Education for hydrogeologists of the future: serving to ensure an environmentally secure world

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A b s t r a c t. What kind of Hydrogeologists will be required for an environmentally secure future world? Noting that Poland is on the threshold of a new future, in which economic and social benefits have fundamentally transformed society from its constraints of three decades ago, this might be a valid question. This paper outlines the tradition of classical geological education from the 18th century, through to the needs of present millennium. In the course of this time span social and economic upheavals have caused an astonishing „roller coaster" ride for educational institutions. These institutions of Poland are reacting in various ways to the most recent stimuli, and geological education is no less changing and developing. There are excellent opportunities for providing contemporary educational opportunities for national and foreign students. Given that groundwater resources in aquifers are a hidden yet utterly indispensable water resource, which will help the planet get over its forthcoming stresses, Poland's hydrogeological institutions can benefit significantly by placing themselves in strategic positions to train regional candidates as well as international candidates in the forthcoming decades, when the role of aquifers in environmental sustainability is increasingly recognised by governments and by global developmental agencies.

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A future for hydrogeology. In February 2005, the *Hydrogeology Journal* (publisher Springer Berlin/Heidelberg) dedicated a volume to *The Future of Hydrogeology* (Voss, 2005) containing 30 invited articles devoted to views and perceptions of well known hydrogeologists. This was the same theme of the Denver Meeting of the Geological Society of America (Denver, Nov. 2004). In the half decade that has gone by since, it may be worth revisiting some of the views expressed then, and also taking a forward look ahead today, in 2010. While this paper is not intended as an in depth analysis of the future, it will relate some of the views that were expressed in 2004 and 2005, to an equally interesting document that has been prepared for Poland, by a Board of Strategic Advisors to the Prime Minister of Poland entitled *Poland 2030 – Development Challenges*. Are there any clues in these publications that might help professional hydrogeologists to prepare for future needs?

Forward look: real and illusory. The International Association of Hydrogeologists (IAH) has embarked on a Forward Look initiative in which a well represented group of the associations international membership will meet (in July 2010, unfortunately after the deadline for the submission of this paper), to brain storm and develop a plan for future actions, responding to a prime question – what will the IAH of 2020 look like? By analogy, one may well ask: What will the hydrogeologist of Poland in 2030 be like? – as a reaction to the aforementioned national strategy for Poland. One may perhaps use for guidance an illusory essay by Patrick Lachassagne (2005), who contemplates *Field hydrogeology in 2059*, in fact for the 17th April 2059! His essay suggests that in 50 years time, the hydrogeologist will benefit from the unachievable today ability to interpret, visualise, analyse and predict aquifer behaviours in the subsurface, and communicate with fellow hydrogeologists (and others) through holographic virtual meetings and discussions – but Lachassagne's contemplation also provides us with a stark revelation that hydrogeologists in 50 years of future endeavour, were not able to have influenced the inexorable declination of the sea level of the Mediterranean, which arguably was the impact of mankind – in other words our theories and analyses of hydrology and hydrogeology were not taken into serious account by the Policy Makers to avoid environmental calamities!

Limitations to problem solving. In his editorial summing up of the 30 articles devoted to the *Future of hydrogeology* Voss (2005) states that hydrogeologic science is not well suited to quantitative prediction and is best suited to providing hydrogeologists with theoretical and science-based intuition that they can apply when suggesting solutions to complex practical problems. Hydrogeologists are faced with being primarily descriptive scientists rather than quantitative scientists, and can employ quantification only to the extent they believe is meaningful and useful. He adds: *Some hydrogeologic problems cannot be solved – they are too complex. This must be admitted and efforts should rather be applied to solvable problems. It should be a major role of hydrogeologists to help managers define the practical questions that are possible to answer.*

Voss' summary above should give us pause for thought – how then, given the above constraints, should the hydrogeologist of the future be trained to provide help to managers to define the practical questions that are possible to answer? What are the likely future problems that hydrogeologists, with their wide ranging grasp of the laws of earth sciences can help to resolve? Robust answers to these questions are required – else the applied science of hydrogeology is likely to be sidelined in the forthcoming years when innovative and far reaching options to address the planets needs are urgently required.

Follow up on broad policy documents – planning for the future. Could we, or should we, as hydrogeologists study broad policy documents and discern how to equip the future hydrogeologist? Can we find useful clues for Poland, given that the strategy document states that the country is

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on the threshold of a new future[2] in which economic and social benefits have fundamentally transformed society from its constraints of three decades ago. What will the next three decades bring on the social, economic and environmental front that sound management of aquifers could underwrite?

The author does not profess to have all the answers, yet as a graduate from a Polish university from the class of 1970, he is modestly offering his views relying on over 35 years of worldwide experience in groundwater based environmental management. He feels that his credibility to comment comes from having more or less kept abreast of developments in Poland, from many short professional and personal visits over the last four decades[3], and through maintaining a very close contact with the graduates of his own peer group (Fig. 1). His opportunities for in depth discussions with the class of the 1970 takes place at „zjazd" (meeting) held once every three or so years, the most recent of which was in June 2010 held in the Sudeten Mountains resorts. The author has thus gratefully accepted the invitation of the Chief Geologist and Under Secretary of State in the Ministry of the Environment of Poland to set out some of his views below.

