HISTORY OF HYDROLOGICAL MONITORING IN VARAŽDIN

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Abstract: *Hydrological monitoring involves the systematic observation and recording of key hydrological parameters, such as water level, flow rate, precipitation, sediment transport, water temperature, and ice conditions, to understand changes in watercourses and river regimes. These observations are conducted at hydrological stations located on rivers, lakes, or reservoirs, providing valuable data for water resource management. The origins of hydrological monitoring in Croatia date back to the first half of the 19th century when the first water gauge stations were established. One of the oldest stations, the hydrological station in Varaždin, was founded in 1821. At that time, the main observations focused on recording river water levels to ensure navigability, monitor floods, and enable flood protection. Over time, hydrological monitoring in Croatia became increasingly sophisticated. With the establishment of national institutions such as the Croatian Meteorological and Hydrological Service (DHMZ) in 1947, data on water levels, flow rates, sediment transport, precipitation, and other hydrological parameters began to be systematically collected, processed, and published. Today, monitoring is carried out through a network of automatic hydrological stations, enabling continuous real-time data tracking and analysis.*
Keywords: *Drava River, hidrological station, water gauge, hidrological parameters, Varaždin.*

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Review paper

1. INTRODUCTION

In northwestern Croatia, on the right bank of the Drava River, lies the city of Varaždin. The name Varaždin was first mentioned on August 20, 1181, in a charter issued by the Croatian Hungarian King Béla III, marking the beginning of the city's recorded history.

The name "Drava" itself reflects the river's fundamental natural characteristic. According to some authors, the origin of the name Drava can be traced back to ancient Indian Sanskrit, where "drava" signifies a river flow. The old Indo-Germanic term "dra" means to rush or move quickly. Thus, the name Drava would denote a fast-flowing river (Obadić 2007).

Throughout history, the Drava River has often served as a border. Its role as a boundary was particularly evident from the late 16th century when it became the frontier between the territories under Habsburg rule and the Ottoman Empire, a status it maintained until the late 17th century. Later, it marked the border between the Military Frontier and the Hungarian counties, like its role in the 16th century (Petrić 2005).

Human influence on the Drava River was first noted in regulatory plans from 1780, but significant changes only began in the early 19th century with the first hydro-regulation works. In the first half of the 20th century, before industrialization and river regulation, the Drava followed its natural course, featuring sandy and gravelly banks. At that time, the Drava Bathing Area was a popular gathering place for the residents of Varaždin and the surrounding areas. It was a social hub where people from all walks of life mingled.

The beginnings of organized monitoring and recording of surface water hydrology date back to the 19th century. Systematic collection and publication of hydrological data have been conducted since 1922. Until 1943, hydrological data were published in the *Reports on Water Sediments, Water Levels, and Water Quantities*, and since 1946, they have been compiled in the *Hydrological Yearbooks*. Today, all data are archived in the Hydrological Information System, HIS 2000, which is managed by the Croatian Meteorological and Hydrological Service (DHMZ).

2. HISTORY OF THE HYDROLOGICAL STATION DRAVA - VARAŽDIN

The Hydrological Station Drava-Varaždin, established in 1821, began its operation as a gauging station with an initial reference point (the "0" gauge level) set at an elevation of 166.06 meters above sea level (m a.s.l). Since then and to this day, its key function has been monitoring and recording water levels. Over the years, the station has undergone numerous changes, primarily concerning its position along the flow of the Drava River, but the zero gauge elevation has remained unchanged since 1878. However, due to limited archival data, the precise location of the gauge between 1821 and 1935 is unknown, but it is assumed to have been attached to one of the pillars of

