The Maintenance of Agricultural Drainage Systems in the Conditions of Climate Change - The Jelas Polje Case Study

Siniša Maričić(✉) and Tatjana Mijušković-Svetinović

Faculty of Civil Engineering and Architecture Osijek, University Josip Juraj Strossmayer of Osijek, Vladimira Preloga 3, 31 000 Osijek, Croatia
{smaricic,tatjanam}@gfos.hr

Abstract. The paper presents the surface drainage of a part of Jelas polje, a field that is situated in the Croatian part of the Sava River valley. It is a complex hydrotechnical system with two safeguarding segments: the subsystem of reception and evacuation of runoff from hills, and the subsystem of flood risk management of the Sava River. The agricultural production in this part of the Jelas polje is mainly oriented towards field crops, which are most endangered by excess water during spring. According to farmers, in this century they are faced with problems they have not experienced before, situations where soil hold the water for an extended period of time and there is no adequate drainage. Direct consequence of such a situation is the decline of agricultural yields. All these problems farmers attribute to "bad and insufficient" maintenance of the channel network, which is under the jurisdiction of Hrvatske vode, legal entity for water management. The deeper hydrological and hydraulic analysis indicates extreme weather events and climate change, as well as the need for better adaptation to such a change. This paper analyzes the rainfall in the first vegetation months, April and May, during the long period from 1963 to 2020. In addition, these rainfalls are analyzed in correlation with the extreme water levels of the Sava River, when sluice gates are closed and drainage was provided by pumping stations. The performed analysis shows that in the last twenty years the amount of spring precipitations has significantly increased, as well as the danger of high Sava River water levels. Unlike in previous forty years, in this period there have been several coincidences of the threat from external and internal waters, which have adversely affected agricultural production for a long time. It all points out to a need for all stakeholders to join in, and with coordinated efforts find a better way to adapt maintenance of agricultural drainage system to the new climate conditions.

Keywords: Drainage · Rainfalls · Water levels · Climate change · Jelas polje

1 Introduction

The lowland area of Croatia has natural conditions for agricultural production and thus a long tradition of its development. For centuries, forested areas have been cleared, wetlands have been drained and plots have been adapted for agricultural work. Such processes also led to the establishment of water management services. By pooling resources

H. Glavaš et al. (Eds.): OTO 2021, LNNS 369, pp. 228–239, 2022.
https://doi.org/10.1007/978-3-030-92851-3_17

and organizing comprehensive works, better conditions for agriculture were created. Thus, since the middle of the last century, extensive work has been done in the Croatian Posavina on the development and management of the agricultural land drainage [1]. These are still the bases of local agriculture today. This paper describes the experience related to a part of the agricultural areas of Jelas polje, near to the settlement of Radovanje, not far from the town of Slavonski Brod. Local farmers suffered major damage in the spring of 2014 and saw the causes of that in poor maintenance of drainage channel networks. It all resulted in an expensive law-suit, thus attracting attention and encouraging writing articles about this subject. In the following chapters, first the existing field drainage system is presented, then the questionable elements of its maintenance are pointed out, followed by a hydrological and hydraulic analyses (of the condition when the problem occurred, but also of similar situations during the past sixty years).

2 Description of the Area and the Field Drainage System

Jelas polje is a left-bank part of the alluvial lowland of the Sava River in the Republic of Croatia, somewhere between its 360th and 400th kilometer. On the north side, Jelas polje is at the foot of Dilj gora (hillish area), and intersected by the international railway and motorway (A3), in parallel with the Sava River. The significant part of the area is used for fish farming. Figures 1 and 2 indicate the location of the respective agricultural land on the edge of the lowland, between traffic corridors (road embankments).

