Estuarine and River Plume Physical Oceanography

Jim Lerczak
COESSING 2021

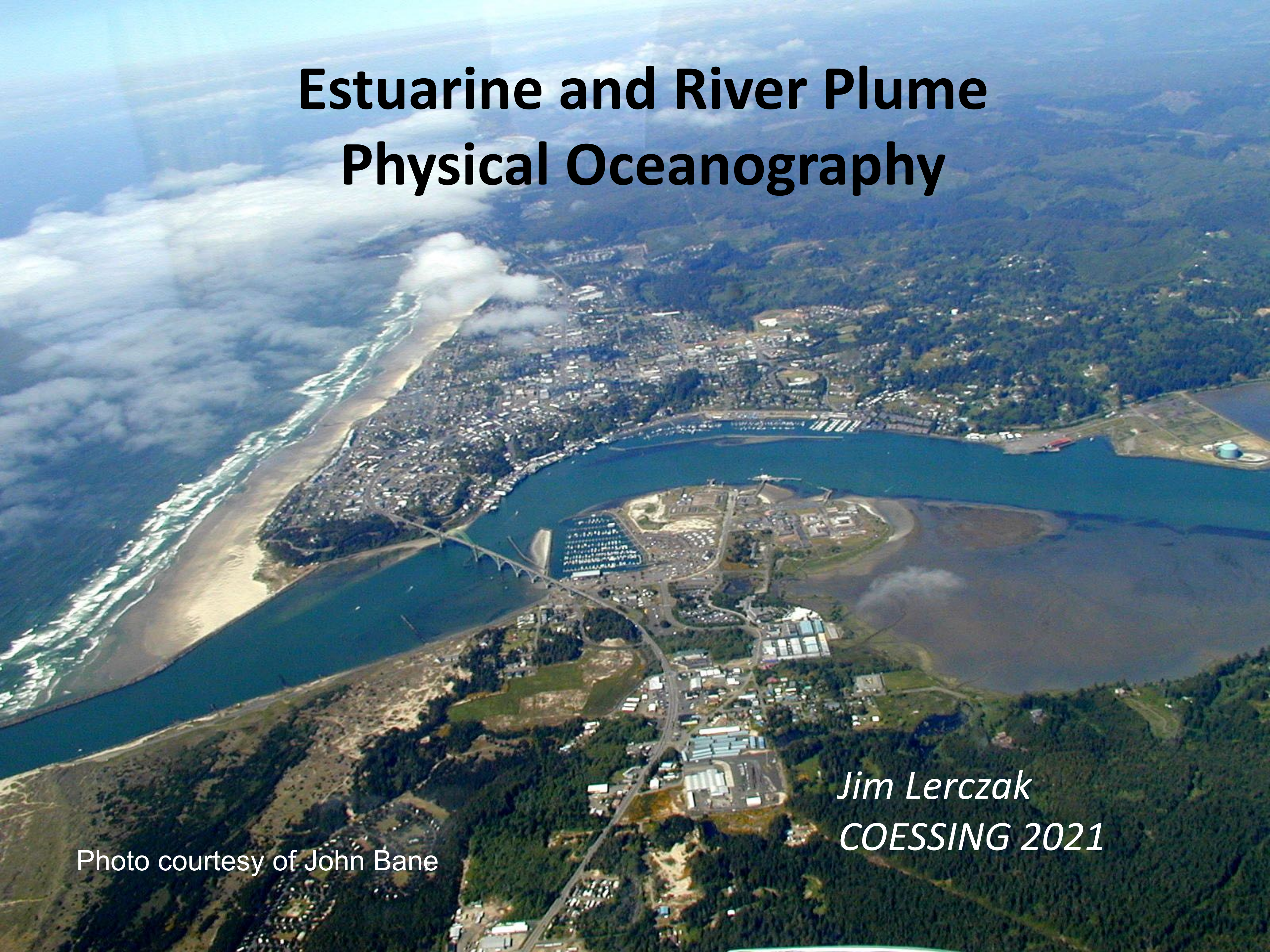


Photo courtesy of John Bane

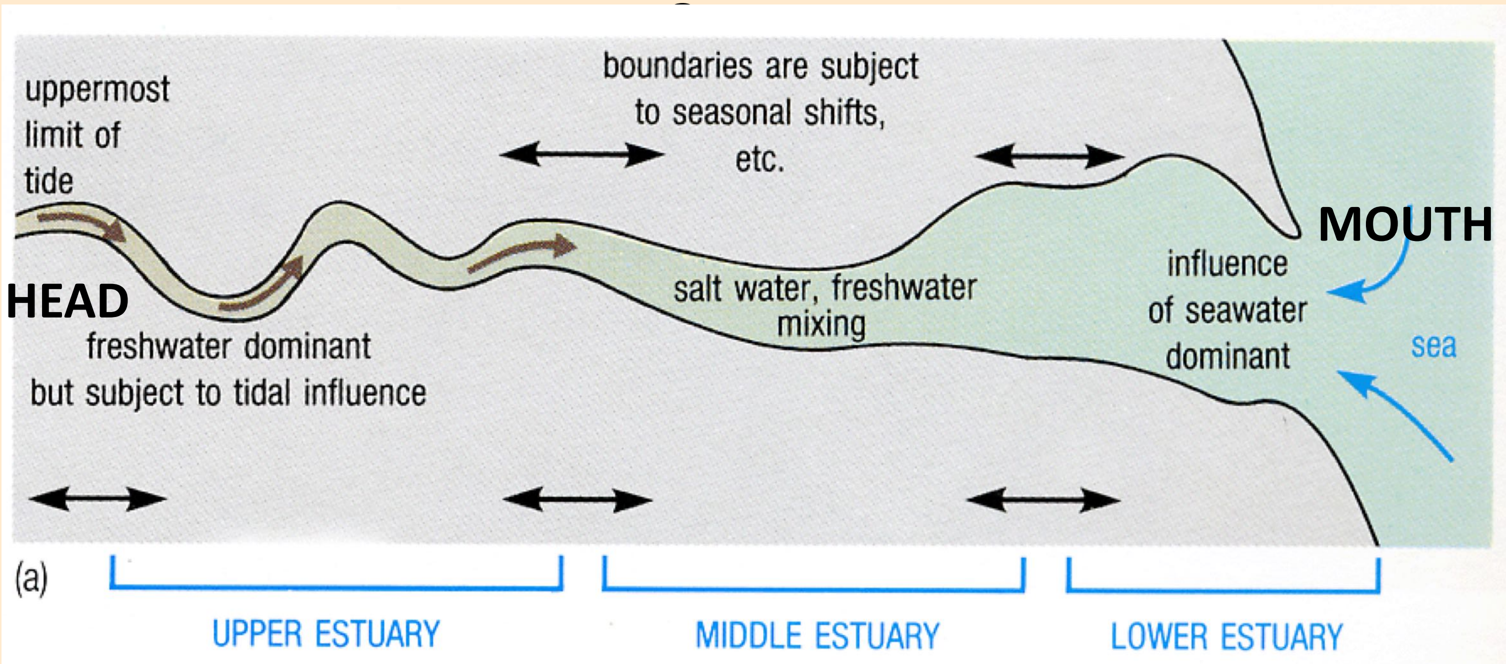
Outline

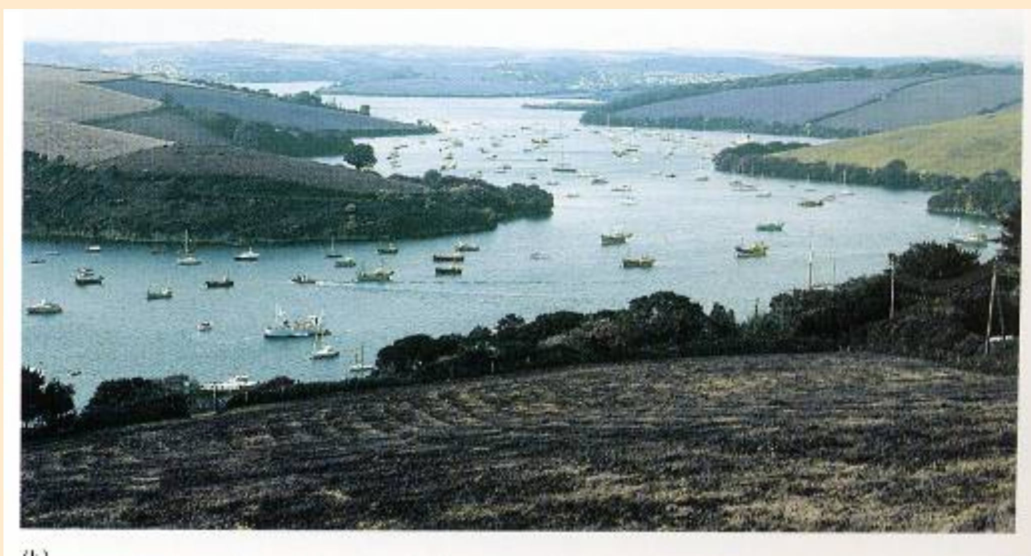
- Estuaries: What are they?
- Classification – by geomorphology.
- Classification – by salt structure.
- Oregon rivers and estuaries (my home state)
- Large rivers around the globe.
- An example of nutrient variations in an estuary.
- River plumes in the ocean.

Estuaries. What are they (physical characteristics)?

Regions where **freshwater** and **seawater mix**. – Segar

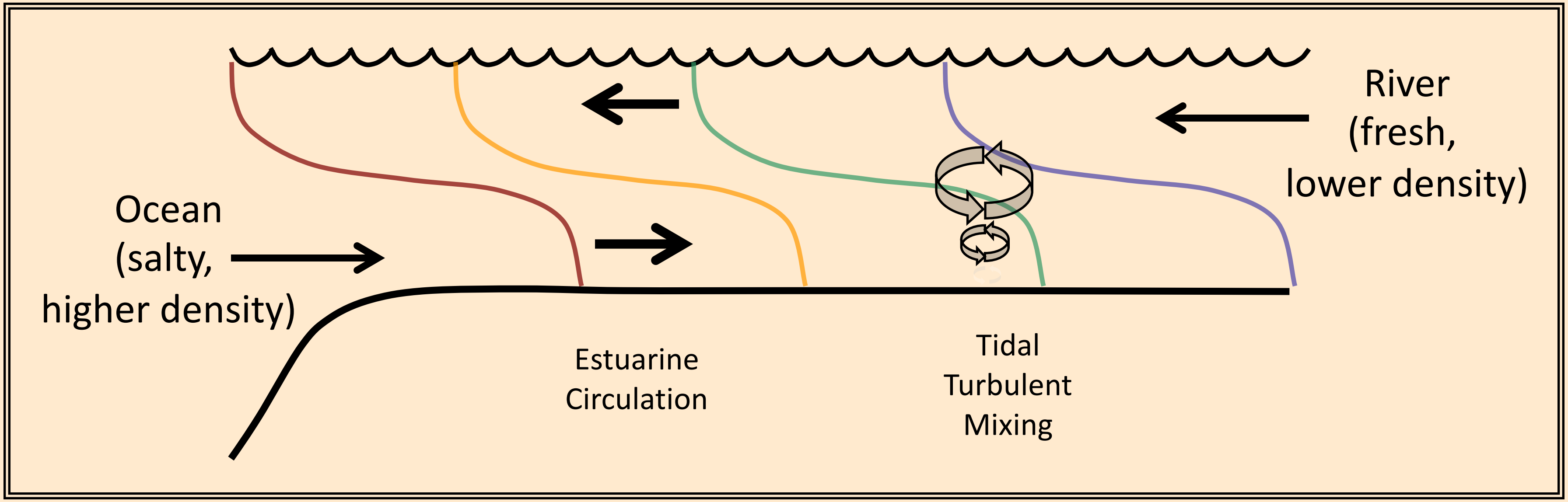
An estuary is a semi-enclosed coastal body of water which has a free connection with the open sea and within which **sea water** is measurably **diluted** with **fresh water** derived from land drainage. – Pritchard (1967).


uppermost
limit of
tide
boundaries are subject
to seasonal shifts,
etc.
MOUTH
HEAD
influence
of seawater
dominant
salt water, freshwater
mixing
sea
freshwater dominant
but subject to tidal influence
(a)
UPPER ESTUARY
MIDDLE ESTUARY
LOWER ESTUARY



Physical Ingredients of an Estuary

- *Salt water* enters estuary from the ocean.
- *Fresh water* flows into the ocean from a river (tends to drive salt out of the estuary).
- *Mixing!!* Principally due turbulence from tides (but also wind and waves).