the then existing road bridge, about 100 m downstream from the railway bridge, approximately at the location where it stands today. A significant change occurred in 1935 when the gauge was fixed to the first river pillar of the bridge, on the right bank of the river. This is a vertical gauge made of cast iron, with height markings divided into 2 cm. During World War I, the destruction of the road and the nearby railway bridge, about 100 m away, resulted in the relocation of the gauge. On August 1, 1945, the restored gauge was placed as a pilot in the riverbed, 30 meters downstream from the collapsed bridge. The new construction included metal plates with a division of 5 cm, while the zero point was lowered by 9.7 mm, reflecting the change in the water level between the old and new locations. Nevertheless, the zero point was retained and recorded unchanged at 166.06 m, preserving consistency in data recording. Water level monitoring was performed by Špičko Nevenka, an official from the Technical Department of the District N.O. in Varaždin. The technical report to the Federal Order of the Ministry of Construction F.H. was submitted by Vodopivec Dragutin and Perger Vladimir on August 7, 1945, in Zagreb. A temporary wooden bridge was built not far from the then-collapsed railway bridge, and due to difficulties in maintaining the gauge on the pilot, on November 7, 1953, the gauge was moved to another pillar of the bridge from the right bank, ranging from 0 to 400 cm. The reference point was then returned to the original height of 166.06 meters above sea level. Furthermore, in the same year, a new reinforced concrete bridge was built at the site of the former railway bridge, which still serves road and rail traffic today. Therefore, on January 8, 1954, the gauge was moved from the temporary wooden bridge to the newly constructed railway bridge, and it was placed on the third concrete pillar from the downstream side, on an oak plate attached to the pillar of the bridge with iron brackets, with plates facing the right bank. The old gauge was not removed, and the observer was instructed to simultaneously read the water level on both gauges since both were set to the same reference point. The observer of the Varaždin gauge, due to having to read two gauges and the temperature of the water, requested an increase in compensation to 2000 dinars quarterly. The changes related to the location of the gauge are shown in **Figures 1-3**.

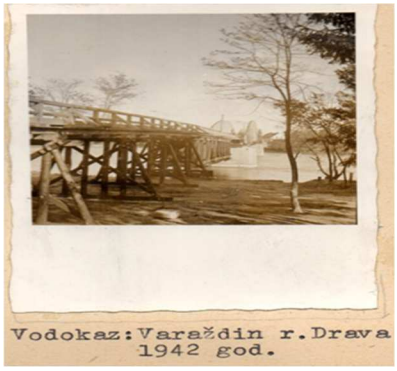


Figure 1 *Damaged bridge in 1942, water gauge relocated to the right bank (DHMZ)*

Figure 2 *New road-rail bridge Varaždin – Čakovec*
Photo: Turner, 1957 (DHMZ)

Figure 3 *Water gauge on the bridge pillar on the downstream side*
Photo: Turner, 1957 (DHMZ)

Furthermore, the water gauge, which was temporarily installed on November 7, 1953, was later dismantled, and the materials were transported to Zagreb. A technical report was submitted to the administration of the Hydrometeorological Service of the People's Republic of Croatia by Satler Leon on January 25, 1954, in Zagreb. In 1960, the construction of a limnigraph began, 150 meters downstream from the road-rail bridge, on the right bank of the river. Alongside the limnigraph, a water gauge with the same reference point was installed. To determine differences in water levels due to the drop in water level between the limnigraph and the bridge, as well as the depression behind the bridge pillar, water levels were simultaneously recorded at both water gauges. Measurements at both locations were conducted from July 7, 1960, to December 31, 1962. The corresponding limnigraph-Varaždin water levels for 1961 and 1962 are shown in **Figure 4** (DMHZ archive).

The limnigraph was of the well-type, housed in a concrete shelter on the slope of the right bank, as shown in **Figure 5** of the cross-sectional profile (DHMZ archive). The first section of the water gauge ranged from 0 to 300 cm and was mounted on a pile, the second section from 300 to 400 cm was attached to an oak plank next to the limnigraph house, while the third section, from 300 to 500 cm, was placed on a pile on the slope of the right-bank embankment.

On December 19, 1962, a decision was made to discontinue the Varaždin water gauge station on the Drava, as a limnigraph—an automatic water level recorder—had been installed nearby, allowing for continuous monitoring (DHMZ archive). Consequently, the director of the Hydrometeorological Service of the Republic of Croatia, Eng. Mile Sikić, decided that observer Mirko Klun would cease water level monitoring on January 1, 1963. Furthermore, hydrological technician Pavao Anić was instructed to dismantle the station and transfer the equipment to the Institute's warehouse. **Figure 6** presents the document that officially declared the closure of the Varaždin water gauge station.

