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European strategies of groundwater monitoring for different aims

Hans-Jürgen Voigt, Florian Jenn, Claus Nitsche

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Abstract Groundwater monitoring systems play an important role in the implementation of the EU Water Framework Directive. Concerning the objectives of groundwater monitoring systems, two types are distinguished: surveillance and operational. The objectives and the strategy of realisation of both types are discussed.

Keywords *Groundwater, monitoring strategy, EU-WFD.*

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INTRODUCTION

The term *groundwater monitoring* covers the *whole complex of continued observation and measurements of hydrodynamic, hydrochemical and hydrobiological parameters, changing in time and space,* which *characterise different processes* in hydrogeological systems *but also their interpretation for genetic and prognostic assessments*.

In the late 1980s monitoring was focused mostly on the collection of data and their statistical interpretation. It goes without saying that we need data, but today we know that groundwater monitoring systems have to be determined by concrete aims. When planning a monitoring system we must answer the following “Six Questions” (Lauterbach & Voigt 1993):

Why? – Who? – What? – Where? – When? – How?

The first and most important question is “*Why* do we need a monitoring system?” this means the determination of the aim of the investigation. With regard to the objectives of groundwater monitoring systems we distinguish between two systems:

- information oriented monitoring (surveillance monitoring)
- decision oriented monitoring (operational monitoring)

INFORMATION ORIENTED MONITORING SYSTEMS (SURVEILLANCE MONITORING SYSTEMS)

The task of this type of monitoring systems is to obtain the regional distribution of groundwater resources and their changing conditions in quality and quantity in order to study the reasons for temporal and spatial changes in groundwater levels and to determine the natural background conditions and their changes by different influences, characterising the vulnerability of the groundwater system.

The monitoring of groundwater quantity has a long tradition in Europe. The EEA report “Groundwater monitoring in Europe” surveys groundwater monitoring in 16 European countries (Koreimann *et al.* 1996). The oldest groundwater monitoring network has been in operation in France since 1845; most of them have been installed at the beginning of the 20th century. The average length of records lies between 30 and 50 years. Monitoring of groundwater quality has been undertaken in most European countries since the 1970s and 1980s. Koreimann *et al.* (1996) present the following conclusions:

- Sample site density in quality networks ranges from 0.003 sites/km² to 0.57 sites/km², and in quantity networks from 0.004 sites/km² to 7.3 sites/km².
- The frequency of measurement is variable. Typically, sampling frequency varies from weekly to two times a year.
- The number of measured water quality parameters varies from 15 to 106 between the monitoring networks. "Basic" programmes often include between 14 and 51 parameters. The selected parameters appear to be adapted to national circumstances and at present cannot be readily compared at a European level.
- The majority of countries have national standardised sampling and analytical methods as well as standardised regulations for precision and accuracy.
- However, as sampling and analysing procedures are key elements of every monitoring programme, evidently it is necessary that regulations for sampling and analysing procedures provide a standard to make the obtained data comparable.

The responsibility for this type of monitoring systems has to lie with government or water supply organisations. (Answer to the question *That has to carry out monitoring?*)

The answer to the questions *what* and *where* must be given by a hydrogeological system analysis, which has to include:

- determination of the catchment area (groundwater body),
- distribution and type of aquifers,
- position of the monitoring point in the hydraulic system of the catchment area (recharge, transit or discharge area; Fig. 1),
- distribution and type of groundwater cover, including soils,

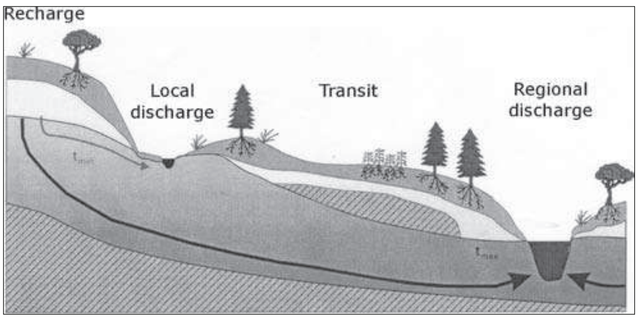


Fig. 1. Hydraulic system of a catchment area.

- distribution of different land uses,
- amount and distribution of precipitation and groundwater recharge.

