Rudarsko-geološko-naftni zbornik	Vol. 13	str. 39–46	Zagreb, 2001.

UDC 628.112 (697.13) *Stručni članak*

NEW SOURCE OF WATER FOR SETTLEMENTS ON DUGI OTOK ISLAND (CROATIA)

Mladen ZELENIKA[1], Božo SOLDO[1], Neven TRENC[2]

[1]*Geotehnički fakultet Varaždin, Hallera 7, HR-42000 Varaždin, Croatia*
[2]*J.U. "Park prirode Medvednica", HR-10000 Zagreb, Croatia*

Key-words: Water supply, Safe yield, Pumping test, Water-source

The water demand in Southern Croatia, where Dugi Otok is situated, is the highest during the summer due to tourism, irrigation requirements and intensive use of water by local dwellers and those in holiday-homes. The availability and cost of safe water there, varies greatly from one settlement to another. Some rural areas and many Adriatic islands remote from regional water-supply systems don't have sufficient safe water, and dwellers are forced to buy at a high price, water supplied by water carriers (truck-tanks and ship-tanks) during the long summer season. Therefore, a pilot water-supply project has been implemented at Dugi Otok island. The useful experience gained from this project can be applied in many other rural settlements in Southern Croatia and wider, after adequate surveying and analysis.

Ključne riječi: Vodoopskrba, Sigurna količina crpljenja, Probno crpljenje, Izvorište vode

Potreba za vodom u južnoj Hrvatskoj gdje se nalazi Dugi otok, najveća je tijekom ljeta zbog turizma, navodnjavanja, te intenzivnog korištenja vode od strane domaćeg stanovništva i onog u kućama za odmor. Cijena pitke vode znatno varira od jednog naselja do drugog. Neka ruralna područja i mnogi Jadranski otoci, udaljeni od regionalnih vodoopskrbnih sustava, nemaju dovoljno pitke vode i tamošnji stanovnici su prisiljeni tijekom duge ljetne sezone kupovati po visokoj cijeni vodu koju dopremaju kamioni-cisterne. Stoga je probni vodoopskrbni projekt realiziran na Dugom Otoku. Iskustva dobivena na ovom projektu mogu se nakon odgovarajućeg terenskog snimanja i analiza korisno primijeniti u mnogim ruralnim naseljima u južnoj Hrvatskoj i šire.

Introduction

Previous publications that address the water supply problems at Island Dugi Otok include Fritz et al. (1977) and Zelenika & Fritz (1994). Geotechnical faculty Varaždin, Geological Institute Zagreb and INA-Naftaplin, Zagreb, posses some unpublished professional reports and data related to the investigation of water at Dugi Otok. These data together with results of some additional hydrogeological reconnaissance were utilized during selection of locality for an additional well at Žmansko polje.

Due to the shortage of safe water at Dugi Otok during the summer season, the price of water transported by sea-carrier from Zadar's regional water supply system is very high. Therefor a 5 meters deep well has been designed in Žmansko polje, where three existing wells used to give up to 3 l/s of water. Becouse of its small depth and the excavation of the designed well was entrusted as an easy job to the local contractor.

More complicated task for water engineers was the pumping test procedure to estimate the safe yield. This value is essential for management of water source and its proper use. The safe yield can be laborious to acquire, because many factors may interplay during pumping test, including capacity of the pump, present condition of the well, the properties of aquifer, decline of groundwater level due to the interference of longer drought period and pumping in other wells, interference of the tide (sea), floodtide etc. Publications by Grout et al. (1992), Clarke and Rushton (1990) and Skinner (1988), relate to wells in the Chalk aquifer of the United Kingdom. The Chalk aquifer has many similarities with the aquifers in karstified limestone at Dugi Otok. These papers explain many of the important issues in safe yield assessment, except the methodology. The formal methodology is described by Beeson at al. (1997).

This paper presents the results of construction and testing of a new source of water. This new source is expected to provide additional safe water at a smaller distance from the biggest settlements at Dugi Otok. The selection of the deepest advisable pumping water level (DAPWL), plotting od drought-bounding curve and data requirements for the assessment of safe yield will be discussed in the paper. The diary of a local engineer Z. Morović (1994-1996) was a very useful source of operational data related to wells at Malo Jezero (Fig. 2). Therefor Mr. Morović was an important crewmember during the implementation of pumping test in October of 1999 and all other operations there.

General data

Dugi Otok (Long Island) is the longest and the biggest Island in the Zadar Archipelago. It is a boundary island with very steep cliffs facing open sea, but on its eastern side, there are 1261 ha of arable land with 99000 olive trees and 215000 wine-stocks. For that reason, human settlements have developed along the eastern side of the island. The area of Island is 114 km^2 with approximately 1600 permanent dwellers in 550 households. Almost 1200 dwellers are concentrated around the Žmansko polje and many hydrogeologists have tried to prove enough groundwater to meet their water demand. The principle problems on the island are water supply and traffic links.

