ICPDR IKSD

International Commission for the Protection of the Danube River

Internationale Kommission zum Schutz der Donau

Floods in Summer 2023 in the Danube River Basin

Brief Overview of Key Events and Lessons Learned

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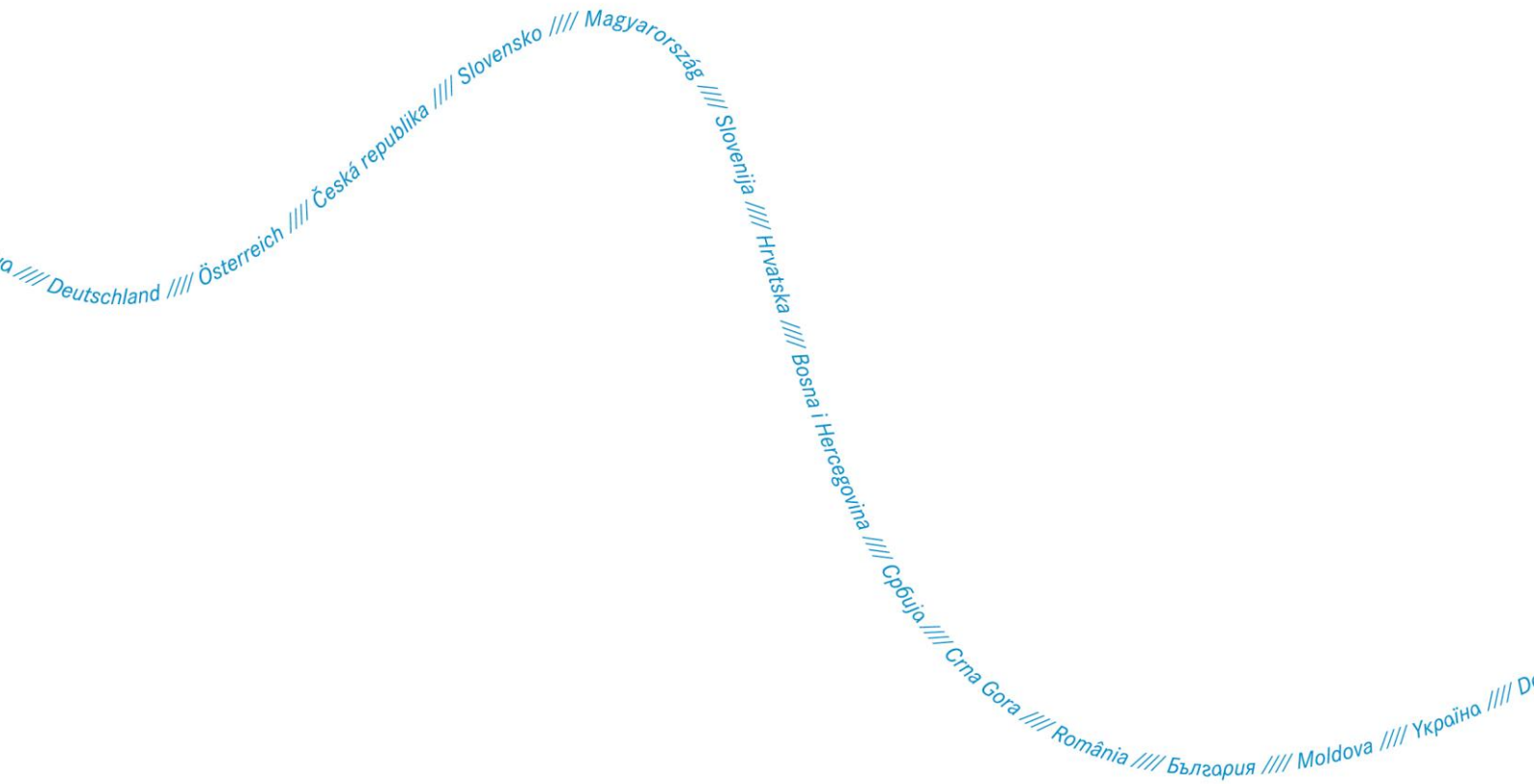

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List of Abbreviations

ARSO	Slovenian Environmental Agency
CEST	Central European Summer Time
CORS	Emergency Reporting Center of the Republic of Slovenia
DHMZ	Croatian Meteorological and Hydrological Service
DRSV	Slovenian Water Agency
EFAS	European Flood Awareness System
FRMP	Flood Risk Management Plan
ICPDR	International Commission for the Protection of the Danube River
PDNA	Post-Disaster Needs Assessment
UTC	Coordinated Universal Time
VAT	Value added tax

1. Meteorological situation/precipitation

An area of low pressure over northern Italy (Genoa low – Vb weather pattern) conveyed humid air from the south. When such an area of low pressure forms over the Gulf of Genoa, it can also move to the north and north-east, causing intense precipitation in the central and eastern parts of Central Europe. The mechanism behind this is the meeting of warm, humid air from the Mediterranean region with colder air north of the Alps, which leads to an upward movement and often long-lasting intense precipitation.

The heavy rainfall occurred across Slovenia from 3rd to 6th August 2023. According to a report from the Slovenian Environmental Agency (ARSO), the typical amount of precipitation for the whole of August fell in just a few hours at some stations. Smaller rainfalls began to appear on the Alpine-Dinaric ridge during the night of 2nd to 3rd August and on the morning of 3rd August, but only a few millimeters of rain fell in some areas. The main rainfall occurred in the evening and through the night to 4th August, when heavy showers from western Slovenia towards Carinthia and northern Styria (in Austria) brought a significant amount of rain. There were severe storms in large parts of Austria from 3rd to 7th August. In some regions, rainfall sums exceeded the monthly average values for August (

Figure 1). Carinthia, southern Styria and southern Burgenland were particularly affected, but there was also heavy rainfall in the Salzkammergut and Vorarlberg.

By 8 AM on 4th August, over 200 mm of rainfall had been measured at certain gauging stations within 24 hours, and almost everywhere from Upper Soča Valley and the Idrija region towards the east-northeast, including the Drava Valley, over 100 mm of rainfall (Figure 1). In most part of Styria and Prekmurje region, the rainfall was smaller, with less than 30 mm in areas near the Croatian border. Very little or no rain was observed from Slovenian Istria and Karst through most of the southern half of Slovenia. Heavier rainfall affected this region during the day on 4th August, and by the morning of 5th August, the heaviest rainfall, up to around 100 mm, was recorded in the southwestern part of Slovenia (Figure 2). Towards the north and east of Slovenia, the rainfall was less but still considerable, ranging from 30 to 80 mm. Rainfall began to subside on 5th August (
Figure 3), but thunderstorms in the western and southern parts of Slovenia brought additional rain on the afternoon of 6th August. In total, within 72 hours, by the morning of 6th August, between 100 and 300 mm of rain fell over most part of Slovenia, with less in parts of Primorska region and along the eastern border with Croatia (Figure 4). High water thresholds were exceeded at 122 gauging stations on 74 rivers in Slovenia[1].

In the night from Thursday 3rd August to Friday 4th August, in Austria precipitation amounts of 50 to over 100 mm fell, especially in the Lower Carinthia and in the Karawanken, as well as in western and eastern Styria to southern Burgenland. GeoSphere Austria even reported precipitation totals of more than 130 mm locally.

1 Nalivi in obilne padavine od 3. do 6. avgusta 2023, ARSO (https://meteo.arso.gov.si/uploads/probase/www/climate/text/sl/weather_events/padavine_3 6avg2023_v29sep2023.pdf)

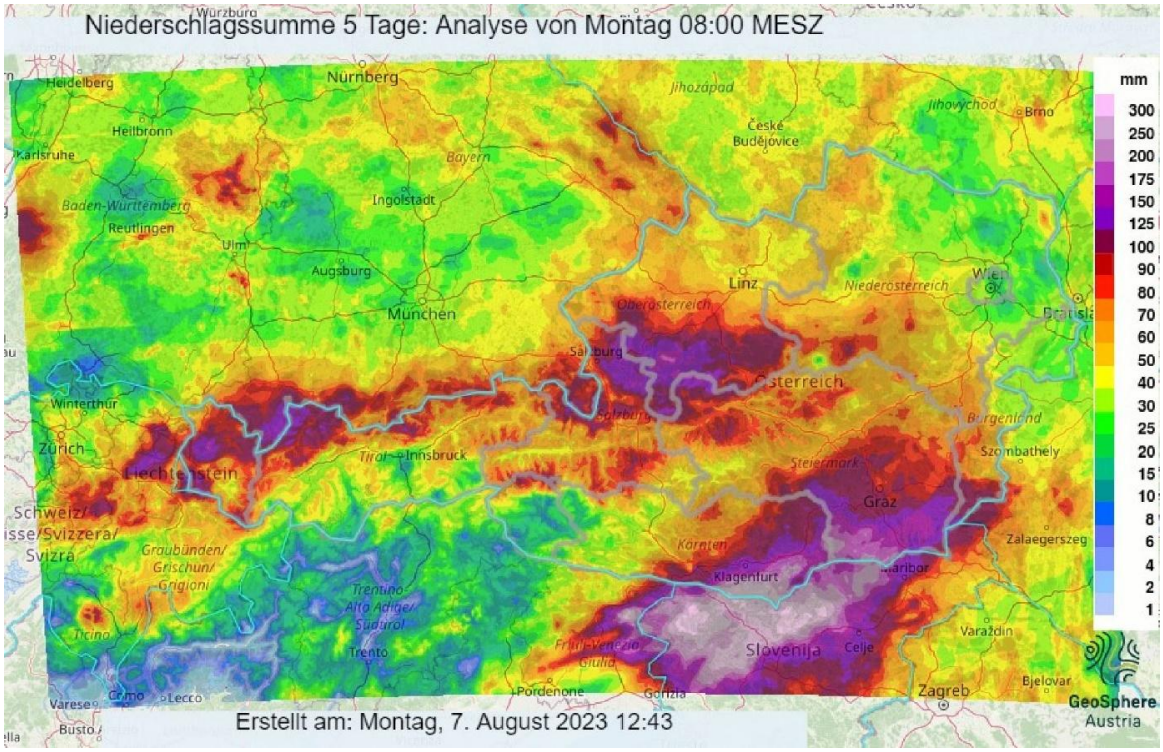


Figure 1: Accumulated precipitation total from Thursday, 3.8.2023 08:00 to Monday, 7.8.2023 08:00. Source: Geosphere Austria.

