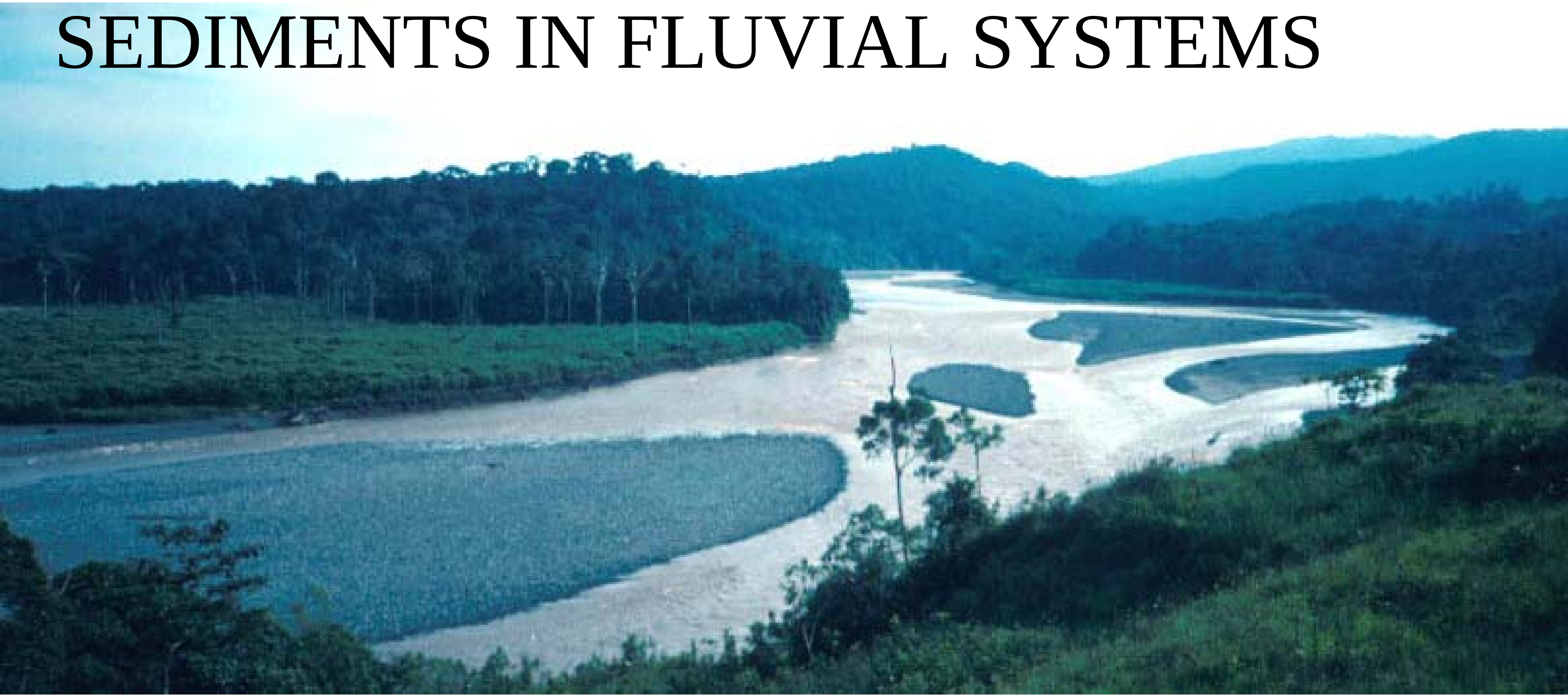
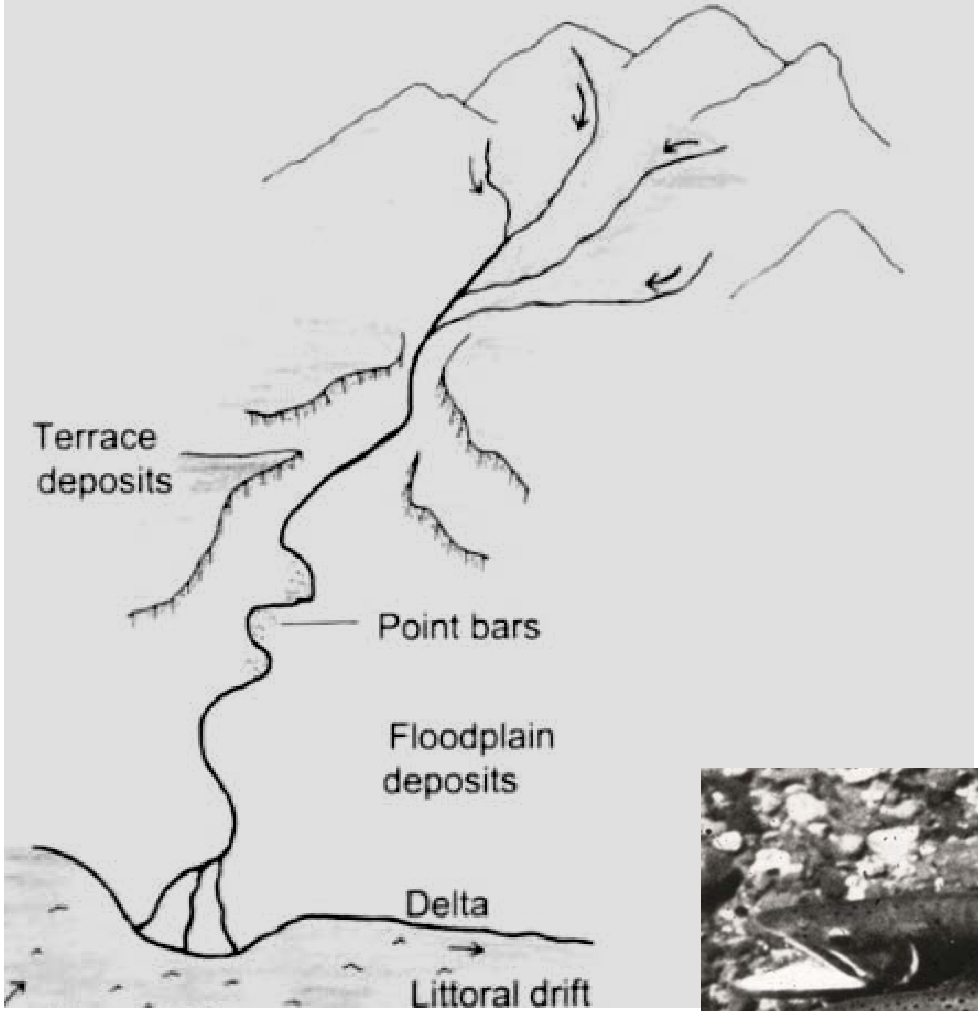
# THE ROLE OF SEDIMENTS IN FLUVIAL SYSTEMS



*Rio Aguarico, Upper Amazon R basin*

G. Mathias Kondolf
University of California

# Just as rivers carry water, so they carry sediment.



Important attributes of rivers:

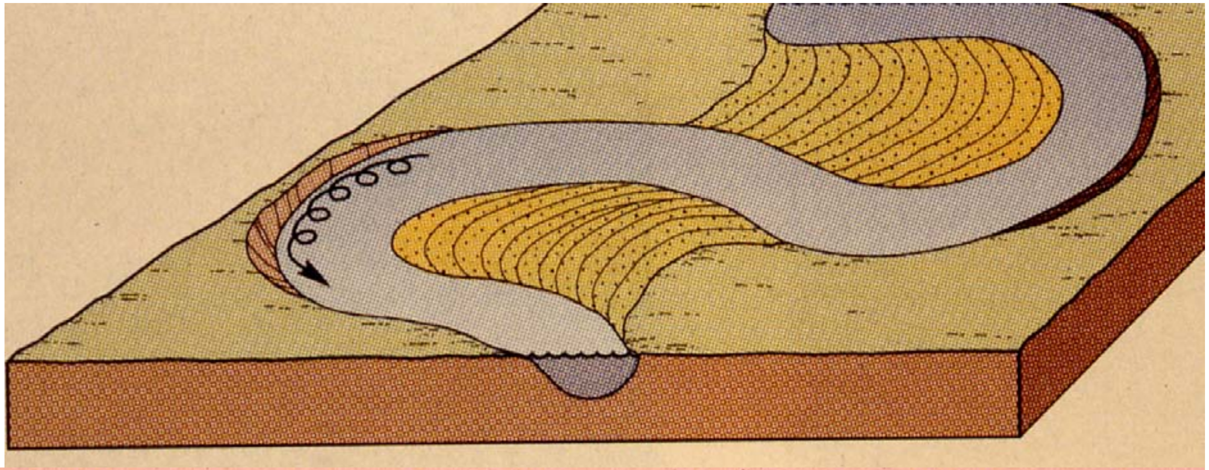
***Longitudinal continuity*** of
 sediment movement
 upstream - downstream

