Drought in the Czech Republic in 2015

CZECH
HYDROMETEOROLOGICAL
INSTITUTE

Ministry of the Environment
of the Czech Republic

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Summary

The 2015 summer drought which hit the Czech Republic ranked among its most serious historical drought episodes.

The precipitation deficit began to manifest itself in the Czech Republic as early as 2014, and from February 2015, it slowly continued during the spring months and had risen to 150 mm by the end of August. At the beginning of summer, the country had already been relatively dry, and the situation was also gradually worsened by recurring heat waves, some of which were extreme and lasted several days in a row. The distribution of high pressure formations and, in particular, the extensive and renewing anticyclones contributed to the fact that Central Europe was not reached by enough moist air from the surrounding seas and ocean. The frontal systems that reached the Czech Republic were not humid enough for the development of thunderstorms. The low relative air humidity and few clouds at the peak of summer also contributed to increased overall evaporation, thus further deepening the shortage of water in the country.

The average air temperature during the growing period (from April to September) was 1.1°C higher than the long-term average for the period from 1981 to 2010. The temperature for the summer months has been the second highest (after the year 2003) during the monitoring period since 1961. Similarly, the 2015 precipitation total has been the second lowest (after the year 2003). Except for Northwest Bohemia, precipitation was below-normal, in some places lower than 60% of normal.

Mid-August can be considered the peak of the drought, when there were abundant rainfalls which significantly helped the country and its vegetation. However, these rainfalls were not enough to end the overall drought situation. The drought thus continued throughout September and early October, when the precipitation deficit rose up to 180 mm. The situation of surface streams was only improved by the precipitation period in mid-October.

The precipitation deficit resulted in a very negative moisture balance and soil drought occurrence. According to an evaluation of the basic moisture balance from August to October, 80% of the country showed values that were 100 mm lower than the long-term average for the period from 1981 to 2010. And in a similar area of the Czech Republic, the available water reserves in medium-heavy soil with grass cover were smaller than 40%. The drought effects included an increased fire danger, in particular during August, and a time shift of the onset of the phenology stages of plants.

The hydrological drought manifestations affected practically the entire Czech Republic in 2015. The water levels of most streams declined significantly below the 355-day discharge value over several weeks, as evidenced by field measurements. In some regions, some streams completely dried up. From the evaluations completed so far, it follows that the recurrence intervals of 30-day and 7-day annual runoff minima varied in a relatively wide range from 10 to 100 years.

The water reservoirs with significant storage volumes contributed to the mitigation of hydrological drought by improving the minimum discharges. In October, most of the reservoirs continued to be filled above 30% of the storage volume. The main drinking water supply reservoirs operated without any drought-related failure. With some exceptions (such as the Klabava and Husinec Reservoirs), the minimum runoff from the reservoirs was also ensured, as required by the Operating Rules.

In terms of groundwater, Northeast Bohemia and Northeast Moravia were the most affected areas. In mid-August, 59% of shallow boreholes and 56% of springs showed the state of drought. Unlike the soil drought and the drought of surface water, the state of drought of groundwater continued with more or less the same intensity into October, when more than one-fourth of the monitoring stations recorded historical monthly minima.

As regards a comparison of the timeline of the 2015 drought with selected historical cases (1904, 1947, 1994 and 2003), the 2003 drought timeline is relatively the most similar. The occurrence of extreme temperatures and heat waves from June to September most resembles the year 1947.

The precipitation deficit was comparable with the most significant cases of drought in 1921, 1976 and 2003, and partially also in 1911 and 1947, (the 1904 drought was not evaluated within this report). In terms of the surface water deficit on the Elbe, Vltava and Odra River basins, the year 2015 ranks among the worst years ever. This is in spite of the fact that, for example, there was a pronounced drought in the south of Bohemia in the Vltava and Otava River basins in 1904 and a more pronounced drought in the Upper Elbe and Sázava River basins in 1947. The 2015 drought was obviously very significant in the Lužnice River basin. Since the groundwater drought manifestations have greater inertia, the 2015 episode ranks among the most significant ones recorded since 1961, besides those of 1973, 1983, 1990, 1992 and 1993.

There were also extreme drought impacts on the soil layer, potential evaporation, evapotranspiration from grassland, and the soil moisture balance in 1973, 1976, the 1990s (1990, 1991 and 1992), and 2003. A comparison of 2003 and 2015 has showed that, in terms of the grassland moisture balance, the most extreme values were reached in 2003.

1. Introduction

In 2015 Western and Central Europe, including the Czech Republic, were affected by a major drought episode, which gradually manifested itself as an occurrence of all drought types and a wide range of drought impacts.

Drought, as a hydrometeorological extreme, is a slowly evolving phenomenon, whose manifestations and impacts occur and propagate with some delay. The meteorological causes of drought, such as a lack of precipitation often combined with high temperatures and high evaporation rates, are first reflected in a soil moisture deficit. With some delay, this leads to reduced stream discharges, followed by declines in groundwater levels. Subsequently, the drought fades away in identical sequence, and therefore, even if above-normal precipitation occurs, the drought may continue to occur in some forms and areas.

Due to the historical development of water management infrastructure in the form of constructed water reservoirs and water supply systems, in 2015 there were no critical impacts (such as major interruptions of water supplies to households). However, some sectors of the economy were affected very significantly, e.g. some agricultural activities and the hydro power sector.

Because of its complex development and impacts, it is very difficult to evaluate drought magnitude using a single criterion, but it is obvious that the drought in 2015 may be compared with known historical drought episodes, such as those of 1947 or 2003.

This 2015 Drought Report is based on the operational data and products of the Czech Hydrometeorological Institute covering the period up to the end of October 2015. The chapter describing the water volumes in selected water reservoirs is based on the data and consultations provided by the River Basin Companies (Povodí state enterprises), and the information on the number of fires was provided by the Fire Rescue Service of the Czech Republic.

Even though as a result of the limited time range of evaluated data, this report covers the drought's culmination in terms of drought manifestations in soils and streams, the drought was still continuing, for example in groundwater terms, when this report was prepared. It is therefore expected that this report will be updated in 2016 to provide a comprehensive evaluation of the drought throughout 2015.

This report aims to provide initial information on the causes and natural manifestations of the drought, as the basis for reviewing the fulfilment of the Resolution of the Czech Government No. 620 of 29 July 2015 and for assessing the socio-economic impacts of the 2015 drought on various sectors. Where this report publishes evaluations related to long-term averages, the reference period is considered to be the period from 1981 to 2010, and if the reference period is different, then it is clearly stated.

2. Meteorological Situation Development from January to October 2015 Leading to Drought Occurrence in the Czech Republic

In 2015 an increase in the atmospheric precipitation deficit occurred in the Czech Republic, which resulted, particularly in the summer months, in a significant lack of water in the terrain and soil, in significantly reduced levels of streams, and in low discharges. That precipitation deficit, i.e. meteorological drought, is caused by atmospheric circulation and anomalies in the atmosphere. However, the drought causes are more complex and are not only associated with the actual lack of atmospheric water. Important factors comprise the interaction between air temperature and humidity, as well as the conditions of the terrain and soil before the onset of the drought itself.

The drought affected not only the Czech Republic but also its neighboring countries. To better understand the drought's formation and development, it is necessary to analyze the atmospheric circulation conditions. From the synoptic perspective, the analysis should be performed over a sufficiently large area such as the Atlantic Ocean – Europe. Generally in the event of drought, there is a lack of rainfall lasting over a longer period of several weeks to months, and, therefore, the beginning of the precipitation deficit occurrence is also to be included in the analysis.

2.1. Meteorological Situation Development in Individual Selected Periods

January–March

In January, eastward air flows prevailed, and within them, individual frontal systems progressed over Central Europe. In the mountains, there was mostly snow precipitation. By contrast, at lower elevations there was rain. In February and March, the precipitation began to gradually diminish (Fig. 2.1.), and two periods of more than 10 days, from 12 to 22 February and from 15 to 25 March, produced almost no precipitation. February with its subnormal precipitation was followed by March with normal precipitation – normal just due to the fact that in late March (and in early April), there was significant precipitation, which mitigated the deepening precipitation deficit. In terms of ground saturation, a certain role was also played by the fact that the winter was the second in a row when no significant amounts of snow fell at lower elevations, and most of the precipitation fell in the form of rain.

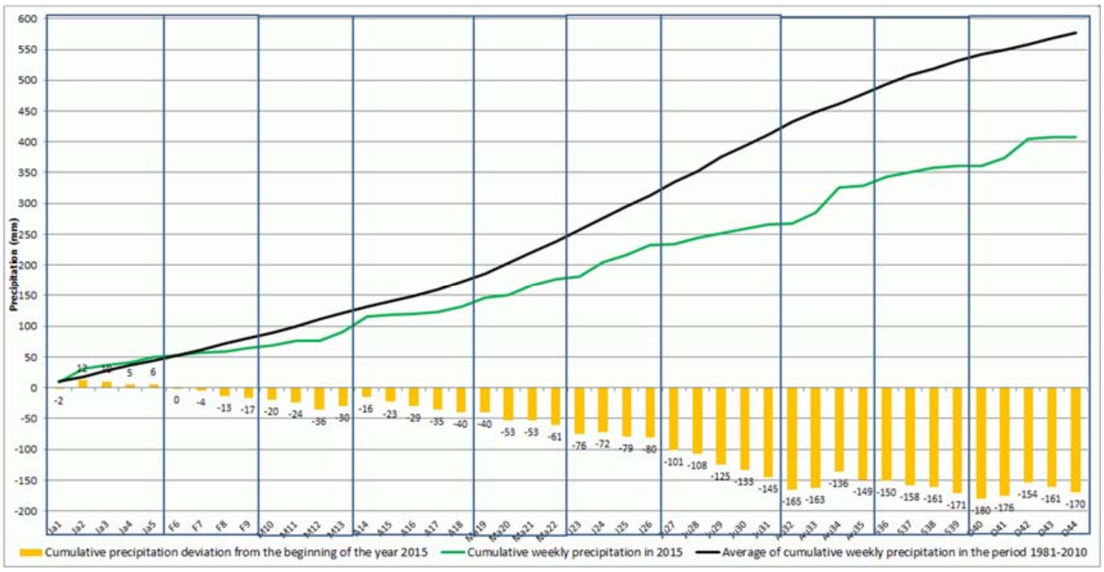
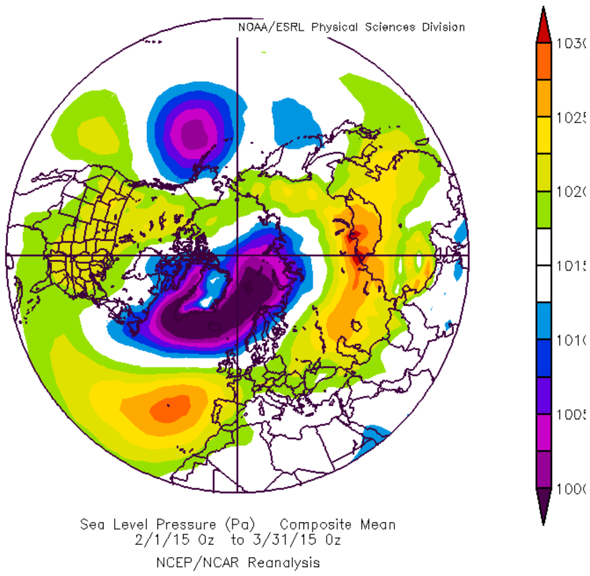


Figure 2.1. Cumulative evolution of precipitation by weeks in the Czech Republic between January and October 2015 compared with long-term values (Comparative period: 1981–2010).

The precipitation deficit in the said period was caused by atmospheric circulation over the Atlantic Ocean – Europe, in particular, due to the presence of two distinct anticyclones – the Azores and Siberian anticyclones (Fig. 2.2.). The blocking Siberian anticyclone caused the jet stream in the British Isles to be divided into two branches, one directed along Norway's coast and the other one heading to the Mediterranean region. This resulted in frontal disturbances progressing mostly from the eastern Atlantic Ocean over Scandinavia to the east and interfering only partially and temporarily with the weather in Central Europe. The Mediterranean branch contributed to the formation of depressions in the Mediterranean region, which consequently determined the character of the weather in that area and its surroundings (North Africa, the Balkans and Eastern Europe) and which rarely had any impact on the weather in the Czech Republic. This circulation pattern did not significantly change until the end of March, when Central Europe started to be approached by frontal systems from the northwest, bringing not only colder weather, but also more significant amounts of precipitation.



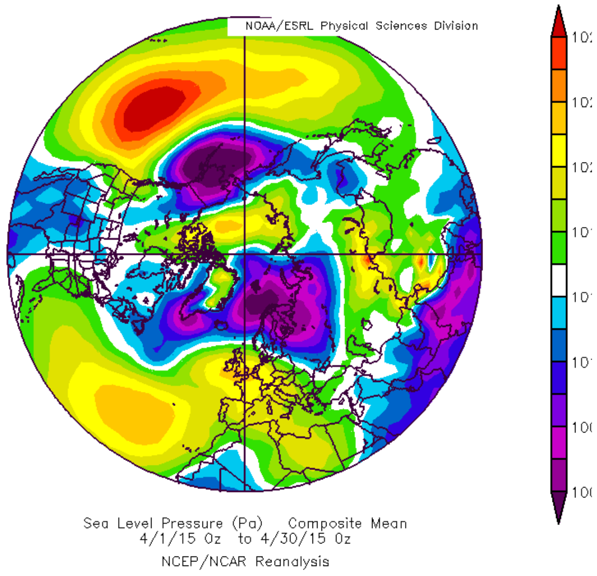


Figure 2.2. Average sea-level pressure field in Pa (1 hPa = 100 Pa) in the Northern Hemisphere between February and March 2015 (Source: NOAA/ESRL).

Figure 2.3. Average sea-level pressure field in Pa (1 hPa = 100 Pa) in the Northern Hemisphere in April 2015 (Source: NOAA/ESRL).

April–May

In April and May, precipitation occurred quite frequently in the Czech Republic, but precipitation totals were mostly low. As such, the precipitation deficit continued to gradually deepen (by 25 mm/month on average).

The weather over Europe in April was affected by the Azores anticyclone extending over the British Isles and Western Europe (Fig. 2.3.). Central Europe was in its peripheral flow, and frontal disturbances, which mostly progressed over Scandinavia to the southeast, partially influenced the weather in the Czech Republic. This led to more frequent precipitation, which greatly varied by region however, and precipitation totals were smaller than usual in April.

In late April and throughout May, frontal disturbances moved over Central Europe mostly from the west and southwest and were frequently alternated by wedges and areas of high air pressure. Due to the stronger eastward flow, the fronts progressed rapidly over Central Europe to the east. Precipitation occurred more frequently in the form of showers and local storm cells. In the Czech Republic, the precipitation totals again varied regionally and, on average, were smaller than the long-term May average value.

June–August

In the summer months, there were four periods in the Czech Republic with significantly above–average temperatures (described below in Chapter 3) and several waves of high maximum temperatures, which even exceeded 35°C.

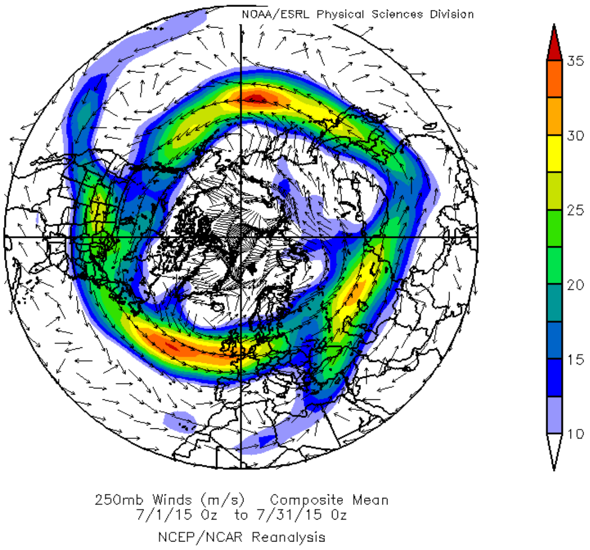
In June the precipitation deficit increased in the most of the Czech Republic. However, significant regional differences started to appear. For the entire month of June, for example, the total rainfall in North Bohemia amounted to 120% of the long-term average, while in South Moravia rainfall was only 43% of average.

The period from the end of June to mid-August was characterized by high temperatures and a significant decline in precipitation. In terms of the frequency of passage of fronts over the Czech Republic, that period in nowise deviated from the long-term average. However, these fronts mostly brought weak rainfalls in the form of showers, only sporadically interspersed with thunderstorms. Even though there were also heavier rainfalls during those thunderstorms, they had almost no effect on the growth of the total deficit.

Between two heat waves in August, there was a period with very heavy precipitation in the middle of the month. In just two days, 17–18 August, the rainfall amounted to almost 40 mm in the Czech Republic, which would have normally caused a significant hydrologic response under normal circumstances. However, that heavy rainfall only temporarily slowed down the deepening precipitation deficit, and as such, at the end of August, the precipitation deficit again returned to the level reached in late July, i.e. approximately 150 mm.

In the first half of June, anticyclonic weather prevailed over a larger part of the European continent, and fronts were directed by steering upper air flows over Scandinavia and only temporarily brought precipitation to Central Europe. Before such fronts arrived, warm air from the southwest reached the Czech Republic. In the second half of June, the air flow turned eastward, and frontal disturbances from the Atlantic Ocean reached the interior of the continent more frequently, bringing intermittent rainfalls.

In July, there was a jet stream from the east coast of the United States, then along the 50th parallel over the British Isles to Northern Germany (Fig. 2.4.). South of that jet stream, i.e. in the southern half of the European continent, there was a prevailing high-pressure area, even in the upper atmospheric layers, which is shown in Fig. 2.5. Since the jet stream around the British Isles was stronger than usual, very warm air was drawn to Western and Central Europe from the southwest and south. Frontal systems proceeded in the southwest flow from the eastern Atlantic Ocean slowly to the northeast and usually undulated. Heavier rainfalls occurred southwest and west of the Czech Republic. Most of the humidity transferred from the Atlantic Ocean and the Mediterranean Sea was captured by the southern slopes of the Alpine Massif, and the Czech Republic was only reached by drier and warm air. In the high-pressure area and at high temperatures, the fronts over the Czech Republic dissipated and brought frequent, but not so significant, precipitation in the form of showers and occasional storms.



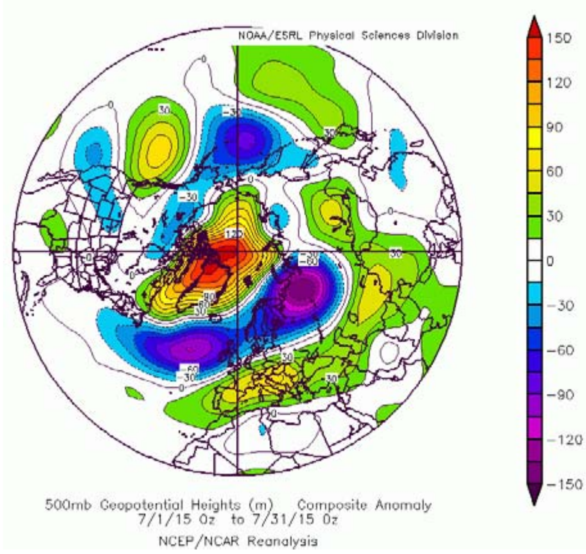


Figure 2.4. Average jet stream (250 hPa) v ms^{-1} in the Northern Hemisphere in July 2015 (Source: NOAA/ESRL).

Figure 2.5. Deviation of geopotential height at 500 hPa in the Northern Hemisphere in July 2015 (Source: NOAA/ESRL).

Fig. 2.6 shows a very distinct anomaly in the distribution of pressure formations over the Atlantic Ocean – Europe during August 2015. Between Iceland and the British Isles, a trough of low pressure maintained itself and was continuously renewed. In the north and northeast of Central Europe, there was a dominating ridge of high pressure, whose axis ran over Poland, the Baltic states, and northern Sweden. Such a distribution of pressure formations caused the progression of frontal disturbances from the Atlantic Ocean eastward to be blocked or slowed down, and, as such, Central Europe was only reached by insignificant fronts and weaker precipitation. Along the trailing edge of the high-pressure ridge over Northeastern Europe, very warm air flowed to Central Europe in the first half of August. The tropical air influx mainly manifested itself in the Czech Republic, Slovakia, and Poland (see Fig. 2.7.).

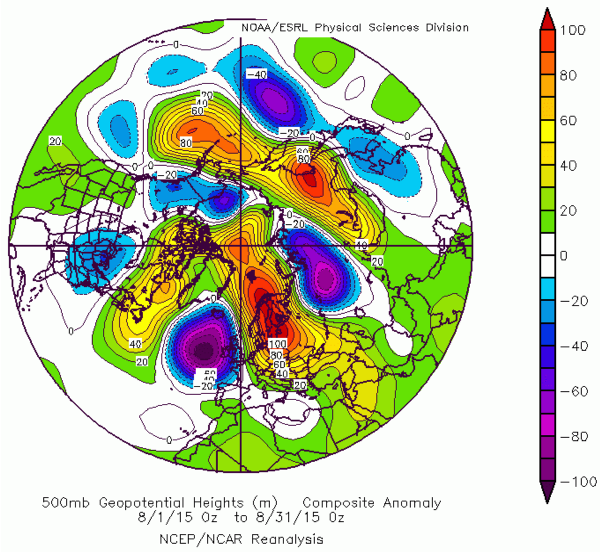


Figure 2.6. Deviation of geopotential height at 500 hPa in the Northern Hemisphere in August 2015 (Source: NOAA/ESRL).

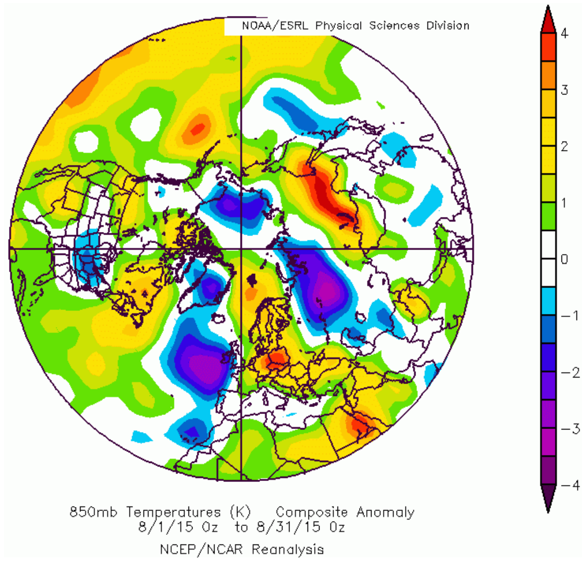


Figure 2. 7. Temperature deviation at 850 hPa in the Northern Hemisphere in August 2015 (Source: NOAA/ESRL).

This circulation was interrupted in the middle of August, when a wavy frontal interface arrived in the area over Central Europe, along a northwest-to-southeast axis for a period of several days (Fig. 2.8.). During that period, most of the Czech Republic experienced heavy precipitation, mostly in the form of continuous rain.

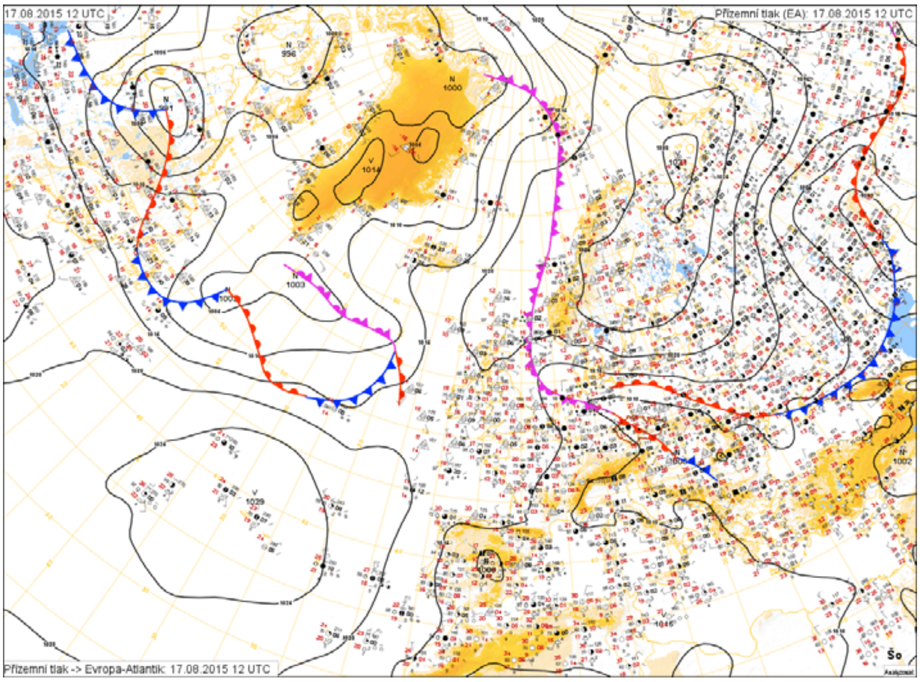


Figure 2.8. Synoptic situation, including frontal analysis over the Atlantic Ocean – Europe at 02:00 p.m. CET on 17 August 2015.

September–October

In early September, a distinctly cold front passed over the Czech Republic, and behind the cold front, temperatures reached their standard September values. At the same time, relatively abundant precipitation occurred. Individual frontal systems passed in the steering southwestern upper air flow (Fig. 2.9.) over Central Europe until the end of the second 10-day period of September. Even though precipitation was recorded almost every day, it was mostly weak. It was mostly comprised of showers, and exceptionally also storms. Over the next few days, the Czech Republic was in an insignificant pressure field, and there were only local rainfalls with low totals.

In the last week of September and early October, a larger part of Western and Central Europe was under the influence of an anticyclone (Fig. 2.10.). During that period, no precipitation occurred at all, and in early September, the precipitation deficit culminated in the Czech Republic, reaching a total of 180 mm since the beginning of the year. Other periods without precipitation when there was a prevailing anticyclone moving over Central Europe to the east occurred between 10–12 October and 23–31 October. By contrast, very heavy rainfalls were recorded between 13–16 October, when the Czech Republic was affected by a wavy frontal interface associated with a depression progressing from the western Mediterranean region over the Balkans to the northeast (Fig. 2.11.). It was just the precipitation of that period, as well as the precipitation in mid-August, that temporarily mitigated the precipitation deficit (see Fig. 2.1.). Subsequent weather patterns caused the precipitation deficit to return in late October to its values of late September, i.e. approximately 170 mm.

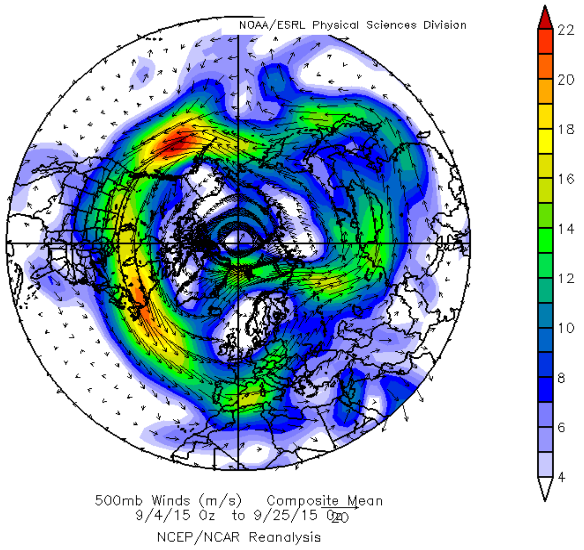


Figure 2.9. Average geopotential height at 500 hPa in the Northern Hemisphere from 4 September to 25 September 2015 (Source: NOAA/ESRL).