Additionally, the limnigraph station was relocated to a new site, about 30 meters upstream from the Varaždin – Čakovec road bridge, on the right bank, approximately 10 meters downstream from the junction with the HE Varaždin canal. The water gauge was a vertical, four-section instrument, ranging from -100 to 500 cm, with the zero reference point remaining unchanged. The limnigraph was a mechanical model of the Seba type.

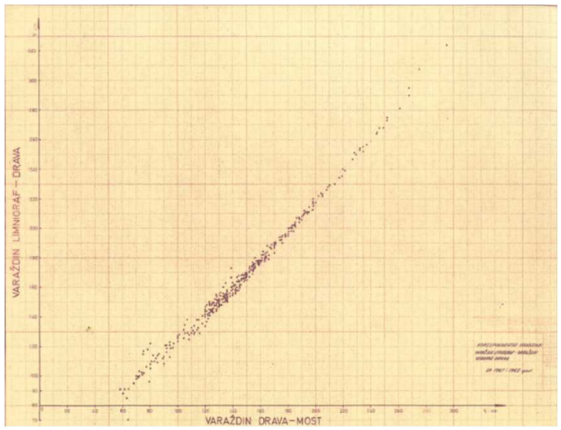


Figure 4 *Correlation between water levels measured at the water gauge and the limnigraph during 1961 and 1962 (DHMZ)*

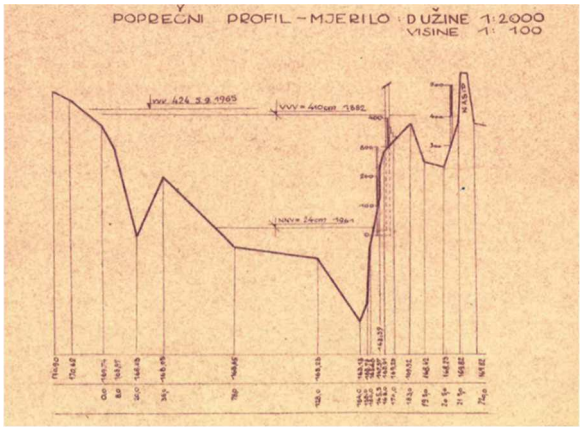
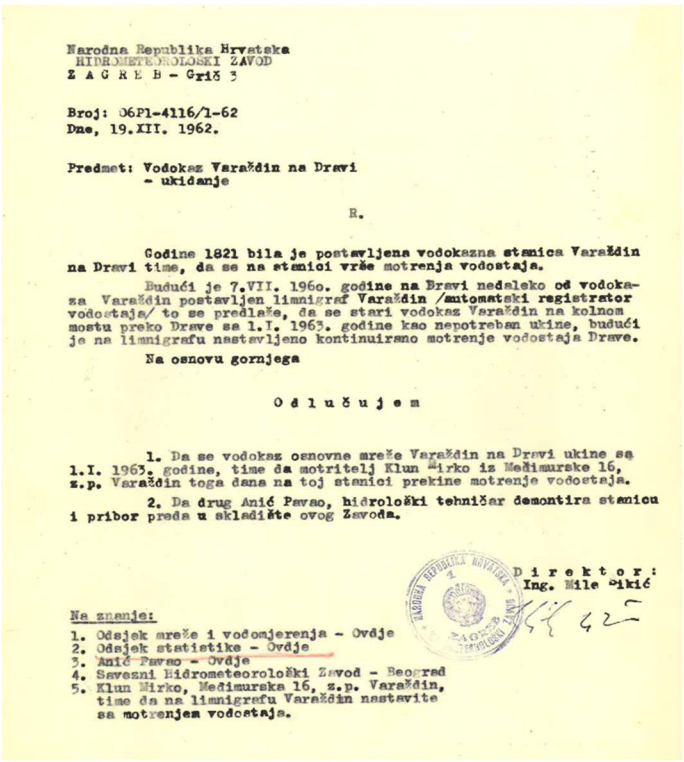


Figure 5 *Limnigraph profile with recorded extreme water levels measured up to 1965 (DHMZ)*



Narodna Republika Hrvatska
HIDROMETEOROLOŠKI ZAVOD
Z A G R E B – Grič 3

Broj: 06Pl-4116/1-62
Dne, 19.XII. 1962.

