What could be the impact of shale gas exploitation on the water management?

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A b s t r a c t. The industry related to the extraction of hydrocarbons from unconventional deposits (shale gas, tight gas, shale oil), developing intensely since the beginning of the 21st century, requires a comprehensive approach to environmental issues arising from the commonly used technology. Because of the hydrauling fracturing process, groundwater management issues are the most important. Analyses should be performed for the aspects of the project's water needs, water circulation system in the process, definition of the water sources, as well as for the issues related to the protection of surface and ground waters in the area of geological operations. In the light of the current European debate about the safe use of unconventional hydrocarbons, the need for integrated water management is particularly important.

Keywords: *water management, shale gas, groundwater resources, groundwater contamination*

It was due to the breakthrough in the possibility of recovering energy raw materials from unconventional resources (shale gas, tight gas, shale oil), which has been made throughout the world in the last decade, that the extractive industry has taken on a new dimension. Directional drillings which are used on an unprecedented scale and new methods of resource stimulation open up great possibilities for the exploitation of resources that have been inaccessible so far, but it also creates the need for a different, complex look at environmental aspects of the extraction process. The territory of the North America, which is the only place where shale gas and tight gas extraction has been carried out for over ten years now, brings a lot of valuable experience. Nevertheless, it differs in having both different geological conditions and different formal and legal conditioning than those in Europe. A transformation of the gas market in the USA and Canada, and first of all a significant drop in price of this raw material is encouraging, and this is why the process of the exploration of unconventional hydrocarbon resources and analyzing their potential extraction has started in many places in the world, including Poland as well. Thanks to the geological information obtained from vintage exploratory boreholes, the most prospective area in terms of potential shale gas occurrence in the lower Paleozoic (Poprawa, 2010) was outlined, in a relatively short period of time, and concessions were granted for prospecting for and exploring resources of a shale gas type. This way Poland found itself within the range of interest of the biggest mining concerns in the world and became, in a way, an experimental area for conducting this kind of activities in Europe. In such an exceptional situation, it is necessary to look at each aspect of the technology being applied and which is subject to constant changes with meticulous care. A period of prospecting for and exploring resources, when the work is carried out on a rather small scale, is the proper time to develop procedures both for the entrepreneurs and public administration organs, including those who are responsible for supervision. Also, it is the time when all potential threats to the environment which result from the technology applied should be considered in a reliable and responsible manner and solutions to minimize the pressure found (Macuda, 2010; Woźnicka & Konieczyńska, 2011).

WATER MANAGEMENT IN THE PROCESS OF SHALE GAS EXPLOITATION

A review of the experiences carried out so far with respect to shale gas exploitation in the North America and the results of the research and exploratory studies conducted by the Polish Geological Institute – National Research Institute (PGI-NRI) in the area of the first drillings in Poland where a hydraulic fracturing process was applied enables it to put forward a thesis that water management, in the broad sense of the term, is one of the key aspects of the whole undertaking (PIG-PIB, 2011). This is because water is, on the one hand, necessary at each stage of work being performed and on the other hand there is a risk of groundwater contamination in the area where an activity is pursued. Therefore, the issues of the water management in a process related to gas exploitation from unconventional resources and their protection are often raised by both ecological organizations and local societies, and they are also an important question submitted for discussion on the European agenda. The debate on this subject is becoming more and more animated and this results in many reports and expert opinions being made that are commissioned by the European Commission (AEA, 2012a, b). Also, some suggestions appear for entities exploring gas that recommend what should be done (e.g. IEA, 2012; Musialski et al., 2013). However, in most cases they are theoretical discussions only that are not supported by experiences from Europe. Activities taken by European organizations indicate explicitly that some system solutions will be required that can guarantee safe extraction of gas from unconventional resources.

A comprehensive look at the process of shale gas exploitation requires that internal elements of water management in an extraction process directly resulting from a technology being applied (Fig. 1) as well as external impacts of the activities being undertaken on the water management of a region (Fig. 2) are defined.