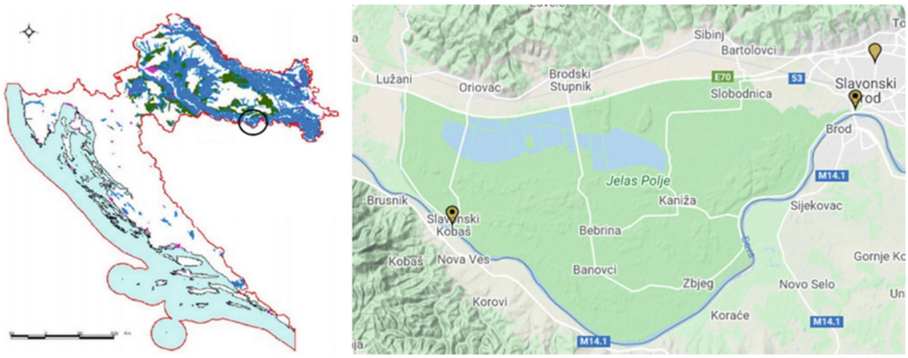

Fig. 1. Areas in the Republic of Croatia with a need for drainage of excess water [2] and the location of the Krčevina agricultural land, part of Jelas polje.

Construction and agricultural production are supported by two safeguarding subsystems. One of the subsystems consists of lateral channels and is a recipient of external surface waters originating from the southern slopes of Dilj gora. The eastern and western lateral channels of the Jelas polje, however, are directing torrential waters into the Sava riverbed, thus protecting the lowland area. The larger, western lateral channel is over 20 km long. Its course is from the mouth of the Sava River in the eastern part of Slavonski Brod to the north, and then from the mouth of the largest tributary of Sava, Glogovica River, turns to the west. The eastern lateral channel of Jelas polje is less than 5 km long, but collects all the streams between the settlement of Radovanja and the Orljava River. There are also some torrent streams (from the slopes of the Maglovac hill) beyond the scope of drainage channels, which drain a part of the settlement Radovanje and flow downstream through culverts under the railway. The second subsystem is the Sava River flood risk management system, encompassing embankments (around 80 km long) and hydrotechnical nodes (i.e. an assembly of a channel sluice gate and a pumping station). Flood risk management of the Jelas polje uses both a gravity and a pressure system, defending approximately 20000 ha large area. The system with four hydraulic nodes (with sluice gates and pumps) was built (between 1938 and 1990) for draining the defended area, at times when the Sava River water levels were high. Altogether, 14 pumps were installed, with total capacity of 32.4 m^3/s [3, 4].

The field drainage system consists of a network of detailed (land lot channels for immediate collection of waters from agricultural surfaces) and basic or main channels. For surface drainage of the area in question (agricultural area Krčevina) there are four long detailed channels (Fig. 2 and 3). On the right side, they transport water to the collecting receiver (the Topolovac River torrential stream), to which much shorter, detailed channels of the adjacent drainage area are connected, as well. The natural stream is regulated (channeled) and capacitated to receive and conduct catchment waters to a larger receiver, the Mrsunja River.

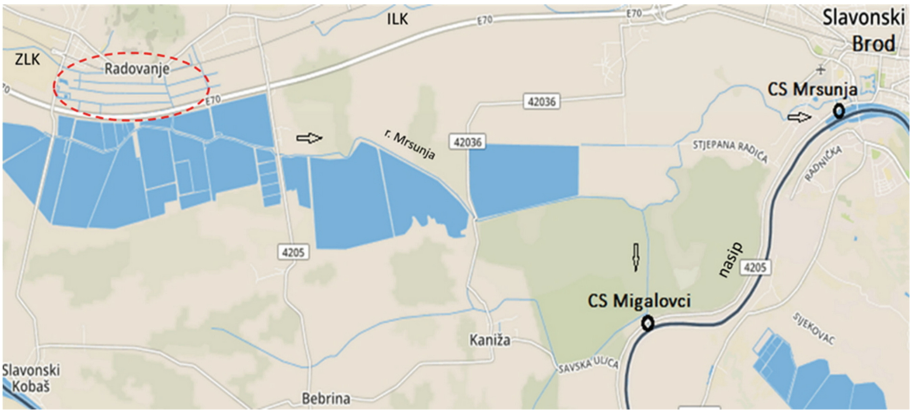

Fig. 2. The location of the Krčevina agricultural land (next to the settlement of Radovanje) in Jelas polje, with corresponding elements of the drainage system – lateral channels (ILK, ZLK), recipients and pumping stations (CS).

