UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION
INTERNATIONAL ATOMIC ENERGY AGENCY
INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
I.C.T.P., P.O. BOX 586, 34100 TRIESTE, ITALY, CABLE: CENTRATOM TRIESTE

SMR/989 - 14

"Course on Shallow Water and Shelf Sea Dynamics"
7 - 25 April 1997

"Estuaries & Plumes"

R. GEYER
Woods Hole Oceanographic Institution
Woods Hole, MA
USA

Please note: These are preliminary notes intended for internal distribution only.

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presented by Rocky Geyer.

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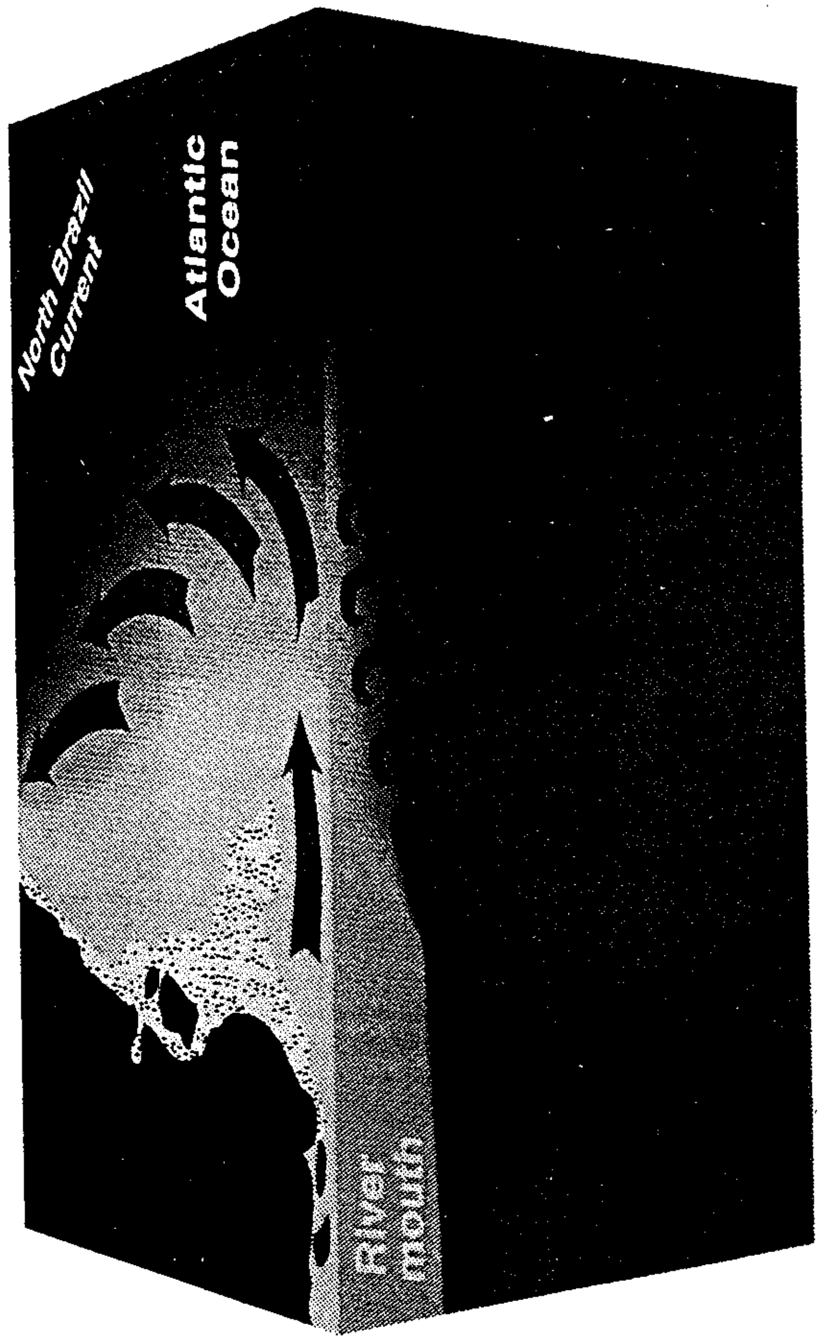
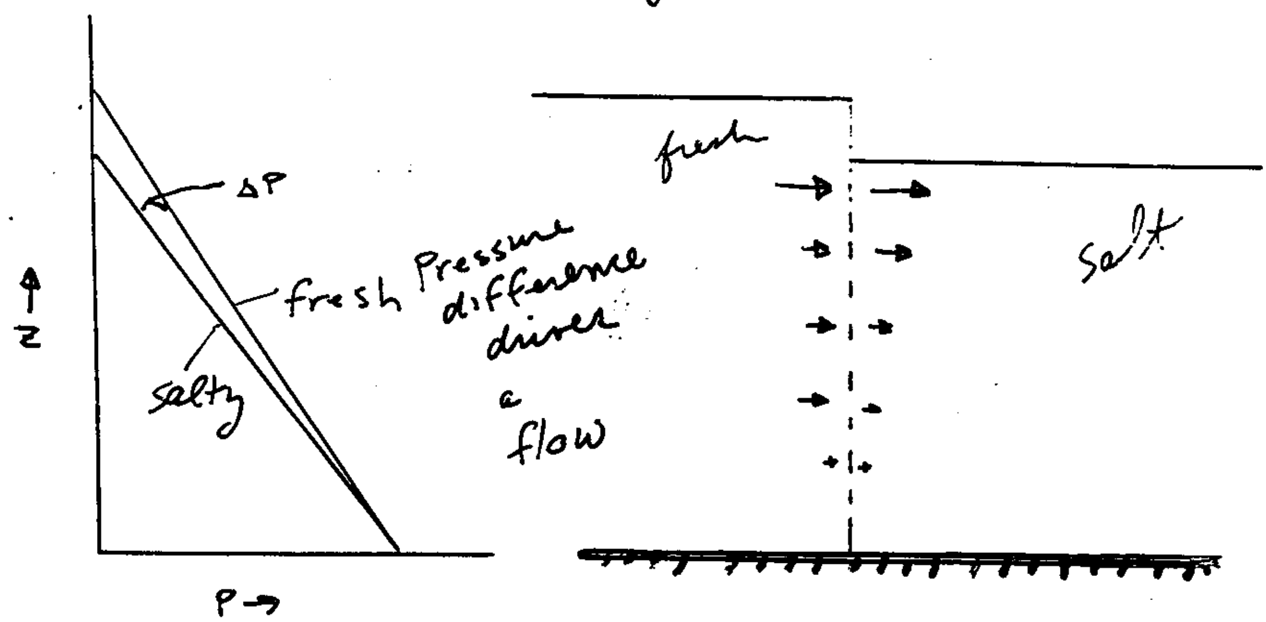
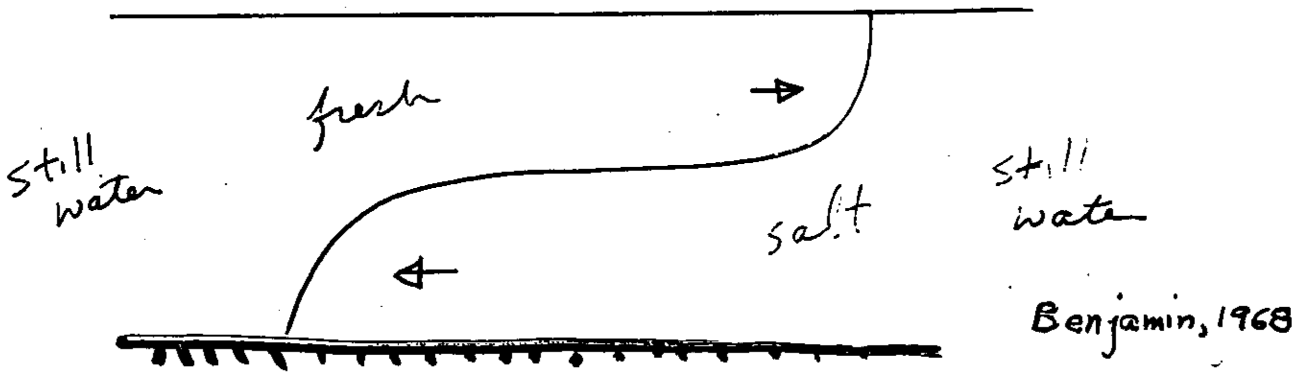
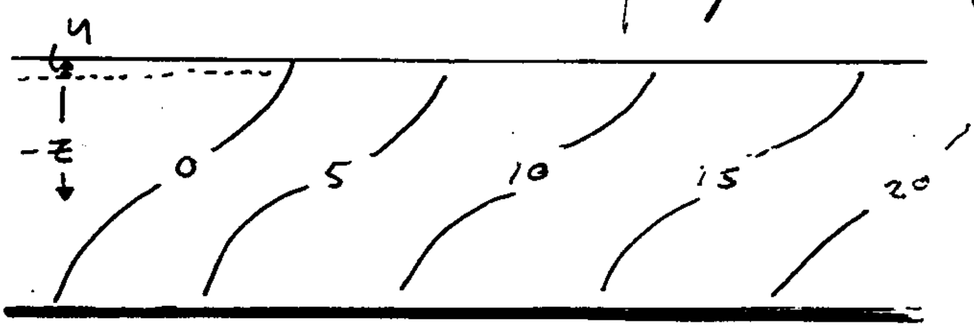

North Brazil Current
Atlantic Ocean
River mouth

LOCK Exchange





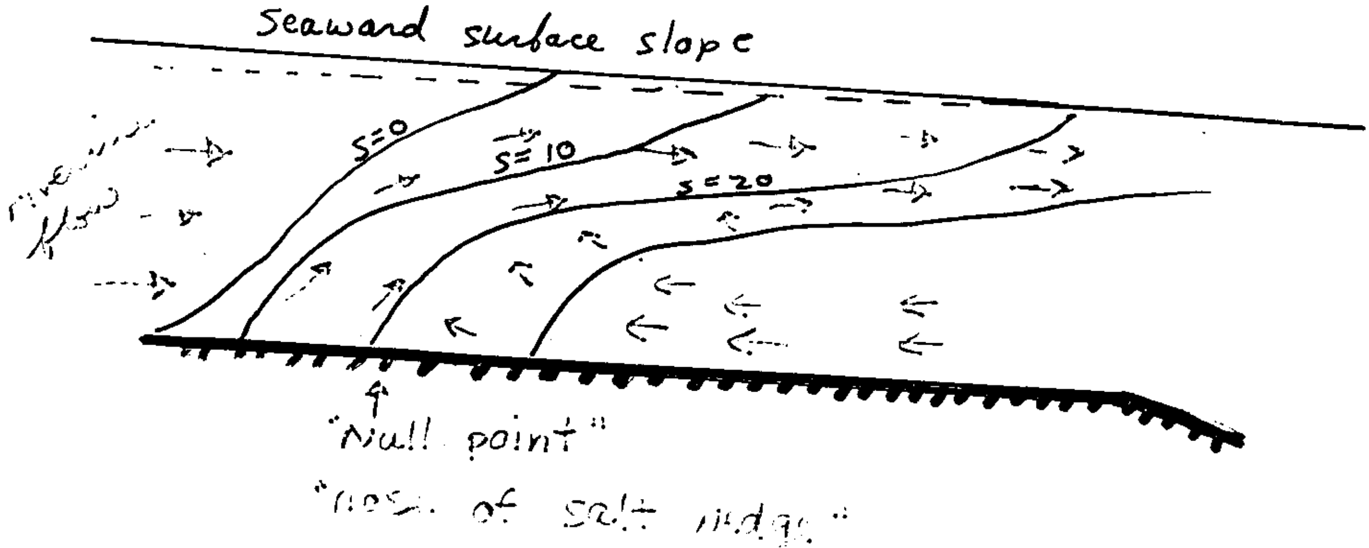
Horizontal salinity gradient



$$\frac{\partial p}{\partial x} = -\frac{\partial}{\partial x}\int_{\eta}^{z} \rho g \, dz = \rho_s g \frac{\partial \eta}{\partial x} - g z \frac{\partial \rho}{\partial x}$$

Surface slope   baroclin. ~ g.

