Groundwater monitoring as a tool of the hydrogeological cartography in Poland in the light of Water Framework Directive

Bogusław Kazimierski*, Andrzej Sadurski*,**

B. Kazimierski

A. Sadurski

A b s t r a c t . The Hydrogeological Map of Poland, 1: 50,000 *has been completed last year and it demands permanent updating in the future. The only source of the new hydrogeological data to this map can be provided by a groundwater monitoring system. The groundwater monitoring in Poland undergoes reconstruction according to Water Framework Directive (WFD) of the European Union. WFD is the general legal act oriented towards the sustainable utilization, protection and improvement of the state of water resources. Delineated groundwater bodies have to be monitored and the results are aimed for the action plans of the water management. Newly prepared directive "Groundwater vs. pollution" comprises more detailed procedures of monitoring, manners of sampling, elaboration of the results and presentation. It should be reflected also in the hydrogeological cartography.*

Key words: *groundwaters, hydrogeological cartography, Water Framework Directive, groundwater monitoring, groundwater protection*

In May 2004 Poland joined the European Union and the Water Framework Directive has been implemented in the water management. The *Hydrogeological Map of Poland 1: 50,000* was finished some months later, but this map has to be updated in the nearest future. The source of new hydrogeological data: the state of water table and quality of groundwater, will come from the monitoring system. This system is under reconstruction at present and the idea of changes is presented in the paper.

Poland's accession to the European Union caused the necessity of implementation of the EU regulations to the Polish law. In the field of water management and protection, the EU introduced a number of directives and among them the major ones are as follows:

- ❏ Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 — the Water Framework Directive (WFD);
- ❏ Directive 91/676/EEC of the Council of 12 December 1991 — the Nitrates Directive (ND);
- ❏ Project of the directive "Groundwater vs. pollution" developed by the European Parliament and by the Council.

In the Water Framework Directive, an important role in water protection and management and in determination of the influence of groundwaters on groundwater-dependent ecosystems has been committed to water monitoring, including also groundwater monitoring.

Groundwater monitoring is to provide data and information processed for the assessment of the state of groundwater and for making decisions in terms of water protection and management. As yet there exist no European regulations concerning water monitoring, but there are a number of methodological handbooks containing instructions how to organize water monitoring.

*Polish Geological Institute, Rakowiecka 4, 00-975 Warszawa, Poland; boguslaw.kazimierski@pgi.gov.pl; andrzej.sadurski@pgi.gov.pl

**Faculty of Biology and Earth Science, University of Nicholas Copernicus, Gagarina 11, 87-100 Toruń, Poland

Monitoring schedule

The process of implementation of the regulations is run according to the schedule described in the Water Framework Directive. It enabled the planning and subsequent organization of the groundwater monitoring system and other necessary related operations.

One of the first steps was identification and preliminary recognition of the so-called vulnerable, protected and transboundary groundwater bodies. Depending on the state and position of groundwater bodies in the natural environment, it is possible to change the range of monitoring (Tab. 1).

Principles of organizing and functioning of monitoring

Neither WFD nor methodological handbooks (Guidance, 2002) provide detailed regulations concerning the manner and range of monitoring. Development of detailed programmes was left up to individual EU members, allowing to take into account local specific hydrogeological conditions and organizational and methodological approach applied in monitoring. However, it was noted that the accepted monitoring programme should be realistic, i.e. should be adequate to financial and organizational possibilities of the implementing institution. The Water Framework Directive defines two types of long term in time monitoring. In Poland, they will be developed in the following ways:

- ❏ water quantity monitoring — through control of the intake of available groundwater resources (by comparison of the total amount vs. use of resources) and groundwater level measurements;
- ❏ water quality monitoring — through investigations of physical and chemical parameters of waters.

The target of monitoring. Groundwater bodies are the objects for monitoring. They are or can be extracted in the amounts of 100 m^3/day. Groundwater bodies also affect land ecosystems and the state of surface waters. It means that monitoring in Poland should cover all groundwater bodies.

