Statistical Analysis of Seepage's Influence on Open-Channel Flow Turbulence

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Outline

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General Overview

- This contribution presents a statistical analysis about seepage's influence on water hydrodynamics.
- The output of the experiments shows that the artificially induced seepage affects the turbulence dynamics of the open-channel flow. Regardless the significantly small magnitude of the groundwater flow.
- It was observable that seepage modifies the shape of the profiles of analyzed time-averaged parameters of turbulence and in many cases; the open channel flows are not following the laws of isotropic turbulence.
- As a consequence, it is expected that seepage modifies the interaction between the flowing water along the channel and the sediments from the bottom.

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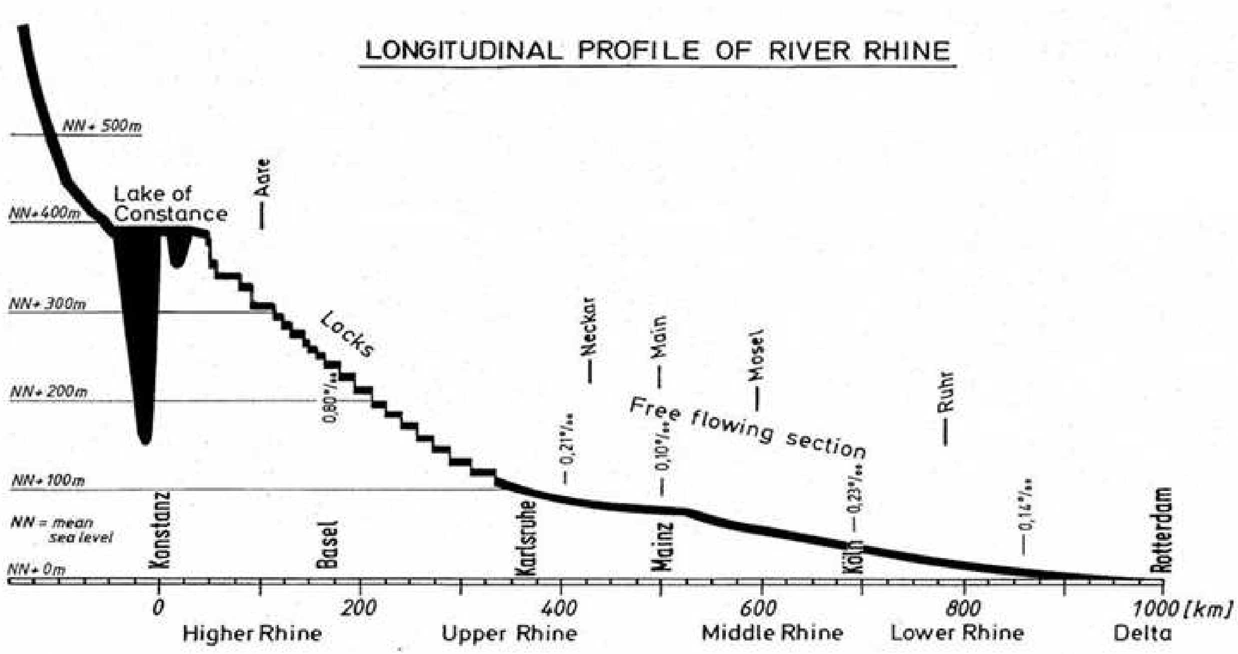
Introduction

Endowed with means that had been reserved for Divine Providence in former times, they change the rain regime, they accelerate the harvest cycle and they change the path of the river, moving it with its white stones and gelid currents to the other extreme of the town, behind the graveyard.

One Hundred Years of Solitude
Gabriel García Márquez [5]

background drawn by *Colin Elliott*, *Anthony Fehr*, *Erik Nelson*, and *Rachel Robertson*

Due to the fact that groundwater flow rates are much smaller than open-channel flow rates; seepage is commonly neglected by river engineers in the analysis of water and environmental issues.



	4200		4550	5600		7000	11 000	11 000		12000	12 000	m³/s	maximum discharge
	1020		1240	1380		1590	1960	2050		2250	2 300	m³/s	mean discharge
	267		335	370		482	560	481		570	600	m³/s	lowest discharge

Figure 1 : Longitudinal profile of the river Rhine (Wetzel, 2002)

There are cases where the uppermost layer of river beds constitute a porous medium and seepage takes place. Downstream, in the vicinity of these structures, seepage is almost upward.

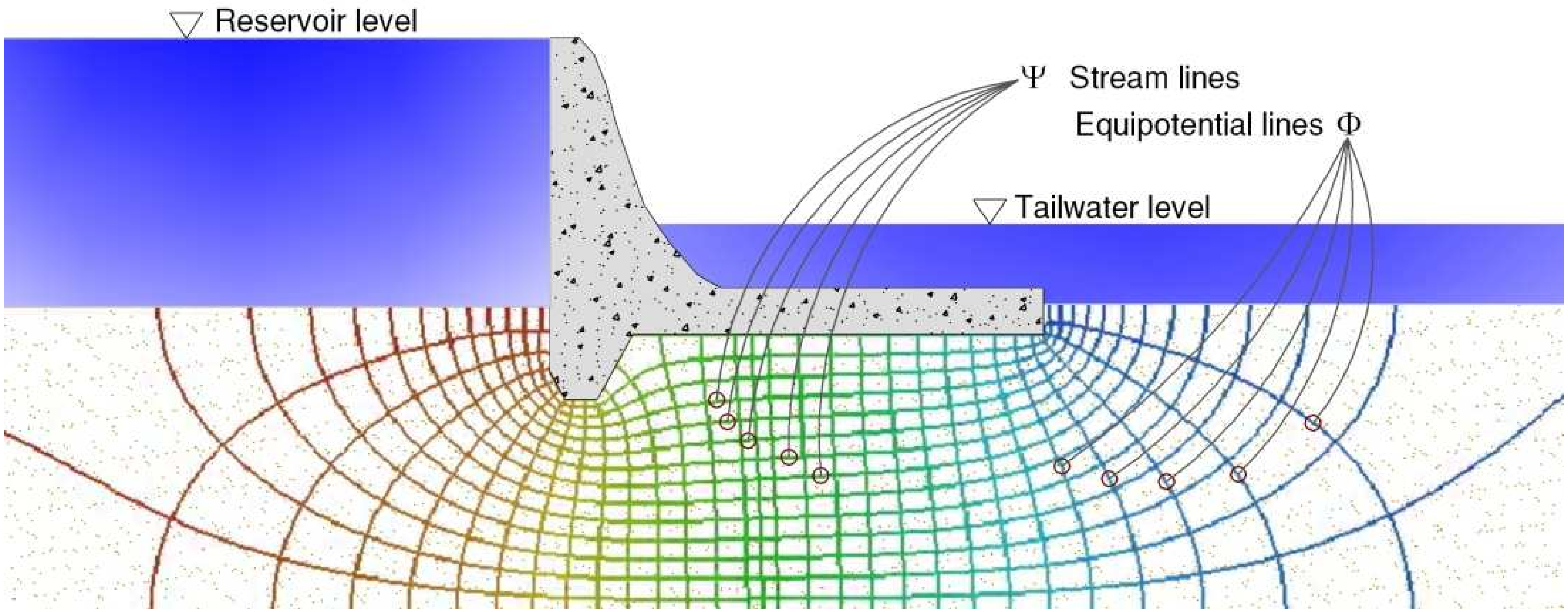


Figure 2 : Upward seepage downstream a concrete weir

Experimental works concerning seepage's influence on river dynamics were carried out by Ali et al. (2003), Chen and Chiew (2004), Dey and Sarkar (2007), Lu and Chiew (2007), Fontana (2008), Sreenivasulu et al. (2010), 2010a and Herrera Granados (2008c, 2010a) among others.

In the majority of the previously mentioned experimental works, seepage's flow rates were considerably high. But in natural conditions, groundwater flows are much smaller in comparison with stream and river flows. Moreover, results from recent research efforts in this area are often inconclusive and sometimes conflicting (Lu et al., 2008).

Outline

The laboratorial research was carried out at the open air laboratory of the Wrocław University of Technology (WUT).

The experimental zone was 8.0 m long, 0.5 m width and 1.0 m high. The first two meters of this experimental zone were used to stabilize the flow in order to address it into subcritical regime to the region where the measurements were recorded.

Figure 3 : The Flume at the laboratory of the WUT

Figs. 4 & 5 depict the tank and the scheme of the connection from the tank to the lowest part of the experimental flume. A thin layer of geotextile was allocated in between the sandy layer and the metal base that was symmetrically drilled.

