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Izvorni znanstveni članak

EFFECTS OF THE ČAKOVEC HYDROELECTRIC POWER PLANT ON GROUND WATER SYSTEM

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Key-words: Reservoir, Ground water, Level changes

Ground water levels of some 20 piezometers from both sides of the Drava River, including the Bartolovec water supply source, before and after the completion of the Čakovec Hydroelectric Power Plant are analysed. As a result of this construction ground water levels in the dam upstream area surrounding the reservoir have increased. And the ground water levels around the derivational part of the hydroelectric scheme and the old Drava riverbed are lowered for good. The range of oscillations in ground water levels of the entire area has become less wide.

Ključne riječi: Akumulacija, Podzemna voda, Promjene razine

Analizirane su razine podzemnih voda na 20-ak pijezometara u lijevom i desnom zaobalju Drave, uključujući i crpilište Bartolovec, prije i poslije punjenja akumulacije HE »Čakovec«. Punjenje akumulacije dovelo je do trajnog povišenja razine podzemne vode u zaobalju akumulacije uzvodno od brane. U području derivacijskog dijela hidroelektrane i starog korita Drave došlo je do trajnog sniženja razine podzemnih voda. Raspon oscilacija razine podzemnih voda na čitavom području hidroelektrane je smanjen.

Introduction

In the Drava area of Croatia extensive hydrogeological explorations have been carried out by the Institute of Geological Surveys in Zagreb since 1960. Both sides of the lowlands along the upstream part of the river were thoroughly investigated for the design and construction purposes of the Varaždin, Čakovec and Dubrava hydroelectric schemes.

The earlier results (Miletić, 1969) were used as a basis for later investigations. Regional hydrogeological surveys provided the lithological data of the region (Babić et al., 1978).

Subsequent interpretations of the structure of layers, regarded also as a result of local water supply developments, have contributed to our knowledge of the Quaternary aquifers in the western Drava basin (Urumović et al., 1990). The dissertation (Grđan, 1989) deals with the effects of surface water resources on the ground water systems of the Varaždin and Čakovec Power Plants.

Croatian Hydrometeorological Institute continues to investigate and collect the informations regarding the changes in the ground water levels for the entire piezometric system of the Drava area since 1960.

To determine the natural or the so-called zero ground water level (medium, low and high waters) a Study of Hydrogeological Relationships upon Completion of Čakovec Power Plant Effecting Ground Waters (Civil Engineering Institute Zagreb, 1976) was made. The assumed water levels are based on a mathematical model after the completion of the power plant and contain the groundwater study maps with the water level contour lines of 11th April 1977 (high water level), 13th December 1976 and 24th November 1980. At the end of 1976, thirty-three additional piezometres were made for closer observations of ground water levels on both sides of the reservoir.

The Drava valley containing the Čakovec power plant stretches from the west to the east. Its width is between 15 and 20 km. It merges with the Mura valley beyond Čakovec. This hydrotechnical complex influences ground waters of a large area.

Most of the investigated area belonging to the Varaždin basin are Quaternary waterbearing deposits linked together and, in hydrogeological sense, consisting of well graduated gravel with various sand contents (Miletić et al., 1971).

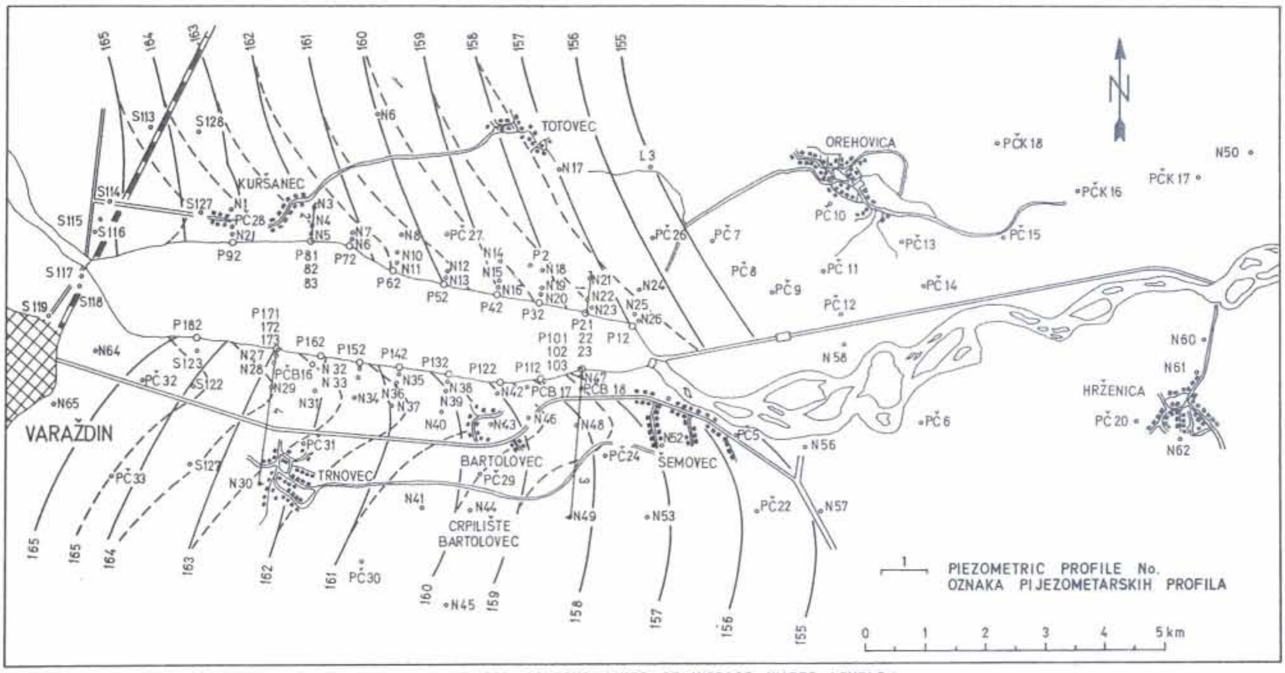
The permeability of these Quaternary deposits allows water leaking from the reservoir. In order to prevent formation of swampy grounds drain canals were constructed along the reservoire embankment. Their duty is to care for the ground water level to remain at a specified depth below the ground surface and to allow drainage of the leaking waters into the original river course. The locations of the piezometers relevant in this case and the sites of individual facilities belonging to the Čakovec Power Plant are shown in Fig. 1.

Study of Effects of Test Filling of Reservoir on Ground Water Levels

The reservoir was test-filled between 20th and 22nd May 1982 when the altitude of the working level reached 168.00 m above sea level. The water levels were measured in all piezometers twice a day.