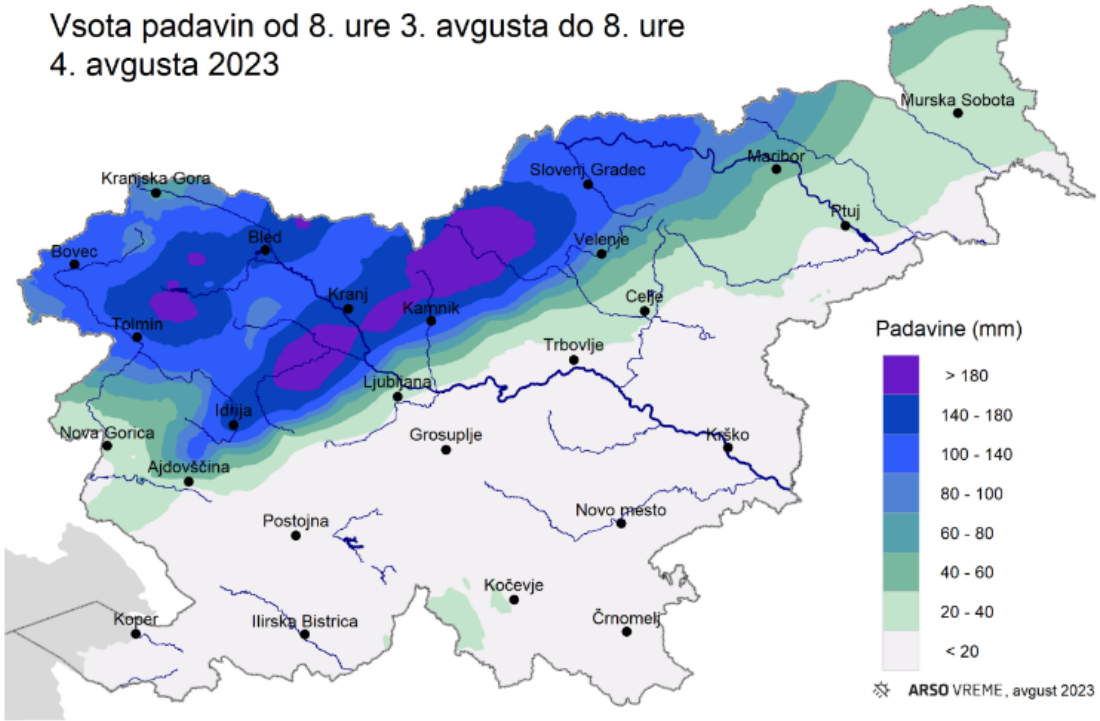


Figure 2: Map of daily (24-hour) precipitation height until 8 AM on 4.8.2023, based on measurements from gauging stations.

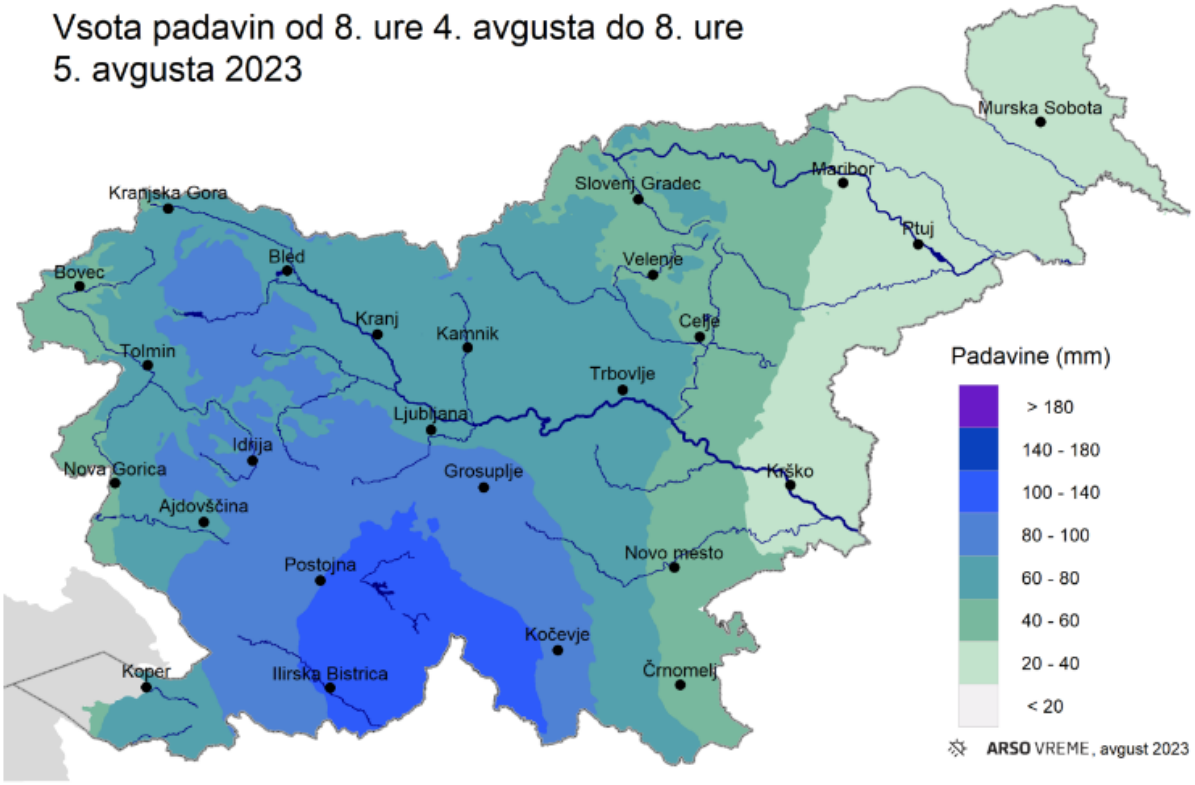


Figure 3: Map of daily (24-hour) precipitation height until 8 AM on 5.08.2023, based on measurements from gauging stations.

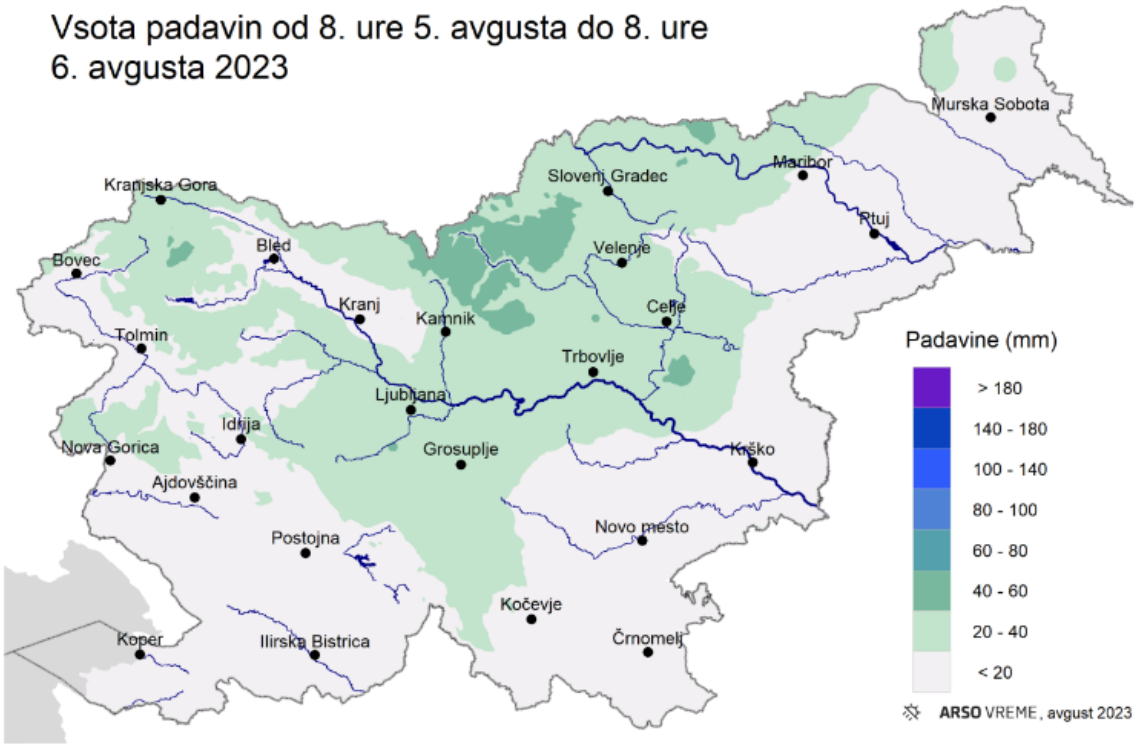


Figure 4: Map of the 24-hour precipitation height until 8 AM on 6 .08.2023 based on gauging station measurements.

