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On the feasibility of controlled overpumping in the Nile Delta, Egypt

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In the Nile Delta, Egypt, by applying so-called controlled overpumping, it is possible to obtain considerably higher yields from many drilled wells without danger of the increase of pumping water salinity.

U delti Nila, Egipat, mogu se pomoću tzv. kontroliranog prekomjernog crpljenja postići znatno veće izdašnosti mnogih bušenih bunara bez opasnosti od povećanja slanosti crpljene vode.

INTRODUCTION

Long ago, in the early sixties, the author spent two years in Egypt employed by a Yugoslav company as a resident hydrogeologist for several ground-water development projects. Ever since the completion of this work, the author has intended to publish an idea related to the largest project, involving 55 Production Well Stations in Delta Region, which is the subject of this paper, but this plan has not materialized so far. This topic combined with another one were studied and prepared for presentation that took place at the 27th International Geological Congres, Section 16 — Hydrogeology, held in Moskow in 1984, but of both topics only a short abstract has been regularly published (Šarin, 1984).

The Delta is a triangle-shaped area with sides 200 to 250 kilometers long and with Cairo, Alexandria and Port Said at its vertices (Fig. 1). Fresh water for irrigation is indispensable for the existence of this sole granary of increasingly populated Egypt. The Delta has enaugh water in later summer owing to flood stages of the Nile and a sophisicated system of irrigation dating back basically to ancient Egypt, to pharaoh times. In the other seasons, the augmentation of irrigation water means the increase in crop yields and in the number of harvests. The only source of additional irrigation water is the underground, very rich in fresh ground water. Probably the highest recorded yields from wells drilled in alluvial deposits were achieved in the Nile Delta and that water is easily available.

The paper deals with a possible increase of the already high effeiciency of production wells in the Nile Delta by their cautious overpumping with a constant control of water salinity.

HYDROGEOLOGIC CHARACTERISTICS OF THE AREA UNDER STUDY

During Quaternary the Nile filled its Delta with up to several hundred meters of sand and gravel with 5 to 35 meters thick cover of clayey silt forming an extensive semiconfined aquifer. The aquifer is saturated with fresh water lying above saline water. The fresh water lens has an extraordinary shape (Fig. 1). Namely, beside its natural thinning out as it approaches the sea, it is also very thin near Cairo although the piezometric pressures are the highest there. The underlying saline water in the south, after Galović (1958), is in fact Neogene connate brine.

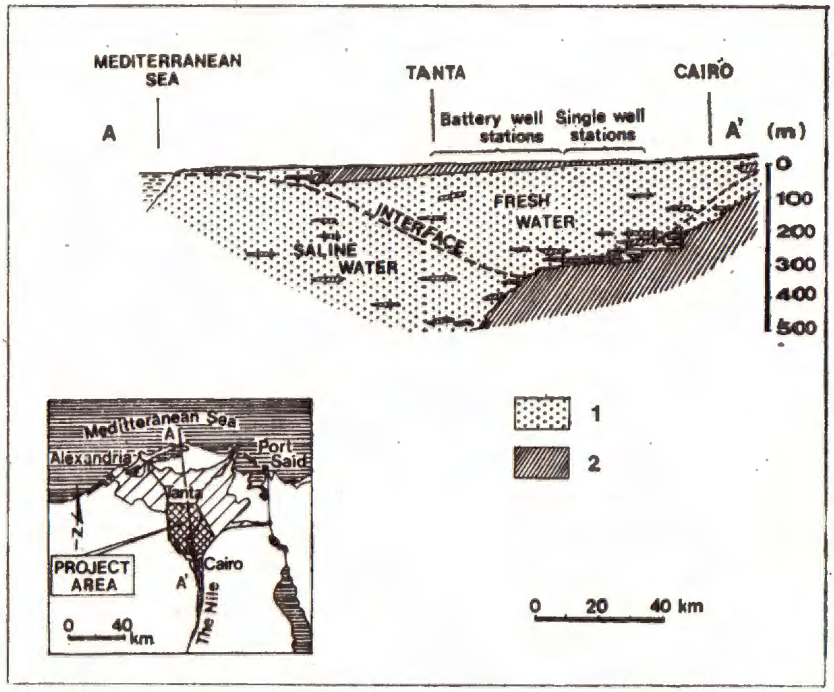

Fig. 1. Longitudinal hydrogeologic cross section through the Nile Delta. 1 — sand and gravel, 2 — silt and clay (after Galović, 1958).

