Report on Risk assessment

Appendix 3: The evaluation of risk associated with the work of geothermal district heating in near-border system.

Proposal of its limitation (the case of the Podhale system, Poland).

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1.1. Geological and hydrogeological characteristics of the geothermal water reservoir exploited by PEC Geotermia Podhalańska SA for the purposes of the district heating network

PEC Geotermia Podhalańska SA has been the operator of the geothermal district heating system in Podhale region (S-Poland) since 1993 (on a larger scale since 2001). The company exploits the geothermal water reservoir "Podhale 1" on the basis of a license. The reservoir is located in the Middle Triassic rocks which belong to the Mesozoic basement of the so-called Podhale Basin. On the top of Triassic formation also the Middle Eocene limestones occur. This reservoir and geothermal system is much larger – it covers the area on the Polish and Slovak side of the border, and in its central part there are the Tatra Mts. They are the recharge area of groundwater supply (including geothermal waters) on both sides of the national border (Fig. 1).

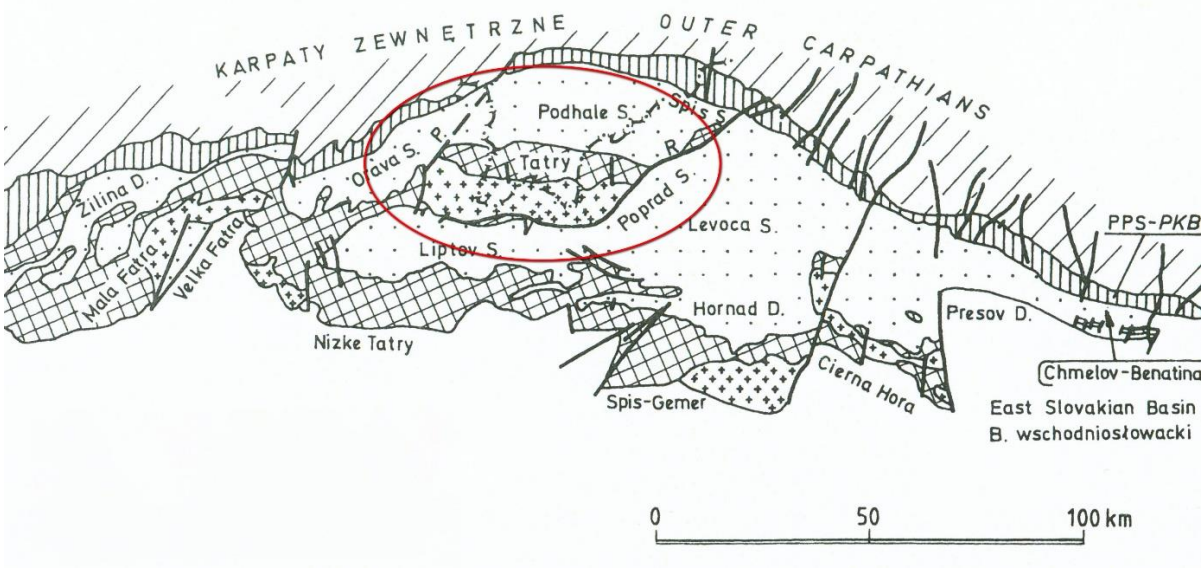


Fig. 1. Location of the Podhale geothermal system on the Polish and Slovakian side of the national border *(based on: Sotak, Janocko 2003)*

The Podhale Basin is filled with flysch formations (Palaeogene) with a thickness of slightly less than 2000 m in the southern region, and more than 2700 m in its northern part. They are mostly underlined by the carbonate rocks of the Middle Eocene ("Nummulitic Eocene") which show great lithological diversity (limestones, dolomites, conglomerates, sandy and shale intercalations) and variable thickness (from 0 to approx. 100 m). At the northern border of the Podhale geothermal system the formations of the flysch and Middle Eocene are faulted - faults parallel to and oblique to the Pieniny Klippen Belt. In the zone of the White Dunajec valley - where the geothermal water reservoir "Podhale 1" is located - the Podhale flysch and the Mesozoic basement are crossed by a large fault of the White Dunajec. Mesozoic rocks (Triassic, Jurassic, Cretaceous) of the basement of the Podhale Basin build many tectonic units, which are separated by thrust fault planes and cut by faults. Directly below the "Nummulitic Eocene" the carbonate reservoir rocks of the Middle Triassic belong to the so-called tectonic unit of the Biały Dunajec (White Dunajec). The geothermal waters contained within it are exploited through five wells: Bańska PGP-1, Bańska PGP-3, Bańska IG-1 (production wells), Bialy Dunajec PAN-1, Bialy Dunajec PGP-2 (injection wells). The maximum thickness of the formations of White Dunajec unit found in the Bańska IG-1 well exceeds 600 m. The top of this unit is located at a depth of approx. 2000 m in the southern part, while in the northern part it is expected to be located at a depth of approx. 3000 m. Below, however, there is a non-water-bearing unit of Bańska (several hundred meters thick, built mainly of Cretaceous marls) and a few smaller units built of Jurassic and Cretaceous formations, mainly Triassic (carbonate or silt-sandy formations).