The average precipitation in Zadar for the period from 1961 to 1979 was 974 mm. The seasonal variations are considerable, i.e. during 3 summer months precipitation amounts to 204 mm, autumn 360 mm, winter 224 mm and spring 178 mm. The precipitation recorded for year 1999 in Sali at Dugi Otok, was 773 mm only. At Dugi Otok there are no rivers. However, the floods of Žmansko polje occur every year during the wet season, and more than a half million of cubic meters of water can be accumulated there. Žmansko polje is an orographically isolated catchment area around Veliko and Malo Jezero with a size of 4,10 to 5,8 km^2 (Fritz et al. 1977). Veliko Jezero has altitude of 1,5 m and Malo Jezero 2,0 m approximately. The flood on Malo Jezero (higher) occurs every year before the flood on Veliko jezero (lower), but flood lasts longer at Veliko Jezero.

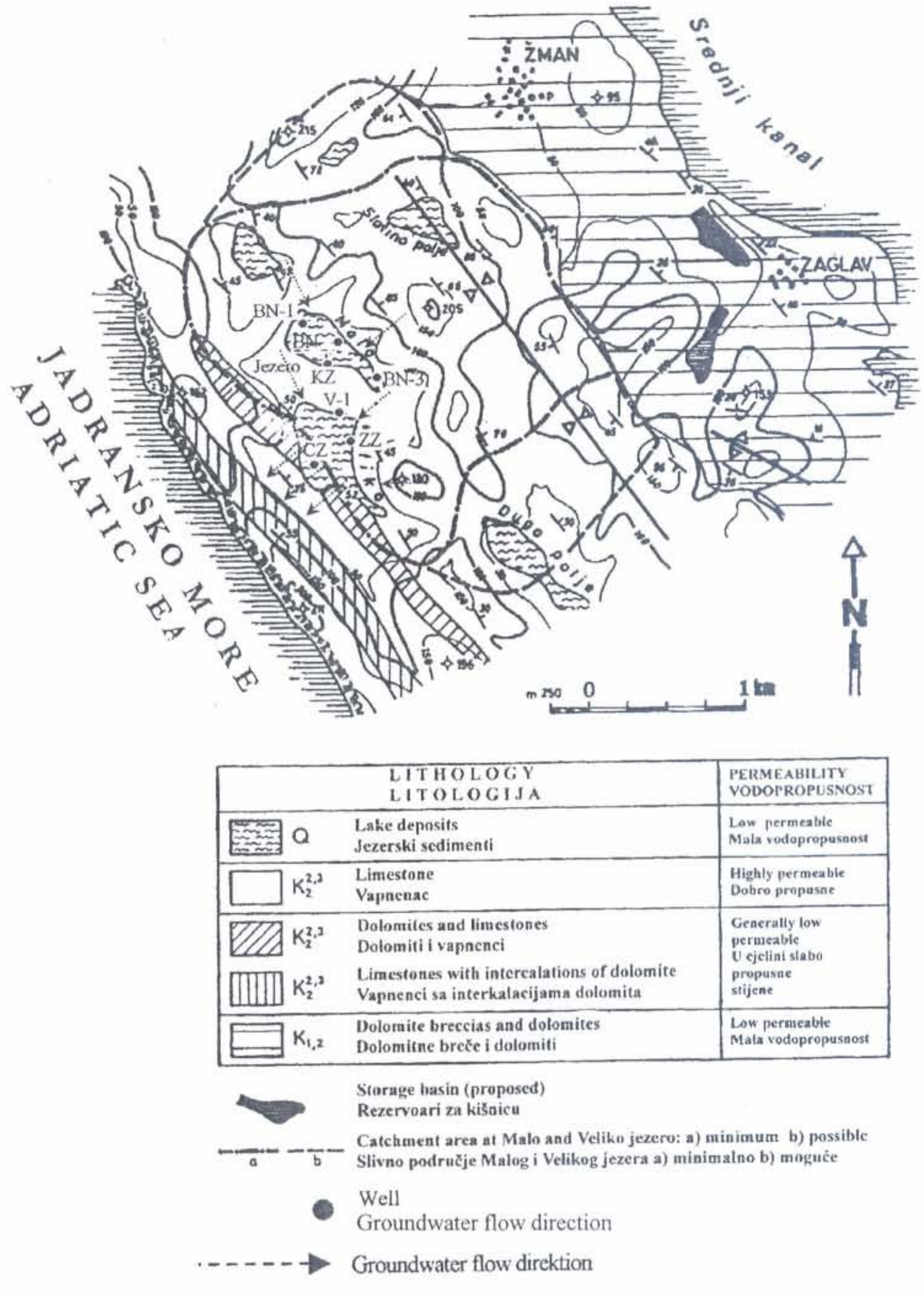

Fig. 1. Hydrogeological map of Žmansko polje (Zelenika & Fritz, 1994)
Sl. 1. Hidrogeološka karta Žmanskog polja (Zelenika & Fritz, 1994)

Adequate investigations of water passage from Žmansko polje to the sea during the flood and the recession of flood have never been performed.

The limestone rocks in alternation with dolomite build the largest part of the Dugi Otok. Quaternary clayey sediments on Malo and Veliko Jezero form a partiall hanging barrier and hinder faster disappearance of water during floods. Figure 1 shows a hydrogeological map of the investigation area with tectonic structure and a legend with locations of public wells at Malo Jezero and few private wells at Veliko Jezero (Fritz & Zelenika 1994).