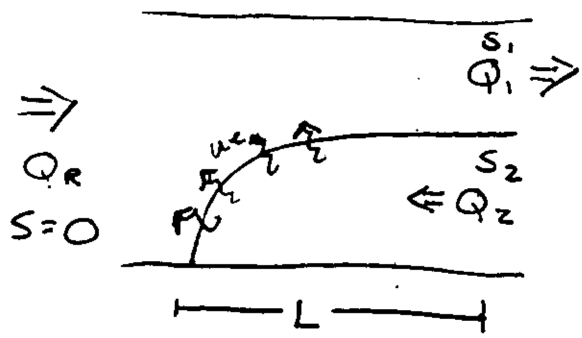
ESTUARINE CIRCULATION



Mass Balance

In = Out

Knudsen's Relation



Mass: $Q_R + Q_2 = Q_1$

Salt: $Q_2 S_2 = Q_1 S_1$

combining: $Q_R + Q_2 = Q_2 \dfrac{S_2}{S_1}$

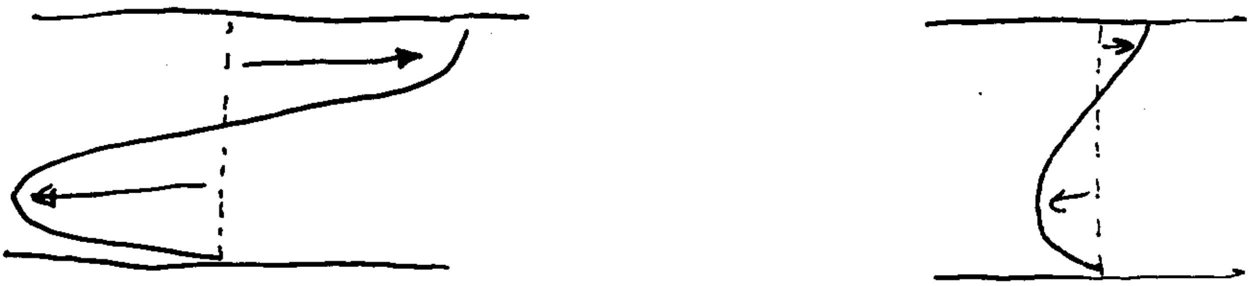
$$Q_2 = Q_R \frac{S_1}{S_2 - S_1} = \text{"Estuarine circulation"}$$

Note: if $Q_1 = Q_R$, $Q_2 = 0$. Also $Q_2 = \int^L u_e \, dx$

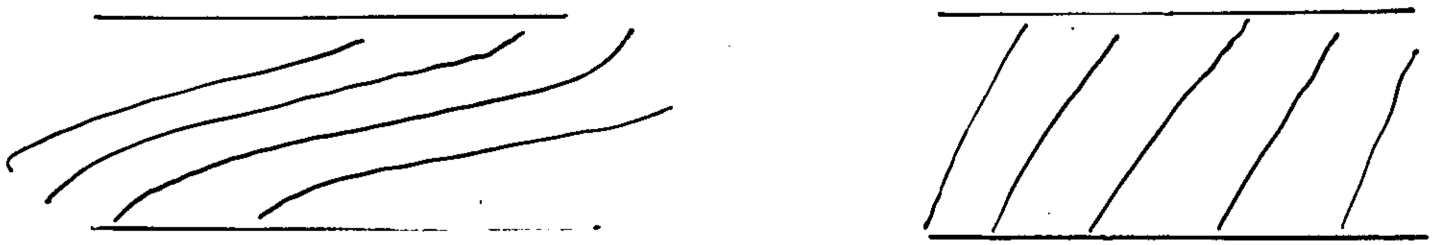
Mixing vs Circulation

Weak Mixing	Strong Mixing
Eddy viscosity K small ↓ Shears large	Eddy viscosity larg ↓ Shears small