More information on the geothermal district heating network operated by PEC Geotermia Podhalańska SA has been provided, among others, in separate elaborations within the GEORISK project (WP2.1, WP3.3).

1.2. The method of exploitation of geothermal waters in the Podhale geothermal system on the Polish and Slovakian side

The exploitation of geothermal waters in Podhale is conducted in the Polish part by six operators active in one reservoir (11 wells work – 9 production wells and 2 injection wells). What is more, due to the transboundary range of the reservoir, extraction is also conducted by Slovak operators (the closest is in Oravice - near the eastern border with Poland, on the northern side of the Tatra Mts – well Z-2 on Fig. 2).

Only PEC Geotermia Podhalańska SA operates for the purposes of the district heating system - the largest in Poland and one of the largest in Europe (installed geothermal capacity approx. 40 MW, total capacity approx. 80 MW, sale of geothermal heat approx. 450 TJ/2018). Geothermal water (produced by 3 wells) after passing through heat exchangers is mostly injected back into the reservoir (through 2 injection wells). Other operators (5) exploit geothermal water for recreational purposes (swimming pools), but do not inject used water and discharge it into sewage systems / surface watercourses (no injection requirement is included in their licenses). Individual centers were opened between 2006 and 2016. These are usually very large facilities, accepting even 1000-3000 person/h. The total approved exploitable geothermal water reserves from all the intakes do not exceed those available for the Polish part of the geothermal system, i.e. disposable reserves (taking into account the injected part of the reserves).

It should be noted, however, that the disposable geothermal water resources of a particular geothermal system (including Podhale) are strictly hydrogeological category and concern only the volume of water. However, they do not take into account their temperature and pressure; these parameters are equally important in the context of possible geological risk (resources) in geothermal heating projects, as well as in other (including recreational) projects, these parameters may change during exploitation, even if the water flow rate / disposable resources

or exploitable reserves (expressed respectively as water flow rate per unit time from a given area or well) are stable. This hydrogeological category may not be sufficient in case of geothermal energy (!).

