AKARSU KENARLARINDA ARTAN BİTKİ ÖRTÜSÜNÜN AKIŞ DİNAMİĞİNE ETKİSİ / THE ROLE OF INCREASING RIVERBANK VEGETATION ON FLOW DYNAMICS

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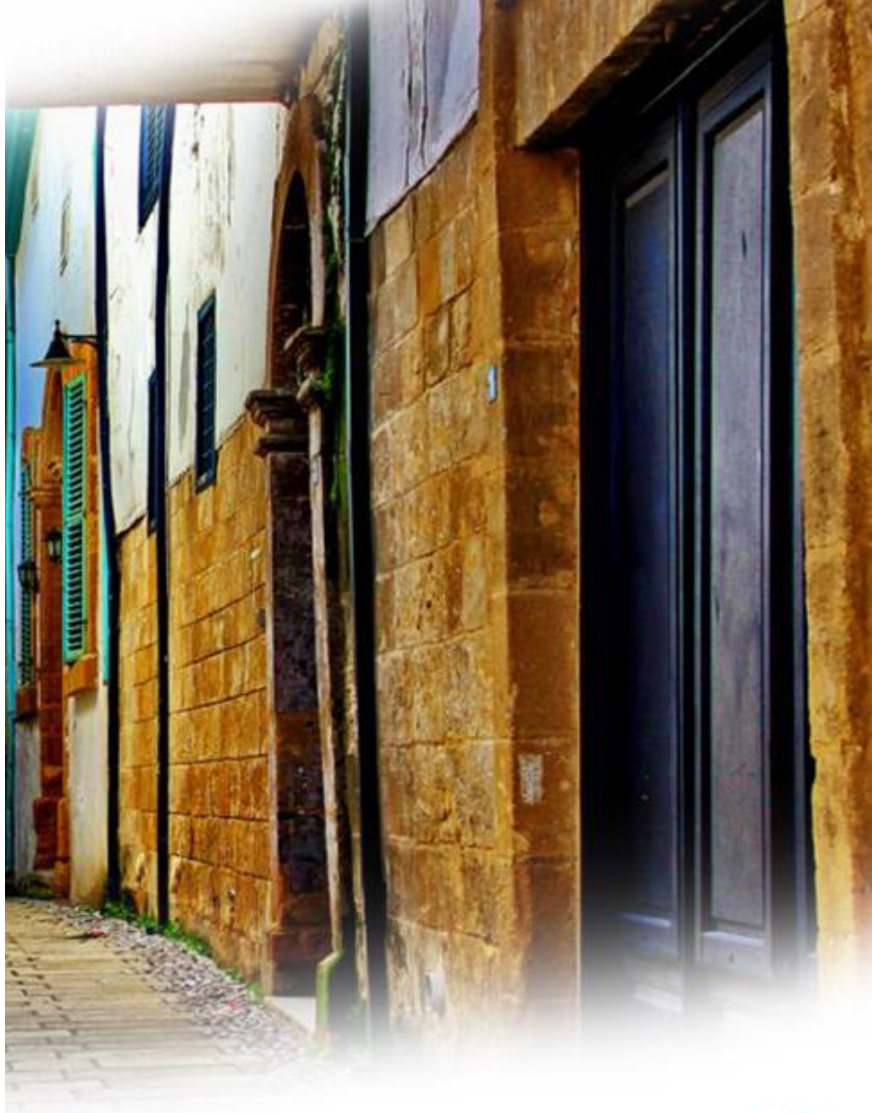


ULUSLARARASI KIBRIS ÜNİVERSİTESİ

Effect of vegetation on flow dynamics

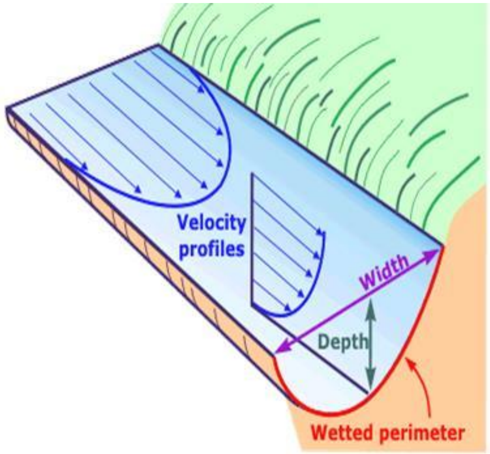
Patch of vegetation causes partly obstructed flow in regular, irregular, compound or composite open channels.

Patch of vegetation disturbs the flow characteristics such as its direction, velocity and behavior, altering the hydraulic properties of the flow and modifying the morphology of the channel.

The effect of vegetation on the channel bed and bank is an important engineering problem that should be clearly analyzed and understood.

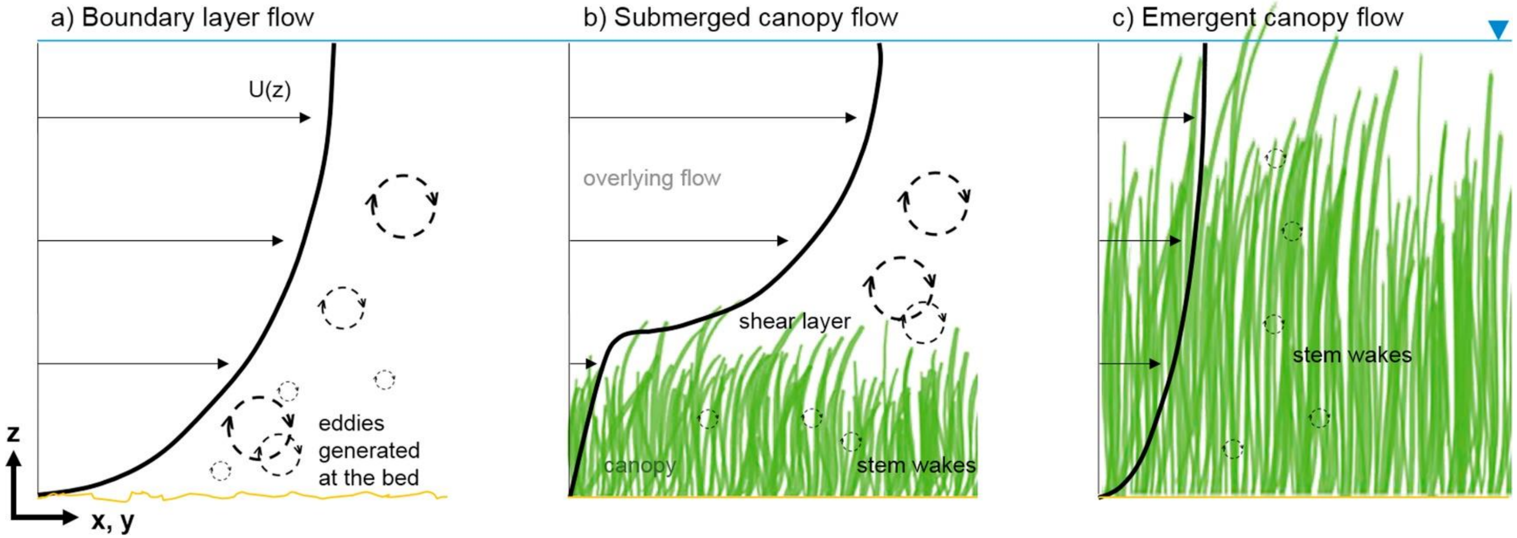
Short notice:

In general, velocity profile in open channels exhibits parabolic distribution.



Effect of vegetation on flow dynamics – streamwise section

Emergent and submerged vegetation can significantly affect flow hydrodynamics. Sketch of three different flow regimes shows the dominant source of turbulence which is respectively (from left to right) the bed, the top of the canopy (shear layer), and the stem wakes.



Short notice:

In general, the vegetation cover in the main channel reduces the mean flow velocity.

