Contribution of the Polish scientific community in solving new practical problems in hydrogeology

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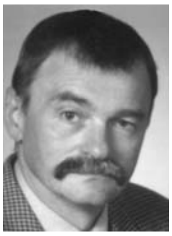
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A b s t r a c t. Geology, and especially hydrogeology is a scientific, and at the same time, a practical discipline that are closely related to each other. Academics do support practitioners by developing methodological guidelines for all practical aspects of their work. Among their activities are: organisation of databases, which are mostly available via the internet; development of geological and hydrogeological cartography, which is a synthesis of all information regarding geological and hydrogeological environment; undertaking groundwater monitoring programmes and interpretations of their results, which allows to diagnose and to forecast groundwater status; undertaking investigations regarding protection of groundwater as well as methodological support for hydrogeological practitioners by organisation of specialised trainings, provision of consultancy, expert judgements and dissemination of knowledge.

Keywords: *hydrogeological geo-information, groundwater monitoring, groundwater resources, protection of groundwater, dissemination of hydrogeological knowledge*

Geology and hydrogeology are scientific and at the same time practical disciplines that are closely related to each other. Academics support practitioners by developing methodological guidelines for all practical aspects of their work. From among the many hydrogeological problems, problems associated with impacts resulting from human activities on groundwater will be discussed in this article, as follows:

- ❏ geoinformation in hydrogeology – all information about groundwater and the environment in which groundwater occurs assigned to specific places on the Earth. These issues include methods for gathering of hydrogeological data, including cartographic field investigations, processing of geoinformation into usable forms, collecting data in databases, making data available to the public in both digital form and as cartographic printouts;
- ❏ groundwater monitoring and its interpretation allow for assessing the status of Polish groundwater resources; forecasting hydrogeological conditions of groundwater resources and controlling effects/results of mitigation measures taken to protect the groundwater environment. The main focus of academics is as follows: realisation of groundwater monitoring, especially on a national scale, development of new investigation methods, guidelines for data interpretation, implementation and testing of new solutions with respect to constructing piezometers and observation boreholes, measuring devices, automatic data loggers and data transmitters. Monitoring is not only a tool for assessing groundwater resources and ecosystems dependent on them, but what is most important, it is a tool used to support making decisions and defining measures to be taken for protecting and managing the groundwater environment;
- ❏ investigations regarding protection of groundwater, and especially developing methods for assessing groundwater vulnerability to pollution, defining phenomena and processes that are hazardous to groundwater in both, agricultural and urban areas; forecasting trends and characteristics of changes in groundwater status and ecosystems dependent on them; forecasting changes in groundwater levels, groundwater quality and quantity;
- ❏ evaluation of the degree of groundwater exploitation, which is used for sustainable groundwater management on a national scale, including planning and implementation of new investments;
- ❏ methodological support for hydrogeological practitioners (academic courses), organisation of specialised training (diploma courses, summer courses, other training), consultancy, expert judgements and dissemination of knowledge *via* publications (student books, guidelines, specialised journals etc.) and organisation of scientific and technical conferences.

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Geoinformation in hydrogeology

The fact that information is of exceptionally valuable merit is indisputable and one can devote much effort and money to getting reliable information. However, another fact that about 80% of information is referenced to a specific place on the Earth is not that obvious for many of us. Passing over that geospatial aspect of a large amount of information makes the information poorer. This impoverishment results from missing the possibility of undertaking spatial analyses of relationships between various phenomena and various processes. At present, one can observe important changes in approach to these issues – geospatial aspects of data are no longer omitted and the entire field of these issues is covered by a new scientific field named *geomatics* or, in different cultural regions, it is called *geoinformatics*. The basic element of the paradigm of this new discipline is the concept of *geoinformation*, which is understood as *organized data assigned to specific places on the Earth*.

In the Earth sciences including hydrogeology, almost 100% of data is geoinformation with geospatial attributes. This fact does not raise any doubts among hydrogeologists, which is proved by the development of hydrogeological cartography and the progress made through numerous achievements in this field, for example the creation of the hydrogeological map of Poland in the scale of 1 : 50 000. Other examples of this kind are hydrogeological databases in which geospatial attributes in the form of coordinates are the most basic attributes.

When observing changes that happen with passing time, one can conclude that traditional *paper* cartography and conventional relational databases no longer fulfil our requirements in this field. Relational database management systems allow selective extraction of information stored in these databases by using the SQL language; however, the spatial aspect is only marginally taken into account in these cases. It is much more widely used in cartographic work. However, a paper map is only a hard copy of a static (frozen) set of geospatial data and this allows very limited spatial analyses and is not appropriate for further processing.

A very significant example of changes that one could observe over recent times was the application of geoinformation systems (such as GIS) for editing paper maps. The present computer techniques used in these cases allows the improvement of editing work and the possibility of obtaining much better results than when using traditional methods. However, a *final product* obtained using computer technologies, despite its attractive appearance, does not differ much from old maps. Apart from that, after each editing process, usually troublesome *post-production leftovers* are produced. This is not the case in the digital mapping process where the *troublesome leftovers*, including geospatial information, are often more valuable than the *final product* itself. However, such surprises are less common these days and at present, there is a high demand for digital geoinformation, which increases every year. There is an increasing demand for not only better quality of data (precision, spatial resolution and spatial extent) but also for thematic variability. In many cases, a 2D geological map of surface deposits is not enough and a 3D model of geological structure is required. Good examples of the requirement for variable hydrogeological data are numerical groundwater flow models.

Every person that has prepared at least one such simple model knows that in these cases various data are always missing. The list of input data necessary to produce such a model is long, starting from information regarding the geological structure of a given hydrogeological unit and finishing with parameters describing the characteristics of ground surface necessary for establishing recharge by infiltration. Especially difficult is the case of modelling for the determination of changes in groundwater conditions which have an impact on the environment caused by humans and inversely, impacts of various environmental activities on groundwater conditions. The processing of such an amount of thematically variable data, usually presented in different forms, into a format required by programs simulating groundwater flow is possible only when all data are in digital form and organised according to a specifically defined structure based on a conceptual model (Michalak, 2003b). Based on past analyses it is apparent that hydrogeology requires not only hydrogeological data but also data from many other disciplines and not only from within the scope of Earth science. It is also apparent that geospatial hydrogeological data in a digital form are required by many other fields of human activities, practical and scientific.

Hydrogeology belongs to these disciplines that not only use geoinformation but also create geoinformation for their own use and for other disciplines. Such a role requires specific means that allow the following:

- ❏ collecting geospatial hydrogeological data, including field cartographic works and encoding them into digital forms,
- ❏ processing geoinformation into a usable form,
- ❏ archiving geoinformation, mainly in databases but also in variable registers and repositories,
- ❏ and, what is most important, making it available for the public, both in digital and paper forms.

Indispensable in that matter is geomatics knowledge, technical tools, which are well equipped in professional software laboratories and servers as well as financial means and adequate administrative structures. These are various aspects; however, in all of the above matters success can be reached only thanks to rational rules of law. Reaching a solution for the above problems is not possible without developing methods for making hydrogeological geoinformation available by using modern distributed processing technologies. This issue is especially important and urgent because this is essential for undertaking environmental impact assessments regarding variable economic and social activities.