VELOCITY



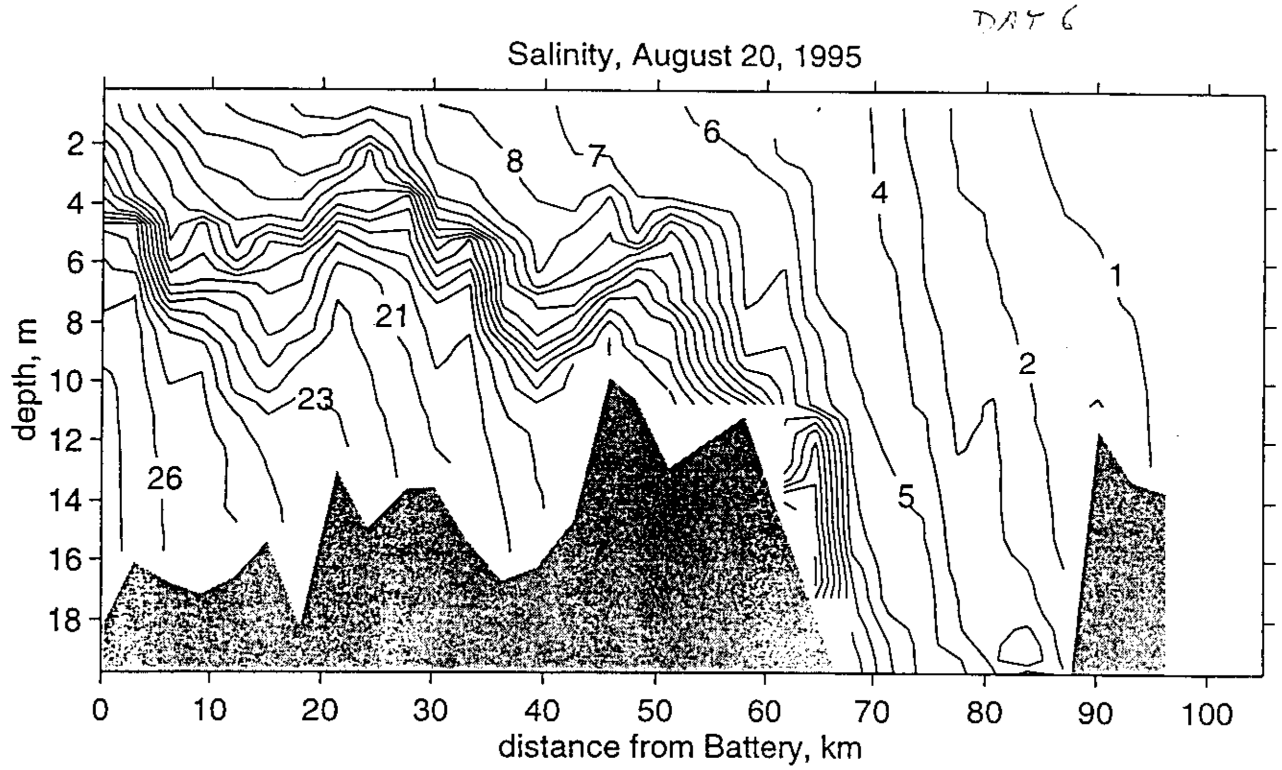
SALINITY STRUCTURE



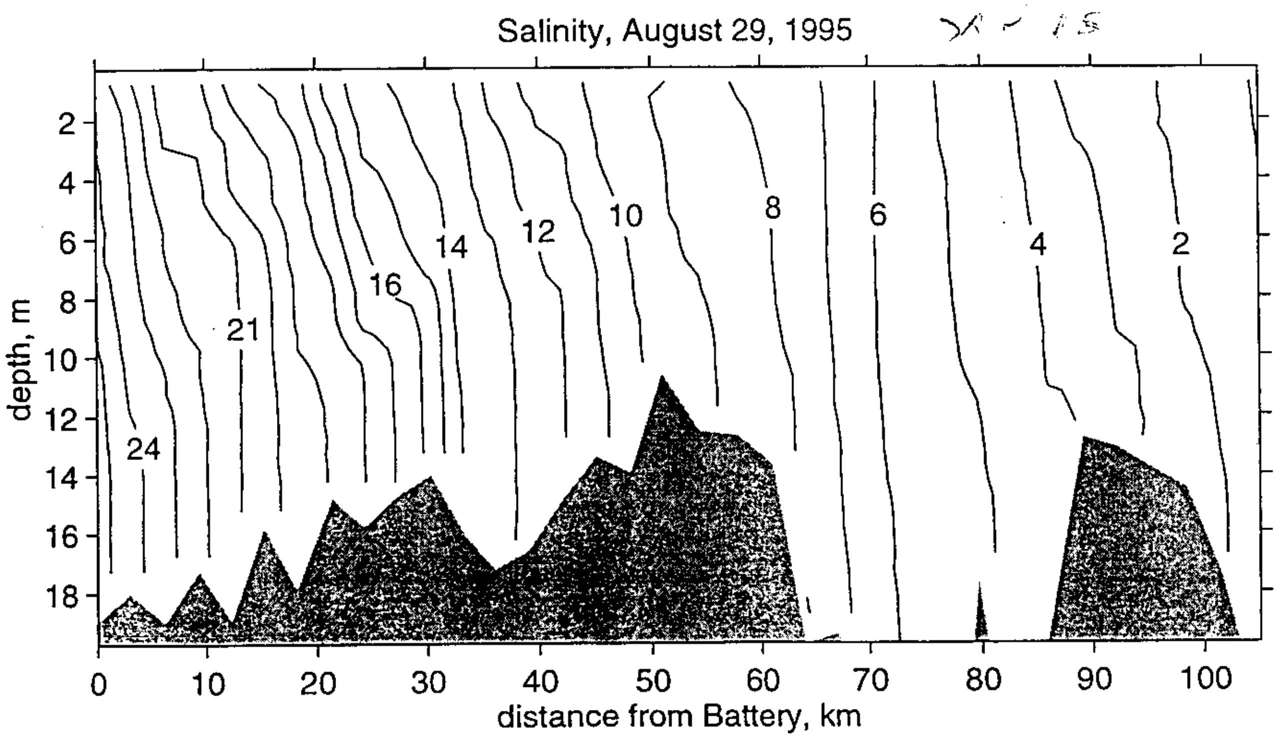
Strongly Stratified	Weakly Stratified

CONDITIONS

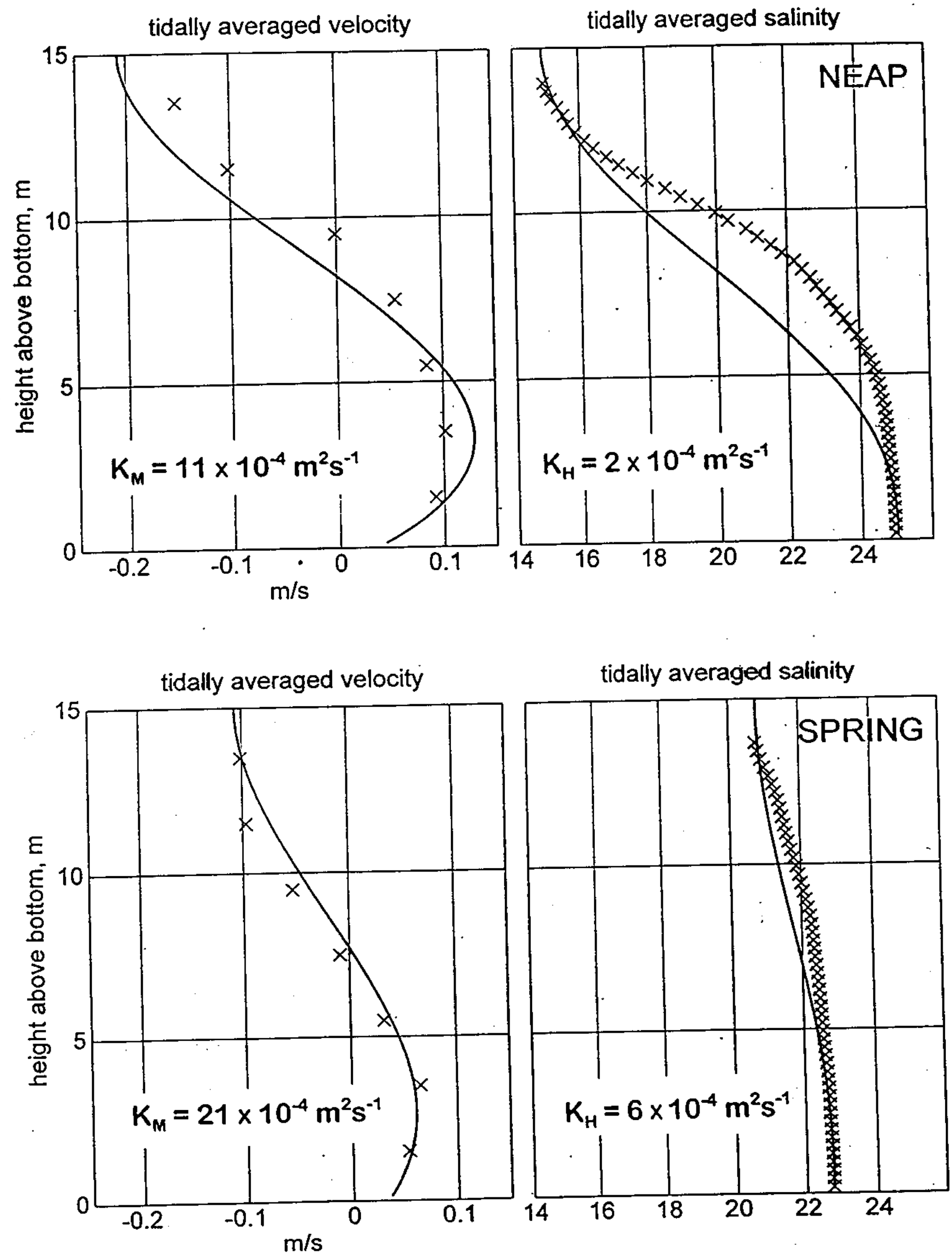
Weak Mixing	Strong Mixing
weak tides	strong tides
strong river dischange	weak river dischange



DAY 6
Salinity, August 20, 1995
depth, m
distance from Battery, km



Salinity, August 29, 1995
depth, m
distance from Battery, km


tidally averaged velocity
tidally averaged salinity
NEAP
height above bottom, m
$K_M = 11 \times 10^{-4}\ m^2s^{-1}$
$K_H = 2 \times 10^{-4}\ m^2s^{-1}$
m/s
tidally averaged velocity
tidally averaged salinity
SPRING
height above bottom, m
$K_M = 21 \times 10^{-4}\ m^2s^{-1}$
$K_H = 6 \times 10^{-4}\ m^2s^{-1}$
m/s

Hansen and Rattray (1965) Coupled balance Momentum and salt

Steady, $\partial s/\partial x$ constant in z

Momentum: $$g\frac{\partial \eta}{\partial x} + \frac{g}{\rho}\int_{-z}^{0}\frac{\partial \rho}{\partial x}\,dz = K_m \frac{\partial^2 u}{\partial z^2} \qquad (1)$$

local salt: $$u\frac{\partial S}{\partial x} = K_H \frac{\partial^2 S}{\partial z^2} \qquad (2)$$

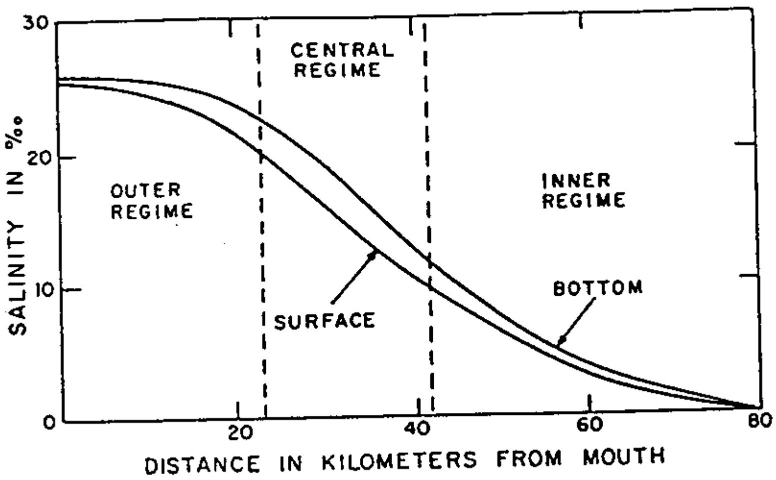
global salt $$u_f \bar{S} = \frac{1}{h}\int_{-h}^{0} u' S'\,dz - D\frac{\partial S}{\partial x} \qquad (3)$$

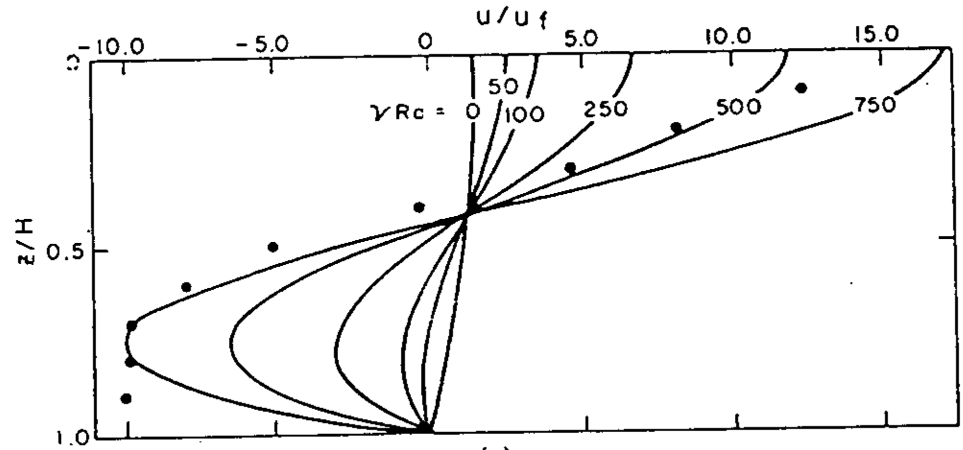
note: $\bar{S}$ denotes vertical average, S' is deviation
$u_f = -\bar{u}$

solution: $$u' = \underbrace{\frac{1}{48}\frac{g}{\rho}\frac{\partial \rho}{\partial x}\frac{h^3}{K_m}}_{u_s}\left(8\left(\frac{z}{h}\right)^3 - 9\left(\frac{z}{h}\right)^2 + 1\right)$$

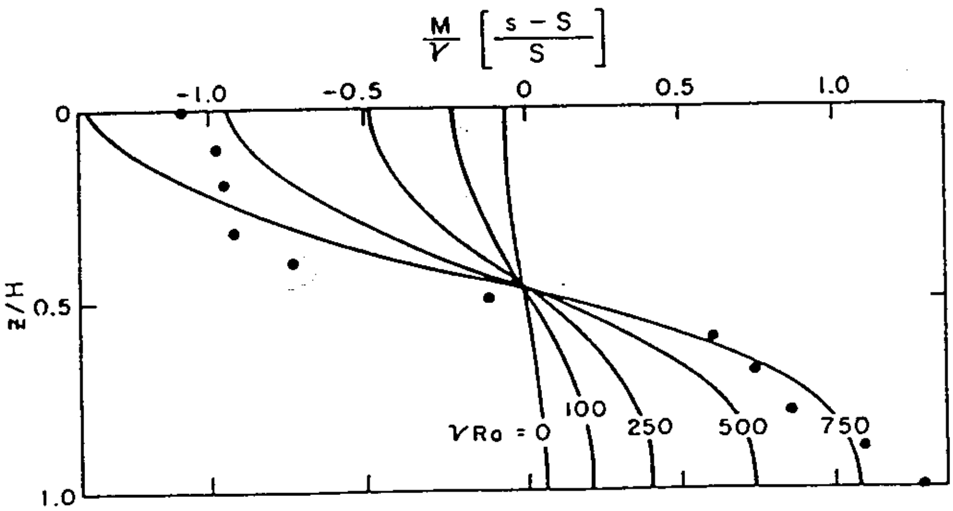
$$S' = \frac{u_s h^2}{K_H}\frac{\partial s}{\partial x}\left(\frac{2}{5}\left(\frac{z}{h}\right)^5 - \frac{3}{4}\left(\frac{z}{h}\right)^4 + \frac{1}{2}\frac{z}{h} - \frac{1}{12}\right)$$

