# DIRECT VELOCITY TOOL
# AN INNOVATIVE TOOL FOR GROUNDWATER VELOCITY MEASUREMENT

**E.ESSOUAYED*, MD. ANNABLE**, O.ATTEIA***, M. MOMTBRUN***

* INNOVASOL, Bordeaux (FRANCE)
** University of Florida
*** ENSEGID, Bordeaux INP

Contact/Information : elyess.essouayed@gmail.com

## Background

In hydrogeological and contaminated site studies, groundwater velocity measurement are useful and can be used to characterize groundwater or indirectly to measure contaminant mass fluxes at a polluted site. Several methods or tools are available for velocity measurement. These tools nevertheless have some disadvantages : measurement time (depending on water velocity), needs for several wells (tracer test), only efficient for high velocity (Colloidal Borescope).

This poster presents an innovative tool for groundwater velocity measurement (Darcy flux), the Direct Velocity Tool (DVT) which intends to provide an in-well test, a measurement without limitation due to vertical flow and a short time of measurement (between 5 and 10 minutes).

## Material and methods

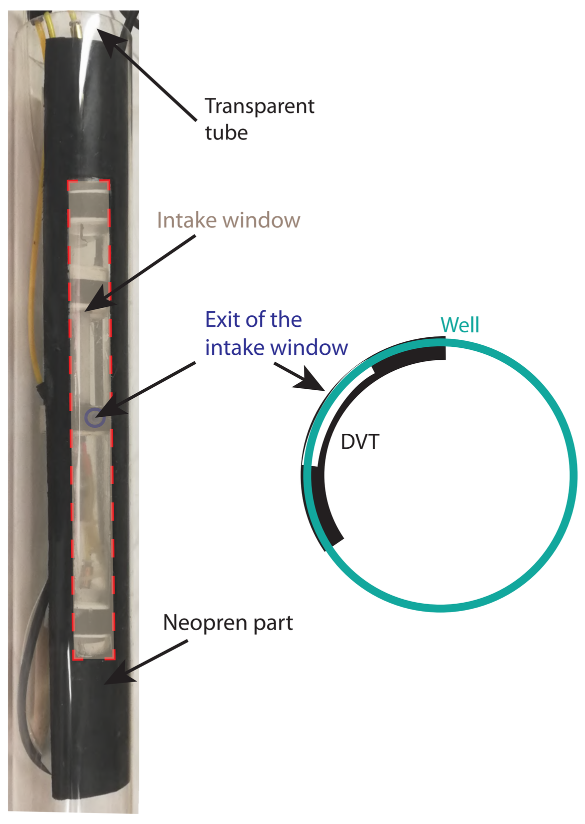
The DVT is maintained in the well screen creating an intake window. The intake window makes it possible :

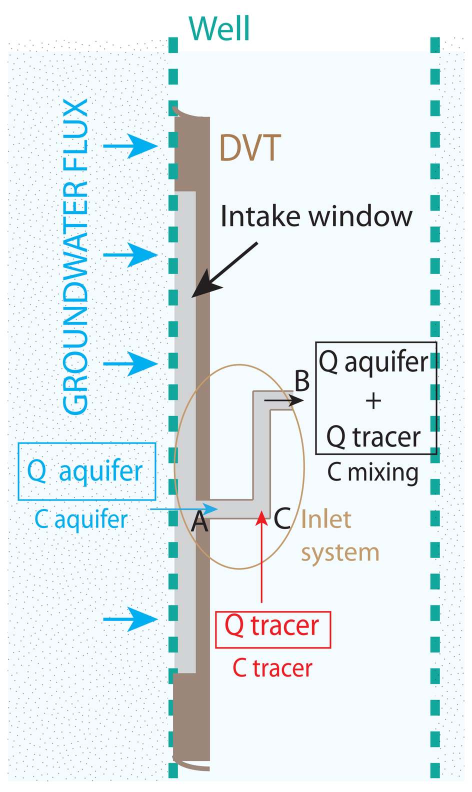
- to isolate a portion of the screen for measurement
- to focus the groundwater flow toward the measurement sensor.

### Mixing principle

Water from the aquifer flows through the intake window and exits at point A. An injection port is installed at point C where the groundwater is mixed with injected solution. The mixed solution is then measured at the exit in the point B.