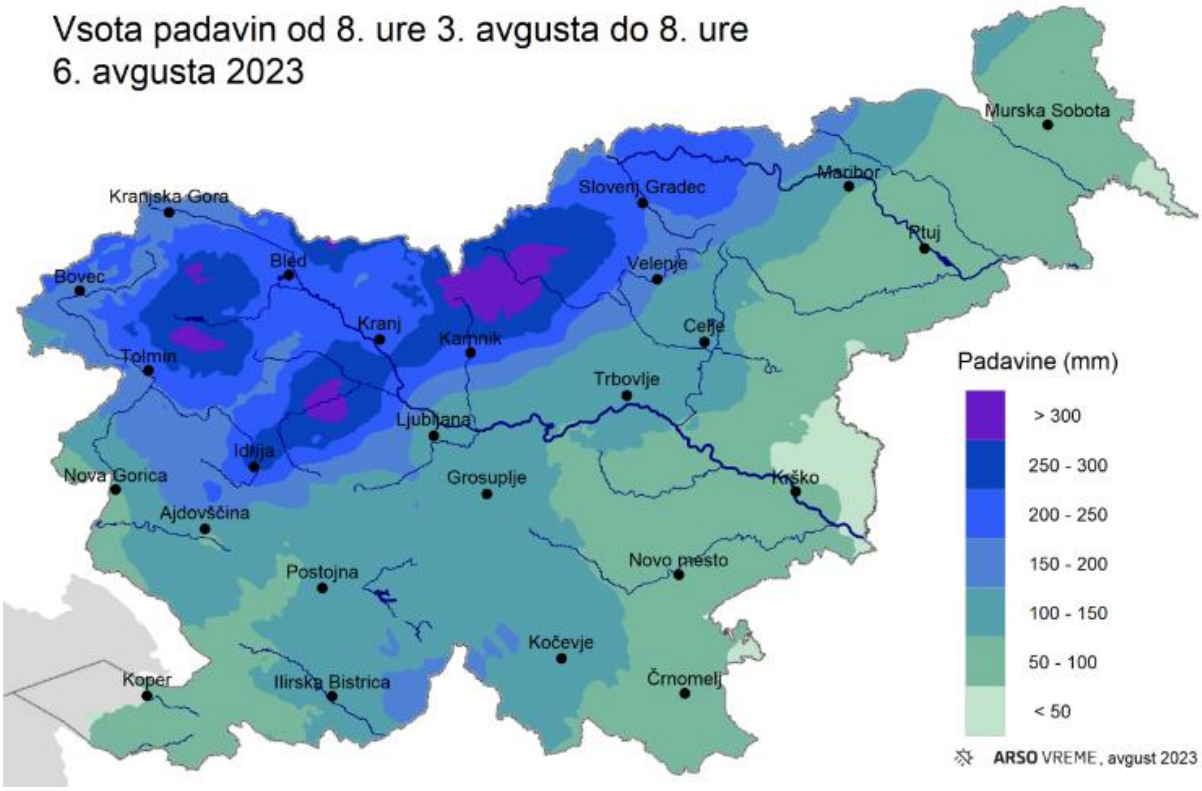


Figure 5: Map of three-day (72-hour) precipitation height from 8 AM on 3 August to 8 AM on 6.08.2023, based on measurements from gauging stations.

In Croatia, significantly lower precipitation quantities were recorded, and as a result, high water situations were limited to Sava, Drava and Mura, i.e. large rivers coming from Slovenia.

2. Key flood events

The first high flows of the rivers began on the evening of Thursday, 3 August 2025. Initially, some smaller rivers in the headwaters of the Meža, Paka, Dravinja, Idrijca, Sava Bohinjka, and Kučnica river basins experienced a temporary sharp increase in flow, leading to the first instances of flooding. During the night into Friday and early Friday morning, numerous torrents, smaller watercourses and rivers in the Meža, Savinja, Kamniška Bistrica, Kokra, Tržiška Bistrica, Sora and Gradaščica basins increase violently to extreme flow levels. Extensive flooding occurred along these river watercourses causing devastating consequences, particularly along Meža, Mislinja, Suhodolnica, Savinja, Lučnica, Dreta, Kamniška Bistrica, Nevljica, Pšata, Sora, Poljanska Sora and their smaller tributaries. In the upstream parts of the Meža and Savinja River basins, the destructive impact continued for more than 24 hours after the flood peak of the flood wave.

On the morning of Friday, 4 August, the Sava River downstream from its confluence with the Sora, the lower course of the Savinja, as well as the Mura and Drava Rivers, experienced a significant rise in water levels. By mid-morning, the Sava had already caused extensive flooding along its riverbed in the area of Ljubljana, later spreading to Zasavje. In the afternoon, the Savinja also caused widespread flooding in the Laško area. The Mura flooded between the embankments, and the Drava flooded especially downstream of the Markovci dam. Both rivers continued to rise, along with the Dravinja and Pesnica. During the afternoon and evening, many rivers that had caused extensive flooding in the morning experienced a temporary rise again. The lower course of the Savinja began to decline, while the Sava downstream from its confluence with the Krka started flooding. The Ljubljanica, Krka, and their karst tributaries also overflowed.

In the morning of Saturday, 5 August, the Sava River had already begun to decline in its middle course, while in the lower course, it continued to flood, reaching a peak flow of nearly 3,400 m^3/s. This caused capture of the Krka River, which, along with its tributaries, continued to rise. In its upper course, the Mura River remained stable at around 1,360 m^3/s, but it was still rising in the lower course. The Drava River downstream of the Markovci dam, as well as the Dravinja, Pesnica, and Ljubljanica River, were also increasing in flow. In the afternoon and evening, the rising trend of the Ljubljanica, the upper course of the Krka and its tributaries, as well as the Dravinja and Pesnica, stabilized. However, in the lower course, the Mura River breached the embankment near Dolnja Bistrica, threatening nearby villages on the left bank.

On Sunday, 6 August, in the morning, the peak of the flood wave was reached by the Mura in the upper course, at around 1460 m^3/s, and the Drava in the lower course, at 1900 m^3/s. In the afternoon, the peak of the flood wave also reached the Krka in the lower reaches, at around 300 m^3/s. The water remained in the flooded areas along the Drava on Tuesday, 8 August, and along the Mura, Krka and Ljubljanica River also on Wednesday, 9 August. The pictures below show the progress of the situation in the areas affected by the floods. Here, high water conditions are shown for each day in four categories (without floods, small spills, floods, large-scale floods), according based on the highest recorded water levels at the corresponding water measuring stations of the individual area.[2]

2 Izjemne poplave v Sloveniji med 4. in 8. avgustom 2023, ARSO (http://hmljn.arso.gov.si/vode/poro%c4%8dila%20in%20publikacije/Porocilo_visoke_vode_in_poplave_avg2023.pdf)

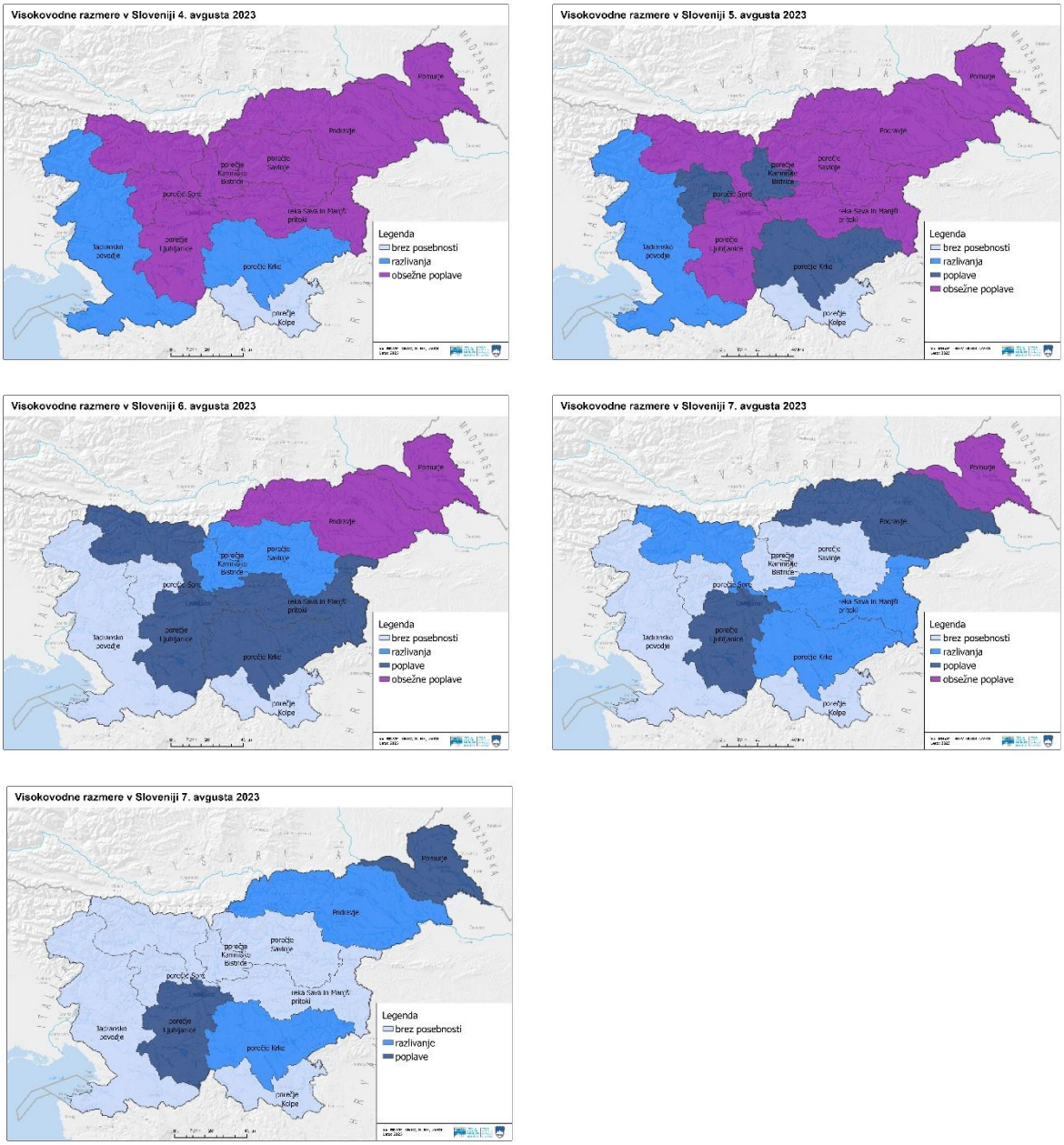


Figure 6: Overview of hydrological events in Slovenia from 04 August to 08 August 2023 (Legend: light blue – regular conditions, blue – spilling, dark blue – flooding and violet - extensive flooding).

