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ARTIFICIAL RECHARGE AS AN ALTERNATIVE METHOD FOR AUGMENTATION OF GROUND WATER SUPPLY IN POLAND

The methods of research works, which have to be performed before the localization of a new intake of artificial ground water, were discussed. Different modes of artificial recharge have been described, a special attention being given to infiltration tanks. The criteria are also given according to which the localization of a new intake of artificial ground water is to be chosen.

1. INTRODUCTION

Retention and artificial recharge of ground water have become in recent years one of the most important problems of water resources management. Considering the facts that water demand is continuously increasing and that discharge of ground water is constant, some measures should be undertaken to use surface waters for artificial ground water recharge.

The principles of this process have been known for a long time, being employed on a large scale in highly industrialized countries. In Poland the artificial recharge of ground water is limited to several municipal water intakes. From the estimated data it follows that in order to meet the expected water demand the exploitation of a number of ground water intakes located in river valleys should be extended in the nearest years.

2. METHODS OF ARTIFICIAL RECHARGE

Artificial recharge of ground water consists of supplying water (most often surface water) into void soil pores existing in rocks. The purpose of a consciously realized artificial recharge is to equalize temporary and regional fluctuations in water exploitation and to improve the treatment of surface water by soil filtration. According to GROMEYER and HERRMANN [12] the artificial recharge can be generally divided into three groups:

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— continuous replenishing of resources; the average level of ground water remaining unchanged,

— filling of previously exhausted spaces,

— filling of existing soil pores for water storage.

Artificial recharge of ground water can be realized by several methods:

— point method, by pumping of water through injection wells, surface method, by flooding of the defined land areas,
flooding of natural land depressions,
construction of inflitration trenches,
construction of infiltration basins.

The method used most often is the construction of infiltration basins. The utilization of land depressions being limited, ground flooding is not always possible. Construction of infiltration trenches for small size water intakes situated in the upper course of rivers is the most economical technique giving the possibility of a natural flow of water through the trench, due to relatively high slopes. Recharge by means of injection wells is most seldom employed because of high costs related to their constructions and to preliminary water treatment.

3. GROUND WATER RECHARGE THROUGH THE INFILTRATION TANKS

The artificial infiltration through tanks is the safest and most economical method of ground water recharge. Its principal advantages are the following:

— it allows to use surface waters with unfavourable physical and chemical parameters,

— the water intake capacity can be maintained at the required level

— the obtained ground water is characterized by high stability of chemical composition and small temperature variations,

— a continuous exploitation can be maintained even at a casual pollution of the surface water source, and periodic stoppage in water uptake for the recharge,

— low maintenance costs of infiltration facilities.

Artificial recharge through tanks is, however, limited by the thickness of the impermeable layer at the surface which should be smaller than 3–5 m. Besides this fundamental requirement there is also a number of other conditions which will be discussed later.

An essential disadvantage of the artificial recharge is that the bottom of tanks should be cleared to remove the deposits accumulated. From the technical point of view the bed cleaning of infiltration basins is a relatively simple but labour consuming process. Since in Poland an efficient equipment for deposit removal has not been developed yet, the basins are cleaned manually. After HUISMAN [13] the entire artificial recharge process from the uptake of surface water to the exploitation of artificial ground water can be divided, into 6 stages:

— surface water uptake,
— flow,
— preliminary treatment,
— infiltration,
— water filtration between the supply and drainage contours,
— exploitation of artificial ground water.

In each of these stages there appear a number of phenomena which change the run of a given stage.

Surface water used for artificial infiltration most often comes from rivers, and in a few cases from lakes. The uptake of lake water is more advantageous, because it contains smaller amounts of suspended matter than in river water. At this stage the essential problem is to obtain water with turbidity as low as possible. Water is usually taken from a plaster cove constructed purposely, or from a drain installed under the river bed, especially in the case of a mountain river. Surface water is then transported through a pipeline or open channel. During the flow through the pipeline no process deteriorating the water quality takes place. Sometimes some substances are precipitated, this process however, is harmful for the pipeline alone.

During water transport through the open channel the primary water treatment can be initiated. It is of a great importance that the water flow be as slow as possible in order to cause precipitation of suspended substance. In some cases supplying trenches are planted with rush or cane to intensify biological self-purification. The application of the preliminary treatment stage is limited to cases, when surface water used directly for infiltration could cause clogging of the basin bottom or the infiltration of undesirable substances from the ground water. In such cases the simplest and most inexpensive methods of water treatment are used. Suspended matter is removed in sedimentation basins, and water before entering them is subject to coagulation (water intake in Kraków). Deferrization and oxygen enrichment take place in multi-stage waterfalls constructed in the water stream. The application of one of these methods or both of them allows to achieve the required grade of purification of the surface water. Infiltration — the main and most complex stage of artificial recharge — depends on many factors, but this process can be presented in the form of 6 infiltration phases [19].

