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EKOHIDROLOŠKI PROCESI NA ZAJEMNEM OBJEKTU ZA HIDROELEKTRARNO PLAVE, SLOVENIJA
ECOHYDROLOGICAL PROCESSES ON THE INTAKE STRUCTURE OF THE PLAVE HYDROPOWER PLANT, SLOVENIA

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Zajem za HE Plave je sestavljen iz 6800 m dolge galerije, s padcem 0,315 ‰ in s premerom 7,80 m. Mirni tok s prosto gladino v kanalu nadzoruje zapornica. V zadnjih desetih letih je proizvodnja moči v letnem času upadla do 10 %. Najprej je bila izvedena preiskava tehniške službe HE, vendar ta ni pokazala pravih vzrokov upada moči. Konec avgusta 2001 so se začele izvajati meritve hitrosti na dovodnem kanalu. Merilec hitrosti z zapisovalcem podatkov je tri dni meril hitrosti. Nadaljnje tri mesece smo merili hitrosti z ultrazvočnim merilcem hitrosti, in sicer do konca novembra. Pri demontaži merilca so bili na instrumentu ugotovljeni trdi izrastki organskega izvora. Vzorec z opreme in trije vzorci za biološko analizo, ki so bili postrgani z obloge kanala, so bili pregledani na Oddelku za biologijo Univerze v Ljubljani. Ugotovljena je bila velika številčnost ličink iz družine Simulidae, ki so prekrivale merilec. Vzorci, postrgani z oblog kanala, so vsebovali perifitonsko združbo relativno majhne raznolikosti. Prevladovale so kremenaste in zelene alge. Z letnimi časi se je spreminjala tudi hrapavost galerije, ki smo jo spremljali tri leta na osnovi proizvodnje HE. Kote vode na dovodnem kanalu in ob iztoku so bile korelirane za stabilne pogoje. S hidravličnim modeliranjem smo analizirali tudi spremembe v hrapavosti.
Ključne besede: *hidroelektrarna, meritve hitrosti vode, hrapavost, ličinka Simulidae.*

The intake structure of the Plave power plant has a 6800 m long tunnel, with a longitudinal slope of 0.315 ‰ and a diameter of 7.80 m. In the tunnel the subcritical free surface flow is controlled by a sluice gate. In summer, the power production has decreased in the past few years up to 10 percent. An in-house investigation was carried out, however failing to show the underlying causes of the power decrease. At the end of August 2001, velocity measurements were launched on the intake structure. For three days, the current meter with an internal memory measured the velocity. After that velocities were measured with ultrasonic current meter for three months, until the end of November 2001. When dismantling the current meter it was discovered that the instrument was covered with unidentified organisms. The sample of biogenesis from the current meter and three samples for biological analysis scraped off of the wall of the tunnel were investigated in the laboratory of the Biological Department of the University of Ljubljana. It was established that the current meter was completely covered with dipteran larvae (f. Simulidae). The three scraped samples were identified as periphyton community with relatively low diversity. Cyanobacteria and diatoms prevailed. The roughness of the tunnel changed seasonally, which was analyzed from the monitoring data of power plant production for a three-year period. Water levels on the intake and outlet and discharge were correlated for steady state conditions. Changes in roughness were also analyzed with hydraulic modelling.
Key words: *hydropower plant, velocity measurements of water, roughness, larvae Simulidae*

1. UVOD

Hidroelektrarna Plave, ki je bila leta 1939 zgrajena na reki Soči, ima 2 turbini z močjo 8 MW in 74 m^3/s pretoka. Rezervoar na dotoku vode v tlačne cevovode HE je s pregrado Ajba povezan s kratkim vstopnim odprtim kanalom in 6800 m dolgo galerijo, ki ima padec 0,315 ‰ in konstantni prečni prerez (slika 1). Skozi galerijo teče voda v toku s prosto gladino. Kota vode pri dotoku na turbine je konstantna in znaša 101,30 m ker je vzdrževana s koto preliva tako, da so tlačne cevi z gornje strani pod konstantnim tlakom.

Pretok v galeriji uravnava zapornica na pregradi. Informacijski center hidroelektrarne je daljinsko povezan z vodomerom na dovodnem delu. Upravljanje obratovanja hidroelektrarne je avtomatsko, tako da se optimizira glede na gladino vode na vhodu v kanal. Optimalna proizvodnja energije z enim agregatom dosega 8 MW moči, pretok 36 m^3/s in 2,2 m proste gladine v galeriji. Pri obratovanju obeh agregatov je optimalna moč 16 MW, pretok 74 m^3/s, prosta gladina vode v galeriji pa 0,75 m pod stropom.