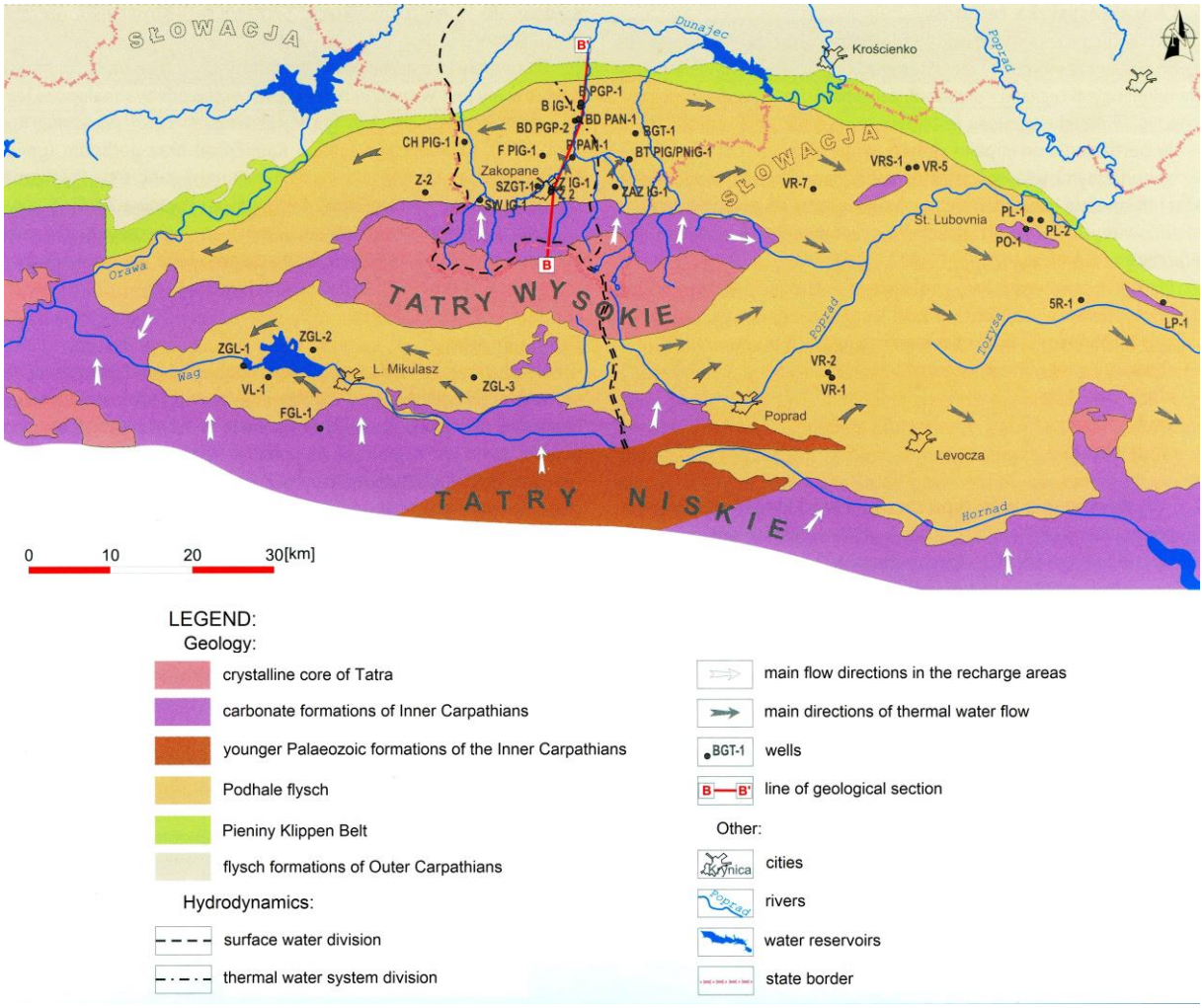


Fig. 2. Location of wells in the Polish and Slovak parts of the Podhale geothermal system (according to Szklarczyk, in: Chowaniec et al., 2007, slightly modified)

Geothermal wells exploited for heating purposes by PEC Geotermia Podhalańska SA are marked as: B IG-1, B PGP-1, B PGP-3 (production), BD PAN-1, BD PGP-2 (injection). More detailed location is shown on Figure 3.

As mentioned above, in the close vicinity to the west of the Polish state border (a dozen kilometres from one of the working wells) on the Slovak side there is a large recreation center based on geothermal water extracted from the well, which, however, is not injected after being used. In Slovakia, such large recreational facilities also operate in the eastern part of the

discussed geothermal system, especially in the southern part (Fig. 4). Moreover, the construction of a geothermal heating system is planned for one of the towns south-west of Oravice, which will also require the introduction of sustainable ways of exploiting geothermal waters (probably including their injection).

