

Applications and Benefits of Horizontal In-Situ Groundwater Flow Measurements

Despite their spatially small-scale resolution and the fact that they provide only point or line information, horizontal in-situ groundwater flow measurements deliver valuable insights into local groundwater flow direction and velocity as well as groundwater flow conditions within the profile of an aquifer.

Furthermore, they represent an attractive alternative to multi-well tracer tests and provide an effective means of determining groundwater flow conditions in deep aquifers where access and investigation efforts are considerable.

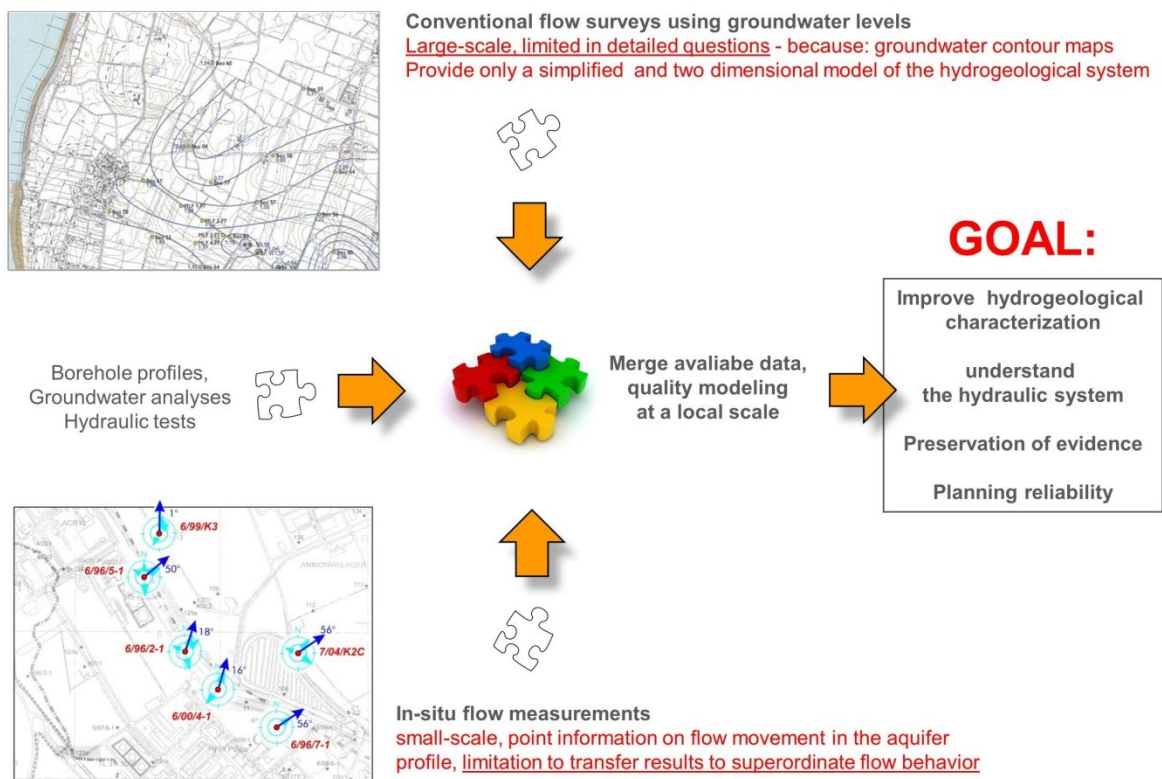
They are particularly useful when conventional methods provide only limited information on groundwater flow, for example in cases of:

- non-correlating groundwater levels,
- a limited number of monitoring wells,
- low hydraulic gradients,
- widely spaced monitoring networks, and
- insufficient information at model boundaries.