From classical to modern

Evolution of the academic cadres. In Poland, as in many other countries of the world, the science of hydrogeology really expanded around the 1950's (Kozerski et al., 2010; Różkowski, 2008). A number of institutions and agencies were involved in this, both in academia and in government supported research institutes. At the Warsaw University, although a department devoted to Geology came into being on the 15th November 1915, and survived the very difficult intervening years of political change and instability. It was not until the 1st October 1952 that a formal Department of Geology was established, with 12 subdepartments and 16 scientific sections, although due to lack of staff resources not all of them were operational. In one of these scientific sections, a future leader of Polish hydrogeology, Professor Józef Gołąb, who even then had unconventional ideas about aquifers and their functions, held the position of director of Geological Mapping. It was not until 1954, that with the decision of the then Ministry of Higher Education, the hydrogeology and engineering geology sections of the Gdańsk University of Technology were transferred to the Warsaw University. Reflecting the trends of the time, the hydrogeology section was within the Subdepartment of Quaternary Geology and Technical (engineering) Geology, under the formal direction of Professor Gołąb. Finally in 1957, formal subdepartments of Hydrogeology and of Engineering Geology were established. The former had such eminent professors as Zdziłsaw Pazdro and Aleksander Tuszko heading them. In 1968, with more political changes, the subdepartments were merged into an

Fig. 1. The Class of 1970, Department of Geology, Warsaw University meets at the Zakopane „zjazd" (May 2008). Photo from S. Puri's archive

[2]See *Poland 2030 – Developmental Challenges*. Board of Strategic Advisors to the Prime Minsiter of Poland; www.Poland2030.pl/www.zds.kprm.pl

[3]Which have since December 2009 been regrettably marred for the author by the Polish Border Guard Services' repeat harassment meted out; see http://www.hfhr.org.pl/Noswiadczenie-157.html

Institute of Hydrogeology and Engineering Geology under the leadership of the enigmatic Professor Witold Kowalski.

Regional needs drive the development of the science. While the classical descriptive hydrogeology was developing and evolving in central and northern Poland, concurrently, the development of mining hydrogeology was also undergoing evolution and development since 1946 at the Akademia Górniczo-Hutnicza in Kraków, known as AGH University of Science and Technology (Kleczkowski & Sadurski, 1999) and later also in the University of Silesia (Różkowski, 2008). It was in the inter war years that the assessment of the dewatering required for deeper coal mining required more detailed analysis and the accurate prediction of groundwater level declines. The complicated multi aquifer systems of the Silesian Coal Basin, consisting of Quaternary, Mesozoic, and Carboniferous formations were a driver for intricate hydrodynamic analysis. The increasing intensity of energy demand for industrial development required coal mining from greater depths, and consequently over the following decades Quaternary, Triassic, and Carboniferous aquifers had to be significantly dewatered, with all of the well known associated environmental impacts.

Moving from the descriptive to the quantitative. Although the science of hydrogeology in Poland has evolved over the last 120 years (Kozerski et al., 2010 – this volume, p. 730), until the mid 1950's it was primarily a descriptive science, with emphasis on cataloguing the natural occurrence of groundwater. Since the Quaternary aquifers of much of central and northern Poland are the main water bearing formation used for public supply, industry and to some extent irrigation, it was these formations in which most of the analyses of intergranular flow were conducted. In southern Poland Palaeozoic and Mesozoic fracture flow aquifers received attention in connection with the mining of coal and other ores. Much of the early quantitative work on evaluating the yield of water supply sources was based on the steady state solutions, well known from the then contemporary literature. In the mid 1960's there was a dramatic change with the need for non steady state analyses, especially in connection with prediction of short term aquifer response in connection with deep mining operations as well as for geotechnical engineering for civil construction.

The growing awareness of the environmental aspect of hydrogeology, firstly in connection with assessments of pollution, and later also of protection of potable supplies, resulted in the 1970's of the establishment of a studium for environmental protection and natural resources, which in 1993 became a full fledged subdepartment at the Warsaw University under the direction of Professor Andrzej Drągowski. Similar developments have taken place in other academic institutions in Kraków, Katowice, Poznań and others (Herbich et al., 2010 – this volume, p. 803). Data are not available that may demonstrate that the present day professionals graduating from the educational institutions are fully suited to the present day needs, but it can be assumed that to a great extent the 2700 hydrogeologists that graduated from Polish universities between 1954 and 2009, are.

A guide to the future expectations. Quoting from the *Poland 2030* document, *Today in 2009, Poland is a completely different country than it used to be two decades ago*, an observation that the author can readily testify to from personal experience. From 1989, the wide ranging social and economic upheavals in the land have also caused an astonishing roller coaster ride for educational institutions. They have had to change, to adapt and to react to the new conditions, often requiring far ranging change in the attitudes to the application of science to the new economic reality – in delivering education and in resolving environmental issues. Has this transformation taken place successfully? The evidence is sporadic, but on the whole the transition has been managed satisfactorily, though pockets of underdevelopment still remain. The *Poland 2030* document warns that if development drifts are allowed to take hold, then there is a r*isk of falling into passiveness, apathy, and self indulgence with past achievements, disregarding the fact that the future calls for imminent action and change adjustment*. How to answer this call to avoid drifts so that the natural science graduate, with groundwater man- agement training, may provide real and measurable value inputs? Such questions might to some extent apply to all natural science academia of Eastern Europe, the countries of the Former Soviet Union and indeed many other parts of the world.

Changing social conditions reflected in institutions

Perceived expectations. Of the various developmental challenges that are described in the *Poland 2030* document, the policies that are related to the improvement of productivity, mobility and adaptiveness of the economy, call for adjusted educational models that address the selection, recruitment and a change in the incentive system, with new funds for science and technology and stimulation of the interest of the private sector in underwriting research leading to cooperation between science and business.

The educational and training institutions of Poland are reacting in various ways to these most recent stimuli, and geological education is no less changing and developing. The extent to which this is reflected in the didactic material can be assessed by a review of the available material. A listing of the most applicable educational material that has accumulated since the late 90's is shown in Herbich et al. (2010) and this illustrates the range of hydrogeological issues that are at the forefront of today's educationalists in groundwater science.

