Estuaries: Classification, Mixing, and Coastal Biogeochemistry

Part II

OCN 623 – Chemical Oceanography
07 Apr 2016

Mixing Curve

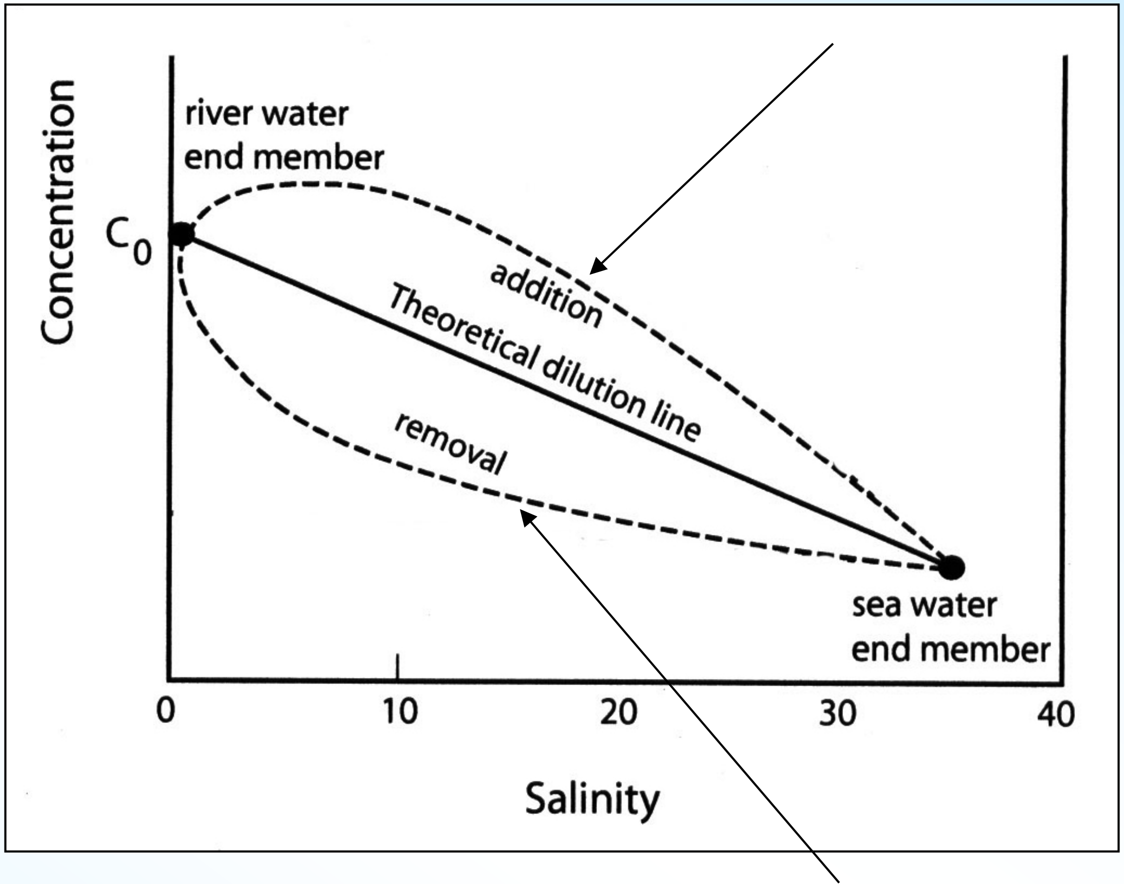
Salinity is a conservative constituent in estuaries and is a good indicator of mixing

Constituent plotted against salinity to determine if distribution is attributable to mixing processes (as opposed to non-conservative processes; nutrient uptake, flocculation, biodegradation, etc.)

If concentration vs. salinity is LINEAR, then the chemical/particle exhibits *conservative* behavior

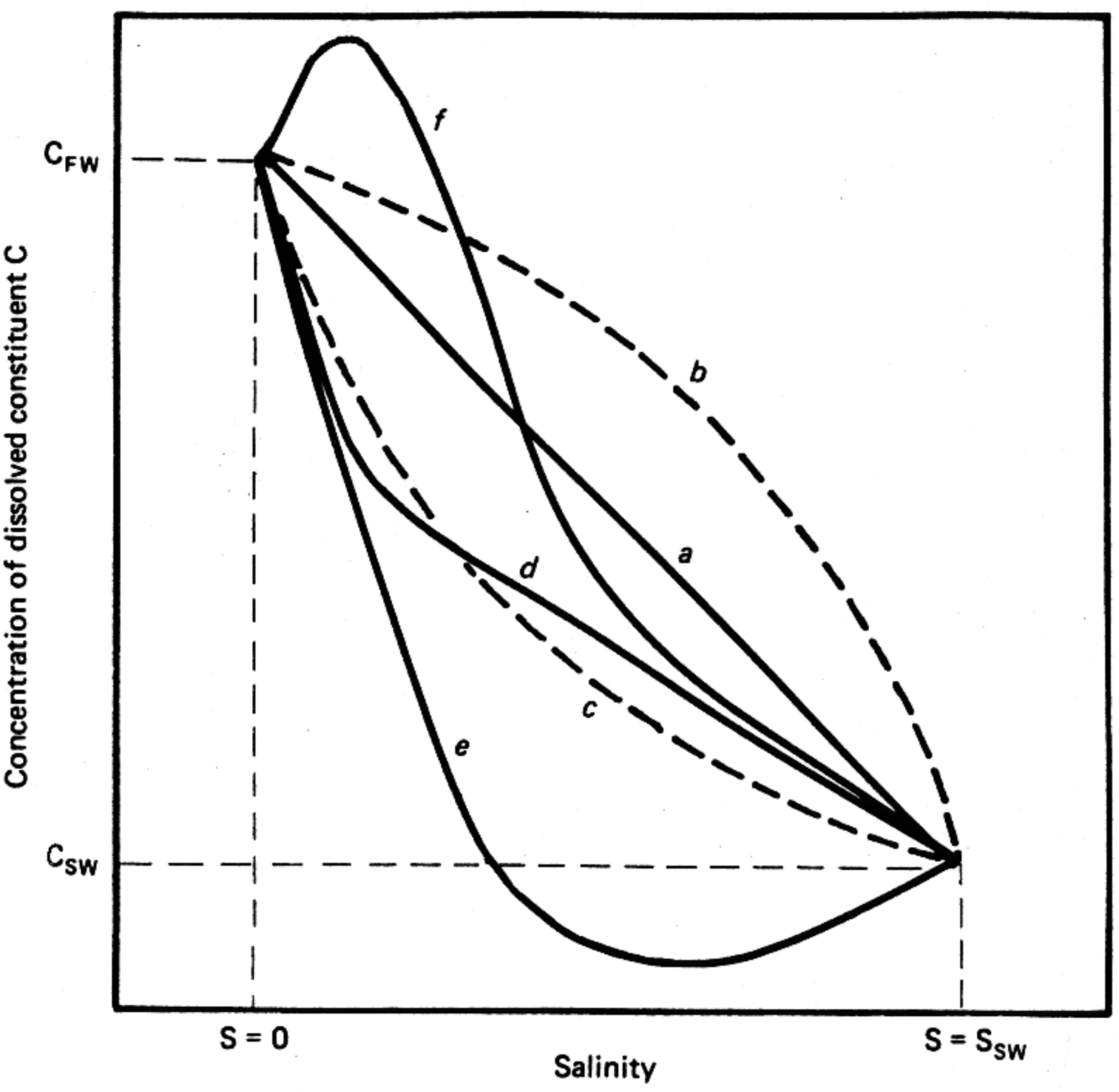
If plot of concentration vs. salinity is NOT LINEAR, then the chemical/particle exhibits *NON-conservative* behavior

Non-conservative mixing (source)



Non-conservative mixing (sink)

Assumes end-members are constant over the flushing time of the estuary



C_{FW}
C_{SW}
Concentration of dissolved constituent C
f
b
a
d
c
e
S = 0
Salinity
$S = S_{SW}$

Elegantly laid out by Morris (1985):

“estuaries are classical examples of complex thermodynamically open systems, subject to constantly changing input and output fluxes and to continuous internal chemical reactions…” which do not usually reach a steady-state equilibrium

Many important reactions & processes are identified

BUT, still difficult to predict process rates & fluxes because of a lack of information on speciation of trace metals, kinetics of reactions, microbial activity, and heterogeneous nature of dissolved and solid phases

This leads to a heavy reliance on salinity as a conservative index for mixing & comparison