Typical applications include:

- verification and plausibility assessment of groundwater flow models,
- characterization of groundwater flow conditions at different depths within an aquifer,
- determination of local groundwater flow, for example in the vicinity of excavation sites,
- monitoring of groundwater remediation measures or to identify responsible polluters,
- providing information to position additional monitoring wells, and
- assessment of the area of influence and effectiveness of groundwater abstraction systems.
- long-term in-situ measurements can document tidal influences, competing groundwater uses and other transient flow events

Because of their small-scale spatial resolution, the results should always be interpreted in conjunction with other site investigation data when extrapolating the findings to a larger area, see below.



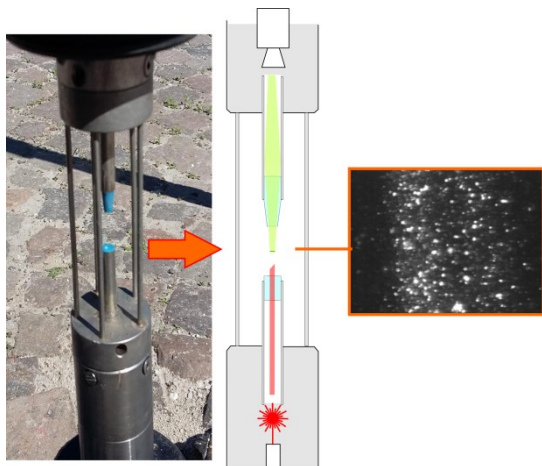
Measurement Technology

PHREALOG's measurement technology is among the most reliable and accurate methods available for in-situ groundwater flow measurements. The technology is based on the imaging, laser-optical detection of naturally occurring suspended particles transported by groundwater, the processing of particle patterns, and their conversion into groundwater flow vectors.

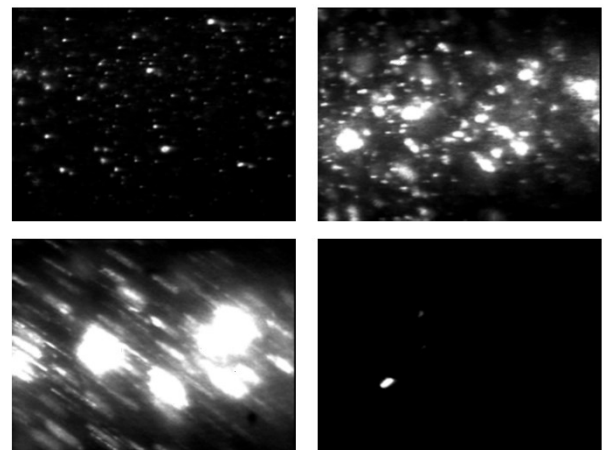
Depending on its grain-size distribution, the granular matrix of an aquifer represents a dynamic reservoir for particles and fine suspended matter. These include humic substances, sediment particles, contaminants, organic compounds and aggregates of various components, which, depending on the prevailing hydraulic conditions, are transported through or released from the pore matrix and pass through the monitoring well in correspondence with the groundwater flow. The amount of suspended matter depends on various environmental factors, such as the hydraulic conditions, the presence of particle reservoirs and depots within the aquifer, the mobilization potential of these deposits, and particle inputs from the unsaturated zone.

Using these natural flow tracers, groundwater transport through the monitoring well is recorded continuously. The measurement probes are equipped with an integrated camera, a laser system and a digital compass. Within a freely flowing measurement section of the probe, passing particles are illuminated by laser light and the backscattered light is continuously recorded by the camera as particle patterns. The displacement of particle patterns per unit time describes the groundwater flow direction and velocity. The images are transmitted as video data to a computer, where image-processing software calculates groundwater flow vectors from successive particle patterns. Measurements are performed at sampling interval of four seconds or less, so that groundwater flow is recorded continuously and with high temporal resolution. The measured flow rate ranges from approximately 10 mm/s down to 0.1 m/day with high accuracy. The method is especially able to record very low groundwater flow velocities.

Since no artificial flow tracers are required, tracer-related sources of error, permitting requirements and extensive field preparation are eliminated. Owing to its non-contact sensing principle, the technology is maintenance-free and highly robust even under chemically aggressive conditions. The system is easy to deploy, requires only a short setup time and does not require field calibration.