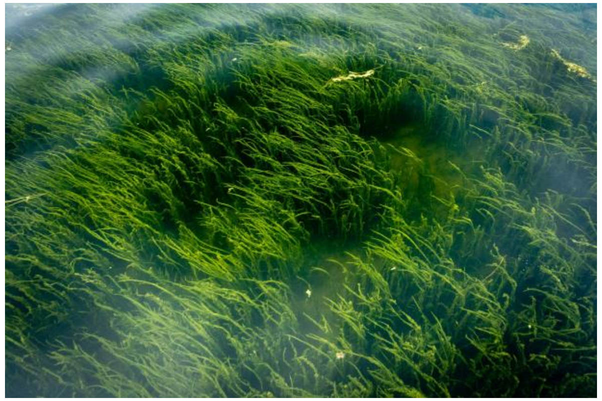
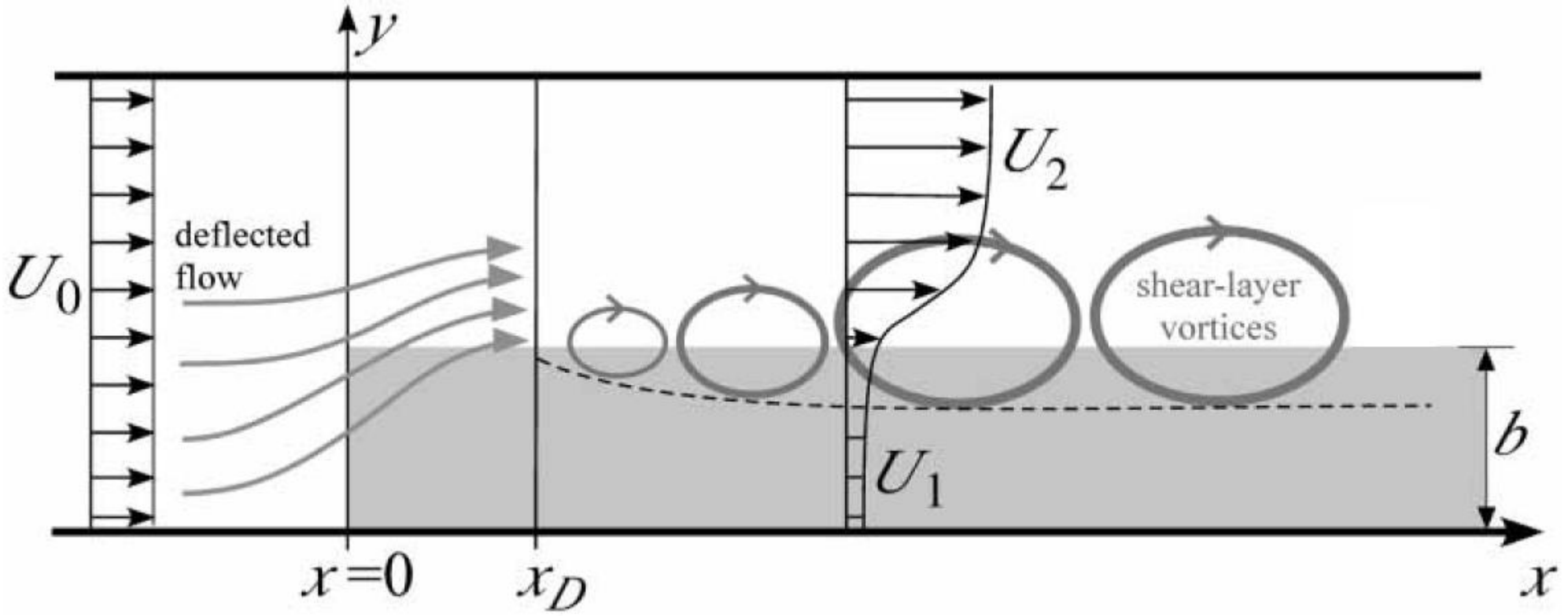


Figure is from Tarandeep et al, (2016), Development of a coupled wave-flow-vegetation interaction model.

Effect of vegetation on flow dynamics - plan

Top view of a channel with a long patch of emergent vegetation along the right bank. The flow begins to deflect away from the patch upstream and continues to decelerate and deflect. After this point, a shear layer forms on the flow-parallel edge and shear-layer vortices form by K-H instability. These vortices grow downstream.



Short notice:

The Kelvin–Helmholtz instability typically occurs when there is velocity difference across the interface between two fluids.

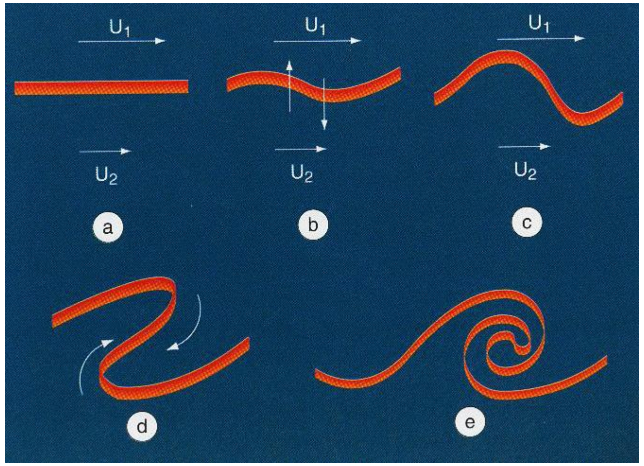
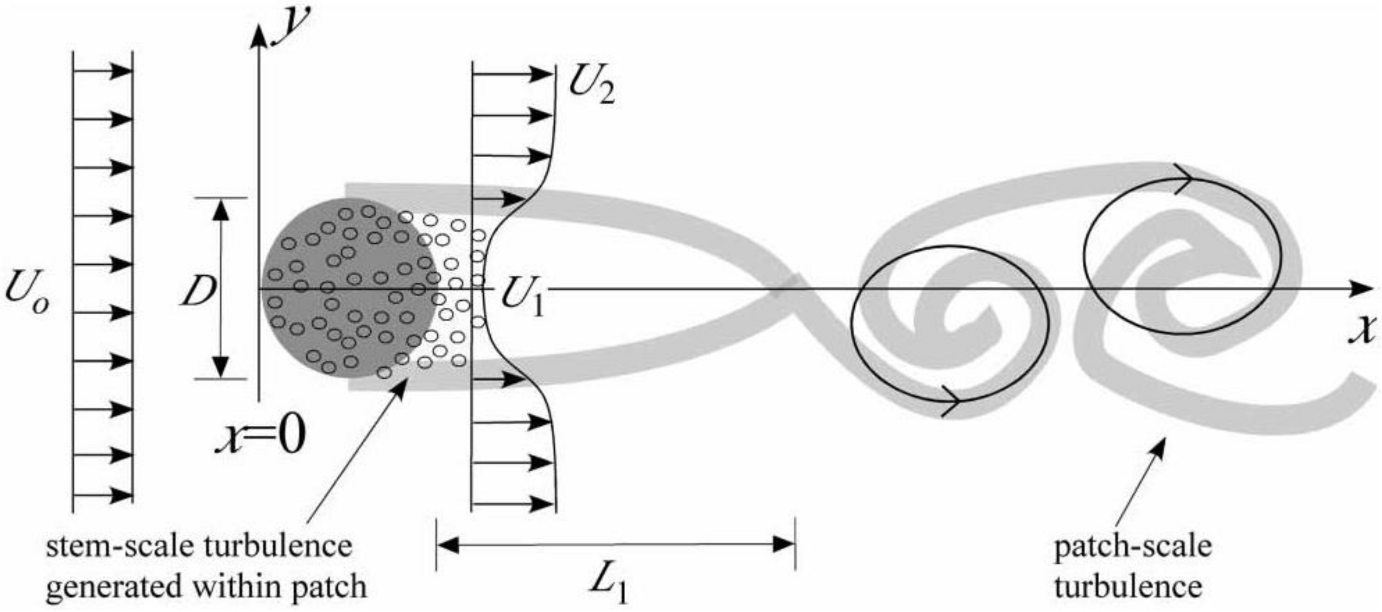


Figure is from Nepf (2012), Hydrodynamics of vegetated channels. The photograph is frın Alligator river, North Carolania

Effect of vegetation on flow dynamics - plan view of a patch effect

Top view of a circular patch of emergent vegetation, turbulence is generated within the patch, but dies out quickly behind the patch. Tracer (grey line) released from the outermost edges of the patch comes together at a distance downstream from the patch and reveals the von Karman vortex street.