What is important for further drainage of the area in question is the Mrsunja riverbed as it allows the water to reach the nodes of Migalovci and Mrsunja, and from there into the Sava River [5]. The sluice gates of these hydrotechnical nodes must be closed when the water level on the Slavonski Brod (elevation 85.60 m above the sea level) water meter measures 380 cm. As the water level rises, the required number of individual pumps are turned on. There are four pumps ($2 + 4 + 4 + 2$ m^3/s) at CS Migalovci pumping station and as well as at CS Mrsunja pumping station (2 + 2 + 2 + 2 m^3/s). The Water Act and its bylaws (i.e. rules and regulations related to the Sava River flood risk management system) regulate the commissioning and operation of the nodes [6, 7].

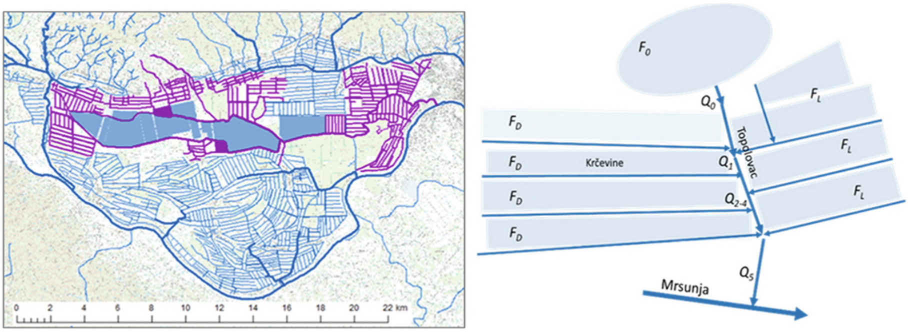

Fig. 3. Hydrographic network of Jelas polje with the part that flows into the Mrsunja River (right) and the calculation scheme of a part of the surface drainage system of the Krčevina land (left).

3 Maintenance of the Field Drainage System

The entire field drainage system needs to be maintained regularly, and this requires a legal, financial and organizational basis, as well as quality manpower and machinery. Stable socio-economic conditions support this, while every disturbance leaves consequences [8]. The economic downturn in the 1980s lead to a neglect of the maintenance of the field drainage systems, and due to the war circumstances during the 1990s, there was a complete halt. As a result, the systems lost their functionality and needed restoration [4, 9]. Then, the processes of privatization and restructuring were taking place, both in agriculture and water management. At the later stage, the Croatian laws were harmonized with the European Union legislation. However, despite all said misfortunate situations, the reconstruction and maintenance of hydrotechnical systems have begun again. For the area in question, and the time of occurrence of the agricultural plot damage (spring 2014) it was stated that a post-war reconstruction of the detailed channel had been carried out; that for a long period there was no silt removal from the riverbed of the first receiver (the Topolovac torrent stream); and that all the channels are regularly (once a year) mowed [5]. Some questions were raised when several road culverts of a small diameter (60 cm) were constructed on detailed channels, to enable simpler mowing. There were also objections that the plant cuttings were not removed from the riverbed, and as it was a swampy vegetation (Fig. 4), it posed a risk of channel congestion at locations with small culverts, in particular.

Referenced literature [8, 10] and the appropriate rulebook [11] indicate the need for mowing at least once a year, in late spring, under vegetative and hydrologically favorable conditions. As swamp vegetation was found in the respective area, it can be concluded that mowing should be even more frequent (2–3 times a year). There is a danger of partial or even complete congestion of culverts with small diameter, which indicates a need for a more frequent control and a more comprehensive cleaning job. The channel with overgrown grass creates an obstacle for water to flow through (for the same discharge value, the water level is higher and the velocity is lower), hence the longer duration of the excess water drainage. Grass overgrowth thus reduces the efficiency of the channel in view of the protection from excess water. In engineering terms, this is interpreted by change of roughness of the riverbed (e.g. by increasing the Manning coefficient) [8, 11]. By checking the runoff for different variants of rain and roughness, one may get an insight into the influence of a particular parameter [5].

Fig. 4. The state of overgrowth with swamp vegetation of one of the detailed channels of the Krčevina field drainage (upstream view), and the Topolovac receiver (view towards the highway downstream) in the spring of 2020.

4 Hydrological and Hydraulic Analysis of Runoff Circumstances

Relevant data needed to be established for these analyses. Rain and water levels data were recorded at the nearby measuring stations. The meteorological station of Slavonski Brod was considered as a representative one, for the climatological features of the entire area of interest. It is located about 20 km east of the observed field drainage system.

