# The Thermo-Flowmeter System – a High Sensitivity Sensor for the Measurement of Vertical Flow in Ground Water Monitoring Wells

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## Summary

A novel sensor system was developed, which is designed to measure vertical velocity profiles in ground water wells. The system has a very high sensitivity, and is therefore designed to measure the relative hydraulic conductivity distribution in the subsurface as well as natural vertical flows occurring in wells, due to pressure gradients between different water bodies. In addition, if combined with a leveled sampling, concentration profiles can be obtained with the system.

## 1 Introduction

The novel Thermo-Flowmeter system is a high-sensitivity device designed for the measurement of vertical flow velocities in ground water observation wells. The device was designed by VEGAS at the University of Stuttgart around the year 1990. The developments led to a series of prototypes which are depicted in figure 1.

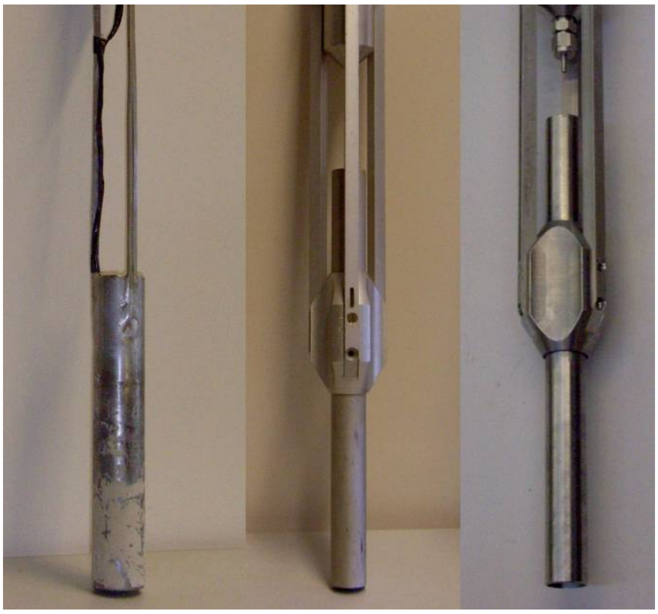

Figure 1: Series of prototypes developed by VEGAS

Although working in principle, the academic prototypes were far from market ready systems. In 2005 the system was transferred to Berghof in order to convert the prototypes to an economical product.

It took several years, however, during which a number of problems were solved. Consequently, the system was completely redesigned and the concept was revised.

The Thermo-Flowmeter system can be operated in two modes, making it very flexible and versatile. The modes of operation are described in detail in chapter 3. The general purpose of the system is on one hand the detection of natural vertical flow in ground water observation wells, and on the other hand the measurement of hydraulic conductivity profiles of the subsurface. With the latter information further calculations are possible; e.g. the calculation of emissions from contaminated sites.

## 2 Description of the System

The system is based on a commercial flow sensor (hot-wire anemometer, see figures 2 and 3).

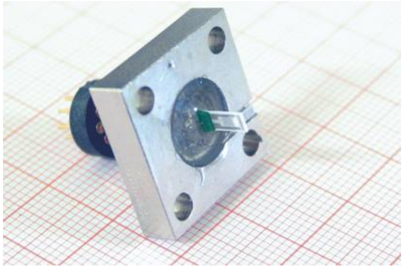

Figure 2: Flow sensor

Figure 3: Sensor housing

The low mass of the sensor yields a fast response and a high sensitivity. The system can detect flow velocities down to a few mm/sec. In contrast to the standard impeller flowmeters, the Thermo-Flowmeter system is much more sensitive and requires significantly less equipment. The whole system is controlled by a computer, which is connected to the sensor via a controller box and a cable. The sensor is automatically moved up and down in the well by a winch (see figure 4).