Sl. 1. Uzdužni hidrogeološki presjek kroz deltu Nila. 1 — pijesak i šljunak, 2 — prah i glina.

The rainfall is scarce. The annual quantity varies from 0.18 meters on the Mediterranean coast to 0.03 meters near Cairo. The aquifer is recharged practically only by the Nile through a network of its branches and irrigation canals. The flood stages of the Nile are soon followed by high piezometric pressures in the aquifer lasting from late summer to early autumn. The piezometric pressures vary on the average about 2 meters a year, being 1 do 4 meters bellow land surface in the southern Delta, but the pressures and depths decrease in the seaward direction.

Through the aquifer or, more exactly, through the cross section passing aprpoximately by the town of Benha, i. e. the boundary between battery and single well station areas (Fig. 2) along the piezometric contour line of 9 meters above sea level in 1958, an average of 58 million cubic meters of fresh water per day flew toward the natural discharge area, toward the Mediterranean Sea (Z a g h l o u l, 1958).

In the upper part of the Delta, where single well stations are situated (Fig. 2), the aquifer transmissivity obtained from partially penetrating wells ranges approximately between 5000 and 8000 square meters per day, resulting in yields as high as 400 liters per second.

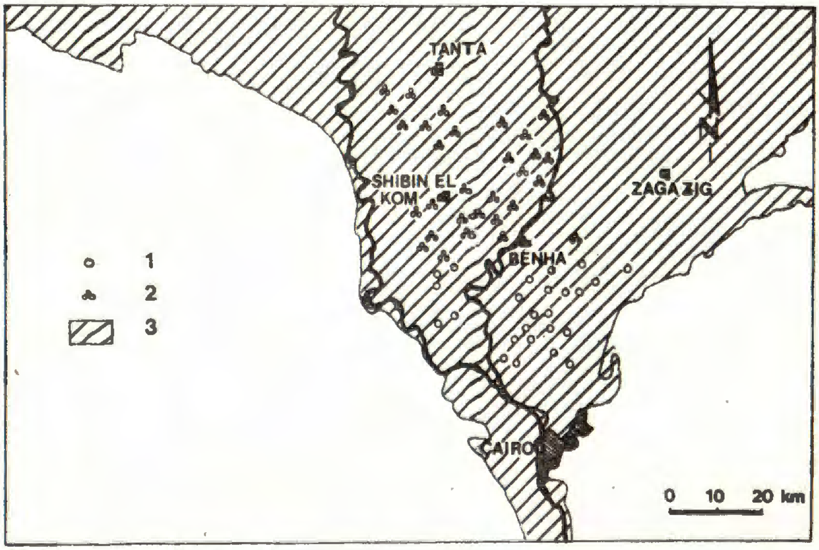

Fig. 2. Situation map of the project area in the Nile Delta. 1 — single well station, 2 — battery well station, 3 — cultivated land (after Š a r i n & G a l o v i ć, 1963).

Sl 2. Položajna karta područja projekta u delti Nila. 1 — stanica s jednim bunarom, 2 — stanica s baterijom bunara, 3 — obrađivano tlo.

SOME DATA ON THE PROJECT OF 55 PRODUCTION WELL STATIONS

The project of 55 Production Well Stations in Delta Region was limited to the upper, southern part of the Nile Delta (Fig. 2). It includes 25 well stations each with only one so-called single well and 30 well stations each consisting of three so-called battery wells placed at the vertices of an equilateral triangle with 20 meters long sides. All three wells of the battery station were pumped with only one pump.