Measuring principle



typical particle flow patterns

Flow inside a monitoring well and consequences on in-hole flow measurements

The interaction of natural and well-specific factors results in the development of an individual hydraulic environment within and in the vicinity of a monitoring well, which may change over time due to ageing processes and the formation of deposits and encrustations.

Typically, the screened interval of a monitoring well is subject to both horizontal and vertical groundwater flow. This can lead to disordered flow conditions and the formation of irregular laminar flow structures and eddies within the well screen. Consequently, reliable information from in-situ groundwater flow measurements can only be obtained if both hydrogeological and well-specific boundary conditions are properly considered. This leads to specific requirements for conducting the measurements and

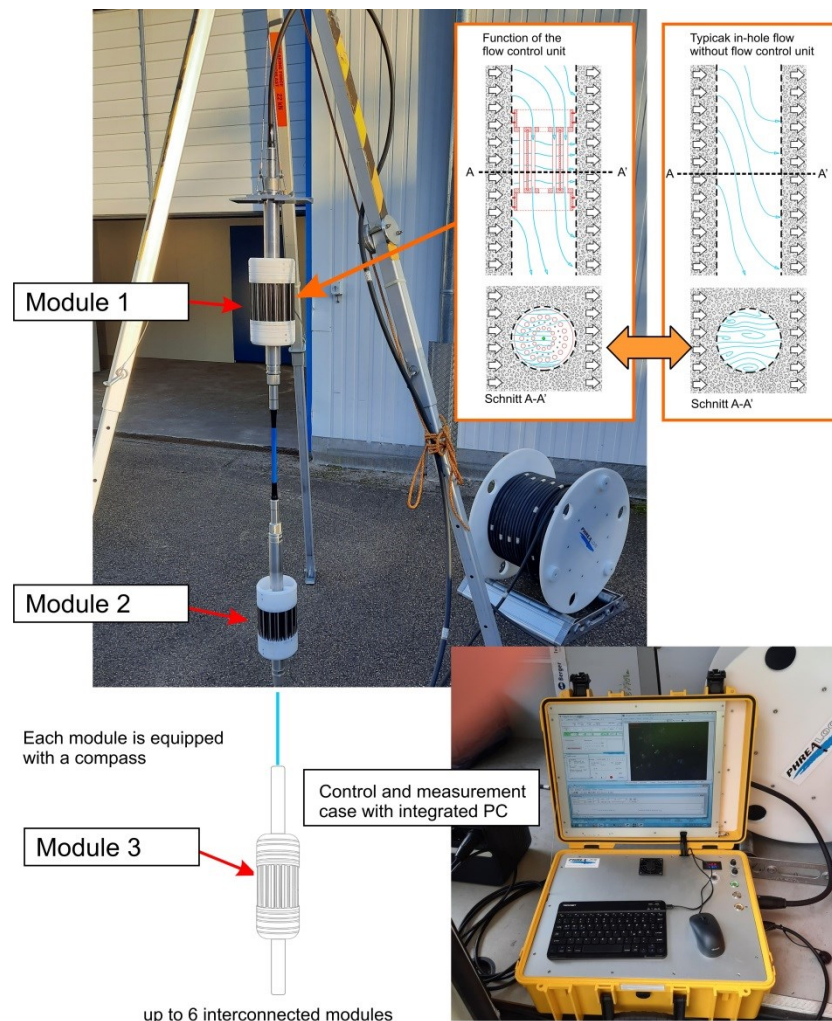
interpreting the flow data. The hydraulic conditions within a monitoring well can be controlled to a certain extent in order to ensure that groundwater flow in the surrounding aquifer can be reliably derived from the flow observed within the well. This is the objective of newly developed flow-stabilization devices currently subject to patent application.

Experience shows, that horizontal flow measurements should always be carried out at several depth positions in order to validate the results, as small-scale hydraulic influences can lead to significant variations in groundwater flow passage over the profile of the screened interval. This objective is addressed by applying multilevel flow measurements. Additional quality assurance measures include borehole camera inspections to verify well construction and condition, the assessment of vertical flow conditions, and the use of flow-conditioning devices to ensure stable flow conditions within the measurement section.

