Protection of groundwater quality and quantity of strategic groundwater resources of the Major Groundwater Basins

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A b s t r a c t. The policy for delineation of the Major Groundwater Basins (MGWBs) was developed in Poland as early as the 1980's. MGWBs are the most important water-bearing structures that yield the highest water productivities and qualities and represent major regional sources of drinking water. To date, 163 MGWBs have been established and 60 of them have been documented, stating, with different degrees of precision, their protection strategies. These actions have preceded the EU recommendations of the Water Framework Directive *(2000) and the* Groundwater Directive *(2006).*

In 2008, following the national strategy for protection of water resources prepared by the Ministry of the Environment and the National Water Management Authority, efforts began for the uniform documentation of the remaining 101 MGWBs, including delineation of their protection zones and the development of rules for groundwater protection. These works were planned for the period of 2009–2015. The task has been undertaken by the Polish Hydrogeological Survey in cooperation with a wide range of academic and research centres and private hydrogeological enterprises.

The establishment of critical protection areas is based primarily on hydrogeological factors. However, recent and future local development and water management planning documents, especially with respect to the sustainability of strategic groundwater resources and development of new water intakes is also taken into consideration.

Hydrogeological documentation of MGWBs will serve Regional Water Management Authorities as the basis for implementation of protection areas in the local development plans and for setting rules for water management in those areas.

Keywords: *Major Groundwater Basins (MGWBs), groundwater protection, groundwater resources*

Main reasons for establishing Major Groundwater Basins (MGWBs)

Over the past 30 years, in Poland, a continuous increase in water demand nationwide together with increasing deterioration of surface water quality have resulted in a growing interest in groundwater resources. This is also related to an increasing public awareness regarding water quality. At the same time, on local and even regional scales, contamination of groundwater with heavy metals, SPCAs and nitrogen compounds has been observed. In a few dozen groundwater intakes, concentrations of pollutants were observed to increase suddenly and many wells had to be closed down or defined as threatened. In the 1970's primary research was undertaken and rules for the protection of groundwater resources were established. Issues of risk assessment with respect to groundwater quality and progressing degradation of national groundwater resources were discussed by Byczyński et al. (1979) and others. It was estimated that some 20% of groundwater resources in Poland (2.8 km^3/a) were polluted at a degree making them unsuitable for urban use. This was an important stimulus for initialisation of actions aiming at stopping and reversing that process.

Cooperation with foreign hydrogeologists working on similar projects in countries adjacent to Poland resulted in the publication in 1984 of a textbook titled *Groundwater protection*, edited by Kleczkowski.

Comprehensive treatment of groundwater protection against declining groundwater quantity and quality combined with conclusions of numerous discussions carried on during scientific meetings and conferences (*Current Challenges in Hydrogeology*) and technical summits (*Challenges in urban water management* – PZITS Częstochowa) were the basis for developing a research project *The strategy for the protection of Major Groundwater Basins in Poland*, which was undertaken within a large scientific programme called National Framework Programme CPBP 04.1.

The programme was carried out during 1985–1990 and was led by Prof. Roman Andrzejewski. The head of the team working on groundwater protection was Prof. Antoni S. Kleczkowski. One of the major achievements of the team was developing a concept of protecting the most valuable groundwater resources, which with minor modifications has been carried out until the present day. The concept was based on defining Major Groundwater Basins – geological structures of regional and greater extent which are abundant in good quality groundwater. Over two hundred hydrogeologists worked on the implementation of the concept.

The development of the concept of delineation and protection of Major Groundwater Basins was inspired by the

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US programme for the protection of groundwater aquifers (U.S. EPA, 1987), which was under development at that time. The programme focused on aquifers that constituted the primary water source for human consumption (SSA – Sole Source Aquifers) and included the establishment of protection zones that were critical for their security (CAPA – Critical Aquifer Protection Areas). The U.S. EPA (United States Environmental Protection Agency) programmes are still in operation today, albeit with less success than the protection strategy of MGWBs in Poland, which is adapted to Polish conditions and remains valid. This success was possible thanks to the large involvement of the majority of Polish hydrogeologists at the early development stage of the concept and, currently, thanks to the activity of the Polish Hydrogeological Survey.

Hydrogeologists working on developing the concept of MGWBs were divided into 17 working groups, which worked on the preparation of regional reports and/or took part in the work of 5 methodological teams, whose work focused on developing classification procedures for the delineation of MGWBs. The classification criteria for defining MGWBs included assessments of hydrochemical background levels, pollutant migration parameters and potential threats from point pollution sources, as well as economic and social aspects and context of local planning and the existing infrastructure.

Detailed methodological guidance for cartographic presentations, legends and table configurations was developed in order to maintain a uniform structure of all documentation.