*Note the similarity of the circulation pattern and density structure to what is seen in the Density currents Fluids Lab!

What are: Stratification, Shear, and Mixing?

- **Stratification** in estuaries is produced by comparatively fresh river water flowing over salty oceanic water. The water becomes stratified with lower density water on top of higher density water.

- **Shear** is produced by tidal currents rubbing against the bottom and by the estuarine circulation itself. Because of this bottom friction, currents tend to be weaker near the bottom compared to closer to the surface.

- **Mixing** acts to homogenize water properties.

- Mixing in the ocean and estuaries does not occur by molecular diffusion alone. **Turbulence** does most of the mixing in real fluids (oceans, estuaries, rivers, atmosphere) – Molecular mixing << Turbulent mixing

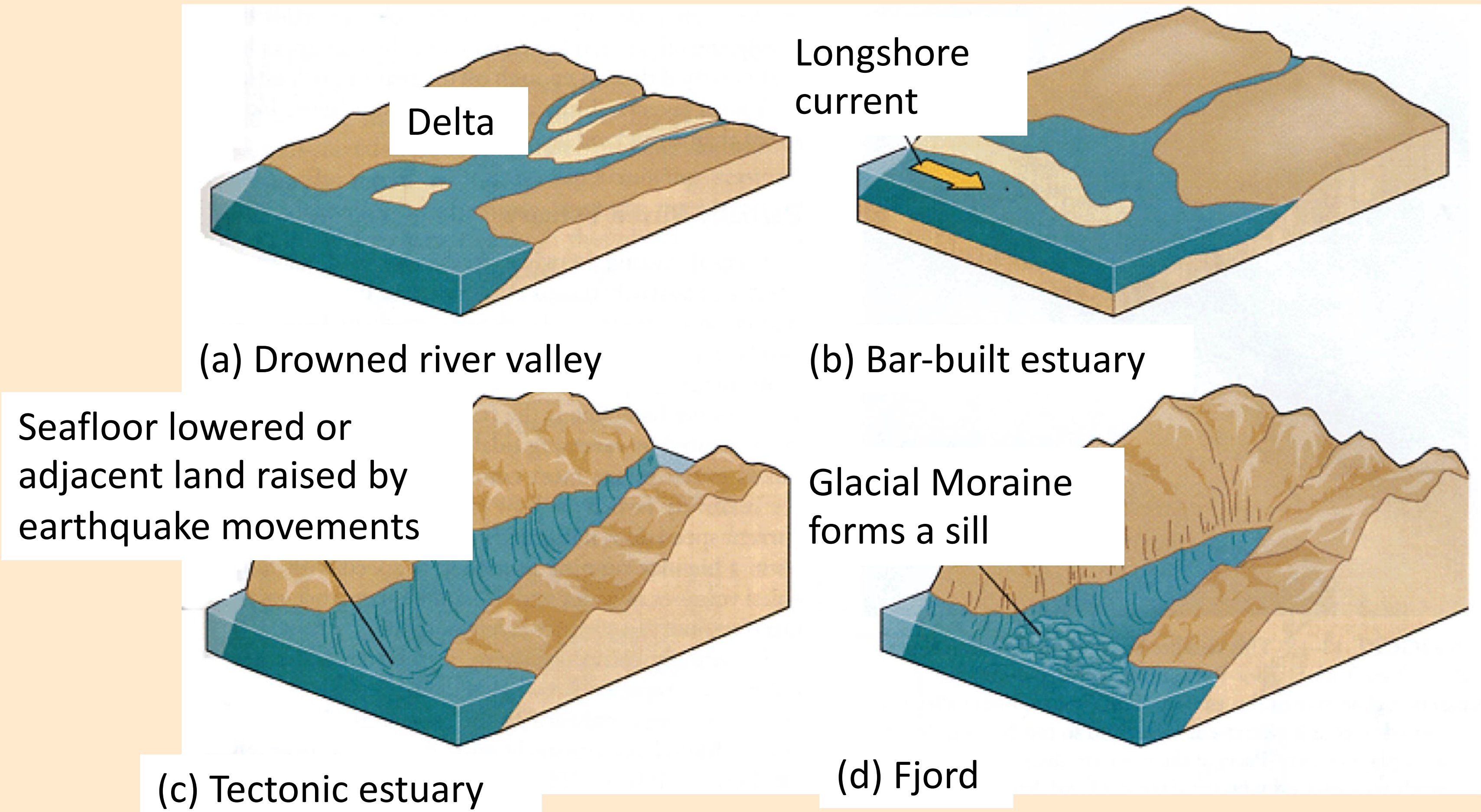
What is river (freshwater) discharge, Q_R?

- River discharge is a measure of how strongly water flows in a river.
- It is a volume flow rate (the volume of water that passes a section of river per unit time).
- Sometimes river discharge is expressed in units of cubic feet per second.
- But usually in scientific research, river discharge is expressed in units of cubic meters per second (m^3/s).

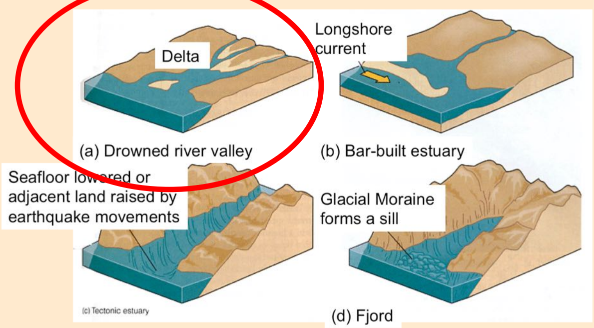
- Estuaries are usually sheltered from ocean waves, but are affected by wind, storm surge, etc, in addition to tides.

- Estuaries are ephemeral on geological time scales.
  - strongly affected by changes in sea level.
    - interglacial high sea-level may mean more estuaries
  - can be filled in by river-borne sediments
    - low sediment discharge, strong tidal action -> estuary
    - high sediment discharge, weak tidal action -> delta

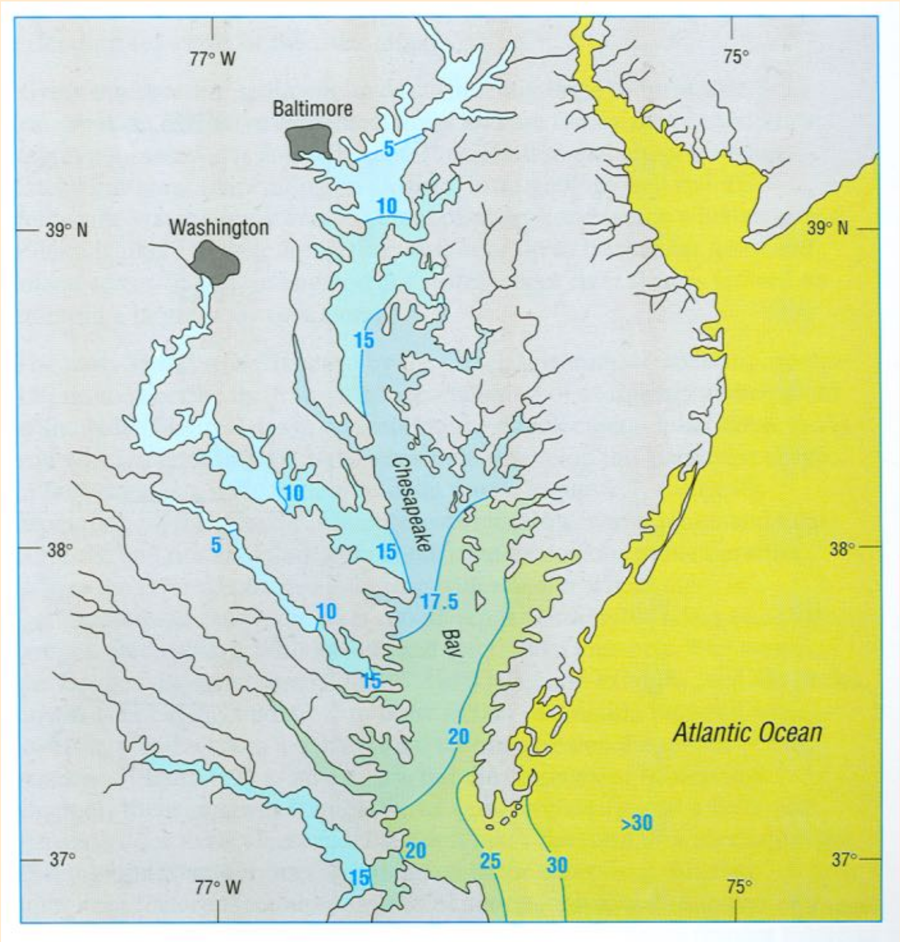
Creating Estuaries: Estuaries classified by geomorphology



Segar (2007)



Example: Drowned River Valley

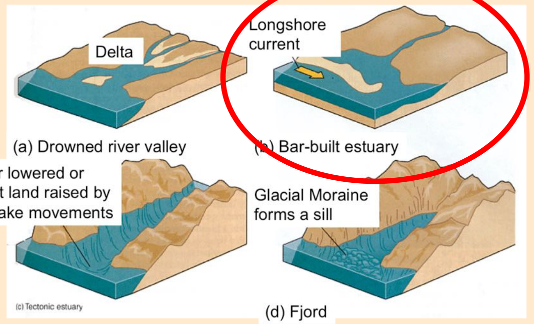


Chesapeake Bay

e.g. Susquehanna R., Potomac R., James R., York R.

Also called "coastal plain estuaries"

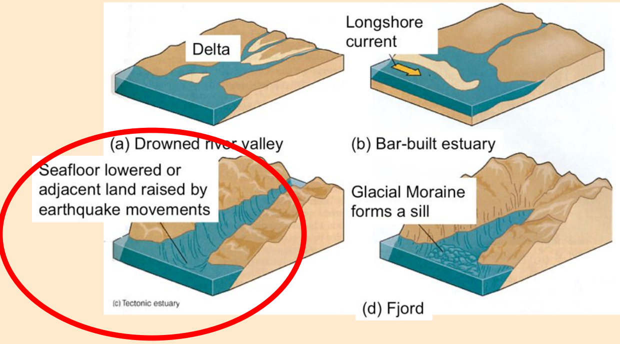
Fig 6.4 Waves Tides and Shallow Water Processes



Example: Bar-built

Pamlico Sound, North Carolina

- Spit/bar shelters sound from wave action
- Lots of sediment deposit
- Often shallow

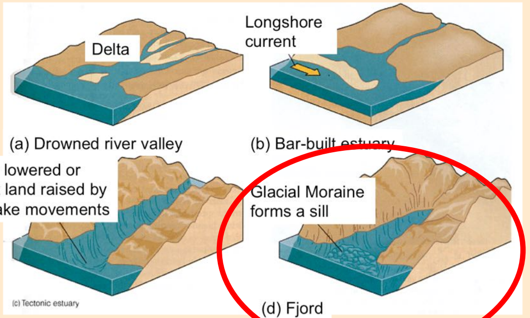


Example: Tectonic

San Francisco Bay

Often found in subduction zones.