New developments deployed since 2025

Since 2025, PHREALOG offers horizontal in-situ groundwater flow measurements in a multilevel configuration. Measurements are performed simultaneously at several investigation depths. The simultaneous measurement of groundwater flow direction, flow velocity and suspended-particle transport at multiple depths enables improved characterization of temporal flow variations and high-resolution long-term monitoring. The main advantage is an increased amount of flow information at reduced field deployment time. This approach reduces project costs while significantly improving the quality and reliability of the results.

The new multilevel measurement modules, each with a length of 0.6 m, can currently be deployed in monitoring wells with diameters of 2 inches and larger and to depths of up to 250 m. All PHREALOG measurement probes have been pressure-tested to an external water pressure of 35 bar (3,5MPa/500PSI).

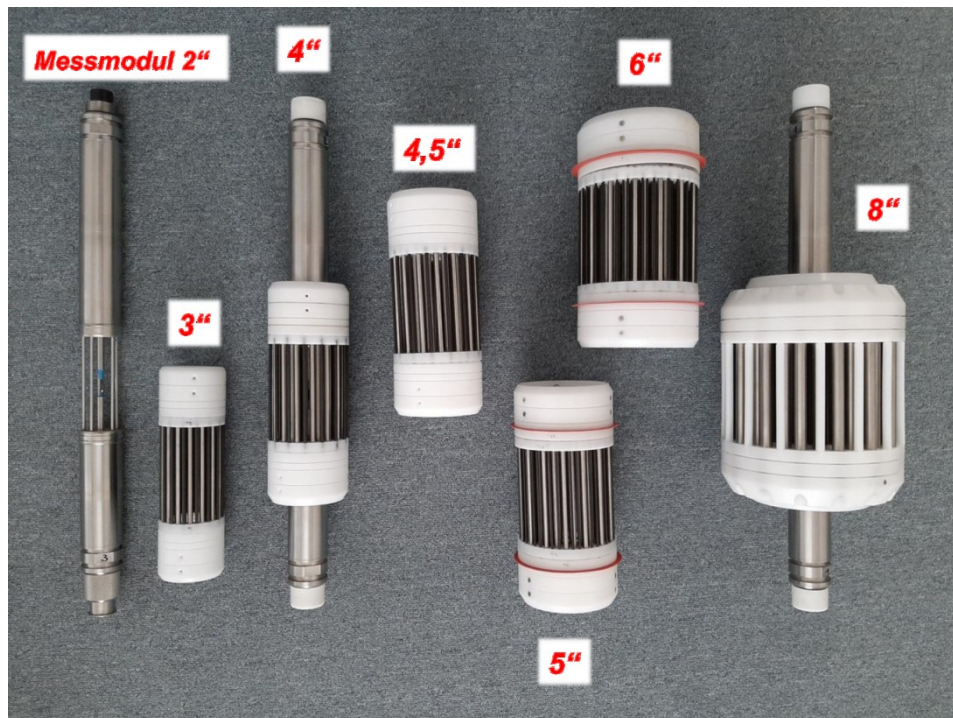


Assembly of a measurement chain of three modules for horizontal flow measurement with attached Flow-Stabilization Devices

HORIZONTAL IN-HOLE FLOW MEASUREMENTS

For installation diameters greater than 3 inches, the probes are equipped with newly developed flow-stabilization devices. Independent of the flow measurement technique used, they serve to provide a uniform, flow distribution in the measuring section and short hydraulic stabilization times.