Such a position was legally expressed in the European Union INSPIRE Directive (2007/2/EC) that establishes the European Spatial Data Infrastructure – ESDI, dedicated mainly to environmental issues in which hydrogeology plays a significant role (Michalak, 2003a). Article 1, paragraph 1 of this document says: *The purpose of this Directive is to lay down general rules aimed at the establishment of the Infrastructure for Spatial Information in the European Community (hereinafter referred to as INSPIRE), for the purposes of Community environmental policies and policies or activities which may have an impact on the environment.*

The general architectural and functional concept of the ESDI is presented in Figure 1. Three annexes to the INSPIRE *Directive* define a detailed thematic scope for geospatial information, in which hydrogeology plays an important

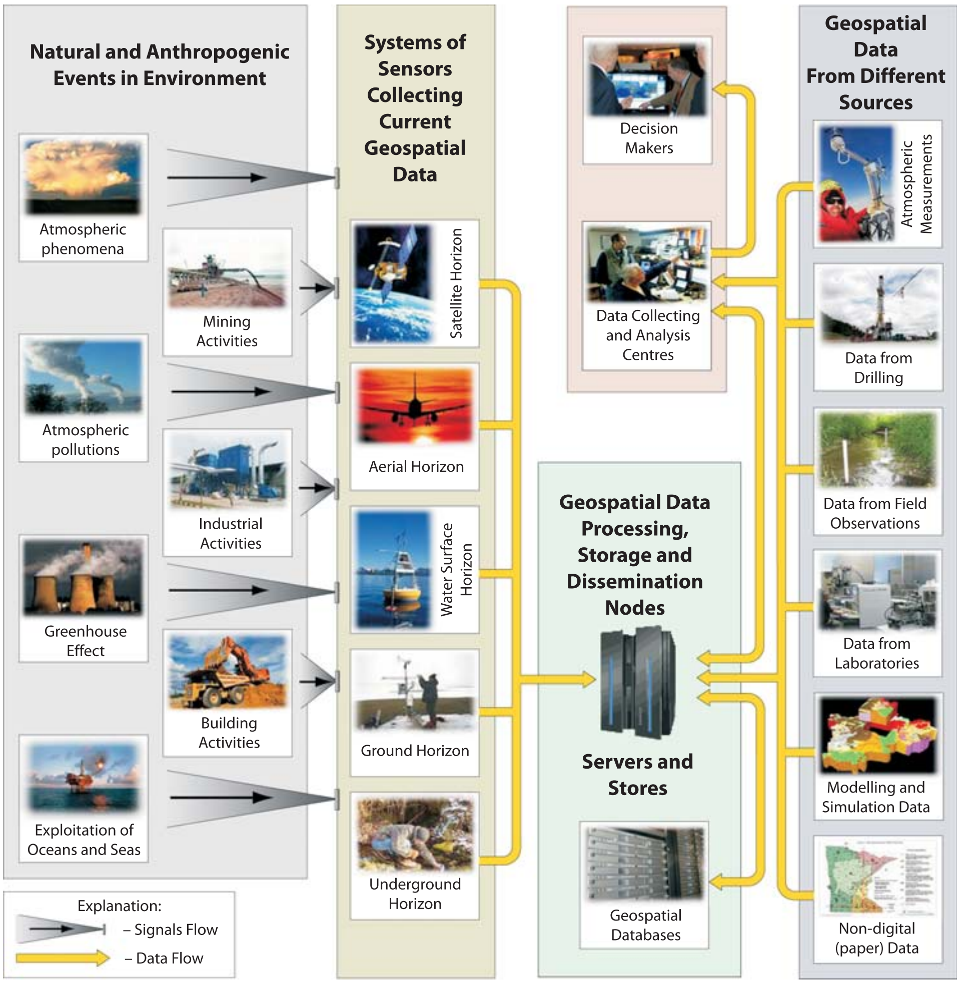

Fig. 1. The general concept of the ESDI structure. Streams of information that come from data loggers, after processing, connect with information gathered in archival data bases, from laboratories, computer simulations and many other sources. As a result, a common stock is created that is required for undertaking analyses and decisions with regard to environmental impacts resulting from various activities (Michalak, unpublished)

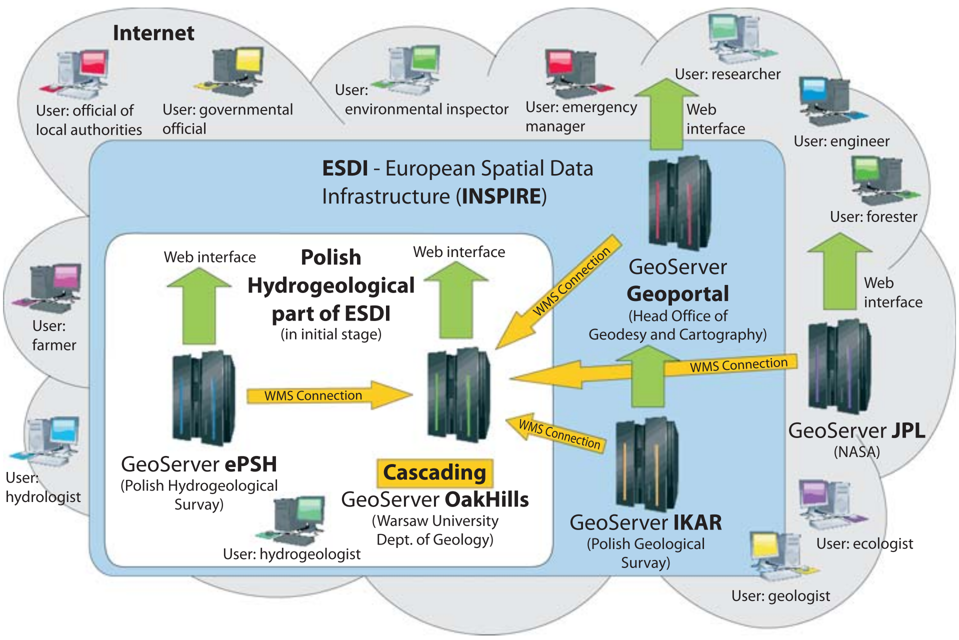

Fig. 2. The general concept of a prototypic element of the Polish ESDI structure regarding hydrogeology. The initial phase comprises two elements: e-PSH geoserver that is run by the Polish Hydrogeological Survey and an experimental cascade geoserver OakHills that provides geospatial data collected from other servers, mainly the e-PSH and Ikar (Michalak, unpublished)

role. Within 34 themes defined in the *Directive*, hydrogeology is included in 9 of them, as follows: hydrography, protected sites, geology, utility and governmental services, environmental monitoring facilities, production and industrial facilities, area management/restriction/regulation zones and reporting units, energy resources and mineral resources.

From the above, one can conclude that the INSPIRE *Directive* is a great challenge for the hydrogeological community, in terms of research, practice and especially in administration. Over the years of 2010–2011, detailed specifications regarding the themes of Annex II will be defined including theme II/4 – Geology. These specifications define a detailed scope for thematic data, their structure and forms. What will be in these final specifications will govern the usability of hydrogeological geoinformation that will be made available under the INSPIRE infrastructure (Michalak, 2009). Within multinational teams of professionals working on detailing the scopes of information with respect to hydrogeological data, Poles are very active. One of their initiatives is experiments and research conducted in the Laboratory of Modelling and Geomatics at the University of Warsaw (LMiG UW), focused on defining optimal solutions for interoperational technologies of distributed geospatial information systems including development of software and structures of processed data. Research is oriented towards the conformity of solutions to the specifications of the Open Geospatial Consortium (OGC), ISO 19100 standards and ultimately to the technical guidelines of the INSPIRE *Directive* (Michalak, 2003c). This work is carried out in cooperation with the Polish Geological Institute and the General Directorate for Environmental Protection as these institutions are legally bound to conduct work regarding the hydrogeological and environmental infrastructure. This co-operation resulted in creating a prototype of a geoserver, the Internet server for geo-spatial data. The general concept of the server is presented on Figure 2. When this geoserver reaches its operational maturity, it will be a model for other components of the Polish environmental geospatial information infrastructure feeding into the INSPIRE.

At the present stage of development of the INSPIRE infrastructure, works is focused mainly on working out technologies for discovering geospatial data – CSW standard (*Catalogue Service Web*) and for viewing geospatial data sets – WMS standard (*Web Map Service*). For both these cases it is possible to use a cascade geoserver technology that, in relation to other servers, plays the role of a client and at the same time is a server for other clients *via* both the web interface and through the WMS standard. Such a technological solution was used for the OakHills geoserver created in the Laboratory of Modelling and Geomatics at the Faculty of Geology, the University of Warsaw. The map that is visible in the window of the web browser (Fig. 3) is composed of 13 layers that come from five separate WMS geoservers: e-PSH (www.psh.gov.pl/epsh, PGI-NRI, Fig. 4), Ikar (PGI-NRI), CubeWerx (Canada), JPL (NASA) and its own data stored in the OakHills geoserver (LMiG UW).