The importance of the position of the monitoring point in the hydraulic system for the interpretation of diffuse contamination is shown (Figs 2 and 3). In recharge areas, elevated nitrate concentrations can be found in deeper parts of the aquifer than in discharge areas. The high concentrations in the medium depths

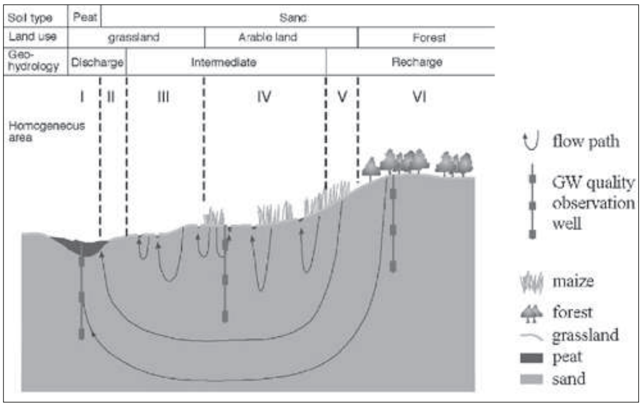


Fig. 2. Monitoring network design in practice of The Netherlands (Broers 2006).

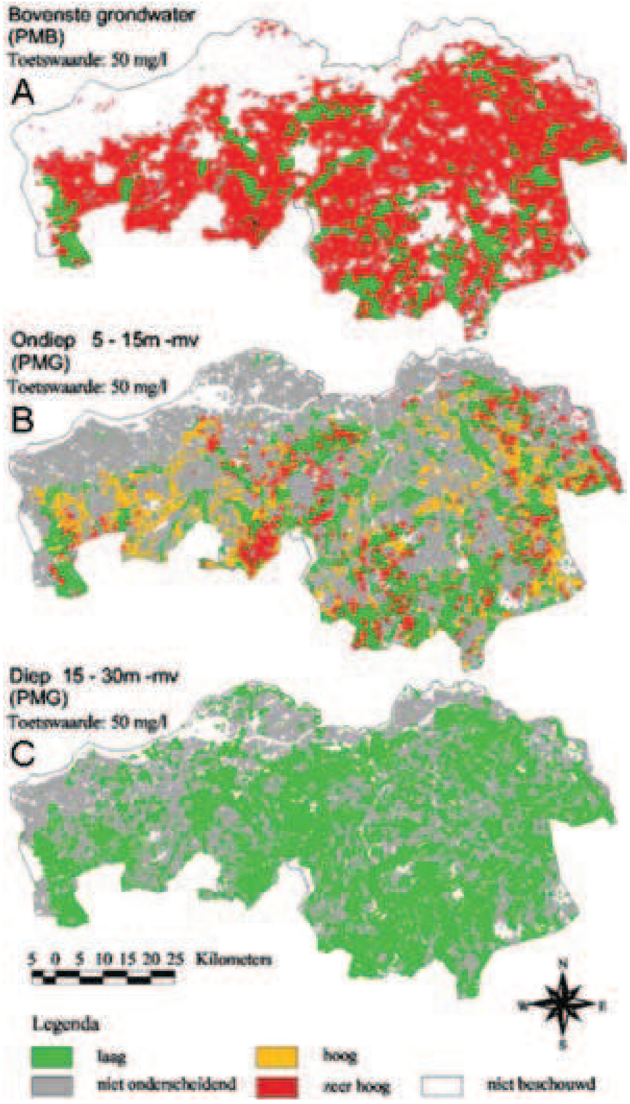


Fig. 3. Distribution of nitrate in aquifers of The Netherlands at various depths. A – uppermost groundwater, B – 5 to 10 m, C – 15 to 30 m. Concentrations: green – low, yellow – high, red – very high (Broers 2006).

(red and orange areas in Fig. 3B) correspond to the recharge areas of the system.

In the result of the hydrogeological system analysis a conceptual hydrogeological model of the investigation area has to be developed. This area might comprise the territory of a whole country, different groundwater bodies or the catchment area of a groundwater well field. In most cases existing wells and springs are used in information oriented networks. It is important for further interpretation that for all monitoring wells the following information has to be available:

• coordinates and elevation of well-head above datum (mean sea level),

• lithological and hydrostratigraphical profile of the borehole,

• well design with information about screen depth, filter packs and protection seals.

Without this information a correlation of data from various monitoring wells is impossible. Additionally, geophysical borehole logging, hydraulic tests, and other information characterising the good condition of the monitoring well are very useful.

In Germany data from surveillance monitoring systems of the federal states were used to determine the natural background conditions of the different aquifer types (Table 1). Other examples of the interpretation of information oriented monitoring systems were presented at the COST 629 Workshops in Rome (Aargard *et al.* 2004) and Larnaca (Tamás & Bíró 2005).