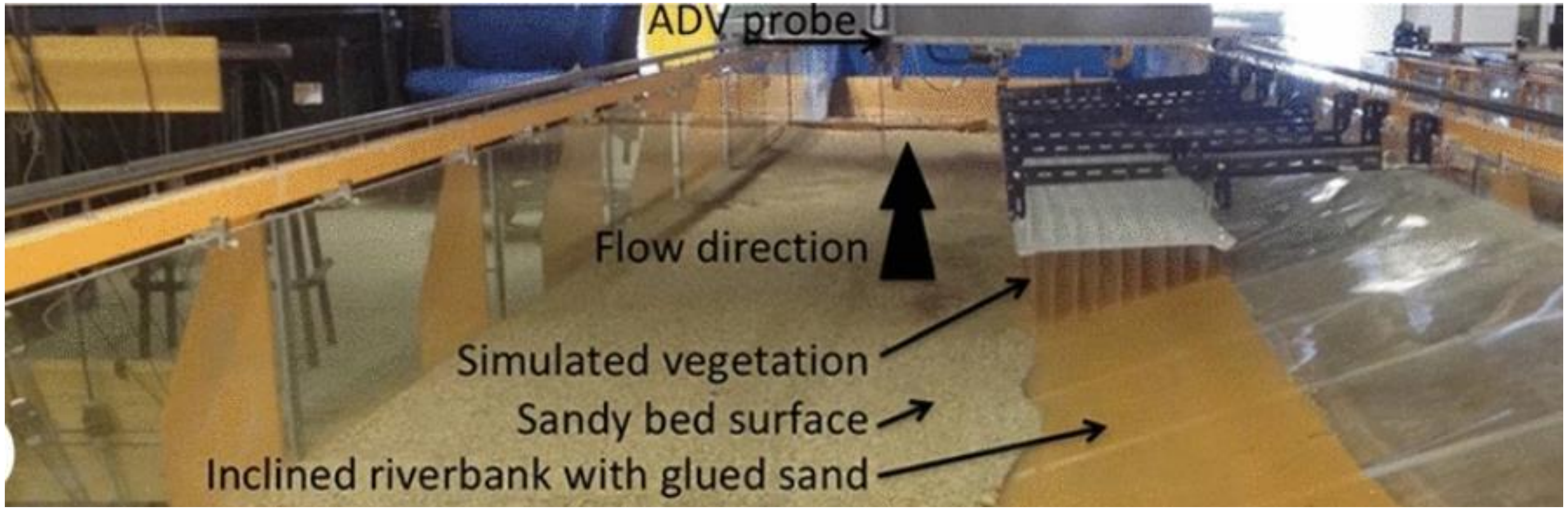
Short notice:

von Karman vortex street is a repeating pattern of swirling vortices which is responsible for the unsteady separation of flow of a fluid around blunt bodies.

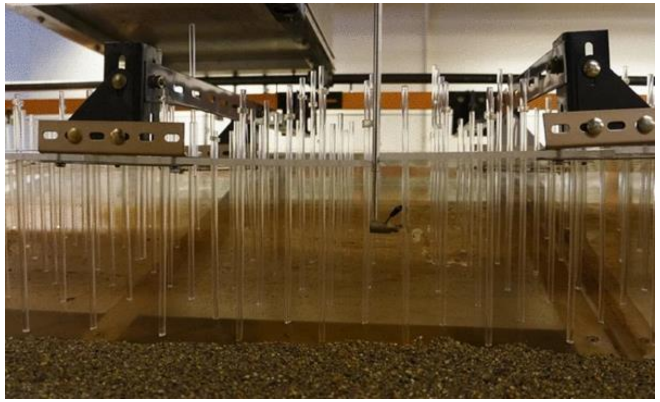
Figure is from Nepf (2012), Hydrodynamics of vegetated channels.

Effect of inclined bank vegetation on flow dynamics - laboratory experiments

An experiment is conducted in a 14m long by 1.8m wide glass flume, with an asymmetrical cross-section, at the Water Engineering laboratory of the University of Glasgow. The streambank is modelled by a series of 0.8 m wide, inclined acrylic panels, running a streamwise length 5m. The characteristic median grain size of the sandy bed was (D_{50}) 0.002m



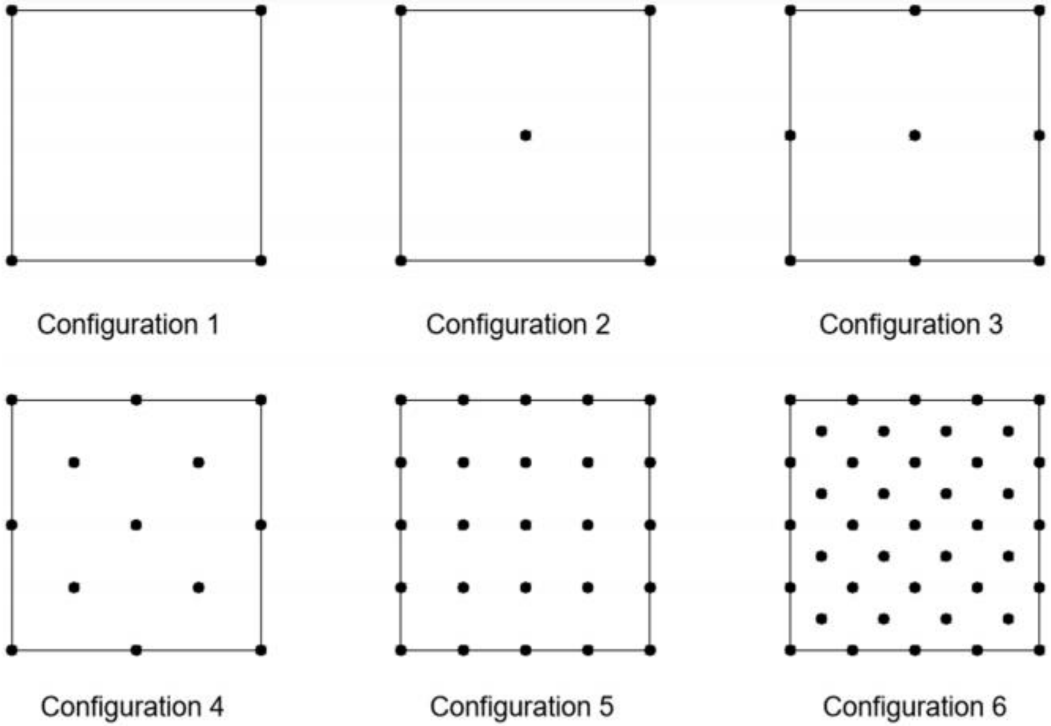
Short notice:
This study focuses on using rigid cylindrical dowels to simulate the effect of vegetation density on the flow field, which may find application to a number of practical hydraulic engineering cases



Figures are from Valyrakis et al. (2021), The role of increasing riverbank vegetation density on flow dynamics across an asymmetrical channel.

Effect of inclined bank vegetation on flow dynamics - laboratory experiments

Definition sketch and the illustration of the configurations of simulated riverbank vegetation used in the experiments.



Increasing densities were achieved from one configuration to the next, by placing additional elements at the locations specified for this configuration

Short notice:

The diameter of acrylic rods were 0.6 cm and they were placed either with linear or staggered geometry.