Figure 4 : The tank that Provoked Seepage

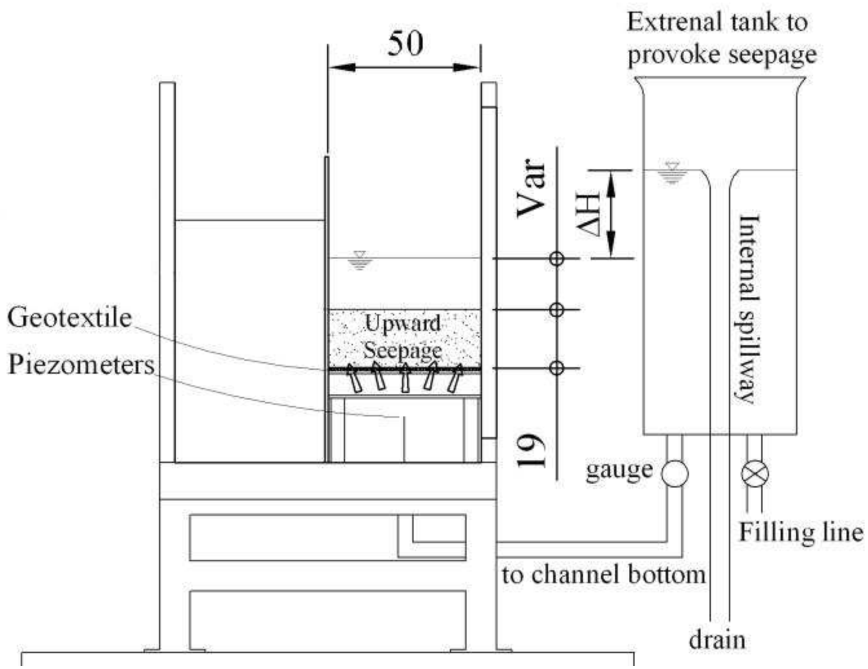


Figure 5 : Tank-Flume's connection

This figure depicts the location of the velocimeter P-EMS in three cross sections of the flume (X = 1.0, 3.0 and 5.0 m according to the established reference frame).

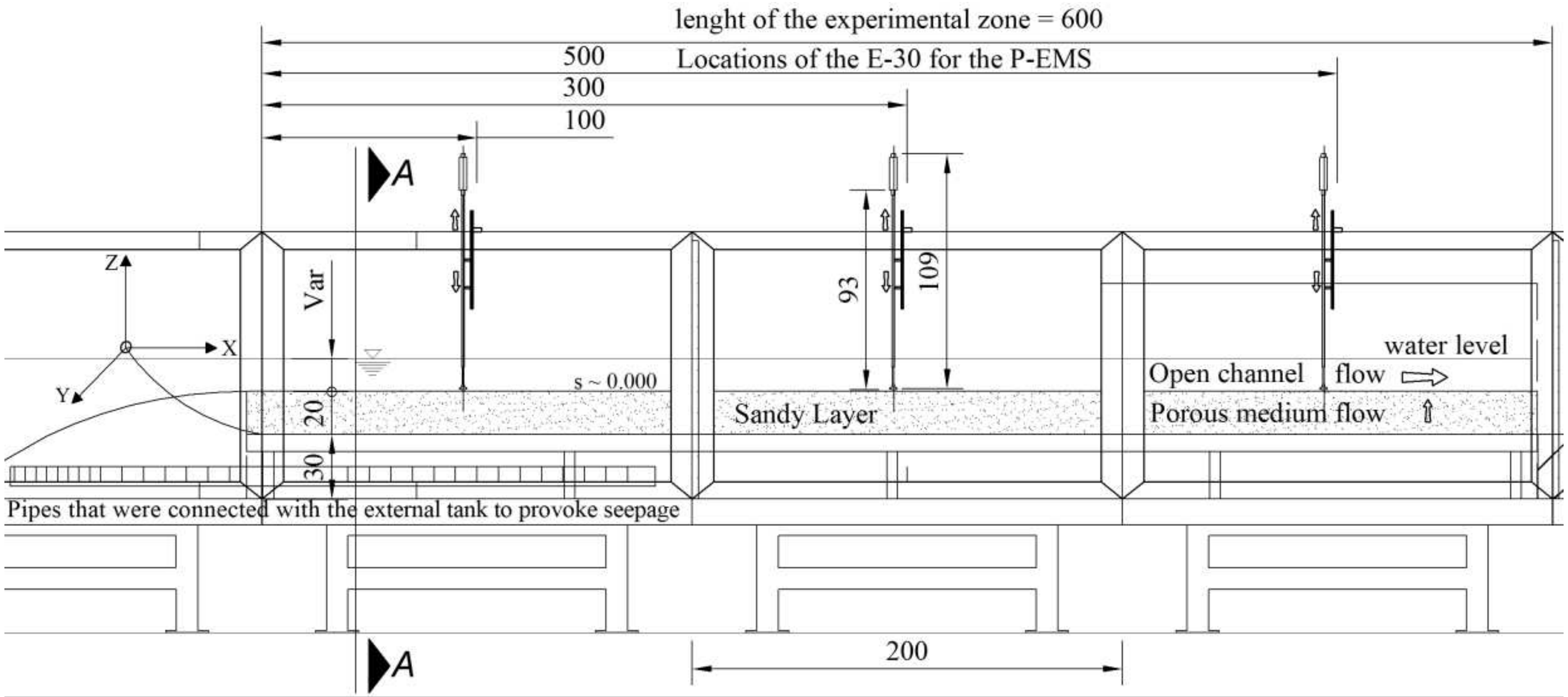


Figure 6 : Location of the P-EMS and the E-30

The turbulent flow measurements were taken in 35 different points at each cross section (depicted in Fig. 6.)

Figure 7 : The probe E-30 of the P-EMS

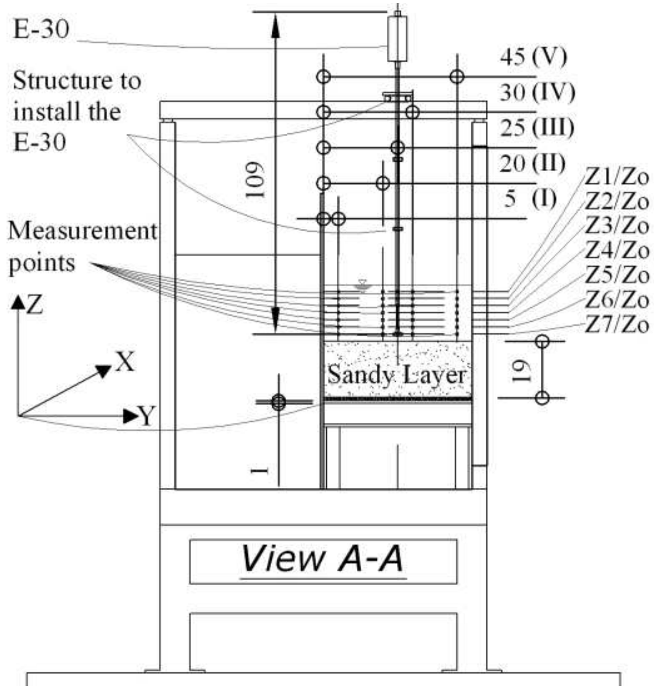


Figure 8 : View A-A of the flume

Using descriptive statistics, time averaged turbulence parameters were calculated such as Reynolds shear stresses in the xy and xz-plane (Directly calculated from the velocity fluctuations). Three open channel flow rates were used during the experiments, depicted in table below.

ID	Flow Rate	Flow Averaged Velocity [m s^{-1}]		Measured k_s	Seepage intensity
	[dm^3 s^{-1}]	a) Open-channel	b) Seepage	[cm s^{-1}]	Rate b/a [%]
Q_1	11.4	0.440	0.000040	0.00402	0.0091
Q_3	20.0	0.530	0.000039	0.00390	0.0073
Q_5	30.0	0.554	0.000038	0.00379	0.0069

A fine sand soil constituted the porous medium; its d_{50} was around 0.299mm while d_{10} of this sand was estimated around 0.08mm and ϕ=30 degrees.

Fig. 9 depicts the mean velocity profiles and one-point statistical moments as a function of the relative depth at the cross section X = 1.0 m without seepage and with different induced Δ.

There is not clear evidence that seepage affecting the open-channel hydrodynamics. Nevertheless, seepage is influencing the turbulence parameters as will be shown next.