In case of the internal elements, which decide in a large measure about the effectiveness of the process, it is essential that the needs for water at each stage of the undertaking

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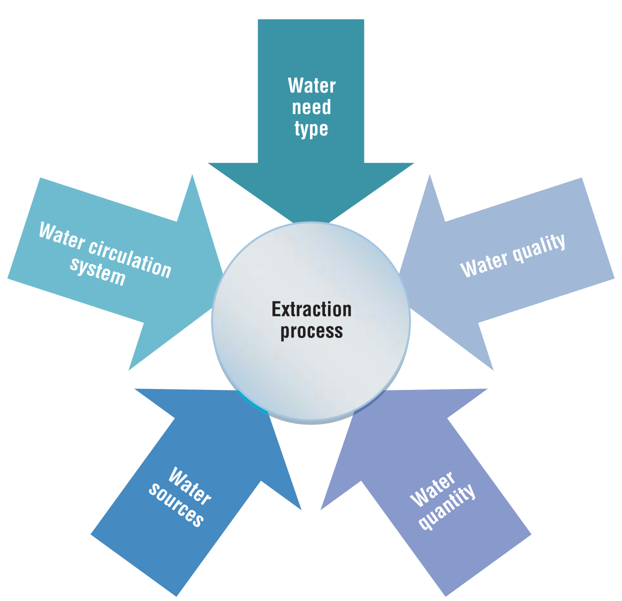


Fig. 1. The internal components of groundwater management in the exploitation of unconventional hydrocarbon deposits

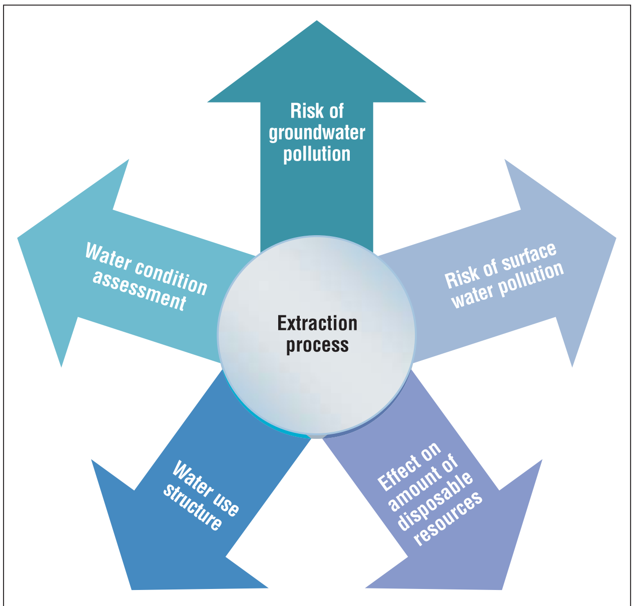


Fig. 2. The influence of exploitation of unconventional hydrocarbons deposits on groundwater management

are determined, also including the quality of water to be used for various purposes. With a water circulation system that enables it to simultaneously monitor the water being used in terms of quantity and quality, it will be possible to rationally use it.

The external impacts should be understood as the influence of extraction activities on water resources that are accessible for management and the potential pollution of the water environment in the area of work. This also applies to long-term impacts that, in a wider sense, show a direct correlation with the evaluation of the state of a part of surface water and groundwater, that is so-called Water Framework Directive (Dyrektywa 2000/60/WE). It is important, insomuch as in the cycle related to the drawing up plans of the management of river basin water it is required that an analysis of pressure and their impact on the waters is made, including a prognosis of the development of the main sectors of the economy in a specified time perspective. As possibility arises of a large-scale industrial exploitation of shale gas, this element must not be omitted in the next planistic cycle.

WATER IN THE TECHNOLOGICAL PROCESS APPLIED TO GAS EXTRACTION FROM UNCONVENTIONAL RESOURCES

The work on gas exploitation from unconventional resources proceeds by stages, on a large scale, and usually decisions about whether to go to the next stage depend in a great measure on the previous stage results. The work is broken down into five stages that are different in their demand for water and the impact on groundwater:

1 – preparatory work – constructing a mining plant, including industrial infrastructure, communication routes, water tanks and social and technical back-up facilities;

2 – drilling boreholes;

3 – multi-stage hydraulic fracturing;

4 – gas collection (exploitation);

5 – liquidation of the mining plant and post-mining area rehabilitation.

