AGH DRILLING, OIL, GAS • Vol. 34 • No. 2 • 2017

http://dx.doi.org/10.7494/drill.2017.34.2.419

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MANY YEARS' EXTRACTION OF GROUNDWATER IN THE CONTEXT OF ESTABLISHED USABLE GROUNDWATER RESERVES***

1. INTRODUCTION

The use of groundwaters from intake wells for communal purposes is common because of its very high qualitative and quantitative stability as compared to the surface waters. Owing to the fact that the principal goal of water supply networks is providing water to the customers, the intakes should be maintained in high hydraulic efficiency and also long and failure-free operation. The starting point for the intake user is establishing the usable groundwater reserves, also understood as guidelines for the use of the well. Determining of these parameters ends the investment stage of building the well, and their values represent the capacity of the intake.

2. FACTORS INFLUENCING THE PROCESS OF ESTABLISHING USABLE GROUNDWATER RESERVES

The usable groundwater reserves are understood as admissible water consumption in a given production system, which should account for significant factors relating to the operation of the well and properties of the aquifer. From the user's point of view, the most important are technological limitations connected with the execution of the well,

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*** The work has been realization of a project within the BLUE GAS – Polish Shale Gas project "Environmentally-friendly and economically feasible technologies of managing water, waste water and waste in the process of shale gas production". Contract No. BG1/EKOŁUPKI/13

cost of water extraction, chemistry of water and environmental issues. Thus, apart from establishing the optimum productivity from the well, the correct economic and correct operation should be based on the established depression conditioning the operation of water intake systems. The stability of the physicochemical composition of water extracted on a certain level is equally important [1].

Technical condition of the well

Wells are one of the most important factors deciding about the magnitude of water extraction. The type and diameter of the applied filter correlated with the properties of the aquifer (filtration coefficient, conductivity), determine the amount and rate of water flow to the well. Determining proper flow rate determines correct sand removal from the aquifer and significantly limits the colmatation of the well and the near-filter zone. Analogously, the quality of performing the well, especially the selection and performing of the gravel pack and the degree to which the well has been activated, significantly influence the hydraulic losses, and so the hydraulic efficiency of the well [4, 6].

The type and quality of material of the well filter should provide protection against the corrosion, which may significantly shorten the life of the well.

Depending on the chemical composition of water extracted from the aquifer, materials used for the well, especially for the filter, and also water flow rate through the filter, the corrosion processes significantly intensify. This leads to the weakening of the construction of the filter and filter column as a result of their, e.g. mechanical erosion (cavitation, abrasion) [2, 5]. Weakening of the filter construction may cause more serious failures, e.g. sanding up of the well in the course of its operation or shorter the filter section by the caving or crater in the well.

Bridge filters, commonly used in the 1980–1990s, had very low resistance to corrosion; they were performed from carbon steel and were coated with paint or zinc. Small breaks in the protecting layer made during the transport or installation of the filter in the well started a quick corrosion of the filter walls from which large perforations were formed. This caused moving of considerable parts of the pack and water-bearing material inside the well, consequently filling it up.

Moreover, the diameter of the casing above filters, especially in the interval between the surface and the pump aggregate level in the well can significantly limit its optimum choice, and so the efficiency of the well. A similar effect on the choice of technical parameters of pump aggregate has the ‘verticality’ of the well. Because of the necessity to stick to the required clearings between the pump aggregate and the internal wall of the casing above filters, the choice of the pumps available on the market is also limited.

Economic aspect of water extraction

From the user's point of view, the economic aspects of water extraction are very important. The magnitude of established usable reserves will be decisive for the number of wells to be drilled to fully cover the water demand. The pump aggregate management is also important. The technical parameters of pump aggregates are selected mainly on the basis of its efficiency, i.e. yield of the well and height at which it has to lift water. The change of these parameters results in the shift of point of work of the pump and results in, e.g. higher electrical energy consumption or limiting of production capacity (drop of efficiency of the pump), thus increasing the cost of water extraction.

Environmental issues

The groundwater extraction causes local changes in the natural flow of groundwaters, and this has frequently impact on the physicochemical properties of the extracted water. This phenomenon has been extensively described in scientific literature; it can be relatively easily diagnosed through regular evaluation of the produced water. In the case of too intensive water production the properties of water may change during the production processes. The change of physical properties of the extracted water is illustrated by the exceeded flow rates on the filter – water becomes opaque and the well is being sanded up. The changes in the chemical composition of water are most frequently caused by the changed flow directions or by higher infiltration. Depending on the geological conditions and intensity of water production, there may be observed an inflow of contaminated waters from the subsurface zone [8] or waters of considerably different physicochemical composition, from lower layers, e.g. brines [3].