The *Poland 2030* document sets out a series of tokens of success in the 2030's in a variety of fields including power and climate safety, knowledge based economy and intellectual capital. In each of these fields a contribution from a sound knowledge of the management of earth natural resources should provide a vital and valuable input... By the 2030's renewal energy sources are expected to provide 20% of the demand, diversification of gas based energy resources with the extraction of domestic gas resources reaching a level of 30% share of the liquefied natural gas.

A more direct field of interest to educational institutions will be the field of knowledge based economy. The document foresees an improvement of the output of graduates of natural sciences and changing the balance of scientists employed by public sector to the private sector. The numerical targets may seem ambitious, being a 32% transfer from public to private.

Impact of the changing needs. Thus it may be surmised that by 2020, ten years from now, the professional demands being made on a graduate with a natural science education, with a sound understanding of the dynamics of subsurface fluid dynamics, may well relate to energy management, and likely to be performed within the private sector. These may include the extraction of heat from groundwater, geothermal resource use, or the production of soil gas and the related groundwater management issues. Although not limited to these aspects of natural resource management, the same professional may well be required to focus on the significant impact of heightened climate variability, an early manifestation of which is even now observed in today's extreme floods. The present day infrastructure (in roads, bridges, residential areas, farming land) is unsuited to the forthcoming climate variability and the professional will be required to engage with this. Additionally there would be many social changes that will have started to become effective – such as changing patterns of water demands, the increasing need to manage groundwater dependent ecosystems driven by a more discerning population resident in semi urban and rural regions, and the general pressures from society for a much more sustainable world.

It would thus seem that further evolutions will be required in the curricula to accommodate these future needs that go well beyond the present day approach to integrated water resource management. However, as shown below the contemporary educational structures offering hydrogeological education may have to adopt a new architecture to respond to the wider needs of society, moving from the more traditional to the more innovative application of hydrogeological analysis to fields in which it is not yet engaged, such as carbon capture and storage and all similar related uses of the subsurface spac found in aquifers.

Contemporary educational structures

The conventional curricula and the benefits. As contemplated above there would seem to be a need to revise the architecture of the curricula in the near future. If this is not done by the more traditional institutions, there is some evidence to suggest that other, non traditional institutions could pick up the opportunities. In Poland there are excellent opportunities for providing contemporary educational opportunities for national and foreign students (Herbich et al., 2010). There are five institutions of Higher Education in Poland that offer education to the aspiring hydrogeologist, producing about 120 graduates each year. In common with other EU countries the education is based on the Bologna System consisting of a First degree (6–7 terms) leading to a degree of Bachelor of Science or Bachelor of Arts; a Second degree (3–4 terms) leading to the degree of Master of Science or Master of Arts and a Third degree – doctoral studies – involving independent research leading to the degree of Doctor of Science.

The current academic institutions. The scope of the teaching at the University of Warsaw includes 2 to 3 hours of weekly lectures, supplemented by tutorials in such topics as hydrogeochemistry, groundwater resources, spoil mechanics, geophysical methods, dynamics of flow, modelling, quality protection, engineering geology, applied hydrogeology, and methods used in the field. The latter field course includes field assessments of hydrogeology and engineering geology, elements of field mapping based on groundwater level surveys in wells, field water quality observations, preparation of cross sections, the impact of anthropogenic activities such as disposal of wastes; these field based training activities are undertaken in and around – Chełm, Krasnystaw, Rejowiec, Zamość, Lublin, Włodawa.

At the subdepartment of Hydrogeology and Engineering Geology, AGH–UST, in Kraków, the emphasis of the graduate studies, in addition to the similar general scope as in Warsaw, is on the mining and engineering geology of coal and other ores. This also includes the interpretation and application of the legislation of the mining sector. Since mine dewatering and maintaining safe under ground working conditions is an important part of mining, the graduates can specialise in this aspect of hydrogeology. The subdepartment also aims to provide the graduate with the full capacity to produce engineering designs and to conduct construction supervision of investments relevant to waste management and environmental engineering.

The Wrocław University offers studies in general hydrogeology and in applied hydrogeology, with the former focussing on groundwater flow dynamics with an emphasis on fractures and karstic formation and the basin wide studies of the SW regions of Poland. The applied hydrogeology, aspects relate to the anthropogenic impacts in the Silesian region, an area that was very heavily impacted in the last century through intensive mining and practically no environmental protection until after the major political changes of the late '80s. Potential graduates wanting to gain an experience in the major transition of long term no action on impacted environments, to significant change, can get good experiences by studying in these regions.

The Adam Mickiewicz University in Poznań offers studies in hydrogeological resources assessment at the basin scale as well as in source development and quality protection. The emphasis is on the monitoring of aquifers and assessment of the migration of pollutants in the subsurface. With regard to water source management, the department is engaged in education of well screen clogging. The consequent reduction of well yields and the related increase of production costs. Changes in land use and its impact on groundwater management have been analysed by the department (Dragon & Górski, 2008) thus linking the important aspect of connecting land use with aquifer management – still a linkage that seems difficult to incorporate in land use policies in many parts of the world.

The transition from the contemporary to the future. As may be surmised from the above, much of the contemporary hydrogeological education, at least at the undergraduate level focuses on the conventional aspects of groundwater resources management. Aspects of the environmental role of aquifers is becoming more important, in response to various legislations principally the *EC Groundwater Directive* (2006), a key driver in the way in which aquifer systems may be protected, as opposed to the just the water within them. Already there is a need to converge aspects of hydrogeology with ecology to address important groundwater dependent ecosystems, an example of which is found in the Polesie National Park that are found overlying a major Cretaceous aquifers system that stretches across Poland, Ukraine and Belarus. This is also an area of significant coal mining both in Poland (Lublin Voivodeship) and Ukraine (Lviv and Volhynia Oblasts), as shown in Figure 2, 3.