At the same time as filling, ground water levels increased rapidly in a broader area and specially around Žabnik, Bartolovec, Šemovec and Trnovec. Žabnik was most endangered. Here the waters were only 0.50 m below ground surface and they spilled out of some piezometres. As a result the basement areas of the houses in Žabnik were flooded.

Additional ground water drain away canals, not originally planned, were constructed together with a whole net of transversal drain canals linked to the



WATER CONTOUR LINES OF AVERAGE WATER LEVELS:
HIDROIZOHIPSE SREDNJIH VODOSTAJA ZA:
BEFORE FILLING OF THE RESERVOIR (19 MAY 1982 MEASUREMENT)
STANJE PRIJE PUNJENJA AKUMULACIJE (MJERENO 19.05.1982.)
AFTER FILLING OF THE RESERVOIR (04 NOVEMBER 1982 MEASUREMENT)
STANJE NAKON PUNJENJA AKUMULACIJE (MJERENO 04.11.1982.)

Fig. 1 Water contour lines of water levels measured on 19 may and 4 november 1982

Sl. 1 Hidroizohipse vodostaja mjerenog 19. svibnja i 4. studenog 1982.

right drain canal of the reservoir embankment to lower the ground water levels at Žabnik and Štefanec. The direction of the 1,840 m long drain coincides with the former riverbed (Fig. 2). With its mouth 157.35 m above sea level it is 0.43 m above the bottom of the right drain canal. To ensure a more efficient seepage from the drain canal into the water-bearing sediment drain wells with natural gravel the sizes of which are $1.5 \times 4.0 \times 2.0$ m were built each 25 metres (Grđan, 1989).

The second half of this additional drain canal, 1,372 m in length, has a slope of 1:2. Due to the bad geotechnical properties of the surrounding soils the slopes had to be covered with a layer of natural gravel 0.30 m thick.

To avoid a canal too deep, and yet to reach to the soil with a greater permeability coefficient, a gravel layer of 1.5 m width and 2.0 m depth was constructed all along underneath the canal in the clay sand. The slopes are covered with gravel of 0.20 m thickness.

This system of additional drain away canals was insufficient for the area in danger so that another drain canal at »Vrbik« near Bartolovec was built. With its 322 m the Vrbik canal is linked with the secondary canal No. 7 as shown in Fig. 2. The slope is one per mille. The bottom of the canal is 1.0 m wide with slopes of 1:2.

Upon the completion of the additional drain canals the flow of water through the mouth of the right drain canal of the reservoir was 18 m^3/s.

These works carried out between the test and final filling of the reservoir influenced locally the behaviour of ground waters around Žabnik and Štefanec. The ground water levels in December 1982 as compared to July of the same year fell for some 0.30 m, which was only possible with such additional drain canals. They do not result in decreased ground water levels in a larger area but only in the areas very close to them. Such additional canals, which were designed and built later, have contributed to an increase in the unit prices of electricity as compared to that originally planned.

Effects of Reservoir on Ground Water System in Surrounding Area

The reservoir was refilled to its final level of 168,00 m above sea level between 19th and 27th June 1982. (The working level of the power plant varies between 167 and 168 m above sea level.) Simultaneously, the measurements of the ground water levels in all piezometers were first carried out three times a day in the first three days, and after that once a day all until 19th July 1982 (Tables 1 and 2).

To determine and evaluate the effect of filling the reservoir to the ground water level the results of two measurements in the piezometers in two basic profiles on the left and right river banks (profiles Kuršanec-Trnovec and Totovec-Bartolovec) on three characteristic dates were analysed (Tables 3 and 4).

The measurements of 19th May 1982 refer to the ground water level just before the first test filling. Because this represents the condition from the natural hydrogeological system, it shall be taken as the natural or 'zero' state of the ground water level in each single piezometer.