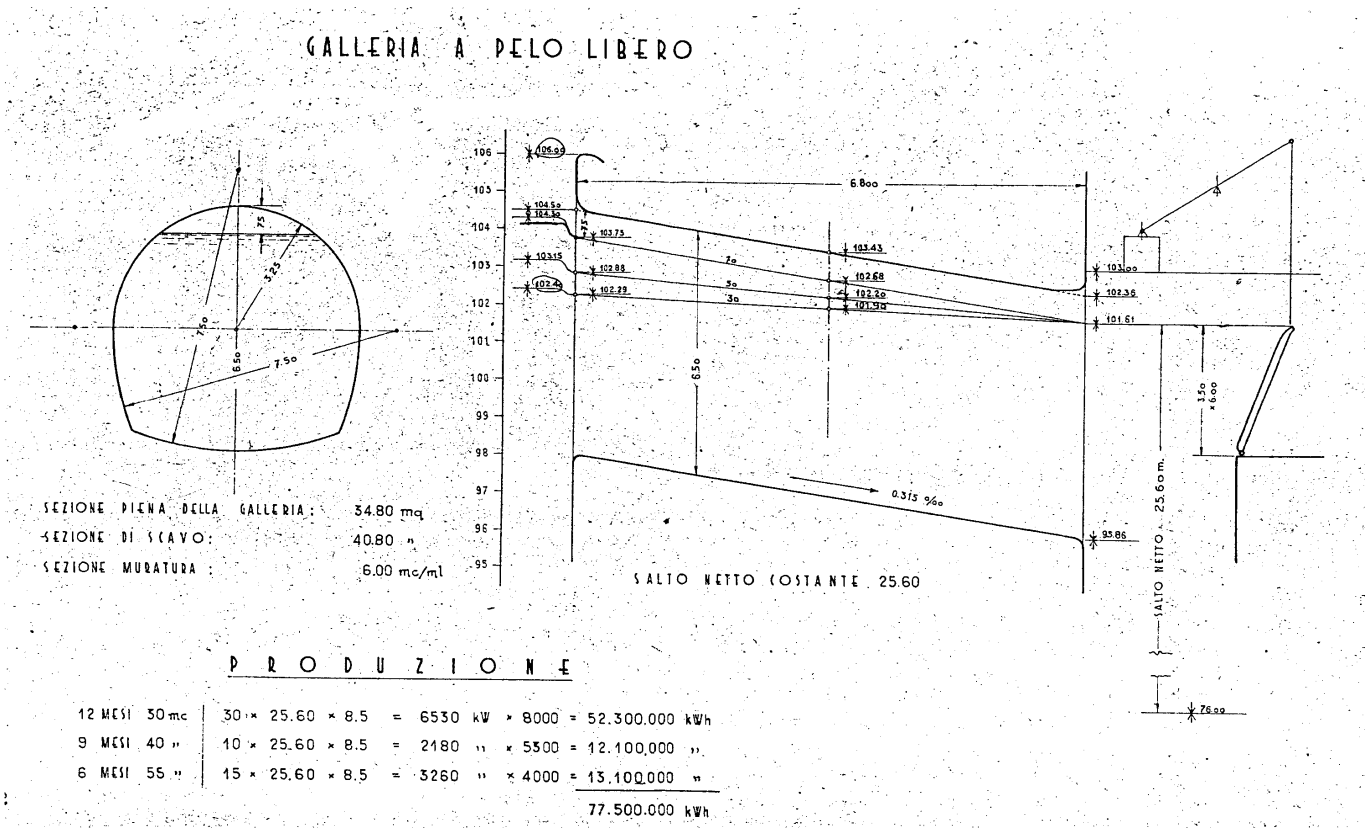
Že leta 1999 je bilo ugotovljeno, da HE z enim agregatom ne dosega maksimalne želene proizvodnje moči. Ob obratovanju enega agregata naj bi bila kota vode pri dotoku na turbine konstanta in naj bi znašala 102,15 m. Junija 1999 je v času nizkega poletnega pretoka upravljalec povečal koto vode pri dotoku na turbine, da bi ohranil maksimalno proizvodnjo agregata, slika 2. Kota vode je v desetih dneh počasi narasla na 102,38 m. Do tega je prišlo že nekajkrat prej, vendar proces pred letom 1999 nikoli ni bil tako značilen. V obratovanju HE se je vodna kota pri dotoku na turbine občasno sicer zvišala in tako za agregate priskrbela enako količino vode. To je bilo možno zato, ker HE (z eno turbino) ne obratuje ob maksimalnem pretoku. Pri obratovanju z obema turbinama to ni možno, saj je obratovanje ob maksimalnem pretoku z obema turbinama programsko omejeno in regulirano z visokovodnim prelivom.