Form estuary from vertical movement at a fault.



Example: Fjord

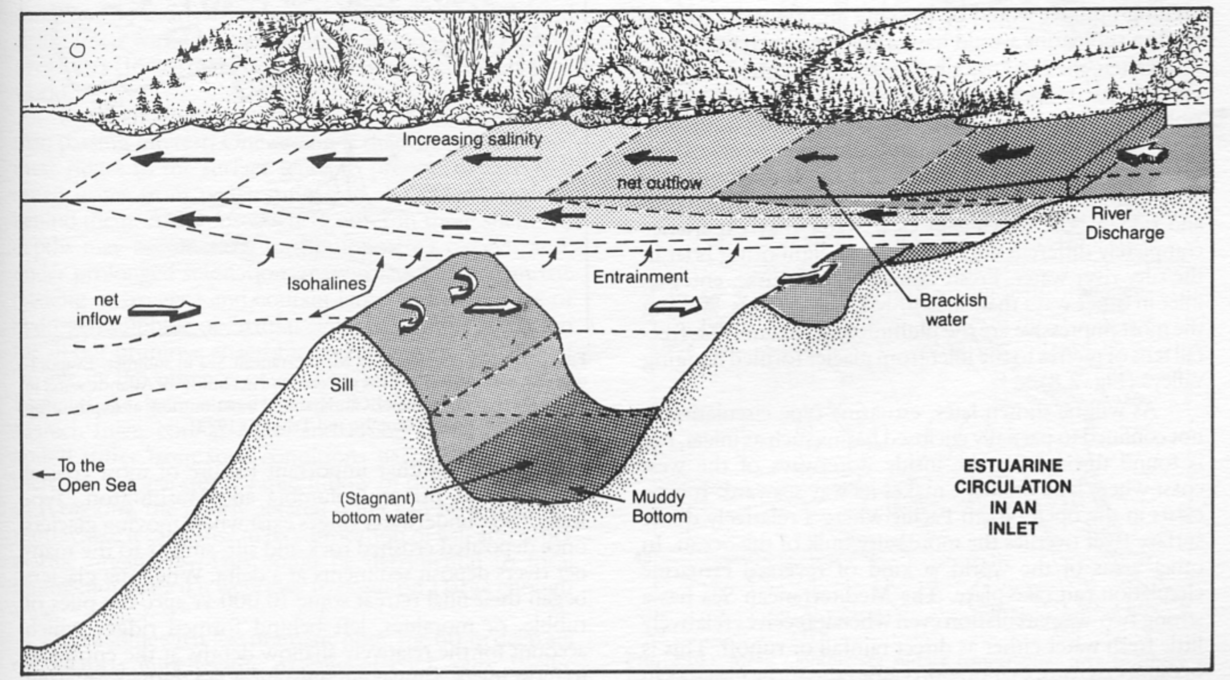


FIG. 2.7. Estuarine circulation in a typical British Columbia inlet. Salt water entrained and carried seaward by river outflow is replenished by a net inflow at depth. Sloping isohalines (lines of equal salinity) indicate a down-inlet increase in salinity in surface brackish layer. Turbulent mixing occurs in vicinity of sill.

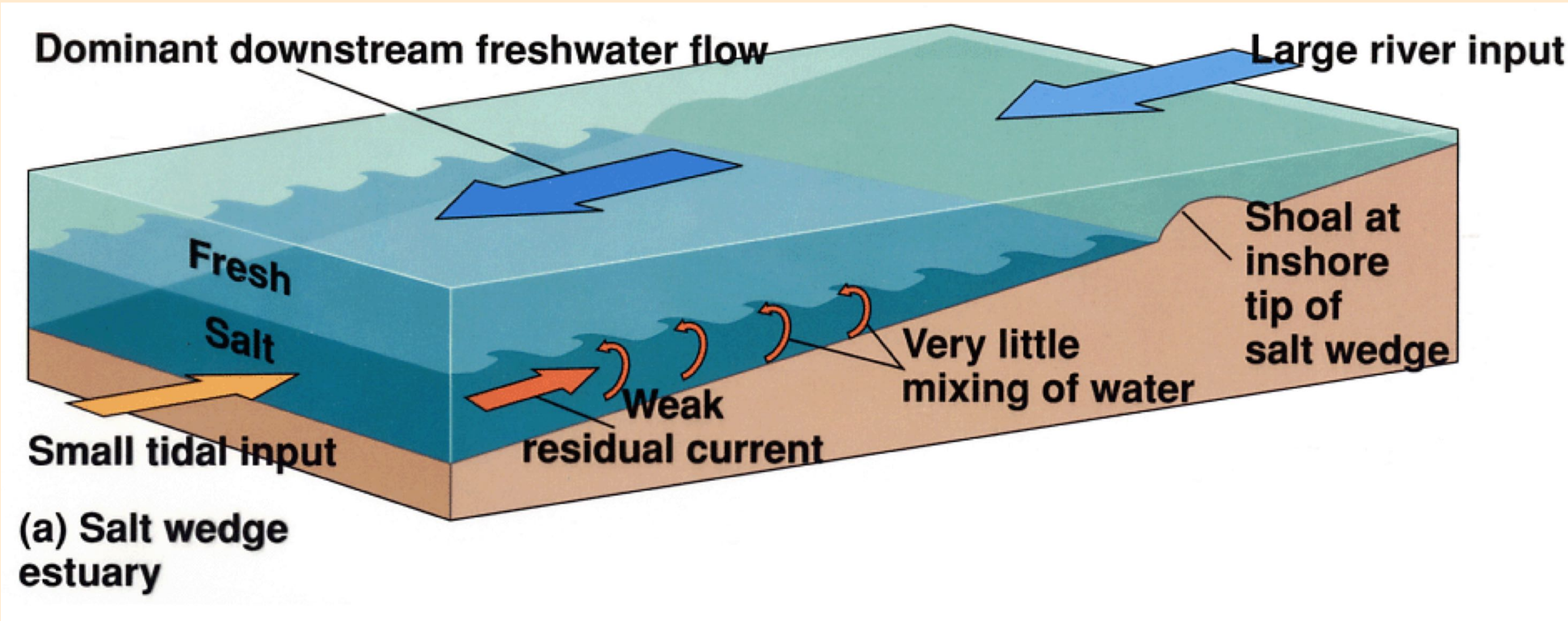
British Columbia fjord-type estuary, from Thomson (1981).
Also Chile, Alaska, Norway, New Zealand.

Steep mountain valleys with sill at mouth. Sill, a remnant glacial moraine, restricts exchange with the open sea.
Deep water can get anoxic. Replenished episodically.

Classification of Estuaries by Salinity Structure

- This structure is primarily influenced by the strength of the **tides** and the strength of the **river discharge**.
- Salt wedge estuary
- Partially mixed estuary
- Well mixed estuary
- (reverse or negative estuary)

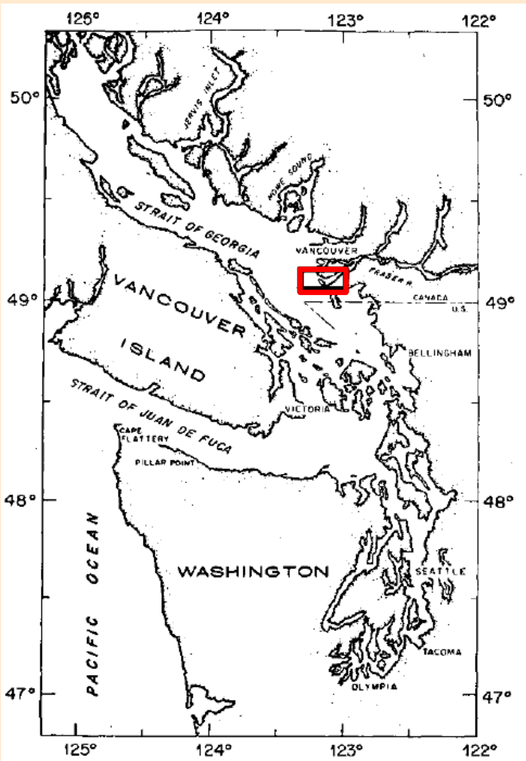
Salt Wedge Estuary

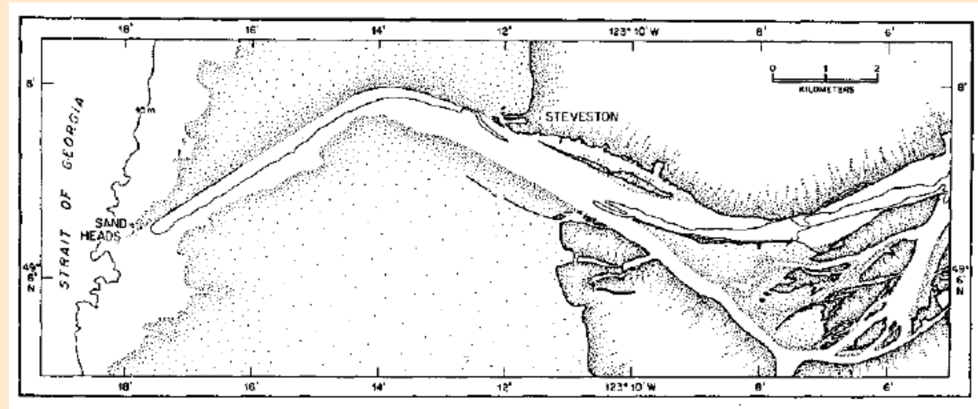


Large river discharge, weakish tides

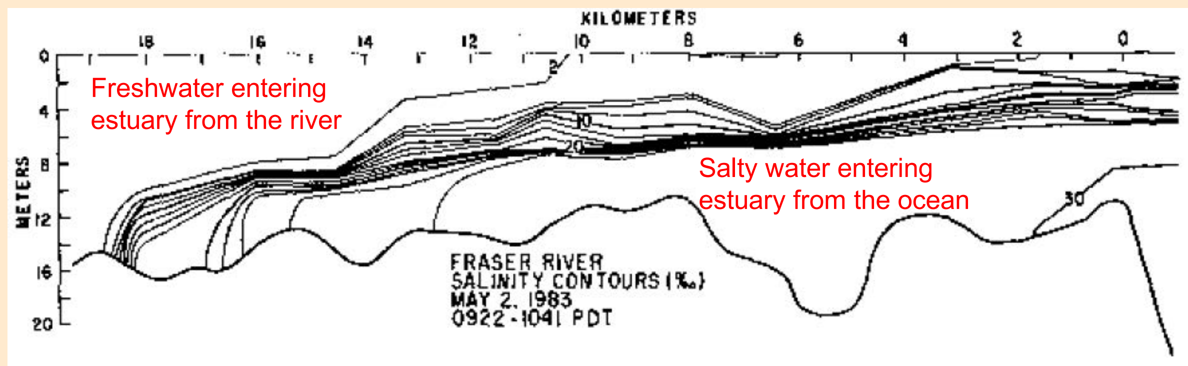
Sharp halocline (strong difference in salinity between upper and lower layers).

