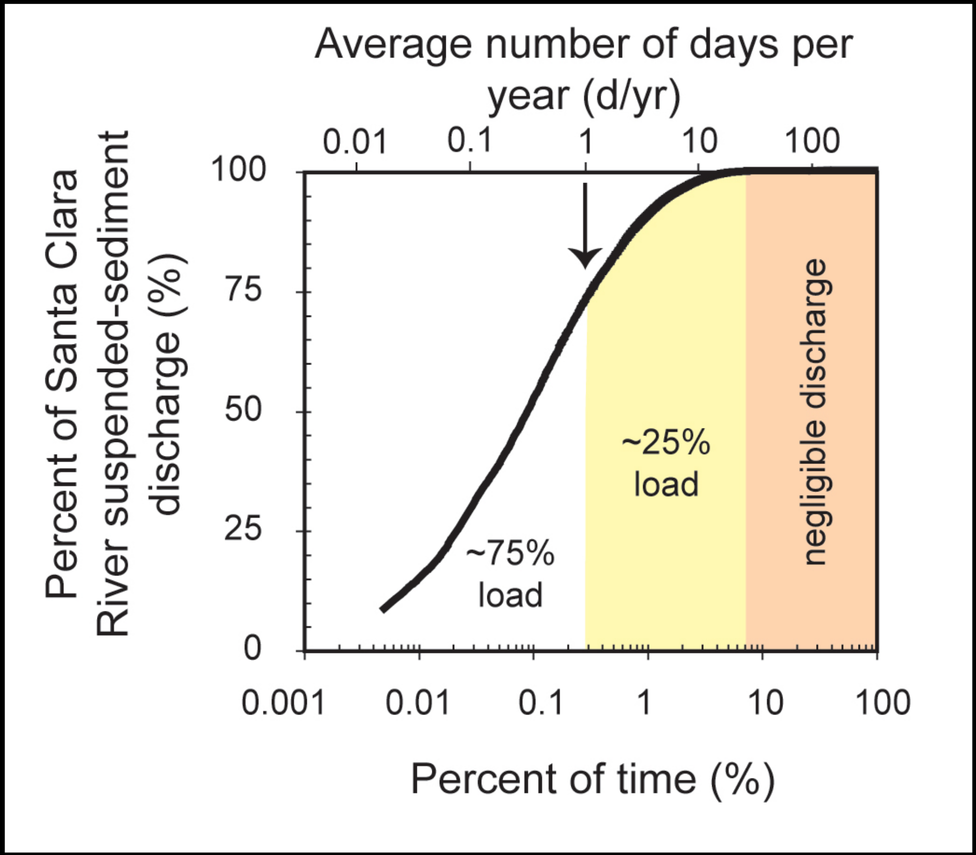
FIGURE 3 Debris production rates during 1978 and 1980.

USGS
science for a changing world

Floods!!!

California coastal rivers respond to <u>wet winter storms.</u>

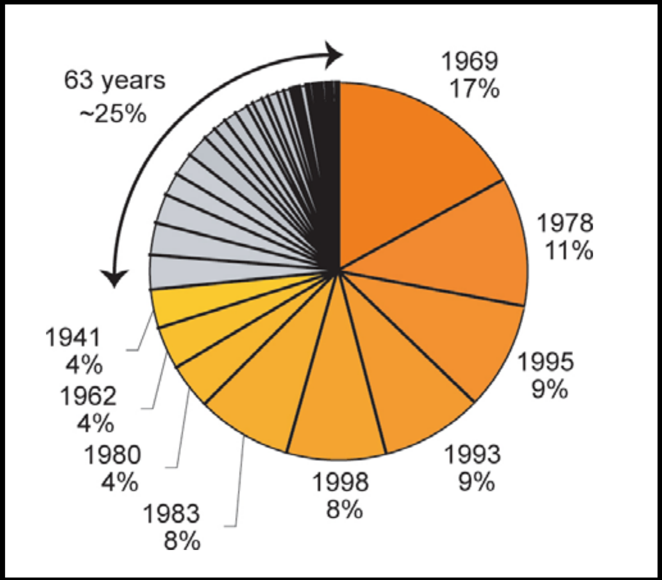
Infrequent events are important.

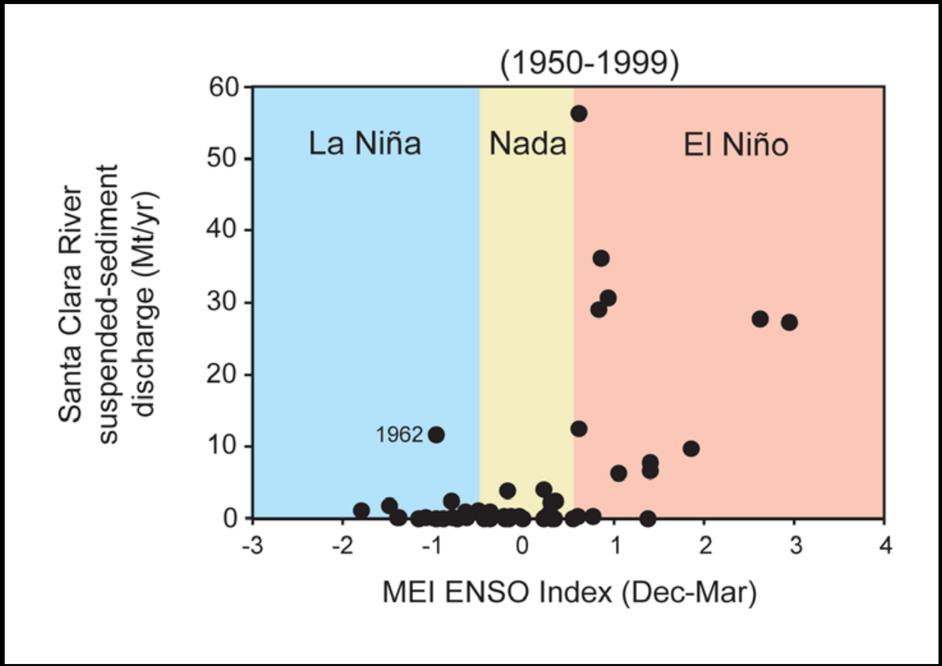


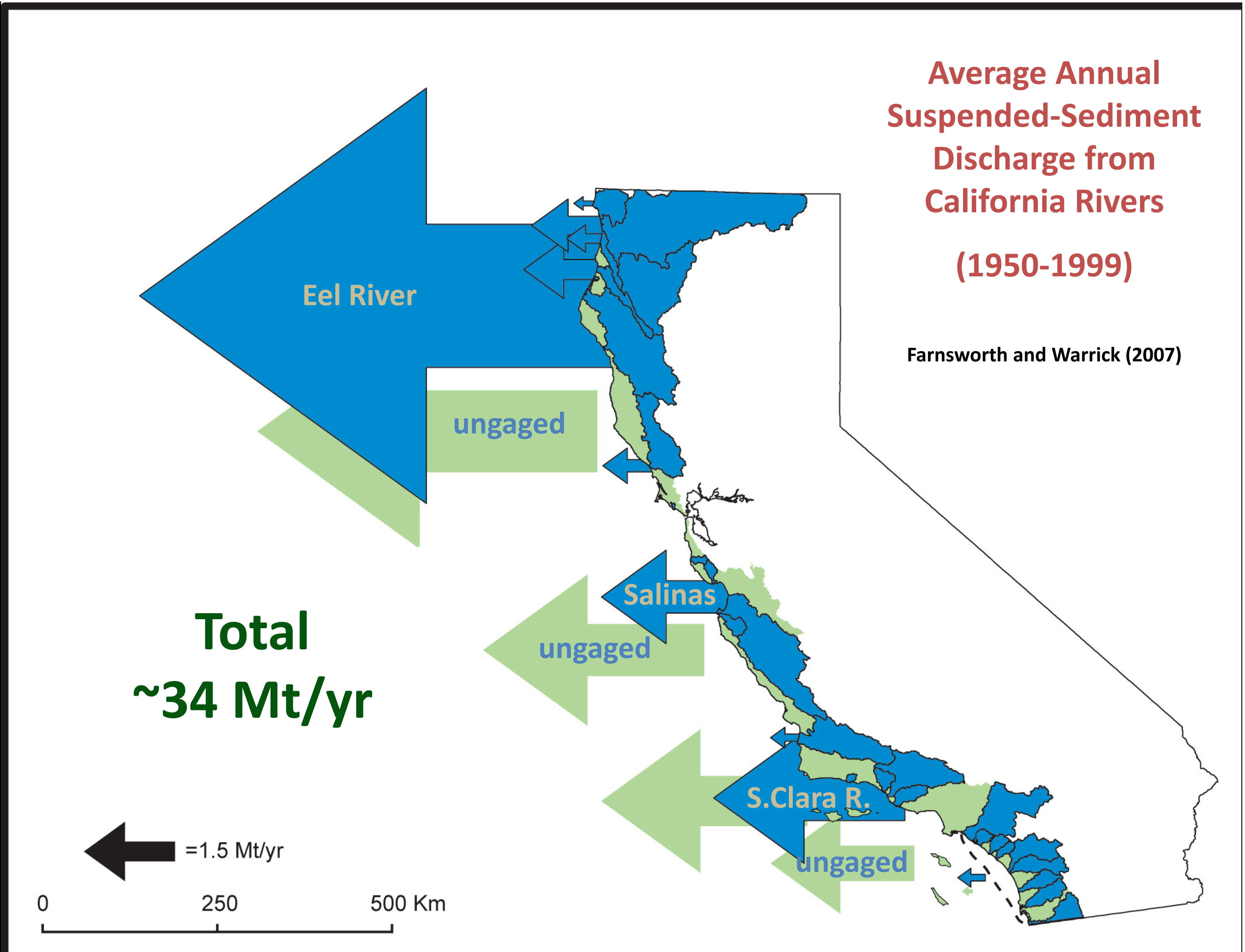
Warrick and Milliman (2003)
Farnsworth and Warrick (2007)

Santa Clara River sediment discharge (75 yr)

Infrequent years are important too…





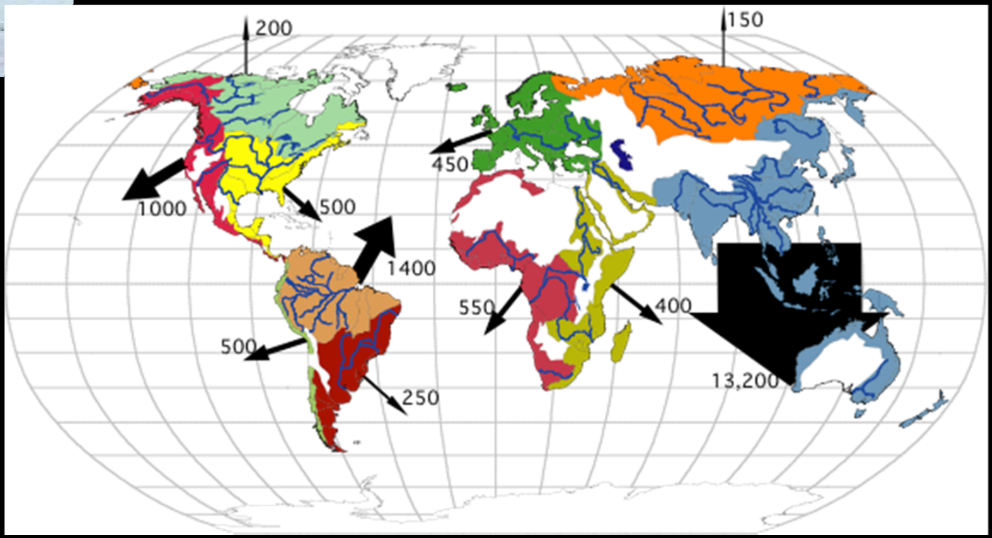

Average Annual
Suspended-Sediment
Discharge from
California Rivers
(1950-1999)
Farnsworth and Warrick (2007)
Eel River
ungaged
Salinas
ungaged
S.Clara R.
ungaged
Total
~34 Mt/yr
=1.5 Mt/yr
0
250
500 Km

How much sediment is 34 million tonnes per year??

These trucks can haul 25 tonnes

~1.5 million trucks/year

[approx. one every 2 seconds]



Milliman and Farnsworth (2011)

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River and Floodplain Substrate

Substrate for Wetlands

[redacted]

Shovel ready. For conservationists in Rhode Island, restoring coastal marshes requires boots on the ground.

WETLANDS

Can Coastal Marshes Rise Above It All?

As climate change causes sea level to rise, wetland scientists are struggling to predict which salt marshes will drown—and which might climb out of danger

WESTERLY, RHODE ISLAND—Biologist Marci Cole Ekberg plunges her shovel into a particularly gloppy spot in a mucky salt marsh near the Atlantic Ocean. Her goal: to drain one of many shallow pools that are creating dead zones in the expanse of otherwise dense grasses, a phenomenon that she's recently observed in more than a dozen other marshes around the state. She fears that the pools are an early consequence of the sea-level rise that is being driven by global warming and an ominous "glimpse of the future" for marshes in New England. Rising oceans will drown the grasses, she worries, eliminating rich habitats and leaving coastlines bare.

Other researchers, however, are skeptical that the pockmarks are a result of climate change, saying winter ice or other causes may be to blame. And Rhode Island isn't the only place where researchers are debating what is really happening in salt marshes today and how the wetlands will fare in a future of higher seas. There's wide agreement that these salt marshes are among the ecosystems most vulnerable to rapid sea-level rise. But few researchers are ready to predict the fate of specific marshes; there's still too much to learn, they say, about how wetlands in different regions accumulate sediments that might allow them to outclimb rising waters and whether they can escape by migrating inland.

Wetlands scientists are mobilizing to reduce the uncertainty. By building improved forecasting models and better monitoring systems—and studying wetland regions already experiencing dramatic sea-level rise—they're hoping to bring some clarity to a murky topic and identify practical steps to protect marshes. The overarching goal, says wetlands researcher Susan Adamowicz of the U.S. Fish and Wildlife Service in Wells, Maine, is to help managers "give marshes the best possible chance to outpace global sea-level rise."

Wet benefit

Although they're not the most glamourous biomes, the United Nations estimates that wetlands are one of the world's most valuable providers of "ecosystem services," such as storm protection, water filtering, and seafood production. They also help lock up as much as 450 billion metric tons of carbon globally, absorbing warming compounds that might otherwise leak into the atmosphere.

Marshes have already experienced centuries of insults—such as pollution, overfishing, and draining for farming and development—that have disrupted the ecological systems that help keep them healthy. Now, rising temperatures are causing land-based ice sheets to melt and seawater to expand. Such changes have already helped push sea level up by an average of 1.4 to 3.7 millimeters per year since 1950, according to a 2010 study published in *Science*. (Other estimates vary.) Climate models predict that the trend will accelerate to 1 centimeter or more per year as Earth continues to warm. And even a few extra centimeters of water can mean the difference between life and drowning for marshes, which typically occupy a narrow coastal band that ends just above the high tide line.

Faced with rising water, marshes have three options, says geologist Matthew Kirwan of the U.S. Geological Survey (USGS) in Charlottesville, Virginia: build in place by trapping and piling up new sediments, migrate to higher ground inland, or die. Predicting which path a marsh might take, however, requires understanding the interplay of a host of factors, including the biological traits of different marsh grasses and how wetlands construct muddy yet firm foundations from grains of sand, silt, and organic litter.

A sinking laboratory

To get a glimpse of how these factors might shape marsh adaptability in the future, researchers have begun to scrutinize one wetland ecosystem already experiencing local sea-level rise: Louisiana's Mississippi delta along the Gulf of Mexico. There, natural and human factors are causing the land to sink relatively quickly, creating a natural laboratory that simulates a sea-level rise of 1 to 2 cm per year. That could be "what it's going to be like everywhere by the end of the century," says ecologist James Morris of the University in South Carolina, Columbia.

Some delta marshes are adapting better than others: While grasses in a spot named Old Oyster Bayou have thrived, for instance, those in nearby Bayou Chitique have been largely submerged. The difference, researchers say, highlights the important role that an adequate supply of fresh sediment can play in marsh survival. While Old Oyster Bayou receives some 70 mg of fresh sediment per liter of river water, allowing it to outclimb rising Gulf waters, Bayou Chitique's sediment infusions are largely blocked by upstream levees, reducing the load to just 20 mg per liter. The "natural process has been interrupted and there's not enough sediment," Morris says.

CREDIT: PETER HANNEY/SAVE THE BAY - NARRAGANSETT BAY

A 2010 modeling study that Kirwan and his USGS colleagues published in *Geophysical Research Letters* underscored the importance of sediment supply. In a scenario that included a rapid global sea-level rise of 1.25 m by 2100, the outlook for the 21st century was grim: "Most coastal wetlands worldwide will disappear," they concluded. But under slower scenarios, there was hope. Although marshes with low sediment availability fared poorly in the models, those with ample supplies often survived. A marsh's tidal range also played a role, the study found, with wetlands located in regions with larger gaps between low and high tide better situated to ride out sea-level rise, apparently because plants adapted for higher tidal ranges better withstand drowning.