1. INTRODUCTION

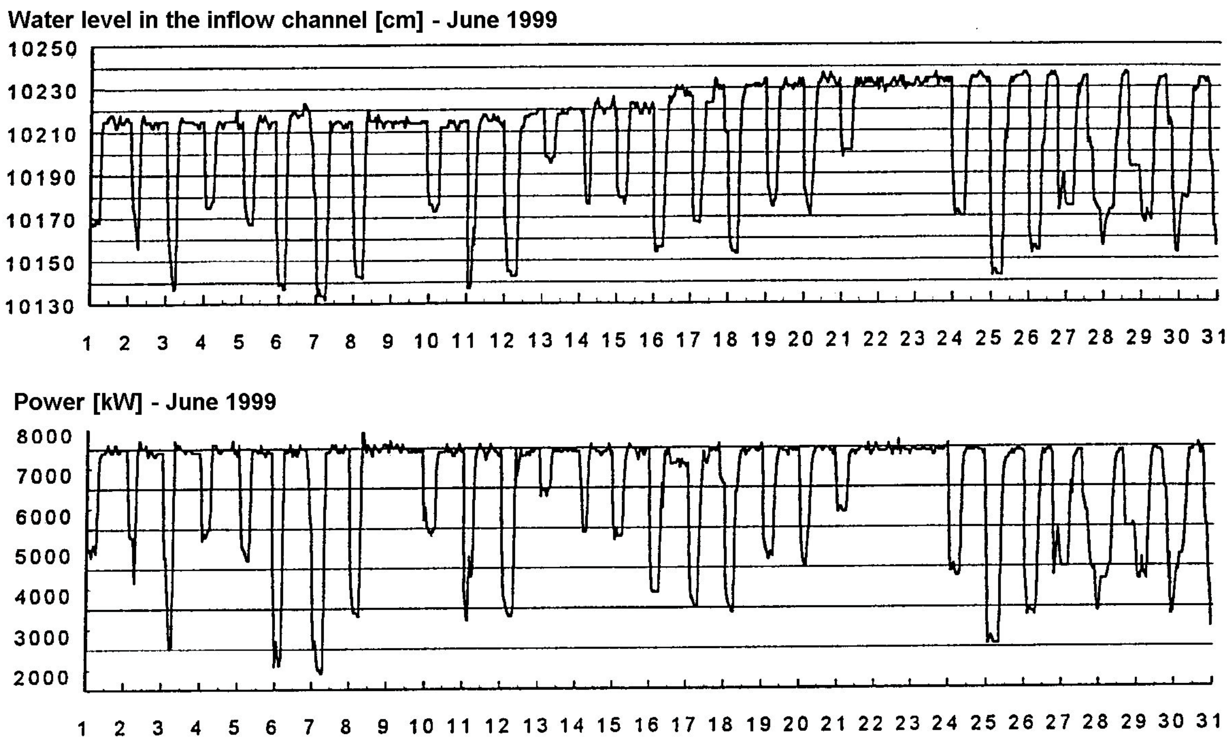
The Hydropower Plant Plave built on the Soča River in 1939 has two turbines of 8 MW power each and discharge of 74 m^3/s. The surge tank on the intake of the penstock supplying the turbines of the hydroelectric power plant is connected to the Ajba dam with a short open channel and 6800 meter long tunnel, which has a longitudinal slope of 0.315 ‰ and a constant cross-section (Figure 1). The water flows through the tunnel as a free-surface flow. The water level at the surge tank is constantly kept at 101.30 m with an overflow spillway; the penstock is under constant pressure on topside.

The discharge in the tunnel is controlled by a sluice gate on the dam. On the inflow channel, the water level gauge is connected online with the information centre of the power plant. The power plant is under automatic control which is optimized on water level in the inflow channel. The optimal production of energy with one turbine is 8 MW with a discharge of 36 m^3/s, and with a 2.20 m of free board in the tunnel. When both turbines operate, the optimal power is 16 MW, discharge 74 m^3/s, board in the tunnel 0.75 m.