Salt Wedge Estuary -
e.g., Fraser River, British Columbia





Contours of salinity along the Fraser River estuary



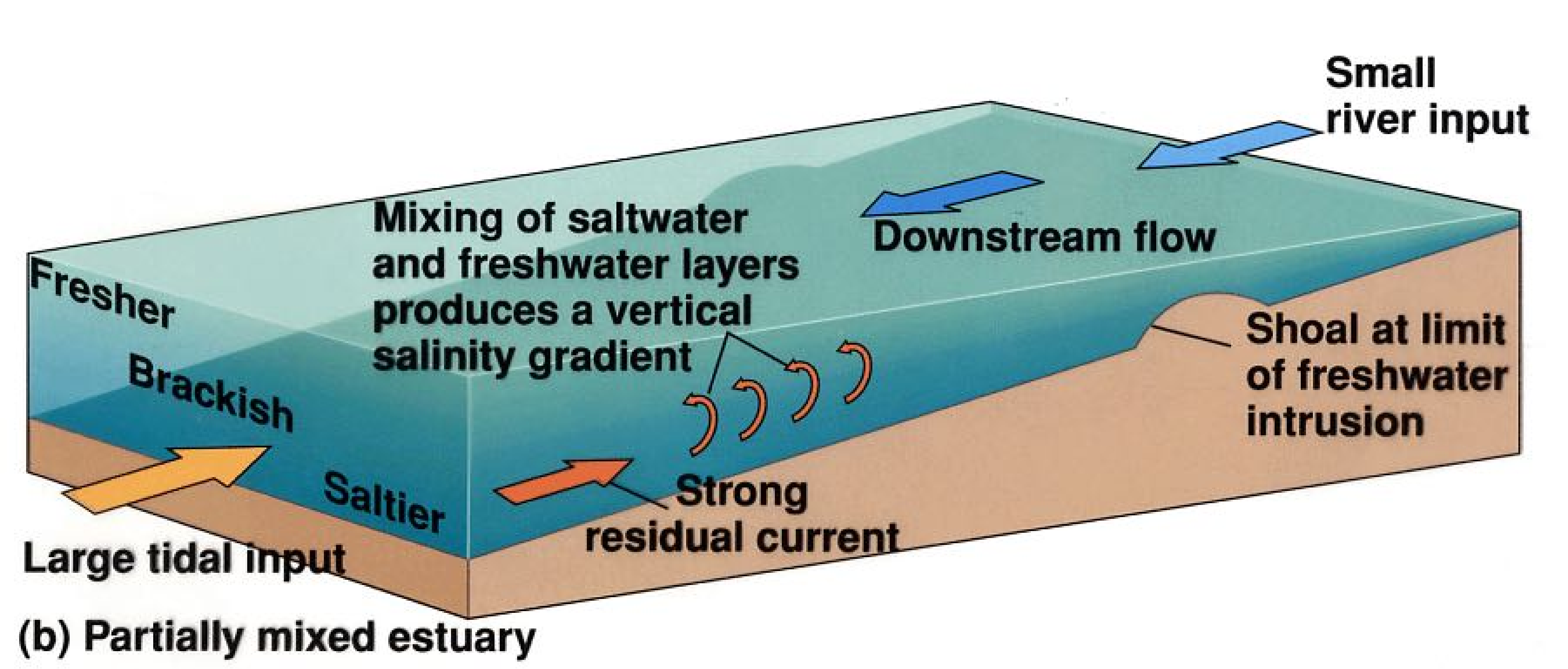
Water depth (m)

Distance along the estuary (km)

Note the very sharp transition between river water and ocean water.

Geyer and Farmer (1989)

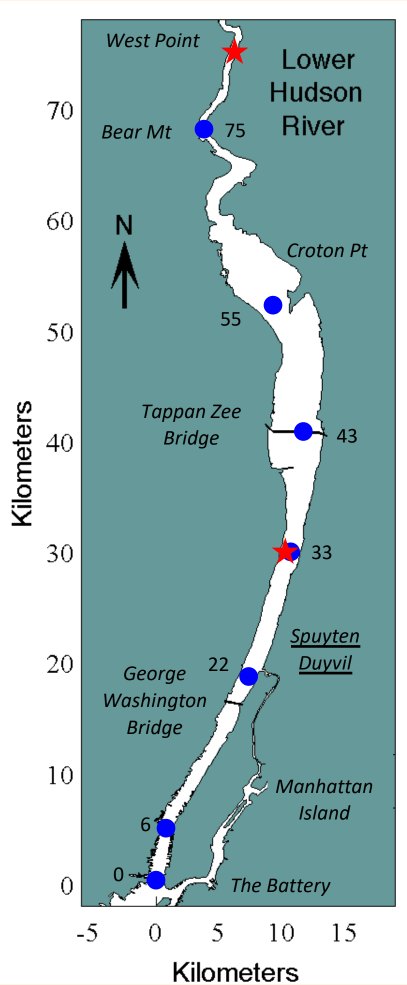
Partially Mixed Estuary



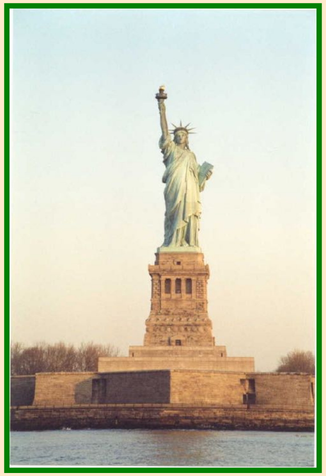
- larger tides, smaller river input, stronger mixing.

Partially-Mixed:
e.g., Hudson River Estuary, New York/New Jersey

George Washington Bridge



Manhattan Island



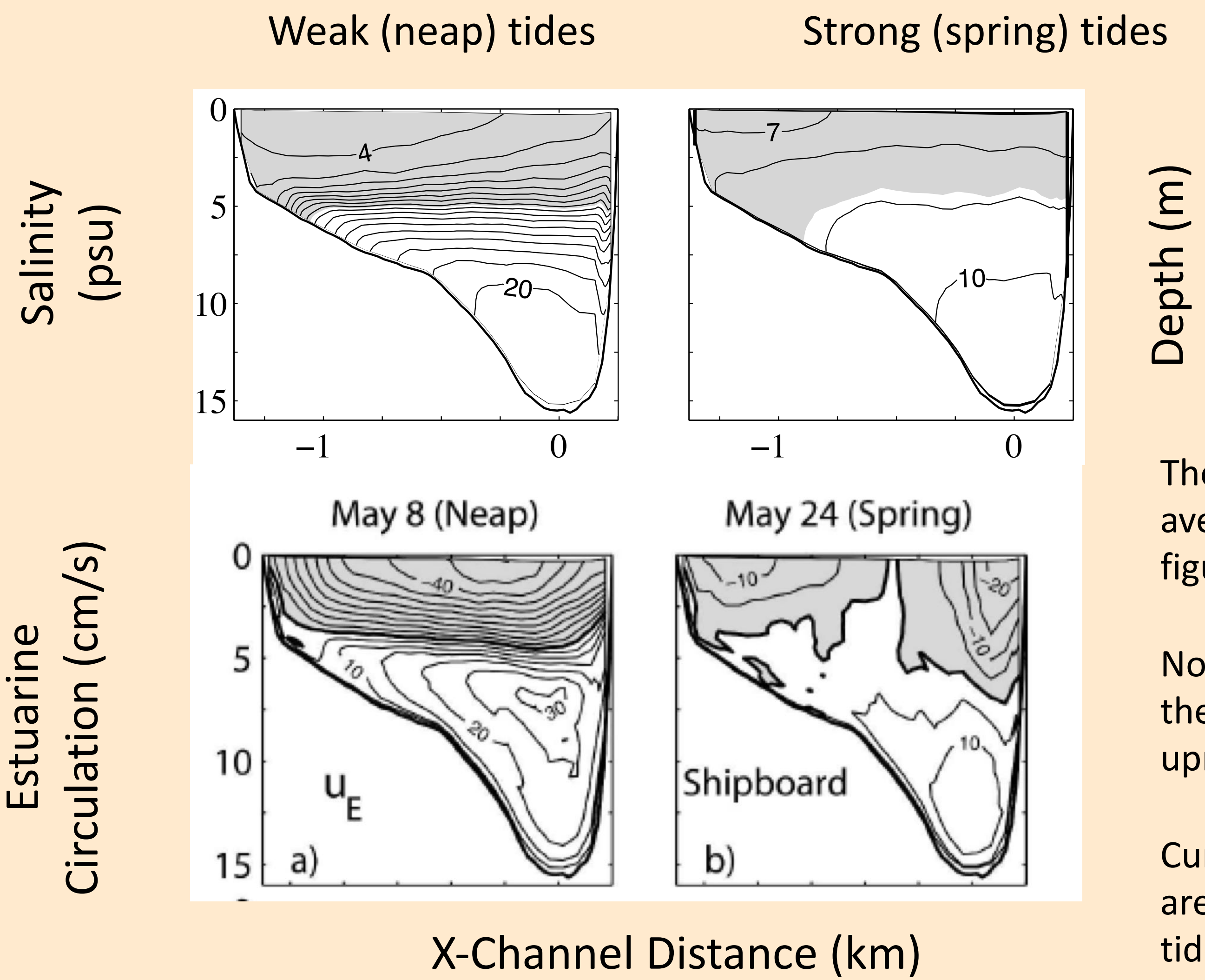
Depth: 15-20 m

Width: 1-2 km

River Discharge: 500 m^3/s (100 to 4000 m^3/s)

Tidal Currents: 0.5 to 1.5 m/s

Cross-section of Hudson River estuary (at Spuyten Duyvil)



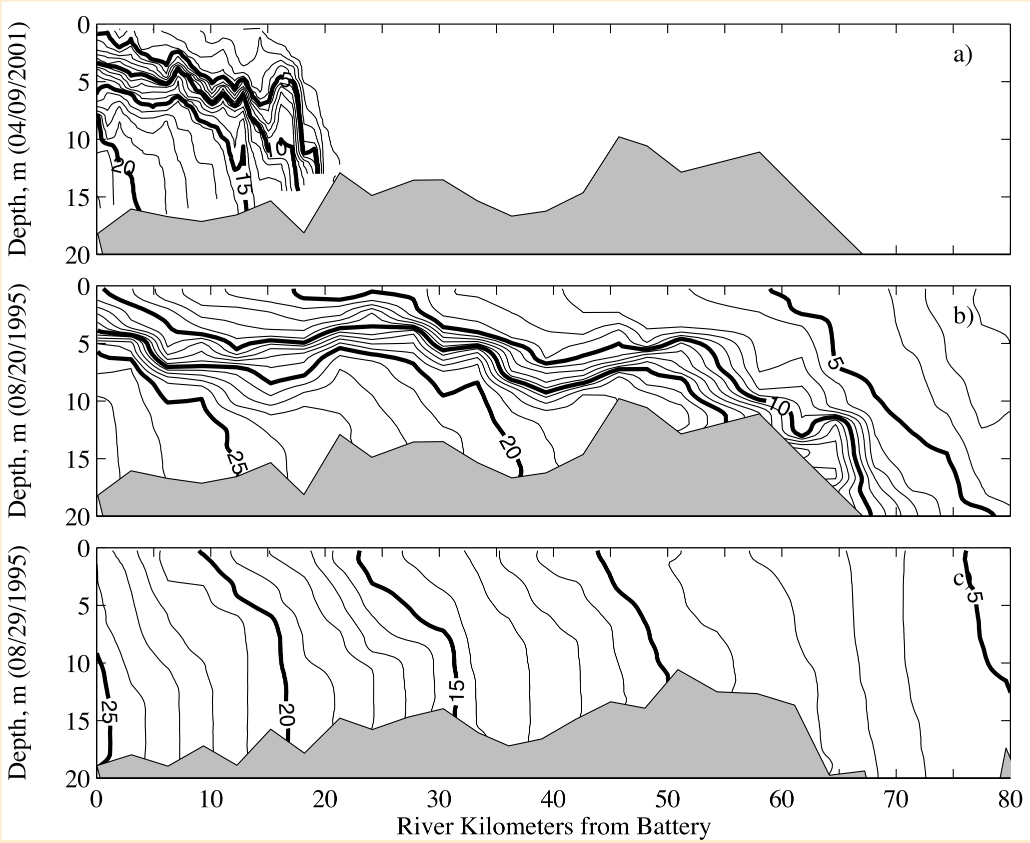
The tides have been averaged over in these figures.