In phase I water is supplied to a cleaned basin. The accumulation of water in the basin is accompanied by formation of ground water table in basin area.

When this table reaches the basin bottom, the infiltration rate decreases and the water level in the basin distinctly rises. This is phase II, and appears also when ground water table does not reach the basin bottom and water is accumulated in the basin as a result of a thin layer of sediment formed on the basin bed. During phase III the infiltration rate remains relatively steady. At the end of this phase it decreases due to the progressing clogging of the basin bottom.

Phase IV begins when hydraulic link between the basin and ground water is broken. In the case when there is no hydraulic link from the beginning of the infiltration process, phase IV follows directly phase II. During phase IV infiltration diminishes gra-

dually and then the supplementation of the basin is stopped. This is the starting moment of the phase V,i.e. the emptying of the infiltration reservoir. When the water remaining in the basin percolates through its bottom and the sediment on the bed is dried then phase VI, i.e. the cleaning of the basin and restoration of its infiltration ability can be started.

The most advantageous phase for the artificial recharge process is the phase III. Unfortunately, its duration is not long, and in certain water intakes with a deep ground water table it does not appear at all.

While discussing the infiltration, the process occurring in the infiltration basin should be mentioned. Water before filtering into the soil remains in the basin for a certain time. If it contains a sufficient amount of oxygen, the process of organic matter mineralization proceeds efficiently. Oxygen is supplied mechanically at waterfalls or by plant organism living in water. The remaining oxygen is usually lost during the infiltration process through the ground, and water reaching the ground water level is usually oxygen-free. Reduction processes occurring in the anaerobic medium result in clogging of filters in the operating equipment [13]. Then, if there exist an aeration zone under the basin bottom, the water infiltrating from the basin has some chances to be enriched with oxygen. However, from the artificial recharge technique point of view the presence of an aeration zone reduces the rate of water infiltration.

The phase of water movement between the supply and catchment area is the least known part of the artificial recharge process. Most often the only data available concern the water in the basin and the water extracted, and are used to draw conclusions regarding the infiltration water behaviour.

In all the cases several processes though with varying intensity, take place at different intakes, namely:

— the temperature of infiltrating water approaches that of natural ground water.

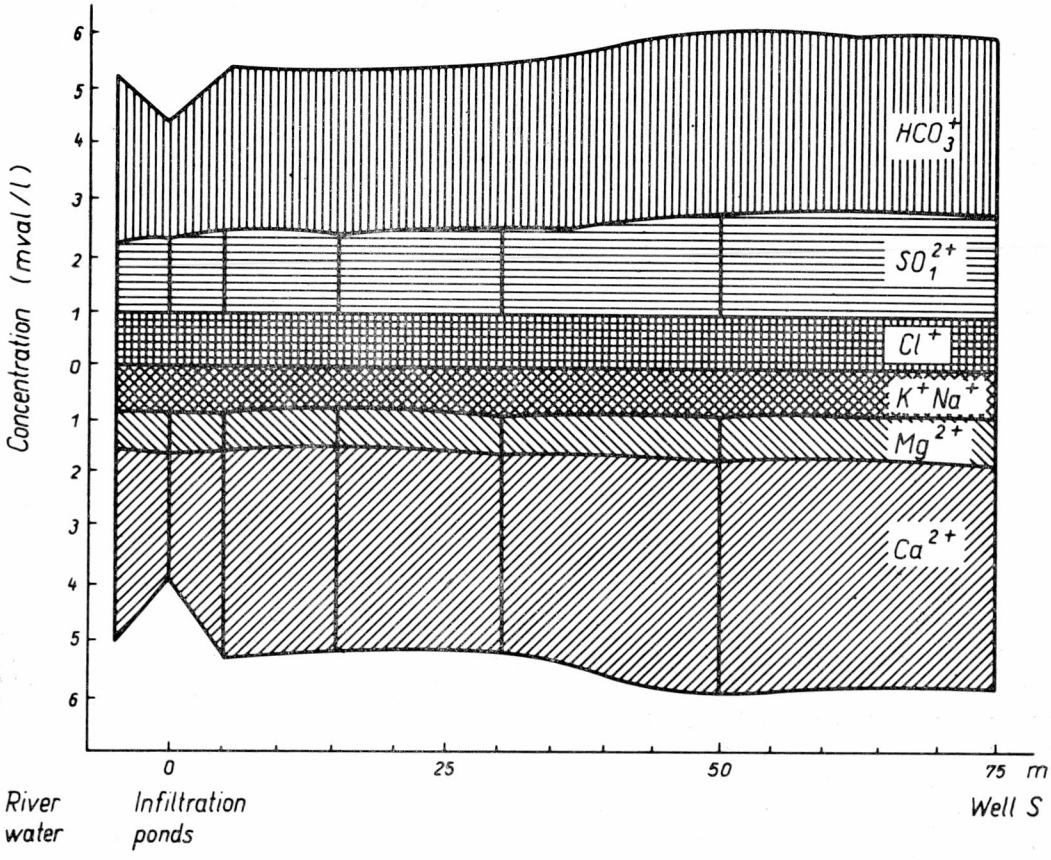
— during the flow of water ion exchange with natural water and with rocky environment take place,