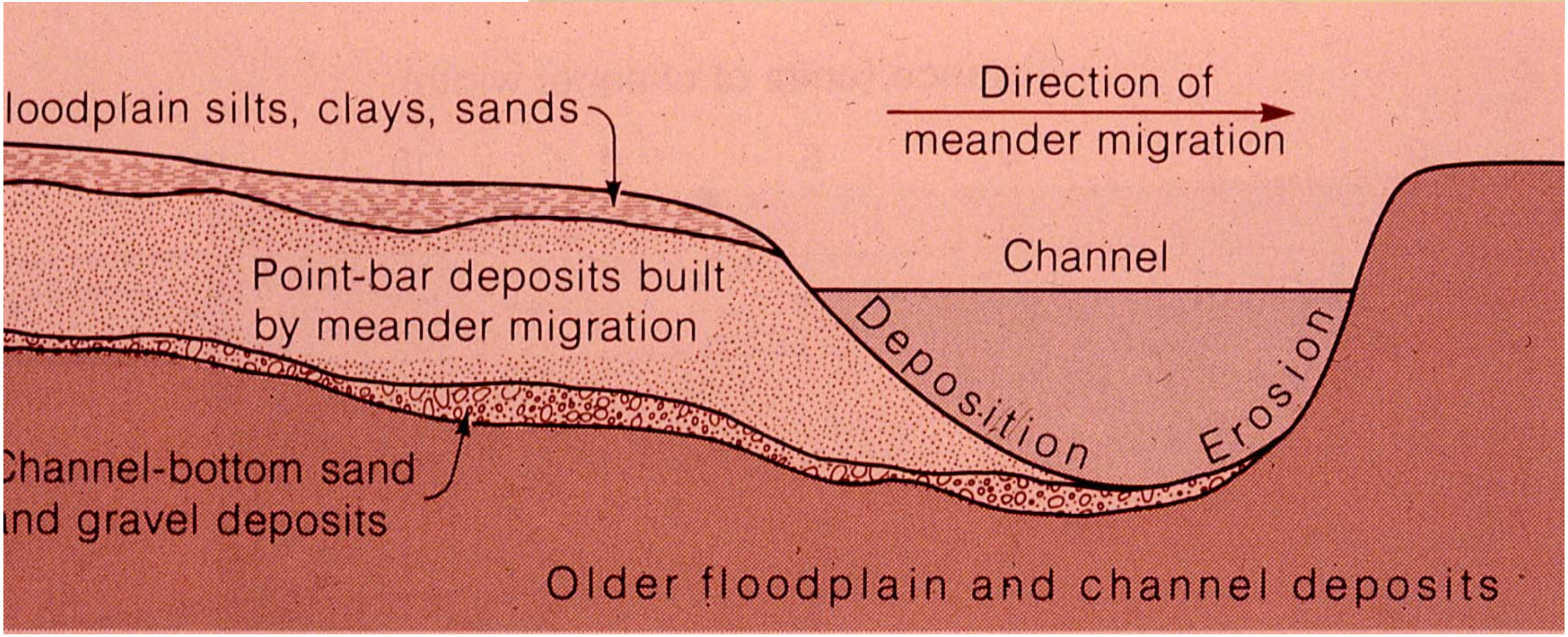
***Lateral exchanges*** of sediment
 channel - floodplain/terraces

Sediment essential for
 fish habitats and reproduction
 *Trout spawn in stream gravel*

# Alluvial channels are formed of their own sediment.

If flow is the ‘architect’ of the channel, sediment is the building material



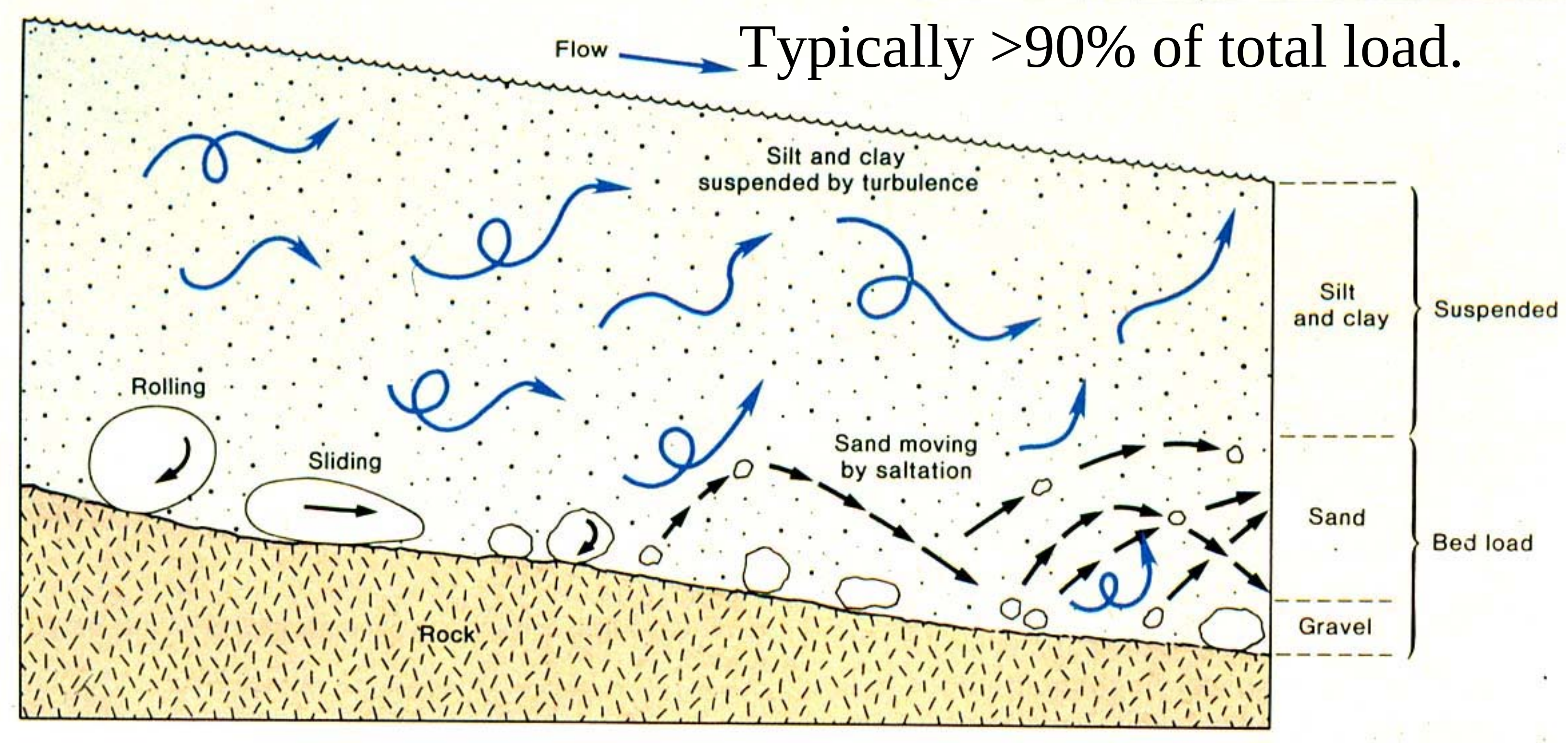


Sediment forms channel features, which in turn provide surface on which riparian vegetation establishes, further influencing channel form and river processes

The amount and calibre of sediment influence the shape and dimensions of the channel

# *Types of Sediment Load*

***Suspended load*** Sediment transported in suspension in the water column (maintained in suspension by turbulence).

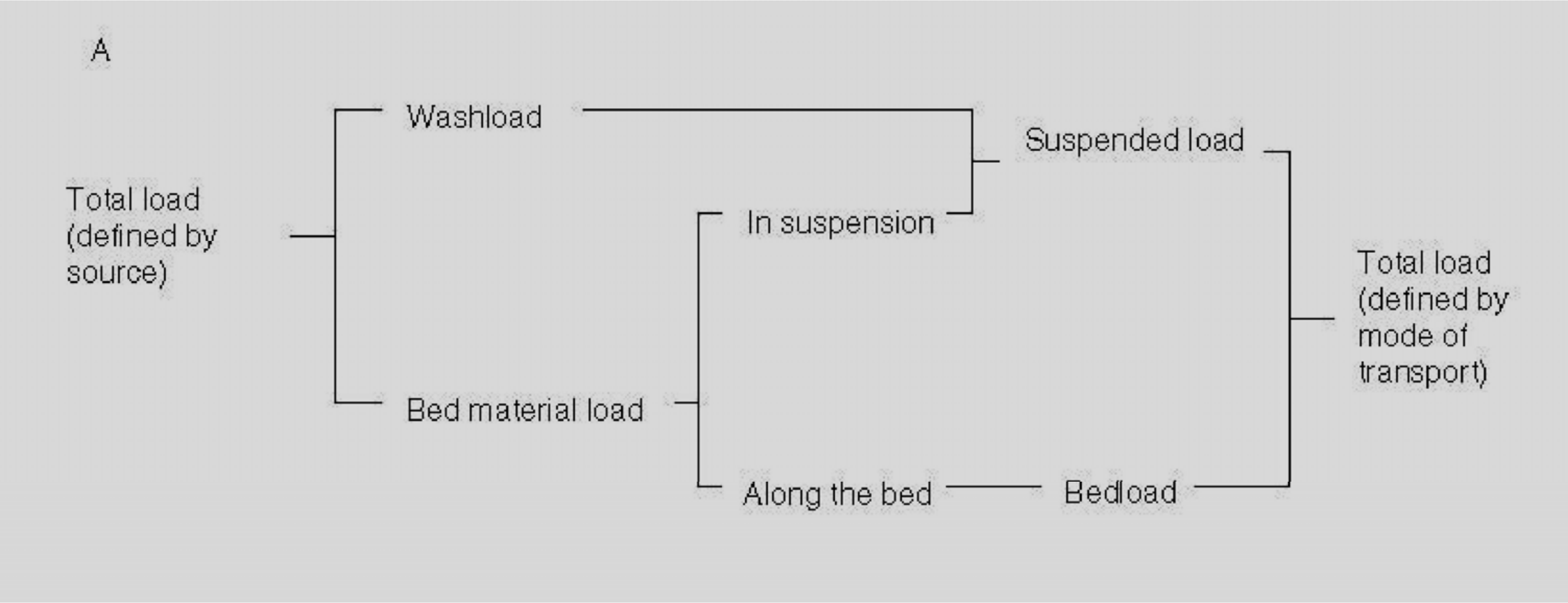


Typically >90% of total load.