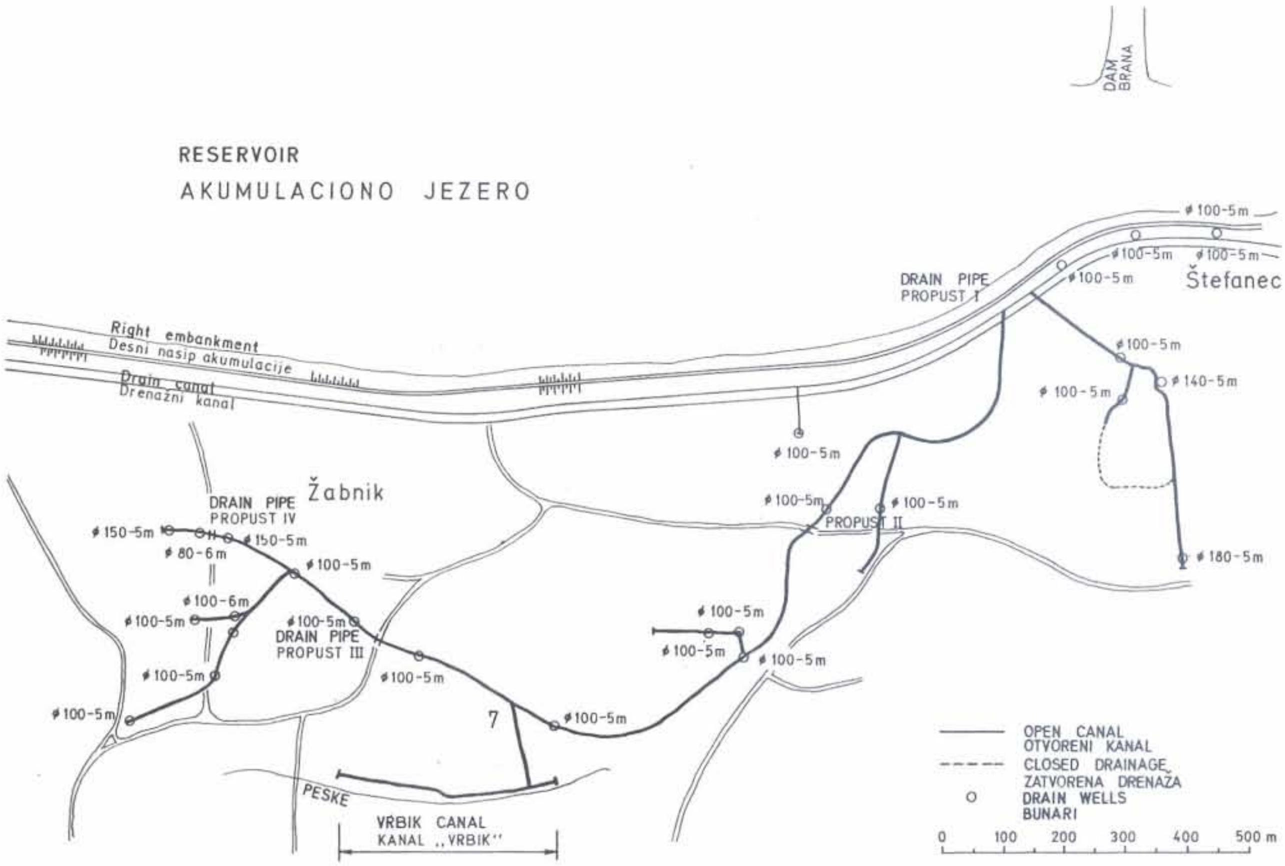


Fig. 2 Line of the ground water drain away canal Žabnik – Štefanec

Sl. 2 Trasa dodatnog drenažnog kanala Žabnik – Štefanec

TABLE 1. RESULTS OF MEASUREMENTS OF GROUND WATER LEVELS OF THE LEFT LOWLANDS DURING FILLING OF ČAKOVEC POWER PLANT RESERVOIR

TABELA 1. REZULTATI MJERENJA RAZINA PODZEMNIH VODA U LIJEVOM ZAOBALJU PRILIKOM PUNJENJA AKUMULACIJE HE „ČAKOVEC"

Date	P_{2-1}	P_{2-2}	P_{2-3}	N23	N22	N21	P_{8-1}	P_{8-2}	P_{8-3}	N5	N4	N3
Datum 1982. god.	Peak altitude m above sea Kota vrha m n.m. 169,362	Peak altitude m above sea Kota vrha m n.m. 165,840	Peak altitude m above sea Kota vrha m n.m. 160,844	Peak altitude m above sea Kota vrha m n.m. 160,432	Peak altitude m above sea Kota vrha m n.m. 160,301	Peak altitude m above sea Kota vrha m n.m. 159,543	Peak altitude m above sea Kota vrha m n.m. 169,278	Peak altitude m above sea Kota vrha m n.m. 166,655	Peak altitude m above sea Kota vrha m n.m. 164,297	Peak altitude m above sea Kota vrha m n.m. 163,811	Peak altitude m above sea Kota vrha m n.m. 165,115	Peak altitude m above sea Kota vrha m n.m. 165,479
25.06	9,61	6,28	1,89	1,67	1,44	1,58	6.00	3,81	1,85	2,00	2,79	3,74
26.06	-	-	-	-	-	-	5,82	3,67	1,75	1,90	2,62	3,10
27.06	9,50	6,22	1,83	1,60	1,30	1,39	5,50	-	-	-	-	-
28.06	9,37	6,10	1,74	1,49	1,17	1,27	5,52	3,42	1,51	1,80	2,51	3,43
29.06	9,39	6,11	1,77	1,48	1,05	1,32	5,52	3,44	1,52	1,79	2,52	3,38
30.06	9,38	6,15	1,84	1,39	1,07	1,30	5,54	3,47	1,52	1,70	2,50	3,40
1.07	9,38	6,12	1,79	1,44	1,08	1,29	5,59	3,44	1,54	1,67	2,35	3,35
2.07	9,46	6,17	1,81	1,46	1,07	1,28	5,58	3,47	1,54	1,65	2,26	3,31
3.07	9,40	6,14	1,79	1,45	-	-	5,62	3,52	1,57	1,66	2.24	3,29
4.07	9,43	6,20	1,81	-	-	-	-	-	-	-	-	-
5.07	9,45	6,21	1,85	1,47	1,10	1,21	5,59	3,44	1,52	1,71	2,28	3,14
6.07	9,46	6,18	1,84	1,50	1,11	1,20	5,60	3,47	1,54	1,73	2,30	3,11
7.07	9,42	6,18	1,85	-	-	-	5,61	3,48	1,56	-	-	-
8.07	9,42	6,18	1,83	1,45	1,07	1,19	5,62	3,50	1,54	1,68	2,21	3,08
9.07	9,42	6,18	1,82	-	-	-	-	-	-	-	-	-
12.07	9,46	6,20	1,83	1,47	1,07	1,18	5,66	3,52	1,55	1,70	2,21	3,08
13.07	-	-	-	1,42	1,03	-	-	-	-	1,72	2,21	-
14.07	9,48	6,21	1,83	-	-	-	5,76	3,57	1,54	-	-	-
15.07	9,49	6,24	1,85	1,48	1,10	1,17	5,75	3,57	1,54	1,76	2,25	3,00
19.07	9,53	6,24	1,86	1,49	1,11	-	5,80	3,61	1,61	1,71	2,22	-

TABLE 2. RESULTS OF MEASUREMENTS OF GROUND WATER LEVELS OF THE RIGHT LOWLANDS DURING FILLING OF ČAKOVEC POWER PLANT RESERVOIR

TABELA 2. REZULTATI MJERENJA RAZINA PODZEMNIH VODA U DESNOM ZAOBALJU PRILIKOM PUNJENJA AKUMULACIJE HE „ČAKOVEC"

Date / Datum	P_{10-1}	P_{10-2}	P_{10-3}	N47	N48	N49	P_{17-1}	P_{17-2}	P_{17-3}	N28	N29	N30
1982 god.	Peak altitude m above sea Kota vrha m n.m. 168,657	Peak altitude m above sea Kota vrha m n.m. 166,456	Peak altitude m above sea Kota vrha m n.m. 160,697	Peak altitude m above sea Kota vrha m n.m. 161,116	Peak altitude m above sea Kota vrha m n.m. 160,806	Peak altitude m above sea Kota vrha m n.m. 160,077	Peak altitude m above sea Kota vrha m n.m. 168,958	Peak altitude m above sea Kota vrha m n.m. 167,770	Peak altitude m above sea Kota vrha m n.m. 166,391	Peak altitude m above sea Kota vrha m n.m. 165,330	Peak altitude m above sea Kota vrha m n.m. 165,470	Peak altitude m above sea Kota vrha m n.m. 164,702
25.06	8,85	6,10	0,30	1,82	1,42	2,08	5,93	4,65	3,41	-	3,38	1,67
27.06	-	-	-	1,77	1,33	-	-	-	-	-	-	-
28.06	-	-	-	-	1,21	1,87	-	-	-	-	3,16	1,67
29.06	7,64	5,60	0,01	-	0,92	-	5,52	4,28	3,11	-	3,12	-
30.06	7,92	5,60	0	-	0,92	1,73	5,54	4,29	3,08	-	3,16	-
1.07	7,94	5,59	0	1,64	0,93	1,66	5,50	4,26	3,07	-	3,04	1,58
2.07	7,93	5,60	0	-	0,88	1,64	5,51	4,29	3,10	1,56	2,98	1,56
3.07	7,91	5,60	0	-	0,89	1,58	5,51	4,29	3,10	1,48	2,98	1,48
4.07	-	-	-	-	0,91	-	5,70	4,41	3,09	-	2,98	1,55
5.07	8,29	5,77	0	1,60	0,88	1,54	5,70	4,41	3,09	1,44	2,88	1,55
6.07	-	-	-	1,58	0,89	1,52	-	-	-	1,50	2,89	-
7.07	8,16	5,76	0	-	-	-	5,64	4,40	3,18	-	-	-
8.07	-	-	-	1,58	0,88	1,52	-	-	-	1,42	2,84	1,53
9.07	8,17	5,78	0,02	1,59	-	1,50	5,65	4,42	3,21	-	-	-
10.07	-	-	-	-	0,84	1,41	-	-	-	-	-	-
11.07	-	-	-	-	0,86	-	-	-	-	-	-	-
12.07	8,09	5,78	0,04	-	-	-	-	-	-	1,41	2,82	1,52
13.07	-	-	-	-	-	-	-	-	-	1,37	2,84	-
14.07	-	-	-	-	0,84	-	5,61	4,46	3,22	1,39	-	-
15.07	8,09	5,76	0	-	-	1,56	-	-	-	1,39	2,82	-
19.07	8,10	5,72	0	1,52	0,82	1,40	5,62	4,42	3,24	1,38	2,80	1,46