Source: SIOL.net

Source: Koroške novice.


Source: Delo.si

Area	The number of water gauging stations where the maximum flow measurement in the measurement history was exceeded	Estimated floods return period [y]	Rivers
Drava Region	6	> 100	Drava, Meža, Suhadolnica, Bistrica, Oplotnica
Savinja River Basin	5	>100	Savinja, Dreta
Kamniška Bistrica River Basin	6	>100	Kamniška Bistrica, Nevljica, Pšata
Sora River Basin	3	>100	Sora, Poljanska Sora
Sava River and smaller tributaries	6	>100	Mostnica, Sava, Kokra
Mura Region	2	50-100	Mura
Ljubljanica River Basin	2	>20	Gradaščica, Šujica
Krka River Basin	0	5-10	Prečna, Grosupeljščica

Table 1: Estimation of the return periods of the measured flow peaks at the water gauging stations in individual areas

The high levels of precipitation at the beginning of August in Austria followed a July that was generally very rainy in the south. The groundwater levels were therefore already at a high level at the beginning of August and the soil was saturated in many places. Floods therefore occurred mainly in Carinthia, southern Styria and southern Burgenland (Figure 7), with rivers overflowing their banks in many places.

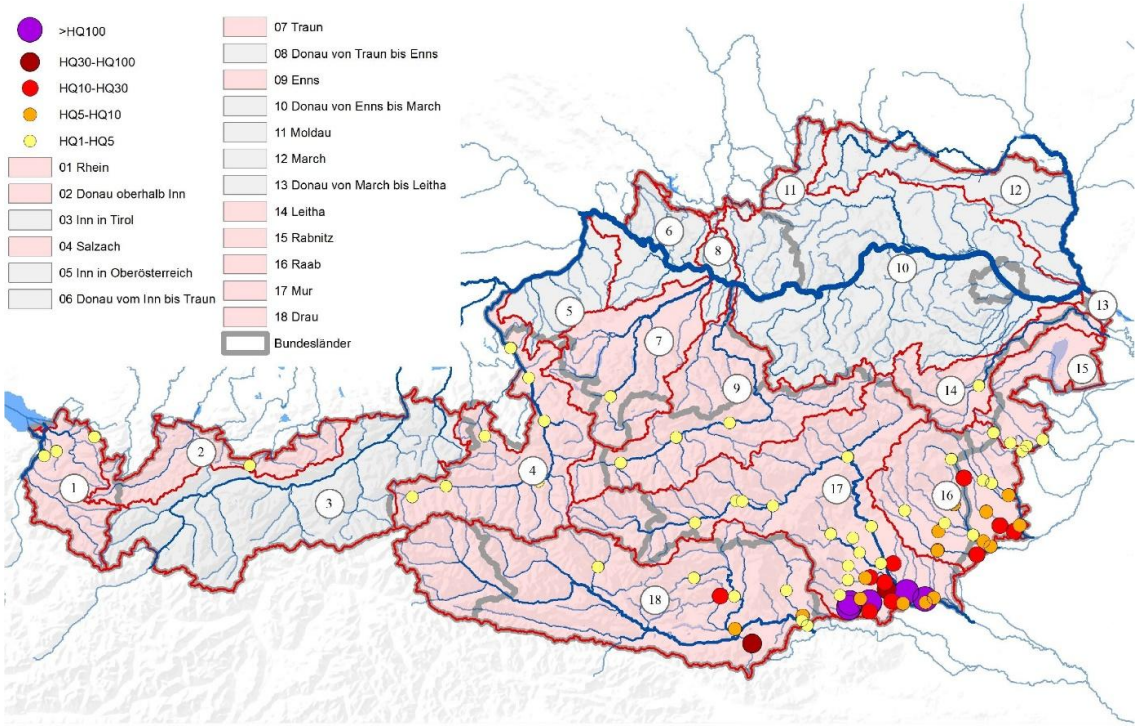


Figure 7: Overview of the recurrence intervals reached at the beginning of August 2023 at selected gauging stations, river basins (red = affected, gray = not affected) and federal states (gray lines). Data basis: Hydrography Austria - BMLUK.

In Carinthia, flood peaks in the range of a 30-year event (HQ30) and above were reached at the Drau tributaries in the lower Drau river basin. The Vellach recorded the highest value at the Miklauzhof gauge with a flow between a 30-year and a 100-year flood, followed by the Glan at the St. Veit gauge with an annuality between 10 and 30 years.

In Styria, the 100-year flood (HQ100) was exceeded at several gauging stations: Gündorf/Saggaubach, Hörmsdorf/Saggaubach, Wies/Weiße Sulm and Lipsch/Schwarzaubach.

In Burgenland, peak discharges of between a 10-year and a 30-year event (HQ10 to HQ30) were recorded on the Strem and Raab rivers. In the other federal states, the highest flows were between a 1-year and a 5-year flood HQ1 to HQ5.

The statistical classifications given are initial estimates. The annuality figures are still subject to uncertainties as, for example, water levels were washed over. More precise information can be provided in the course of ongoing follow-up measurements and evaluations by the Hydrographic Provincial Services.

The impact of the high precipitation on the groundwater was also very clear. At some groundwater measuring points in Carinthia, southern Styria and southern Burgenland, new record highs were even recorded for the month of August. The high groundwater levels are only decreasing very slowly and continue to cause problems, for example in the basements of residential buildings.

Equally problematic are high lake water levels, which are also only declining very slowly, especially in Carinthia at Lake Millstätter See, Lake Ossiacher See, Lake Faaker See, Lake Wörthersee and Lake Klopeiner See.

Credits: Bundeswasserbauverwaltung Steiermark

Maximal flows at the entrance to Croatia were estimated at 3 400 m^3/s for Sava, 2 000 m^3/s for Drava and 1.400 m^3/s for Mura. Consequently, new maximal levels were recorded on several gauging stations.

Record-breaking water levels[3]					
		historical max		Flood of 2023	
RIVER	GAUGING STATION	date	WL (cm)	date	WL (cm)
Mura	Mursko Središće	15.09.2014.	528	07.08.2023.	543
Drava	Botovo	16.09.2014.	577	07.08.2023.	616
	Novo Virje Skela	16.09.2014.	502	08.08.2023.	532
	Vrbovka	19.09.2014.	689	10.08.2023.	704
Sava	Dubrovčak Lijevi	10.11.1948.	865	07.08.2023.	876
	Ustava Prevlaka	15.09.2014.	633	07.08.2023.	705

Sava flood wave, formed upstream of the city of Zagreb, is considered the second largest recorded, since beginning of reliable measurements in 1900. The largest occurred in the October of 1964, causing devastating Zagreb flood.

[3] PRIKAZI br. 35, PRAĆENJE I OCJENA KLIME U 2023. GODINI, Državni hidrometeorološki zavod, Zagreb, prosinac 2024. (https://klima.hr/razno/publikacije/prikazi/prikazi_35_2023.pdf)

3. Flood warning and monitoring

3.1 National systems

The Hydrological Forecasting Service of ARSO continuously monitored the current conditions and forecasts during the state of emergency and provided updates. Between 3rd and 7th August 2023, it issued multiple daily warnings about flooding. Hydrological warnings, consisting of textual information and graphical representations of Slovenian regions colored according to the level of danger and type of event, were issued for the day of publication and the following day. These warnings were published on the ARSO website, social media (Twitter and Facebook), and sent via email to specific recipients.

Through telephone communication, the ARSO forecasting service maintained regular contact with CORS (The Emergency Reporting Center of the Republic of Slovenia), DRSV (Slovenian Water Agency) and their regional units, as well as with the commander and regional headquarters of the Civil Protection of Slovenia.

To inform the wider public, emergency press conferences were organized. On Wednesday, 2nd August, preparations for the first conference began, and it was held on Thursday, 3rd August, at 1:00 PM. Subsequent press conferences took place during the event on 4, 5, and 6 August. These were broadcast live on the first channel of the national television RTV Slovenia.

ARSO representatives also reported on the current situation through other Slovenian television and radio programs.