The regional use of groundwater reserves is a serious factor deciding about how to establish parameters of production intakes. This mainly applies to areas where waters are managed intensively. They are protected against excessive extraction by administrative decisions which define allowable production levels to provide environmental protection to the groundwater environment. For the sake of limiting the regional cone of depression in the Łódź area during intensive water production for the needs of textile industry in the 1960s, through the decision of the Commission for Hydrogeological Documentation the admissible lowering of the dynamic water level in the Upper Cretaceous and Lower Cretaceous wells was set on the level of +100 m a.s.l. Permanent lowering of the groundwater level also influenced the production parameters of the wells (lowering of the water table, increased depression). After textile industry collapsed in the 1990s the water level started to restore, which has been proved by observations in the water supply wells. The restoring of groundwater horizons of the Upper and Lower Cretaceous are presented in Figures 1 and 2.

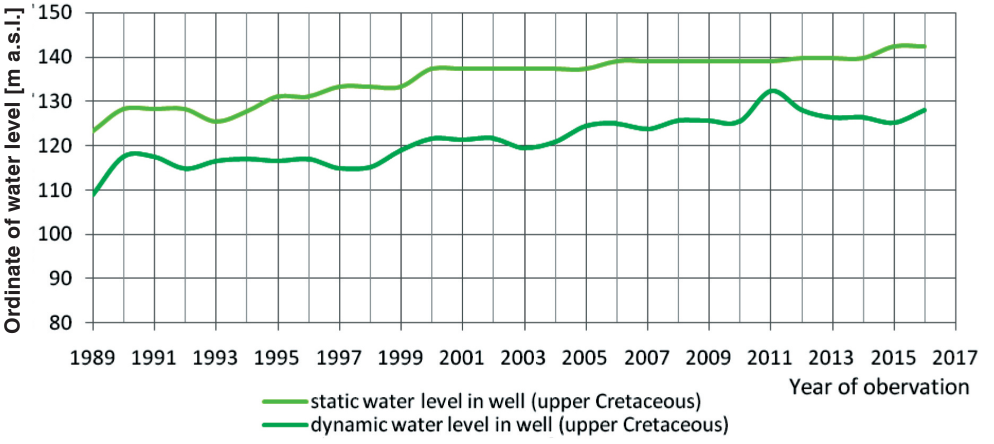

Fig. 1. Changes of static and dynamic water level during extraction of Upper Cretaceous wells in the years 1989–2016.

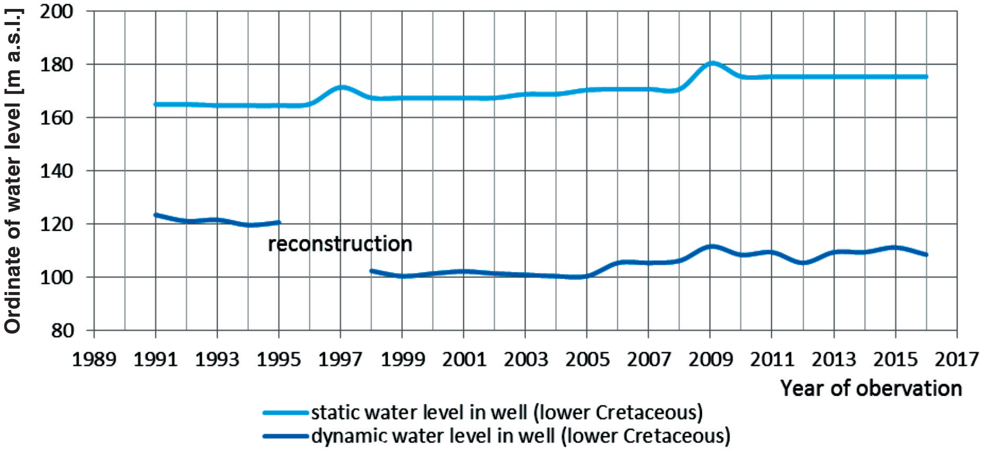

Fig. 2. Changes of static and dynamic water level during extraction of Lower Cretaceous wells in the years 1989–2016.

3. SCOPE OF INVESTIGATIONS OF THE TECHNICAL CONDITION OF WELLS AND HYDROGEOLOGICAL OBSERVATIONS FOR ESTABLISHING USABLE GROUNDWATER RESERVES

Establishing production parameters of wells is based on the results of tests in the well and hydrogeological observations. The scope and type of diagnostics should be personalized taking into account the best recognized conditions of water flow in a given well and the technical condition of the well [7].