— with the increasing length of flow path biological processes in water decrease and the number of bacteria diminishes,

— the amount of suspended matter in water decreases,

— the amounts of some soluble salts (chlorides) penetrating the aquifer are unchanged.

An interesting example of the change in the chemistry of river water since its uptake till the moment it is taken through wells is given by Błaszyk and Pawuła [4] for one of Polish artificial ground water intakes. The characteristic bend of the curve is interpreted by them as a drop of mineralization in the basin (fig. 1). The authors have observed an initial reduction of iron content in water flowing from the basin to the well, followed by a sudden increase of iron content in river water. This is due to the presence of a peat/mud zone. The filtration parameters of the layer between the basin bottom and the wall can also be affected by water flowing through it. According to Casati [7] the velocity of initial infiltration in Muttenzer Hard ponds was 35m/day and after 3.5 years decreased to 7.5 m/day. After the filtration layer had been flushed, the velocity became steady, with the value of 16.5 m/day. These changes are due to the migration of fine sand fractions and



Characteristic variatins in the chemical compositions of water
Charakterystyczne zmiany w składzie chemicznym wody

clogging of pores caused by water flowing quickly through permeable sand during the infiltration process. After the flushing the infiltration velocity reaches an average value, depending on the type of ground, no further displacement of fine sand fractions takes place, and a stabilized condition is created. The artificial ground water is drawn by means of wells or drains, the latter being used seldom and for small capacity intakes. What is essential in planning an exploitation method is to locate water collecting facilities in such a way as to prevent excessive leakage of the infiltrated water into the aquifer.

4. METHODOLOGY OF RESEARCH WORK (PRECEDING THE CHOICE OF LOCATION FOR A NEW INTAKE OF ARTIFICIAL GROUND WATER)

The above-mentioned aspects of artificial ground water recharge indicate that it can be numbered among difficult and complex problems. A comprehensive recognition of the hydrogeologic structure intended for utilization secures breakdown-free utilization of the water intake. From the literature published so far it appears that no uniform methodology of research work preceeding the location of a new intake with artificial recharge has been developed. The construction of existing intakes was always preceded by certain studies, but they had no general character. Such procedure was justified during the first years of construction of water intakes with artificial recharge, because each of them was constructed in different conditions. In view of the current necessity of constructing a great number of such intakes, an attempt should be made to determine a methodology of research work.

We assume that:

— before a new water intake with artificial recharge is localized, some work forecasting the basic operational parameters of the intake should be carried out,

— due to a great number of intakes designed, the hydrogeological conditions are similar in groups of intakes,

— the constantly growing experience in intake construction allows to give more and more precise methodology for designing a new intake.

A fundamental condition for construction of an efficiently operating intake with artificial recharge is the choice of suitable hydrogeological structure. This postulate can be realized if determined research works are performed; we divide them similarly to DOODY's conception [9], into three stages:

I — hydrogeologic and geologic survey,

II — detailed hydrologic and geologic studies,

III — model studies of a selected filtration area in order to determine and forecast operating conditions.

Beginning with the stage I, certain criteria of a hydrogeological unit suitability for basin-type recharge should be taken into account. They can be divided into three groups:

— geological and hydrogeological criteria:

a) voids existing in rock situated not deeply, to be filled with water,

b) the presence of an aquifer with good filtration parameters,

c) the absence of thin slowly permeable and impermeable layers between the basin bottom and the saturation zone,

d) the absence of compounds in the rocky medium whose displacement during the infiltration process could deteriorate the quality of water, or clog internally the aquifer,

— hydrological/metrological and morphological criteria:

a) the proximity of a source of surface water with an established quality, and assuring an adequate flow,

b) weather conditions not promoting an excessive evaporation of pond water in summer or a complete freezing in winter,

c) suitable land configuration protecting the water intake against spring floods,

— technical/economic criteria:

a) possibility of occupying a sufficiently large area of land,

b) suitable geologic/engineering conditions,

c) distance from the energy sources and transportation network,

d) possibility of laying out the facilities ensuring the required rate of water infiltration and a sufficiently long path, and adequate time of water flow through the ground [13],

e) low construction and operations costs of an infiltration-type water intake, compared to those of a conventional surface water treatment plant.