The following figures provide an overview of the issued high-water forecasts and hydrological warnings from 2 August to 7 August 2023. All listed times of issued forecasts and warnings are given in Central European Summer Time (CEST). [4]

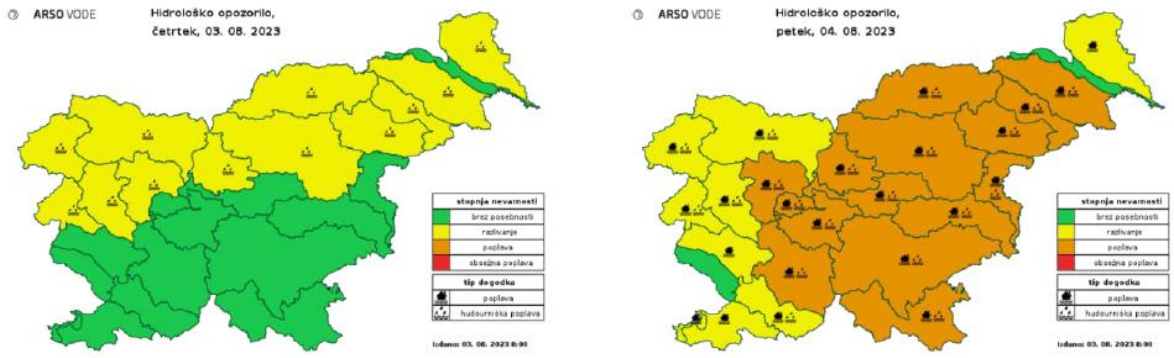


Figure 8: Warning - 03.08.2023 08:00 – Expected large-scale floods

4 Izjemne poplave v Sloveniji med 4. in 8. avgustom 2023, ARSO (http://hmljn.arso.gov.si/vode/poro%c4%8dila%20in%20publikacije/Porocilo_visoke_vode_in_poplave_avg2023.pdf)