***Bedload*** Sediment (sand & gravel) moved along the bed by rolling, sliding, & bouncing. <10% of total load.

***Dissolved load*** Constituents in solution. Important in areas of limestone or tropical areas (chemical weathering)

**Another way to classify**
***Washload*** Silt and clay that remain in suspension and “wash” through the river system.
***Bed Material Load*** Bed material transported as bedload (gravel and some sand) or as suspended load (sand).

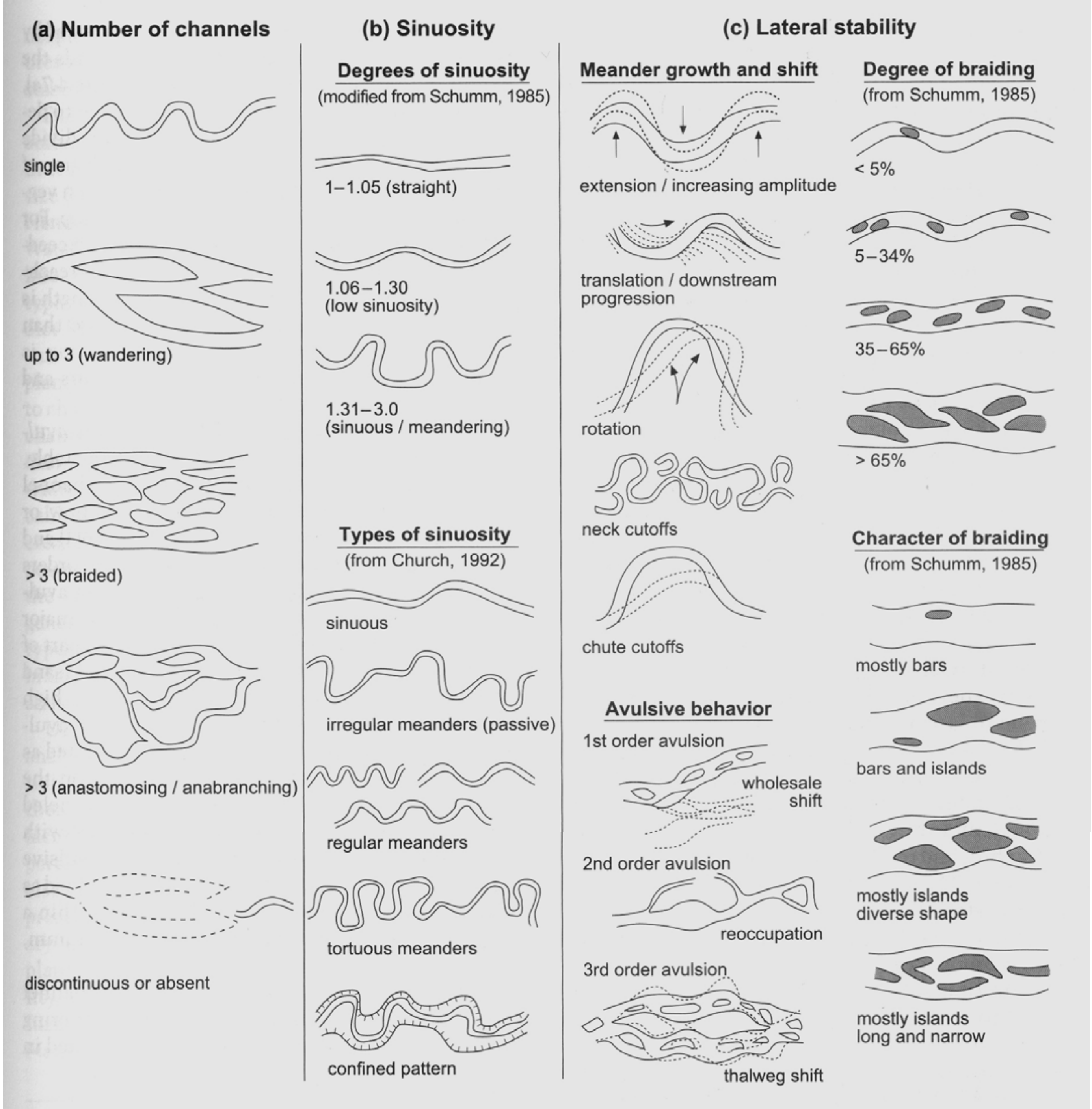


High bedload supply
*Rakaia River, New Zealand*

*San Joaquin River, California*
Suspended load dominated
Relatively low supply

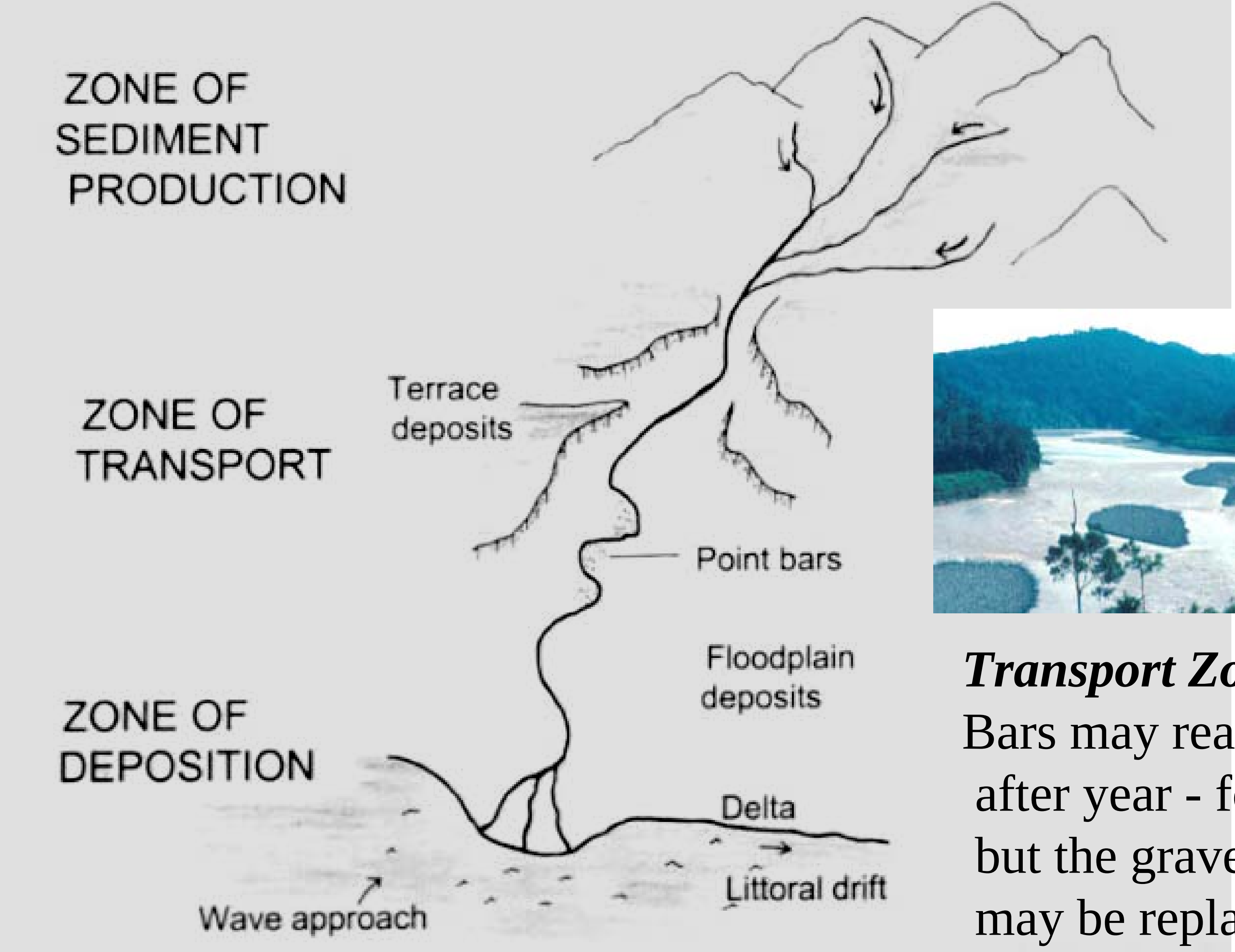
Tremendous variety of channel forms

Depend largely on sediment load



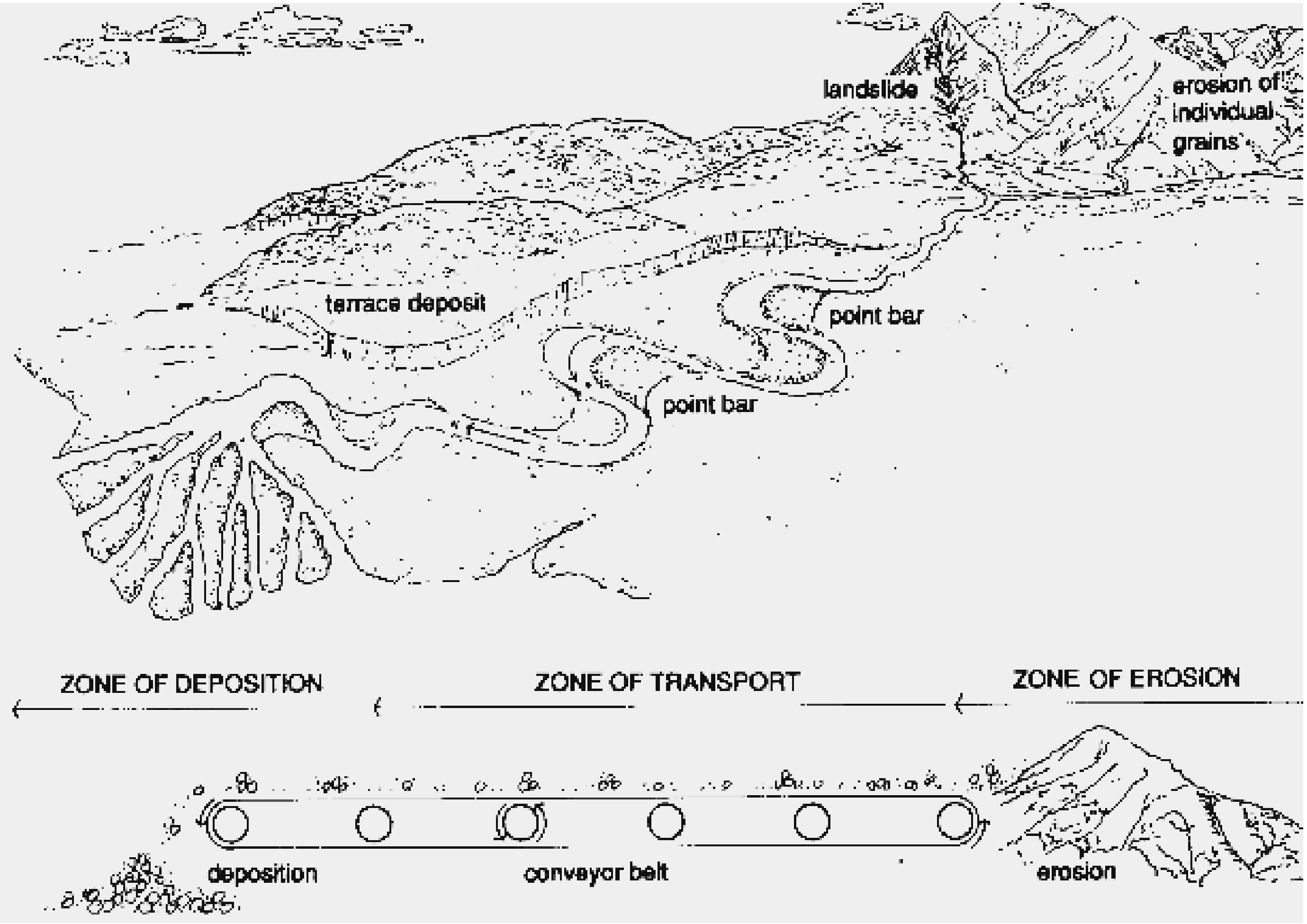
*from Brierly & Friars 2005*

# Longitudinal Continuity



***Transport Zone:***

Bars may reappear year after year - form is stable but the gravel particles may be replaced annually



The transport zone may be likened to a conveyor belt, transporting sediment from the steeper zone of erosion down to depositional zones, storing sediment temporarily. If this flux of sediment is disrupted, imbalances result.

# Dams

interrupt longitudinal connectivity of sediment transport

Releasing clear ‘hungry’ water, depriving downstream reaches of sediment,

And filling reservoirs with sediment, resulting in loss of capacity.

# Reservoir sedimentation has serious effects:

- reduces or eliminates water storage capacity
- interferes with operation of hydroelectric generators