It should be noted that the investment profitability is of principal importance for the development of infiltration-type water intakes. The hydrological and geological survey (stage I) should allow to determine the geological structure of the area considered and water supply sources. The works necessary at this stage comprise: analysis of historical records, field work, elaboration of a general balance sheet for surface water, and a preliminary evaluation of surface and ground water quality.

The stage II, with the available results of stage I, serves for realization of detailed hydrological and hydrogeological studies and examinations. The first two stages should provide the following detailed information concerning

— form and spread of the aquifer and of the strata lying above it and below,
— thickness and variations of these strata,
— directions and inclination angles of geological strata,
— tectonics of the area,
— hydrogeological parameters of the aquifer and the top layer,
— graining of permeable layers,
— ground and surface water regime,
— existence of sources which could endanger the quality of ground and surface water,
— quality of surface water intended for artificial recharge,
— forecasts regarding the chemical composition of artificial ground water.

The two stages do not only supply arguments for a given location, but also give sufficient data necessary for the construction of a model simulating the filtration area investigated, i.e. for stage III.

The stage III comprises model studies of water exploitation and recharge for a given infiltration area. Mathematical model of the infiltration area allows to evaluate the range of alternative solutions and selection of an optiumum version from the technical and economic point of view.

Model studies enable in particular:

— evaluation of hydrogeological parameters, which have not been obtained by field works, and verification of the parameters related to the whole structure represented by the model,

— complete evaluation of water system interrelations,

— selection of the rational (efficient) method of artificial recharge and water exploitation, and determination of the operational parametres,

— correct localization of recharge and exploitation facilities,

— determination of the extent of recharge and exploitation influence,
— estimation of the maximum operational resources,
— evaluation of the degree of water contamination by pollution sources.

After completion of the works in stage III, the construction of a selected variant in the area determined can be started. If during the construction of a water intake new data, differing from those assumed in previous stages, are obtained the filtration area model can be easily corrected, and a new most favourable variant searched for.

We hope that the suggested outline of methodology of studies prior to localization of a new water intake with artificial recharge will be continuously expanded and supplemented due to the groving experience in infiltration system design. In Poland the solution of the problem of water shortage for municipal and industrial supply is very urgent since it prevents the economic development.

One of the remedies to increase water resources and to meet the demands in a short time is the construction of infiltration water intakes. This type of intakes will be able to use surface waters which are of waste quality.

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SZTUCZNE WZBOGACANIE JAKO SPOSÓB ZWIĘKSZENIA EKSPLOATACJI WÓD PODZIEMNYCH W POLSCE

W artykule zaproponowano metody prac badawczych, które należy wykonać przed lokalizacją nowego ujęcia sztucznych wód podziemnych. Brak wody na cele komunalne i dla potrzeb przemysłu grozi poważnym ograniczeniem rozwoju gospodarczego kraju. Jednym ze sposobów szybkiego zwiększenia ilości wody i zaspokojenia w krótkim czasie zapotrzebowania na nią jest budowa ujęć infiltracyjnych. Dzięki temu będzie można wykorzystać wody powierzchniowe, tracone dotychczas bezpowrotnie.

KÜNSTLICHE ANREICHERUNG ALS ALTERNATIVE EINER GRÖSSEREN NUTZUNG DES GRUNDWASSERS IN POLEN

Der Beitrag beinhaltet Vorschläge zum Versuchsprogramm der einer Lokalisierung neuer Grundwasserfassungen — die künstlich angereichert werden — vorangehen sollte. Die Wasserknappheit für kommunale und industrielle Zwecke, bedroht eine reibungslose Weiterentwicklung der Wirtschaft. Als praktisch einzige Alternative ist die schnelle Beschaffung größerer Wassermengen von entsprechender Qualität zu nennen. Dies ist aber nur durch Fassung der künstlich angereicherten Grundwässer möglich. Auf diese Weise können Oberflächenwässer, die bisher nutzlos abfliessten, erfasst und genutzt werden.

ИСКУССТВЕННОЕ ОБОГАЩЕНИЕ КАК АЛЬТЕРНАТИВА РАСШИРЕНИЯ ЭКСПЛУАТАЦИИ ПОДЗЕМНЫХ ВОД В ПОЛЬШЕ

Предложена методика исследовательских работ, которые необходимо выполнить прежде чем указать место для нового каптажа вод из искусственного подземного водоема. Недостаток воды для населения и для промышленности может стать серьезным препятствием для экономического развития страны. Единственным способом увеличения водных ресурсов и удовлетворения растущей потребности в воде является построение инфильтрационных водозаборов, в результате чего может стать возможным использование поверхностей воды, которая до сих пор теряется безвозвратно.