While determining hydraulic parameters of wells it is very important to properly conduct the tests and well interpret the results of pump tests, especially determine the stabilized dynamic and static water table. They are a reference point when defining the depression for the assumed pumping capacity. The regional changes of water level, e.g. Łódź depression, influence the results of observations by lowering the groundwater level. Another condition frequently limiting the scope of investigations is the time of observations of groundwater level. The three-level pumping measurement performed in identical spans of time does not suffice to determine extraction parameters of the well with empirical formulae. Especially in observations conducted with higher pumping grades (higher yield), when the dynamic water level is not stabilized, a lower depression value is taken. With thus assumed results, a too high yield of extraction can be established. With time this may cause a growing depression and so the higher water flow rate to the filter (turbulent movement).

Another important element is the correct identification of the technical condition of the well after it has been performed and during controlled exploitation. Such diagnostics provides numerous reliable pieces of information about the depth of the well, zones from which water flows to the filter, degree of its colmatation or the gravel pack or progress of corrosion processes, etc. The results of recognition of the technical conditions shall help establish the real technical and hydrogeological conditions of the intake, so that the interpretation refers to the active parts of the filter or actual depth of the well [9].

4. RESULTS OF MANY YEARS' OBSERVATIONS OF WATER EXTRACTION IN SELECTED WELLS IN THE ŁÓDŹ AREA

Establishing lower reserves than in reality may stem from insufficient activity of the well after it has been performed, limited diagnostics, lack of appropriate technological solution, equipment for bringing water to the surface or lower water demand. It also frequently results from the regional variation of geological and hydrogeological conditions as in the case of the Upper Cretaceous well operating within the well of ZWiK Sp. z o.o., localized in the NE part of Łódź, where the reserves were established in a few stages, determining their periodical durability. The observation was based on at least 10 years of operation of the intake (Tab. 1). The well was performed in 1962 without filters; it produced water from the Upper Cretaceous marly rocks. The initial reserves established after drilling the well constituted 40% of reserves assessed on the basis of observations. The decision was also dictated by the technical limitations imposed by parameters of then available pump aggregates, the size of which (and so the output) were limited by the inner diameter of the intermediate casing column ϕ 14". After 16 years of exploitation, for the sake of increasing the productivity, there were performed hydrogeological tests (measurement pumping, measurement of depth of the well), during which 20 m of caving material was removed from the filter column. As a result of this and the applied new and more efficient pump aggregates, a 135% productivity of the well was established for almost the same depression value. Owing to the regional lowering of water table, the durability of these production parameters was defined for 10 years. The controllable extraction from the well could confirm the stability of the established reserves (Fig. 3). With time the water table was found out to increase systematically.

Table 1

List of established groundwater reserves in the Upper Cretaceous well in the NW part of Łódź (well ZWiK sp. z o.o.) in the years1964–2016

Year	Established reserves		Unit yield q [m^2/h]
	Yield Q_e [m^3/h]	Depression s_e [m]	
1964 (established) (assessed)	85.0	9.10.2017	9.341
	210.91	22.0	9.587
1980 (durability 10 years)	200.0	8.0	25.000
1990 (durability 10 years)	200.0	7.20	27.778
2000	200.0	12.0	16.667
2016	191.0	14.0	13.643

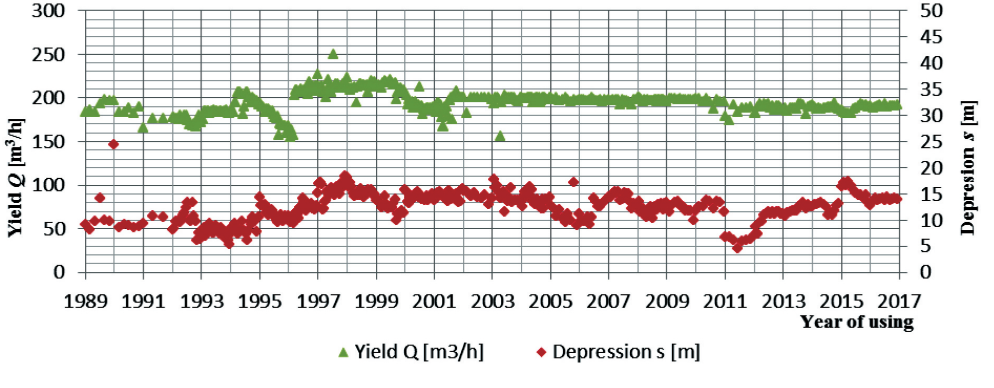

Fig. 3. Changes of the yield and depression in the Upper Cretaceous well in the years 1989–2016

Depression observed in the well in the years 1980–2000 was referred to a much lower water level, which failed to restore during the observation time (72 hrs of idle time of the well), hence the unit yield was established on a high level.

