UNIVERSITY OF ALBERTA

MODELING STRATIFICATION UPSTREAM OF A DAM: IT'S IMPACT & NECESSITY

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OUTLINE

Introduction

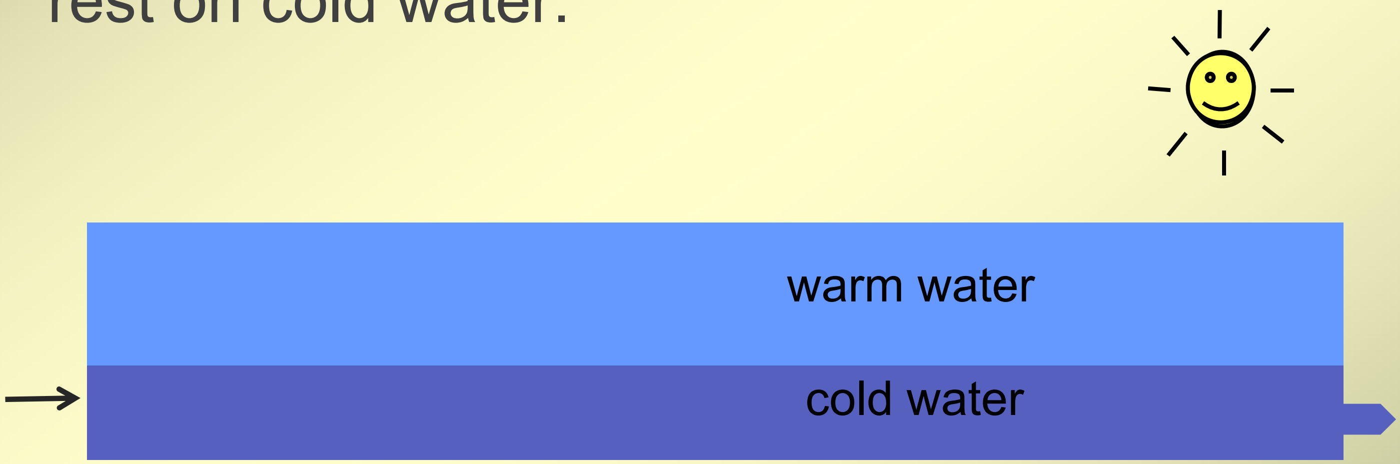
CFD modeling of stratification

Theoretical works on stratification

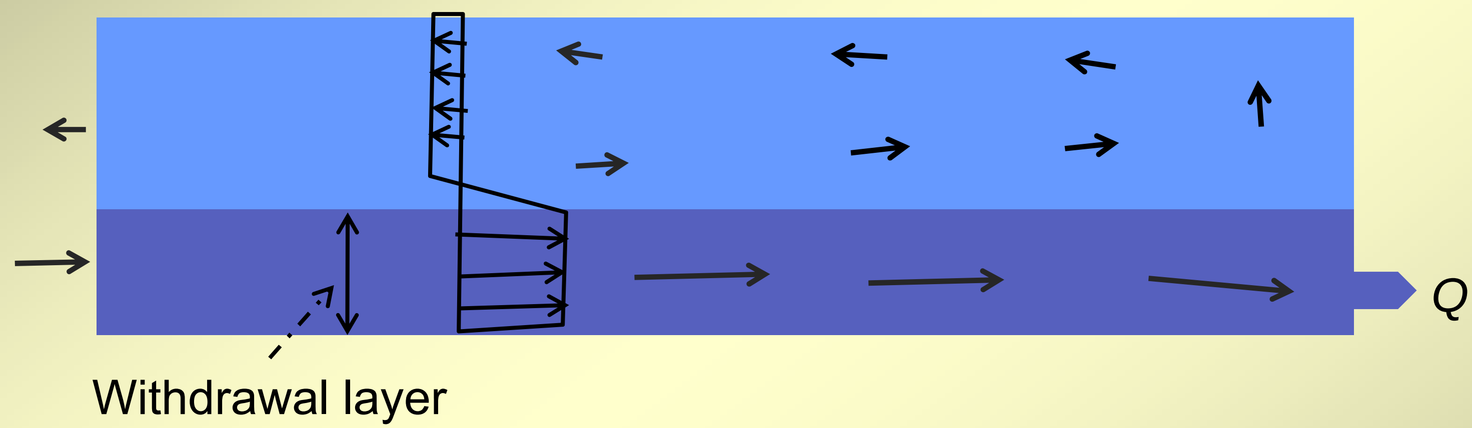
Conclusions

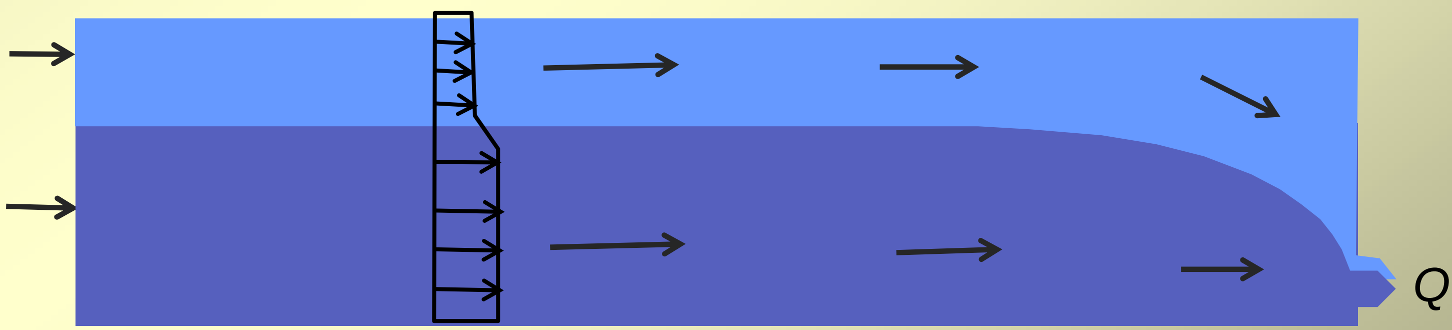
STRATIFICATION

Water in a reservoir can be heated and warm water can rest on cold water.



