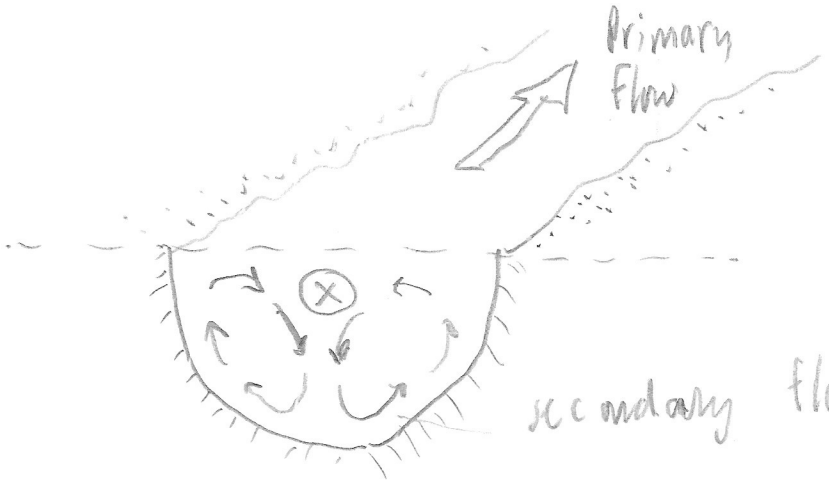
AG

Secondary Flow (circulation)

8/16/2019

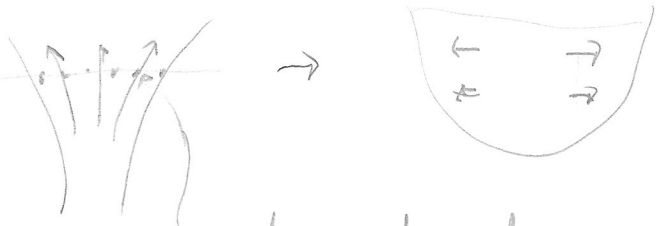
(1)



5-20% of the magnitude of vel. of primary flow

But the stronger $\partial s/\partial y$ makes them of primary importance.

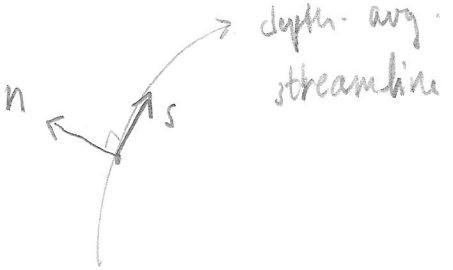
1) Curved channel (e.g. meandering river)
2) Ekman boundary layers
3) Differential Advection

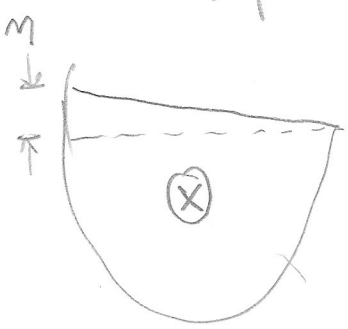


this is "v" but it is not what we call secondary circulation

analysis approach:
rotate at each point so that $\bar{v} = 0$ (depth avg.)