TABLE 3. DEPTHS BETWEEN GROUND SURFACE AND GROUND WATER LEVELS OF THE LEFT LOWLANDS OF ČAKOVEC POWER PLANT: MEASUREMENTS 19 MAY, 15 JULY AND 4 NOVEMBER 1982

TABELA 3. DUBINA OD POVRŠINE TERENA DO PODZEMNE VODE U LIJEVOM ZAOBALJU HE „ČAKOVEC" MJERENA 19. SVIBNJA, 15. SRPNJA I 4. STUDENOG 1982. GODINE

Piezometer / Pijezometar	Piezometer Peak altitude m above sea / Kota vrha pijezometra m n.m.	Date of measurement / Datum mjerenja 19.05.1982. [m]	15.07.1982. [m]	4.11.1982. [m]	Piezometer / Pijezometar	Piezometer Peak altitude m above sea / Kota vrha pijezometra m n.m.	Date of measurement / Datum mjerenja 19.05.1982. [m]	15.07.1982. [m]	4.11.1982. [m]
P_{1-1}	169,255	12,00	8,71	9,45	P_{5-3}	162,958	3,45	1,38	1,90
P_{1-2}	165,454	16,66	2,77	3,30	N 13	162,782	3,40	1,88	2,06
P_{1-3}	160,352	2,80	0,15	0,50	N 12	163,118	3,64	1,51	1,67
N 26	159,320	-	0,60	0,76	P_{6-1}	169,202	9,37	6,85	7,45
N 25	158,909	1,70	0,55	0,60	P_{6-2}	166,581	6,68	4,24	4,75
N 24	159,158	2,53	1,41	1,42	P_{6-3}	163,337	3,53	1,67	2,12
P_{2-1}	169,362	11,85	9,49	9,82	N 11	162,928	3,00	1,51	1,67
P_{2-2}	165,840	8,39	6,24	6,47	N 10	163,121	3,07	1,20	1,35
P_{2-3}	160,844	3,58	1,85	2,05	N 9	162,864	3,02	1,33	1,41
N 23	160,432	3,00	1,48	1,52	P_{7-1}	169,118	8,56	6,21	6,77
N 22	160,301	2,81	1,10	1,15	P_{7-2}	166,874	6,21	3,98	4,55
N 21	159,543	2,21	1,17	1,25	P_{7-3}	164,042	3,48	1,60	2,07
P_{3-1}	169,791	11,12	7,81	8,31	N 8	163,840	3,18	1,53	1,76
P_{3-2}	165,451	7,29	4,42	4,92	N 7	164,162	3,63	1,75	1,78
P_{3-3}	161,435	3,25	1,23	1,55	N 6	164,473	-	4,02	3,55
N 20	160,252	2,94	0,69	0,90	P_{8-1}	169,278	8,15	5,75	6,44
N 19	160,374	2,37	0	0,10	P_{8-2}	166,652	5,48	3,27	4,21
N 18	160,542	2,99	1,37	1,43	P_{8-3}	164,297	3,11	1,54	2,00
P_{4-1}	169,059	10,81	7,94	8,42	N 5	163,811	2,73	1,76	1,82
P_{4-2}	166,240	7,76	5,21	5,64	N 4	165,115	3,82	2,22	2,22
P_{4-3}	162,152	3,83	1,75	2,16	N 3	165,477	4,45	3,00	2,87
N 16	161,521	3,34	1,15	1,38	P_{9-1}	169,383	6,17	4,61	5,03
N 15	161,357	3,02	0,73	0,82	P_{9-2}	166,917	3,81	2,42	2,85
N 14	161,905	3,60	1,80	1,85	P_{9-3}	166,066	2,62	1,41	1,81
P_{5-1}	169,266	10,70	7,08	7,76	N 2	166,172	2,82	1,91	2,07
P_{5-2}	165,962	6,45	4,08	4,68	N 1	167,569	4,64	3,35	3,17

TABLE 4. DEPTHS BETWEEN GROUND SURFACE AND GROUND WATER LEVELS OF THE RIGHT LOWLANDS OF ČAKOVEC POWER PLANT: MEASUREMENTS 19 MAY, 15 JULY AND 4 NOVEMBER 1982

TABELA 4. DUBINA OD POVRŠINE TERENA DO PODZEMNE VODE U DESNOM ZAOBALJU HE „ČAKOVEC" MJERENA 19. SVIBNJA, 15. SRPNJA I 4. STUDENOG 1982.