Notice that currents flow to the ocean at the surface and upriver at the bottom.

Currents and stratification are stronger during neap tides compared to spring tides.

Other examples: Many rivers on east coast of USA

Along-Estuary Salinity Structure of the Hudson River Estuary



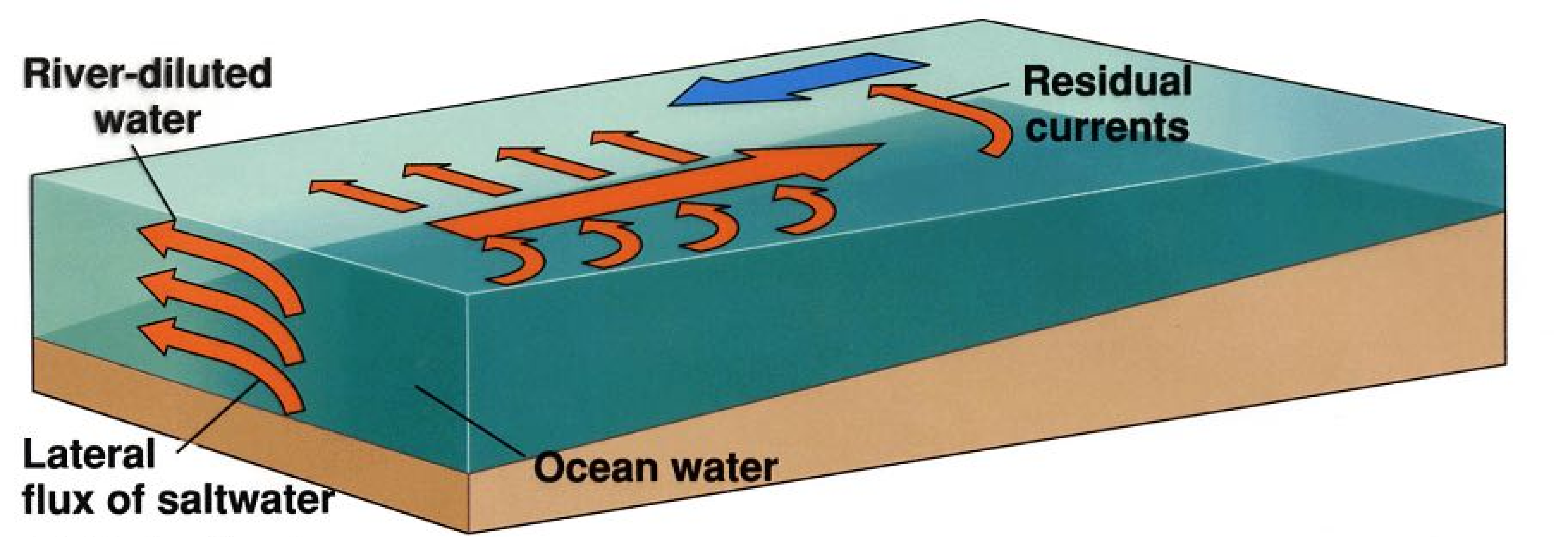
Strong River Flow
Neap Tides

Low River Flow
Neap Tides

Low River Flow
Spring Tides

Changes a lot depending on how strong the tides and river discharge are.

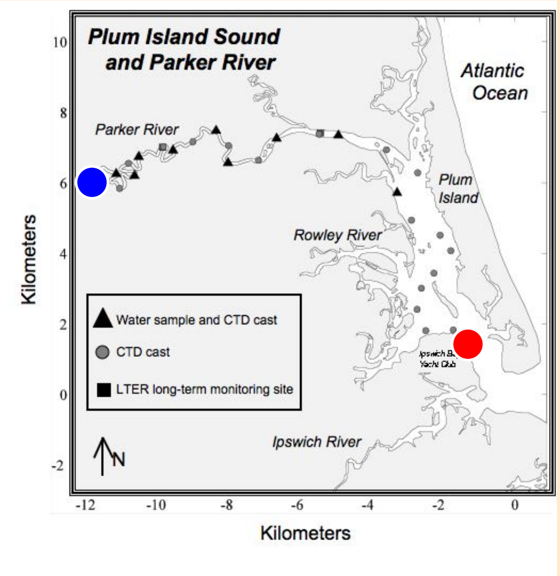
Well Mixed

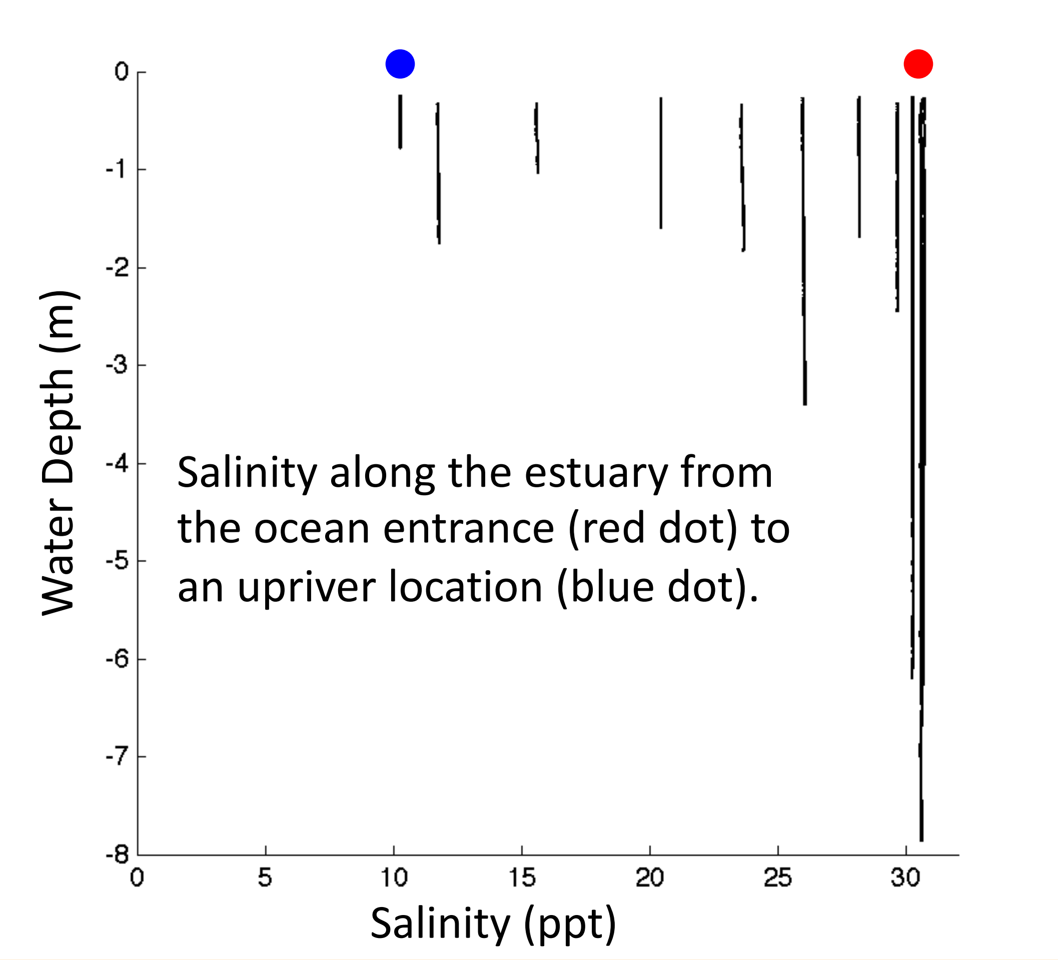


(c) Well-mixed estuary

- strong tides, weak river input, strong mixing.
- changes in salinity are small vertically (well mixed).

Well-Mixed – e.g., Plum Island Estuary, Massachusetts

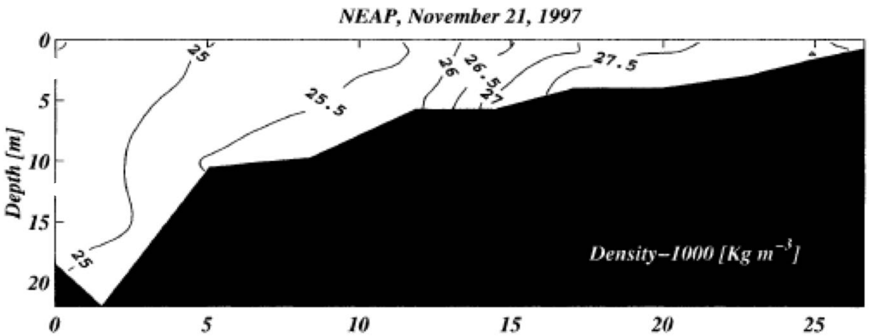




Vertically well-mixed. Salinity decreases as you move up the river.