The OakHills geoserver is a prototype which is the first Polish geoserver that fulfils many requirements of the INSPIRE *Directive* technical specifications. Among other things, it gives a possibility to choose a coordinate reference system from a list of six different reference systems defined in the Directive specifications. Another functional characteristic of the geoser-

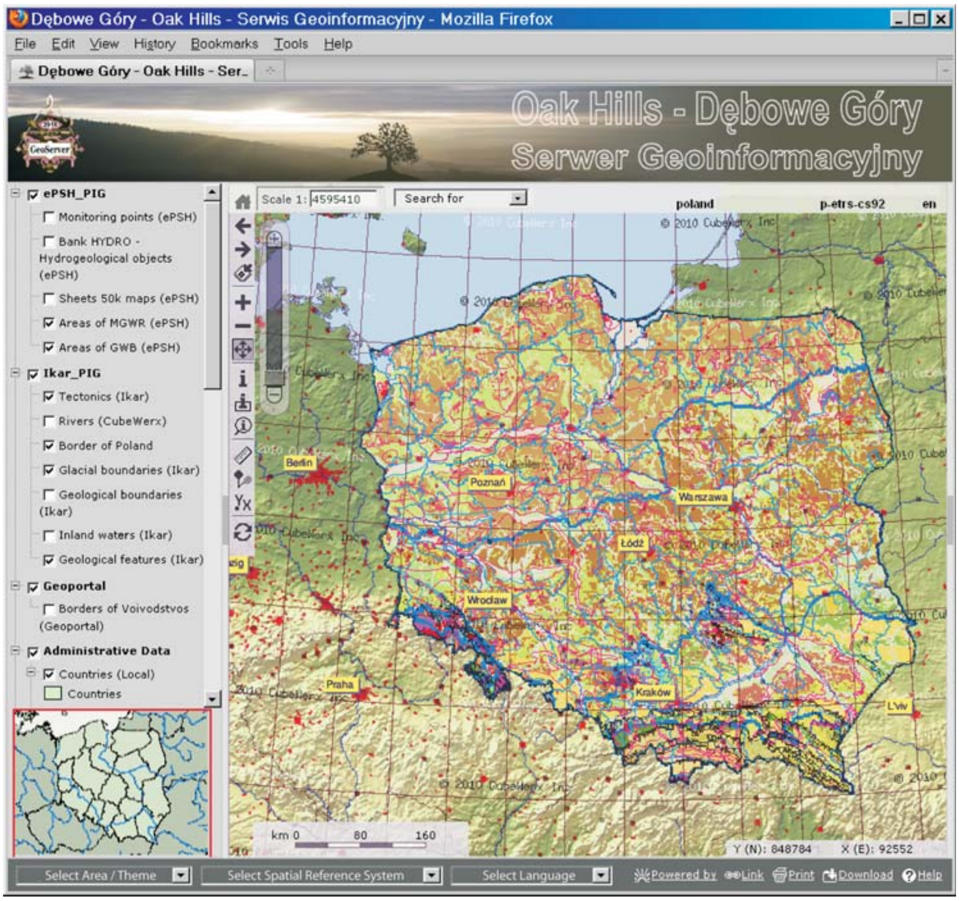

Fig. 3. Web interface of the OakHills geoserver for users use a web browser for viewing maps. Specific map layers come from four separate geoservers: OakHills – University of Warsaw, cascade data from the e-PSH server – Polish Geological Institute, cascade data from the Ikar geoserver – Polish Geological Institute and cascade data from the CubeWerx geoserver – Canada (Michalak, unpublished)

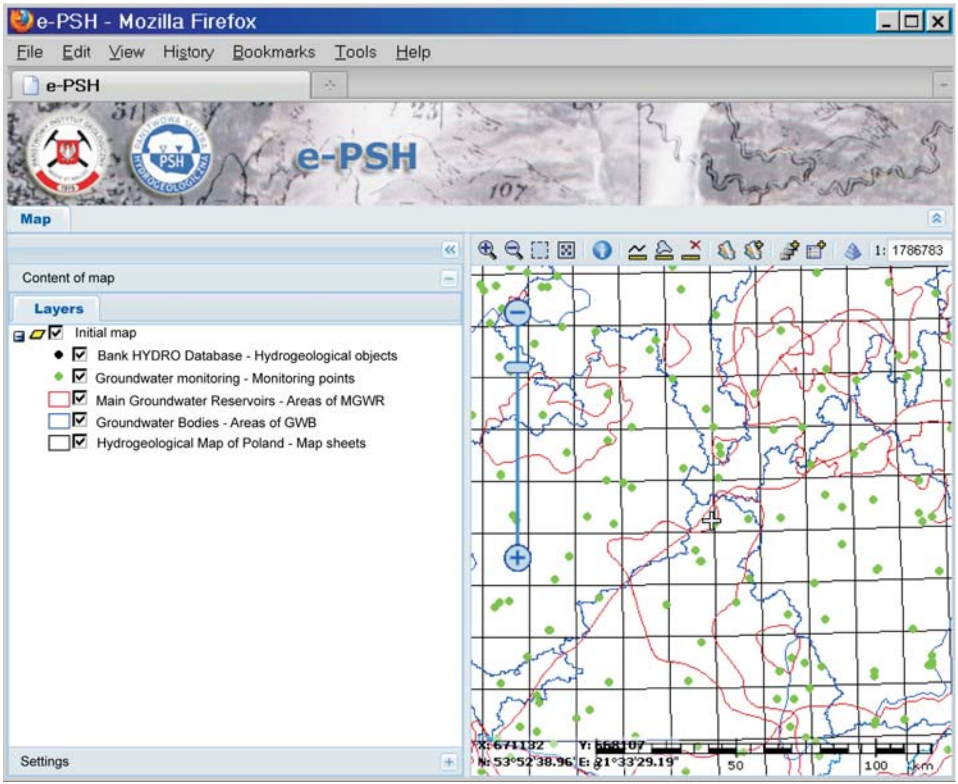

Fig. 4. Web interface of the e-PSH geoserver dedicated to users that use a web browser. The geoserver is run by the Polish Hydrogeological Survey and provides a web browsing service in a WMS standard for more advanced users or other servers operating the cascade system

ver is an option to choose the interface language out of 22 languages including most European Union official languages.

It is worth noting that all software components of the server are *Open Source* software. Such a status of system components means that they are free of charge and this means that they can be unlimitedly installed in various institutions and be used for various needs, the only expense being the cost of hardware. Such software can be easily modified and developed, which is very important when it is used for solving specific problems which have never been solved before. All advantages of open source software do not raise any doubts and for that reason the EU policy clearly points out the necessity of using applications based on *Open Source* components, especially for the major European initiatives such as the INSPIRE infrastructure.

The present functionality of the OakHills geoserver is a result of the first phase of research which will be continued. The majority of further work will focus on the implementation of services for downloading data from the geoserver used for hydrogeological and similar projects. The technological base in this case will comprise the following services: WFS (*Web Feature Service*) for downloading data regarding selected features (objects) or selected collections of features and as well WCS (*Web Coverage Service*) for continuous data that describe geospatial variability.

Groundwater monitoring and groundwater status assessment

Groundwater monitoring and results of its interpretation in regional and local scales provide a diagnosis of groundwater status and allow hydrogeological conditions to be forecast and measures taken to protect the groundwater environment to be controlled. Undertaking groundwater monitoring programmes, developing new methodologies for work, making rules for interpreting groundwater data, introducing and testing new solutions for constructing groundwater monitoring points, measuring devices, automatic data loggers and data transmitters is the domain of scientific communities. At present groundwater monitoring is not only a tool for assessing the state of groundwater resources and ecosystems dependent on them but, what is most important, it provides information for making decisions and defining mitigation measures with respect to environmental protection and management of groundwater resources.

The mission of the groundwater monitoring is to provide data for the following tasks:

- ❑ protection of groundwater resources from quantitative and qualitative degradation,
- ❑ realization of tasks related to management and protection of groundwater resources,
- ❑ protection of surface waters and terrestrial ecosystem dependent on groundwater resources,
- ❑ management of groundwater impacts resulting from economic activities and mitigation measures,
- ❑ defining management strategies and preparation of river basin management plans,
- ❑ fulfilment of national duties with respect to international cooperation including the EU,
- ❑ informing the public on the state of national groundwater resources.

The realisation and organisation of the groundwater monitoring programme in Poland have been adapted to the requirements of the EU directives. However, its specific features resulting from the distinction of the Polish geological and hydrogeological structure as well as years of experience in this matter have been retained. The monitoring is carried out in three spatial scales, i.e. national, regional and local. The major role is played by the national groundwater monitoring programme that covers the entire country and all groundwater levels that are important on a regional scale.