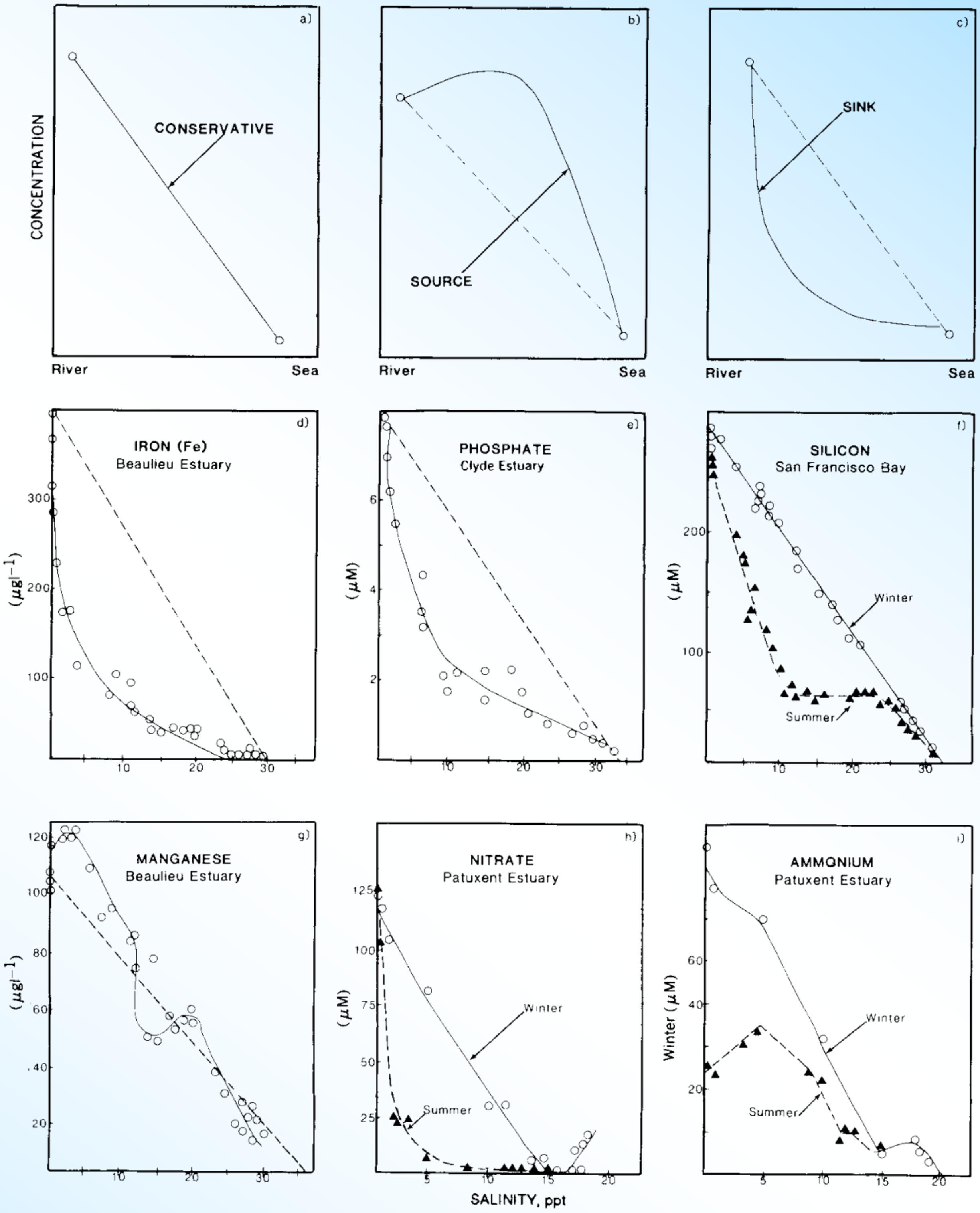
Pitfalls can include defining end-members, role of tributaries, and mixing of different water masses along the estuary

Mixing Diagram Examples

Mixing line assumptions:

Concentration & flux are constant

Only 2 significant end-members

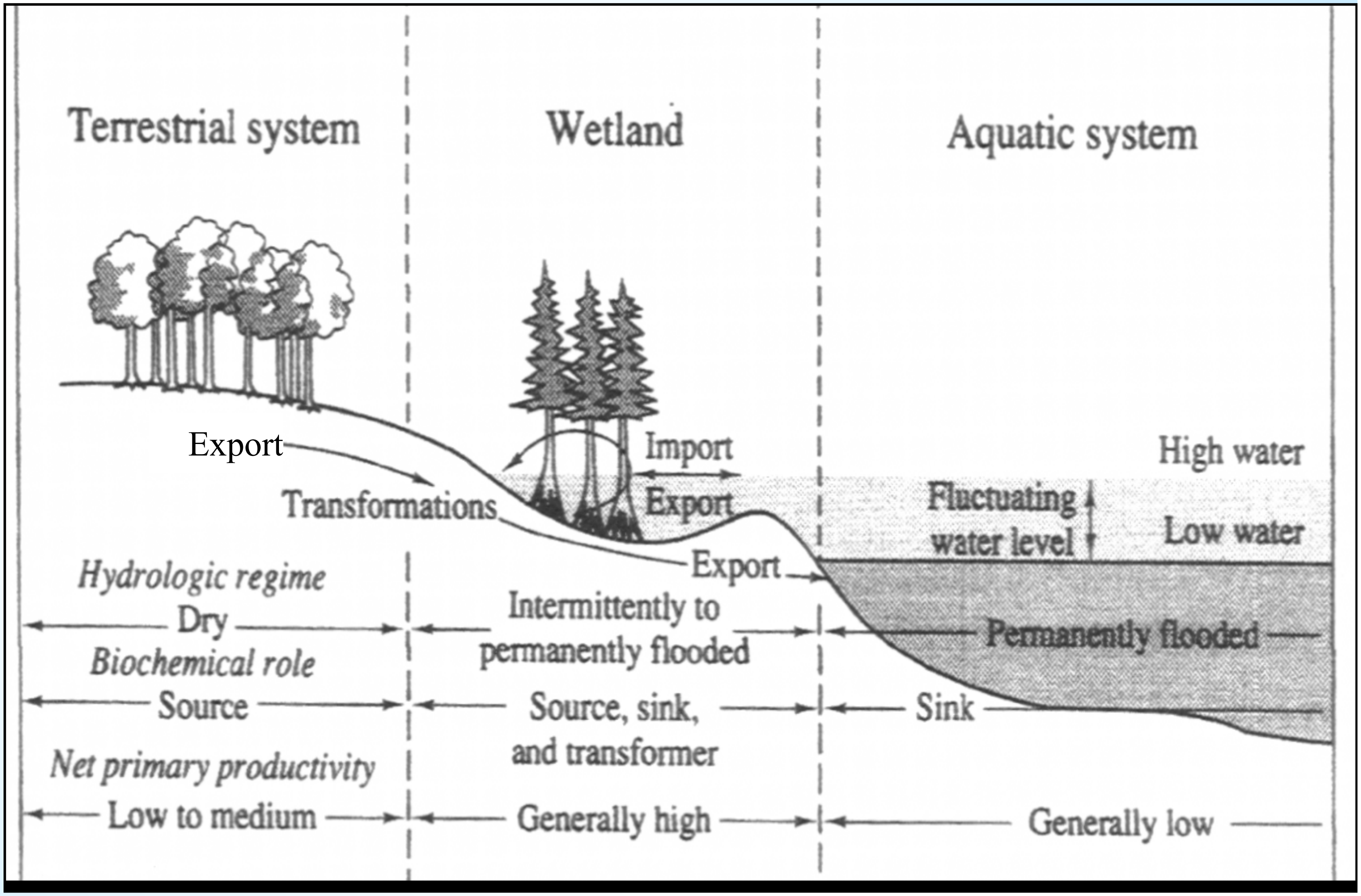


(from Day et al. 1989)

https://www.youtube.com/watch?v=Gfch_b45zoQ#action=share

Wetlands Are the Interface Between Terrestrial and Aquatic Systems

- Terrestrial (dry) systems tend to have medium NPP, high + NEP
- Wetlands have high NPP, + or - NEP
- Aquatic systems have low NPP, - NEP