The properties of the climate were determined by statistically processing the rainfall data for the period from 1963 to 2018. The area in question is specific for a low annual amount of precipitation (annual sum of precipitation over a multiannual period is 769.8 mm). In addition, it is worth noting that the oscillations of precipitation are considerable in certain years. During 2005, there was significantly more rainfall, 1006.8 mm, than during 2011 when it was merely 433.1 mm. The months with most rain were July and August, while large deviations from average rainfall were measured for all other months. In 2014, the above average rainfall was recorded during five months, among which April, May and August were the rainiest ones (Fig. 5).

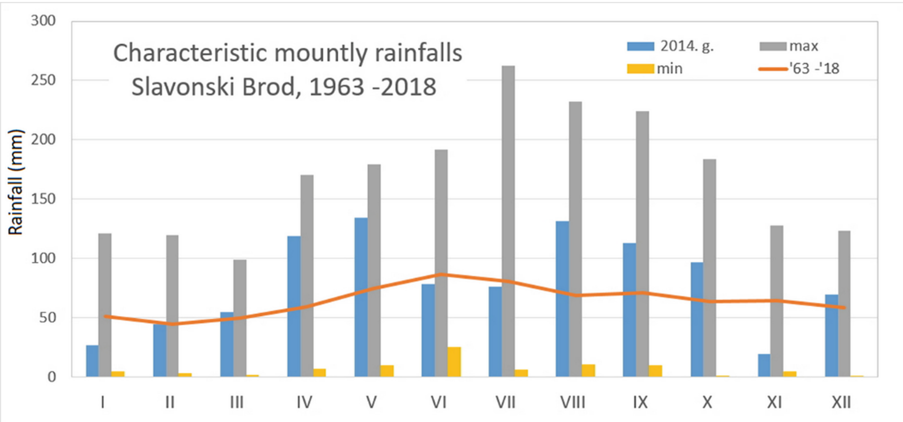

Fig. 5. Characteristic monthly rainfalls for a period of 56 years [12], for the meteorological station Slavonski Brod.

Figure 6 shows the results of the statistical analysis of daily (24-h) precipitation for the period from 1991 to 2010, in the area around Slavonski Brod. The highest rainfall occurred in the period from May to October, and the 24-h rainfall extreme was recorded at the level of more than 70 mm.

Humidity data for April and May 2014, and a multiannual average (1961–1990) for the surrounding area of Slavonski Brod indicate an extremely rainy April and a very rainy May. It was concluded that those were the months in which there was 200% and 183% more precipitation than average. The return period of such monthly precipitation was 100 years in April, and 10 years for May [13].

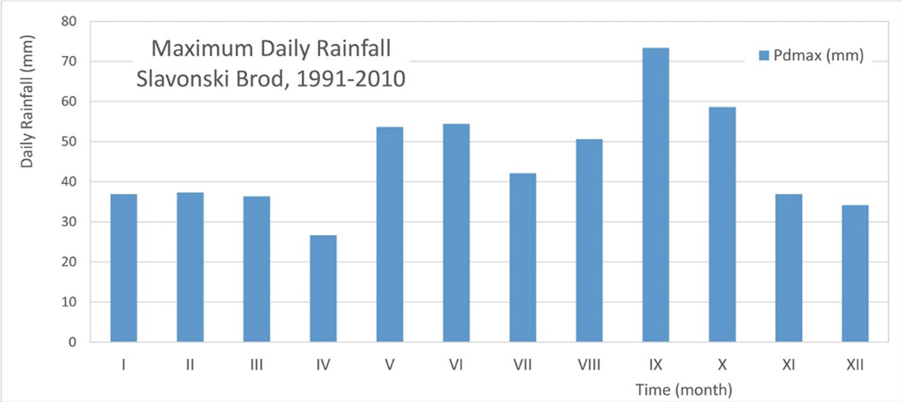

Fig. 6. Maximal daily rainfalls for a 20-year period [3], for the meteorological station Slavonski Brod.