During the pumping test of V-1 well in October of 1999 the influence of sea-tide on groundwater level was proved in all observed wells at Veliko Jezero and BN-3 well at Malo Jezero. The influence of tide on groundwater level was not proved in observed Seocki and Kunčev wells at Malo Jezero (Zelenika, 2000).

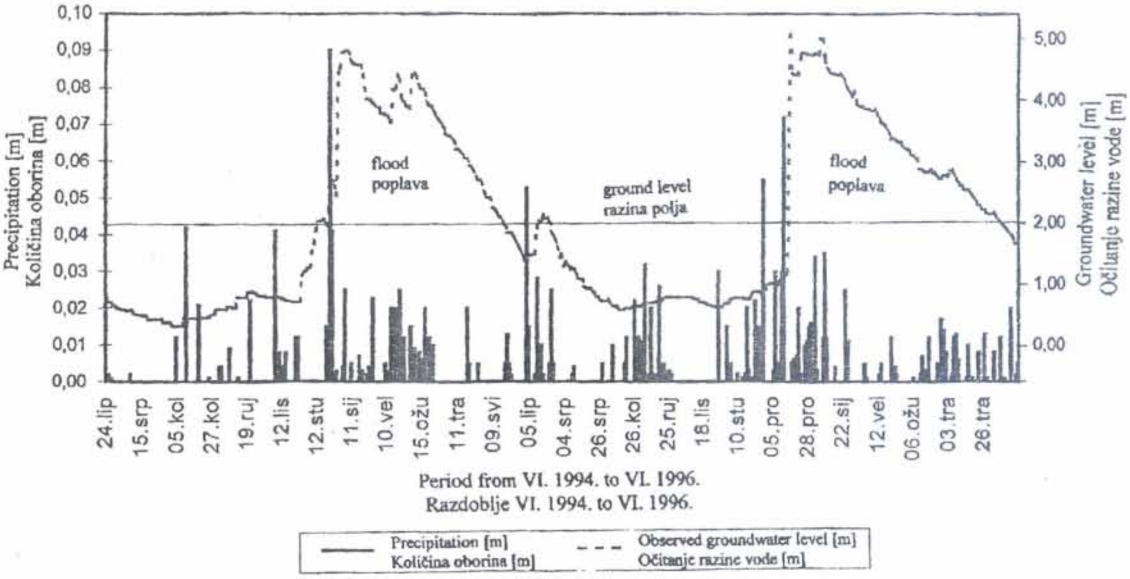

Fig. 2. Diagram of precipitations values in Sali and groundwater level in well BN-3 in Malo Jezero (Morović, 1996)
Sl. 2. Dijagram precipitacije u Saliju i razine podzemne vode u bunaru BN-3 u Malom Jezeru (Morović, 1996)

Traditional resources of water and Water demand

Dugi Otok inhabitants use for rainwater harvesting approximately 20 public and 950 private traditional reservoirs with the total volume of approximately 48500 m^3. Since the average area of houseroofs is large enough and intensive rains are available during the wet seasons, the average quantity of harvested rainwater can be estimated as more than 65000 m^3/year or approximately 2,1 l/s. On the island Dugi Otok there are 10 water ponds, predominantly for animal use. At Žmansko polje, water is available in approximately 5 private dug wells and three public wells. It is estimated that the owners of these 50 private wells provide approximately 15 000 m^3/year of water for their gardens and households. Three available public wells are providing approximately additional 5000 m^3/year. Thus, the total quantity of water pumped during dry season (5 months) is 20 000 m^3. The maximal quantity pumped per one day from the mentioned private and public wells is estimated to be 25 m^3.

Water demand during winter season is less than 300 m^3/day or approximately 3,5 l/s. Up to 10000 people used to stay at Dugi Otok during the summer due to large number of holidays houses, guests and tourists. These people consume more than 300 l/day/capita, which is equal to approximately 3000 m^3/day or 35 l/s. Such high consumption lasts only for period shorter than 50 days. The important factor in solution of the problem is a more rational use of traditional water sources in combination with desalination of groundwater on adequate number of wells using the reverse osmosis filtration system and construction of additional reservoirs at the relevant positions.

Former investigation

Institute for geological investigation, Zagreb, has performed a complex and extensive hydrogeological investigation at Žmansko polje on Dugi Otok in the period from 1973 to 1977 (F r i t z et.al., 1977). They surveyed hydrological and hydrogeological characteristics of the area, cleaned and pumped water from the traditional dug wells, recorded meteorological and other relevant data and analyzed the effects of rain and pumping on groundwater level. They discontinued the pumping of water from wells during nights and acquired no data related to interferences among the wells at Malo and Veliko Jezero. This investigation proved through colour tracing some kind of connection of well BN-3 and intermittent spring V-1. According to their records the precipitation smaller than 30 mm/month does not affect the groundwater level, but data recorded in diary of Mr. Morović oppose this statement (Fig. 2).