Voss' arguably pessimistic and perhaps conservative view (see above, Voss 2005) of the future might surely lead us to the drift that is warned against in the *Poland 2030* document. Hydrogeological education should not be allowed fall into the *passiveness, apathy, and self indulgence with past achievements, disregarding the fact that the future calls for imminent action and change adjustment*. There is indeed quantitative uncertainty in the science of hydrogeological analysis and prediction, but the position of Tartakovsky and Winter (2008) of an uncertain future for hydrogeology may promote the drift that is mentioned above. His argument for a radical overhaul in educational curricula, from high school through graduate school has the goal of improving quantitative skills to include, biogeo-

Fig. 2. The river Bug Basin, approximate extent of Palaeozoic-Mesozoic Aquifer Systems

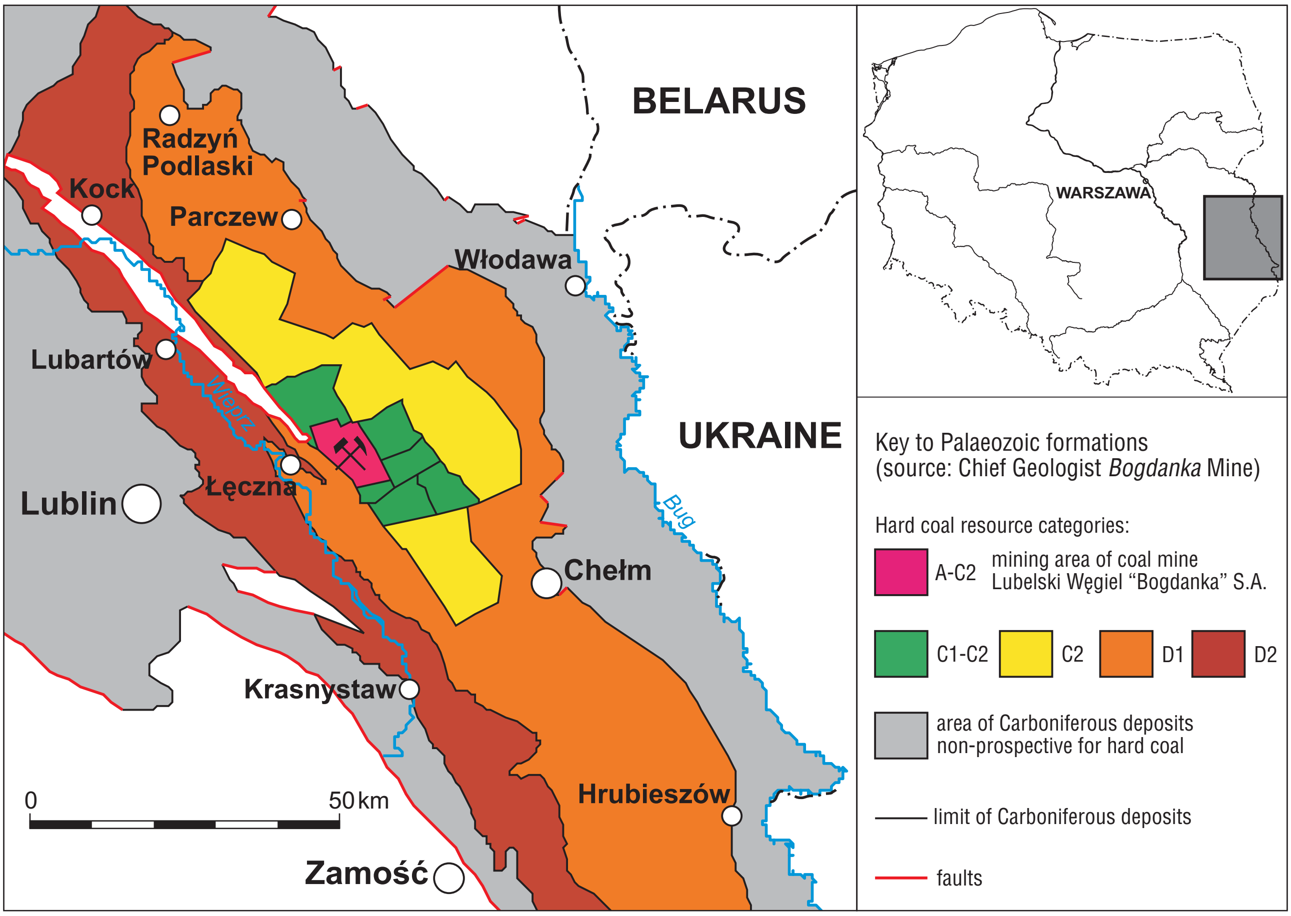

Fig. 3. Carboniferous formations in Lublin Coal Basin area

chemical processes, ecohydrology, effects of global change, and scientifically sound management of water resources. In the view of this author this is insufficient.

The subsurface space in aquifers is a remarkable under recognised and under utilised resource. It can be used for multiple applications and cross sectoral benefits, as is briefly outlined next based on the example of the Palaeozoic-Mesozoic Aquifer System that is found underlying the Polesie National Park.

Aquifers are indispensable for sound environmental development

Given that groundwater resources in aquifers are a hidden yet utterly indispensable as water resources, occupying freely available space in the pores and rock fractures, they can help the planet get over its forthcoming stresses. Poland's hydrogeological institutions can benefit significantly by placing themselves in strategic positions to train regional candidates as well as international candidates in the forthcoming decades, when the role of aquifers in environmental sustainability is increasingly recognised by governments and by global developmental agencies. One example of applying such multidisciplinary and multi-use training could be the Polesie region (Puri, 2006) that can be used for a reality check.