Inverse/Reverse/Negative Estuary

Density (-1000)



- No river input
- Greater evaporation than precipitation leads to salinity greater in estuary than in open ocean
- Inflow at surface
- Outflow at bottom

e.g., Laguna San Ignacio, Mexico

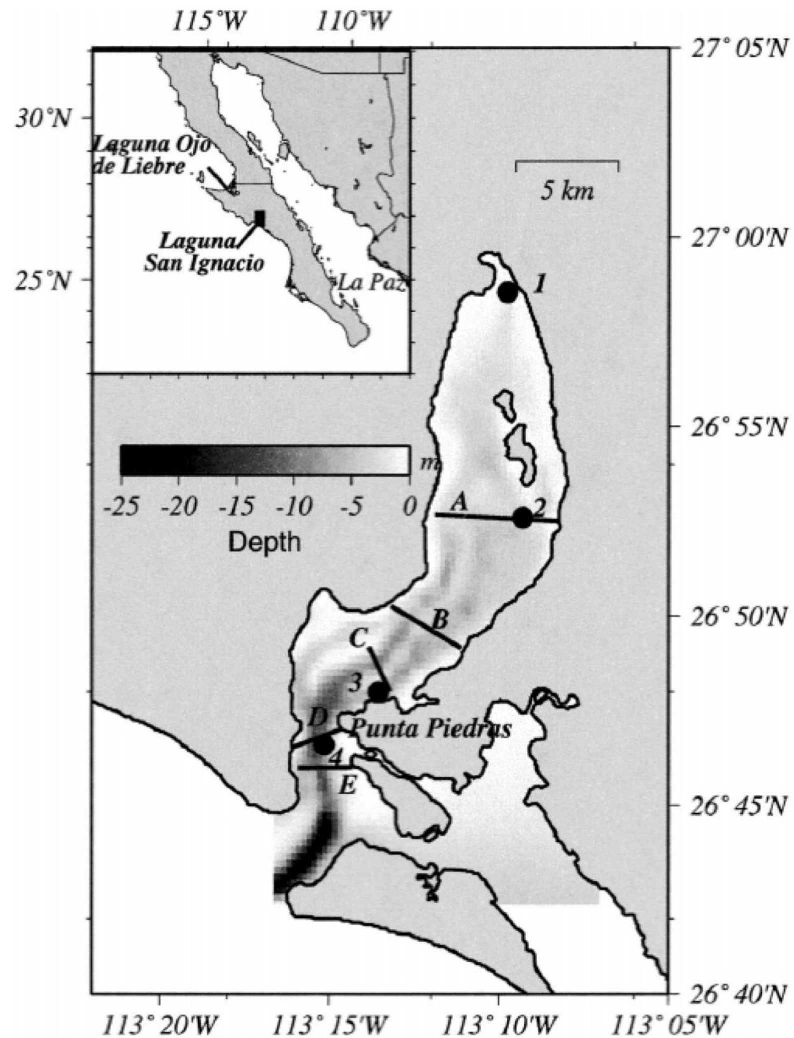
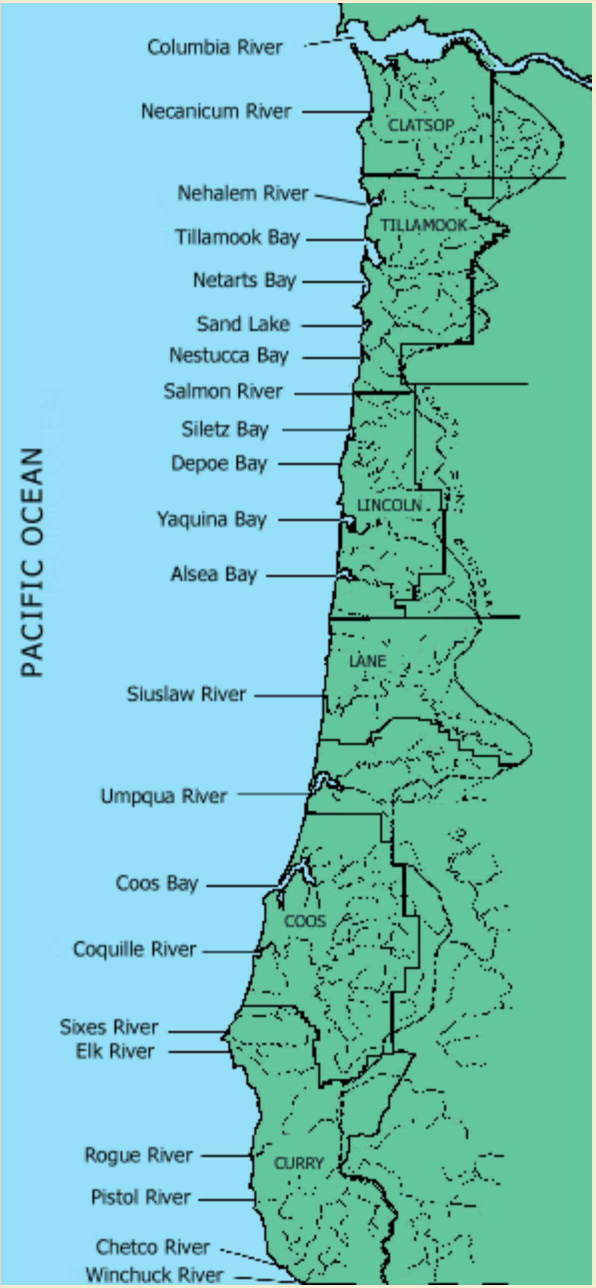


FIG. 1. Location map. Moored stations are located by solid circles and identified by numerals. Heavy lines mark the position of tidal transects, identified by letters.

Winant and Gutiérrez de Velasco (2003)



River Flow: Oregon Estuaries (Close to my home University)

- Oregon has a huge geographic diversity of estuaries with different watershed sizes and inflows.

- There is lots of seasonal variability in estuarine classification.

- Examples:

River	**Avg. River Flow (m^3/s)**	**Drainage Area (km^2)**
Columbia	7200	660,000
Siletz	43	520
Yaquina	7	190
Alsea	42	870
Rogue	163	10,200

What are the major rivers in your home country? Where do they flow into the ocean?

Some Oregon Estuaries

Alsea Bay (Waldport)

Sixes River (Blanco)

Sand Lake (Otis)

Rogue R. (Gold Beach)

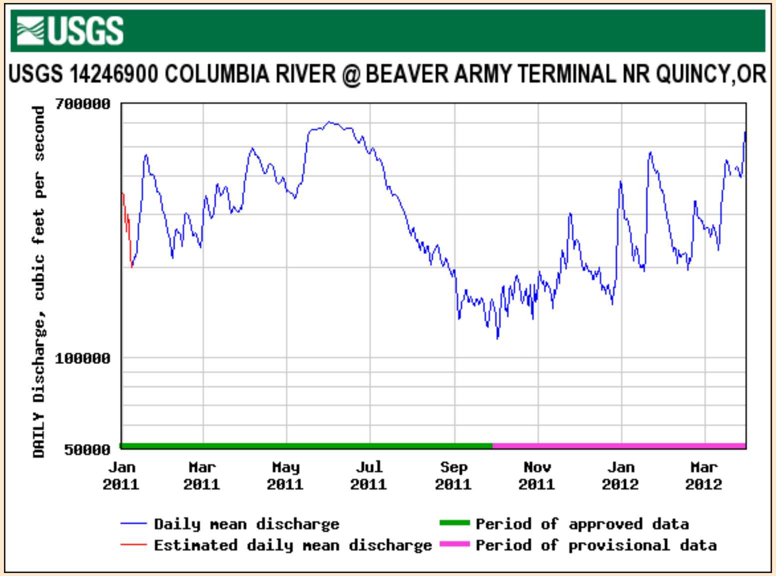
Coquille River

Nehalem

http://www.coastalatlas.net

Compare River Discharge -- Columbia and Alsea Rivers ,2011

Columbia River



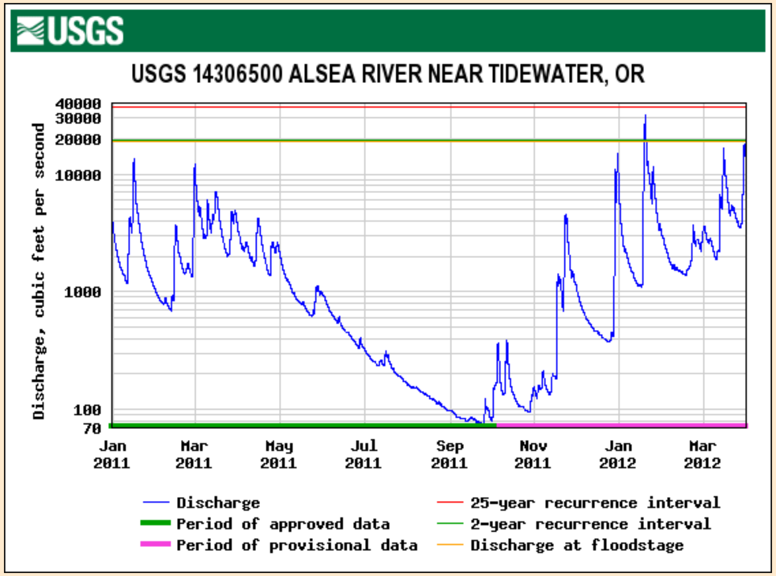
17,000 m^3/s

5,660 m^3/s

2,830 m^3/s

1,420 m^3/s

Alsea River



1130

570

28

2

Can you identify some of the differences between the rivers?

Notice that the y-axis has a logarithmic scale.

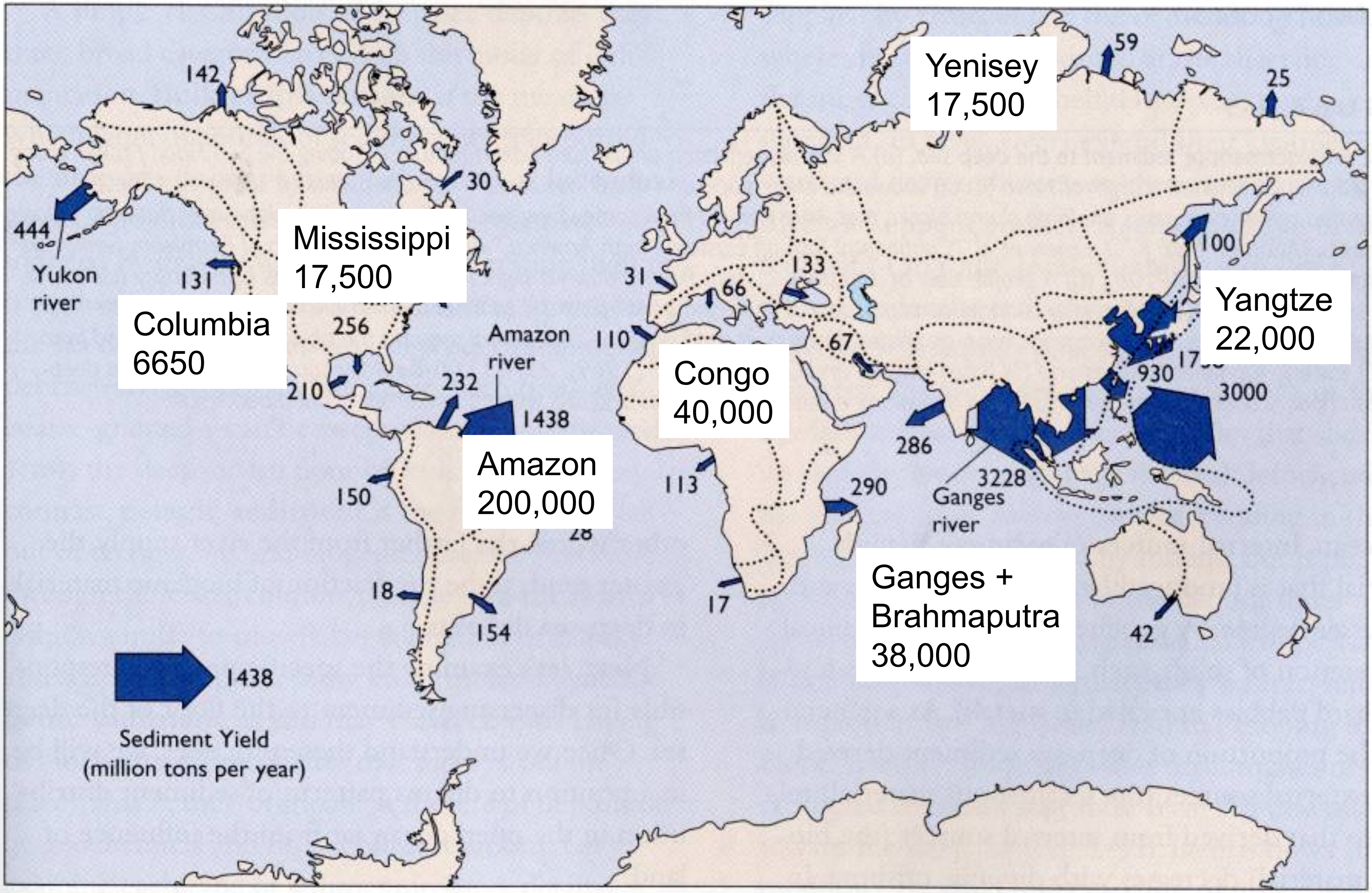
Major Floods

Columbia: 1450 (220,000 m^3/s); 1894 (35,000); 1948 (29,000); 1996 (24,000)