- makes dams seismically unsafe: not designed to withstand dynamic loads of increased weight of sediment in water
- costly to mechanically remove

*San Clemente Dam,*
*Carmel River, USA*

# Bar-lin Dam, Dahan River, Taiwan

Reservoir partly filled with sediment by 1999,
when damaged by earthquake.
2004 typhoon filled completely - 10.4 million m3 sediment.
Located in inaccessible reach of river.

October 2002

Sept 2004 - dam full of sediment

Sept 2005

Sept 2006

# Progressive failure during typhoon in 2007

9 July 2007

19 Sept 2007

19 Sept 2007
failure complete

*Causes:*
*Earthquake damage,*
*Large flood*

Eventually, all dams will either fill with sediment, or their concrete will become unstable.

*Thus all dams will require decommissioning*

*Yet these costs are not considered in economic analyses for dams*

Matilija Dam, Ventura River (NW of Los Angeles)

*Built 1947, now full of sediment and unsafe*

*Plan to remove*
*1.5 million m3,*
*stabilize remaining*
*sediment in place.*
***Cost: $83million***

# *San Clemente Reservoir on the Carmel River*

*(at the confluence of San Clemente Ck) (drainage area 325km2)*

*Reservoir now full of sediment, seismically unsafe*

*Remote location, difficult to transport sediment from the site*

# *Most sediment will be stabilized in place*

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

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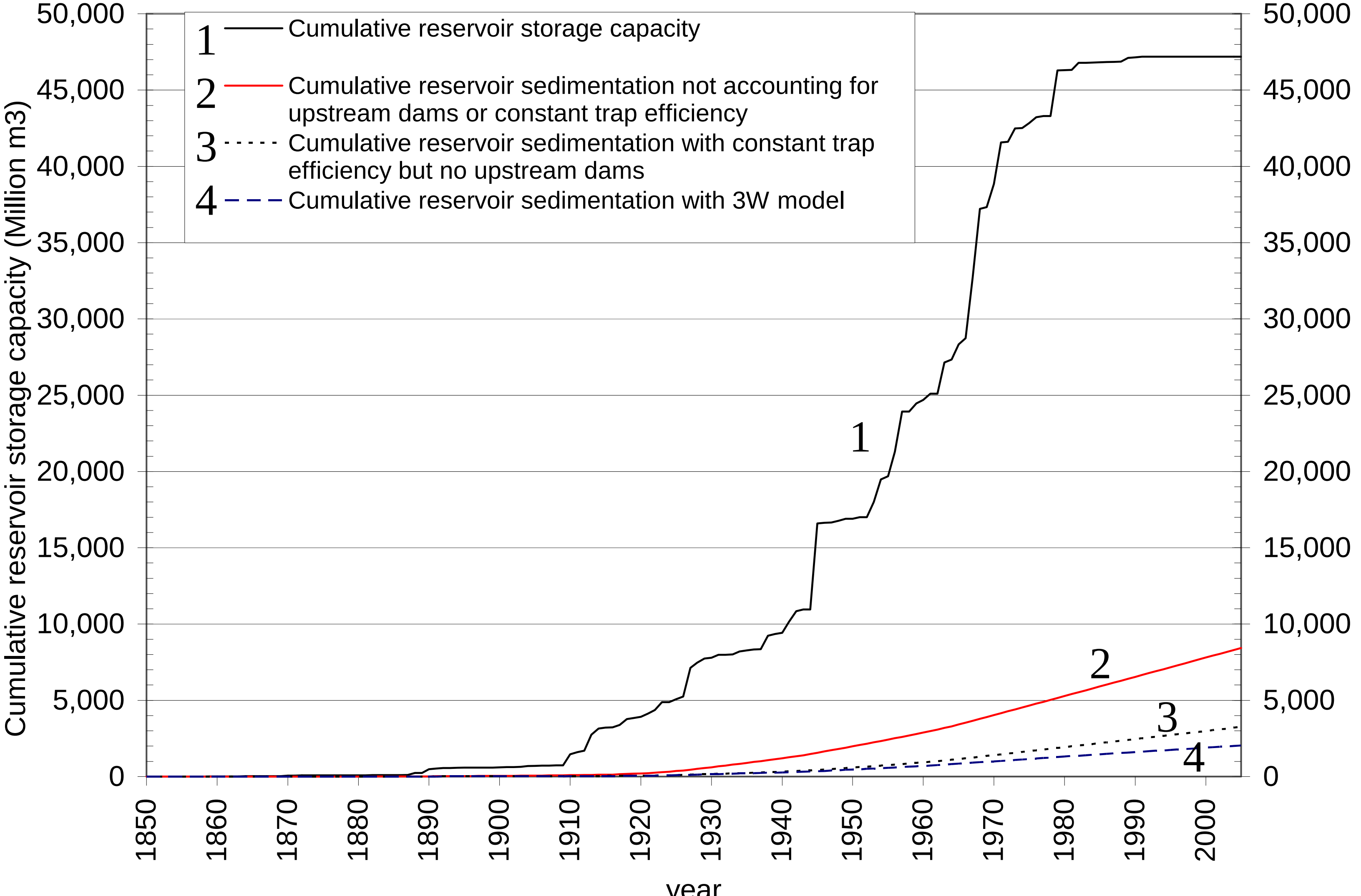
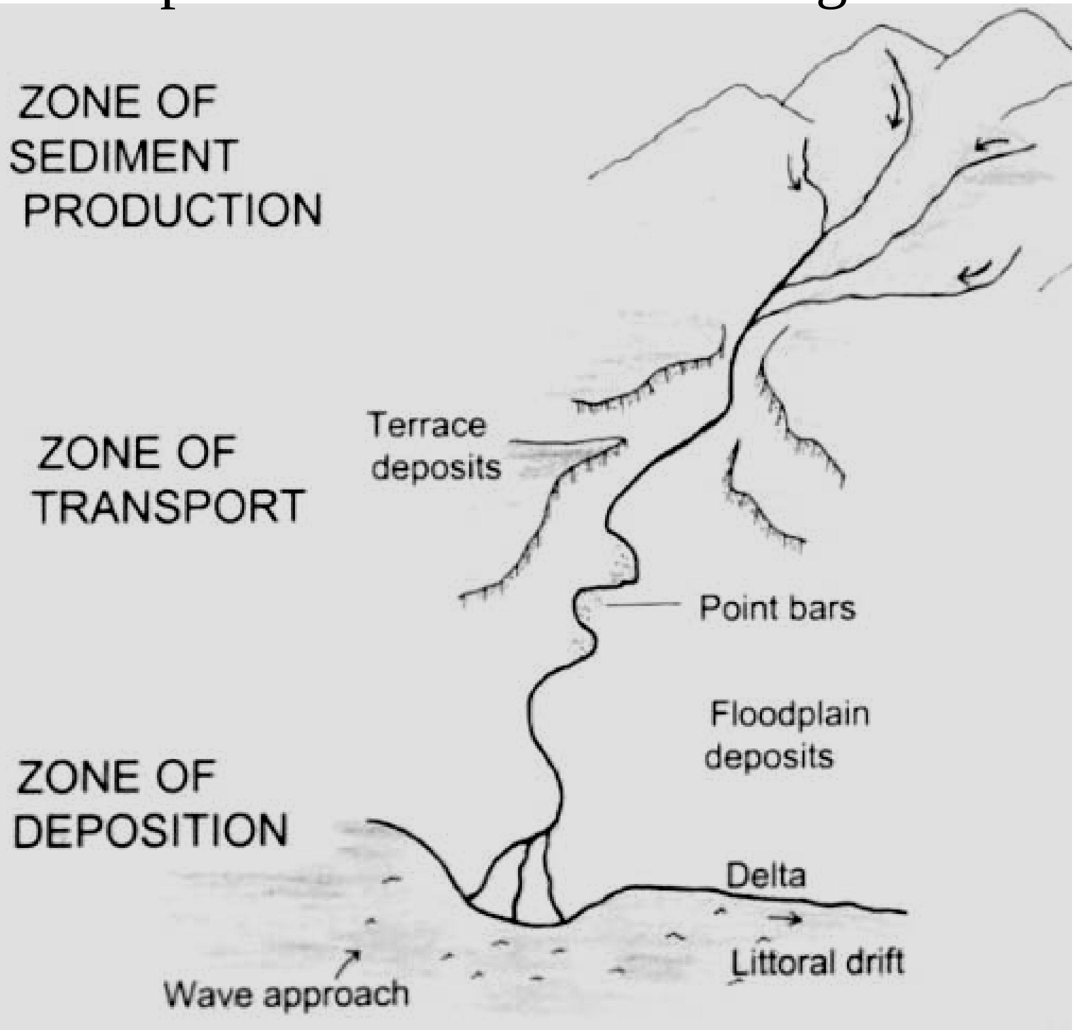
*River will be diverted around sediment, through a hill into canyon of San Clemente Creek, tributary.* ***Cost: $144 million***