The national groundwater monitoring programme consists of undertaking measurements within the national groundwater monitoring network, obtaining information from other monitoring networks, data bases and archives. The organisational structure of the monitoring is presented in Figure 5. The majority of data come from measurements undertaken within the national groundwater monitoring network that covers the entire country (Fig. 6). This regards physio-chemical analyses undertaken within the qualita-

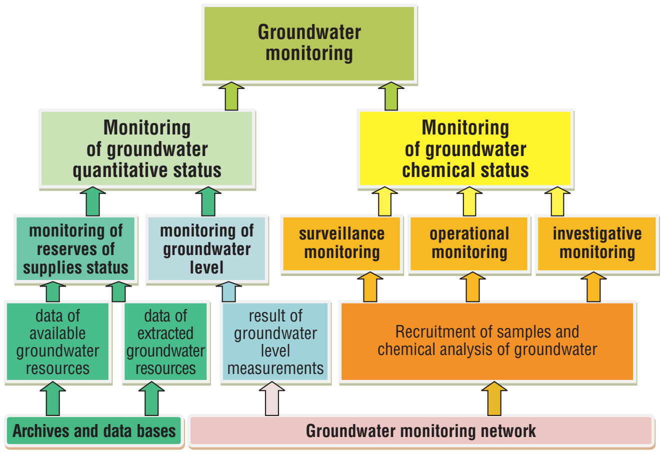

Fig. 5. The groundwater monitoring structure adopted for monitoring of groundwater bodies in Poland

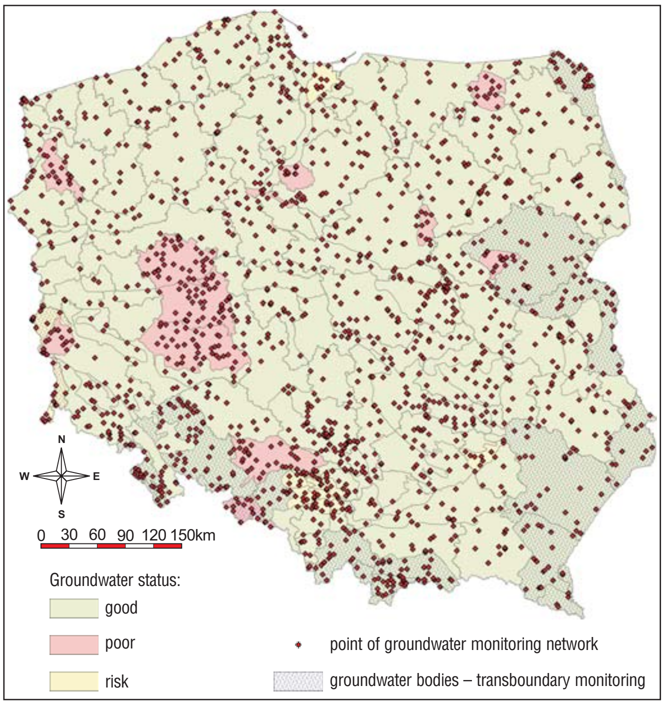

Fig. 6. Localization of hydrogeological stations within the national groundwater monitoring network in Poland

tive monitoring as well as measurements of water levels and spring discharges within the quantitative monitoring. The remaining data originate from other data bases and archives – this refers to quantities of disposable resources and groundwater abstractions. At present the national groundwater monitoring network consists of some 1100 points including 830 points of water level and spring discharge monitoring stations; 790 surveillance monitoring points and 310 operational monitoring points. In some sampling points, measurements are carried out by automatic data loggers and data are transmitted directly into servers gathering the data. This allows the continuous assessment of hydrogeological conditions (Fig. 7).

Data gathered in the Groundwater Monitoring Data Base (MWP) contain the following information:

- ❑ results of monitoring of water level and spring discharges (the oldest data are from 1966),
- ❑ results of groundwater chemical analyses (the oldest data are from 1991),
- ❑ data on groundwater exploitation volumes attributed to specific abstraction points,
- ❑ data on available resources attributed to specific groundwater bodies.

Results of this monitoring programme are processed within a standard scope once a month for groundwater quantity and once a year for groundwater quality. With respect to water level measurements, data interpretation includes defining the following: monthly, quarterly, 6-month (summer and winter), annual and long term water levels, presented with respect to mean water levels from previous observation periods and long term means. With regard to chemical measurements, groundwater quality assessment is done once a year and includes presentation of concentrations of specific parameters, classification of water quality with respect to national regulations regarding environmental quality standards and health regulations as well as defining the type of groundwater. Groundwater balance within units of groundwater bodies is undertaken once a year and this allows disposable groundwater resources, groundwater abstractions and finally, the national groundwater reserves to be determined.

Results of standard procedures are archived in the Groundwater Monitoring Data Base (MWP) and are used for hydrogeological expert evaluations. These data are used for preparing official reports for the public administration at national and regional scales as well as for crisis management centres. These reports include:

1. *Announcements on the current hydrogeological situation* and *Forecasts of the hydrogeological situation*, prepared for infiltration and abstraction zones. These are undertaken quarterly or more often if necessary;
2. Information on the status of the groundwater environment;
3. Warnings of groundwater hazards – prepared only when required.

Results of groundwater monitoring are released to a broader public *via* the internet and publications. The Central Geological Archives of the Polish Geological Institute, on the basis of specific regulations, releases data gathered in the MWP to the administration, private companies, academic centres and to the public. Certain rules of law define groups of recipients to which these data are given free of charge and those to whom certain fee charges apply. This money is returned to the Treasury. These data are used for reporting the status of groundwater resources prepared for the EU Commissions, EEA and international and national organisations.

The following reports are distributed *via* the internet or publications:

- ❑ *Quarterly Bulletin of Groundwaters* – published once every three months. Includes information on groundwater monitoring points, rules for interpreting monitoring results and results of statistical analyses of water levels and spring discharges (tables) and an assessment of the hydrogeological situation in a given quarter;
- ❑ *Hydrogeological Annual Report* – published once a year; includes results of statistical analyses of water level measurements and spring discharges, results of chemical analyses (tables) and an assessment of the hydrogeological situation in a given year;
- ❑ announcements, forecasts, information and warnings – listed above in points 1–3 are published on the web page;
- ❑ results of groundwater monitoring undertaken by PGI-NRI, presented *via* the internet at e-PSH. Presents groundwater monitoring results in forms of tables, maps, charts and histograms.

The e-PSH browser gives a possibility to download files containing results of groundwater monitoring in a processed form (tables etc.) that are easily and attractively presented, which is a good way of publishing and popularising information on groundwater resources and ecosystems dependent on them.

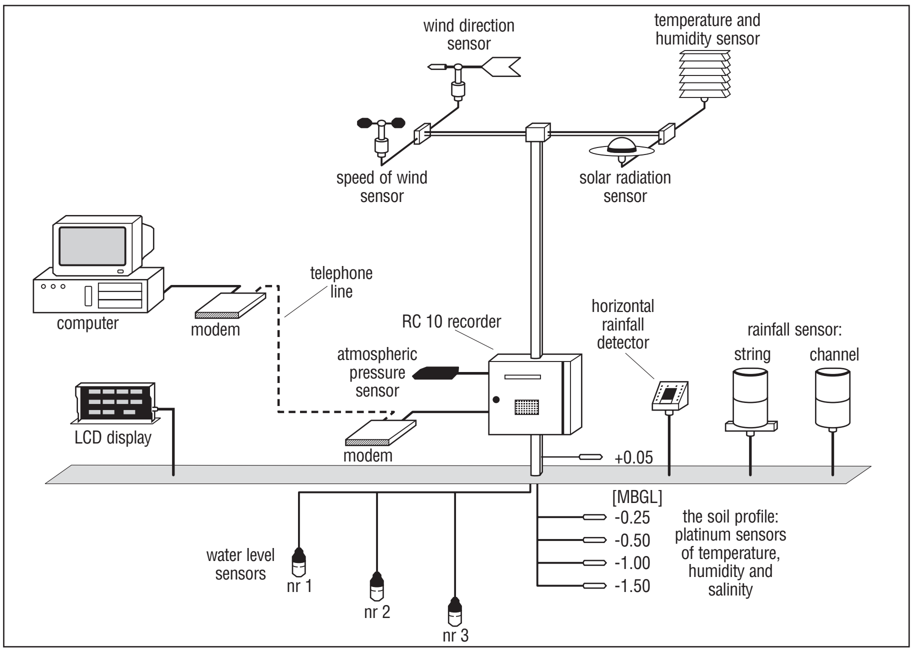

Fig. 7. Schematic diagram of an automatic system employed for measuring and transmitting data from a hydrogeological station

Results of the groundwater monitoring and the assessment of groundwater status are broadly utilized by public administration. They are used when making decisions regarding the resource management and the protection of groundwater; undertaking projects in the field of water management and informing people about the general status of groundwater resources with respect to their quality and quantity. Informing people, in a professional and easy to understand way, about the actual state of the groundwater environment, in various water regions with variable anthropogenic pressures is an important element of the public consultation process. It reminds people that groundwater is the most valuable water resource for human consumption and urban use and that it requires the utmost protection offered by not only the public administration but by individual users as well.

