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Istraživanje antičkih vodnih zahvata na izvoru rijeke Jadro

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728.8(497.583Split)"652"
628.113(282.2Jadro)+
(398Salona)"652"
Izvorni znanstveni članak
Primljeno: 17. 7. 2017.
Prihvaćeno: 31. 7. 2017.

Pristup dovoljnoj količini kvalitetne vode oduvijek je bio preduvjet za održiv život na nekom području. Dobar primjer jest izvor rijeke Jadro, koji se

A study of Roman water intake structures at the Jadro River's spring

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Original scientific paper
Received: 17 July 2017
Accepted: 31 July 2017

Access to quality potable water in sufficient quantity has always been a precondition for the sustainability of every form of life in a certain area. An excellent

nalazi u blizini zaštićene i pristupačne obale. On je bio važan resurs za nastanak i razvoj dviju značajnih rimskih naseobina, Salone, najvećega rimskoga grada na istočnoj obali Jadrana, i palače cara Dioklecijana. Dovoljan kapacitet, dobra kakvoća te visinski položaj izvora u odnosu na obalnu crtu omogućili su izgradnju dvaju pouzdanih vodoopskrbnih sustava, akvedukta Salone, koji je bio u funkciji od I. stoljeća pr. Kr. do VII. stoljeća, i akvedukta Dioklecijanove palače, koji je bio u funkciji od IV. do VII. stoljeća. Ovaj potonji rekonstruiran je krajem XIX. stoljeća, a danas je više od pola njegove trase još uvijek u funkciji. U radu se prezentiraju rezultati istraživanja antičkih zahvatnih građevina salonitanskoga i Dioklecijanovog akvedukta na izvoru rijeke Jadro te povijesni slijed razvoja zahvata od prirodnog terena do danas kroz 6 karakterističnih faza.

Ključne riječi: Jadro, vodovod, akvedukt, Salona, Dioklecijanova palača

example is the spring of the Jadro River, situated near a well-sheltered and accessible coast. This water resource was of great importance to the emergence and development of two significant Roman settlements: Salona, the largest Roman city on the eastern Adriatic coast, and Emperor Diocletian's palace. Due to a sufficient capacity and quantity of quality water, and the elevation of the spring, two reliable water supply systems were constructed: the Salona Aqueduct, which functioned continually from the 1st century BC to the 7th century AD, and the Diocletian Aqueduct, which functioned from the 4th to the 7th centuries. The latter, over half of which is still in use today, was reconstructed in the late 19th century. This paper will present the results obtained by analysis of the two Roman water intake structures at the Jadro River's spring, one belonging to the Salona Aqueduct and the other to the Diocletian Aqueduct. The chronological development of these water intake structures at the Jadro's spring will be presented through six distinctive phases from the natural terrain up to the present time.

Key words: Jadro, water supply system, aqueduct, Salona, Diocletian's Palace

Na Fakultetu građevinarstva, arhitekture i geodezije Sveučilišta u Splitu provodi se istraživački projekt Hrvatske zaklade za znanost pod naslovom: "Antički vodni sustavi grada Salone i Dioklecijanove palače i njihov utjecaj na održivost urbane sredine".[1] Multidisciplinarni tim znanstvenika sastavljen od arheologa, arhitekata i inženjera građevinarstva istražuje dva rimska vodna sustava napajana s istog mjesta. Ovdje će biti prezentirani rezultati istraživanja zahvatnih građevina obaju akvedukata na izvoru rijeke Jadro.

Uvod

Salona, glavni grad rimske provincije Dalmacije, dobila je svoje ime po rijeci Salon (danas Jadro), koja joj je osiguravala vodoopskrbu. Izvor rijeke Jadro nalazi se na zapadnom obronku Mosora, na koti 32,00 - 33,50 m.n.v., 3 km istočno od antičke Salone i 7 km sjeveroistočno od Splita (sl. 1). Duljina rijeke od izvora do ušća procijenjena je na 4318 m s ukupnim padom od oko 30 %. To je tipični kraški izvor s iznimno promjenjivim protokom koji varira od minimalnog ljetnog, 3,72 m^3/s, do maksimalnog zimskog, 70,1 m^3/s.[2] Voda se i danas koristi za piće bez ikakva posebnog tretmana osim dezinfekcije. Kod većih se kiša zamućuje, što stvara probleme u radu vodovoda. U X. stoljeću car Konstantin Porfirogenet hvali ovu vodu i navodi da je najukusnija od svih voda.[3] Može se reći da izvor Jadra u cijelosti zadovoljava smjernice koje Vitruvije navodi za odabir zahvata vode za vodoopskrbu rimskih gradova.[4]

U I. stoljeću pr. Kr. sagrađen je akvedukt dužine 5 km od izvora Jadra do Salone. Dimenzije kanala variraju od 62 do 100 cm u širini i od 72 do 121 cm u visini. Kapacitet vodovoda kod visine punjenja od 50 cm iznosi od 450 l/s do 650 l/s, što ovisi o nagibu i presjeku kanala.[5] Akvedukt Dioklecijanove palače, dužine 9,5 km, sagrađen je na prijelazu iz III. u IV. stoljeće. Dimenzija protočnog dijela kanala jest 60 na 120 cm,[6] a kapacitet iznosi 356 l/s kod visine punjenja

1 Oznaka projekta: HRZZ IP-11-2013-9852; akronim projekta: RWSCSDP; trajanje: 2014.-2018.; voditelj: prof. dr. sc. Jure Margeta, dipl. ing. građ.; istraživači: doc. dr. sc. Davor Bojanić, dipl. ing. građ.; dr. sc. Miroslav Katić, dipl. arheolog; izv. prof. dr. sc. Katja Marasović, dipl. ing. arh.; doc. dr. sc. Snježana Perojević dipl. ing. arh.
2 Bonacci 2012.
3 Kečkemet 1999, str. 29; Bulić 1923, str. 111-112.
4 Vitruvius 1997, str. 166.
5 Marasović *et al*. 2016, str. 150-153.
6 Marasović *et al.* 2014, str. 168.

A research project, financed by the Croatian Science Foundation, has been conducted at the Faculty of Civil Engineering, Architecture and Geodesy, University of Split under the title "Roman Water Systems of Salona and Diocletian's Palace and Their Impact on the Sustainability of the Urban Environment".[1] A multidisciplinary team of scientists consisting of archaeologists, architects and civil engineers set out to investigate the two Roman water systems fed by the same source. In this paper, the results of a study of the two water intake structures at the Jadro River's spring will be presented.

Introduction

Salona, the capital of the Roman province of Dalmatia, derived its name from the Salon (today Jadro) River, which ensured its water supply. The Jadro River's spring is situated on the western slopes of the Mosor range, at an elevation of 32.0-33.5 m a.s.l., 3 km east of the Roman city of Salona, and 7 km northeast of the city of Split (Fig. 1). The length of the river, from the spring to its mouth, is approximately 4,318 m, with a roughly 30% gradient along its entire course. It is a typical karst spring with an uneven flow rate, varying from a 3.72 m^3/s minimum summer rate to a 70.1 m^3/s maximum winter rate.[2] The water is used for drinking without any specific treatment except disinfection. Heavy precipitation contributes to the water's turbidity, thus causing problems for the operation of the aqueduct. In the 10th century, Emperor Constantine Porphyrogenitus praised this water and said that it has the most delicious taste.[3] Overall, the Jadro River's spring meets the criteria specified by Vitruvius in his guidelines for the organisation of water supply systems to Roman cities.[4]

The Salona Aqueduct, with an overall length of 5 km, was built in the 1st century BC, extending from the Jadro's spring to the city of Salona. The dimensions of its channel vary from 62 to 100 cm in width, and from 72 to 121 cm in height. Its capacity, at water depth of 50 cm, varies from 450 l/s to 650 l/s, depending on

1 Project code: HRZZ IP-11-2013-9852; Project acronym: RWSCSDP; Duration: 2014- 2018; Project manager: Professor Jure Margeta, Ph.D., Civ. Engineer.; Researchers; Assistant Professor Davor Bojanić, Ph.D., Civ. Engineer.; Miroslav Katić, Ph.D., Archaeologist.; Associate Professor Katja Marasović, Ph.D., Architect.; Assistant Professor Snježana Perojević, Ph.D., Architect.
2 Bonacci 2012.
3 Kečkemet 1999, p. 29; Bulić 1923, pp. 111-112.
4 Vitruvius 1997, p. 166.

Sl. 1. Zahvatne građevine na izvoru rijeke Jadro (foto: M. Žabčić)
Fig. 1. The water intake structures at the Jadro River's spring (photo: M. Žabčić)

od 72 cm.[7] Salonitanski akvedukt išao je desnom stranom rijeke Jadro, a Dioklecijanov lijevom (sl. 2).

Najezdom Avara i Slavena u VII. stoljeću porušena je Salona, a onesposobljena su i oba akvedukta te je tada započela njihova razgradnja.[8] Stanovnici Salone naselili su se unutar sigurnih zidina Dioklecijanove palače i tako utemeljili grad Split koji danas ima 180000 stanovnika. Salona, međutim, nikada više nije dosegnula svoj nekadašnji sjaj. U njezinom jugoistočnom dijelu formiralo se središte novoga grada, Solina, dok je velik dio ukupnog areala antičke Salone, od 73 ha, ostao neizgrađen i zaštićen kao arheološki lokalitet nacionalne vrijednosti.

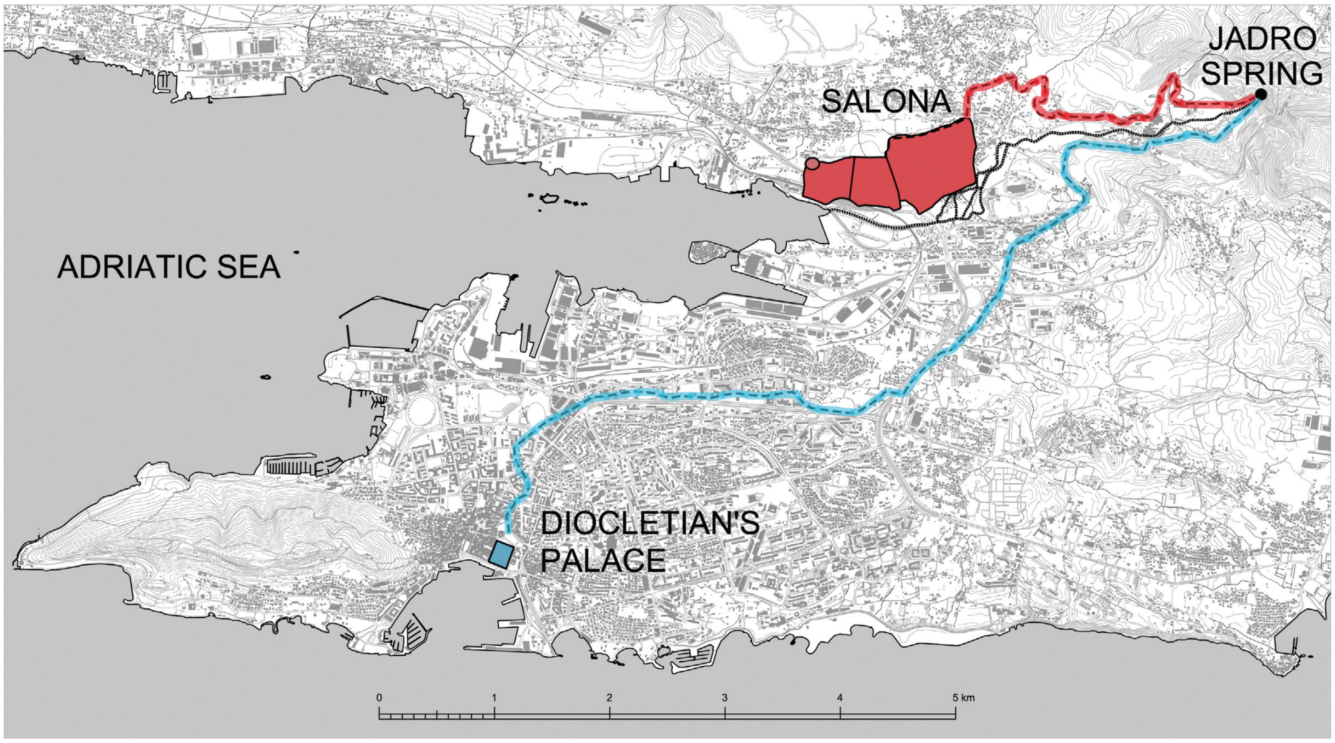
U razdoblju od VII. do XIX. stoljeća naselja na ovom području opskrbljivala su se kišnicom, vodom iz brojnih bunara, manjih lokalnih izvora i izravno iz rijeke Jadro. U Splitu su se uglavnom koristile kućne cisterne punjene kišnicom te javni bunari kojima bi se ljeti značajno smanjio kapacitet kao i kakvoća vode. Zbog toga se voda dovozila s rijeke Jadro i skupo

7 Margeta 2017.
8 Novak 2005, str. 42.

the slope of different channel sections.[5] The Diocletian Aqueduct, with an overall length of 9.5 km, was built at the turn of the 4th century. The dimensions of its channel is 60 by 120 cm.[6] This Aqueduct has a capacity of 356 l/s, at a water depth of 72 cm.[7] The Salona Aqueduct was built on the right bank of the Jadro River, and Diocletian's on its left (Fig. 2).