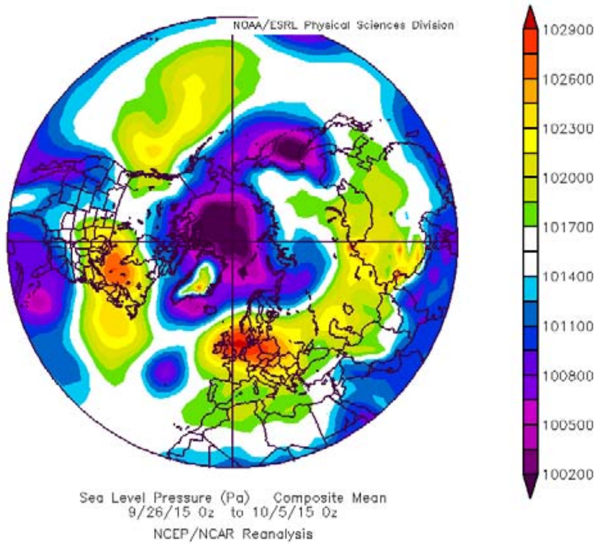


Figure 2.10. Average sea-level pressure field in Pa (1 hPa = 100 Pa) in the Northern Hemisphere from 26 September to 5 October 2015 (Source: NOAA/ESRL).

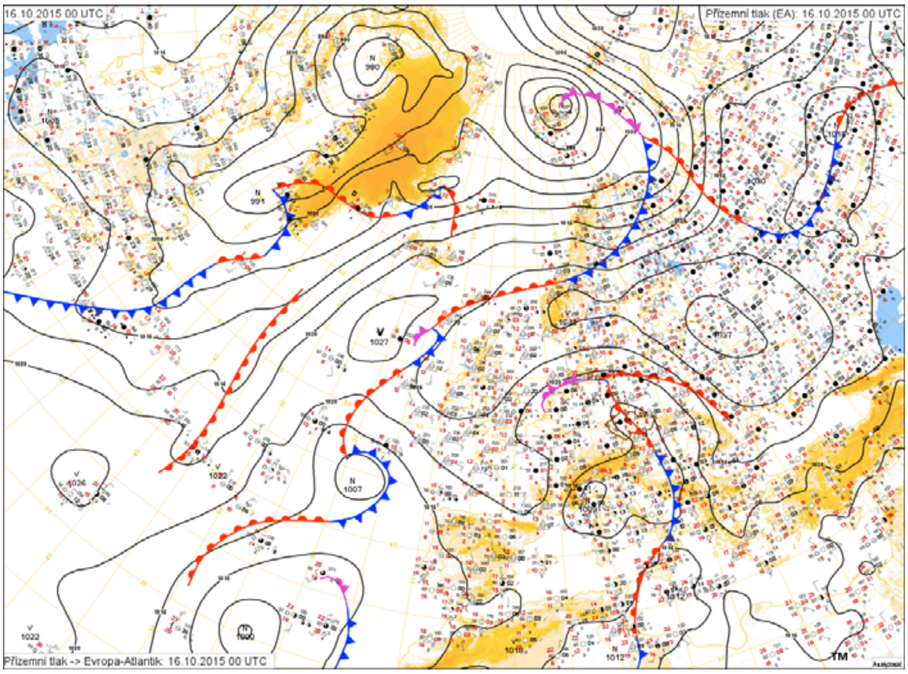


Figure 2.11. Synoptic situation, including frontal analysis over the Atlantic Ocean – Europe at 02:00 p.m. CET on 16 October 2015.

2.2. Summary of Meteorological Causes of Drought

The precipitation deficit in the Czech Republic started to manifest itself as early as February 2015 and slowly continued during the spring months. During June, the deficit since the beginning of the year settled at around one-fourth of the precipitation total, as compared with the average from 1981 to 2010, and reached 150 mm in late August. From the perspective of the whole monitored period, it can be said that it was mostly an atmospheric precipitation deficit growing over time.

The precipitation deficit in late winter and early spring was caused by the presence of anticyclones over a larger part of the Atlantic Ocean – Europe area, i.e. due to the absence of low pressure areas and related fronts.

If no periods with the moisture-laden prevailing westward flow had occurred in May and June, the precipitation deficit decline would have been even more distinct.

In early summer, the ground was already quite dried out, and the situation was also gradually worsening with recurring heat waves, some of which were extreme and lasting a number of days in a row. The distribution of pressure formations and, in particular, the extensive and renewing anticyclones contributed to the fact that Central Europe was not reached by sufficiently moist air from the surrounding seas and ocean. The frontal systems that reached the Czech Republic did not have enough moisture for the development of thunderstorms, which are the predominant source of precipitation in summer. The dry terrain with its lack of moisture combined with the relatively stable air layering did not contribute to the formation of either air-mass thunderstorms or prefrontal thunderstorms, which represent another source of precipitation in summer.

The low relative air humidity and sparse cloud cover at the peak of summer, when the daily length of sunshine is at its peak, also contributed to greater overall evaporation. The very warm air present was able to absorb large quantities of water vapor, thereby contributing to the additional aridity of the land. In the Czech Republic, all these factors led to much less precipitation than usual, and moisture was subsequently drawn out of the soil and terrain.

In mid-August, heavy rainfall occurred and significantly helped the environment and vegetation, but it was not enough to significantly improve the overall situation over the next few weeks. The situation also worsened during September, and after a considerably dry beginning of October, the precipitation deficit in the Czech Republic finally culminated at 180 mm. Even though the period of above-average precipitation in mid-October improved the precipitation situation, it did not significantly reduce the overall deficit at all.

In conclusion, it is possible to say that if the rainfall in the two aforementioned periods of significant precipitation in mid-August and mid-October had occurred in conditions of average or above-average soil saturation, it would have most likely resulted in a flood situation of at least regional dimensions.

3. 2015 Precipitation and Temperature Characteristics

3.1 Basic Characteristics

In the Czech Republic, we registered above-normal air temperatures and low precipoitation totals as early as late 2014. As documented by the graph in Fig. 3.1., the monthly mean air temperature was above the 1981–2010 normal from September 2014 to January 2015. November 2014 with a deviation of 3.1°C from the normal was even extraordinarily above-normal in terms of temperature, and December with a deviation of 2.5°C was strongly above-normal.

In terms of precipitation, September 2014 was above-normal, and October 2014 was normal. However, November 2014 with a precipitation total of 23 mm, which represents 47% of the 1981–2010 normal, ranked among the months with strongly below-normal precipitation (Fig. 3.2.). Even though the December and January precipitation totals were at the normal level, no significant snow cover was formed. The maximum height of snow cover in the Giant Mountains (Krkonoše) at the Labská Bouda station and in the Beskydy Mountains at the Lysá Mountain station, reached 140 cm and 145 cm, respectively, in February; however, at the other mountain stations, it remained below 100 cm. Snow cover in the Šumava Mountains did not even reach 50 cm. The spring months of March to May were normal in terms of precipitation and temperature; however, the average precipitation totals were rather below-normal and were not sufficient to make up the moisture deficit. Based on the course of average precipitation totals in the Czech Republic and soil drought indicators, the beginning of drought occurrence can be defined as early June.

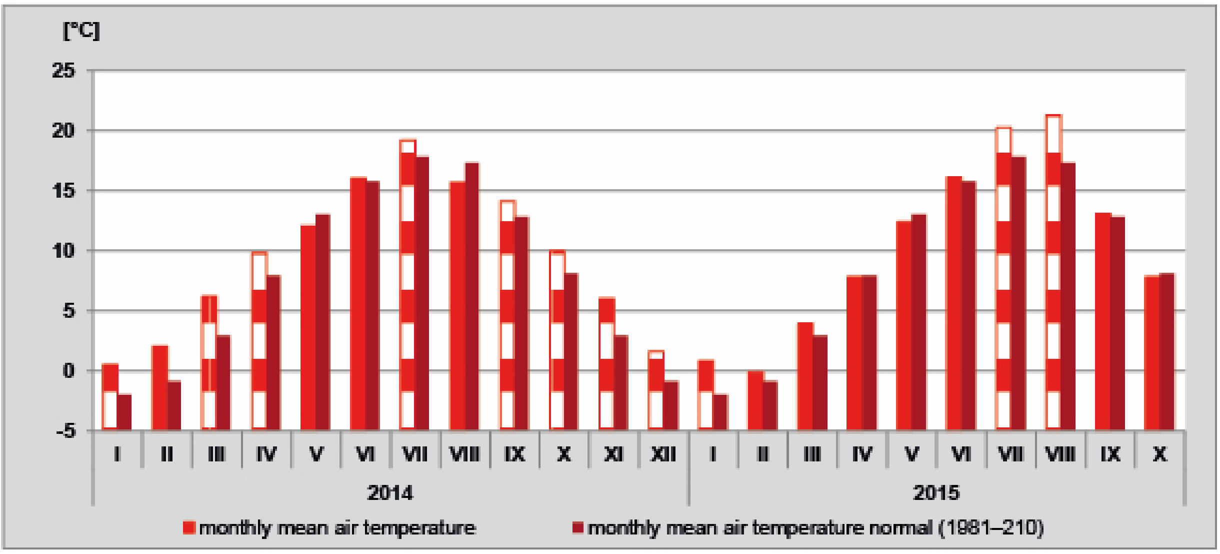


Figure 3.1. Course of monthly mean air temperatures in the Czech Republic from January 2014 to October 2015. The months when the monthly mean air temperature was strongly or extraordinarily above-normal are hatched.

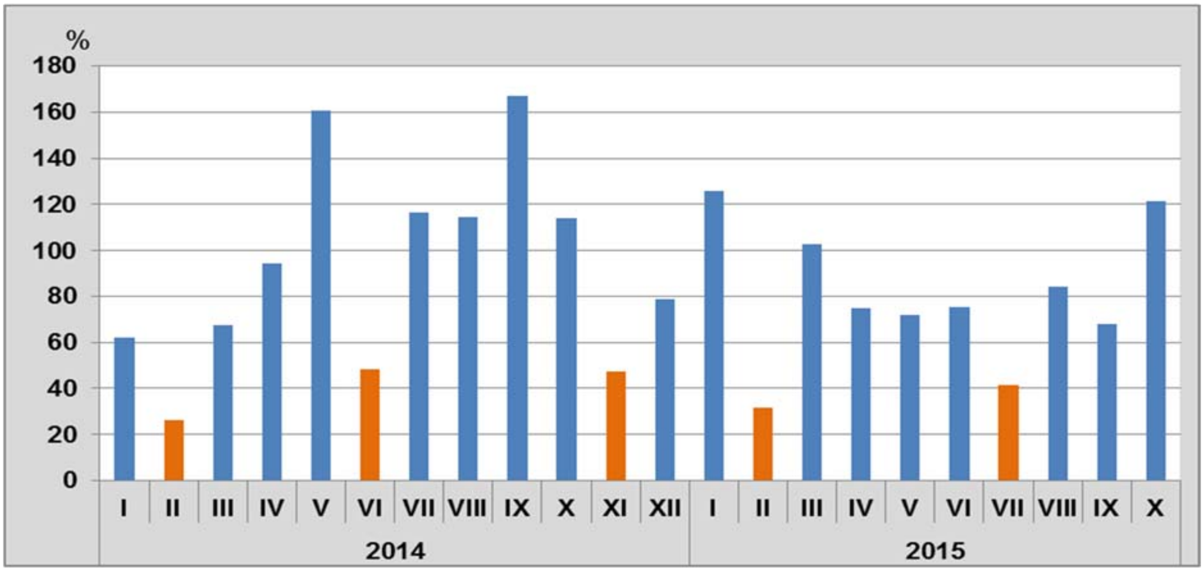


Figure 3.2. Course of monthly precipitation totals in the Czech Republic expressed as a percentage of the 1981–2010 normal from January 2014 to October 2015. The months when the precipitation total was strongly or extraordinarily below-normal are marked in color.

3.2. Temperature and Precipitation Conditions in the Czech Republic from 1 January to 31 October 2015

The distribution of mean air temperature and its deviation from the 1981-2010 normal for the period from the beginning of 2015 to 31 October 2015 are shown in the maps in Figs. 3.3. and 3.4. Precipitation total is given in mm in Fig. 3.5., expressed as a percentage of the 1981–2010 normal in Fig. 3.6. Since the phenomenon of meteorological drought led to the occurrence of an agricultural drought, we also present the maps of mean air temperature and its deviation from normal (Figs. 3.7., 3.8.) and precipitation totals in mm and as a percentage of normal for the growing season, i.e. for the period from early April to late September 2015 (Figs. 3.9. and 3.10.).

The highest mean air temperature for the above-mentioned periods was recorded in Moravia in the Dyje-Svratka, the Lower Morava, and the Upper Morava River Valleys. In Bohemia, high temperatures were recorded almost throughout the region (except at higher elevations in the Bohemian-Moravian Highlands and in the borderland mountains). The mean air temperature for the period from January to October 2015 for the Czech Republic amounted to 10.4°C (1.1°C above normal), and the mean growing season air temperature of 15.2°C was also 1.1°C above normal. The deviation of the mean air temperature from the 1981–2010 normal for the said periods was positive throughout almost the entire Czech Republic (Figs. 3.4., 3.8.).

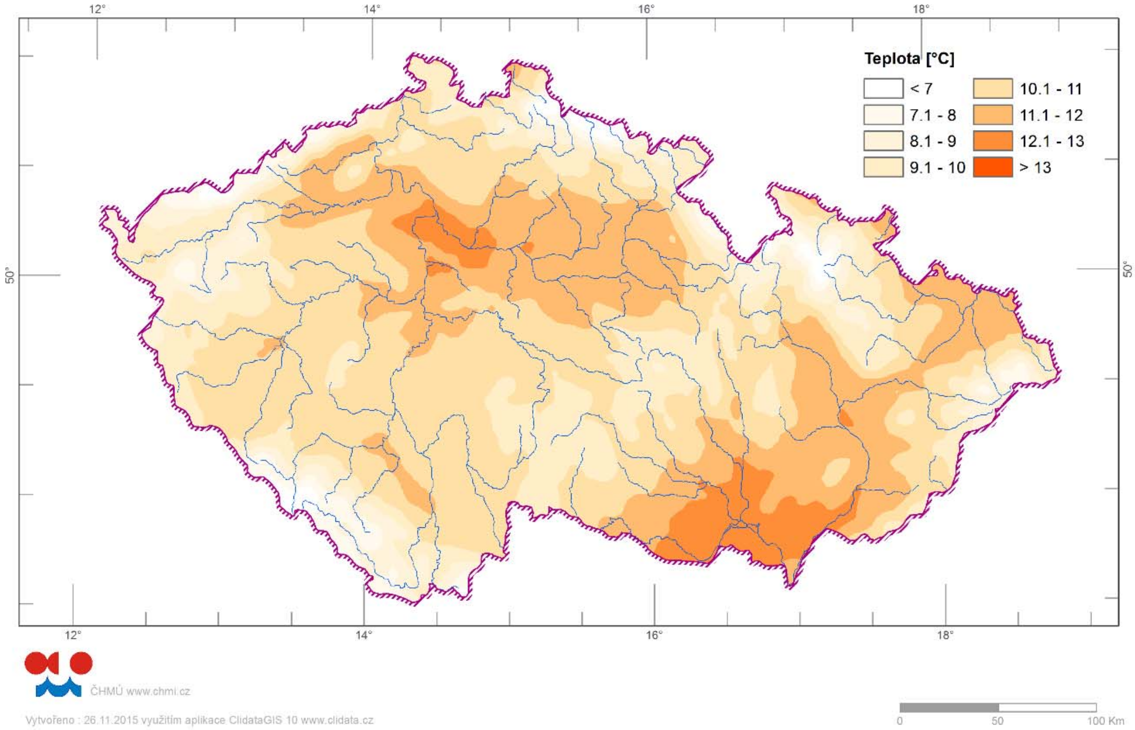


Figure 3.3. Mean air temperature distribution from 1 January 2015 to 31 October 2015.

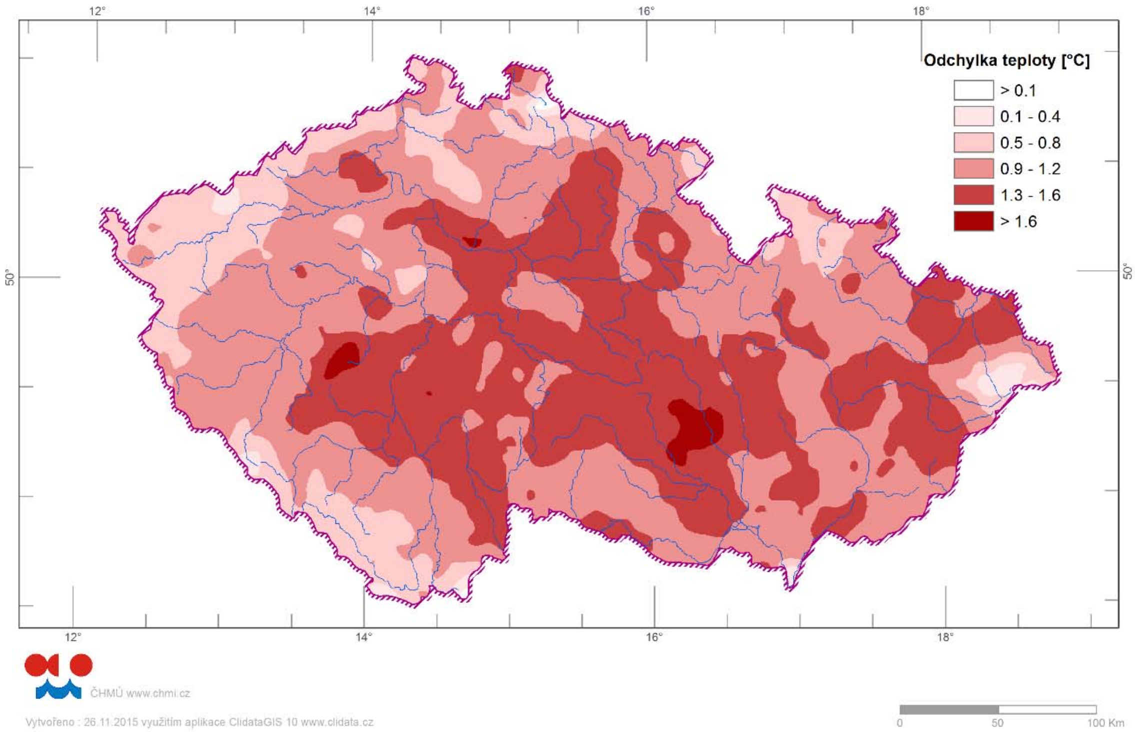


Figure 3.4. Deviation of mean air temperature from the 1981–2010 normal for the period from 1 January 2015 to 31 October 2015.

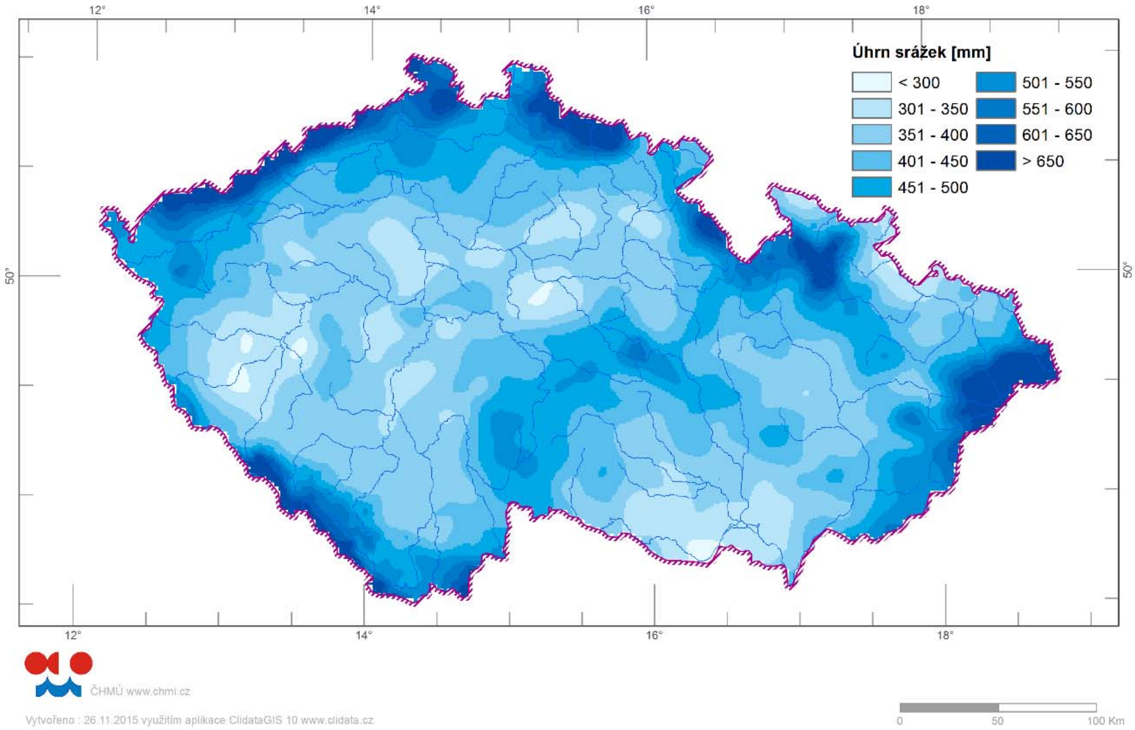


Figure 3.5. Precipitation total in mm from 1 January 2015 to 31 October 2015.

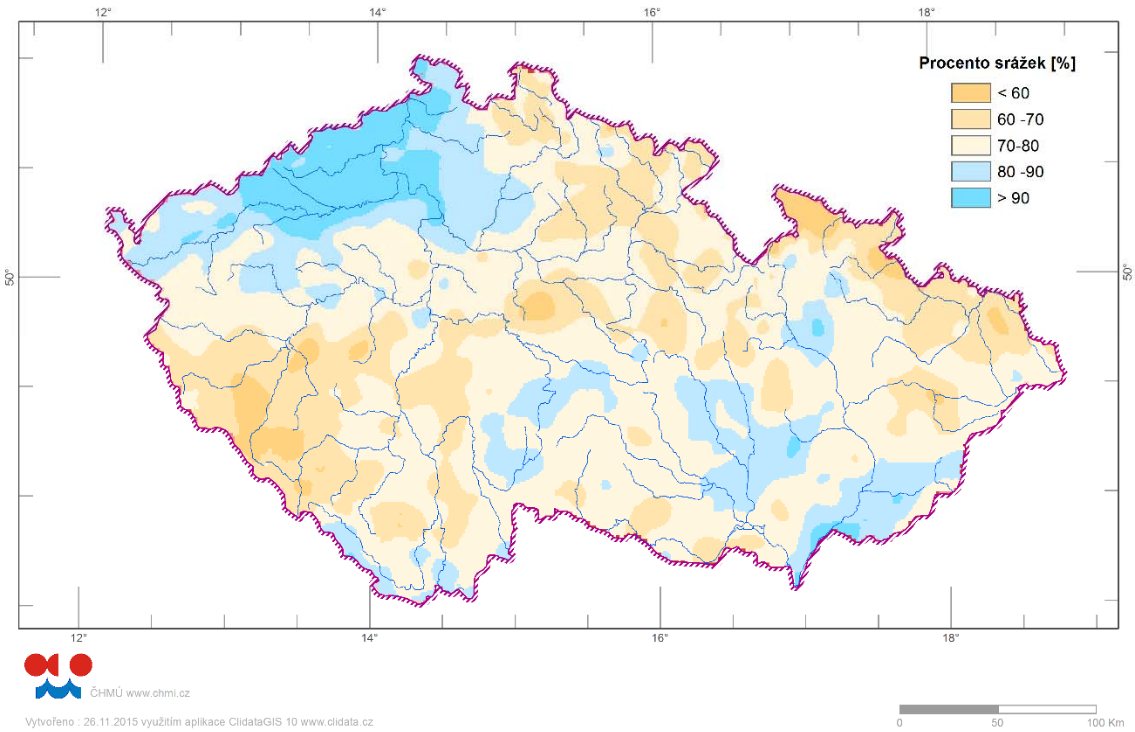


Figure 3.6. Precipitation total from 1 January 2015 to 31 October 2015 as a percentage of the 1981–2010 normal.

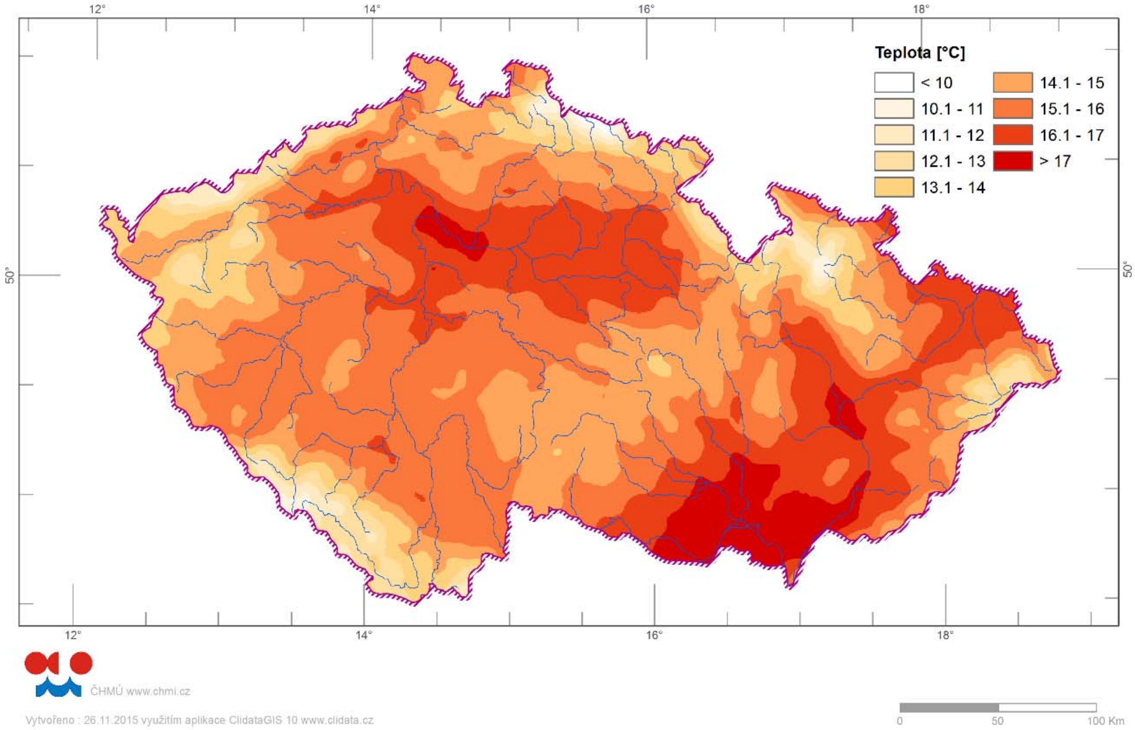


Figure 3.7. Mean air temperature distribution for the growing period (April to September) 2015.