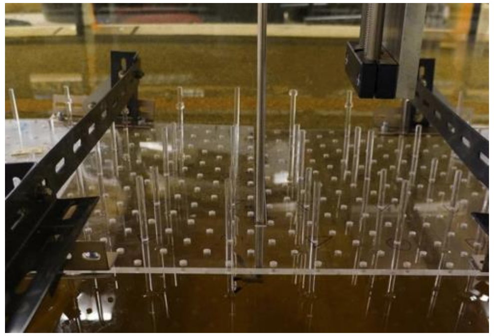
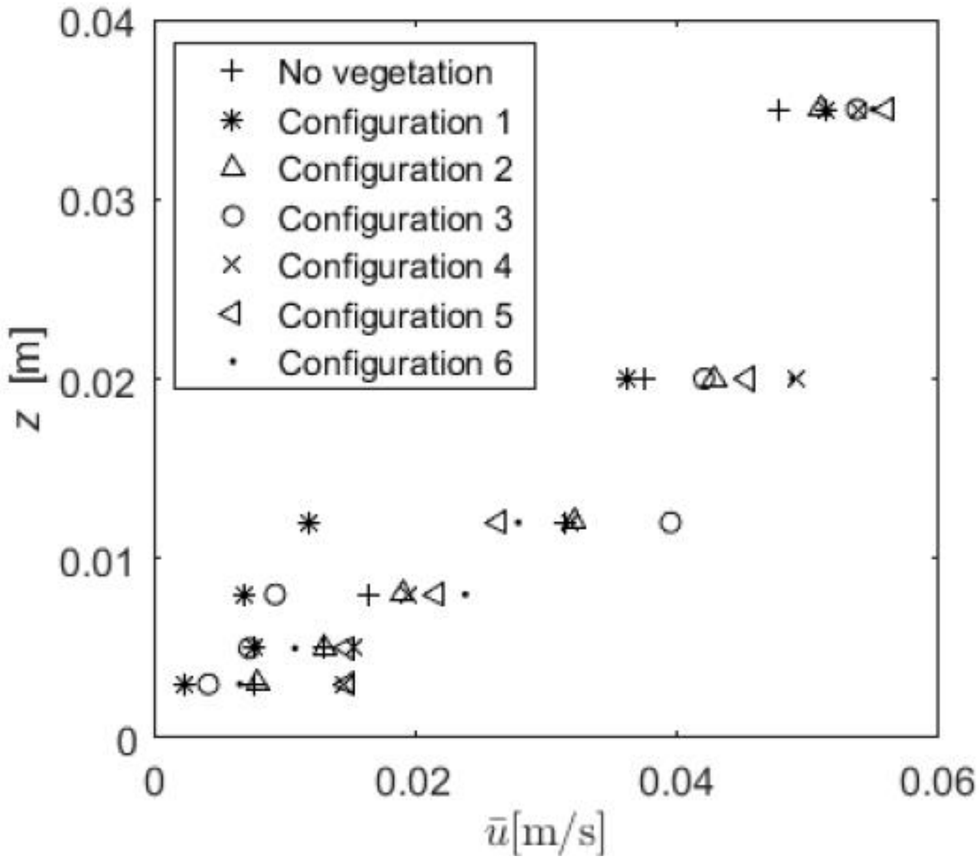


Figure is from Valyrakis et al. (2021), The role of increasing riverbank vegetation density on flow dynamics across an asymmetrical channel

Effect of inclined bank vegetation on flow dynamics - laboratory experiments (variations in flow velocity)

Streamwise mean velocity profiles measured at the centerline of the main channel.



The measurements were held at 10 different profiles at 8 relative positions just before the flow leaves the vegetated region.

Short notice:

A side looking, acoustic Doppler velocimeter (ADV) from Nortek® is used to record sufficiently long time series of the three components of the instantaneous flow velocities.

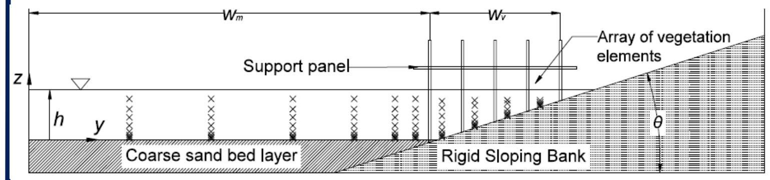
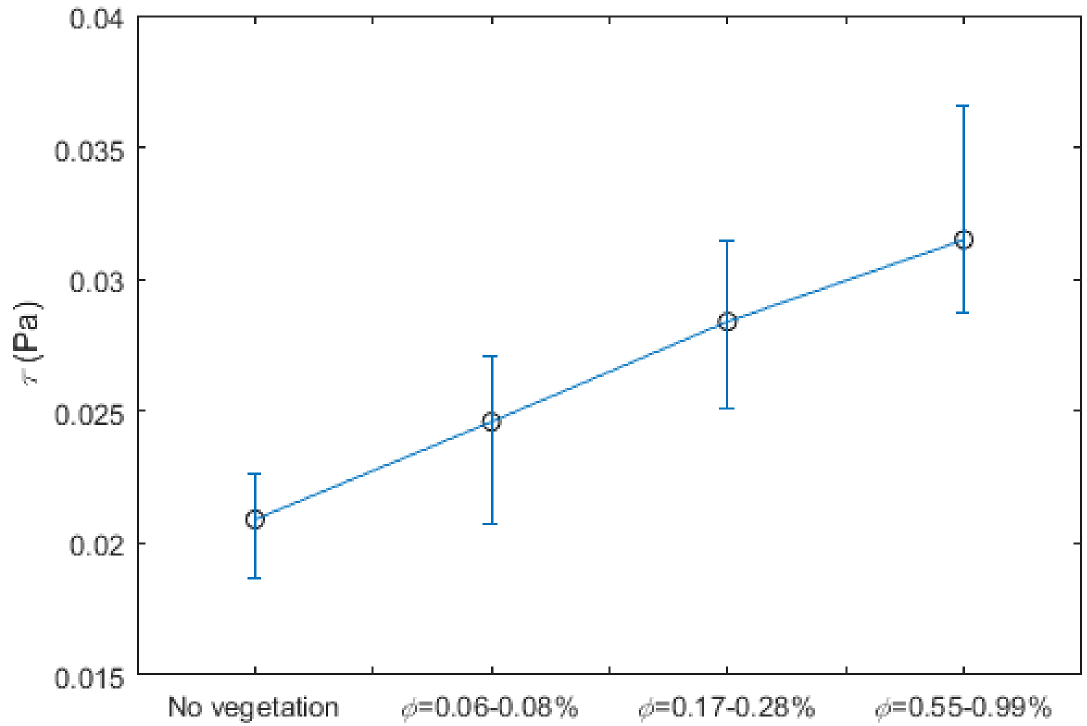


Figure is from Valyrakis et al. (2021), The role of increasing riverbank vegetation density on flow dynamics across an asymmetrical channel

Effect of inclined bank vegetation on flow dynamics - laboratory experiments (variations in bed shear stress)

Variation of bed shear stress at the main channel for various ranges of vegetation densities representing a gradual overall increase of the near bed shear stresses, with increasing riverbank vegetation densities.



Bed shear stress demonstrate 84% increase at the main channel and 23% increase near the toe of the inclined bank.

Short notice:

An increase in the bed shear stress reduces the stability of the stream's bed surface increasing the erosion risks.

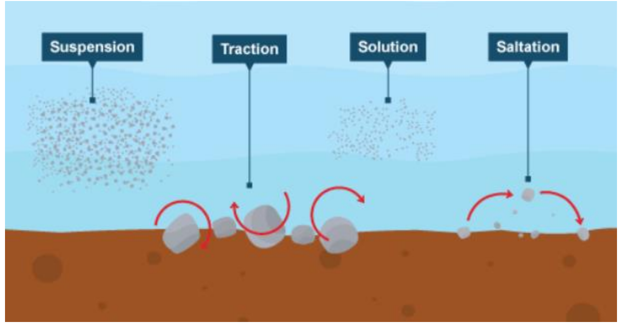


Figure is from Valyrakis et al. (2021), The role of increasing riverbank vegetation density on flow dynamics across an asymmetrical channel

Concluding remarks for exmerimental work.

It is found that with increasing vegetation density, flow velocity increases at the main channel, while reducing at the riverbank.

Bulk flow velocity at the riverbank region, progressively decreases from the case of no vegetation to that of dense vegetation configurations, exhibiting a drop of up to 17%.

The increase of riverbank vegetation is seen to lead to an approximate doubling of mean bed shear stresses at the centerline of the main channel as well as an increase of the bed roughness.