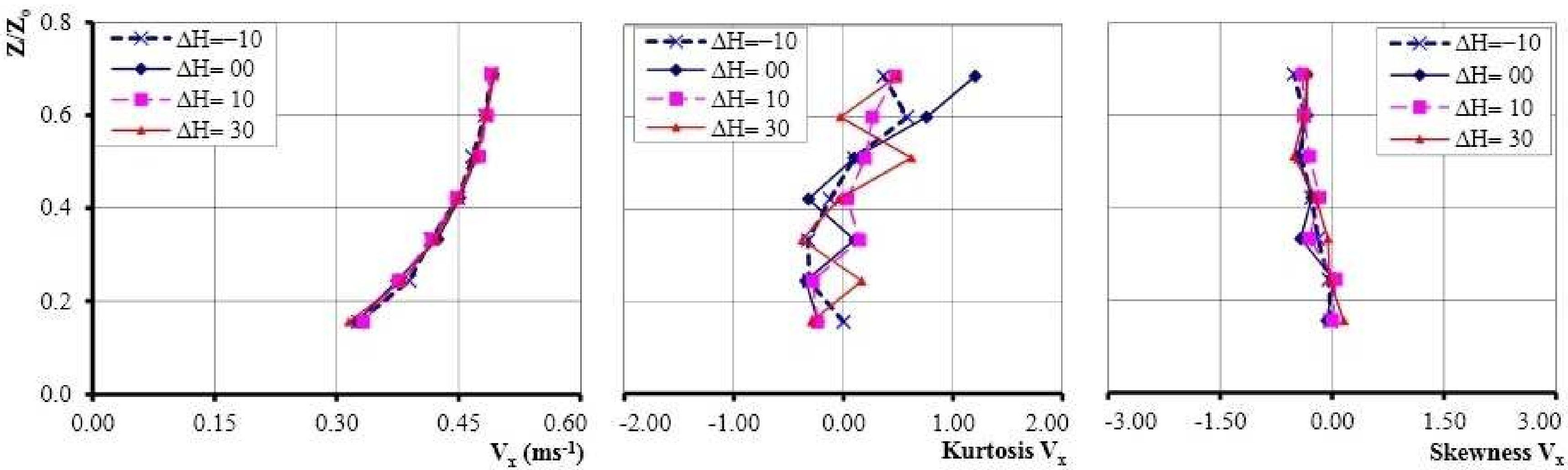


Figure 9 : Velocity profiles of the experiments

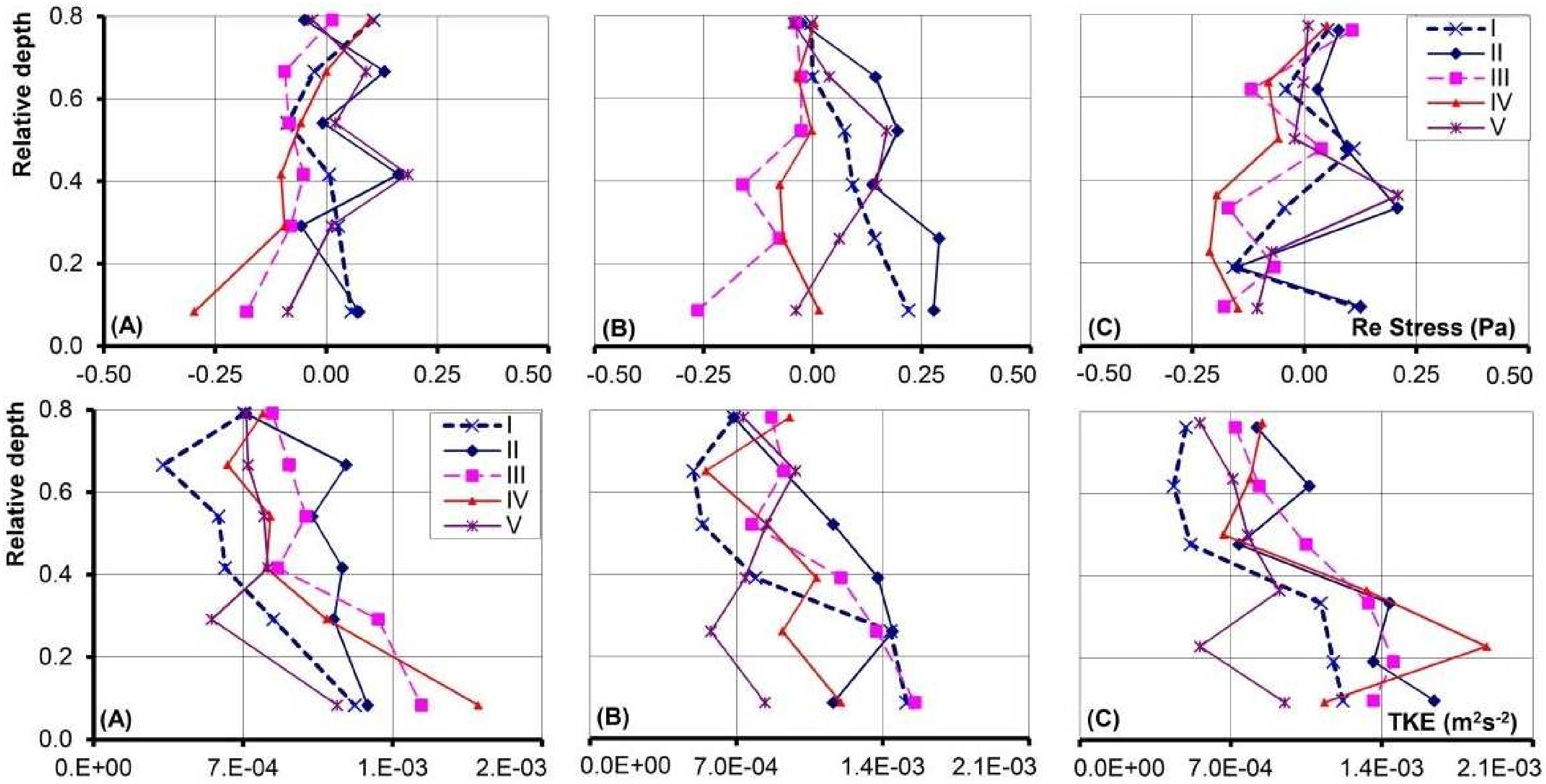


Figure 10 : *Re* stresses and *TKE* for different Δ H

Nonetheless, as shown in Fig. 25 the time averaged turbulent parameters of Q_5 are affected.

Fig. 11 depicted TKE and Re Stresses for Q_3.

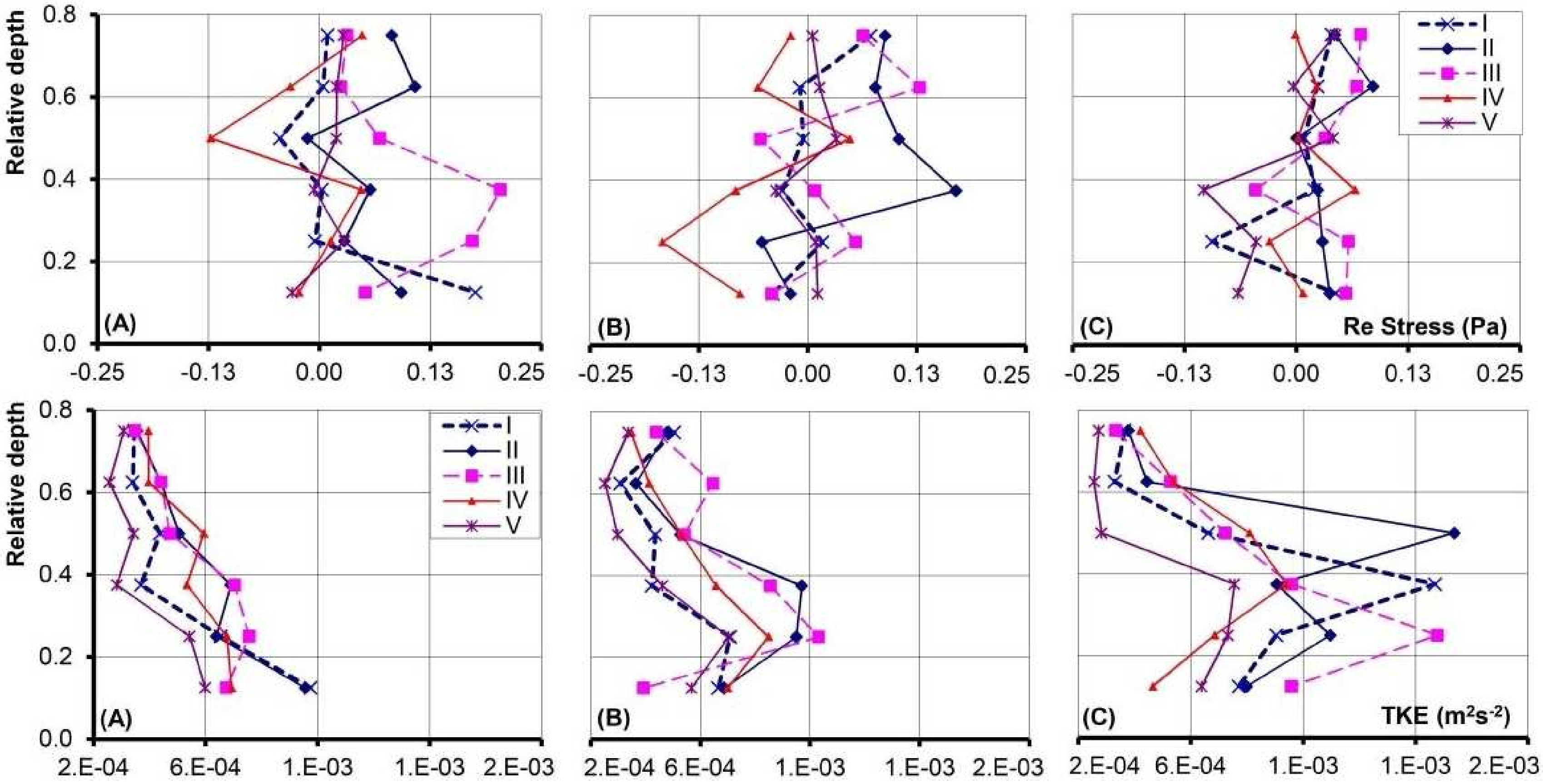


Figure 11 : *Re* stresses and *TKE* for different Δ H

A good picture of the difference between *isotropic* and *anisotropic* turbulence was presented by Kundu and Cohen (2002) and it is depicted in Fig. 12. The energy cascade process can be pictured by the *Kolmogorov Spectrum* (see Fig. 13).