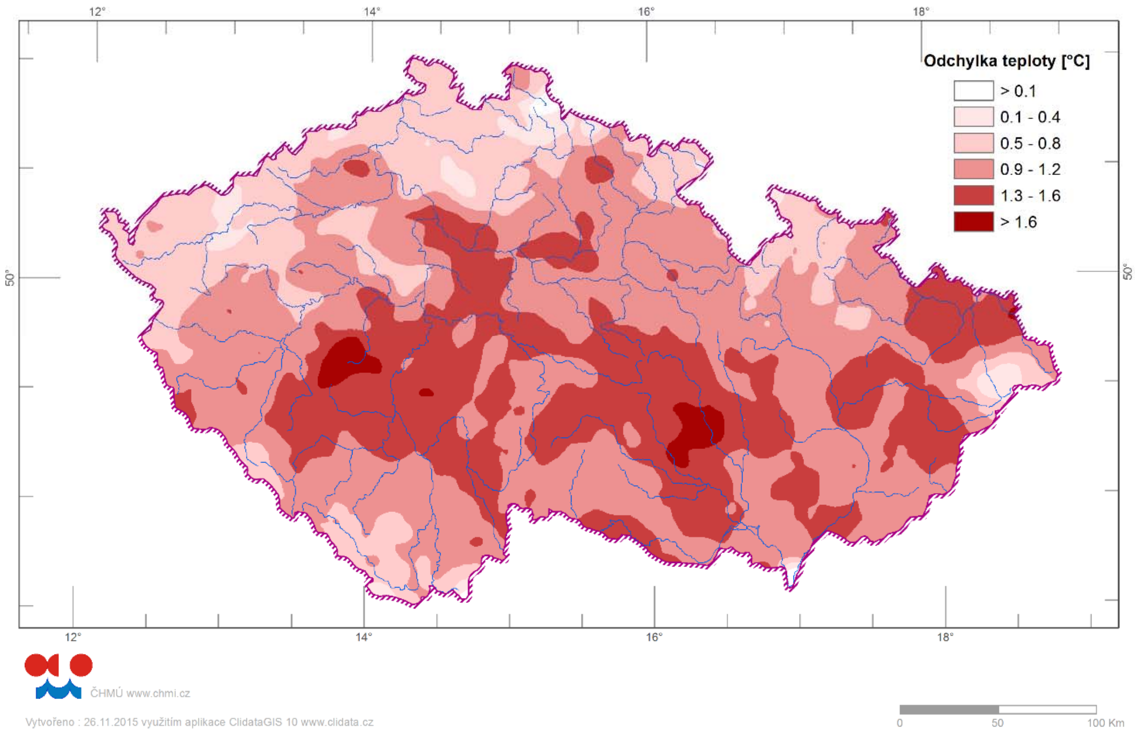


Figure 3.8. Deviation of mean air temperature from the 1981–2010 normal for the growing period (April to September) of 2015.

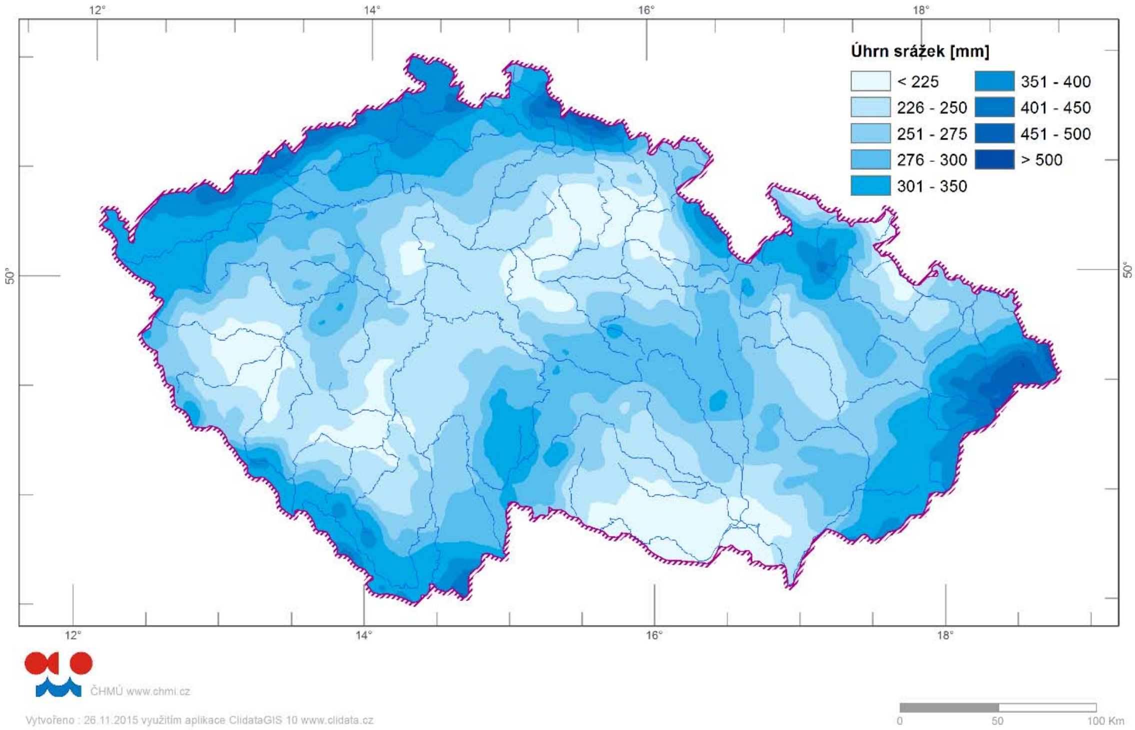


Figure 3.9. Precipitation total in mm for the growing period (April to September) of 2015.

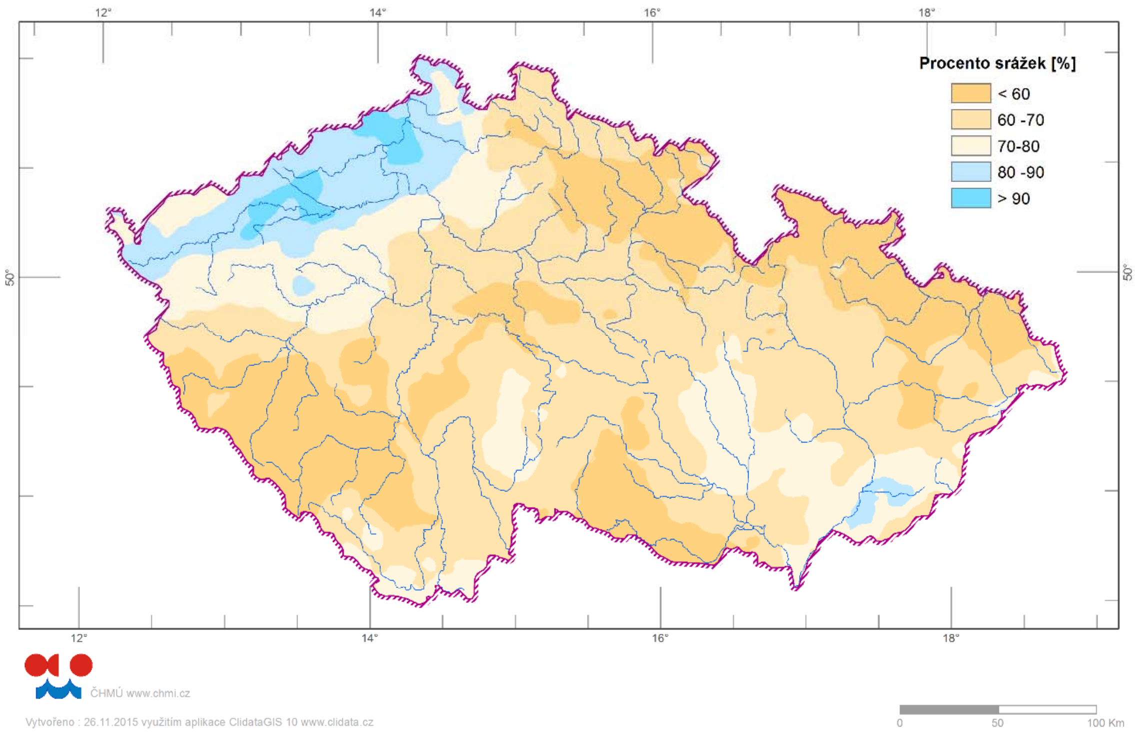


Figure 3.10. Precipitation total for the growing period (April to September) of 2015 as a percentage of 1981–2010 normal.

On average, the precipitation from 1 January to 31 October 2015 amounted to 438 mm in the Czech Republic, which was the second lowest precipitation total for the said period since 1961, and the only lower total of 429 mm was recorded in 2003. In 77% of the Czech Republic, less than 80% of the 1981–2010 (Fig. 3.6.) precipitation normal was recorded for the said period. Most precipitation fell in the mountainous regions of the Czech Republic (1,062.3 mm at the Labská Bouda station, 945.8 mm at the Lysá hora station). Totals exceeding 700 mm were also measured at some medium elevations in the north of Moravia in the Jeseníky Mountains and the Beskydy Mountains (e.g. Morávka, Uspolka 863.8 mm, Staré Hamry 740.4 mm), the Jizera Mountains (Rokytnice nad Jizerou, 723.7 mm) and in the north of Bohemia (Chřibská 708.9 mm). The lowest precipitation totals (less than 400 mm) were recorded in some areas of South and Central Moravia, in some places of North Moravia, and with the exception of the north, throughout the remaining area of Bohemia.

3.3. Temperature and Precipitation in the Drought Period (June–October 2015)

The mean air temperature in the summer months (June to August) reached 19.2°C in the Czech Republic, which was the second warmest summer since 1961, and the highest mean summer air temperature of 19.3°C was recorded in 2003. June, with an monthly mean air temperature of 16.1°C, was normal in terms of temperature; however, it was then followed by a very warm July and August. July, with an monthly mean air temperature of 20.2°C which was 2.4°C above the 1981–2010 normal, ranks among the months with strongly above-normal temperatures. August, with extraordinarily above-normal temperatures when the mean air temperature of 21.3°C was 4.0°C higher than the normal, was the warmest August in the Czech Republic since 1961. The only higher monthly mean air temperature was recorded in July 2006 (21.4°C). The mean air temperatures for the individual regions are shown in Fig. 3.11. The greatest deviation in the July temperature from the normal (2.8 °C) was recorded in the Vysočina Region, where there was also a very high deviation in the mean air temperature from the normal in August (4.2°C). The greatest deviation in the August temperature from the normal occurred in the Central Bohemian and Hradec Králové Regions (4.3°C).

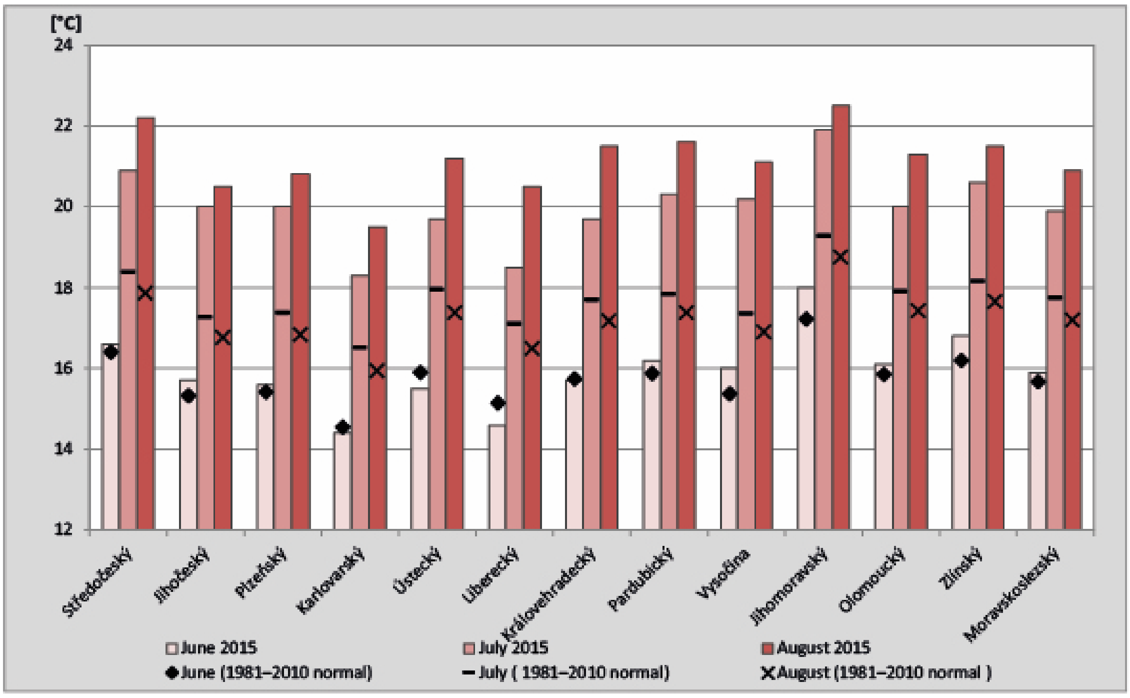


Figure 3.11. Monthly mean air temperature for June–August 2015 in individual regions of the Czech Republic compared with the 1981–2010 normal.

The very hot summer was associated with an incidence of heat waves. The first heat wave was recorded in early July in the period from 1 to 8 July. The high temperatures culminated on 5 and 7 July, when the maximum daily temperatures exceeded 35°C at many stations. The highest maximum temperature were measured at the Brandýs nad Labem (38.4°C) and the Pilsen-Bolevec stations (38.2°C) on 5 July. The highest maximum temperature in Moravia and Silesia in that period was measured at the Brod nad Dyjí station (37.1°C) on 7 July. A slight drop in temperatures was then followed by a second heat wave. Between 16 and 25 July, there was a period with very high temperatures. The highest temperatures were measured on 22 July, when temperature values again exceeded 35°C at many stations. The warmest sites were those of the Pilsen-Bolevec and Dobřichovice stations with a daily maximum temperature of 38.0°C. The highest maximum temperatures in Moravia and Silesia in that period were measured at the Strážnice (37.8°C) and Brod nad Dyjí stations (37.5°C) on 22 July.

A very strong heat wave, in terms of both duration and intensity, occurred in early August. The extraordinarily warm period lasted 14 days (from 3 to 16 August) throughout the Czech Republic. The high temperatures during that heat wave culminated on 7 and 8 August, when the daily maximum temperatures exceeded even 38°C at some stations. In that period, there were a total of up to 9 days when the maximum temperature reached 37°C, and even more at some stations. The highest maximum temperatures in that period were measured at Husinec, Řež (40.0°C), Dobřichovice (39.8°C) and Ústí nad Labem, Vaňov (39.1°C) on 8 August. The highest maximum temperature in Moravia and Silesia was measured at the Javorník station (38.2°C) on 8 August. The period of high temperatures ended upon the arrival of a cold front on 16 August. The last heat wave was recorded in late August and lasted until the beginning of September (from 27 August to 1 September). The highest maximum temperatures were measured at the Rožmitál pod Třemšínem station (37.5 °C) on 31 August and at the Javorník station (37.4 °C) on 1 September.

The occurrence of above-average temperatures was also documented through the recorded number of tropical days (days with a maximum temperature of ≥30°C) and nights (days with a minimum temperature of ≥20°C). The highest number of tropical days during July 2015 (18 days) was recorded at the Brno-Žabovřesky, Lednice, Brod nad Dyjí, Strážnice and Dyjákovice stations, and the most tropical nights (11 nights) were recorded at Prague-Klementinum. In August 2015, the highest number of tropical days (20 days) was recorded at the Dobřichovice station, and the most tropical nights (15 nights) occurred at Prague-Klementinum.

The autumn months of September and October with the mean air temperatures of 13.1°C (0.3°C above the 1981–2010 normal) and 7.8°C (0.3°C below the 1981–2010 normal) rank among the months with normal temperature, yet the mean air temperature for the entire Czech Republic for the period from January to October 2015 was the third highest since 1961. During both months, the daily mean air temperature fluctuated around the normal value. But there were alternating periods when the daily average temperature was either highly above normal or, by contrast, significantly colder than normal. In September and October, the warmest weather was in Moravia, where the highest average temperatures were recorded in the South Moravian and Zlín Regions.

The precipitation total for the period from June to October 2015 amounted to 247 mm, which was the fourth lowest precipitation total for the said period in the Czech Republic since 1961. The lowest precipitation total for that period occurred in 1962, when the precipitation total only amounted to 227 mm. Even lower than in previous years was the precipitation total for the period from June to September 2015 (195 mm), which was the second lowest in the Czech Republic since 1961. The lowest precipitation total for that period only occurred in 2003, when the precipitation total amounted to 182 mm.

The precipitation total distribution was spatially and temporally uneven, as documented in the graph in Fig. 3.12. While in most regions of the Czech Republic the precipitation total for the five-month period from June to October 2015 was significantly lower than the 1981–2010 normal, the Ústí nad Labem Region recorded precipitation total comparable with the 1981–2010 normal. The lowest precipitation total for that period occurred in the Pilsen Region (213 mm, which amounted to 62% of the 1981-2010 normal) and the Moravian-Silesian Region (221 mm, which amounted to 52% of the 1981–2010 normal). By contrast, the highest precipitation total, as compared to normal, were recorded in the northwest of Bohemia in the Ústí nad Labem Region (313 mm, i.e. 101% of the 1981–2010 normal) and the Karlovy Vary Region (296 mm, i.e. 85% of the 1981–2010 normal).

In most regions, the precipitation total for the period from June to October 2015 was lower than 80% of the 1981–2010 normal. From Fig. 3.12., it is obvious that, in some regions, the five-month precipitation total was comparable with or even lower than the 1981–2010 normal for the three-month period from June to August. The precipitation total that occurred in the Moravian-Silesian Region in the entire period from June to October 2015 was even comparable with the normal value for the two-month period from June to July. Low precipitation totals were recorded in June mainly in the east of the Czech Republic, and less than 70% of the normal precipitation amount fell in the Pardubice, Vysočina, South Moravian, Olomouc, Zlín and Moravian-Silesian Regions. In all the regions, precipitation total was below-average, especially in July when the precipitation total in almost all regions amounted to less than 50% of the 1981–2010 normal. The only exceptions were the Ústí nad Labem and Karlovy Vary Regions, where the precipitation totals in July amounted to 59% and 66% of the normal, respectively. In the southwest of Bohemia (the South Bohemian, Pilsen and Central Bohemian Regions) and in the Hradec Králové and Moravian-Silesian Regions, the precipitation total even amounted to less than 40% of the normal in July. In the South Moravian, Zlín, and Moravian-Silesian Regions, the precipitation totals for June and

July approximately corresponded to the precipitation normal for June. The precipitation totals for August were then around the normal value in most of the regions. The lowest precipitation totals for August were recorded in the South Bohemian, Pilsen and Moravian-Silesian Regions – less than 60% of the 1981-2010 normal. By contrast, the highest precipitation totals related to the normal were recorded in the South Moravian Region (143% of the 1981–2010 normal), the Zlín Region (119% of the 1981–2010 normal) and the Ústí nad Labem Region (111% of the 1981–2010 normal).

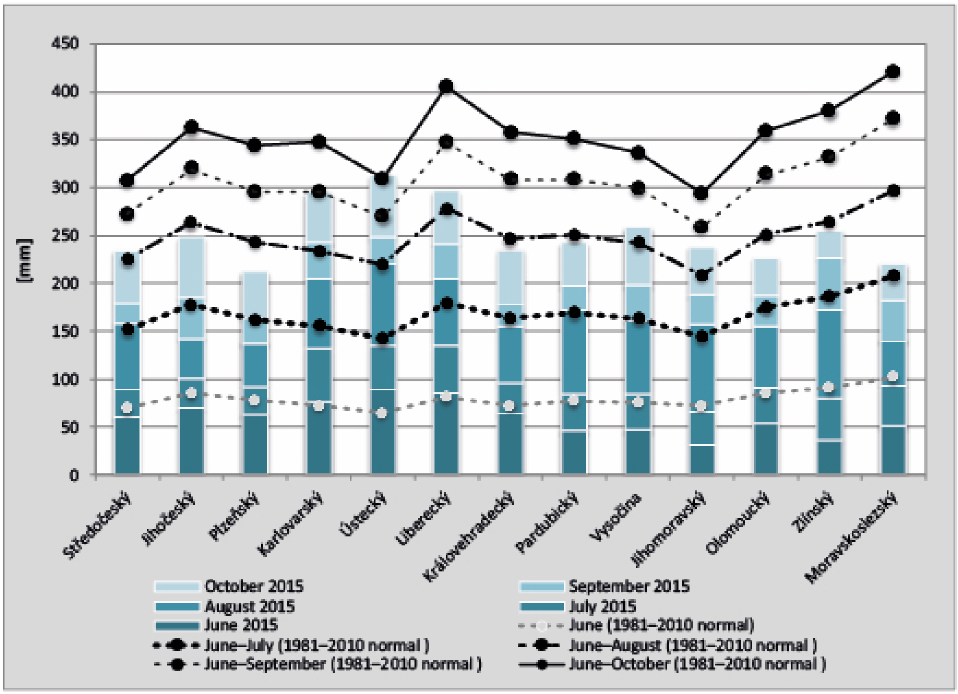


Figure 3.12. Monthly mean precipitation totals for June–August 2015 in individual regions in comparison with the 1981–2010 normal.

However, most of the August precipitation total stems from the abundant rainfall during 14–19 August, when the highest daily precipitation totals exceeded 50 mm, and in places, they reached even 80 mm. During those days, the most plentiful rainfall occurred in the zone stretching from the Ústí nad Labem Region across the country to the South Moravian and Zlín Regions (Fig. 3.13.). The highest daily precipitation total of 81.4 mm for this period was recorded at the Bukovinky station (Blansko District) on 17 August, and exceeded 50-year return level value. Even though the one-day precipitation totals were not so significant in terms of extremity, in the case of two-day and three-day precipitation total, exceeded 100-year return level value.

In the next month (September), the precipitation totals in all the regions were also below the 1981–2010 normal. The lowest precipitation totals as compared with the normal were recorded in the east of Bohemia in the Hradec Králové and Pardubice Regions (37% and 42% of the 1981–2010 normal, respectively), as well as in the Central Bohemian Region (44% of the 1981–2010 normal). In October, the precipitation totals were evenly distributed spatially. While in the east of the Czech Republic (the Moravian-Silesian, Zlín and Olomouc Regions), they continued to be below the normal values, in some regions, they highly exceeded them. As compared with the normal, the lowest precipitation total occurred in the Zlín Region (60% of the 1981–2010 normal). By contrast, the highest precipitation total occurred in the Ústí nad Labem Region (64 mm, which was 160% of the normal), the Central Bohemian Region

(55 mm, which was 159% of the 1981–2010 normal) and the Vysočina Region (61 mm, which was 157% of the 1981–2010 normal).

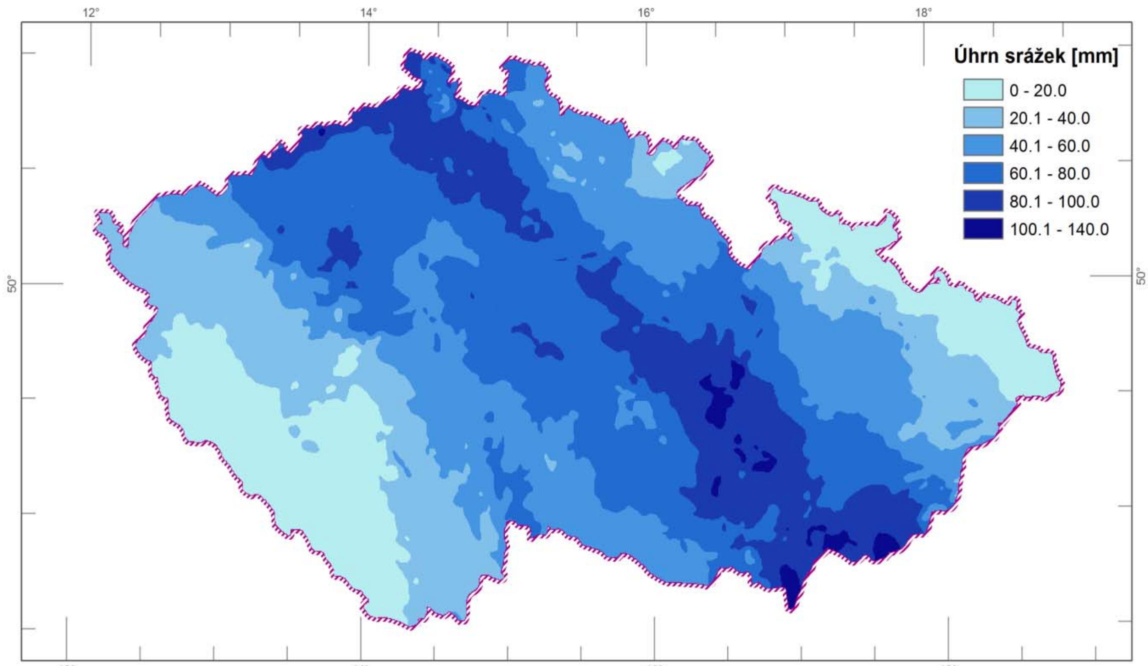


Figure 3.13. Precipitation total in the Czech Republic from 16 to 19 August 2015.

4. Evaluation of Evaporation, Evapotranspiration and Moisture Balance

Chapter 4 very briefly summarizes and analyzes selected modeled agro-climatic characteristics supplemented with the measured water surface evaporation data. The current year 2015 has been processed for the period until mid-October with a special emphasis on the months of June to September, which were characterized by distinct signs of drought in most of the Czech Republic. The evaluation covers the actual level or course of the agro-climatic characteristic at hand in 2015 and comparison of such data with the long-term average for 1981–2010.

A brief description of the special elements evaluated is provided in Technical Appendix 4.

4.1. Evaluation of Measured Water Surface Evaporation

Contrary to the agrometeorological characteristics, evaporation from the water surface has been measured. Fig. 4.1. shows the monthly totals for selected stations for the period from May to September, including a comparison of 2015 with the long-term total for 1981–2010. The maps are for informational purposes only.