The values of altitude of groundwater in wells are registered from 0,75 m to 1,75 m (above sea level), specific yield q = 4 l/s/m in Malo Jezero and 11 l/s/m in wells in Veliko Jezero. Transmissivity was 120 m^2/day in Malo Jezero and 500 m^2/day in wells at Veliko Jezero. The value of aquifer storage coefficient was estimated, S= 0,01, and the value was proved in October of 1999.

Short hydrogeological reconnaissances in 1994 and 1998 as well as the analyses of data in the mentioned diary, brought additional essential data and understanding relating to flood, use of private and public wells, possibilities for construction of additional wells, and harvesting of additional quantities of rain water. The renewal of groundwater level in dependence of precipitation is shown in Figure 2 (Z e l e n i k a , 1994, 1999 and 2000).

INA-Naftaplin has drilled at Dugi Otok a 4037 meters deep petroleum investigation borehole. They reported existence of groundwater aquifer extending to the depth of 2400 m, saturated with groundwater that has a content of chlorides lower than 3 g/l (C o t a et. al. 1993).

It is difficult to obtain enough information related to present technical condition of wells, capacity of private and public pumps, the properties of aquifer, decline of groundwater level and increase of salt content in water, due to the interference among wells during the more intensive continuous pumping, longer drought period in the area of the aquifer, interference of tide (sea), flood-tide etc. To answer some of these questions, new well V-1 was located, excavated and tested in October of 1999.

Location and construction of a new well

Results of the earlier research were the basis for the reconstruction of three old open wells (BN-1, BN-2 and BN-3) at Malo Jezero (Fig. 1), which are estavelas. These wells have been equipped with pumps that have capacity of more than 500 m^3/day, but only one well at a time was utilized for few hours per week and pumped up to 200 m^3/day causing the drawdown of 1,0 m, e.a., lowering the groundwater level from + 1,2 to + 0,20 m above sea level (M o r o v i ć , 1996). In the vicinity of the most productive well BN-3, earlier researchers tried to dig an additional well, and it was a failure. The fissures and cracks between big blocks of limestone were filled with dry compact clay even below the sea level. It was a discouraging experience for digging of new wells.

The new well was located at an intermittent spring V-1 at the edge of the lower polje, Veliko Jezero (Fig. 1). This location was selected in order to reduce the risk of striking the groundwater aquifer and a harmful interference of its utilization on the groundwater level in present wells at Malo Jezero.

Well V-1 was designed to the depth of at least 5 m. Local contractor using his best equipment and experience succeeded to excavate only 1,99 m deep well, from the altitude + 0.85 to -1,14 m (Fig 3). The excavation crew followed the only one productive "channel" to bring groundwater in the excavated well; all other cracks, fissures and caves were filled with hard clay placed between the huge blocks of limestone. Before the pumping test has been started and realized, the workers had to remove a large amount of sediments from the well using the manual tool and 2 pumps.

Groundwater level has been observed during the pumping test at new well V-1 at the mentioned BN-3 well and old private wells Seocki and Kunčev zdenac at Malo Jezero, and on V-1, Didov and Zorin zdenac at Veliko Jezero. Pumping tests have been carried out from October 09 to October 20, 1999, after a very long dry season, when a nonpumping groundwater level at BN-3 well was reached even 0,60 m above sea level, which is a real minimum (Fig 2). The intermittent continuous, round o'clock pumping test lasted during periods of 36+33+121=190 hrs, and periods of 12+12+12+24=60 hrs of surveying of the the recovery of groundwater level at all 6 mentioned survey points.

Estimating Deployable Output and Safe Yield

The water engineer in the Municipality should decide the value of deployable output for the new well V-1 for different seasons. After above mentioned cleaning and pumping test of V-1 well, the reliable Contractor Geotehnika, d.d. Zagreb, reported the value of safe yield q = 7 l/s/m, or 605 m^3/day the output having drawdown of 1 m (K o r o l i j a , 1999). Geotechnical faculty Varaždin recommended the deployable output of only 450 m^3/day during the summer season (Z e l e n i k a , 2000).

Figure 2 shows groundwater level fluctuations in the well BN-3 at Malo Jezero in dependence of the precipitation values in Sali (M o r o v i ć , 1996). The amount of groundwater drawn out from private and public wells per each dry season (5 months) is approximately 20 000 cubic meters. No systematical operational records exist for any well at Veliko Jezero, therefore an analytical approach has been applied in order to estimate the reliable yield of V-1 well using the Cooper-Jacob equation (1946).

$$s_t = \left(\frac{2{,}3 \cdot Q}{4 \cdot \pi \cdot T}\right) \cdot \log\left(\frac{2{,}25 \cdot T \cdot t}{r^2 \cdot S}\right)$$