Then, $\frac{\partial s}{\partial x}$ is determined implicitly based on (3)

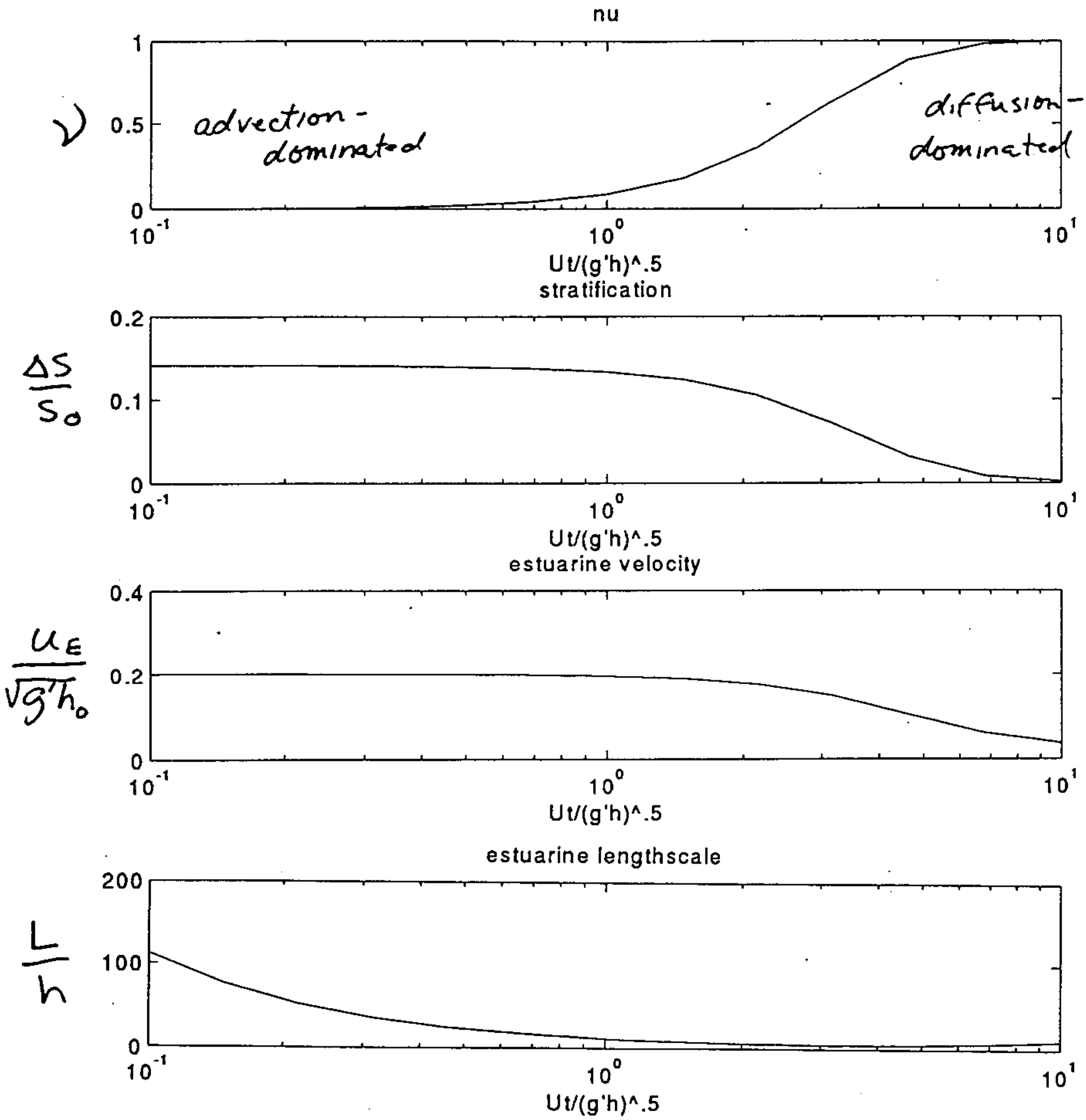

30
20
10
0
SALINITY IN ‰
CENTRAL REGIME
OUTER REGIME
INNER REGIME
SURFACE
BOTTOM
20
40
60
80
DISTANCE IN KILOMETERS FROM MOUTH

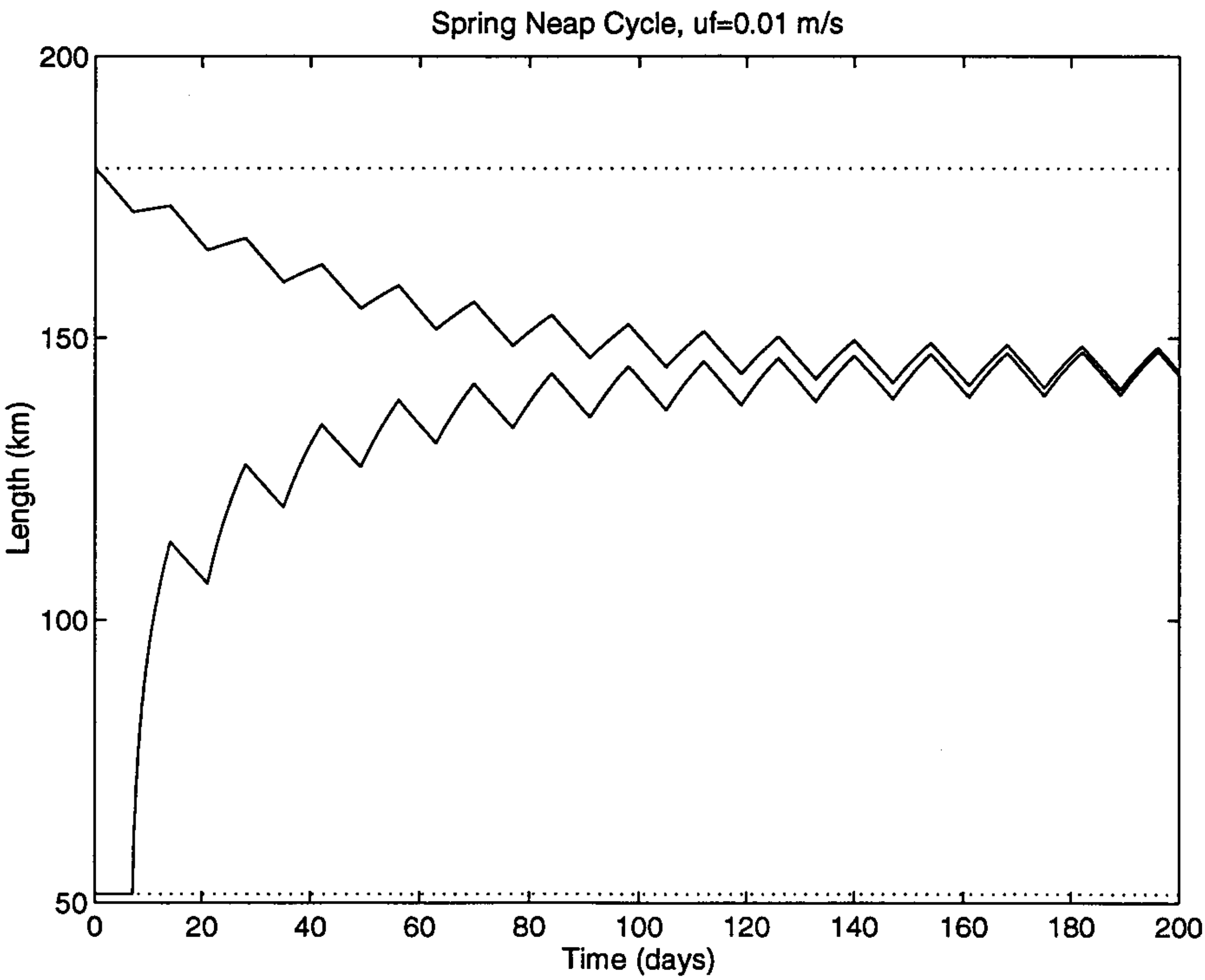

u / u f
-10.0
-5.0
0
5.0
10.0
15.0
γRc = 0
50
100
250
500
750
z/H
0.5
1.0

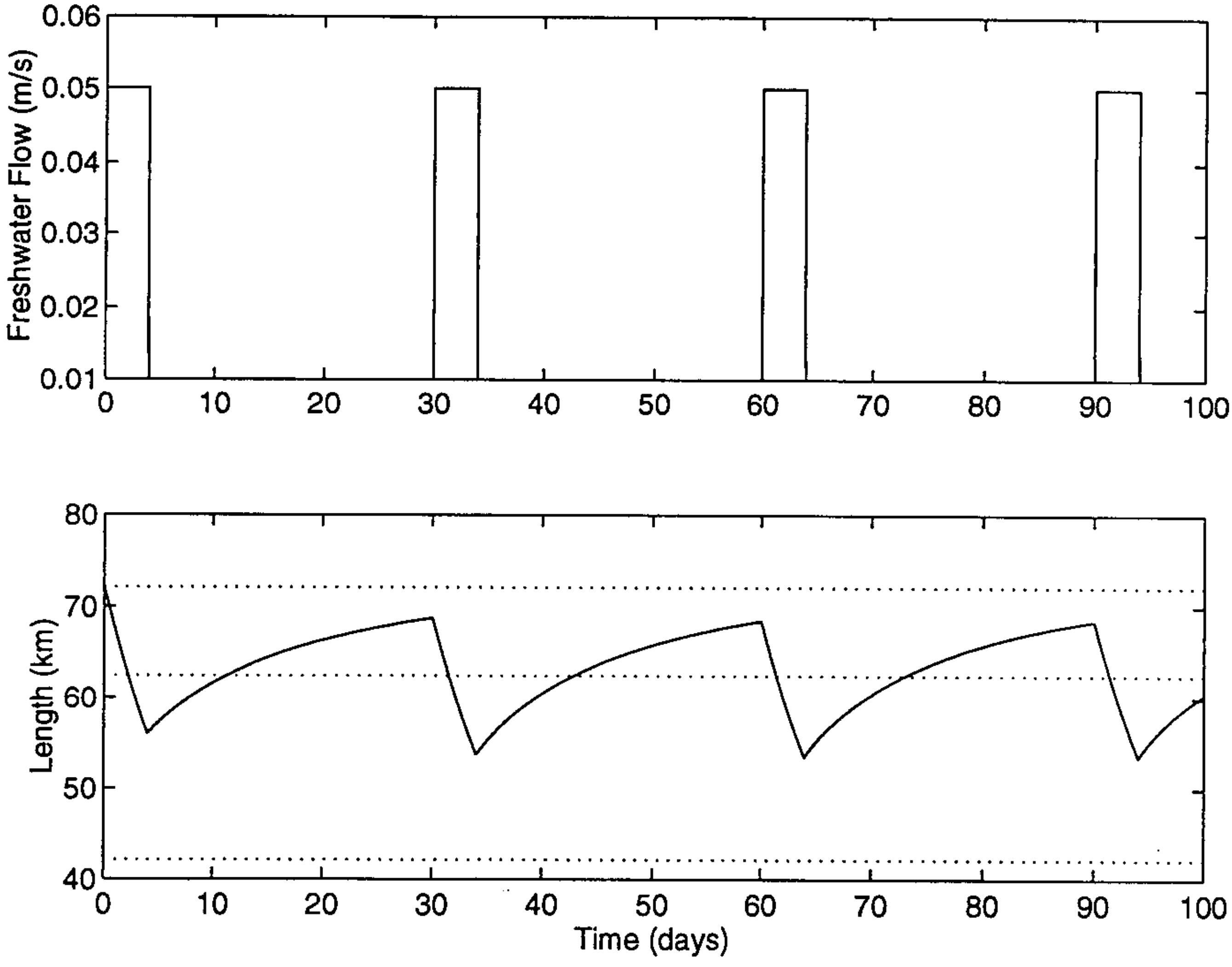
(a)