The preparatory stage includes various types of work related to the setting up a mining plant, and indicating a water supply source that is the most essential issue from the point of view of water management. It is a common practice to build an intake from which water is supplied to serve current needs of the mining plant, drilling and hydraulic fracturing as well. Also, at this stage water tanks are built and filled with water or other methods of collecting a sufficient amount of water are selected (e.g. cushion pool). An addition, some actions are taken aimed at preventing groundwater from being polluted from the land surface. This is done by sealing the land surface (with the use of concrete slabs, foil, sand-gravel aggregate, etc.) in the area of so-called a dirty zone, i.e. a place where chemical substances, fuels are stored and in the area adjacent to the well. Both the scope and the method of carrying out the work at the preparatory stage are of paramount importance with the view to the safety of groundwater.

What seems to be the most essential during the drilling stage, is that the boreholes must be to high standards of construction and workmanship which can guarantee safe exploitation in future. Each water-bearing horizon should be isolated by a separate column of casing pipes and a layer of cement, the leaktightness of the cementing to be checked (Fig. 3). It is very much important because the gas or fracturing return fluid that are potentially migrating in the inter-pipe space after they reach a permeable layer, which in fact is a water-bearing horizon, may penetrate to groundwater. The only instance where groundwater was found contaminated in the United States was due to improper workmanship in a well at an early stage of exploitation work.

After a well or wells have been drilled, the principal stage of work takes place which is connected with hydraulic fracturing. This process consists in injecting fracturing fluid with proppant (usually with sand) which causes that in rock a net of small and dense cracks is formed, i.e. the so-called artificial porosity (Fig. 3). The necessity of carrying out the processes of resource stimulations results