Adopting a simple mass conservation and assuming groundwater and solution are homogeneously mixed, the flow water from the aquifer can be calculated and give the Darcy flux q measured by the tool :



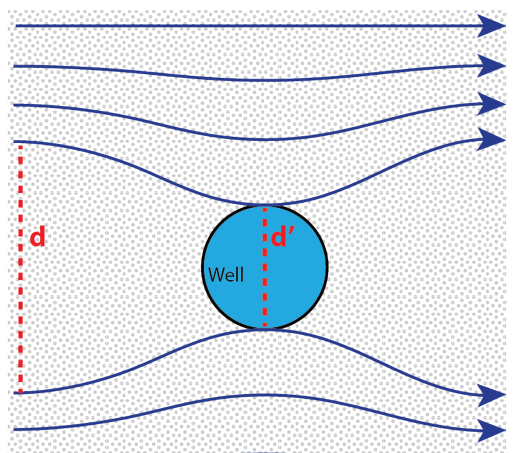



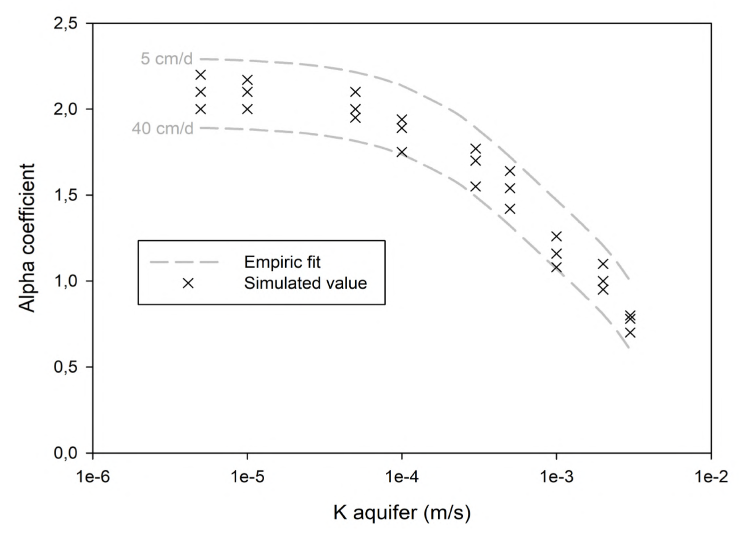

$$Q_{DVT} = Q_{tracer}\frac{C_{mixing} - C_{tracer}}{C_{aquifer} - C_{mixing}} = q_{DVT}S_{Intake\ window}$$

*Q : flow rate*
*C : concentration*
*q : Darcy flux*
*S : section*

### Distortion calibration of the DVT

Because the Darcy flux measured by the DVT is apparent, different test were modelled to assess the distorsion flow $\alpha$ of the DVT in order to calculate the real Darcy flux ($q\ real = q\ DVT / \alpha$). Figure below shows the distribution of the DVT distorsion for a range of Darcy flux in function hydraulic conductivity K. An empirical fit was developed to calculate the corresponding $\alpha$ using the following equation : $\alpha = 0.7exp^{-2300K} - 200K + 1.2$




## DVT calibration in laboratory tests

### Sand tank experiments

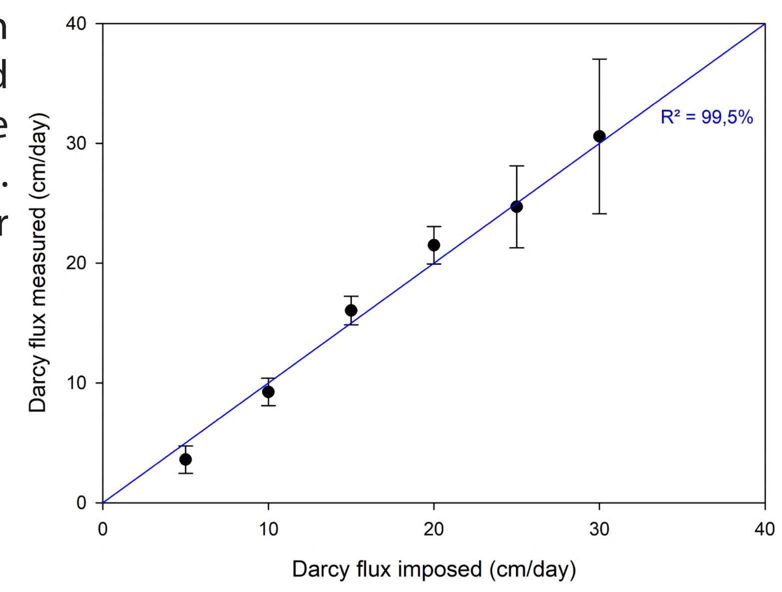
The DVT was first tested in a sand tank A with 68 cm long, 12 cm wide and 50 cm height. An 80 mm diameter screen well was installed in the center of the sand box.