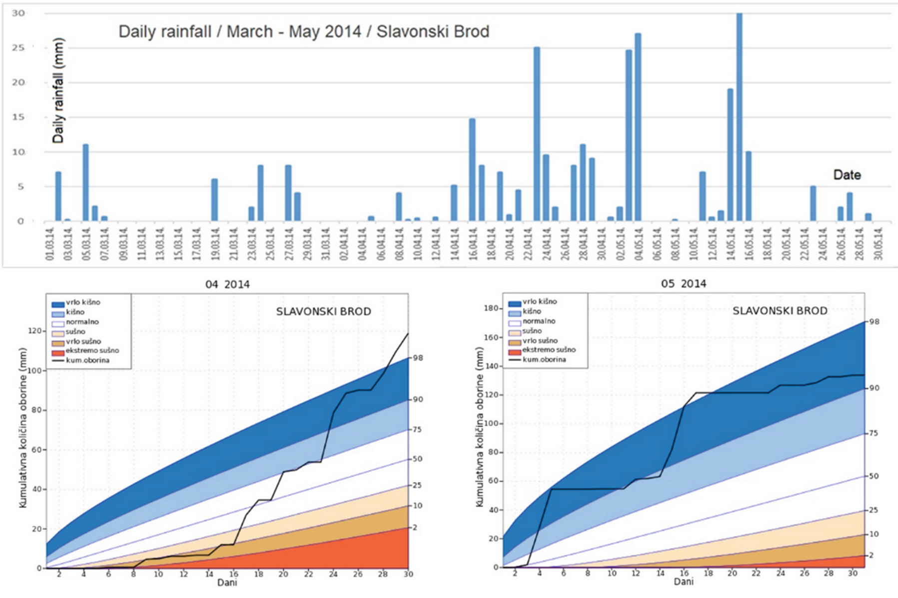

Fig. 7. The distribution of daily rainfall and an analytical presentation of the cumulative amounts of rain [14], for spring 2014 in the Slavonski Brod area.

Figure 7 shows that rain has soaked the soil for 10 days during March, and it intensified during the following two months. In the period from April 16 to May 16, there was 221.6 mm more rain per square meter, which falls into the category of the months with most rain ever (30 days), during the observed period from 1963–2018 (VII-262.2 mm/m^2; VIII-232 mm/m^2; IX-224 mm/m^2).

From the analytical statement (DHMZ [14]) of the cumulative amounts of precipitation during April and May 2014, with marked probability zones according to the multiannual average (1961–2000), it is noticeable that on three occasions during multiple days there was a state of great return period (25–100 years), i.e. greater than the 96th percentile.