The minimal depth of the single and battery wells had to be 90 and 75 meters. respectively, and the drawdown not greater than 10 and 4 meters at the yields of 1000 and 350 cubic meters per hour (278 and 97 liters per second) after 24 hours of continuous test pumping. All these and a number of other technical stipulations were met.

The project was accomplished by the Yugoslav company GEOISTRAŽIVANJA (now GEOTEHNIKA), Zagreb, from 1962 to 1964.

CONTROLLED OVERPUMPING

The upper 60 to 80 meters of the alluvial aquifer has been extensively and accurately lithologically explored in the southern Delta, not only by means of the production wells shown in Fig. 2, but also by many other production and exploratory wells situated in that region. The lithologic logs of the explored upper 60 to 80 meters of the aquifer reflect the predominance of beds composed of coarse sand and fine gravel, i. e. grain size classes between 0.6 and 6 millimeters. But, the lithologic log is not entirely uniform. Within the explored portion of the aquifer there exist also interbeds of finegrained deposits, such as silty sand or pure silt. These interbeds have the shape of lenses of limited extention, as shown in Fig. 1. A lens of silt, interbedded into a porous medium composed of coarse sand and fine gravel behaves as a semipermeable bed if the production well does not perforate the lens. The effect o semipermeability depends directly upon leakage coefficient and magnitude o extension of the lens. The semipermeability effect does not affect only well hydraulics but also the quality of pumped water.

The effect of semipermeability is depicted in Fig. 3, for which the meanings of symbols WD_1, WD_2, PWL_1 and PWL_2 are well depths and pumping water levels for cases 1 and 2, respectively.

Case 1 represents the usual practice followed in the project of 55 Production Well Stations. If the contract stipulations, such as minimal well depth or minimal length of the well screen, had not been reached, the lens would be penetrated. In that case, the well yield or its drawdown is completed only above the semipermeable lens, still produces the the sea level in accordance with the Ghybens-Herzberg equation.

Case 2 represents a modified situation. If the semipermeable lens is one or more meters thick and encountered at sufficient depth, it will not be penetrated but, on the contrary, can be plugged with cement to avoid more permeable flow conduits from the underlying porous media. By »sufficient depth« we mean the situation in which the production well, if completed only above the semipermeable lens, still produces the required quantity of water, that is 100 liters per second for wells resembling the described battery wells.

What is the critical depth, above which no semipermeable interbed should be treated as suggested here? The answer depends on the supervising hydrogeologist's assessment but, very probably, it is the depth at which 20 to 25 meters of medium to coarse sands and coarser deposits suitable for installing the well screen woud already be penetrated. Such a well, satisfying other technical prerequisites cited for the battery type of production wells, should yield the required 100 liters per second.

Case 2 is limited by the extension of the semipermeable lens or, more precisely, by the distance between the well and the nearest edge of the lens (point A in Fig. 3). The well yield may be increased until the interface 2 reaches point A. Once that point is reached, saline water has free way to enter the well and degrade water quality.

Because of leakage through the semipermeable lens, a negligible quantity of saline water penetrates into the well even before interface 2 reaches point A. The quality decreases with the increase of the leakage