The principles of the research project were presented in the following two summary documents:

- ❏ *The map of the critical protection areas (CPA) of the major groundwater basin (MGWB) in Poland in scale 1 : 500 000* (Kleczkowski, 1990a),
- ❏ *Current state and research trends in groundwater protection in Poland* (Kleczkowski, 1991).

Achieved results

The collaboration work integrated scientists with practitioners. Workshops, conferences and symposia played an important role in developing a common nomenclature applied by both groups, and generated more or less formal working teams that continue until the present day. During discussions, new research aims arose including proposals for amending administrative and legislative structures necessary for the implementation of regional water management and the need for protecting groundwater quality and quantity. These ideas continue, for example, through the implementation of the *Water Framework Directive* (2000/60/EC), the *Groundwater Directive* (2006/118/EC), and other environmental directives of the European Union. Among various forms of protection offered to usable water resources, e.g. source protection areas, the Polish strategy for the protection of MGWBs is applicable not only at present but also in future, while implementing further resolutions of the *Water Framework Directive*.

Major goals of the long term programme were the two aforementioned summary documents. They were achieved in 1990 by completion of the MGWBs map (Kleczkowski, 1990a) including delineation of the critical protection areas (CPAs) requiring the maximum protection (MCPA) and requiring high protection (HCPA), and by publishing in 1991 a synthesis report titled *Current state and research trends in groundwater protection in Poland* (Kleczkowski, 1991).

On the MGWB map (Kleczkowski, 1990a), locations of the 180 primarily established MGWBs along with their protection areas were delineated according to primary criteria (for 140 MGWBs) and individual criteria (for 40 MGWBs). These works were referred to the hydrogeological regions of Poland as defined by Kleczkowski (1988) and modified by the working groups of the research programme (Fig. 1 and Table 1). Particular regions were given hydrogeological names that referred to geomorphologic and hydrographical criteria within a lowland province (Pn, Pp, Pr, Ppk and Pps) as well as a mountain-upland province (M – massif, MoK-S – monocline, N – basin). Within large, strongly stratigraphically and lithologically diversified structures, subtroughs and subbasins were also defined. The prefix „sub" indicates either a deeper location below younger sediments, or lower groundwater resources of a particular MGWB due to impeded recharge (Table 1). A graphical supplement of the map consists of ten cross sections that characterize MGWBs with respect to their structure, lithology, parameters and their hydrodynamics (groundwater flow directions, recharge and drainage conditions, etc.). These constitute conceptual models of MGWBs (Fig. 2).

Apart from graphical explanations included in the MGWB map in 1: 500 000 scale (Kleczkowski, 1990a), the publication was additionally enriched by a 38-page long booklet titled *Explanations to the map...* (Kleczkowski, 1990b) counting 19 tables, which included a description of the methodological aspects for delineating the MGWBs and their protection areas. This publication was prepared in Polish and English versions. In the later period, Prof. Antoni Kleczkowski proposed a conceptual model of the hydrogeological conditions of Poland (Fig. 3), which included major characteristics of all hydrogeological structures within which the MGWBs had been located.

MGWBs were selected according to the following qualitative and quantitative criteria: transmissivity of aquifer rocks of more than 10 m^2/h, potential well productivity of 70 m^3/h and potential for building groundwater supplies exceeding 10 000 m^3/d, groundwater quality within the first quality class – according to the classification developed by Macioszczyk (1987). These criteria aimed at selecting groundwater supplies available for supplying people with groundwater with no need for purification or requiring little treatment using economical technologies.

The main impulse for creating the concept of MGWBs was a legal act from 1983 regarding environmental protection, which aimed at stopping the progressing degradation of groundwater resources and retaining good quality waters to be used by future generations. Areas of the maximum (MCPA) and high (HCPA) protection, by definition, shall not exceed 10–30% of the country's surface area and shall include recharge areas that are threatened by degradation. The main criterion for delineation of the MCPAs and HCPAs areas areas was the time needed for water infiltration from the ground surface into a saturated zone. In that way potential hazards to an aquifer were evaluated based on infiltration time needed by the fastest migrating conservative pollutants. The following was defined:

- ❏ less than 2 years – category A1 – very high risk,
- ❏ 2–5 years – category A2 – high risk,