Table 1. Parameter ranges for natural groundwater conditions of some aquifer types in Germany (Voigt *et al.* 2005; Wendland *et al.* 2005).

Parameter	Unit	1st confined aquifer in North Germany (Pleistocene)		Jurassic limestone (Malm)		Triassic limestone (Muschelkalk)		Triassic sandstone (Buntsandstein)	
		from	to	from	to	from	to	from	to
Elec. Cond.	µS/cm	187	490	360	578	486	581	47.7	354
O_2	mg/l	0.1	5.4	4.6	10.8	6.0	9.4	5.6	10.5
pH	–	6.7	7.9	7.2	7.7	7.2	7.7	5.6	7.4
DOC	mg/l	0.9	5.0	0.5	1.4	0.3	0.8	0.2	1.6
Ca^{2+}	mg/l	28.0	99.2	62	112	35.3	107	5.8	48.1
Mg^{2+}	mg/l	2.9	21.0	2.6	32	3.3	19.5	1.5	17.5
Na^+	mg/l	5.8	28.0	1.0	5.0	2.0	4.9	1.7	8.6
K^+	mg/l	0.8	4.6	0.3	2.3	0.4	1.3	1.2	3.1
NH_4^+	mg/l	0.01	0.7	0.0	0.01	0.01	0.01	0.00	0.03
Fe^{2+}	mg/l	0.1	4.5	0.0	0.07	0.00	0.05	0.00	0.07
Mn^{2+}	mg/l	0.01	0.4	0.0	0.01	0.00	0.01	0.00	0.04
HCO_3^-	mg/l	67.1	341	234	361	97	331	8.5	204
Cl^-	mg/l	9.4	46.0	2.5	11	2.9	13.3	3.1	12.5
SO_4^{2-}	mg/l	6.3	99.1	10	35.1	11.7	51	3.4	36.1
NO_3^-	mg/l	0.1	1.0	1.2	9.5	3.3	8.1	1.8	8.9

DECISION ORIENTED MONITORING SYSTEMS (OPERATIONAL MONITORING SYSTEMS)

The objectives of decision oriented monitoring are quite different from information oriented systems. Typical examples are:

• Scientific studies of different processes in the unsaturated or saturated zone, e.g.:

– study of the distribution of moisture and special substances in bedded soils

– investigation of the behaviour of water compounds during artificial recharge

– study of the impact of transport related parameters of the aquifer on the distribution of dissolved groundwater compounds or colloids by tracer experiments in test sites

– detection of contamination plumes from different emission sources and control of the effectiveness of remediation measures

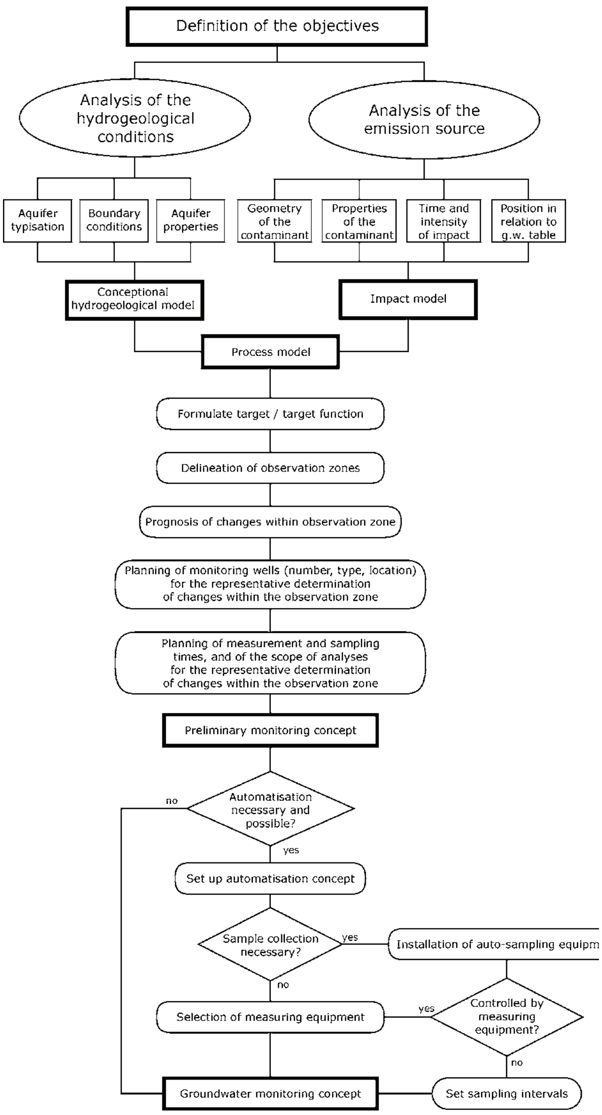
• Control of the influence of different hydrotechnical measures on the groundwater table, e.g.:

– development of the groundwater depression by civil engineering operations in urban areas

– drawdown of groundwater table or flooding in connection with mining activities

Many examples of monitoring and remediation measures in different countries have shown that without a hydrogeologically based conceptualisation these measures were not effective. This is why in the EU Guidance on Groundwater Monitoring (2007) a conceptual model is recommended as the basis for the monitoring protocol.