***Many more dams will fill, will require removal.*** Modeling of reservoir sedimentation rates for California shows sedimentation rates don't threaten reservoir capacity state-wide, but identifies many reservoirs at risk *(Minear and Kondolf in review)*



## *Impacts of hungry water downstream of dams:*

To assess the potential impacts of hungry water, consider the context. Impacts will differ depending on position within the drainage basin.



e.g.,
different impacts
in upper reaches
vs delta.

# Sediment-starved “hungry water” downstream of dams

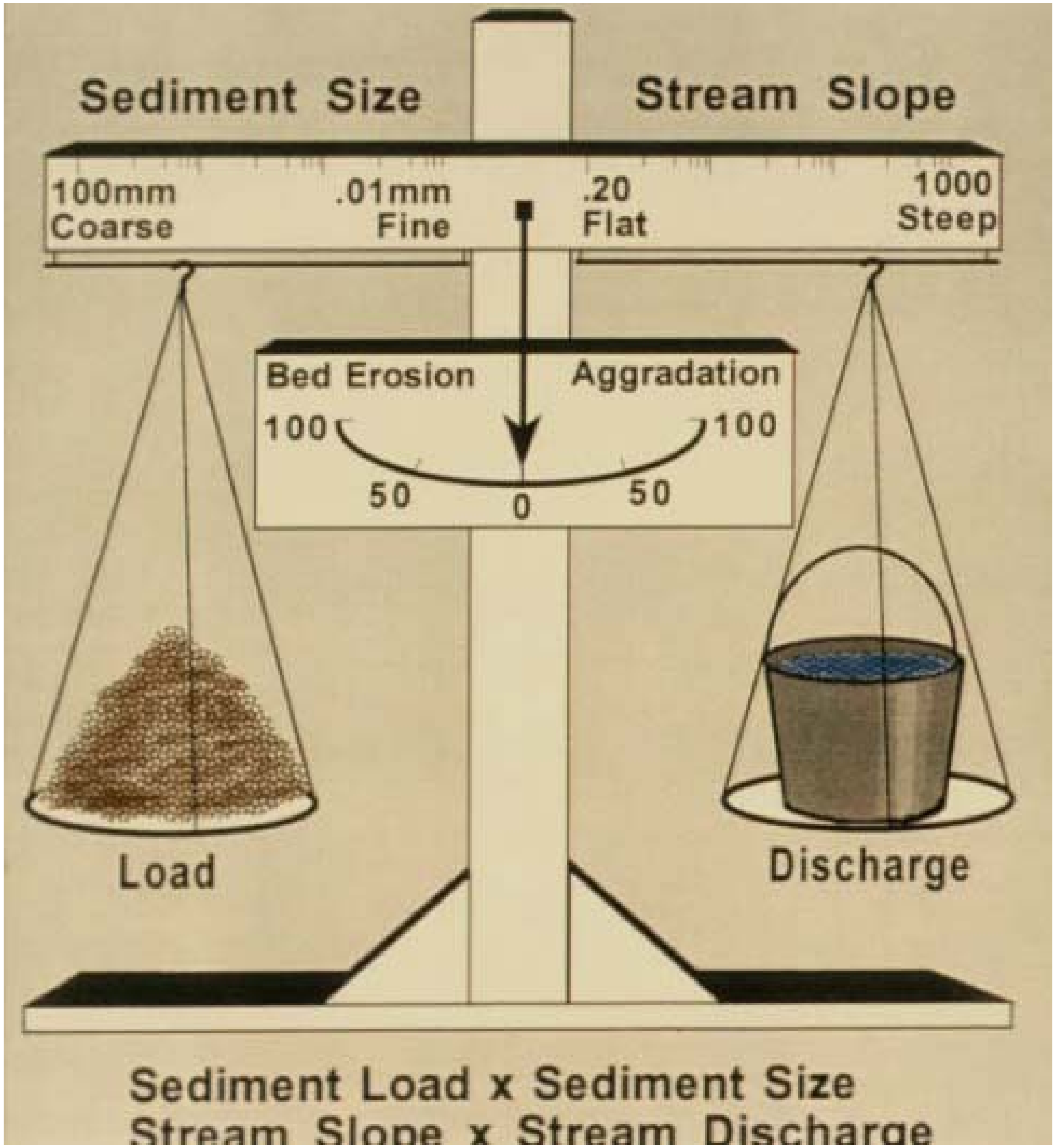
can reduce sediment supply to deltas, causing erosion and loss of land in delta.

*Nile River Delta*

After construction of Aswan High Dam, reduced suspended sediment and nutrients from the Nile caused the sardine fishery to collapse

# ***Alluvial channel change in response to changes in flow, sediment load***

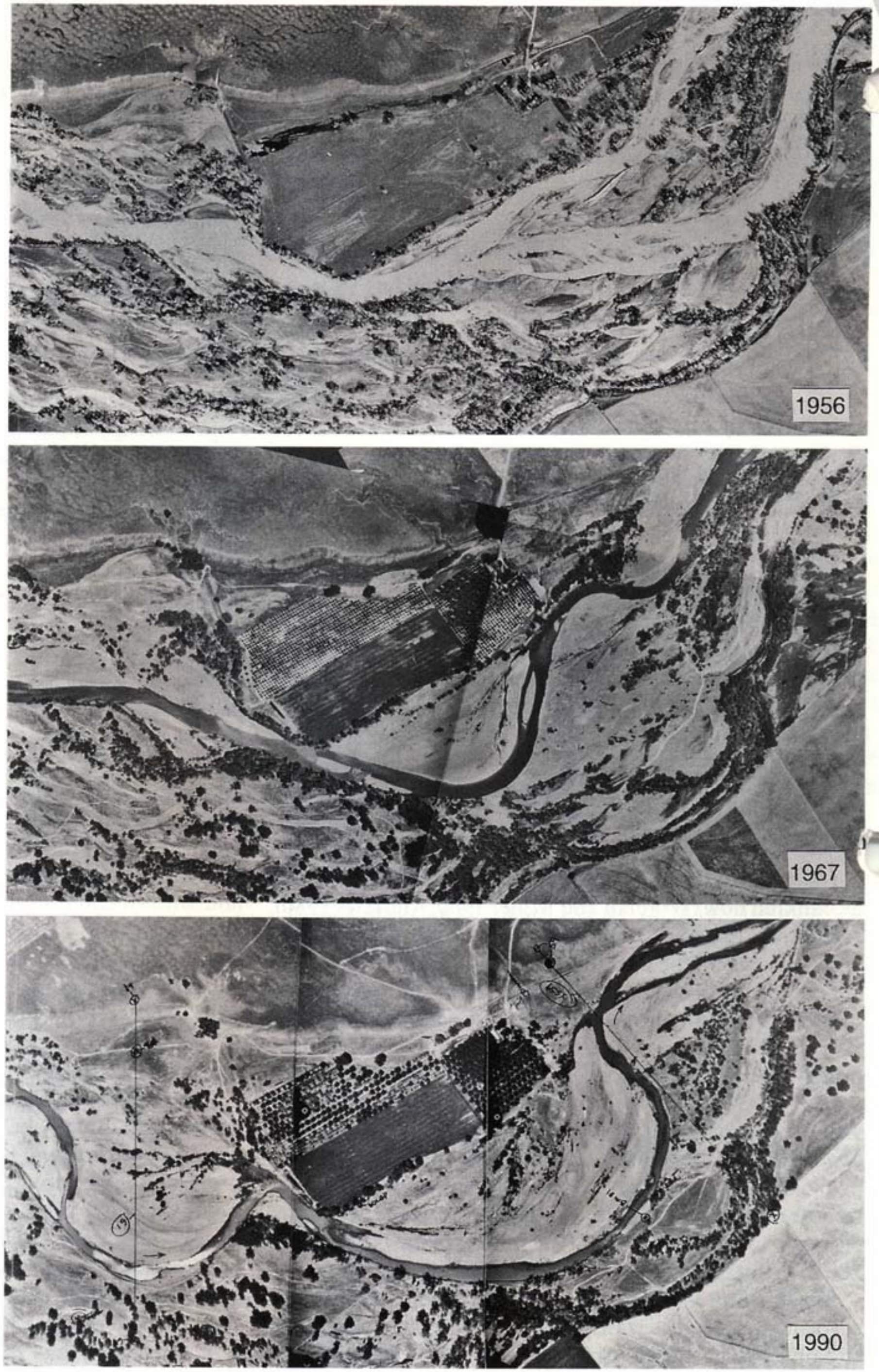
Lane's *'Stable Channel Balance'*: reduced sediment leads to channel erosion, incision; So too sediment fining