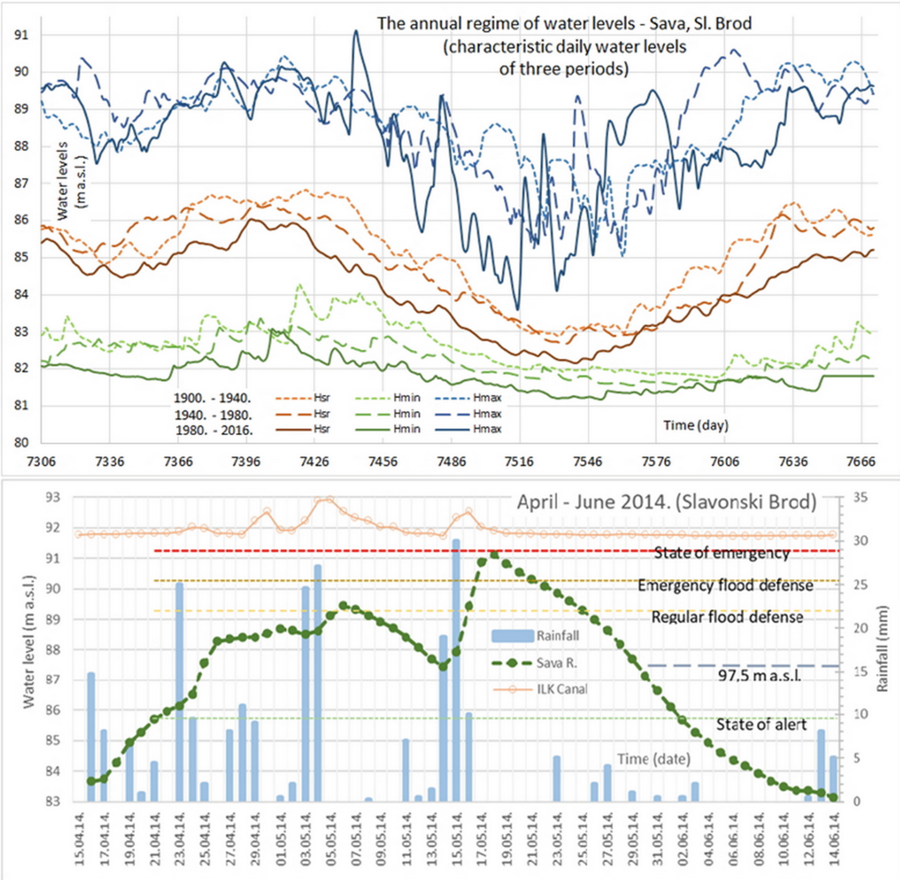

Fig. 8. Annual course of the Sava River water level [15], and the water wave in the spring 2014 at the gauging station Slavonski Brod, with marked reference (flood risk) water levels.

Along Jelas polje there are two gauging stations on the Sava River (Fig. 1), and they are located in Slavonski Brod (360.0 r.km) and Slavonski Kobaš (390.5 r.km). From the analysis of the annual characteristic water levels at the Slavonski Brod gauging station (Fig. 8, above [15]), it is evident that the highest water levels occur most often around April, and they can go up to over 90 m above sea level (or, even somewhat over 91 m above sea level). Water levels at this station are appropriate for managing a complex hydrotechnical system. The water level at which sluice gates close is at 85.69 m above sea level, while at the water level of 89.3 m above sea level a state of regular flood risk management is declared. In addition, by analyzing the cartographic data, a terrain altitude of 87.5 m a. s. l. was determined as a feature of low terrain in the agricultural area of Krčevina near Radovanje. The ratio of these elevations and the fluctuation of the Sava water level near Slavonski Brod in the spring of 2014 is presented in Fig. 8. It is obvious that at that time the problems of high water levels occurred simultaneously with the problems of heavy rainfall and that the possibility of draining the excess water with the existing system was significantly reduced.

The suitable runoff modelling for daily rainfall of 40 mm and 70 mm in conditions without the backwater of the Sava River, as well as with the backwater present, shows the inevitability of the occurrence of damage to crops in the weather conditions of spring 2014 in the area of the Krčevina. The question arose as to how often such conditions occurred, so further analyses were carried out.

5 The Coincidence of Spring Hydrological Extremes in Slavonski Brod

Prior to the analysis, it is necessary to emphasize that the spring conditions (April and May) have a strong influence on the development of field crops. Excess soil moisture can completely ruin yields in a span of 14 days, while in other stages of plant development it takes a few more days than that. That is why this period was further observed.

Firstly, a review of bimonthly spring precipitation (April + May) was made with the available data (monthly precipitation for the period 1963–2020). The data is shown in Table 1 and brings us to the conclusion that the "extreme" values (over 200 mm) appeared only eight times in almost 60 years, in 1975, 1980, 1989, 2004, 2010, 2014, 2017 and 2019.

Secondly, a review (Fig. 9) of the isolated water levels near Slavonski Brod was made (for the 90-day period around April/May) for the same period (1963–2020). With this process then a similar number of problematic water levels was noted: 1970, 1981, (1986), 2004, 2013, 2014, 2016, and again approximately in 2019. The coincidence of simultaneous high water levels of the recipient (Sava), and large amounts of rain occurred only three times, in 2004, 2014, and 2019, indicating a relatively rare occurrence. Nevertheless, during the last 40 years of the 20th century, there were 3 springs with abundant rain, and 2 or 3 occurrences the water levels were threatening, without occurring simultaneously. On the other hand, during the 20 years of this century there were already five conditions with heavy rainfall and high water levels, with unfortunate overlap during three of those situations. This, most likely, indicates climate change.

Table 1. Bimonthly (April, May) rainfall (mm) and its extremes (>200 mm) for Slavonski Brod during the period 1963–2020.