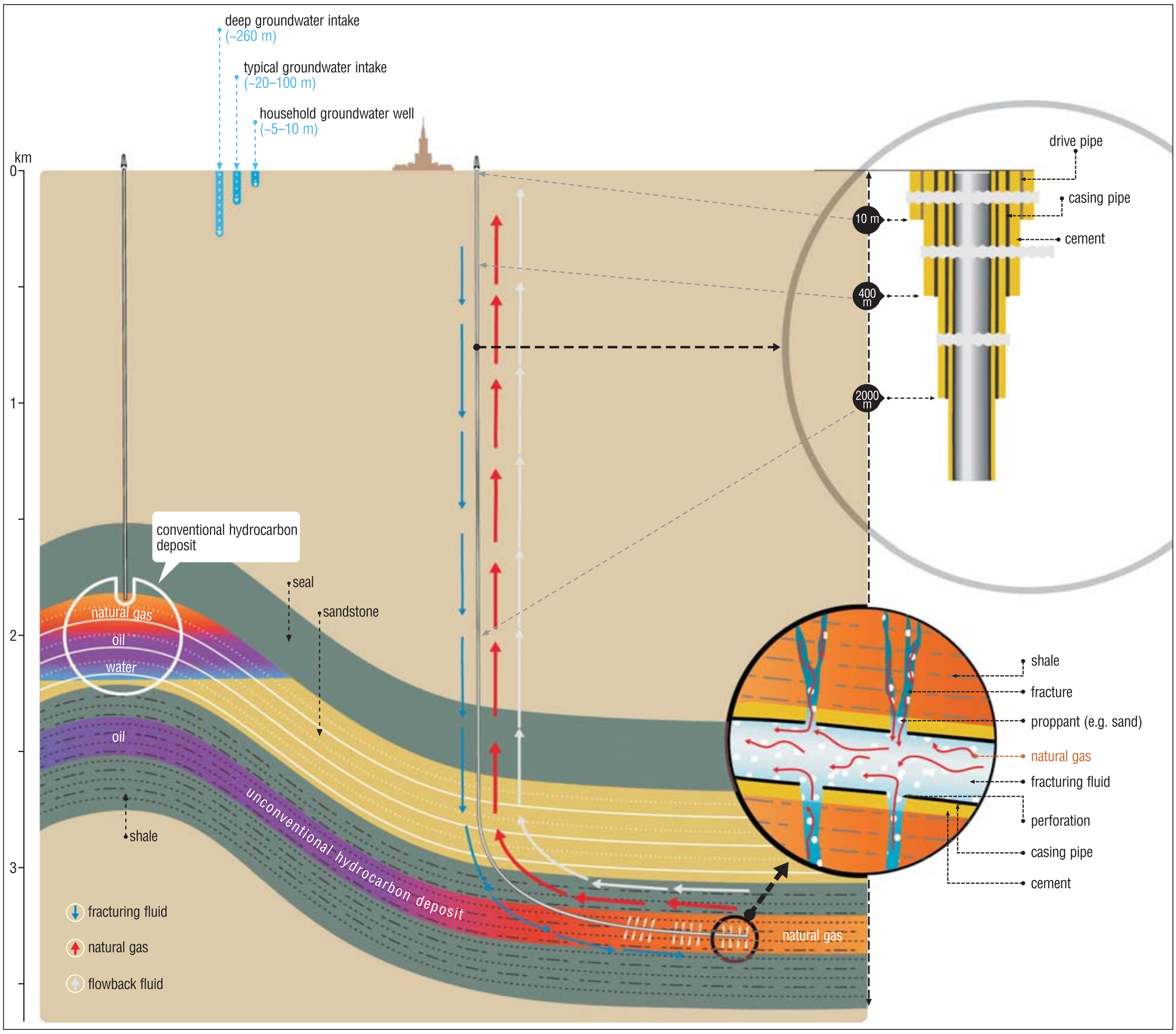


Fig. 3. A scheme of hydrauling fracturing process

from low permeability of gas-bearing formations that are the source rock and the reservoir rock at the same time. Gas is drained only from the zone which remains within the range of the cracks formed, that provide routes for the gas migration, and which makes it necessary to carry out hydraulic fracturing in possibly the longest horizontal sections of the wellbore (up to 3 km). At each stage of prospecting and exploring resources, single boreholes are drilled, whereas at the stage of exploitation from one location there are usually a dozen or so such wells which enables it to drain gas from a vast acreage with only small area being occupied. (Ground Water Protection Council and ALL Consulting, 2009).

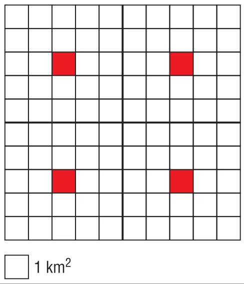
Extensive development can be seen in both the field of directional drillings and the stimulation process techniques that is in a great measure due to environmental requirements. Among others, studies and tests are carried out, aimed at working out a fracturing technology where water is not needed. However, if we take into consideration the fact that in the technology which is universally being applied, water is the primary working medium used in the hydraulic fracturing process, the accessibility of water is a prerequisite for the work to be done. In order to carry on the fracturing process in a section about 1 km long, in order to carry on the fracturing process along a section that is about 1 km long, a dozen a so thousand cubic meters of water is required (Table 1) of which amount from 15% up to 30% comes back to the land surface as return fluid which can be used again after it has been slightly cleaned.

Table 1. Average quantities of water needed for the hydrauling fracturing process

Production area	Water quantity per one well needed for full fracturing process [m^3]
Barnett (USA)*	8700
Marcellus (USA)*	14 300
Fayetteville (USA)*	10 900
Haynesville (USA)*	10 200
Łebień (Poland)**	17 300

* Source: Ground Water Protection Council and ALL Consulting (2009), averaged values from many wells.
** Source: PIG-PIB (2011), actual amount for one well.

Despite the fact that the prospective area indicated in Poland is rather vast, possible gas exploitation will take



Production field acreage	100 km²
Number of production fields	4
Number of wells in a single location	16
Amount of water per 1 well	17 000 m³
Amount of water in case of 15% water recycling	14 000 m³
Amount of water needed for gas production from a 100 km² field	896 000 m³

Fig. 4. Schematic development of an area of 100 km² and an estimate of the amount of water needed for shale gas production in this area

place only in places having the best resource parameters, so-called sweet spots. They can be small areas that after a decision to extract is taken will be developed to the maximum. To this end, a net of directional drilling is to be designed which enables it to drain gas from the whole area. For the purpose of an analysis of water utilization during the gas exploitation, an assumption can be made that in the area of 100 km² (10×10 km), four mining plants may be located, and sixteen directional drillings can be carried out in which of them. When we assume that the average water consumption per one well is of 14 000 m³ (in case 15% of return fluid is to be used again) the approximate amount of water required is about 900 000 m³. Although it is a hypothetical estimation only, it makes it possible for the extent of the process to be shown and reference made with respect to the manageable water reserves (Fig. 4). Location of the exploitation areas will depend on the length of the horizontal boreholes and the crack propagation range, and in this respect a great technological advance can be observed nowadays.