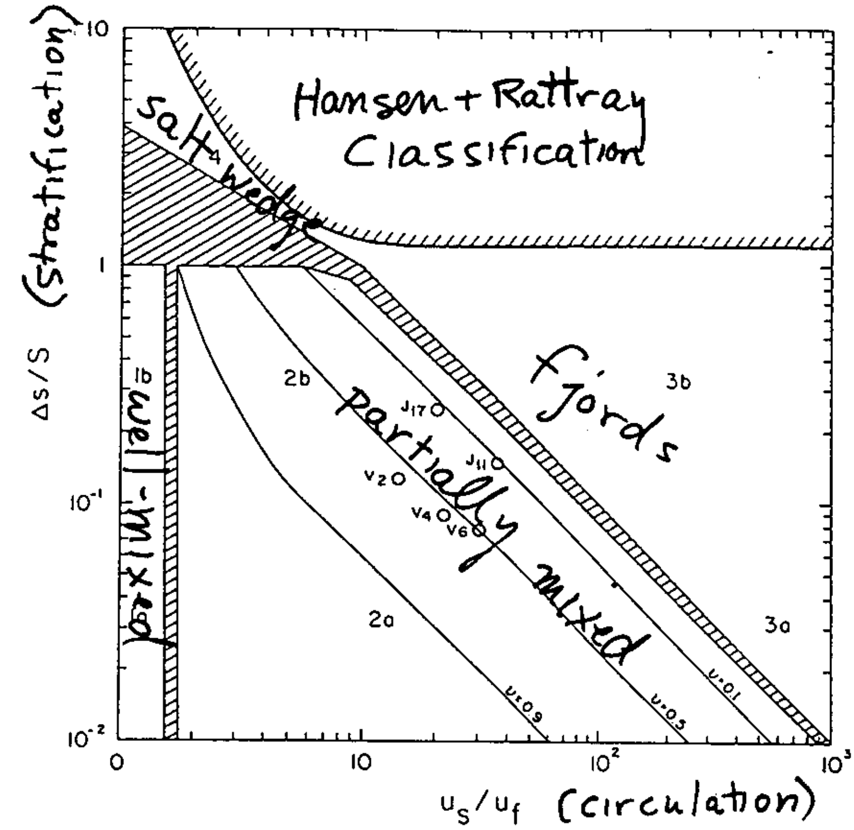

M/γ [s − S / S]
-1.0
-0.5
0
0.5
1.0
0
z/H
0.5
1.0
γRa = 0
100
250
500
750

Example: $\frac{u_f}{(g'h_o)^{1/2}} = 0.01$: Hansen - Rattray Solution

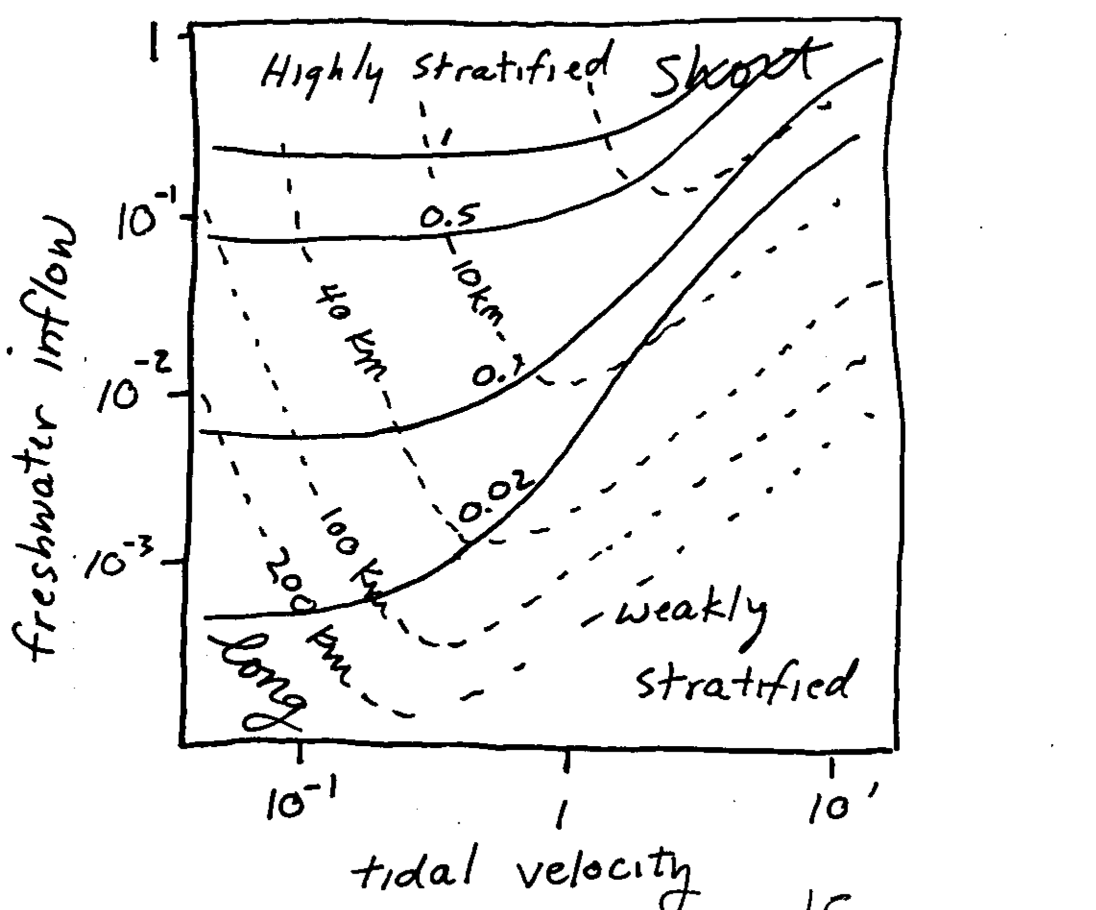


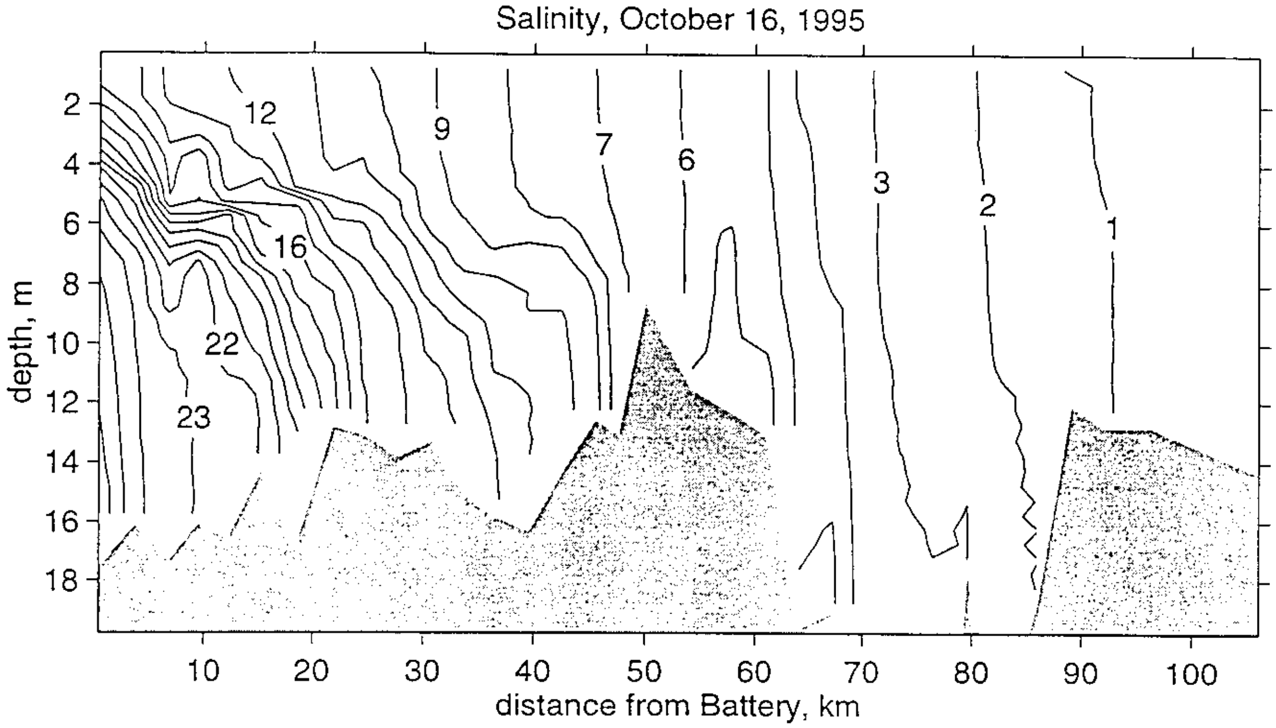

Spring Neap Cycle, uf=0.01 m/s
200
150
100
50
Length (km)
0
20
40
60
80
100
120
140
160
180
200
Time (days)