Piezometer Pijezometar	Piezometer Peak altitude m above sea Kota vrha pijezometra m n.m.	Date of measurement Datum mjerenja			Piezometer Pijezometar	Piezometer Peak altitude m above sea Kota vrha pijezometra m n.m.	Date of measurement Datum mjerenja		
		19.05.1982. [m]	15.07.1982. [m]	4.11.1982. [m]			19.05.1982. [m]	15.07.1982. [m]	4.11.1982. [m]
P_{10-1}	168,657	10,83	8,10	8,43	N 37	163,480	2,74	1,26	1,14
P_{10-2}	166,456	8,45	5,72	6,02	P_{15-1}	168,785	8,12	5,74	5,91
P_{10-3}	160,697	2,74	0,0	0,19	P_{15-2}	167,165	6,05	3,76	3,92
N 47	160,700	2,95	0,84	1,27	P_{15-3}	164,900	3,59	1,82	1,91
N 48	161,106	2,97	1,51	1,47	N 32	163,786	2,36	1,27	1,26
N 49	160,177	1,98	1,41	1,56	N 33	164,437	2,91	1,42	1,34
P_{11-1}	168,855	10,52	7,52	7,73	N 34	165,010	3,46	2,12	2,00
P_{11-2}	166,145	7,76	5,46	5,62	P_{16-1}	169,357	7,20	5,30	5,26
P_{11-3}	161,684	3,20	1,52	1,41	P_{16-2}	167,626	5,65	3,90	3,90
P_{12-1}	168,847	11,28	8,12	8,24	P_{16-3}	165,101	3,37	2,14	2,04
P_{12-2}	166,635	8,32	5,48	5,69	N 31	165,160	3,56	2,47	2,20
P_{12-3}	162,470	3,66	1,90	1,95	P_{17-1}	168,958	6,76	5,62	5,76
N 42	161,284	2,50	0,67	0,86	P_{17-2}	167,700	5,00	4,46	4,34
N 43	160,253	2,18	0,0	0,0	P_{17-3}	166,391	3,74	3,22	3,10
P_{13-1}	169,171	9,04	5,14	6,50	N 27	165,333	2,70	2,11	1,98
P_{13-2}	166,380	6,27	3,66	4,02	N 29	166,484	3,72	2,82	2,42
P_{13-3}	163,321	3,21	1,62	1,73	N 30	164,702	1,74	1,46	1,23
N 38	161,963	1,93	0,40	0,52	P_{18-1}	169,210	4,72	3,90	3,61
N 39	161,285	1,28	0,0	-	P_{18-2}	168,289	3,92	3,14	2,85
N 40	162,654	2,48	1,20	1,20	P_{18-3}	167,266	2,96	2,13	1,90
P_{14-1}	168,781	8,83	5,76	5,92	S 121	-	2,45	2,20	1,84
P_{14-2}	166,901	6,64	3,90	4,06	N 53	157,935	1,35	0,98	1,10
P_{14-3}	164,062	3,76	1,72	1,73	N 44	160,839	1,40	0,69	0,45
N 35	163,262	2,80	0,40	0,51	N 41	161,202	1,14	0,56	0,39
N 36	163,034	2,57	0,60	0,58					

The second measurements of 15th July 1982 refer to the ground water level after the filling when the ground water reached its maximum height. It can be easily seen that these values again are at their maximum around Žabnik, Bartolovec-Zamlaka, Trnovec, and the Bartolovec water supply source.

The final, third values of 4th November 1982 refer to the ground water levels about a hundred days after the filling of the reservoir. These values were used for the production of the map showing the water contour lines on 19th May and 4th November 1982 (Fig. 1).

Right Lowlands

The ground water levels in the right lowlands are influenced by the reservoir and a tiny river called the Plitvica. This part of the entire area that is being influenced by the reservoir is important because it also includes the Bartolovec water supply source.

The analysis of the ground water behaviour of the broader right lowland area deals with the values from 1977 until the end of 1986. A comparison of the minimal and maximal water levels at observation points for the conditions before and after the completion of the Čakovec Power Plant was made based on the water contour lines. For the piezometers used to control the water levels of the Bartolovec water supply source the analyses was based on izo-piezometric lines. Here are the results of the analyses for the following piezometres: PČ–32, PČ–31, PČ–29, PČ–24, PČ–30 and PČ–33.

From 1977 until May, 1982 the ground water level in PČ–32 varied between 164.32 and 165.83 m above sea level. After filling these values were between 165.16 and 166.62 m. The water level, expressed either in terms of low or high levels, increased between 0.70 and 0.80 m.

Between 1977 when the piezometer PČ–31 was formed and the filling of the reservoir the depth to the ground water level in PČ–31 varied from 1.76 and 2.95; after the reservoir had been filled, the oscillations ranged between 0.89 and 2.57 m. The rises in the minimal and maximal ground water levels were 0.38 m and 0.87 m respectively.

Greatest changes of ground water levels were observed in PČ–29 (Fig. 3). And yet, it is not the closest to the reservoir. Whereas before the filled reservoir the ground water level varied between 1.05 and 2.93 m in depth, it was between 0.46 and 1.93 m below the ground after the filled reservoir. The increase of the lowest, specially that of the highest ground water level, is of particular importance as regards the fact that the Bartolovec water supply source is only 750 m to the south of PČ–29.

Until May, 1982 the ground water level in PČ–24 varied between 157.40 and 159.07 m above sea level. After the filled reservoir it was between 158.08 and 159.86 m above sea level. The rises in minimal and