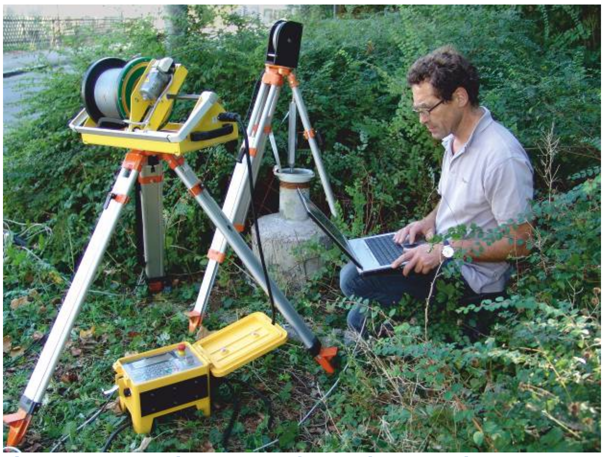

Figure 4: Complete setup for a Thermo-Flowmeter measurement

## 3 Modes of operation

### 3.1 Detection of Hydraulic Short Circuits

Hydraulic short circuits can originate from wrong positioned or erroneous installed wells. If a pressure gradient is present between two aquifers separated by a low conducting layer (confined aquifer conditions) and these aquifers are connected as shown in figure 5, a hydraulic short circuit is produced. In such a situation a constant flow of ground water is created, resulting in water samples of low representativeness.

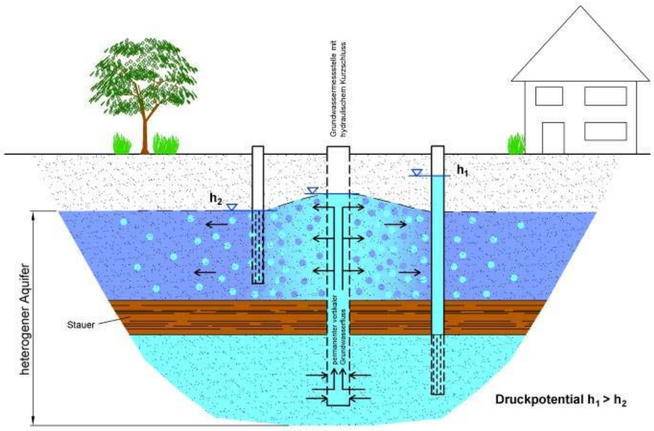


Figure 5: Principle of a hydraulic short circuit

In order to detect such a short circuit, the Thermo-Flowmeter system is used with the well at rest, i.e. without using a pump in parallel. An example of such a situation is shown in figure 6. Moving the sensor system down starting from the ground water table at around 15 m below the well head, a constant signal is obtained, indicating no vertical movement in the ground water. At around 22 m a sudden rise in the signal is detected, indicating a water flow into the aquifer. Between 23 m and 26 m, an almost constant vertical flow of the ground water is indicated, followed by a sudden decrease of the velocity caused by a flow from the aquifer into the well. Below 27 m no abnormality is visible.

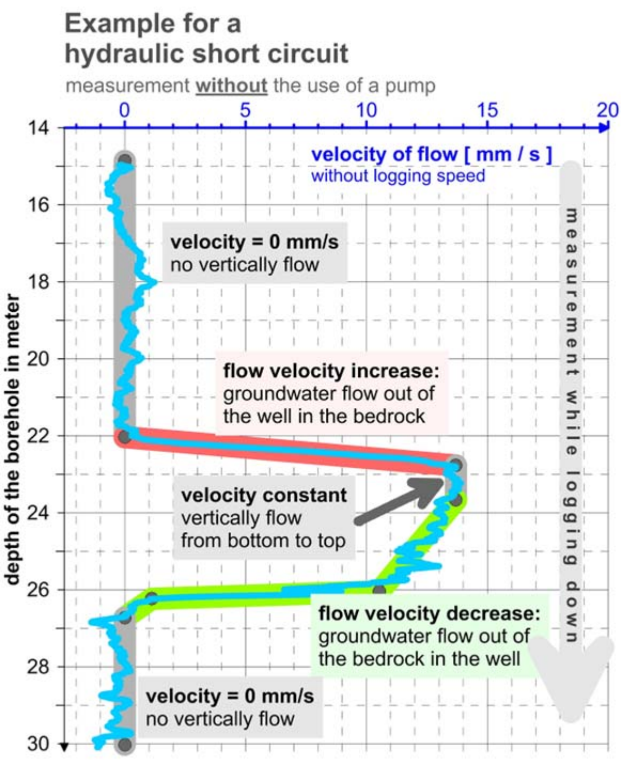


Figure 6:  Thermo-Flowmeter signals from a well with a hydraulic short circuit

This example clearly shows the possibility of the system to be used for the quality assurance of ground water observation wells.