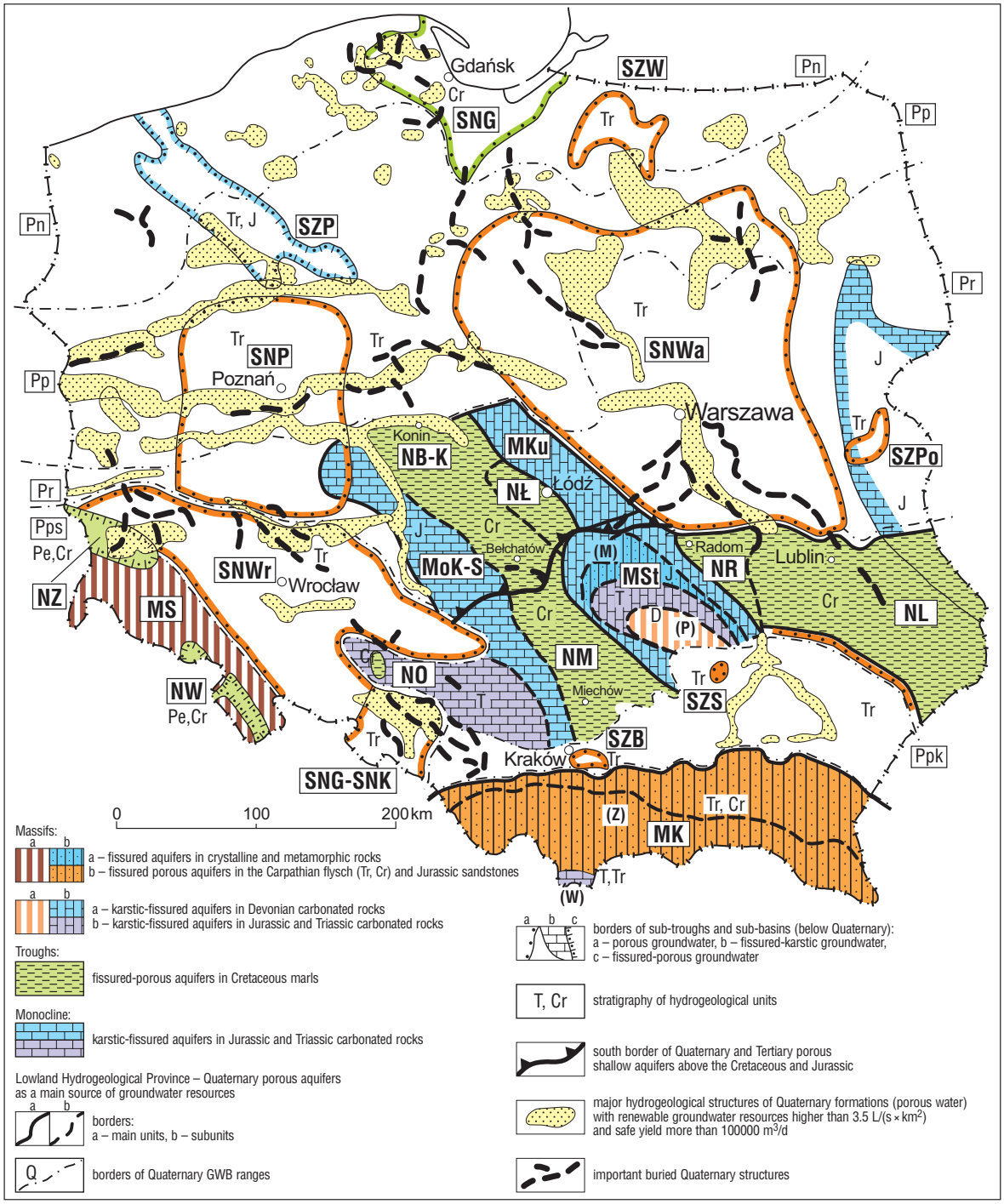

Fig. 1. Major hydrogeological units and structures of Poland (after Kleczkowski 2002, modified); stratigraphy of hydrogeological units: D – Devonian, Pe – Permian, T – Triassic, J – Jurassic, Cr – Cretaceous, Tr – Tertiary. All other abbreviations – see Table 1

- ❏ 5–25 years – category B – medium risk,
- ❏ 25–100 years – category C – low risk,
- ❏ more than 100 years – category D – very low risk.

It was estimated that within the 180 established MGWBs, the total disposable reserves were some 7.35 km^3/a, 58% of which constituted MGWBs that were established according to individual criteria; 53 aquifers had reserves exceeding 100 000 m^3/d (abt. 78.9% of the total disposable reserves of MGWBs). Aquifers within Quaternary sediments and of a porous nature dominated (51.7 %). The total area of the 180 originally established MGWBs was 163 441 km^2, which is 52.2% of the total area of the country, the total MCPA area was 30 173 km^2 (9.6%) and HCPA 59 506 km^2, constituting 19% of the country's surface area. Groundwater protection requires implementation of a system of orders and bans within the CPAs, which was developed in cooperation with specialists from different disciplines including urban planning, law, environmental protection, ecology and economy.