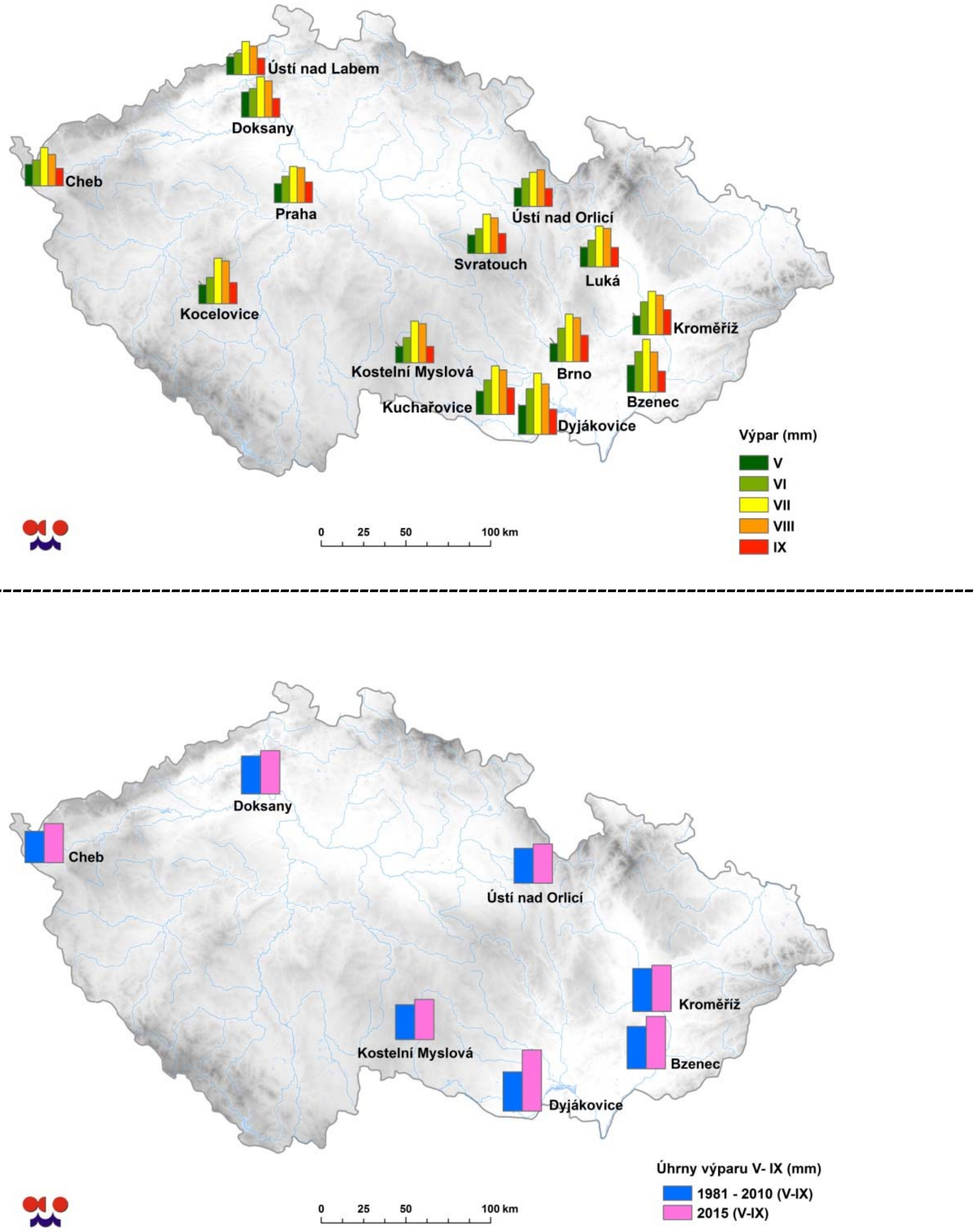


Figure 4.1. Evaporation from the water surface at selected climatological stations of the Czech Republic in 2015 and comparison with the long-term average for 1981–2010.

In 2015 the highest monthly data are typical for the summer months of July and August. Should we compare the overall total for the period from May to September 2015 with the long-term average for 1981–2010, then at all the selected stations the 2015 totals prevail, which indicates generally very favorable conditions for drought occurrence. This fact is very significant at the stations in South Moravia.

4.2. Evaluation of Evaporation from Bare Soil

As of the selected dates in 2015 (14 June, 12 July, 16 August and 20 September) in the Czech Republic, the maps in Figs. 4.2. and 4.3. analyze a continuous level of potential evaporation from bare soil (hereinafter referred to as PEVA_HP, data in mm) and a continuous level of actual evaporation from bare soil (hereinafter referred to as AEVA_HP, data in mm) and their mutual comparison with the long-term values for 1981–2010, (the resulting values are in percentages). In both cases, the resulting evaporation totals are continuously accumulated for the period from 1 March.

The higher the percentage is, the higher the PEVA_HP or AEVA_HP value for 2015 is, as compared with the long-term 1981–2010 average, and the higher the probability of negative moisture balance and the probability of the fulfillment of conditions for drought occurrence are.

Should we take PEVA_HP and its comparison with the long-term conditions into consideration, then from the maps in Fig. 4.2., it is possible to observe the gradually worsening moisture conditions throughout most of the country, and it was proven that the atmospheric drying capability had increased. Up to July (inclusive), the dominant intervals ranged from 90 to 100% and from 100 to 110% of the long-term average. However, commencing in August, the interval ranging from 110 to 125% of the long-term average started to strongly prevail in the Czech Republic, which generally indicates worsened moisture conditions and better conditions for drought occurrence.

Through a detailed analysis of AEVA_HP (Fig. 4.3.), we come to somewhat different conclusions than for PEVA_HP (Fig. 4.2.). During the period from June to September, we observe the growing importance of the presence of the intervals from 75 to 90% and from 90 to 100% of the long-term average. As in the case of grassland, this fact can be logically explained through a lack of water for actual evaporation. As per the PEVA_HP data, the atmospheric drying capability is high, but in the environment itself there is only a limited amount of water that is available for actual evaporation (AEVA_HP value).

During the growing season, this year's evaporation conditions showed a deepening negative development trend. In terms of PEVA_HP, the least favorable situation occurred at the end of the monitored period in August and September.

Structured by weeks (over the period from April to mid-October) for the entire Czech Republic, the graphs in Figs. 4.4 and 4.5 provide a percentage comparison of the daily cumulative PEVA_HP and AEVA_HP totals (always accumulations from 1 March) in 2015 with the long-term conditions in the period from 1981 to 2010. In both graphs, it is possible to easily find out which part of the Czech Republic, expressed in percentages, fell into the selected intervals (< 80% … > 140% of the long-term average for PEVA_HP and AEVA_HP).

From the graph in Fig. 4.4 (PEVA_HP analysis), it follows that the interval of 100 to 120% of the long-term average, which is less favorable in terms of moisture, had a dominant presence in the Czech Republic practically throughout the period from May to mid-October. (Commencing in August, the share of the interval ranging from 120 to 150% of the long-term average was concurrently increasing.) From the graph in Fig. 4.5. (AEVA_HP analysis), it follows that the interval of 80 to 100% of the long-term average had a dominant and very significant presence in the Czech Republic practically throughout most of the analyzed period.

The timeline of the daily cumulative PEVA_HP and AEVA_HP totals in 2015 (in the period from January to October), expressed as a percentage of the long-term average for 1981–2010, is shown for the Doksany and Strážnice climatological stations in Figs. 4.6. and 4.7.

The graphs in Figs. 4.8. and 4.9. document the time course of daily average cumulative totals of PEVA_HP and AEVA_HP in 2015 (for the period from April to September) and their comparison with the long-term average for 1981–2010 for selected areas of the Czech Republic (areas of Haná, South Moravia, the Elbe River basin, the Ohře River basin, the Bohemian-Moravian Highlands). Each of the areas is represented through a set of selected climatological stations.

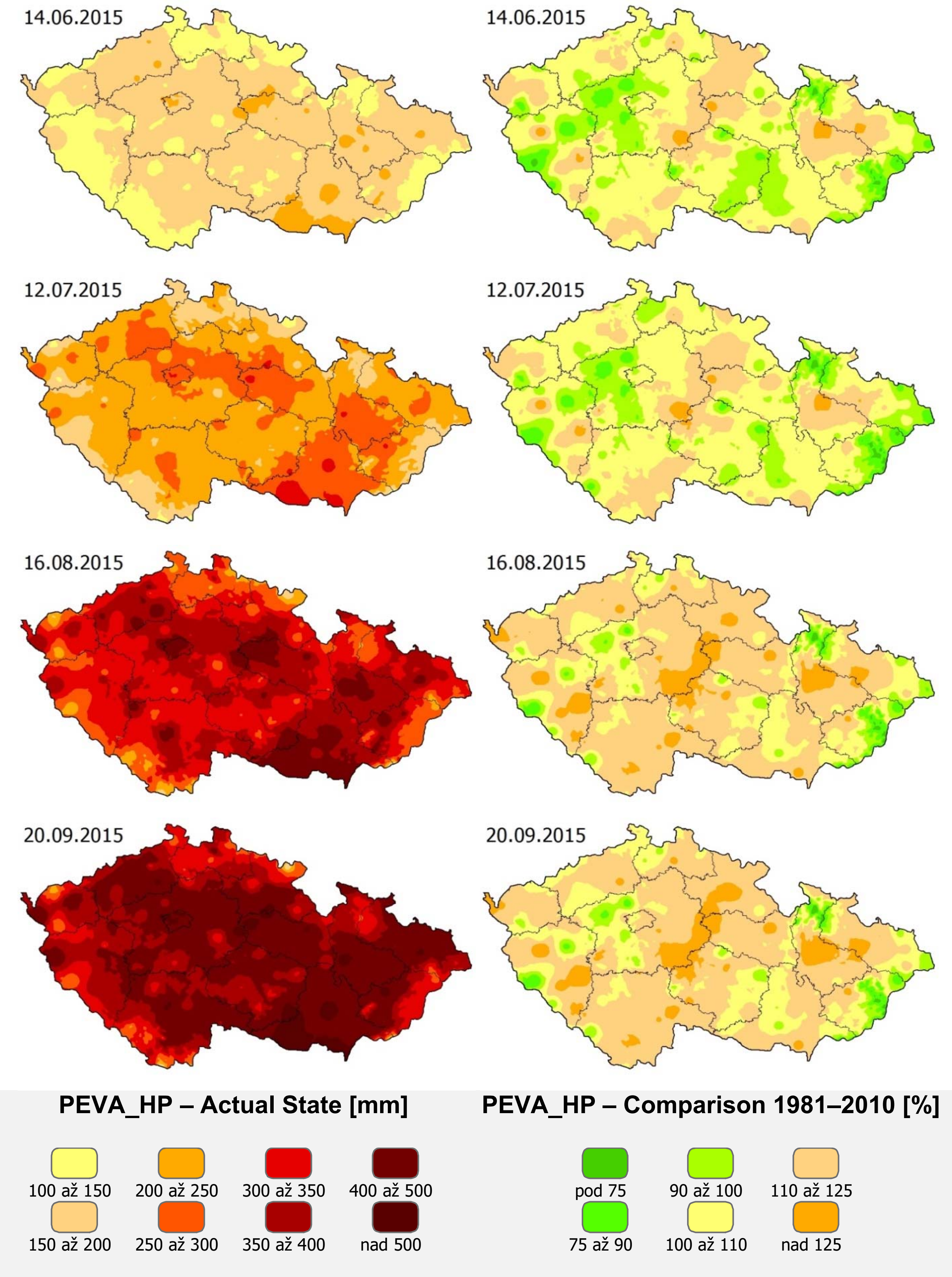


Figure 4.2. Potential evaporation from bare soil in the Czech Republic, cumulative totals from 1 March for selected days in 2015 and their comparison with the long-term average for 1981–2010.

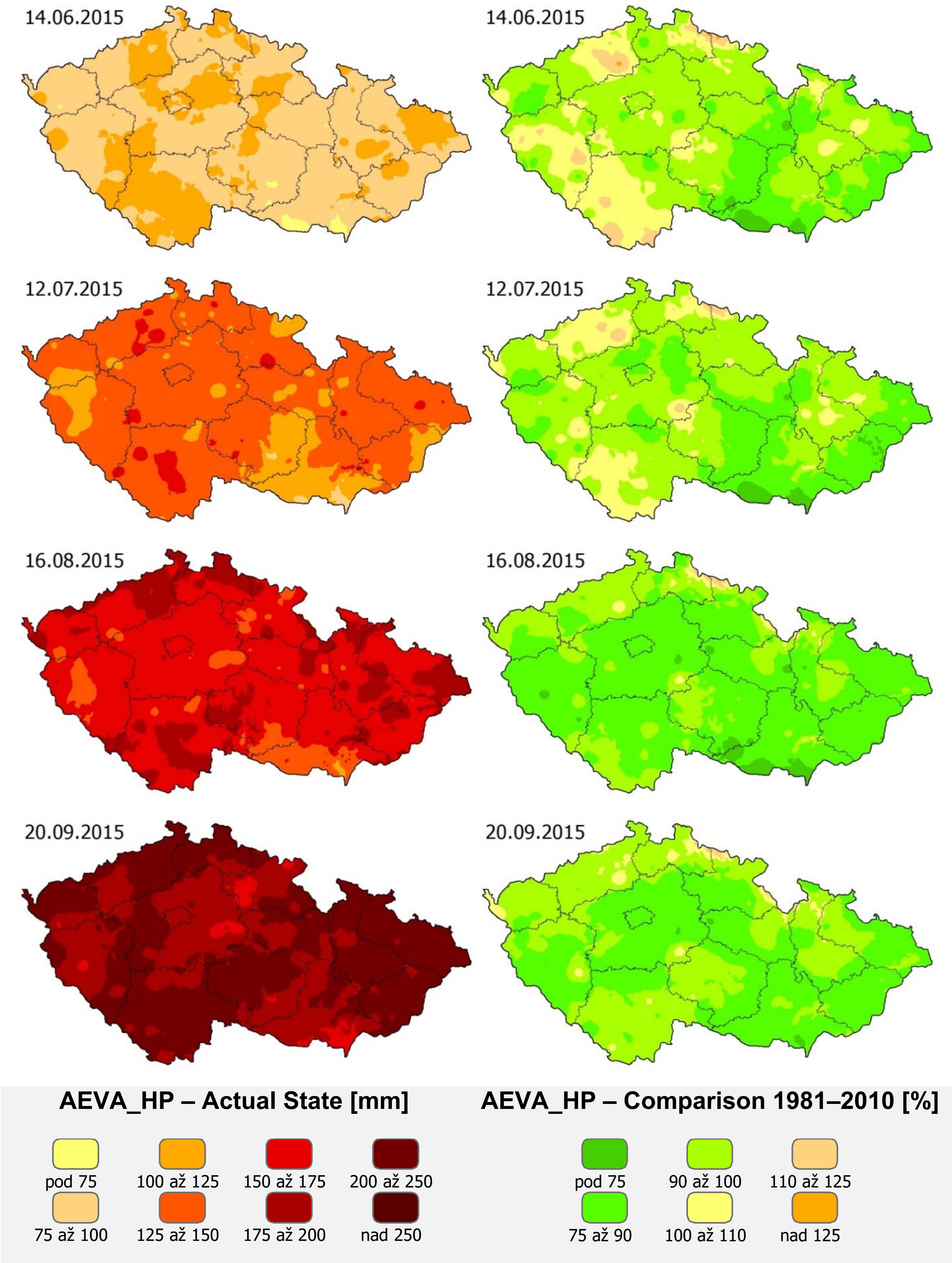


Figure 4.3. Actual evaporation from medium-heavy bare soil in the Czech Republic, cumulative totals from 1 March for selected days in 2015 and their comparison with the long-term average for 1981–2010.

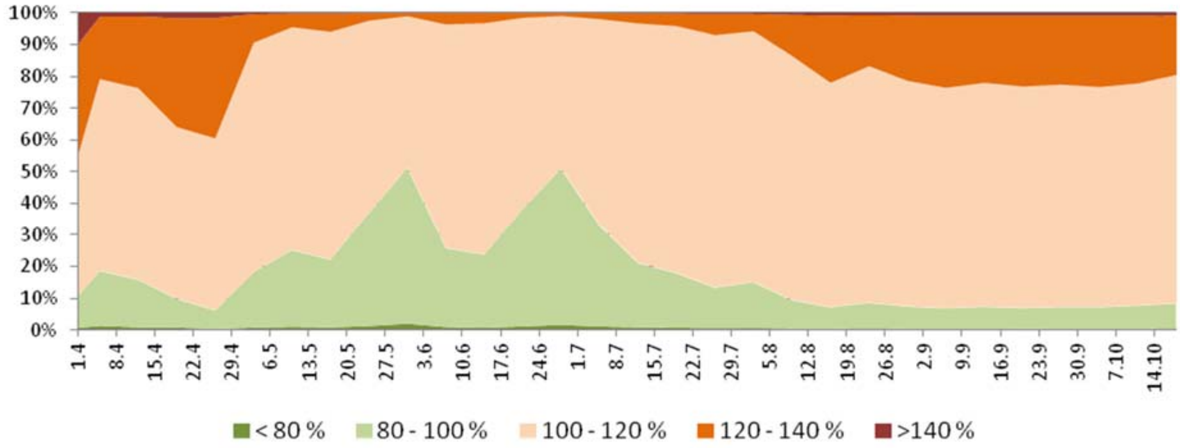


Figure 4.4. Comparison of potential evaporation from bare soil in 2015 with the long-term average for 1981–2010 in percentages, shares of areas of selected intervals in the Czech Republic (%), values accumulated from 1 March.

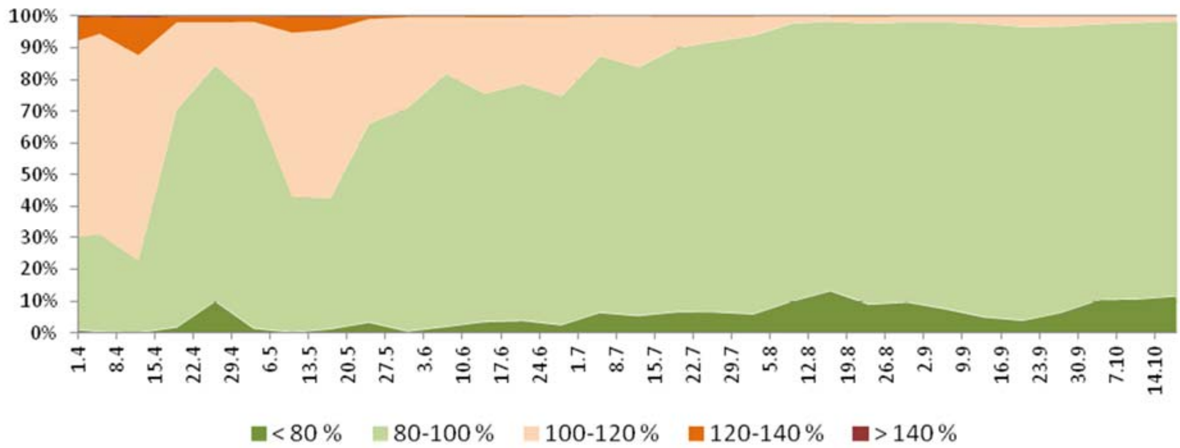


Figure 4.5. Comparison of actual evaporation from medium-heavy bare soil in 2015 with the long-term average for 1981–2010 in percentages, shares of areas of selected intervals in the Czech Republic (%), values accumulated from 1 March.

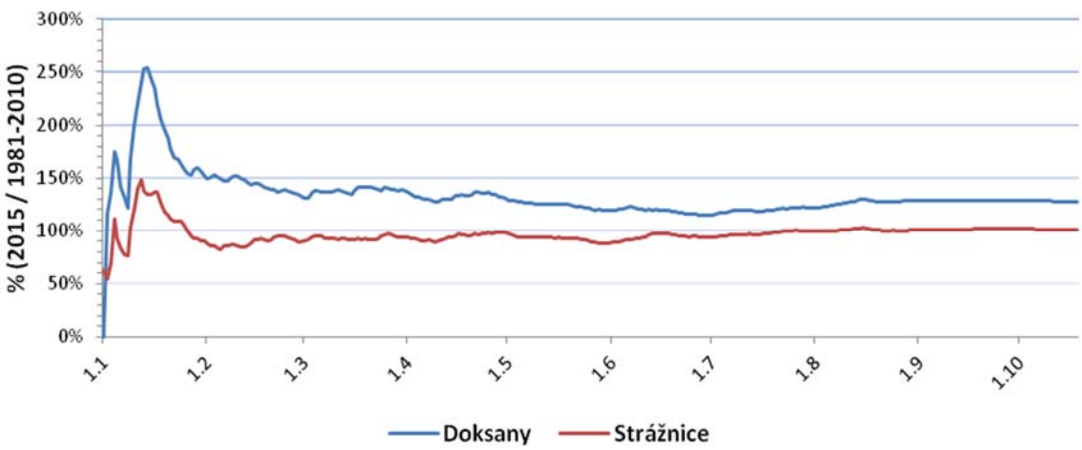


Figure 4.6. Doksany and Strážnice stations, cumulative total potential evaporation from bare soil in 2015 expressed as a percentage of the long-term average for 1981–2010.

Figure 4.7. Doksany and Strážnice stations, cumulative total actual evaporation from medium-heavy bare soil in 2015 expressed as a percentage of the long-term average for 1981–2010.

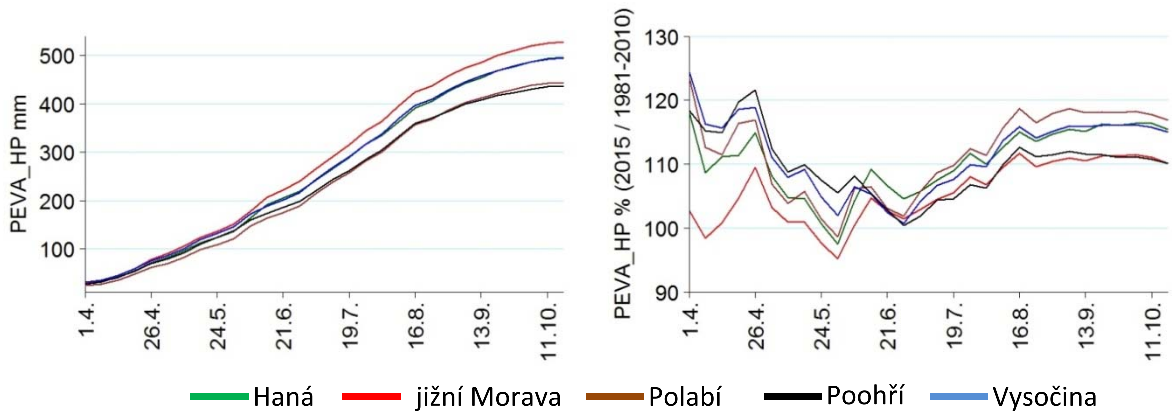


Figure 4.8. Areas of Haná (green), South Moravia (red), the Elbe river lowland (brown), the Ohře river lowland (black), the Bohemian-Moravian Highlands (blue), average cumulative total potential evaporation from bare soil in 2015, continuous accumulation from 1 April (left graph) and comparison with the long-term average for 1981–2010 (right graph).

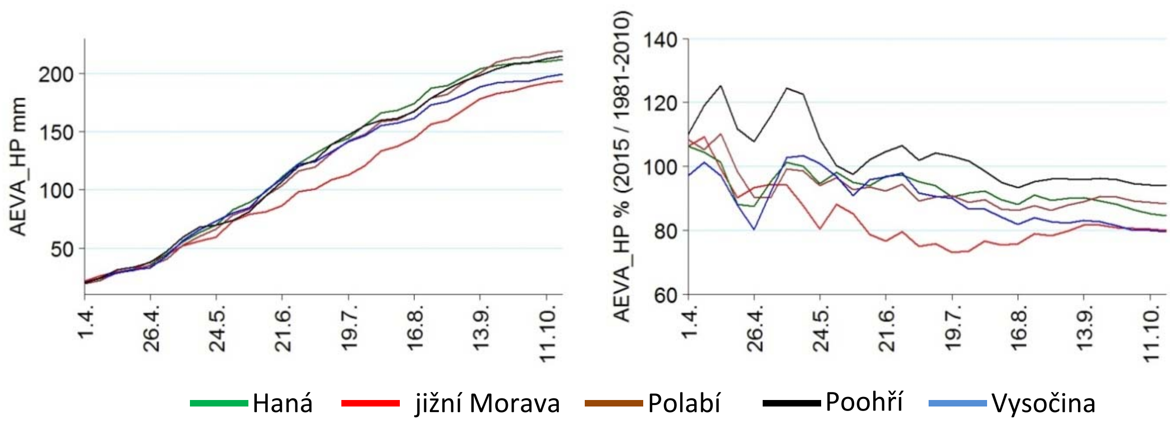


Figure 4.9. Areas of Haná (green), South Moravia (red), the Elbe river lowland (brown), the Ohře river lowland (black), the Bohemian-Moravian Highlands (blue), average cumulative total actual evaporation from medium-heavy bare soil in 2015, continuous accumulation from 1 April (left graph) and comparison with the long-term average for 1981–2010 (right graph).

4.3. Evaluation of Evapotranspiration from Grassland

As of the selected dates in 2015 (14 June, 12 July, 16 August and 20 September) in the Czech Republic, the maps in Figs. 4.10. and 4.11. analyze a continuous level of potential evapotranspiration from grassland (hereinafter referred to as PEVA_TP, data in mm) and a continuous level of actual evapotranspiration from grassland (hereinafter referred to as AEVA_TP, data in mm) and their mutual comparison with the long-term data for 1981–2010. (The resulting values are in percentages.) In both cases, the resulting evapotranspiration totals are continuously accumulated for the period from 1 March.

The higher the percentage is, the higher the 2015 PEVA_TP or AEVA_TP value is in comparison with the long-term average for 1981–2010 and the higher the probability of negative moisture balance and the probability of the fulfillment of conditions for drought occurrence are.

Should we take into account the PEVA_TP and its comparison with the long-term conditions, then from the maps in Fig. 4.10., it is possible to observe the gradually worsening moisture conditions throughout most of the country, or in other words, the increased drying capability of the atmosphere has been proven. Up to July (inclusive), the interval of 100–110% of the long-term average was dominant. However, commencing in August, the intervals of 110 to 125% and >125% of the long-term average started to significantly prevail in the Czech Republic, which generally indicates an increased drying capability of the atmosphere, worsened moisture conditions, and better conditions for drought occurrence.

Through a detailed analysis of AEVA_TP (Fig. 4.11.), we come to conclusions that are slightly different from those of PEVA_TP (Fig. 4.10.). During the period from June to September, we observe an increasing share of the interval of 90 to 100% of the long-term average (to a smaller extent, also an increasing share of the interval of 75 to 90% of the long-term average), and by contrast, a decreasing share of the interval of 100 to 110% of the long-term average. As in the case of bare soil, this fact can be logically explained through a lack of water for actual evaporation. As per the PEVA_HP values, the drying capability of the atmosphere was high, but in the environment itself, there was only a limited amount of water available for actual evapotranspiration (AEVA_TP value).

This year the evaporative conditions showed a deepening negative development trend during the growing season. In terms of PEVA_TP, the least favorable situation occurred at the end of the monitored period in August and September.

The graphs in Figs. 4.11. and 4.12. present, for the entire Czech Republic structured by weeks (period from April to mid-October), a percentage comparison of the daily cumulative totals of PEVA_TP and AEVA_TP (always accumulation from 1 March) in 2015 with the long-term conditions for 1981–2010. From both graphs, it is possible to easily find out which part of the Czech Republic, expressed in percentages, fell into the selected intervals (< 80% … > 140% and < 70% … > 130% of the long-term average for PEVA_TP and AEVA_TP, respectively).

From the graph in Fig. 4.12. (PEVA_TP analysis), it follows that the dominant share was held by the interval of 100 to 120% of the long-term average, which was less favorable in terms of moisture, practically for the entire period from May, or as the case may be, even from April, to mid-October. (From August, there was also an increasing share of the interval of 120 to 150% of the long-term average.) From the graph in Fig. 4.13. (AEVA_TP analysis), it follows that in the Czech Republic, a dominant and very significant share was held by the interval of 90 to 110% of the long-term average practically for the vast majority of the analyzed period.

The time course of daily cumulative totals of PEVA_TP and AEVA_TP in 2015 (for the period from January to October) expressed as a percentage of the long-term average for 1981–2010 is presented in Figs. 4.14. and 4.15. for the Doksany and Strážnice climatological stations.