The changes of the yield and depression in the years of observation show to the stability of established usable groundwater reserves and that they are maintained in the conducted extraction system (cyclic work 18 hrs/d).

The increased water demand frequently becomes a cause of high or even overestimated reserves, which cannot be maintained over a longer period of time. The lack of systematic control of the extraction may lead to the lowering of work parameters of the well, and in further perspective, its 'technological death' (by the cratering material in the well and corrosion of the construction leading to the collapse of the well).

The Lower Cretaceous wells, extracted water from fine, weakly-consolidated sandstones disposed at considerable depths, are a significant source of water supplied in the Łódź area. Depending on the localization, the top of these formations can be found at a depth of 280 to 750 m b.s. For instance, a well used for the needs of a water supply network, performed in 1991 had a failure after 5 years of operation. The lower part of the filter was filled with material because the filter was made of a too weak material which did not withstand the crushing forces (perforated filter with a bridge filter on it). The filter made of two different types of steel was highly vulnerable to corrosion.

In 1998 a decision was made to workover the well. After removing the previous filter, a new one was installed. It had a continuous fracture, was shorter by about 2/3 from the old one and had a high unit yield of q_f = 19.7 m^3/h per 1 r.m. of filter. This solution allowed for carrying production only in the upper part of the aquifer, insulated with a package of weakly permeable mudstones. The usable groundwater reserves for the new construction were established on the basis of a short 4-grade pumping for unsteady state assumptions (Tab. 2).

Table 2

List of established reserves of the Lower Cretaceous well in the southern part of Łódź (well ZWiK Sp. z o.o.) in the years 1991–2016

Year		Established reserves		Unit yield q [m^3/h]
		Yield Q_e [m^3/h]	Depression s_e [m]	
1991		300.0	42.8	7.009
1998	(after workover)	215.0	59.3	3.626
	(production)	165.0	64.0	2.578
2000	(production)	130.0	66.0	1.969
2016		135.0	61.5	2.195

The introduction of the worked over well to continuous production with the established yield resulted in the lowering of water table below admissible values (+100.0 m a.s.l.), visible drop of unit yield and higher cost of water extraction (necessity to use high power pump aggregates). Only after 2 years of production too high production parameters could be recorded. For the sake of protecting the well against excessive exploitation, a safe level of its work parameters was assumed, as proved by 16 year observations presented in Figure 4.

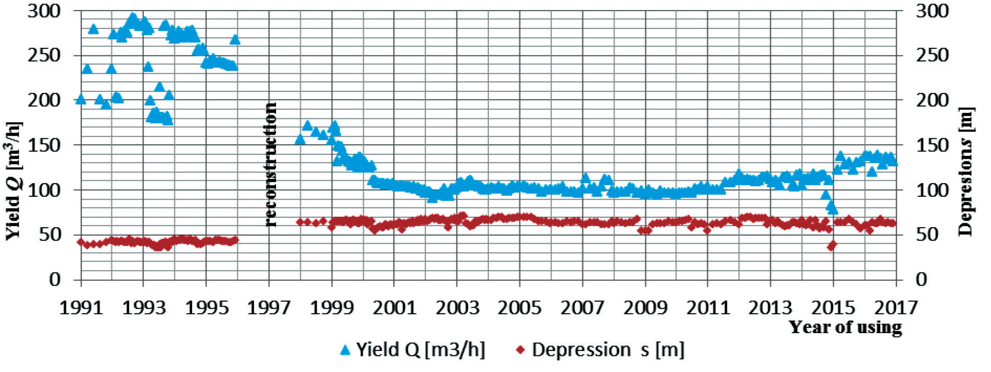

Fig. 4. Changes of the yield and depression in the Lower Cretaceous well in the years 1989–2016

5. SUMMING UP AND CONCLUSIONS

This paper was aimed at showing that a long lasting exploitation of wells requires cross validation of production parameters after a certain time of using the wells. Among the simple methods for observing the parameters of well's operation is the many years' controllable exploitation, thanks to which one can evaluate the profitability of the production, stability of chemical composition of produced water, or impact on other water intakes working in the given work conditions. A good production practice shows to the necessity to conduct simultaneous observations of hydrogeological parameters (yield of the well, depression, hydraulic efficiency of the well), technical condition of the well and quality of extracted water (physicochemical parameters). This will allow for establishing an optimum yield and depression for the assumed exploitation system (continuous operation, co-operation of wells and the aging rate).

It was also stated that the changes of regional hydrogeological conditions and also all changes in the construction of the well necessitate periodical updates of previously assumed exploitation parameters and evaluation of their durability during the operation of the well. The conducted observations of work of the groundwater intake also create basis for the evaluation of regional water use trends (development of the depression cone, the impact value and restoring of the aquifer reserves).

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