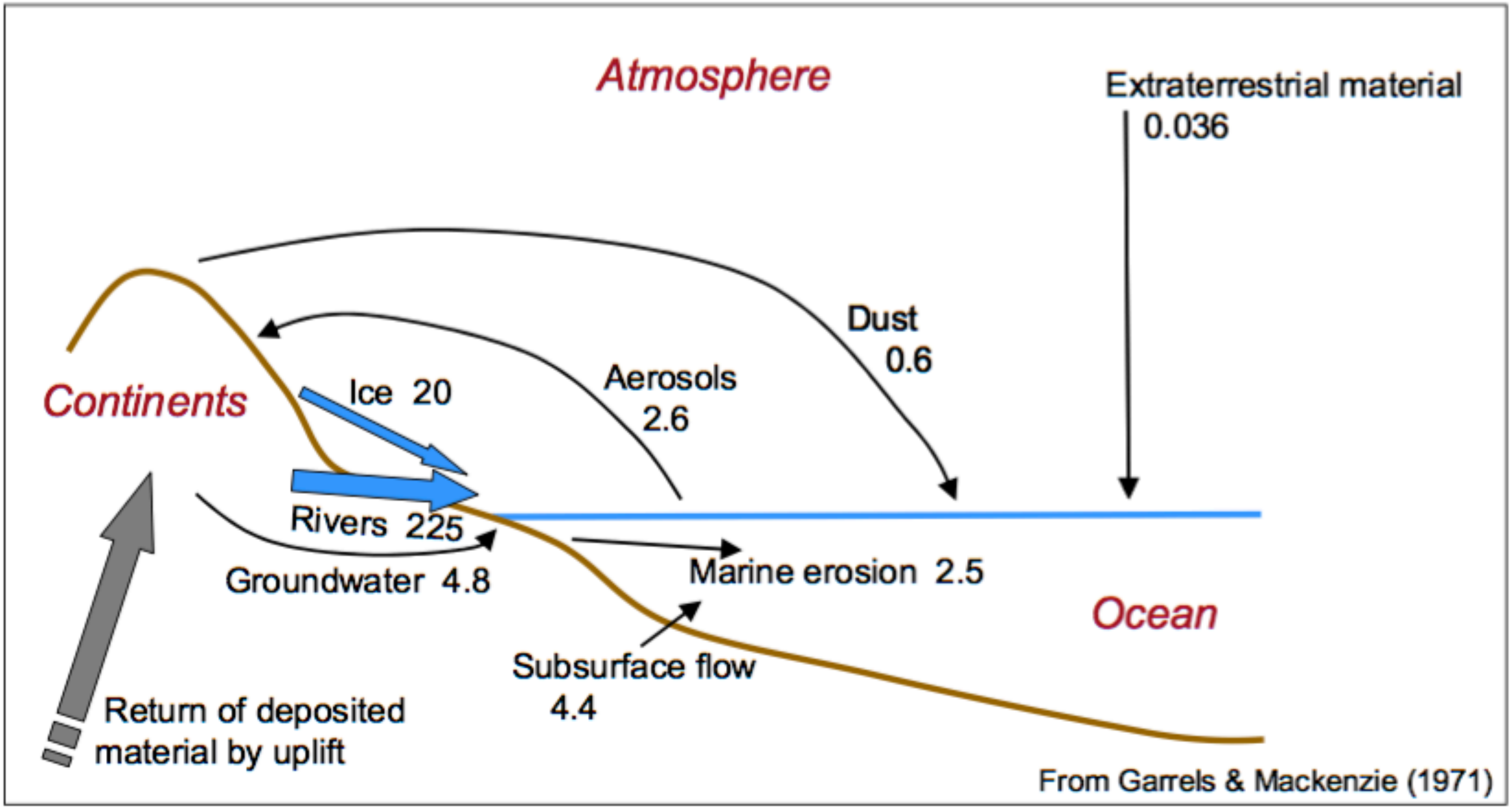


Drained wetlands or aquatic systems are major sites of "old C" oxidation

NPP = net primary production

NEP = net ecosystem production (P-R)

Masses of Materials Entering/Leaving the Ocean

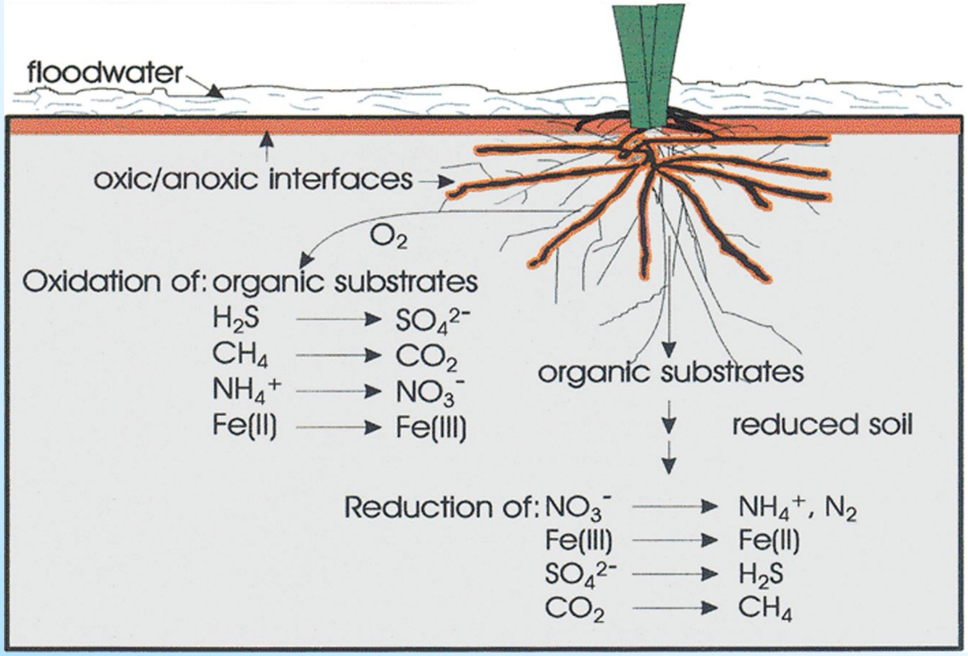


From Garrels & Mackenzie (1971)

Transport rates are 10^{14} g/year

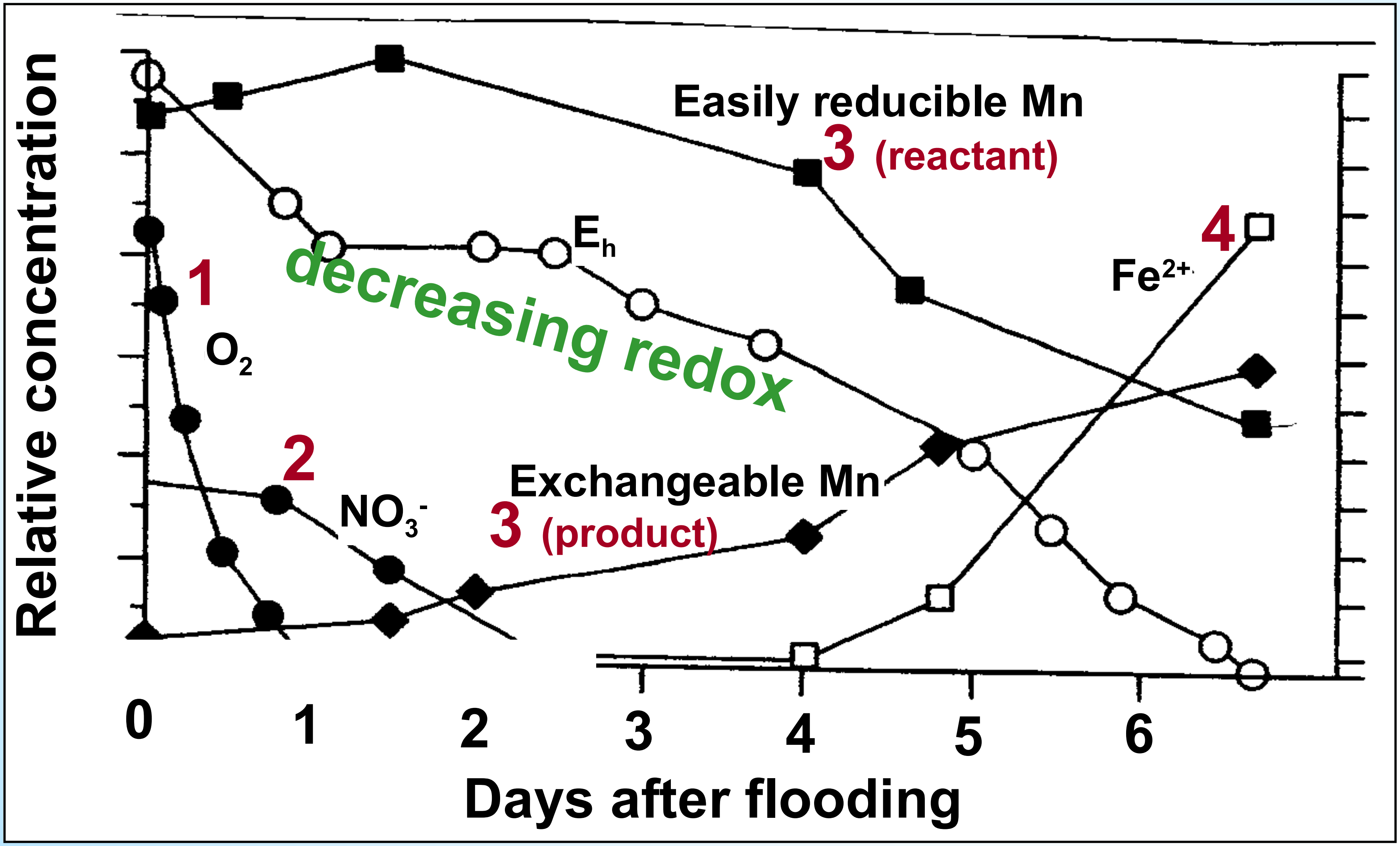
Dissolved solids in global ocean = 470×10^{20} g

Drained Soil vs. Flooded Soil



Example: Changing Composition in Flooded Soils

Temporal pattern reflects decreasing energy yield:



Salinity Effects on Salt Marsh Biogeochemistry

Salt marshes can exist over a wide range of salinities (and, thus, sulfate content), so there will be large variations in the biogeochemistry of different marshes:

Organic matter oxid	Oxidant	Reductant
Aerobic oxidation	O_2	H_2O
Manganese reduction	MnO_2	Mn^{2+}
Nitrate reduction	HNO_3	N_2
Iron reduction	Fe_2O_3	Fe^{+2}
Sulfate reduction	SO_4^{2-}	S_2^-
Methanogenesis	CO_2	CH_4