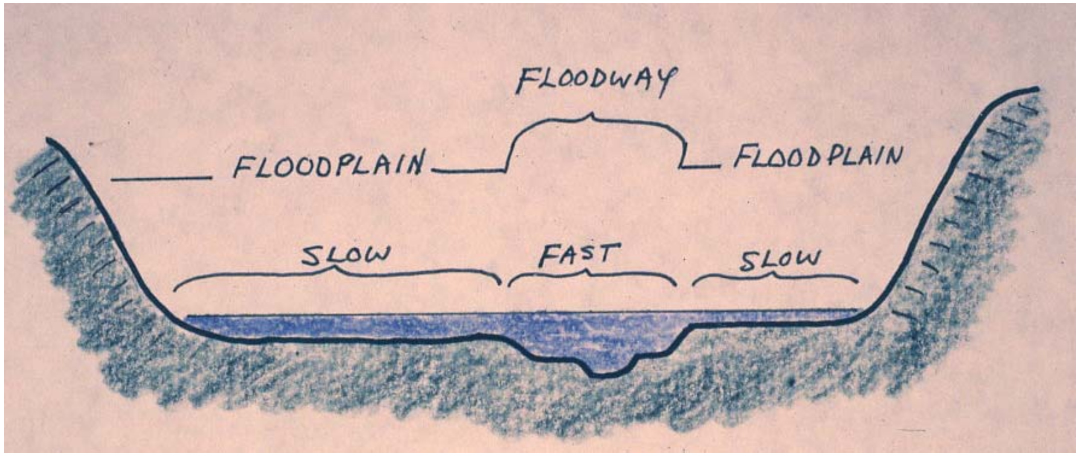
***Stony Creek, California***

After construction of
of Black Butte Dam in 1963

The supply of bedload was reduced and the creek changed to a single-thread, meandering channel



# Lateral Connectivity - Channel-Floodplain



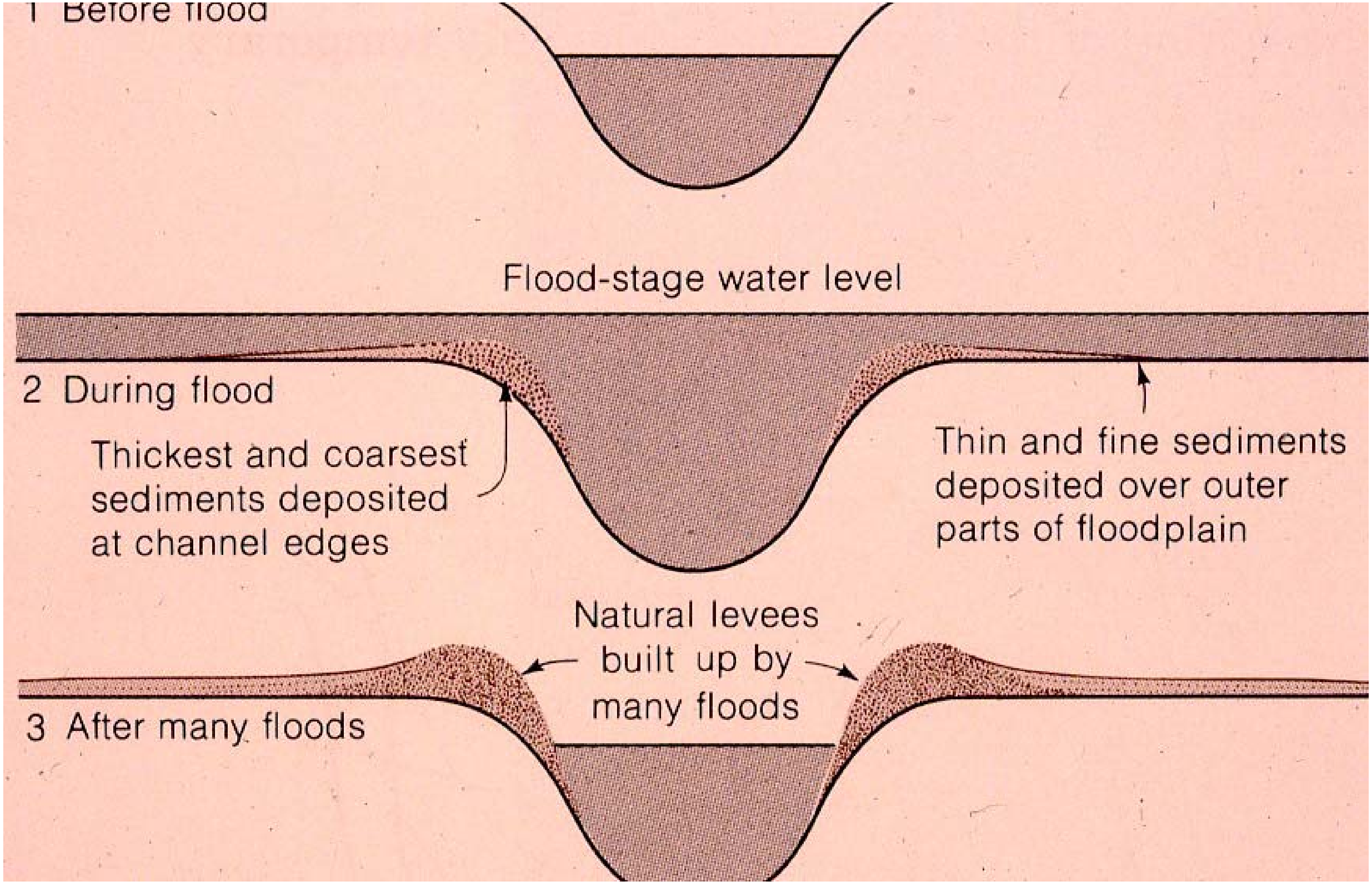
Overbank flows deposit silt over floodplain, building the floodplain and sustaining fertility - until Aswan High Dam at least

*The Nile Floodplain near Luxor*

# Natural Levees & Backswamp deposits

Sand-sized sediment along channel margins

Silt-clay over floodplain



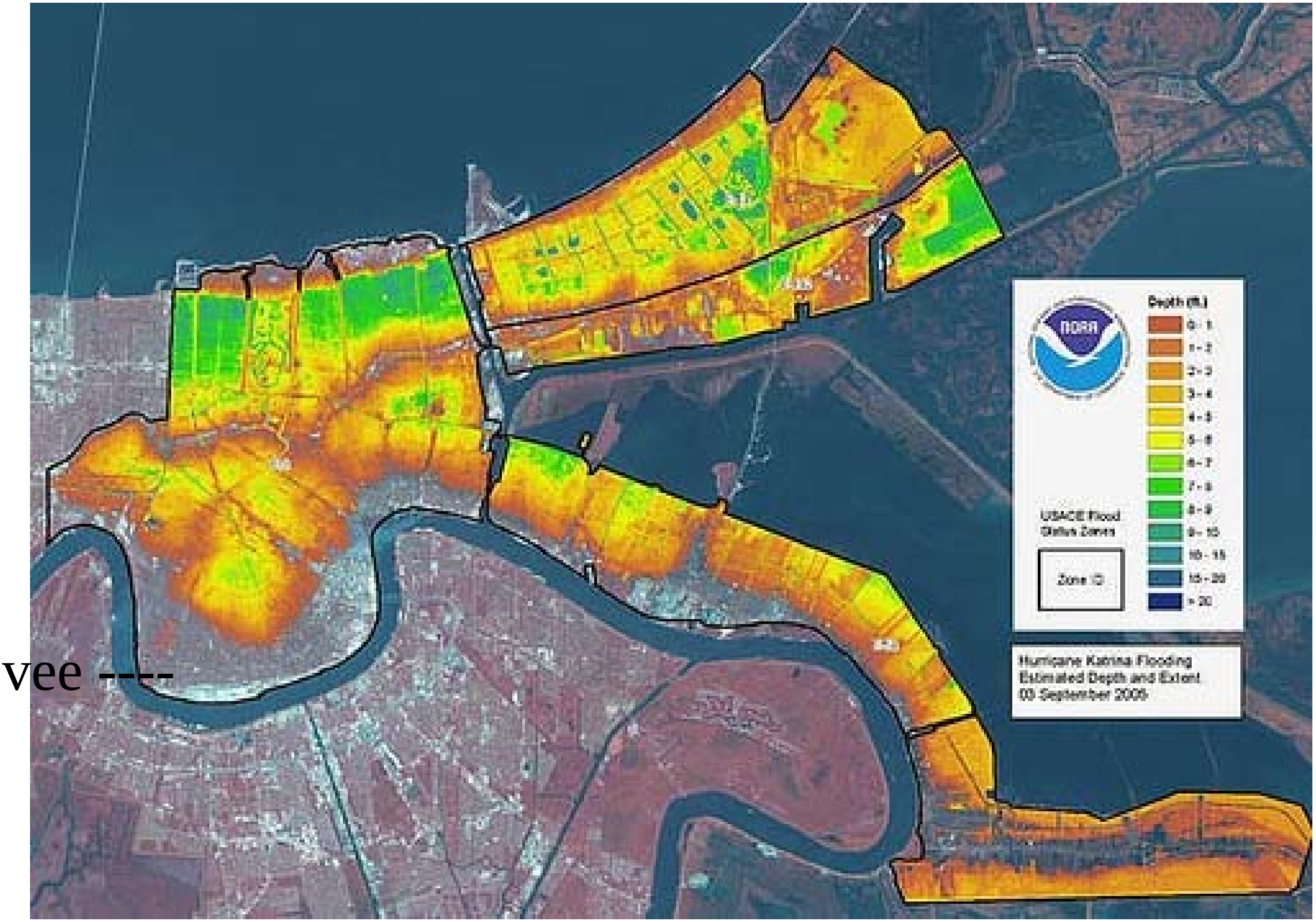
# Example: The Mississippi River across from Hannibal, Missouri

One day after a flood:

Fresh deposits of sand on the natural levee

While the lower, backswamp areas have standing water long enough that silt and much clay can settle out.