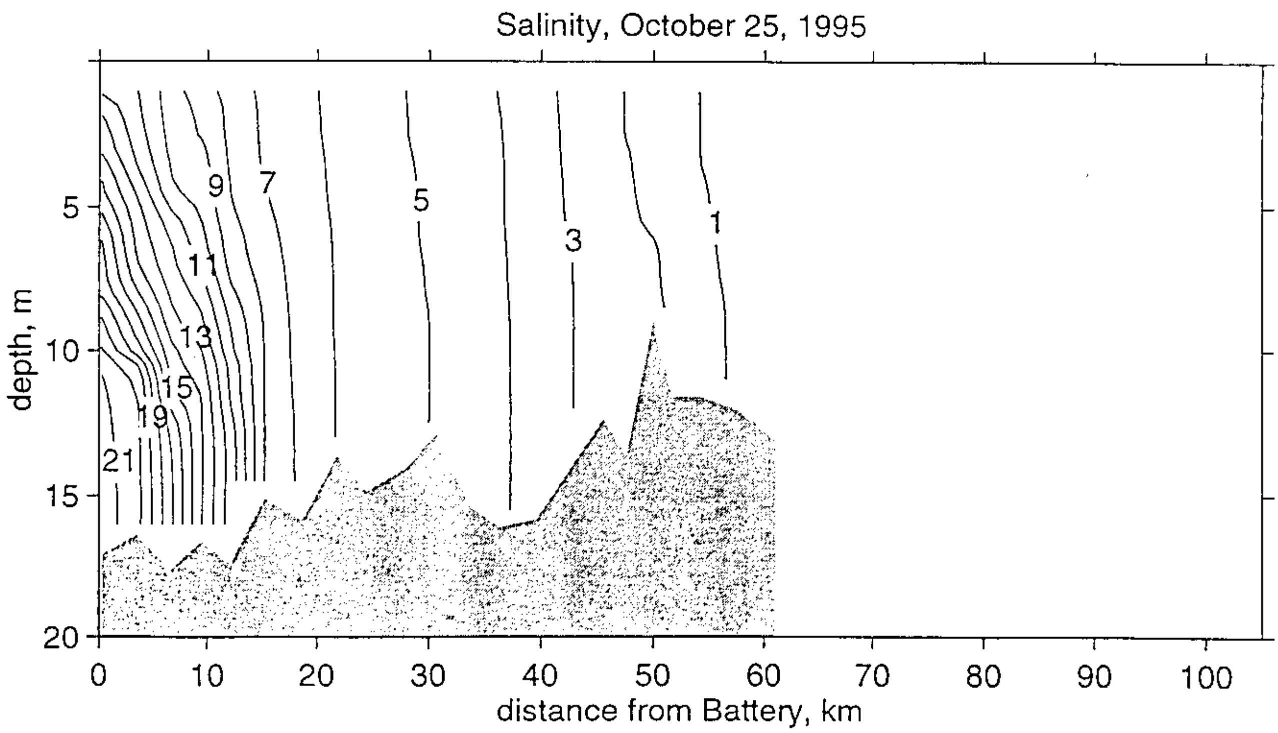

0.06
0.05
0.04
0.03
0.02
0.01
Freshwater Flow (m/s)
0
10
20
30
40
50
60
70
80
90
100
80
70
60
50
40
Length (km)
Time (days)



Classification based on forcing

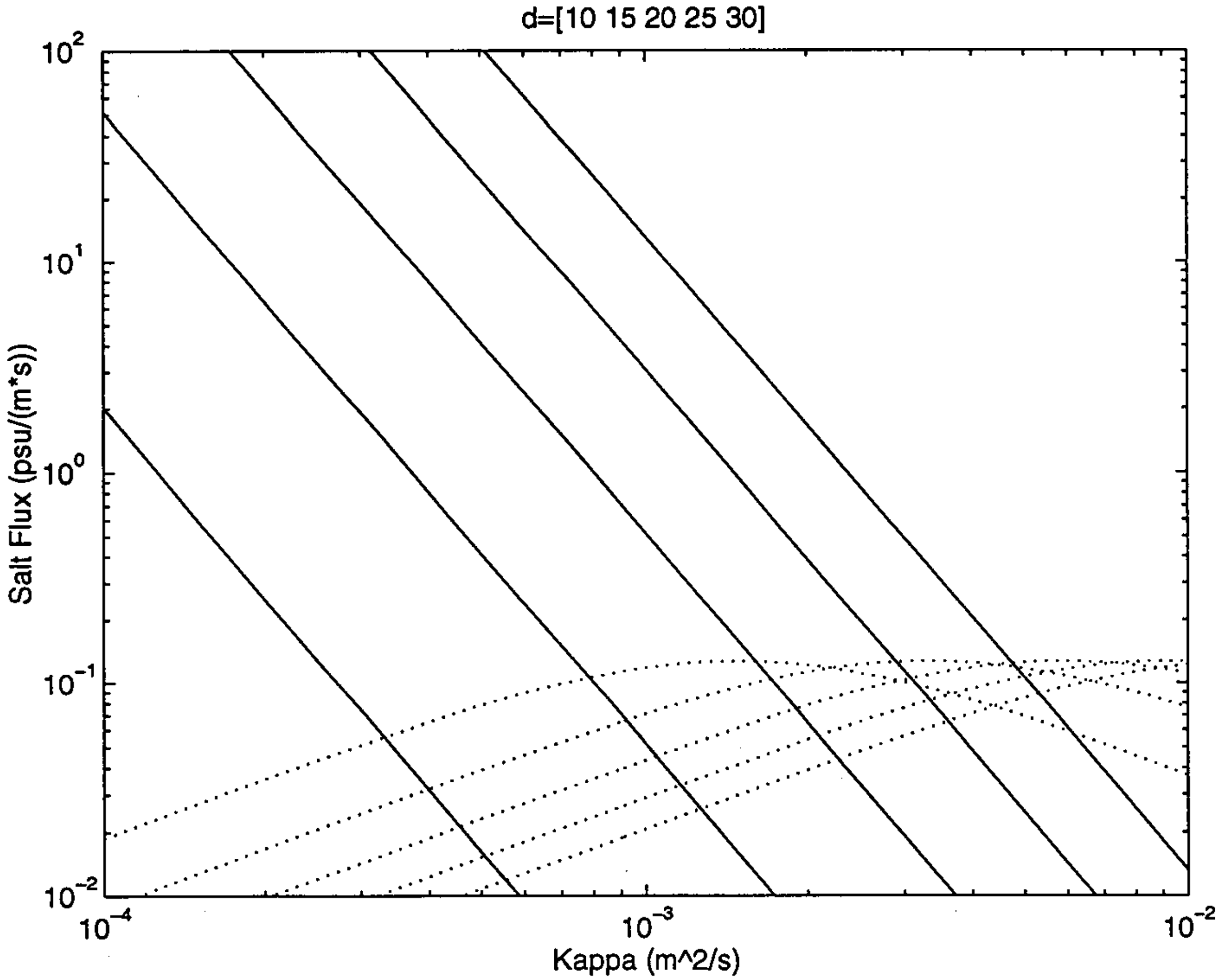



Salinity, October 16, 1995
depth, m
distance from Battery, km
12
9
7
6
3
2
1
16
22
23

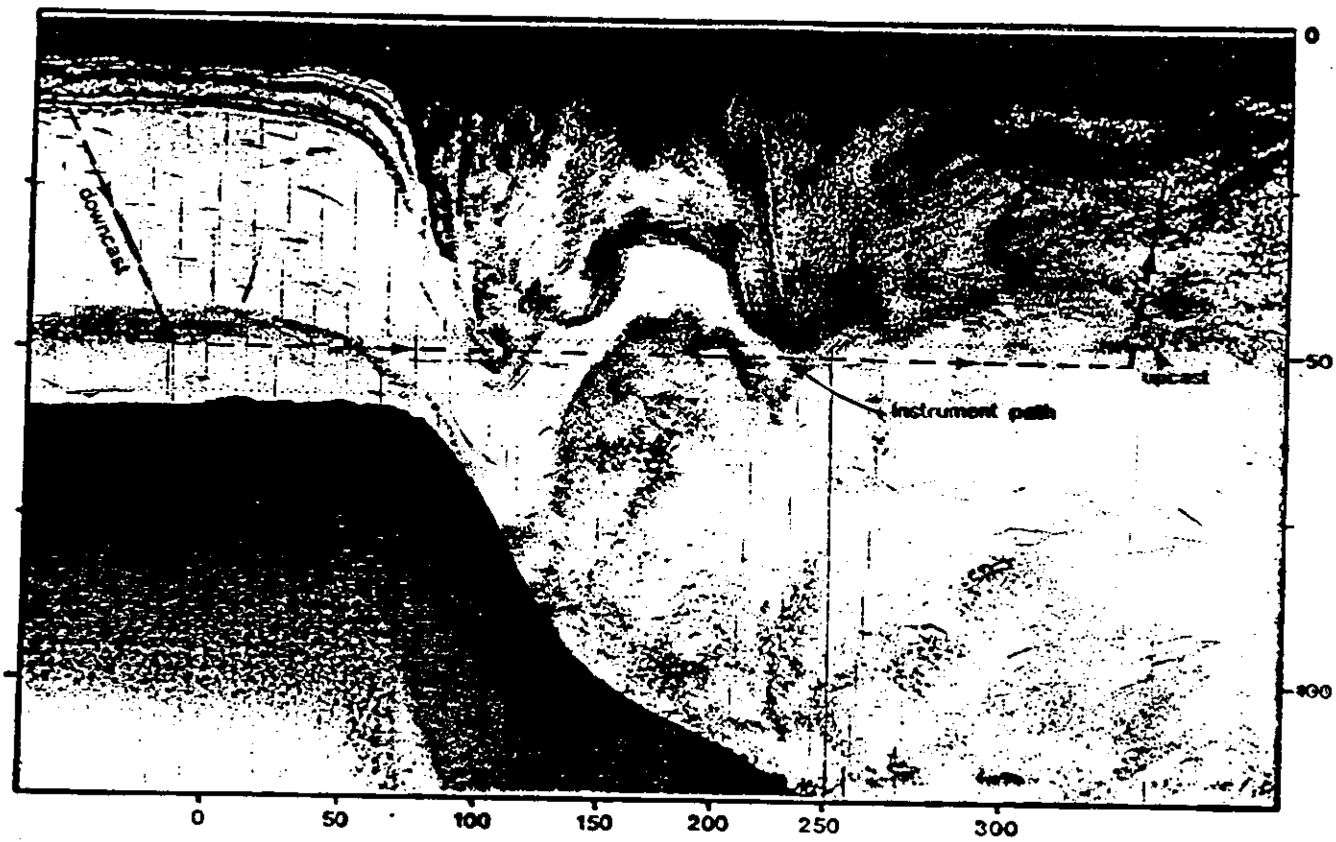

Salinity, October 25, 1995
depth, m
distance from Battery, km
9
7
5
3
1
11
13
15
19
21