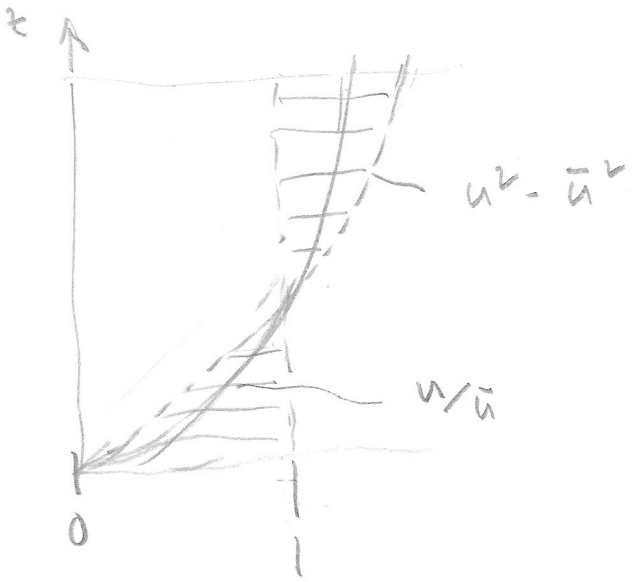
1) Curved channel



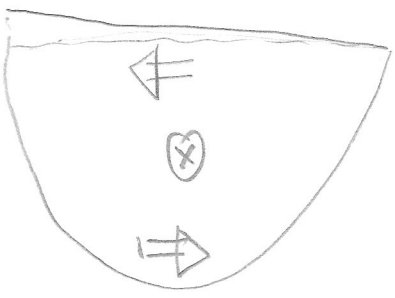


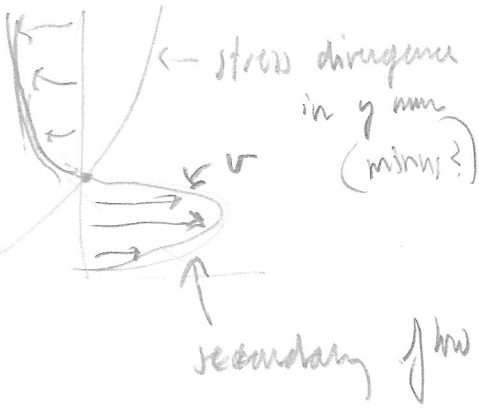
$$-\frac{\overline{u}^2}{r} = -g\frac{\partial \eta}{\partial n}$$

the fact that this is depth averaged is important

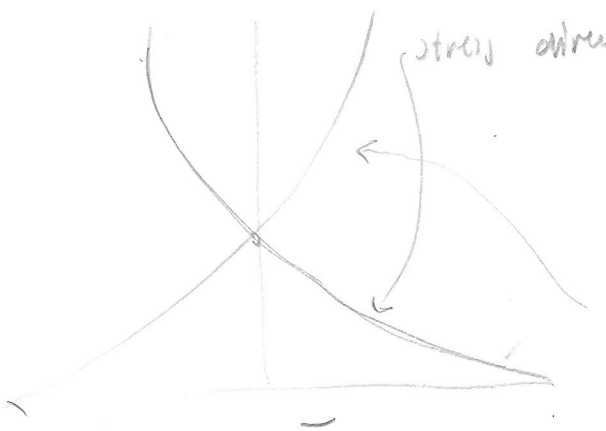


F = out of balance part of PG driving secondary flow





$$\frac{\tau}{\rho} = -K\frac{\partial u}{\partial z}$$



$= -\frac{\overline{u^2}}{r}$ $\qquad \frac{u^2}{r} - \frac{\overline{u^2}}{r}$?

in mom $\qquad -\frac{u^2}{r} = -g\eta_n + \frac{1}{\rho}\frac{\partial \tau}{\partial z}$

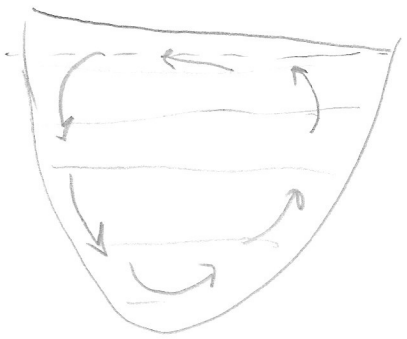
$\frac{1}{\rho}\frac{\partial \tau}{\partial z} = -K V_{zz}$

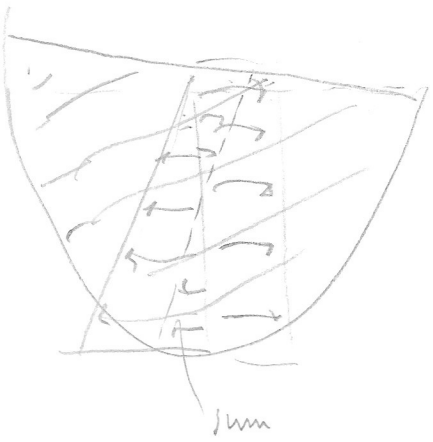
$\Rightarrow \quad -\left(\frac{u^2}{r} - \frac{\overline{u^2}}{r}\right) = -K V_{zz}$ to within a sign error.