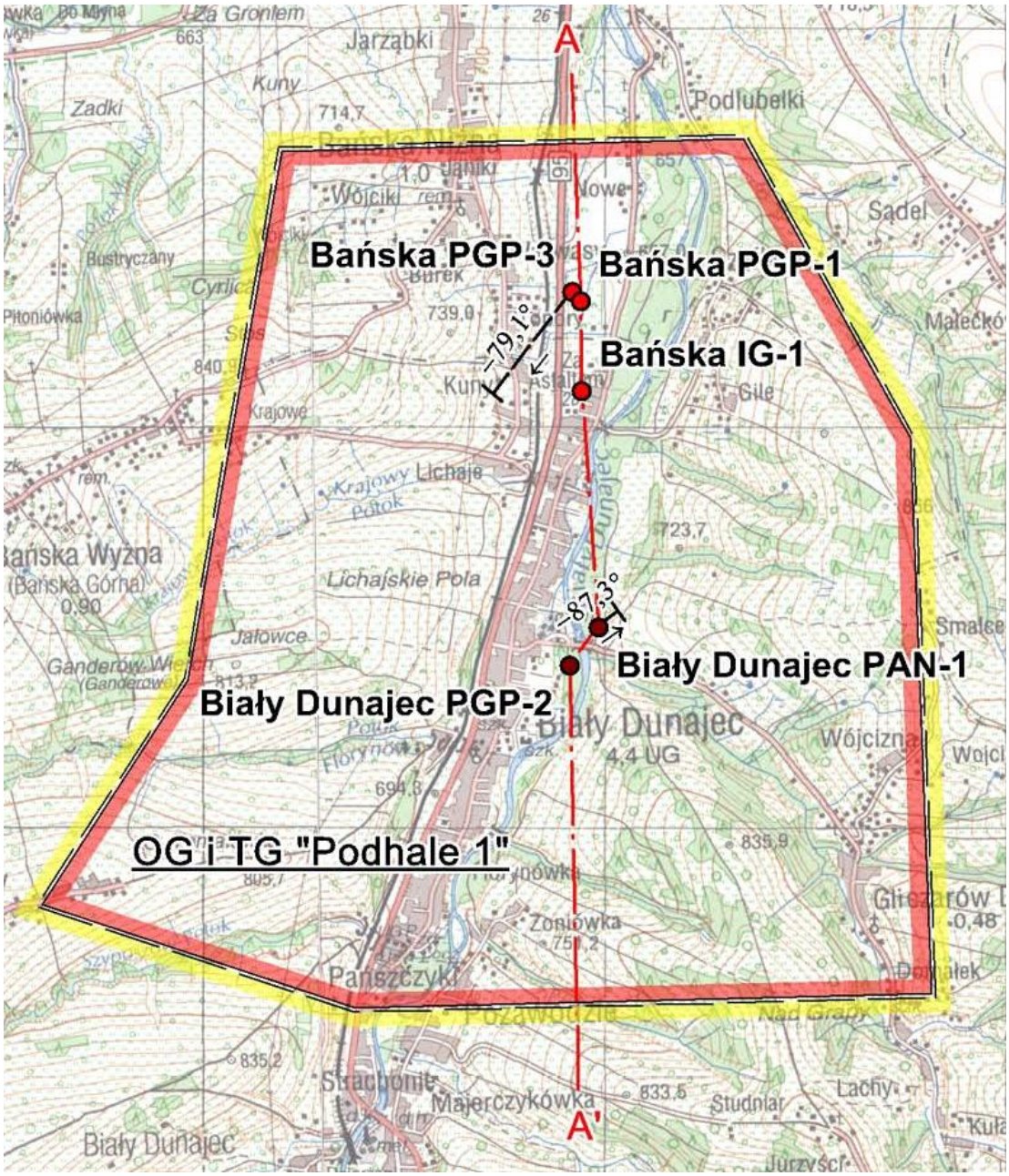


Fig. 3. Location of wells exploited for heating purposes by PEC Geotermia Podhalańska S.A. Polish part of the Podhale geothermal system (OG i TG “Podhale 1” – mining area “Podhale

1" for which the company has an exploitation license). Bańska IG-1, Bańska PGP-1, Bańska PGP-3 (production wells), Biały Dunajec PAN-1, Biały Dunajec PGP-2 (injection wells)

