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HYTECH Aquatic Interfaces

Effects of vegetation density and wetland aspect ratio variation on hydraulic efficiency of wetlands

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Outline

- Free water surface wetlands
- Hydraulic efficiency
- A numerical model
- Aspect ratio and vegetation density variation
- Results

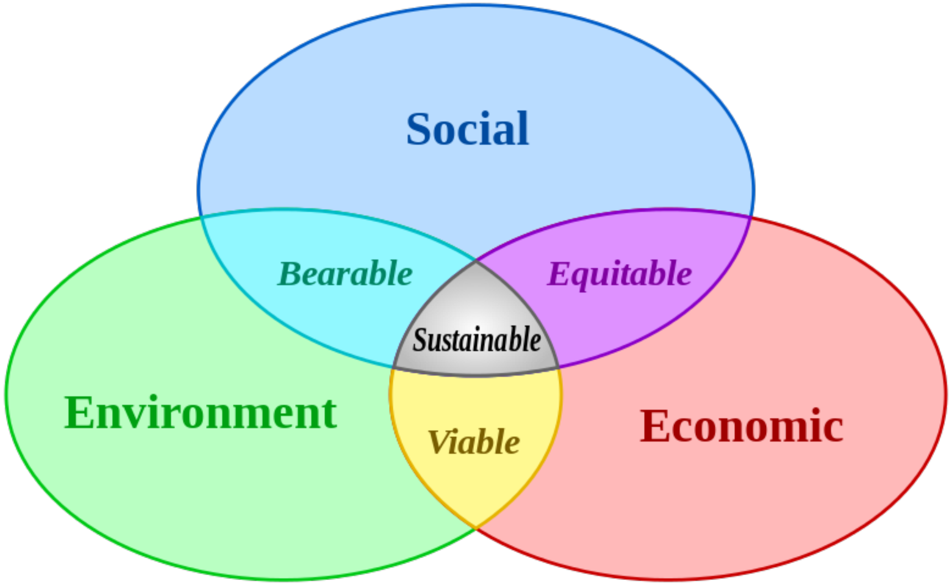
Why wetlands are wastewater treatment options?

•Alternative for conventional treatment plants

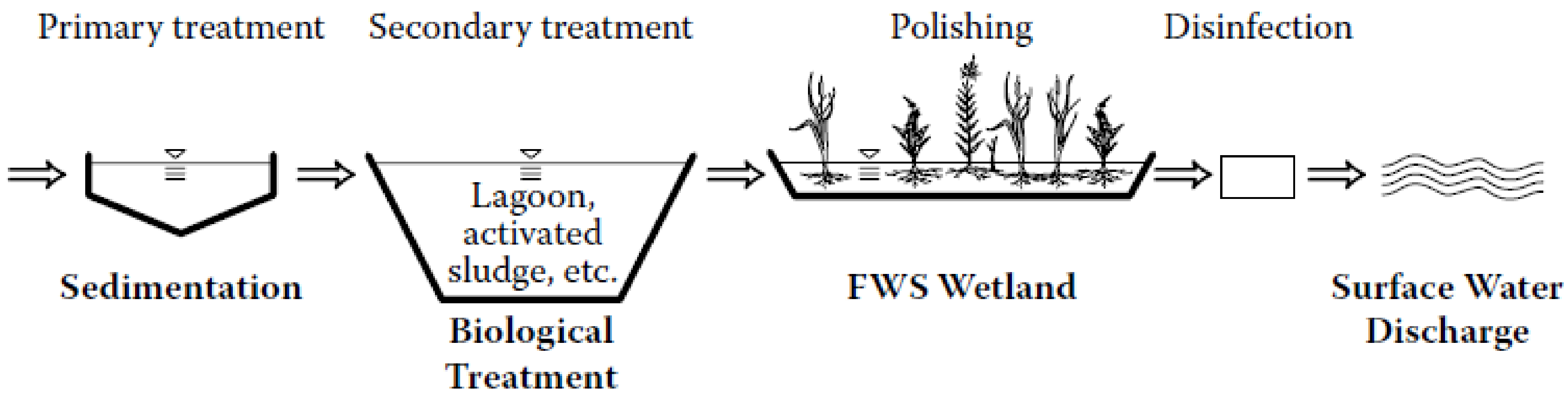
•Economical (building, maintanance)