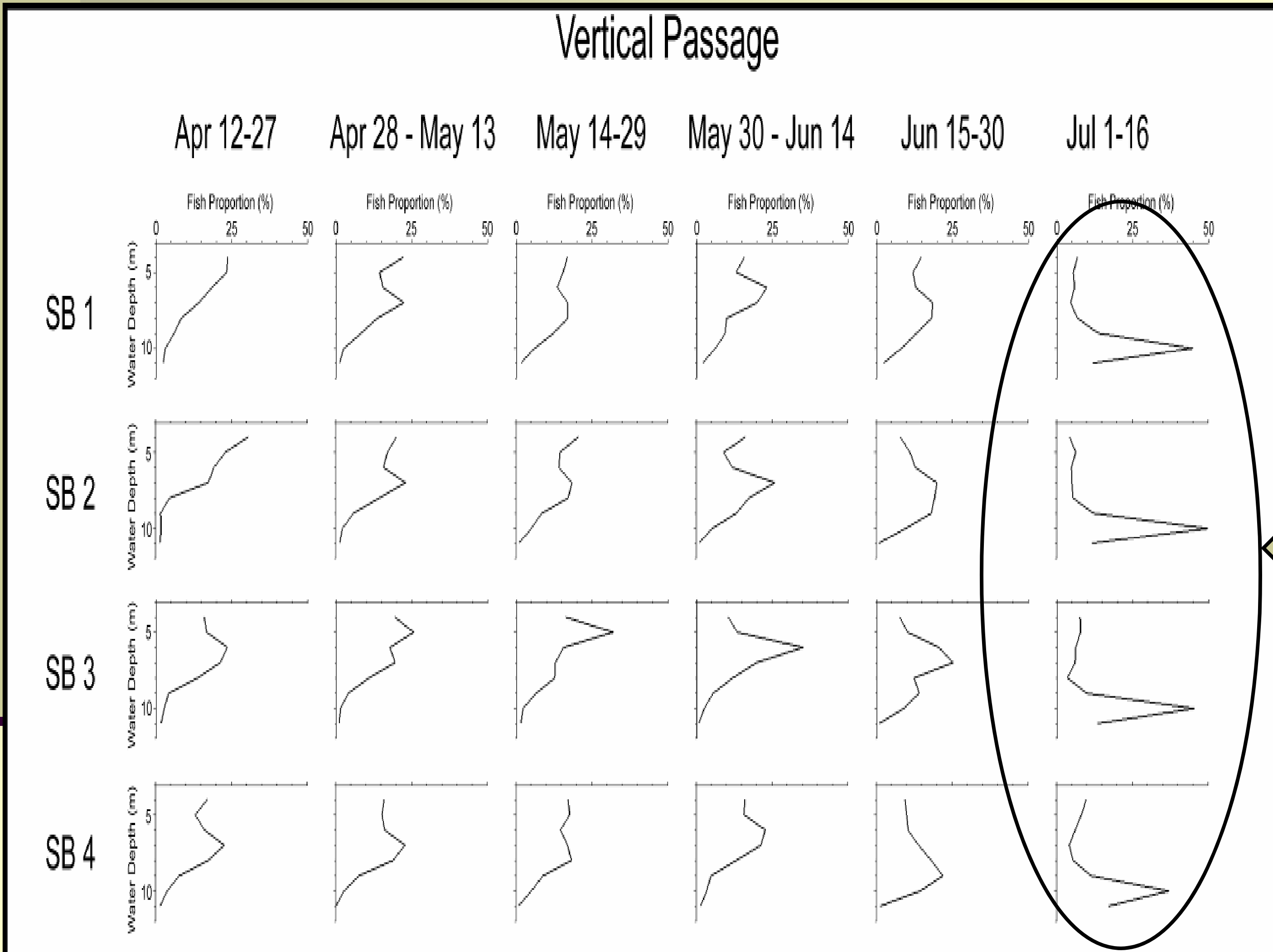
Hydropower intake can withdraw one layer or both layers.





This may affect fish entrainment pattern

SEVERAL EVIDENCES

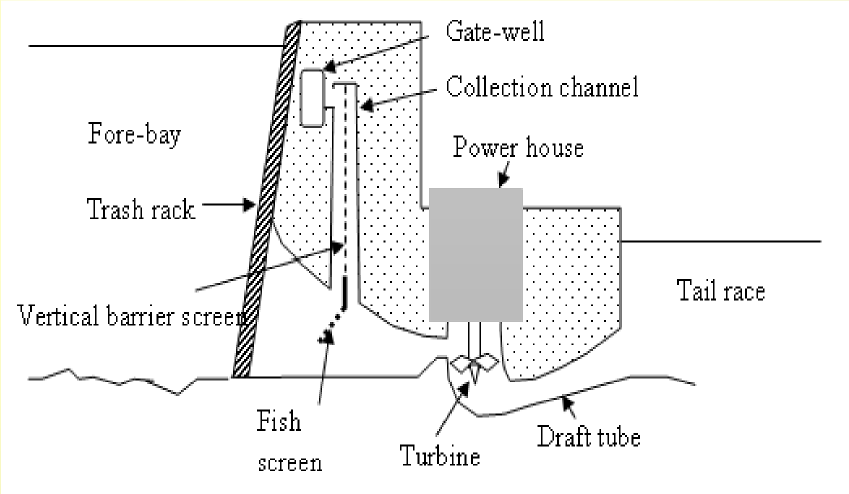


Distribution is different in Summer.

Vertical distribution of entrained fish at The Dalles dam spillway (Johnson et al., 2007)

Ploskey and Carlson (1999) found lower Fish Guidance Efficiency (FGE) in summer compared to the FGE in spring in the John Day dam.