Predmet: Vodokaz Varaždin na Dravi
– ukidanje

R.

Godine 1821 bila je postavljena vodokazna stanica Varaždin na Dravi time, da se na stanici vrše motrenja vodostaja.

Budući je 7.VII. 1960. godine na Dravi nedaleko od vodokaza Varaždin postavljen limnigraf Varaždin /automatski registrator vodostaja/ to se predlaže, da se stari vodokaz Varaždin na kolnom mostu preko Drave sa 1.I. 1963. godine kao nepotreban ukine, budući je na limnigrafu nastavljeno kontinuirano motrenje vodostaja Drave.

Na osnovu gornjega

O d l u č u j e m

1. Da se vodokaz osnovne mreže Varaždin na Dravi ukine sa 1.I. 1963. godine, time da motritelj Klun Mirko iz Međimurske 16, s.p. Varaždin toga dana na toj stanici prekine motrenje vodostaja.

2. Da drug Anić Pavao, hidrološki tehničar demontira stanicu i pribor preda u skladište ovog Zavoda.

D i r e k t o r :
Ing. Mile Pikić

Na znanje:
1. Odsjek mreže i vodomjerenja – Ovdje
2. Odsjek statistike – Ovdje
3. Anić Pavao – Ovdje
4. Savezni Hidrometeorološki Zavod – Beograd
5. Klun Mirko, Međimurska 16, s.p. Varaždin, time da na limnigrafu Varaždin nastavite sa motrenjem vodostaja.

Figure 6 *Decision on the closure of the Drava-Varaždin water gauge station, December 19, 1962, HMZ of the People's Republic of Croatia (DHMZ)*

In August 2016, the station underwent reconstruction, during which the water gauge boards were replaced. The water gauge became a three-section combination: a vertical section in the riverbed ranging from 0 to 100 cm, and an inclined section along the bank protection steps, spanning 100 to 222 cm and 222 to 402 cm (**Figure 8**).

On August 5, 2018, a new electronic limnigraph, OTT-CBS, was installed and put into operation (**Figure 9**). Prior to this, a new pressure conduit and solar power supply were set up, along with the establishment of remote water level reporting (**Figure 8**).

As part of the Water Ecological Monitoring and Risk Analysis (VEPAR) project in 2023, the station was modernized, and a radar system was installed on the downstream side of the bridge to monitor water levels in real time (**Figure 7**).

Figure 7 *New road-rail bridge Varaždin – Čakovec, June 24, 2024, Photo: Maloić, J.*

Figure 8 *Hydrological station Drava-Varaždin and water gauge, June 24, 2024, Photo: Maloić, J.*

Figure 9 *Limnigraph, January 19, 2021, Photo: Oskoruš, D.*

3. HYDROLOGICAL PARAMETERS AND THE HISTORY OF THEIR PUBLICATION

At the Drava-Varaždin hydrological station, in addition to water levels and flow rates, water temperature was also measured (**Figure 10**), ice conditions were recorded, and from 1967 to 1984, daily water samples were taken for the analysis of suspended sediment concentration. Daily sediment transport was recorded until the end of 1981. Hydrological measurements conducted up until January 1, 1963, are shown in **Figure 11**. Additionally, their correlation is graphically represented, with a note that data points 1-13 were obtained from the archives of the National Water Management Office (OVF) in Budapest.