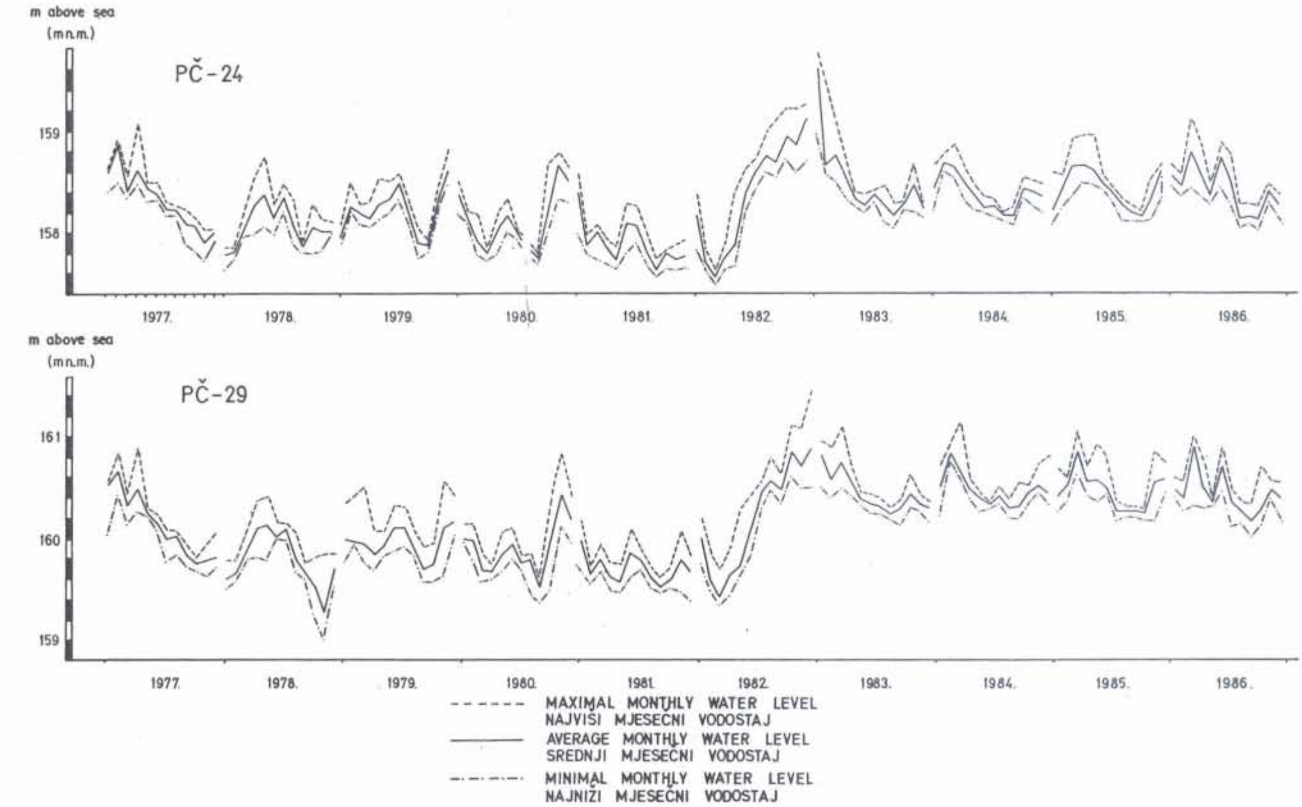


Fig. 3 Ground water levels measured in the piezometers PČ-24 and PČ-29 between 1977 and 1986

Sl. 3 Nivogrami pijezometara PČ-24 i PČ-29 od 1977. do 1986.

maximal ground water levels were some 0.70 m and 0.80 m respectively (Fig. 3).

Increased ground water levels were also observed in the piezometers marked PČ–30 and PČ–33. Yet, because these are some distance away, it amounts to only 0.30 m.

The construction of the Čakovec Power Plant has caused a permanent increase of both lowest and highest water levels of the right lowlands of the reservoire. The greatest changes have been observed in the piezometres PČ–29, PČ–32, PČ–31, and PČ–24.

The Bartolovec water supply source lies 7 km to the south-east of Varaždin and 2.2 km to the south of the Čakovec Power Plant reservoir. It supplies water for some parts of the communities around Ludbreg, Novi Marof and Varaždin. The water is catched in gravel deposits of unknown thickness through two drilled wells of 800 mm diameter at a depth of 29.5 metres. The yield quantities of individual wells amount between 70 and 85 dm^3/s. The gravels are covered with a thick layer of clay-and-silt sand the thickness of which is between 0.9 and 1.2 m (Košić et al., 1984).

A system of piezometres is formed in a broader area around the wells, thus providing good basis for determination of the changes in the behaviour of ground waters caused by the filling of the reservoir. For this purpose the measurements in the piezometres N–41, N–44, and N–45 are used.

Following the filling of the reservoir the ground water level was raised for as much as 1.0 – 1.2 m in the piezometer N–41. The increase in N–44 and N–45 showed values of 0.5 m and 0.3 m respectively.

For 1983, based on the value for the middle water, the levels of only 0.4 and 0.7 m below ground surface in N–41 and N–44 respectively may be determined.

The completion of the Čakovec power plant has produced constantly raised ground water levels also around the Bartolovec water supply source. In other words, since the filling of the reservoir the ground water level has always been oscillating also within the clay-and-silt layer (Košić et al., 1984).

Left Lowlands

The ground water levels in this area are under the influence of the reservoir and a stream called Trnava. The analysis of the ground water levels in the left lowlands were based on the water contour lines for the minimal and maximal water levels in the piezometers S–127, S–115, S–113 and PČ–27.

From 1977 until the filling of the reservoir the ground water level in S–127 varied from 163.86 to 164.70 m above sea level. After the filling it was between 165.59 and 166.02 m above sea level. It can be seen that the minimal and maximal water levels were increased for 1.7 m and 1.5 m respectively accompanied by a decrease in the difference between the levels.

Increased ground water levels – minimal 0.90 m, and maximal 0.60 m (Fig. 4) – were observed in the piezometers S–115 and S–113.

The oscillations in the water level in PČ–27 until June, 1982 showed values between 158.94 m and 160.95 m above sea level. Following the filling of the reservoir the minimal water level increased for

1.5 m, and the maximal 0.3 m. The difference between lowest and highest water levels in PČ–27 decreased from 2.01 m, the value it had before the filling of the reservoir, to 0.78 m after the filling was over.

The increased minimal and maximal ground water levels upstream of the dam are shown in the maps of the water contour lines for minimal and maximal water levels before and after the filling of the reservoir (Figs. 5 and 6).

We may say that the completion of the Čakovec hydroelectric scheme has permanently increased the minimal and maximal ground water levels on both sides of the reservoire. The oscillations of the minimal and maximal monthly water levels have become fewer so that extreme water levels have become more moderate as well as more uniform.

The completion of the Čakovec Power Plant reservoir has brought about new behaviour of the Drava waterflow at that section. It is characterized by tiny yearly oscillations in water levels and a continued level increase as compared to natural conditions. Because of this and rather permeable Quaternary deposits there is a constant seepage into the both sides of the reservoir.

Effects of the Hydroelectric Scheme on Ground Waters between Dam and Restitution

The derivational canal of the hydroelectric scheme is on the left bank of the old Drava riverbed. Its headwater canal, covered with asphalt concrete, is impervious with no effect to ground water levels.