Research regarding groundwater protection

Research in the field of groundwater protection is carried out at many parallel platforms in Poland, and includes methodological guidance documents and syntheses regarding assessments of groundwater vulnerability to pollution; guidance documents providing practical solutions, defining processes and structures that negatively affect water environments; methods for protecting and remediation of groundwater. The scope of work carried out in Poland, its results and future prospects are in line with the message of the *Water Framework Directive* (2000/60/EC) saying that water is not a commercial product like any other but, rather, a heritage which must be protected, defended and treated as such. Therefore, results and achievements of Polish research with respect to groundwater protection, apart from the important practical aspect, are important for their merits, pointing out and often commanding definite moves and measures to be taken, which will result in important effects that will be possible to be defined in future.

Research studies in a wide field of water protection in Poland are carried out using up to date methods that are acknowledged worldwide, commonly cited and adapted by numerous practical initiatives. Polish hydrogeologists participate in many international projects and consortia, in which they play leading roles. A spectacular case is the fact that even studies undertaken at brown field sites, which are often classified by the WFD in their groundwater status assessment as poor, allow conclusions to be drawn pointing out new, useful and applicable research methods or procedures for solving problems with respect to water protection to be proposed.

A good example among many studies associated with water protection is the successful work on developing methods for assessing groundwater vulnerability, which is one of the Polish bids, already being welcomed and often applied in practice within the international community of professionals. Vulnerability assessments allow trustworthy and objective opinions to be made for formalising conclusions and administrative orders, e.g. decisions regarding proposed localisations and development plans, planning documents, protection plans etc. Legal procedures regarding water protection, in the case of the realisation of an investment that could potentially impact the environment, require preparation of an environmental impact statement. Groundwater vulnerability assessments at regional and local scales, next to development plans, belong to the most important instruments of environmental protection, which results from transposing the EU directives into the Polish law. Polish experience with that respect is important and, being continuously developed, it gains recognition worldwide. Especially important is the methodological aspect that can be used in developing actual procedures for assessing groundwater vulnerability to pollution. Great interest in Polish achievements in that field shown by foreign colleagues is demonstrated in the participation of Polish hydrogeologists in numerous instances of collaborative work within international projects. Issues of groundwater vulnerability assessment have been presented at numerous international conferences including the International Conference *Groundwater Vulnerability Assessment and Mapping* in Ustroń (a conference organised in 2004 by the University of Silesia; Witkowski et al., 2007), a congress of the International Association of Hydrogeologists in 2008 in Japan and the *World Water Week* in 2009 in Stockholm.

One of many examples illustrating definite results of research in that field, presented at numerous scientific conferences, which is used to some degree by local authorities as part of the planning process, is work focused on assessing groundwater vulnerability in the Vistula river valley. The area of the study is partially protected under the designation of the Kampinos National Park (KNP) and the *European Ecological Network of Natura 2000* and includes a zone of protected landscape and other forms of legal protection. Results of this wide research are especially interesting due to the fact that the study area is adjacent to Warsaw city. Based on its hydrodynamics and environmental settings, a few hydro-zones were distinguished within the area (Krogulec, 2004): a flooding terrace of the Vistula River, wetlands, dunes and sands as well as grasslands. Such a complex regionalisation of the study area, apart from methodological indications, allowed good adaptation and usability of the results of the vulnerability assessment in similar geo-environmental settings of other hydrogeological systems.

The groundwater vulnerability assessment for the KNP area was performed using the DRASTIC method (Fig. 8) and by looking at the migration time of conservative pollutants. Input data for the groundwater vulnerability assessment were gathered in a hydrogeological data base structured in a GIS system. The database included information such as depth to water table, effective infiltration, lithology of the water bearing zone, type of land surface, topography, lithology of the aeration zone, filtration coefficient of the water bearing zone. Computations of the groundwater vulnerability were undertaken within the defined study area. Input parameters were averaged out for 61 737 computational blockages of 100 × 100 m. Results of the assessment, broadly described by Krogulec (2004; Fig. 8) demonstrated that the KNP area and its surroundings show relatively high (52% of the area, which is over 318 km^2) and medium (37% of the area and some 228 km^2) vulnerability to pollution. Application of the GIS methods allowed continuous expansion of the database and permanent verification and enhancement of results that continues with improving identification of the problem. Results of this work are directly used in work related to the planning of the Kampinos National Park and its surroundings and apart from that, they are used as a baseline model for planning studies for other similar hydrogeological systems.

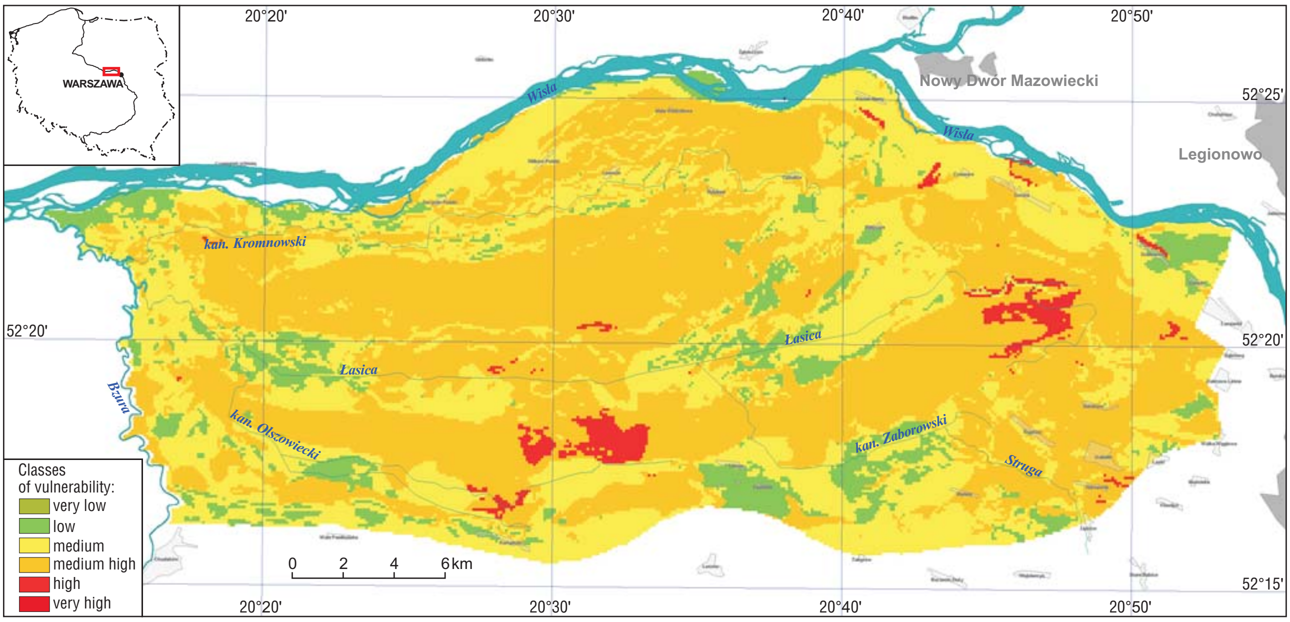

Fig. 8. Groundwater vulnerability map of the Vistula river valley within the Kampinos National Park (Krogulec, 2004)

The Scientific Board of the Kampinos National Park is an authority that has been established by the Ministry of the Environment. Similar boards exist in other national parks in Poland. The Board decides on the practical use of research projects carried out within the park. Some of the most usable results are those of hydrogeological character, including groundwater quality and status assessments within the Park. The Board consists of highly respected scientists representing numerous scientific disciplines associated with environmental protection, as well as people representing local authorities, the public and administration, which together constitute a unique discussion panel, debating on all issues that interfere with the natural environment of the park. Results of the groundwater vulnerability assessment have also been discussed and were acknowledged when taking numerous decisions by councils that lay within the territory of the park or adjacent to it. It is this opportunity of an open discussion between scientists and administration, that is facilitated by the Board, which allows hydrogeologists to present scientific backgrounds of specific assessments and this is an important element of work exercised by Polish hydrogeologists. The following stage of the work of the panel is undertaking discussions with local communities. This is a very commonly used method for disseminating scientific results of hydrogeological research and has been included in interdisciplinary research projects which focus not only on specific scientific tasks but also include social and economic aspects.