Synthesis of the research project published in 1991 (Kleczkowski, 1991) was intended to generate further research projects focused on implementation and documentary work. It can be said that the combined results of the map and the synthesis laid down directions for a strategic action plan in order to protect national groundwater re-

serves. The authors intended also to prepare the Polish hydrogeological community to continue the research and documentation activities, leading to the better management of groundwater reserves and their protection. These actions preceded the *Water Framework Directive* by a decade and they are still continued.

The synthesis comprised the following elements:

- ❏ an assessment of the status of the research on groundwater protection in Poland against decreasing quantity and quality;
- ❏ a strategic concept for the protection of major groundwater basins;
- ❏ a methodology for cartographic presentations of groundwater hazards and protection;
- ❏ an action plan for developing the above methodology, including a requirement of using mathematic modelling to assess pollutant migration processes, determining the scale of groundwater hazards, and quantifying disposable and exploited reserves;
- ❏ an evaluation of hydrogeochemical background levels and groundwater quality;
- ❏ the potential use of markers and geophysical methods in relation to groundwater protection.

It was at that time that development plans, based on results from the monitoring of surface and groundwater, as well as the identification of pollution sources, were identified as the most valuable tools for protecting groundwater resources. The need for amendments of the law and restructuring of the leading administrative institutions, in order to implement results of the long-lasting research in water management, was highlighted. The idea of the protection of MGWBs was employed mainly during planning processes for strategic linear investments in Poland i.e. highways. Apart from these syntheses, other very valuable elaborations are basic cartographic documents in scales of 1 : 200 000; 1 : 100 000; 1 : 50 000 and smaller. In total, over 200 items of documentations and data bases were gathered in the project's archives.

Results and conclusions that were drawn in these documents became a basis for further work including legislative documents. Eventually, in 2006, by the order of the Polish Minister of the Environment, 162 Major Groundwater Basins

Table 1. Regionalization of fresh groundwater in Poland (after Kleczkowski, 2002 – see Fig. 1)

Region	Area [km^2]
Mountain-Upland Hydrogeological Province:	**90 000**
Massifs M:	
– **MK** – Carpathian Massif	19 800
– (W) – inner part	
– (Z) – outer part with overlying Quaternary aquifers in river valleys	
– **MS** – Sudetic Massif – with the intermountain Permian-Cretaceous troughs (outer – NZ and inner – NW)	6 500
– **MSt** – Świętokrzyski Massif	9 800
– (P) – Paleozoic part	
– (M) – Mesozoic part	
– **MKu** – Kujawy Massif	3 400
Troughs (Cretaceous)	
– **NB–K** – Bełchatów–Konin Trough	7 200
– **NL** – Lublin Trough	16 600
– **NŁ** – Łódź Trough	1900
– **NM** – Miechów Trough	7 700
– **NR** – Radom Trough	4 200
– **NO** – Opole Trough	(150)[1]
Monocline Kraków–Silesia – MoK–S	**12 900**
– **J** – Jurassic part	
– **T** – Triassic part	
Lowland Hydrogeological Province:	**221 900**
Ranges of Quaternary GWB's:	
– **Pn** – coastal range	41 700
– **Pp** – lake district range	85 400
– **Pr** – plain range	59 100
– **Ppk** – forecarpathian range	1770
– **Pps** – foresudetic range	18 000
Subtroughs:	
– **SNG** – Gdańsk Cretaceous Subtrough	(6 000)[1]
– **SNP** – Poznań Tertiary Subtrough	(20 000)[1]
– **SNWa** – Warszawa Tertiary Subtrough	(51 000)[1]
– **SNG-SNK** – Głubczyce & Kędzierzyn Subtroughs	(9 000)[1]
Tertiary	
– **SNWr** – Wrocław Tertiary Subtrough	(7 000)[1]
Subbasins (the biggest):	
– **SZPo** – Podlasie Jurassic Subbasin	
– **SZP** – Pomeranian Tertiary+Jurassic Subbasin	
– **SZW** – Warmia Subbasin	
– **SZS** – Staszów Subbasin	
– **SZB** – Bogucice Subbasin	