Fig. 4 shows a schema for the strategy of decision oriented monitoring which was developed in the framework of the EU COST Project 629. In contrast to information oriented monitoring systems, decision oriented monitoring systems must always be based on an analytical or numerical *process model*, which includes a conceptual model of the hydrogeological situation and an impact model, e.g. of the source of contamination. A possible schema of systematisation of hydrogeological conditions was developed by Voigt



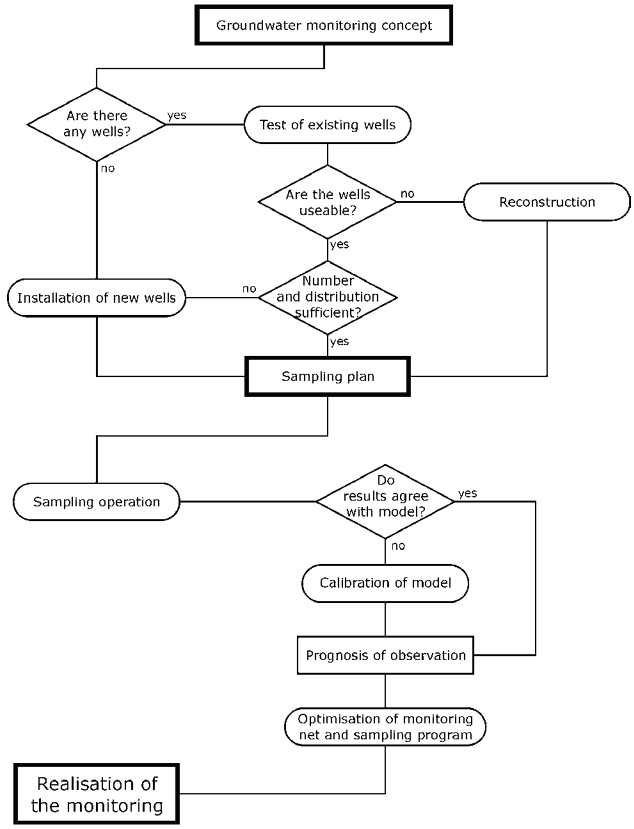


Fig. 4. Strategy for operational monitoring.

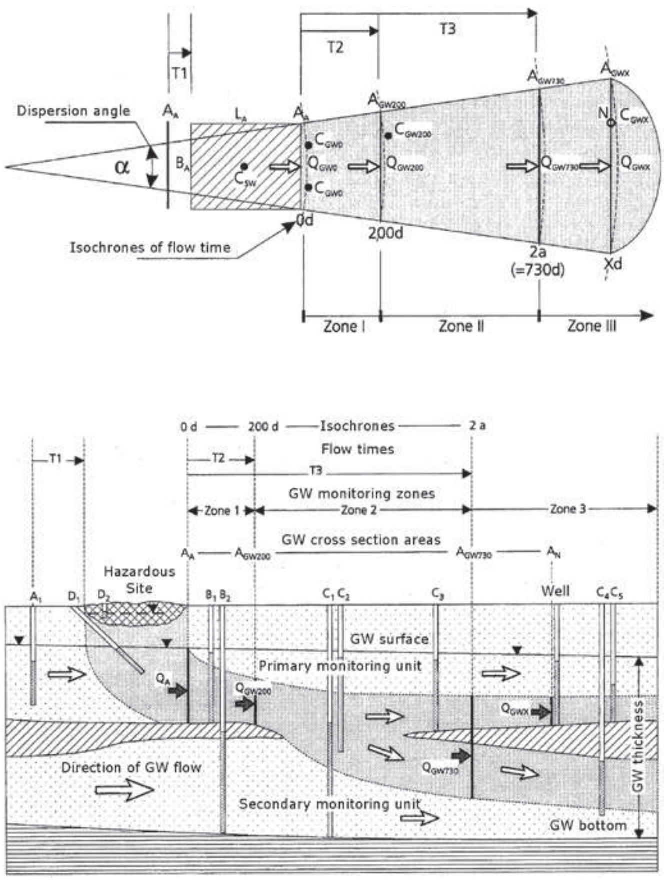


Fig. 5. Zoned monitoring approach (after Dörhöfer & Huch 1998).