•Environemntal friendly (energy consumption, material, enhancing ecological diversity)

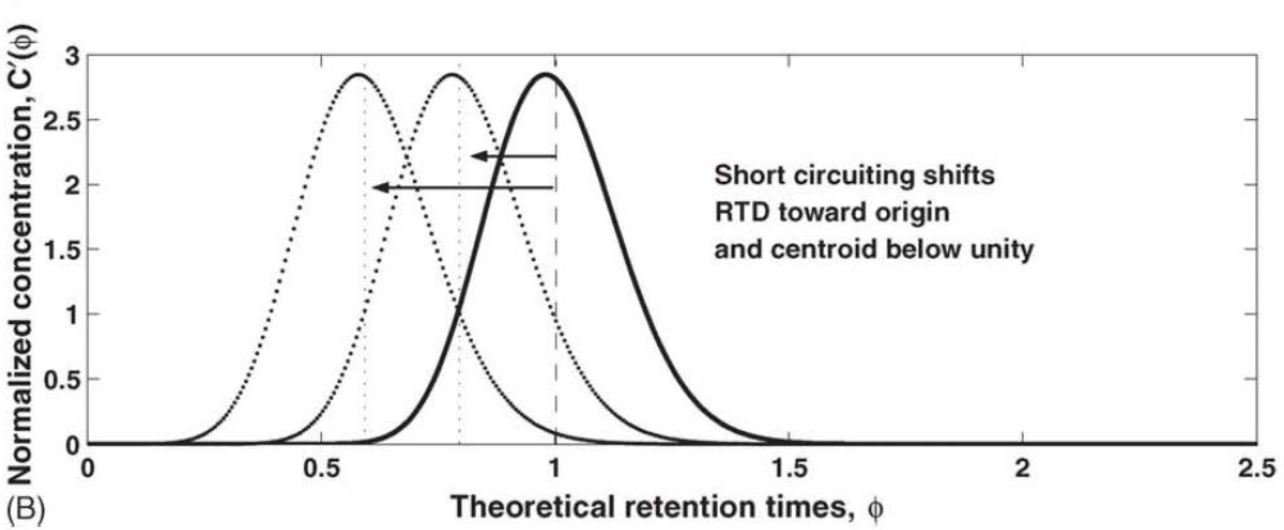
•Sustainable solutions



Free Water Surface Constructed Wetlands (FWS)