[1]Area of subunits lying on or below the main units

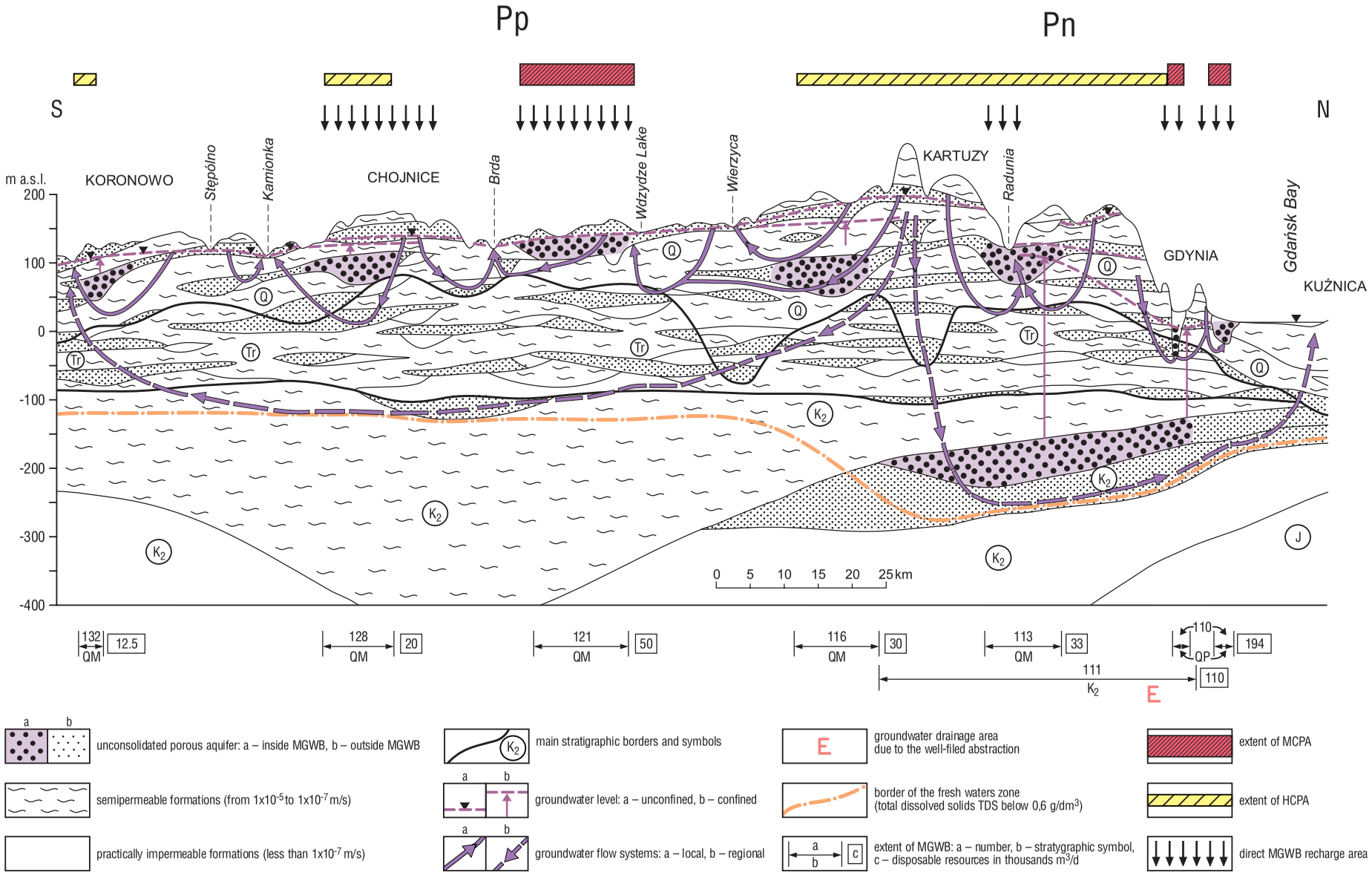

Fig. 2. Conceptual model of MGWB in N Poland according to A. Sadurski (in Kleczkowski, 1990a). Axis Y presented in metres above sea level; Q – Quaternary, Tr – Tertiary, K_2 – Upper Cretaceous, J – Jurassic