Trench warfare

For conservationists, such studies suggest that it might be possible to help threatened wetlands adapt—for instance, by removing levees or dams to restore sediment, or even pumping in new mud. And in Rhode Island, the idea of ultimately aiding drowning marshes is what motivated Cole Ekberg, a biologist with the conservation group Save The Bay, to recently lug a shovel into a marsh here that is pockmarked with shallow grassless pools.

The origins and meaning of the pools is the subject of local debate, some fierce. Cole Ekberg and others say that their spread is a relatively recent development, documented in just the last few years in the higher-elevation parts of marshes in Rhode Island, Connecticut, Massachusetts, and Maine. And she's been running a restoration experiment of sorts, draining the pools to see if the grasses come back. "It's the best part of the day when water begins to move," she says.

Other marsh researchers are skeptical, blaming winter ice damage, invasive weeds, or geology. Mark Bertness, a marine ecologist at Brown University, sees "no evidence" of sea-level rise in the pools and says that the Save The Bay staff members are "well-intentioned but naïve."

Bertness also wonders whether the focus on sea-level rise is diverting attention from more immediate threats. His own studies, for instance, have shown that overfishing has resulted in a boom in a population of crabs that chow on marsh grass, sometimes causing severe damage. "I was just dumbfounded what these crabs have done over a 2, 3-year period," he says. "Sea-level rise is going to come along, but this is happening now."

No escape route

All sides, however, appear to agree that if a marsh doesn't have a sediment source that will allow it to build up, "then the question becomes will it be able to migrate," Kirwan says.

Increasingly, the answer is no. Marshes around the world are hemmed in by development that essentially blocks migration to higher ground. In many areas, the obstacles are concrete or stone sea walls built to protect seaside homes or industrial sites. In Europe and parts of Asia, studies have found that two-thirds or more of many shorelines have been "armored." Even sparsely populated sites can leave marshes little room: A 2000 study of Maine's lightly inhabited Casco Bay found that one-fifth of its shoreline was armored.

Some researchers are beginning to look at ways to clear such obstacles. Around the Blackwater National Wildlife Refuge near Maryland's Chesapeake Bay, for instance, a coalition of conservation and government groups has embarked on an ambitious effort to identify potential obstacles and protect possible migration paths. The group is even eyeing pine forests and farm fields that may have the right topography and soil types to be converted to future marshes. The Nature Conservancy has launched a similar effort on Long Island in New York state, while Rhode Island officials, scientists, and activists are working on a statewide assessment to map out risks to wetlands under different scenarios.

It could take decades to realize such forward-thinking efforts, planners say. In the meantime, scientists say that they need better ways to monitor how marshes are doing now. A good start, a team of USGS researchers argued in an April paper in *Nature Climate Change*, would be to create a global network of 14,000 relatively simple devices called surface elevation table markers. Secured to the ground beneath marshes, mangroves, and wetlands, they can register changes in the height of the marsh surface to an accuracy of 0.01 cm, more precise than surveys, LiDAR, or satellite readings. The authors say the network, which might cost $8 million to create, "would allow policymakers to prioritize wetland sites for intervention."

That's a goal that Save The Bay's Cole Ekberg supports. "Someone might ask what's the point of protecting salt marshes anyway, if they're doomed in the long run," she says. "My answer is if we can extend their lives 20 or 30 years, it's a valuable investment."

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Bayou blues. Louisiana's disappearing marshes offer a glimpse of how global wetlands may respond to rising seas.

CREDIT: P. R. HOAR/NOAA/NESDIS/NCDDC

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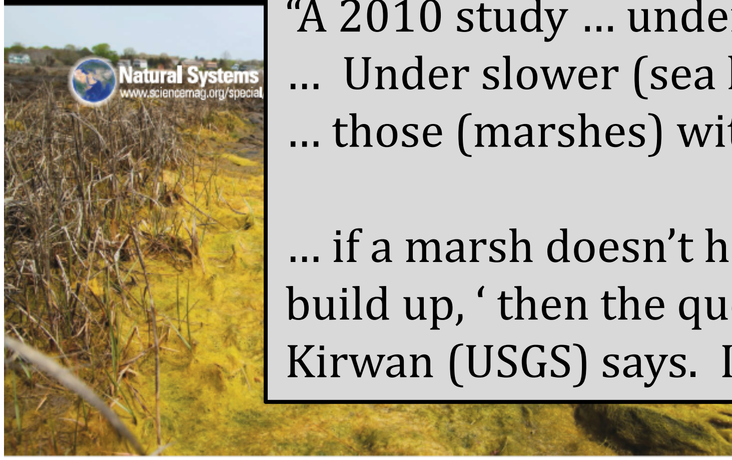

SPECIALSECTION

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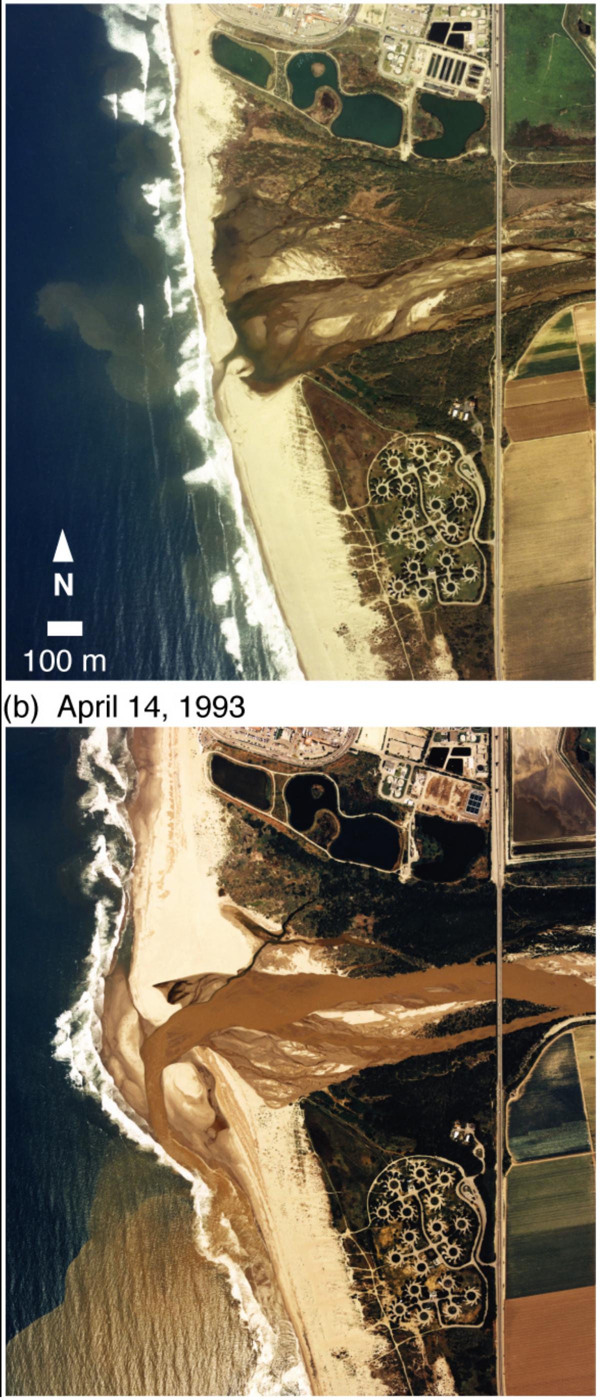
CREDIT: P. R. HOAR/NOAA/NESDIS/NCDDC

Beach Sediment

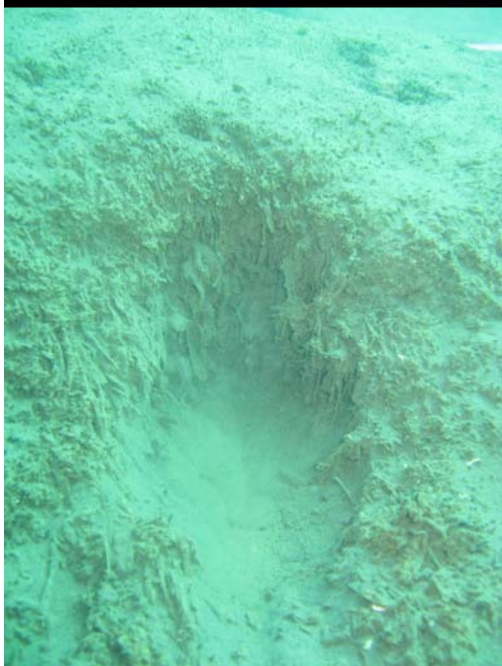
Photo courtesy of the
California Coastal Conservancy, taken in 2005

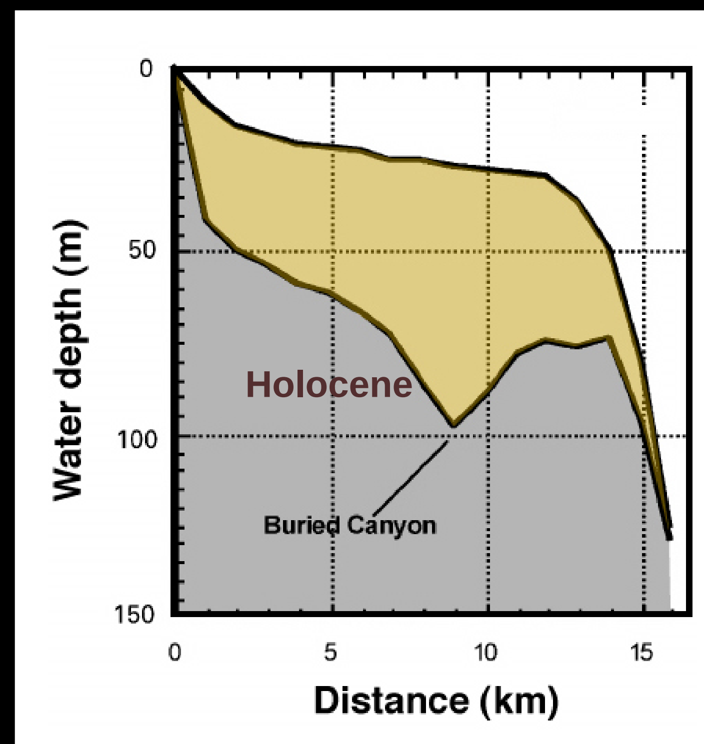
Barnard and Warrick (2009)
Marine Geology



USGS
science for a changing world

Marine Sediment





Grey Whale Feeding

Negative biological effects of suspended sediment

"In water, **agricultural contaminants** are most noticeable when they produce immediate, dramatic toxic effects on aquatic life, although more subtle, sublethal chronic effects may be just as damaging over long periods. …

… Although **suspended sediment represents the largest volume** of aquatic contaminants, pesticides, nutrients, and organic enrichment are also major stressors of aquatic life."

--Cooper (1993)

Negative biological effects of suspended sediment

(i) Effects of sediment:

-Behavioral – alarm reaction, avoidance, attraction, …

-Physiological – respiration changes, choking, reduced filtering, …

(ii) Effects of turbidity on light:

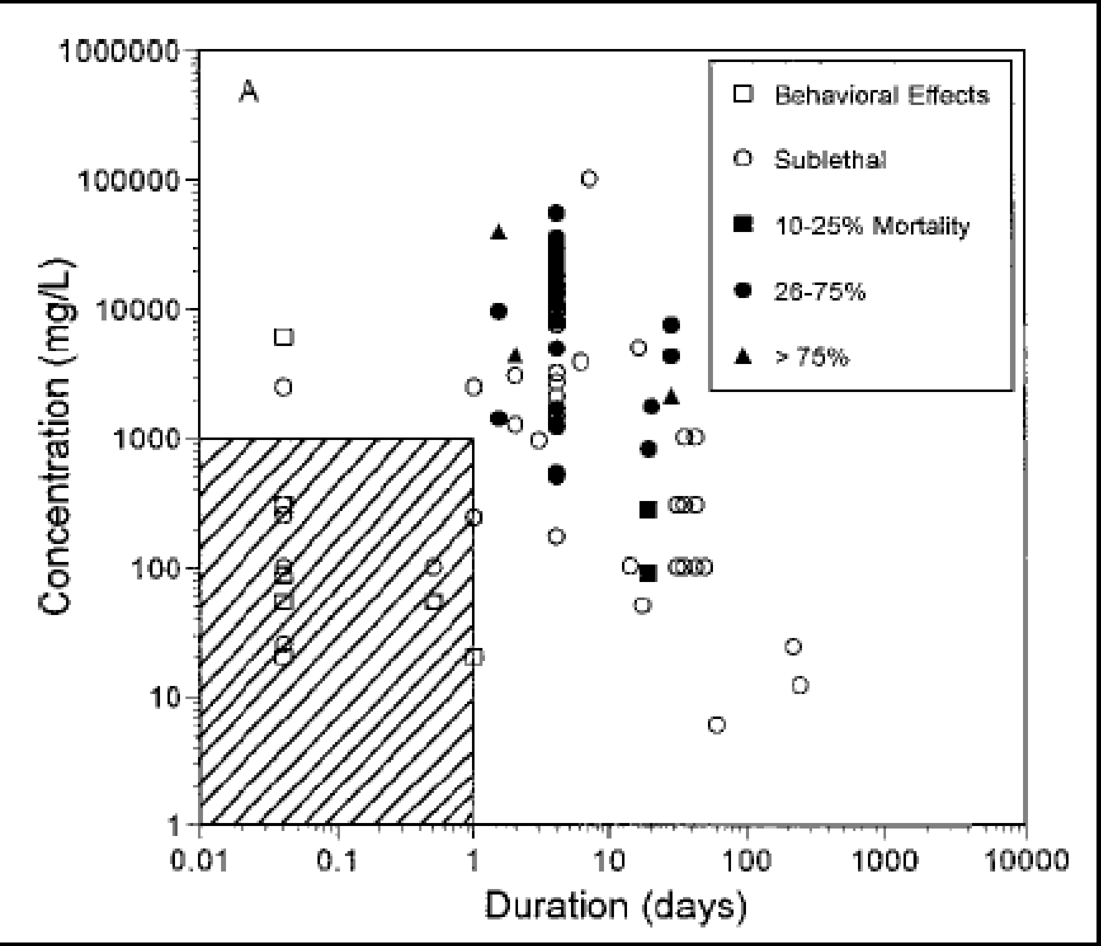
-Behavioral – reduced feeding, avoidance, attraction, …

-Physiological – lower photosynthesis, …

Results: Increased mortality, decreased growth, lower reproduction

--after Wilber and Clarke (2001)

How can we understand these biological effects?



Juvenile salmonids

Wilber and Clarke (2001)

How can we understand these biological effects?

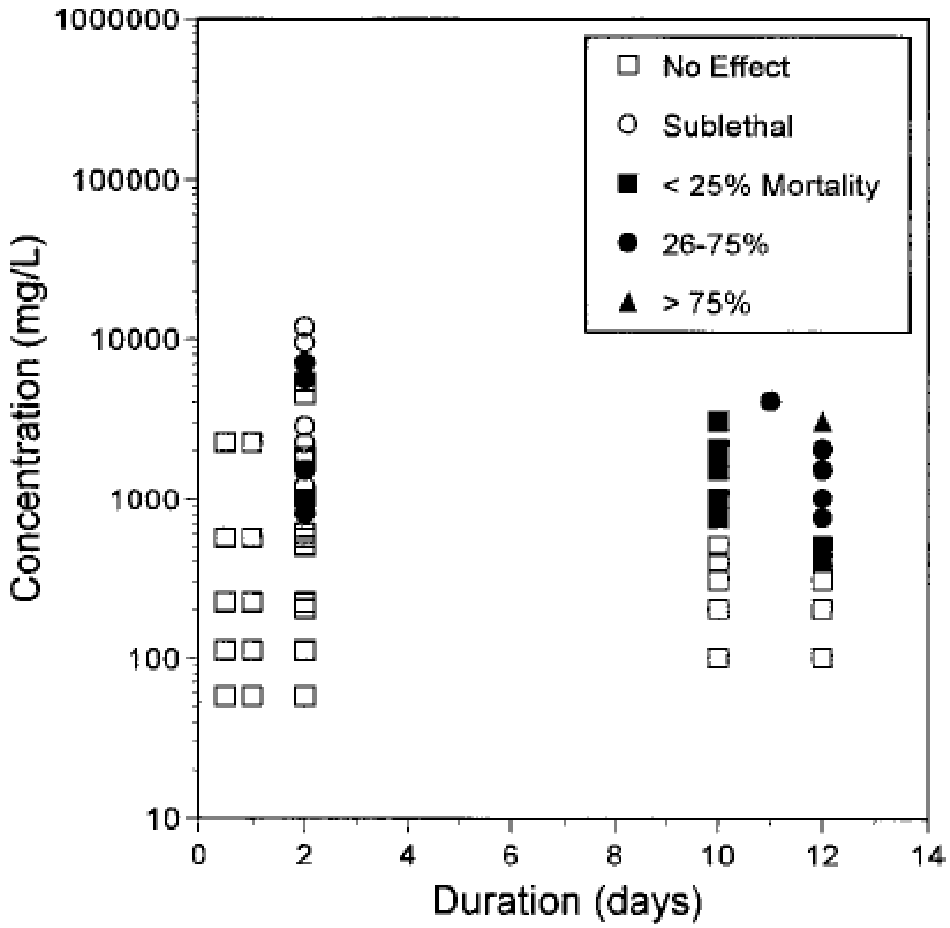


FIGURE 6.—Responses of larval bivalves to suspended sediment concentrations at the given exposure durations.