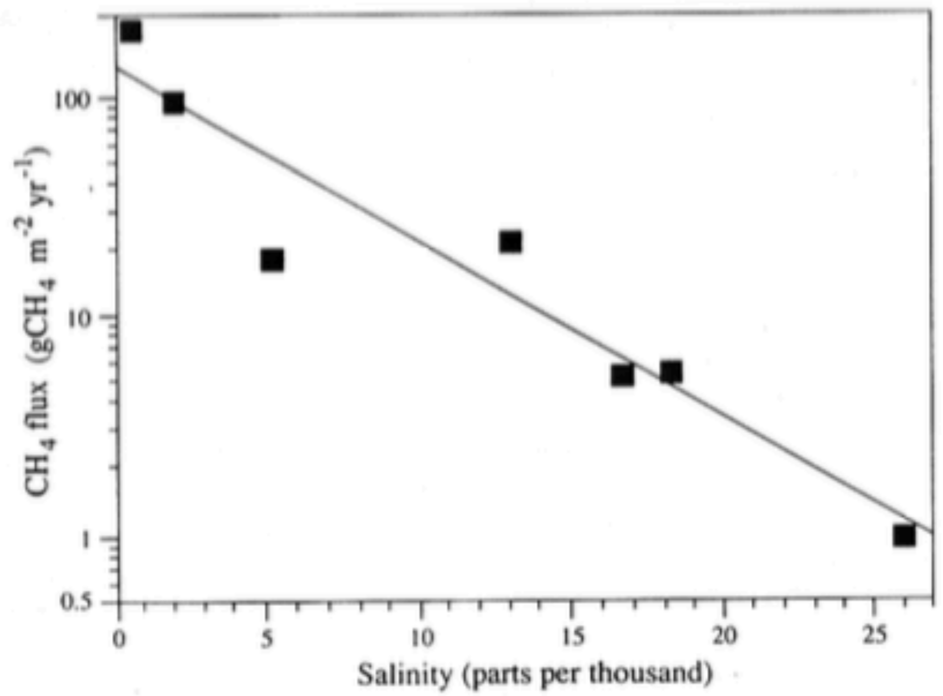
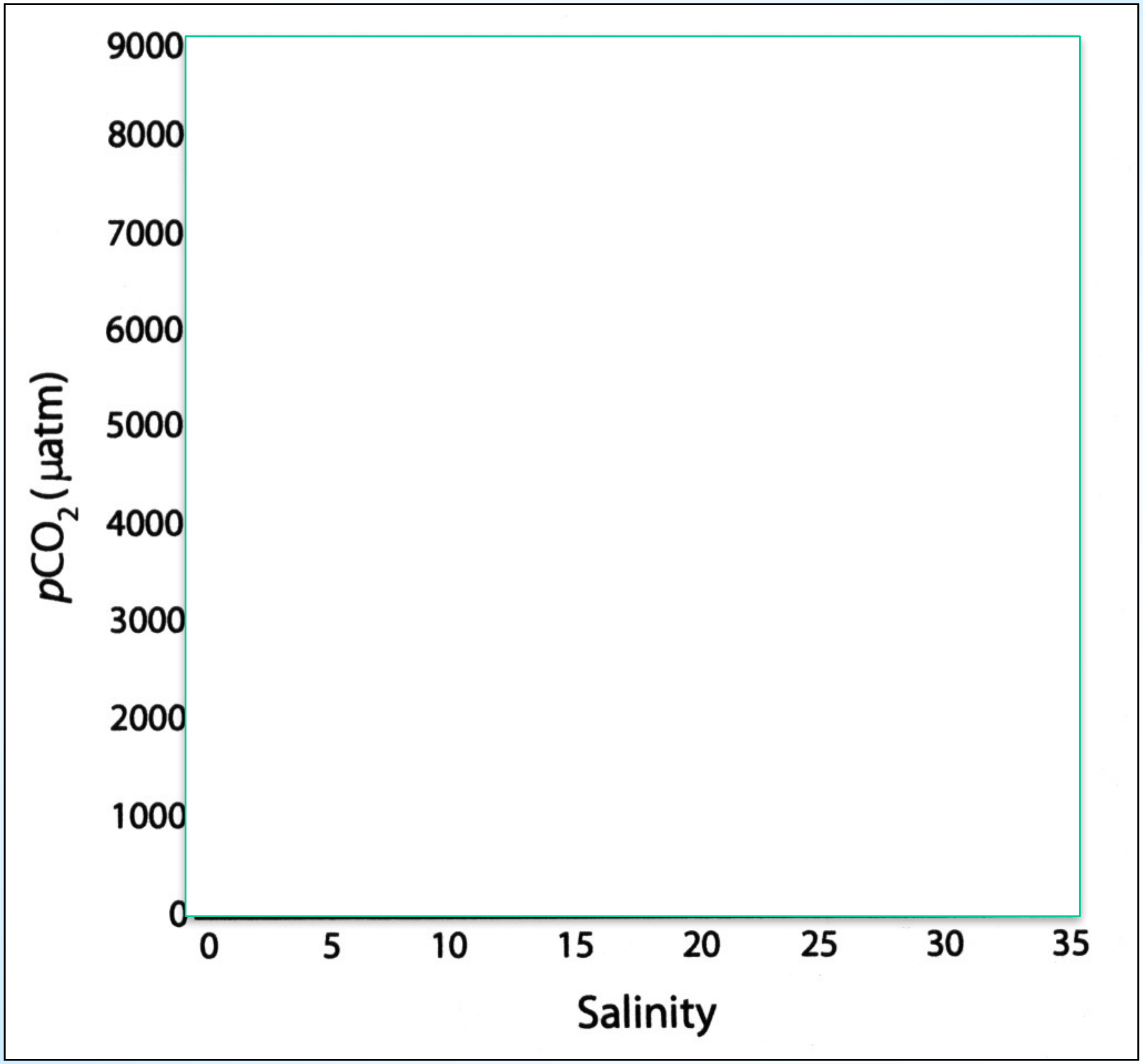


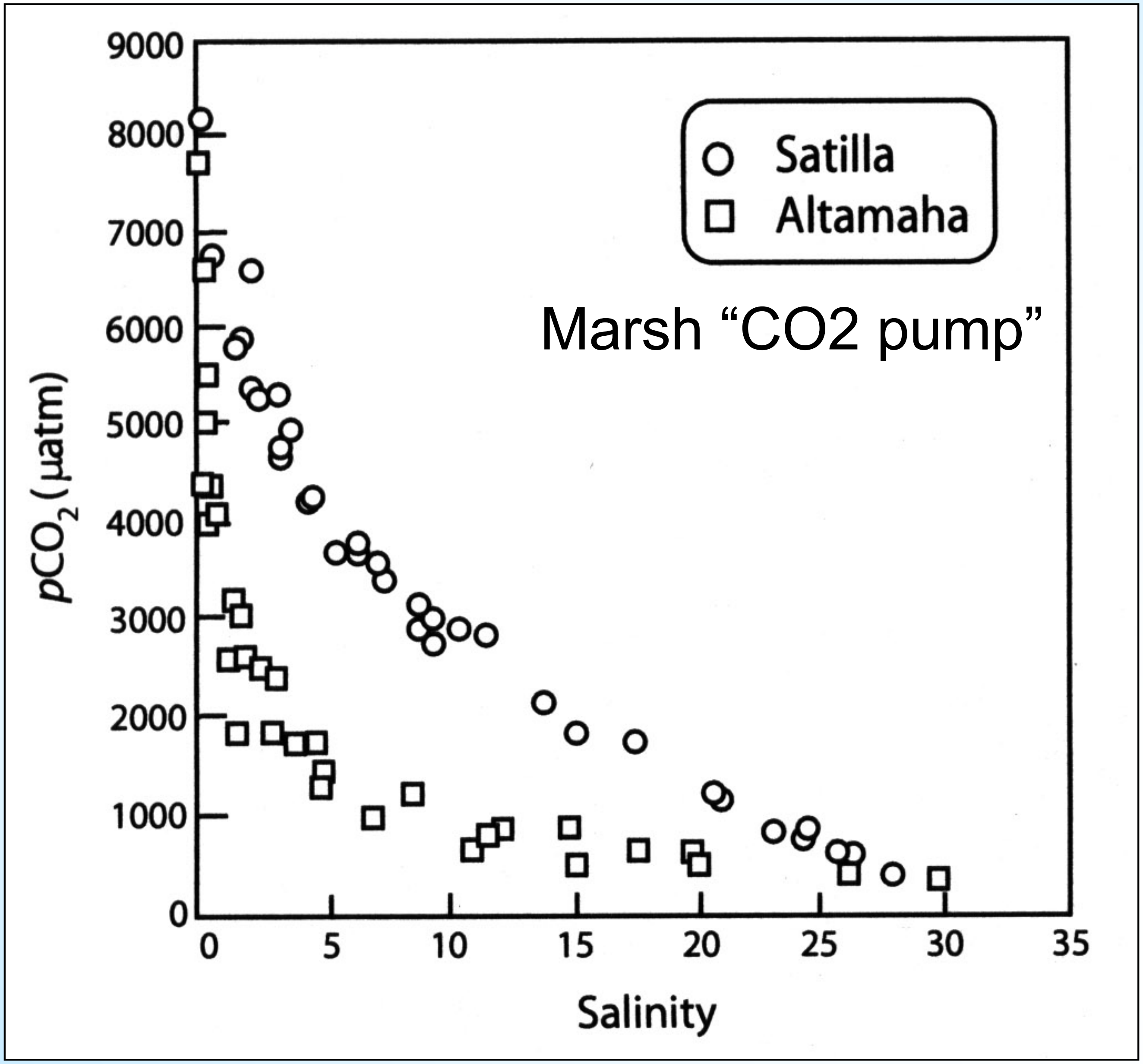
Figure 8.11 Annual methane lost from salt marsh soils as a function of salinity. From Bartlett et al. (1987).

What about pCO2 along a salinity gradient then?

Is this a mixing line or something different?



Highest pCO2 is found in the lowest salinity waters (<10), with Corresponding CO2 fluxes 20->250mol m-2 y-1.