Lessons from the field for a reality check. The planned transboundary West Polesie Biosphere Reserve (UNESCO, 2008) is a region of forested of lowlands including the entire region of the Polish Łęczyńsko-Włodawski Lake District, the Ukrainian watershed of the Bug and the Prypiat known as the Volyn'ske Polesie and the Belarusian Malorita fluvioglacial plains (Fig. 4, 5). From the groundwater dependent ecosystem perspective the regions landscape is a prime area for increasing the environmental resilience of the highly valuable wetlands, moors and swamps. The underlying Cretaceous aquifers discharge into a series of lakes and water bodies. In the 50's there were 68 lakes larger than 1 ha in the Polish part. By the end of the 20th century the majority have been drained or have become overgrown. A similar fate has been met in the rest of the transboundary region.

As described in the UNESCO project document, currently these groundwater dependent ecosystems display trophic diversity: ranging from mezotrophic; ditrophic lakes; and 50 eutrophic lakes. Polesie's lakes also have a large diversity of fisheries. The limnologic and fish diversity of these lakes is accompanied by the high diversity of ecotone zones.

The potential multiple use, for multiple benefits, in multiple sectors. A full hydrogeological description of the region is beyond the scope of this paper that is directed to assessing the future education needs of hydrogeologists. Nevertheless this Palaeozoic-Mesozoic subsurface system (Fig. 6) provides a remarkable example of the potential diversity of the type of training and education that may be required, if not now, then certainly by the time that the *Poland 2030's* recommendations have matured.

Here we have at depth (in the Carboniferous sequence) an energy source (operated by a very modern mining company *Lublin Węgiel*) which is expected to continue to operate for at least 2040; the removal of coal provides space for other materials – recent information from the Office of the Marshal of the Lublin Voivodeship suggests that all the hazardous industrial asbestos of the region might be safely stored in the space created due to the extraction of coal. The same information source has also explained that due to the regions water shortages, there are plans to increase surface storage in small dams and surface reservoirs. However, could not the space being created by the mining of coal also be now designed as a future sub surface store for water (ensuring that it is safe from pollution)? The water for filling these future safe cavities would be from the excessive floods that the Lublin region suffered from in June 2010,

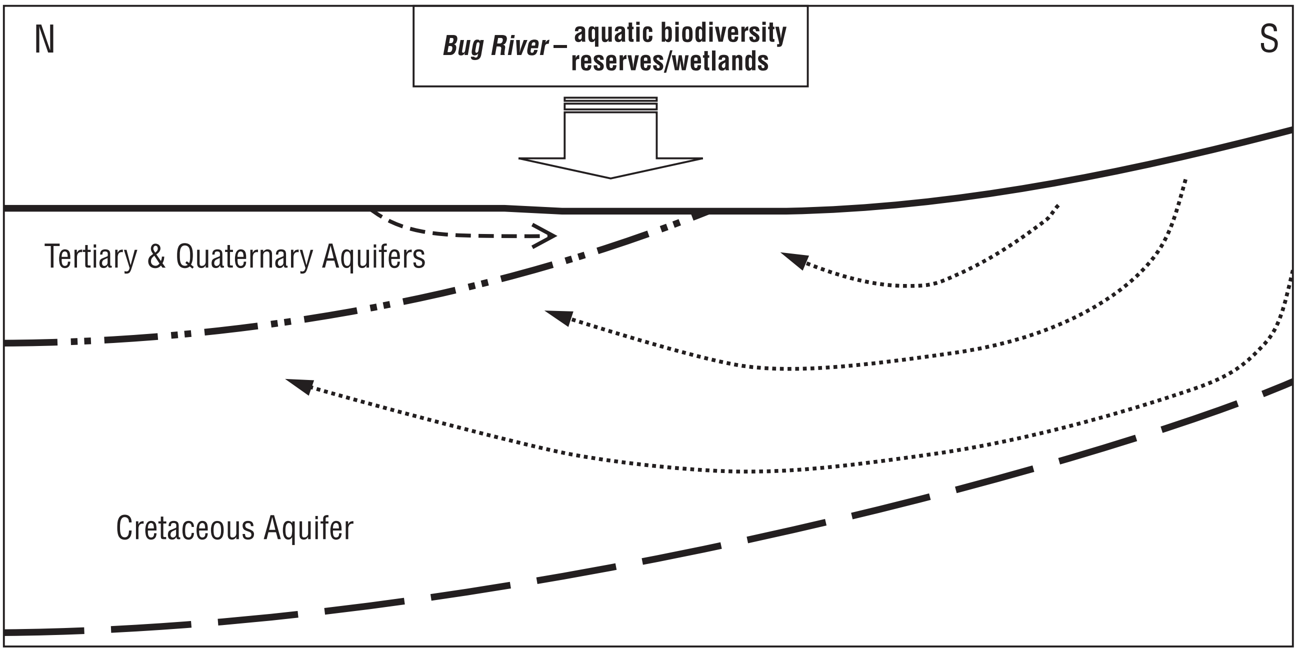

Fig. 4. Schematic cross section of the Mesozoic Aquifer System, showing the postulated support to the groundwater dependent ecosystems of Polesie region