et al. (2000) and for the analysis of the source of impact by Voigt (1990). The process model must give the answer to the questions *why* and *what has to be investigated*, but also to the most important issue for decision oriented monitoring: *where and how have the monitoring wells to be installed?*

Dörhöfer and Huch (1998) suggest a zoned monitoring approach. It provides a sound hydraulic basis for the evaluation of compound-specific transport behaviour and mechanisms linked to early warning capabilities (Fig. 5). The zones are divided using the travel time of groundwater for 200 days and 2 years. In realisation of EU Water Frame Work Directive we recommend to change Zone 2 to a travel time of 6 years in order to yield suitable information about the trends after realisation of concrete measures.

In a second step it should be considered if the process of measurement and of data collection can be automated. Continuous groundwater monitoring with various sensor techniques offers possibilities for:

• reduced personnel costs for

– manual measurement activities, travel, data collection and processing

– control efforts at the monitoring wells and of sampling mistakes

• less potential for errors in sampling, sample preparation and transport

• increased quality and quantity of data:

– automated measurement in arbitrary time steps

– data transmission in arbitrary time steps

– automated measurement of indicator parameters and time-related measurement of other parameters in relation to the process model

• carrying out operative solutions and initiate corresponding protection measures

• enhancing the reliability and effectiveness of remediation measures.

There are also disadvantages and limitations which must be taken into account, for example:

• interference sensitivity of the equipment and the necessary maintenance and management

• expense for controlling, calibration and maintenance of the equipment

• additional costs for data transmission systems (remote query/control) or for redundant systems to protect against data loss in case of sensor malfunction

• expense for personnel to handle and to maintain the automated measurement and transmission systems

• protection measures against vandalism

• different control volumes (observation zones) of sensors compared to samples taken by pumping water from the aquifer (Fig. 6).

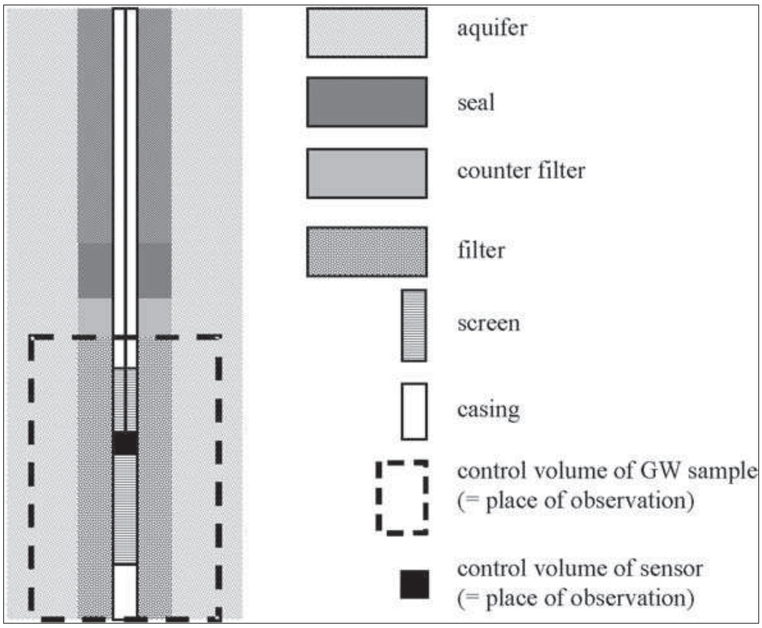


Fig. 6. Different control volume (observation zone) of a sensor compared to a sample taken by pumping from the aquifer.

The results of quality monitoring with sensor techniques can be affected by vertical water movement in the monitoring well, exchange of oxygen with the air and vertical differentiation of the water column in the well by evaporation and condensation processes. To minimize these influences a packer around the filter must be installed.

Before starting the installation of new monitoring wells, there must be an investigation whether there are any existing wells which can be used in the monitoring conception. Existing wells have to pass a functional test (quality test), which includes

• Ensuring the hydraulic connection of the filter to the aquifer. To verify this, various hydraulic test methods or tracer techniques can be used.

• Checking for damages of screen and casing. For this, different borehole geophysical methods are available.

• Make sure that there is no vertical water movement in the well.

Recommendations for quality tests of existing wells are given in a lot of publications.