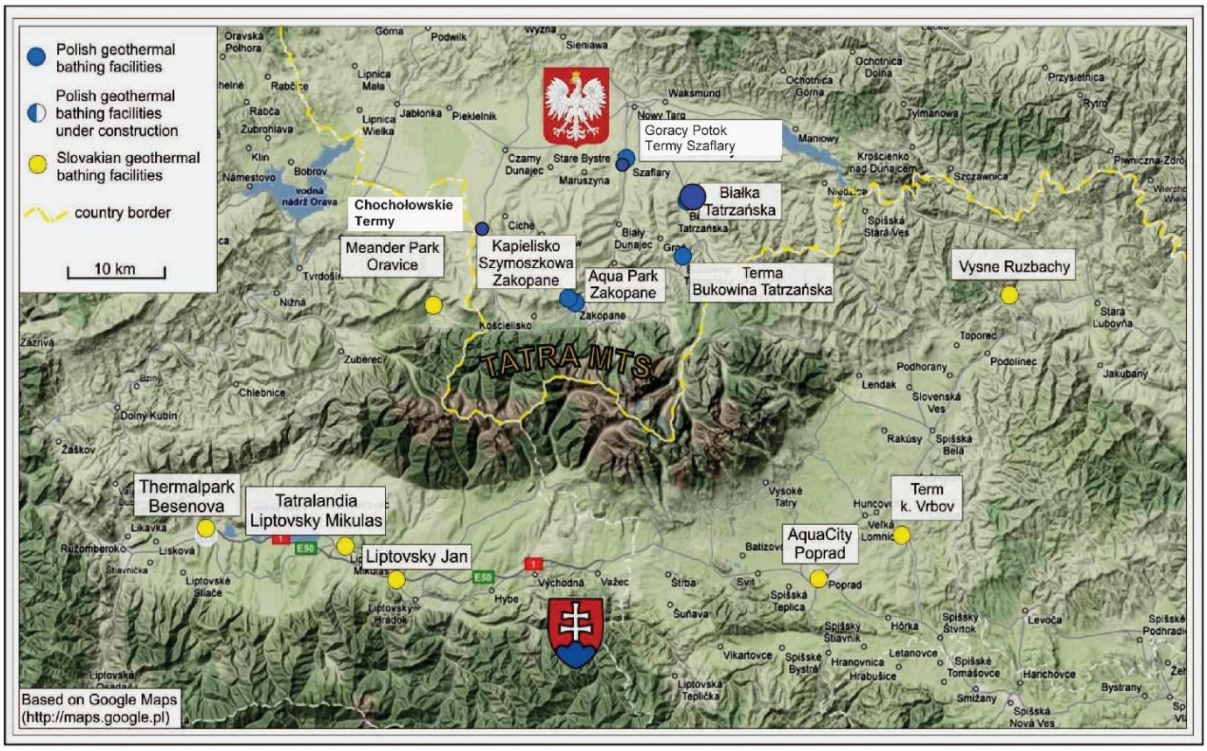


Fig. 4. Recreational centres based on geothermal waters in the Polish and Slovak part of the Podhale geothermal system (according to Jasnos 2008, updated Kępińska 2013)

1.3. Current and possible impacts of the geothermal water's exploitation method in terms of potential geological risks. Proposals for necessary actions.

To this day, there is no comprehensive geological and hydrodynamic model of the geothermal system and reservoir in the Podhale region, nor any system of complete current and long-term exploitation monitoring that would cover the entire Polish part, not to mention the Slovak part. Since one reservoir is exploited, the mutual influence of exploitation (especially without injection) in individual installations is already visible on changes in the values of basic exploitation parameters in wells working in other installations - e.g. during long-term

exploitation (over 25 years) PEC Geotermia Podhalańska SA observed a drop in pressure by several atmospheres (!) on the wellheads of exploited wells (this is recorded in the production history). If not a very high artesian pressures, this could even lead to their disappearance, and consequently - instead of producing water in conditions of self-outflows, this could be done with the use of downhole pumps, which would be connected with, amongst others, the necessity of incurring significant costs of purchasing downhole pumps, as well as additional costs of purchasing electric energy to power them, periodical repairs, replacement, etc.

Similar risks may also be faced by operators on the Slovak side of the system.

Cooperation of individual geothermal system operators from Poland and Slovakia and mutual sharing of exploitation data would help to identify possible exploitation problems (reservoir, technical) and the risk of lowering basic parameters. It would also serve the long-term planning of safe and sustainable exploitation by each operator and for the entire system (on the Polish and Slovak sides). So far, such data and information are not exchanged between operators - there is no such will in most cases, all the more so as there are no relevant legal provisions (neither in Poland, nor Slovakia nor internationally).

As mentioned above, at present the exploitation of the Podhale reservoir is conducted by six operators (Polish), however only PEC Geotermia Podhalańska SA conducts the exploitation with the injection of the prevailing amount of geothermal waters into the reservoir after taking heat from them. Other operators discharge spent geothermal waters into surface watercourses or sewage systems. So far, there has been no system of joint monitoring and management of the reservoir. There are also no legal grounds for sanctioning the necessity of cooperation between operators in the scope of joint actions for the protection (rational exploitation) of the reservoir and reduction of potential geological risk.