A different example of the direct use of these results is hydrogeological work associated with building a wastewater treatment works *Mokre Łąki* in Truskaw, abandonment of constructing a housing estate in the direct neighbourhood of the Park, replacement of the old sewage network within the Park, conclusions made with respect to a potential localisation of a landfill for Warsaw and many others.

Another important research experience was gained by developing a methodology for assessing groundwater vulnerability as a scale of service maps (Witczak, 2005) and cyclical hydrogeological maps. One of the major components of digital maps of Poland (*Hydrogeological Map of Poland 1 : 50 000*, prepared under the auspices of the Polish Hydrogeological Survey) is preparation of a GIS layer showing the groundwater vulnerability to manmade pressures, agriculture and industry. At present, another layer is being prepared, called *the first water level layer – vulnerability and quality* which complements significant achievements of the Polish hydrogeological cartography.

Interesting results were gained with respect to groundwater protection in urban and industrial areas. Waters in these regions are often degraded or exposed to heavy degradation and despite that, they still constitute basic water resources for human consumption. For that reason these resources require effective and continuous protection. Undertaking research studies within urbanised areas is complicated due to technical difficulties (built up areas with complex water drainage and sewage networks, numerous pollution sources etc.) and environmental settings (for example localisation of towns within infiltration areas of major groundwater aquifers, locally disturbed hydrogeological conditions, specific microclimate etc.); therefore a systematic and compilatory approach for all measures is required. And in this point, apart from other hydrogeological assessments, one of the elements of such measures is the assessment of groundwater vulnerability to pollution. Usually, groundwater vulnerability maps refer to larger areas and contain all hydrogeological systems, groundwater aquifers or basin areas, where urban, industrial and areas changed due to manmade pressure often occur. In Poland and in the World, procedures for assessing the groundwater vulnerability to pollution in urbanised areas are adapted to specific hydrogeological data bases and other environmental information as well as to the type of hydrogeological unit being assessed. For urban areas, the DRASTIC system is commonly used, which can be easily modified to reflect local hydrogeological conditions of fissured bedrock and specific land use characteristics. A few selected examples portray and confirm Polish achievements in regard to assessment of groundwater vulnerability to pollution within urban and industrial areas.

A groundwater vulnerability assessment was performed for a karstic area of the middle Triassic system near

Chrzanów, where ores of zinc and lead were intensively extracted (Witkowski et al., 2003). A modified DRASTIC model was used with some hydrogeological parameters: recharge by infiltration, permeability of a water bearing layer, groundwater flow velocity within the water bearing zone and its thickness. Computations were performed using a typical algorithm of the DRASTIC model; however, a broad deployment of GIS methods and results of groundwater modelling that were used for establishing input data to the model produced very good results. This allowed the applied modification to be recommended for assessing groundwater vulnerability within fissured-karstic bedrock systems.

An interesting assessment of groundwater vulnerability to pollution was undertaken for the Upper Silesian Coal District (Bukowski et al., 2006), and was later continued as part of a project financed by the EU structural funds, titled: *Developing a methodology for assessing groundwater vulnerability to pollution within areas affected by the Upper Silesian Coal District* (2009–2012). In connection to limiting the coal production in Poland, issues of mine liquidations have become more and more important. It is broadly acknowledged that groundwater resources are at risk in these areas, not only from the ground surface but also from waters gathered within mine pits. In already finalised studies, when defining specific parameters of the DRASTIC system, a distinction was made for mines that are operational and for mines that have been liquidated.

In many areas where numerous economic activities are carried out, apart from works focused on assessing groundwater status and groundwater vulnerability to pollution, other hydrogeological assessments in the form of maps are being prepared, which can be used as components of local development plans. Hydrogeological maps constitute sort of scenario maps that show different concepts of groundwater protection depending on local land use, future development plans or, for example, planned mining operations. Work on these issues is undertaken by two academic centres at the AGH in Cracow (among others: Witczak et al., 2008) and the University of Warsaw (among others: Krogulec, 2004), and constitute a novel approach to hydrogeological research in Poland and worldwide.

Another trend in interest presented by Polish hydrogeologists is associated with multidisciplinary research on ecosystems dependent on groundwater. Hydrogeologists play an important role in programmes aiming at the rehabilitation and re-naturalisation of wetland areas. A good example of such work is studies carried out within a project financed by the Norwegian Fund and by the EOG Fund, titled: *Development of the method for reconstruction of primary hydrological conditions in the Kampinos National Park in order to restrain nature degradation and improvement of biodiversity status*. One of the major tasks of the project was identification of present groundwater conditions in the background of historical changes within the hydrogeological regime. The study required building hydrodynamic and hydrogeochemical numerical models (a tool in the project that was created by the Faculty of Geology at the University of Warsaw). The model, apart from computing the water balance, allowed also determination of recharge volumes, evapotranspiration and changes in these processes resulting from different scenarios of hydrogeological conditions that occurred after incorporating into the model the following elements: the Łasica river, which is the major surface watercourse in the KNP; filling up the river; significant expansion of wetland areas and other potential changes in the surrounding environment. The defined spatial discretisation of the hydrogeological model (that was in line with a grid used for assessing groundwater vulnerability to pollution and GIS grids) allowed multiple use of modelling results.

Building a modern database in a GIS system, numerical hydrodynamic models and complex hydrogeochemical results comprise a basis for drawing conclusions regarding forecasting the future of botanical habitats, potential for regulating surface watercourses in the Park; allow researchers to analyse and draw conclusions with respect to registered and forecasted changes in soil conditions as well as changes in faunal and floral habitats. Such research is among the first in Europe and its final effect will constitute economic and social analyses of environmental effects resulting from the introduction of changes into the natural environment including water. Results of this analysis (unpublished) explicitly point out the role of hydrogeologists in studies focused on ecosystems dependent on groundwater resources, often not taken into consideration, which results in negative impacts on hydrogeological regimes (Krogulec, 2005). Results of this work presented among a broad forum of specialists indicate the priority of hydrogeological studies within multidisciplinary teams working on defining a restoration model and mitigation measures.

The small spectrum of studies presented above that were or are carried out in Poland to no extent exhausts the list of Polish achievements in that matter. It only presents examples of multivariate and complementary studies, broadly published and presented at national and international forums that are used in practice and in academic research.

Evaluation of the degree of groundwater exploitation

To meet economic and living needs, exploitation of groundwater must take into account sustaining certain needs of aquatic and terrestrial ecosystems dependent on groundwaters. According to the national and the EU law system, in the hierarchy of water users considered in water management plans, the ecosystem is at least as significant as urban needs and far more important than industry, mining, or agriculture. The *Water Framework Directive* states clear priorities for the water policy of the EU. These are stated in the Preamble: [...] *water is not an economic good as any other, but it is an inherited good, which must be protected, guarded and treated as such*.

According to the *Water Framework Directive*, the main criteria for good groundwater quantity status are ecologically sufficient river flows and groundwater levels, and sustaining stable groundwater chemistry that does not show significant anthropogenic changes and ingression of water with different chemical composition. Reaching a good status of groundwater is the target, which determines action plans and water management strategies within catchments. Evaluation of the degree of groundwater exploitation for urban and economic needs is another element of the quantity assessment. Accordingly, the major territorial units for quantitative assessments and management of groundwater are river basins, monitored for anthropogenic pressures and their influence on groundwater dynamics (Herbich, 1997, 2005; Szczepański & Szklarczyk, 2009).

The already mentioned article of the *Water Framework Directive* and its transposition into the *Water Act* (J.L. No. 129, pos. 2019 with later changes) anticipate (in special cases) a possibility for departure from the major rule of pursuing a good status of groundwater in the context of environmental goals. Those departures (derogations) concern areas of groundwater that are already in poor condition, groundwater in good condition but already under potential anthropogenic influence that shows a delayed reaction (Szczepański, 1999; Kania & Witczak, 2007; Kmiecik et al., 2007), or related to areas of current projects (Szczepiński & Stachowicz, 2007). Derogations must be motivated, without doubts, by technical and economic factors (e.g. failure to meet the deadline for reaching a good status of degraded groundwater or avoiding their degradation by applying financial resources and technical actions), social factors (e.g. no possibility for creating an alternative water supply for people than the one responsible for degradation of the environment), or strategic (e.g. the need for ensuring national energy security). There is also an issue of compensation measures, on local and regional scales, that will guarantee sustainability or stimulation of endangered ecosystems. The above note is also valid when analysing the degree of groundwater use. Investigating anthropogenic threats to groundwater and ecosystems dependent on them is a multidisciplinary field of research that has a rich literature, the review of which is beyond the scope of this paper.