These sedimentation patterns were clearly reflected in patterns of flooding in New Orleans in 2005.



Natural levee ----

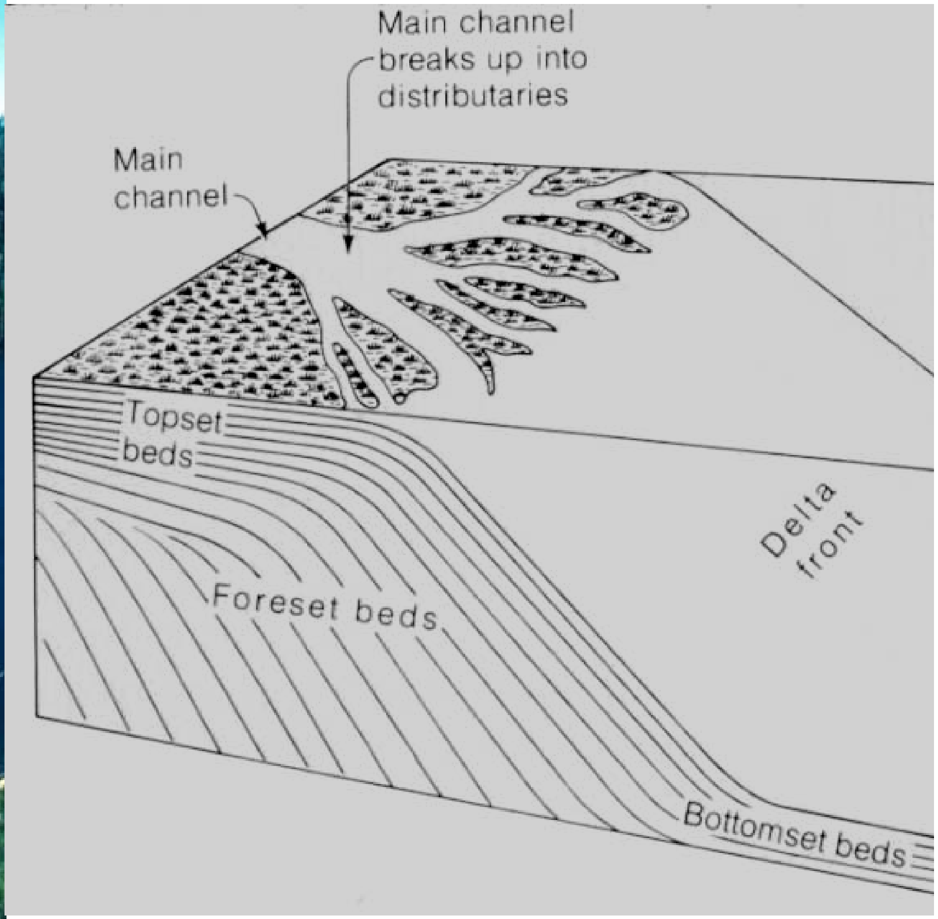
*The higher, sandy natural levees remained dry, while back-swamp areas were inundated*

# Disrupting lateral exchanges of sediment:

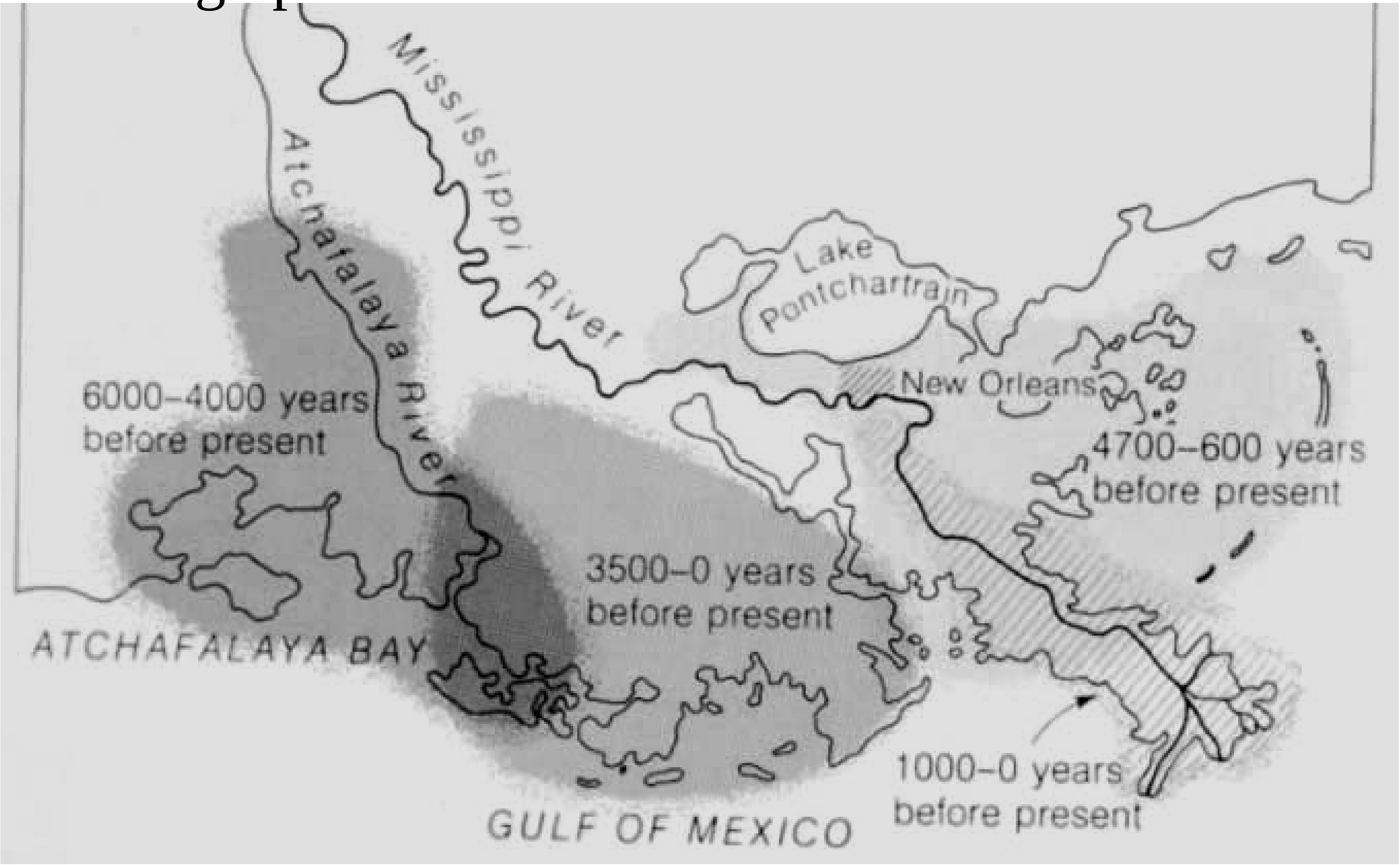
Levees prevent overbank flows and thus prevent sediment from depositing on floodplain.

On Chorro Creek, California, levees were removed to restore lateral exchange, allowing Chorro Creek to flood and deposit sediment on its floodplain