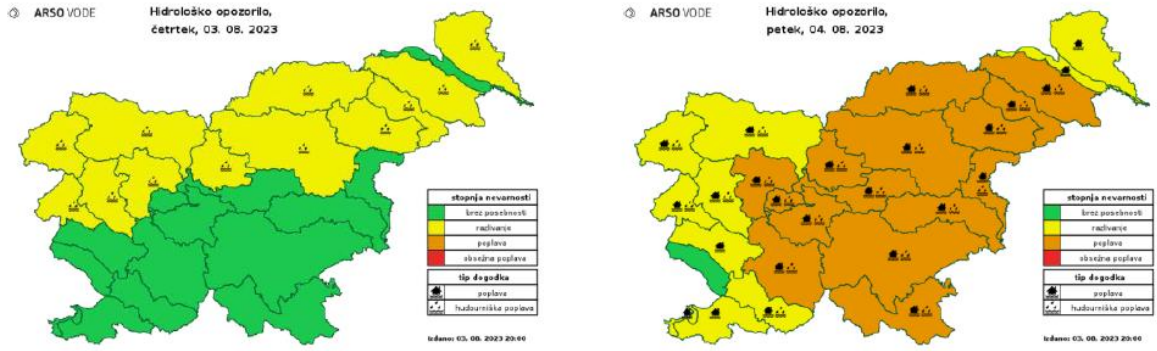


Figure 9: Warning - 03.08.2023 20:00 – Expected large-scale floods

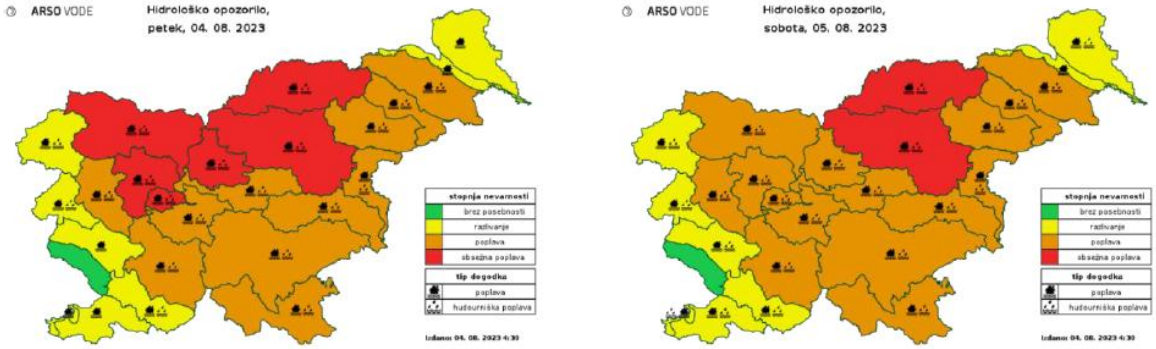


Figure 10: Warning - 03.08.2023 22:10 – Expected large-scale floods

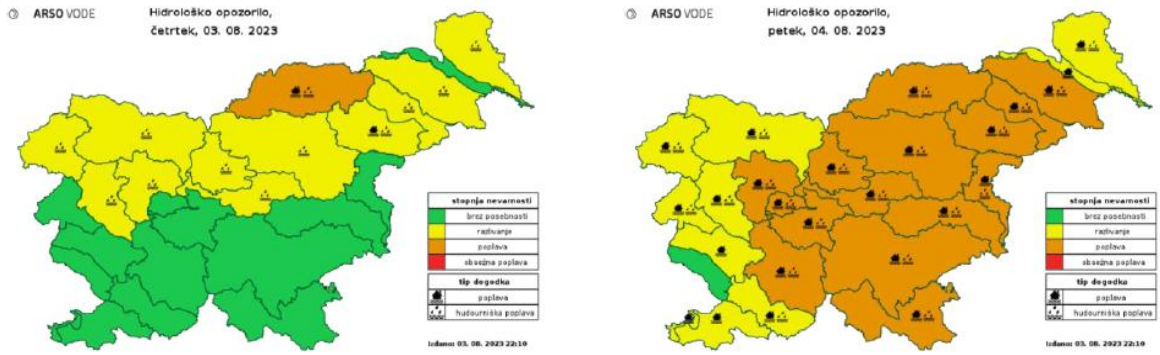


Figure 11: Warning - 04.08.2023 02:30 – Large-scale torrential floods

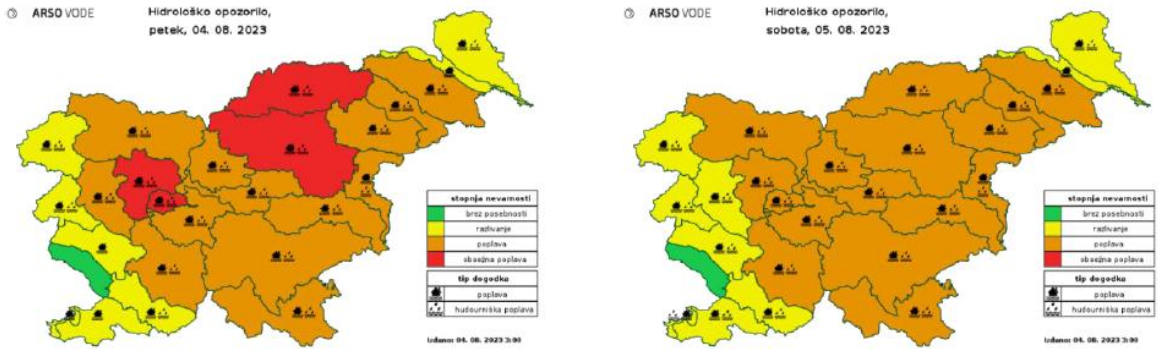


Figure 12: Warning - 04.08.2023 04:30 – Large-scale floods

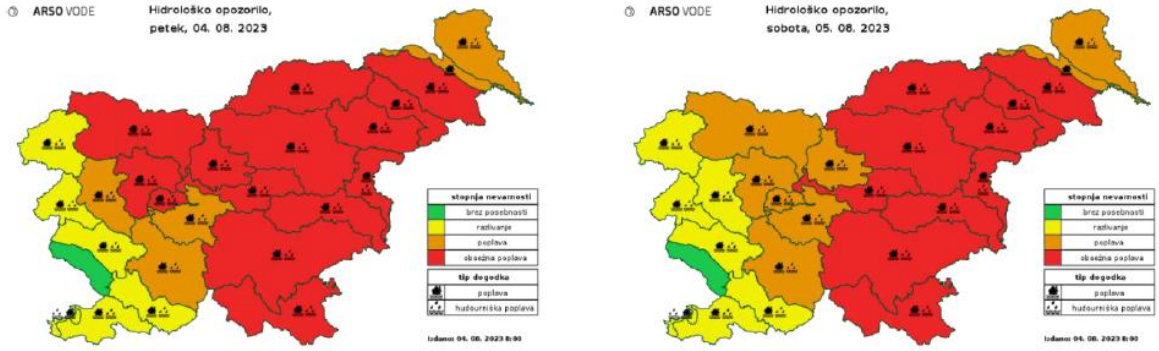


Figure 13: Warning - 04.08.2023 08:00 – Large-scale floods

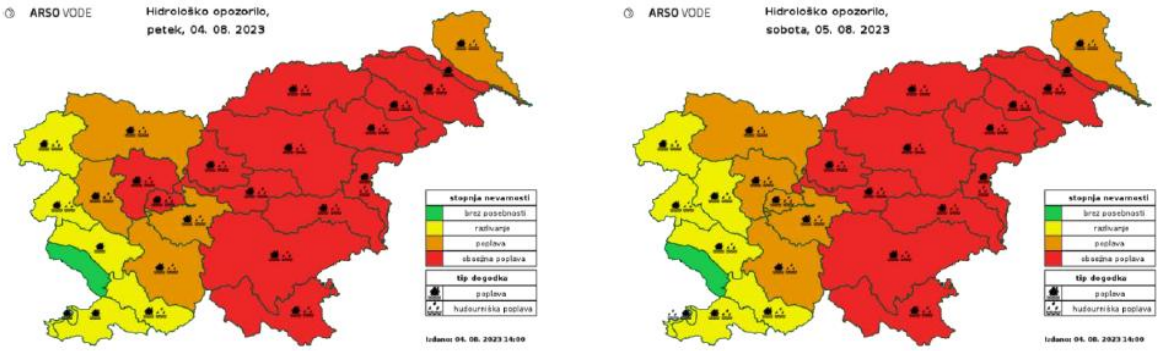


Figure 14: Warning - 04.08.2023 14:00 – Large-scale floods

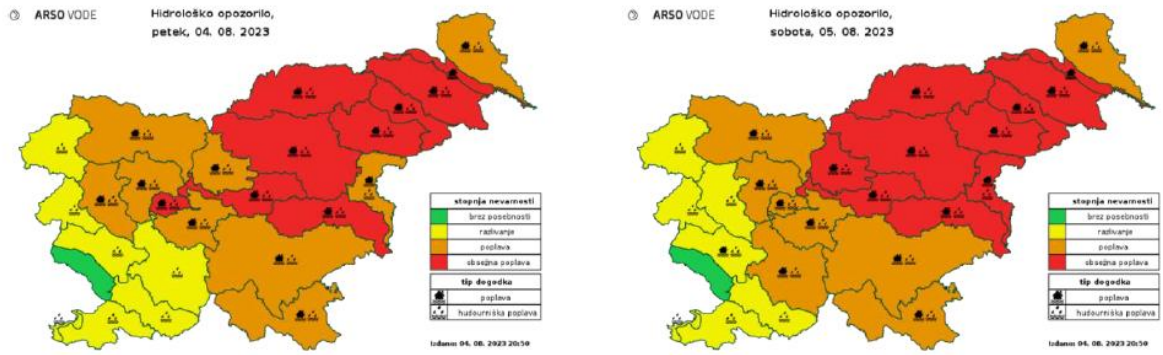


Figure 15: Warning - 04.08.2023 20:50 – Large-scale floods

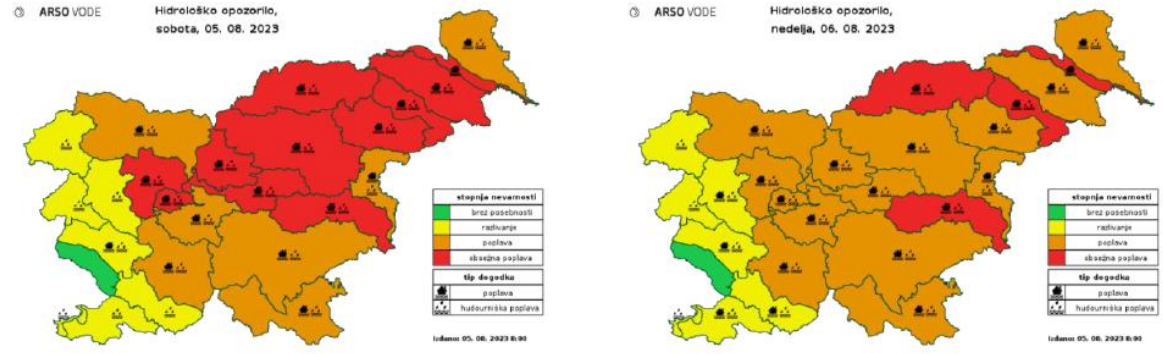


Figure 16: Warning - 05.08.2023 08:00 – Large-scale floods

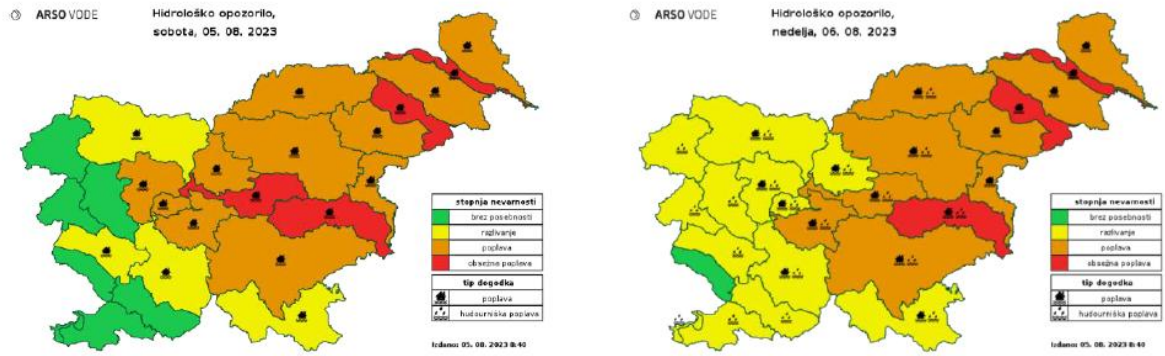
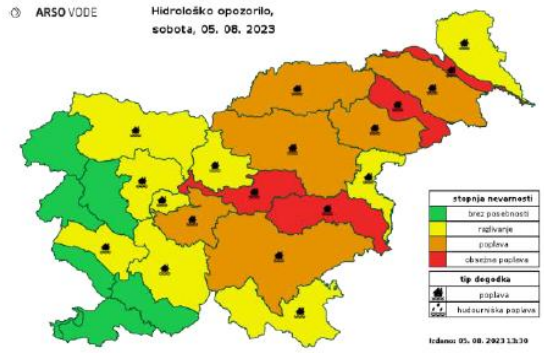


Figure 17: Warning - 05.08.2023 08:40 – Large-scale floods



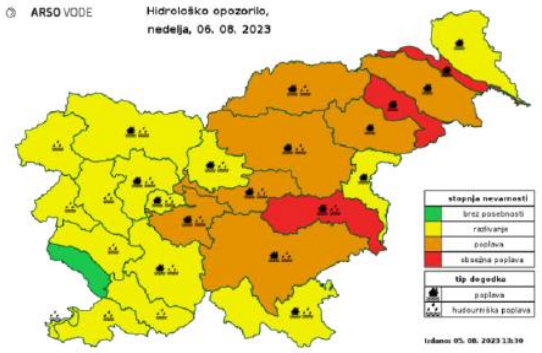
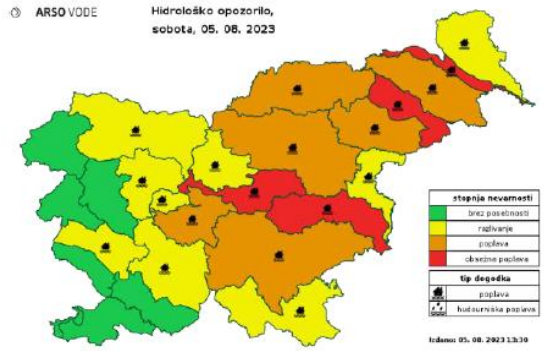


Figure 18: Warning - 05.08.2023 13:30 – Large-scale floods



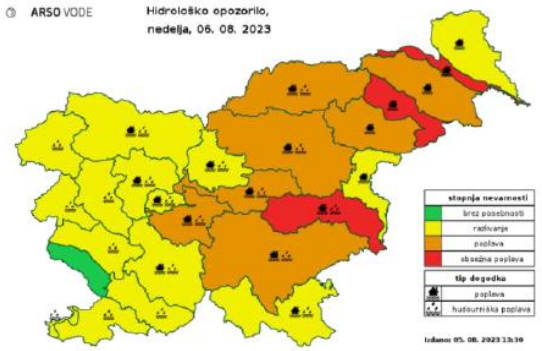
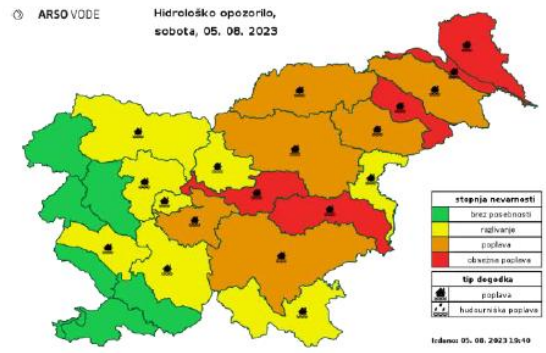