At the stage of a well exploitation, i.e. the collection of gas from a deposit, two aspects related to the water management are to be taken into consideration. The first issue is the collection and management of return fluid and the second one – the safety of exploitation. It should be kept in mind that the system of boreholes which is located in a small area can be operated (and produce gas) for a long period of time (a dozen or so or even several dozen years). During this period, a small amount of production water, which have to be properly managed, is usually collected at the same time.

After the exploitation has been completed, the mines are to be liquidated and the area of the former extraction rehabilitated. At this stage, it is obvious that it is essential to determine the scope of any possible changes in the groundwater environment that might have been due to the activities carried out which can be done after an environment state evaluation is completed. Given the fact that there exists a possibility of both cumulated impacts and exploitation-period related impacts, it seems to be sensible to make long-term monitoring tests.

POTENTIAL WATER SOURCES

Focus should be put on two essential issues, while one is analyzing the water demand of the process. Firstly, in case an exploitation is launched, necessity might arise for a significant water extraction in a little area (so-called cumulative intake), however, at the current, early stage ofprospecting and exploration it is almost impossible to indicate regions and areas of future exploitation. The second issue, that results from the necessity to collect a full amount of water in a mining plant before the fracturing process gets started, is the demand for a large amount of water in a relatively short period of time. In case of the exploitation in a single mining plant, having the area of a few hectares, from ten to twenty boreholes can be localized which will be subject to fracturing directly one after another. This condition requires that specific sources are indicated that will enable it to get water, however, the groundwater does not and should not be the only source of water supply.

The total amount of normal groundwater resources that are manageable as at the state of exploration of 31 December 2012 in Poland is around 36 million m³ per day, including 18.7 million m³ per day determined as disposable according to the procedure of the hydrogeological documentation for the area representing 56% of the Poland's territory (Fig. 5). The annual registered water intake to serve industrial and municipal purposes is around 1.58 billion m³, while the intake needed for coalmines dewatering is about 900 million m³ per year. Manageable groundwater resources that are currently being used are at the level of 19%, therefore, the reserves are ample. The amount of manageable groundwater reserves in a balance area constitutes basic information that is indispensible for a water economy balance to be created was well as for setting out the conditions for the use of drainage area water, and for a water-legal permit to be granted for the water intake. Thus, it is a tool which can guarantee that groundwater is not excessively depleted.

Nevertheless, in spite of the significant resource reserves, in accordance with the provisions of the Act on Water Law ("Ustawa z dnia 18 lipca 2001 r. – Prawo wodne"), groundwater as being water of the best quality should first of all serve the consumer needs of the society. Therefore, the assessment of the possibilities of using alternative sources of water supply for the purpose of shale gas exploitation poses a serious challenge now. Given the fact that the water used to prepare fracturing fluid does not need to comply with high quality standards, a few possible sources of its supply can be indicated. The most proper path of proceedings seems to be, first of all, cleaning the fluid that returns from the well and then using it again in the next process of fracturing in another borehole. With such a solution, the needs for water in the process is reduced as well as the amount of waste.

Moreover, in the hydraulic fracturing processes not only return fluid can be used, since also technological water of various types may be applied successfully, e.g. refrigerating water, water from biogas production plants, etc. Another issue worth consideration is the possibility of using purified waste water or so-called municipal water, i.e. water from a rain sewage system. In case of a favourable location, also water from a mining excavation drainage system can be used, and as regards the offshore zone, a possible use salt water is being considered. In addition, brines which are common in Jurassic levels are very much promising.

Therefore, it seems there are a lot of alternative sources of water supply for the purpose of shale gas extraction, but their formal-legal as well as regional conditioning requires some consideration, as long-distance transport of water is