The graphs in Figs. 4.16. and 4.17. document the time course of daily average cumulative totals of PEVA_TP and AEVA_TP in 2015 (for the period from April to October) and their comparison with the long-term average for 1981–2010 for the selected areas of the Czech Republic (Haná, South Moravia, the Elbe River basin, the Ohře River basin, the Bohemian-Moravian Highlands). Each of the areas is represented through a set of selected climatological stations.

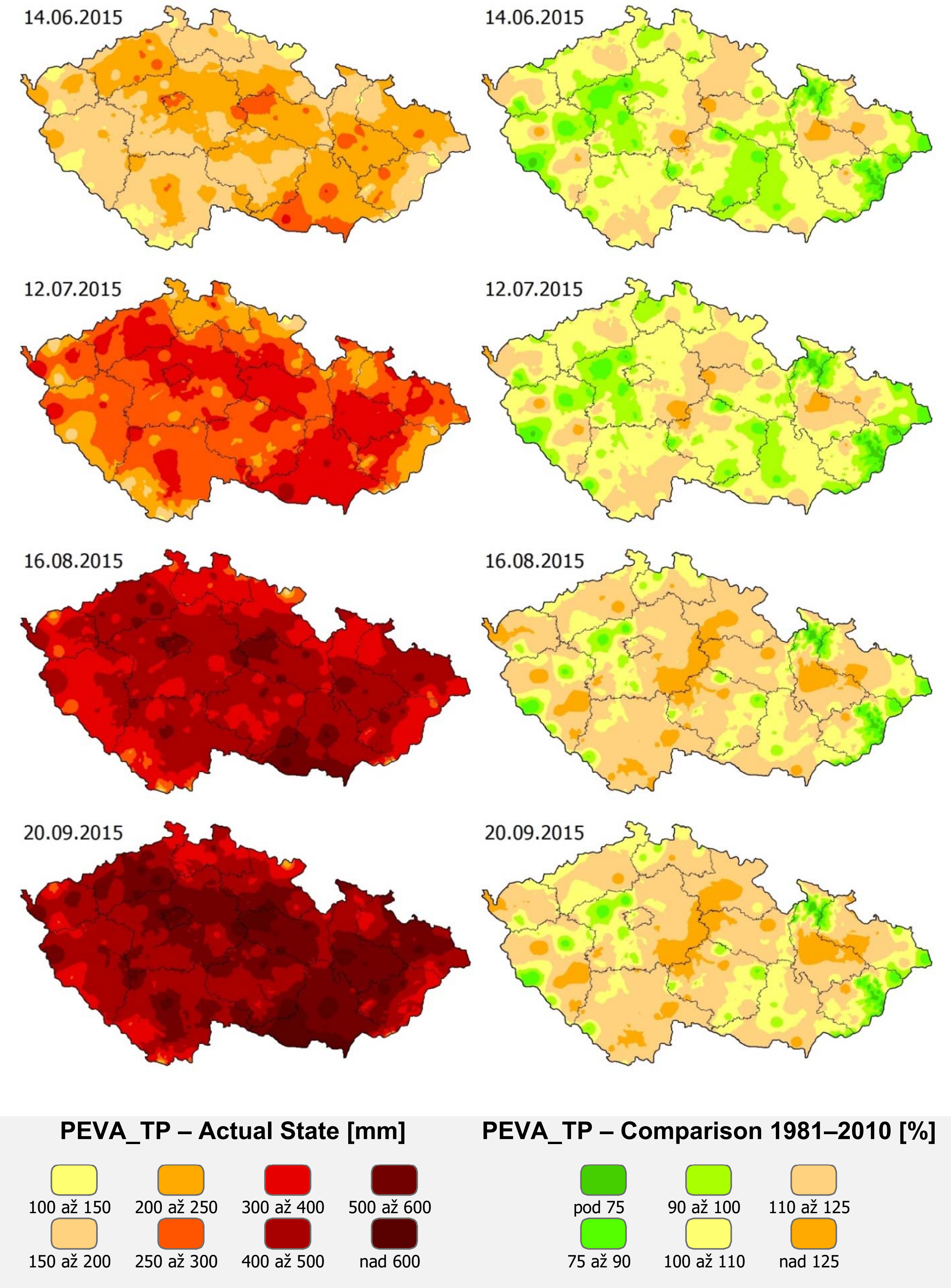


Figure 4.10. Potential evapotranspiration from grassland in the Czech Republic, cumulative totals from 1 March for selected days in 2015 and their comparison with the long-term average for 1981–2010.

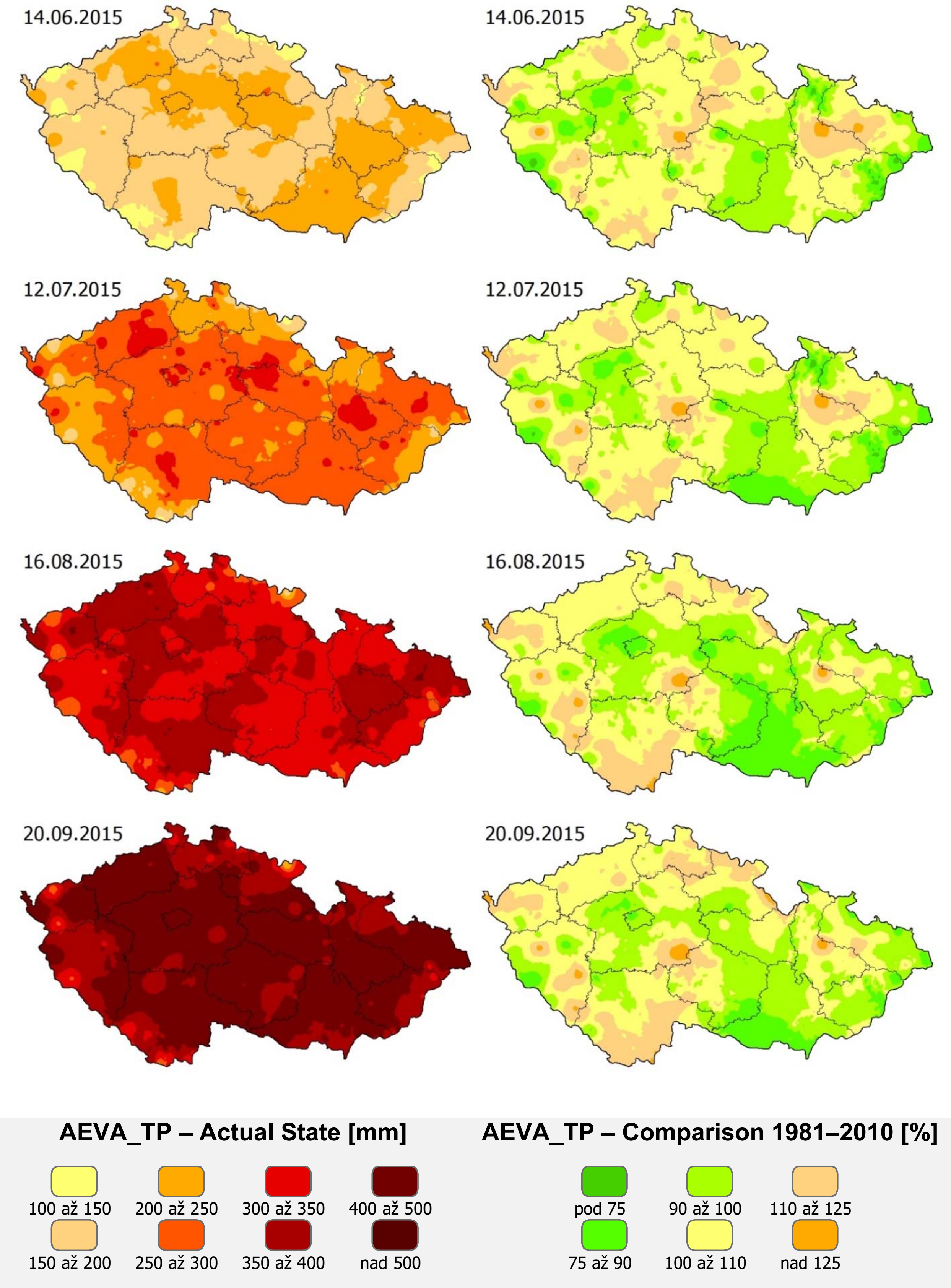


Figure 4.11. Actual evapotranspiration from grassland with medium-heavy soil in the Czech Republic, cumulative totals from 1 March for selected days in 2015 and their comparison with the long-term average for 1981–2010.

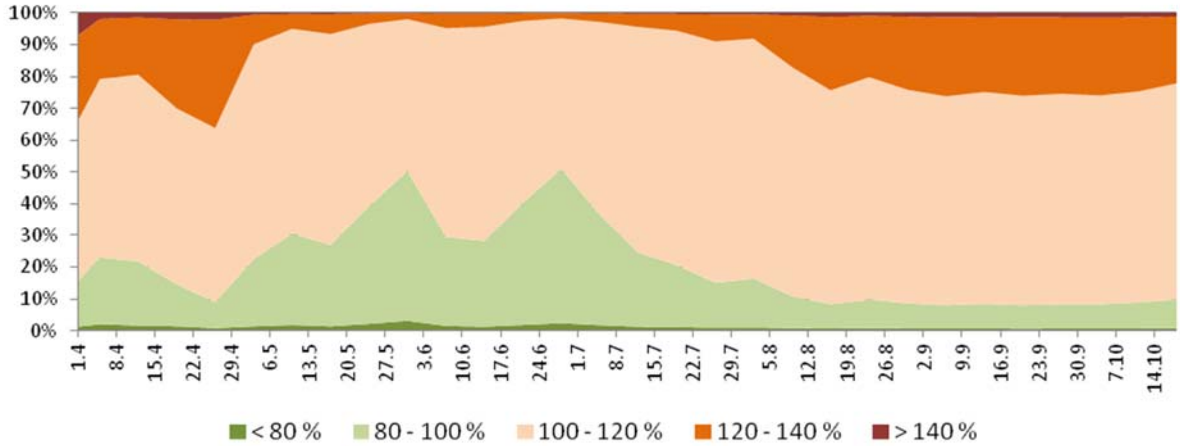


Figure 4.12. Comparison of potential evapotranspiration from grassland in 2015 with the long-term average for 1981–2010 in percentages, shares of areas of selected intervals in the Czech Republic (%), values accumulated from 1 March.

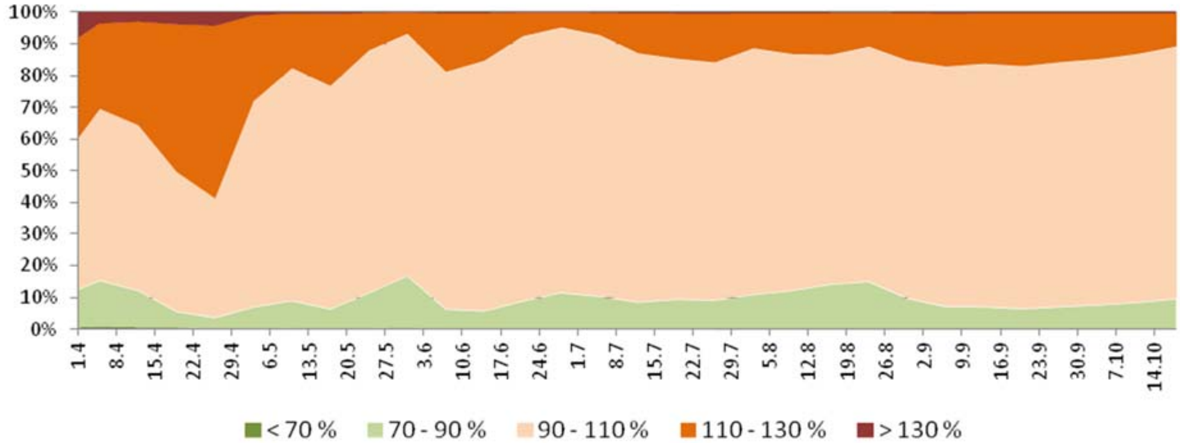


Figure 4.13. Comparison of actual evapotranspiration from grassland with medium-heavy soil 2015 with the long-term average for 1981–2010 in percentages, shares of areas of selected intervals in the Czech Republic (%), values accumulated from 1 March.

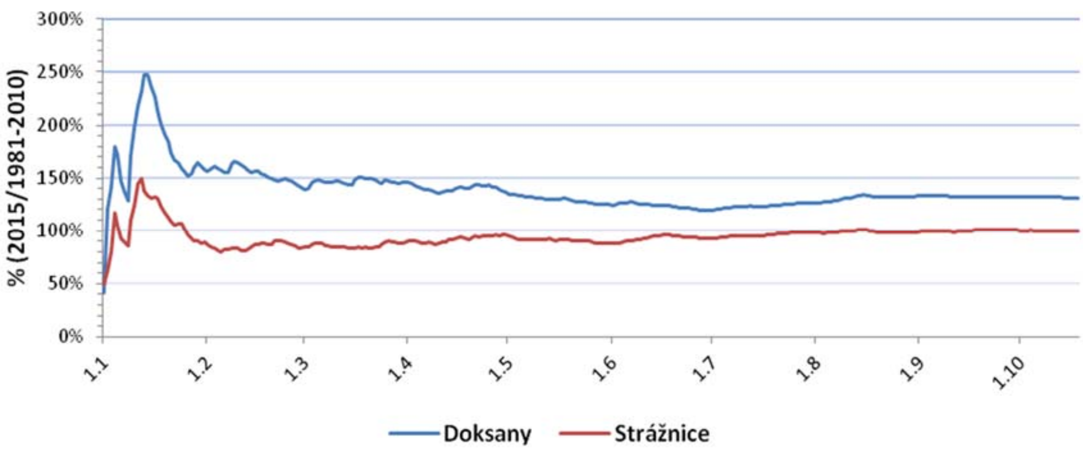


Figure 4.14. Doksany and Strážnice stations, cumulative totals of potential evapotranspiration from grassland in 2015 expressed as a percentage of the long-term average for 1981–2010.

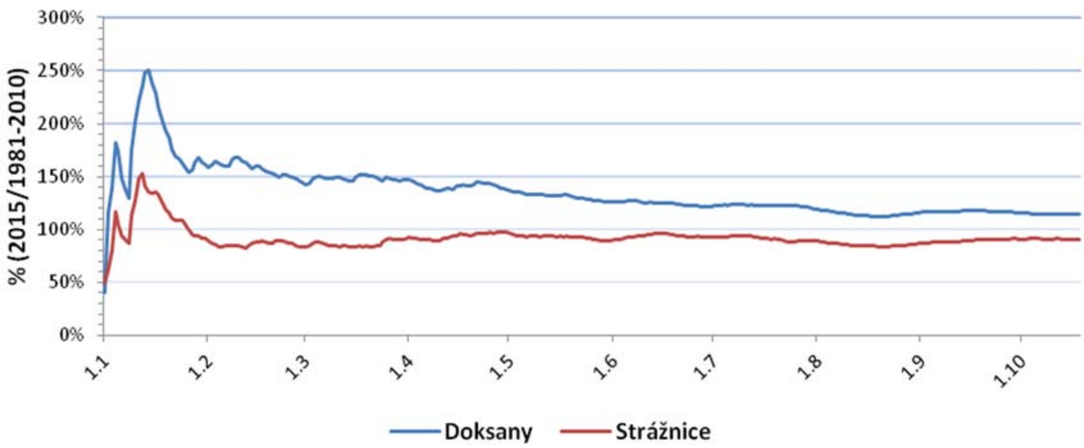


Figure 4.15. Doksany and Strážnice stations, cumulative totals of actual evapotranspiration from grassland with medium-heavy soil in 2015 expressed as a percentage of the long-term average for 1981–2010.

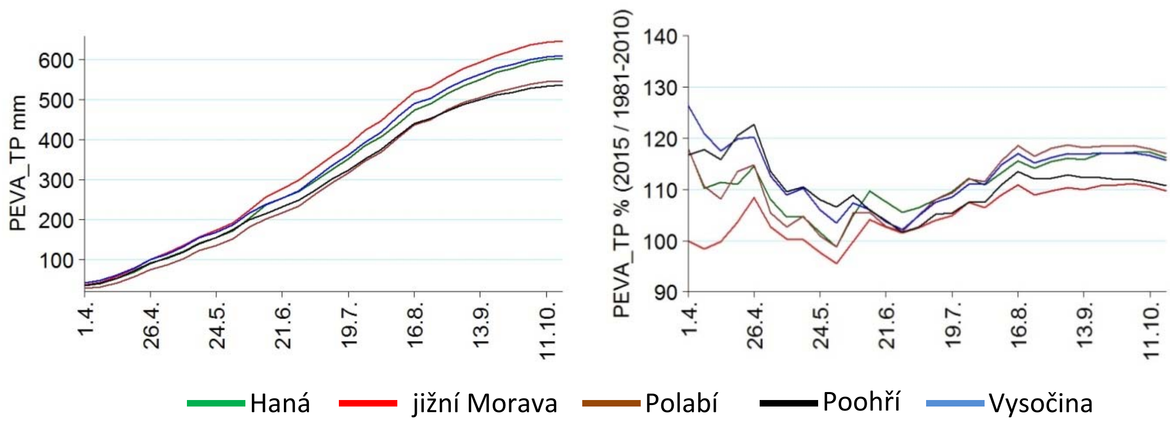


Figure 4.16. Areas of Haná (green), South Moravia (red), the Elbe river lowland (brown), the Ohře river lowland (black), the Bohemian-Moravian Highlands (blue), average cumulative totals of potential evapotranspiration from grassland in 2015, continuous accumulation from 1 April (left graph) and comparison with the long-term average for 1981–2010 (right graph).

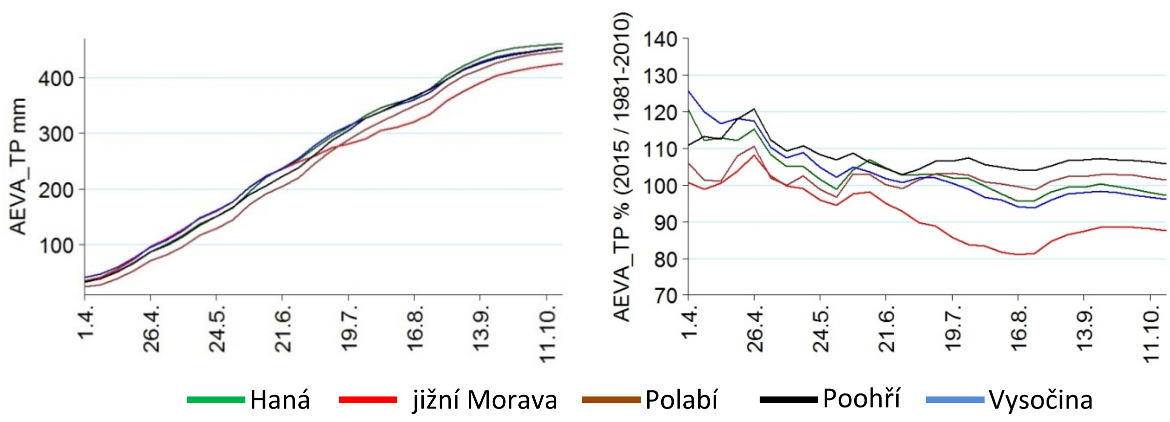


Figure 4.17. Areas of Haná (green), South Moravia (red), the Elbe river lowland (brown), the Ohře river lowland (black), the Bohemian-Moravian Highlands (blue), average cumulative totals of actual evapotranspiration from grassland with medium-heavy soil in 2015, continuous accumulation from 1 April (left graph) and comparison with the long-term average for 1981–2010 (right graph).

4.4. Grassland Moisture Balance Evaluation

As of the selected days in 2015 (14 June, 12 July, 16 August and 20 September) in the Czech Republic, the maps in Figs. 4.18. and 4.19. analyze a continuous level of the basic moisture balance of grassland (hereinafter referred to as ZVLBI_TP, data in mm) and a continuous level of the actual moisture balance of grassland (hereinafter referred to as AVLBI_TP, data in mm) and their comparison with the long-term values of 1981–2010, (and the resulting data are again expressed in mm). In both the cases, the resulting moisture balance totals are continuously accumulated from 1 March.

The lower the differences between the precipitation and evapotranspiration from grassland (as assumed for ZVLBI_TP and AVLBI_TP) are, the worse the moisture conditions are, and therefore, the higher the probability of the fulfillment of conditions for drought occurrence in the country is. Similarly, the lower the differences between ZVLBI_TP or AVLBI_TP in 2015 and the long-term average for 1981–2010 are, again, the higher the probability of drought occurrence in the country is.

Should we take into account the actual level of PVLBI_TP from the maps in Fig. 4.18., it clearly follows that there was a trend of gradual worsening of the moisture balance in the Czech Republic. In mid-June 2015 the interval of -100 to 0mm still strongly prevailed, but, during August and September, the situation got significantly worse throughout the Czech Republic. The dominant share was already held by the intervals of -200 to -100mm and -300 to -200mm which were very unfavorable in terms of moisture. A significant share was also held by the interval of -300mm and less (most of South Moravia, part of Haná, the eastern Elbe River basin and Central Bohemia).

A similar development trend follows from a comparison of the actual level of PVLBI_TP with the long-term average for 1981-2010 (Fig. 4.18.). In June, the deviation from the long-term average across most of the Czech Republic was still in the interval of -100 to -50mm or -50 to 0mm, but in July, it had already reached the interval of -150 to -100mm or -100 to -50mm. Across most of the Czech Republic, August and September were characterized by the prevailing intervals of -250 to -200mm and -250mm and less (Northeast Moravia, West Bohemia and to a lesser extent, the Elbe River basin), which are, however, very unfavorable in terms of moisture.

A detailed analysis of the actual level of AVLBI_TP (Fig. 4.19.) documents a similar development trend as in the case of PVLBI_TP. At the beginning of the monitored period, the intervals of -100 to -50mm and -50 to 0mm prevailed throughout the Czech Republic, but, as early as mid-July, a large area of South Moravia fell into the interval of -150mm and less, which was very unfavorable in terms of moisture. Worsened moisture conditions were also documented by the maps for 16 August and 20 September with the strongly prevailing intervals of -150 to 100mm and -150mm throughout the Czech Republic. (The most affected areas were those of South Moravia, Haná, some areas of the eastern Elbe River basin, Central and South Bohemia.)

A comparison of the actual level of AVLBI_TP with the long-term conditions (Fig. 4.19.) again shows a similar pattern as that of PVLBI_TP (Fig. 4.18.). During August and September, a substantial part of the Czech Republic showed the largest deviations of AVLBI_TP from the long-term average (-250 to -200mm, sporadically up to -250mm and less) in Northeast Moravia, South and West Bohemia and also in the Giant Mountains (Krkonoše).

A brief textual analysis of the maps in Figs. 4.18. and 4.19. is provided for the areas of the Czech Republic situated at low and medium elevations for which a negative and sometimes even significantly negative ZVLBI_TP and AVLBI_TP value was determined. By contrast, during 2015 the borderland mountains of the Czech Republic (Giant Mountains – Krkonoše, Ore Mountains - Krušné Hory, Šumava, Jeseníky, Karpaty and Beskydy Mountains) were mostly characterized by a positive moisture balance. In other words, precipitation as of a specific date always prevailed over evapotranspiration, which follows from the respective maps.

During the growing period of 2015, the moisture conditions showed a deepening negative development trend. In conclusion, it is possible to say that from the perspective of ZVLBI_TP and AVLBI_TP, the least favorable situation occurred at the end of the monitored period in August and September.

The graphs in Figs. 4.20.–4.23. present, for the entire Czech Republic structured by weeks (of the period from April to mid-October), the actual level of ZVLBI_TP and AVLBI_TP (always accumulation from 1 March) in mm in 2015 and its difference from the long-term conditions for 1981–2010. From both graphs, it is possible to easily determine which part of the Czech Republic, expressed in percentages, fell into the selected intervals (< -250mm … > 50mm and < -200mm … > 0mm for ZVLBI_TP, or, as the case may be, < -150mm … > 0mm and < -150mm … > 50mm for AVLBI_TP).

From the graphs in Figs. 4.20 and 4.21 (PVLBI_TP evaluation), it follows that commencing in August, the dominant shares were held by the intervals of < -250mm and -250 to -150mm, which were the least favorable in terms of moisture, (Fig. 4.20., approximately 70% of the Czech Republic), or, as the case may be, < -200mm and -200 to -100mm, (Fig. 4.21., more than 80% of the Czech Republic).

The AVLBI_TP processing results (Figs. 4.22. and 4.23.) are very similar. From the graphs in Figs. 4.22. and 4.23., it follows that again commencing in August, the dominant shares were held by the intervals of < -150mm and -150 to -100mm, which were the least favorable in terms of moisture (Fig. 4.22, almost 70% of the Czech Republic; Fig. 4.23., more than 60% of the Czech Republic).

Should we take into account the actual level of moisture balance (Figs. 4.20. and 4.22.), then the least favorable moisture intervals occurred in the Czech Republic as early as June (ZVLBI_TP) and May (AVLBI_TP).

The time course of ZVLBI_TP and AVLBI_TP totals in 2015 (in the period from January to October) expressed in mm as a difference from the long-term average for 1981–2010 is shown for the Doksany and Strážnice climatological stations in Figs. 4.24. and 4.25.

The graphs in Figs. 4.26. and 4.27. document the time course of average totals of ZVLBI_TP and AVLBI_TP in 2015 (in the period from April to October) and their comparison with the long-term average for 1981–2010 for selected areas of the Czech Republic (Haná, South Moravia, the Elbe River basin, the Ohře River basin, the Bohemian-Moravian Highlands). Each of the areas is represented through a set of selected climatological stations.