During the Slav and Avar invasions in the 7th century, the city of Salona was destroyed and both aqueducts ceased functioning, which led to their deterioration.[8] Inhabitants from the city of Salona settled inside the strong walls of Diocletian's Palace, which resulted in the establishment of the city of Split with a current population of 180,000. However, the city of Salona never reached its former glory. The new town of Solin and its centre formed in its south-eastern part, while a very large portion of the total area of ancient Salona of 73 ha. remained mostly undeveloped and,

5 Marasović *et al*. 2016, pp. 150-153.
6 Marasović *et al.* 2014, p. 168.
7 Margeta 2017.
8 Novak 2005, p. 42.



Sl. 2. Antički vodovodi Salone i Dioklecijanove palače (izvor: autori)
Fig. 2. Two Roman aqueducts; the Salona Aqueduct and the Diocletian Aqueduct (source: authors)

prodavala.[9] Zbog naglog razvoja grada Splita za vrijeme druge austrijske uprave (1813. - 1918.) javila se potreba za izgradnjom općinskog vodovoda.

Prvi prijedlog izgradnje vodovoda Splita, u kojem su predložena četiri različita rješenja vodoopskrbe, izrađen je 1845. godine.[10] Jedna od varijanti bila je obnova Dioklecijanova vodovoda, koju je gorljivo zastupao Vicko Andrić. Posebno je naglašavao važnost tog pothvata kao značajnog kulturnog doprinosa Carstvu. Njemu je 1855. gradonačelnik Splita Šimun Michieli Vitturi povjerio obnovu vodovoda,[11] a na tom ga je poslu 1859. zamijenio općinski inženjer Locati.[12] Samu obnovu pokrenuo je gradonačelnik dr. Antun Bajamonti 1862. godine.[13] Osim za vodoopskrbu grada vodovod je trebao poslužiti za navodnjavanje Splitskog polja te naročito za potrebe splitske željezničke stanice jer su tada lokomotive bile pokretane parnim strojem. Vodovod je pušten u promet 14. ožujka 1880.[14] Imao je isti tehnološko-gravitacijski koncept opskrbe vodom kao i rimski, a unutar grada je za opskrbu stanovništva bilo planirano postavljanje 25 fontana.

9 Belamarić 1999, str. 12; Bulić 1923, str. 111.
10 Kečkemet 1999, str. 31.
11 Kečkemet 1999, str. 33.
12 Belamarić 1999, str. 13.
13 Belamarić 1999, str. 15.
14 Belamarić 1999, str. 15.

consequently, became protected as an archaeological site of national importance.

Rainwater, numerous wells, minor local water springs and the Jadro River were used to supply all of the communities in this area between the 7th and 19th centuries. Private domestic cisterns, which collect rainwater, and public wells, where water would significantly decrease in quantity and quality during the summers, were mostly used in Split. Therefore, water was transported from the Jadro River, and it was costly.[9] Rapid urbanisation of the city of Split during the second period of Austrian rule (1813-1918) led to the need for a municipal water supply system.

The first proposal for the construction of the Split water supply system, which suggested four different water supply solutions, was presented in 1845.[10] One proposed solution was the reconstruction of Diocletian's water supply system, which was eagerly advocated by Vicko Andrić. He emphasized the importance of this venture as a significant cultural contribution to the Empire. In 1855, the mayor of Split, Šimun Michieli Vitturi, entrusted the reconstruction of the water supply system to him,[11] and in 1859 he was replaced by a municipal engineer named Locati.[12]

9 Belamarić 1999, p. 12; Bulić 1923, p. 111.
10 Kečkemet 1999, p. 31.
11 Kečkemet 1999, p. 33.
12 Belamarić 1999, p. 13 .

U sklopu obnove Dioklecijanova akvedukta sagrađen je na izvoru Jadra zahvat vode, poštujući u potpunosti osnovno rimsko rješenje, što će biti elaborirano u poglavlju "Zahvatna građevina vodovoda Dioklecijanove palače". Godine 1885./1886. pred samim je zahvatom sagrađena niska barijera/prag, čiji se ostaci vide na dnu današnjeg jezera, a o čemu svjedoči natpis na hridi, postavljen upravo iznad te barijere, na kojem piše:

GOD 1885 - 1886
SPLITSKA OBĆINA
OVU RADNJU IZVRŠI
DA KROZ STARODAVNI RIMSKI VODOVOD
NA VIEKE
VODOM OBSKRBI SPLIT

Nakon rekonstrukcije Dioklecijanova akvedukta sljedeći veliki zahvat na izvoru Jadra bila je izgradnja gravitacijskog kanala godine 1908. koji je napajao hidrocentralu cementne industrije. Sagrađen je na desnoj obali izvora, iznad kanala akvedukta Salone.[15] Njegov maksimalni kapacitet iznosio je 6000 l/s uz ograničenje pri nižem vodostaju zbog osiguranja dovoljne količine vode splitskom vodovodu.[16] Tada je izgrađena betonska brana s ustavama koja je regulirala razinu i protok vode u oba kanala: u kanalu hidroelektrane i kanalu splitskog (Dioklecijanovog) vodovoda (sl. 3).

Između dvaju svjetskih ratova, u svrhu bolje regulacije protoka, podignuta je nova velika armiranobetonska brana ispred cijelog izvorišta, čime je stara ostala bez funkcije. Tijekom 1946. nad samim je izvorom podignuta zaštitna građevina koja je osiguravala izvor od odrona kamenja sa strmih okolnih litica.[17] Za potrebe kemijske industrije (tvornica *Jugovinil*) sagrađen je 1950. godine, uz Dioklecijanov kanal (na lijevoj obali rijeke Jadro), novi betonski kanal maksimalnog kapaciteta 2000 l/s.[18] Maksimalna dozvoljena količina vode od strane Državne uprave za vodoprivredu (rješenje od 20. VI. 1958.) bila je 2000 l/s, kako bi se osigurao biološki minimum u rijeci Jadro. Novi kanal trebao je zamijeniti Dioklecijanov te osigurati vodu širem području Kaštelanskog zaljeva, ali i gradu Splitu. Naime, u nastavku ovog kanala prema Splitu, od Kunčeve grede do crpne stanice Ravne njive, napravljen je godine 1970. novi gravitacijski cjevovod promjera 1000 mm. Dioklecijanov kanal ipak nije prestao s radom, kako se predviđalo, jer novoizgrađeni kanal nije zadovoljavao potrebe za vodom, koje su se na području Splita stalno povećavale.

15 Bulić 1911, str. 66.
16 Celegin 1923, str. 216.
17 Franić 1959.
18 Muljačić 1969, str. 55.

The actual restoration was initiated a later mayor, Dr Antonio Bajamonti, in 1862.[13] Besides supplying the city, the water supply system had to be used to irrigate the Split field. Furthermore, it had to be used for the needs of the Split railway station because locomotives were then powered by steam engines. The aqueduct was put into operation on March 14, 1880.[14] It had the same technological and gravitational concept as the Roman water supply system. On the top of that, there were plans to install 25 fountains within the city in order to supply the inhabitants with water.

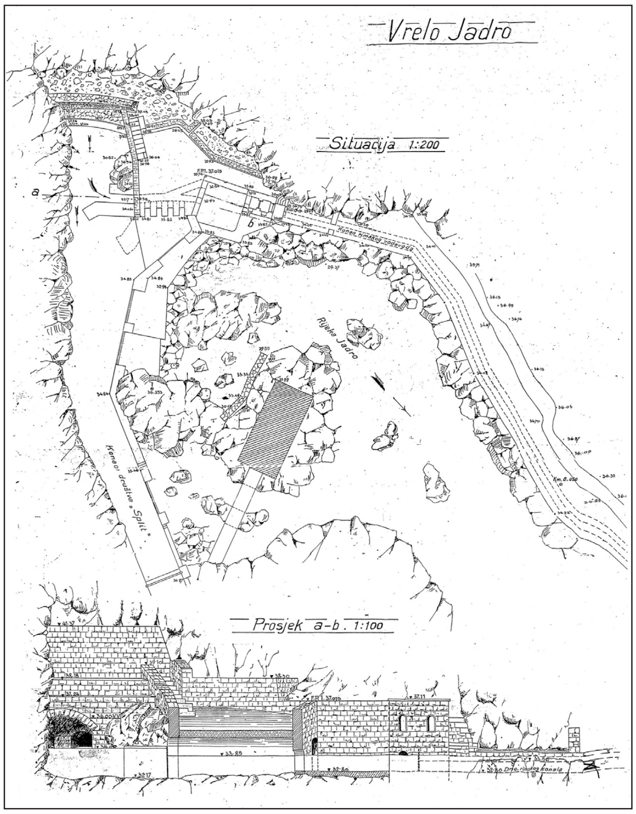
As part of the reconstruction of the Diocletian Aqueduct, the water intake structure was built at the Jadro's spring, in accordance with the original Roman design, which will be further elaborated in the chapter "Water Intake Structure of the Diocletian Aqueduct". In 1885/1886, a small barrier/ground sill was built at the bottom of the reservoir (lake), the remains of which are still visible at the bottom of today's reservoir, as is evident from the inscription on the cliff just above the barrier. The inscription reads:

1885 - 1886
THE CITY MUNICIPALITY OF SPLIT
PERFORMED THIS WORK
IN ORDER TO, VIA THE ANCIENT ROMAN
AQUEDUCT, SUPPLY
FOR ALL TIME
WATER TO THE CITY OF SPLIT

After reconstruction of the Diocletian Aqueduct, the next major intervention was the construction of the gravity fed channel in 1908 at the Jadro's spring, in order to supply the hydroelectric power plant which was built for the needs of the cement industry. The channel was built on the right bank of the Jadro's spring, above the Roman channel of the Salona Aqueduct.[15] Its maximum capacity was 6,000 l/s, taking into account the lower water stage restriction as a means of ensuring a sufficient quantity of water for Split's urban water supply.[16] A concrete dam with sluices, which regulated the water level and flow rate in both the hydroelectric power plant's channel and the city's water supply channel, was built at the time (Fig. 3).

A new large concrete dam was built in front of the spring in the interwar period for the purpose of better regulation of the flow rate, while the old one lost its function. The concrete protection structure was built

13 Belamarić 1999, p. 15.
14 Belamarić 1999, p. 15.
15 Bulić 1911, p. 66.
16 Celegin 1923, p. 216.



Sl. 3. Vodni zahvati na izvoru Jadra 1908. godine (izvor: Arhiv Cemexa)
Fig. 3. The water intake structures at the Jadro River's spring in 1908 (source: Cemexarchive)

Poslije 1990. smanjena je potrošnja vode u vodovodu za više od 35 %, tako da nije bilo potrebe za daljnjim intervencijama na zahvatu.[19] Realizacijom projekta *EKO - Kaštelanski zaljev* došlo je do značajnih preinaka i proširenja vodoopskrbnog sustava, ali i povećanja njegove učinkovitosti. Upravo je u tijeku izrada projektne dokumentacije novog dovodnika prema Splitu, čime će rekonstruirani Dioklecijanov kanal izgubiti funkciju redovite opskrbe nakon više od 130 godina.

Iz iznesenog je vidljivo da je izvorište Jadra tijekom vremena imalo razne namjene, zbog čega su se zahvatne građevine kao i izgled samog izvorišta postupno mijenjali (sl. 4).

Od prestanka rada salonitanskoga i Dioklecijanovog akvedukta u VII. stoljeću do rekonstrukcije Dioklecijanovog akvedukta u XIX. stoljeću prošlo je dvanaest stoljeća. U tom dugom razdoblju njihove je zahvatne građevine (*castellum fontis*) na izvoru Jadra razrušila voda i djelovanje čovjeka. Međutim, snagu vode koristile su još od srednjeg vijeka mlinice,[20] koje su se djelomično sačuvale do danas (sl. 11).

19 Margeta 2010, str. 215-216.

20 Katić 1952, str. 215.

in 1946 just above the Jadro River's spring to prevent rockslides from steep cliffs.[17] A new concrete channel with a maximum capacity of 2,000 l/s was built in 1950 next to the Diocletian channel (on the left bank of the Jadro River) for the needs of the chemical industry (Jugovinil factory).[18] The State Water Management Administration (decision dated 20 June 1958) allowed the maximum amount of water of 2,000 l/s in order to ensure a biological minimum of the Jadro River. This new channel, which was a replacement for the Diocletian channel, had the purpose of supplying water to the wider area of Kaštela Bay and the city of Split. Namely, a new gravity pipeline with a diameter of 1,000 mm was made towards the city of Split, from Kunčeva greda to the Ravne Njive pumping station, in 1970, as an extension of the aforementioned channel. However, the Diocletian channel did not cease to function as expected, because the newly constructed channel did not meet the continuously increasing water requirements of the Split area.