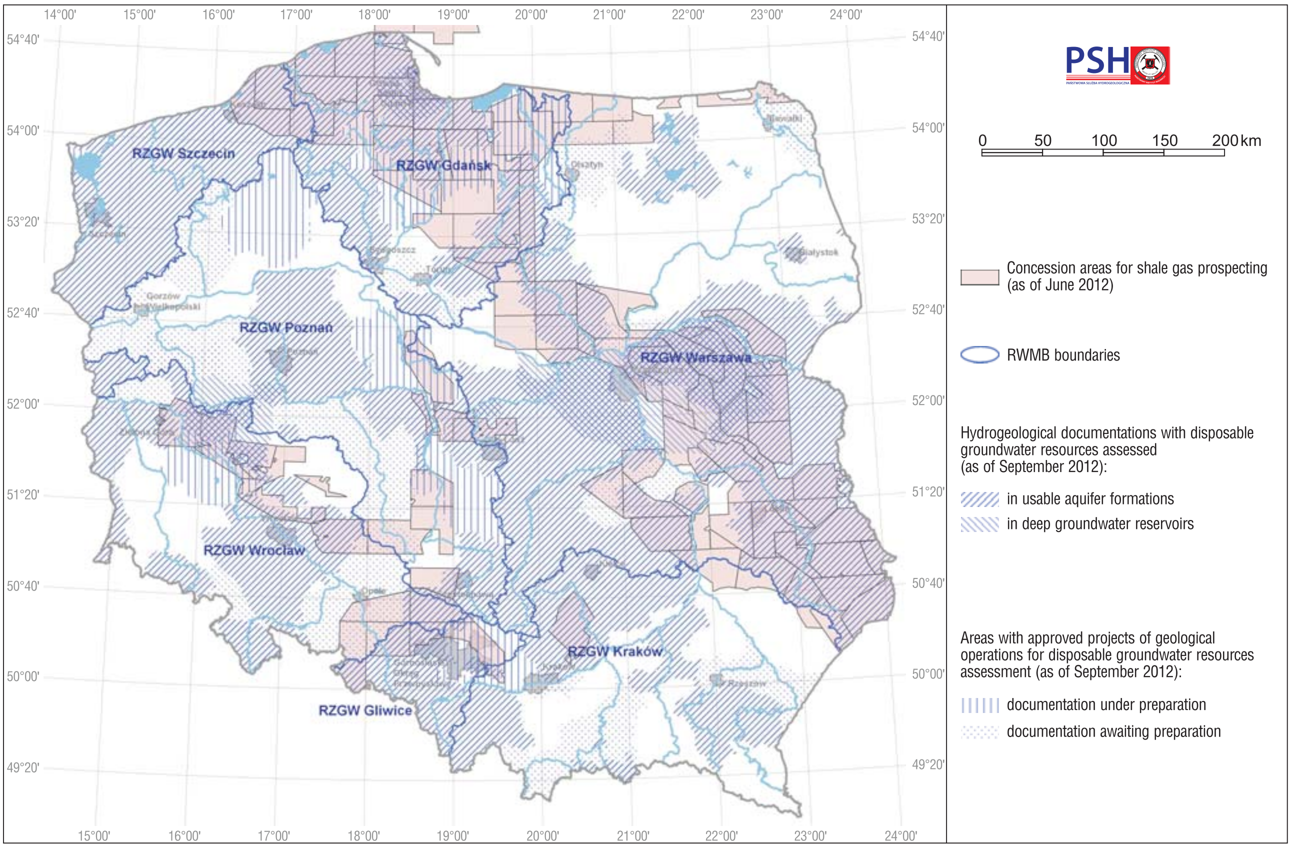


Fig. 5. The state of documenting groundwater resources in Poland in concession areas for shale gas prospection and exploration (Mordzonek et al., 2012)

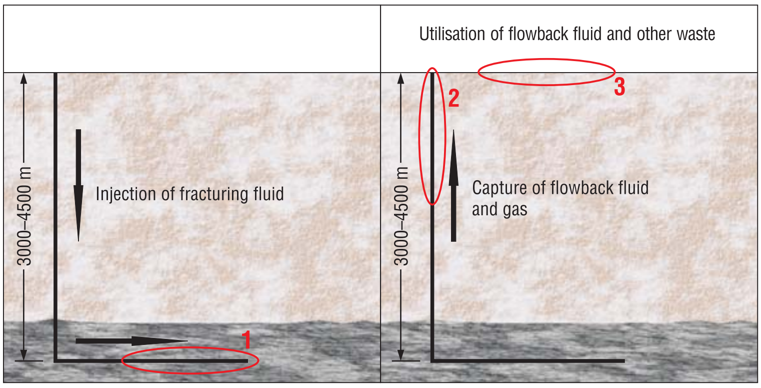


Fig. 6. A scheme of theoretical routes of pollutants migration (1 – from the horizontal section of well, 2 – from the near-well zone of its vertical section, 3 – from the surface)

not advisable. Preferably, at the stage when a decision is taken about the localization of exploitation work, a study of the possibilities of water supply for the purpose of the activity planned will be conducted, and possible diversification of water sources envisaged.