In summer 1999, the power plant failed to reach its maximum production with one turbine. With one turbine in operation, the water level on the intake structure should be constant i.e. 102.15 m. In June 1999, the operator increased the water level on the intake structure to maintain the maximum production of the plant during the summer low flow season (Figure 2). The water level slowly increased to 102.38 m in ten days. The phenomena had occurred several times before, but the process was never as significant as in 1999. From time to time, the operator on the power plant increased the water level in the inflow channel to provide the same amount of water. This was possible because (with only one turbine) the power plant operates below the maximum discharge. However, this is not possible during maximum discharge operation with both turbines, because the water level in the inflow channel is controlled by the overflow spillway.



Slika 1. Prečni prerez dovodnega tunela HE Plave –
kopija originalne dokumentacije v italijanskem jeziku.
*Figure 1. Cross sections of the Plave hydropower plant tunnel –
copy from the original documentation in Italian.*



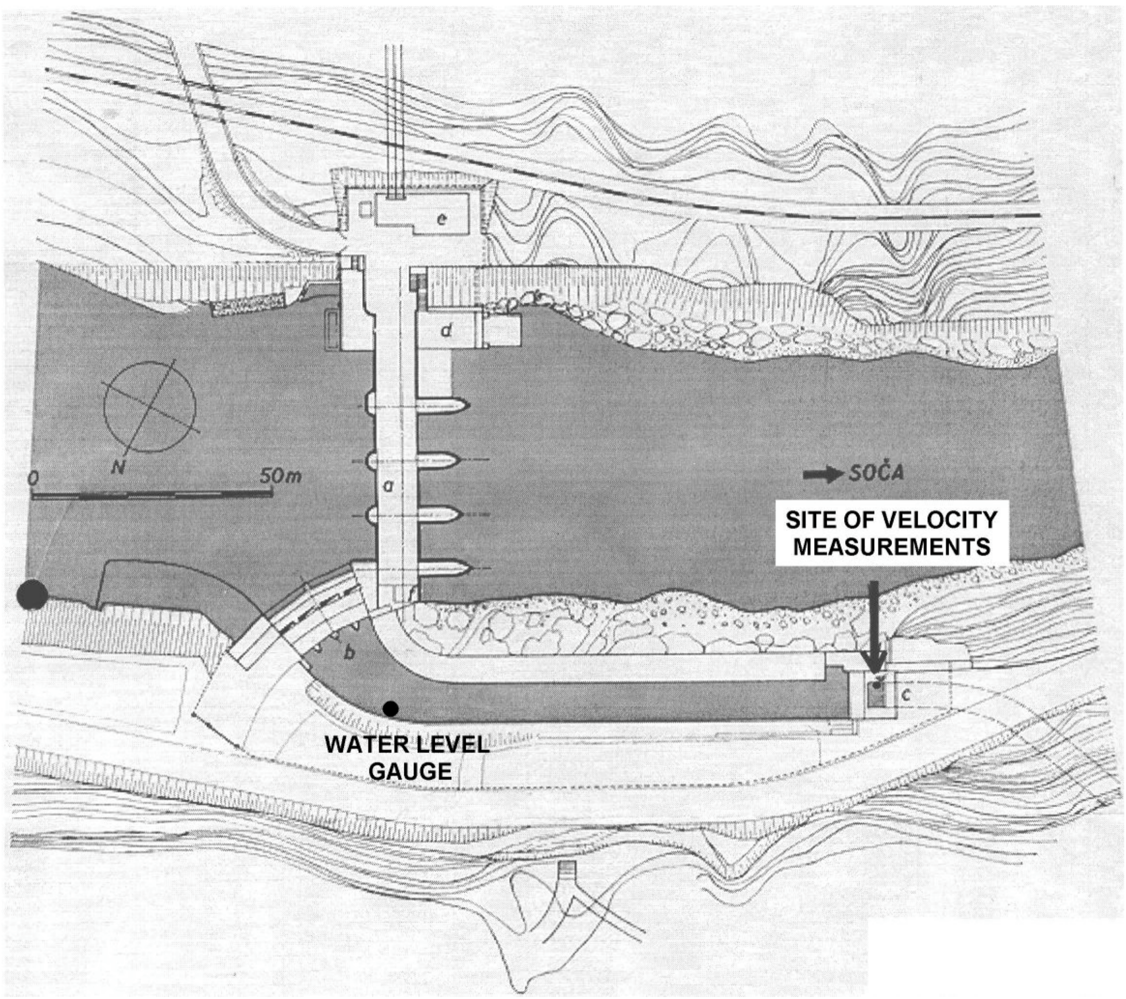
Slika 2. Proizvodnja energije v juniju leta 1999.
Figure 2. Power production data in June1999.