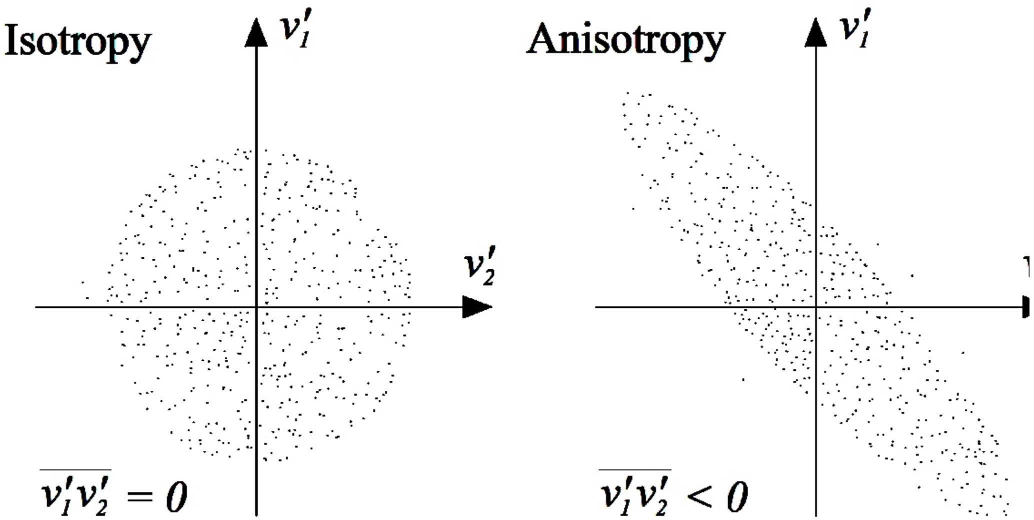


Figure 12 : Types of velocity fields

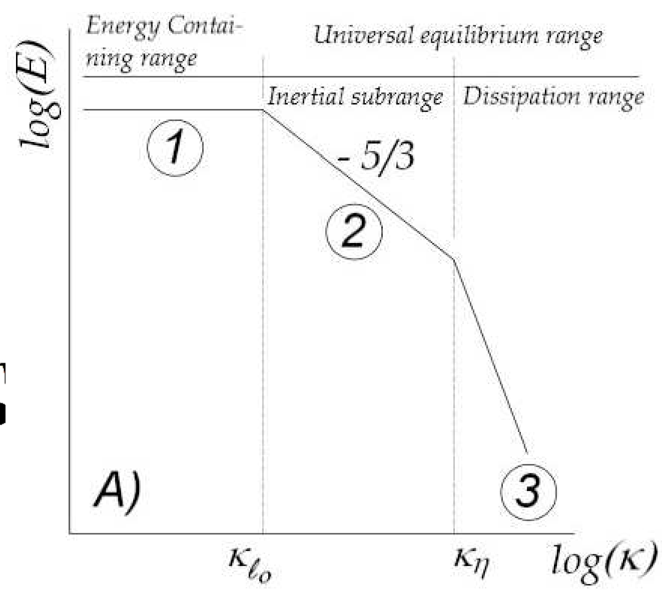


Figure 13 : Kolmogorov's Spectrum

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Quadrant analysis was carried out to check whether seepage is affecting bursting events.

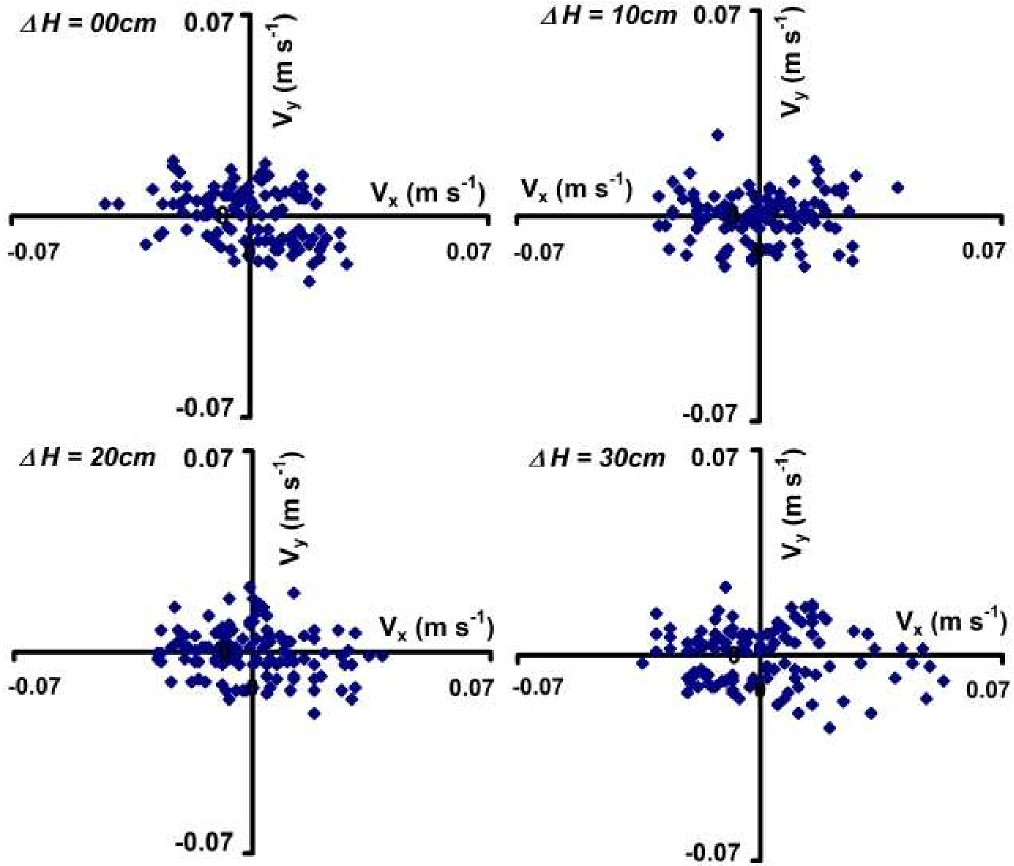

Figure 14 : Seepage's influence on the velocity fluctuations

Autocorrelation functions, Second order structure functions and Energy Spectra for different ΔH were calculated based on the theory of frozen turbulence (Taylor, 1938).

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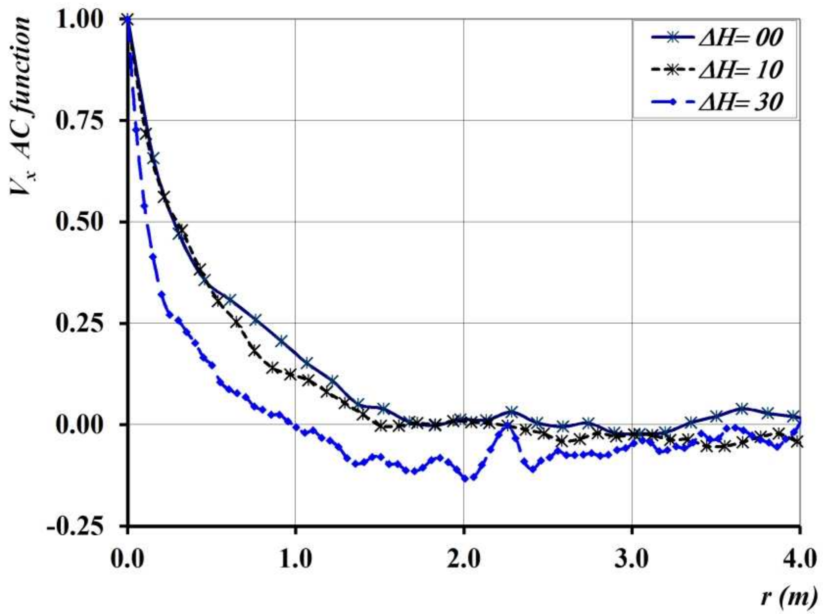

Figure 15 : V_x Autocorrelation functions for Q_1

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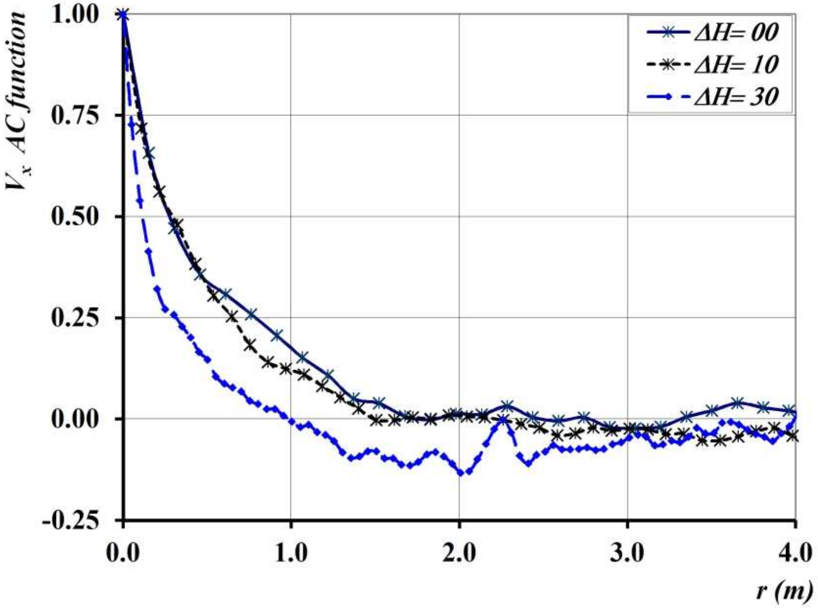