Two clay zones were added between the box walls and the well in order to avoid water deviation around the well. Using a peristaltic pump, different flow rates were imposed in the system producing a homogeneous velotity.

Another calibration was conducted in a second laboratory tank B (100 cm long, 50 cm wide and 50 cm height) at PERL facilities (TOTAL R&D). Only two imposed velocities were tested at 16 cm/day$^{-1}$ and 26 cm/day$^{-1}$ to provide a comparison between the DVT and the Point Velocity Probe developed by Prof J.F Devlin from Kansas University.

### Sand tank A results

Six rates were tested with the DVT from 5 to 30 cm.day$^{-1}$. As shown in the figure on the right, measurement are repeatable and proportional to the imposed flow rate. Error bar represent one standard deviaton from the mean of 3 measurements for each rate. For the higher Darcy fluxes, the measurement had a higher standard deviation.




### Sand tank B results

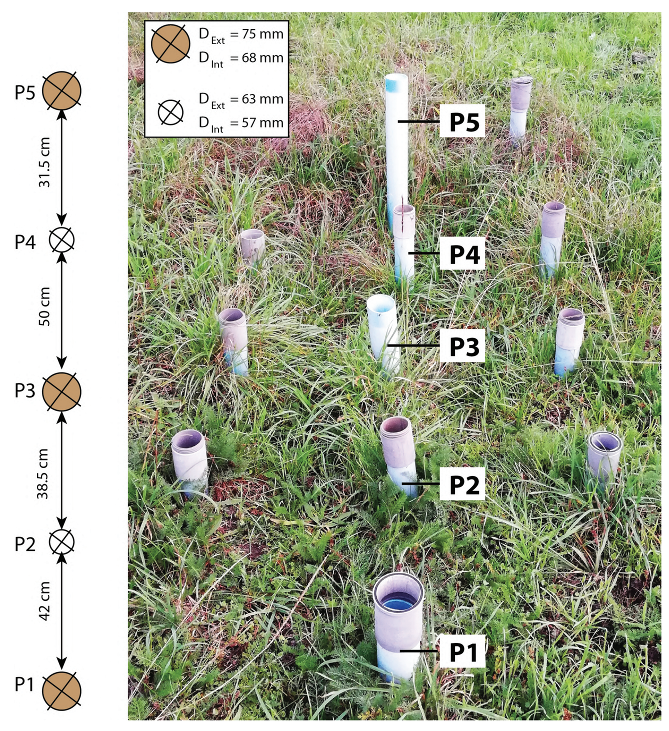
| | Sand tank | PVP | DVT |
|---|---|---|---|
| Darcy flux cm.day$^{-1}$ | 26 | 30 ± 3 | 31 ± 4 |
| | 16 | 23 ± 2,3 | 26 ± 1,5 |