Volumetric efficiency-Retention time

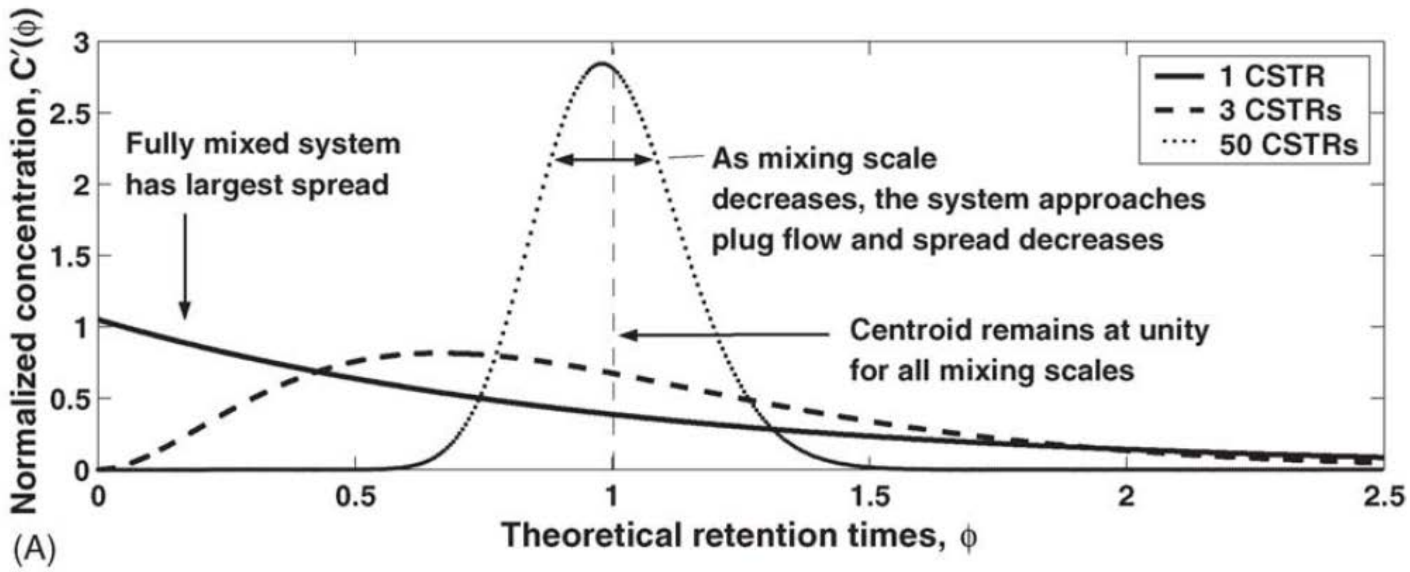


- The RTD curves are generated as a response to a pulse injection.

- The centroid of an RTD falls below the theoretical retention time when short-circuiting causes the loss of effective retention volume.

$$\int_0^\infty t\, f(t)dt = \tau$$

Mixing and dispersion



$$\int_0^\infty (t-\tau)^2 \, f(t) \, dt = \sigma^2$$

where

σ^2 = DTD variance,

Efficiency evaluation

$$N = (\sigma_\theta)^{-2} = (\frac{\sigma}{t_n})^{-2}$$

Measure of dispersion, (Persson, 1999)

$$e = (\frac{t_m}{t_n}) = (\frac{V_{effective}}{V_{total}})$$

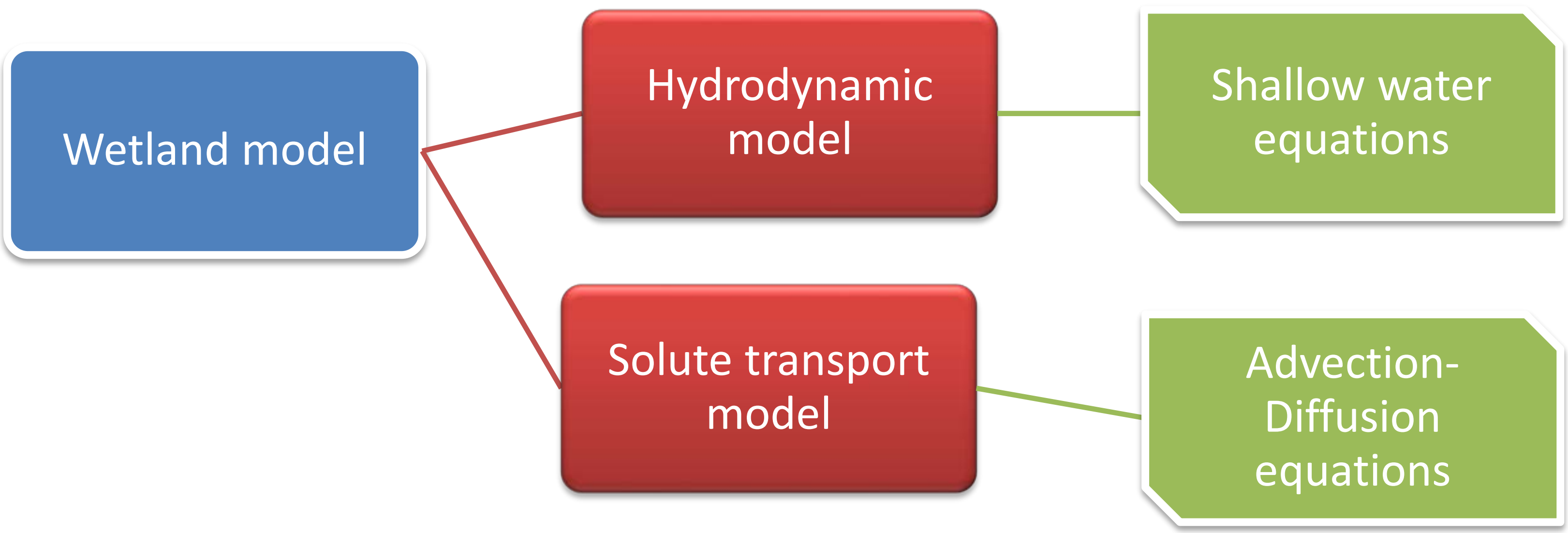
Dimensionless retention time, (Thakston, 1987)