POSSIBLE CONTAMINATION OF GROUNDWATER

A separate group of problems, that are not of less significance than the water needs of an undertaking, constitutes the possibility of contamination of the groundwater environment in the area where exploitation work is carried on. Three potential routes of waste water migration to groundwater can be identified (Fig 6):

1 – from the horizontal section of well,
2 – from the near-well zone of its vertical section,
3 – from the surface.

If one takes into consideration the depth at which a deposit stimulation process is carried out in Poland (3000–4000 m), and also the significant thickness of insulating units in the overburden, including salt beds in a vast area, it seems to be practically impossible for pollutants from the vertical section of a well to penetrate to groundwater. Such a case can be considered only in terms of the presence of large dislocation zones that might provide migration routes for gas and fracturing fluid. The range of cracks that are formed during hydraulic fracturing is usually not longer that 100–200 m, so it is quite limited and what is important – before a decision about localization of the work has been taken, a detailed analysis of an orogene tectonic engagement is conducted so that the boreholes projected will not encounter any dislocation zones.

Another possibility of pollutant migration to groundwater should be looked into in terms of a well wrong structure or craftsmanship. A well screen adjacent zone may consists in this case, as in each drilling irrespective of its purpose, a potential route for technological fluid migration. However, when a well is properly made and tightness control principles observed a safe exploitation can be guaranteed.

Water-bearing horizons that lie near the land surface in the area where work is carried out might be exposed to

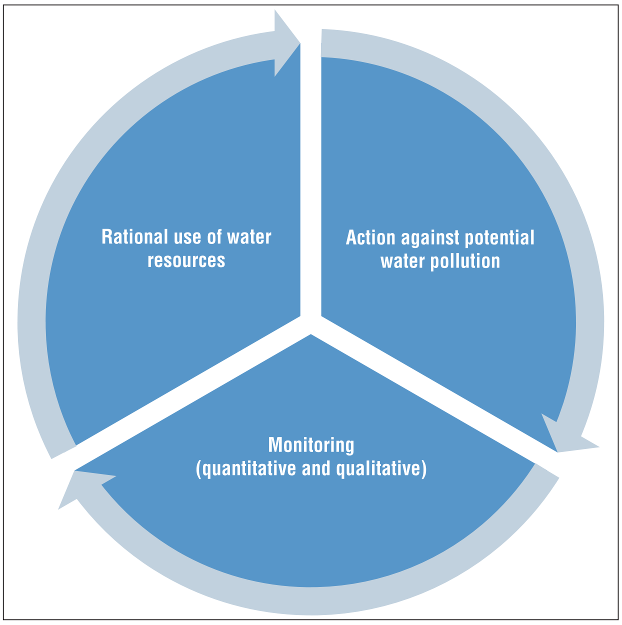


Fig. 7. The principles of rational water management in the shale gas production process

the risk of being polluted from the land surface. This may happen when a breakdown happens in the mining plant or the protection of the land surface is insufficient. However, there exist procedures in case such a situation takes place, and it is essential that the area of work is monitored. Control determination of some selected indicators of water quality and groundwater environment enables possible changes to be detected and prevention action taken or – if need be – of an intervention character.

SUMMARY

Given the specificity of undertakings related to prospecting for, exploring and possible exploitation of gas from unconventional resources as well as the technology being currently applied, one can say that water management is one of the key elements in the extraction process. Both the effectiveness of an activity pursued and its safety depend in a great measure on a rational water management in the project that covers both quantitative aspects (water demand) and qualitative ones. Taking actions which prevent any potential pollution and dedicated test monitoring constitutes an efficient tool that can guarantee safe exploitation (Fig. 7). Only with a complex water management system adopted in the process at its each stage, from preparatory work, drilling, fracturing, exploitation to the end of production and liquidation of a mining plant, it will be possible for the extraction activity to be conducted in a safe way on an economically recoverable scale without any consequences in the form of water state deterioration.

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