### 3.2 Measurement of the Hydraulic Conductivity Distribution

A second possibility arises from the use of the system together with a pump. If a constant flow of ground water is produced with a pump, which is installed near the ground water table, a sum curve can be measured with the Thermo-Flowmeter system. This sum curve represents the relative distribution of the hydraulic conductivity as shown in figure 7.

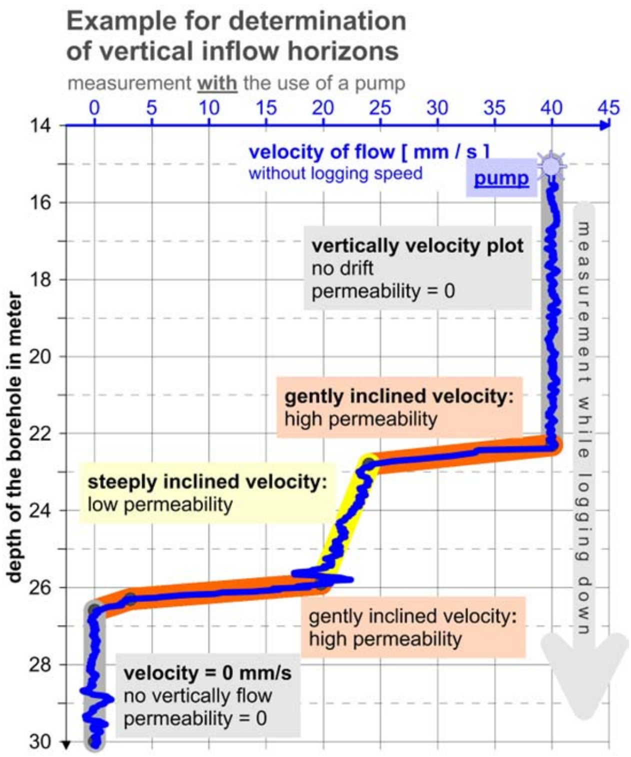


**Figure 7: Hydraulic conductivity profile produced with the Thermo-Flowmeter system**

In this case (same well as chapter 3.1), the sensor is moved downward detecting a constant flow velocity (which is now much larger than in figure 6, caused by the flow produced by the pump) down to 22 m. Between 22 m and 23m a significant change in the velocity occurs, indicating a high hydraulic conductivity in this horizon. Between 23 m and 26 m an area with a lower hydraulic conductivity can be distinguished and between 26 m and 27 m again a high permeable horizon can be identified.

The conclusions that can be drawn from the profiles shown in figure 6 and 7 are very consistent, underlining the efficiency and versatility of the system. How the use of the system can be further extended by combining the Thermo-Flowmeter measurements with special sampling techniques will be presented in the next chapter.

## 4 Combination of the Device with a Special Sampling Strategy - a Field Application

### 4.1 Principle

For recording vertical concentration profiles, samples are taken in sections in parallel to the operation of a pump. In doing so a vertical water flow is forced in the well. The pump is located in the well either near the top of the water table or at the bottom of the well (see figure 8), and maintains a constant upward or downward ground water flow during the whole sampling procedure.

After vertically segmenting the water depth, a sample from each segment is taken. Beginning with the layer furthest away from the pump, the concentration of a sample taken at a certain depth is decomposed to the mixed concentration of the adjacent layers up (or down) to that depth and the concentration within the layer using the law of mixing. A weighting factor accounts for the relative contribution of each layer to the overall well production and is inferred from the corresponding hydraulic conductivity. The depth profile of hydraulic conductivity has to be known from previous flow meter measurements.