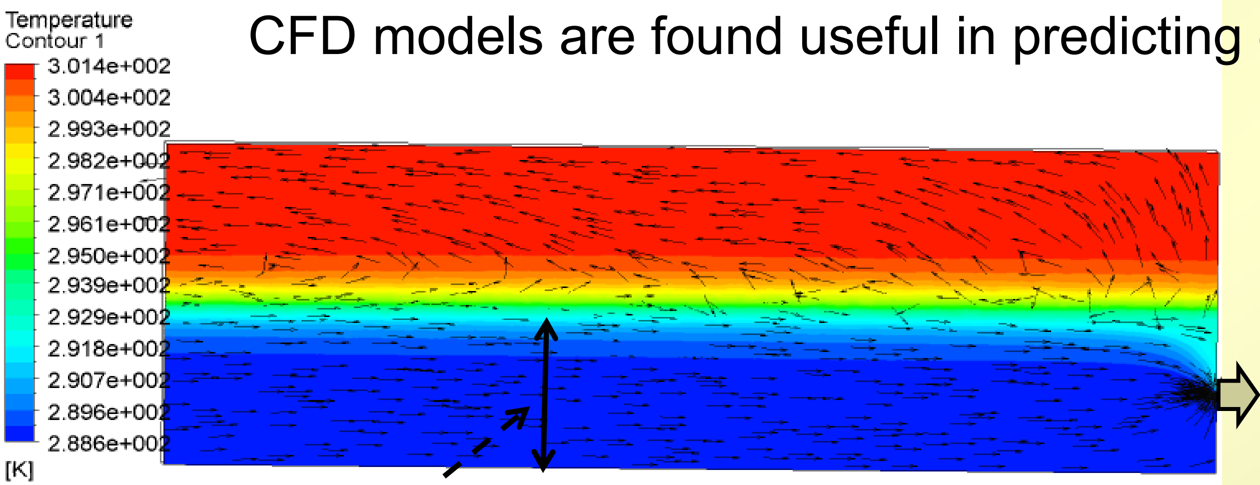
FGE = fish caught in screen/ total entrained fish



Stratification can be a cause of seasonality in fish entrainment pattern along with other causes.

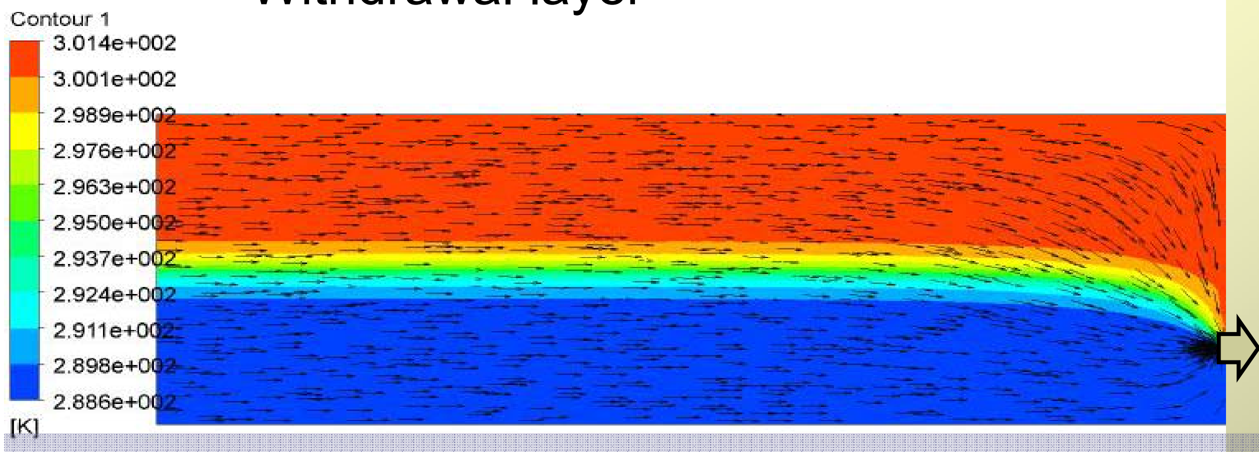
CFD MODELING of STRATIFICATION

CFD models are found useful in predicting effect of stratification.



Froude number 0.6
(point sink)