$$\lambda_p = e(1 - \frac{1}{N})$$

Hydraulic efficincy, (Persson, 1999)

- Both mixing and retention criteria must be satisfied.

Numerical model



- A coupled model to simulate wetland flow patterns and mass transport mechanisms.

Shallow water equations

➢ the depth-averaged velocity field and water depth can be described by the following equations .

$$\frac{\partial(hU_x)}{\partial x} + \frac{\partial(hU_y)}{\partial y} = 0$$

(Wu, 2007)

$$\frac{\partial(hU_x{}^2)}{\partial x} + \frac{\partial(hU_xU_y)}{\partial y} = -gh\frac{\partial(z_s)}{\partial x} - \frac{\tau_{bx}}{\rho} - \frac{\tau_{vx}}{\rho}$$

$$\frac{\partial(hU_xU_y)}{\partial x} + \frac{\partial(hU_y{}^2)}{\partial y} = -gh\frac{\partial(z_s)}{\partial y} - \frac{\tau_{by}}{\rho} - \frac{\tau_{vy}}{\rho}$$

Assumptions
•hydrostatic pressure,
•stationary flow,
•negligible wind & Coriolis forces

Bed shear stresses

$$\tau_{bx} = \rho C_b U_x \sqrt{{U_x}^2 + {U_y}^2}$$

(Kadleck, 1990)

$$\tau_{by} = \rho C_b U_y \sqrt{{U_x}^2 + {U_y}^2}$$

$$C_b = \frac{3\mu}{h\rho\sqrt{{U_x}^2+{U_y}^2}} + \frac{M^2 g}{h^{\frac{1}{3}}} = \frac{3}{Re_b} + \frac{M^2 g}{h^{\frac{1}{3}}}$$

- Under laminar and transitional flow ($Re \leq 500$), the first term of the equation dominates, whereas the turbulent term characterized by Manning equation becomes important for larger Reynolds numbers ($Re \geq 1250$)

Vegetation shear stresses

$$\tau_{vx} = \rho C_D a l \frac{U_x}{2} \sqrt{{U_x}^2 + {U_y}^2}$$

$$\tau_{vy} = \rho C_D a l \frac{U_y}{2} \sqrt{{U_x}^2 + {U_y}^2}$$

$$a = n_s d$$

(Arega & Sanders, 2004)