Larval Bivalves

Wilber and Clarke (2001)

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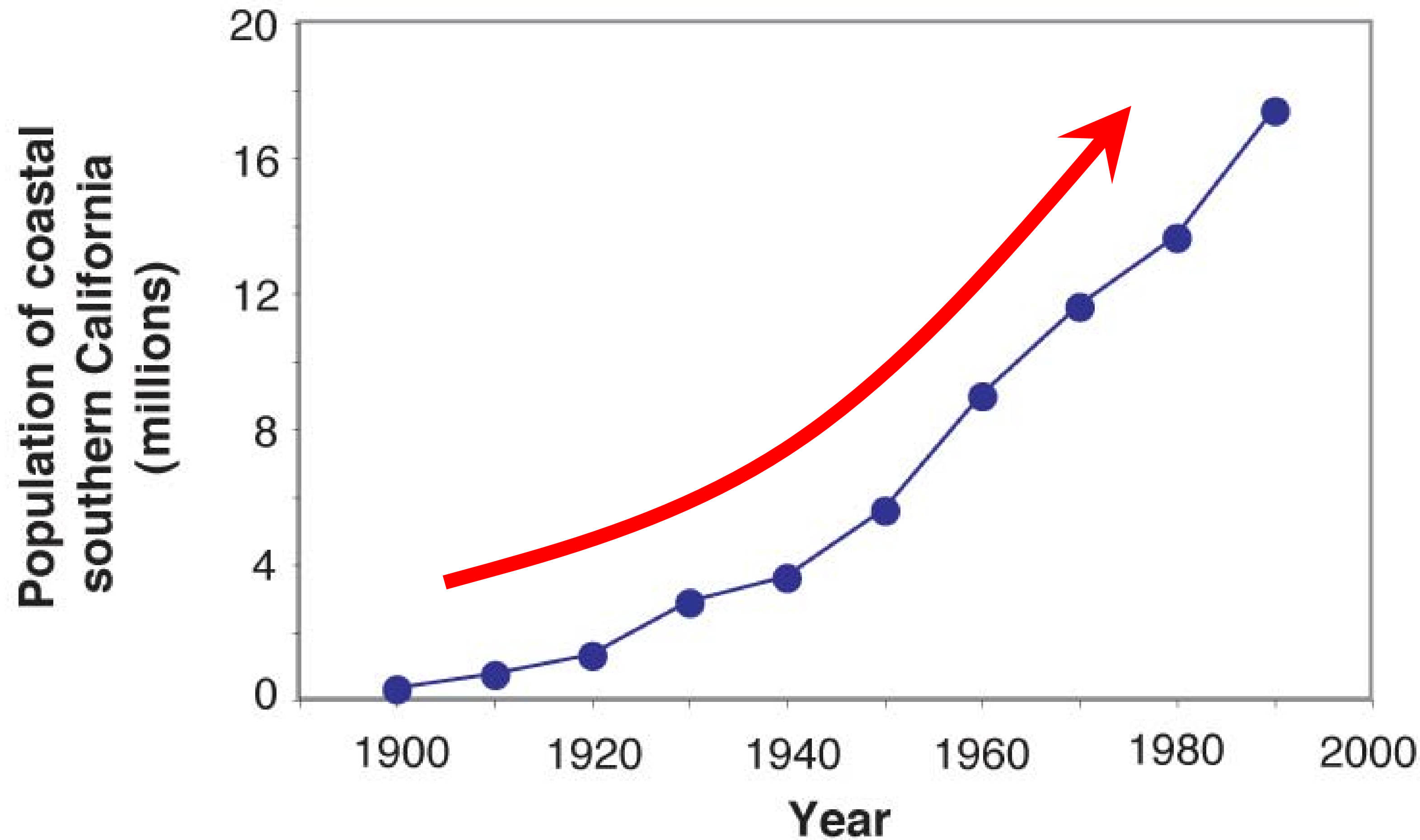
DAMS

38% of the coastal CA watershed is dammed.

~25% decrease in sand discharge to beaches.

Willis and Griggs (2003)

Population Growth



U.S. Census

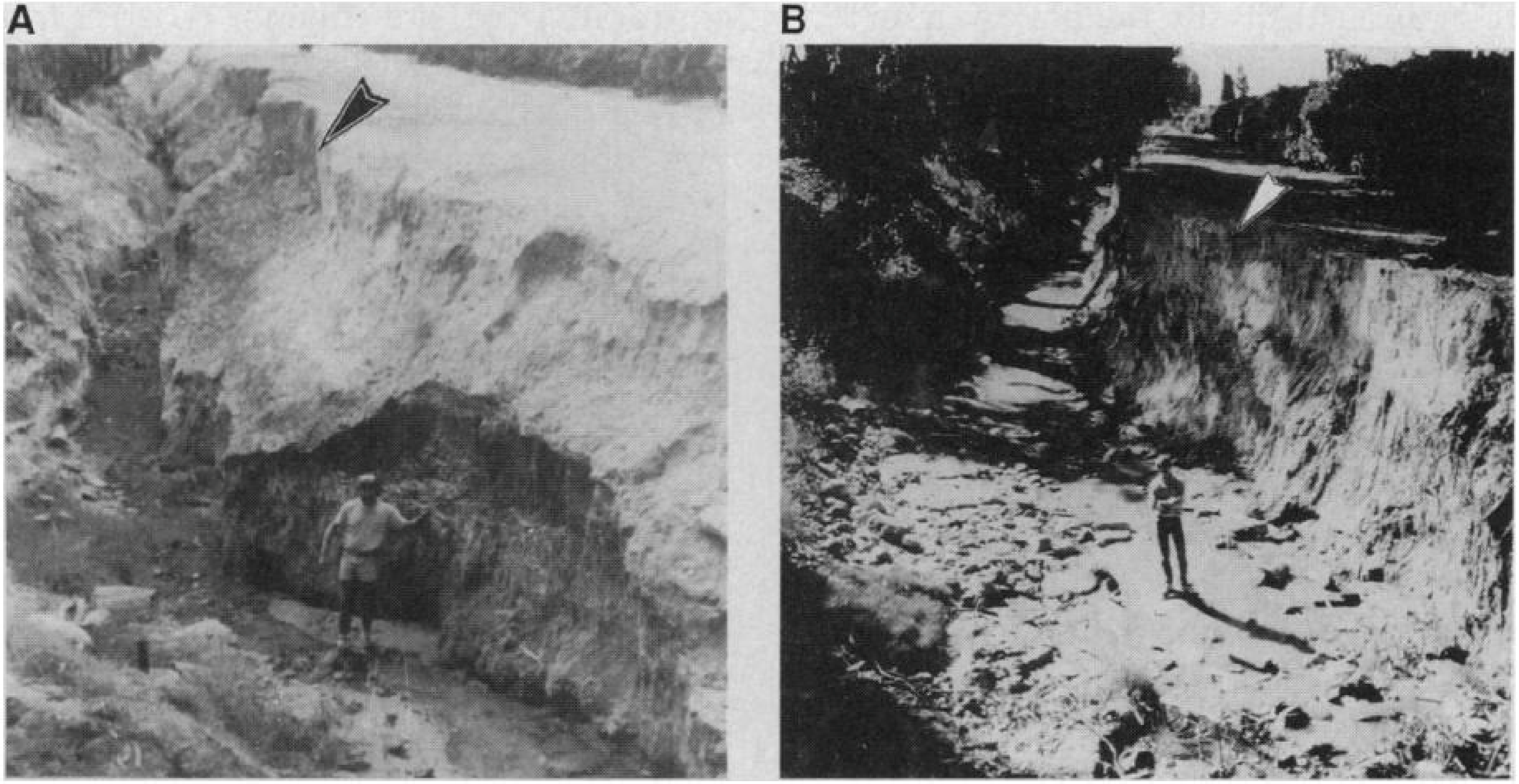
Pacific Ocean

Prado Dam

2000

"Much of the urban and suburban development occurred on lands formerly devoted to citrus, subtropical and deciduous orchards."

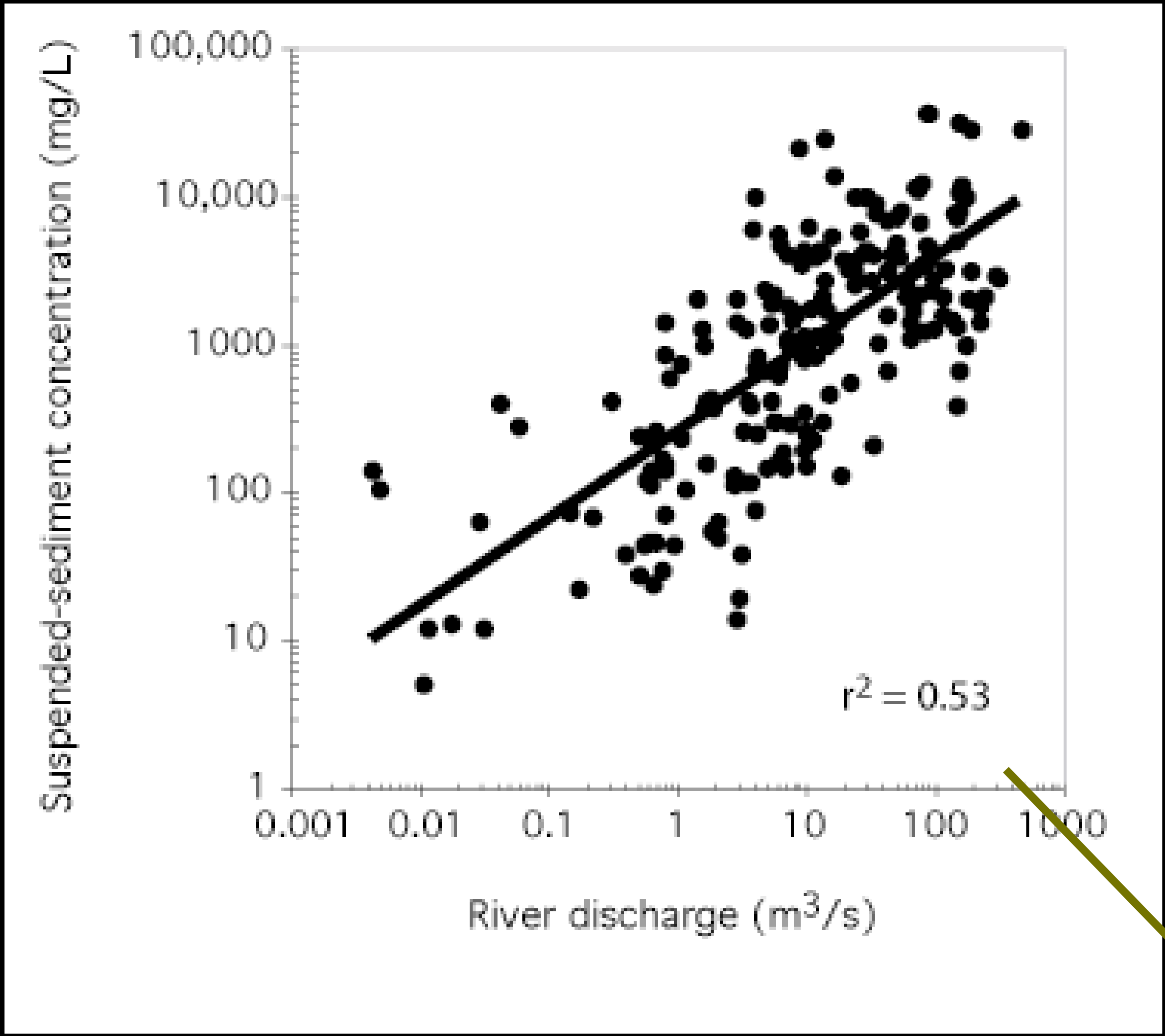
Channel Erosion Following Urbanization

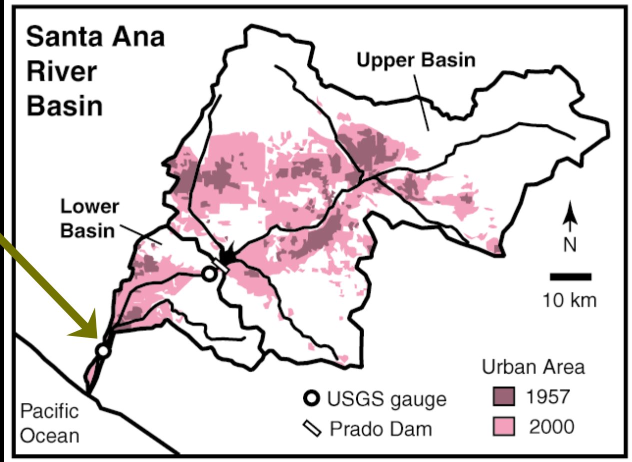


Trimble (1997)


USGS
science for a changing world
Santa Ana River Watershed ($4200\ km^2$)
Southern California Imagery by NASA MODIS