Bimonthly rainfall, Weather station Slavonski Brod					
Year	Mo. IV + V	Year	Mo. IV + V	Year	Mo. IV + V
1963	72.6	1982	99.2	2001	103.1
1964	171.2	1983	95.1	2002	134.0

(*continued*)

Table 1. (*continued*)

Bimonthly rainfall, Weather station Slavonski Brod					
Year	Mo. IV + V	Year	Mo. IV + V	Year	Mo. IV + V
1965	176.9	1984	173.6	2003	85.6
1966	114.2	1985	144.5	**2004**	**244.7**
1967	166.7	1986	108.5	2005	129.9
1968	96.8	1987	145.1	2006	176.1
1969	150.1	1988	75.7	2007	76.3
1970	114.0	**1989**	**251.5**	2008	140.1
1971	80.5	1990	61.5	2009	56.6
1972	121.6	1991	181.6	**2010**	**214.3**
1973	106.0	1992	71.1	2011	61.5
1974	93.9	1993	74.3	2012	173.1
1975	**215.2**	1994	89.9	2013	125.8
1976	131.3	1995	111.8	**2014**	**253.1**
1977	95.6	1996	180.1	2015	171.2
1978	191.5	1997	120.8	2016	107.4
1979	62.1	1998	106.6	**2017**	**246.0**
1980	**240.9**	1999	146.1	2018	122.5
1981	103.5	2000	79.8	**2019**	**235.8**

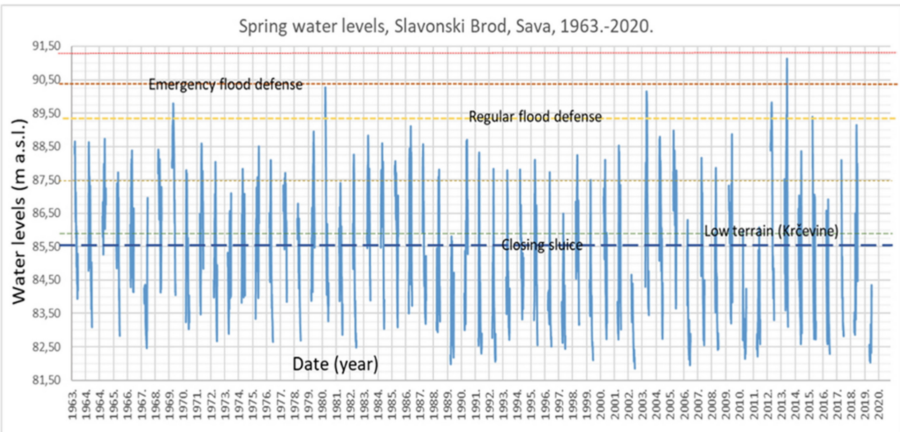

Fig. 9. The spring (15 April–15 June) water levels of Sava River (gauging station Slavonski Brod) in the period from 1963 to 2020 under boundary condition - closing sluice gates, low terrain of Krčevina and a flood risk management phase.

6 Conclusion

In the spring of 2014, Jelas polje was affected by large amounts of rain and high water levels of the Sava River. From the conducted analyses, it is evident that what we have been dealing with is above-average and long-lasting phenomena that have led to severe damage to agricultural crops. Hence, this was a natural disaster, which was then officially declared. The majority of the population is not familiar with the characteristics of the hydrotechnical system which improves the water-air regime of the soil and protects the local economy. Faced with a natural disaster, people also form wrong opinions about its causes. Many human dilemmas require expert clarification which encouraged the creation of this research paper.

Analyses have shown that two unfavorable effects on the water-air regime of the soil were a rare occurrence. Under such conditions, the efficiency of the existing drainage system is significantly lowered. Sluice gates need to be closed, and drainage has to be done with pumps. Pumping stations have a limited capacity, so the runoff is difficult and takes place with deceleration (higher water levels in the channel network). Then even the well-maintained (mowed) channels do not help the cause. However, a properly (according to the valid Rulebook) arranged network of channels preforms drainage much faster and shortens the time of wetting the soil in the rhizosphere (plant root zone). It is important that all elements of the hydrotehnical system are functional and in good condition (sluice gates, pumps, channels, culverts, …), and this is achieved with specified, regular and quality maintenance. In the shown example, remarks were made on the quality of maintenance, which should be considered, as well as it should be worked on respective improvements. It is also possible to control the system in a more complex way according to the weather and hydrological forecasts, which certainly needs to be comprehensively examined.