CONCLUSIONS

There are different opinions regarding the construction of monitoring wells. Different types of monitoring wells are shown (Fig. 7). Until about 1995, fully penetrating or multiple-screened wells were constructed in the most of the old states of Germany and also in most European countries for decision oriented monitoring. The idea was to get a hydraulic weighted average water sample of the whole aquifer or a depth oriented sample using double (straddle) packers. The different hydraulic conditions of various types of monitoring wells in layered aquifers are shown (Fig. 8). The hydraulic

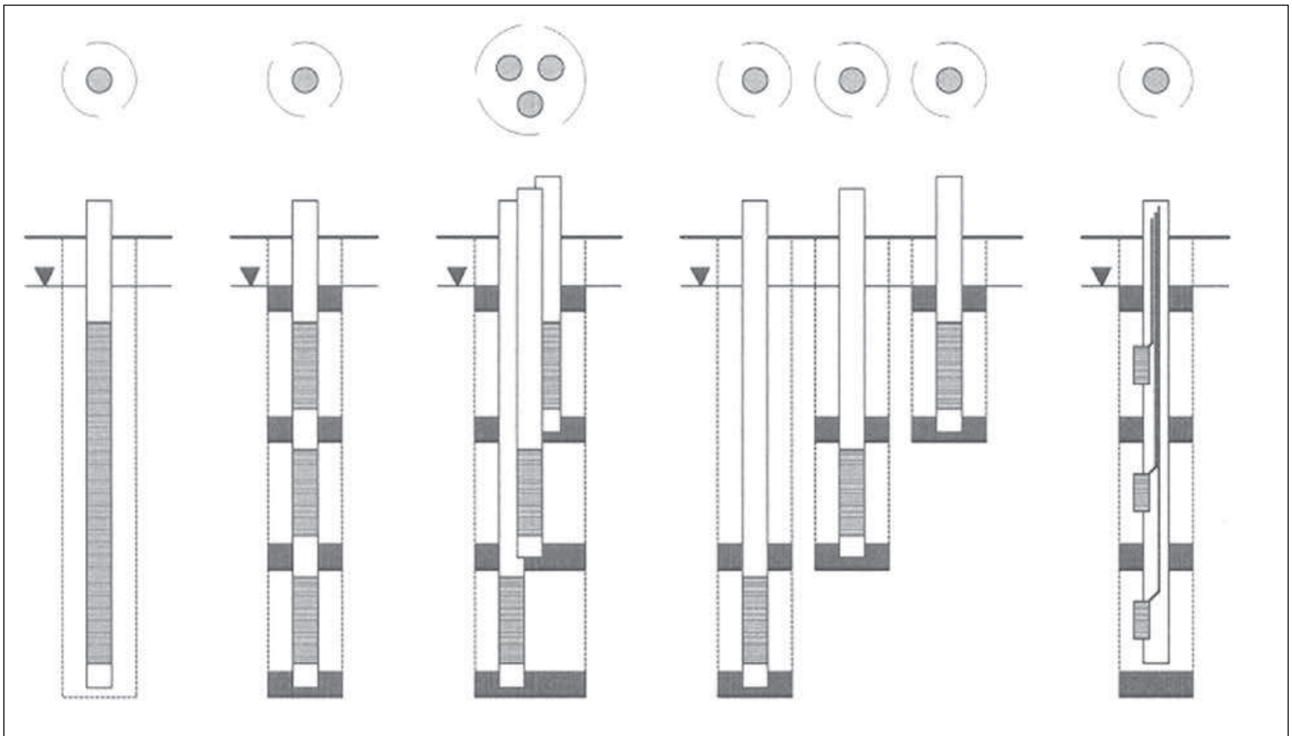


Fig. 7. Types of monitoring wells.

studies by Kaleris (1992) and Barczewski *et al.* (1993) show the impossibility of hydraulic separation of different screened zones or packered intervals (Fig. 9A) within the aquifer. Dehnert *et al.* (2001) describe the risk of mixing contaminated water downstream of fully penetrating and multiple-screened wells. Our own investigation confirms this effect. At a test site, a contamination plume was detected in a depth between 3 and 6 meters by Cone Penetration Testing (CPT). A fully penetrating well was installed and after 2 months tested with a double packer system. Contaminated water was found in all tested intervals (Fig. 9B).