Alsea: 1964 (1180 m^3/s)

Major Rivers Around the World

River discharge in meters cubed per second (top 7 plus Columbia)

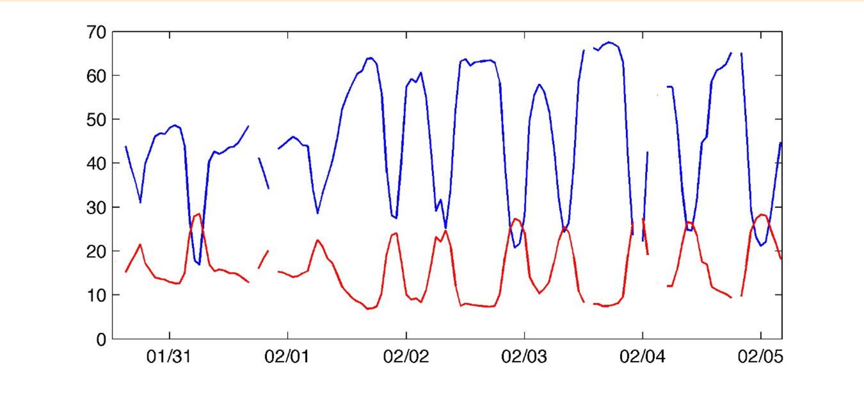


(b) RIVER INPUT OF SILT TO OCEANS

An example of nutrient changes in an estuary (Yaquina Bay estuary, Oregon).

Time series from sensors in the estuary (2008)

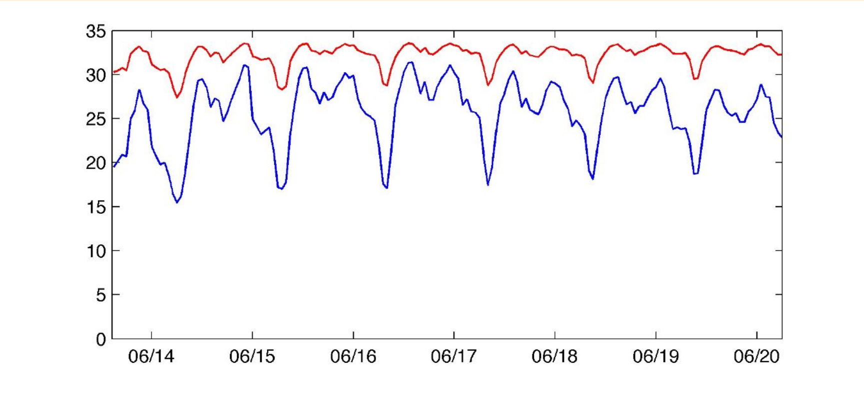
Jan-Feb



Nitrate (μM)

Salinity (psu)

June



What are some differences in nutrient levels in the estuary between seasons?

How does the relationship between nutrients and salinity change between seasons? Why?

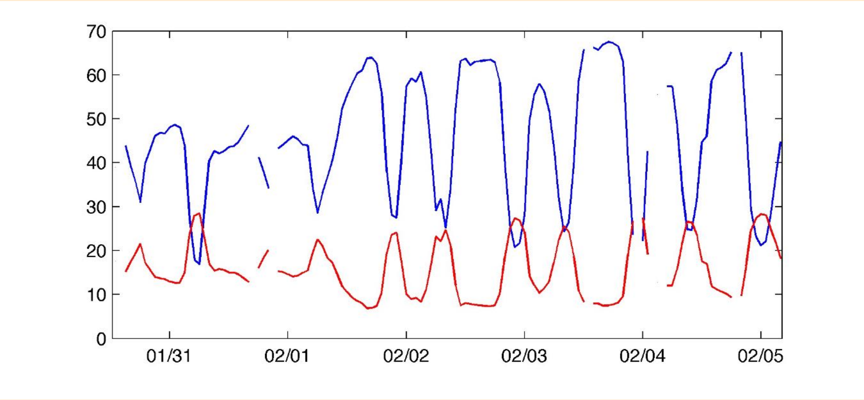
What might be causing this differences?

Now let’s plot nitrate vs. salinity to see if that helps us interpret the data …

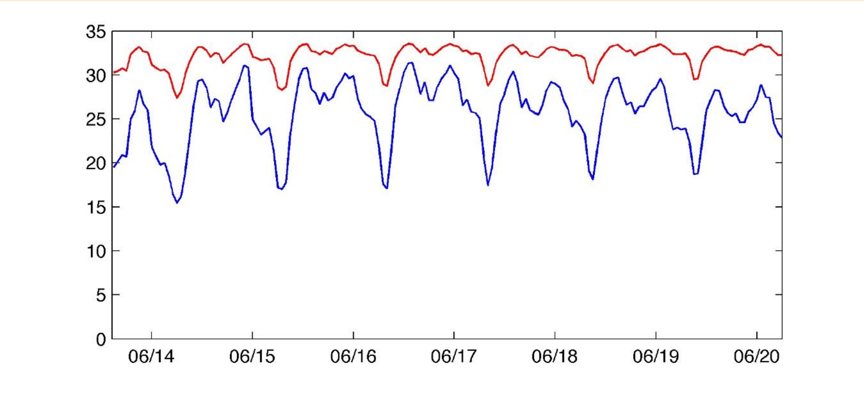
An example of nutrient changes in an estuary (Yaquina Bay estuary, Oregon).

Time series from sensors in the estuary (2008)

Jan-Feb



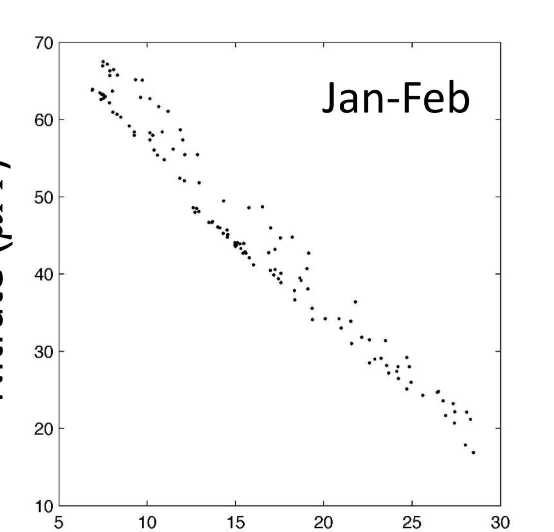
June



Nitrate (μM)

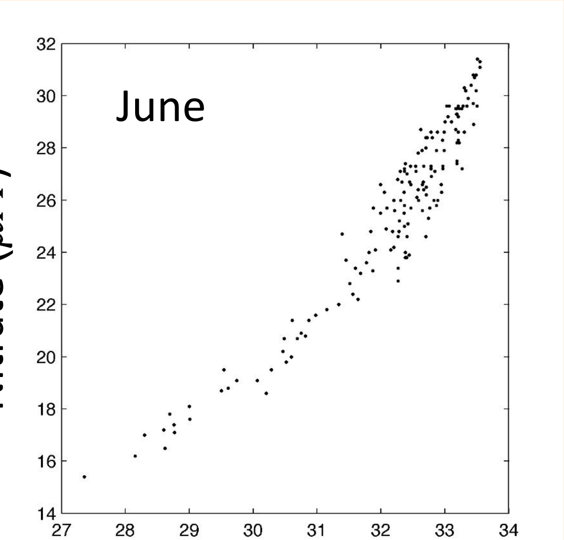
Salinity (psu)

Nitrate (μM)



Salinity (psu)

Nitrate (μM)

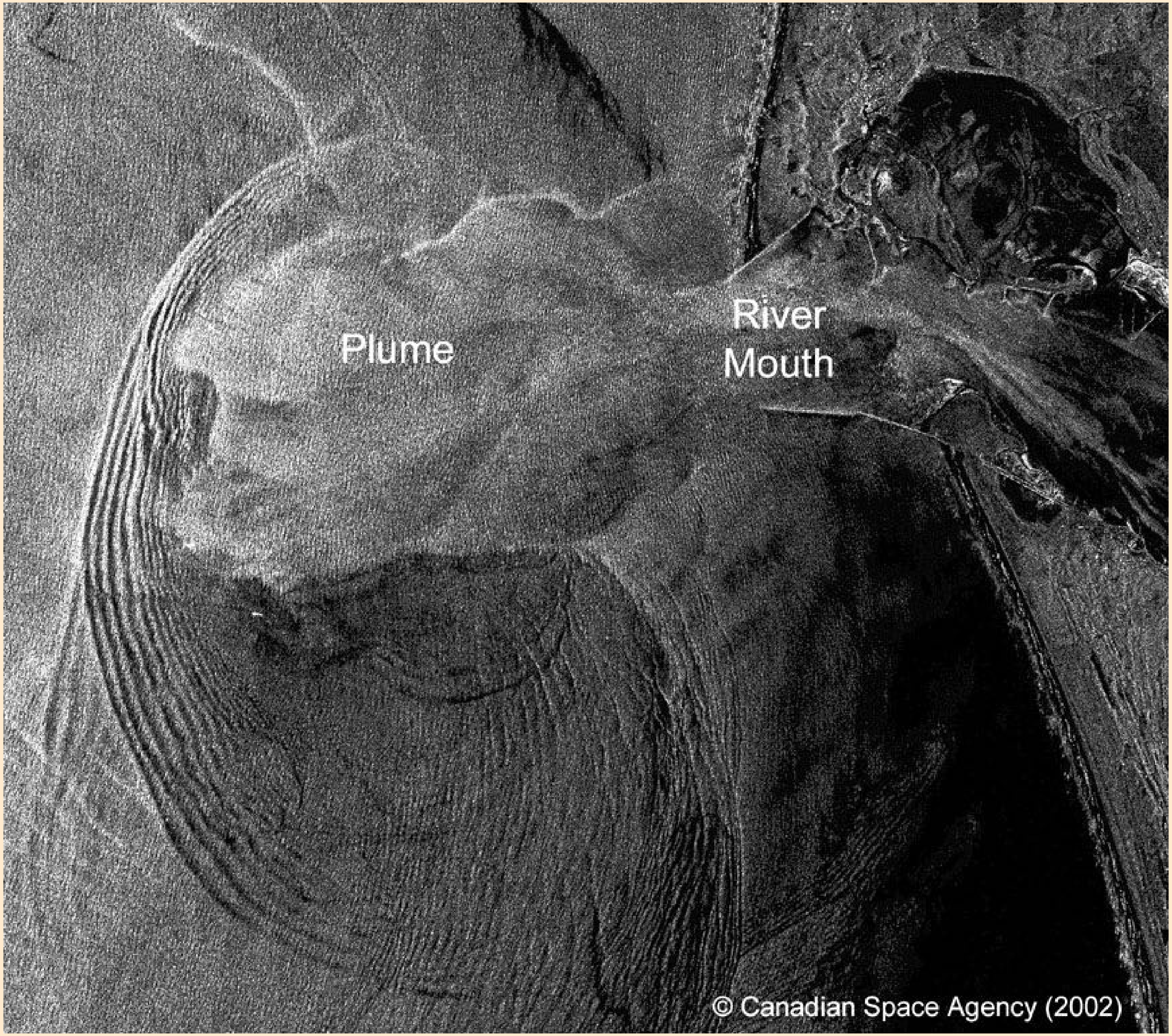


Salinity (psu)

How Do Rivers Influence the Physics of the Coastal Ocean?