An optimal solution would be to introduce a network of information flow on exploitation parameters and to develop a model of the reservoir and its simulation based on current exploitation parameters from all wells in the geothermal system. However, in order to create a model, legal instruments are needed to regulate the way and scope of data transfer. The next step would be to create a system for processing received data. The data administrator should be a specialized institution independent from the operators. The administrator's task would be to process received data, calibrate and simulate the reservoir 's operation and its reaction to the exploitation, to react to changes in the parameters of the reservoir, as well as to assess the risks associated with the exploitation (with the change of parameters that may adversely affect the exploitation) and to prevent any possible adverse phenomena if they depend on the technical parameters of the system's operation. The reservoir monitoring system would

operate on the basis of parameters recorded by each operator on an ongoing basis (pressure, temperature, capacity) or periodically (mineralization, water physicochemical composition, gas content, corrosion and scaling tendency). In the future, other parameters could be added in justified cases. Such a necessity has been indicated from the very beginning of the geothermal project in Podhale by Polish specialists involved in it. However, so far there has been no such comprehensive monitoring, as well as no common geological and hydrodynamic model.

In order to establish cross-border cooperation, it would first be necessary to conclude international agreements defining the form and manner of information transfer between operators and the transfer of data to the administrator who would have overall control over the exploitation of the reservoir regardless of the existing national borders. This suggestion refers to the already ongoing work on the introduction of regulations and joint action by certain countries on transboundary groundwater flows. Poland also belongs to them (https://www.pgi.gov.pl/psh/zadania-psh/8989-zadania-psh-monitoring-graniczny.html), however, no monitoring of geothermal water flows in the near-border area of Poland and Slovakia has been carried out so far.

This is the first step at the national decision-making level (perhaps also at EU level), which should be followed by further, more detailed rules at lower levels, concerning even individual operators' obligations. It is also very important due to, among others, the pursuit of stable (with the lowest possible risk of decrease of basic reservoir / exploitation parameters) long-term operation of the geothermal heating network in Podhale, operated by PEC Geotermia Podhalańska SA. This is because it is a strategic project and a source of heat, for the construction of which outlays of over PLN 270 million have been incurred so far (see T3.3) and further development is being carried out. It is also important to ensure the security of supplies of the heat with constant and appropriate parameters to customers (geothermal heating in the Podhale region is a way to significantly reduce coal combustion and GHG emissions). The interests of other operators in the Podhale system (in Poland and Slovakia) are taken into account as well - they also incurred large financial outlays for the construction of recreation centers. Therefore, the functioning of these centers at the appropriate level of exploitation parameters is crucial. However, they must be aware of the possibility of incurring costs for injection wells (which is difficult for them to accept yet), and also actively join the efforts proposed above.

What is more, there is an urgent need for a common transboundary reservoir model, its calibration and simulation for the needs of current and future long-term exploitation, as well as for joint studies of this system, harmonisation of maps and information on it. These should be