Galerijo so odklopili, vodo izpustili in temeljito pregledali objekt. Tehnična analiza HE ni nakazala možnega vzroka, nekontrolirana izguba vode zaradi razpok ali fizičnih poškodb galerije v objektu HE pa je bila izključena.

Poleti 2001 je pojav raziskala Univerza v Ljubljani. Na vhodu v tunel sta bila postavljena dva merilca pretočnih hitrosti (slika 3): mehanični merilec hitrosti z zapisovalcem podatkov in Dopplerjev merilec hitrosti. Meritve so se začele avgusta in zaključile oktobra 2001 (slika 4). Pri demontaži merilca Valeport je bil merilec prekrit s trdimi izrastki. Konec oktobra so bili z oblog kanala in galerije odvzeti še vzorci za biološko analizo.

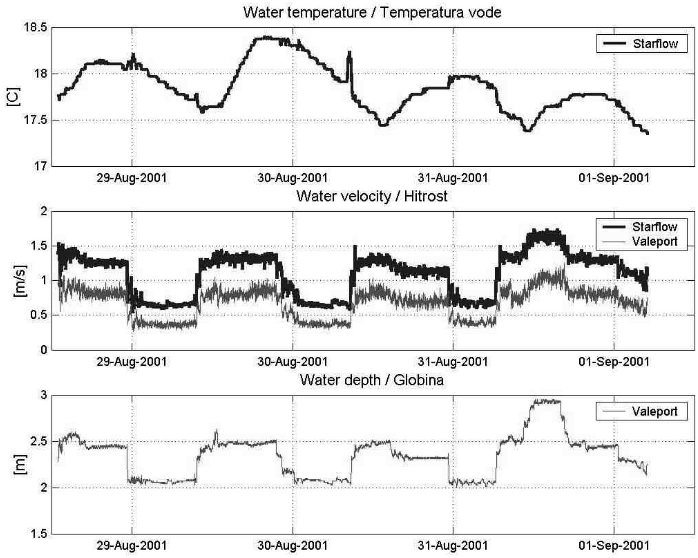
The tunnel was switched off, the water evacuated and the structure carefully inspected. Technical analyses of the power plant functioning failed to reveal the origin of the problem, while uncontrolled water loss due to tunnel cracks or other physical damage on the power plant construction was excluded as the underlying cause.

In summer 2001, the phenomena were investigated by the University of Ljubljana. Two current meters were put into the intake channel (Figure 3): a mechanical current meter with a memory unit and a Doppler velocity meter. The measurements and observations started in August and were finished in October 2001 (Figure 4). Upon dismantling of the equipment the current meters were completely covered with small features. In October 2001 we started with biological sampling in the tunnel.



Slika 3. Pregrada Ajba in dotok v galerijo HE Plave.

Figure 3. Ajba Dam with intake structure of tunnel HE Plave.



Slika 4. Meritve hitrosti, gladine in temperature vode na vtoku v galerijo
Figure 4. Measurements of velocity, level and temperature of water in intake structure of the tunnel

Fenomen zmanjševanja obratovalne moči je bil analiziran na osnovi obratovalnih podatkov HE Plave iz let 1999, 2000 in 2001. Analizirani so bili predvsem podatki o proizvodnji moči, agregatnih pretokih in gladini vode na vstopu v galerijo, cevovod pod tlakom in iztok HE.

The phenomenon of decreasing power production was analyzed on the basis of the operational data of the Plave hydropower plant in years 1999, 2000, and 2001. Data on power production, turbine discharges and water levels in the inflow channel, surge tank and the outlet of the plant were analyzed.

2. ANALIZA PODATKOV O OBRATOVANJU HE

Podatki o proizvodnji moči in obratovanju sistema HE, ki so bili zbrani na terenu, so bili shranjeni v podatkovno banko. Podatki so bili zbrani za zelo kratke, vendar različno dolge nekaj sekundne časovne intervale. Pred analizo je bilo treba obsežno množico izmerjenih podatkov urediti. Podatke smo izbrali tako, da smo se izognili nihanju, ki ga povzročajo nestabilni operativni pogoji sistema zaradi sprememb v proizvodnji moči ali vpliv visokih voda reke Soče na izlivu iz turbine. Iz arhivirane podatkovne bazi so bili zbrani in obdelani predvsem podatki v stabilnem in stalnem stanju na nekaj ur. Zbrani so bili naslednji podatki: pretok na agregatih, proizvodnja moči na sistemu, kota vode na vstopu v galerijo in kote vode v vodostanu. Podatki so bili obdelani in predstavljeni kot