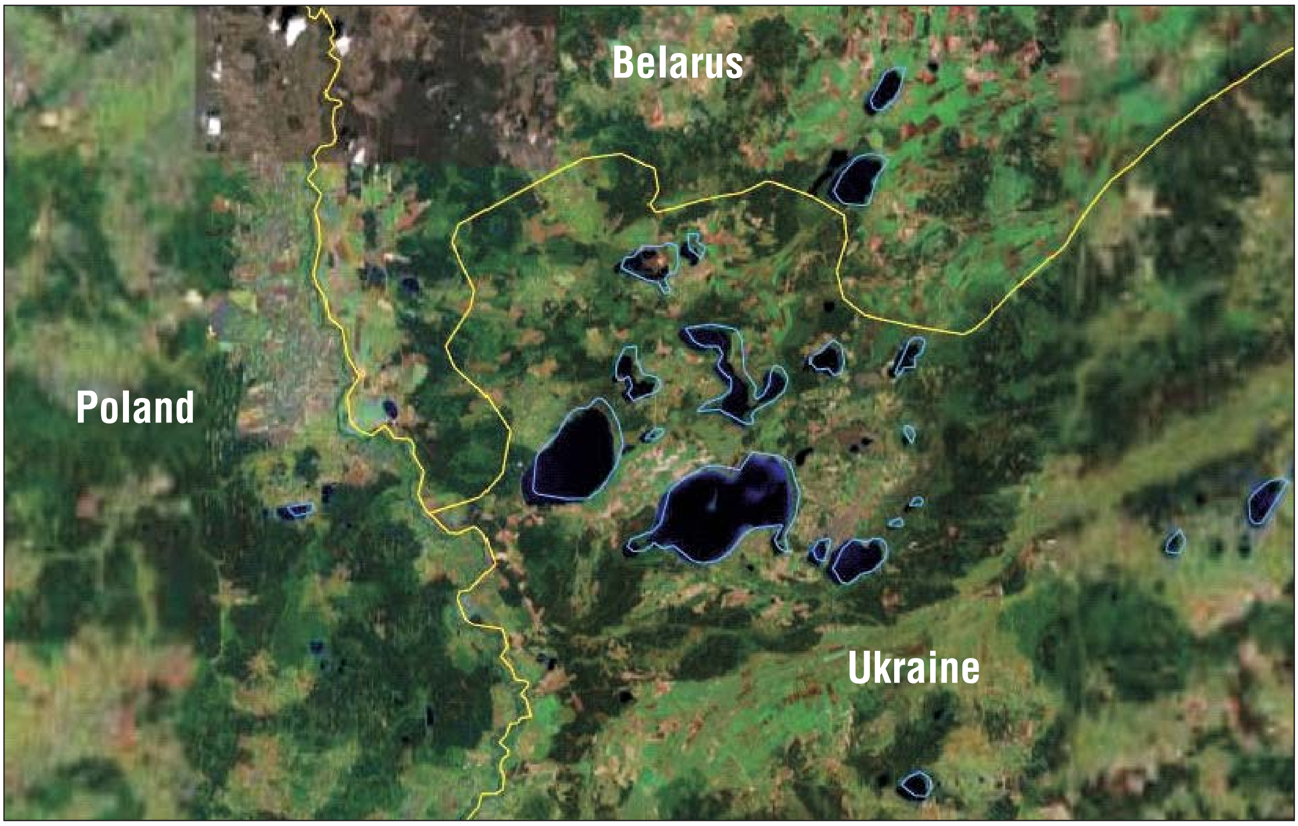

Fig. 5. The Polesie lake systems in the planned transboundary natural park between Poland–Ukraine–Belarus (source: Google)

and will continue to, if climate variability intensifies. The lining of the cavities can be devised from suitable expandable plastic liners, which will provide a good fit to the dimensions of the old mining cavities. Further, if the cavities will be accessed by the 600 m retrofitted mine shafts, then there is also the potential to generate micro-hydro power as the surface water is dropped by gravity to the cavities in the previous coal mines. There is thus a potential for multiple gains both economic and environmental.

Above this potentially high value subsurface space, there are the overlying aquifers of the Cretaceous that contain high quality water naturally discharging to the dependent ecosystems of the Polesie wetlands. Adoption of new land use approaches in the farmed lands to incorporate managed aquifer recharge would ensure that the aquifers are replenished regularly. At times of deep drought the water stored in the coal mine cavities at depth could be deployed to protect ecosystems at risk. The presence of karstic features means that some of the dependent lakes (Svityaz, Pulemetske, Pisochne in the Ukrainian territory) are susceptible to the features of such aquifers – rapid drainage, fast transport of pollutants.

The above example, which has only pointed to the most obvious features of a coupled subsurface system, can illustrate the range of educational skills that a future hydrogeologist working in a multi disciplinary team will have to deploy – aquifer hydraulics to demonstrate the linkage to dependent ecosystems, surface water ecology, land use practices and linkage to social stimulation of managed aquifer recharge, geotechnical conditions in mines for their after use, impact of climate variability on infrastructure and potential to use the excess waters, power generation from micro hydro sources and several other aspects including transboundary aquifer legislation (Aureli et al., 2007). If by the 2030's graduates of hydrogeological training will not have the skills to contribute to such multi source, multi user and multi national issues, in past called exotic uses (Puri & Edworthy, 1986), their roles might simply be taken over by others, who in the view of this Author, would be educationally less well prepared to grasp the opportunities for sustainable development of the planet.

The potential that such an area provides (as an illustration) as a training ground for re shaping the education of hydrogelogists can of course be significantly enhanced, since the Warsaw University uses this area for its annual field based training. If the future ten generations of trainee hydrogeologists could, as part of their training, also provide the input needed for applying the multiple approach to resource management, this could surely provide multiple benefits to education, training and awareness raising.

What kind of hydrogeologist will be required in the future?