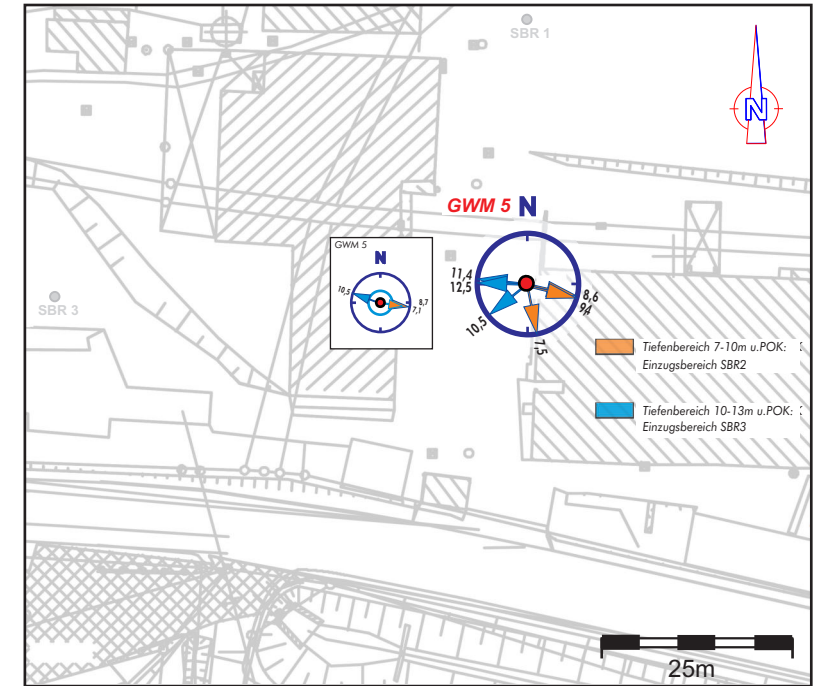
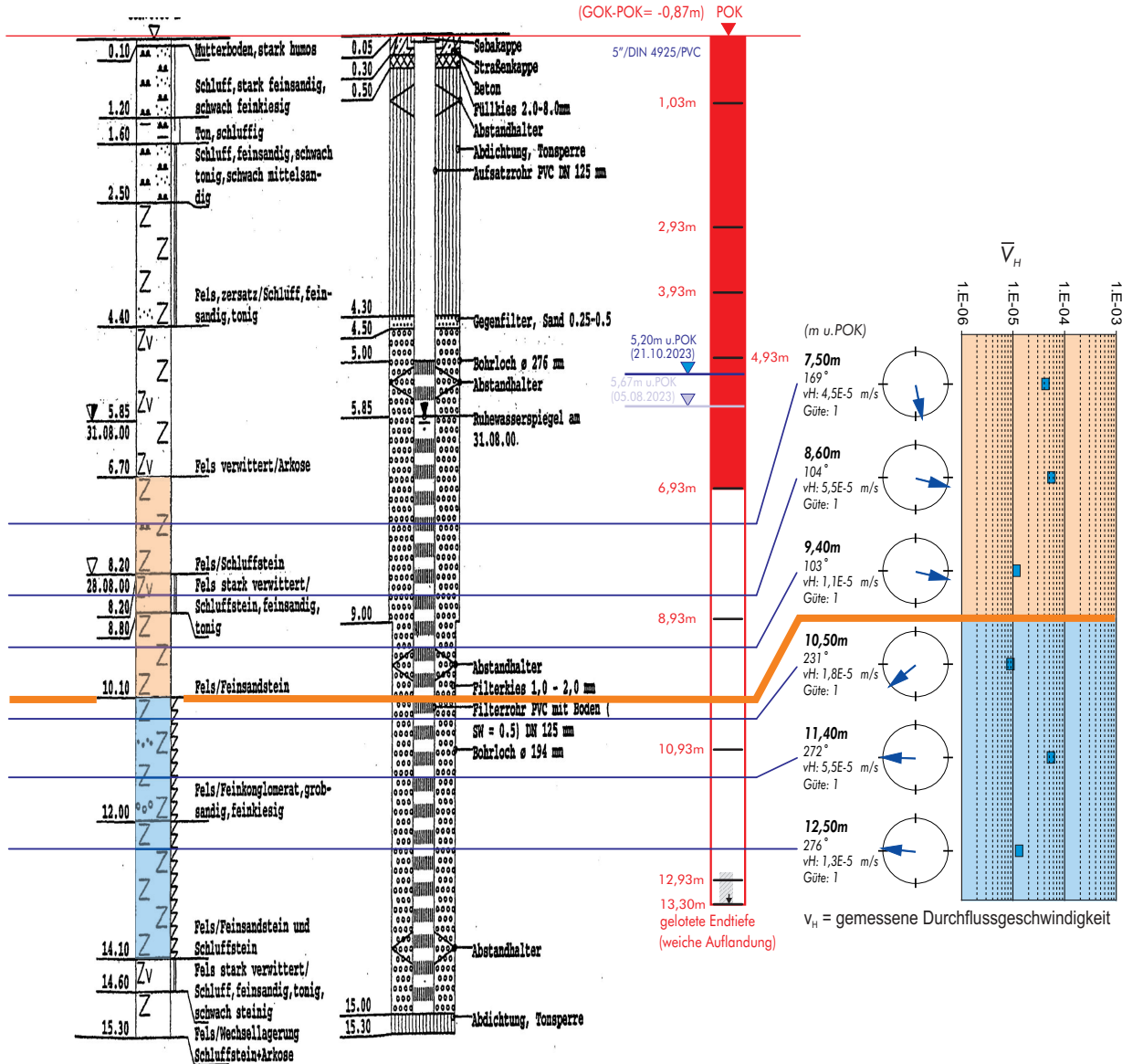
The new developed flow stabilization devices consist of circular, radially symmetrical arrangements of vertical struts positioned between two sealing elements, thereby enclosing the measurement cell. The struts act as an array of flow diffusers designed to achieve a homogenized horizontal flow field, ensuring stable, eddy-free and uniform horizontal flow inside the measurement section. At the same time, hollow struts act as bypass elements for vertical flow thereby largely eliminating the influence of vertical flow on the horizontal flow in the measurement section. Furthermore, the bypass function allows for easy installation of a multilevel measurement chain of several modules into water-filled casings without hydraulic counter-pressure, thereby significantly reducing the hydraulic recovery time following installation.