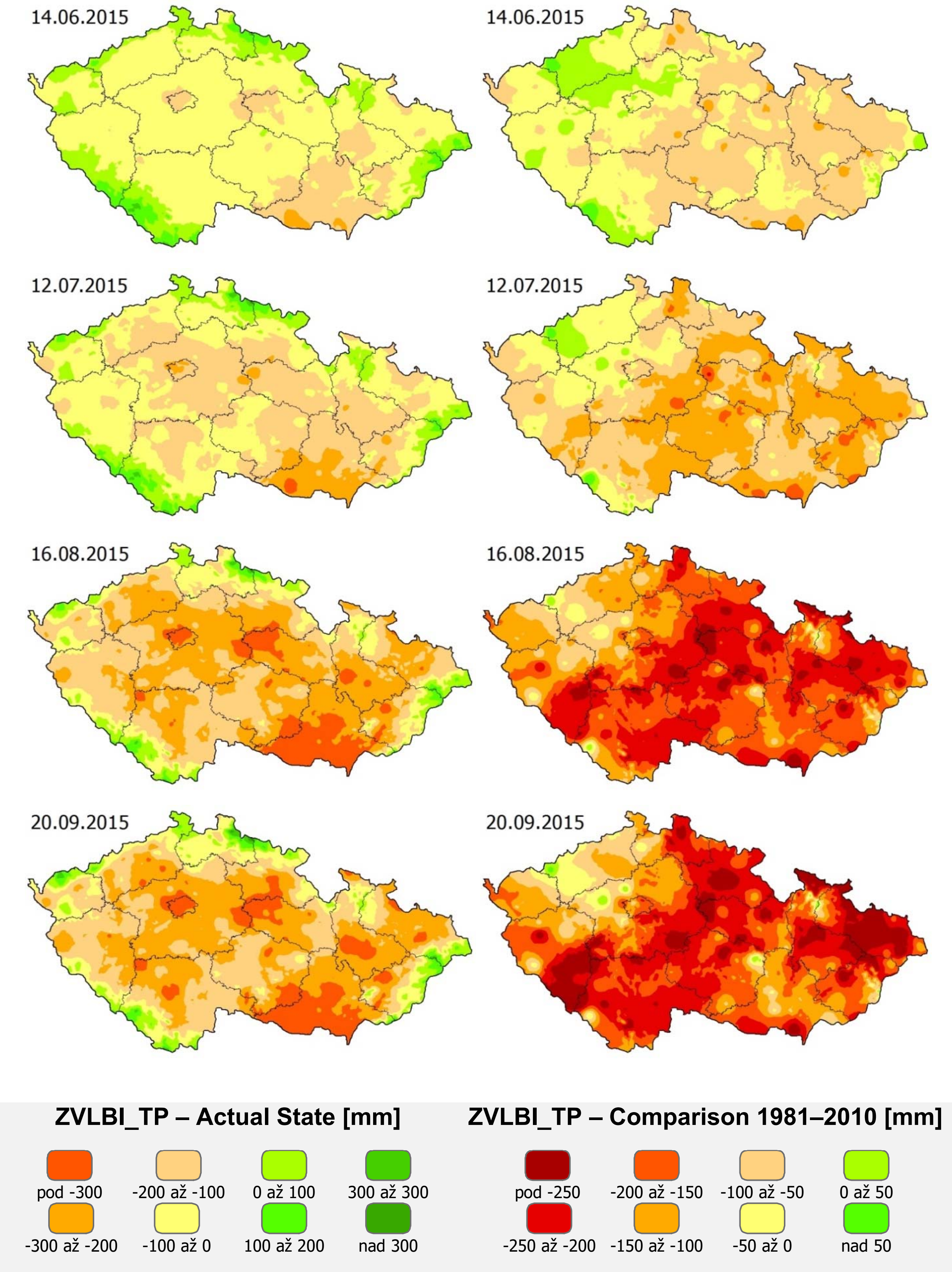


Figure 4.18. Basic moisture balance of grassland in the Czech Republic, cumulative values from 1 March to selected dates in 2015 and comparison of such data with the long-term average for 1981–2010.

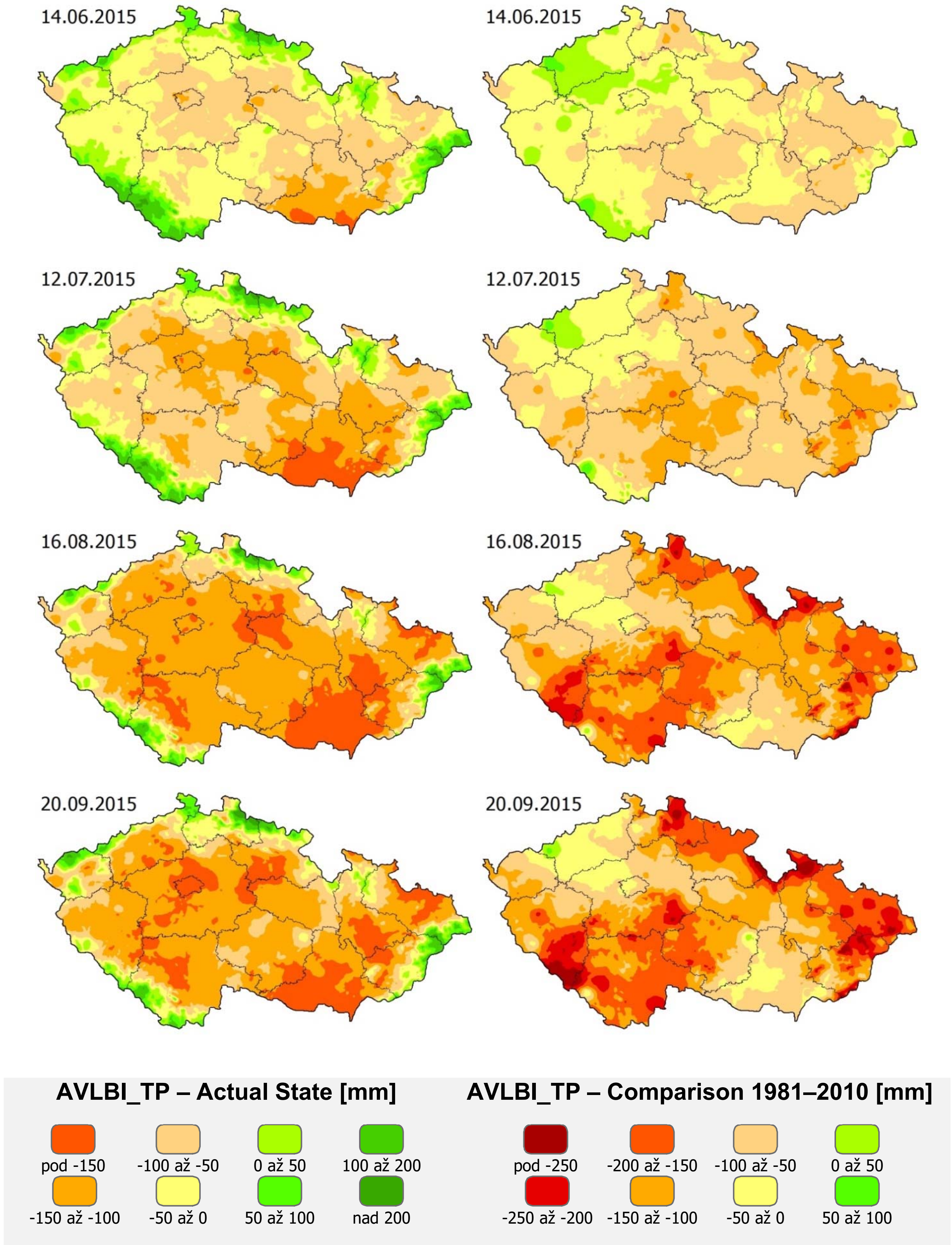


Figure 4.19. Actual moisture balance of grassland of medium-heavy soil in the Czech Republic, cumulative values from 1 March to selected dates and comparison of such data with the long-term average for 1981–2010.

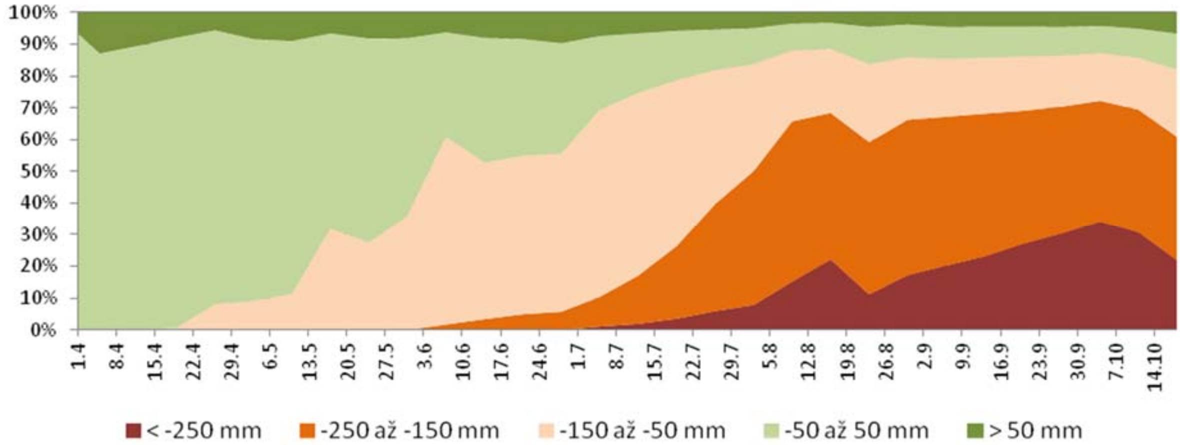


Figure 4.20. Basic moisture balance of grassland in millimeters, shares of selected intervals in the Czech Republic (%) in 2015, cumulative values since 1 March.

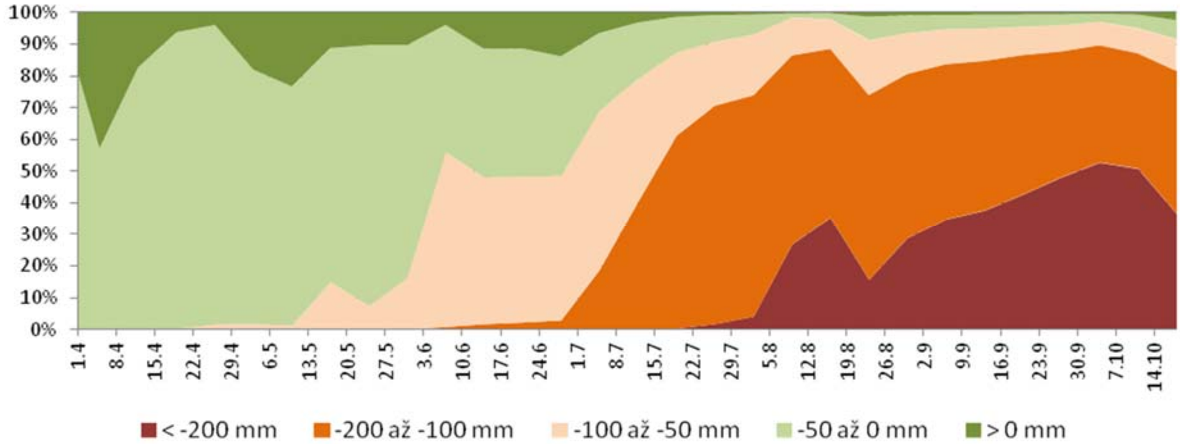


Figure 4.21. Comparison of the basic moisture balance of grassland in 2015 in millimeters with the long-term average for 1981–2010, shares of selected intervals in the Czech Republic (%) in 2015, cumulative values since 1 March.

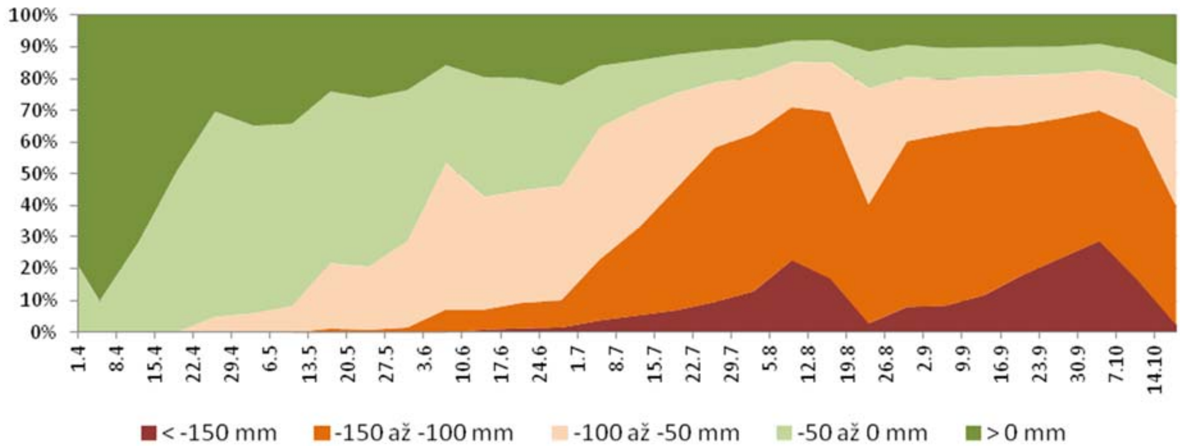


Figure 4.22. Actual moisture balance of grassland of medium-heavy soil in millimeters, shares of selected intervals in the Czech Republic (%) in 2015, cumulative values since 1 March.

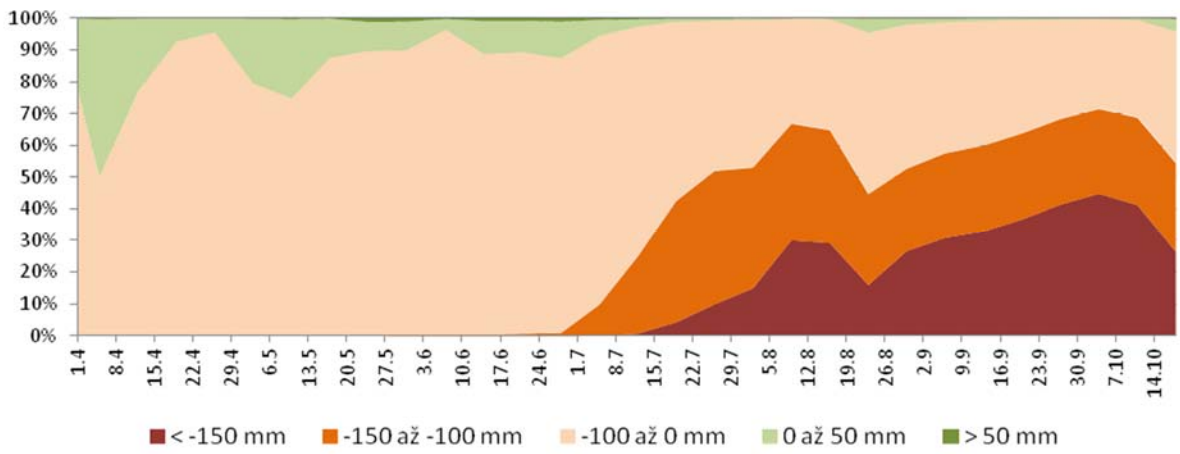


Figure 4.23. Comparison of the actual moisture balance of grassland of medium-heavy soil in 2015 in millimeters with the long-term average for 1981–2010, shares of selected intervals in the Czech Republic (%) in 2015, cumulative values since 1 March.

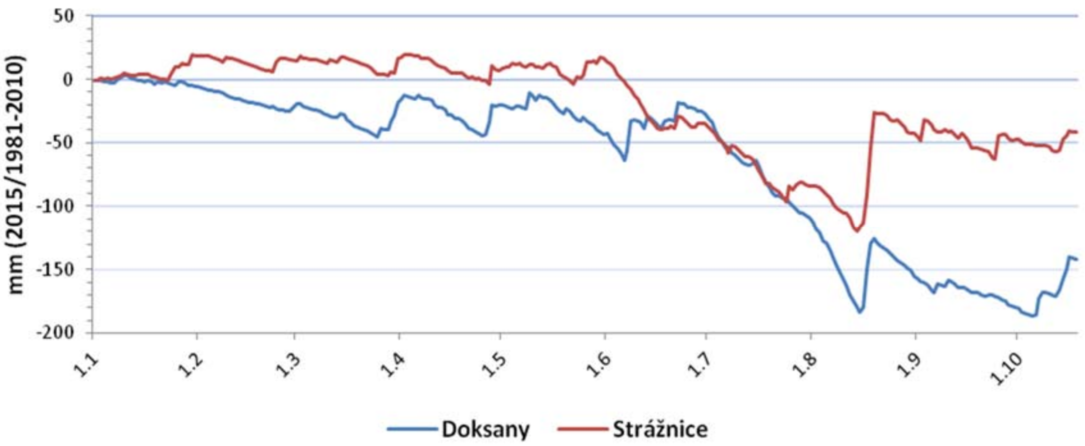


Figure 4.24. Doksany and Strážnice stations, basic moisture balance of grassland expressed in millimeters of the long-term average for 1981–2010.

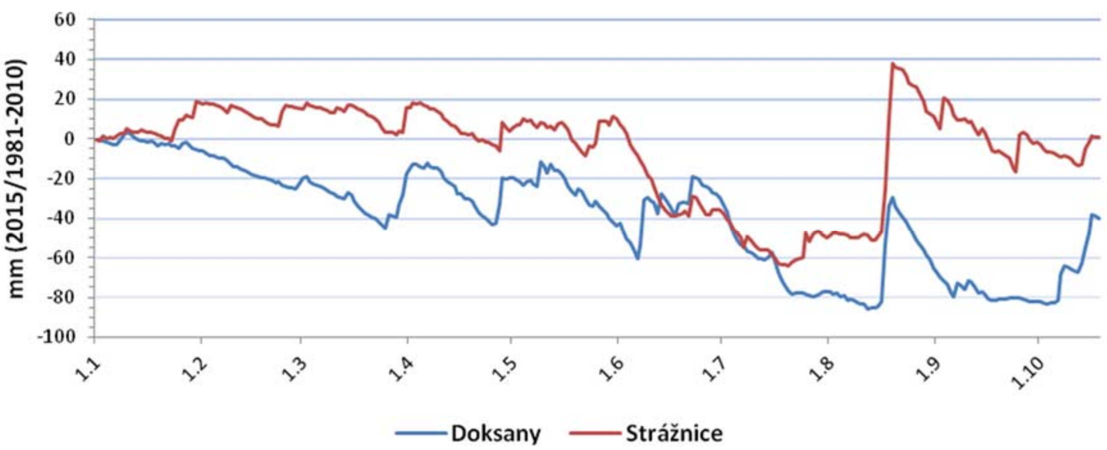


Figure 4.25. Doksany and Strážnice stations, actual moisture balance of grassland of medium-heavy soil in 2015 expressed in millimeters of the long-term average for 1981–2010.

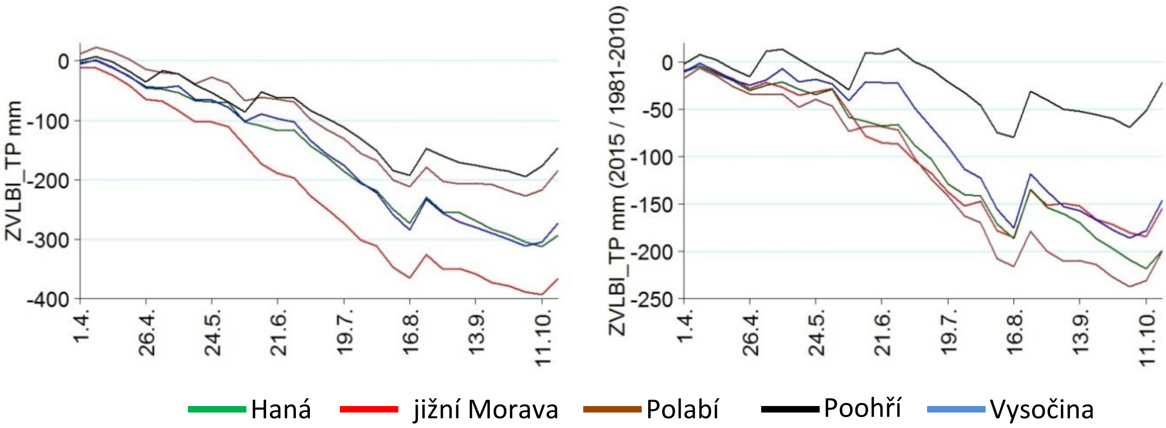


Figure 4.26. Areas of Haná (green), South Moravia (red), the Elbe river lowland (brown), the Ohře river lowand (black) and the Bohemian-Moravian Highlands (blue), average basic moisture balance of grassland in 2015, continuous accumulation since 1 April (left graph) and comparison with the long-term average for 1981–2010 (right graph).

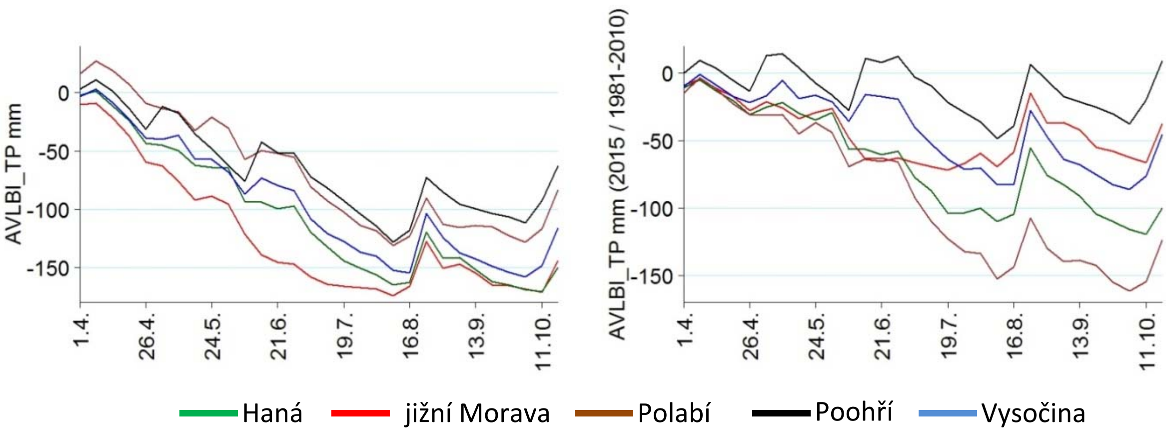


Figure 4.27. Areas of Haná (green), South Moravia (red), the Elbe river lowland (brown), the Ohře river lowand (black) and the Bohemian-Moravian Highlands (blue), average actual moisture balance of grassland of medium-heavy soil in 2015, continuous accumulation since 1 April (left graph) and comparison with the long-term average for 1981–2010 (right graph).

5. Evaluation of Soil Moisture and Drought Impacts on Vegetation

5.1. Evaluation of Measured Soil Moisture

At present, the Czech Hydrometeorological Institute measures soil moisture at 42 meteorological stations. Sensors are installed at the measuring station site under grass cover at a layer of 0 to 10 cm, 10 to 50 cm and 50 to 100 cm. The soil moisture is measured in percent by volume of water. And for the purposes of presentation and use in practice, such values are often expressed as a percentage of available moisture water capacity, which is the maximum volume of water available to plants at a given soil profile. Mathematically, it is the difference between the basic hydro-limits, i.e. between the wilting point and field water capacity of the soil profile. At an available moisture water capacity of approximately 30%, the water availability to the plant root system begins to significantly decline, and therefore, available moisture water capacity values lower than 30% can be considered a (soil) drought.

Like in the case of modeled soil moisture values, this year it was not possible to observe a significant drying-out process until the summer months. Even in late June, the average soil moisture at a layer of 0 to 100 cm was lower than the available moisture water capacity of 30% only at 25% of the stations. In mid-July this was already recorded at 35% of the stations and in late July and mid-August at 57% and 75% of all the stations, respectively. After the cooling and occurrence of increased precipitation in the second half of August, this moisture value was only recorded at 28% of the stations. September's drop in moisture was not as pronounced as in the previous period. In late September, the average moisture of the whole measured profile lower than an available moisture water capacity of 30% was found at one-third of the stations.

The graphs in Figs. 5.1. to 5.3. describe the changes in soil moisture at the Doksany, Strážnice and Kuchařovice stations during the growing period of 2015. The Doksany station represents the lowland areas in the Elbe and Ohře River basins, and the Strážnice station documents the situation in Southeast Moravia. The course of moisture at the Kuchařovice station can be considered typical for the dry region of South Moravia.

As a result of the dry autumn and winter periods of 2014/2015, the soil moisture significantly dropped at the Doksany station, in particular, at the deepest monitored layer, where the moisture maintained itself below an available moisture water capacity of 30% throughout the monitored period, and the trend of its values continued to decline. Both the topsoil layers, in particular that of 0 to 10 cm, responded in a more pronounced way to the occasional spring and June rainfalls, and drier periods alternated with more humid ones. A significant drop occurred in early July and culminated at the end of the second ten-day period of August, which was then followed by a significant increase in the moisture and then again by a decrease and a relatively balanced course in September. In late September, there was a decline in the soil moisture at all levels to the minimum values of the entire growing period.

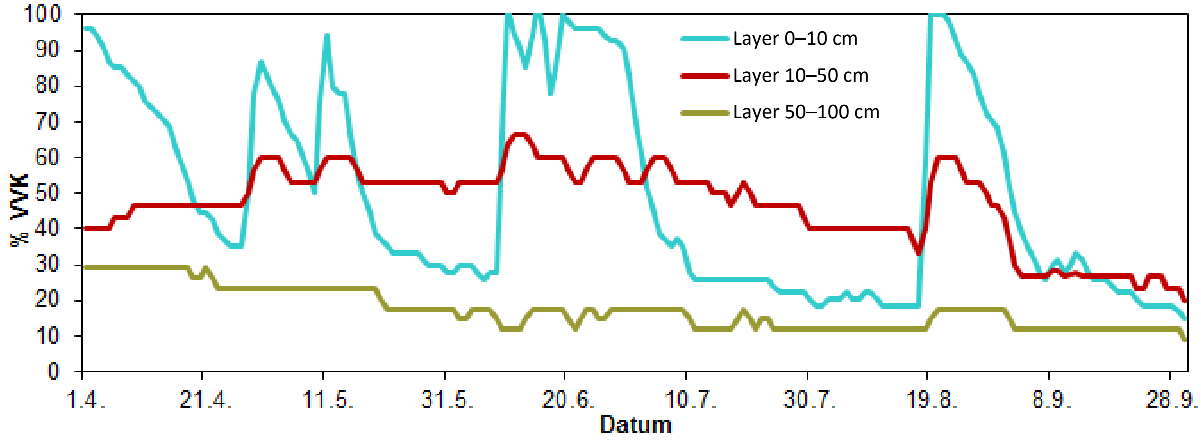


Figure 5.1. Course of soil moisture expressed as a percentage of available moisture water capacity at the Doksany station in the growing period of 2015.

A somewhat different course of soil moisture was recorded at the Strážnice station. At the beginning of the growing period at a layer of 10 to 50 cm and even 50 to 100 cm, there were high soil water reserves. These reserves then began to decline, more precipitously at a layer of 10 to 50 cm, where the temporary increase of moisture from the storm precipitation in late July was followed by a drop down to an available moisture water capacity of 30% at the beginning of the second half of August. After a temporary improvement, the moisture again decreased in September, and at the end of September, it was even identical with that of the deepest layer. Drying-out at the deepest soil layer was significantly milder, but it continued until the end of August. The course of moisture was then balanced from there. At the top layer, there were apparent fluctuations due to occasional rainfalls, and commencing in late June, the course of moisture at that layer was almost identical with that at the layer of 10 to 50 cm. At the end of the growing period, however, the specific values were higher at the topsoil layer.

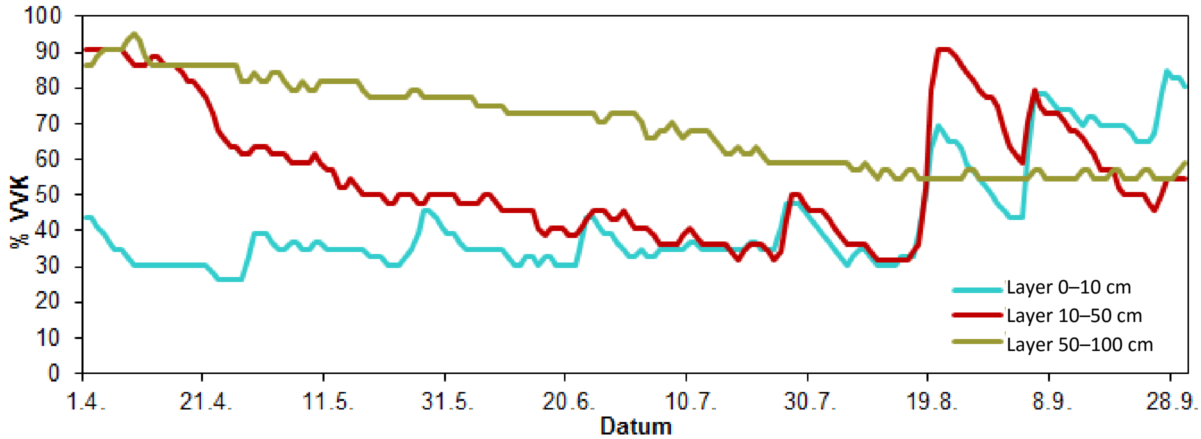


Figure 5.2. Course of soil moisture expressed as a percentage of available water capacity under grass cover at the Strážnice station in the growing period of 2015.