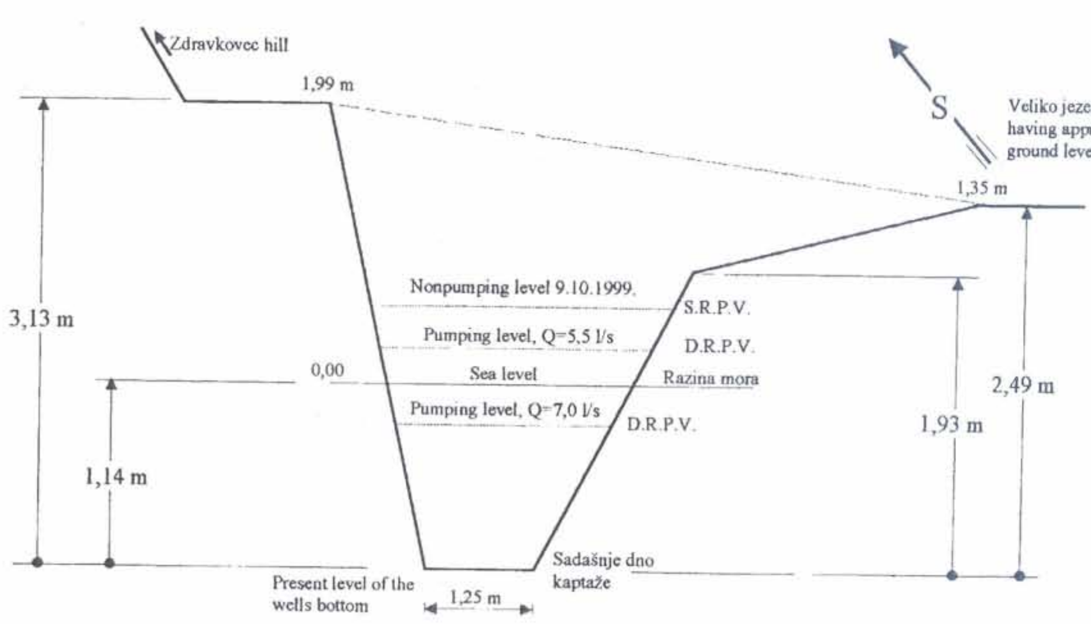

Fig. 3. The section of new water source
Sl. 3. Presjek kroz novi izvor vode

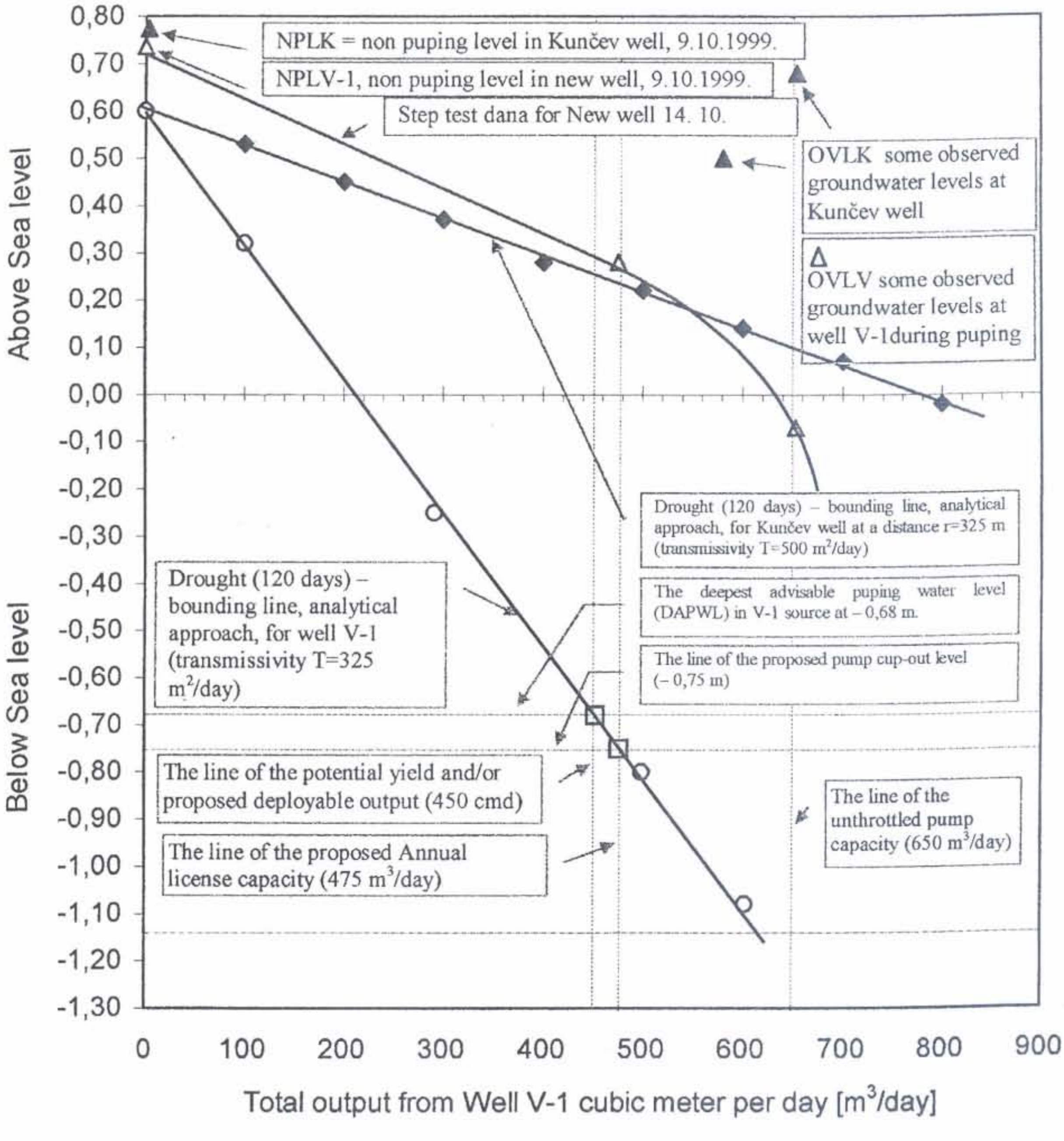

Fig. 4. Relation between water level and total output
Sl. 4. Odnos između razine vode i ukupne proizvodnje

s_t = the drawdown (m) at one well produced by pumping at a rate Q (cubic meters per day) at a distance r (m),
S = the aquifer storage coefficient (0,01),
T = the aquifer transmissivity (500 and/or 325 m^2/day)
t = time of continuous pumping (120 days) at a Q discharge (450 m^3/day) without rain (recharge)

Using the above equation, through analytical approach, the lines and curves were plotted at Figures 4. and 5 in order to elaborate the possibilities for the utilization of the well V-1. The abscise on Fig 4 is the scale of discharge rate Q in cubic meters per day (m^3/day), and the ordinate on Fig 4 is the groundwater level. Trough a detailed analyses of data recorded during the pumping test in October of 1999 and the relevant calculation, using the above mentioned equation, following curves were plotted:

1. Step test curve for the new well V-1 (October 14, 1999),
2. 120 days drought - bounding line, analytical approach, for new well V-1 (transmissivity T = 325 m^2/day),
3. 120 days drought - bounding line, analytical approach, for Kunčev well at a distance r = 325 m (transmissivity 500 m^2/day)
4. The line of the potential yield and/or deployable output (450 m^3/day)
5. The line of the Annual license capacity (475 m^3/day)