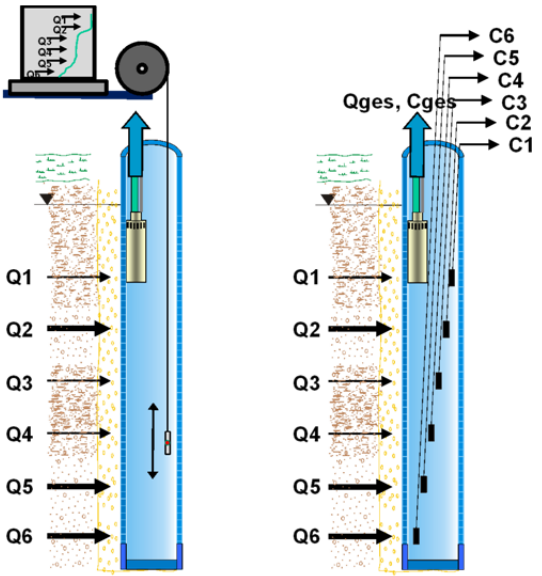


**Figure 8: Principle of segmented sampling from a fully screened well**

The concentration obtained is evaluated by applying the general law of mixing (equation 1):

$$C_{M(T)} = C_T \cdot \frac{q_T}{q_{Tot_T}} + C_{M(T-1)} \cdot \frac{q_{Tot_{T-1}}}{q_{Tot_T}} \qquad \textbf{(11)}$$

With:

| | | |
|---|---|---|
| $C_{M(T)}$ | - | concentration of mixture in depth T = measured value |
| $C_T$ | - | concentration in depth T |
| $C_{M(T-1)}$ | - | (mixed) concentration in adjacent segment (away from pump) |
| $q_T$ | - | inflow to segment T |
| $q_{Tot(T)}$ | - | total inflow to segment T (away from pump) |
| $q_{Tot(T-1)}$ | - | total inflow to segment T-1 (away from pump) |

Solving equation (1) for $C_T$ gives equation (2):

$$C_T = C_{M(T)} \cdot \frac{q_{Tot_T}}{q_T} - C_{M(T-1)} \cdot \frac{q_{Tot_{T-1}}}{q_T} \qquad \textbf{(22)}$$

Thus, if the relative hydraulic conductivities ($q_i/q_T$) are known from the Thermo-Flowmeter measurements, the concentration of each layer can be easily calculated. The sampling should be done using low-flow or scoop techniques so that the flow regime is not disturbed.

Following this strategy, segmented sampling has been successfully applied in the investigation of a contaminated site to assign the concentrations of leached halogenated hydrocarbons as presented in the next chapter.

## 4.2 Field Application and Results

The method described has been used at a contaminated site with a 1,1,2-trichloro-trifluoroethane contamination. In a well with two screens from 21-26 m and 34-40 m, a low-flow-sampling parallel to pumping has been conducted. Before this a Thermo-Flowmeter measurement had been performed. The data obtained is shown in table 1, together with the calculated concentrations according to the principle described in chapter 4.1. A graphical representation of the location of the pumps, the results from the Thermo-Flowmeter measurements, and the calculated concentrations are given in figure 9.