Figure 15 : V_x Autocorrelation functions for Q_1

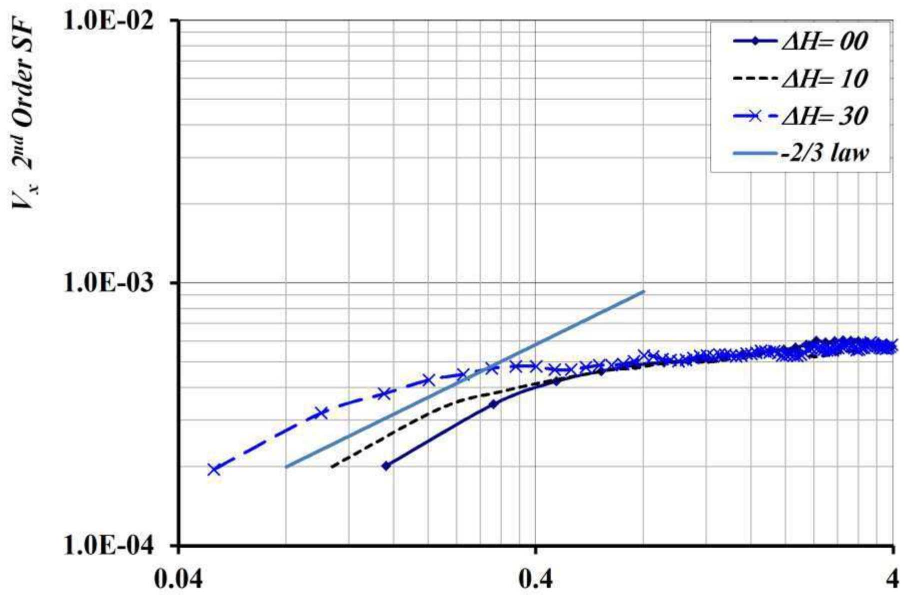

Figure 16 : Second order structure function for Q_1

We can see that the initiation of the inertial range depends on seepage intensity. The Yule-Walker Method was applied to calculate the spectra.

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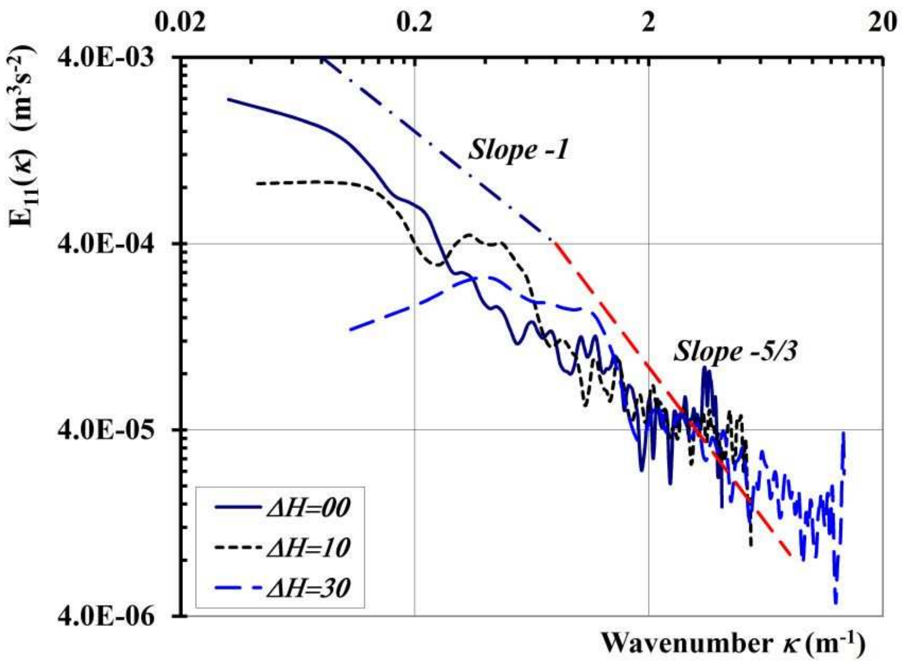

Figure 17 : V_x Spectra for Q_1

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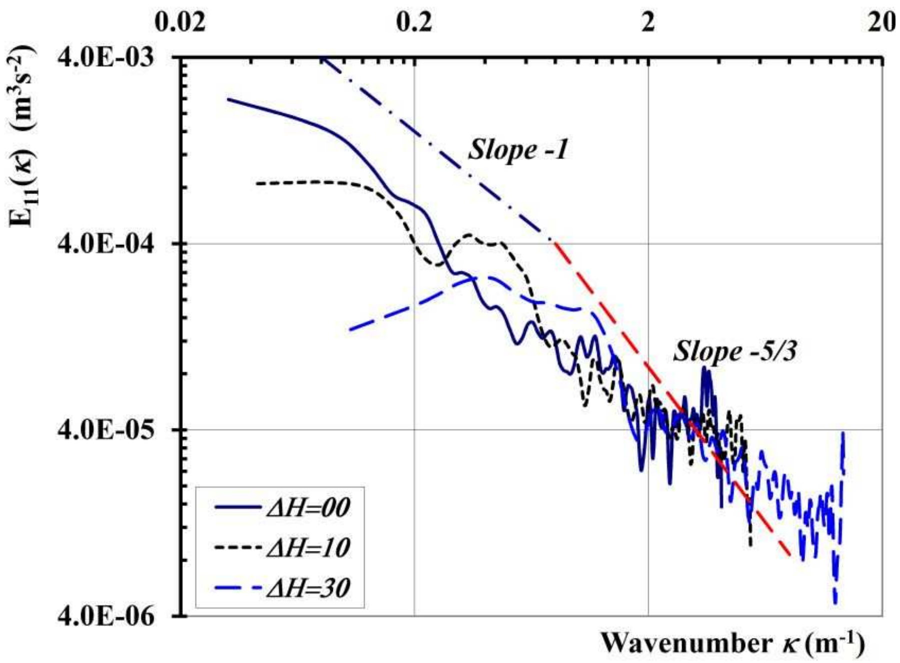

Figure 17 : V_x Spectra for Q_1

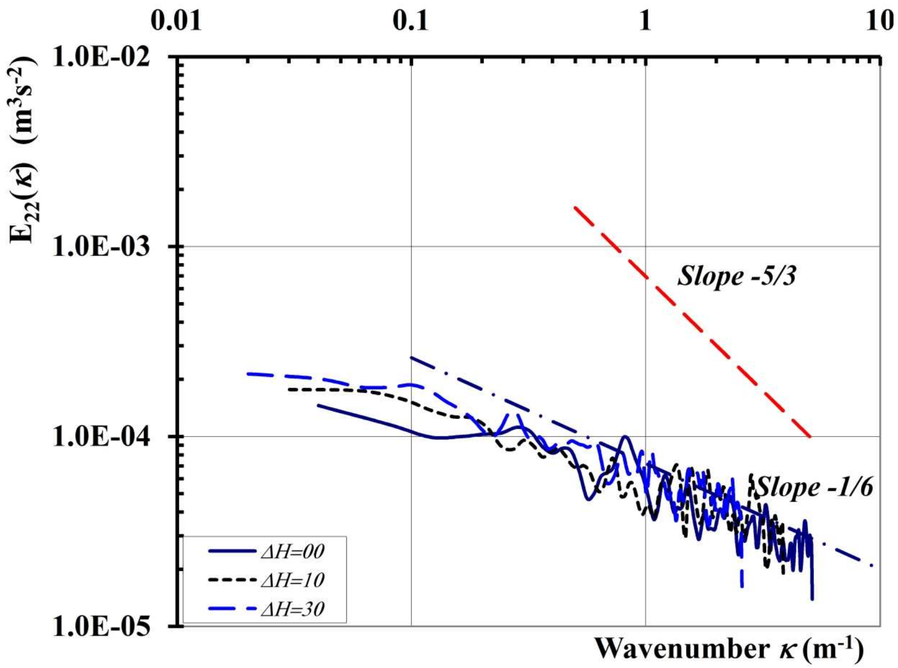

Figure 18 : V_y Spectra for Q_1

Power spectra E_{11} of Fig. 19 were estimated in the middle of the channel at five different distances without seepage. Power spectra E_{11} of Fig. 20 were calculated with seepage flow.