Figure 19: Warning - 05.08.2023 13:30 – Large-scale floods



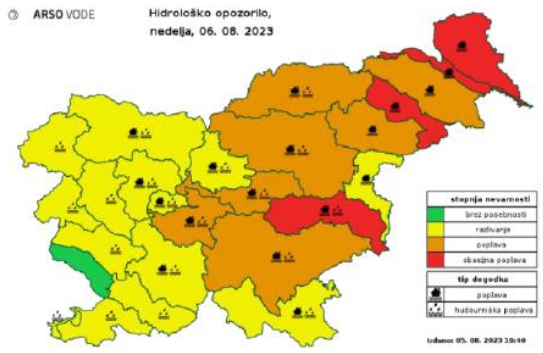


Figure 20: Warning - 05.08.2023 19:40 – Large-scale floods

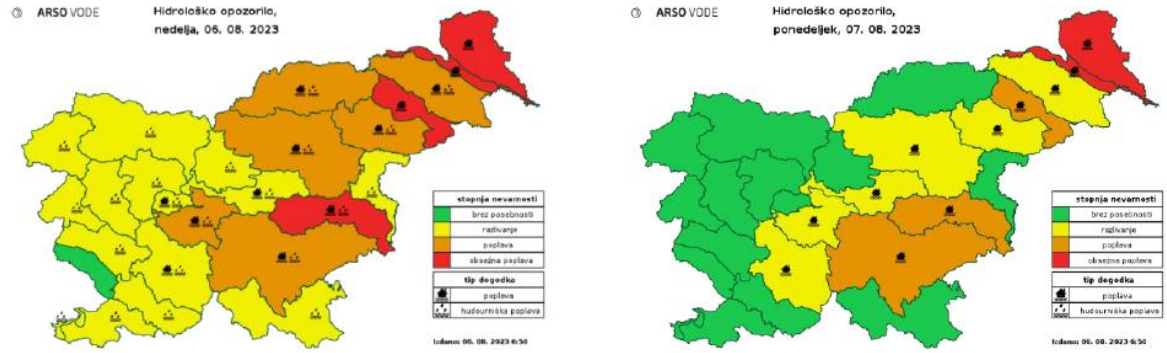


Figure 21: Warning - 06.08.2023 06:50 – Large-scale floods

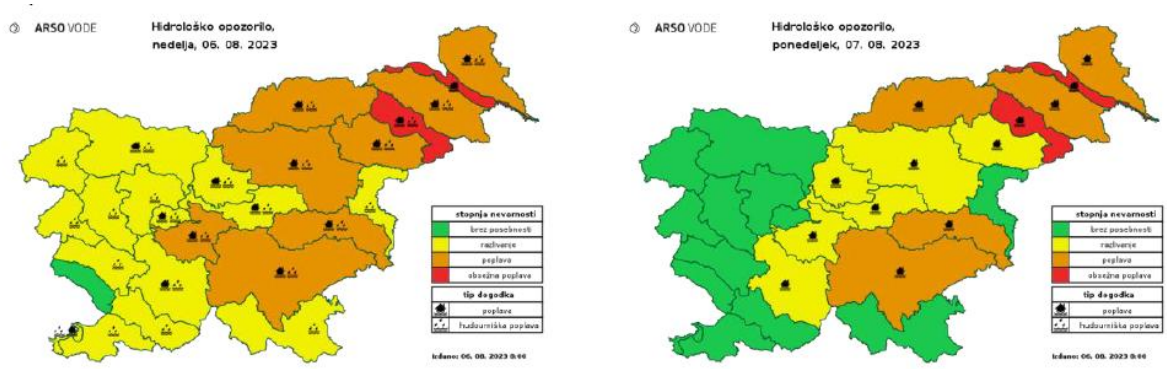


Figure 22: Warning - 06.08.2023 06:50 – Large-scale floods

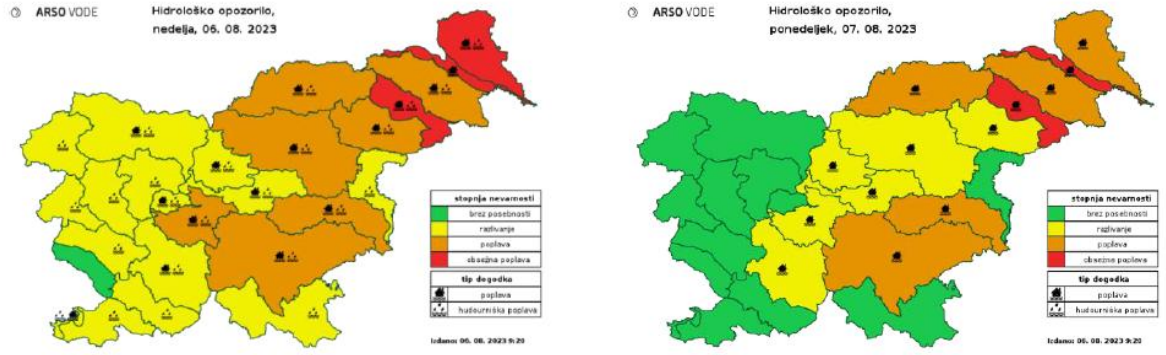


Figure 23: Warning - 06.08.2023 09:20 – Large-scale floods

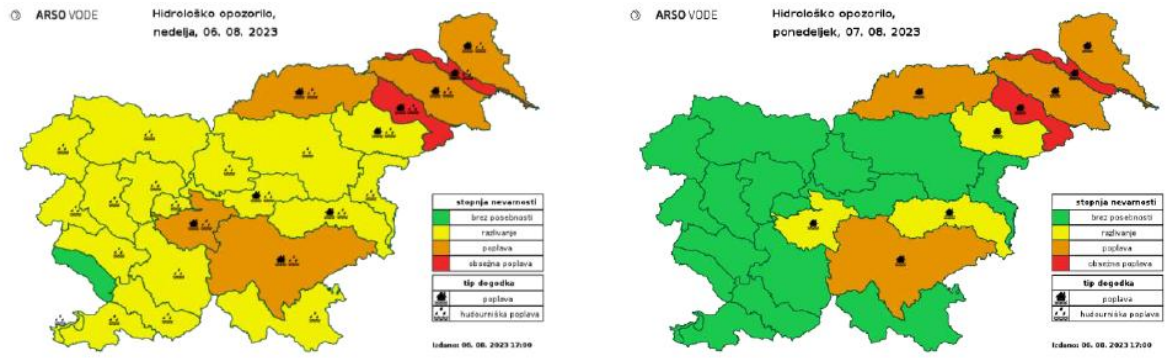


Figure 24: Warning - 06.08.2023 17:00 – Large-scale floods

For several days, meteorological forecast models used by Croatian Meteorological and Hydrological Service (DHMZ) had consistently predicted the development of events that included local intense storms and possible heavy precipitation in Croatia, as well as in neighbouring countries to the northwest. Based on meteorological forecast models and situational analysis, as well as hydrological models, on 3 August a press release by DHMZ was issued. On the same day, at 10:00 AM, the Main Flood Defense Center of Hrvatske vode issued a warning to all Flood Defense Sectors about the possibility of heavier rainfall and a potential sudden and significant rise of the water levels of the Sava, Mura, and Drava rivers, as well as of the Sava's upstream tributaries (Kupa, Dobra, Mrežnica, Korana, Sutla, Krapina, etc.) and Drava's upstream tributaries (Bednja, Plitvica).

3.2 Danube EFAS response

EFAS provided a first informal flood notification for a high risk of flooding starting around 4-5 August in the Drava/Drau river (Austrian part) on 1 August 2023 to the relevant authorities in Austria and Slovenia. Subsequently, further formal/informal notifications were sent for the Mur River (Austrian part as well as Slovenian part), Drava River, and Saalach (Austria). EFAS flash flood notifications were sent for the Slovenia regions Osrednjeslovenska, Zasavska, Posavska, Savinjska, Koroska, Podravska, Pomurska and for the Austrian regions Salzburg, Steiermark, Kaernten and Burgenland. An overview of the active EFAS notifications for the forecast from 4 August 2023 12UTC is shown in the Figure below. It should be noted that this event was predicted with EFAS v4.8 which used still a spatial resolution for the hydrological model of 5km. EFAS v5.0 was released on 20 September 2023 which increased the spatial resolution of the hydrological model to ~1.5km and included also a new model calibration.

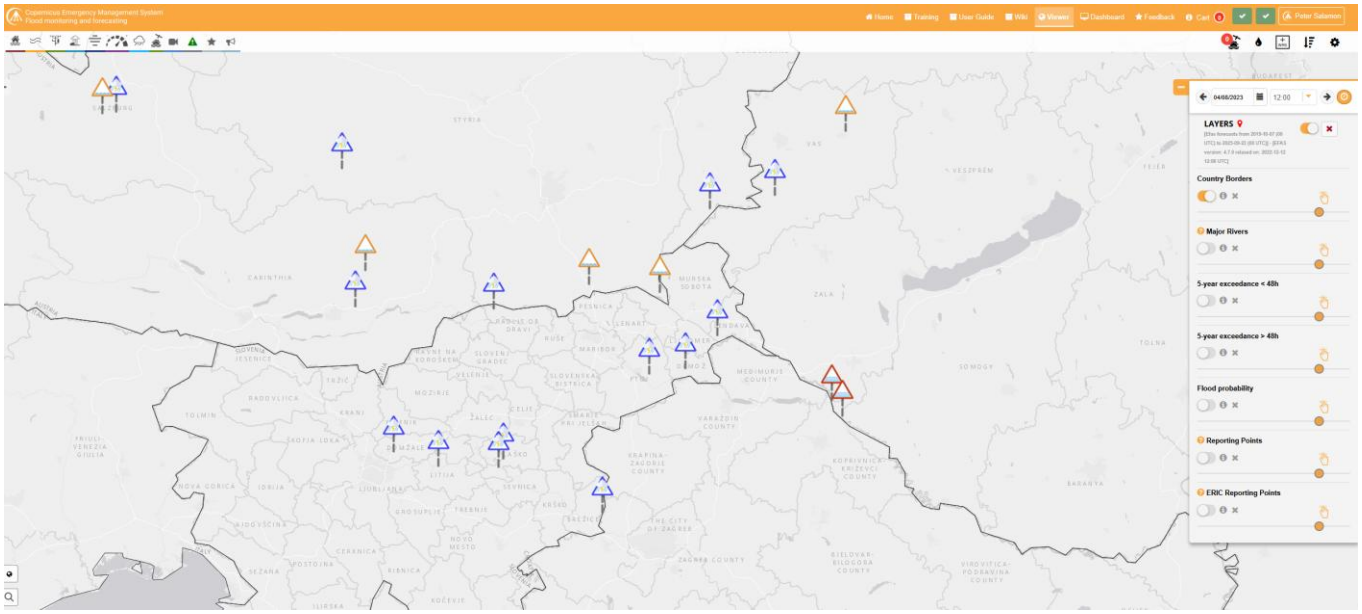


Figure 25 Active EFAS notifications for the forecast 04-08-2023 12UTC

ARSO in Slovenia, as a national authority with legal obligation to provide flood forecasts, is a partner of the EFAS system. The Hydrological Forecasting Service continuously monitored various forecast products available through the User Interface as well as evaluated the Notifications received. The spatial aspect of the flood forecasts and notifications was correct; however, the intensity of the flood event was underestimated. Considering the characteristics of the medium-range meteorological models integrated into the system, it is reasonable to expect such underestimation of the local and very intense convective precipitation that triggered the floods in the first hours of the event.

4. Flood interventions and affected area

The floods that hit Slovenia in August 2023 are considered the worst natural disaster in the country's history, causing devastating consequences for approximately two-thirds of its territory. As a result of the event, 171 municipalities or 12 regions were affected.