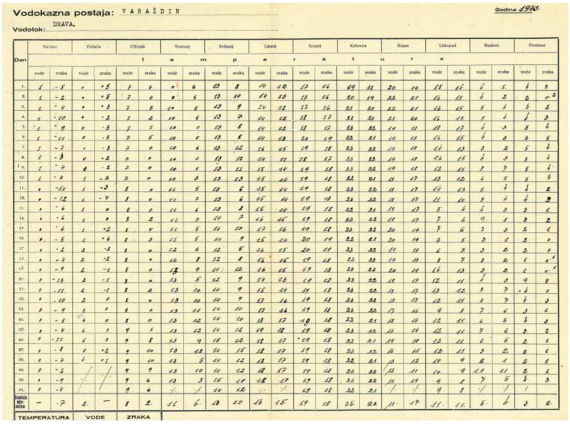


Figure 10 *Annual record of water and air temperature for HP Drava-Varaždin, 1943 (DHMZ)*

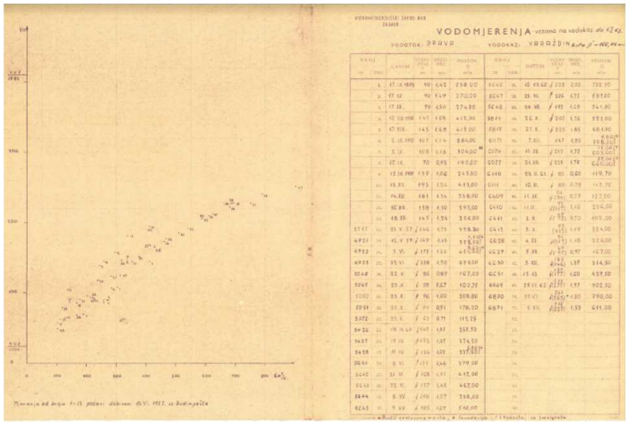


Figure 11 *Record and graphical representation of water measurements conducted at HP Drava-Varaždin until 1963 (DHMZ)*

The maximum water level of the Drava River at the Varaždin gauge was first recorded on October 30, 1882, at a height of 410 cm, while on September 5, 1965, it reached 424 cm. The minimum water level was recorded on February 15, 1901, at a height of 24 cm, and later on September 4, 1961, at 59 cm.

The graph of characteristic water levels clearly illustrates the significant variability of the gauge profile due to regulation works and the highly unstable riverbed of the Drava. Before regulation works, in the period from 1879 to 1912, periodic deposition and removal of gravel material occurred within the river profile. Between 1921 and 1926, although these processes continued, their frequency significantly decreased due to extensive regulation works carried out within the profile itself, as well as upstream and downstream, which greatly stabilized the Drava's riverbed (Bognar 1995).

In general, the gauge profile of the Drava near Varaždin is characterized by high variability in the riverbed. For the period from 1913 to 1920, there are no recorded water level data, likely due to wartime conditions that prevented monitoring (**Figures 12 and 13**).

The Croatian Meteorological and Hydrological Service (DHMZ) has water level records only from 1879 onward, while it is unclear whether data prior to 1878 were ever published. From 1879 to 1893, data were published in printed publications titled “Observations of Water Levels on Rivers in the Kingdoms of Croatia and Slavonia” (**Figure 14 a, b**). From 1921 to 1924, water levels were published in a report titled “Reports on Water Sediments,

Water Levels, and Water Quantities". Between 1941 and 1944, they were printed and published in the "Annual Reports on Water Levels," and since 1945, they have been included in the "Hydrological Yearbook". Today, all data from 1900 onward are archived in the Hydrological Information System, HIS 2000, for whose maintenance and updating DHMZ is responsible.