160 groundwater bodies have been identified in the territory of Poland as a result of the hydrogeological works

Table 1. The schedule of monitoring for its implementation according to the WFD (Guidance..., 2002)

Formal requirements of WFD	Monitoring operations necessary to make decisions	Time needed	Last date of start	Date of termination
Preliminary identification of groundwater bodies		1 year	2002	begining of 2003
Characterisation of groundwater bodies according to Enclosure II		2 years	2002/3	end of 2004
Recognition of demand for information	Development of monitoring strategy based on groundwaters characterisation	half a year	2004	2005
Planning and organizing of monitoring system	Implementation of strategy for quantitative and chemical monitoring	1 year	2005	2006
	Comparison of existing monitoring points/systems with the strategy	half a year	2005	end of 2005
	Creation of new monitoring points, modification of existing points if required	1 year	2005	2006
	Starting monitoring system			end of 2006
Monitoring operation and data collection	Monitoring of groundwater quantity	1 year	2006	2007
	Monitoring of groundwater chemistry diagnostic and operational monitoring	1 year	2006	2007
Assessment of monitoring results, interpretation and report on groundwater quality	Securing good quality, quality control	half a year	2008	2008
Detailed specification of schedule of works for plans of groundwater use in drainage basin		half a year		2003-5
Identification of strategic points of groundwater management	Water management cannot be based on monitoring results because they will not be available yet	half a year	2005	2007
Publication and discussion of preliminary plans for groundwater management in drainage basins	Water management can be based on preliminary results of monitoring if they are available	1 year	2007	2008
Publication of plans for groundwater management in drainage basins, development of action programme	Based on assessment of state according to monitoring results	half a year	2008	end of 2009
Implementation of action programme		3 years (?)		2012
Continuation of first monitoring cycle		7 years	2008	2015
Second monitoring cycle	Aim: among others verification of action effects	6 years	2016	2021

done. The main criteria for their identification were the following: water dynamics, facies development of water-bearing layers, reaction to external factors and the amount of anthropogenic influence. In addition, an organizational criterion has been established in order to secure joint operations in monitoring and investigations on the balance between groundwaters and surface waters. This working phase of the programme was called stage I. The identified groundwater bodies are represented by complex, multi-level groundwater systems. During the next stages of the programme, it is planned to identify separate groundwater bodies of main and deep usable aquifers. Aquifers that show the highest dynamics and those which are anthropopressure-sensitive have the highest priority for monitoring. These are represented by shallow or usable groundwaters of unconfined aquifers (high dynamics) and by main usable aquifers (due to abstraction pressures caused by water extraction). Water-rich Quaternary aquifers are dominant in Poland. Monitoring must also cover deeper confined aquifers isolated from the ground surface, if they are designated or can serve as water supply (aquifers of confirmed disposable groundwater resources or delineated groundwater resources of drainage basin).

The map in Fig. 1 illustrates the distribution of groundwater bodies, with the following ones marked:

- ❏ those which are threatened by not being able to comply to the requirements of the WFD, i.e. they are now overexploited (mainly due to mine dewatering) or of degraded quality;
- ❏ those whose boundary requirements will be lowered; in case of the occurrence of industrial objects exerting strong abstraction pressures, but for the economic reasons production cannot be abandoned or limited;
- ❏ groundwater bodies located in border areas (cross-border ones will be delineated later);
- ❏ groundwater bodies protected by the law (nature reserves, recharge areas, protected catchment areas).

Conceptual models. Recognition of the hydrogeological condition is described as the conceptual model, which is constructed to enable a mathematical filtration model and a mass transport model. Such models can be developed for purposes of monitoring system construction, groundwater