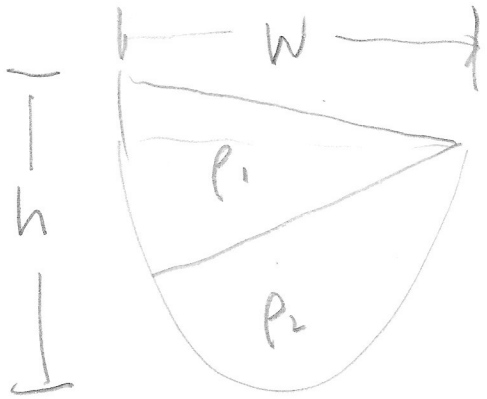
UPWELLING smooth water

$\frac{h}{C_d L}$? $\frac{\text{advection}}{\text{friction}}$

what if it is stratified ?







Scaling from Harvey Seim

$$g' = \frac{g(\rho_2 - \rho_1)}{\rho_0}$$

$$\frac{g'h}{W} > \frac{\frac{1}{2}(\Delta u)^2}{r}$$

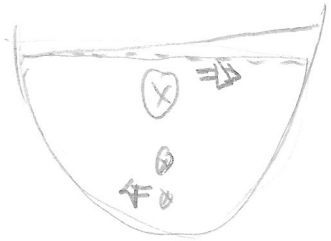
or else flow overturns

or

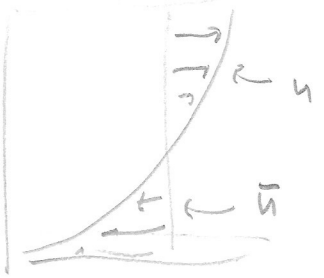
$$\frac{g'h}{(\Delta u)^2} > \frac{1}{2}\frac{W}{R}$$ ← same as r

like a Richardson #, typically $Ri > 1/4$

2) Coriolis - straight channel

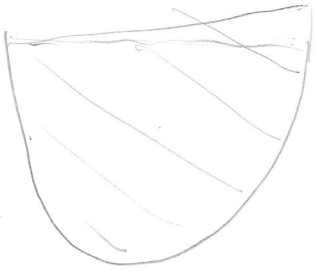


$$fv = -g\frac{\partial \eta}{\partial y}$$



Ageostrophic flow
≡ going downhill

w/ stratification

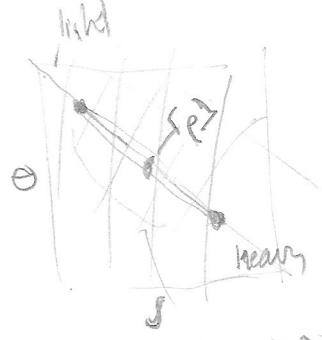


Coriolis: the signs of secondary flow change flood vs. ebb.

Curvature: signs do not change in flood vs. ebb.

Scaling of the shut-down condition

$$\frac{g'h}{W} > f\Delta u \quad \text{or} \quad \frac{g'h}{\Delta u^2}\,\frac{\Delta u}{fW} > 1$$



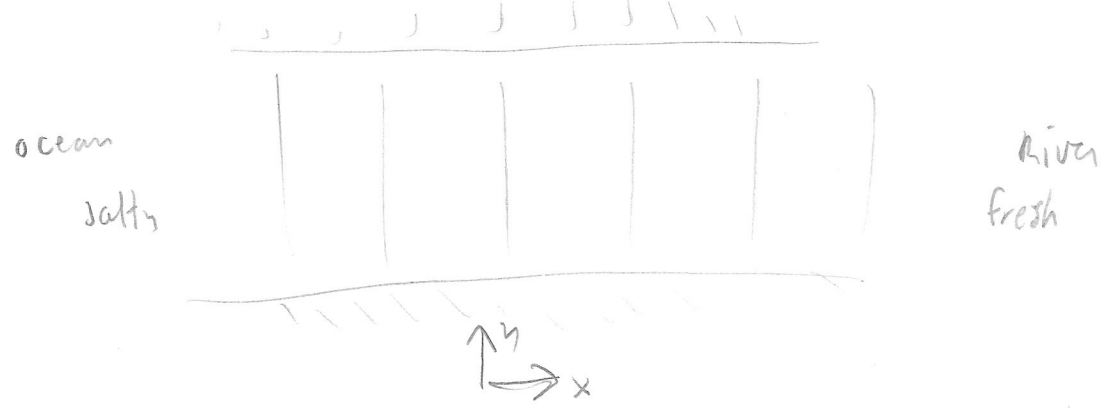
Narrow = stiff

Wide = not stiff

$\frac{g'h}{\Delta u^2}$: Richardson #, a dimensionless expression of how stratified it is