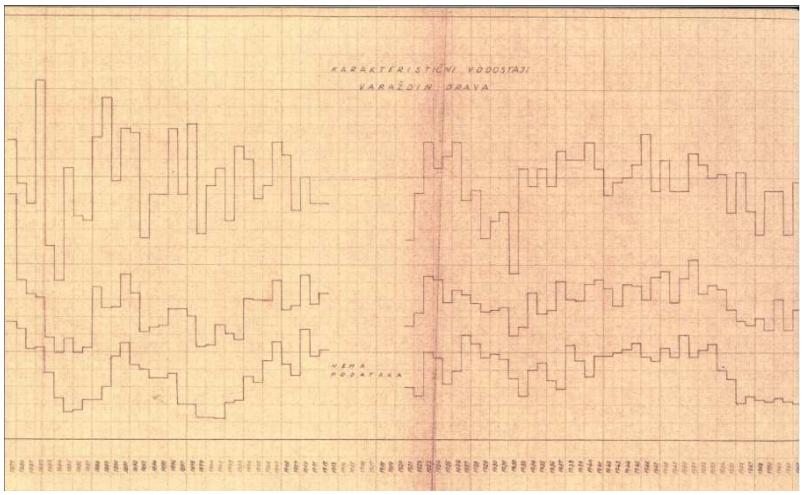
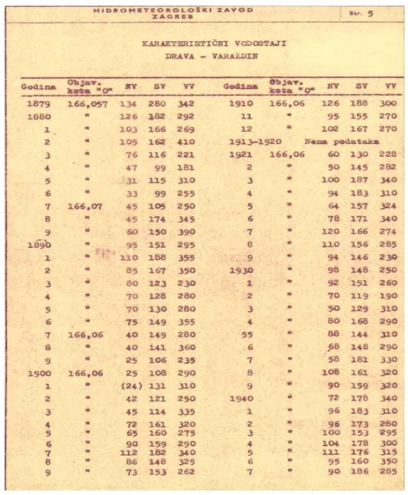


Figure 12 *Characteristic water levels measured at the Drava-Varaždin gauge, period 1879–1962 (DHMZ)*

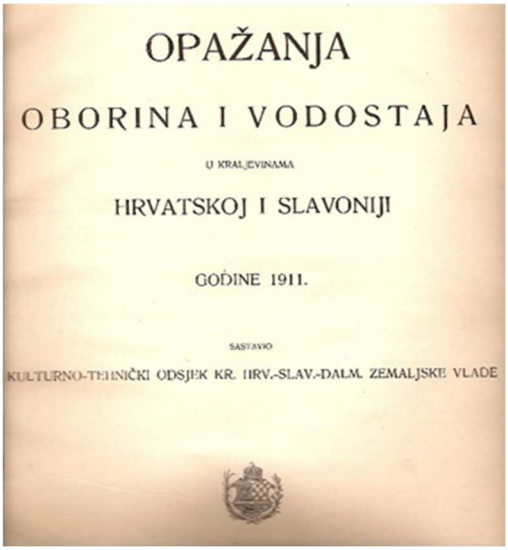

HIDROMETEOROLOŠKI ZAVOD ZAGREB

Str. 5

KARAKTERISTIČNI VODOSTAJI
DRAVA – VARAŽDIN

Godina	Objav. kota "O"	NV	SV	VV	Godina	Objav. kota "O"	NV	SV	VV
1879	166,057	134	280	342	1910	166,06	126	188	300
1880	"	126	182	292	11	"	95	155	270
1	"	103	166	269	12	"	102	167	270
2	"	105	162	410	1913–1920		Nema podataka		
3	"	76	116	221	1921	166,06	60	130	228
4	"	47	99	181	2	"	50	145	282
5	"	31	115	310	3	"	100	187	340
6	"	33	99	255	4	"	94	183	310
7	166,07	45	105	250	5	"	64	157	324
8	"	45	174	345	6	"	78	171	340
9	"	60	150	390	7	"	120	166	274
1890	"	95	151	295	8	"	110	156	285
1	"	110	188	355	9	"	94	146	230
2	"	85	167	350	1930	"	98	148	250
3	"	80	123	230	1	"	92	151	260
4	"	70	128	280	2	"	70	119	190
5	"	70	130	280	3	"	50	129	310
6	"	75	149	355	4	"	80	168	290
7	166,06	40	149	280	55	"	88	144	310
8	"	40	141	360	6	"	58	148	290
9	"	25	106	235	7	"	58	181	330
1900	166,06	25	108	290	8	"	108	161	320
1	"	(24)	131	310	9	"	90	159	320
2	"	42	121	250	1940	"	72	178	340
3	"	45	114	335	1	"	96	183	310
4	"	72	161	320	2	"	98	173	280
5	"	65	160	275	3	"	100	153	295
6	"	90	159	290	4	"	104	178	300
7	"	112	182	340	5	"	111	176	315
8	"	86	140	325	6	"	95	160	350
9	"	73	153	262	7	"	90	186	285