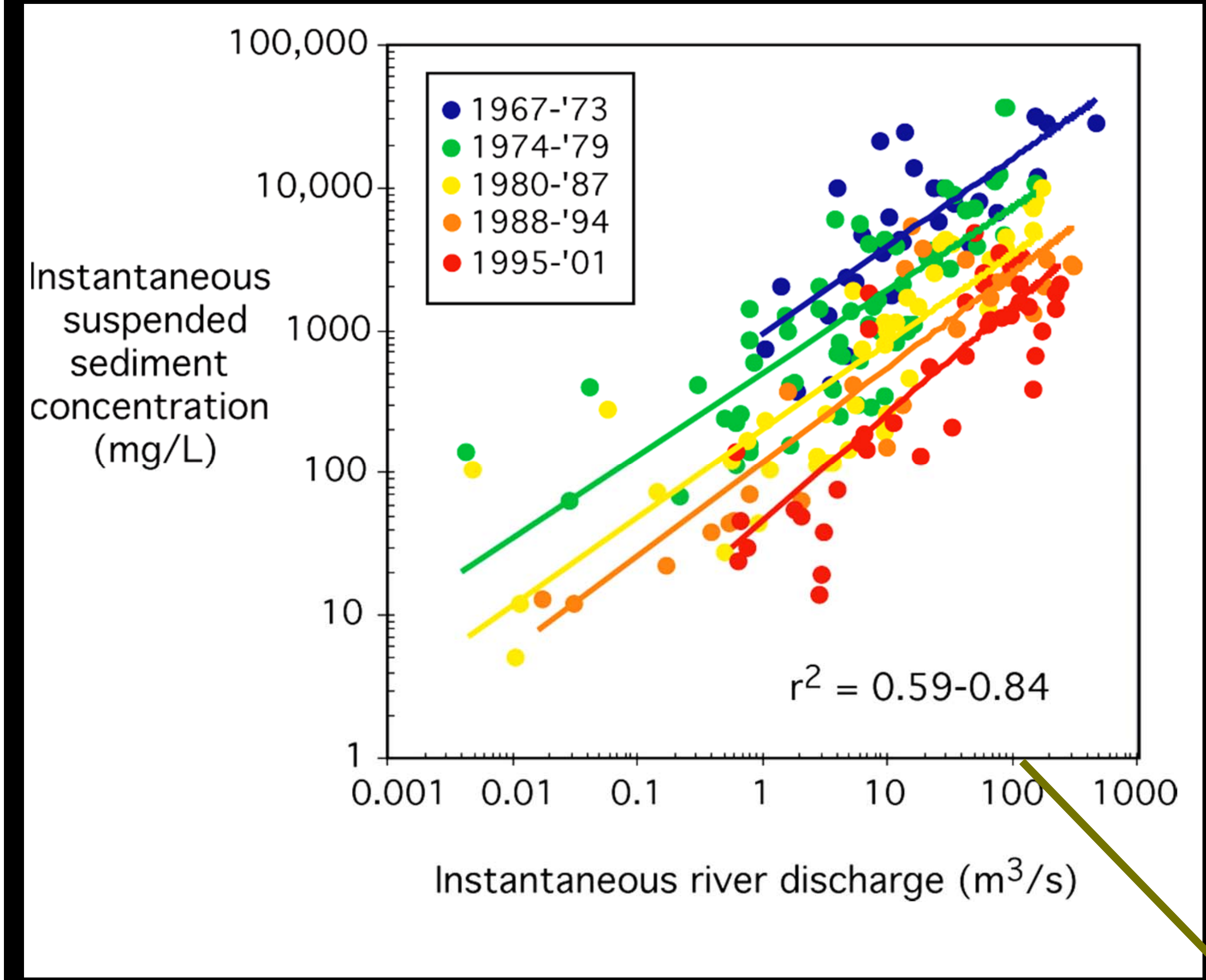
Suspended Sediment Rating Curve



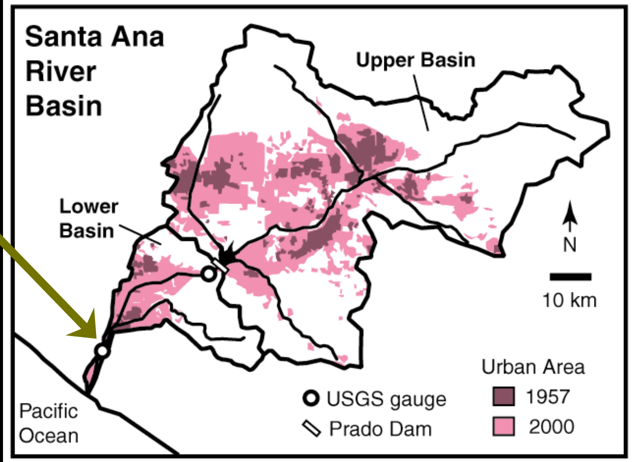


Warrick and Rubin (2007) JGR

Suspended Sediment Rating Curve

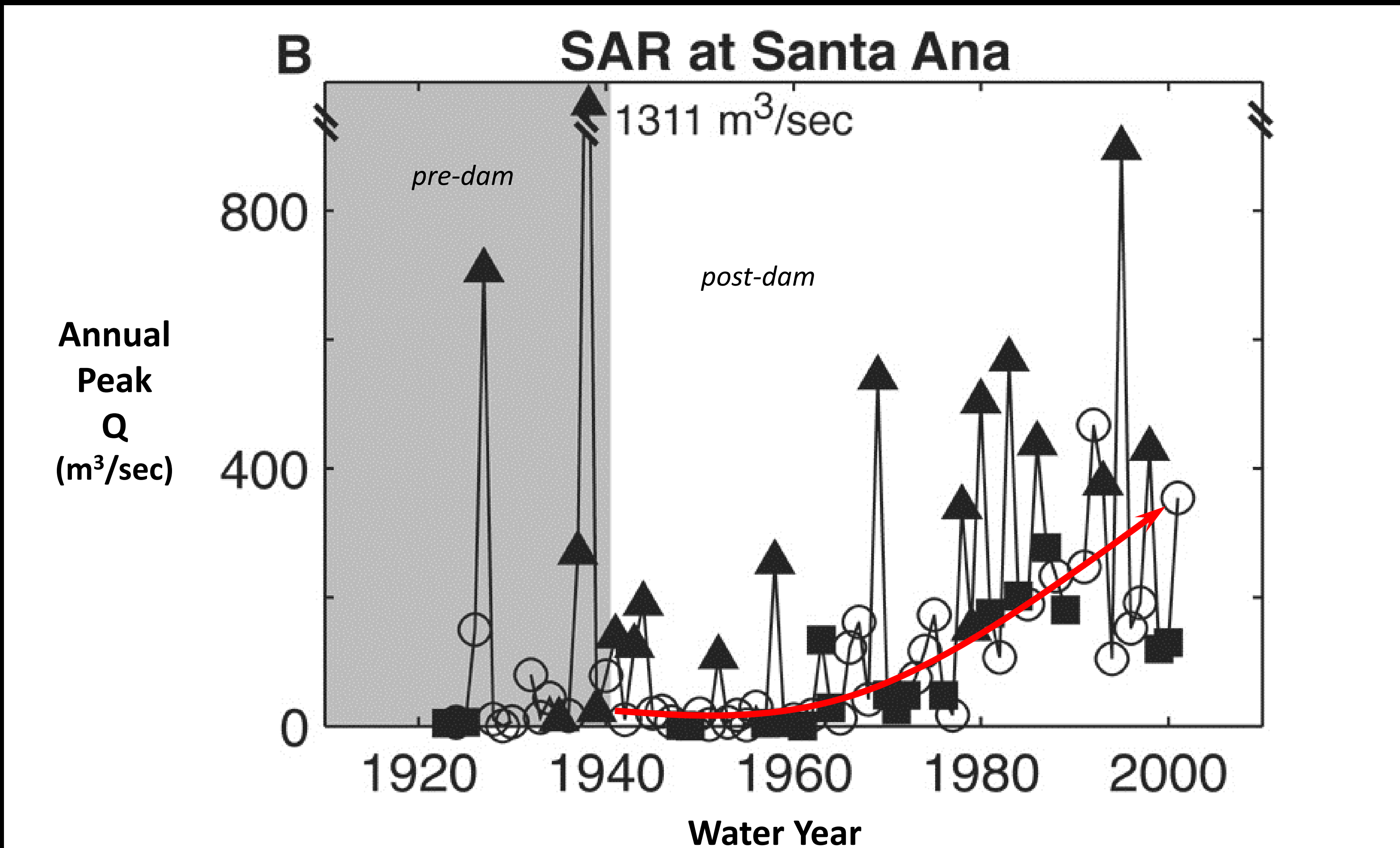


~20x Drop

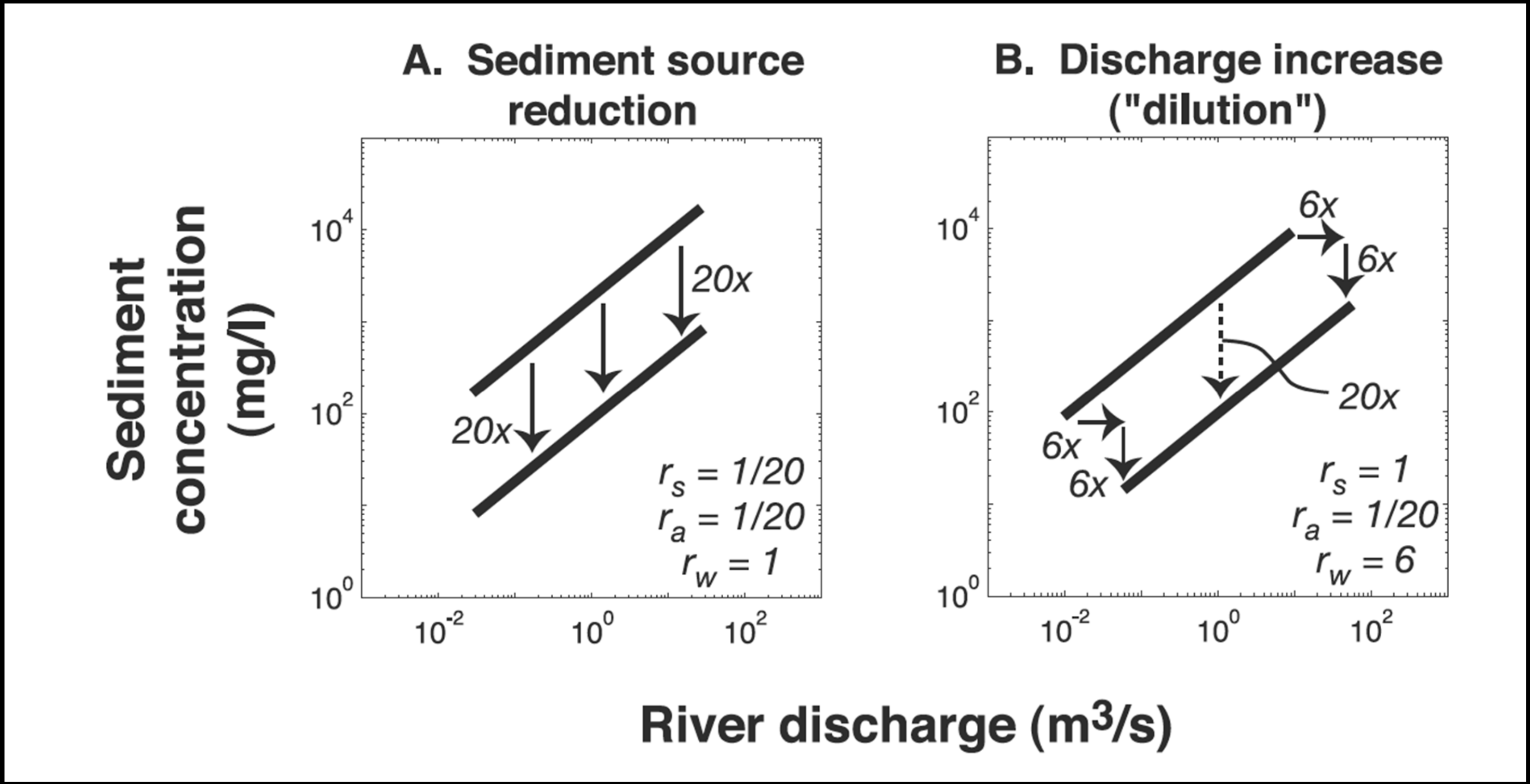


Warrick and Rubin (2007) JGR

Discharge has increased substantially!!



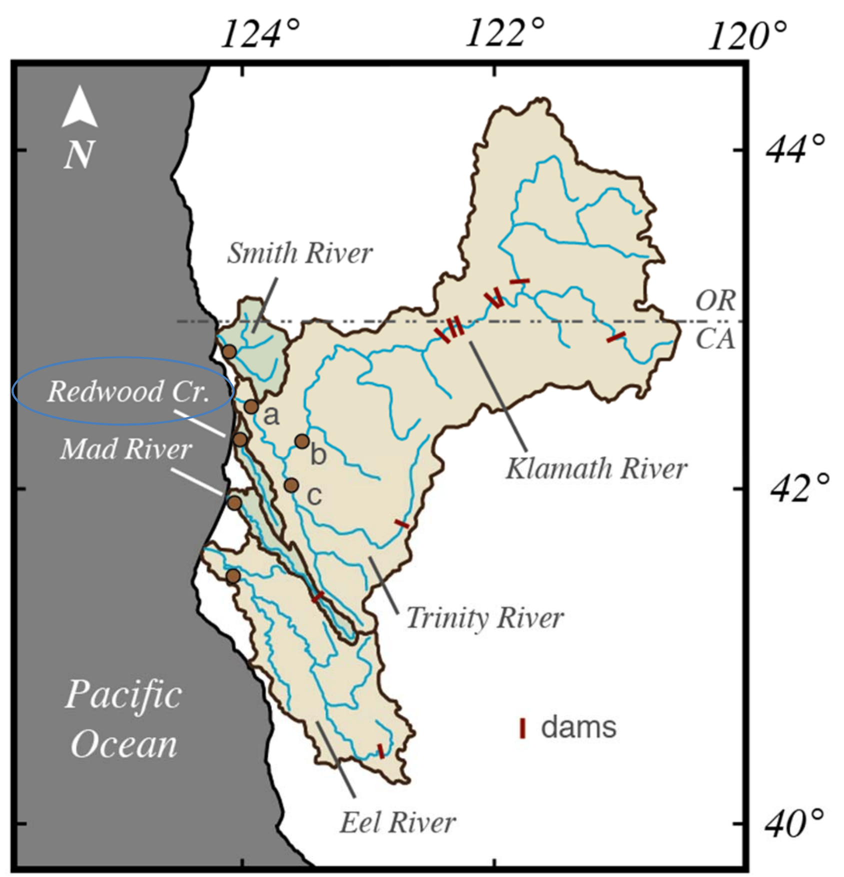
Two ways “rating curves” may change…



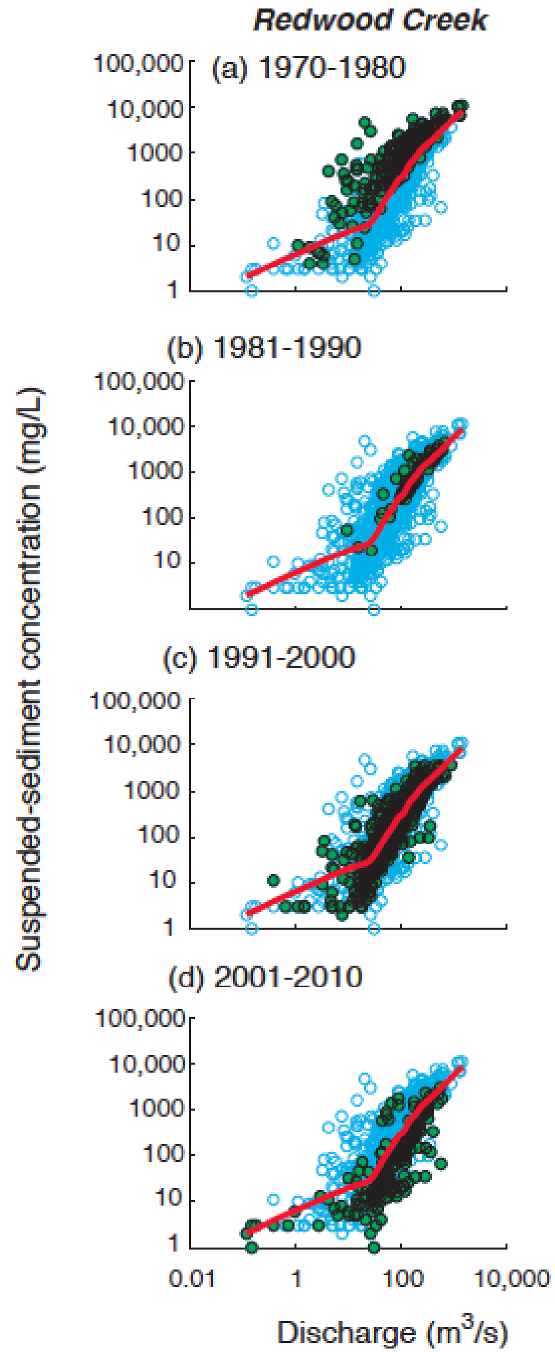
Warrick and Rubin (2007) ***JGR***

Northern California Rivers

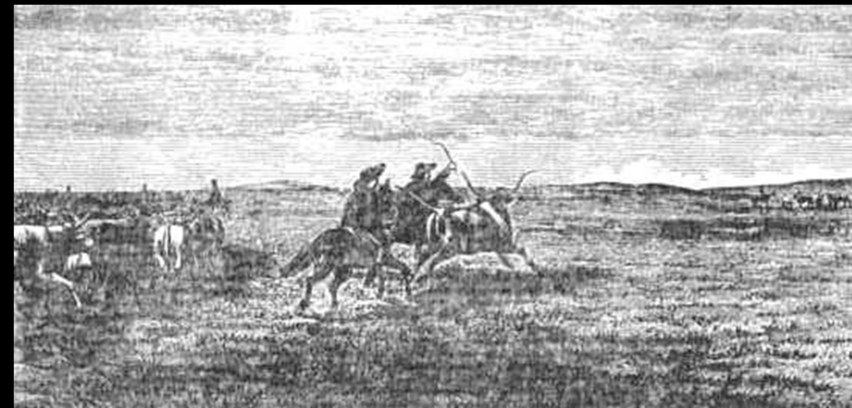
Redwood Creek



Warrick et al (2013) J. Hydrology



What about other Human Impacts?