Short notice:

The arrangement of riparian vegetation can be as important as that of the density, in modifying the mean flow field of the main channel, for low riparian densities.

Effect of inclined bank vegetation on flow dynamics - Computational Fluid Dynamics Model.

The numerical simulation of the proposed open channel research study, in the presence of rigid vegetation on an inclined bank, can be solved by a numerical model governed by conservation of mass and momentum and the turbulence equations. The conservation of mass and momentum for viscous, incompressible flow conditions can be solved in Cartesian coordinates by three-dimensional Navier-Stokes equations, respectively, as follows

$$\frac{\partial u_i}{\partial x_i} = 0$$

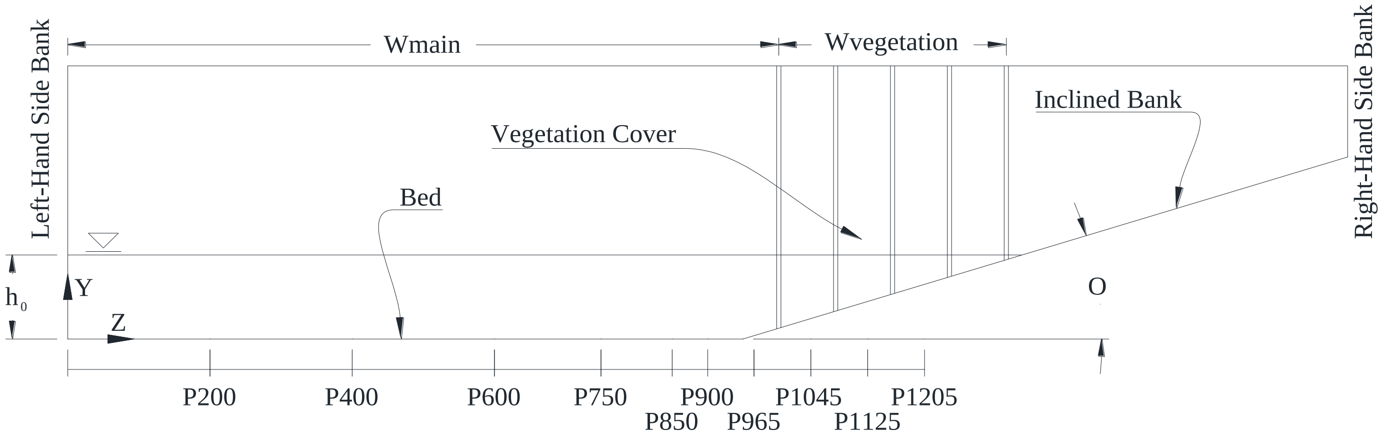
$$\frac{\partial u_i}{\partial t} + \frac{\partial}{\partial x_j}\left(u_i u_j\right) = \frac{1}{\rho}\frac{\partial P}{\partial x_i} + \upsilon\frac{\partial^2 u_i}{\partial x_j \partial x_j} + \frac{1}{\rho}F_i$$

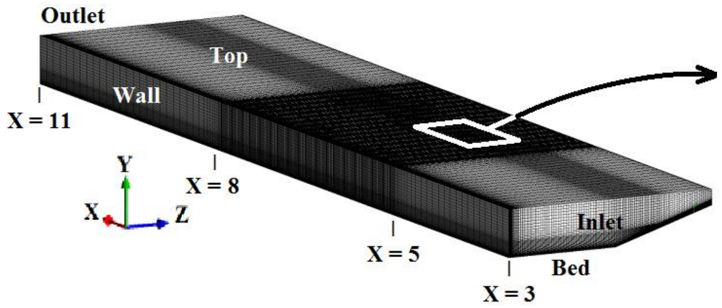
Short notice:

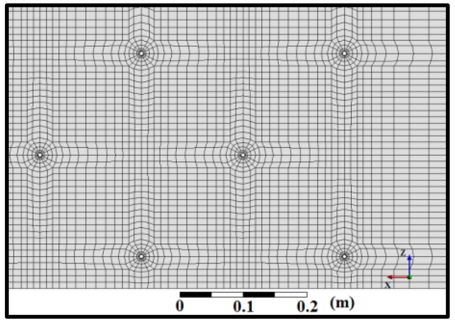
CFD modelling helps to understand the physical behaviour at minor and major scale.

ANSYS is one of the worldwide used engineering software used for CFD analysis

Effect of inclined bank vegetation on flow dynamics - Computational Fluid Dynamics model.







Short notice:

A structured quadrilateral mesh was used for the simulation with aspect ratio of 1.25

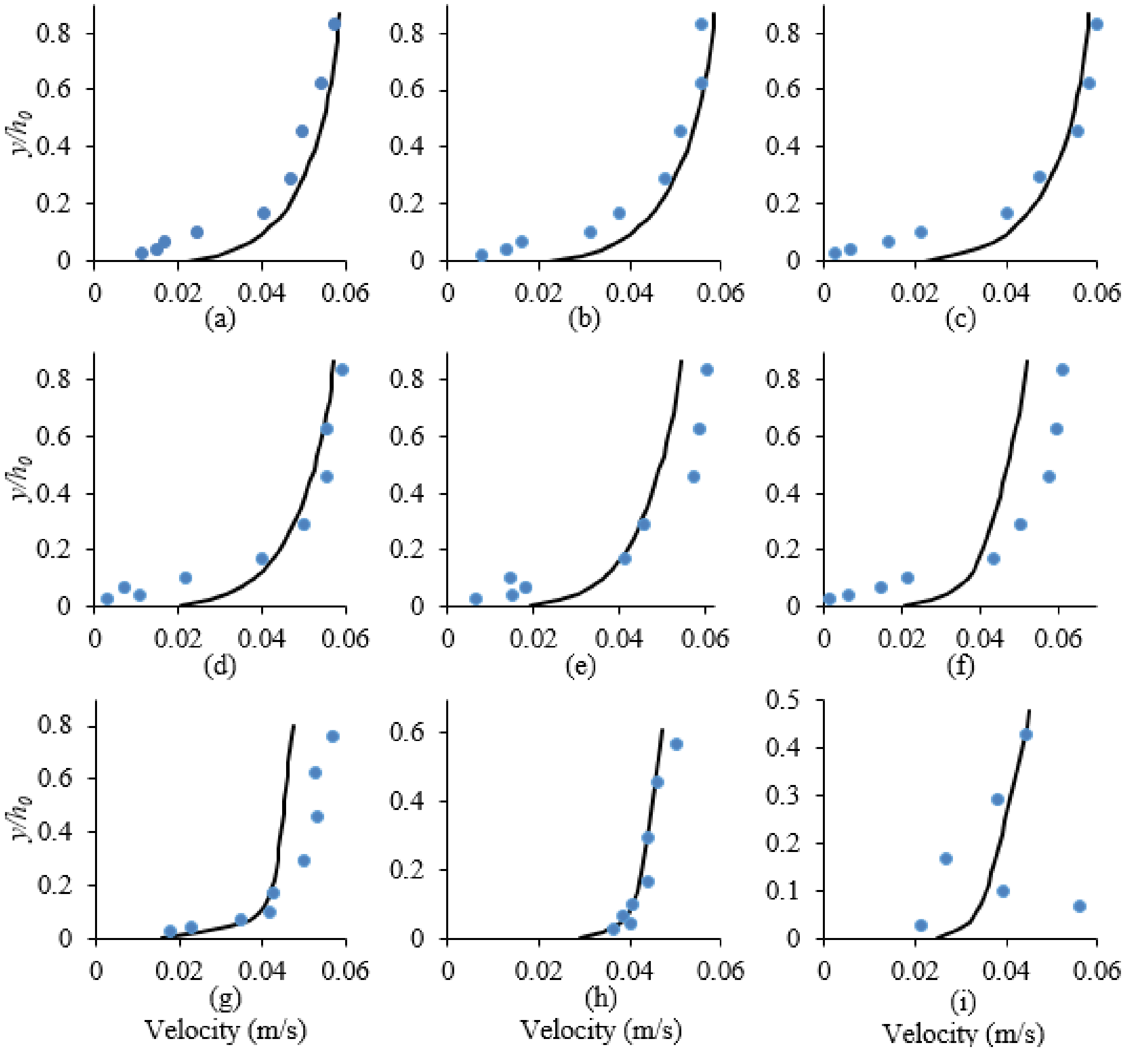
The smallest size of the mesh elements was 1.5 mm.