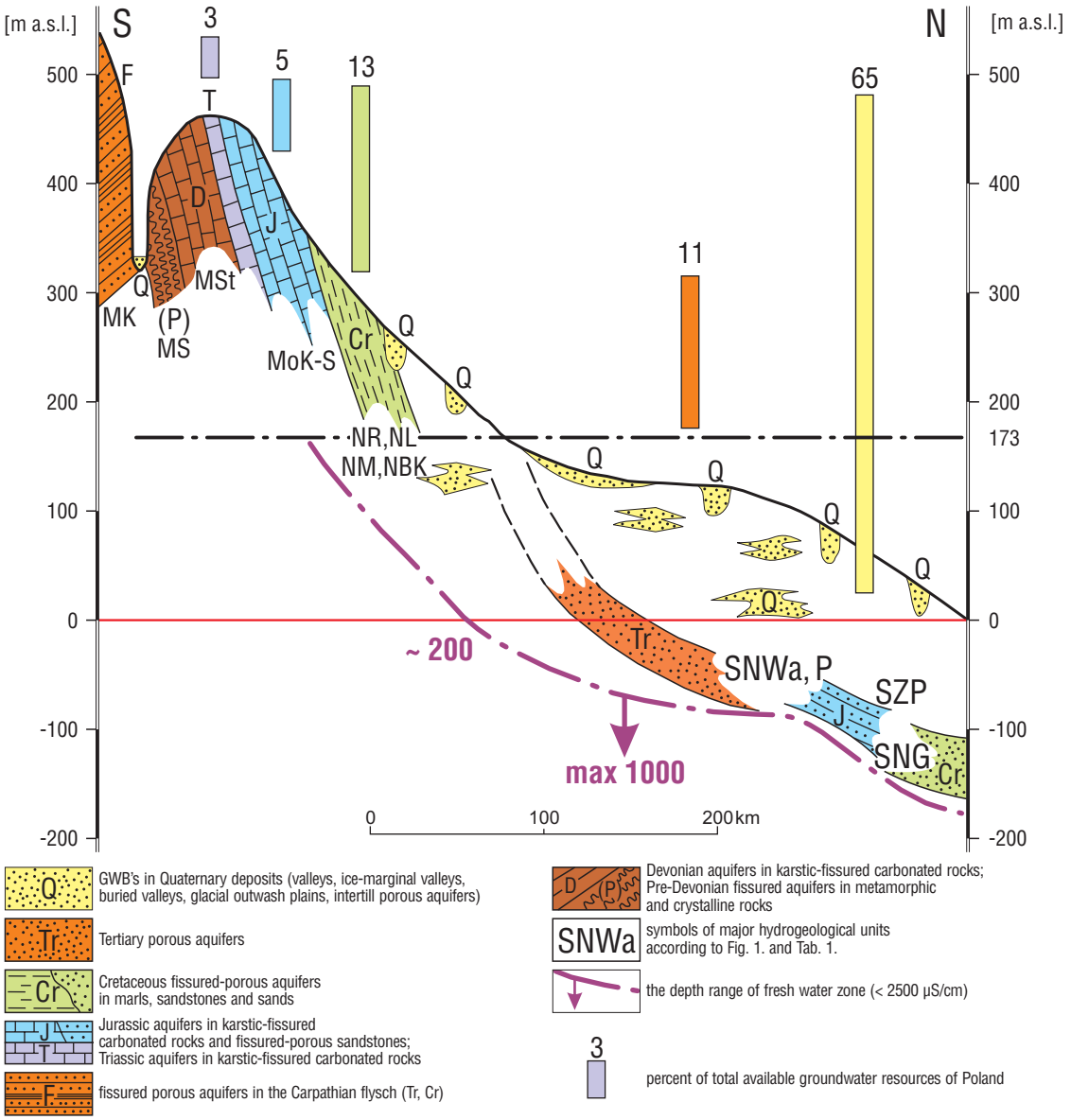

Fig. 3. Conceptual model of groundwater resources in Poland (Kleczkowski & Witczak, 2005). Simplified cross-section S–N according to Fig. 1 – Major hydrogeological units and structures of Poland. All other abbreviations – see Fig. 1 and Table 1

were legally established. Detailed work on delineating protection areas surrounding individual MGWBs began and was included in the major duties of the Polish Hydrogeological Survey. The Survey itself was established in 2006. For many scientific centres such as universities and local branches of the PGI (Polish Geological Institute), this work constitutes an important element of scientific programmes, subjects of doctorates and postdoctoral works.

This work has preceded recommendations and requirements of the EU *Water Framework Directive* (2000/60/EC), the *Groundwater Directive* (2006/118/EC) and is exceptionally well adjusted to the strategy for groundwater protection prepared by the Polish Ministry of the Environment and the National Water Management Authority (NWMA).

The national research programme for documenting Major Groundwater Basins

In 2003, while preparing for the national programme of the protection of MGWBs, all documentation of MGWBs available at that time were indexed. Results of work from the 1990's were compared with information presented on the map of the critical protection areas (CPA) of the Major Groundwater Basins (MGWB) in Poland (Kleczkowski, 1990a). The existing MGWBs were assessed for conformity with the four selection criteria for MGWBs, assessment of risk to groundwater resources and selection of protection areas. The indexing process has shown that the documented MGWBs included mainly those basins that required urgent delineation of protection areas, which confirmed that the general direction of work carried out by the Ministry was correct. The initial indexing of MGWBs that had not been documented was performed on the basis of new regional reports undertaken within areas where individual MGWBs had been delineated and of the hydrogeological map of Poland in the scale of 1 : 50 000.