# Similarly, deltas build up as sediment carried in distributary channels is deposited across the delta.



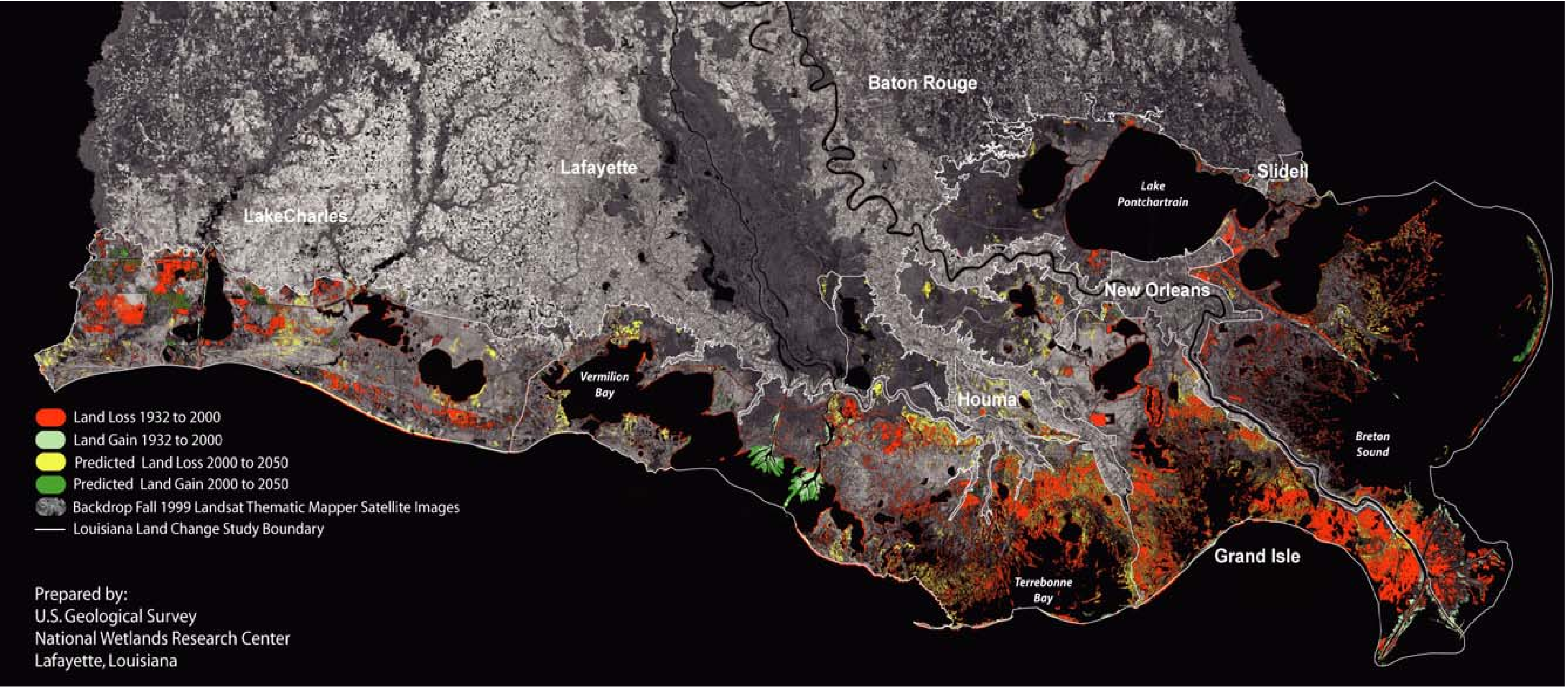
Naturally, the Mississippi River used multiple channels, shifted its main channel, and during floods, spread out over the delta surface, depositing sediment and building up the elevation of the delta.



Currently, most of the flow of the Mississippi is forced to stay in one channel, so nearly all of the river's sediment load is discharged into deep water.

The result: As the delta subsides (mostly natural) there is no fresh sediment deposition to compensate.

# *The Mississippi River Delta*



Areas in red represent lands lost to subsidence.

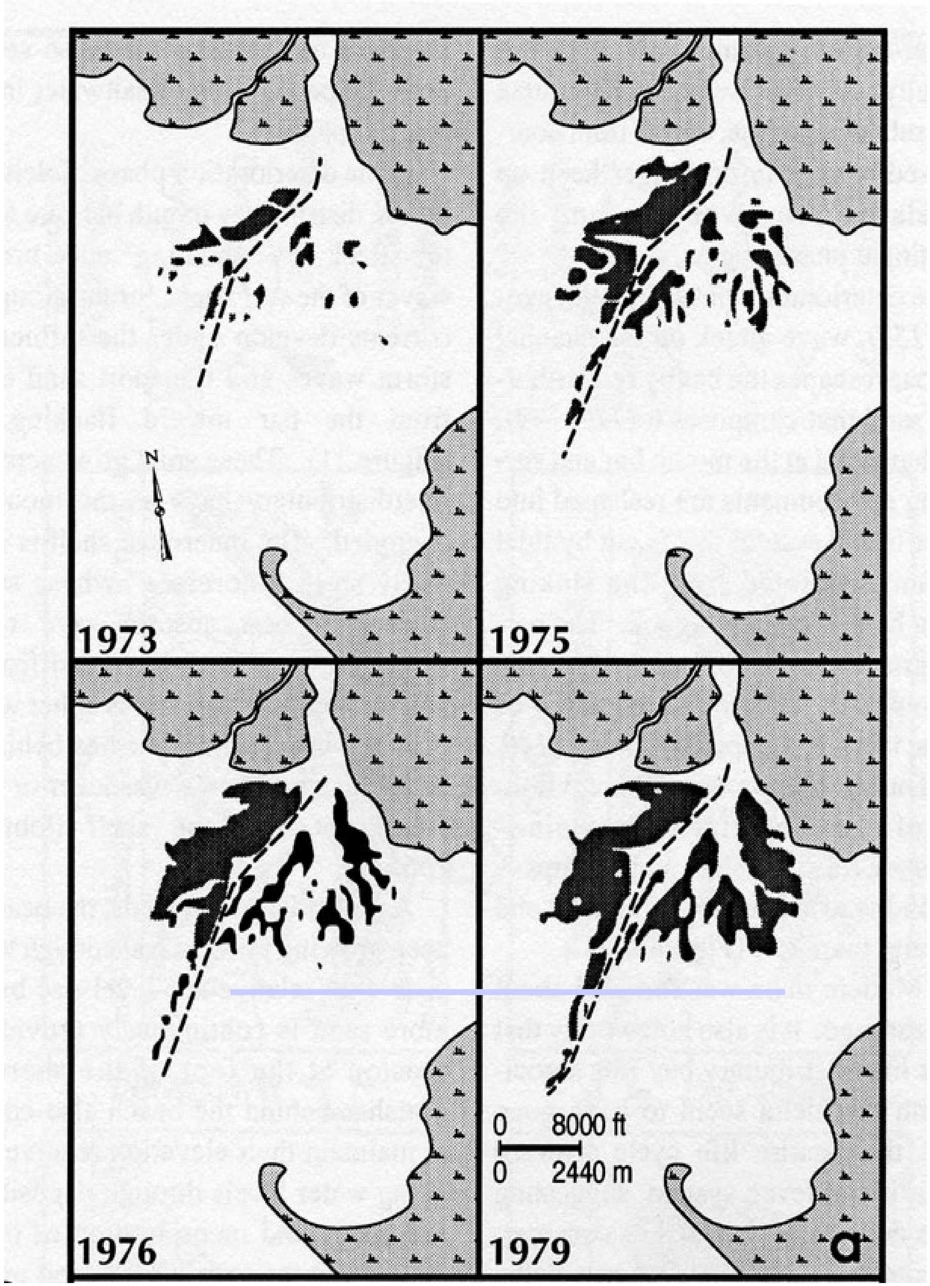
The cause is both reduction in sediment from upstream due to dams (notably on the Missouri), but more importantly preventing sediment from depositing on the delta.

(both longitudinal continuity and lateral exchange lost)

Part of the Mississippi R discharge flows through the Atchafalaya channel.
The sediment carried by the Atchafalaya built up a delta in the 1970s

To recover lost land in the Mississippi Delta, we must reconnect the river’s water and sediment to the delta.

Some experimental projects have been undertaken



*Growth of the Atchafalya delta*

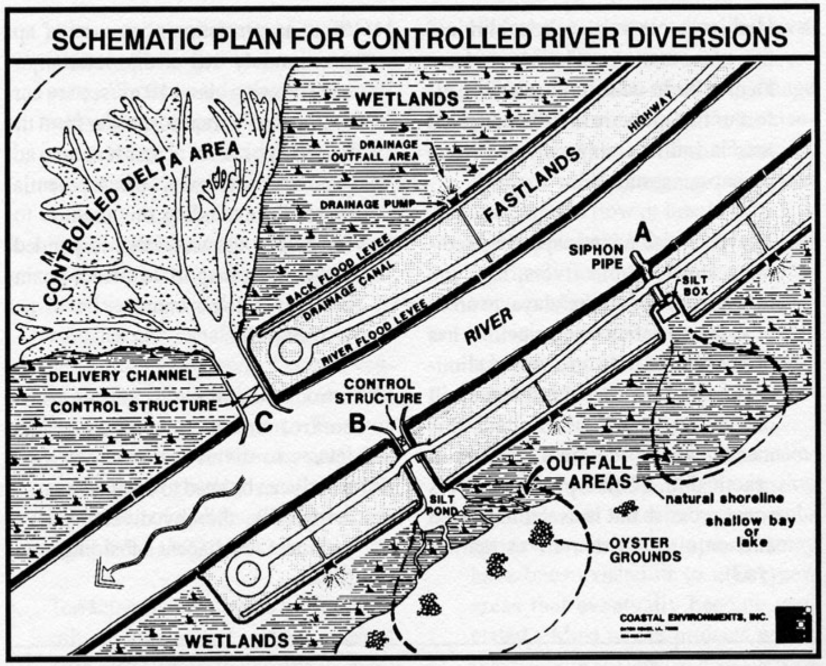


Figure 16. *Schematic of three basic types of controlled river diversions: A. siphon; B, gated diversion; and C, controlled subdelta. Published with the permission of S.M. Gagliano, (51).*

Dredged sediments being placed in open water to restore marsh that has been lost.

*Experimental small-scale diversion at Caernarvon, Louisiana*

*The Mississippi River Diversion at Caernarvon*

The concept is to allow water and sediment to flow from the current channel onto the Delta and thereby build up the land surface at multiple places.

The current 'bird's foot' delta would be abandoned.

# Conclusion

-Often overlooked, a river’s sediment exerts a profound influence on the river ecosystem (channel, floodplain, habitats)

-Sediment is characterized by longitudinal continuity and lateral exchanges. If these are disrupted, problems may ensue

-Changing sediment supply (e.g., by trapping in dams) can induce strong changes in channel form, loss of habitats, and damage to infrastructure

-Deltas and other coastal erode if starved of sediment

-Reservoirs inevitably trap sediment, which will require decommissioning in the future

-Reservoirs filled with sediment become seismically unstable

-Costs of decommissioning can be substantial: $83 - $144 million for two small dams in California - costs need to be incorporated in economic analyses of dams