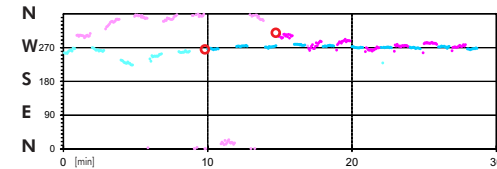
Flow-stabilization devices are available for all common monitoring well diameters. The design as well as the arrangement, number and diameter of the flow-conditioning struts are the result of extensive numerical simulation studies. The development of the flow-stabilization devices is based mainly on findings from the research project FLIMSYS (BMBF Grant No. 02WQ1192), funded by the German Federal Ministry of Education and Research (BMBF).

To ensure the proper execution of all measurements, a borehole camera inspection is carried out prior to every field deployment as part of the quality assurance procedure.

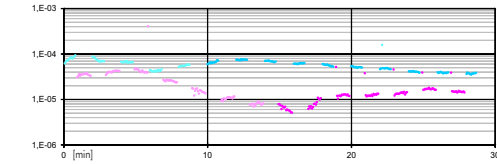
The following page presents an example of measurement results, including the identification of hydraulically separated horizons within the capture zone of several remediation wells. Horizontal groundwater flow measurements were performed as multilevel measurements, with quasi-simultaneous observations at two measurement depths and a measurement cycle of two minutes.



Fließrichtung [°]



Fließgeschwindigkeit v_H [m/s]



● v_H am Messpunkt gemessenen Durchflussgeschwindigkeit
● Gültige, zur Auswertung verwendete Vektordaten
■ Stabilisierungsphase/Fehlzeiten
● Start der Auswertungsphase

Rose/Tabelle: Häufigkeitsverteilung der gültigen Fließrichtungen pro 10° Segment. Intensivfarbe: bilanzierte Ergebnisse