## Field comparison with other tools

### TEST 1 : Controlled Field

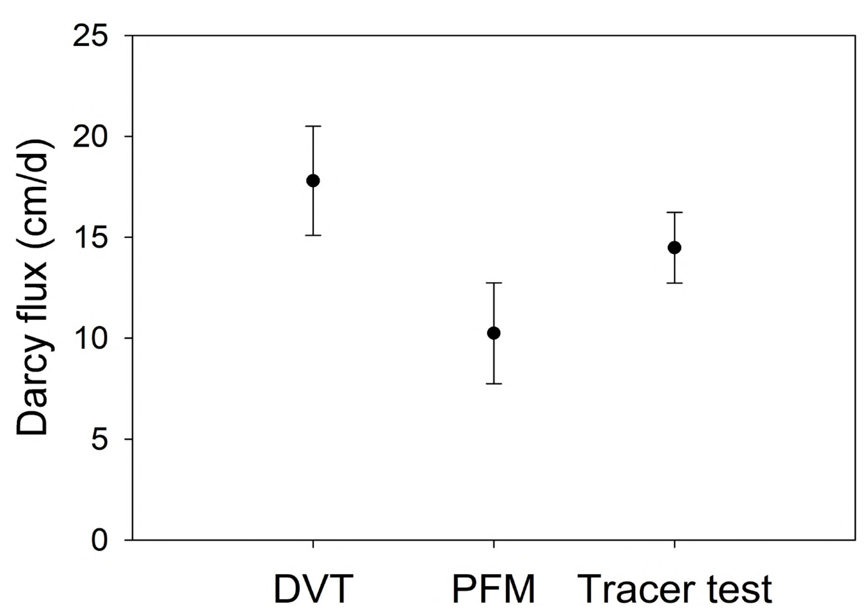
The DVT was deployed in a natural unconfined aquifer for comparison with other tools. This aquifer is on a formation composed of variable coarse sands. The bottom of the aquifer is delimited by a clay aquitard at 3 m depth.

The test was conducted using several wells shown in the figure on the right. Pumping in P5 and injection in P1 was imposed continuously during three weeks with a flow rate of 75 L.h$^{-1}$. P3 was used for measurements. The methods and tools used for the comparison with the DVT were a tracer test, a borehole dilution test and the Passive Flux Meter (PFM).




### Results

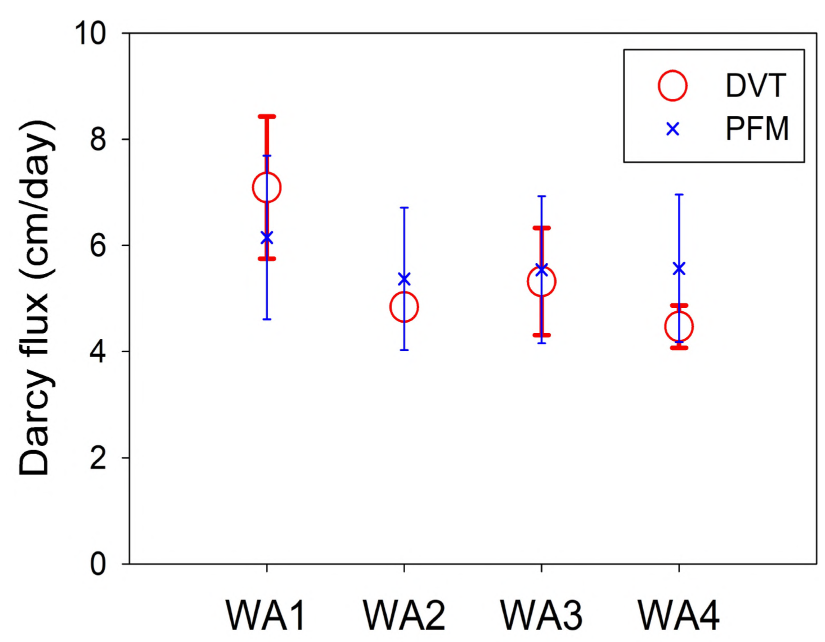
PFM and DVT measured respectivly velocities equal to 10.25 cm.day$^{-1}$ and 17.8 cm.day$^{-1}$ (figure on the right). DVT and PFM present respectively an uncertainty of 2.70 and 2.50 cm.day$^{-1}$. For the Tracer test, the software TRAC was used to estimate the porosity and Darcy flux, giving a value equal to 14.50 cm.day$^{-1}$ with an uncertainty of 1.8 cm.day$^{-1}$.




Borehole dilution test overestimated the velocity by an order of magnitude (145 cm.day$^{-1}$ versus 10-15 cm.day$^{-1}$). This gap is probably due to (i) the density flow induced during the injection of the tracer and (ii) an inhomogeneous mixure between the solution and groundwater.

### TEST 2 : Contaminated site

The contaminated site presents a semi-confined alluvial aquifer composed of (i) heterogeneous sand deposits and (ii) a local clay lenses. A clay unit was located from 7.50 to 9.50 below surface and defined the bottom of the alluvial aquifer. Four wells with same characteristics (depth, screen and diameter) were tested at this site (WA1, WA2, WA3 and WA4). This site was used for the comparison between DVT and PFM.