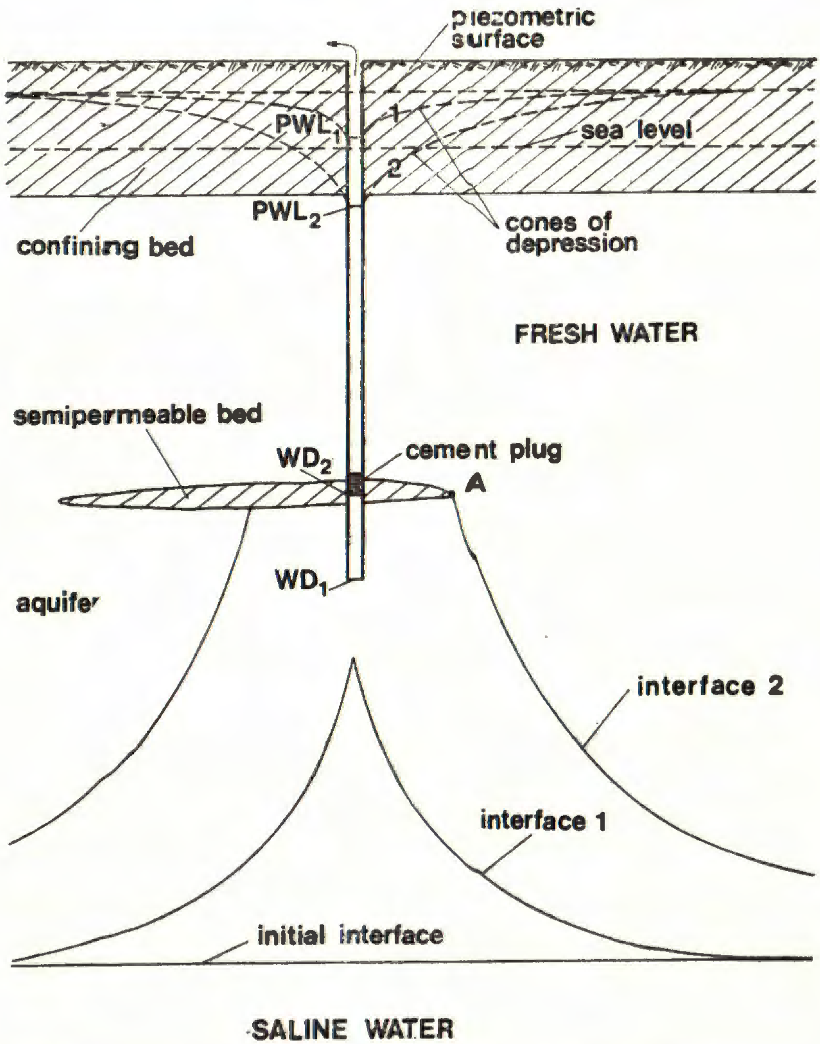

Fig. 3. The controlled overpumping concept in the Nile Delta.

Sl. 3. Koncepcija kontroliranog prekomjernog crpljenja u delti Nila.

coefficient and the drop of PWL_2 below the sea lavel. That amount is negigible in comparison with the quantity of fresh ground water entering the well and it cannot substantially affect water quality. Once the highest permissible salinity of pumped water is exceeded, the well yield has reached its maximum and cannot be increased further. Anyway, that yield is considerably greater than if the well were completed as shown in case 1.

ACKNOWLEDGEMENT

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O mogućnostima kontroliranog prekomjernog crpljenja u delti Nila, Egipat

A. Šarin

Autor ovog rada je davno proveo 2 godine u Egiptu kao hidrogeolog na nizu istražnih i eksploatacionih radova na podzemnu vodu koje su izvodili GEOISTRAŽIVANJA (sada GEOTEHNIKA) iz Zagreba. Od tog vremena autor namjerava iznijeti jednu ideju o postizanju većih bunarskih izdašnosti od do tada postignutih, ali je taj materijal samo usmeno prikazan zajedno s još jednom temom na 27. Međunarodnom geološkoj kongresu u Moskvi 1984, a od toga je objavljen samo kratak sažetak u pretkongresnim materijalima (Šarin, 1984).

U prenapučenom Egiptu obradivo je samo 3% teritorija države i najveći dio tog područja nalazi se u delti Nila. Ova je delta uobičajenog nepravilnog trokutnog oblika sa stranicama dugim 200 do 250 km, a na vrhovima trokuta su Kairo, Aleksandrija i Port Said sa Sueskim kanalom (sl. 1).