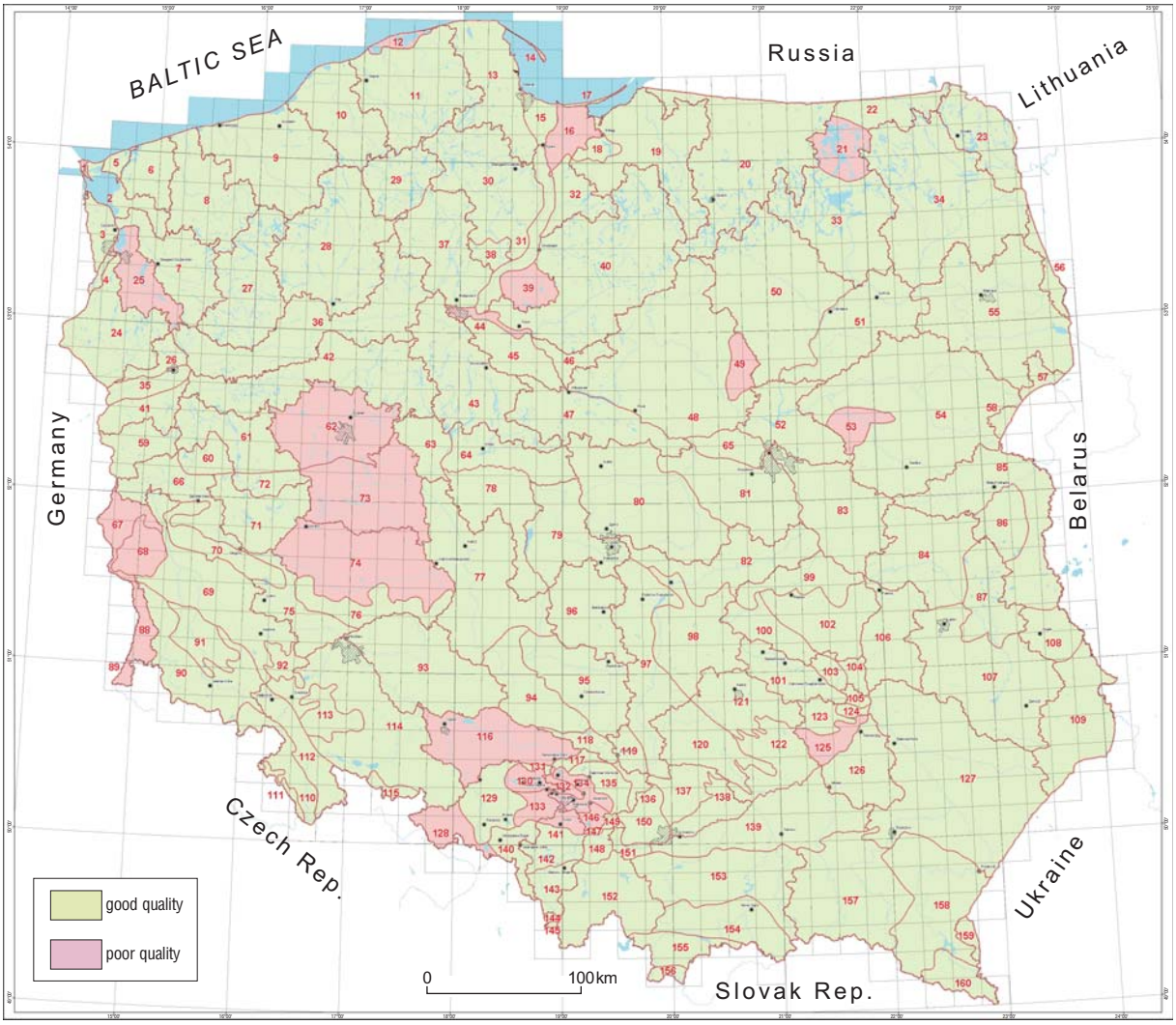

Fig. 1. Distribution and state of groundwater bodies in Poland

state prognoses and for assessments of quantity and chemistry (quality) of groundwaters. During the initial modelling stage, simple (description) models can be developed and, as monitoring data volumes continue to grow, the models can be made more detailed (e.g., by presenting as cross-sections, maps, block diagrams or schemes). Figure 2 shows a scheme and individual stages of groundwater monitoring system construction starting from conceptual models of groundwater bodies. The model should image the state of knowledge about the groundwater circulation system, system parameters and exerted external abstraction pressures. Monitoring should provide data essential for testing and improving of the model. It is necessary to attain the required confidence level of monitoring results.

The scope and frequency of monitoring measurements. Monitoring, consistent with the requirements of the WFD, covers investigations of the groundwater state defined as water quantity and quality. The monitoring process is run within a groundwater body separately for each of these two parameters, basing on different sets of indicators. However, most of water samples are collected from the same observation wells.