Time Line:

1700 — *Native Peoples*

European Contact & Settlement

1800 — *Ranchos*

Gold Rush

1900 — *Agricultural Development & Deforestation*

Dam Construction

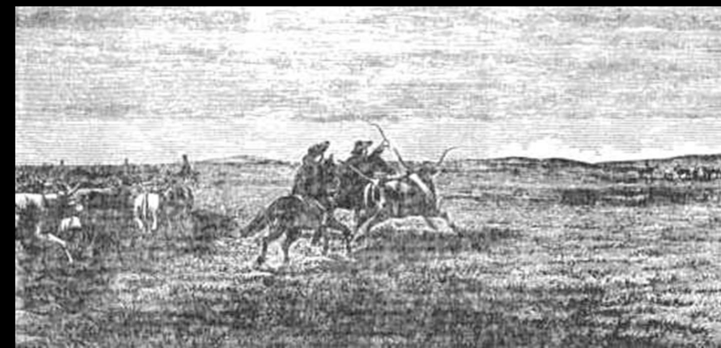
2000 — *Post-WWII Population Boom*

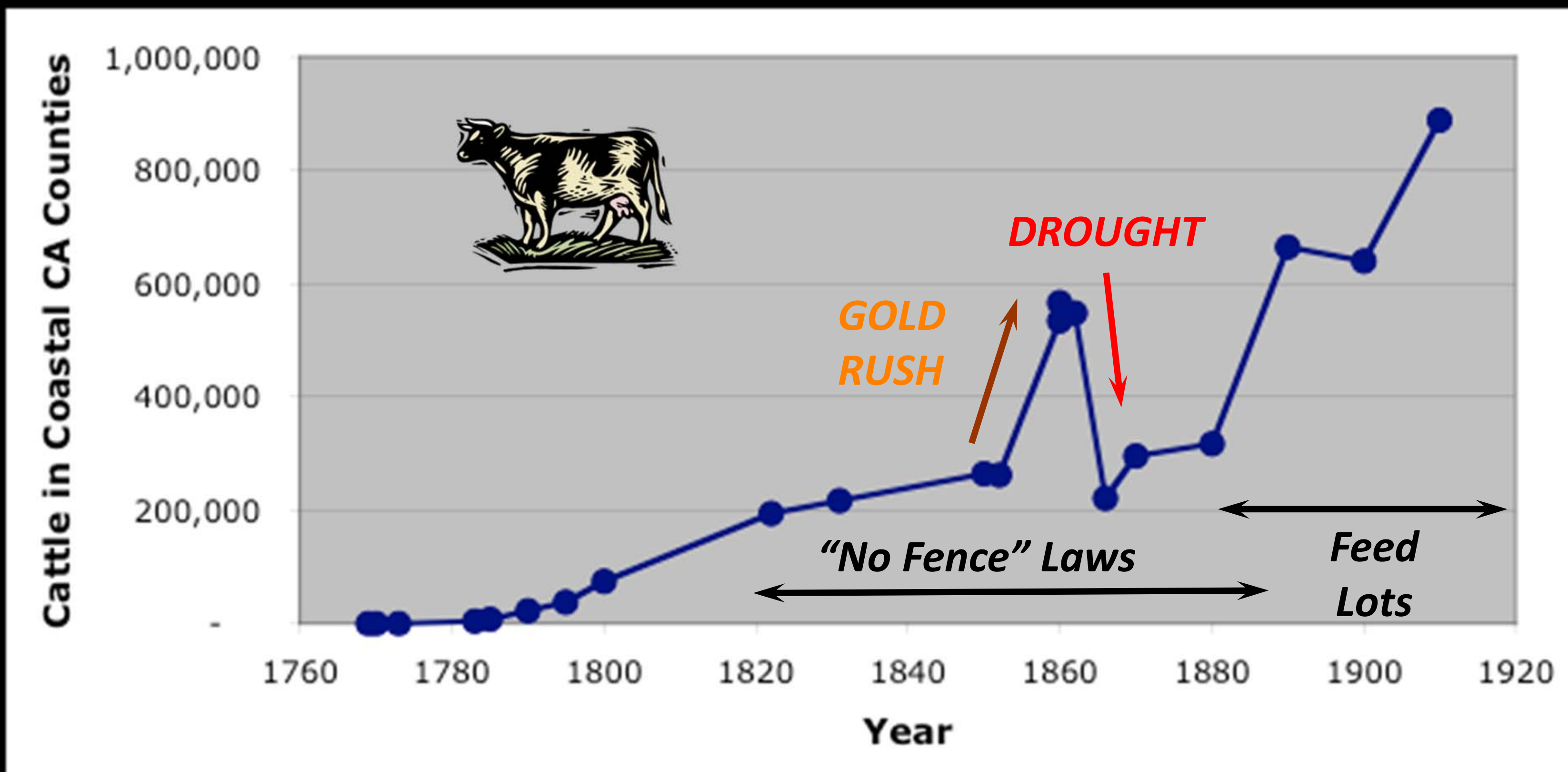
Native Grasses Degraded

Widespread Barren Lands Reported

Rangeland Dominated by Non-Native Annuals

Consider the cattle industry…





Pulling (1944)

"Stock … (are) forced to depend upon the scant feed found upon the **waste lands** now devoted to grazing."

-Napa Reporter (1873)

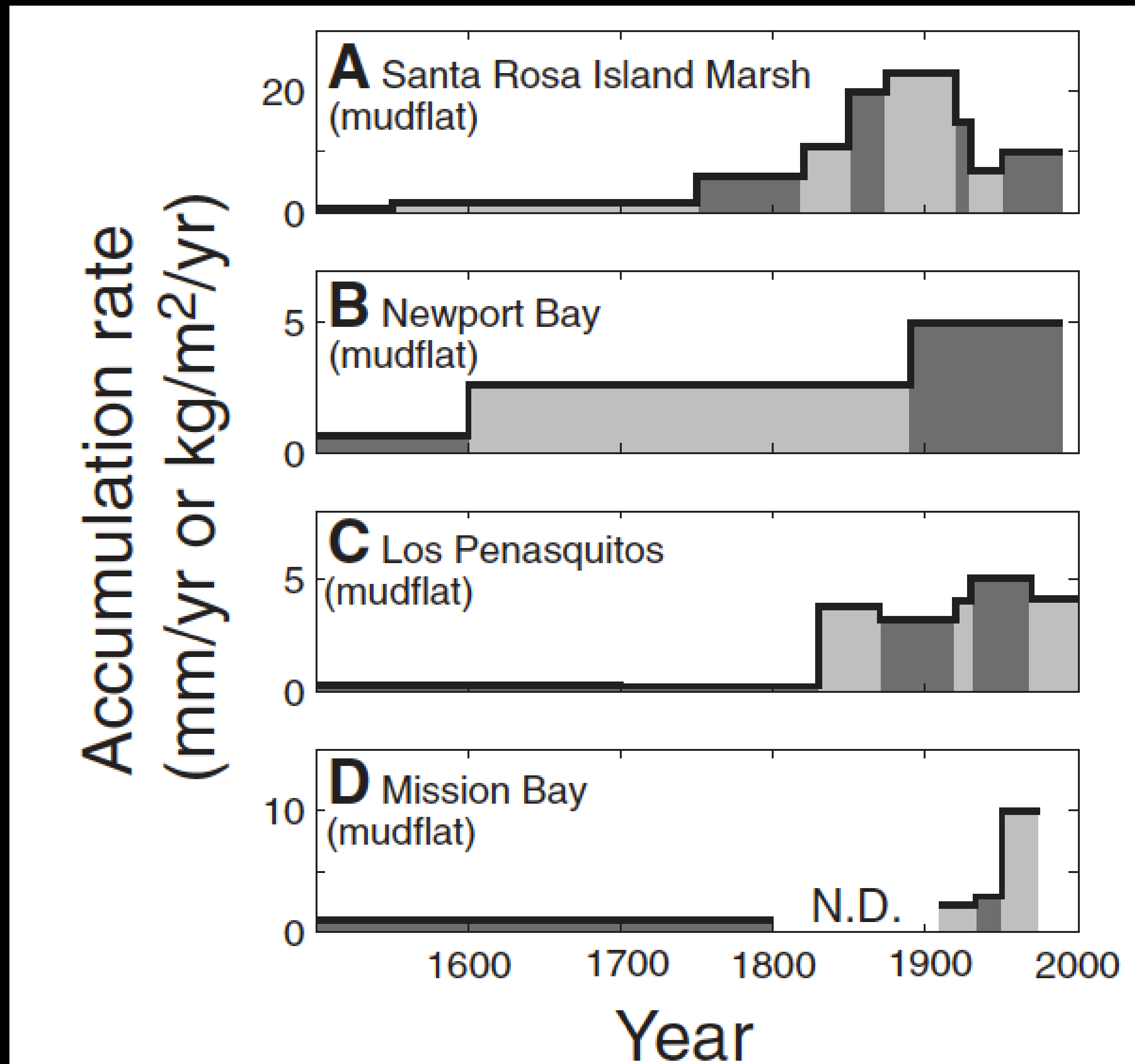
"It is a fact to be regretted that the grass ranges are **not what they formerly were** … We have not taken sufficient care of our stock and our grazing lands."

-Los Angeles Evening Express (1873)

"During the three years from 1868 to 1871, south of Monterey **neither grass nor grain grew** … Hundreds of farms were abandoned … In February, 1870 **not a blade of grass** was to be seen over the extensive valley of the Santa Clara …"

-Hazel Pulling (1944)

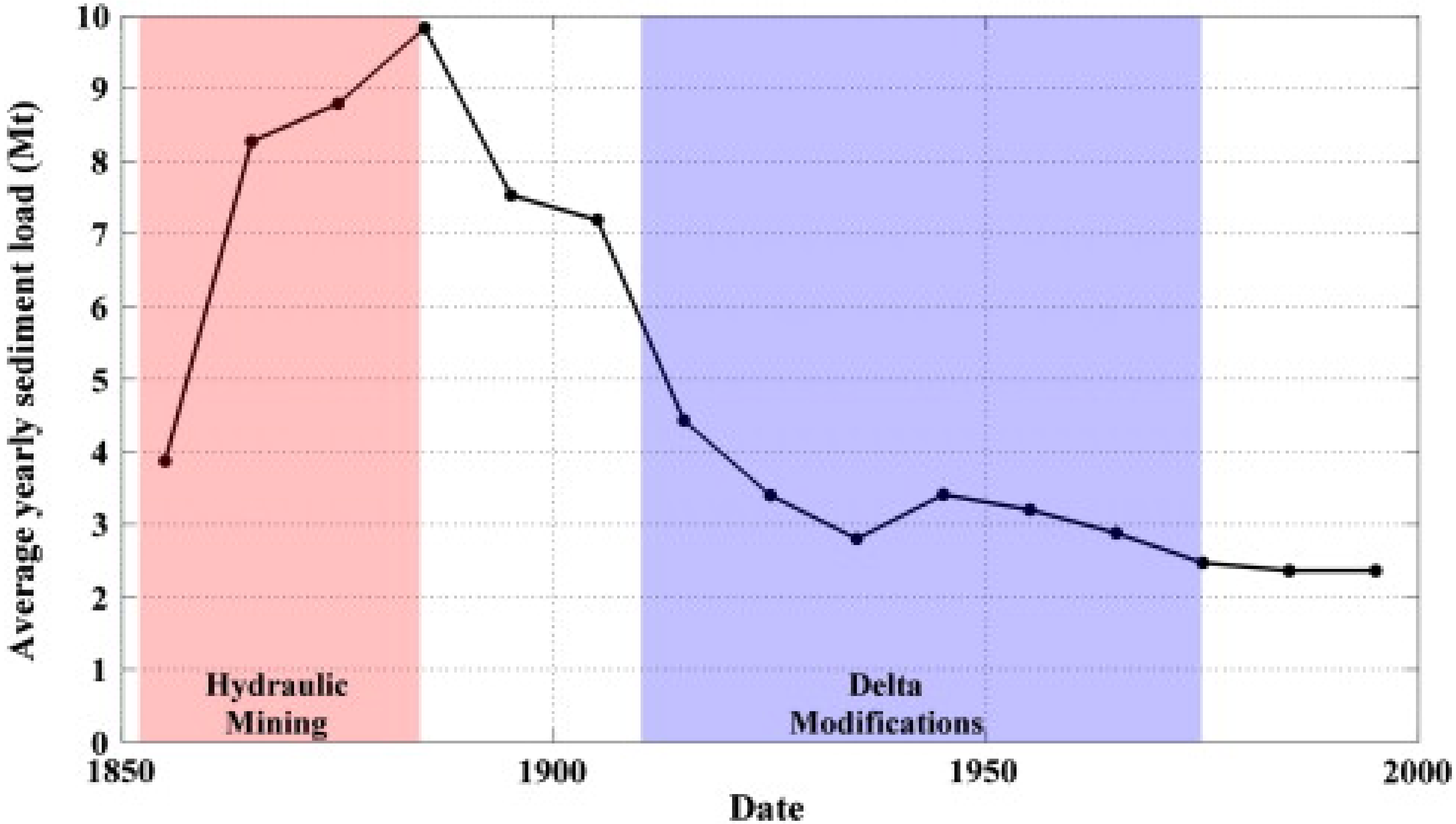
Mudflat Sedimentation Rates



After: Cole and Liu (1994), Davis (1992), Cole and Wahl (2000), and Mudie and Byrne (1980)

Sediment Load to the Bay Delta

After Ganju et al. (2008)



Things to take home:

1. Sediment is an important part of the **natural geologic cycle**.

2. Sediment may both enhance **and** degrade river and coastal habitats.

3. **Humans** have disrupted U.S. West Coast sediment cycles for at least hundreds of years.

4. Sediment is being managed in **novel ways** up and down our coast.

USGS science for a changing world

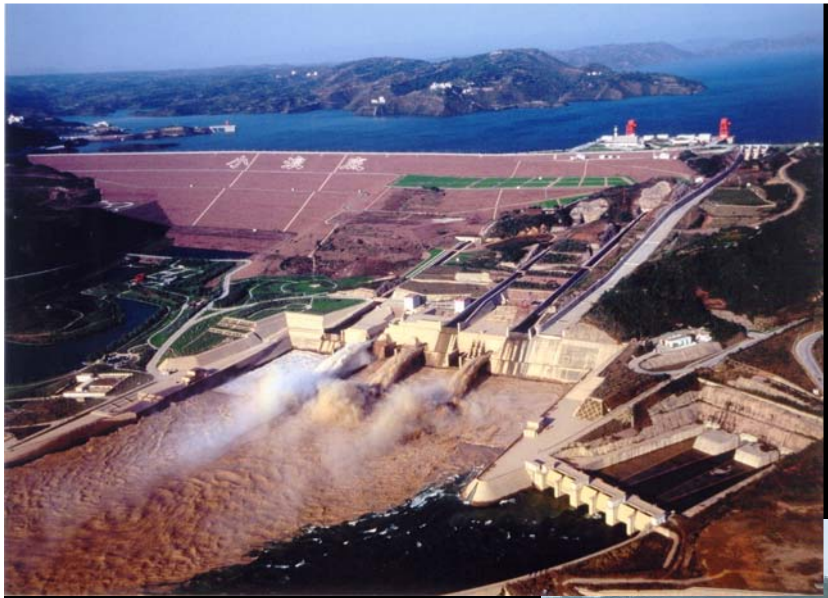
Active Nourishment of the California Shoreline

(a) March 17, 1987

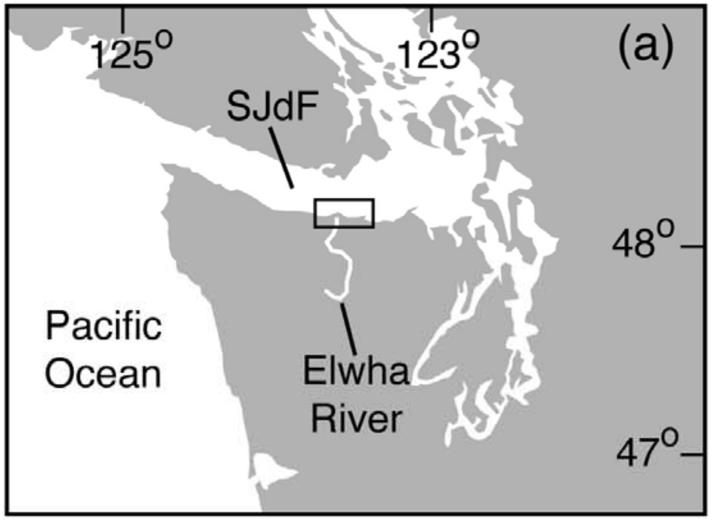
(b) April 14, 1993

VS.