The number of nodes at the edges, for highest vegetation density (C5), were 355, 44, and 139 in X, Y, Z directions, respectively.

the number of elements for the most complex geometry (C5) were 2,913,216.

Effect of inclined bank vegetation on flow dynamics - Model Validation

The results of simulations were compared against the experimental data. The root mean square error calculations are used to assess the quantitative performance and predictive ability of the presented method.



Short notice:

$$RMSE = \sqrt{\frac{\sum_{m=0}^{N} u_m^2}{N}}$$

N: the total number of data points

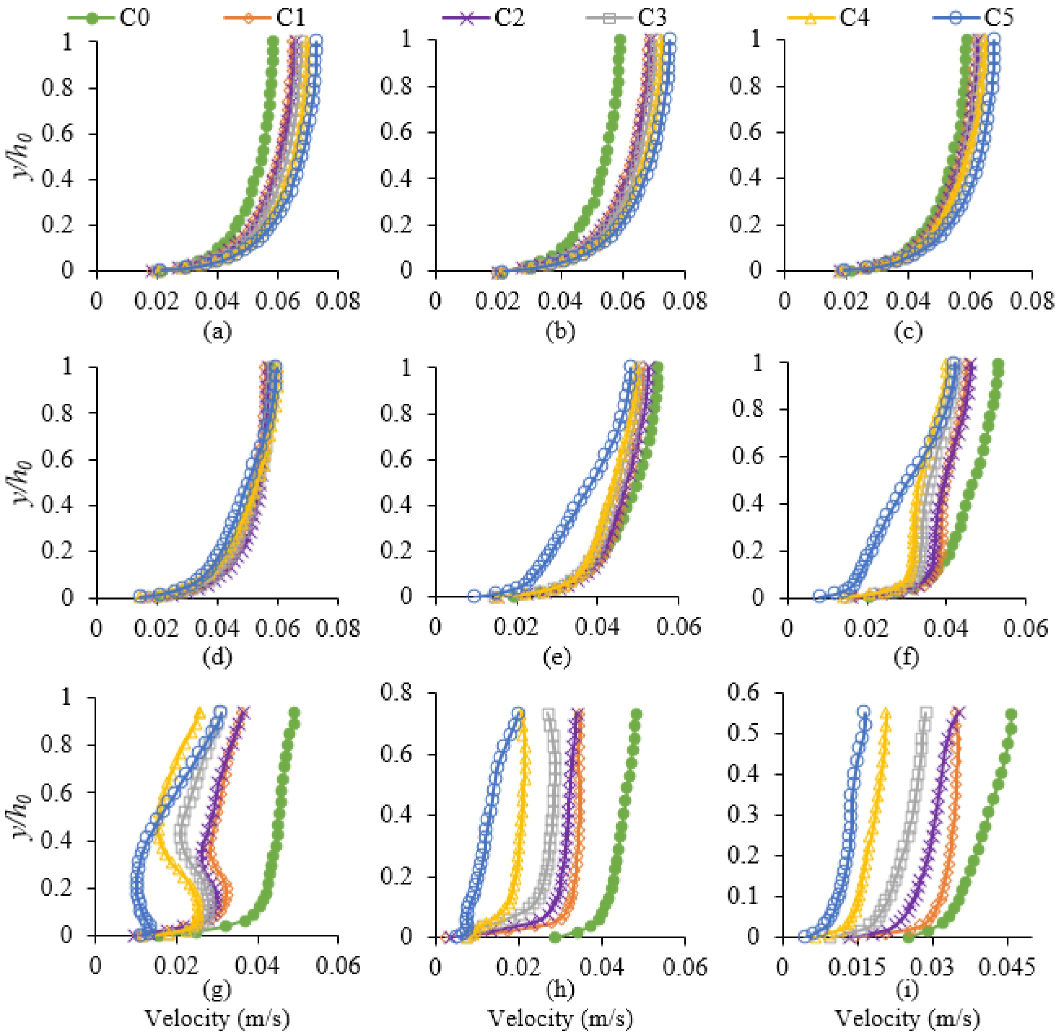
u_m: the difference between the numerically calculated, and experimentally collected data, of *m'th* observation

RMSE varied for each section in between 0.01 and 0.00708

The Figure shows the C0 arrangements at a) P200, b) P400, c) P600, d) P750, e) P850, f) P900, g) P965, h) P1045, and i) P1125

Effect of inclined bank vegetation on flow dynamics - Velocity Profiles

The average streamwise velocity profiles within the vegetated cover (from P900 to P1125) appear to diverge from the logarithmic profile as the lateral distance increases. This is true even for the bare bank case because the flow becomes shallower, forming more of a sigmoidal shaped profile



Short notice:

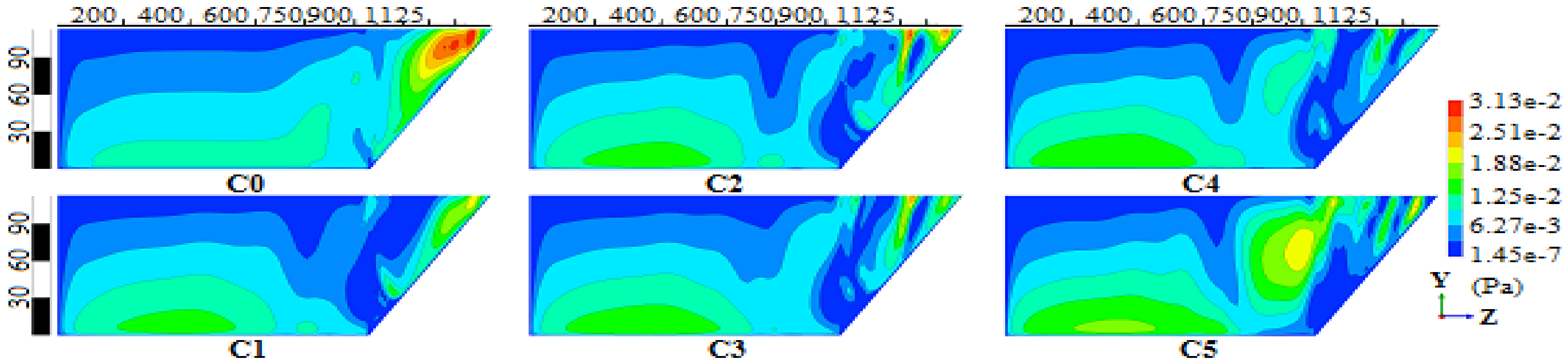
As the configuration number increases, the smaller velocities are observed clearly on the inclined bank

These profiles reveal large oscillations over the bank

These fluctuations can be attributed to the strong impact of secondary current at the boundary between the inclined bank and the main channel.

The Figure shows comparison between simulation results for streamwise velocity profiles at a) P200, b) P400, c) P600, d) P750, e) P850, f) P900, g) P965, h) P1045, and i) P1125

Effect of inclined bank vegetation on flow dynamics - Reynolds Shear Stresses



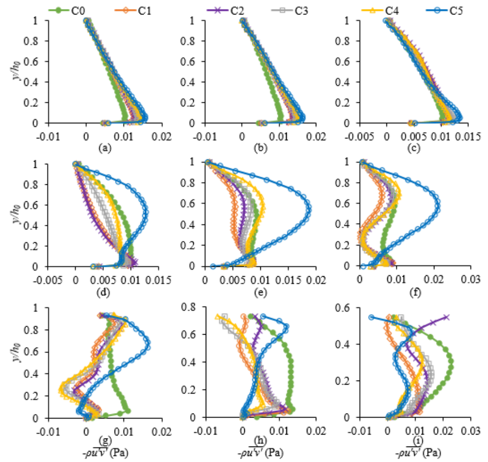
Reynolds shear stress distribution at different configurations placed at X = 7.76 m

As the density of vegetation increases two independent peaks are formed in the channel. One at the center of the main channel, second at the interface of the bank and the channel.