Between 1994 and 2007 many items of documentation of MGWBs were completed. In this process, after detailed analyses of water bearing structures, some basins were disqualified as they did not fulfil the requirements stated for a MGWB. As a result of this work 60 MGWBs have been documented. Some of this work, especially older

documentations did not fully complete requirements allowing the delineation of critical protection areas according to the current law. Such documentations need to corrected and adjusted to the current legal requirements.

At present, after the indexing, requirements set for MGWBs are fulfilled by 163 basins. In the case of 103 of them, there is no documentation of hydrogeological setting and the extent of critical protection areas (Fig. 4). Due to the fact that field investigations were not included in the work schedule for 2009–2015, two MGWBs of the Paleogene–Neogene, MGWB no. 215 Mazovian Trough including its central part no. 215A, were excluded from the list of basins defined for documenting in that period.

In 2008, the Ministry of the Environment together with the Polish Hydrogeological Survey put forward an initiative to delineate CPAs for all MGWBs nationwide. The work schedule included delineation of CPAs for 101 MGWBs that have not been documented so far. In order to unify the layout of hydrogeological documentations for all MGWBs, a methodological guidance document titled *Methodology of delineating protection areas of Major Groundwater Basins for planning and water management in river catchment areas* was published by the PGI in 2009 (Herbich et al., 2009). It is anticipated that documentations for all MGWBs will be completed in three stages in 2009–2015, as follows:

- Phase I: 2009–2011 – documentation of 29 MGWBs and 15 adjustments to already existing documentation that was completed prior to 2008,
- Phase II: 2011–2013 – documentation of 33 MGWBs,
- Phase III: 2013–2015 – documentation of 39 MGWBs.

Major Groundwater Basins will be documented within the entire territory of Poland, in all different hydrogeological structures, with variable degrees of pressure from industry, agriculture and public services. Maintaining the methodological integrity of cartographic presentations, data bases, numerical modelling for all documentations that is being prepared in parallel and its completion on time require good and continuous coordination which has been given to the specially created MGWBs coordination unit within the Polish Hydrogeological Survey.

Results of the research programme

As results of the above research programme, the following products will be delivered:

- hydrogeological documentation for defining CPAs for 101 MGWBs including digital versions of reports, GIS files, mathematical models and exported thematic and final maps;
- adjusted hydrogeological documentation for 15 MGWBs for which original documentation was pre-