2. ANALYSIS OF THE POWER PLANT OPERATIONAL DATA

Online collected field data of power production and operation of the hydropower plant system were stored in a data bank. Data were collected with very short, though differently-sized time steps of several seconds. There was a large amount of the measured data that needed to be arranged before an analysis. The data were chosen in a way as to avoid the oscillation produced by unstable operational conditions of the system, caused by changes in power production or impacts of the high water level of the Soča river on the outlet from the turbine. Data of stable, steady state of several hours were collected and processed from the archive database. The following data were collected: discharge on turbines, power production of the system, water levels in the inflow channel, and water levels in the surge tank. Data were processed and extracted from srednje urne vrednosti.

Najprej so bili analizirani podatki iz opazovalnega obdobja med avgustom in oktobrom 2001. Nizki pretok reke Soče je bil vzrok nizki proizvodnji moči na enem od agregatov od konca avgusta do sredine septembra. Visok pretok od sredine septembra do sredine oktobra je omogočal optimalno proizvodnjo moči na obeh agregatih. V razmerju med pretokom in koto vode na dovodnem kanalu ni bilo izrazitih razlik.

Nadalje smo analizirali arhivirane podatke od začetka leta 1999 do obdobja terenskih opazovanj iz leta 2001. Podatki so bili obdelani na podoben način kot v prvi stopnji analize. Diagram, ki prikazuje razmerja med močjo in kotami vode na dovodnem kanalu, je prikazan na sliki 5. Prikazane so izrazite spremembe v kotah vode na dovodnem kanalu. Opazovalno obdobje med avgustom in oktobrom je minilo brez bistvenega upada prevodnosti galerije.

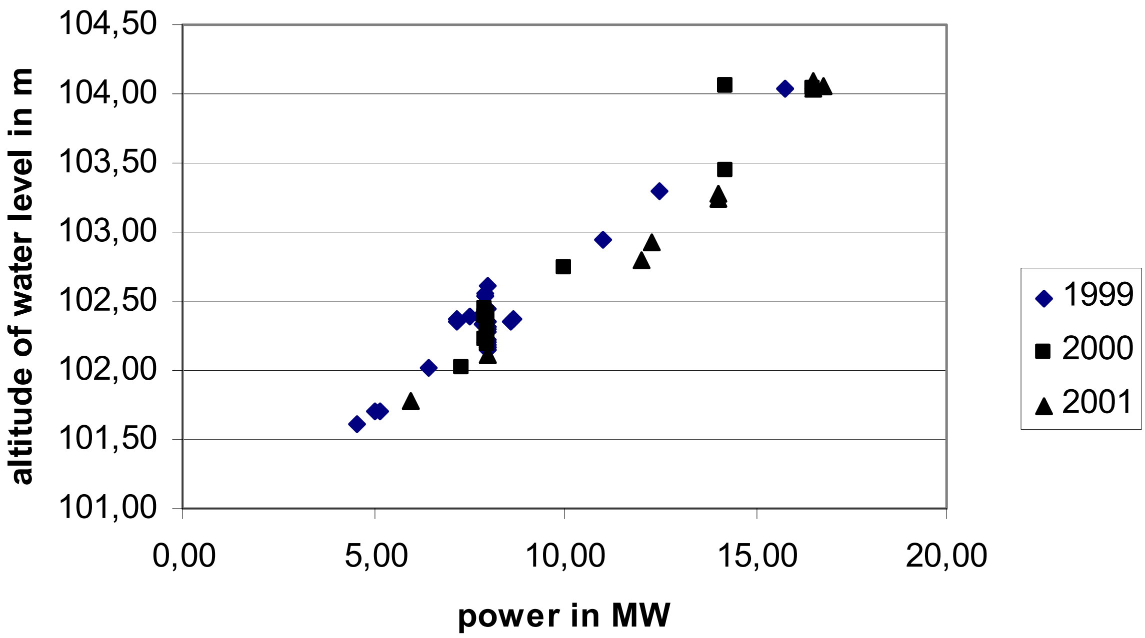
Hidravlični izračuni pretoka v kanalu so temeljili na Manningovi enačbi (Brater in ost., 1996). Rezultati izračunov so prikazani v preglednici 1. Koeficient hrapavosti se izrazito spreminja. Manningov koeficient hrapavosti je bil preračunan na absolutno višino hrap. Ta sega od 0,012 mm v dobrih pogojih do 4,4 mm v najslabših pogojih v kanalu.

the archive as mean hourly values.