The quantity of groundwater resources of groundwater body shows to what extent it is exposed to direct and indirect water extraction and to the associated lowering of water level. It is assumed that the assessment is based on the following monitoring parameters:

- ❏ amount of available groundwater resources, understood as the amount of disposable groundwater resources, and if these are lacking, as the amount of groundwater resources of drainage basin, expressed in m^3/day;
- ❏ amount of measured long-term (average) water intake from groundwater catchments, in m^3/day;
- ❏ groundwater level in metres a.s.l., or water spring discharge in l/s;
- ❏ groundwater flow direction and flow rate (can be determined based on data from the *Hydrogeological Map of Poland, 1 : 50,000*).

Assessment or verification of available groundwater resources and of water sampling is made once a year. Measurements of groundwater level or spring discharge are made once a week, with the following exceptions:

- ❏ hydrogeological monitoring sites or other observation points with automatic measuring and data transmission devices installed — once an hour;

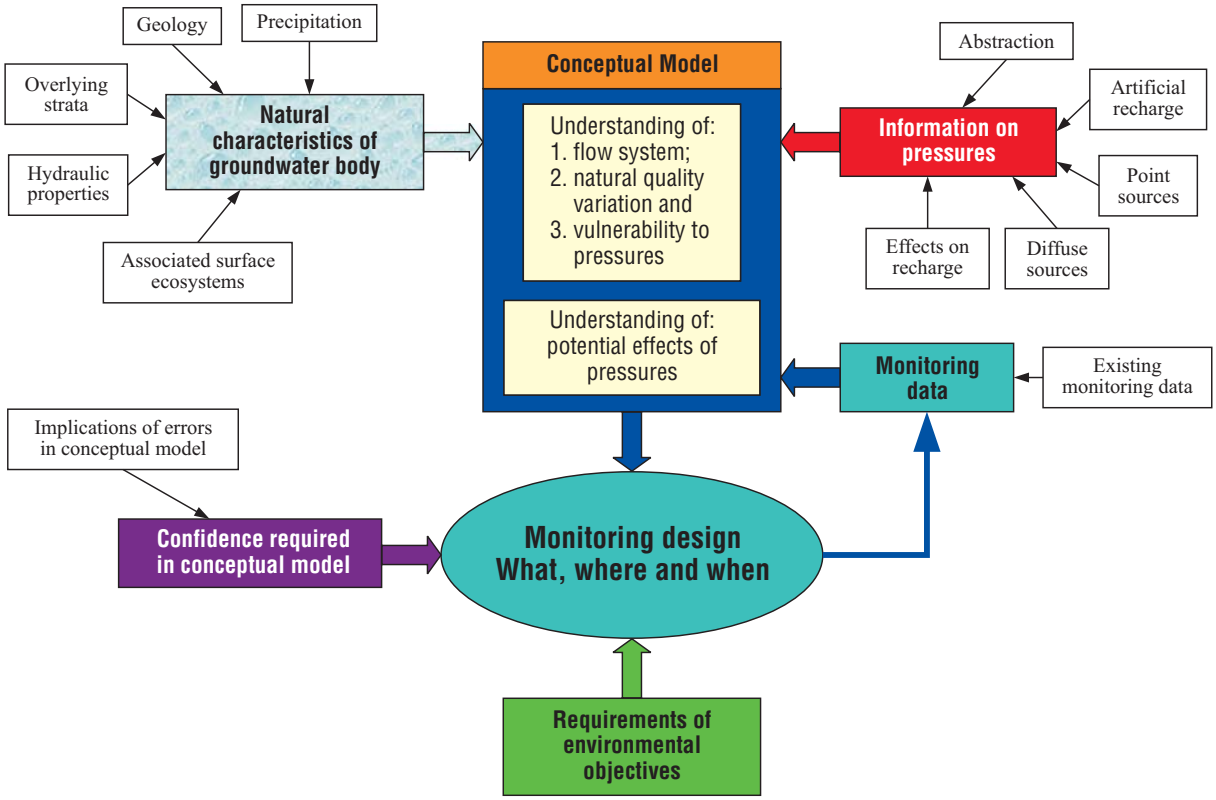

Fig. 2. A scheme of monitoring programme development with use of a conceptual model of the groundwater bodies system

❏ transboundary observation points — once a month.