A very balanced course of soil moisture at all monitored layers is evident at the Kuchařovice station, and there were only some apparent minor fluctuations at the topsoil layer until mid-August. From the initial value at a level corresponding to an available water capacity of approximately 50%, the moisture of all layers declined until mid-August. In the following period, the moisture at the deepest layer was balanced. The topsoil layers significantly moistened in late August, and during September, they again dried up. In late September, the moisture at all layers stabilized at an available water capacity of approximately 20%.

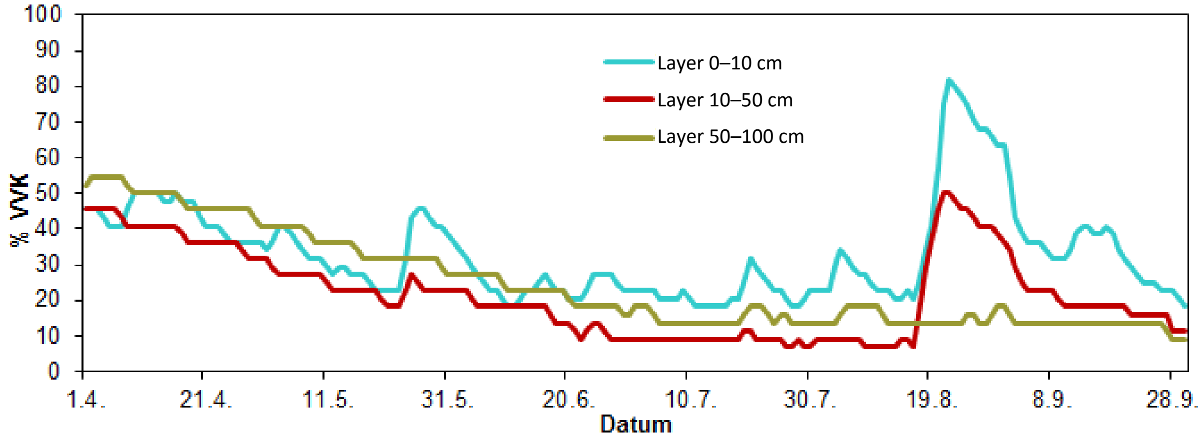


Figure 5.3. Course of soil moisture expressed as a percentage of available water capacity under grass cover at the Kuchařovice station in the growing period of 2015.

5.2. Evaluation of Modeled Soil Moisture under Grass Cover

Given the sparse network of stations with direct measurements of soil moisture and also the soil diversity in the Czech Republic, it is necessary to primarily use modeled outputs for evaluating the soil moisture in terms of the area. In order to monitor the soil moisture and thus also droughts, the Czech Hydrometeorological Institute operates several models primarily based on balancing precipitation as an incoming component of water and evaporation as an outgoing component. In the vast majority of these models, evaporation is represented by the potential or actual evapotranspiration from grassland, which forms a standard surface of the meteorological stations. To illustrate the soil conditions in the monitored period, we have selected examples of two models that use different approaches to estimate the soil moisture at the arable layer and a profile of 0 and 100 cm under grass cover.

Layer of 0 to 40 cm (Arable Layer)

This sub-chapter presents the BASET Model outputs evaluating the course of soil moisture under grass cover at a layer of 0 to 20 cm, 20 to 40 cm and 0 to 40 cm. In this specific case, the layer of up to 40 cm, which most closely resembles actual agricultural lands in the Czech Republic, was designated as arable land. This model is based on the daily precipitation balance and actual evapotranspiration. For each station included in the calculation, the available water capacity value is defined according to the soil conditions of the station or its closest surroundings.

In comparison with the layer of up to 100 cm, the layer of up to 40 cm reacts “more vigorously” to the weather progression, which means that relatively small amounts of precipitation may temporarily stop the drying-out of this layer. By contrast, if a precipitation deficit lasts a long time, the arable layer moisture may decline more significantly than the moisture of the layer of 0 to 100 cm. The extremity of this past summer is documented, among other things, by the fact that the progression of moisture at that layer with its almost continuous decline was very similar to the progression of moisture at deeper layers.

The first manifestations of soil drought at the evaluated layer were recorded as early as April, but a relatively colder May with weaker, but fairly evenly distributed rainfalls, partially stabilized the situation. More pronounced manifestations of the drought did not begin to appear until the end of May. During June, such manifestations gradually became stronger. The map in Fig. 5.4. shows the situation in mid-June, when mainly South Moravia was hit by drought.

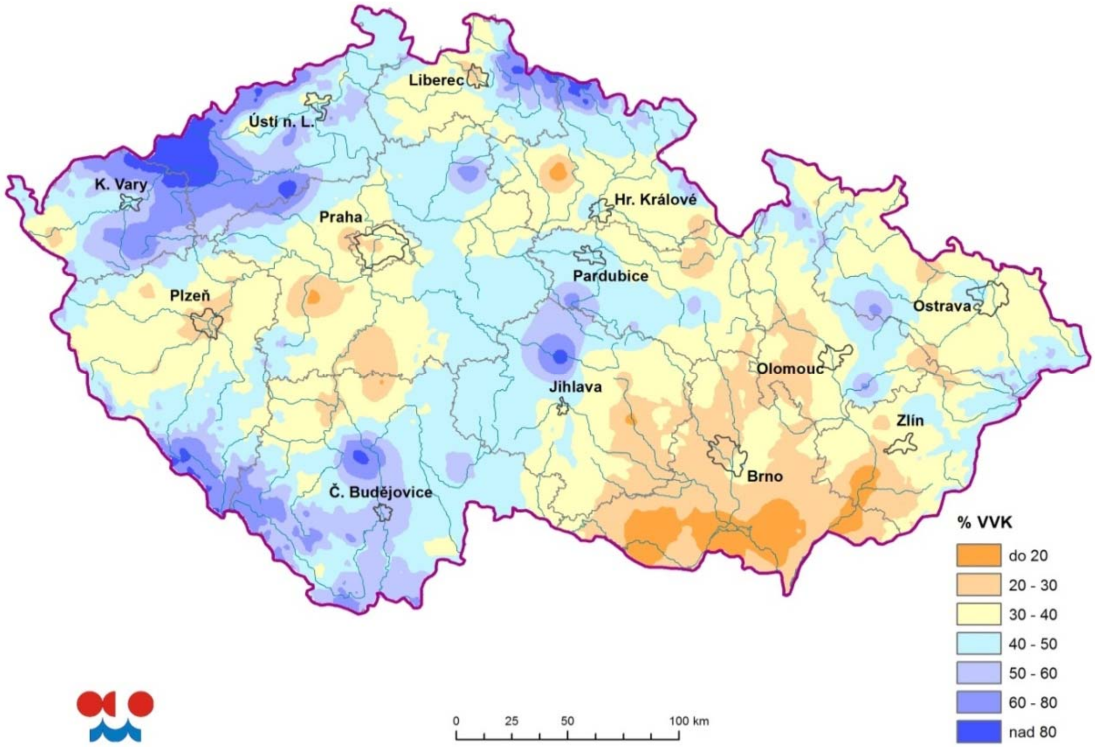


Figure 5.4. Modeled soil moisture expressed as a percentage of available water capacity (VVK) at a layer of 0 to 40 cm under grass cover in the Czech Republic, situation as of 14 June 2015.

The subsequent deepening of the moisture deficit is evident from the map in Fig. 5.5., showing the situation around mid-July when the majority of lower elevations were already affected. The lowest values are found south of Prague.

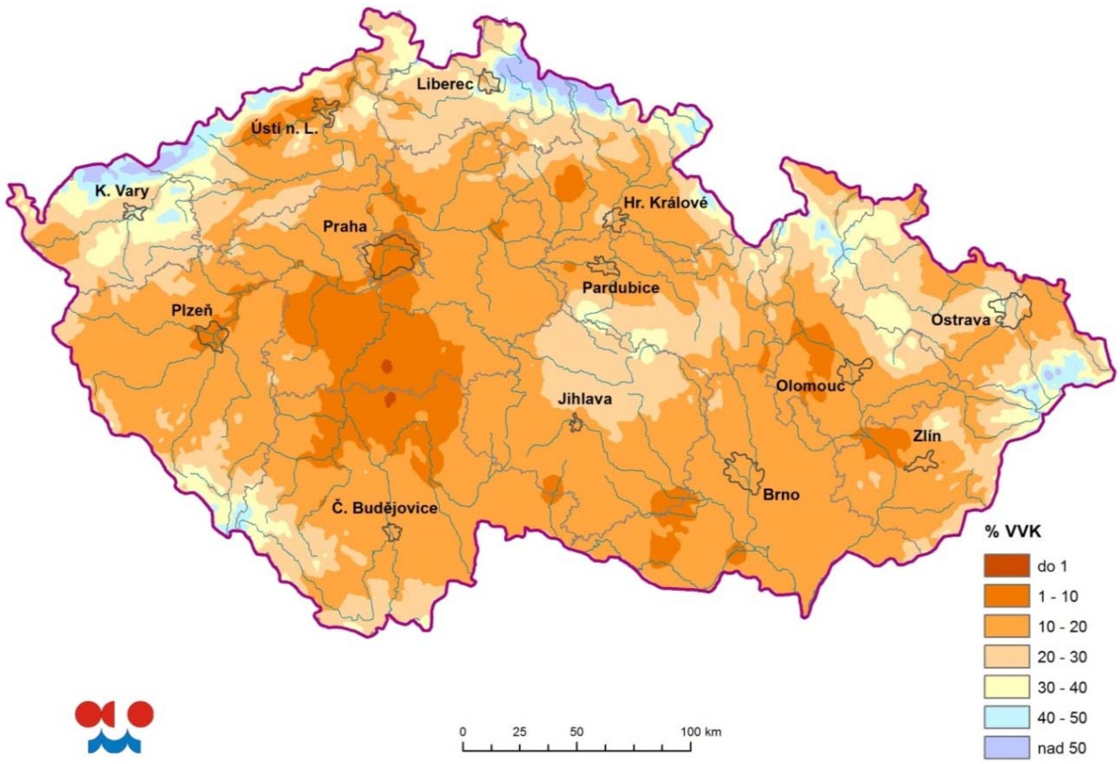


Figure 5.5. Modeled soil moisture expressed as a percentage of available water capacity (VVK) at a layer of 0 to 40 cm under grass cover in the Czech Republic, situation as of 19 July 2015.

The map in Fig. 5.6. shows the situation as of 12 August, when the drying-out of the arable soil layer culminated in the Czech Republic. In some areas, that process continued over the following two to three days. However, at the same time, more abundant rainfalls began to occur at other locations. From the map, it is obvious that, in practically the entire Czech Republic, the moisture values were below an available water capacity of 30%, and in most of the country, they were even below an available water capacity of 10%, i.e. close to the wilting point. In general, it is possible to say that the most affected areas were those at lower elevations; in terms of administrative divisions of the Czech Republic, they included the South Moravian and Central Bohemian Regions.

After the cooling and relatively heavy precipitation in mid-August, the moisture situation at the layer of up to 40 cm improved, but the drought in large parts of the country continued with lessened intensity until the end of the second ten-day period of October, when a significant improvement occurred. The situation typical for most of September is shown in Fig. 5.7.

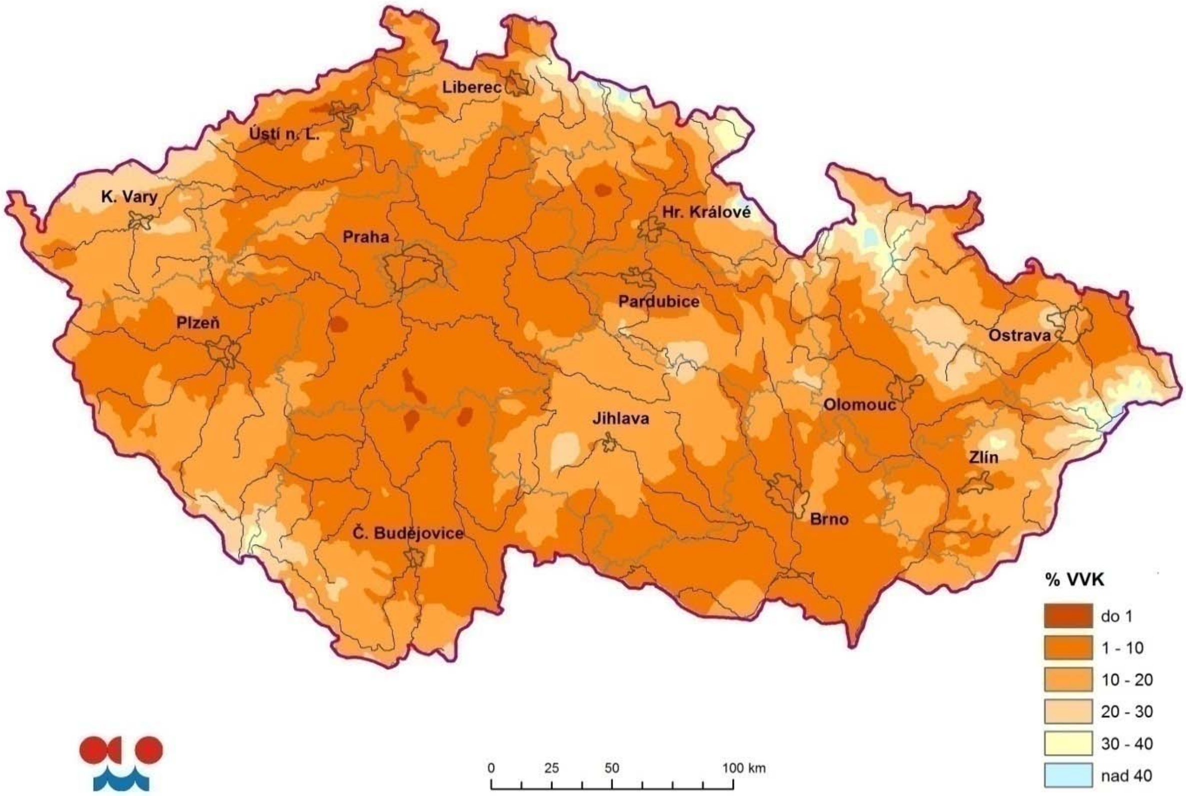


Figure 5.6. Modeled soil moisture expressed as a percentage of available water capacity (VVK) at a layer of 0 to 40 cm under grass cover in the Czech Republic, situation as of 12 August 2015.

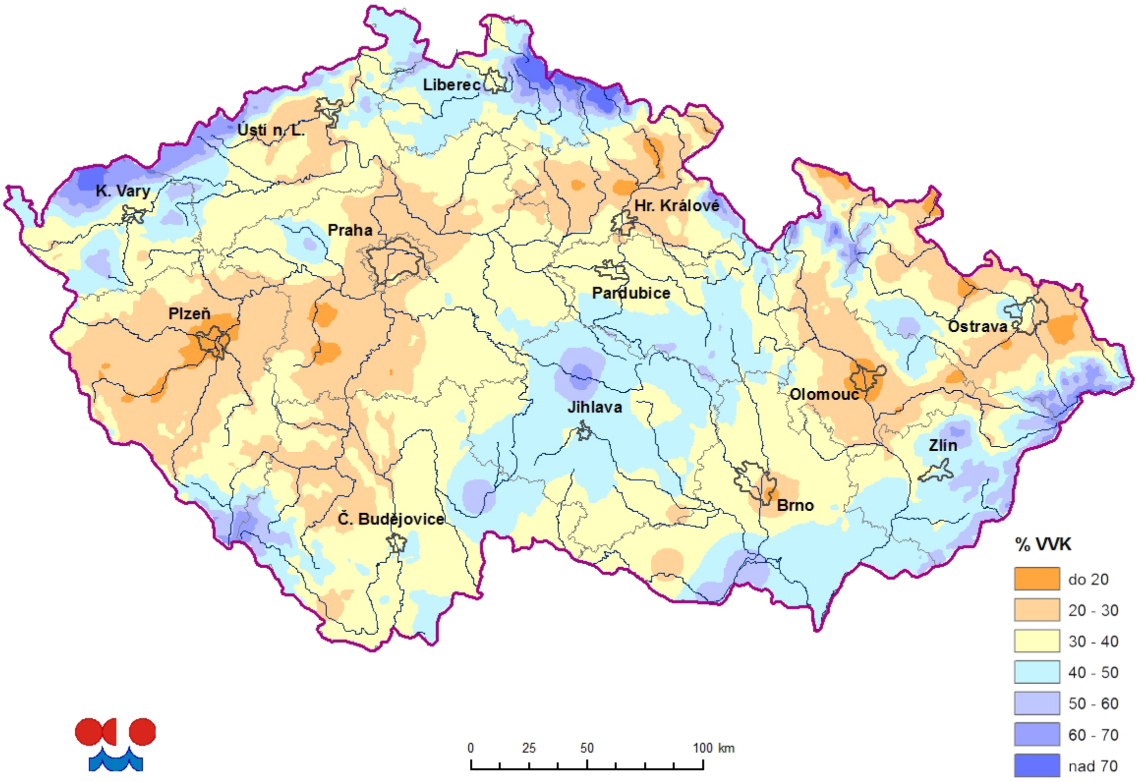


Figure 5.7. Modeled soil moisture expressed as a percentage of available water capacity (VVK) at a layer of 0 to 40 cm under grass cover in the Czech Republic, situation as of 13 September 2015.

The last significant decline in soil moisture at the monitored layer was detected in early October (Fig. 5.8.), and the Elbe River basin, a vast area south of Prague and Central Moravia were the most drought-affected areas. Since the second half of October, drought in the arable soil layer has only been recorded quite sporadically.

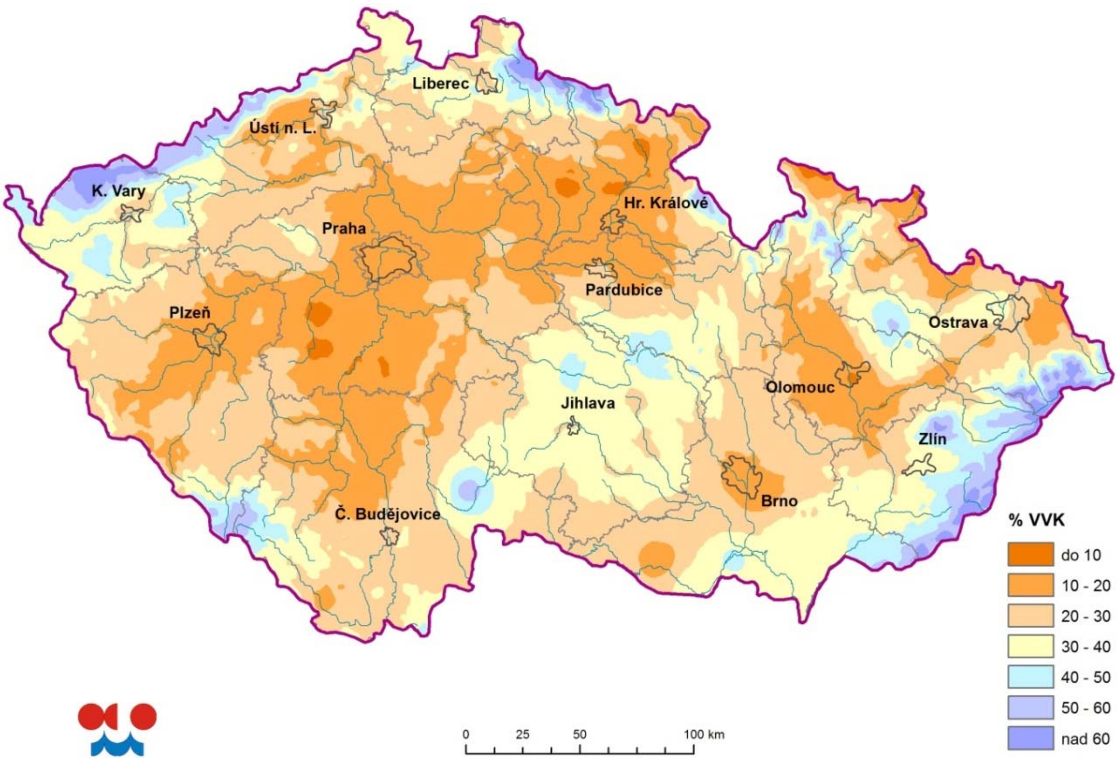


Figure 5.8. Modeled soil moisture expressed as a percentage of available water capacity (VVK) at a layer of 0 to 40 cm under grass cover in the Czech Republic, situation as of 4 October 2015.

The graphs in Figs. 5.9. and 5.10. show the course of calculated soil moisture values on a weekly basis for the Doksany and Strážnice stations from the last week of May to the end of September 2015. For the sake of comparison, the uppermost layer of up to 20 cm, where even lower moisture values were recorded, is also presented. At Strážnice, values approached the wilting point throughout most of the summer until mid-August. The graphs clearly show a significant moistening of both soil layers in the second half of August, a return to the low values at the beginning of September, and a relatively balanced course of moisture in September.

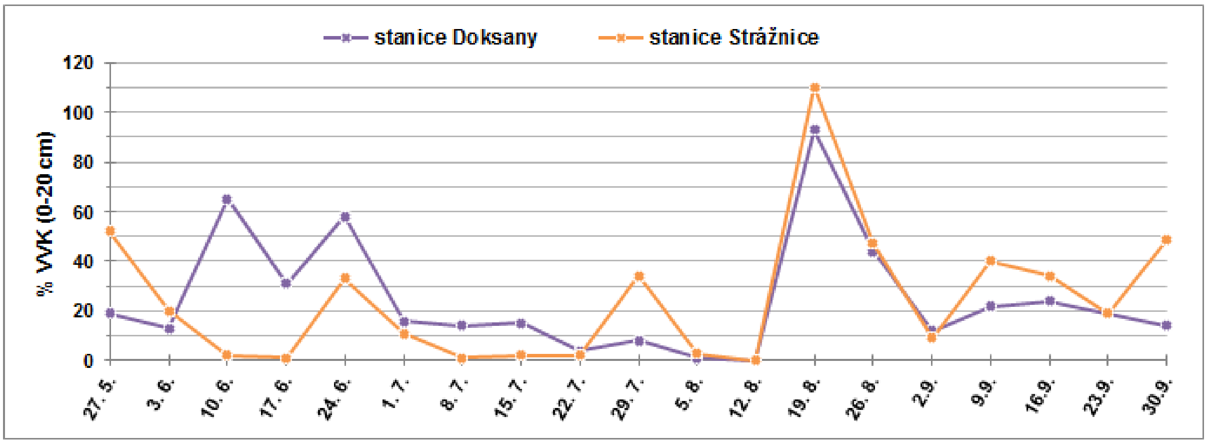


Figure 5.9. Course of the modeled soil moisture expressed as a percentage of available water capacity (VVK) at a layer of 0 to 20 cm under grass cover at the Doksany and Strážnice stations from late May 2015 to late September 2015.

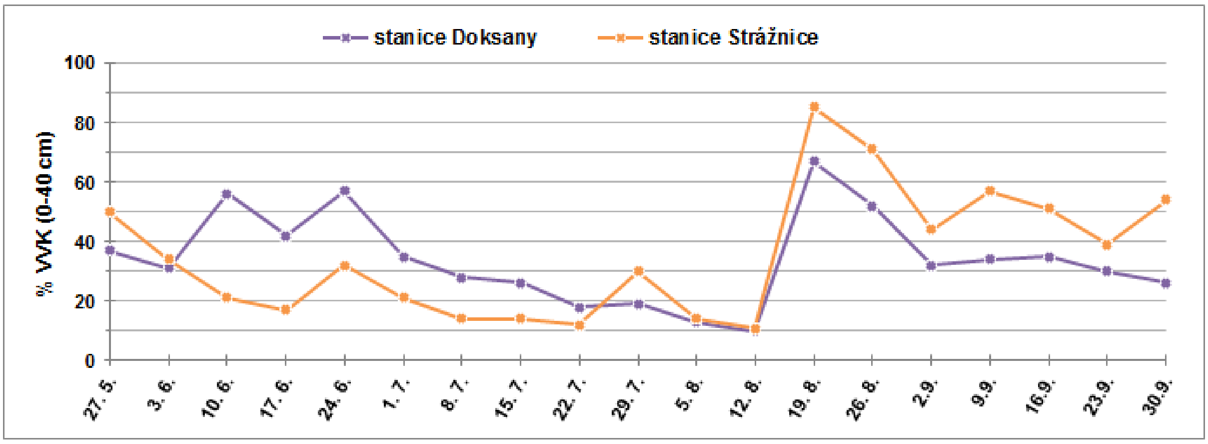


Figure 5.10. Course of the modeled soil moisture expressed as a percentage of available water capacity (VVK) at a layer of 0 to 40 cm under grass cover at the Doksany and Strážnice stations from late May 2015 to late September 2015.

Layer of 0 to 100 cm

To present the soil moisture under grassland at a profile of 0 to 100 cm, AVISO Model outputs were used. The basic outputs of the model include daily data for the actual water deficit in mm, which is the amount of water available in the soil that is missing to establish the field water capacity. The presented evaluation is based on a uniform hydrological limit of available water capacity of 170 mm/1m of soil horizon; in terms of soil types, this represents the medium-heavy soils that prevail in the Czech Republic. The evaluation results in a modeled available water storage in grassland soil (hereinafter referred to as ZVVP_TP) expressed as a percentage of available water capacity.

Generally, it is possible to say that the lower the actual values of ZVVP_TP expressed as a percentage of available water capacity are or the lower the share of actual values of ZVVP_TP in the long-term average is (maps in Fig. 5.11.), the higher the probability of occurrence of unfavorable soil moisture conditions is, and therefore, the higher the probability of risk of soil drought occurrence is.

As of the selected days of this year (14 June, 12 July, 16 August, 20 September), the well-arranged maps in Fig. 5.11. analyze the actual level of ZVVP_TP as a percentage of available water capacity and its comparison with the long-term conditions for 1981–2010 expressed in percentages.

Up to late May, no value of modeled ZVVP_TP below 20% of available water capacity was reached for a soil layer of 0 to 100 cm; values ranging from 20 to 40% of available water capacity were sporadically found in South Moravia. A significant worsening of the soil moisture conditions occurred as early as June and manifested itself most intensively during the summer months of July and August, as well as during the first autumn month of September, which is evident from the above-mentioned maps.

From the perspective of ZVVP_TP, the moisture situation in medium-heavy soils to a depth of 100 cm was very unfavorable on Sunday, 16 August, and the soil moisture continued to reach very low values until the second half of September in the vast majority of the Czech Republic.

According to the map in Fig. 5.11., the actual level of ZVVP_TP on Sunday, 16 August shows extreme soil moisture values below 10% of available water capacity in large areas of Moravia, East, South and West Bohemia. Other large areas of the Czech Republic fell into the category of 10 to 20% of available water capacity. Similar conclusions were drawn when comparing the actual level with the long-term conditions. Practically the same areas of the Czech Republic showed very unfavorable moisture conditions (ZVVP_TP was mostly below 30% of the average) in comparison with the long-term average for the period of 1981–2010. A better soil moisture situation was only determined when using the model for the borderland mountains of the Czech Republic. A very similar situation in late September was documented using the map as of 20 September.