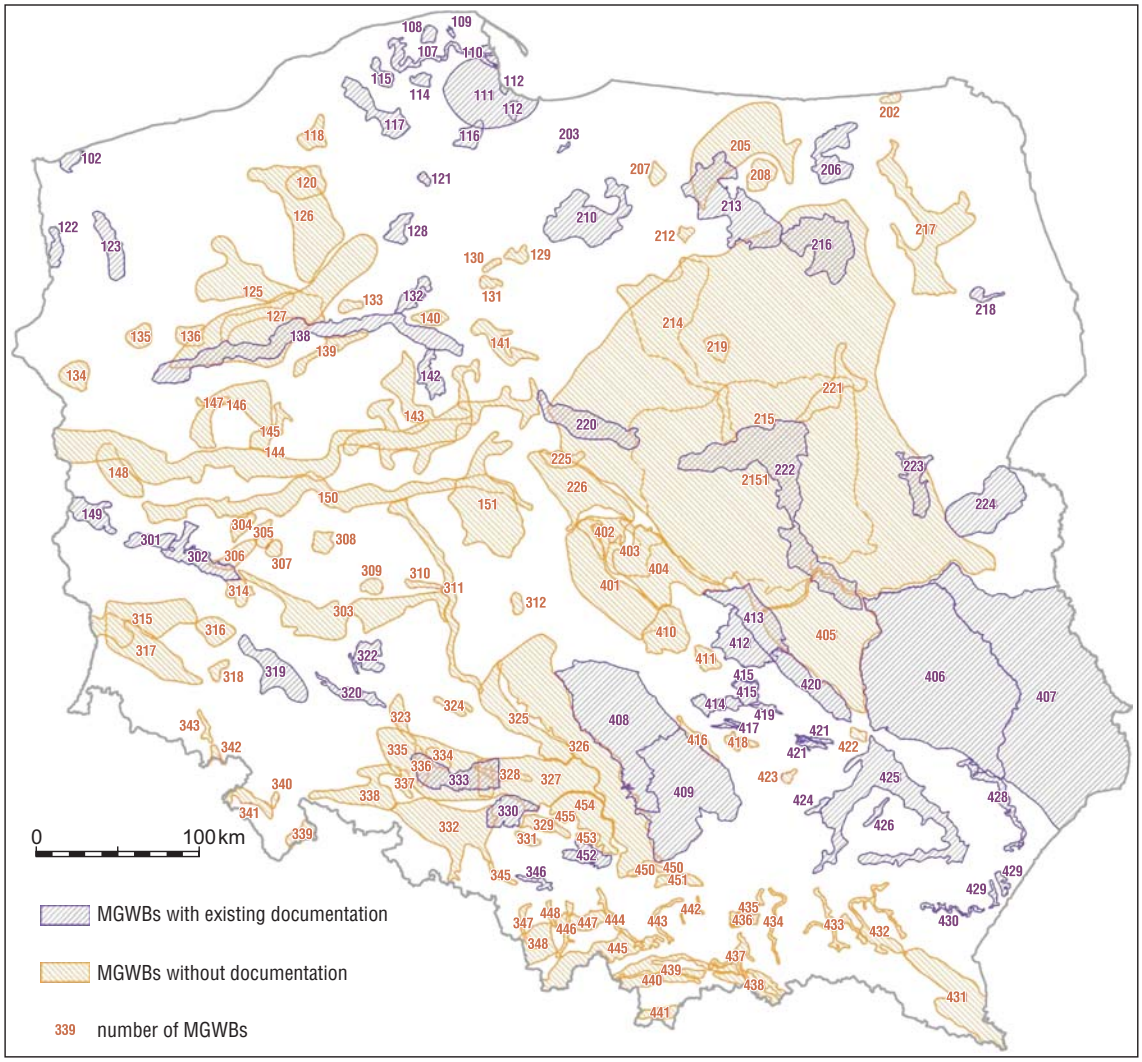

Fig. 4. Major Groundwater Basins (MGWB) – state of documentation: March 2010

pared before 2008 including digital versions of reports and GIS files;
- ❏ an integrated database of all digital models for individual MGWBs.

For optimal implementation of the defined CPAs into planning documents, apart from hydrogeological aspects, current planning documents have been taken into consideration when delineating CPAs. The procedure for delineating critical protection areas comprises two stages:
- ❏ firstly, boundaries of a CPA for a selected MGWB is delineated based on hydrogeological conditions where the dominating factor is time of groundwater flow towards a basin;
- ❏ in the second stage, this boundary is verified and adjusted according to results of a land use analysis. Specific rules regarding general land use and land management practices for the final extent of a CPA are defined with respect to the existing and future development plans.

The Critical Protection Areas of MGWBs are areas where detailed rules including bans and orders with respect to land use, land management practices and water exploitation shall be respected in order to protect groundwater resources from degradation.

Summary

Details included in the hydrogeological documentation for individual Major Groundwater Basins are the basis for the formal establishment of their Critical Protection Areas, which constitutes an important element of defining and implementing water management plans within river basins, for which National and Regional Water Management Authorities are responsible. These water management plans, which aim at sustaining good quality groundwater for human consumption, are required by the EU *Water Framework Directive* (2000/60/EC) and the *Groundwater Directive* (2006/118/EC).

The urgent need for documenting and establishing the CPAs results from requirements of the *Polish Water Act* and the EU *Water Framework Directive*. The latter imposes on the Member States a requirement for determining and implementing groundwater protection programmes aiming at achieving good groundwater status by 2015, or (in special cases only) in 2027.

In order to assure proper water management, including the protection of groundwater for human consumption, it is anticipated that future local development plans will include requirements regarding land use management as defined in hydrogeological documentation established for individual MGWBs. It is also important that local development plans and their amendments shall be agreed by the director of the appropriate Regional Water Management Authority.

The proposed unified methodology for delineating CPAs will allow not only for completing the specific task of defining protection areas but will also support the Polish administration responsible for water management (NWMA and RWMAs) in developing and implementing national water management plans with a view to achieving good quality of water in future. Apart from that, the *Polish Water Act* states that hydrogeological documentations prepared for defining hydrogeological conditions of MGWBs and their protection must be taken into account when defining conditions for water use within units of water regions and water basins.

The extent of information attached to specific layers of hydrogeological documentation for a MGWB was defined in a way that allows for smooth integration of spatial data originating from different sources and their common use by multiple users and for multiple applications, especially for applications used by the Polish Hydrogeological Survey and the major beneficiary of the work – Regional Water Management Authorities. The GIS system being created is fully adapted to the requirements of the EU *INSPIRE Directive* (2007/2/WE).

The idea of defining MGWBs as the most productive groundwater bodies in Poland has preceded achievements of other EU Members States. Realization of the principles of groundwater protection within MGWBs through the delineation of the CPAs and implementation of land and water management rules within their territories, as carried out by the Polish Hydrogeological Survey is concurrent to principles of the EU *Water Framework Directive*. Results of work that is planned for 2015 will allow the National Water Management Authority to prepare better water management plans for river basins in order to achieve their good quality status. Apart from that, the results will support local authorities in defining conditions for water use within a region or a basin.

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