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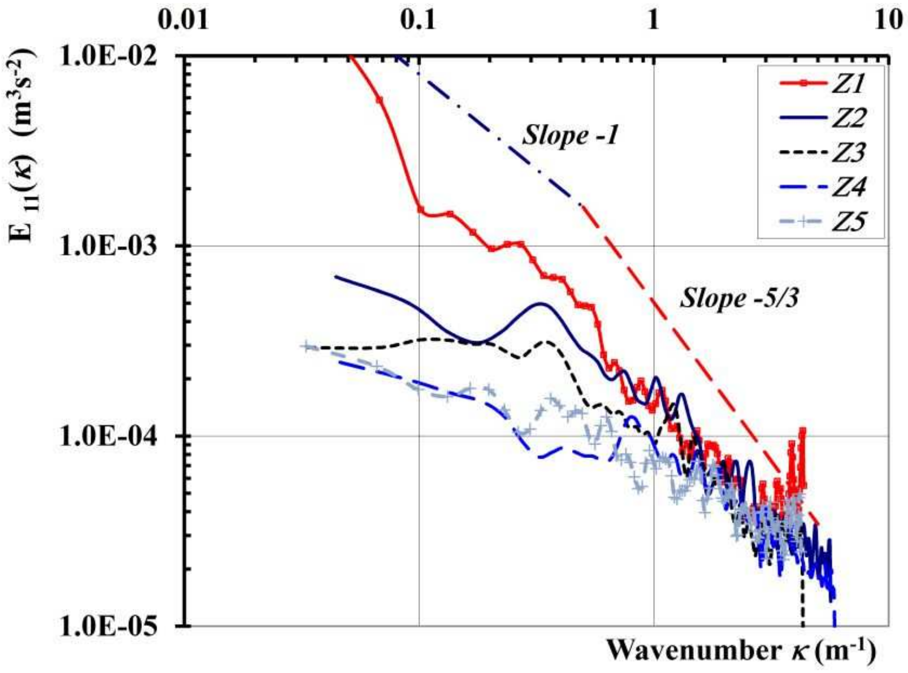

Figure 19 : V_x Spectra without seepage

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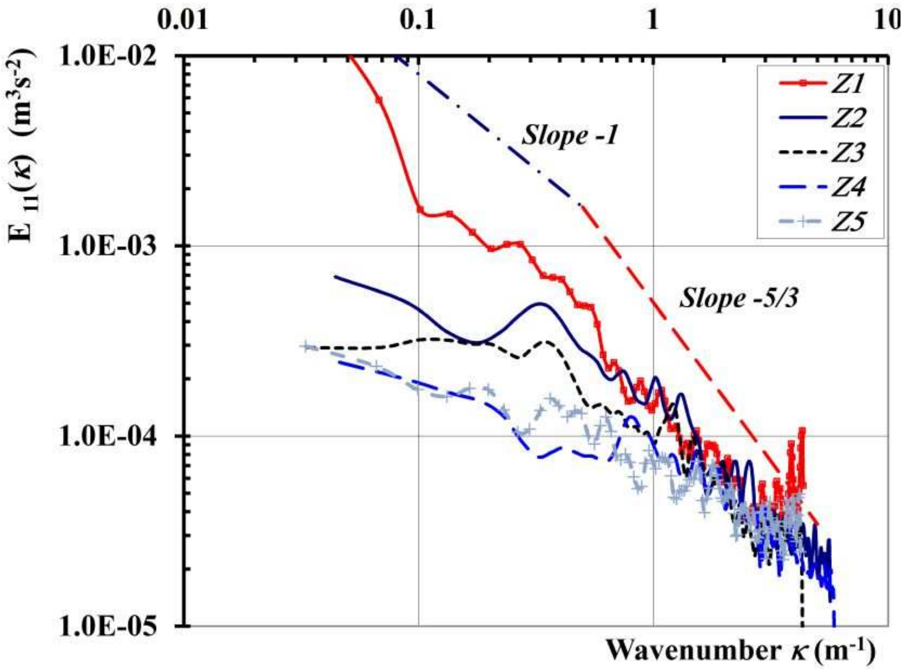

Figure 19 : V_x Spectra without seepage

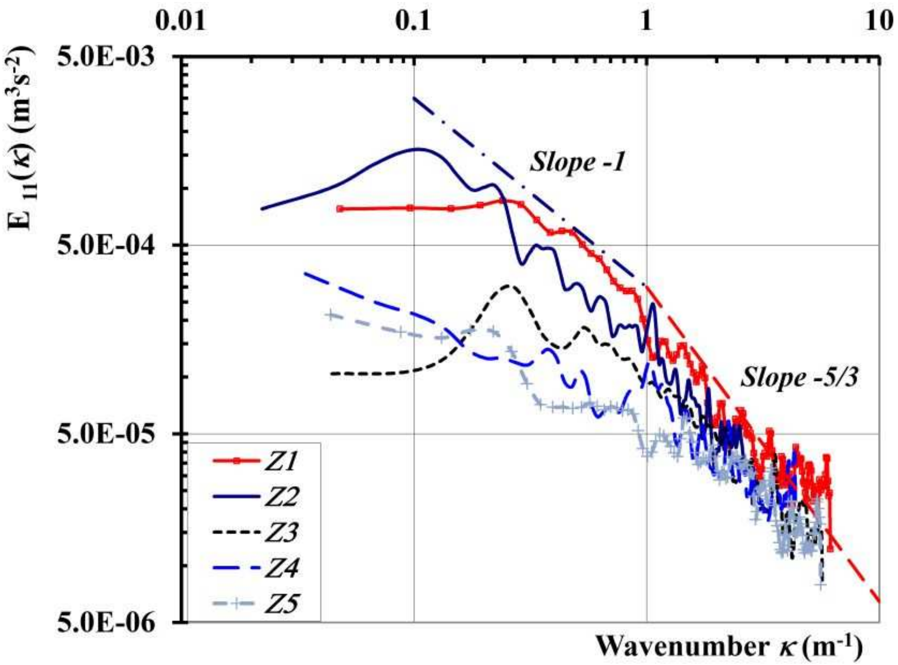

Figure 20 : V_x Spectra with seepage

Fig. 21 depicts 1D spectra in the spanwise direction without induced groundwater flow through the flume's bed. Fig. 22 depicts 1D spectra in the streamwise direction for Q_3

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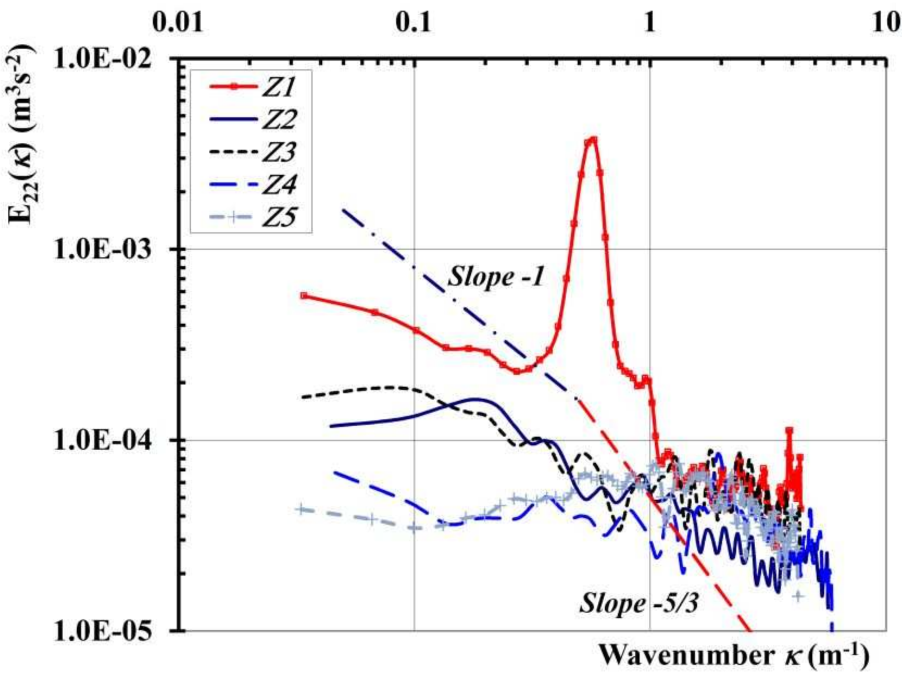

Figure 21 : V_y Spectra without seepage

Fig. 21 depicts 1D spectra in the spanwise direction without induced groundwater flow through the flume's bed. Fig. 22 depicts 1D spectra in the streamwise direction for Q_3