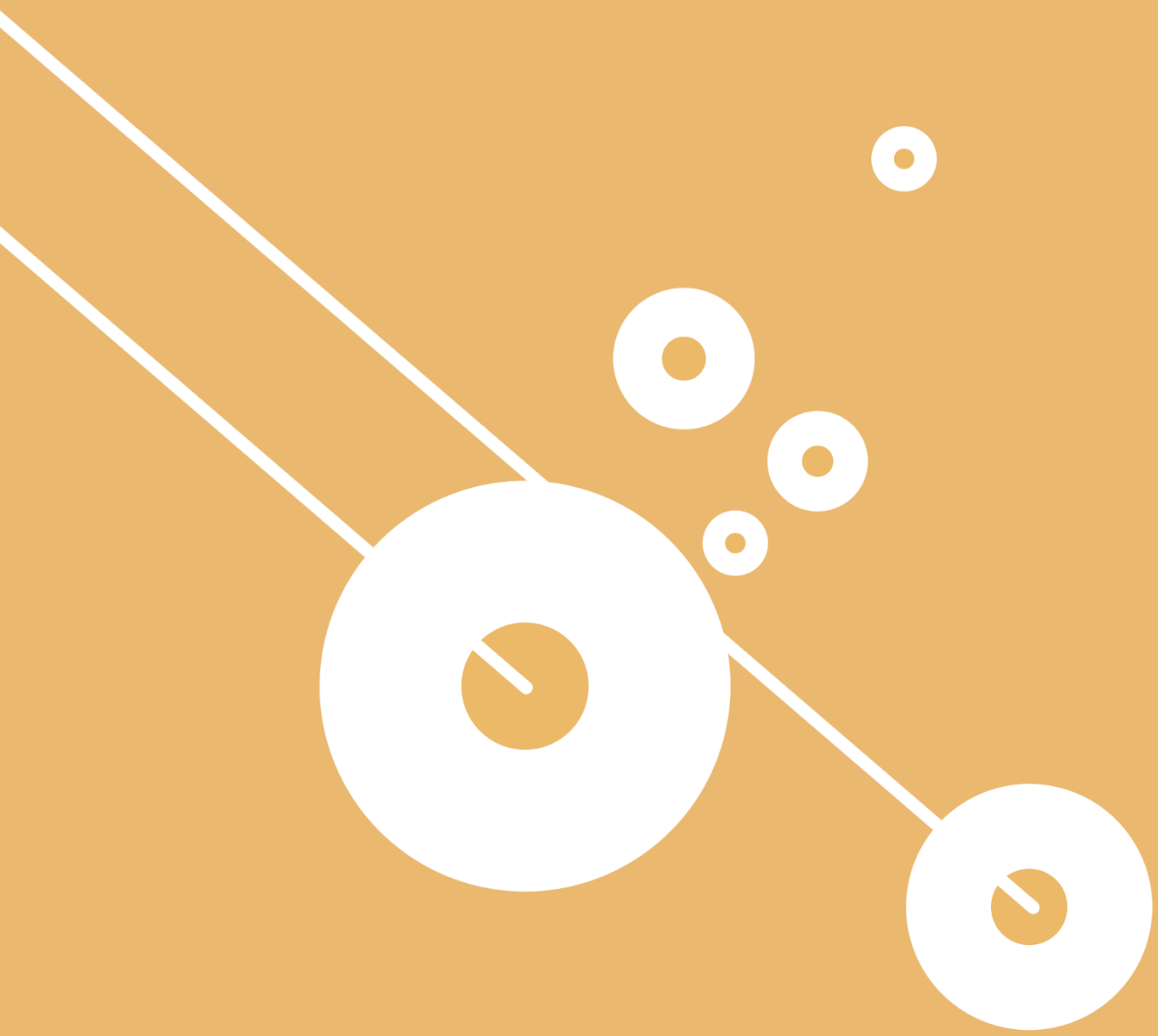
first of all common hydrodynamic maps (reservoir pressures, water flow directions and their variability over time; geological transboundary cross-sections through well areas, etc.).
The next step to implement the proposed actions could be to jointly consider and propose by the relevant national services along with Polish and Slovak operators ways to reduce the transboundary geothermal risks associated with the exploitation of the discussed system on the Polish and Slovak sides. It would also prepare the ground for the possible introduction of a common international/regional geological risk mitigation tool in geothermal projects, in addition to the necessary national geothermal risk mitigation tools.
At present, PEC Geotermia Podhalańska SA does not conduct any exchange of information concerning exploitation, although such information would help to understand the phenomena occurring within the jointly exploited reservoir. Such knowledge would also help to minimize the "exploitation" risk and would help in the rational use of geothermal water resources.
An example of cooperation in the field of transboundary monitoring and harmonization of sustainable water exploitation from the geothermal system is, among others, a fragment of the Pannonian Basin in the area of Hungary and Serbia (Geocom project carried out a few years ago; www.geothermal-communities.eu). It is appropriate for the Podhale system in Poland and Slovakia.
Guidance and inspiration will also provide the example of Pannonian Basin, which is also the subject of WP2.2 within the GEORISK project.

1.4. Closing remarks

The importance of the raised issue of geological risk stems also from economic reasons: on the Polish side of the Podhale geothermal system, over PLN 270 million was invested in the geothermal system in the years 1998-2008 (EUR 63 million, EUR 1 = PLN 4.3, July 2019); very large funds were also invested in big recreation centres on both the Polish and Slovak sides of the system (on the Polish side only, the costs were at least PLN 500 million). This is also the reason why long-term exploitation of geothermal waters in conditions allowing the lowest possible level of geological risk is necessary. The proposals contained in this elaboration may serve this purpose, among other things. The postulated, among others, common hydrodynamic model of the reservoir, common monitoring and management of the reservoir and geothermal system is in the interest of all operators, including in particular PEC Geotermia Podhalańska SA. The financial outlays necessary for this would be only a small percentage of the financial resources invested so far for the construction of a geothermal

heating system and recreational centers. We also see a need to consider the regional risk insurance scheme.

In other words, the lack of a common model, monitoring and management of geothermal reservoirs in the transboundary system of Poland and Slovakia is in itself a major potential risk factor, and it is therefore necessary to take appropriate measures, such as those proposed in this opinion.



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