The requirements for the EU admission, effective since 2003, constitute more precise and developed regulations that have been effective in the national legal system since the early 1990s. The *Geological and Mining Act* of 1994 (J.L. No. 27, pos. 96 with later changes), together with executive regulations (J.L. No. 201, pos. 1673), according to the superior rule of sustainable development that respects rational water needs and protection of the natural environment, defines groundwater disposable resources within a balancing unit as the amount of water available for abstraction dependent on two factors, i.e. hydrogeological settings and requirements of the environment. That general rule was developed in methodological guidebooks (Paczyński et al., 1996). Guidelines compiled in the textbooks were later further developed, especially during work of the Commission of Hydrogeological Documentations by the Minister of the Environment that evaluated documentations regarding the assessment of groundwater disposable resources within balancing units. Work by the Commission and investigations led, among others, by members of the Commission, resulted in developing procedures for evaluation of groundwater disposable resources respecting needs of surface waters and regional criteria for the degree of acceptable changes in hydrogeological balance and in piezometric water levels in response to forecasted groundwater exploitation. These procedures were further developed in a period of time when national regulations had to be adapted to EU legislation (among others Herbich, 1997, 1999; Kania et al., 2009; Szczepańska et al., 2009; Szczepański & Szklarczyk, 2009).

Analysis of the degree of groundwater disposable resources available for exploitation is the basis for preparing regional strategies for water usage within a water region and reception basins. These documents are fundamental for issuing permits for, among others, groundwater uptake (Tyszewski et al., 2008).

Groundwater disposable resources are estimated based on investigations and studies undertaken according to a project of geological work that includes detailed recognition of geological setting, hydrogeological properties, water circulation, renewability, potential treats, and quality of groundwater defined within usable water-bearing levels of a balancing unit. These estimations are also based on groundwater modelling for evaluating groundwater availability for urban, industrial and agricultural needs taking into consideration environmental protection, interactions with surface watercourses and preservation of good groundwater quality. In 2009, the total area of documented disposable groundwater resources, assessed in line with regulations stated in the *Geological and Mining Act*, constituted 44% of the total area of the country.

In a situation where only part of the country was assessed for disposable groundwater resources, there was an urgent need for completing the recognition of the national groundwater reserves. In areas lacking documented hydrogeological resources, so called prospected groundwater resources were estimated using simplified hydrogeological methods, based on information collected in hydraulically connected surface waters (Herbich, 2005).

Groundwater disposable resources and groundwater prospected resources compared with information regarding the actual groundwater abstraction are the basis for determination of the amount of groundwater reserves available for additional exploitation (Tab. 1).

The degree of groundwater usage available for exploitation (*DZ*) within balancing units was described by an index α, and takes into account groundwater uptake (*UP*) from groundwater wells that require legal permits for collective, industrial and agricultural water supplies as well as drainage wells excluding groundwater supplies for individual users at homes and farms, which do not require formal registration:

$$\alpha = \frac{UP}{DZ} \cdot 100\%.$$

Groundwater usage and changes in groundwater abstraction rates as well the structure of groundwater use over 1990–2005 was broadly researched under the leadership of the Polish Geological Institute, commissioned by the Ministry of the Environment.

The national groundwater balance, estimated taking into account the amount of the national groundwater abstraction volume for 2008, shows the reserves being at 80% of the average long term groundwater resources available for exploitation (Fig. 9).

The basic balancing unit for estimating the groundwater reserves is a water region that is designated with respect to river catchments that are controlled at river gauging stations, location of hydrogeological structures and anthropogenic groundwater drainage structures of regional importance, as well as river basins managed by Regional Water Management Agencies. There are 646 such water regions of an average area of 300 km^2 to 700 km^2, established throughout the country.

The α index and its presentation on a map (Tab. 2 and Fig. 10) are updated once a year.

Table 1. Groundwater resources available for abstraction (the total of disposable and prospected resources) within river basin units managed by Regional Water Management Agencies (RWMA), according to the situation on February 28th, 2009 (Polish Hydrogeological Survey unpublished materials)

RWMA Location	RWMA area [km^2]	Disposable resources ZD [m^3/d]	Prospected resources ZP [m^3/d]	Resources available for exploitation DZ (DZ = ZD + ZP) [m^3/d]
1	2	3	4	5
Gdańsk	35 083.5	2 130 145	1 769 329	3 899 474
Gliwice	7 796.8	438 858	1 022 000	1 460 858
Kraków	43 702.9	936 465	3 847 600	4 784 065
Poznań	54 479.9	1 297 352	5 829 600	7 126 952
Szczecin	20 420.4	2 677 860	25 273	2 703 133
Warszawa	111 448.8	5 504 281	7 036 400	12 540 682
Wrocław	39 538.8	2 037 301	2 857 000	4 894 301
The whole country	312 471.1	15 022 263	22 387 202	37 409 465

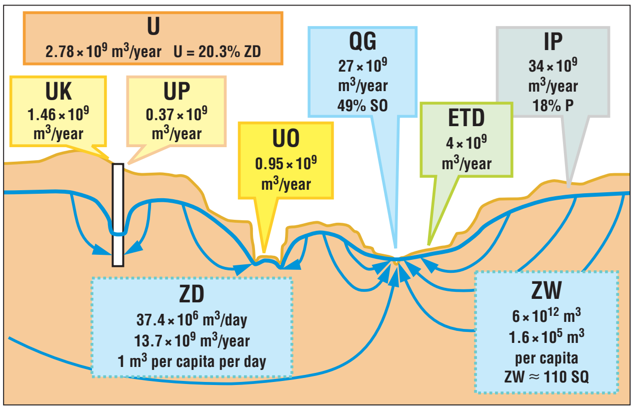

Fig. 9. The groundwater budget and water management balance in Poland; **UK** – groundwater withdrawal for needs of population (for water-line system supply – water with drawal intakes); **UP** – groundwater extraction for industrial production; **UO** – main drainage and building constructions; **U** – overall groundwater withdrawal for needs of the national economy and population; **ZD** – available groundwater resources; **ZW** – volume of free groundwater within the useful aquifers; **IP** – long term annual average rate of the overall recharge of groundwater; **P** – long term annual precipitation; **QG** – groundwater outflow; **SQ** – long term annual average rate of the overall outflow (**SQ** = 54.8 × 10^9 m^3/year); **ETD** – evapotranspiration from the groundwater

Table 2. The degree of groundwater usage in Poland in 2009 (Polish Hydrogeological Survey unpublished materials)

Index value	Amount of groundwater reserves	Area of the country [%]	
$\alpha \leq 15$	very high	72.8	91.0
$15 < \alpha \leq 30$	high	18.2	
$30 < \alpha \leq 60$	medium	5.7	
$60 < \alpha \leq 75$	low	0.7	
$75 < \alpha \leq 90$	very low	1.2	
$90 < \alpha \leq 100$	endangered with no reserves	0.1	1.4
$\alpha > 100$	no reserves = deficit	1.3	

Contribution of the Polish scientific community to solving new practical problems in hydrogeology (didactics)

The dynamic development of economy requires many practical problems to be solved including many hydrogeological problems. Therefore, the practice is a simulator for academic research and then the academic progress provides for the economic growth of the country.

The phrase *hydrogeology* was first introduced into the Polish language over 100 years ago. It was N.I. Krisztafowicz that used this phrase for the first time when describing the groundwater occurrence in the vicinity of Lublin city (Kleczkowski & Sadurski, 1999). The first hydrogeological reports were created in Poland in the times before Polish independence. Starting from the times between the two wars, and then in the post second world war period, a very fast development of research centres, academic centres and the private sector working in the field of hydrogeology occurred.

The major academic centres in Poland where modern hydrogeology has been developing include Warsaw, Cracow, Wrocław, Poznań and Sosnowiec. Hydrogeological aspects have been the subject of work and academic research at universities that do not directly promote hydrogeology, such as Toruń, Gdańsk or Łódź. Apart from academic centres, the biggest scientific potential with regard to hydrogeology has always been gathered in the Polish Geological Institute and its numerous local branches.

The activity of academic centres including promoting new human resources, organising training and consultations, advising and disseminating hydrogeological knowledge in the form of publications, organising scientific conferences support hydrogeological practitioners.