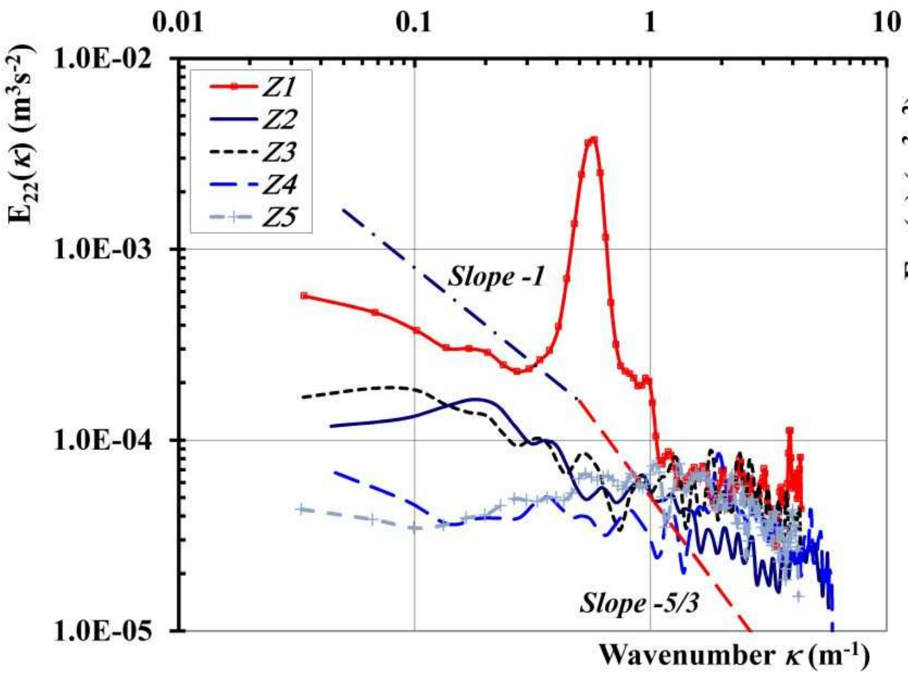

Figure 21 : V_y Spectra without seepage

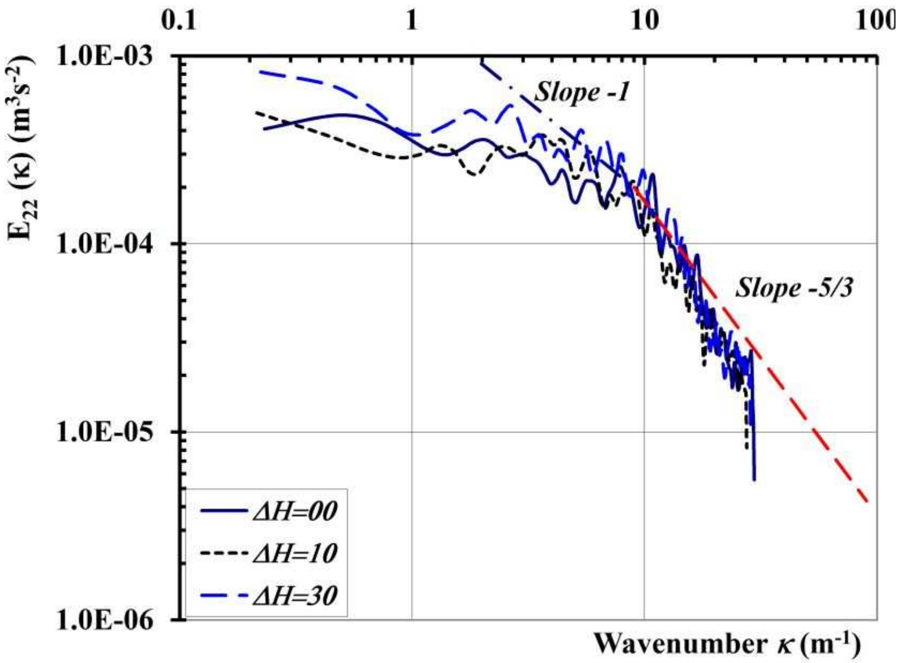

Figure 22 : V_x Spectra for Q_3

Outline

In previous experimental works, it was observable that regardless the small seepage intensity, the flow through the porous medium is affecting the bed evolution and deposition.

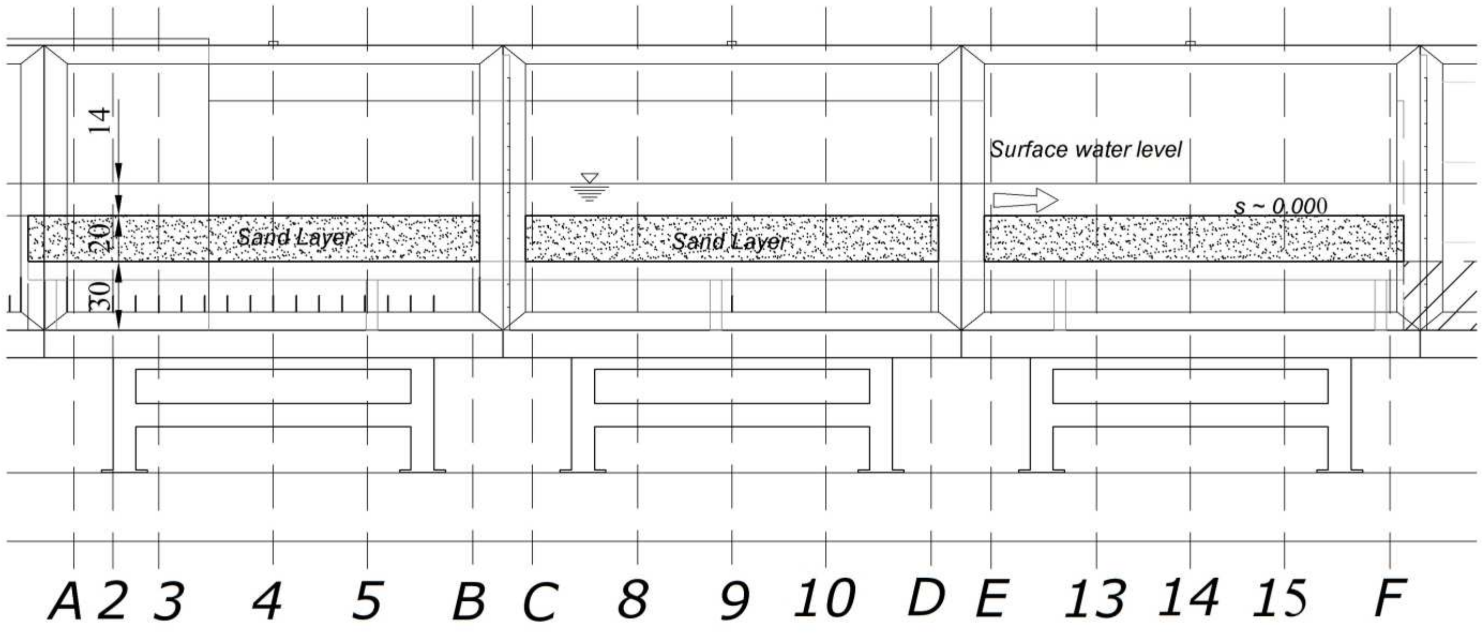

Figure 23 : Cross sections were bed changes were measured

Experimental Works
Previous Experimental Works

In Fig. 24, the bed height changes were compared for the same four seepage intensities ΔH = 10, 20, 25 and 30 cm. At the cross section 3, the bed deformation was more intense for ΔH = 10 cm during the first 30 minutes that the experiments lasted for Q_5.

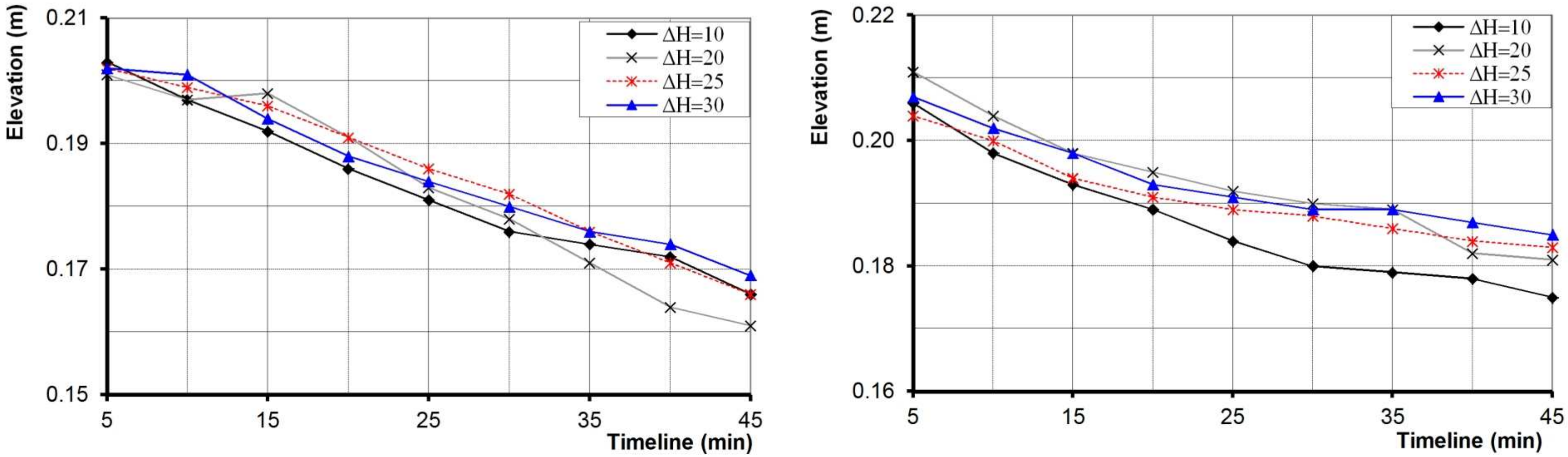

Figure 24 : Bed changes under different seepage intensities conditions.