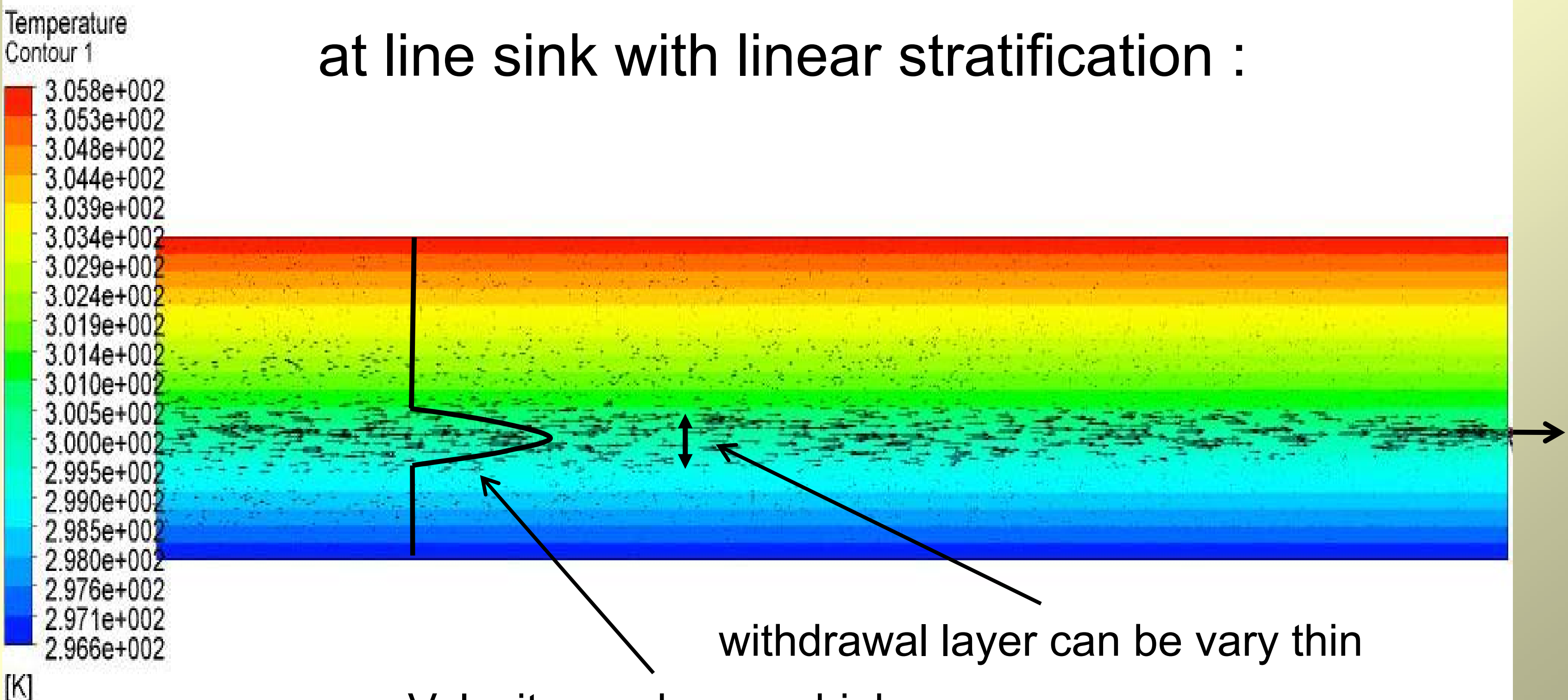
Withdrawal layer



Froude number 3.0
(point sink)

(Arrows showing direction only)

at line sink with linear stratification :

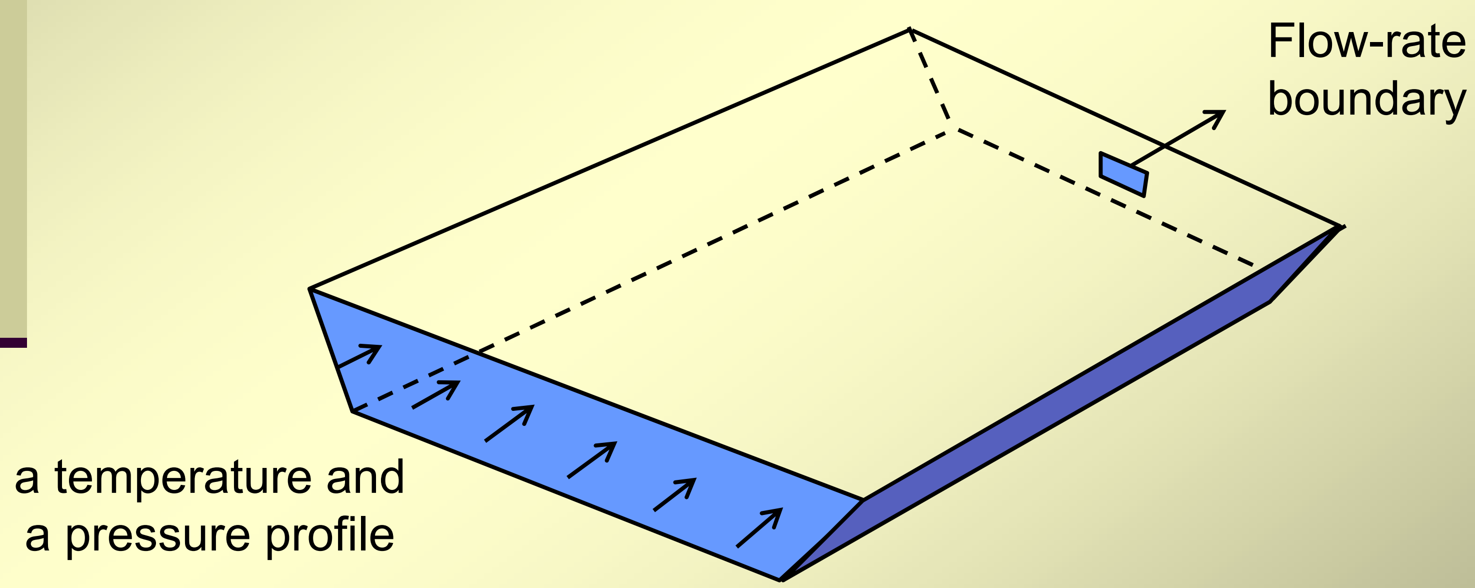


withdrawal layer can be vary thin

Velocity can be very high

This may drift small fish towards the intake

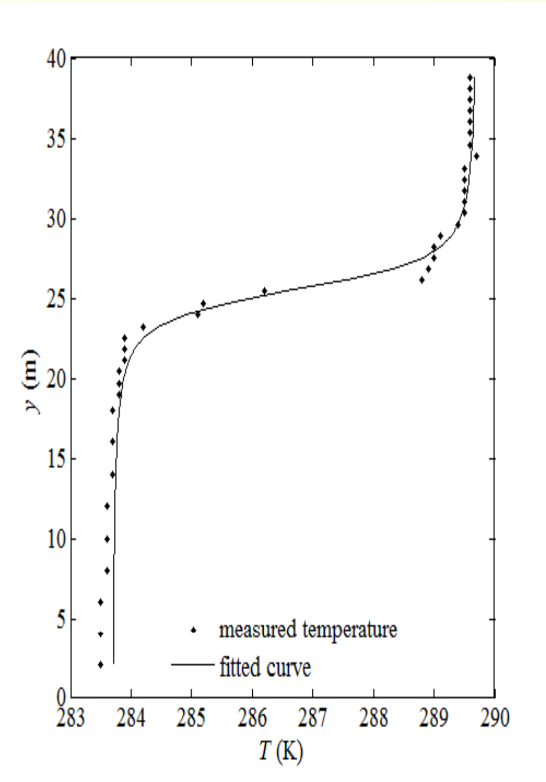
MODEL DESCRIPTION



TEMPERATURE PROFILE

Temperature profile:

$$T = \frac{c_1\left(y - c_2\right)}{\sqrt{c_3 + \left(y - c_2\right)^2}} + c_4$$