After 1990, water consumption in the water supply was reduced by more than 35%, thus further interventions at the water intake structure were not needed.[19] Implementation of the ECO-Kaštela Bay Project resulted in significant changes and the expansion of the water supply system, as well as in increases to its efficiency. The project documentation for the new pipeline toward the city of Split is currently being prepared; consequently, the reconstructed Diocletian channel will lose its regular supply function after more than 130 years.

It is evident that the spring was used for different purposes over the course of history, which gradually affected the water intake structures as well as the appearance of the spring itself (Fig. 4).

Twelve centuries passed from the 7th century, when the Salona Aqueduct and the Diocletian Aqueduct ceased functioning, until the reconstruction of the Diocletian Aqueduct in the 19th century. During that long period, their water intake structures (*castellum fontis*) at the Jadro's spring were destroyed by water and human activities. However, since middle ages, water was used to power mills,[20] which are partially preserved to this day (Fig. 11).

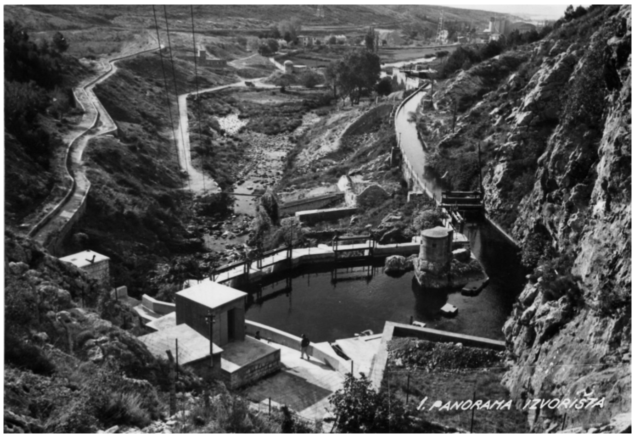
Due to reconstruction of the Diocletian Aqueduct at the end of the 19th century, the construction of the hydroelectric power plant channel at the beginning of the 20th century, and various later interventions, the remains of Roman structures in the area have been

17 Franić 1959.

18 Muljačić 1969, p. 55.

19 Margeta 2010, pp. 215-216.

20 Katić 1952, p. 215.



Sl. 4. Panorama zahvata na izvoru Jadra 1959. godine (izvor: Franić 1959)
Fig. 4. Panoramic view of the water intake structures at the Jadro River's spring in 1959 (source: Franić 1959)

Rekonstrukcijom Dioklecijanovog vodovoda krajem XIX. stoljeća i izgradnjom kanala hidrocentrale početkom XX. st. te raznim kasnijim intervencijama ostaci antičkih građevina na tom mjestu bivaju prekriveni ili uništeni. Međutim, zahvaljujući povijesnim dokumentima, starim crtežima, fotografijama i planovima te tragovima na hridima i na dnu današnjeg jezera moguće je okvirno rekonstruirati osnovni koncept obaju antičkih zahvata vode.

Geološke i hidrološke karakteristike slijeva Jadra

Jadro je pouzdan izvor vode dobre kakvoće zahvaljujući specifičnim hidrogeološkim i drugim prirodnim značajkama slijevnog područja. Izvor danas ima uže, direktno, i šire, indirektno, slijevno područje. Uže slijevno područje jest ono prirodno, koje je postojalo i u antičko doba. Vanjsko ili prošireno slijevno područje odnosi se i na dio slijeva rijeke Cetine. Ono je uvijek postojalo, ali nije bilo toliko izraženo kao što je to u novije vrijeme nakon izgradnje hidroelektrana i akumulacija na rijeci Cetini. Izgradnjom hidroelektrana i promjenom režima voda rijeke Cetine njezin utjecaj na vode Jadra postaje značajan, a bit će sve značajniji u budućnosti. Za razliku od danas, u antičkom razdoblju utjecaj čovjeka na režim voda bio je vrlo malen.

Uže slijevno područje seže duboko u zaleđe splitskog bazena i zauzima središnji dio Splitsko-dalmatinske županije, između topografskih barijera, sjeverno od Mućkog polja, i barijere u priobalnom području (sl. 5). Slijevno područje izvora Jadra uglavnom se promatra kao cjelina sa slijevnim područjem izvora Žrnovnice, a graniči sa sljevovima rijeke Pantan na zapadu, rijeke Čikole na sjeveru te rijeke Cetine na istoku. Prema raznim autorima ukupna veličina

either covered or destroyed. Nevertheless, historical documents, old drawings, photographs, and maps, as well as traces on the surrounding rock and at the bottom of the present-day reservoir made it possible to roughly reconstruct the basic concept of both Roman water intake structures.

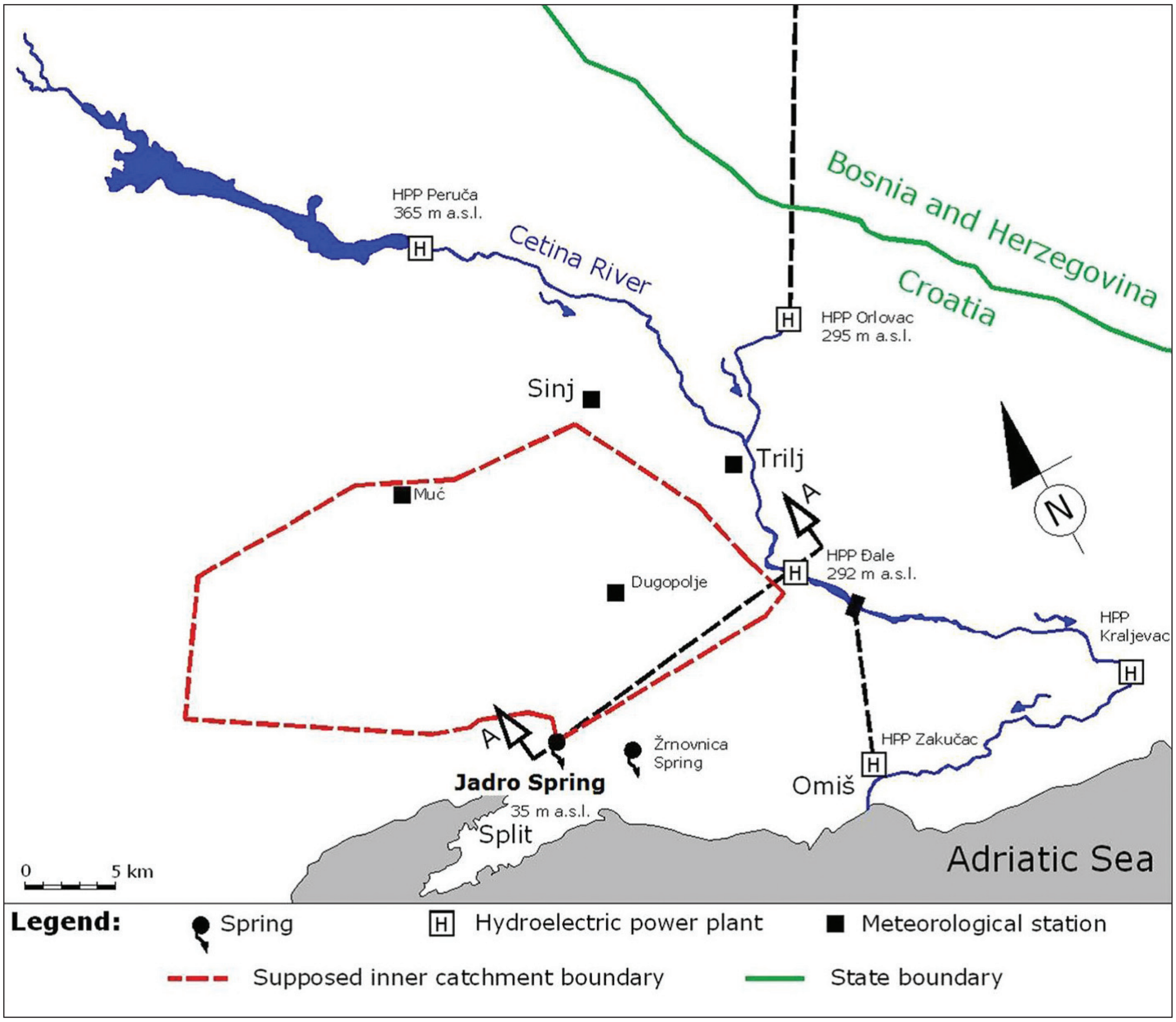
Geological and hydrological characteristics of the spring

The Jadro River is a reliable source of good quality water due to the specific hydrogeological and other natural features of the catchment area. The Jadro River's spring currently has an inner or direct, and an outer or indirect, catchment area. The inner catchment area is the natural one that existed in Antiquity. The outer or extended catchment area also includes a part of the Cetina River catchment area. It has always existed, but it was not as relevant as it was in recent times, after the construction of hydroelectric power plants and reservoirs on the Cetina River. The construction of hydroelectric power plants and changes in the water regime of the Cetina had a significant impact on the Jadro River, which will be even greater in the future. Unlike now, in Roman times the human impact on the water regime was low.

The inner catchment area extends deep into the hinterland of the Split basin and covers the central area of Split-Dalmatia County, between topographic barriers north of the Mućko polje, and the barrier at the littoral zone (Fig. 5). The spring catchments of Jadro and Žrnovnica Rivers are generally perceived as one, and this catchment borders with several others: the Pantan River in the west, the Čikola River in the north, and the Cetina River in the east. According to various authors, the total area of the Jadro and Žrnovnica spring catchment area covers between 450 and 550 km^2, where the higher number includes the flow from the nearby Cetina River catchment.[21]

The vertical indentation of the catchment area terrain is characterised by typical karst phenomena: limestone ridges, plateaus, karren, vertical shafts, narrow dry dales, karst depressions, sinkholes and smaller fertile fields. There are more than 100 natural sinkholes (*ponors)* and vertical shafts in the catchment area. Smaller and larger karst fields, karst dales and plateaus at an elevation of approximately 300 to 350 m a.s.l., are situated between series of peaks with elevations of 550 to 680 m a.s.l. The Jadro River spring catchment is a part of the Outer Dinarides and is characterised by a prevalence of carbonate rocks and intensive tectonic disturbances. It is formed by

21 Bonacci 1986; Kapelj *et al*. 2001.



Sl. 5. Karta užeg slijevnog područja izvora Jadra i rijeke Cetine (izvor: Bonacci 2014)
Fig. 5 Map of the Jadro spring inner (topographic) catchment and the Cetina River (source: Bonacci, 2014)

zajedničkih sljevova Jadra i Žrnovnice iznosi između 450 i 550 km^2, pri čemu se kod veće brojke računa i dotok iz susjednog slijeva rijeke Cetine.[21]

Reljef slijevnog područja vertikalno je dobro razveden, a karakteriziraju ga tipični krški fenomeni: vapnenački grebeni, zaravni, škrape, jame, uske i suhe udoline, uvale, ponikve i manja plodna polja. Na području slijeva nalazi se više od 100 prirodnih ponora i jama. Između niza vrhova visine 550 - 680 m nad morem nalaze se veća i manja krška polja, udoline i zaravni nadmorskih visina od 300 - 350 m. Slijevno područje izvora Jadro pripada vanjskim Dinaridima, a karakterizira ga prevlast karbonatnih stijena i visok stupanj tektonske poremećenosti. Tvore ga sedimentne stijene trijasa, jure, krede, tercijara i

Triassic, Jurassic, Cretaceous, Tertiary and Quaternary sedimentary rocks.[22] The catchment area is a karst terrain with sparse vegetation.

The construction of four reservoirs for the purpose of hydroelectric power plants (Peruća 1960, Prančevići 1962, Buško blato 1973 and Đale 1986) led to significant changes to the Jadro River's spring flow since 1950 due to the regulation of the Cetina River's flow. The Jadro spring flow increases, especially the minimum value, while the water quality decreases due to the surface water runoff from the Cetina River.

The flow of the Jadro River's spring during the year is largely determined by the topographic and hydrogeological features of the area, climate and especially precipitation. In other words, the climate in the

21 Bonacci 1986; Kapelj *et al*. 2001.

22 Fritz 1981, p. 97.

kvartara.[22] To je kamenjar sa siromašnim vegetacijskim pokrivačem.