16

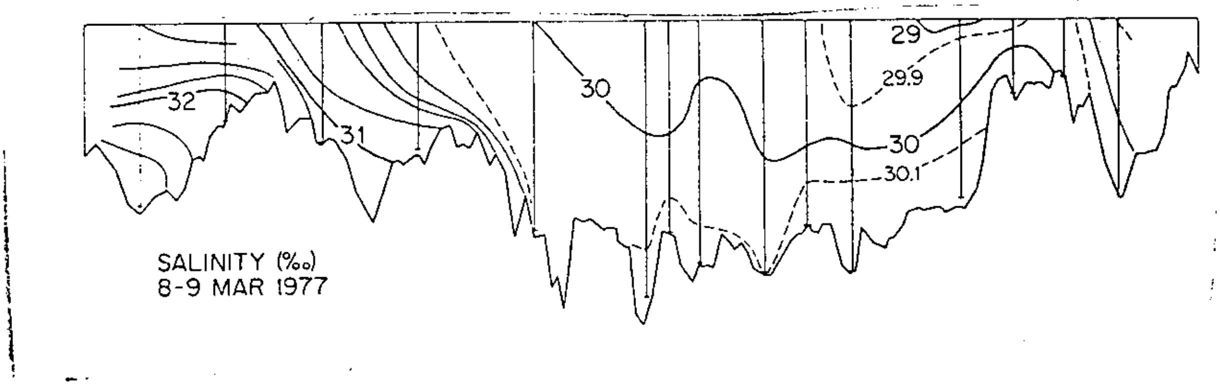
Oscillatory shear dispersion vs mean estuarine circulation



KNIGHT INLET SILL

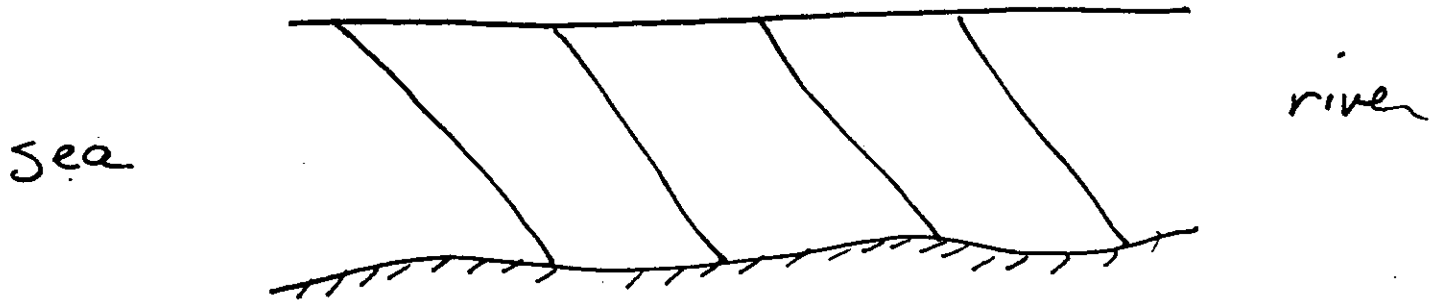


Farmer + Freeland, 1983

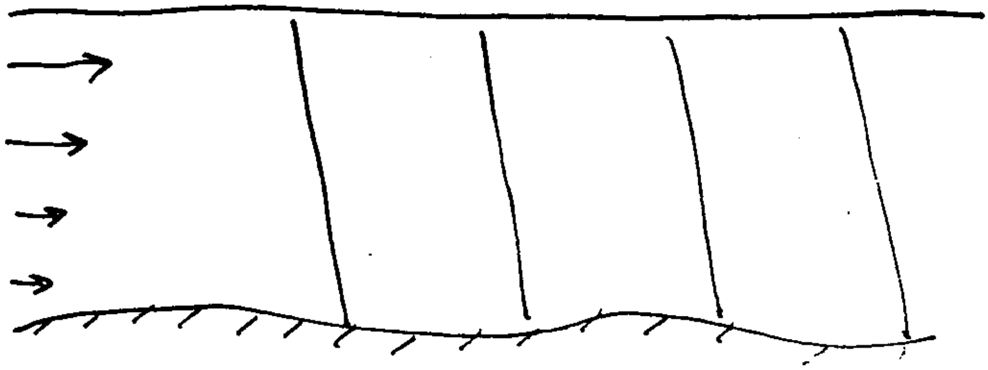


Tidal Straining

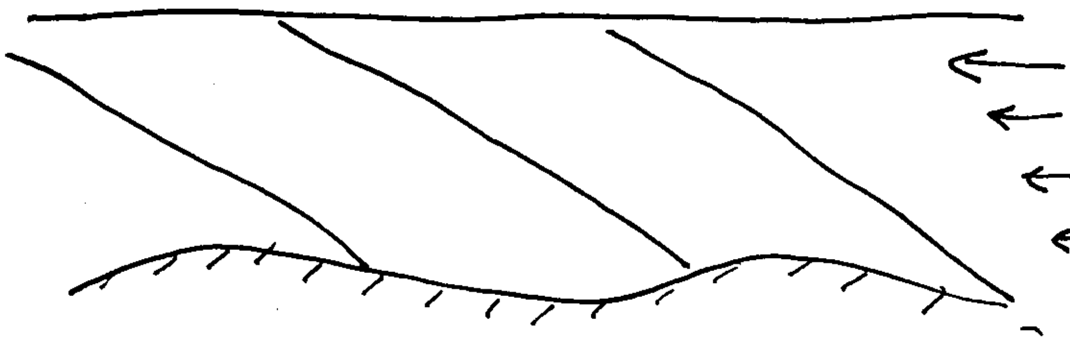
Mean salinity structure



Flood

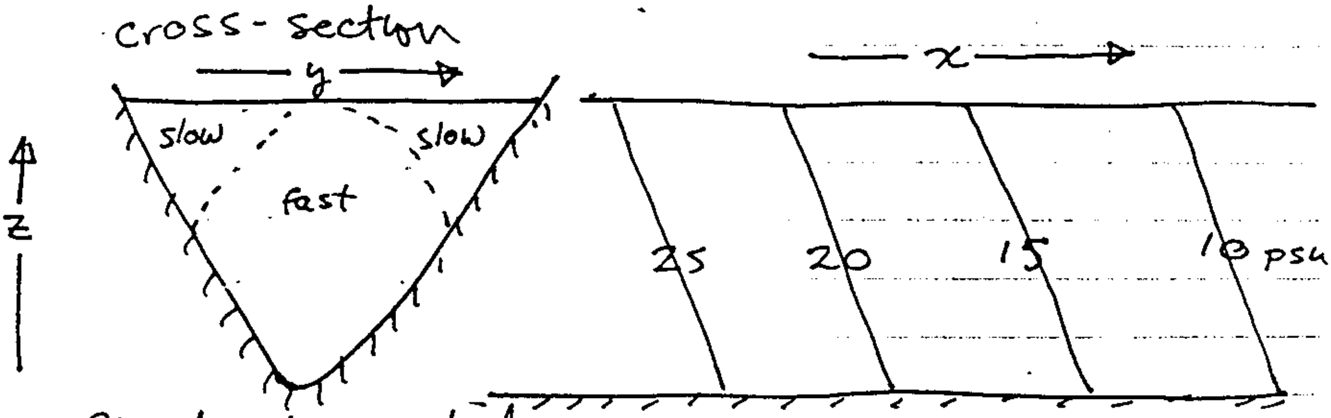


Ebb

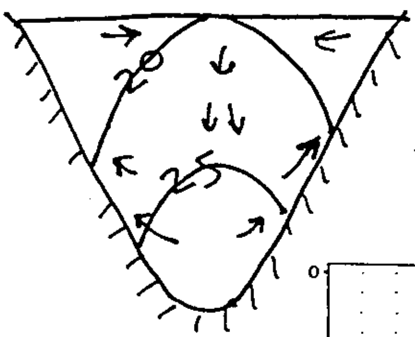


May have implications on vertical mixing rates and bottom stress — but note — $\frac{\partial S}{\partial z}$ is in quadrature with $\frac{\partial u}{\partial z}$

Lateral convergence fronts



flood - strong tides



Nunes and Simpson, 1985.

Axial convergence in a well-mixed estuary 645

Est. Coastal Shelf Sci. 20 637-645

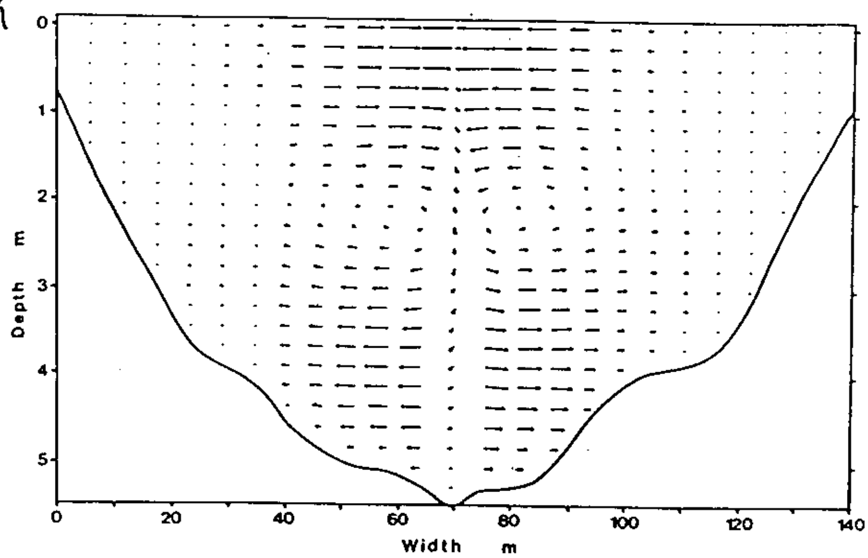
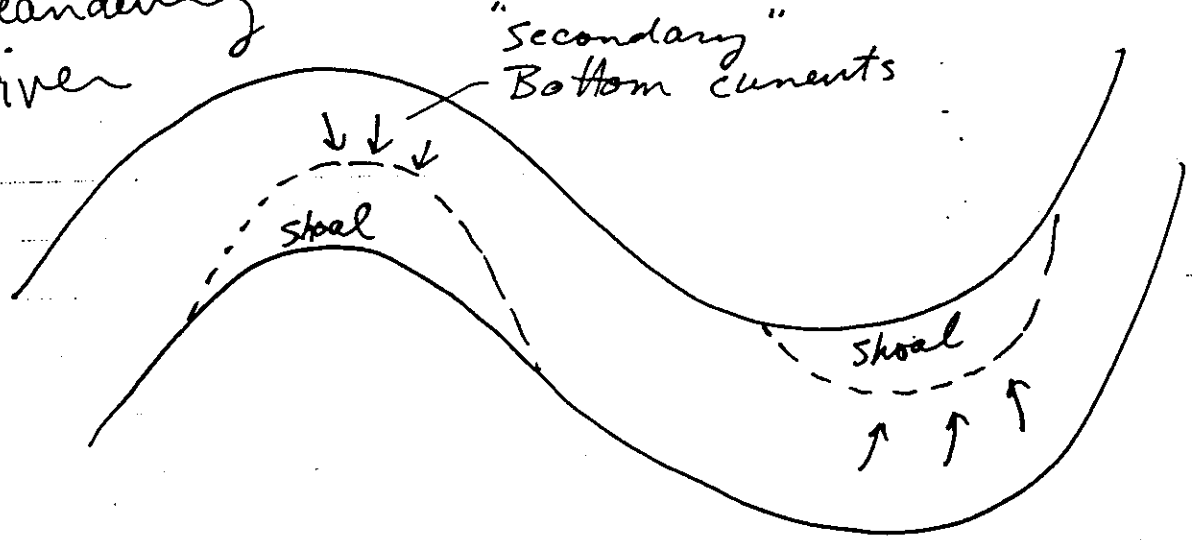
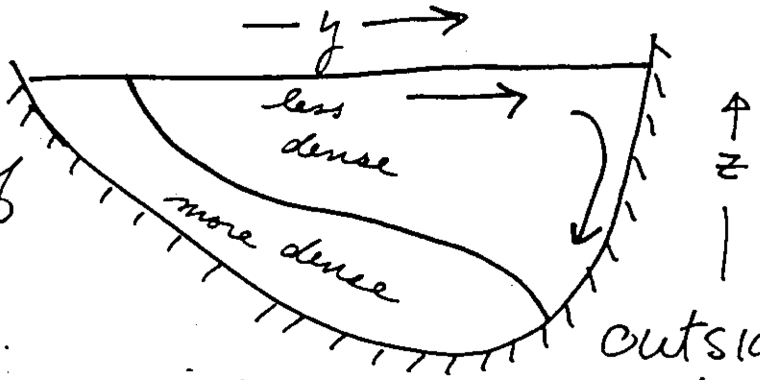