By performing additional analyses, a conclusion was drawn regarding the possible climate change. In comparison to the first two thirds of almost a sixty-year period to date, for its last third, it was observed that there was a significant increase in the occurrence of extreme rainfall events, and high Sava water levels, as well as the simultaneous occurrences of these two phenomena. Here is where we find the answer for the statements and the amazement of the population about how “We’ve never seen this before in our lives”. Nevertheless, this also requires finding adequate approaches to agriculture under these new circumstances. In that sense, we recognize a need for all social actors to find a way to team up in an excelling way and contribute to adapting to these new agricultural circumstances through joint and coordinated efforts.

References

1. Piha, D.: WMBO for little basin “Brodska Posavina”. J. HRVATSKA VODOPRIVREDA **213**(13), 24–33 (2015). (in Croatian)
2. Husnjak, S.: Croatian agricultural lands and the need for land reclamation measures. In: Reclamation Measures for the Improving Rural Areas, The Croatian Academy of Sciences and Arts (HAZU), pp. 21–37, Zagreb (2007). (in Croatian)
3. Tadić, Z.: Brod - Posavina County Irrigation Plan. Hidroing d.o.o. Osijek, Brod - Posavina County and Croatian Water, Osijek (2007). (in Croatian)

4. Budišić, D.: Condition of reclamation systems in the Sava River basin district. Croatian Water **45**(11), 465–477 (2003). (in Croatian)
5. Maričić, S.: Protection against excess water (part of Jelas Polje). In: Raos, P., et al. (eds.) 19th Natural Gas, Heat and Water Conference, 12th International Natural Gas, Heat and Water Conference, pp. 98–107. University of Slavonski Brod, Mechanical Engineering Faculty, Osijek (2021). (in Croatian)
6. Water Law (Official Gazette 53/2009, 63/2011, 130/2011, 56/2013 and 14/2014)
7. The Flood Defense Implementation Plan for defended areas, Sector D, the middle and lower part of Sava River. Croatian Water, Zagreb (2014). https://www.voda.hr/sites/default/files/clanak/bp_10_-_provedbeni_plan_obrane_od_poplava.pdf. Accessed 21 Aug 2021
8. Kos, Z.: Needs, principles and methods of maintenance of drainage hydromelioration systems. Manual for hydrotechnical reclamation, I. volume Drainage; Book 6. Maintenance, Croatian Society for Drainage and Irrigation, Zagreb, pp. 1–25 (1991). (in Croatian)
9. Šoštarić, J., Romić, D., Marušić, J., Josipović, M., Petošić, D.: The condition of melioration systems for drainage and irrigation in the Republic of Croatia. In: Pospišil, M., Vnučec, I. (ur.) 51st Croatian and 11th International Symposium on Agriculture, pp. 10–17. University of Zagreb, Faculty of Agriculture, Zagreb (2016). (in Croatian)
10. Lambert, K., Smedema, L.K., Vlotman, W.F., Rycroft, D.: Modern Land Drainage - Planning, Design and Management of Agricultural Drainage Systems, 2nd edn., pp. 420–425. CRC Press, London (2004)
11. Regulation on technical, economic and other conditions for the development of melioration drainage systems and bases for technical and economic maintenance of the systems (Official Gazette 4/98)
12. Croatian Meteorological and Hydrological Service, Whether Information for Slavonski Brod (1963–2000). https://meteo.hr/klima.php?section=klima_podaci&param=k1&Grad=slavonski_brod. Accessed 29 July 2021
13. Croatian Meteorological and Hydrological Service, Whether information for Slavonski Brod for April and May in 2014. https://meteo.hr/klima.php?section=klima_pracenje&param=klel&Grad=slavonski_brod&Mjesec=04&Godina=2014. Accessed 29 July 2021
14. Croatian Meteorological and Hydrological Service, Whether information for Slavonski Brod for April and May in 2014. https://meteo.hr/klima.php?section=klima_pracenje&param=spi&el=koa&Grad=SlavonskiBrod&Mjesec=05&Godina=2014. Accessed 29 July 2021
15. Maričić, S., Mijušković-Svetinović, T.: Water levels of the major rivers in Slavonia. In: Pelivanovski, P., Jovanovski, M., Petkovski, Lj., Donevska, K. (eds.) 16th International Symposium on Water Management and Hydraulic Engineering WMHE 2019, pp. 181–193. Ss Cyril and Methodius University, Civil Engineering Faculty - Skopje, Skopje (2019)