Značajne promjene protoka izvora Jadra događale su se od 1950. godine zbog regulacije toka rijeke Cetine gradnjom četiriju akumulacija, a sve radi hidroenergetskog iskorištavanja (Peruća 1960., Prančevići 1962., Buško blato 1973. i Đale 1986. godine). Zbog prelijevanja površinskih voda rijeke Cetine povećava se protok izvora Jadra, posebno onaj minimalni, a kakvoća se vode pogoršava.

Uz topografske i hidrogeološke značajke prostora, protok izvora rijeke Jadro tijekom godine uvelike određuje klima, a posebno oborine. To znači da je klima u antičko doba definirala značajke izvora kao što to određuje danas. U obzir se, međutim, moraju uzeti i utjecaji čovjeka vezani uz regulaciju i modifikaciju vodnih resursa. U novije doba osnovno obilježje klimatskih prilika u užem slijevnom području izvora Jadra karakterizira mediteranska klima jadranskog tipa. Prosječna godišnja temperatura iznosi 13° C. Najveće su srednje mjesečne temperature u kolovozu (24,7° C), a najmanje u prosincu (5,8° C). Srednja dnevna temperatura zraka mijenja se tijekom godine u rasponu od -7,2° C, u siječnju i prosincu, do 29,8° C, u srpnju i kolovozu. Mraz se može pojaviti od listopada do travnja, prosječno 15 dana u godini. Oborinski režim ima sve značajke maritimnoga sredozemnog kišnog tipa s osnovnom značajkom neravnomjernog rasporeda kiša tijekom godine. Od ukupnih godišnjih oborina, od oko 1200 mm, najveća količina padne u razdoblju rujan-ožujak, oko 2/3 ukupnih oborina.

Izdašnost izvora Jadra promjenjiva je tijekom godine i u funkciji je oborina. Srednji protok u kolovozu, kada je izdašnost najmanja, iznosi oko 5,17 m^3/s. U zimskim mjesecima, kada su oborine najveće, srednji mjesečni protok u prosincu iznosi 17,31 m^3/s. U tom razdoblju srednji dnevni protok naraste i iznad 60 m^3/s. Srednji godišnji protok izvora rijeke Jadro iznosi oko 9,82 m^3/s. Najmanji zabilježeni protok bio je 3,72 m^3/s (1995.), a najveći 70,1 m^3/s (2004.).

Kakvoća izvora vode Jadro rezultat je pritiska koji generiraju pokretači prirodnoga i socioekonomskog onečišćenja u užem slijevnom području, te specifičnih procesa otjecanja i samopročišćavanja koji se odvijaju u krškim vodonosnicima. Voda izvora Jadra svrstava se u skupinu izrazitih krških pukotinskih voda podložnih zamućivanju. To su vode kalcijsko-hidrokarbonatnog tipa. Sadržavaju mali isprani ostatak, male su mineralizacije, imaju malu ukupnu i karbonatnu tvrdoću (meke ili umjereno tvrde vode), sadrže malo otopljenog CO2, klorida i sulfata.[23]

22 Fritz 1981, str. 97.

23 Štambuk-Giljanović 2006, str. 147-158.

Roman era defined the features of the spring as it does today. However, human influences arising from regulation and modification of water resources must also be taken into account. In recent times, climatic conditions of the inner catchment area of the Jadro River's spring are characterised by the Adriatic type of Mediterranean climate. The average annual temperature is 13°C. Maximum mean monthly temperatures are recorded in August (24.7°C), and minimum temperatures in December (5.8°C). Mean daily temperature varies over the year, from - 7.2°C in January and December, to 29.8°C in July and August. Frost can occur from October to April, and the average number of frost days in a year is 15. The precipitation regime's characteristics are the same as Mediterranean maritime climate characteristics; the main feature is the uneven yearly distribution of rainfall. Total annual precipitation is ca. 1,200 mm, and maximum precipitation (2/3 of total precipitation) is most likely to occur in September through March.

The flow capacity of the Jadro's spring varies during the year and is perceived as precipitation. The average flow is 5.17 m^3/s in August, when the flow capacity is the lowest. The average monthly flow is 17.31 m^3/s in December, during the winter months when the precipitation is the highest. During that period, the average daily flow increases by more than 60 m^3/s. The average annual flow of the Jadro's spring is approximately 9.82 m^3/s. The minimum flow recorded in 1995 was 3.72 m^3/s and the maximum, in 2004, was 70.1 m^3/s.

The water quality of the Jadro's spring is a result of pressure generated by the natural and socioeconomic pollution drivers in the inner catchment area, the specific outflow and self-purification processes, which occurs in karst aquifers. Water from the Jadro's spring is classified as karst fissure water, which is likely to be turbid. The chemical composition of these waters is hydro carbonate calcium. They are characterised by the minor amount of evaporation residue, low mineralisation, and low total and carbonate hardness (medium hard water and soft water), small amounts of dissolved CO_2, chloride and sulphate.[23] The variability in the ionic composition, saturation state, and partial pressure of CO_2 monitored over the years at the Jadro and Žrnovnica springs indicate insufficient homogenisation, and the rather short-term storage of water in the aquifer, i.e., a rapid water exchange in aquifers.[24] The main feature of all water quality indicators is primarily annual and seasonal variability.

23 Štambuk-Giljanović 2006, pp. 147-158.

24 Kapelj *et al*. 2002.

Varijabilnost osnovnog ionskog sastava, stanja zasićenosti i parcijalnog pritiska CO2, praćena tijekom godina na izvorima Jadra i Žrnovnice, pokazatelj je nedovoljne homogenizacije i relativno kratkog vremena zadržavanja vode u vodonosniku, odnosno brzog prolaza svakog novog doprinosa kroz vodonosnik.[24] Osnovna značajka vrijednosti svih pokazatelja kakvoće vode uglavnom je velika promjenjivost, i to godišnja i sezonska. Takve osnovne kemijske značajke voda je imala i u antičko vrijeme.

Mutnoća, kao jedan od kumulativnih pokazatelja ukupnog zagađenja, na neki način najbolje oslikava prirodu promjena kakvoće vode. Ono što je značajno za mutnoću je sezonski karakter pojave. Na pojavu oborina izvor vrlo brzo reagira povećanjem protoka, a naročito u razdoblju kada je vodonosnik ispunjen vodom. Zagađenje koje oborine ispiru s površine, ali i iz podzemlja (istaloženo u podzemlju), naročito nakon sušnog razdoblja godine, vrlo brzo dospijeva do izvora.

U antičko su doba prirodne značajke u slijevnom području izvora Jadra bile slične današnjima. Na ovom prostoru živjelo je relativno malo stanovništva, tako da su ratarske površine bile vrlo male. Zbog slabe naseljenosti bilo je i malo stoke te se može zaključiti da stanovništvo nije utjecalo na značajke kakvoće vode izvorišta. Može se pretpostaviti da se takvo stanje zadržalo sve do vremena austrougarske uprave, kada započinje značajniji razvoj u regiji. Voda, koja se u Split dovodila obnovljenim Dioklecijanovim kanalom, pročišćavala se. U nešto se manjoj mjeri pročišćavala sve do oko 1950. godine, kada je kod rekonstrukcije crpne stanice Kopilica srušena filtarska stanica. Od tada se voda u splitskom vodovodu više ne pročišćava. Jedino se vrši dezinfekcija vode kloriranjem. S druge strane, u zaleđu se razvija industrija, nalaze se prometnice s velikim prometom i odvijaju se druge antropogene aktivnosti, zbog čega dolazi do ispuštanja različitih onečišćenja te se kakvoća vode postupno pogoršava. U svakom slučaju, sadašnja kakvoća vode lošija je od one koju su konzumirali Rimljani.

Geometrija i hidrauličke osobine izvora

Rijeka Jadro izvire iz vapnenačke pećine koja se nalazi na dnu kamene udoline između strmog sjevernog i blažeg južnog obronka u podnožju planine Mosor. Zbog takve konfiguracije prilaz izvoru desnom obalom, prije ikakvih intervencija, bio je otežan, ako ne i nemoguć, dok je prilaz lijevom obalom bio značajno jednostavniji. Obronke tvore lapori s ulošcima pješčenjaka, vapnenca i breča.

24 Kapelj *et al*. 2002.

These main chemical properties of the water were the same in Roman times.

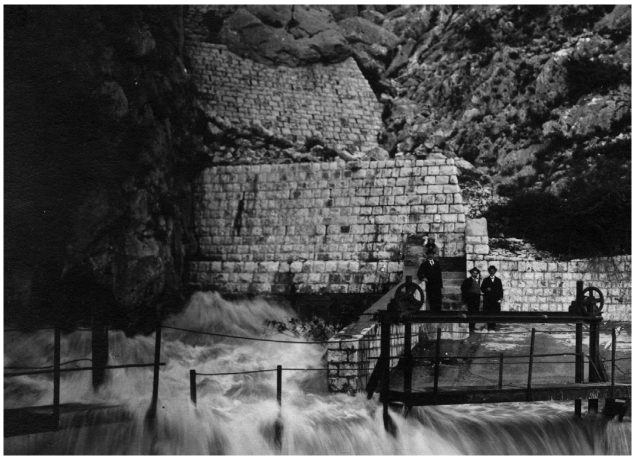
Turbidity, as a cumulative indicator of overall pollution, in some way reflects changes in water quality. Seasonal precipitation and its characteristics are a significant factor of water turbidity. The spring flow increases rapidly with the occurrence of precipitation, especially when the aquifer is filled with water. During precipitation, pollutants coming from surface and underground (deposited at underground sites), especially after the dry season, rapidly reach the spring.

The present-day natural features of the Jadro spring catchment area are similar those of the Roman era. This area was sparsely populated; therefore arable surfaces were not large. Due to the low population density, livestock density was also low; hence, it can be concluded that the population did not affect the water quality properties of the spring. It may also be assumed that this remained unchanged until Austro-Hungarian rule, when rapid development in the region proceeded. The water, which was transported to the city of Split through the renewed Diocletian channel, was purified. To a lesser extent, it was purified until about 1950, when the filter station was destroyed during reconstruction of the Kopilica pumping station. Since then, the water in the Split water supply system has no longer been purified, apart from chlorination, which has been the only method used to disinfect water. On the other hand, water quality decreased due to industrial development in the hinterland, construction of higher-capacity roads and other anthropogenic activities, causing the release of various pollutants. In any case, the present-day water quality is worse than that consumed by the Romans.

The geometry and hydraulic characteristics of the spring

The source of the Jadro River is a limestone cave situated on a karst dale between the steep northern and gentle southern slope at the foot of the Mosor range. This configuration made access to the spring from the right bank difficult, if not impossible, prior to any human intervention. Access to the spring from the left bank was significantly easier. The slopes are composed of marl with thin beds of sandstone, limestone and breccia.

The source is comprised of 4 larger ascending springs (openings), with different yields, situated by the north and east slopes of the cliff, and a number of smaller karst fissures. These springs are clustered; therefore, separate streams of particular springs are difficult to notice even during the lowest water stages. The distance between the first and last source is only 7 m.



Sl. 6. Potporni zid iznad izvora Jadra s kraja XIX. stoljeća (foto: Muzej grada Splita)
Fig. 6. The retaining wall above the Jadro River's spring at the end of the 19th century (photo: Split City Museum)

Sl. 7. Potporni zid s kraja XIX. stoljeća iznad izvora Jadra unutar zaštitne građevine iz 1946. (foto: N. Cingeli)
Fig. 7. The retaining wall above the Jadro River's spring from the end of the 19th century, within the protective structure from 1946 (photo: N. Cingeli)

Izvorište se sastoji od 4 veća uzlazna vrela (otvora) različite izdašnosti smještenih uz sjevernu i istočnu padinu klisure te većeg broja manjih pukotina. Ova vrela zbijena su tako da se ne primjećuju posebni tokovi pojedinih vrela ni pri najnižim vodostajima. Udaljenost od prvog do zadnjega vrela iznosi svega 7 m.

Voda izbija iz dubokih slojeva podzemnog vodonosnika. Utvrđeno je da je podzemni dio izvora vrlo velik i da se sastoji od velikih podzemnih kanala i pećina.[25] Voda po izlasku iz podzemlja otječe stjenovitom vapnenačkom površinom, vrlo neravnom i razvedenom, te se, nakon otjecanja preko jednog zaravnjenog dijela ispred izvora, slijeva u udolinu gdje formira rijeku Jadro. Na izlazu izvora do danas su se djelomično sačuvale stijene različitih veličina, koje su bile prepreka otjecanju vode. Kod malih voda otjecanje se odvijalo oko ovih stijena, dok je kod velikih protoka otjecanje prekrivalo manje stijene, a samo su veće ostajale nepotopljenima. Takvo stanje zadržalo se sve do izgradnje velike armiranobetonske brane, u razdoblju između dvaju svjetskih ratova, čime je veći dio izvora stalno potopljen. Sve do tada voda je po izlasku iz špilje izvora formirala više slapova u dužini od oko 70 m i visinskoj razlici od 12 m, tako da je izvor bio vrlo atraktivan.