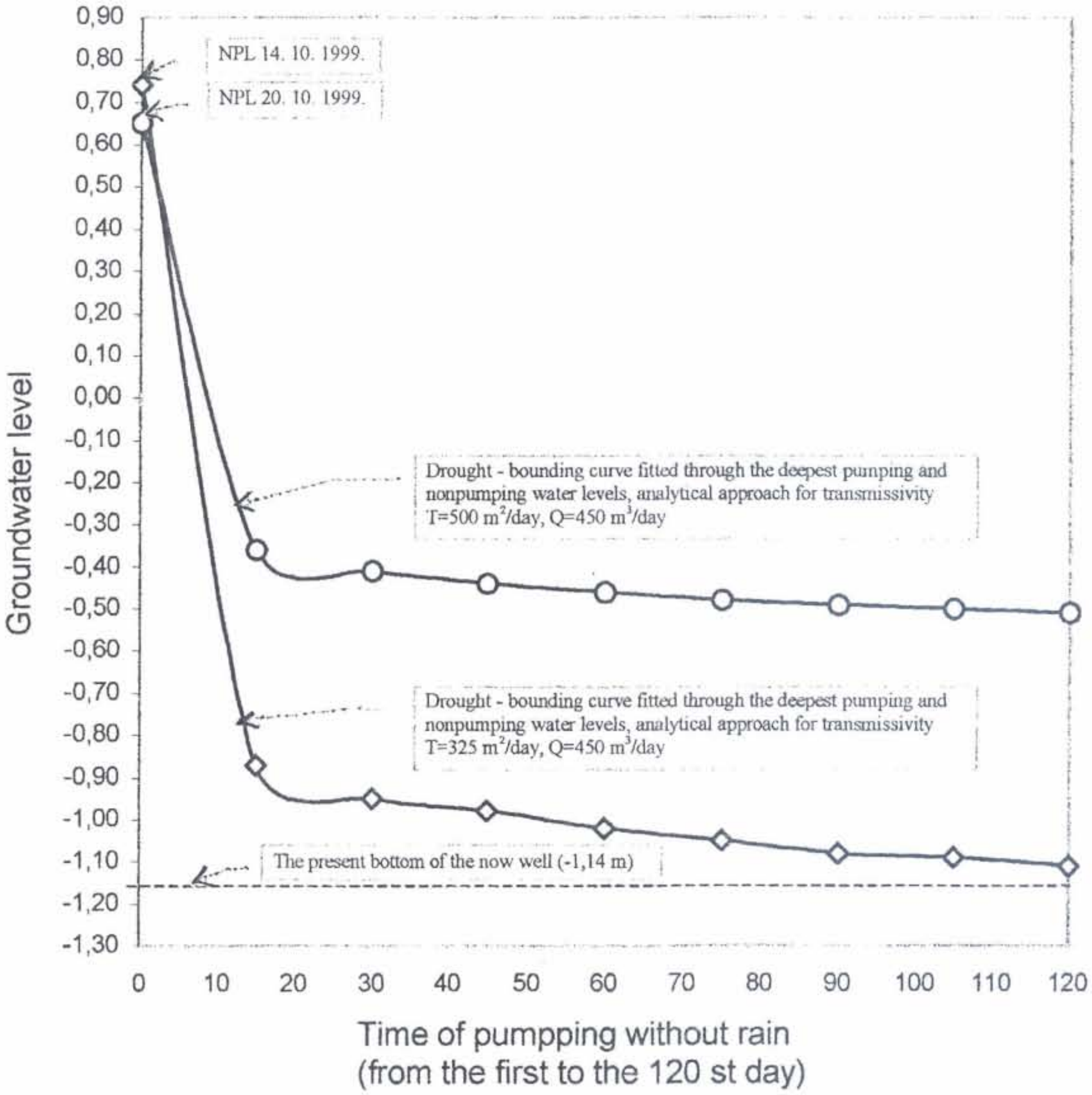

Fig. 5. Relation between water level and time pumping 450 m^3/day
Sl. 5. Odnos između razine vode i vremena crpljenja 450 m^3/dan

6. The line of the unthrottled pump capacity (650 m^3/day)
7. The deepest advisable pumping water level (DAPWL) in V-1 source at - 0,68 m,
8. The line of pump cut-out level (-0,75 m)
9. The level of the present V-1 well-bottom (-1,14 m),
10. Some observed groundwater levels at Kunčev well OVLK, and OVLV at new well, V-1, during the pumping test.

The deepest advisable pumping water level (DAWPL) is usually uncertain when operating data are not available for a sufficiently long period of monitoring. Since we are dealing with a fissured heterogenous aquifer whose character has not been explored, the DAPWL should be selected to permit a maximum of only 50% of the total thickness of the aquifer penetrated by the well to be dewatered (B r u c e et. al., 2000). If we are following the mentioned recommendation, it should be adviced the deepest pumping water level -0,27, and pump only 300 m^3/day (Fig. 4).

A drought bounding curve is fitted through the deepest pumping and nonpumping water levels in order to indicate the performance of the source during the worst drought conditions on the record. For continuously pumped single-source V-1 well the step-test curve has a convex shape (Fig. 4). DAPWL in V-1 source should be at least 0,54 m higher than the level of the well-bottom, -1,14+0,54=0,68 m. DAPWL is the level (-0,68 m). It is 73% of the saturated thickness of the aquifer penetrated by the well. Below this level the undesirable effects, such as dewatering or sand pumping, may occur.

The *potential yield* is taken from the intersection of the drought curve and DAPWL. The *Annual license capacity* is estimated from the intersection of the drought curve with the smallest constraint on output, and it could be defined by the pump cut-out level.

Figure 5 shows two drought-bounding curves for V-1 well, analytical approach using, **a)** the value of transmissivity T = 500 m^2/day for higher, and **b)** the transmissivity value T = 325 m^2/day for the lower curve. The abscise is the scale of continuous pumping, of 450 m^3/day, and the ordinate on Figure 5 is the groundwater level. It is clear that well V-1 should be deepened if we would be in a urgent need of 450 m^3/day, if the value of transmissivity would be proved lower than 500 m^2/day. Before excavation of a deeper well, the thickness of the saturated aquifer should proved. Deeper well and deeper pumping level in V-1 well have at least two additional constraints:

1. An unwelcome decline of groundwater level in Kunčev and other private wells at Malo and Veliko Jezero, and
2. Unwelcome higher salinity content in discharged water.

The drought-bounding curve for Kunčev well (Fig. 4) shows only 0,35 m drawdown after 120 days of pumping at the rate 450 m^3/day. The observations of chlorides contents in pumped water from V-1 during the pumping test in October of 1999, proved decline of chlorides content, but it should be proven in a sufficiently long period of systematical monitoring and analysis of observed data.

During 190 hours of pumping test and cleaning of the new source V-1, approximately 4500 cubic meters of water have been drained and delivered in a 325 m distant "Crni" well, where all water was gulped down, without any flood or any cleaning action there. This fact gives hope for determination of even better locations for additional wells than the well V-1, and geophysical program of investigation has been recommended (Z e l e n i k a , 2000).

The quality of groundwater was improved during the pumping test, since the content of chlorides declined from 1136 mg/l on October 10, 1999 to only 774 mg/l on October 19, 1999 (the reason for decline of groundwater salinity should be investigated). The groundwater quality may change in a opposite direction during the long summer months and continuous pumping of the recommended 450 m^3/day. Therefore the designer/producer of desalination equipment should provide an equipment for treatment of feed water with chlorides content, which may be even higher than 5000 mg/l. Otherwise a long period of careful monitoring and analysis of observed data should take place.

Recommendations

During 10 hours of pumping test and cleaning of the new source V-1, approximately 4500 cubic meters of water have been drained and delivered in a 325 m distant "Crni" well, where all water was sinked down, without any flood or any cleaning action there. this fact gives hope for determination of even better locations for additional wells than the well V-1, and geophysical program of investigation has been recommended (Z e l e n i k a , 2000).

Before excavation of a deeper Well in Žmansko polje, the thickness of the saturated aquifer and quality of groundwater there, should be investigated and proved. Deeper well and drawdovn bigger than 3 m in new wells, may have at least two serious constraints:

1. Unwelcome decline of groundwater level in Kunčev and other private wells at Malo and Veliko Jezero and
2. Unwelcome higher salilnity content in discharged water.