Short notice:

The Reynolds stresses are found to be dependent on the density of the vegetation, and their arrangement, the linear and staggered distribution.

Due to rigid bank vegetation Reynolds shear stress distribution follows non-linear structure and shows parabolic changes



Effect of inclined bank vegetation on flow dynamics - K-H Type instabilites

Based on the findings, due to bank vegetation the flow is subject to the two characteristic velocities; *the convection velocity*

$U_C = (U_1+U_2) / 2$ *and,*

the differential velocity

$\Delta U = U_2 - U_1$

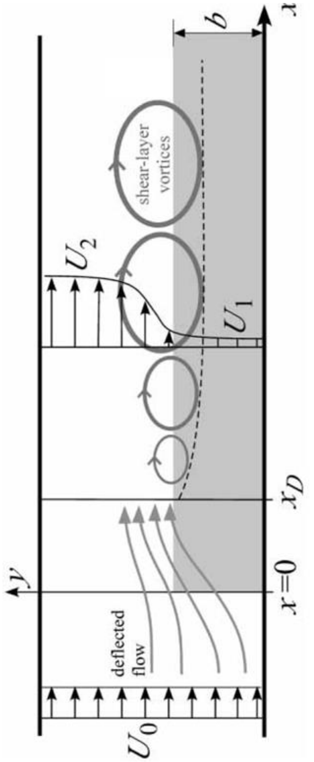
where the U_1 and U_2 are the velocities in the rigid vegetation at an inclined bank and main channel

The mixing layer that generates K-H type vortex in the channel is quantified by the **velocity ratio** λ

$$\lambda = 0.5 \Delta U / U_C$$

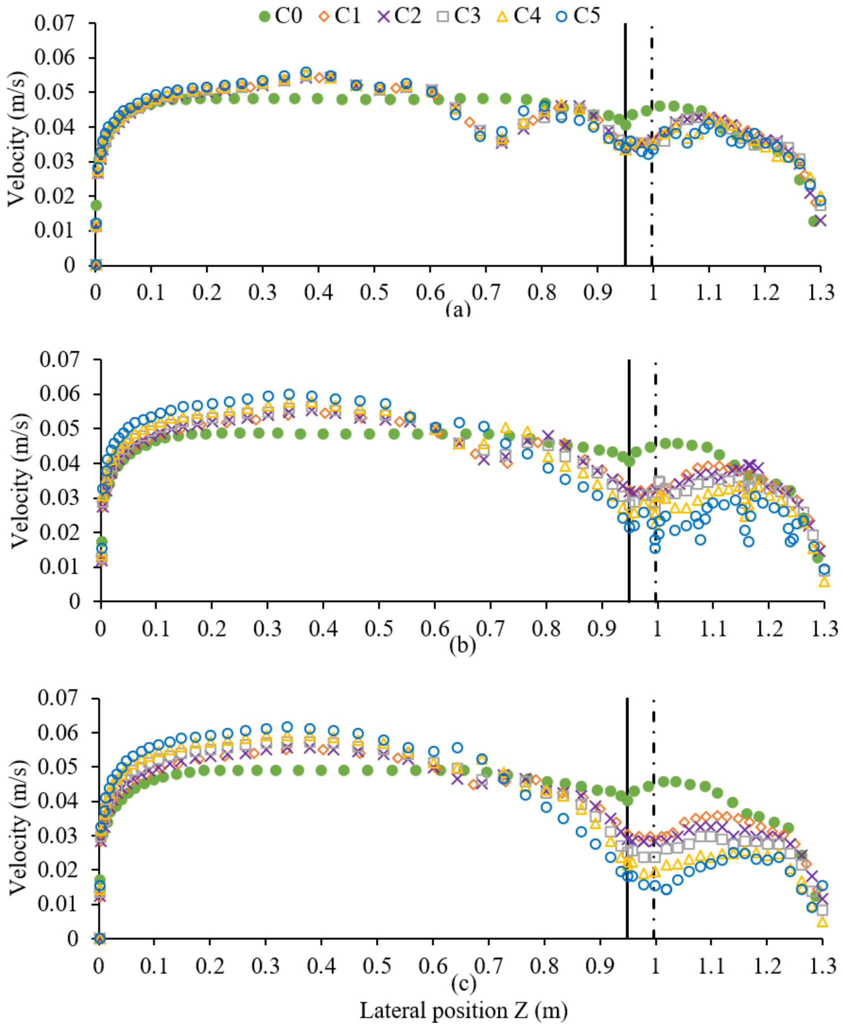
Short notice:

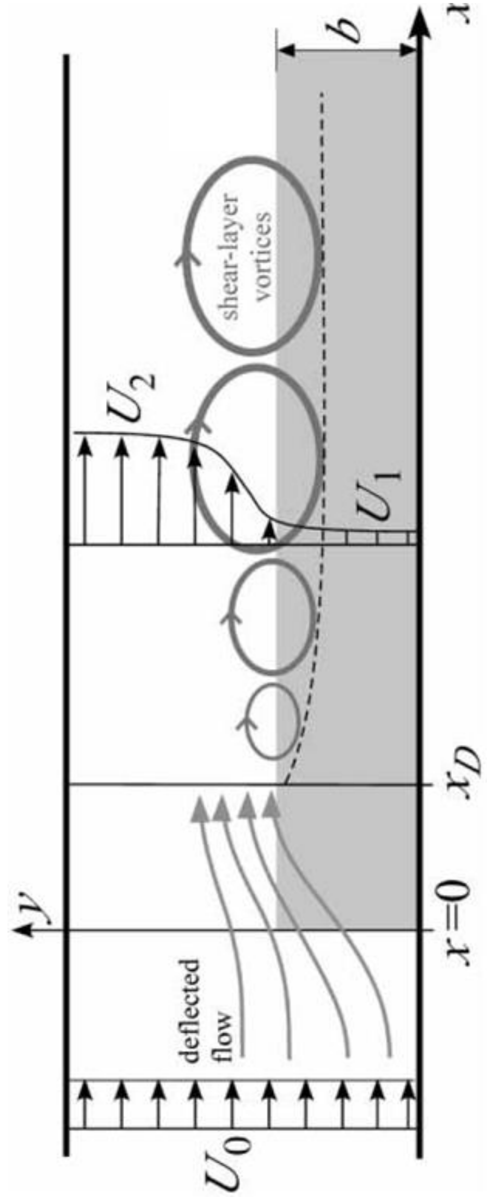
the threshold of velocity ratio for the appearance of KH coherent vortices in compound channels is $\lambda \approx 0.3$