The above review and assessment is based on discussions with representatives of a series of educational institutions of Poland, scientists and experts, as well as with the Chief National Geologist of Poland. The issues that were illustrated in connection with the Polesie Biosphere Reserve are just a small example of the range of that future hydrogeologists will have to address – as it became clear in a meeting that was held in May 2009 to celebrate the 90th

Anniversary of the Polish Geological Institute and to establish GEOBRIDGE (Sadurski & Skrzypczyk, 2010 – this volume, p. 797; Kleczkowski & Sadurski, 1999). The GEOBRIDGE is an initiative involving representatives of Ukraine, Belarus and other experts, including the EuroGeoSurveys under which Polish institutions and those of the neighbouring regions would cooperate, to expand their activities in a range of issues including education in the field mentioned earlier. Although not explicitly discussed in those meetings, the question that arose then was: what kind of hydrogeologists would be required for the future?

As global change of the economies, society, and communications accelerates, it may not be too easy to predict the future. However some principles can be assured. As Devlin (2004) suggests, the hydrogeologists of the future, in addition to the old, new and borrowed, will require something else. The something else is not a nebulous idea. Indeed it is *a stream of qualified, inquisitive and enthusiastic people, excited by the breadth and challenges of the discipline and by the positive contributions they can make to society by studying it*. If this need is fulfilled, the research will naturally follow and the future of hydrogeology will be assured.

Aquifer systems, as key components of the natural and the built environments are increasingly being recognised by many and varied communities – from small farm land owner through to major industrialists, from district councils through to national governments and from specialised UN (United Nations) agencies through to international financial institutions. A major break through that has been achieved by the many experts and scientists of the UNESCO-IHP (UNESCO International Hydrological Programme) and the IAH is the recognition by the Global Environment Facility that the subsurface space in an aquifer system is of significant environmental value that can contribute to global environmental gains. The UN's International Law Commission has also pondered with great care and attention to the advice given by hydrogeologists and have submitted to

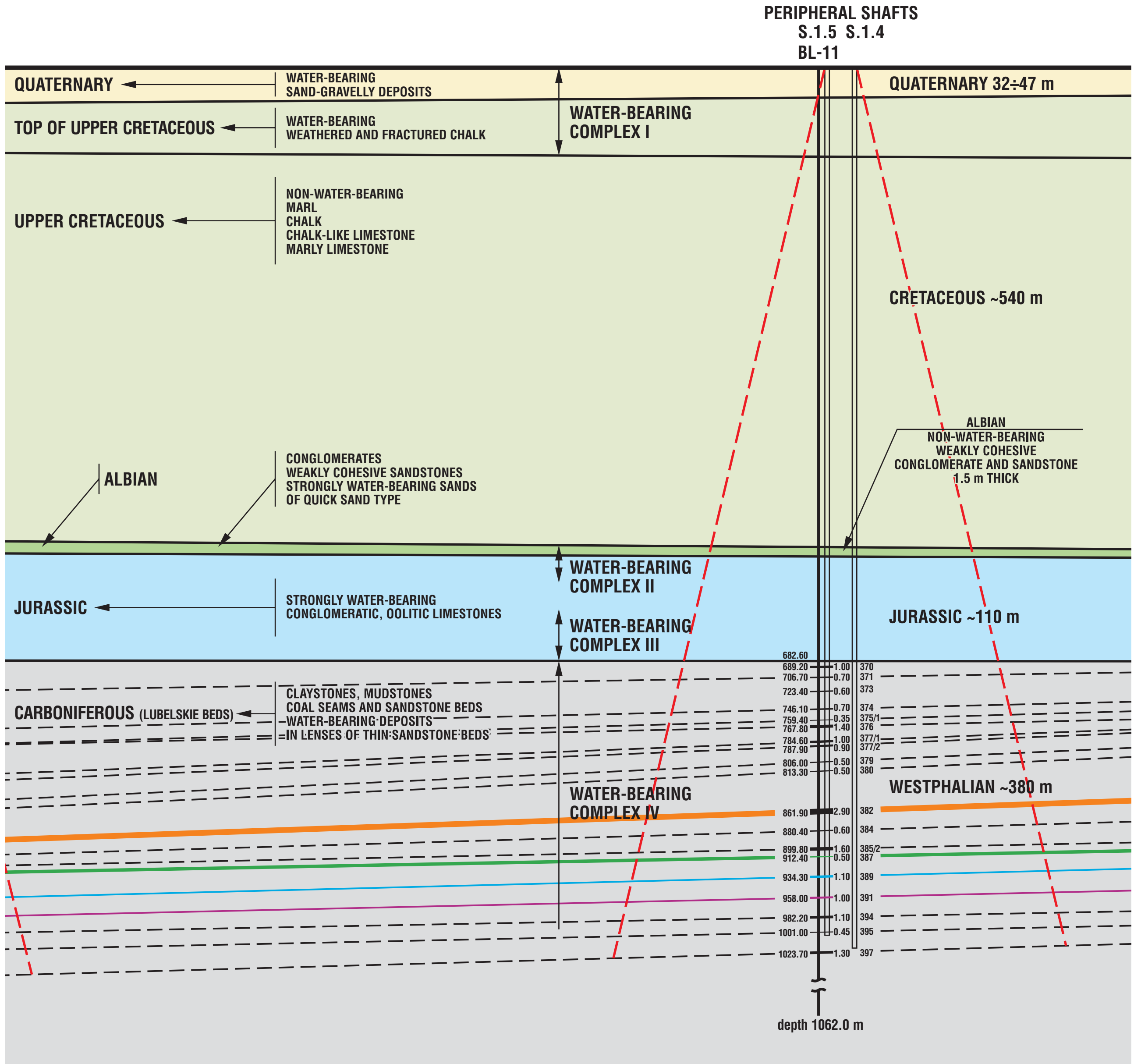

Fig. 6. Scheme of conformable Palaeozoic-Mesozoic sequence in the Lublin Coal Basin, SE Poland

the UN General Assembly a legal document that addresses the use of transboundary aquifers and helps countries that jointly rely on these resources. These legal Articles have been adopted by the UN General Assembly, and by 2011 the UN is poised to possibly adopt them as a binding instrument. The process to assist countries to understand these articles and indeed the value of aquifers has been described in Puri & Struckmeier (2010).