$\frac{\Delta u}{fW}$: Rossby #, a dimensionless expression of how wide the system is

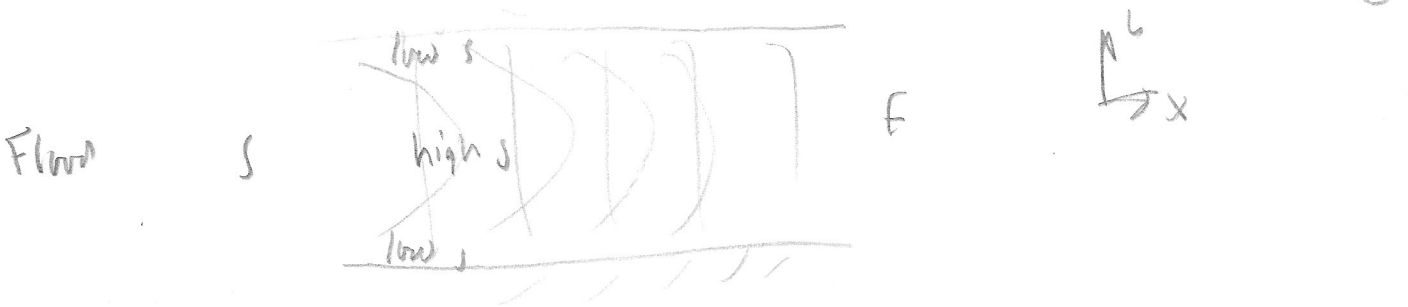
3) Differential advection

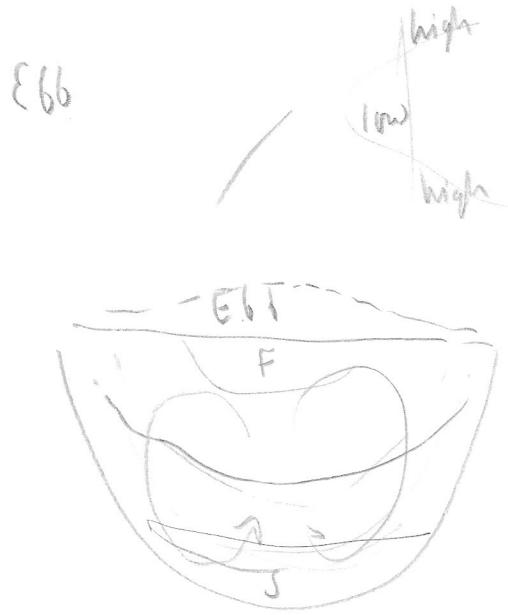


$$u_t + g\frac{\partial \eta}{\partial x} + \frac{C_d|u|u}{h} = 0$$

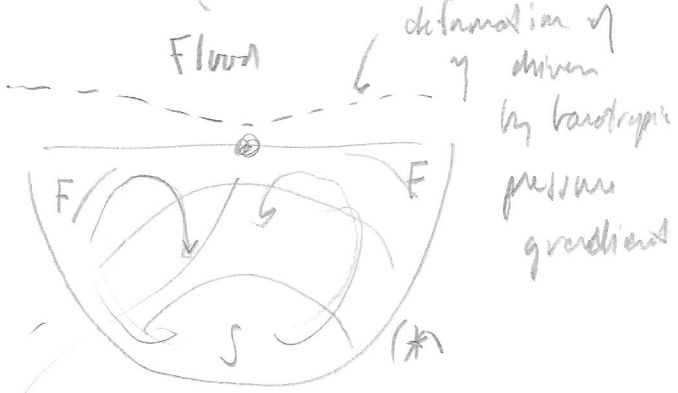
this is the main balance in shallow places