Figure 13 *Record of characteristic water levels, period 1879–1947 (DHMZ)*


OPAŽANJA

OBORINA I VODOSTAJA

U KRALJEVINAMA

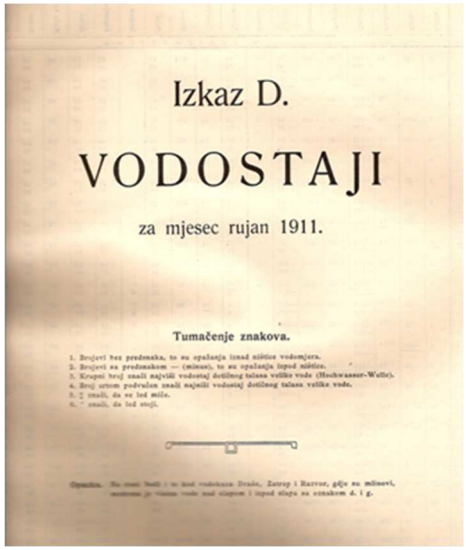
HRVATSKOJ I SLAVONIJI

GODINE 1911.

SASTAVIO

KULTURNO-TEHNIČKI ODSJEK KR. HRV.-SLAV.-DALM. ZEMALJSKE VLADE

Figure 14. *a. Cover page of "Observations of Precipitation and Water Levels in the Kingdoms of Croatia and Slavonia", Cultural-Technical Department of the Royal HR.-SLAV.-DALM. Provincial Government (DHMZ)*


Izkaz D.

VODOSTAJI

za mjesec rujan 1911.

Tumačenje znakova.

Figure 14*. b. Contents of the publication with hydrological data for September 1911 (DHMZ)*

Table 1 provides an overview of hydrological data collected at the Drava-Varaždin station, which are stored in the national HIS 2000 database. Furthermore, **Figure 15** presents a graphical depiction of maximum, average, and minimum annual water levels from 1961 to 2020, along with trend lines (Kos 2023).

At the Varaždin hydrological station, a negative trend is observed in maximum annual water levels, while minimum and average water levels show a positive tendency. This pattern can be explained by the influence of reservoirs and the operation of hydroelectric power plants in Slovenia, which mitigate peak flows by retaining them in reservoirs. Additionally, it can be noted that after 1982 (yellow line), water levels stabilized due to the construction of the Čakovec reservoir and the formation of a backwater effect. Following the construction of HE Čakovec, flow measurements at the Varaždin station were discontinued. **Figure 16** illustrates the flow rates for the period 1961–1981, where a decline in average annual flow rates can be observed (Kos 2023).

Table 1 *Overview of hydrological data collected at the Drava – Varaždin station (source: https://hidro.dhz.hr/)*

HYDROLOGICAL PARAMETERS	MEASUREMENT PERIOD	EXTREMES	
		Min	Max
Water level, H (cm)	1900-1912, 1920-1944, 1946-2024	9.12.1978. -106 cm	5.9.1965. 424 cm
Flow rate, Q (m³/s)	1957-1981	25.12.1977. 22,13 m³/s	21.8.1966. 2 842 m³/s
Water temperature, T (°C)	1954-1985, 2007-2010, 2012-2024	2.1.1954. 0,0 °C	21.7.1964. 27,0 °C
Suspended sediment concentration, C (g/m³)	1967-1984	6.12.1975. 0,020 g/m³	10.9.1967. 496 g/m³
Sediment transport, P (t/day)	1967-1981	6.12.1975. 0,430 t	26.9.1973. 45 164 t