Effect of inclined bank vegetation on flow dynamics - K-H Type instabilites

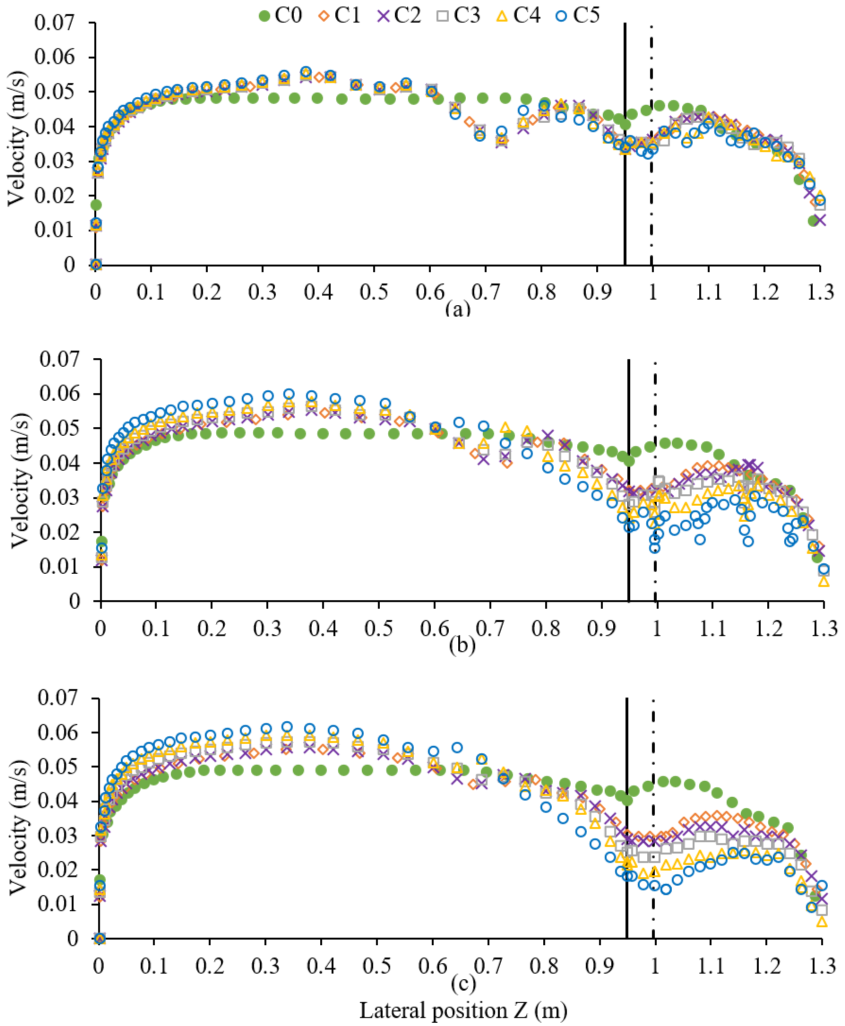
Depth-averaged streamwise velocity profile at different cross-sections placed, a) just at the beginning (X = 5.12 m), b) in the middle (X = 6.44 m), and c) just at the end (X = 7.76 m), of the vegetation's cover.





Effect of inclined bank vegetation on flow dynamics - K-H Type instabilites

Run	Config.	Q (l/s)	V_m (m/s)	Fr	h_0 (m)	Vegetation Cover	U_1 (m/s)	U_2 (m/s)	U_c (m/s)	ΔU (m/s)	λ
I	C0	6.56	0.048	0.048	0.120	Start	0.041	0.048	0.045	0.007	0.078
						Mid	0.040	0.049	0.045	0.009	0.100
						End	0.040	0.049	0.045	0.009	0.100
II	C1	6.68	0.049	0.049	0.120	Start	0.033	0.054	0.044	0.021	0.239
						Mid	0.032	0.055	0.044	0.023	0.261
						End	0.030	0.055	0.043	0.025	0.291
III	C2	6.68	0.049	0.049	0.120	Start	0.033	0.055	0.044	0.022	0.250
						Mid	0.031	0.055	0.043	0.024	0.279
						End	0.028	0.056	0.042	0.028	0.333
IV	C3	6.69	0.049	0.049	0.120	Start	0.034	0.055	0.045	0.021	0.233
						Mid	0.028	0.056	0.042	0.028	0.333
						End	0.024	0.058	0.041	0.034	0.415
V	C4	6.69	0.049	0.049	0.120	Start	0.034	0.055	0.045	0.021	0.233
						Mid	0.025	0.058	0.042	0.033	0.393
						End	0.019	0.059	0.039	0.040	0.513
VI	C5	6.68	0.049	0.049	0.120	Start	0.032	0.056	0.044	0.024	0.273
						Mid	0.021	0.060	0.041	0.039	0.476
						End	0.015	0.061	0.038	0.046	0.605



Effect of inclined bank vegetation on flow dynamics - Conclusions

The shear stress at the centerline of main channel tends to grow as the vegetation density at the inclined bank increase (up to 90%)

The partly obstructed flow in an asymmetric open channel in which rigid vegetation at an inclined bank alters the flow characteristics is numerically analyzed and investigated. It has been revealed that the mean flow velocity at the main channel increase by 33% as the vegetation density at an inclined bank increase. Meanwhile, the mean velocity at the inclined bank decreased approximately fivefold

Effect of inclined bank vegetation on flow dynamics - Conclusions

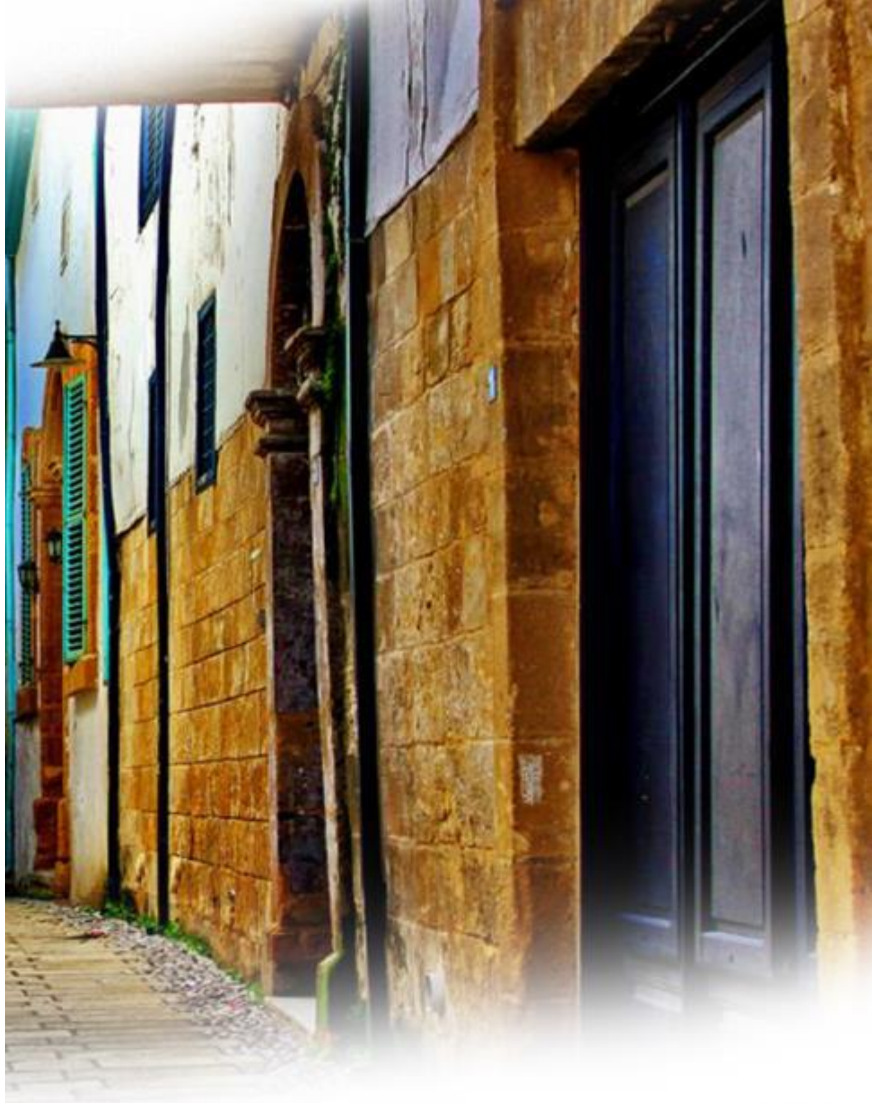
The staggered arrangement of rigid vegetation elements penetrated more than linear arrangement on the magnitude of velocity ratio, and has more tendency to establish a favorable condition for onset K-H vortices.

The Kelvin-Helmholtz type instability was clearly observed where vegetation configuration was dense (C4 and C5).

Related papers:

Valyrakis, M., Liu, D., Turker, U. , Yagci, O.
The role of increasing riverbank vegetation density on flow dynamics across an asymmetrical channel.
Environ Fluid Mech **21,** 643–666 (2021).
https://doi.org/10.1007/s10652-021-09791-9

Masouminia, MH, Turker, U.
Numerical investigation of the effect of rigid vegetation at an inclined bank, on streamflow hydrodynamics
Acta-Geophysica (under review)



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Da Liu

Thanks for listening…