Density profile:

$$\rho = a_1 T^2 + a_2 T + a_3 \qquad 277 \le T \le 313$$

PRESSURE PROFILE

Pressure profile is computed by solving the integration:

$$\int_{y}^{h_b} dp = \int_{y}^{h_b} \left(\rho - \rho_{ref}\right) g\,dy$$

which yields:

$$p = a_1 c_1^2 + a_1 c_4^2 + a_2 c_4 + a_3 - \rho_{ref})(H - y)g + (2a_1 c_1 c_4 + a_2 c_1)g$$

$$\left[\left\{ \left(H - c_2\right)^2 + c_3 \right\}^{1/2} - \left\{ \left(y - c_2\right)^2 + c_3 \right\}^{1/2} - a_1 c_1^2 \sqrt{c_3} \left\{ \tan^{=1}\left(\frac{H - c_2}{\sqrt{c_3}} \right) - \tan^{=1}\left(\frac{y - c_2}{\sqrt{c_3}} \right) \right\} \right]$$

This pressure profile is to be used in the upstream boundary.

THE CFD SOLVER (ANSYS CFX)

Temperature transport:

$$\frac{\partial \rho T}{\partial t} + \frac{\partial \rho u_j T}{\partial x_j} = \frac{k_t}{c} \frac{\partial}{\partial x_j}\left(\frac{\partial T}{\partial x_j}\right)$$

Density estimation:

$$\rho = a_1 T^2 + a_2 T + a_3 \qquad 277 \le T \le 313$$

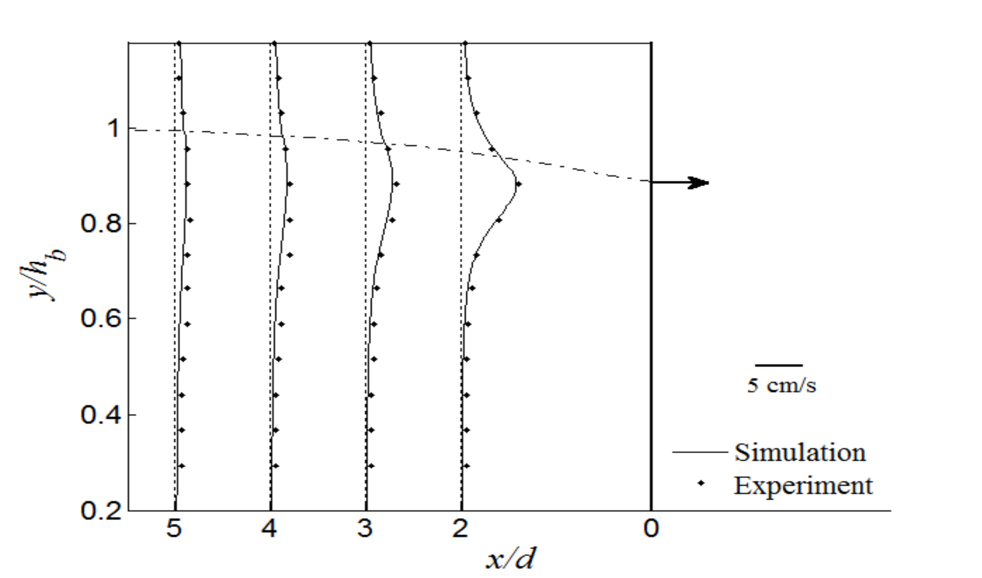
Turbulence model: Eddy viscosity (μ_t)

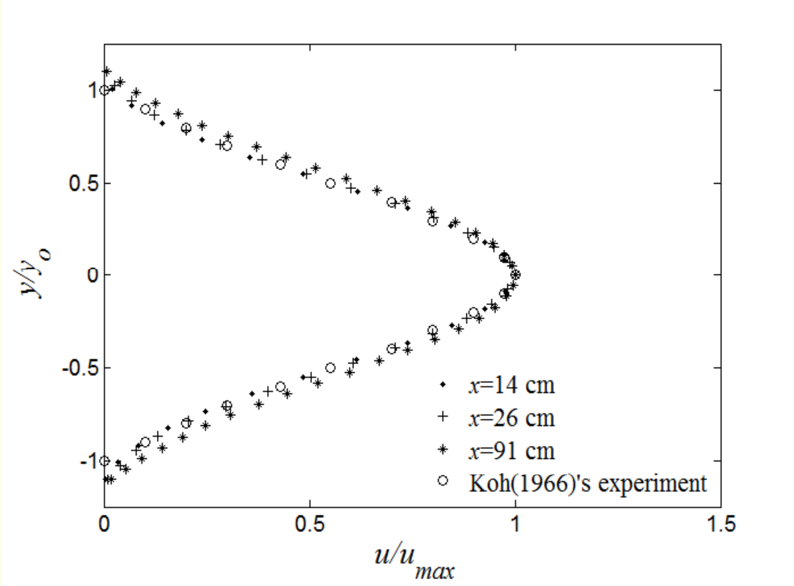
Navier-Stokes:

$$\frac{\partial \rho}{\partial t} + \frac{\partial \rho u_j}{\partial x_j} = 0$$

$$\frac{\partial \rho u_i}{\partial t} + \frac{\partial \rho u_j u_i}{\partial x_j} = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}\left\{(\mu + \mu_t)\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right) - \frac{2}{3}\rho k \delta_{ij}\right\} + (\rho - \rho_{ref}) g_i$$