Beach nourishment of Imperial Beach, CA - 2012



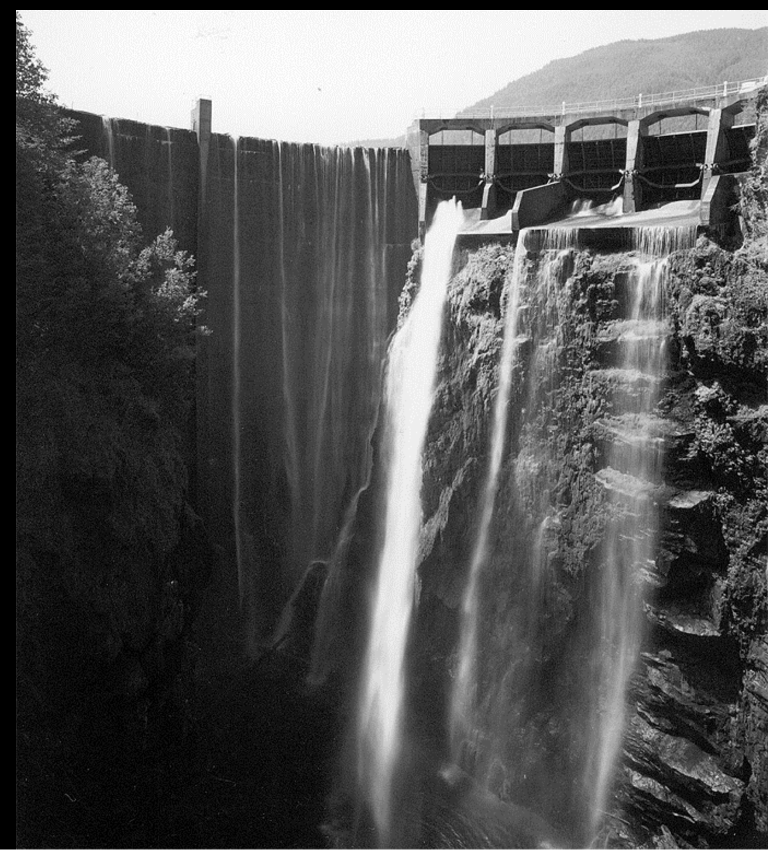
Desilting Reservoirs
Xiaolangdi Dam
Huange He (Yellow River), China



Dam Removal

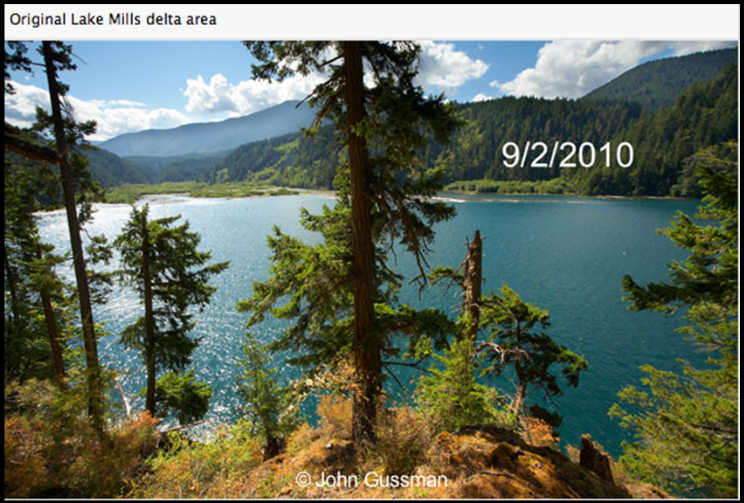
Elwha River Dams

Washington, USA



Images courtesy NPS

Lake Mills Delta



April 2012

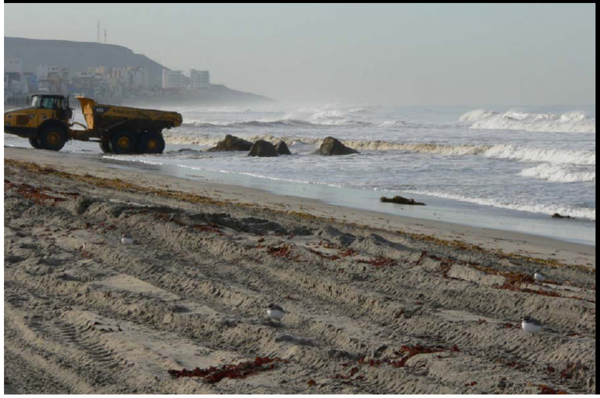
Dam Removal
Elwha River Dams
Washington, USA

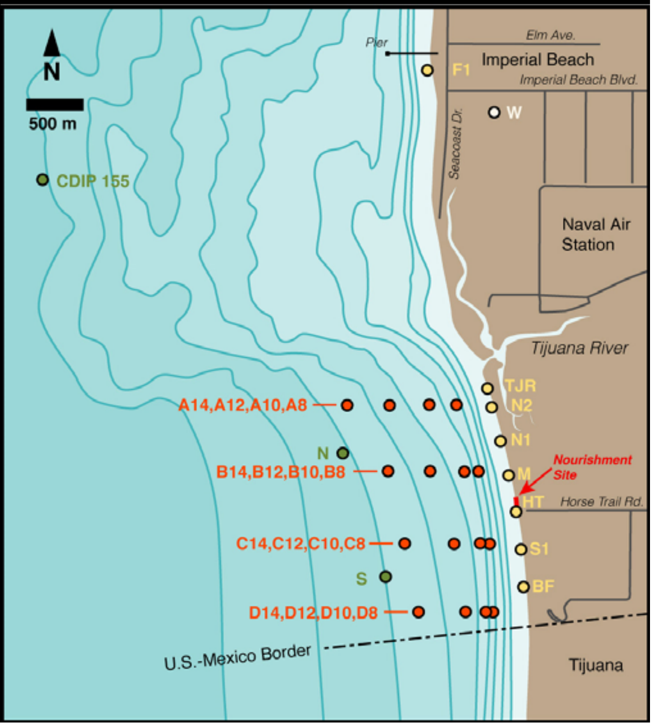
Beneficial Reuse
Tijuana River Estuary
California, USA

USGS
science for a changing world

PROJECT PARTNERS:

- **Government Agencies:**
  - California Coastal Conservancy
  - California Ocean Protection Council (OPC)
  - Tijuana Estuary National Research Reserve
  - California State Parks
  - California Department of Boating and Waterways (DBW)
  - California Sediment Management Workgroup (CSMW)
  - U.S. Army Corps of Engineers
  - U.S. Geological Survey
- **Private Sector and Non-Profits**:
  - Southwest Wetlands Interpretive Association (SWIA)
  - Moffatt & Nichol Engineers
  - Nordby Biological Consulting
  - Nautilus Environmental
- **Academic Partners/Collaborators**
  - University of California, Santa Cruz
  - University of California, San Diego
  - Delft Hydraulics (a.k.a. Deltares)

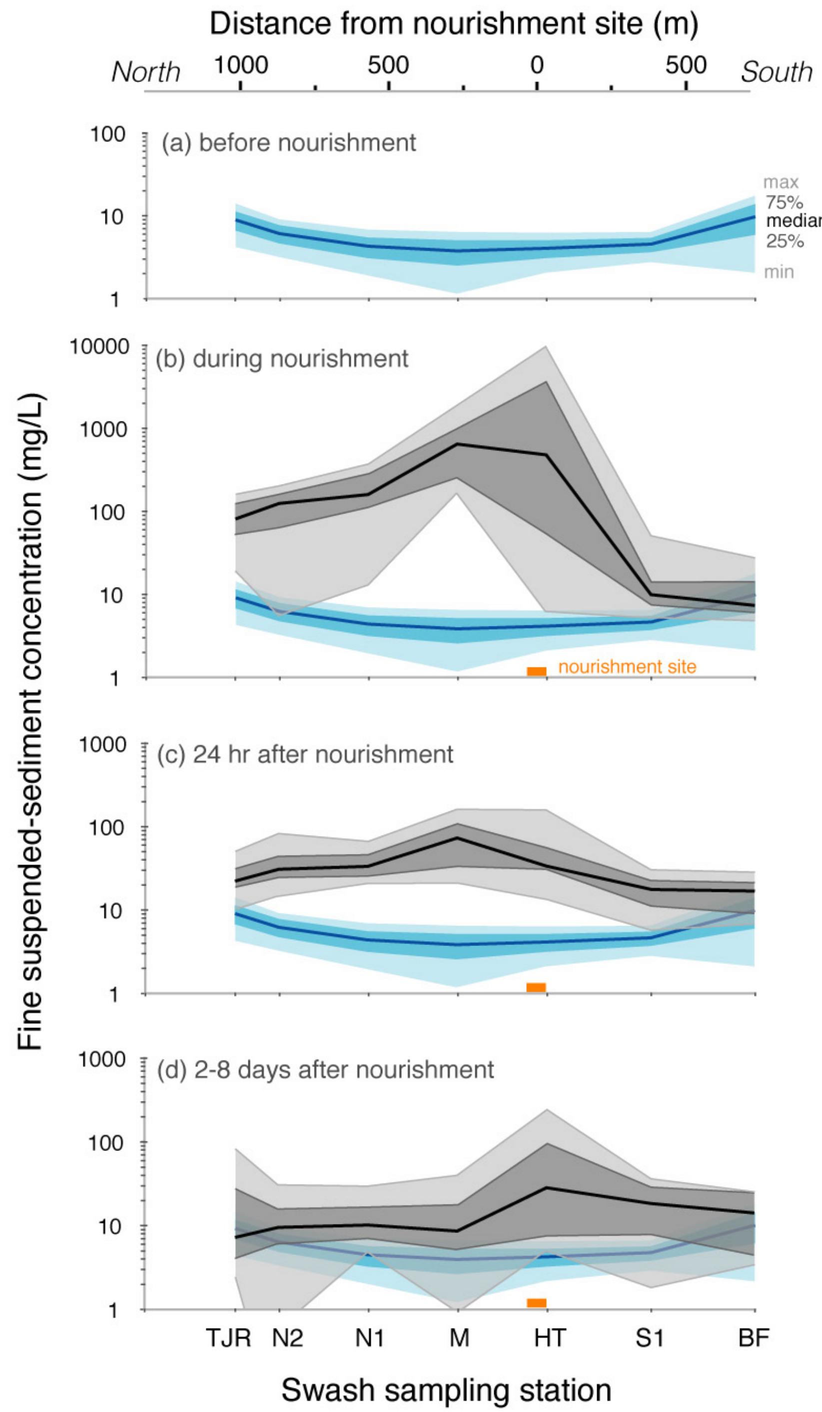




Beach Water Samples During Beneficial Reuse Project

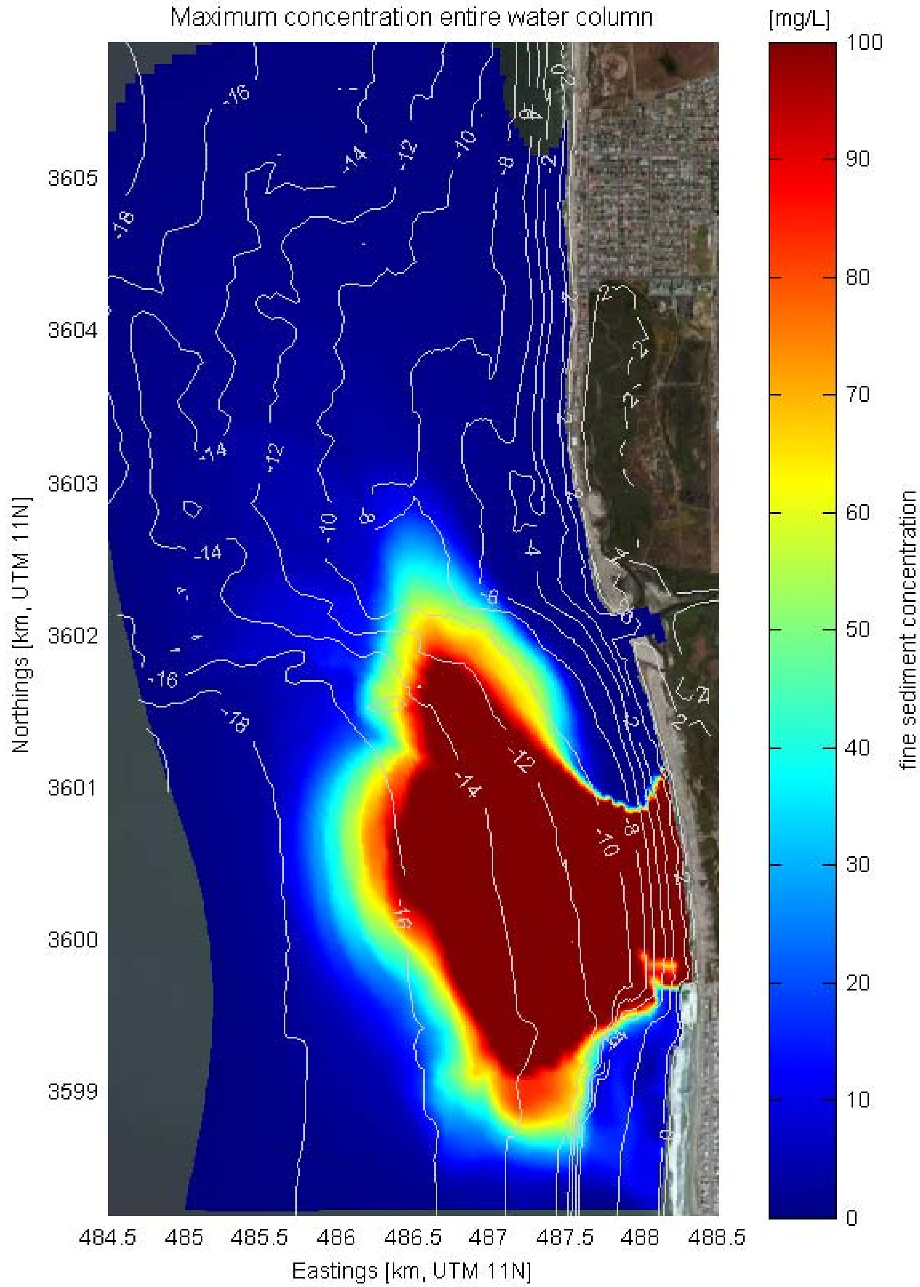
Tijuana River Estuary
California, USA

Warrick (2013)



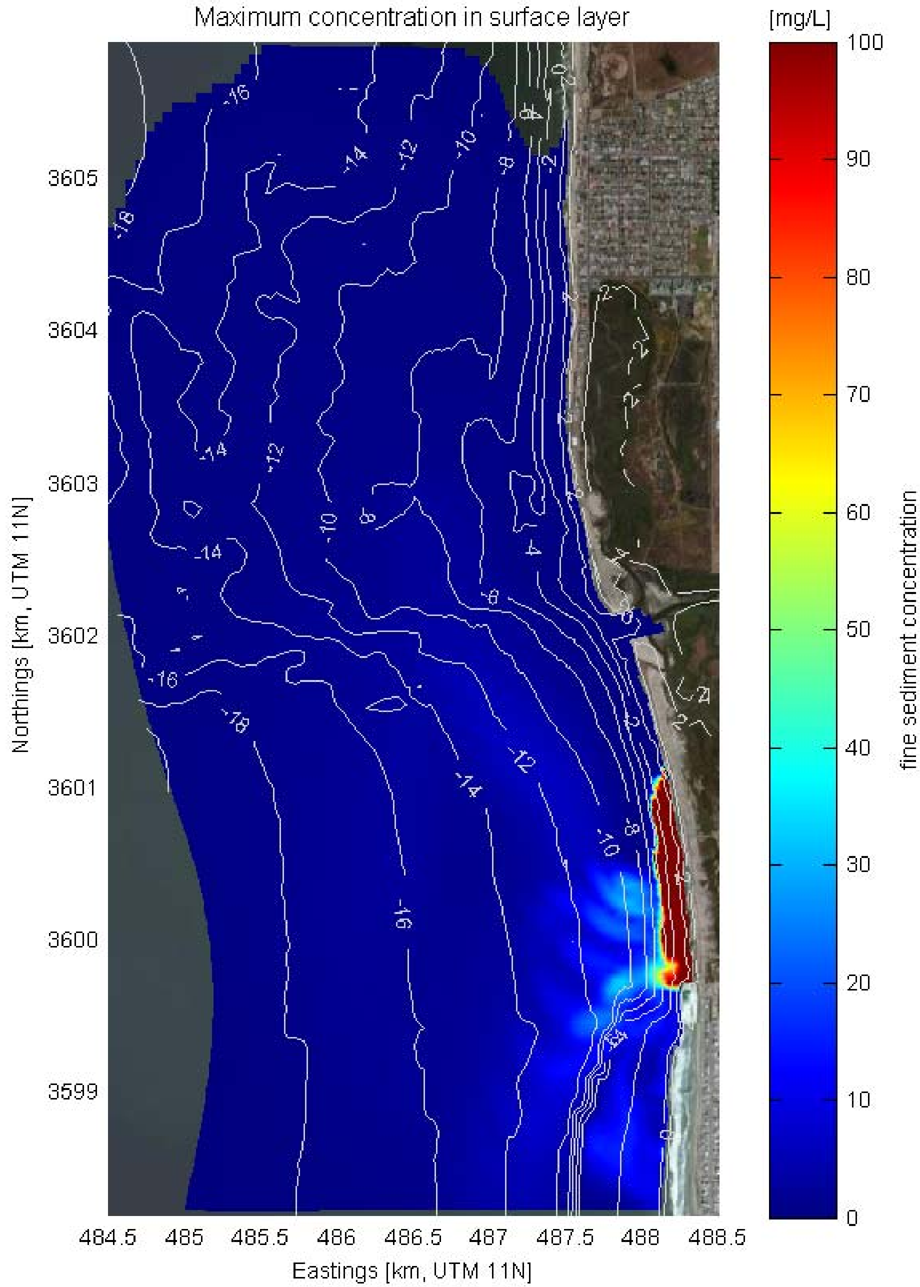
Numerical Modeling with Deltares

Maximum Suspended-Sediment Concentration (mg/L)