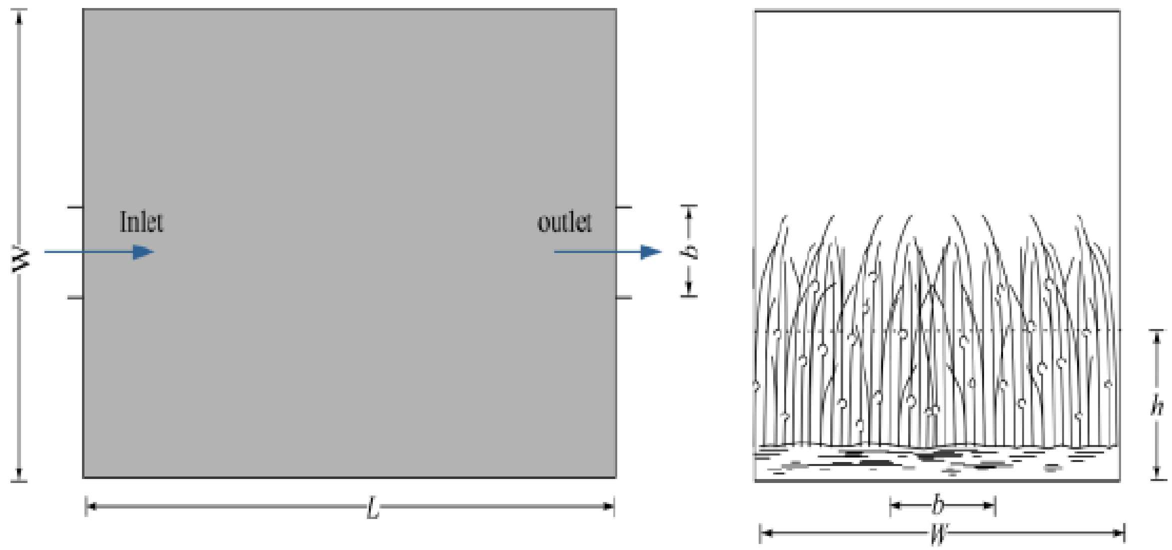
- C_D is the vegetation-drag coefficient (dimensionless), and l is the stem density (assumed equal to water depth), the vegetation density parameter (a),
- The plants are modeled as cylinders,
- n_s is the number of vegetation stems per unit area ($1/m^2$), and d is the cylinder diameter of vegetation (m).

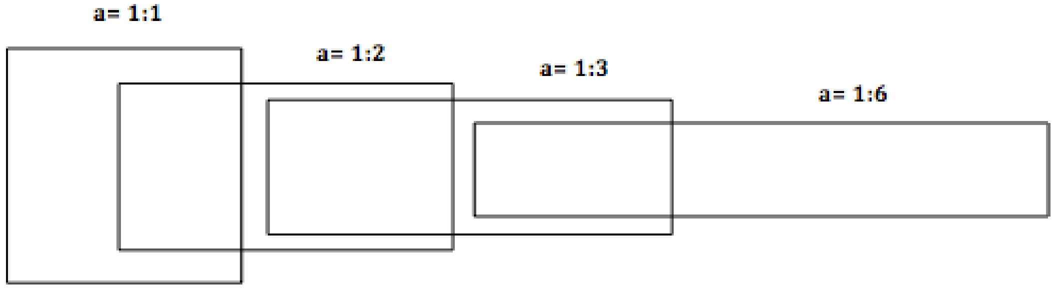
Mass transport

$$\frac{\partial(hC)}{\partial t}+\frac{\partial(hU_xC)}{\partial x}+\frac{\partial(hU_yC)}{\partial y}=\frac{\partial}{\partial x}\left(hE_{xx}\frac{\partial C}{\partial x}+hE_{xy}\frac{\partial C}{\partial y}\right)+\frac{\partial}{\partial y}\left(hE_{yx}\frac{\partial C}{\partial x}+hE_{yy}\frac{\partial C}{\partial y}\right)$$

- C is the depth-averaged solute concentration, whereas the coefficients Eij, account for both turbulent diffusion and shear dispersion due to vertical velocity gradients.