Marsh “CO2 pump”

(in Bianchi 2007)

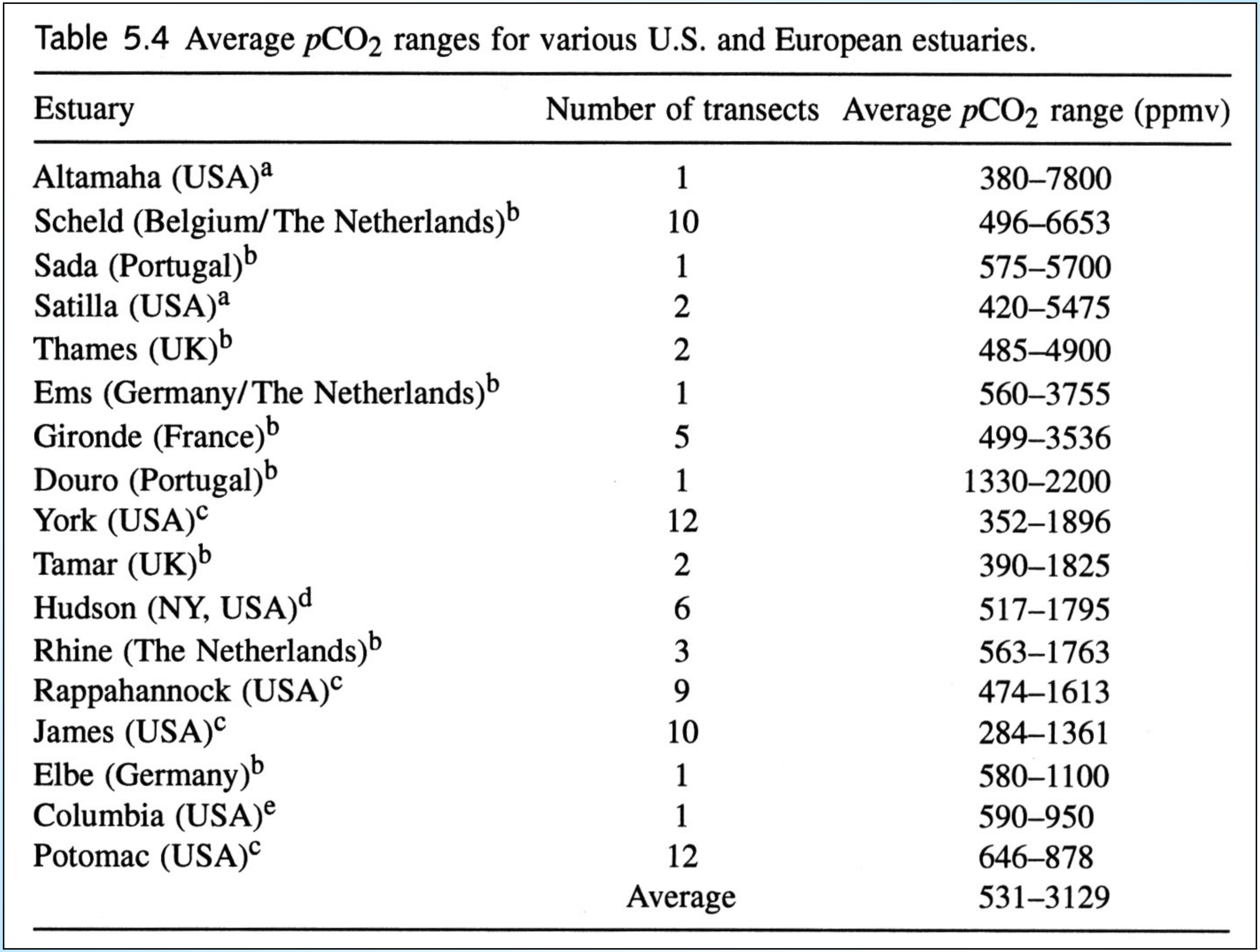
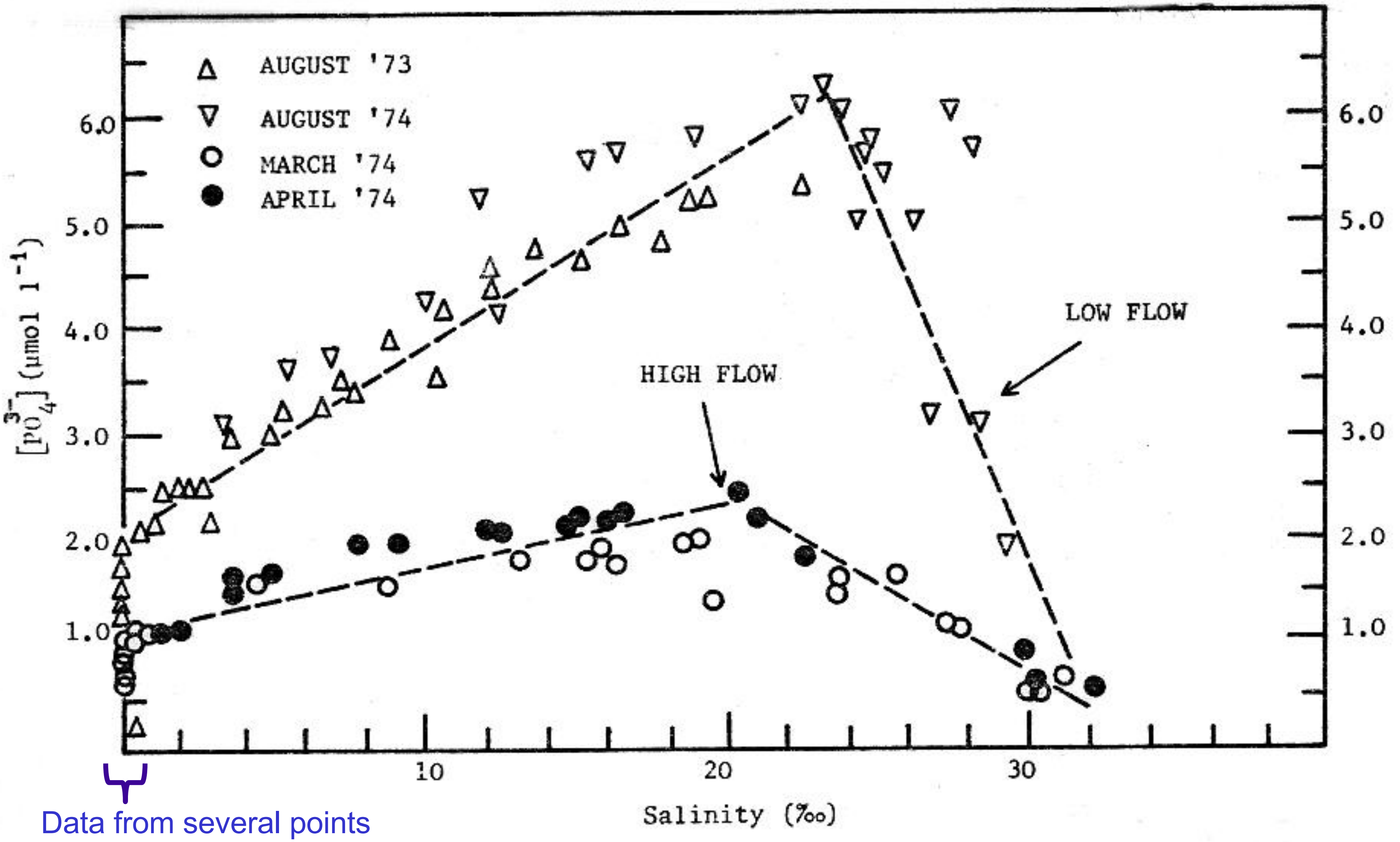


Table 5.4 Average pCO_2 ranges for various U.S. and European estuaries.

Estuary	Number of transects	Average pCO_2 range (ppmv)
Altamaha (USA)[a]	1	380–7800
Scheld (Belgium/The Netherlands)[b]	10	496–6653
Sada (Portugal)[b]	1	575–5700
Satilla (USA)[a]	2	420–5475
Thames (UK)[b]	2	485–4900
Ems (Germany/The Netherlands)[b]	1	560–3755
Gironde (France)[b]	5	499–3536
Douro (Portugal)[b]	1	1330–2200
York (USA)[c]	12	352–1896
Tamar (UK)[b]	2	390–1825
Hudson (NY, USA)[d]	6	517–1795
Rhine (The Netherlands)[b]	3	563–1763
Rappahannock (USA)[c]	9	474–1613
James (USA)[c]	10	284–1361
Elbe (Germany)[b]	1	580–1100
Columbia (USA)[e]	1	590–950
Potomac (USA)[c]	12	646–878
	Average	531–3129

An Example of Seasonal Effects



Data from several points up-river

FIG. 41.8. Phosphate (molybdate-reactive) as a function of salinity in the Hudson Estuary (after Simpson *et al.*, 1975). Results for high-flow and low-flow conditions are illustrated.