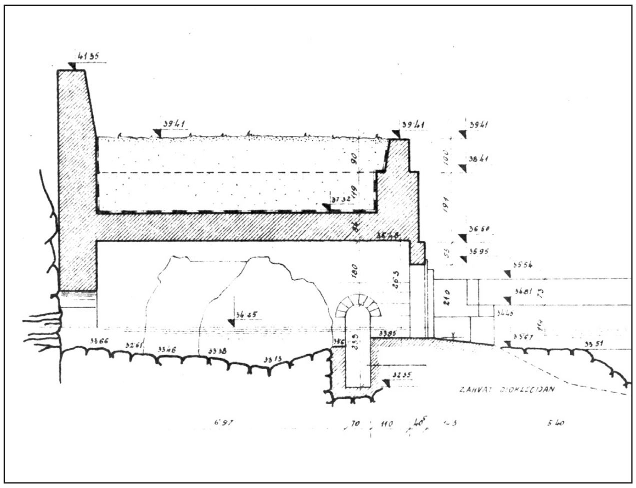
Godine 1959. obavljeno je precizno geodetsko i arhitektonsko snimanje izvora Jadra te su ti podatci za sada jedini pouzdan pokazatelj geometrije izvora.[26] Geometrija je vrlo složena u poprečnom i uzdužnom

Water comes from deep layers of the underground aquifer. It has been determined that the underground part of the spring is very large, consisting of immense underground channels and caves.[25] After surfacing, the water flows through a very uneven indented rocky limestone surface. Having flowed over one of the flat parts in front of the spring, it flows into the dale, where the Jadro River is formed. Several rocks of different sizes which prevented water runoff were preserved in the front of the spring. Water runoff occurred around these rocks during meagre water flows, while water runoff covered smaller rocks during heavy flows; hence, only larger rocks remained dry. The situation remained unchanged until the construction of a large reinforced concrete dam during the interwar period, leaving a large part of the spring under water. Until that time, water which emerged from the spring's cave formed numerous waterfalls over a length of roughly 70 m, and a total height of approximately 12 m, making the spring very attractive.

In 1959, a precise topographic and architectural survey of the Jadro River's spring was conducted and these data are thus far the only reliable indicator of the spring's geometry.[26] The geometry is very complex in a transverse and longitudinal direction, with an abundance of surface roughness. Since the spring has no specific terrain elevation, there is no uniform depth of water in the area outside of the spring as well. The terrain/bottom elevations at the spring range from 32

25 Zaron u izvor Jadra; 9.2.2016 (http://speleologija.hr/arhiva/1466).
26 Franić 1959.

25 Dive in the Jadro River's spring; 9 February 2016 (http://speleologija.hr/arhiva/1466).
26 Franić 1959.

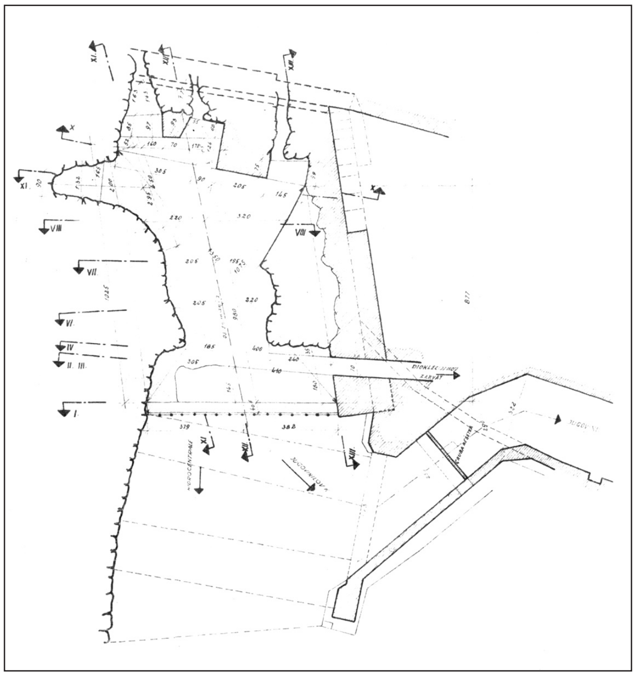


Sl. 8. Horizontalni presjek kroz izvor 1959. godine (izvor: Franić 1959)
Fig. 8. Horizontal section through the spring from 1959 (source: Franić, 1959)

smjeru, s puno neravnina. Izvor nema jednu određenu kotu terena, a time ni jednoliku dubinu vode na prostoru ispred izvora. Kote terena/dna na izvoru kreću se od 32 m.n.v. pa do 33,5 m.n.v. Međutim, količina vode i geometrija prostora izvora uvjetuju razinu vode kod niskog vodostaja na koti većoj od 33 m.n.v. Ta je razina vrlo povoljna za vodoopskrbu priobalnih područja Salone i Splita te određuje moguće područje gravitacijskog i vodoopskrbnog sustava.

Relativno mala površina pećine dovodi do toga da tijekom velikih protoka (50-70 m^3/s) nastaje velika brzina istjecanja vode, i do 6 m/s. Kod minimalnih protoka (oko 4 m^3/s) brzina je bitno manja i kreće se oko 0,5 m/s. Upravo te značajke izvorišta, velika varijabilnost protoka i brzine, velika energija vode te kamene strme litice na mjestu izbijanja vode predstavljale su najveći izazov rimskim graditeljima. U ovakvim uvjetima trebalo je izgraditi pouzdan zahvat vode, koji će funkcionirati u svim režimima protoka vode. Opisane značajke izvora, koje su zatekli rimski graditelji, odredile su položaj i rješenje zahvata vode.

Tijekom vremena na izvoru su se događale promjene kako u samoj špilji tako i u dubljem podzemlju. Za vrijeme rekonstrukcije Dioklecijanova vodovoda (1877./1880.) izvor je zaštićen od odrona stijena sa strmih litica izgradnjom potpornog zida (sl. 6), a godine 1946. iz istog je razloga iznad izvora izgrađena zaštitna armiranobetonska građevina oslonjena na ranije spomenuti potporni zid (sl. 7). Projektom iz 1959. planiran je produžetak zaštitne građevine kako bi se zaštitio početak *Jugovinilova* kanala, što nikada nije realizirano.[27]



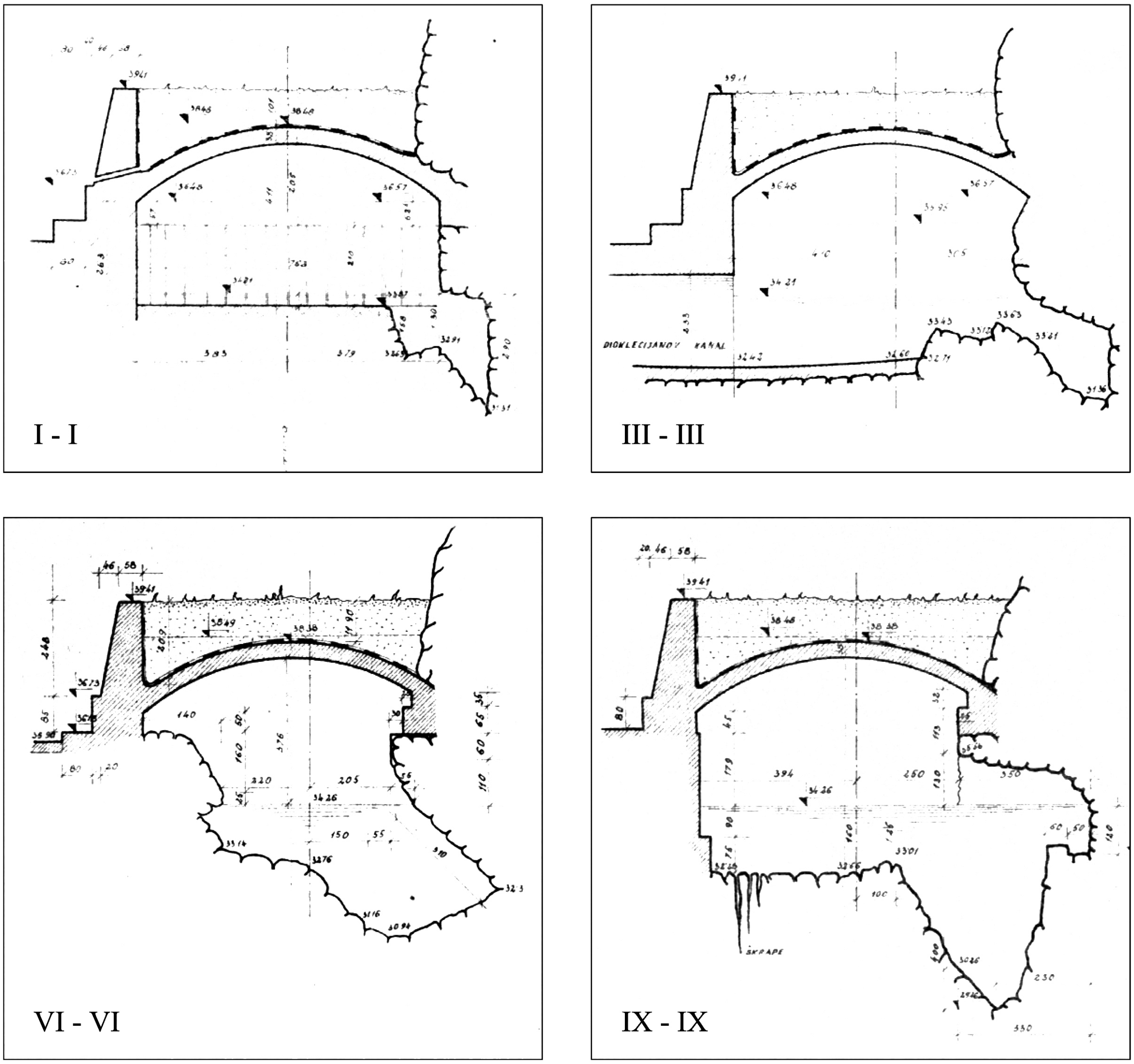
Sl. 9. Uzdužni presjek izvora i zaštitne građevine 1959. godine s početkom Dioklecijanovog kanala (izvor: Franić 1959)
Fig. 9. Longitudinal section of the spring and the protective structure from 1959 and the starting point of the Diocletian Aqueduct's channel (source: Franić, 1959)

m a.s.l. up to 33.5 m a.s.l. However, the amount of water and the geometry of the spring area indicate that the water level at the low-water stage is at an elevation higher than 33 m a.s.l. This level is very favourable for the water supply of Salona's coastal areas and the city of Split and it determines the possible area of the gravity flow water supply system.

A rather small cave area is responsible for a high rate water discharge which amounts to 6 m/s during increased water flows (50-70 m^3/s). During minimum flows (ca. 4 m^3/s) the rate is significantly lower and is ca. 0.5 m/s. These source features - high variability of the flow and the rate and high water energy, steep karst cliffs at the spring itself - were considered the greatest obstacle confronted by Roman architects. Given the circumstances, a reliable water intake had to be built that would function in all water flow regimes. These spring characteristics found by Roman architects were used to determine the position of the intake structure and the solution for water treatment.

Over time, changes occurred within the spring, the cave itself and even deeper underground. During reconstruction of the Diocletian Aqueduct in 1877/1880, the spring was protected from falling rocks from steep cliffs by a retaining wall, which was built at the time (Fig. 6). In 1946, a reinforced concrete protection structure was built above the spring for the same rea-

27 Franić 1959.



Sl. 10. Poprečni presjeci izvora i zaštitne građevine 1959. godine (izvor: Franić 1959.)
Fig. 10. Typical cross-sections of the spring and the protective structure in 1959 (source: Franić 1959)

Zahvatna građevina salonitanskog akvedukta

Prije nego je godine 1908. na izvoru Jadra sagrađen kanal hidrocentrale upravo iznad kanala akvedukta Salone, Bulić je istražio prvih 200 m antičkog kanala.[28] Nažalost, detaljniji opisi i nacrti nisu pronađeni. Međutim, na fotografiji iz zraka mogu se uočiti tragovi antičkog kanala na dnu današnjeg zahvatnog jezera. Tu se jasno vidi njegov južni rub usječen u živoj stijeni, prag početka kanala od kamenih blokova te koso postavljen zid koji kod malih protoka usmjerava vodu u kanal (sl. 11). Duljina kamenog praga

son, leaning against the aforementioned retaining wall (Fig. 7). The extension of the protection structure, which was proposed in the project from 1959 in order to preserve the starting point of the Jugovinil channel, was never carried out.[27]

Water intake structure of the Salona Aqueduct

Bulić explored the first 200 m of the Roman channel prior to construction of the hydroelectric plant channel in 1908, at the Jadro River's spring just above the

28 Bulić 1911, str. 66.

27 Franić 1959.

iznosi oko 250 cm, što približno odgovara ukupnoj širini kanala s bočnim zidovima.[29]

Visinski položaj početka kanala salonitanskog akvedukta može se precizno definirati na temelju najnovijih istraživanja trase salonitanskog akvedukta.[30] Ako se od zadnje precizno izmjerene točke dna akvedukta ide trasom kanala prema izvoru u nagibu od 0,25 %, koji preporučuje Vitruvije,[31] dno početka kanala na izvorištu bilo bi na 32,26 m.n.v. Originalni prag, koji je sačuvan na tom mjestu, nalazi se na koti 32,45 m.n.v. pa se upravo ta kota s velikom vjerojatnošću može uzeti za početnu točku kanala salonitanskog akvedukta. Da bi se ove pretpostavke potvrdile, potrebno je arheološki istražiti dno zahvatnog jezera i obaviti precizna mjerenja.