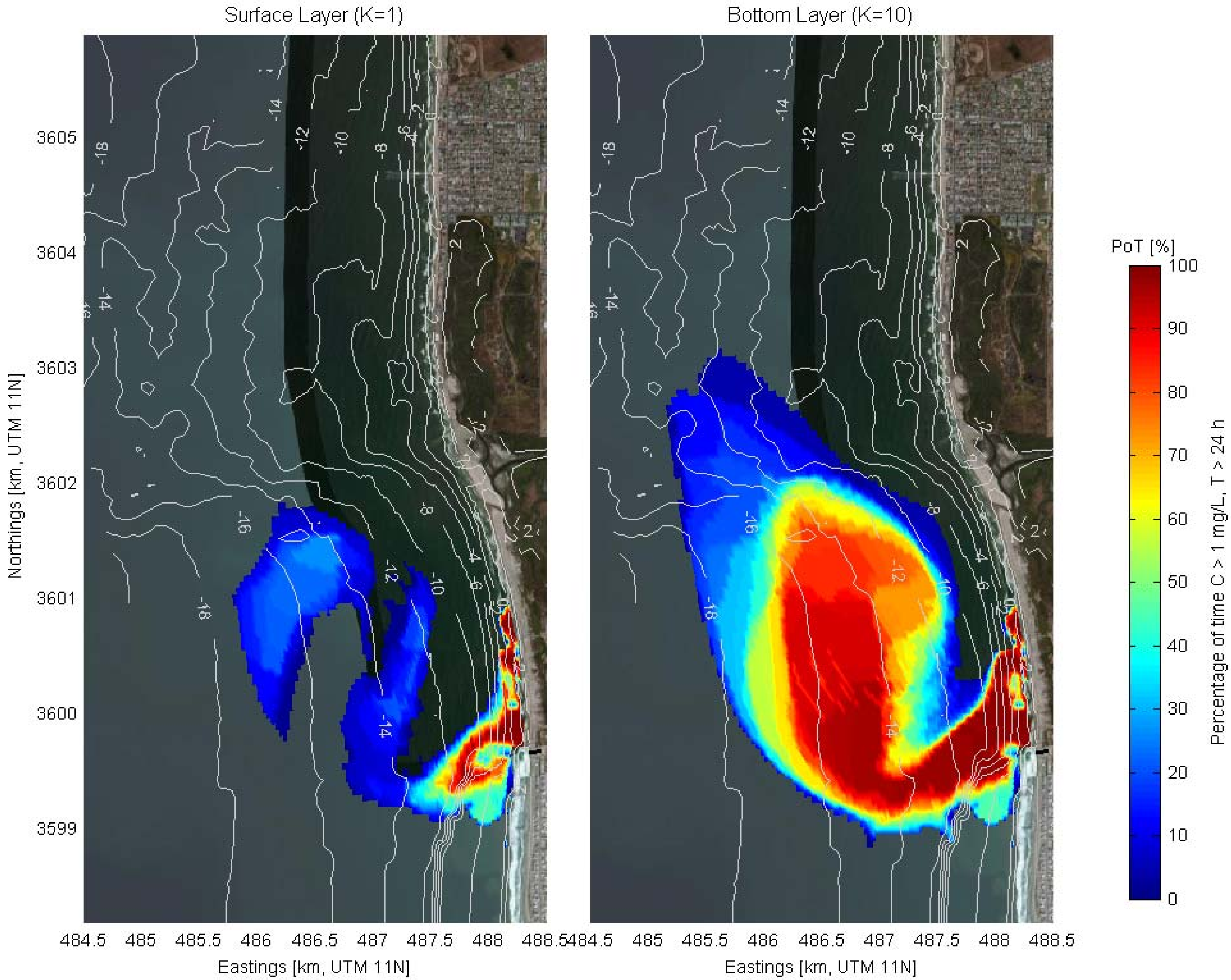


Numerical Modeling with Deltares

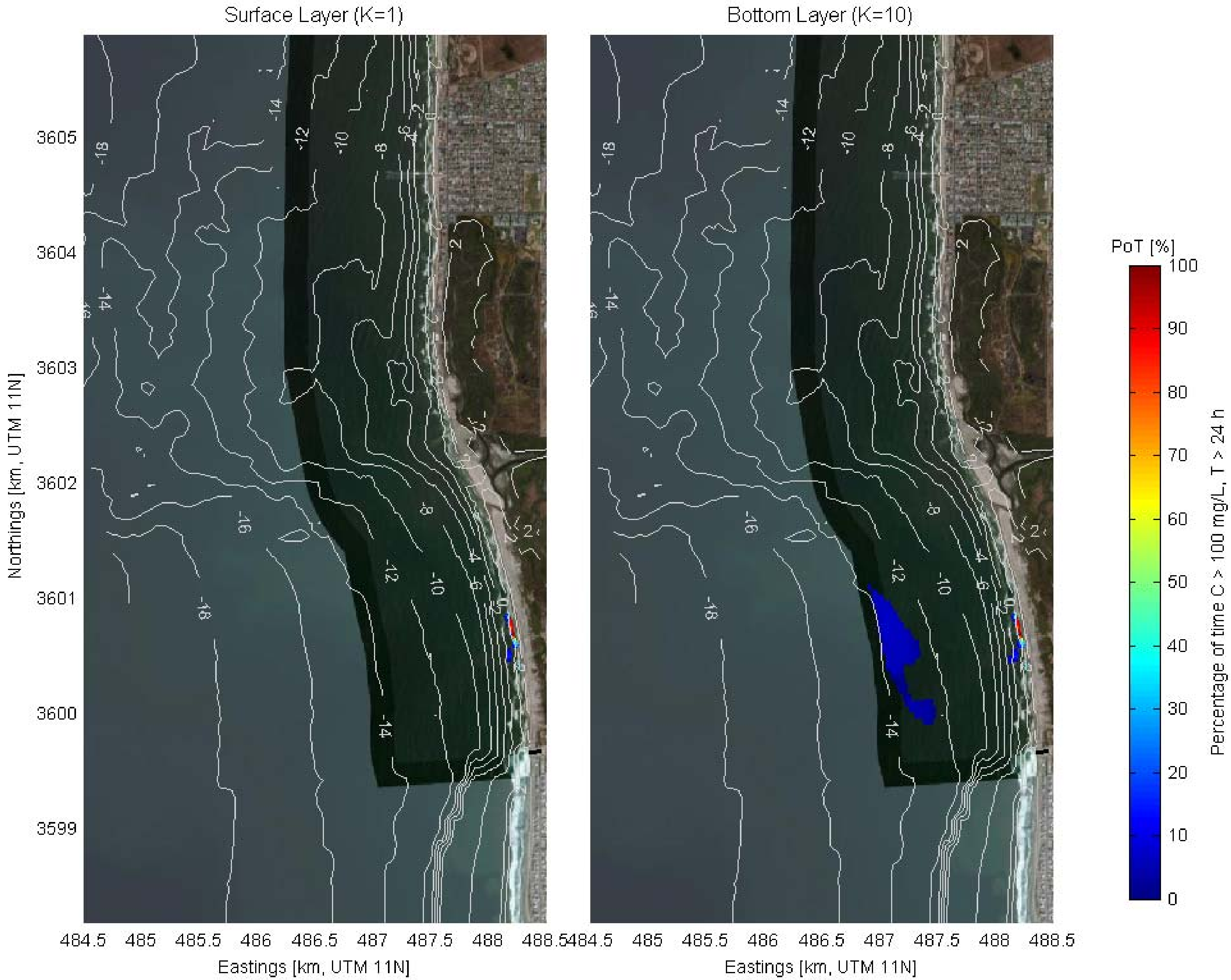
Maximum Suspended-Sediment Concentration In the Surface Waters (mg/L)



Concentration – Duration Relationships
(1 mg/L for 24 hours)



Concentration – Duration Relationships
(100 mg/L for 24 hours)



Closing Thoughts…

Sediment is **very different** from other pollutants.

Sediment supply is **important** for our coastal rivers and wetlands.

Management and regulation of sediment should aim to **reintroduce and mimic** natural geologic and hydrologic processes.

Monitoring, analyses and open sources of data are increasing important in this time of change and limited resources.

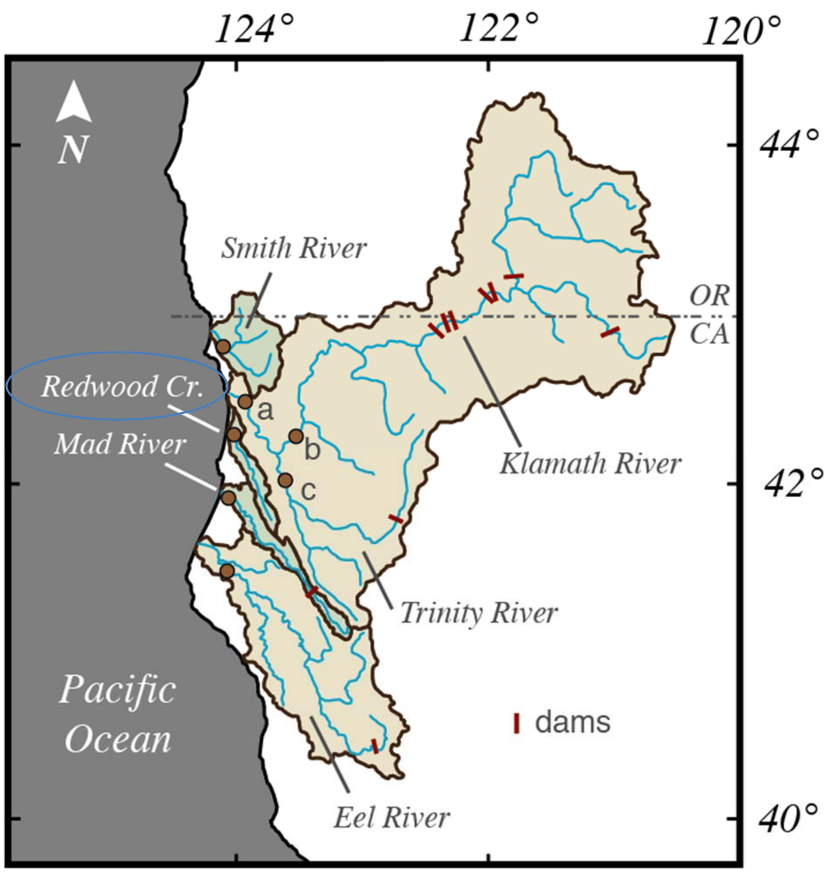
Thank You.

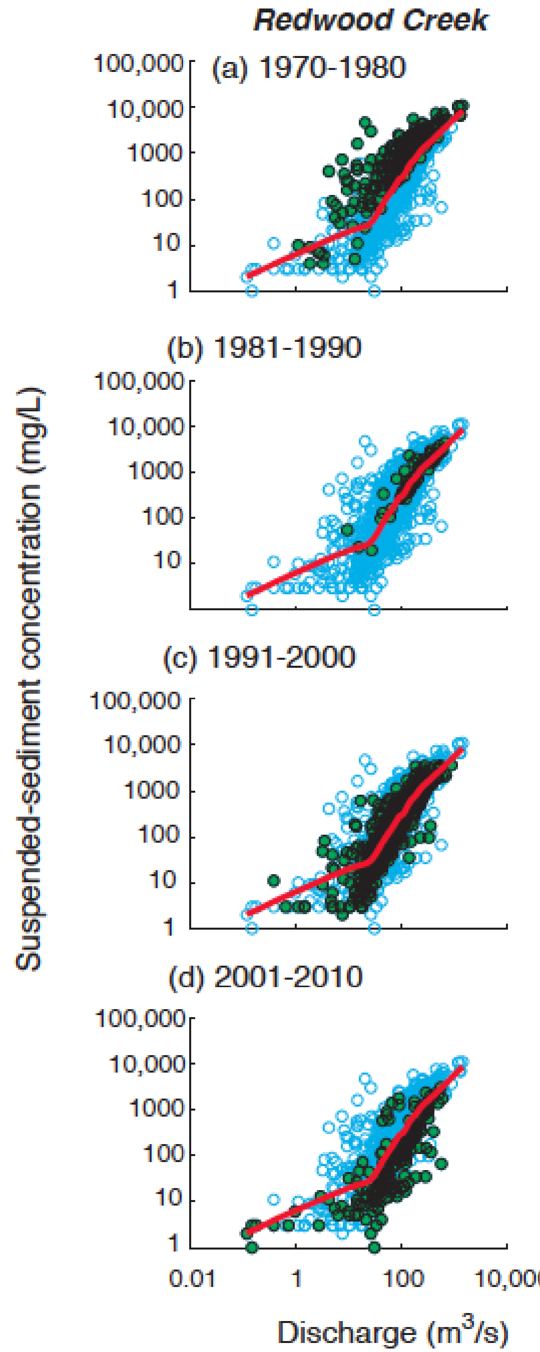
Contact:

jwarrick@usgs.gov

Northern California Rivers

Redwood Creek





Warrick et al (2013) J. Hydrology

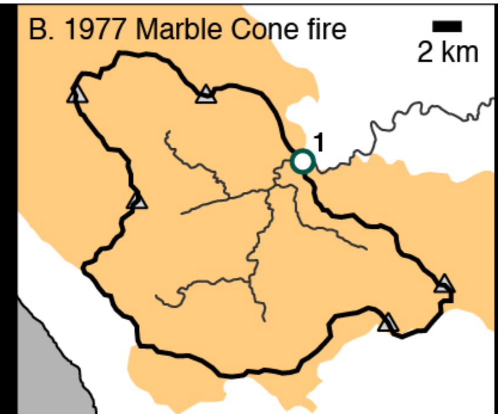
Turbid Plumes from the Tijuana River

Coastal turbidity following the 17 Dec 08 discharge event from the Tijuana River

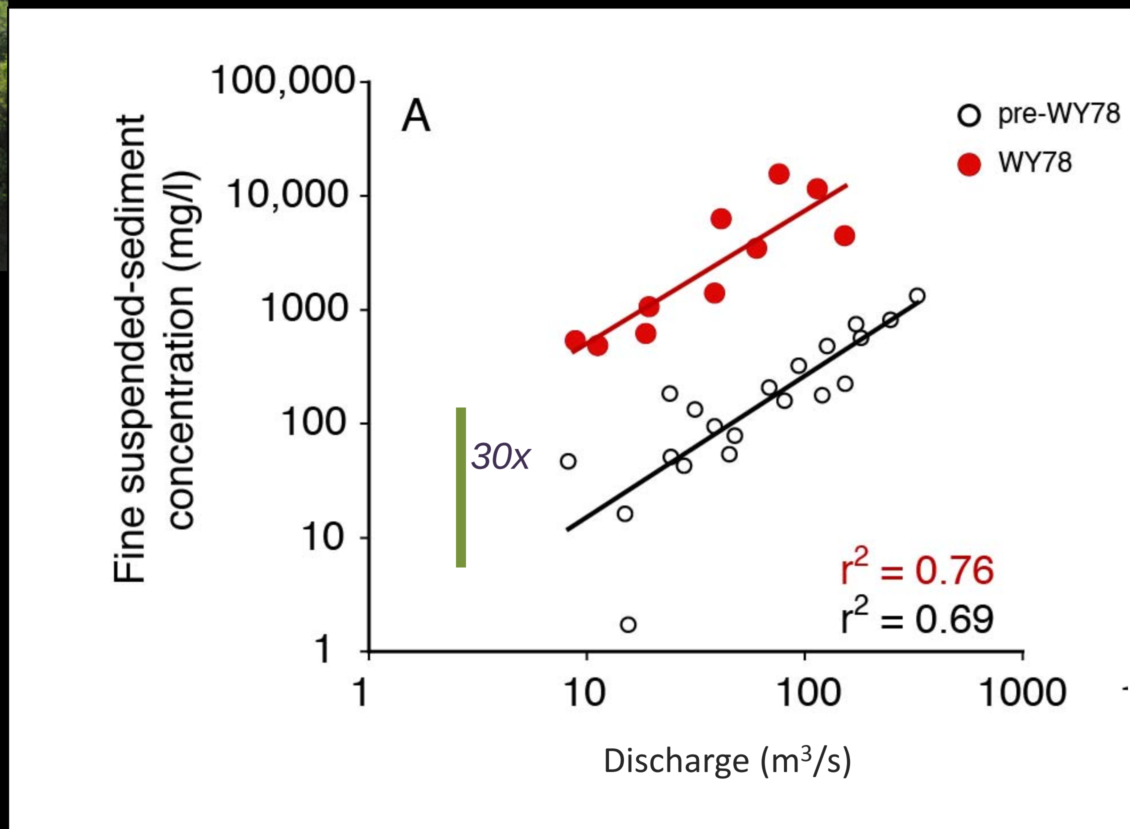
Coastal turbidity following the 15 Dec 08 discharge event from the Tijuana River