Further Research

Upgrade the experiments that were previously present:

- Using better instrumentation (e.g. laser-based velocimeter, using bed profilers, etc.)
- Increasing the seepage intensities. Carrying out experiment with downward seepage
- Using different soils for the porous medium

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To model the studied phenomenon by a numerical approach is the next step of this research. The output of the numerical model will be compared with the results from the experiments.

There are three proposals to seepage influence on open channel dynamics:

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- The zero boundary condition at the channel bed has to be changed considering seepage as a Dirichlet boundary condition (upward inflow = constant).
- To analyze the initiation of sediment motion under seepage conditions.
- Coupling the interaction of seepage and channel hydrodynamics in the same numerical approach. That means that there is a necessity to analyze together laminar or quasi-laminar seepage and turbulent flow in the same model.

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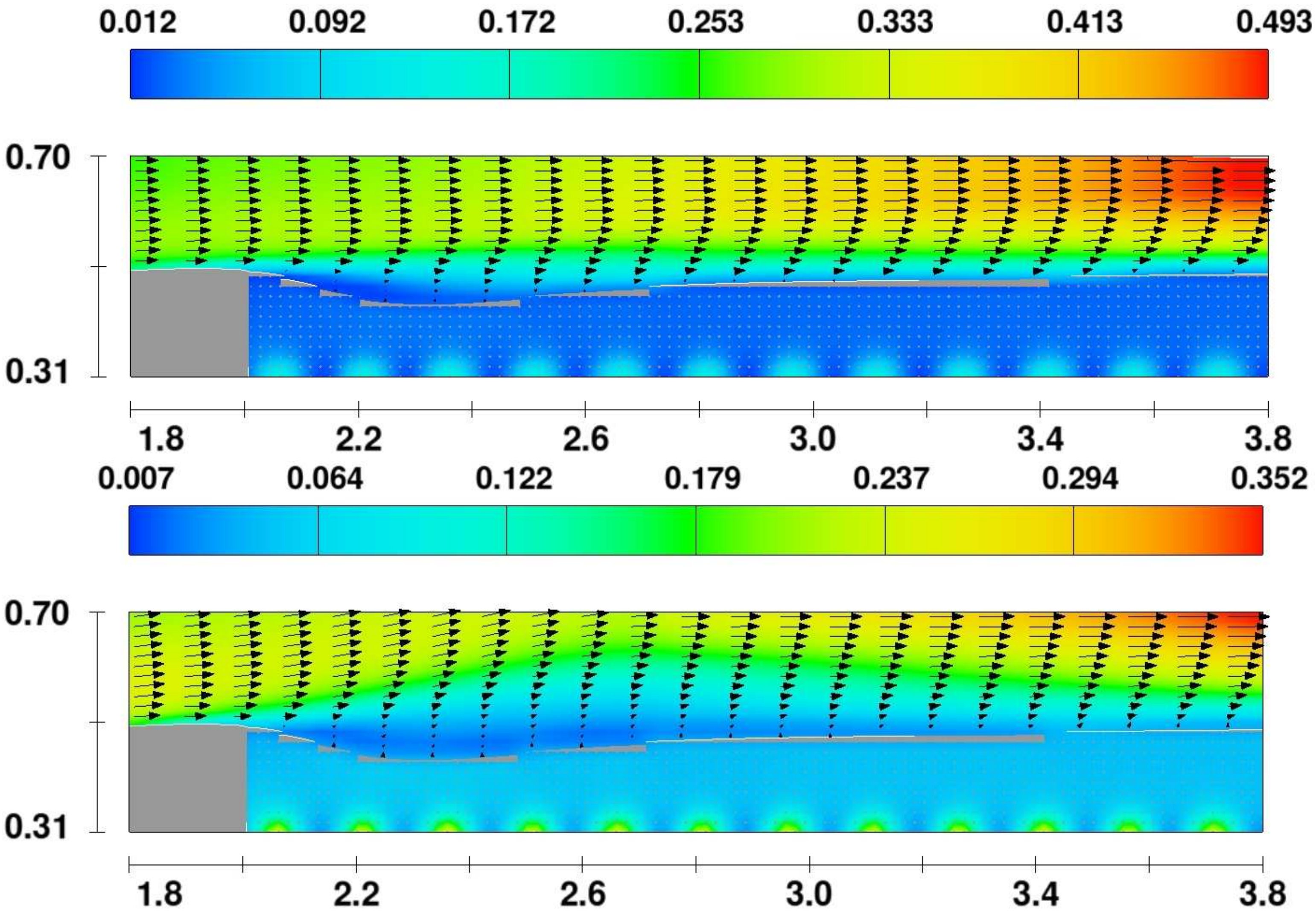
It is evident that the third option is more complex.

Modelling both phenomena is the ongoing task.



But it is necessary to be careful with this. Some measurements were carried out for this hydrodynamic conditions and the quadrant analysis depicts this completely anisotropic field (See Fig. 26).

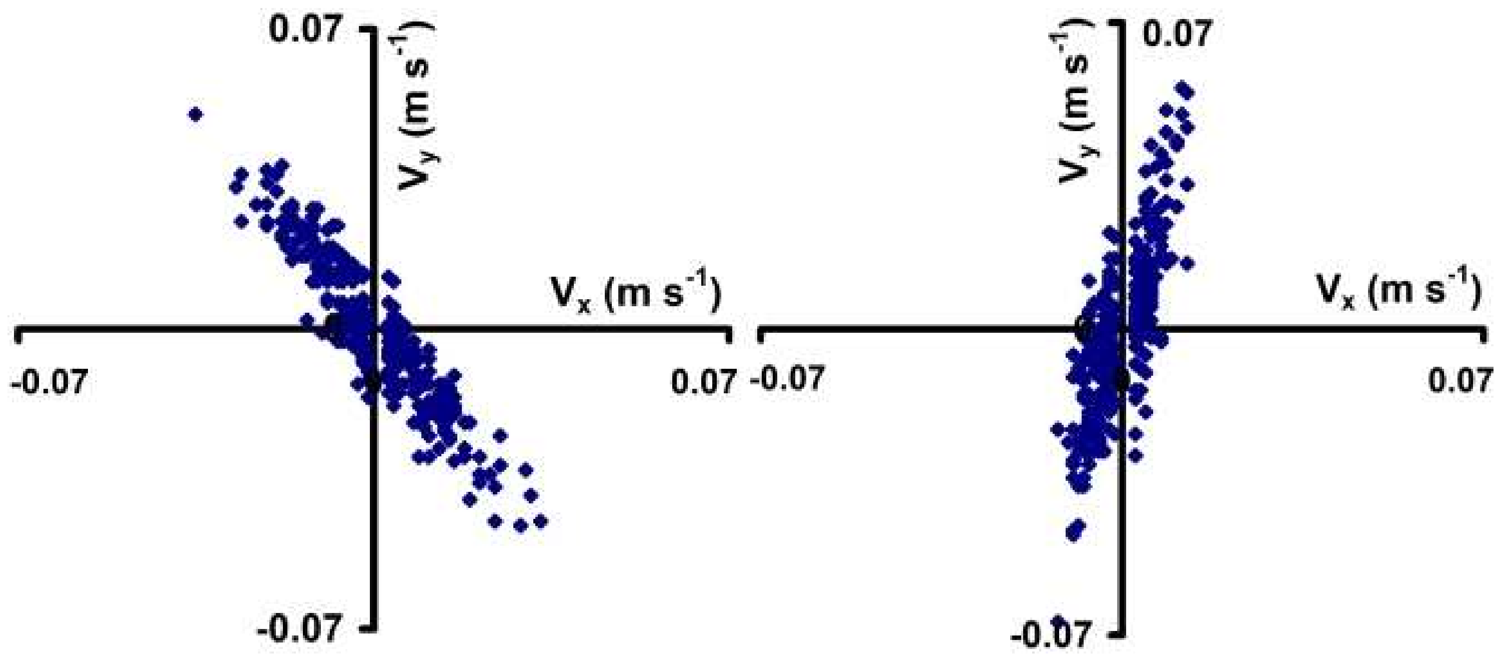


Figure 26 : Quadrant analysis under high induced seepage.

Outline

Conclusions

The previous analysis demonstrates that the presence of upward seepage influences the velocity fluctuations of the open channel turbulent flow.

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- The presented figures showed that the velocity field is changing when flow through the hyporheic zone exists.
- Additionally, the TKE and the Reynolds stresses are affected by the presence of this groundwater flow.
- Seepage affects the isotropic behavior of the open channel instantaneous velocity field.
- The modification in the behavior of the turbulent stresses can be one of the reasons why seepage is changing sediment transport mechanisms.

A future step of this research is to perform the numerical analysis of this phenomenon:

A future step of this research is to perform the numerical analysis of this phenomenon:

- Treating the seepage flow as a new boundary condition in a turbulent model (Easier).
- Integrating the interaction of both processes; which means that there is a necessity to analyze together seepage and open-channel hydrodynamics in the same numerical approach (More difficult).
- Modifying the criteria of predicting sediment incipient motion under seepage conditions (hydrodynamics are neglected).

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Thank you very much
for your attention