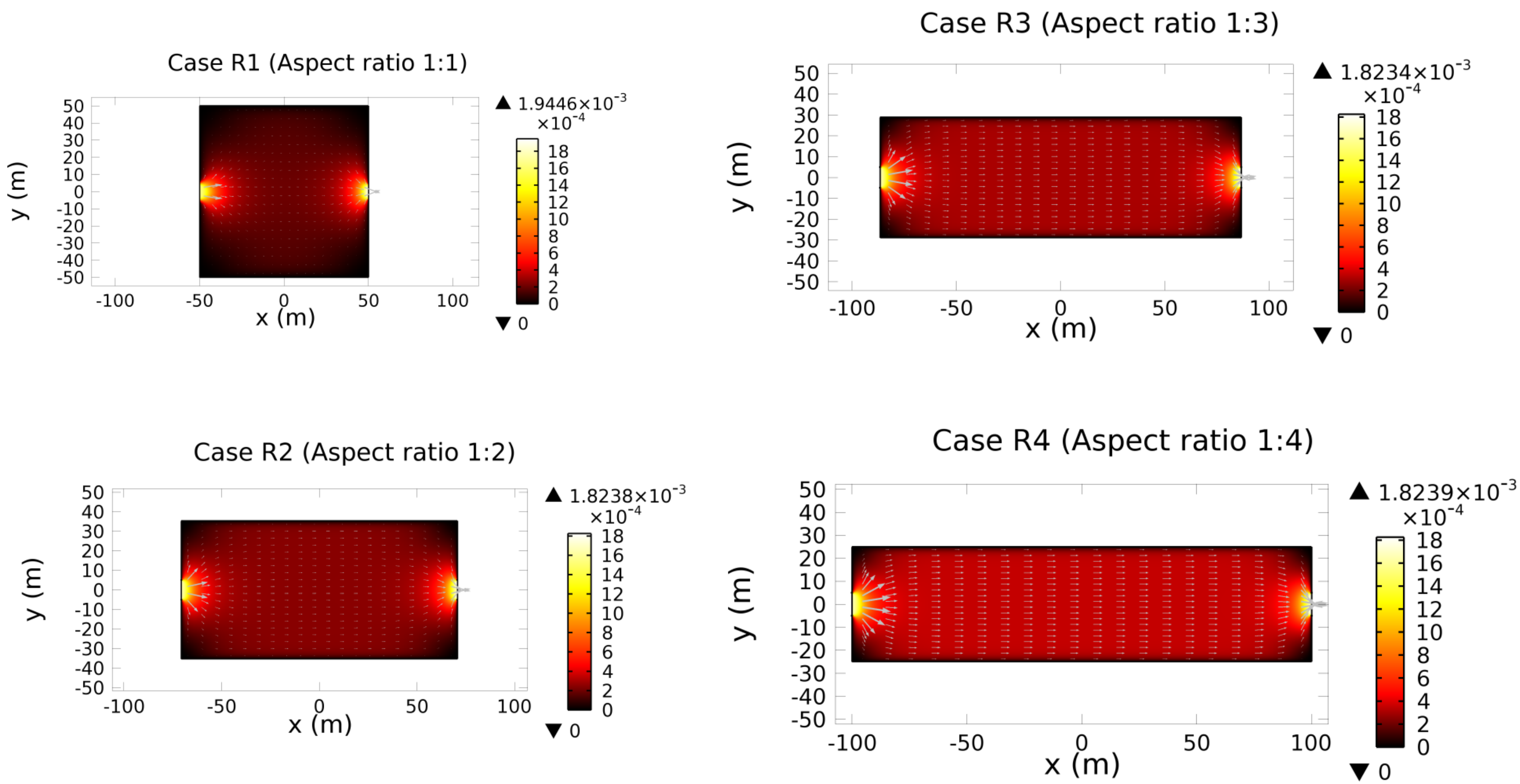
Effect of aspect ratio



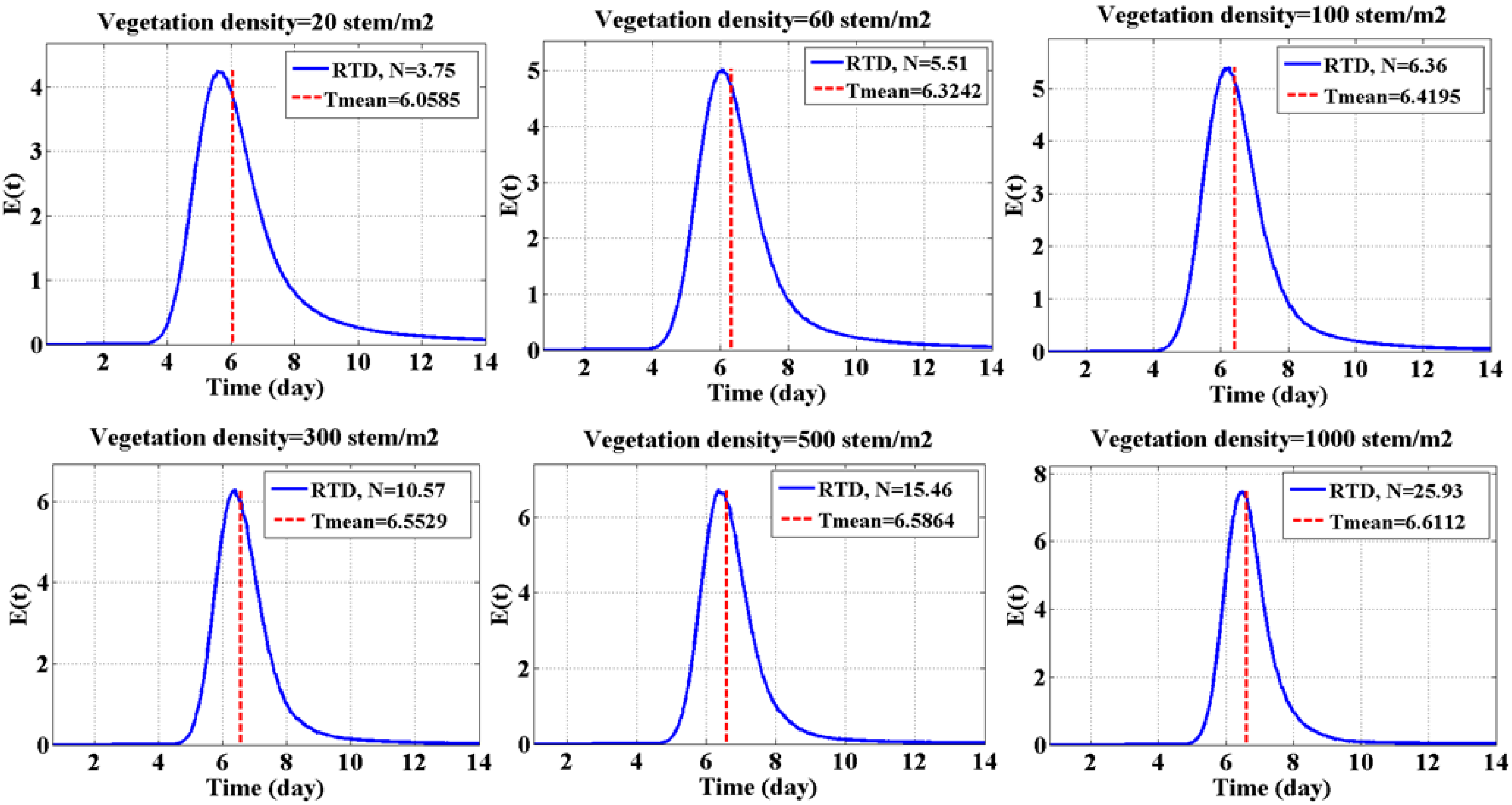


a: Aspect ratio

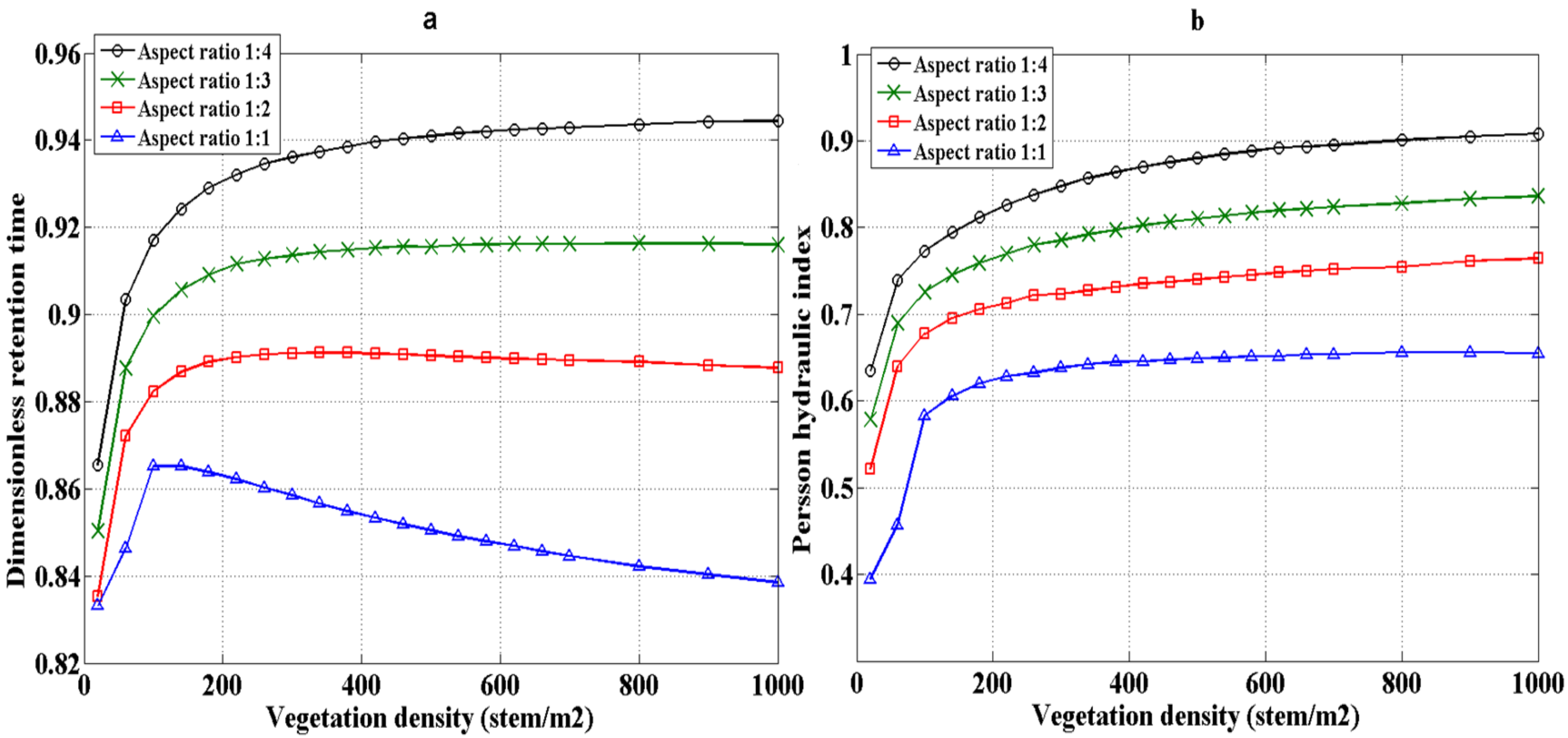
Velocity field-different aspect ratios



Residence Time Distribution graphs (RTDs)



results


a
b
Aspect ratio 1:4
Aspect ratio 1:3
Aspect ratio 1:2
Aspect ratio 1:1
Dimensionless retention time
Persson hydraulic index
Vegetation density (stem/m2)
0.96
0.94
0.92
0.9
0.88
0.86
0.84
0.82
1
0.8
0.7
0.6
0.5
0.4
0
200
400
600
800
1000

Results

- Vegetation density and aspect ratio are important factors affecting the hydraulic efficiency.

- In response to vegetation density increase, both retention time and dispersion efficiencies became constant before reaching to a maximum value .

- Vegetation density higher than a certain level does not necessarily improve hydraulic efficiency.

Results

- in response to vegetation density increase, retention time decreases for wide rectangular wetlands.

- Sparse vegetation cover in combination with low aspect ratios causes efficiency problems in wetlands.

- The current study can be complemented by inclusion of an appropriate uptake function in the solute transport model, and studying the impact of more complex geometric wetland shapes and heterogeneous vegetation patterns.

Thanks for listening