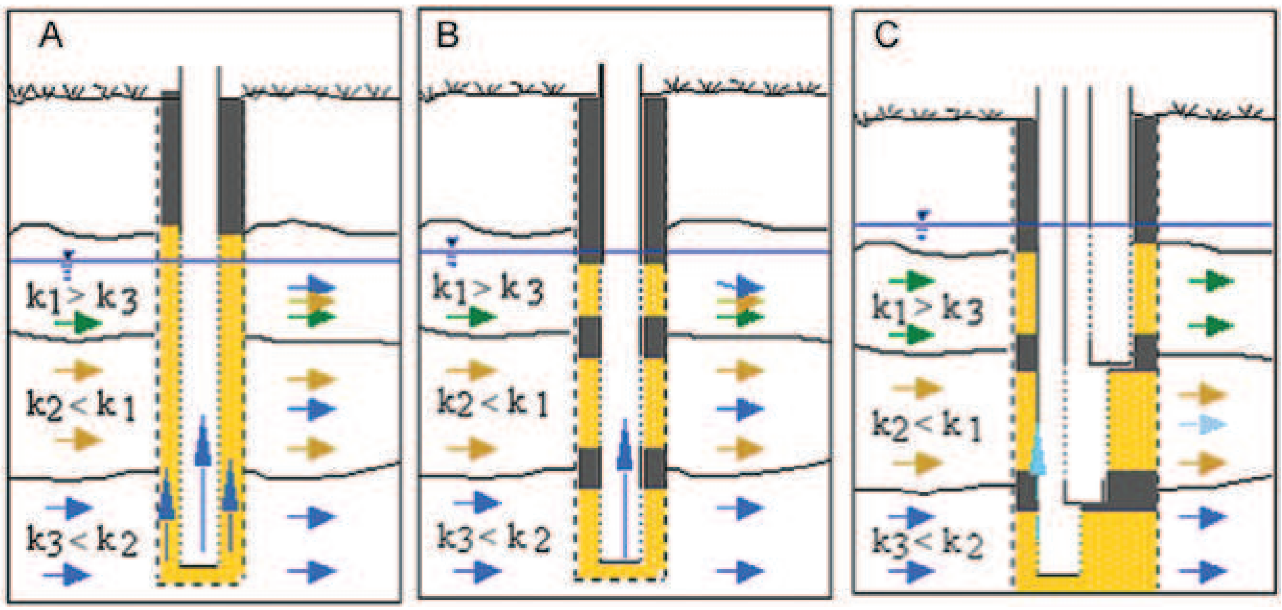


Fig. 8. Hydraulic conditions for different well types. A – fully penetrating well, B – multiple-screen well, C – nested well.