MODEL VALIDATION





Shammaa and Zhu (2010)'s experiment:
Point sink, discrete stratification

Koh (1966)'s experiment:
Line sink, linear stratification

Field measurement of M. Langford and B. Robertson used for validation

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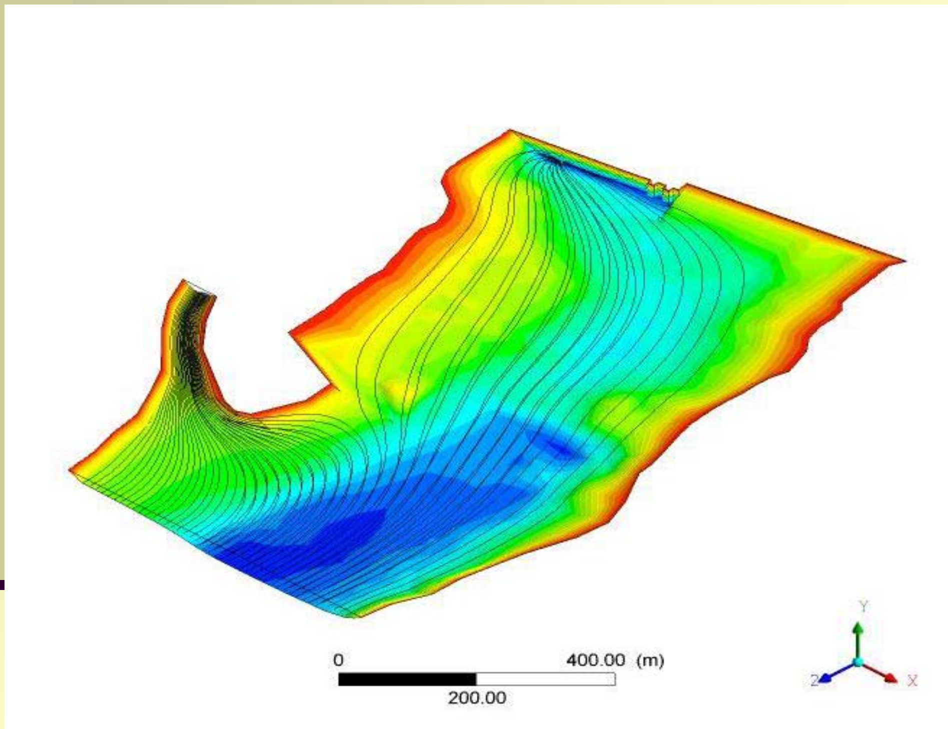
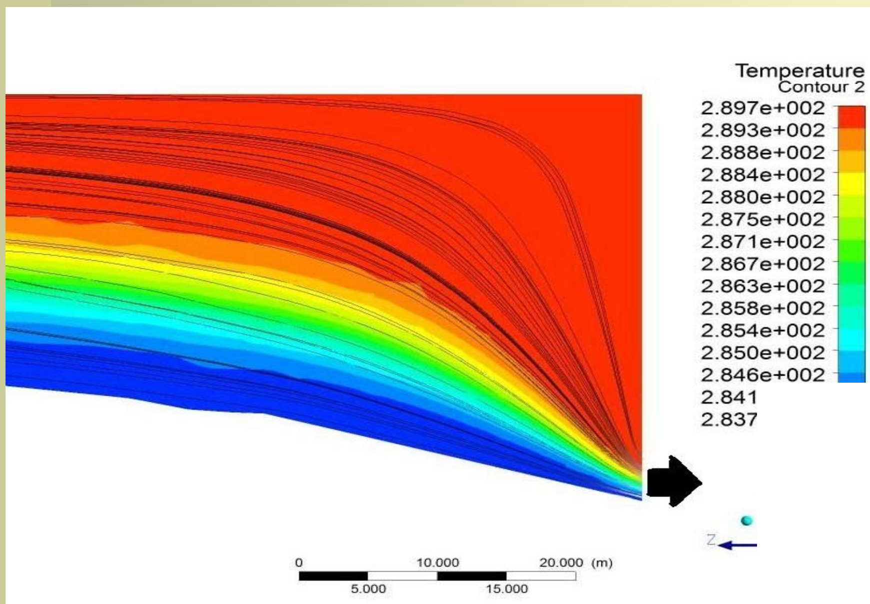
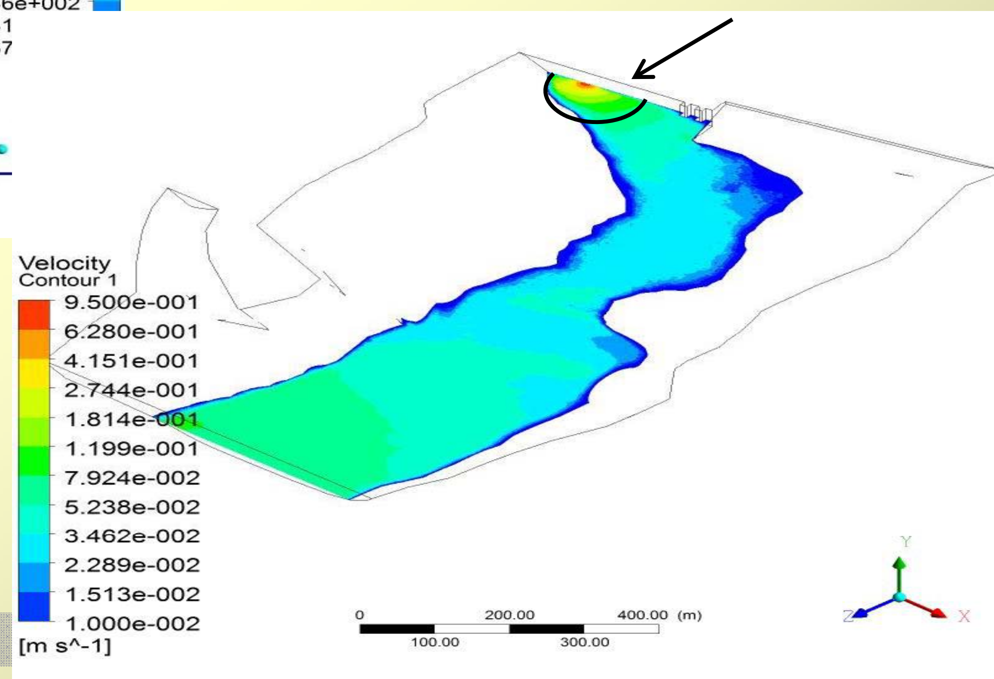