The hydrogeologist of 2030 will therefore be required to address many of these aspects of aquifer systems and their management. The skills will have to move well beyond the physics, chemistry and mathematics of ground water flow – they will have to be able to address the social, the financial and the institutional aspects of the management of sub surface space. Clearly no single hydrogeologist of the future will be an expert in every one of the above endeavours, but will probably specialise in various aspects, though having a clear understanding of the full range. Therein lies the challenge to the educators of the forthcoming years!

The potential for Polish education institutions to prepare the hydrogeologist of the future

In conclusion it may be stated that there is nothing to lose and everything to be gained by setting out some bold steps to reshape and re structure the educational range of the hydrogeological curricula that is on offer. Such a change will of course take a few years to develop and to adopt. Time nevertheless is of the essence and as the *Poland 2030* document notes, *the future starts today and not tomorrow*. With the economic crises of recent months that have battered financial commitments from governments, and there is every indication that the worst is not yet over, efforts to make changes in poorly funded educational institutions, the suggestions to make far reaching change will not be welcome in many quarters. Experience shows however that a bold vision and a workable plan of action will in the end prevail. If the *Poland 2030* document is any guide, then that process has started and the institutions that are the subject of this paper should not miss that train.

Among the many organisations and agencies that might provide support to educational facilities are included the resources of the UNESCO's International Hydrological Programme, the International Association of Hydrogeology and the many professional bodies that operate within Poland. With the support of the supervising bodies of the country, a new partnership to promote the development of *Hydrogeology 2030* could be set up. A board of advisors drawn from international resources could be mobilised to give strategic advice. A series of industrialists, including mining companies that have a stake in the sound and innovative management of the sub surface space, could be mobilised to give an additional impetus to any such initiative. Finally, the alumni of these institutions, potentially over 2700 in number, could be mobilised to provide the moral and the intellectual support to go forward with the changes.

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References

AURELI A., FRIED J., MARTIN-BORDES J.L., PURI S. & STEPHAN R.M. 2007 – Education and training for transboundary groundwater management as an instrument of dialogue and communication. [In:] Darnault C.J.G. (ed.) Overexploitation and Contamination of Shared Groundwater Resources: Management, (Bio)Technological, and Political Approaches to Avoid Conflicts, 25–33.

DEVLIN J.F. 2004 – The future of hydrogeology lies in something old, something new, something borrowed and something else. Presented at the GSA Annual Meeting and Exposition, Denver, Colorado, November 7–10.

Directive 2006/118/EC of the European Parliament and of the Council of 12 December 2006 on the protection of groundwater against pollution and deterioration. Official Journal L 372/19 (Groundwater Directive).

DRAGON K. & GÓRSKI J. 2008 – The influence of the land reclamation drainage systems on groundwater quality [in Polish]. [In:] Sozański M., Dymaczewski Z. & Jeż-Walkowiak J. (eds.) Mat. VIII Międzynarodowej Konferencji: Zaopatrzenie w wodę, jakość i ochrona wód, Poznań- Gniezno Poland, 1: 201–208.

HERBICH P., KAZIMIERSKI B., KROGULEC E., MAŁECKI J.J. & MICHALAK J. 2010 – Contribution of the Polish scientific community in solving new practical problems in hydrogeology. Prz. Geol., 58: 802–815.

KLECZKOWSKI A.S. & SADURSKI A. 1999 – Genesis and evolution of Polish hydrogeology [in Polish]. Biul. Państw. Inst. Geol., 388: 7–33.

KOZERSKI B., PACZYŃSKI B., SADURSKI A. & SKRZYPCZYK L. 2010 – Evolution of Polish hydrogeology. Prz. Geol., 58: 730–736.

LACHASSAGNE P. 2005 – Field hydrogeology 2059: A contemplation. Hydrogeol. J., 13: 47–50.

Poland 2030 – Development Challenges. Report of the Board of Strategic Advisers to the Prime Minister of Poland. July 2009, Warszawa.

PURI S. 2006 – Sustainable use of the Mesozoic Transboundary Aquifer System (SUMTAS) – Belarus, Poland, Ukraine. Project designed for implementation by UNEP DGEF, Nairobi (using funds from the Global Environment Facility, Washington).

PURI S. & EDWORTHY K. 1986 – Groundwater and aquifers; an overview of exotic uses. Quart. J. Eng. Geol., 19: 87–95.

PURI S. & STRUCKMEIER W. 2010 – Aquifer resources in a transboundary context: A hidden resource? – Enabling the practitioner to 'See it & Bank It' for good use. [In:] Earle A., Jägerskog A. & Öjendal J. (eds.) Transboundary Water Management Principles and Practice. Earthscan Publications UK (in press).

RÓŻKOWSKI A. 2008 – History and state of hydrogeological investigations of the Upper Silesian Coal Basin and surrounding areas [in Polish]. Wydawnictwo Uniwersytetu Śląskiego, Katowice.

SADURSKI A. & SKRZYPCZYK L. 2010 – Polish Hydrogeological Survey – the response to European Directive implementation. Prz. Geol., 58: 797–802.

TARTAKOVSKY D.M. & WINTER C.L. 2008 – Uncertain future of hydrogeology. ASCE J. Hydrol. Engrg., 13: 37–39.

UNESCO IHP 2008 – Conservation and sustainable use of a transboundary wetland in the Polesie region. Poland, Belarus and Ukraine - project developed in cooperation with the National Academy of Sciences of Belarus, with support of Japanese grant funds.

VOSS C. J. 2005 – The future of hydrogeology. Hydrogeol. J., 13: 1–6.