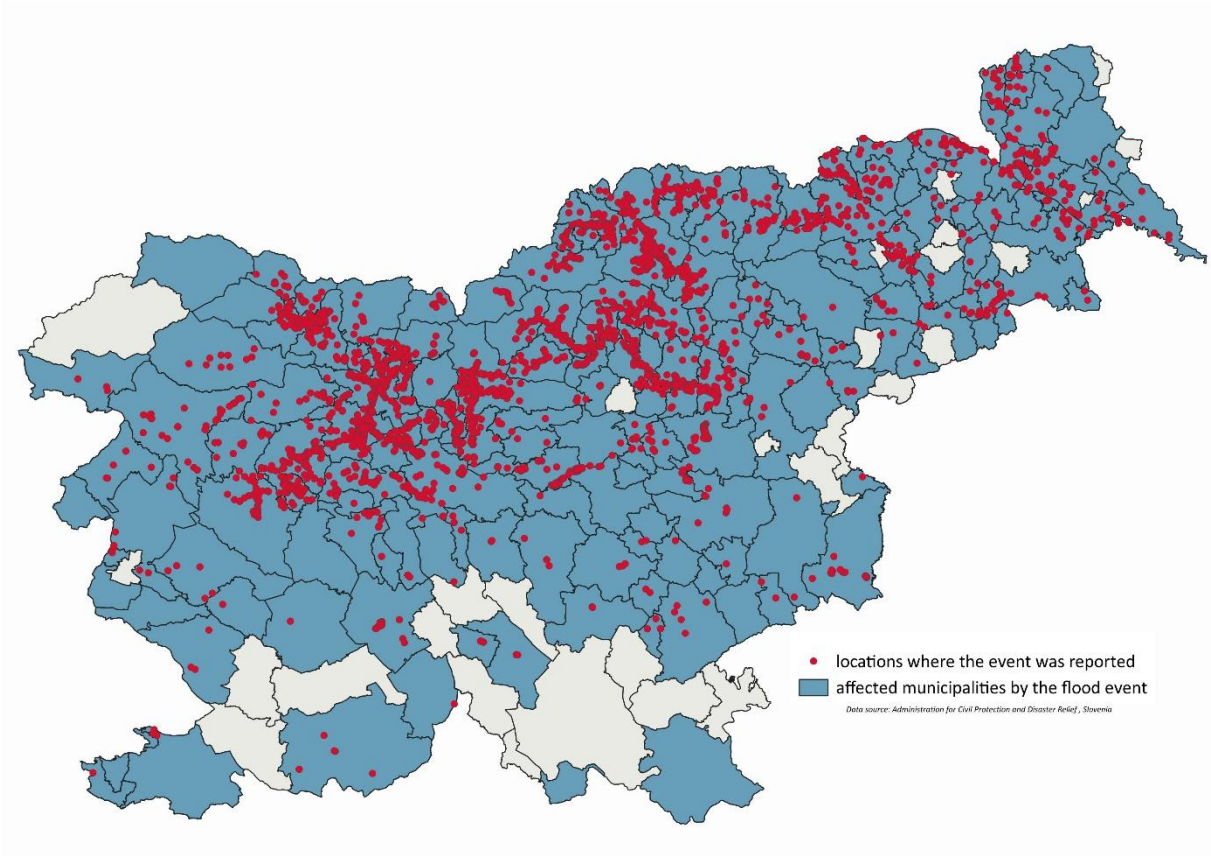


Figure 26: Map of municipalities where material damage or problems due to heavy rainfall and intense downpours were reported from 3 to 6 August. Data source: Administration of the Republic of Slovenia for Civil Protection and Disaster Relief, Information System for Reporting Interventions and Disasters.

In Croatia, operative flood defence activities started immediately after warning was issued by Main Flood Defense Center on 03.08. 2023. The lowest parts of the Sava inundation in the Brdovec municipality area were affected. During Saturday, 5 August agricultural land, roads, basements, and yards in the villages of Drenje Brdovečko, Zdenci Brdovečki, Javorje, and Šibice were flooded. At the highest water level of the Sava River, around 20 buildings were in contact with water.

To reduce water levels of Sava, starting from afternoon of 4 August, for the next five days, sluice Prevlaka was opened releasing approximately 120 million m^3 of water into Lonjsko Polje. In the night between 5-6 August relief canal Sava-Odra was activated, sixth time since its construction in 1979, transporting 700-750 m^3/s to Odransko polje retention area, reducing water levels of Sava for approximately one meter and protecting the city of Zagreb from flooding. Downstream of the city of Sisak, due to favourable hydrological condition of Kupa and Una Rivers, there was no threat of flooding. Although the water levels of the Mura River were above record levels, there were no major issues.

At Drnje, Šoderica, Torčec, and Sigetec, Drava River has flooded residential and commercial buildings as well as numerous agricultural and forest areas, roads, and some residents had to be evacuated. At one point, the floodwaters of the Drava River found a way and broke through to Lake Šoderica, which began to rise rapidly and threaten to flood surrounding area. On 13 August, backwaters of Drava caused failure of summer embankment of the Vučica (Karašica) River between the settlements of Satnica and Petrijevci, flooding agricultural areas and pastures, as well as several structures built in the floodplain.

Major flood fighting activities were finished by 14 August. During that time more than 5 350 persons, 157 trucks, 40 high-capacity pumps, and other equipment was engaged. More than 22 km of temporary flood defence systems were built, and more than 500 000 sandbags were used.

5. Casualties and assessment of damages

5.1 Casualties

As a result of the flooding event or in connection with it, 7 people lost their lives in Slovenia.

5.2 Damages

Post-Disaster Needs Assessment (PDNA)

The damage caused by the disaster in Slovenia was assessed using the internationally recognized PDNA (Post-Disaster Needs Assessment) methodology. The total estimate of the direct damage and consequences for the affected population, economy and environment calculated with PDNA method was 9,993,287,280.49 euros. The assessment of damage and consequences covers all aspects of the disaster, from the provision of replacement of buildings, rehabilitation of watercourses, restoration of infrastructure, protection and reconstruction of cultural heritage sites, waste disposal and management, etc. This value meant that the border for a major natural disaster was reached, which is a prerequisite for applying for assistance from the EU Solidarity Fund. Experts from Croatia (an estimate of the Zagreb/Petrina post -air renovation, December 2020) and the World Bank were also included in the evaluation.

Damage assessment – Decree on the Methodology for Damage Assessment

The assessment is based on the Decree on the Methodology for Damage Assessment (Uradni list RS, št. 67/03, 79/04, 33/05, 81/06 in 68/08). It is based on the reporting of an individual damage case - the facilities - and considers only direct material damage to the damaged things, considering the remaining value (deducted amortisation), and does not include VAT values.

The Government of the Republic of Slovenia has approved the final assessment of damage to property due to the consequences of heavy rain, severe flooding, and landslides on 4 August 2023. The total amount is 2.999.802.159,20 euros.

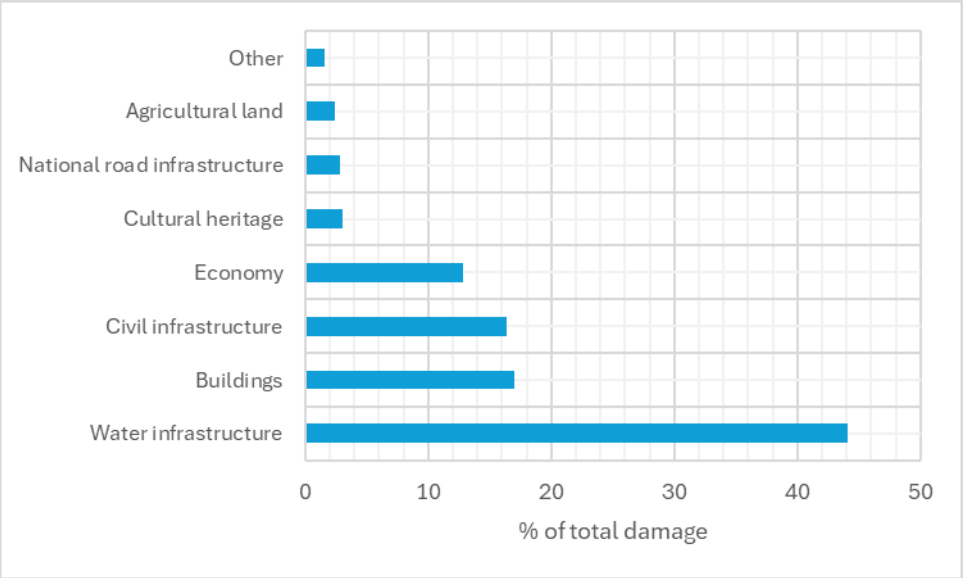


Figure 27: The distribution (by percentage) of the assessed damage to property by groups of claims in Slovenia

6. Lessons learned

6.1 Land Use and Spatial Planning

Floods are a natural phenomenon that cannot be prevented. In relation to spatial planning, Slovenia is currently preparing an amendment to the flood regulation, which will strengthen the conditions for construction in flood-prone areas.

6.2 Structural measures

Considering the growing trend of natural disasters caused by climate change, Slovenia aims to ensure that flood protection infrastructure is designed to be more resilient.

In Austria and Croatia implemented retention basins worked well according to their design level. Substantial damage, therefore, could be prevented.

6.3 Non-structural measures

During the August flood event in Slovenia, the non-structural flood protection measures proved to be very important, as they can contribute significantly to reducing damage, especially material damage.

6.4 Preparedness and mitigation (rapid disaster response)

Slovenia has established a very effective system for preparedness and response, which was proven to work well during the August floods.

6.5 Awareness raising

Raising awareness is also one of the measures that is crucial in reducing flood risk. In Slovenia, FRMP includes a measure focused on this activity, under which they organize various events (e.g., raising awareness among young people in schools about flood risk).

In reaction to damages due to increased convective rainfall events as well as to recorded behavior of people in the frame of all flood related processes, Austria recently launched a campaign shared with municipalities and especially schools and kindergartens to increase the flood awareness (https://www.bmluk.gv.at/themen/wasser/wasser-oeffentlich/hochwasserschutz-kampagne.html).

6.6 Financing aspects

Considering the growing frequency of disasters, it is crucial to place even more attention on this issue, which consequently requires increased financial investment.

6.7 Climate change impacts

The impact of climate change is evident and is expected to intensify even further in the future. For this reason, we must be prepared for even more extreme events.

A currently published paper (https://www.nature.com/articles/s41586-025-08647-2) highlighted that the probability of floods in small catchments is very likely to increase, however, this trend is not as strong for large scale weather patterns like the Vb pattern causing this severe flood event.