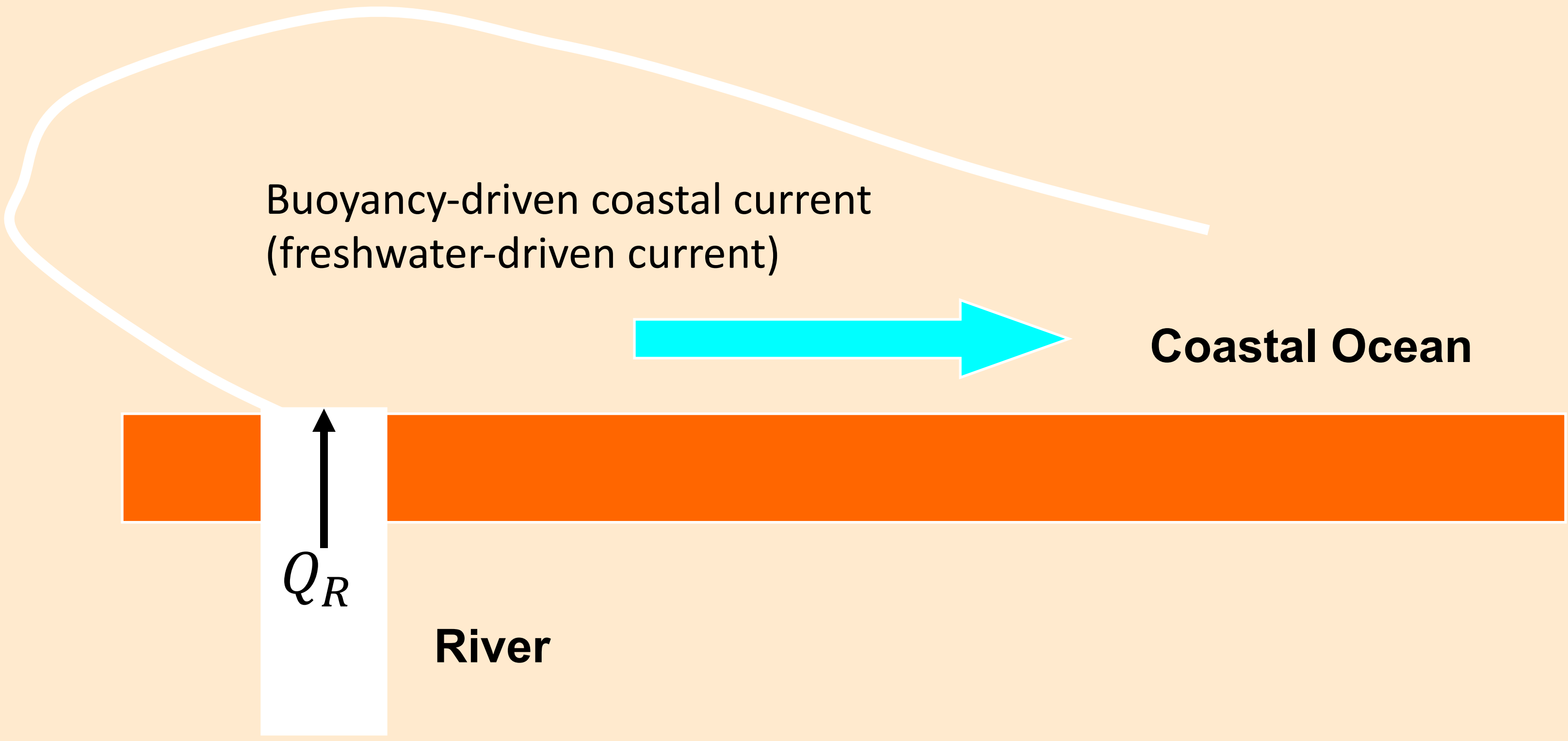
Tides, Plumes, and Coastal Currents

Columbia River Plume from Space



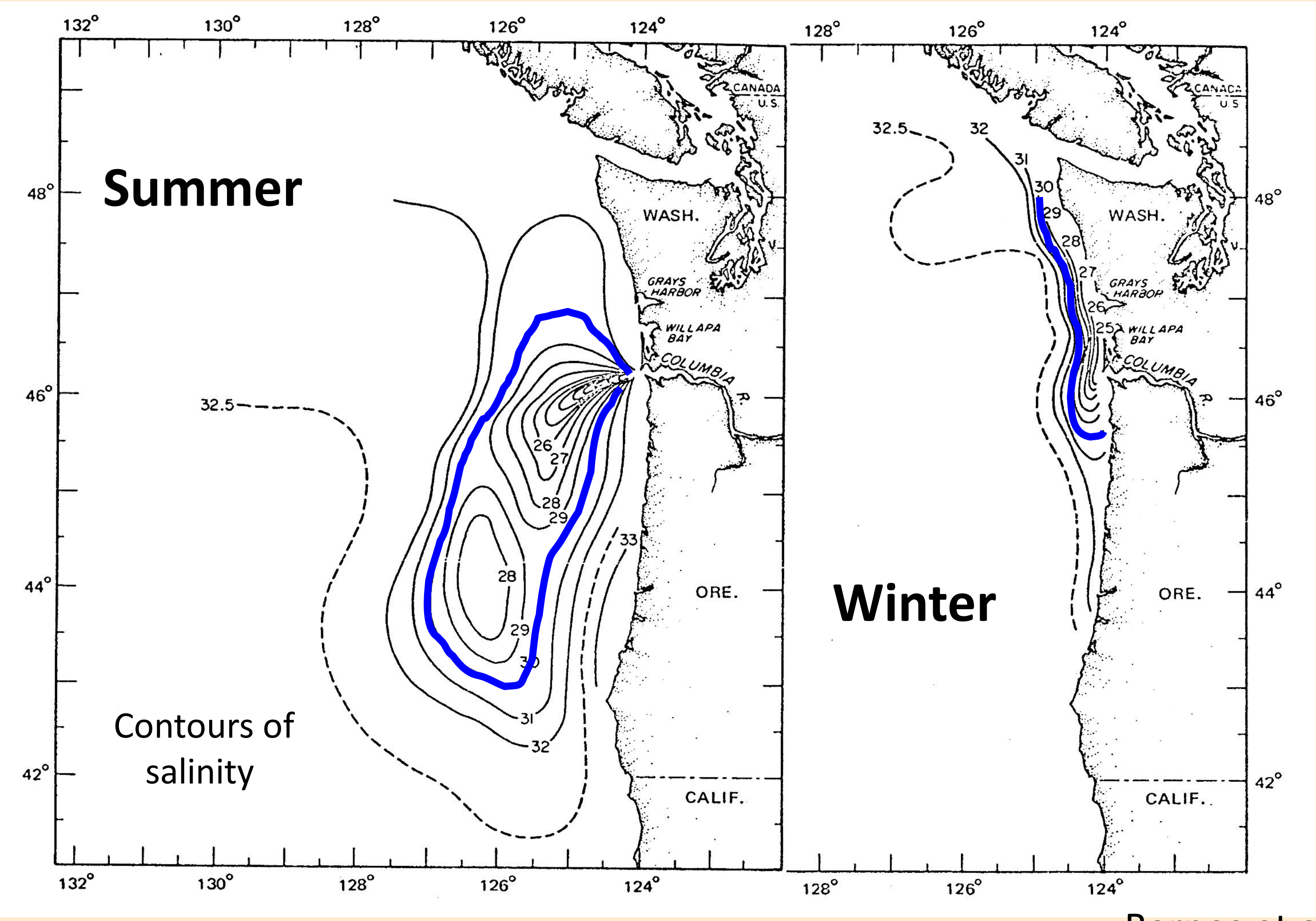
Courtesy of P. Orton (OHSU)

For a big river plume, rotation is important and plume turns right at the coast (in the northern hemisphere)



Columbia River outflow influenced by Earth's rotation, ocean currents, and wind

along-shelf, southward summertime currents can overcome natural tendency of plume to move to right in northern hemisphere



Barnes et al. (1972)

Rivers are major sources of sediment to the ocean
Flood of Eel River, CA (1974)

Lonnie Leithold (NC State)

Gulf of Maine Buoyant Coastal Current and HABs

Near-Surface Salinity: April 28-30, 1993

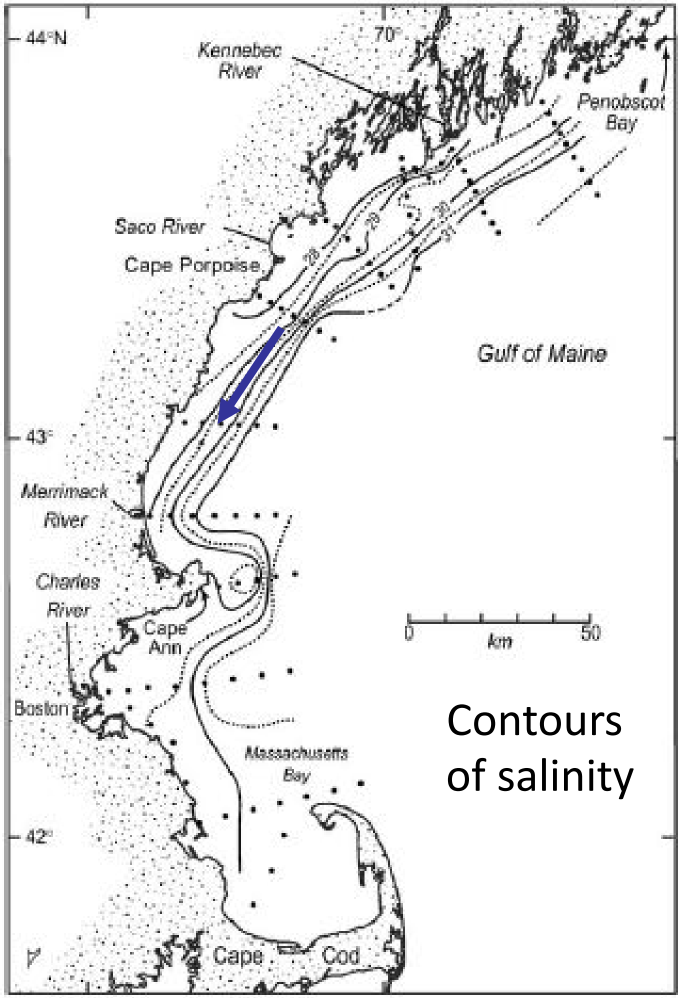


Fig. 5. Near-surface (2-m depth) salinity distribution during 1st large-scale hydrographic survey in 1993. Contour interval is 0.5 psu.

Multiple river sources (Penobscot, Kennebec, Androscoggen, Saco, Merrimack Rivers).

Current flows along coast (to south (~25 cm/s).

Critical to dynamics of harmful algal bloom (HAB) development and transport.

Geyer et al. (2004)

Thank you!

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