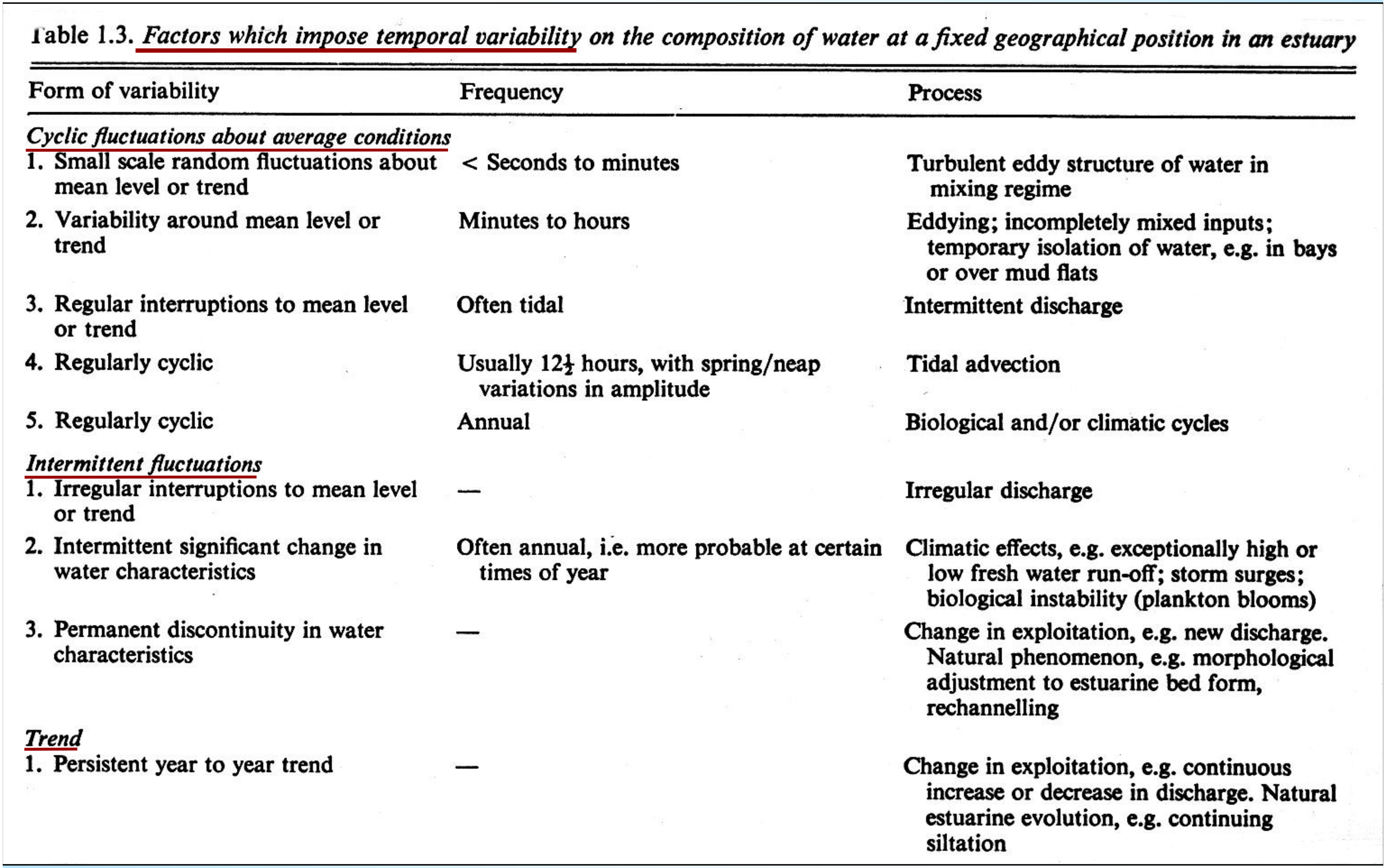
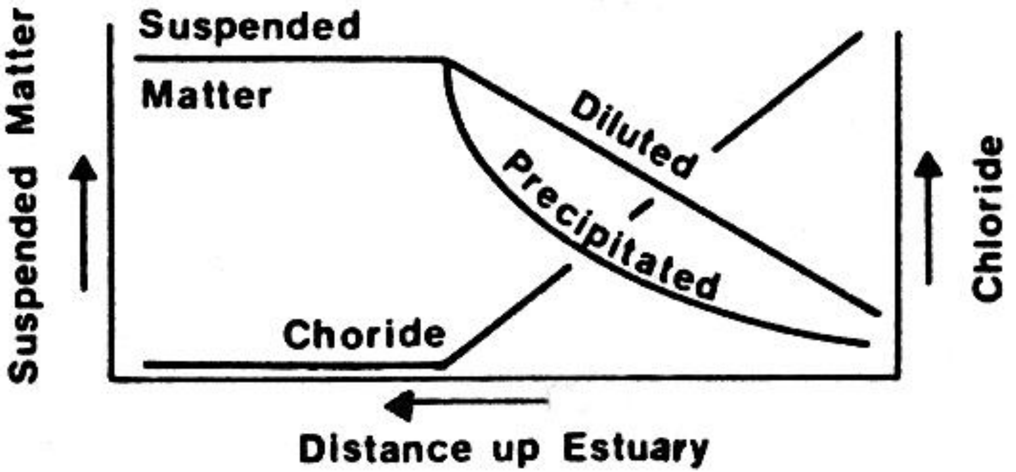


Table 1.3. *Factors which impose temporal variability on the composition of water at a fixed geographical position in an estuary*

Form of variability	Frequency	Process
Cyclic fluctuations about average conditions		
1. Small scale random fluctuations about mean level or trend	< Seconds to minutes	Turbulent eddy structure of water in mixing regime
2. Variability around mean level or trend	Minutes to hours	Eddying; incompletely mixed inputs; temporary isolation of water, e.g. in bays or over mud flats
3. Regular interruptions to mean level or trend	Often tidal	Intermittent discharge
4. Regularly cyclic	Usually 12½ hours, with spring/neap variations in amplitude	Tidal advection
5. Regularly cyclic	Annual	Biological and/or climatic cycles
Intermittent fluctuations		
1. Irregular interruptions to mean level or trend	—	Irregular discharge
2. Intermittent significant change in water characteristics	Often annual, i.e. more probable at certain times of year	Climatic effects, e.g. exceptionally high or low fresh water run-off; storm surges; biological instability (plankton blooms)
3. Permanent discontinuity in water characteristics	—	Change in exploitation, e.g. new discharge. Natural phenomenon, e.g. morphological adjustment to estuarine bed form, rechannelling
Trend		
1. Persistent year to year trend	—	Change in exploitation, e.g. continuous increase or decrease in discharge. Natural estuarine evolution, e.g. continuing siltation

The Mid-estuary Turbidity Maximum

Expected:



Turbidity max is due to both 1) chemical flocculation and 2) sediment resuspension

Measured:

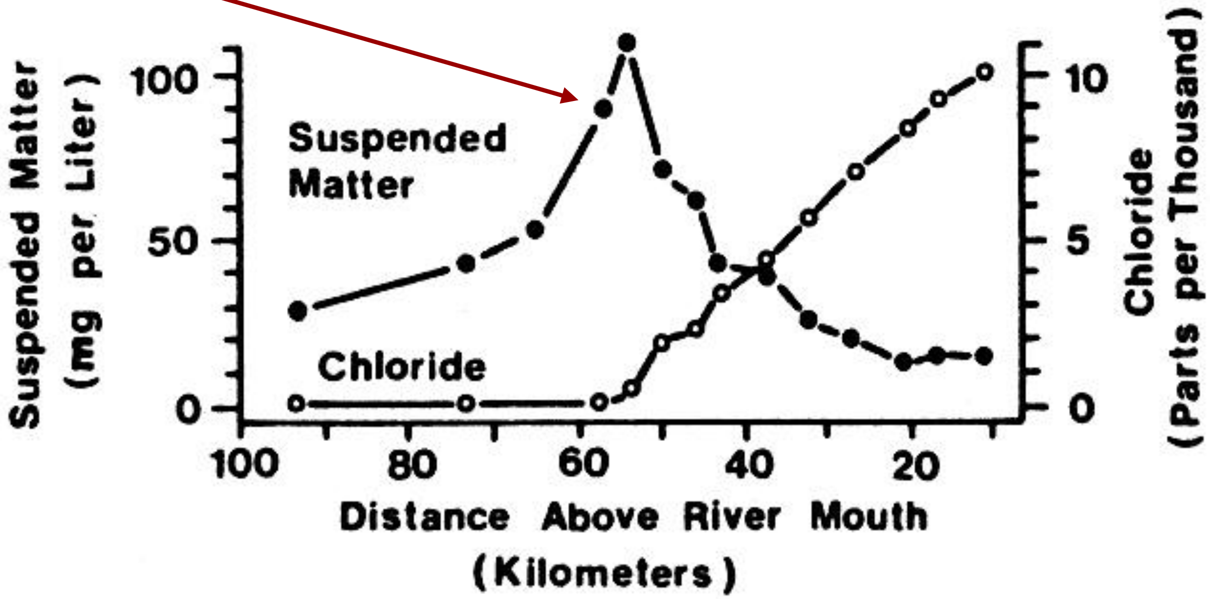
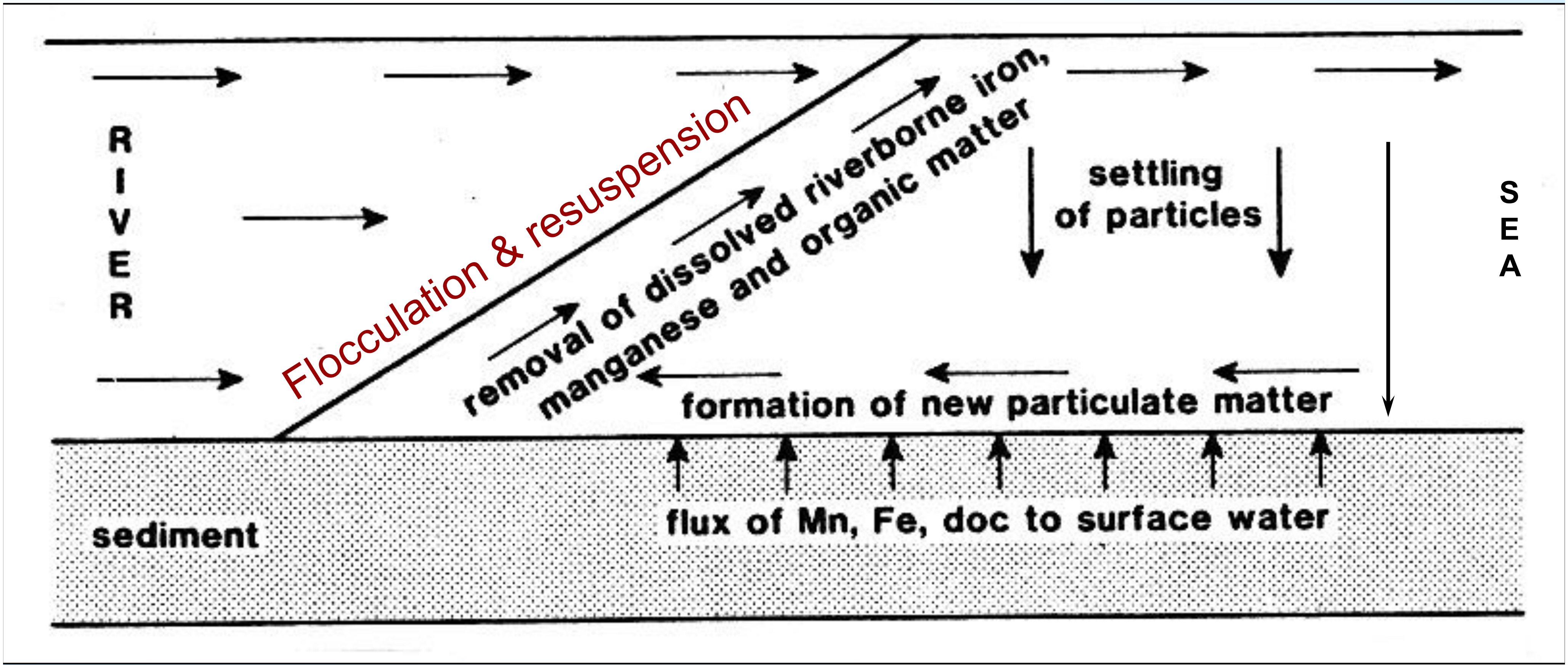