Data for the observation period from August to October 2001 were analysed first. Low flows in the Soča River resulted in low power production of one of the turbines from the end of August to mid-September. From mid-September to mid-October, high flows enabled optimal power production on both turbines. There were no significant differences in relations between discharge and water levels in the inflow channel.

In the next stage we analysed the archived data from the beginning of 1999 to the period of field observations in 2001. Data were processed in the same way as in the first stage of the analysis. A diagram with relations between power and the water levels in the inflow channel is shown on Figure 5. There are significant changes of water levels in the inflow channel. Observation period from August to October was without a significant decrease in the conductivity of the tunnel.

The hydraulic calculation of the flow in the tunnel was based on the Manning equation (Brater *at al.*, 1996). Results of these calculations are shown in Table 1. The coefficient of roughness varies significantly. The Manning roughness coefficient was recalculated to the absolute roughness height. The roughness height varies from 0.012 mm in good conditions of the tunnel to 4.4 mm in the worst conditions.



Slika 5. Razmerje: moč–kota vode.

Figure 5. Relation power–water level.

Preglednica 1. Rezultati hidravličnih izračunov.
Table 1. Results of hydraulic calculations.

datum – *Date*	pretok v m^3/s – *Discharge in m^3/s*	koeficient hrapavosti – *Roughness coefficient*	hrapavost v mm – *Roughness in mm*
07-06-1999	36,5	0,012	0,087172
04-08-1999	36,8	0,0165	4,388972
07-11-1999	71,4	0,0129	0,335985
10-05-2000	64,7	0,0143	1,109794
28-06-2000	35,8	0,0138	0,729321
27-10-2000	36,1	0,0118	0,052941
28-05-2001	74,8	0,0123	0,1721
12-08-2001	35,4	0,0115	0,012501

3. ANALIZA BIOLOŠKIH VZORCEV

Vzorci z merilne opreme in oblog kanala so bili odvzeti v oktobru in poslani Skupini za limnologijo Oddelka za biologijo Univerze v Ljubljani. Mikroskopski pregled je potrdil prisotnost večjega števila ličink iz družine *Simulidae* (slika 5, Moss, 1988; Barnes in ost. 1995; Ruppert in Barnes 2001).

Vzorci, postrgani s kovinskih delov merilne opreme, so vsebovali za tekoče vode tipično perifitonsko združbo. Najbolj pogoste so bile kremenaste in zelene alge ter posamezne praživali (*Protozoa*). Zanimivo je, da je kovinski substrat pokrivalo veliko število ličink mušice dvokrilcev iz družine *Simulidae.*

Te majhne, manj kot 1 cm velike ličinke, so pomemben sestavni del makrozoobentoških združb in so pritrjene na kamnih v vodah s hitrim tokom. Prehranjujejo se z delci, ki jih vodni tok plavi s seboj, ličinka pa izkoristi organski detritus.

Koncentracija organskih snovi je eden izmed omejujočih dejavnikov rasti populacije ličink v rekah. V primeru reke Soče je količina suspendiranih snovi v vodnem stolpu zadostna za razvoj obilne populacije *Simulidae*. Vir suspendiranih snovi je fitoplankton, v zajezitvah na Soči pa tudi odtrgani perifiton, ki ga reka plavi. Dinamika populacije je značilna za slovenske klimatske pogoje, njena številčnost pa je največja poleti.