MODEL RESULTS

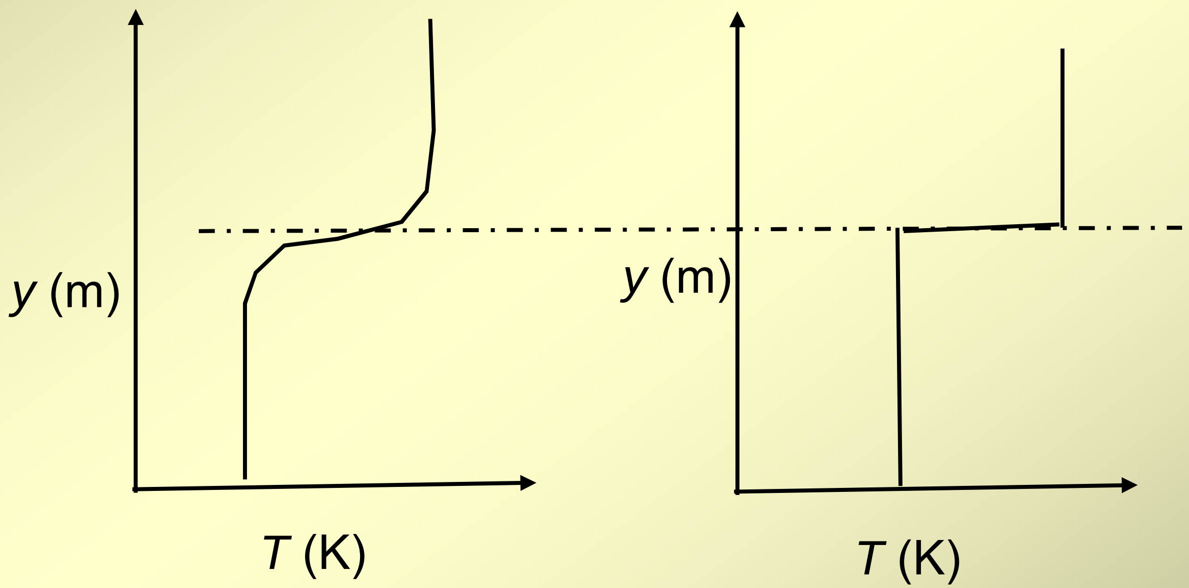


Acceleration zone



THEORETICAL WORKS

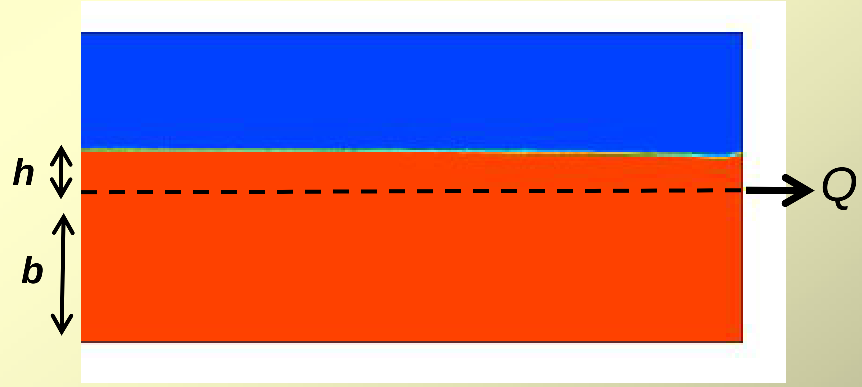
Continuous stratification of a lake can be imagined as a discrete stratification.



THEORETICAL WORKS

Craya (1949) derived a Froude number for discrete stratification:

$$F_p = \frac{Q}{\sqrt{g\frac{\Delta\rho}{\rho}h^5}}$$



Both layers will be withdrawn when *F*>2.55

This can be created by changing *Q, h,* or $\Delta\rho$

Craya (1949)'s theory is applicable when intake is located far from the boundaries.

This study developed theory when point sink is located close to the boundaries (bottom / surface).

$$\frac{Q}{\sqrt{\frac{\Delta\rho}{\rho} g y_s^5}} = \frac{\sqrt{2}\pi\left(y_s + 2b\right)^{5/2}}{\sqrt{\left(y_s + 2b\right)^2 + y_s^{\,2}}\sqrt{\left(y_s + 2b\right)^3 + y_s^{\,3}}}$$

$$\frac{Q}{\sqrt{\frac{\Delta\rho}{\rho} g(h-y)}} = \frac{2\sqrt{2}\pi}{\left\{\frac{1}{y^2} + \frac{1}{(y+2b)^2}\right\}}$$

For a given *Q*, *h* can be estimated and vice versa.

F_p = 1.26 when point sink is located close to the bottom.

F_p = 2.55 at $b/h > 2.0$

LINE SINK AT BOTTOM

This study developed theory for line sink located at bottom.

$$\frac{q}{\sqrt{\frac{\Delta\rho}{\rho} g y_s^3}} = \frac{\pi}{2} \qquad \frac{\Delta\rho}{\rho} h + \frac{q^2}{2gh^2} = \frac{\Delta\rho}{\rho} y_s + \frac{q^2}{2gy_s^2}$$

For a given *q*, *h* can be estimated and vice versa.

$F_l \approx 0.6$ for sink located at bottom.