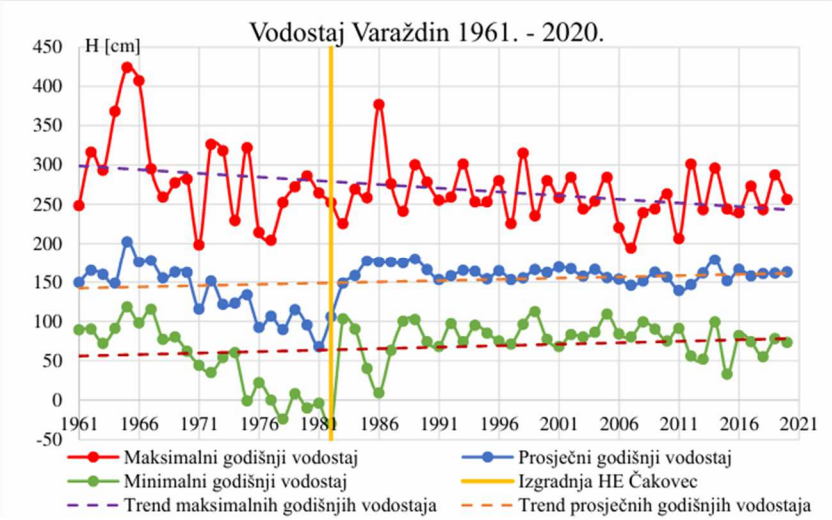


Figure 15 *Maximum, average, and minimum annual water levels at HP Varaždin in the period 1961–2020, with trends (Kos 2023)*

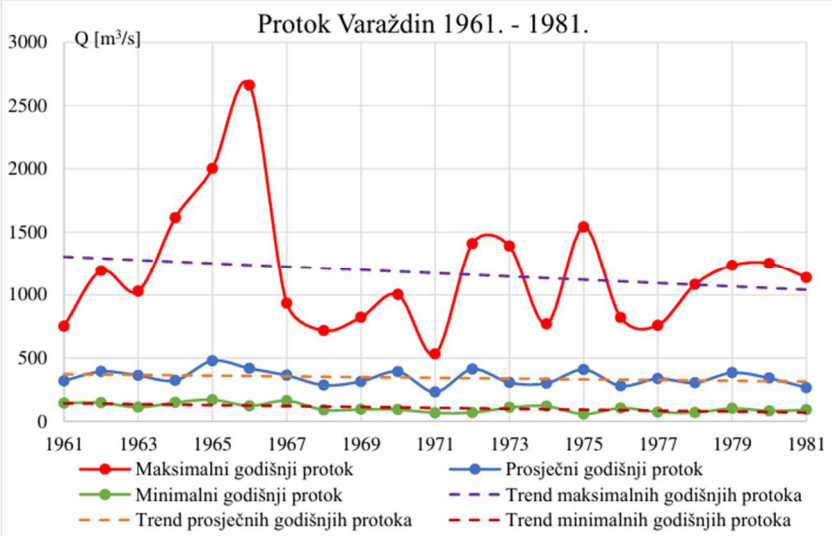


Figure 16 *Maximum, average, and minimum annual flow rates at HP Varaždin in the period 1961–1981, with trends (Kos 2023)*

4. CONCLUSION

This paper provides a brief overview of the history of hydrological monitoring in Varaždin during various governmental administrations that were responsible for it over a period of more than two hundred years. It presents part of the archival documentation related to the Varaždin hydrological station on the Drava River, which is particularly significant as it is the second oldest hydrological station in the Republic of Croatia, established in 1821. The preserved historical series of hydrological data measured at this station is of inestimable value today, as it allows us to assess changes in the hydrological regime of the Drava River, whether due to anthropogenic influences and/or climate change.

The paper also acknowledges key individuals and institutions whose contributions the authors aimed to highlight for current generations of young professionals and scientists, providing them with insight into the importance of hydrological monitoring and the rich historical heritage of the city of Varaždin.

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Petrić, H. (2005): Prilozi poznavanju prometnog značenja rijeke Drave u Gornjoj hrvatskoj Podravini od kasnog srednjeg vijeka do 19. stoljeća, Varaždin: Hrvatska akademija znanosti i umjetnosti (HAZU), 2005. str. 133-137