Estuaries

- Important coastal ecosystems
  – Semi - enclosed and protected
  – High nutrients & biological production
  – Ports & development
- Physical Processes:

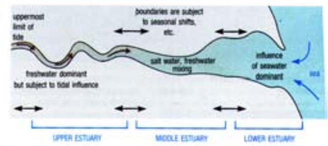
•Circulation within an estuary to conserve mass, water, & salt

CMWS 601

Estuary - an inlet of the sea reaching into a river valley as far as the upper limit of tidal influence

Estuaries:

- Mixing zones of dense seawater and less dense freshwater
  - described by mode of formation or by circulation features
  - 4 principal types of circulation:
    - salt-wedge
    - well-mixed
    - partially-mixed
    - fjords
  - mixing depends on:
    - strength of tides
    - volume of freshwater influx (river flow)
    - topography



CMWS 601

Estuaries are categorized either by **Geologic Origin** or by patten of **Mixing** of fresh & salt water

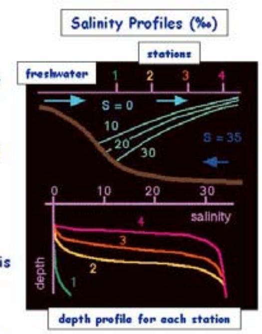
- Mixing:
- a) salt-wedge estuary
- b) partially mixed estuary
- c) well-mixed estuary
- d) fjord
- e) reverse or negative estuary

(based on relative rates of fresh water flow & tidal mixing)

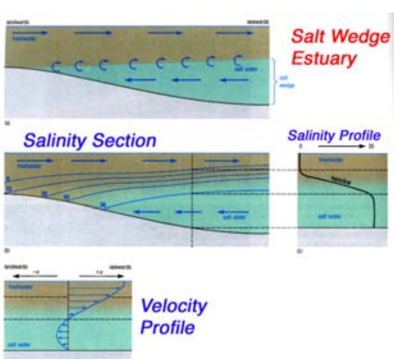
CMWS 601

Salt-Wedge Estuary:

- River Flow:
  - large; strong surface flow of freshwater
- Tidal Range:
  - low; small surface flux of seawater
- Result:
  - stratification: water is salty at depth
  - lower layer of salt water is entrained by freshwater
  - gradual mixing occurs
  - surface water salinities only increase toward ocean



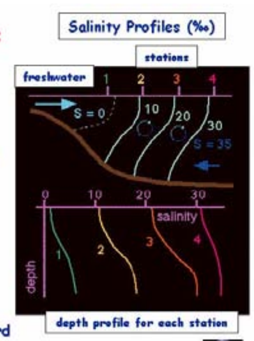
CMWS 601



CMWS

Partially-Mixed Estuary:

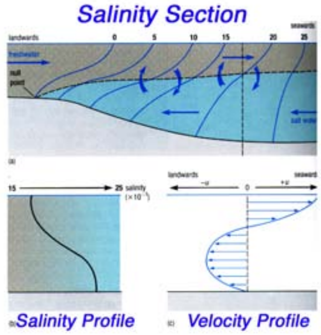
- River Flow:
  - moderate; surface flow of freshwater
- Tidal Range:
  - moderate; gradual mixing of seawater and freshwater
- Result:
  - some stratification
  - strong net seaward flow of freshwater
  - surface water salinity gradually increases seaward



CMWS 601

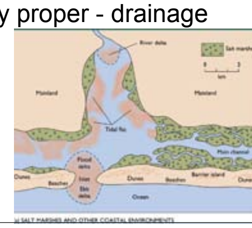
Partially Mixed Estuary

Salinity Section



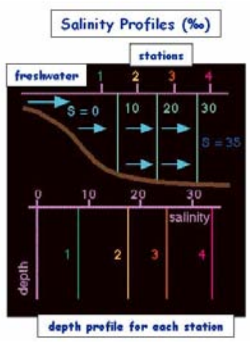
Coastal Plain Salt Marsh Estuary

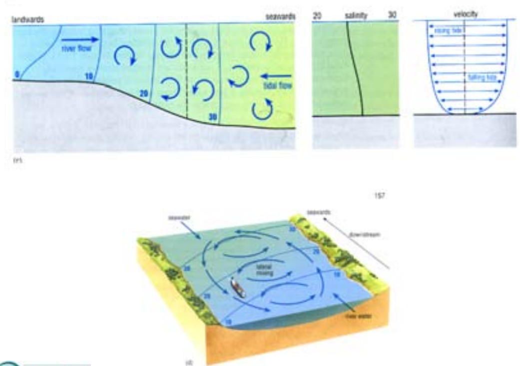
- sediment infilling from river; sedimentation much more extensive in salt marsh
- Carolinas to Florida - narrow tidal inlets, exchange into estuary proper - drainage canals



Well-Mixed Estuary:

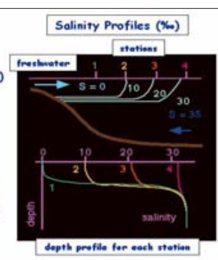
- River Flow:
  - low; weak surface flow of freshwater
- Tidal Range:
  - high; strong mixing of seawater and freshwater
- Result:
  - little depth stratification
  - turbulent mixing
  - surface water salinity progressively increases seaward

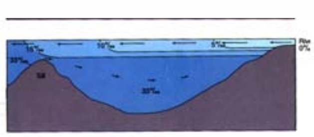




Fjord-Type Estuary:

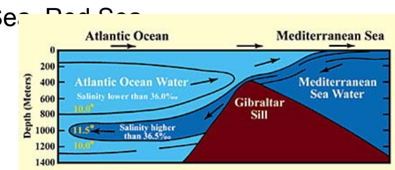
- Ocean Connection:
  - may be restricted by shallow sill (glacial moraine)
- River Flow:
  - moderate; surface flow of freshwater
- Tidal Range:
  - little tidal mixing of seawater and freshwater
- Result:
  - strong stratification, little mixing below surface
  - surface water salinity gradually increases
  - little influx of seawater





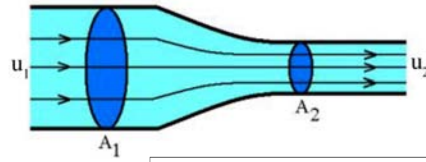
Inverse Estuaries

- High Evaporation, low river input
- Water leaves along bottom - saline outflow
- Water enters above - influx of "normal" seawater
- Med. Se



Conservation of Mass (Continuity)

- Mass In = Mass Out
- "per unit volume" means M / Vol = ρ
- Fluid conserves mass by adjusting its flow (its velocity)
- We are only considering advection and ignoring diffusion

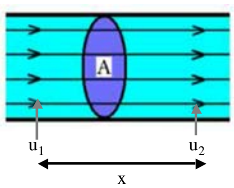


Continuity in 1-dir

$$\frac{\text{mass in}}{\text{time}} = \frac{\text{mass out}}{\text{time}}$$

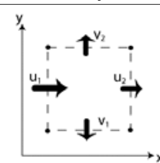
$$\rho A_1 u_1 = \rho A_2 u_2$$

- To conserve mass the east - west velocity adjusts (changes) in the east-west direction:
- Mathematically this is du/dx
- du = $u_2 - u_1$
- dx $x_2 - x_1$



2-D Continuity

$$\frac{du}{dx} + \frac{dv}{dy} = 0$$

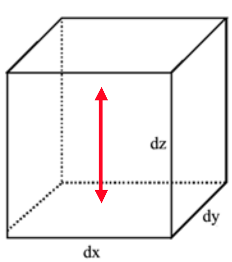


All sides of the box are 10 m in length.

If u_1=5m/s and u_2=2m/s, what is du/dx?
What is dv/dy?
What are some ways to get dv/dy = .3?

3-D Continuity

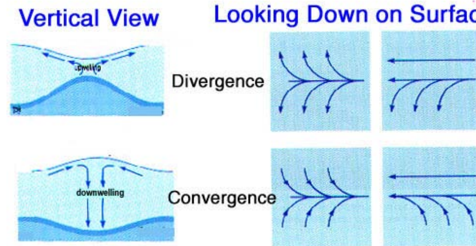
$$\frac{du}{dx} + \frac{dv}{dy} + \frac{dw}{dz} = 0$$



If du/dx + dv/dy does not add up to zero, what has to happen?

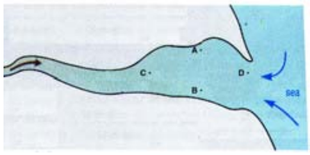
Divergences

Vertical View **Looking Down on Surface**



- By knowing the horizontal flow, the vertical flow can be determined

Use of 3-D Continuity Equation



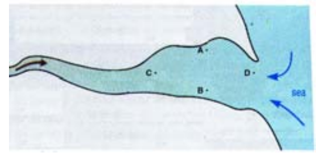
- $\frac{du}{dx} + \frac{dv}{dy} = -\frac{dw}{dz}$

$$\frac{Ud - Uc}{dx} + \frac{Va - Vb}{dy} = -\frac{(W_2 - W_1)}{(-Z_2 - -Z_1)}$$

Always choose Z_1 to be 0 m since w = 0 there

CMWS 601

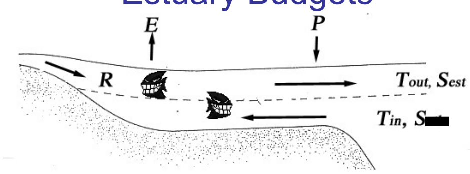
Use of 3-D Continuity Equation



$$(Z_2)\left[\frac{Ud - Uc}{dx} + \frac{Va - Vb}{dy}\right] = \underline{(W_2\ )}$$

CMWS 601

Estuary Budgets



$$T_{in} + R + P = T_{out} + E$$

(all in m³/s)

$$T_{in} \bullet S_{oc} = T_{out} \bullet S_{est}$$

CMWS 601

Residence Time = $\frac{\text{total amount of substance}}{\text{rate of supply or removal}}$

For Estuaries with large freshwater input:

- **% of freshwater in the estuary**
  - **=(Soc - Sest)/Soc**
- **Transport of Freshwater out of the estuary**
  - **= ((Soc - Sest)/Soc) • Tout**

CMWS 601

Residence Time = $\frac{\text{total amount of substance}}{\text{rate of supply or removal}}$

For Estuaries with large freshwater input

- **Volume of freshwater in the estuary**
  - **V_{fw} = ((Soc - Sest)/Soc) • Vol_{est}**
- **Residence Time = V_{fw}/R**

CMWS 601

Residence Time

For well mixed estuaries (R small)

- Res Time = $\frac{\text{Volume}}{\text{(Tidal Flow•Surface Area)}}$
- Tidal flow = Tidal Range • # of tidal cycles/day

CMWS 601