Arroyo Seco

Monterey County, CA

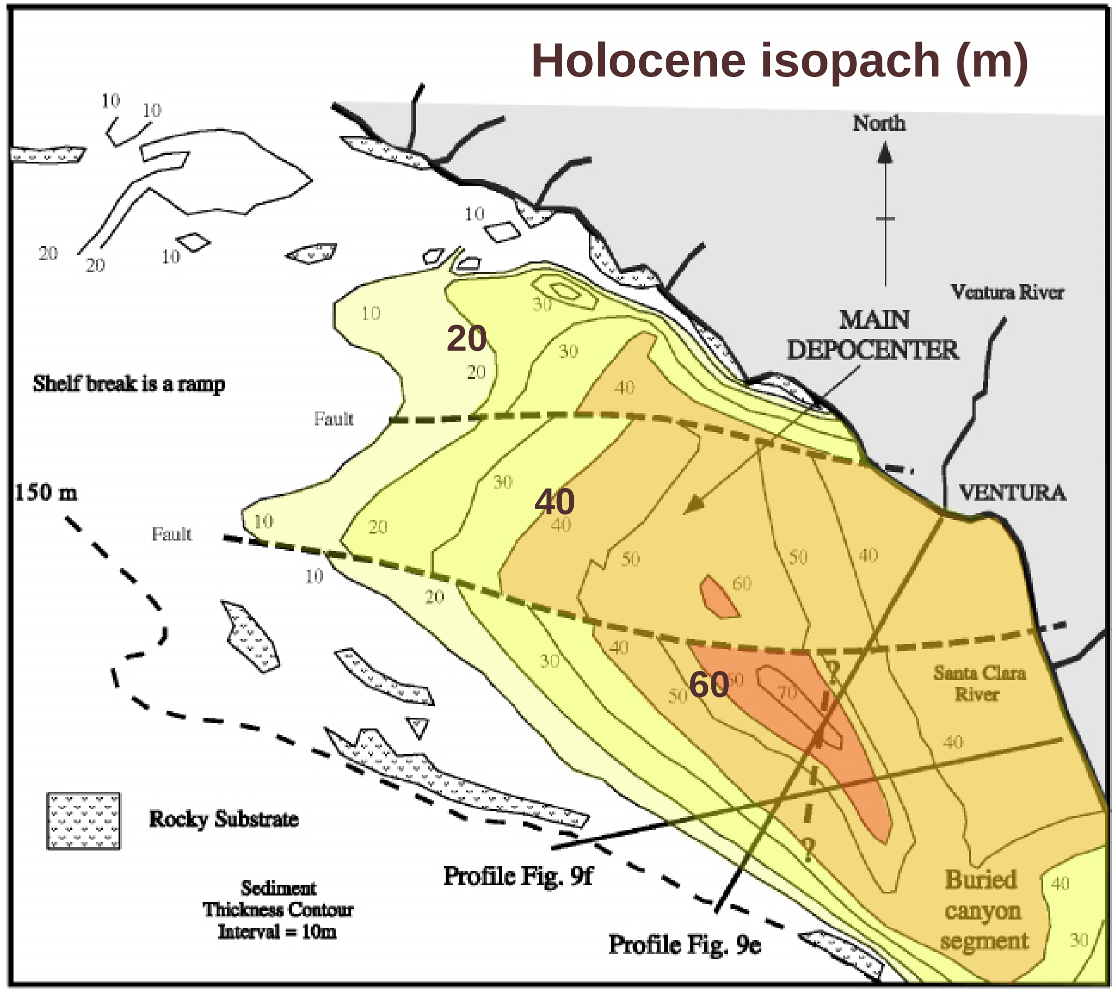


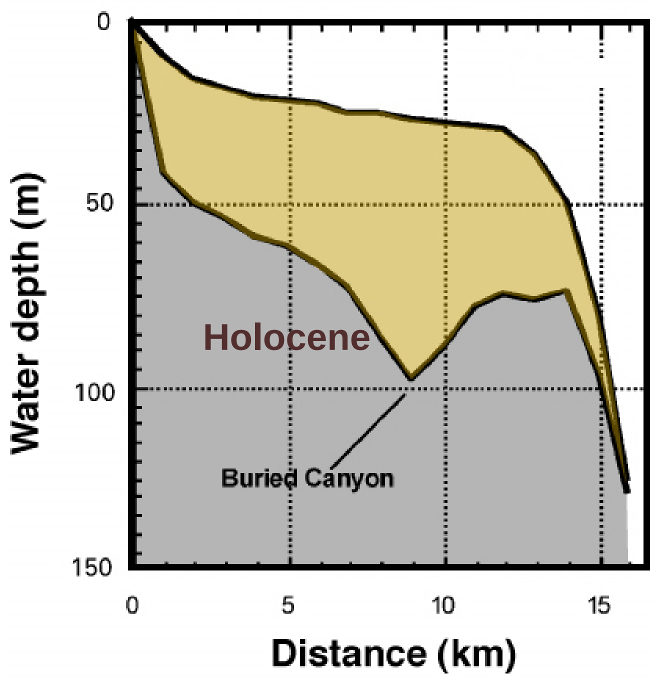
1977 Marble Cone Fire



Warrick et al. (2012) GSAB

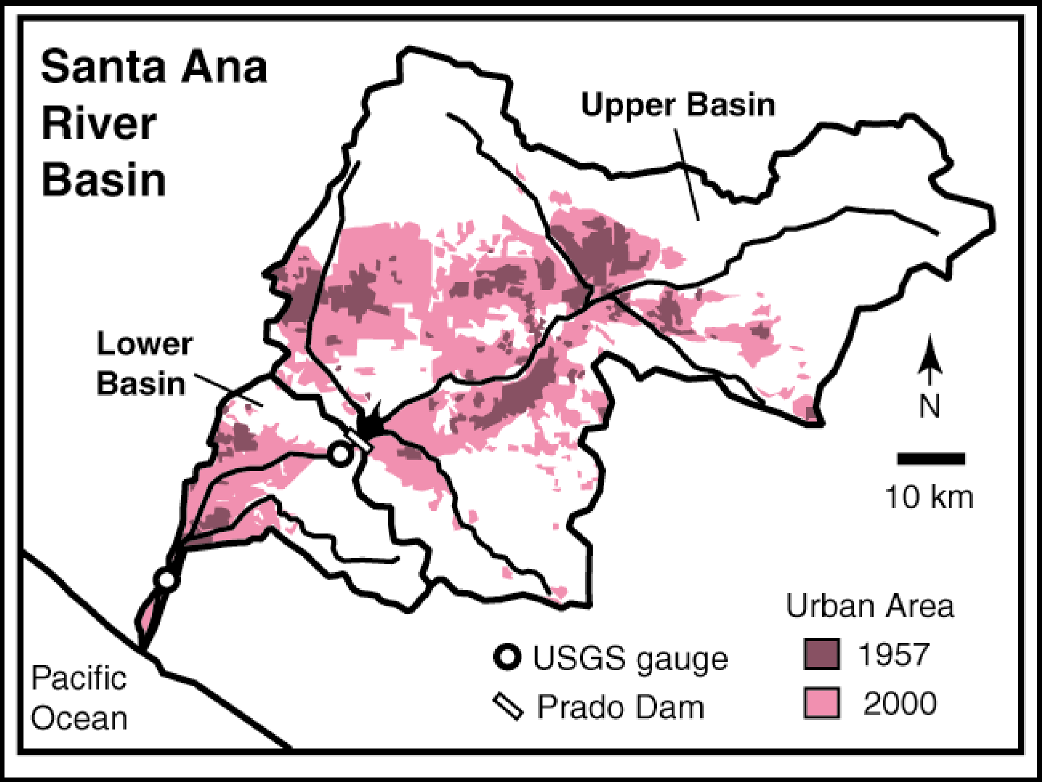
Mud Deposition on the Continental Shelf

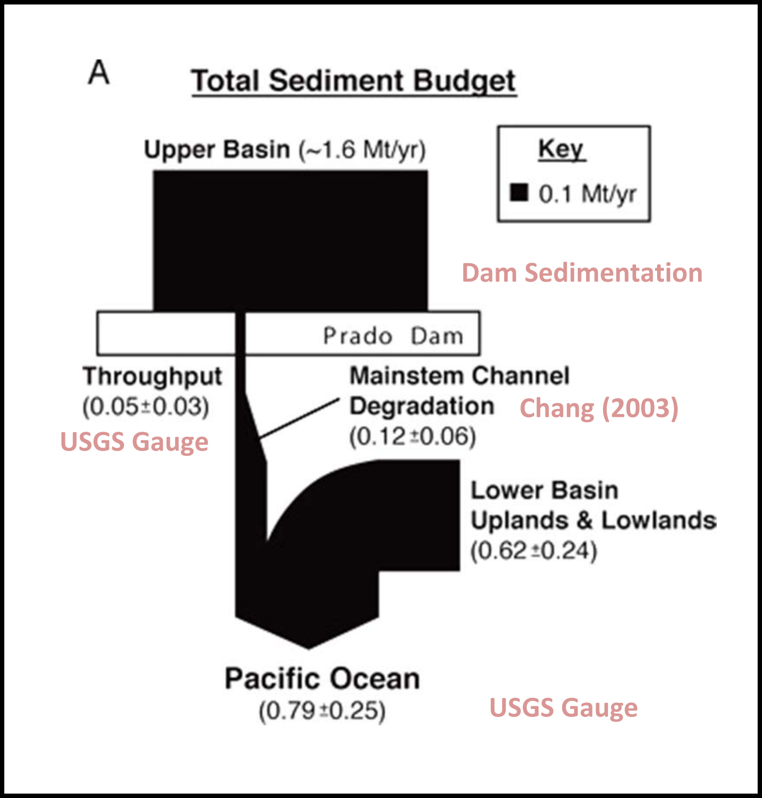




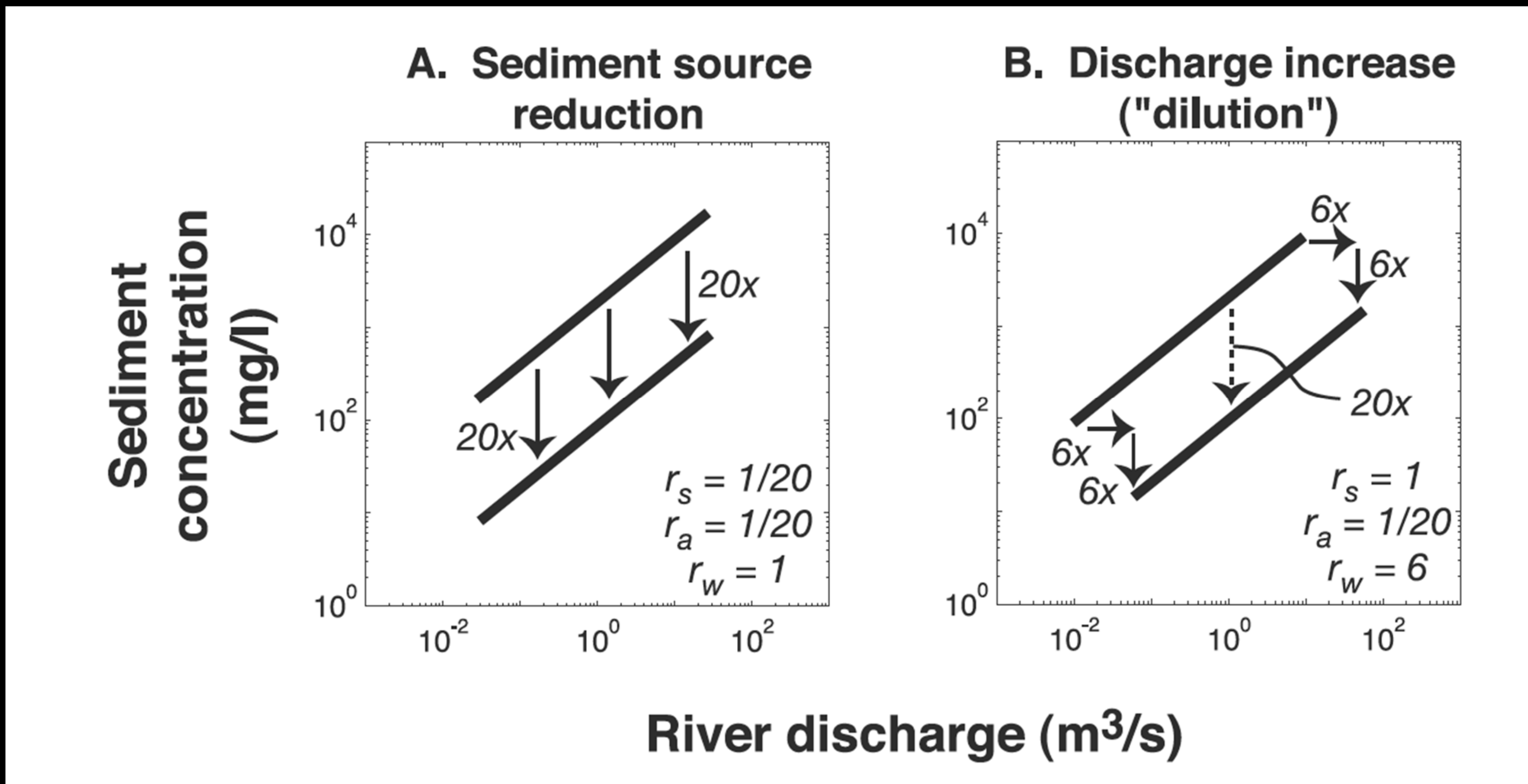
Slater et al. (2002)

Santa Ana River Sediment Budget



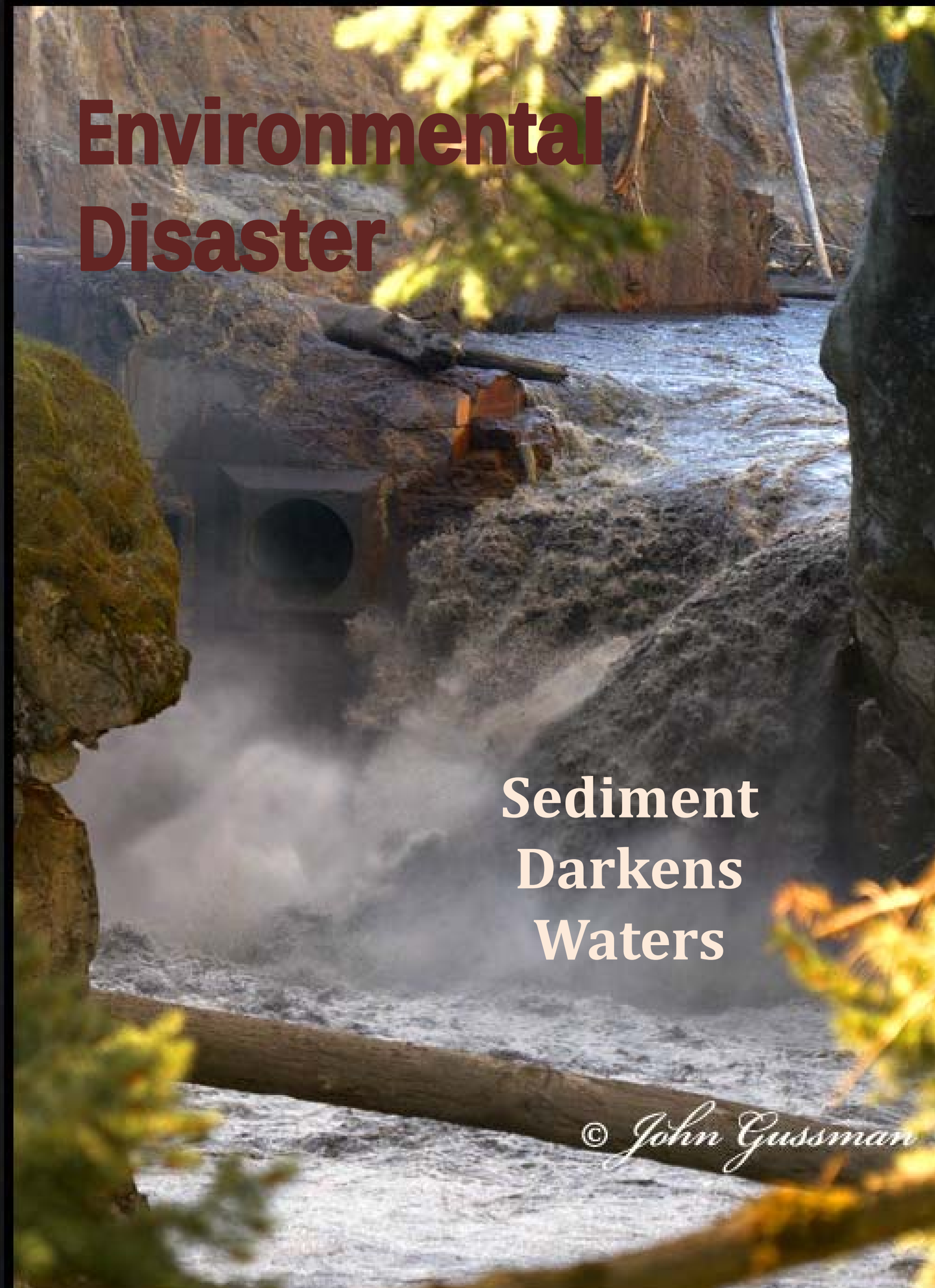


Warrick and Rubin (2007) JGR


A. Sediment source reduction
B. Discharge increase ("dilution")
Sediment concentration (mg/l)
River discharge (m3/s)
10^4
10^2
10^0
10^-2
10^0
10^2
20x
20x
r_s = 1/20
r_a = 1/20
r_w = 1
6x
6x
6x
6x
20x
r_s = 1
r_a = 1/20
r_w = 6

What is the story?

What is the story?



What is the story?