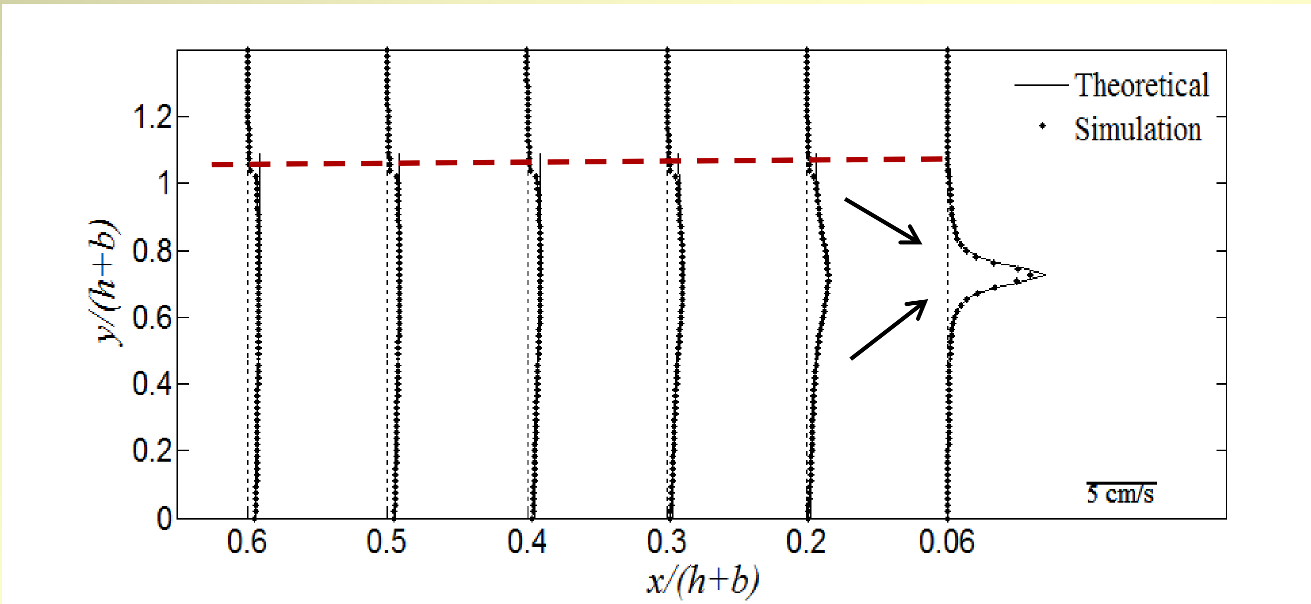
$F_l \approx 1.55$ when $b/h > 4.0$

THEORETICAL VELOCITY PREDICTION

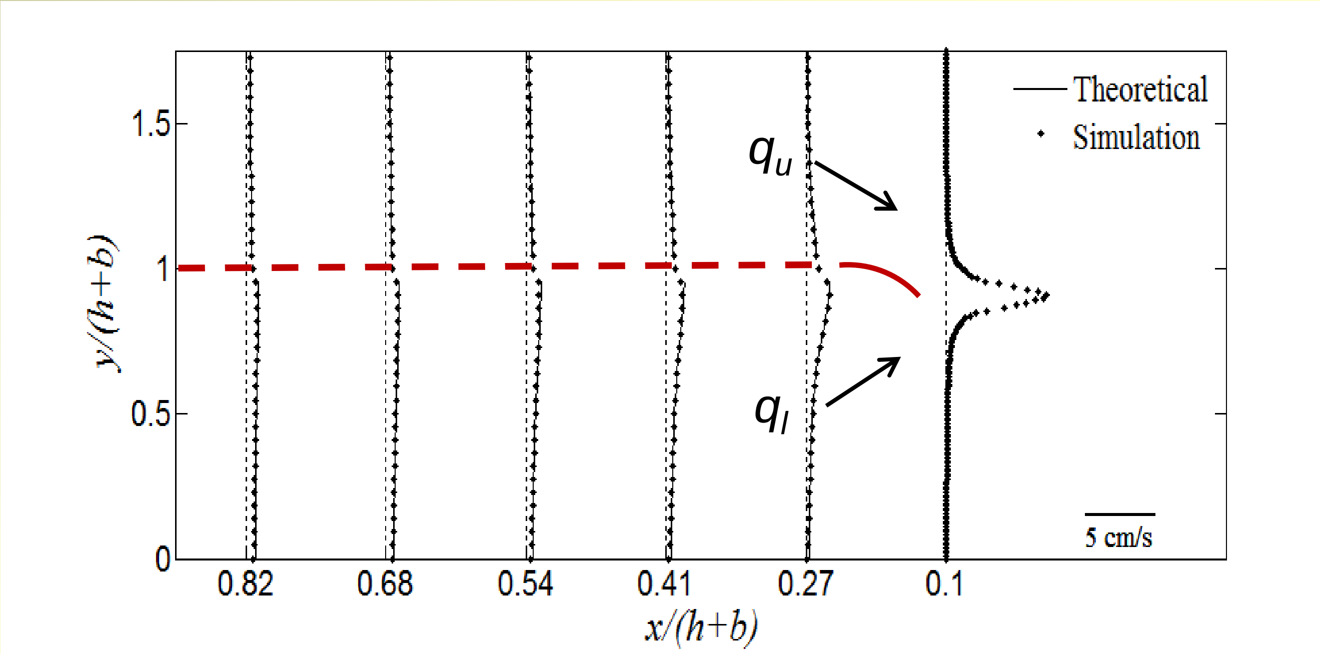
For intake problem, theoretical velocity predictor is available for unstratified condition.

With some modifications, the unstratified equations can be applied in stratified condition.

Line sink, discrete stratification:



For $h > h_i$ unstratified equation is applicable considering interface as an upper boundary.



For $0 > h > h_i$, unstratified equation is applicable by splitting *q*.

CONCLUSIONS

1.CFD model is found reliable in predicting stratified flow upstream of an intake.

2.A pressure profile is developed to be applied in simulations.

3.Theoretical equations are developed to account for boundary effect for both point and line sinks.

4.Theoretical velocity equations can be applied for velocity prediction in stratified conditions.

QUESTIONS ?