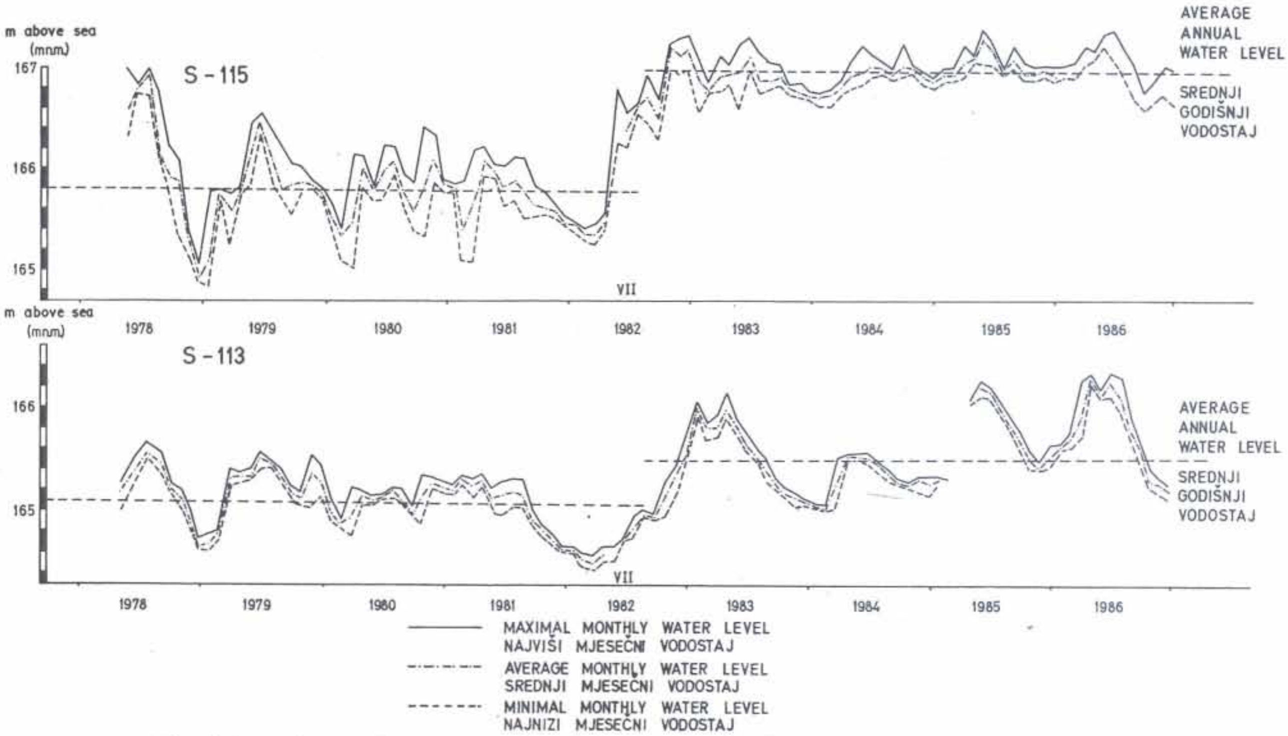


Fig. 4 Ground water levels measured in the piezometers S-113 and S-115 between 1978 and 1986

Sl. 4 Nivogrami pijezometara S-113 i S-115 od 1978. do 1986.

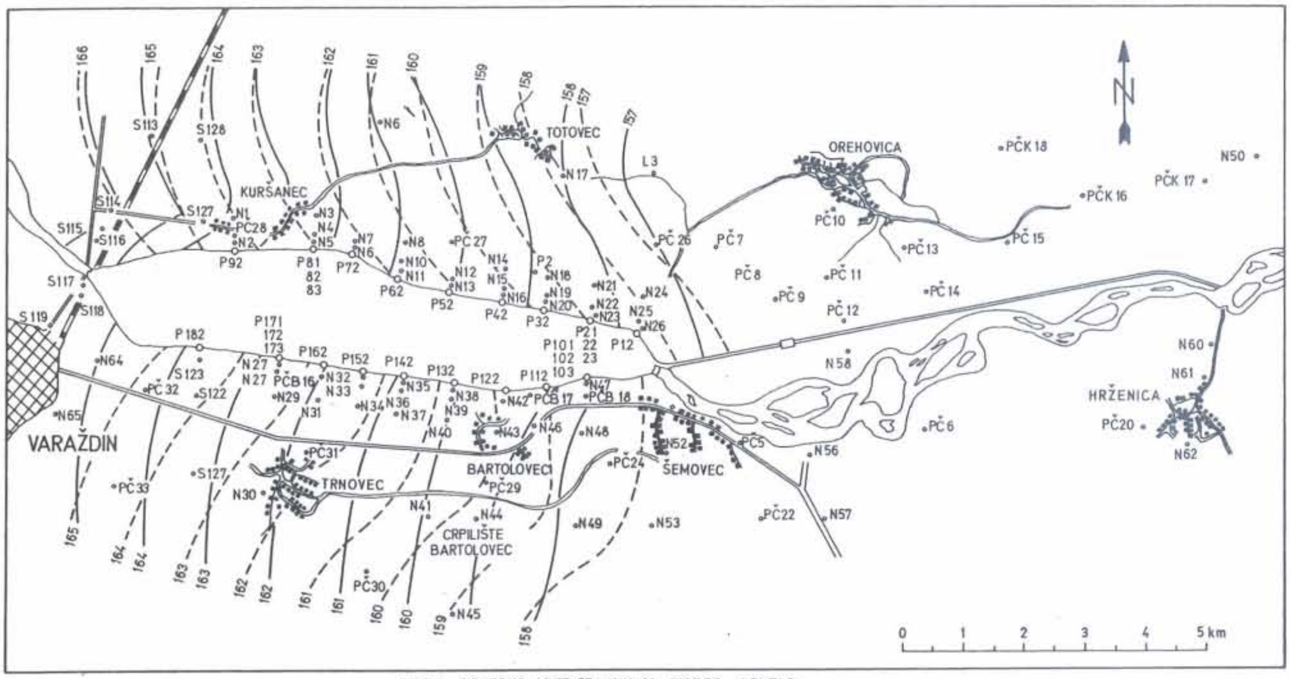
Extreme water levels that occured prior to the filling of the reservoir were caused by rainfalls or high waters of the Drava River. Due to the fact that in the period between the filling of the reservoir and the end of 1982 the total precipitation was as much as 800 mm, it is likely that increased ground water levels were decisively affected by the infiltration of rain into the soil. However, the draught only a year after, 1983, with precipitation as little as 610 mm had been the most severe one for the past twenty years; and yet, continued raised water levels were recorded in the piezometers upstream the dam.

That year the dam working level was 0.5 m less than planned, resulting in an unexpected loss of energy (Elektroprojekt, 1985). Lower working level of the reservoir caused a minor increase of the surrounding ground water levels.

The discharge canal has no such cover. The water table at the power station is 9 m below the ground surface. As a result, it is hydraulically directly linked with the aquifer acting as a powerful drain able to lower ground water levels.

Before the filling of the reservoir the ground water levels in the piezometers located locally along the Drava riverbed between the dam and the restitution varied between 0.8 and 2 m below ground surface.