Fig. 115. Example of the non-conservative behaviour of suspended matter in estuaries and the formation of a turbidity maximum at the fresh-sea water interface (Meade, 1972)

A Mid-estuary Trap for Riverborne Material



Particle Distribution *vs.* Estuary Type

Note tidal asymmetries

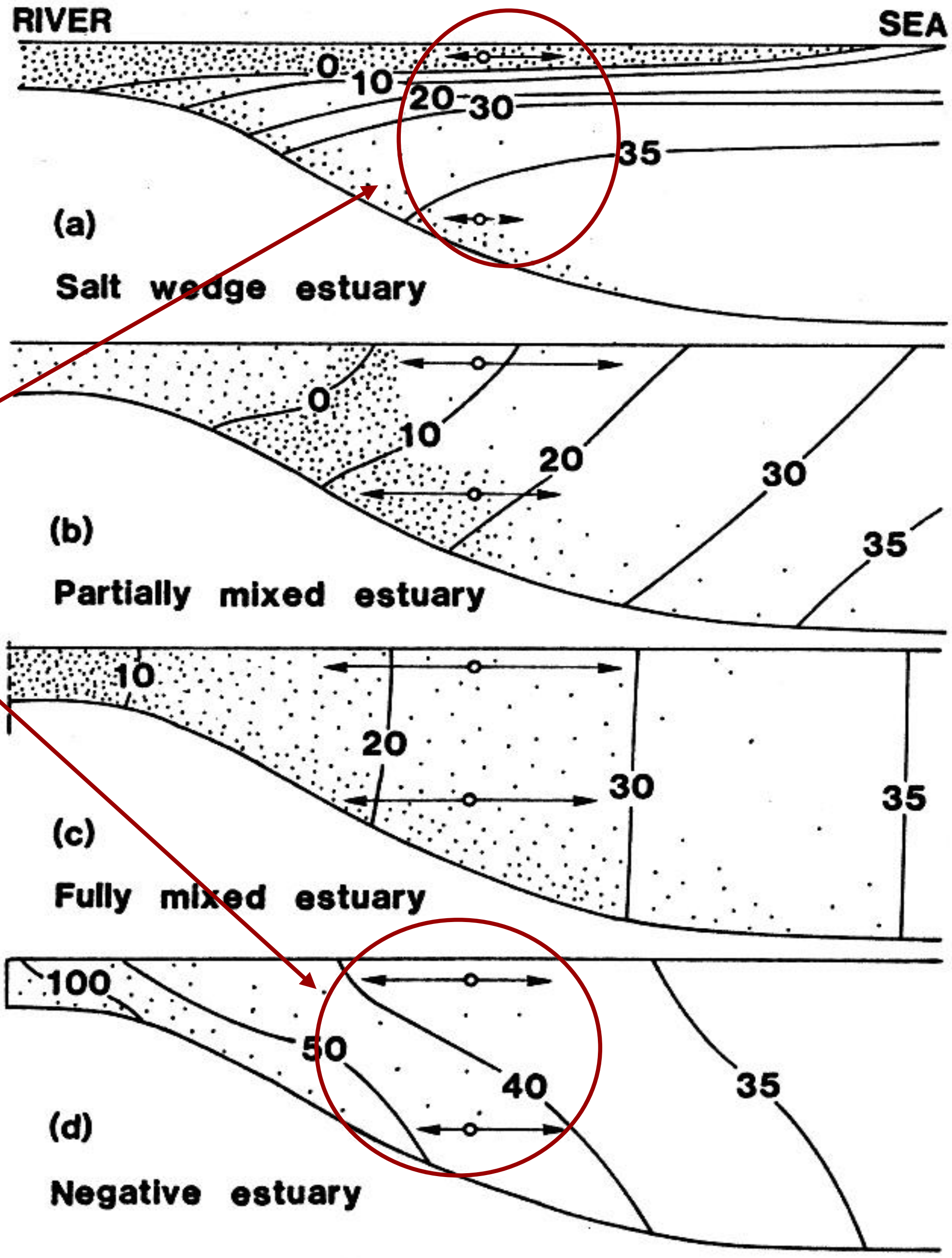


Fig. 113. Schematic presentation of types of estuaries. The dots indicate sediment concentration and the arrows the net water movements over ebb and flood. (Postma, 1980). 0–35 are ‰ Salinity (S) isolines. For explanation see the text

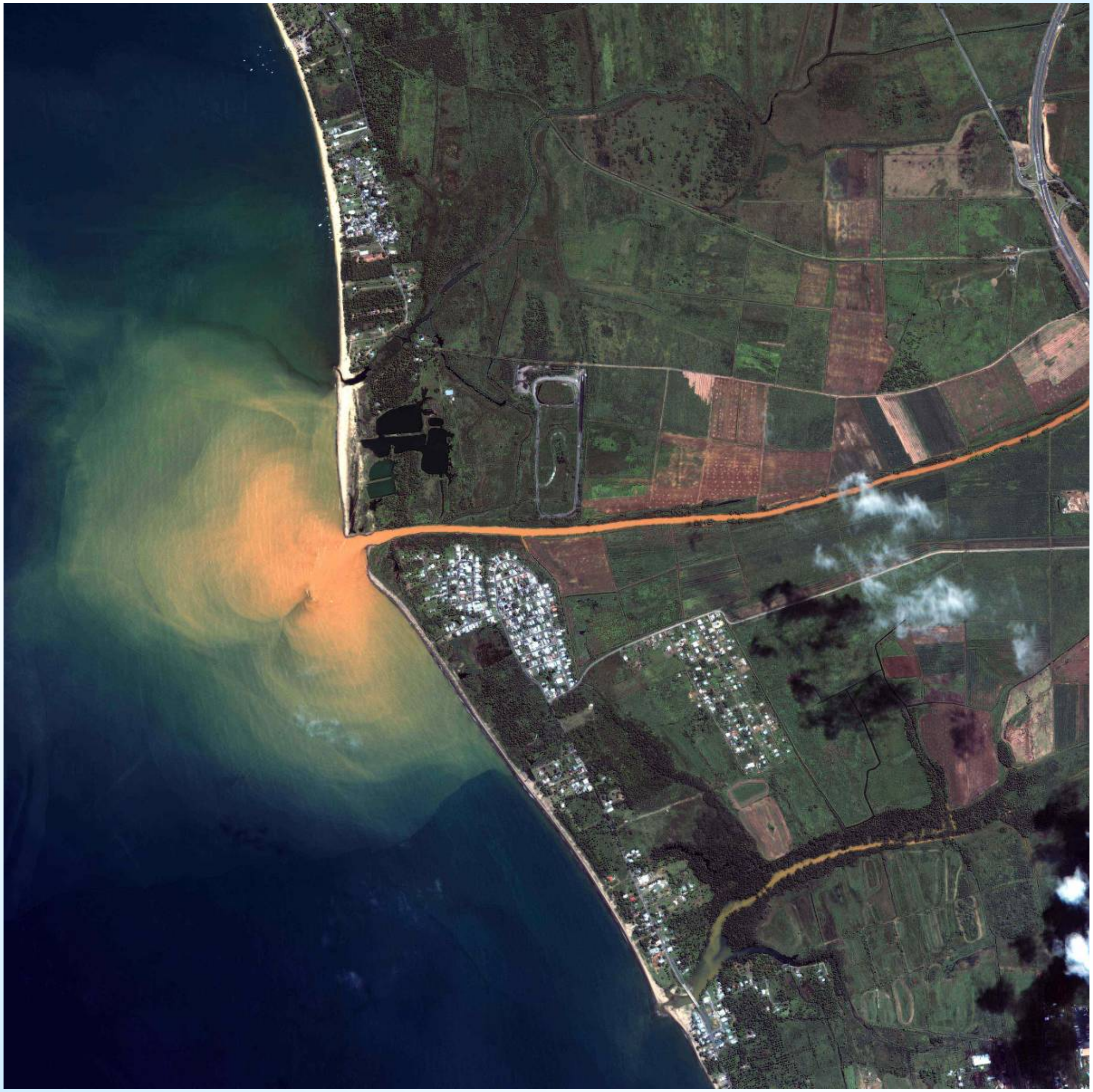
Effects Of The Mid-estuary Particle Maximum