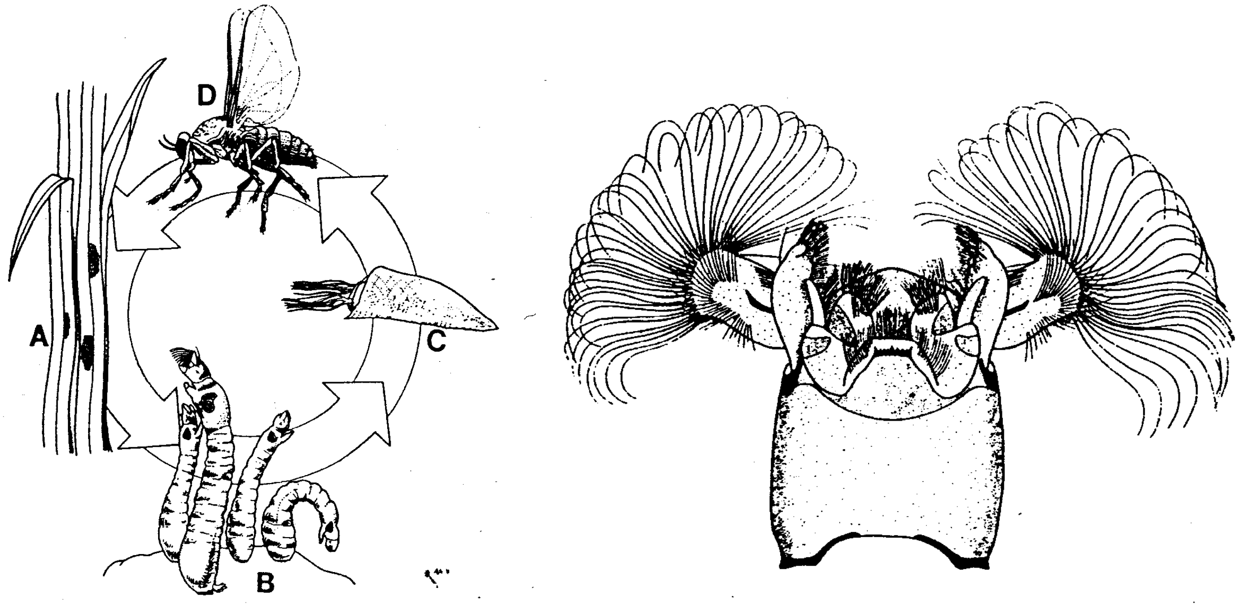
3. ANALYSIS OF BIOLOGICAL SAMPLES

Samples from the hydraulics equipment and the walls of the tunnel were taken in October and sent to the Group of Limnology of the Department of Biology, University of Ljubljana. The microscopic examination confirmed a high number of dipteran larvae *Simulidae* (Figure 5, Moss, 1988; Barnes *et al*., 1995; Ruppert & Barnes 2001).

Samples scraped off from the metal parts of hydraulics equipment contained a periphyton community, typical for running waters. Most abundant were diatoms and green algae as well as protozoan taxa. Surprisingly, numerous dipteran larvae from the *Simulidae* family covered the metal substrate.

Small, 1 cm large larvae are important part of the macrozoobenthic community in turbulent running waters and are commonly fixed on stones. The suspension feeding animals feed on organic detritus.

Organic matter concentration is one of the restrictive factors of larvae growth in rivers. In the case of the Soča River, the amount of suspended solids in water column is sufficient for development of an abundant *Simulidae* biomass. The source of suspended solids is the phytoplankton community in reservoirs on the Soča River as well as the drifting periphyton assemblages. Population dynamics is characteristical for Slovenian climate conditions. *Simulidae* larvae are most abundant in summer.



Slika 5. Razvojni krog dvokrilca družine *Simulidae* in glava ličinke s filtrirno napravo.
Figure 5. Development cycle of diptera Simulidae and the head of larvae with filtration device.

4. RAZPRAVA IN ZAKLJUČKI

Vzrok za spremembe hidravlične prevodnosti kanala, ki je bil raziskan v okviru terenske raziskave, je treba iskati v vplivu biotskih dejavnikov na sistem. Ekološko stanje sistema HE Plave je odvisno od načina obratovanja in zunanjih vremenskih pogojev (temperature zraka, vlažnosti ipd.). Zunanjih dejavnikov sicer ne moremo spreminjati, lahko pa vplivamo na notranje dejavnike in zmanjšamo vpliv omenjenega pojava.

Najboljše razmere za pospešeni razvoj pojava so ravno v poletnem času, ko HE obratuje le s polovico kapacitete kanala. Zaradi manjšega pretoka vode je bilo v tunelu več zračnega prostora, pretočna hitrost vode je bila nižja, to pa so bile ugodne razmere za razvoj ličink.

4. DISCUSION AND CONCLUSIONS

Variations in hydraulic conductivity of the tunnel found in the field study were caused by the influence of biotic factors on the system. Ecological conditions in the Plave hydropower system depend on the operation scheme and outside weather conditions (air temperature, humidity etc.), and hydrological conditions (water discharge and water quality). It may not be possible to change the outside factor, but we could adapt the inside factors to decrease the influence of the phenomenon.

The best conditions for persistent blooming are present during summer months when the hydropower plant operates only with half of the tunnel capacity. Due to smaller water discharge, there was an abundance of airspace in the tunnel, and water velocity was lower, all of which stimulated the development of larvae.

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