Detaljnom analizom konfiguracije prirodnog terena i kamenih hridi na izvoru može se zaključiti da su antički graditelji salonitanskog vodovoda u kamenom obronku brda napravili usjek dužine 35 m i širine 2,5 m, kako bi najkraćim putem došli do izvora, pritom izbjegavajući glavni tok i energiju vode (sl. 15). Nakon dva milenija usjek se značajno urušio pa je južno od kanala ostala stršiti hrid zabilježena na crtežu izvora s kraja XIX. stoljeća (sl. 12). Početkom XX. stoljeća, kada se gradio kanal hidrocentrale, usjek je proširen s obje strane, a za vrijeme Drugoga svjetskog rata zaravnana je hrid južno od kanala kako bi se na njoj sagradio bunker. Moglo bi se pretpostaviti da je, umjesto u otvorenom usjeku, kanal salonitanskog akvedukta na tom mjestu bio položen u tunel.

Da bi se osigurala dovoljna količina vode u kanalu tijekom minimalnih protoka, trebala je na izvoru postojati barijera za održavanje minimalne razine vode u zahvatnom jezeru. Osiguranje potrebne razine vode radi kontinuiteta opskrbe te sigurnost rada svih zahvata kod velikih i silovitih protoka vode na izvoru povod su za izgradnju barijera i formiranje jezera vode nizvodno od izlazne pećine. U slučaju salonitanskog zahvata, koji je imao kapacitet od oko 450-650 l/s,[32] a koji je bio položen u usjeku desne obale zahvata, trebalo je graditi nisku barijeru/usmjerivač toka vode prema desnoj obali. Ona je trebala održavati minimalni protok od barem 60 cm visine (kota 33,05 m.n.v.) na mjestu ulaza vode u kanal akvedukta. Barijera je vjerojatno bila izgrađena od masivnih kamenih blokova koji su morali biti stabilni i kod velikih protoka i brzina vode. Može se pretpostaviti da

29 Širina početka kanala salonitanskog akvedukta iznosi 80 cm (Bulić 1911, str. 66), a širina bočnih zidova oko 80 cm (Marasović *et al*. 2016, str. 144).

30 Marasović *et al*. 2016, str. 153.

31 Vitruvius Pollio 1997, str. 166.

32 Marasović *et al*. 2016, str. 150-153.

Salona Aqueduct channel.[28] Unfortunately, detailed descriptions and designs were not found. However, an aerial photograph shows traces of the Roman channel at the bottom of the reservoir/lake, the southern edge of the Roman channel carved into solid rock, the stone ground sill situated at the start of the channel, and the side wall, which served as a means to direct water into the channel during low flows (Fig. 11). The length of the sill is ca. 250 cm and is approximately equivalent to the total width of the channel, including the side walls.[29]

The elevation of the initial point of the Salona Aqueduct channel can be defined on the basis of the latest study of the Salona Aqueduct's route.[30] Following the channel route towards the spring, taking into consideration the 0.25% grade which is recommended by Vitruvius,[31] the bottom of the channel's starting point at the source would be at 32.26 m a.s.l. The original ground sill, which has been preserved at the site, is at an elevation of 32.45 m a.s.l., therefore, this exact elevation, with great probability, can be considered the starting point of the Salona Aqueduct channel. Further archaeological excavations and precise measurements inside the reservoir will be necessary to verify this hypothesis.

After conducting a detailed analysis of the configuration of the terrain and karst cliffs at the spring, it may be concluded that the Roman architects working on the Salona Aqueduct made a ravine in the karst mountain, 2.5 m wide and 35 m long, in order to find the shortest route to reach the spring, avoiding the main stem and its energy (Fig. 15). The remaining portion of the cliff, situated south of the channel, significantly deteriorated over the course of two millennia, and its remains can be seen in a late 19th century drawing (Fig. 12). At the beginning of the 20th century, during construction of the hydroelectric power plant channel, the ravine was extended on both sides, and during World War II, the cliff south of the channel was flattened in order to build a bunker on it. It may be assumed that the Salona Aqueduct channel was not an open ravine type of channel at this very site, but rather a tunnel.

The barrier should have been built at the spring to maintain the water level at the reservoir (lake) in order to ensure water in sufficient quantity during

28 Bulić 1911, p. 66.

29 The width of the starting point of the Salona Aqueduct channel is 80 cm (Bulić 1911, p. 66), and the thickness of the side walls is ca. 80 cm (Marasović *et al*. 2016, p. 144).

30 Marasović *et al*. 2016, p. 153.

31 Vitruvius Pollio 1997, p. 166.

Sl. 11. Izvor Jadra, tragovi kanala salonitanskog akvedukta (izvor: autori)
Fig. 11. The Jadro's spring, traces of the Salona Aqueduct channel (source: authors)

Sl. 12. Izvor Jadra s mlinicama 1880., E. Misera (izvor: Duplančić 2008)
Fig. 12. The Jadro's spring and water mills 1880, E. Misera (source: Duplančić 2008)

je položaj te barijere bio na mjestu južnog kraka brane iz 1885./1886. (sl. 15).

Analizirajući arhitektonsku snimku izvora iz 1959. godine, može se primijetiti da desna sjeverna strana izvora u dnu ima nepravilan zasjek, odnosno protočni prostor (sl. 10). Može se pretpostaviti da ovakvo oblikovanje stijenske mase nije samo rezultat prirodnih sila nego i čovjekovih intervencija. Kota dna ovog zasjeka nalazi se na oko 32 m.n.v., što potvrđuje prethodnu tezu o početnoj koti salonitanskog kanala. U svakom slučaju, ovako oblikovana desna strana izvora formirala je nepravilni protočni kanal vrlo povoljne dubine vode za zahvaćanje voda kod malog vodostaja. Središnje visoke stijene tada ostaju suhe i stvaraju branu istjecanju vode iz izvora tako da se razina vode u protočnom dijelu podiže na kotu od oko 33,00 m.n.v. Za antičke graditelje to je bilo vrlo važno jer se zasijecanjem kanala omogućavalo zahvaćanje dovoljnih količina vode i kod najmanjih vodostaja na izvoru, a sve kako bi se osigurala trajna vodoopskrba. U nastavku, na izlazu iz izvora, ovaj se kanal najvjerojatnije nastavljao kroz zasječenu bočnu stijenu sve do početka kanala akvedukta. Tijekom sedam stoljeća funkcioniranja salonitanskog akvedukta bilo je sušnih i vlažnih razdoblja tako da se vjerojatno geometrija zasječenog protočnog prostora tijekom vremena mijenjala i prilagođavala stvarnom stanju na izvoru. Stanje izvora zabilježeno 1959. osiguravalo je funkcioniranje zahvata i u najsušnijim razdobljima postojanja zahvata.

Opisani koncept zahvata salonitanskog akvedukta vrlo je kvalitetno rješenje zahvaćanja vode krškog izvora s izrazito promjenjivim protocima. Ovakvom izvedbom omogućeno je pouzdano zahvaćanje malih voda, a, s druge strane, kanal je dobro zaštićen od velikih i silovitih voda koje istječu iz špilje. Naime, zahvatni je kanal dovoljno bočno izmaknut i usječen

minimum flows. The availability of the minimum water level required for the continuity of the water supply and the operation of water intake structures during high and torrential water flows at the spring were the reason for constructing barriers and the formation of the reservoirs (lakes) downstream from the cave spring. For the needs of the Salona Aqueduct water intake structure with a capacity of 450 - 650 l/s[32] situated in the ravine on the right shore of the reservoir (lake), a low barrier should have been built as a means to direct water towards that shore. The barrier should have maintained a minimum flow at least 60 cm deep (elevation of 33.05 m a.s.l.) at its point of entry into the Aqueduct's channel. It was probably built from massive stone blocks, which had to remain stable during high water flows and high rate water flows. The barrier can be assumed to have been situated at the same site as the dam, i.e. its southern part, which was built in 1885/1886 (Fig. 15).

By analyzing the 1959 architectural survey of the spring, it can be observed that the right, northern side of the spring has an irregular notch at the bottom, i.e., a flow area (Fig. 10). It may be assumed that such a rock mass formation is not merely the result of natural forces but also of human intervention. The elevation of this notch bottom is at about 32 m a.s.l., which confirms the previous theory on the initial elevation of the Salona Aqueduct channel. In any case, the thusly shaped right side of the spring formed an irregular flow channel of a very favourable depth for water intake during low-water stages. The central high rocks hence remain dry and obstruct water discharge from the spring; consequently causing the level of water in the flow area to rise to about 33.00 m a.s.l. This was

32 Marasović *et al*. 2016, pp. 150-153.

u stijeni, položen izvan glavne struje mlaza vode koji se strmo slijeva u korito Jadra. Zbog takve konfiguracije terena na izlazu iz izvora razina vode na mjestu zahvata kod velikih voda značajno se ne podiže, što omogućuje ravnomjerno dotjecanje vode u zahvatni kanal i dalje prema Saloni.

Zahvatna građevina vodovoda Dioklecijanove palače

Kada se krajem XIX. stoljeća rekonstruirao Dioklecijanov akvedukt, 35 % kanala bilo je u potpunosti sačuvano, uključujući izvornu antičku žbuku, 25 % je trebalo presvoditi, a 40 % je trebalo rekonstruirati.[33] Kako je već rečeno, zahvatna građevina na izvoru Jadra nije bila sačuvana. U svom izvješću o Dioklecijanovu akveduktu iz 1860. godine ing. Locati, koji je bio zadužen za njegovu obnovu, navodi da na izvoru nema nikakvih ostataka zidanih konstrukcija osim dna antičkog kanala na nekoliko mjesta te zasjeka na hridima.[34] Te tragove možemo vidjeti i na fotografiji izvorišta s kraja XIX. stoljeća prije rekonstrukcije Dioklecijanova vodovoda (sl. 13). Kanal, visine 1,87 i širine 0,63 m, bio je u potpunosti sačuvan tek na udaljenosti od 70 m od izvora.[35]

Ovaj je kanal, za razliku od salonitanskog, koji je bio longitudinalno postavljen u odnosu na istjecanje vode iz izvora, bio bočno/okomito postavljen u odnosu na izvor. Za kontinuirani rad vodoopskrbnog sustava voda se mora zahvaćati kod najnižih vodostaja, protoka, a kod silovitog istjecanja za vrijeme velikog vodostaja zahvat mora biti zaštićen. Postavljanjem zahvata bočno na smjer istjecanja vode iz izvora, između dviju hridi, on je bio dovoljno zaštićen kod najvećih protoka. Prostor između kanala i lijeve, istočne obale izvora bio je zasut/zatvoren te se sva voda usmjeravala prema desnoj, sjevernoj strani izvora. Ovim je prostor za otjecanje vode sužen/smanjen, što je rezultiralo podizanjem razine vode na izvoru, posebno kod malih voda. Velike su se vode slobodno prelijevale preko hridi, nasipa i samog kanala prema izlazu, ne ugrožavajući rad zahvata.

Prema crtežu zahvatnih građevina na izvoru Jadra iz 1908. (sl. 3) početna točka dna rekonstruiranog kanala nalazi se na 32,17 m.n.v., ali se u dužini od 11 m postupno penje do kote od 32,80 m.n.v. te otud bla-

33 Bulić 1927, str. 111-112.

34 Domančić 1999, str. 105, Izvještaj ing. Locatija iz 1860. o stanju ostataka antičkog akvedukta Dioklecijanove palače, broj. 1877-35.

35 Domančić 1999, str. 117, Pismo Glavinića barunu Rodiću, vojnom zapovjedniku Dalmacije, od 6. 6. 1877., broj. 1877-30.

extremely important for the Roman architects, because the channel notching allowed for sufficient water intake even at the lowest water stages at the spring, all with the aim of ensuring a permanent water supply. Further on, at the spring's exit point, the channel most likely continued through the notched side rock all the way to the start of the Aqueduct channel. During the seven centuries in which the Salona Aqueduct functioned, there were both dry and wet periods, so the geometry of the notched flow area was probably changed and adapted to the actual condition of the spring over time. The condition of the spring recorded in 1959 ensured the water intake even during the driest periods of its existence.