At present hydrogeologists can gain their scientific degrees at five universities in Poland, i.e. at the University of Warsaw, the AGH-UST in Cracow, the University of Silesia, the University of Wrocław and at the University of Adam Mickiewicz in Poznań. Didactical training in the scope of hydrogeology includes courses at bachelor, master and Ph.D. levels as well as post diploma courses. Based on very scarce data it is estimated that since the 1950s some 2700 students have graduated from hydrogeological courses. The leading institutions promoting hydrogeological professionals are the AGH University of Science and Technology and Universities in Warsaw and Wrocław.

The oldest academic centre in Poland teaching hydrogeology is the Faculty of Geology at the University of Warsaw, where the Department of Hydrogeology was created in 1952 and it will be celebrating its 60th anniversary soon. With time, the requirement for specialists in this field increased and other academic centres were created which resulted in a regularly increasing number of hydrogeology graduates. At present some 120 students graduate every year with a degree in hydrogeology in the above five academic centres.

The importance and dynamic development of hydrogeological research in Poland is also reflected in the number of graduates with the third level education degree. Nearly 160 doctors have successfully defended their theses in the above-listed academic centres. The leading role in that aspect is played by the AGH-UST in Cracow and the University of Warsaw where some 74% of all Ph.D. studies have been undertaken. Apart from the aforementioned institutions, Ph.D. studies in hydrogeology have been undertaken also in the Polish Geological Institute and the Polish Academy of Sciences.

Apart from master and Ph.D. courses, important elements of dissemination of hydrogeological knowledge are post diploma courses. Such studies are an offer of the scientific community to hydrogeological practitioners and local and non-governmental administration which are responsible for solving problems of a geological nature. Examples of issues that are most often the subject of post diploma courses regarding hydrogeology are themes of courses carried out since 1975 by the Faculty of Geology at the University of Warsaw: *Modern methods for hydrogeological assessments; Modelling methods in hydrogeological assessments; Hydrogeology and groundwater protection*.

Hydrogeological diplomas from courses run by numerous didactical centres in Poland that specialise in hydrogeological research have been obtained by over 150 people. Graduates of these courses have received a wide spectrum of new information regarding current methods of groundwater assessments, they have broadened their knowledge with new techniques of data interpretation and received new research tools helping to resolve numerous practical problems regarding the general groundwater management.

An important element of integration between academics and hydrogeological practitioners are numerous

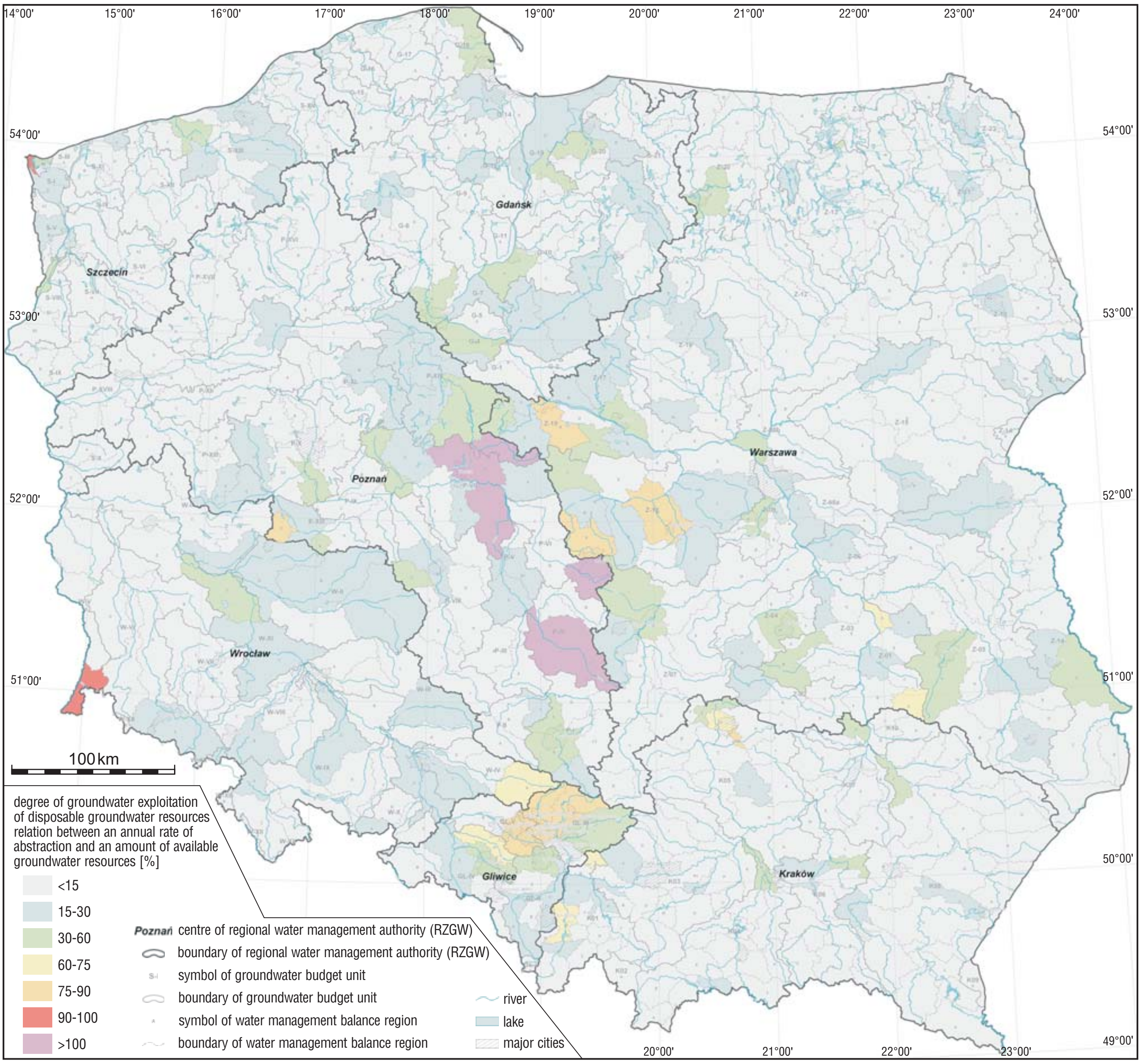

Fig. 10. Map presenting the degree of groundwater exploitation of disposable groundwater resources (PHS unpublished materials)

hydrogeological symposia that are frequently organised in Poland. The most prominent of such meetings is a scientific conference titled: *Current challenges in hydrogeology* that is organised once every two years by one of the major academic centres. The conference was initiated by hydrogeologists of the University of Warsaw, and since 1980 it has provided an opportunity for exchanging experiences, dissemination of results of various studies, correlation of practical results with theory and at the same time, it promotes Polish hydrogeology and helps to sell its products.

Supporting hydrogeological practitioners by academic centres means also expressing professional opinions, providing consultancy services, and cooperating with scientific institutions and academic centres. An example of such cooperation is the creation of the hydrogeological map of Poland in scales of 1 : 200 000 and 1 : 50 000. Cooperation of hydrogeologists from numerous academic centres resulted in publishing a few comprehensive publications such as the *Hydrogeological Dictionary* (2002) edited by Dowgiałło, Kleczkowski, Macioszczyk and Różkowski, or the newest monographic work titled *Regional Hydrogeology of Poland* (2007) edited by Paczyński and Sadurski.

Hydrogeology, which belongs to the environmental scientific field, is an applied science and for that reason results of hydrogeological research become direct offers of the scientific community for solving real hydrogeological problems.

Summary

The active involvement of the hydrogeological scientific community in cooperation with hydrogeological practitioners provides a fast transfer of scientific achievements and new methodological solutions into practical applications. At present, the best example for that is hydrogeological geoinformation. The intensive development of this field of science finds its use in numerous projects which allow a broader and faster access to research and digital databases of geospatial data. This large and easily accessible data base, both as input and processed data, is a result of numerous research studies, observations and hydrogeological measurements that were carried out on a large scale using the newest methodologies and telecommunication methods.

The academic community provides hydrogeological professionals with continuous professional development, raising qualifications through numerous conferences and post diploma courses. Together with geological administration, a list of guidance documents and guidance books is agreed, which are prepared by the entire academic community and later published and disseminated.

This short review of offers that the academic centres have for hydrogeological practitioners will be concluded with the information that scientists also make use of cooperation with practitioners, not only by feeding their institutions with funds from selling their information, knowledge and technologies but also indirectly by providing scientists with research material originating from works carried out in the field.

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