The measurement network of groundwater level will finally include about 1500 observation points (wells and springs), of which 900 points will cover measurements of shallow unconfined groundwaters.

Both the WFD and Polish legal acts — the Water Law — say that groundwater monitoring for chemistry investigations should be performed through diagnostic, operational and investigative monitoring.

Diagnostic monitoring serves to assess and verify the influence of anthropogenic activity on groundwaters, and to recognize long-term changes in the groundwater state. Results of diagnostic monitoring are a basis for planning or verification of operational monitoring (Guidance..., 2002).

Investigations conducted within diagnostic monitoring include the following sets of indicators:

❏ General indicators: pH, Total Organic Carbon, electrolytic conductivity at 20°C, temperature, dissolved oxygen.

❏ Inorganic indicators: ammonia, antimony, arsenic, nitrates, nitrites, barium, beryllium, bohrium, chlorides, chromium, free cyanides, tin, zinc, fluorides, phosphates, aluminium, cadmium, cobalt, magnesium, manganese, copper, molybdenum, nickel, lead, potassium, mercury, selenium, sulphates, sodium, silver, thallium, titanium, uranium, vanadium, calcium, bicarbonates, iron.

❏ Organic indicators: AOX — Adsorbable Organic Halogens, benzo(a)pyrene, benzene, BTX — volatile aromatic hydrocarbons, phenols, phenol index, oil derivatives, pesticides, total pesticides, anionic surface active agents, anionic and non-ionic surface active agents.

Investigations of shallow groundwaters are made every third year, of deep groundwaters — every sixth year.

Operational monitoring provides data necessary to achieve the required confidence level in the classification of poor or good quality groundwater bodies at risk, or to detect significant increasing trends in pollution contents.

This type of monitoring is aimed at:

❏ identification of the chemical state of all groundwater bodies or groups of groundwater bodies defined as being at risk;

❏ identification of the presence of any long-term increasing trends in pollution contents, caused by human activity.

The range of investigations includes the following features of the groundwater environment:

❏ Obligatory indicators: temperature, conductivity, pH, dissolved oxygen, ammonia, nitrates, nitrites, Cl^-, SO_4^{2-}, PO_4^{3-}, HCO_3^-, Na^+, K^+, Ca^{2+}, Mn^{2+}, Fe^{2+};

❏ Indicators whose contents, determined by diagnostic monitoring, make the groundwater bodies fall into the group of "poor";

❏ Other indicators characteristic of anthropogenic influence in the given groundwater body.

Frequency of measurements is not less than once a year, but in justified cases the monitoring staff can make dispositions for additional measurements.

Investigative monitoring is organized and functions similarly to local monitoring and water intake protective monitoring but during short time only. This type of "monitoring" is established if required, often as a result of a decision to extend the range of diagnostic monitoring and to

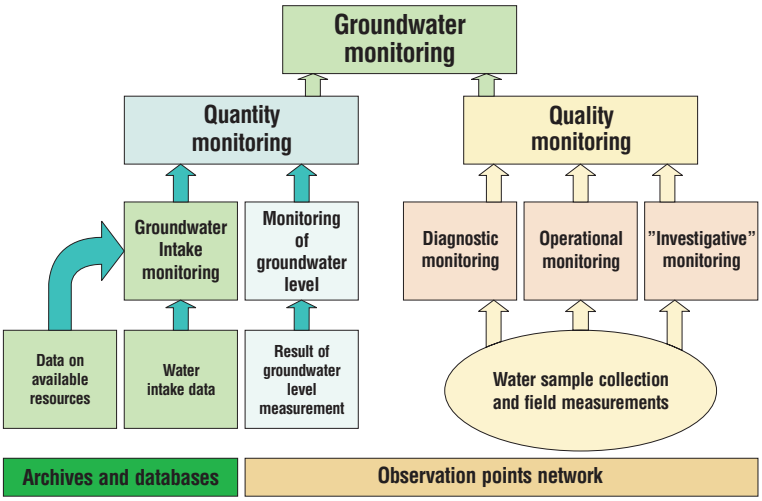

Fig. 3. Organizational scheme of groundwater bodies monitoring consistent with the agreement of the WFD

recognize the reasons, amount and effect of incidental pollution. Investigative monitoring can be run to assess the state of groundwater bodies determined as threatened by not being able to achieve environmental goals for which no operational monitoring has been established yet.