expression of bottom friction in shallow places



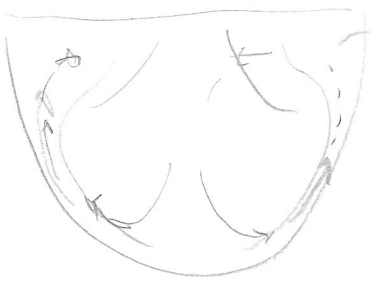


Nunes & Simpson 1985



makes a "convergence front" down the middle of the estuary

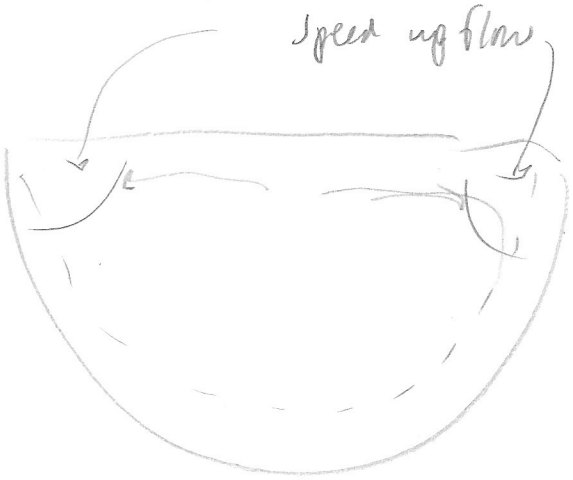
Next - from Lerczak & Geyer 2004 the structure in (*) has an effect on the primary flow



slow flow advected up here

FLOOD

and * reduces vertical shear

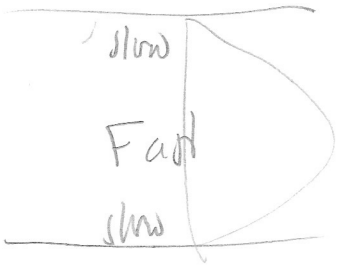


EBB

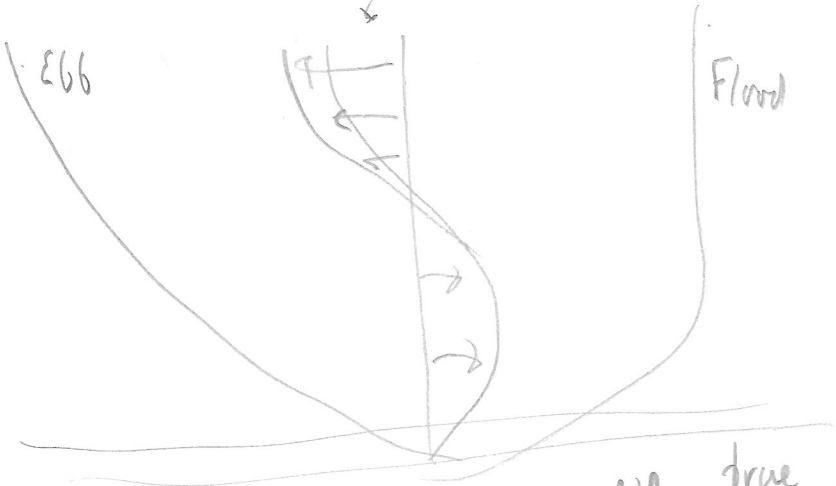
adds more vertical shear to primary flow

Both work to flatten the isopycnals

this argument stacked with cross channel shear:



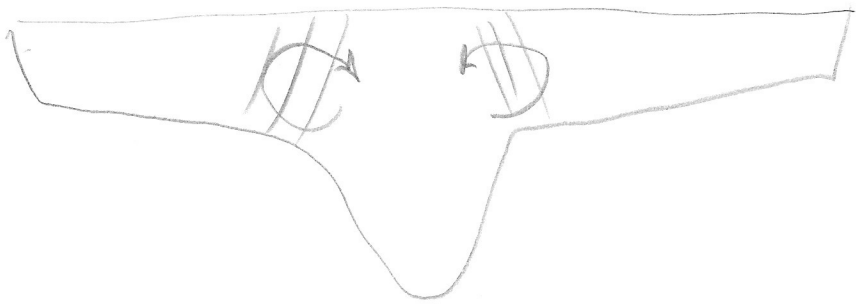
Gives rise to the estuarine circulation



up to ½ augmentation of gravitational circulation

esp. true in case w/ weak stratification, in narrow estuaries

Delaware Bay Coast



concept