### Results

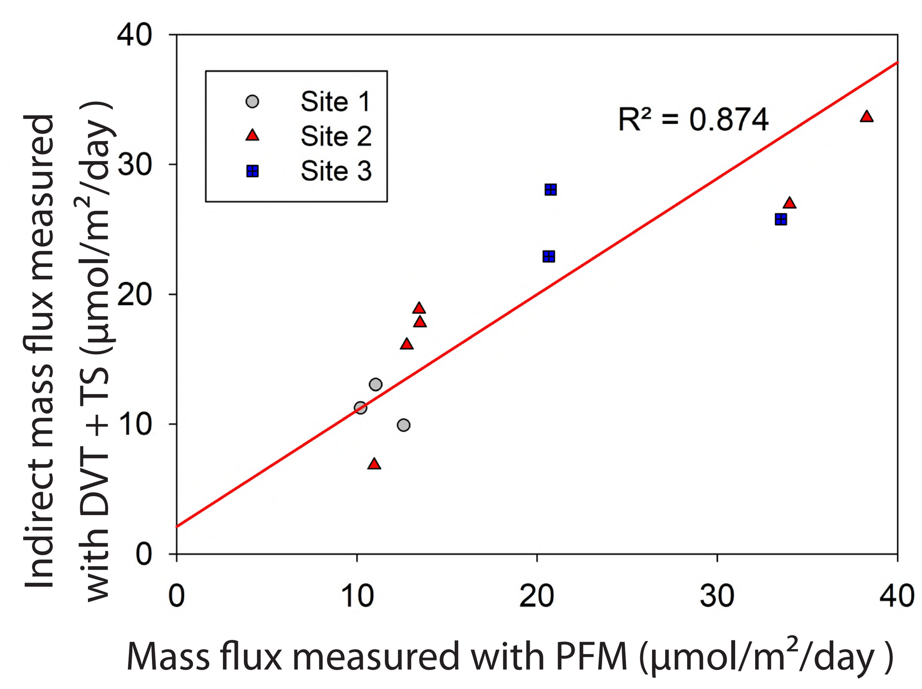
In the figure on the left, results of DVT and PFM are presented for each well at the same depth. The DVT measured Darcy fux varied from 4 to 8 ± 1.0 cm.day$^{-1}$ (standard deviation of 3 measurements at the same depth). For the PFM, an uncertinaty of 25% was considered. The PFM measured Darcy flux from 5 to 9 ± 1.8 cm.day$^{-1}$.

### TEST 3 : Mass fluxes comparison

The Darcy flux *q* measured by the DVT can be combined with a concentration *C* to have indirectly the contaminant mass fluxes *J* (*J = q x C*).

On the right, in the figure, a comparison between Indirect mass fluxes measured with DVT and Mass fluxes measured with PFM is presented. The test was conducted in 3 different sites.

The figure shows a $R^2$ equal to 0.87, which is an interesting result but more measurement must be conducted in other sites to have a better comparison.




## Conclusion

Velocity measurement showed close results (i) in the controlled field test with PFM, DVT and Tracer test ; (ii) in the contaminated site with PFM and DVT ; (iii) in the sand box with PVP and DVT. The DVT offers an innovative solution for Darcy flux and indirect contaminant mass fluxes measurement. The new tool can be deployed easily and Darcy flux are measured rapidly for each interval tested. It's possible to measure vertical distribution of horizontal velocity for a well in 1 - 2 hours. Additionnal measurements are needed to validate the DVT in other field with different geological context.. Future research should also include tests of modified inlet system in order to minimize the head loss and optimise the measurement range of the DVT.

## References

Annable, Michael D., et al. "Field-scale evaluation of the passive flux meter for simultaneous measurement of groundwater and contaminant fluxes." (2005)

Devlin, J. F.,G. Tsoflias, M. McGlashan, and P. Schillig. "An inexpensive multilevel array of sensors for direct groundwater velocity measurement." (2009)

Hatfield, Kirk, Michael Annable, Jaehyun Cho, P. S. C. Rao, and Haradl Klammler. "A direct passive method for measuring water and contaminant fluxes in porous media." (2004)

Labaky, W., J. F. Devlin, and R. W. Gillham. "Field comparison of the point velocity probe with other groundwater velocity measurement methods." (2009)