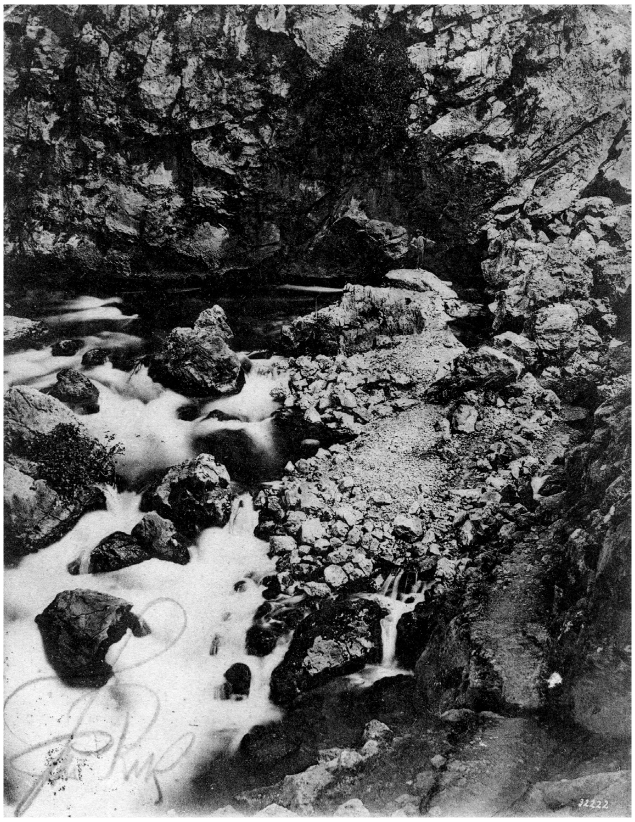
The described concept of the Salona Aqueduct intake structure is a high-grade solution for the intake of water from a karst spring with extremely variable flows. Such construction enables a dependable intake of low-level waters, while the channel is on the other side and thus well protected from the high and torrential waters flowing from the cave. Namely, the intake channel is sufficiently shifted laterally, notched into the rock, and laid out of the main flow of the stream that steeply flows into the Jadro's riverbed. Due to such a terrain configuration at the exit point of the spring, the water level at the intake point does not rise significantly when the water level is high, allowing for an even flow of water into the intake channel and further towards the city of Salona.

Water intake structure of the Diocletian Aqueduct

During reconstruction of the Diocletian Aqueduct at the end of the 19th century, 35% of the channel was entirely preserved along with the original Roman plaster, 25% had to be vaulted, and 40% was reconstructed.[33] As already mentioned, the water intake structure was not preserved at the spring itself. Locati, the engineer in charge of reconstruction of the Diocletian Aqueduct, reported in 1860 that there were no masonry structural remains at the spring except for the bottom of the Roman channel at several sites and the notches on the cliff.[34] Those traces can be seen in a photograph of the Jadro's spring from the end of the 19th century prior to Aqueduct reconstruction (Fig. 13). The channel was completely preserved only at a

33 Bulić 1927, pp. 111-112.

34 Domančić 1999, p. 105; A report by Locati dated from 1860 on the condition of the remains of the Diocletian Aqueduct, no. 1877-35.



Sl. 13. Izvor Jadra prije rekonstrukcije Dioklecijanovog akvedukta (foto: Muzej grada Splita). U desnom donjem kutu vidi se dno antičkog kanala
Fig. 13. The Jadro's spring prior to reconstruction of the Diocletian Aqueduct (photo: Split City Museum). The bottom of the Roman channel is visible in the lower right corner

gim padom ide prema Splitu. Taj se isti kontrapad na početku kanala spominje u opisu ostataka antičkog kanala iz 1877. godine. Autor opisa tvrdi da za taj detalj nema objašnjenja.[36] Taj bi se kontrapad mogao objasniti kao prepreka za krupniji nanos i suspenzije koje voda kod velikog vodostaja nosi iz prostora izvora te za ublažavanje oscilacija razine vode. Sudeći prema crtežima zahvatnih građevina iz 1959. (sl. 8 -10), početak rekonstruiranog Dioklecijanovog kanala kasnije je preuređen tako da je početna kota kanala malo viša (32,48), ali zadržan je kontrapad koji na 11 m od izvora završava uzlaznom stepenicom. Ta je stepenica služila za postavljanje zapornice i nije imala posebno hidrauličko značenje. Detaljnom analizom fotografije izvora prije obnove Dioklecijanova akvedukta (sl. 13) i crteža izvora iz 1908. godine (sl. 3) može se zaključiti da je antički kanal na izvorištu

36 Domančić 1999, str. 117, Pismo Glavinića barunu Rodiću, vojnom zapovjedniku Dalmacije, od 6. 6.1877., broj. 1877-30.

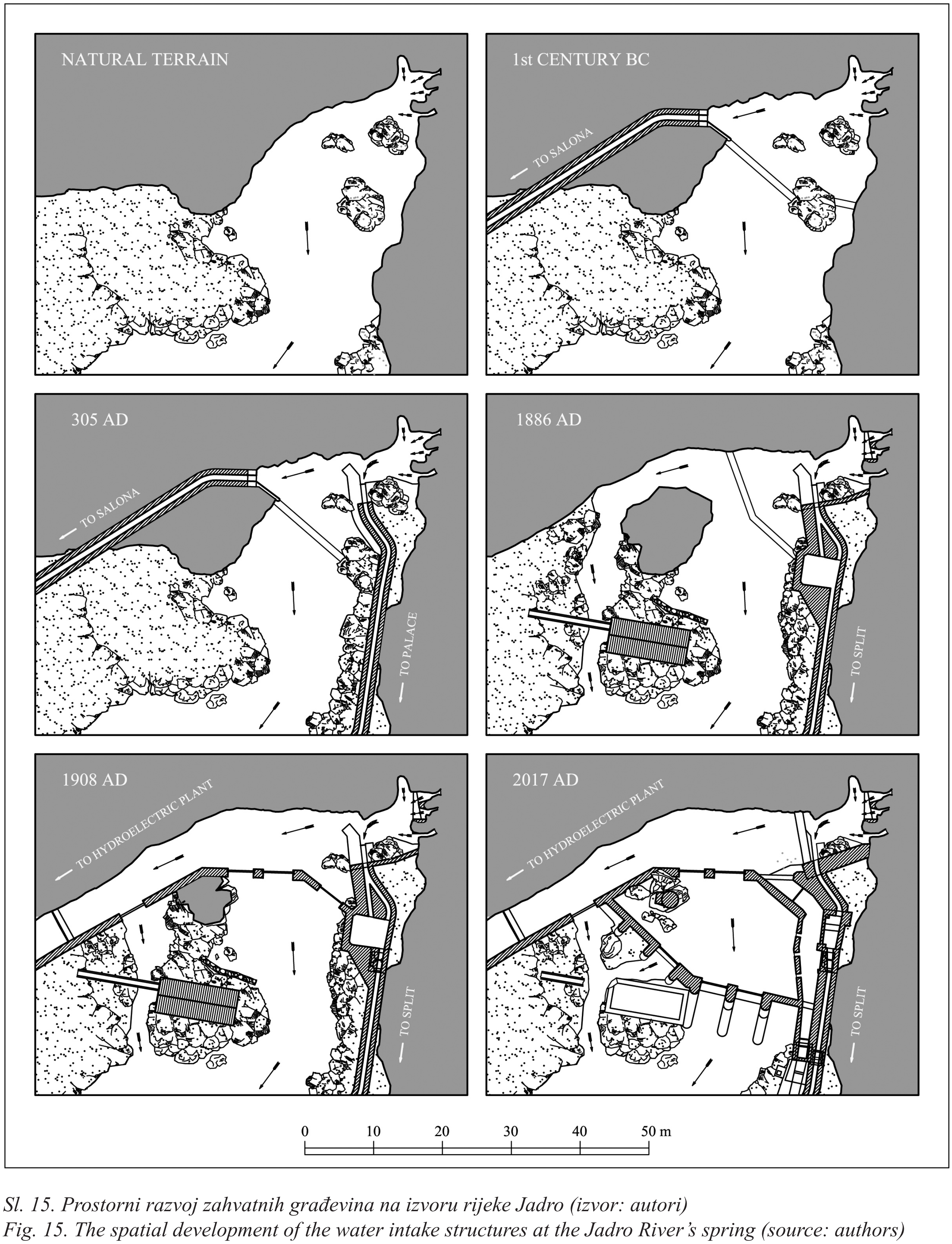
Sl. 14. Početak rekonstruiranog Dioklecijanovog kanala (foto: I. Matijaca)
Fig. 14. The starting point of the reconstructed Diocletian Aqueduct's channel (photo: I. Matijaca)

distance of 70 m from the spring, where it was 1.87 m high and 0.63 m wide.[35]

This channel, unlike Salona's, which was set longitudinally with the spring water discharge, was lateral/perpendicular to the spring. For continuous operation of a water supply system, the water must be taken in at the lowest water stages and flows, while at the same time the intake structure must be protected against the torrential flows occurring during the high water stage. By setting it laterally with the spring's water discharge, between two cliffs, the intake structure was sufficiently protected in case of the highest flows. The area between the channel and the left, east side of the spring was levelled/closed and all water was directed to the right, north side of the spring. Thus, the water discharge area was narrowed/reduced, which led to the water level at the spring rising, particularly at low water level periods. The high waters freely overflowed the cliffs, embankment and the channel itself towards the exit, not compromising the operation of the intake structure.

According to a 1908 sketch (Fig. 3) of the water intake structures at the Jadro River's spring, the starting point of the bottom of the reconstructed channel is at 32.17 m a.s.l., but the elevation gradually increases to 32.80 m a.s.l. after 11 m and, following a mild slope, descends toward the city of Split. This very same reverse slope at the starting point of the channel is mentioned in 1877, in the description of the Roman channel remains. The author claimed he

35 Domančić 1999, p. 117, a letter from Glavinić to Baron Rodić, Military Commander of Dalmatia, dated 6 June 1877, no. 1877-30.



Sl. 15. Prostorni razvoj zahvatnih građevina na izvoru rijeke Jadro (izvor: autori)
Fig. 15. The spatial development of the water intake structures at the Jadro River's spring (source: authors)

dosljedno rekonstruiran u tlocrtnom i visinskom pogledu.

Važno je znati da su salonitanski i Dioklecijanov vodovod zajedno zahvaćali oko 1000 l/s, a da je pretpostavljena ekstremna minimalna izdašnost izvora u antičkom razdoblju bila oko 3000 l/s. To znači da je na izvoru uvijek slobodno istjecalo najmanje 2000 l/s u rijeku. Ako je dubina vode u Dioklecijanovu zahvatnom kanalu bila oko 0,7 m,[37] razina je vode u izlaznom prostoru izvora na mjestu zahvata morala kod minimalnog vodostaja biti na 32,87 m.n.v. Na mjestu Dioklecijanova zahvata izlazni je prostor izvora najuži tako da je taj položaj najpovoljniji za zahvaćanje malih voda jer je na tome mjestu dubina vode najveća. Polazeći od geometrije izvora i količine vode koja je istjecala iz izvora, izračunat je vodostaj te je zaključeno da je kota površine vode na izvoru, uz uzimanje vode salonitanskoga i Dioklecijanovog vodovoda, uvijek bila viša od 33,50 m.n.v., što je bilo dovoljno za punjenje obaju zahvata. Danas se razina vode uvijek održava iznad kote od 34 m.n.v. Ta razina vode osigurava veću dubinu zahvaćanja vode i time osigurava veći kapacitet zahvata.

Zahvaćanje vode Dioklecijanovim kanalom kod malih protoka riješeno je oblikovanjem dna terena/korita na izvoru. Prema istoku dno izvora/špilje prirodno opada sve do kote 30,94 i dublje u podzemlje (sl. 10, presjek VI-VI). Međutim, prema izlazu na zapadu, kota na sredini izlaznog prostora raste do 33,40 m.n.v. Kao što je već rečeno, prilikom izgradnje zahvata salonitanskog akvedukta na desnoj strani izvora oblikovan je protočni kanal do kote dna od oko 32 m.n.v. kako bi se kod malih voda nesmetano punio salonitanski kanal. Okomito na to produbljenje/usjek, u smjeru Dioklecijanova kanala, također je zasječeno dno i oblikovan kanal u dnu izvora kako bi se i on nesmetano punio vodom kod malih voda.