Figure 6. Transverse circulation for flood on 15 October 1980, computed from equation (7) and the density gradients of Figure 4 (b)—maximum $v = 7{\cdot}53$ cm s^{-1}, maximum $w = 1{\cdot}65$ cm s^{-1}.

Meandering river



Estuary



"cyclostrophic" balance

$$\frac{g}{\rho}\frac{\partial \rho}{\partial y} = -\frac{2u}{R}\frac{\partial u}{\partial z}$$

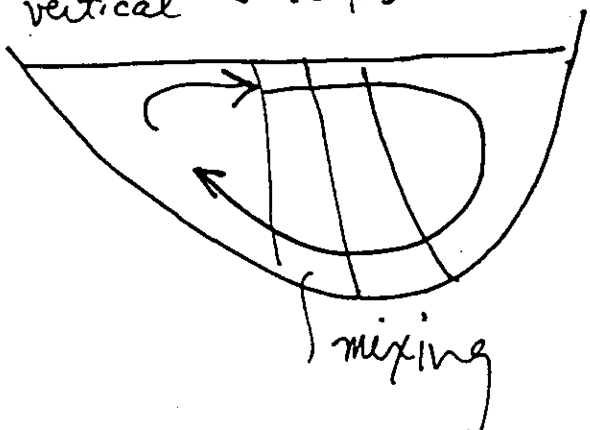
Take $u = 1\ m\,s^{-1}$, $\partial u/\partial z = 0.1\ s^{-1}$

$R = 1\ Km$

$$\frac{g}{\rho}\frac{\partial \rho}{\partial y} = 2\times10^{-4}$$

about 10 psu / 500 m -
a good gradient!

If $\Delta S_{\text{vertical}} < 10\,\text{psu}$

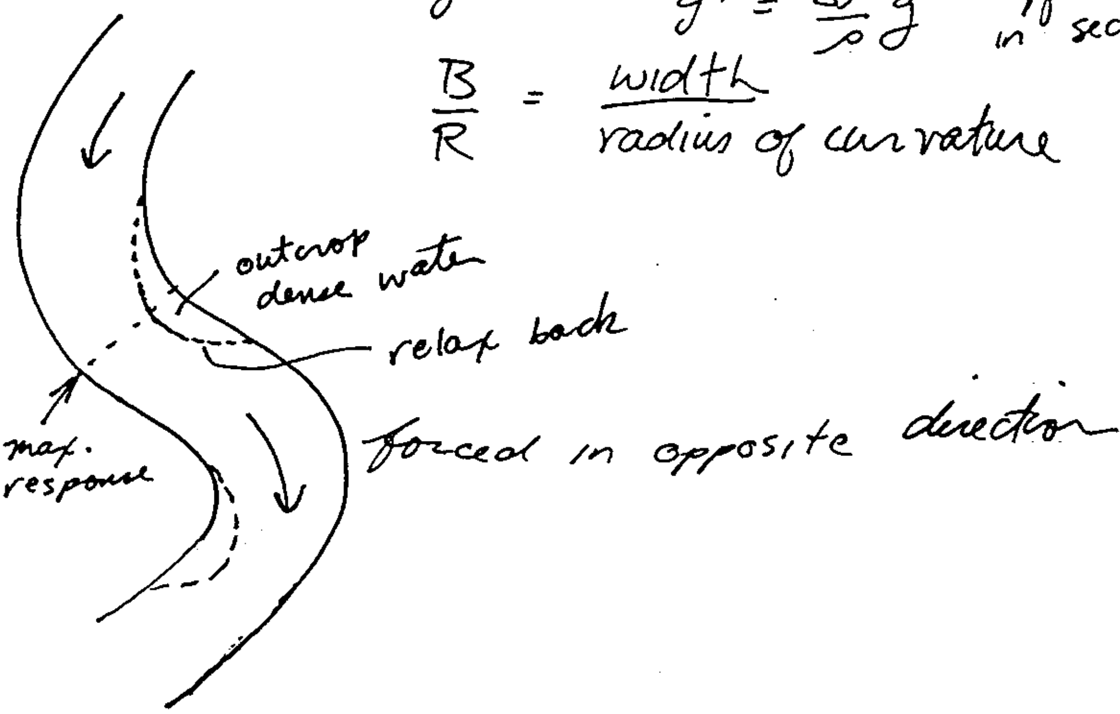


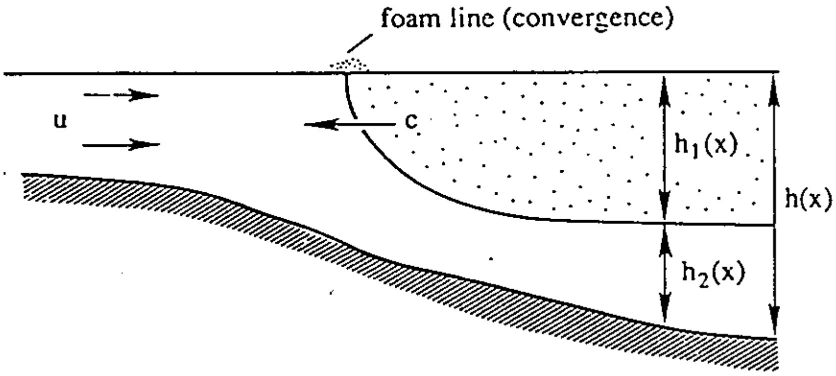
Based on cyclostrophic balance — criterion for mixing (approximate)

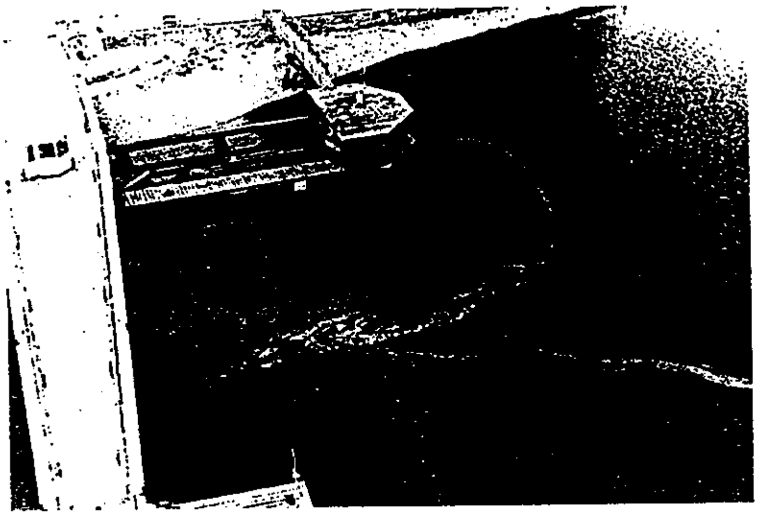
$$\frac{u^2}{g'h}\frac{B}{R} > 1$$

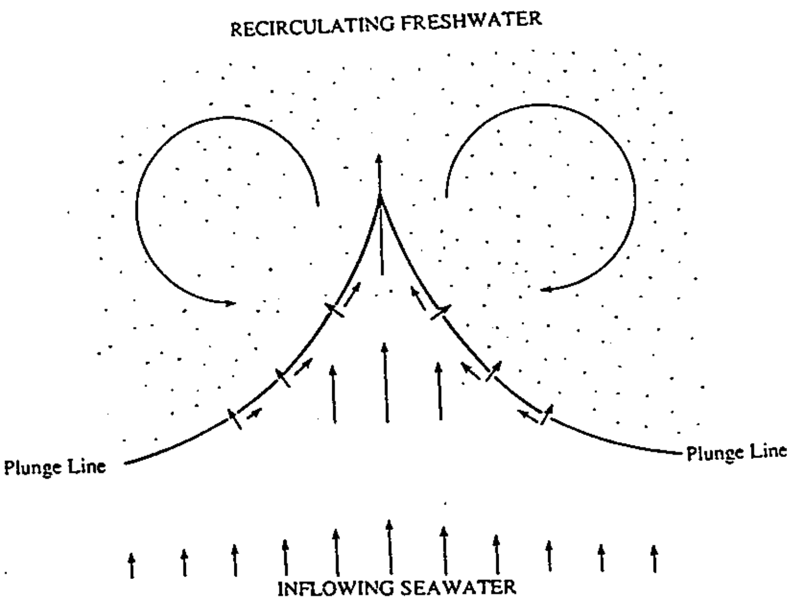
$g' = \frac{\Delta\rho}{\rho} g$ ($\Delta\rho$ = total density difference in section)

$\frac{B}{R} = \frac{\text{width}}{\text{radius of curvature}}$




foam line (convergence)
u
c
$h_1(x)$
$h(x)$
$h_2(x)$




RECIRCULATING FRESHWATER
Plunge Line
Plunge Line
INFLOWING SEAWATER