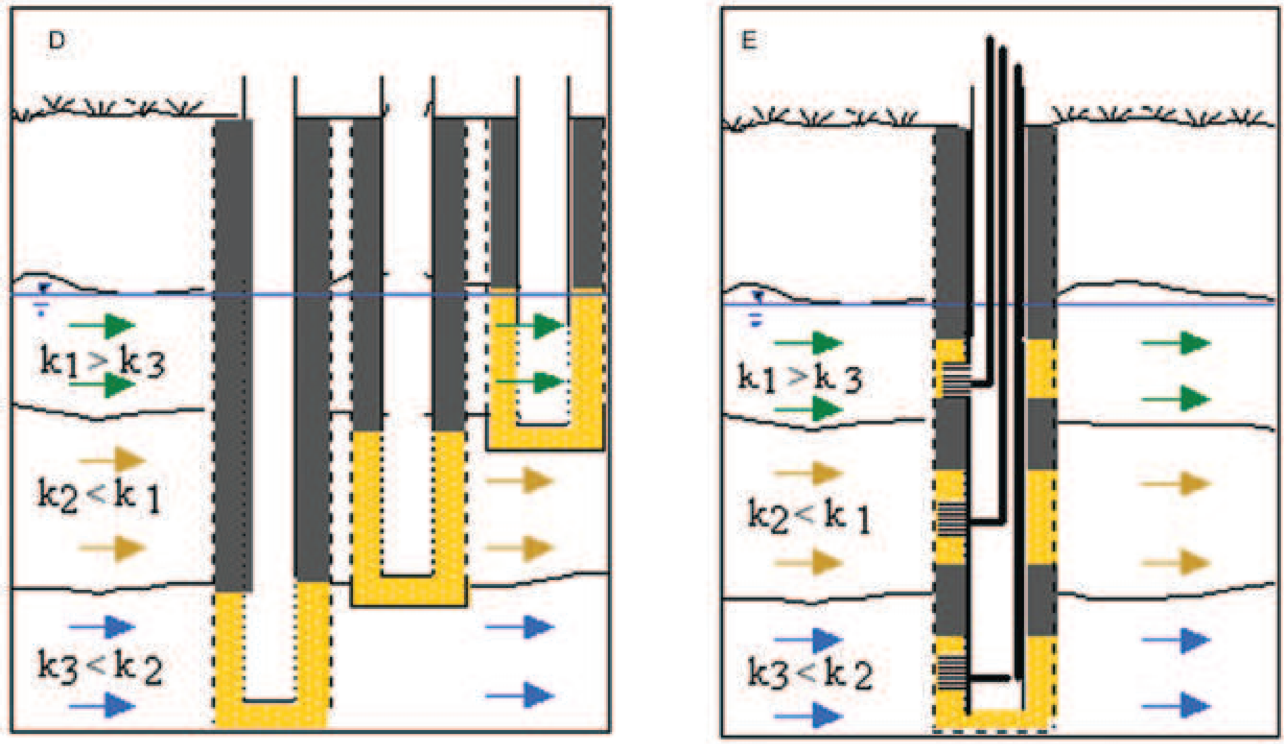


Fig. 8. D – well group, E – special well with depth-oriented mini-sampling equipment.

The state of the art for sampling methods and equipment, the definition of monitoring parameters (indicator / screening substances), and measuring intervals are discussed in detail in Knödel *et al.* (2007).

As shown in our strategy schema (see Fig. 4), the results from the first sampling operation must be compared with the results of the process model. The model must be re-calibrated if necessary, or in some cases the layout of the monitoring network must be changed. Planning of all following operations has to be based on a prognosis of the intended measures (for example natural attenuation, remediation of the contaminated site, or in relation to the aims of various scientific studies) using the process model.

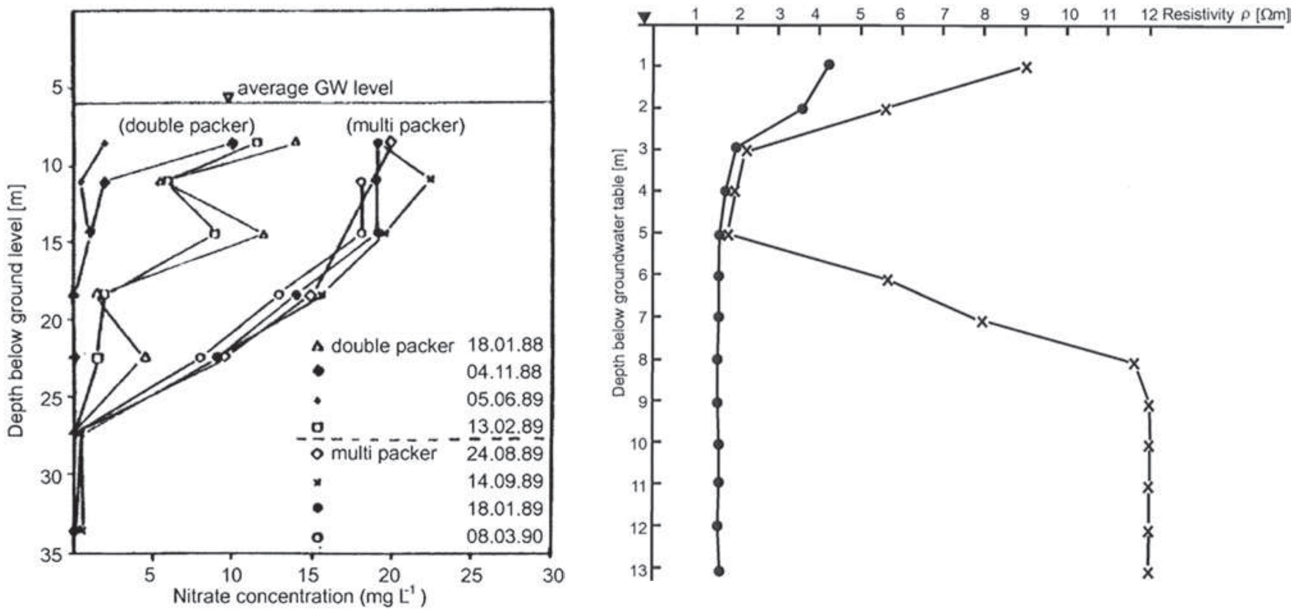


Fig. 9. Influence of well construction and sampling method on the results of analysed groundwater quality. A – influence of packer types on depth-oriented sampling results in fully penetrating wells (Barczewski *et al.* 1993). B – influence of a fully penetrating well: electric resistance of groundwater measured with CPT (×) and in the fully penetrating well 2 months after installation (•).

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