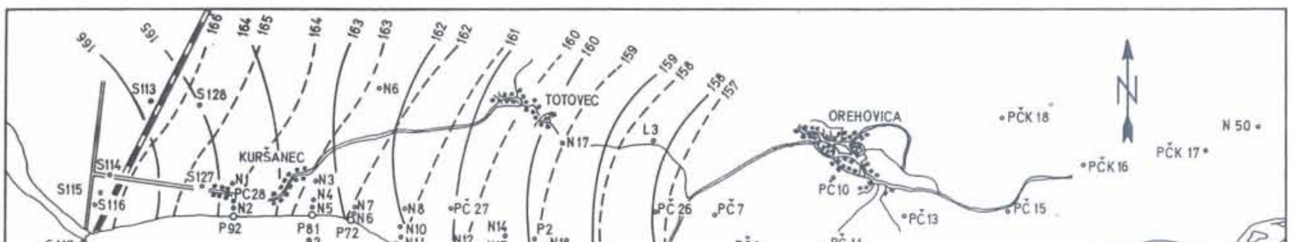
Following the full operation of the hydroelectric scheme the ground waters around the power station were lowered for about 8 m. This influence becomes less active with distance from the canal. However, lower water levels have been found in the left lowlands as much as 4.5 km away from the facilities. Excessively high lowerings are recorded in the piezometers PČ–9, PČ–10, PČ–11, PČ–12, PČ–14 and



WATER CONTOUR LINES OF MINIMAL WATER LEVELS:
HIDROIZOHIPSE MINIMALNIH VODOSTAJA ZA :
——— BEFORE FILLING OF RESERVOIR (FROM 1977 UNTIL JUNE 1982)
RAZDOBLJE PRIJE PUNJENJA AKUMULACIJE (OD 1977. DO LIPNJA 1982.)
- - - - AFTER FILLING OF RESERVOIR (BETWEN JUNE 1982 AND DECEMBER 1986)
RAZDOBLJE NAKON PUNJENJA AKUMULACIJE (OD LIPNJA 1982. DO PROSINCA 1986.)

Fig. 5 Water contour lines of minimal water levels of the lowlands around Čakovec power plant

Sl. 5 Hidroizohipse minimalnih vodostaja u zaobalju akumulacije HE Čakovec



WATER CONTOUR LINES OF MAXIMAL WATER LEVELS:
HIDROIZOHIPSE MAKSIMALNIH VODOSTAJA ZA :
——— BEFORE FILLING OF RESERVOIR (FROM 1977 UNTIL JUNE 1982)
RAZDOBLJE DO POČETKA PUNJENJA AKUMULACIJE (OD 1977. DO LIPNJA 1982.)
- - - - AFTER FILLING OF RESERVOIR (BETWEN JUNE 1982 AND DECEMBER 1986)
RAZDOBLJE NAKON PUNJENJA AKUMULACIJE (OD LIPNJA 1982. DO PROSINCA 1986.)

Fig. 6 Water contour lines of maximal water levels of the lowlands around Čakovec power plant

Sl. 6 Hidroizohipse maksimalnih vodostaja u zaobalju akumulacije HE Čakovec

PČ–15 between Orehovica and the discharge canal (Fig. 1).

Due to more complex hydrogeological conditions and the former Drava riverbed, drainage by the discharge canal in the right lowlands is aggravated. Minimal water level decreases are never higher than 1 m, but can be observed within a distance of 5 km (Elektroprojekt-Zagreb, 1984).

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Utjecaj izgradnje HE »Čakovec« na režim podzemnih voda

D. Grđan i B. Kovačev-Marinčić

HE »Čakovec« koristi energetski potencijal rijeke Drave između Varaždina i Hrženice, a druga je u nizu izgrađenih hidroelektrana. Dravska dolina, u kojoj je smještena HE »Čakovec«, širine je 15 do 20 km, a usmjerena je od zapada prema istoku. Dužina akumulacijskog jezera iznosi 8,7 km, površina 10,5 km^2, a zapremina $51,4 \times 10^6$ m^3, te ima utjecaj na režim podzemnih voda na velikom prostoru. Najveći dio na kojem se nalazi cijeli objekt hidroelektrane zauzima kvartarni vodonosni sloj koji je jedinstven i izgrađen od granuliranih šljunaka s različitim postotkom pijeska.

Pokusno punjenje akumulacije na radnu kotu 168 m n. m. uvjetovalo je naglo dizanje razine podzemne vode, naročito u predjelu Žabnika, Bartolovca, Šemovca i Trnovca. Nakon jednodnevnog održavanja radne kote u akumulaciji prišlo se ispuštanju vode iz jezera te izradi dodatnih kanala u naseljima Žabnik i Štefanec. Izvedeni dodatni drenažni kanali djelovali su lokalno na sniženje razine podzemne vode oko 0,30 m u neposrednoj blizini kanala.

U lipnju 1982. godine akumulacijsko jezero se ponovo i konačno puni na radni nivo između 167 i 168 m n. m. Da bi se ustanovila i kvantificirala promjena režima podzemnih voda u području akumulacijskog jezera, analizirani su podaci mjerenja na 70-ak pijezometara, kroz dva osnovna profila lijevog i desnog zaobalja.

Razina podzemnih voda u desnom zaobalju nalazi se pod utjecajem akumulacijskog jezera i rječice Plitvice. Punjenjem akumulacijskog jezera u desnom zaobalju došlo je do trajnog dizanja razine podzemnih voda za 0,90 do 0,30 m. Na pijezometrima bliže akumulacijskom jezeru taj porast je do 0,90 m, a na većim udaljenostima (pijezometar PČ–30 i PČ–33) iznosi 0,30 m. Na području vodocrpilišta Bartolovec porast razine podzemne vode iznosi 1,00–1,20 m (pijezometar N–41).

Na razinu podzemne vode lijevog zaobalja osim akumulacije utječe i potok Trnava. Nakon punjenja akumulacije u lijevom zaobalju minimalna razina podzemnih voda povećala se za 1,50 m, a maksimalna za 0,30 m. Razlika između najnižih i najviših vodostaja smanjila se od 2,01 m na 0,78 m. U lijevom i desnom zaobalju kolebanja maksimalnih i minimalnih mjesečnih vodostaja znatno su smanjena, pa su ekstremi vodostaja postali ublaženi i jednolićniji.

Nakon puštanja hidroelektrane u pogon razina podzemnih voda između brane i restitucije snižena je na području oko strojarnice za 8 m. Udaljavanjem od odvodnog kanala smanjuje se njegov utjecaj, ali se trajna sniženja na razinu podzemnih voda manifestiraju na tom području na udaljenosti do 5 km.

Stvaranjem akumulacijskog jezera i puštanjem hidroelektrane u pogon uspostavljen je novi režim toka Drave na tom području, koji karakteriziraju vrlo male oscilacije nivoa vode u toku godine, trajno povišenja razina podzemnih voda u području akumulacijskog jezera, a sniženja od strojarnice do restitucije u odnosu na prijašnje prirodno stanje.