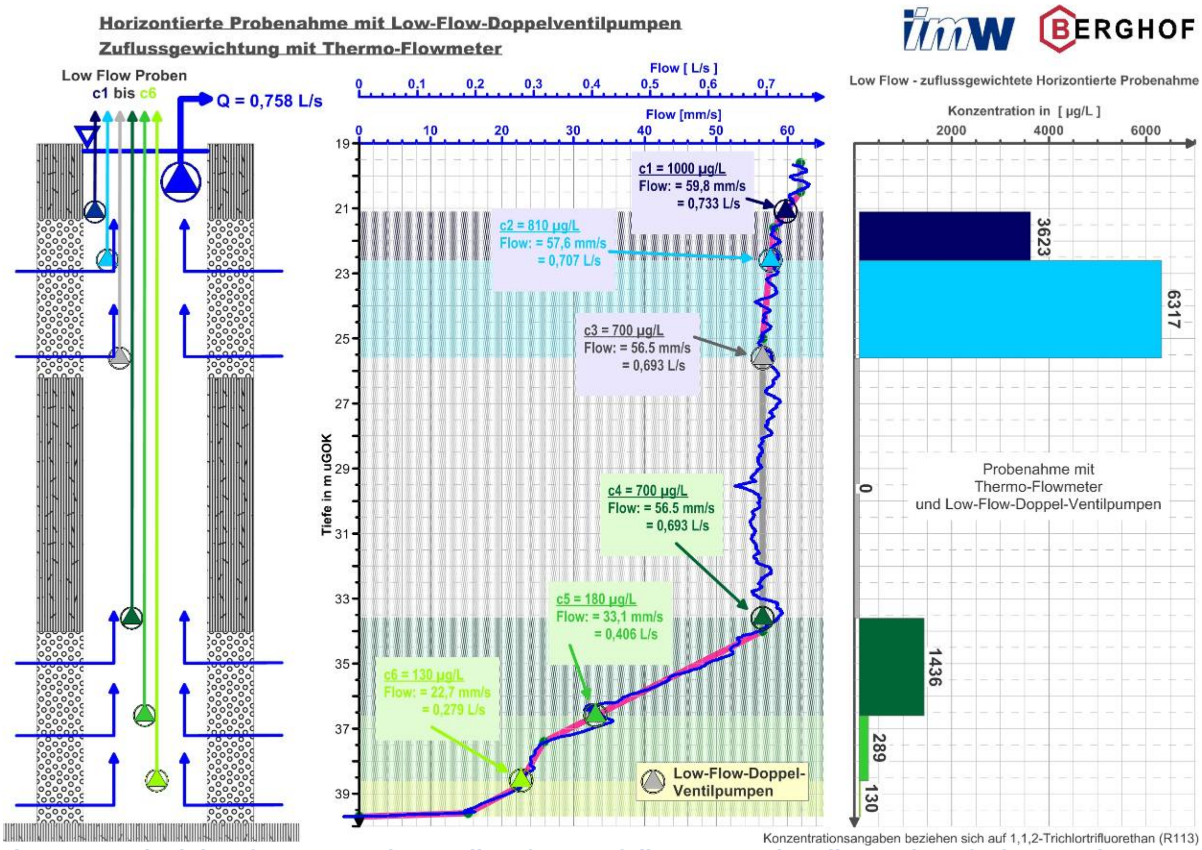


**Figure 9: Principle of segmented sampling from a fully screened well, results of Thermo-Flowmeter measurments and calculated concentrations**

**Table 1: Results of a segmented sampling and calculated concentrations**

| *Sampling location* | *Depth below well head* | *Flow [ L/s ]* | Concentration measured [ µg/L ] | Concentration calculated (see equation (2)) [ µg/L ] |
|---|---|---|---|---|
| *C1* | 21,1 | *0,733* | *1000* | ***3623*** |
| *C2* | 22,6 | *0,707* | *810* | ***6317*** |
| *C3* | 25,6 | *0,693* | *700* | ***0*** |
| *C4* | 33,6 | *0,693* | *700* | ***1436*** |
| *C5* | 36,6 | *0,406* | *180* | ***289*** |
| *C6* | 38,6 | *0,279* | *130* | ***130*** |

## 5 Conclusions

The Thermo-Flowmeter system developed within a cooperation of the University of Stuttgart and Berghof can be effectively used to either characterize the quality of ground water observation wells or to assess the hydraulic conductivity of an aquifer, as described above. The two modes of operation have been presented and a practical application in combination with a special sampling technique have been described.

With regard to the development process, the long duration of this process has been pointed out. The reasons therefore arise on one hand from the limited commercial potential of measurement systems in the field of contaminated sites, while on the other hand it is difficult to get funding for such developments. The first problem mainly concerns companies considering taking over academic prototypes to convert them to commercial products. The second issue makes it difficult for universities or researchers to bring developments to a status where it starts to get interesting for companies.

These boundary conditions are a clear hindrance for innovations and an obstacle to investments.

## 6 Literature


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