The deepest advisable pumping water level (DAPWL) is uncertain in wells without enough operational data. Since we are dealing with a fissured heterogenous aquifer whose properties are not yet explored, the DAPWL should be selected by water engineer very carefully, having in mind the thickness of aquifer and the depth of well penetration.

Received: 2001-03-14
Accepted: 2001-10-23

REFERENCES

B e e s o n , S., M i s t e a r , B . D . R . , v a n W o n d e r e n , J.J. (1997): Assessing the reliable outputs of groundwater sources. *J. Inst Water Environ Manage 11,* 295-304.

C l a r k e , K.F. & R u s h t o n , K.R. (1990): The reliability of groundwater sources to meet increasing demands. *J. Inst Water Environ Manage 4,* 500-505.

C o t a , L., K r i š t o f e k , B. & B e l a m a r i ć , A. (1993): Hidrogeološke spoznaje o naslagama priobalja Jadrana stečena istražnim bušenjem, INA-Naftaplin-Zagreb.

F r i t z et al. (1977): Dugi Otok - Malo i Veliko jezero, vodoistražni radovi, Arhiv Geološkog instituta Zagreb.

G r o u t M.W., A l e x a n d e r D.W., S i m p s o n R.J. (1992): Practical aspects of yield investigations of groundwater sources, *J. Inst. Water Environ Manage 6,* 397-407.

K o r o l i j a , R. (1999): Izvješće o uređenju i pokusnom crpljenju Kaptaže Veliko Vrelo na Žmanskom polju na Dugom Otoku, Arhiv Geotehnike d.d., Zagreb.

M o r o v i ć , Z. (1994-1996): Dnevnik opažanja količina crpljenja, razine i kakvoće podzemne vode u zdencima na Malom Jezeru (manuscript).

M i s s t e a r , B.D.R. & B e e s o n , S. (2000): Using operational data to estimate the reliable yields of water-supply wells, *Hydrogeology Journal 8,* 177-187.

S k i n n e r , A.C. (1988): Practical experience of borehole performance evaluation. *J. Inst Water Environ Manage 2,* 332-340.

Z e l e n i k a , M. & F r i t z , F. (1994). Mogućnosti dopunske opskrbe vodom žetvom kišnice na Dugom Otoku, Zbornik radova - Strategija održivog razvitka hrvatskih otoka, Hvar.

Z e l e n i k a , M. (1999): Komentar na lokaciju nove kaptaže uz polje Veliko jezero na Dugom Otoku, Arhiv Geotehničkog fakulteta, Varaždin.

Z e l e n i k a , M. (2000). Izvješće o rezultatima istražnih radova vodoopskrbe na Dugom Otoku, Arhiv Geotehničkog fakulteta, Varaždin.

Novi izvor vode za naselja na Dugom otoku (Hrvatska)

M. Zelenika, B. Soldo i N. Trenc

Preporuke

Tijekom 190 sati probnog crpljenja i čišćenja novog izvora vode, oko 4500 kubičnih metara vode iscrpljeno je i odvedeno do 325 m udaljenog zdenca "Crni", koji je bez pojave poplava i provođenja čišćenja, progutao svu vodu. Ova činjenica daje nadu za još bolji smještaj dodatnih zdenaca, u usporedbi sa zdencom V-1 te se stoga preporuča izvođenje geofizičkog istraživačkog programa.

Prije kopanja dubljeg zdenca u Žmanskom polju treba biti istražena i dokazana debljina zasićenog vodonosnika i kakvoća vode u njemu. Dublji zdenac i spuštanje razine podzemne vode u novim zdencima veće od 3 m može imati barem dvije veoma štetne posljedice:

- Neželjeno sniženje razine podzemne vode u Kunčevom zdencu i drugim privatnim zdencima u Malom i Velikom jezeru i
- Neželjeno povećanje saliniteta dobivene vode.

Najdublji prihvatljivi nivo podzemne vode (NPNPV) nije pouzdan u zdencima ako nema dovoljno podataka prikupljenih tijekom njihova rada. Kako se ovdje radi o raspucanom nehomogenom vodonosniku čiji karakter nije istražen, inženjer mora pažljivo odabrati NPNPV tako da se uzme u obzir debljina vodonosnika i dubina penetracije zdenca.

Kakvoća podzemne vode poboljšala se tijekom posljednjeg probnog crpljenja. Sadržaj klorida se smanjio od 1136 mg/l 10. listopada, 1999. na samo 774 mg/l izmjereno 19. listopada, 1999. Kakvoća podzemne vode se može promijeniti i u suprotnom smjeru tijekom dugih ljetnih mjeseci i kontinuiranog crpljenja preporučenih 450 m^3/d. Stoga, projektant/proizvođač opreme za desalinizaciju treba osigurati opremu koja će moći preraditi ulaznu vodu sa sadržajem klorida čak većim od 5000mg/l. U suprotnom je nužan duži period pažljivog praćenja i analize opažanih podataka.