Da bi se osiguralo pouzdano dotjecanje vode u kanal te povećao protok vode, odnosno kapacitet zahvata za vrijeme ekstremno malih protoka na izvoru, kod rekonstrukcije zahvata 1877./1880., ispred početka Dioklecijanovog kanala, izvedena je betonska barijera/potopljena brana, malo kraća od cijele širine otvora špilje s kotom krune vjerojatno istom kao što je i danas (33,85 m.n.v.). Na taj način smanjen je protočni prostor te je podignuta razina vode na izvoru do kote veće od 34 m.n.v., što je dovoljno za kontinuirano punjenje Dioklecijanova kanala. Pregrada je omogućavala i veće zahvaćanje vode i time veći protok vode u Dioklecijanovu kanalu. Može se pretpostaviti da je u antici postojalo isto rješenje. Naime, Dioklecijanov vodovod bio je u funkciji u razdoblju od IV. do VII.

37 Margeta 2017.

had no explanation for this detail.[36] The reverse slope could be explained as serving as an obstacle to larger alluvium and suspensions carried by the water from the spring area during high-water stages, and to mitigate water level oscillations. According to the 1959 drawings of the water intake structures (Figs. 8-10), the starting point of the reconstructed channel for Diocletian Aqueduct was later modified so that its initial elevation became somewhat higher (32.48), but the reverse slope, which ends in an ascending step at 11 m from the spring, was preserved. This step was used to set up a floodgate and had no particular hydraulic significance. By a detailed analysis of the photograph taken before reconstruction of the Diocletian Aqueduct (Fig. 13) and the 1908 drawings of the spring (Fig. 3), it may be concluded that the Roman channel at the spring was consistently reconstructed in terms of ground plan and elevation.

It is important to know that the combined intake of the water supply systems of the Salona Aqueduct and the Diocletian Aqueduct was about 1,000 l/s, and that the assumed extreme minimum yield of the spring in the Roman era was about 3,000 l/s. This means that at least 2,000 l/s were always released into the river freely from the spring. If the depth of the water in the Diocletian intake channel was about 0.7 m,[37] it means that the water level in the spring exit area at the intake point must have been 32.87 m a.s.l. at the minimum water stage. The spring exiting area is the narrowest at the site of the Diocletian intake structure, making this position most favourable for the intake of low waters because the depth of the water is greatest here. The water stage was calculated based on the geometry of the spring and the amount of water discharged from it, and it was concluded that the elevation of the water's surface at the spring, regardless of the intake of water by the Salona and Diocletian Aqueducts, had always been higher than 33.50 m a.s.l., which was enough to fill both intake structures. Today, the water level is always maintained above 34 m a.s.l. This water level ensures a greater depth for the water intake and thus a higher capacity of the intake structures.

The intake of water by the Diocletian Aqueduct's channel at low flows was solved by forming the bottom of the terrain/bed at the spring. Towards the east, the spring/cave bottom naturally slopes up to the elevation of 30.94 m and deeper down into the underground (Fig. 10, section VI-VI). However, towards the exit on the west, the elevation in the middle

36 Domančić 1999, p. 117, a letter from Glavinić to Baron Rodić, Military Commander of Dalmatia, dated 6 June 1877, no. 1877-30.

37 Margeta 2017.

stoljeća, koje je poznato po značajnim promjenama klime. U tom razdoblju utvrđene su ekstremno sušne godine[38] i time vjerojatno mali protoci vode iz izvora pa je gradnja pregrade bila jednostavno i praktično rješenje za zahvaćanje dovoljnih količina vode.

Zaključak

Antički zahvati na izvoru Jadra jedinstven su primjer gradnje i funkcioniranja dvaju zahvata na istom izvoru. Stoljećima su ova dva vodovoda funkcionirala ne ugrožavajući rad jedan drugom, što je za graditelje bio poseban izazov. Uz zahvaćanje potrebnih količina vode oni su nastojali osigurati što višu radnu kotu vodoopskrbnog sustava (razinu vode) koja je određivala moguće područje vodoopskrbe (gravitacijski sustavi). Za graditelje Dioklecijanova vodovoda izazov je bio veći jer je područje vodoopskrbe bilo gotovo dva puta udaljenije nego u slučaju Salone. Izvor Jadra, vrlo atraktivan prirodni vodni fenomen na suhom i krševitom terenu, bio je od velike važnosti za vodoopskrbu, ali i za održavanje života u rijeci i na ušću rijeke (proizvodnju hrane). Zbog toga je trebalo voditi računa na koji se način i u kojim količinama voda zahvaća.

Rekonstrukcija antičkih vodnih zahvata na izvoru rijeke Jadro i njihova usporedba s kasnijim intervencijama zorno prikazuje kako su antički graditelji na jednostavan, ali učinkovit način rješavali pouzdano zahvaćanje vode bez velikih utjecaja na izvorište, odnosno na njegove prirodne značajke. Zahvati su kontinuirano funkcionirali u različitim klimatskim razdobljima nekoliko stoljeća. U cijelom tom razdoblju prilagođavali su se promjenjivom režimu voda izvora. Izmicanjem zahvatnih objekata izvan glavne struje toka vode, koji uvijek nosi i najveće onečišćenje, zahvaćala se voda bolje kakvoće. Moderno rješenje o tome nije vodilo računa, jer se danas voda intenzivno miješa i zadržava, te sa svim suspenzijama i drugim nečistoćama usmjerava u zahvat, što rezultira i lošijom kakvoćom vode. Izmicanjem zahvata izvan glavnog toka vode oni su bili zaštićeni i od razarajuće sile velikih voda.

Zahvaćanje potrebnih količina, odnosno osiguranje potrebne razine vode na zahvatu, kod ljetnih malih voda, riješeno je stvaranjem protočnih kanala zasijecanjem i modificiranjem dna i bočnih strana izvora. Osim toga, u slučaju ekstremno sušnih godina mogle su se graditi i manje pregrade radi povećanja razine vode. Velike vode u antičko vrijeme nisu predstavljale velik problem za rad zahvata u smislu dizanja razine vode iznad tjemena kanala jer je prostor za

38 McCormik *et al*. 2012.

of the exiting area increases to 33.40 m a.s.l. As already mentioned, during construction of the Salona Aqueduct water intake structure, a flow channel was formed on the right side of the spring reaching the bottom elevation of approximately 32.00 m a.s.l. to insure the Aqueduct's channel could be filled without interruption in the event of low waters. Perpendicular to this deepening/notch, in the direction of the Diocletian Aqueduct's channel, the bottom was also notched and a channel was formed at the bottom of the spring to ensure that it could also be filled even in the event of low waters.

During the 1877/1880 reconstruction of the intake structure, a concrete barrier/overflow dam was constructed directly downstream from the Diocletian's channel, somewhat shorter than the total width of the cave span with the elevation of the crest of 33.85 m a.s.l., which is probably the same today, in order to ensure a dependable water intake into the channel and increase the water flow, i.e., in order to insure the capacity of the intake structure at extremely low flows at the spring. In this way, the flow area was reduced and thus the water level at the spring increased to an elevation higher than 34 m a.s.l. which is enough to continuously fill the Diocletian Aqueduct's channel. The barrier also allowed for a greater water intake and, consequently, a greater water flow into the Diocletian channel. It can be assumed that the same solution existed in the Roman era. Namely, the Diocletian Aqueduct was in operation from the 4th to 7th centuries, known for significant climate changes. Extremely dry years[38] and thus probably low spring water flows have been identified during this period, so constructing such a barrier was a simple and practical solution for taking in sufficient amounts of water.

Conclusion

The Roman water intake structures at the Jadro River's spring are a unique example of two intake structures being constructed and functioning at the same spring. For centuries, these two aqueducts have functioned without impeding one another, representing a special challenge for their architects. In addition to taking in the required amounts of water, they sought to provide the highest possible operating elevation of the water supply system (water level), which determined the potential water supply area (gravity fed water systems). The challenge was even greater for the architects of the Diocletian Aqueduct, as its water supply area was almost twice as far away than in the case of Salona. The Jadro River's spring

38 McCormik *et al.* 2012.

istjecanje vode iz izvora bio otvoren i širok, tako da se voda odmah slijevala niz strme stijene u korito rijeke Jadro stvarajući atraktivne, široke i visoke, slapove. Iz tog razloga nije se stvarao uspor na prostoru izvora zbog kojeg bi se površina vode na zahvatu značajnije uzdizala i potapala zahvate. Zahvati su imali i odgovarajuću opremu nužnu za rad (zapornice, otvori za aeraciju, otvori za čišćenje, preljevi viška voda, zaštita od vanjskih voda i onečišćenja, zaštita od urušavanja i zatrpavanja itd.). Za sada ostatci i zapisi o tim elementima zahvata nisu pronađeni.

Izvor rijeke Jadro dobar je primjer utjecaja kvalitetnog i pouzdanog izvora vode na razvoj nekog područja. Dugogodišnje korištenje za potrebe vodoopskrbe i iskorištavanje potencijalne energije izvora rezultiralo je trajnim preinakama izvora i objekata zahvata. Temeljem analize povijesnog slijeda građenja jasno se vidi da su osnovne značajke izvora bile prepoznate u antici (velika varijabilnost protoka i brzine istjecanja vode) budući da su se implementirala specifična rješenja kojima se osiguravao pouzdani rad zahvata, u smislu osiguranja dovoljnih količina vode i energije nužne za njezin gravitacijski transport. U radu je prikazan prvi pokušaj rekonstrukcije pojedinih etapa korištenja izvora u različitim socioekonomskim razdobljima razvoja šireg prostora s naročitim naglaskom na rekonstrukciju antičkih zahvatnih građevina salonitanskog i Dioklecijanovog akvedukta.

Priznanje

Ovaj članak se temelji na istraživačkom radu koji financira Hrvatska zaklada za znanost - HRZZ, istraživački projekt IP-11-2013 pod naslovom "Antički vodni sustavi grada Salone i Dioklecijanove palače i njihov utjecaj na održivost urbane sredine". Ovom prilikom zahvaljujemo JKP-u Vodovod i kanalizacija d. o. o. Split koji je omogućio pristup izvorištu i arhivskoj građi. Zahvaljujemo i tvrtki *Geoprojekt* d. d. Split koja nam je ustupila geodetske podloge potrebne za istraživanje.

was a rather attractive natural water source situated in a dry and karst area of great importance not only for the water supply, but also for maintaining life in the river and at the river's mouth (food production). Therefore, it was necessary to take into account how and how much water was taken.

The reconstruction of the Roman water intake structures at the Jadro River's spring and their comparison with later interventions clearly shows that the Roman architects had a simple, yet efficient way of providing dependable water intake without major interventions in the spring, i.e., its natural features. The water intake structures have continued to function in different climatic periods for several centuries. Throughout this time, they adapted to the changing water regime of the spring. By shifting the intake structures outside the main water flow stream, which always brings the greatest pollution, higher quality water was taken in. The modern solution has not taken this into account, since now water is being intensively mixed and retained and, together with all of the suspensions and other contaminants, directed into the intake structure, which results in poorer water quality. By shifting the intake structures outside of the main water flow stream, the water intake structures were protected from the destructive force of high waters.

Taking in the required quantities of water, i.e., ensuring the required water level at the water intake structure in case of low water levels during the summer was solved by creating additional flow channels, and by notching and modifying the spring bottom and sides. Additionally, in case of extremely dry years, smaller barriers could have been built in order to increase the water level. High-level waters in Roman times did not represent a major problem for the operation of the water intake structures in terms of increasing the water level above the channel top, because the area for discharging water from the spring was open and wide, so the water immediately poured down the steep rocks of the Jadro River, creating wide, high and attractive waterfalls. Due to this, no backwater was created in the spring area that could cause the water surface to significantly rise and overflow the intake structures. The intake structures were also equipped with the appropriate equipment needed for their operation (barriers, aeration openings, cleaning openings, excess water overflows, external water and pollution protection, collapse and landslide protection, etc.) Thus far, the remains and records on these elements of water intake structures have not been found.

The Jadro River's spring is an excellent example of a quality and reliable water source and its influence on the development of a specific area. Long-term public water supply requirements and the exploitation of the potential energy from the spring resulted in permanent modifications of the spring and water intake structures. Based on an analysis of the chronological order of construction activities, it is evident that the main features of the spring were acknowledged in Roman times (high variability of the flow and the rate), which resulted in the implementation of specific solutions that ensured reliable operation of the water intake structure, i.e., supplying a sufficient amount of water and energy necessary for gravity fed water transportation. This paper presents the first reconstruction attempt of particular phases in spring water exploitation, taking into consideration various socioeconomic stages of the wider area's development with an emphasis on reconstruction of the Roman water intake structures belonging to the Salona and Diocletian Aqueducts.

Acknowledgements

This paper is based on work primarily supported by the Croatian Scientific Foundation under the HRZZ Research Project IP-11-2013 under the title "Roman Water Systems of Salona and Diocletian's Palace and Their Impact on the Sustainability of the Urban Environment". We would like to take this opportunity to thank J.K.P. Vodovod i kanalizacija d.o.o. Split (Water Supply and Sewage Public Utility Company) that provided access to the spring and the archival materials. Furthermore, we would like to thank Geoprojekt d.d. Split, a company which provided us with the land survey maps necessary for this research.

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