Opskrba slatkom vodom za navodnjavanje delte je egzistencijalno pitanje Egipta. U ovom je području dovoljno vode za navodnjavanje u kasnom ljetu zbog poplava Nila. Složenim sustavom irigacionih kanala, dijelom izgrađenih još u doba faraona, površinska se voda dovodi do bilo kojeg prednjela delte. Kada bi vode bilo dovoljno i u ostalim godišnjim dobima, zbog povoljne klime bilo bi moguće ostvariti tri visoko-prinosne žetve. U većem se dijelu delte ta voda može dobiti jedino iz podzemlja.

Delta Nila je izvanredno bogata podzemnom vodom. Ona protječe prema sjeveru, prema Sredozemnom moru, kroz do nekoliko stotina metara debele pjeskovito-šljunkovite naslage prekrivene 5 do 35 m debelim pokrovom od zaglinjenog praha koji vodonosniku daje subarteški karakter. Slatka podzemna voda pliva poput leće na slanoj vodi koja je na vrhu delte, prema S. Galoviću (1958), konatnog podrijetla, dok je na sjeveru to infiltrirano Sredozemno more. Sredinom delte je u 1958. god. prosječno otjecalo podzemljem prema Sredozemnom moru 58 × 10^6 m^3/dan slatke vode (Zaghloul, 1958). Razina podzemne vode je kod Kaira 13—14 m nad morem i postupno se spušta idući prema moru. U južnom dijelu delte transmisivnost vodonosnika varira između 5000 i 8000 m^2/dan rezultirajući s izdašnošću pojedinačnih bušenih bunara i do 400 l/s.

Od radova na podzemnu vodu, na kojima je učestvovao autor ovog članka, najveći je bio izrada 55 bunarskih stanica u delti Nila. Tu je uključena izrada 25 stanica s po jednim bunarom i 30 baterijskih stanica s po tri bunara udaljenih međusobno 20 m (sl. 2). Tehnički uvjeti izrade bili su ekstremno strogi: uz ostale uvjete, osamljeni bunar (stanica s jednim bunarom) morao je dati 1000 m^3/dan (278 l/s) vode uz maksimalno sniženje od 10 m, a baterijski bunar 350 m^3/dan (97 l/s) uz sniženje ne veće od 4 m. Bunari su izbušeni metodom reversne cirkulacije i svi su tehnički uvjeti ispunjeni.

Investitor je inzistirao na velikoj izdašnosti bunara, ali još više na strogo ograničenim sniženjima zbog opasnosti od zaslanjenja crpljene vode, do čega može doći spuštanjem crpnih razina ispod razine mora.

Pratimo li detaljno litološki sastav vodonosnika, možemo vidjeti da unutar pretežno krupnozrnih pijesaka i sitnozrnih šljunaka postoje i ulošci prašinastog pijeska ili čistog praha ograničenog prostiranja koji se u bunarskoj hidraulici ponašaju kao polupropusni slojevi. Njihov efekt ovisi o veličini njihova koeficijenta vertikalnog procjeđivanja i prostranstvu.

Prisustvo takvog sitnozrnog uloška ne utječe samo na veličinu izdašnosti nego i na slanost crpljene vode. Naime, ako se takav uložak nalazi pri dnu bunara, bolje ga je ne probušiti, ili ga cementnim čepom zatvoriti ako je ipak probušen. Tada se mogu dopustiti tako velike crpne količine koje bi, da nema tog uloška, uzrokovale prodor slane vode u bunar. Postojanjem takvog uloška, crpna se količina smije povećavati dok granica slane i slatke vode ne dosegne položaj 2 (interface 2 na sl. 3) što se može kontrolirati redovitim mjerenjem saliniteta crpljene vode. Ako se slanost vode poveća iznad dopuštene veličine, smanjenjem crpne količine samnjit će se i slanost crpljene vode.

Ovakvim se načinom povećava eksploataciona izdašnost pojedinog bunara, što znači da se smanjuju investicioni troškovi bunarskog zahvata.