Figure 3 illustrates the organizational scheme of groundwater monitoring consistent with the directives of the WFD, accepted to be implemented in Poland.

Interpretation of the results

Interpretation of the results relies on data processing to obtain information about the state of water environment. The information is stored and processed with use of a computer database of the Oracle system. The complete database contains all monitoring data which characterise the hydrogeological system, exerted abstraction pressures and investigative devices with their specifications. The database ensures the possibility of processing of all data. As a result of the interpretation, we obtain tabular, cartographic or chart information about the quantity and chemical composition of waters. The water quantity is good if the criteria of keeping up the minimum reserve of resources are fulfilled (it ensures maintaining of biological flow), and the water level is appropriate for the land ecosystems. The quantity is good if the quality criteria of the monitoring classification are fulfilled and the water meets the quality standards determined for drinking waters with use of simple treatment systems. Information about trends in changes in contents of the major physical and chemical indicators is helpful in such assessment. A distinct increasing trend in the contents can be a reason for regarding the chemical state of the groundwater body as being at risk or poor. A chemical type and background should also be identified for groundwaters.

The results of monitoring are the basis for reports and assessments of the groundwater state and groundwater bodies. A report contains a description of monitoring cycles or stages. It also includes information about the range of monitoring and its results. The results of monitoring can be compiled in the repost as raw source data, i.e. prior to the final verification, presented in tables or recorded in a digital form. The report must include information about all difficulties during the monitoring process and about all deviations from the standard procedures of measuring and sampling. The assessment of the state covers the results of monitoring investigations in an integrated form, showing the state of the environment and its changes. It also includes recommendations concerning environmental protection. The following valuation classes are in use: basic, periodical and extraordinary.

Conclusions

The implementation of the Water Framework Directive into the legal system of Poland resulted in some changes in the previous procedures of the groundwater monitoring process. The obligatory monitoring systems were classified according to the extent of monitoring, including domestic, regional and local monitoring. Those systems have been replaced by the GWB system focusing on the control of the quantitative and qualitative state of groundwaters.

By 2012, it is necessary to double the number of observation points of groundwaters in Poland, and to organize observation points in border areas and in areas of groundwaters threatened by pollution derived from the land surface.

The currently implemented new directive "Groundwaters vs. pollution" will include procedures of sampling and physical and chemical analyses of shallow groundwaters. It will also define the manner of data processing and storage in databases. Results of monitoring will be available on websites and in bulletins of the Polish Hydrogeological Survey. The results of monitoring system comprising more than 1000 points together with local system in the vicinity of water intakes, dumping sites and overexploited areas enables current updating of the *Hydrogeological Map of Poland, 1 : 50,000*.

References

Council Directive 91/676/EEC of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources. Official Journal L 375, 31/12/1991.

Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. Official Journal of the European Communities, 327.

Guidelines on Monitoring and Assessment of Transboundary Groundwater's. Work Programme 1996–1999. Leystad. March 2000.

Guidance on monitoring for the Water Framework Directive, 2002 — Water Framework Directive-Common implementation strategy. Working group 2.7.Monitoring.

Guidance on Reporting, 2004 — Towards a Guidance on Reporting under the Water Framework Directive. Common Implementation Strategy for the Water Framework Directive (20000600EC). 30 November 2004.

Groundwater body characterisation, 2004 — Technical report on groundwater body characterization issues as discussed at the workshop of 13th October 2003. Common Implementation Strategy for the Water Framework Directive (20000600EC). Final draft 11.04.2004.

Proposal for a Directive of the European Parliament and of the Council on the protection of groundwater against pollution. Political agreement, 2005.