1. Scavenging of surface-active materials
    - 70-100% of riverine Fe is removed (most at low salinity)
    - 60-80% of humic acids are removed
    - 5% of total DOM is removed

2. Increased turbidity
    - Lower primary production
    - Reduction of photochemical reaction rates

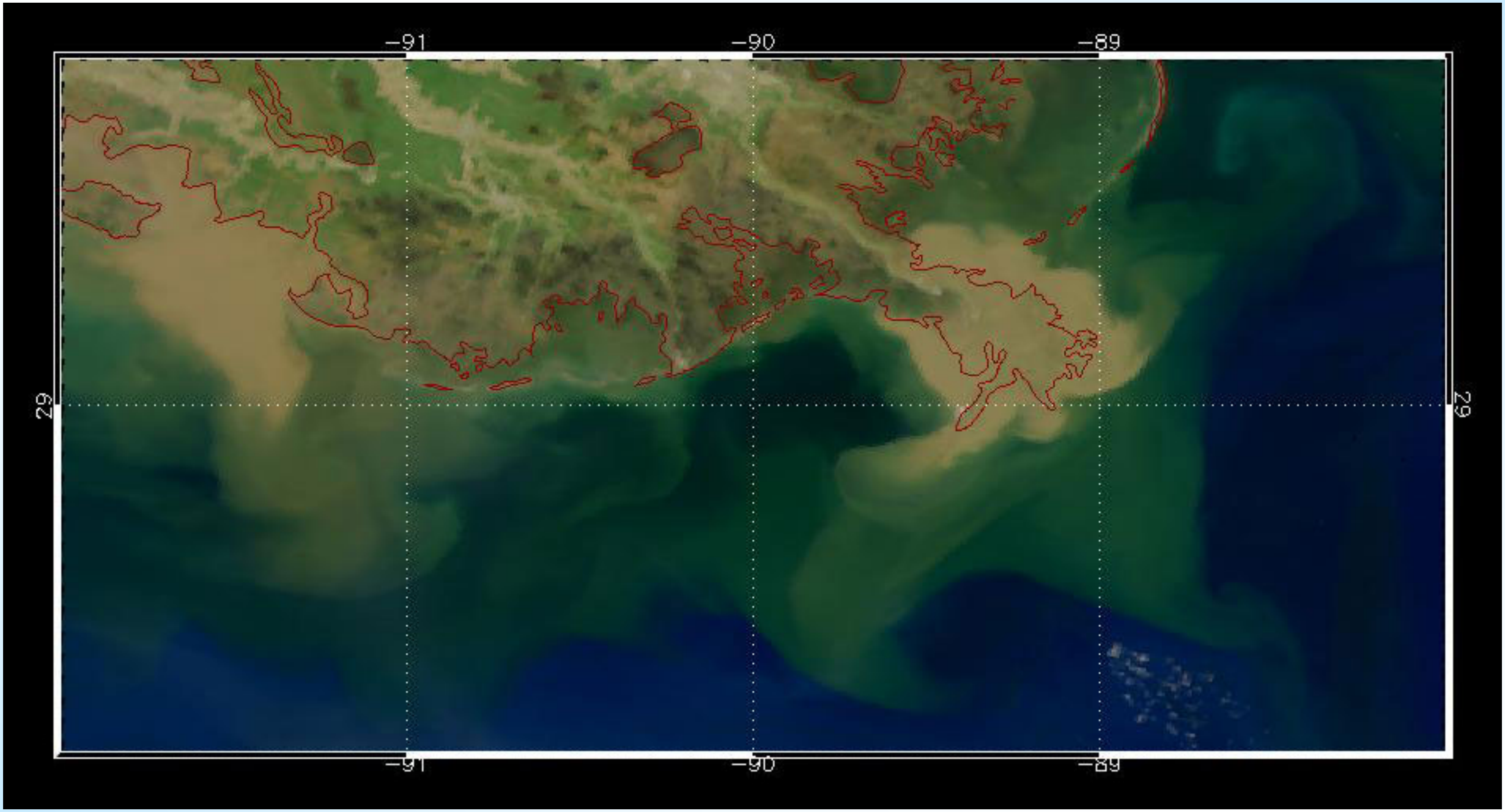
3. Enhanced transport rates downstream / offshore
    - Enhanced sedimentation rates downstream / offshore

Estuarine Plumes on the Continental Shelf



cacique.uprm.edu/gers/anasco_plume.jpg

Estuarine Plumes on the Continental Shelf



gulfsci.usgs.gov/.../ofrshelf/images/seawifs.jpg

Estuarine Plumes on the Continental Shelf

Surface Runoff

MANY POINTS OF ENTRY

Pollutants that are harmful to Hawai'i's reefs can enter the ocean in many ways, including through storm drains and streams. Sediment runoff is a particular problem in some coastal areas, such as along East Honolulu's Maunalua Bay. The pollutants flush into Maunalua via nine major streams that have been altered to speed storm runoff and through dozens of neighborhood drainage systems that eventually empty into the streams or the bay. Other areas with similar sedimentation problems face the same challenge as East Honolulu: How to reduce the amount of dirt and other pollutants washing into the ocean.

Sources: Malama Maunalua, city records

The Honolulu Advertiser

An Estuarine Summary

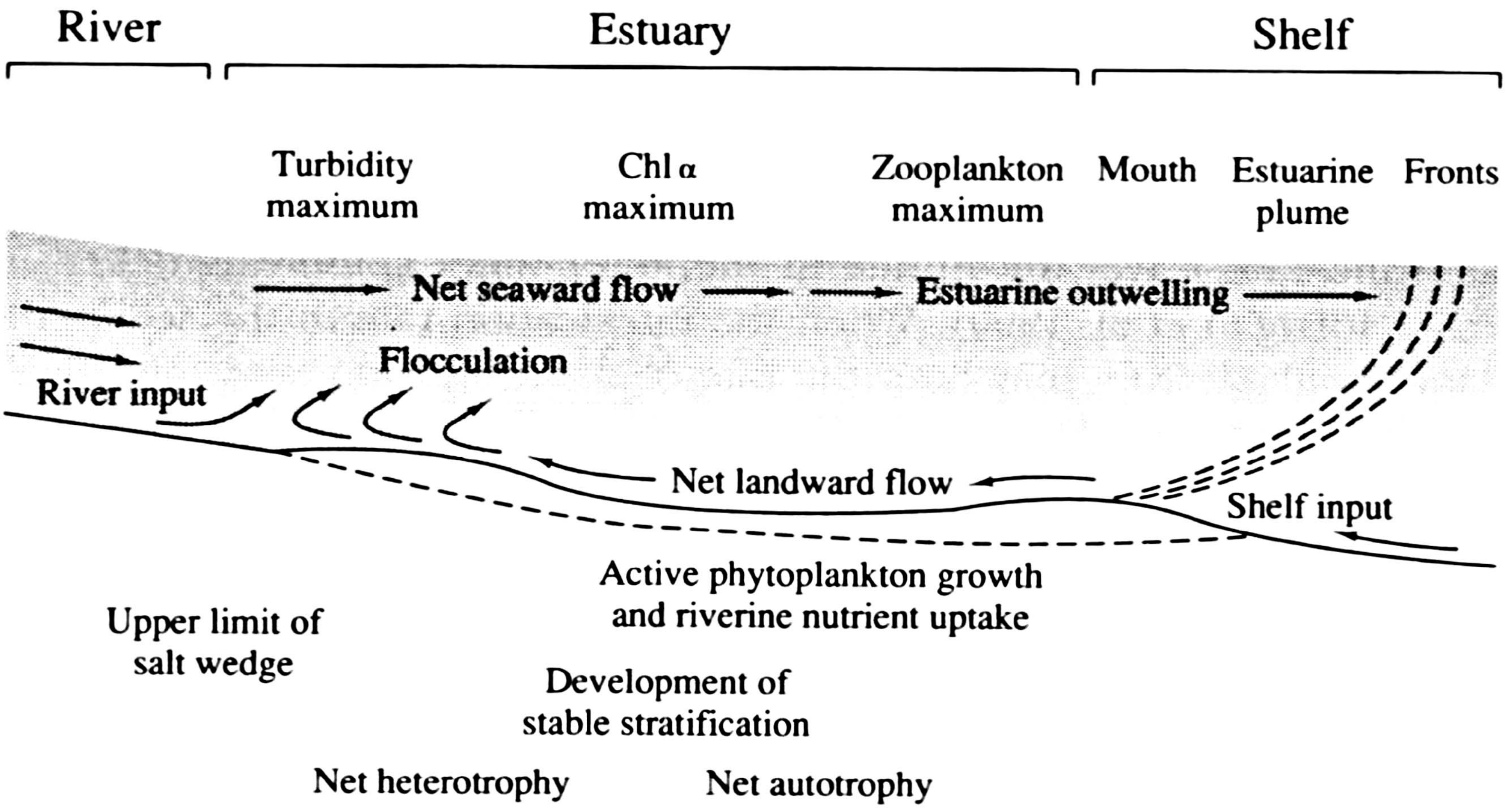


Figure 8.13 Conceptual model of the chemical and biological structure in estuaries. As the suspended load settles from the entering river waters and nutrients are made available, phytoplankton production increases, fueling an increase in zooplankton production and higher trophic levels. From Fisher et al. (1988).