A detailed analysis has documented that this year’s soil moisture conditions showed deepening negative development trends in the period from June to October, and the least favorable situation occurred in mid-August and in the second half of September.

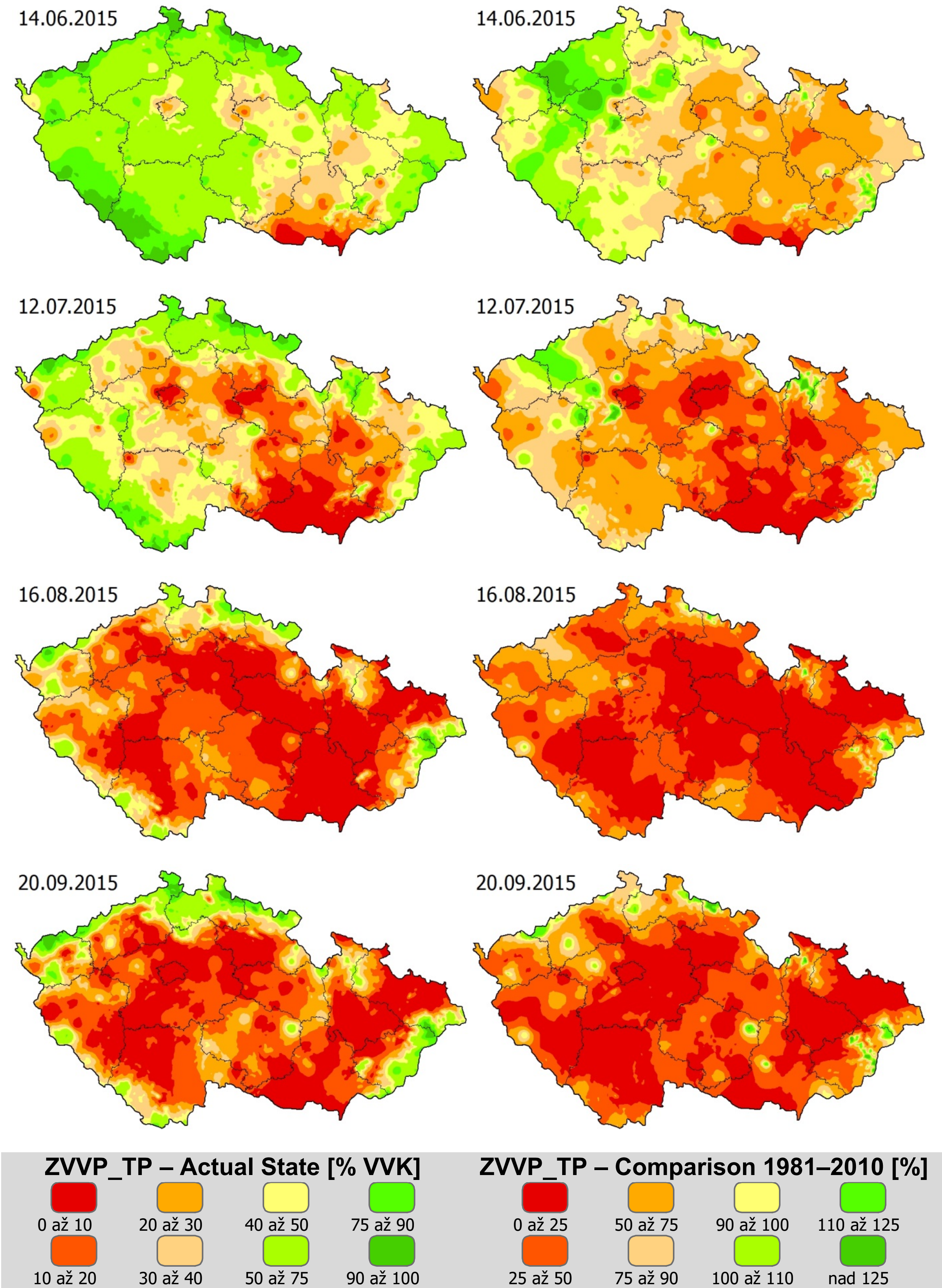


Figure 5.11. Available water storage in medium-heavy soils (available water capacity (VVK) = 170 mm/1m of soil profile) under grassland in the Czech Republic, actual level and comparison with long-term conditions (1981–2010) for selected days.

The graphs in Figs. 5.12. and 5.13. present the actual 2015 levels and a comparison of weekly ZVVP_TP data with the long-term totals for 1981-2010 for the entire Czech Republic structured by weeks for the period from March to mid-October. From both graphs, it is clear which part of the Czech Republic, expressed in percentages, fell, continuously and structured by weeks, into the selected intervals (< 20% of available water capacity … > 80% of available water capacity, or < 20% … > 110%). From the graphs presented, it follows that the intervals with the least favorable moisture values had a very strong presence.

From the graph in Fig. 5.12., it is obvious that from mid-August to mid-October, both the least favorable intervals (< 20% of available water capacity and 20–40% of available water capacity) continuously characterized approximately 80% and more of the Czech Republic, mostly at the lowest and medium elevations above sea level. The only significant increase in the actual ZVVP_TP data manifested itself in the middle of the last ten-day period of August, when heavy rainfall in most of the Czech Republic caused a short-lived improvement in the soil-moisture parameters. It can be said that, commencing in mid-June, the share of both the least favorable moisture intervals was continuously and moreover also significantly increasing in the Czech Republic.

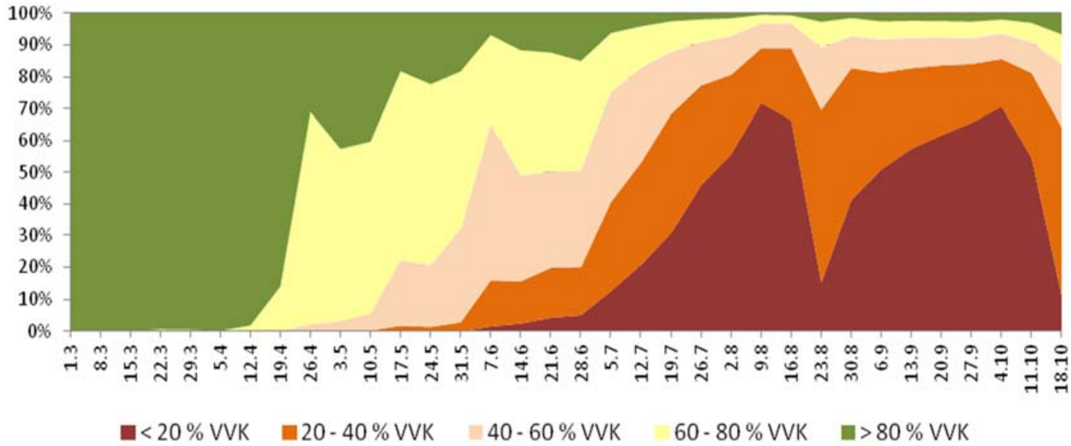


Figure 5.12. Available water storage (VVK) in medium-heavy soils with grass cover in the Czech Republic, shares of areas of selected intervals in the Czech Republic (%) in 2015 (March to October).

A comparable situation follows from an analysis of the graph in Fig. 5.13. Heavy rainfall in the middle of the last ten-day period of August caused a temporary improvement in the soil moisture conditions even in comparison of 2015 with the long-term conditions. The significant negative effects of the soil drought in most of the Czech Republic also follows from the graph in Fig. 5.13. Approximately from mid-July until the end of the monitored period of ZVVP_TP, more than half of the Czech Republic was below 50% of the long-term average for 1981–2010.

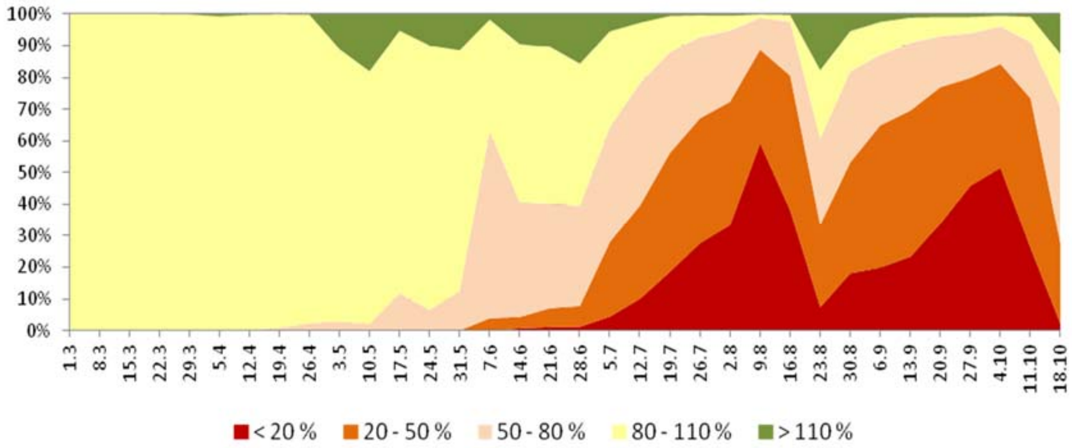


Figure 5.13. Comparison of available water storage (VVK) in medium-heavy soils with grass cover in 2015 (March to October) with the long-term average for 1981–2010 in percentages, shares of areas of selected intervals in the Czech Republic in percentages.

The time course of daily values of ZVVP_TP in 2015 (April to October) expressed as a percentage of the long-term average for 1981–2010 is presented for the Doksany and Strážnice stations in Fig. 5.14.

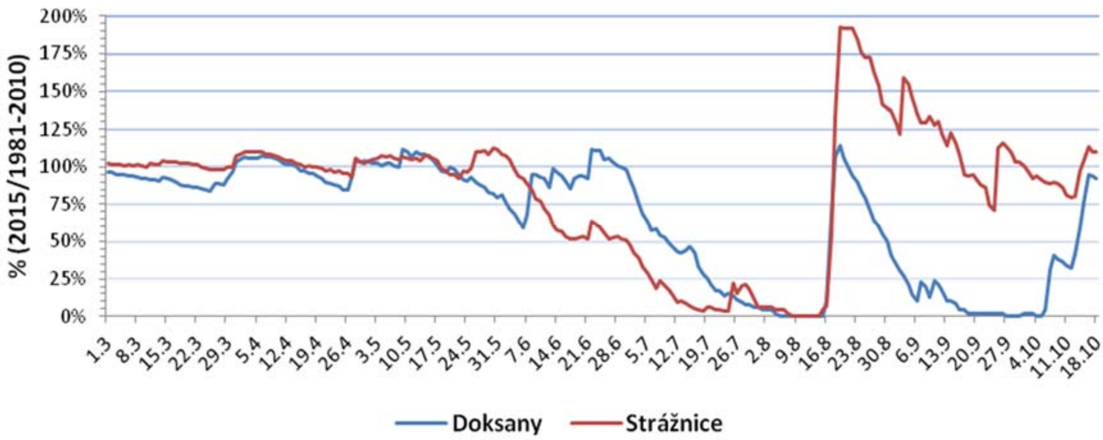


Figure 5.14. Doksany and Strážnice stations, available water storage in medium-heavy soils with grass cover in 2015 (April to October) expressed as a percentage of the long-term average for 1981–2010.

The graphs in Fig. 5.15. document the time course of average values of ZVVP_TP in 2015 (April to October) and their comparison with the long-term average for 1981–2010 in percentages for selected areas of the Czech Republic (Haná, South Moravia, the Elbe River basin, the Ohře River basin, the Bohemian-Moravian Highlands). Each of the areas is represented through a set of selected stations.

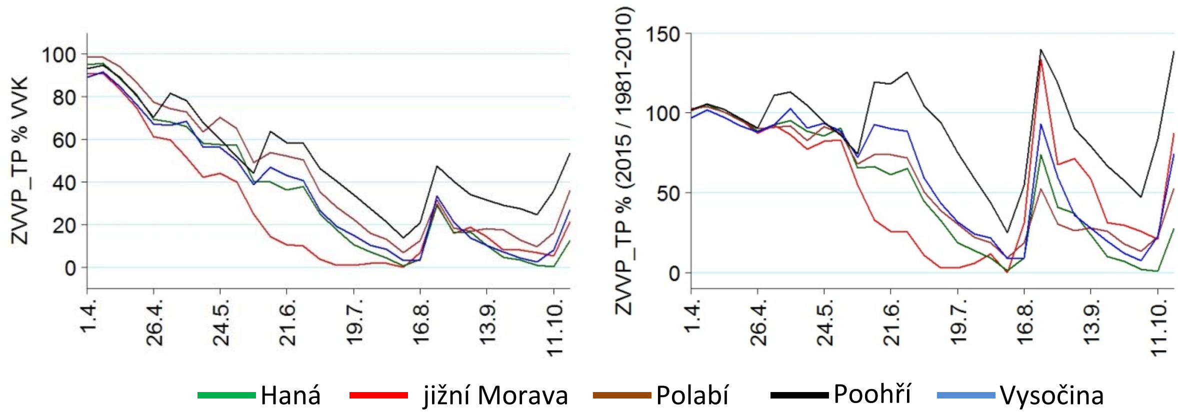


Figure 5.15. Areas of Haná (green), South Moravia (red), the Elbe river lowland (brown), the Ohře river lowand (black) and the Bohemian-Moravian Highlands (blue), average available water storage in medium-heavy soils with grass cover in 2015 as % of available water capacity (left graph) and comparison with the long-term average for 1981–2010 in percentages (right graph).

5.3. Assessment of the Modeled Level of Fire Danger

To assess the danger of fire occurrence and spread through vegetation in open country, the Czech Hydrometeorological Institute has been modeling a Fire Danger Index (FDI) since 2006. During the growing period, the FDI assesses the fire danger for the next two days using the following five classifications: 1 – very low, 2 – low, 3 – medium, 4 – high, 5 – very high. The FDI calculation is based on predicted values of the daily maximum wind gust, maximum air temperature, relative air humidity and soil moisture in the surface layer, (using both the measured and the modelled data). The FDI is presented in maps and is used by the Czech Hydrometeorological Institute's forecast stations within the Integrated Warning Service System.

While in past years, high FDI levels were particularly recorded in the spring, this year a combination of climate and soil droughts with very high temperatures created extremely favorable conditions for fire occurrence in the summer months. In early July, a medium fire danger still prevailed in most of the Czech Republic. However, in the second half of July, the fire danger was already high, and in early August, there were even areas with a very high fire danger rating. According to the preliminary data of the Fire Rescue Service of the Czech Republic, the number of summer fires fought by firefighters was the highest for the last 20 years. In comparison with the long-term average, the number of fires in July was twice as high, and in the first half of August, it was even four times higher. A frequent cause of these fires was human negligence and carelessness. The number of fires in the course of each day corresponded well to the issued forecast. The graph in Fig. 5.16. shows the trend in the number of fires in the Czech Republic in July and September 2015 and the FDI maps for selected days. From the maps, it is obvious that, while on 22 July a medium fire danger prevailed in most of the country (marked in orange), by 10 August there was a high fire danger rating (marked in red). By 14 August, the fire danger was already very high (marked in violet). The precipitation in mid-August very quickly reduced the degree of fire danger to the lowest level. In September, the conditions for fire occurrence were less favorable, and the graph shows a balanced number of fires throughout the month. The period with a temporary increase of the risk of fire occurrence, at the end of September and at the beginning of October, was followed by a period when such risk dropped to a minimum.

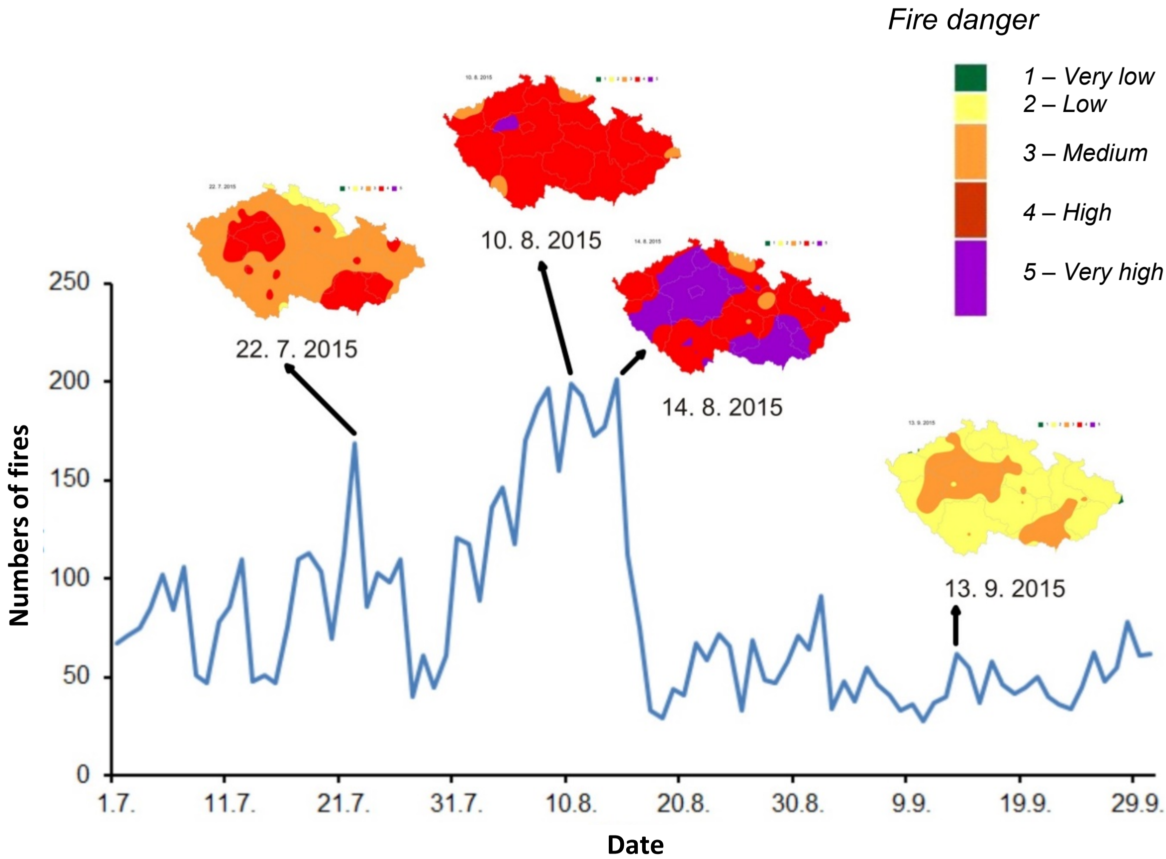


Figure 5.16. Trend in the number of fires recorded in the Czech Republic and maps with the Fire Danger Index forecast for selected days from July to September 2015. Source of data on the number of fires: Fire Rescue Service of the Czech Republic (preliminary data).

5.4. Evaluation of Drought Impacts on the Phenological Development of Plants

Drought conditions in the Czech Republic are almost always accompanied by other meteorological factors, which amplify their intensity and also have negative effects on plant organisms. In particular, this year these included periods of very high daily maximum temperatures, above-average number of sunshine hours, low values of relative air humidity, as well as high soil temperatures. All these factors increased the soil moisture deficit and also created conditions that are referred to as “heat stress”, i.e. a high-temperature stress-related threat to plants.

Assessing the drought’s impact on plant organisms should be divided into an evaluation of field crops and wild species. Due to the fact that the phenological network of field crops was cancelled, the Czech Hydrometeorological Institute does not currently have any data available from observations using a uniform methodology to document drought impacts on agricultural production. However, based on an agro-meteorological analysis of the drought‘s progression, open-field observations and also publicly available information, it is possible to draw the following preliminary conclusions:

- Even though the first manifestations of soil drought occurred in the spring (from March to May), such manifestations did not have any dramatic impact on most agricultural crops. The precipitation deficit was still not very high, and the relatively cold weather in May also had positive effects.
- The summer period (from June to August) brought high temperatures and a strong decline in moisture. However, those factors acted differently according to the

development phase in which they “caught” particular species. The harvests of some cereals and oilseed rape and their quality were mostly positively affected by the drought. Similarly, the effects on grapevines can also be positively evaluated. By contrast, for other crops, the drought became a major problem, sometimes with liquidating effects. For example, some crops concerned were potatoes, hops, vegetables, corn, catch crops and fodder for livestock.

- Early autumn (September and October) brought some complications during the germination of winter crops, in particular, that of oilseed rape, whose optimum sowing season is in September. By contrast, during the sugar beet harvest in October, there were problems resulting from moisture in the surface soil layer.

For an evaluation of drought impacts on wild vegetation, we already have data available from the observations performed within the phenological network of the Czech Hydrometeorological Institute, as well as from our own special-purpose observations performed during critical periods. In addition to the information on the negative impacts of the drought on vegetation, the observations also brought quite surprising findings on the response of plants to the return of more favorable moisture conditions, even if such a return was only temporary.

The smallest drought effects on vegetation were those in North Bohemia, where we were reported almost no effects on vegetation. By contrast, the most striking impacts of drought were recorded in South and Central Bohemia and in the southeast of Moravia.

In the case of herbs, the drought caused their withering or scorch, which particularly concerned grasses (of the Poaceae family) and various species of clover. With the exception of North Bohemia, there was almost no aftergrass.

In the case of wood species, we met with different reactions. The only coniferous tree affected by the drought was the Norway spruce under the combined effects of meteorological factors and bark beetles, which easily attacked weakened trees. Small groups of withered older trees were found in the south of Bohemia and north of Moravia. Younger trees withered throughout the south of the Bohemian-Moravian Highlands. In the Šumava Mountains and the southern half of the Bohemian-Moravian Highlands, cones were withering and falling. By contrast, at other locations, for example in the Jeseníky Mountains, the Moravian-Silesian Beskydy Mountains, and South Bohemia, an unusually large number of cones could be seen.

In many places, broadleaved species reacted to the extreme conditions by a premature colouring of their leaves, mostly 1 to 2 months ahead of time (e.g. black elder, small-leaved lime, and silver birch – somewhere in the blanket manner). However, leaves of some species, such as those of the rowan tree and the European hornbeam, withered but did not fall. A number of wood species shed their leaves without colouring, which could be observed in the case of black elder (completely shedding their leaves, somewhere in the blanket manner), European beech, apple tree, common hazel, silver birch, and, at exposed locations, black locusts. In North Moravia, the sycamore maple and the Norway maple also partially shed their leaves. Leaf colouring, withering and shedding led to a reduction of the leaf area, and thus also to a reduction of water consumption by wood species. This is because leaf area is the dominant factor in evapotranspiration. Other species were found in a stage of partial to complete leaf necrosis (death of leaf tissues), which was observed, for example in all maple and oak species, in warmer areas in some places even in the blanket manner.

Tables 5.1. and 5.2. show examples of the drought impacts on leaves of selected wood species. The negative deviation from the long-term average (for 1992–2010) indicates an earlier onset of the relevant phenological phase. The three highest negative deviations from the average are marked in blue in each of the tables.

*Table 5.1. Onset of 10%-*colouring *Phase at Selected Phenological Stations of the Czech Hydrometeorological Institute.*

Station/Wood Species	**Silver birch**	**European beech**	**Pedunculate oak**	**Small-leaved lime**	**Rowan tree**	**Black elder**
	date/ deviation	date/ deviation	date/ deviation	date/ deviation	date/ deviation	date/ deviation
Běleč nad Orlicí	12 Aug -28 days	15 Aug -46 days	16 Aug -40 days	8 Aug -33 days	20 Aug -19 days	10 Aug -46 days
Mšecké Žehrovice	10 Aug -41 days	x	x	10 Aug -18 days	x	x
Příkosice	X	7 Aug -49 days	9 Aug -46 days	6 Aug -47 days	25 Aug -27 days	7 Aug -48 days
Zbiroh	15 Aug -26 days	x	x	8 Aug -29 days	x	x

Tab. 5.2. Onset of 10%-leaves fallen Phase at Selected Phenological Stations of the Czech Hydrometeorological Institute.

Station/Wood Species	**Silver birch**	**European beech**	**Pedunculate oak**	**Small-leaved lime**	**Rowan tree**	**Black elder**
	date/ deviation	date/ deviation	date/ deviation	date/ deviation	date/ deviation	date/ deviation
Běleč nad Orlicí	27 July -55 days	30 July -75 days	1 Aug -68 days	x	1 Aug -64 days	x
Mšecké Žehrovice	12 Aug -61 days	x	x	12 Aug -37 days	x	x
Příkosice	x	12 Aug -56 days	x	x	11 Aug -54 days	11 Aug -51 days
Zbiroh	18 Aug -31 days	x	x	11 Aug -34 days	x	x

The adverse conditions were also reflected in the formation and ripening of fruits. Achenes of all maple species growing in our country, European ash, as well as hazel nuts were the most affected dry fruits. These did not become ripe, but they dried out and fell down. Similarly, the development of acorns of various oak species also stopped, and the acorns remained green. Then, they quickly turned brown and fell down. In particular, the most affected fleshy fruits included (i) the pomes of rowan tree, which shriveled during ripening in many places, (ii) the aggregate fruit of blackberry, which dried out in different stages of development in the blanket manner, and (iii) the drupe of black elder, which dried out in large quantities during ripening. The fruits of some species stagnated in their development and did not ripen, including, for example, pomes of the common pear tree or of various hawthorn species, as well as common dogwood berries.

In exposed places, stands of common heather (Fig. 5.17.) and bilberries completely withered.

Figure 5.17. Completely withered bushes of common heather (Calluna vulgaris) on the Borecké Rocks in Czech Paradise in late October 2015.

Figure 5.18. Newly budding leaves of the black elder (Sambucus nigra) in Prague-Komořany; on the right, delayed ripening fruit can be seen; early September 2015.

Very exceptional findings were obtained in the period from late August to October, when some of the most drought-affected vegetation reacted through the onset of “spring” phases and actually started a new growing period.

Similar signs of recovery of damaged vegetation can sometimes be observed in the spring months, when new leaves emerge on wood species to replace leaves damaged or completely destroyed by late frosts. (The last time this was in 2010 and 2011.) In late summer and autumn, such manifestations are limited to a few species. If they do occur, they do not usually result from damage to vegetation due to adverse weather conditions, but they arise from diseases and pests. For example, this is a common reaction of the horse-chestnut tree to attacks by the horse-chestnut leaf miner. The autumn flowering of many species is also a fairly common phenomenon that is not associated with previous damage to plants due to the weather.

Commencing in September, new leaves gradually started to emerge on some wood species that shed their leaves in August. In the case of trees, this could be particularly observed among younger individuals and, in the case of shrubs, among all age groups. The black elder was the first wood species that came into leaf at lower elevations

(Figure 5.18.), and so did the small-leaved lime in areas scattered across the country. Later, the black locust joined this group – sporadically in drier areas in the Central and Lower Vltava River basins and quite sporadically in other areas. Furthermore, the pedunculate oak and the sessile oak came into leaf at lower elevations. New leaves could also be observed on younger trees of the European hornbeam and wych elm. In the case of the rowan tree, this phenomenon could be observed sporadically in various parts of the country. In late September, the sycamore maple and the Norway maple also started to come into leaf sporadically at lower elevations. Only later, during October, new leaves rarely emerged on the European beech and goat willow. In late October, the wayfaring tree came into leaf at many locations. The most striking reaction was that of the bilberry on which new leaves started to grow at many locations throughout the country from early September to late October. The European bilberry's leaves grew to full size, while in the case of leaves of other mentioned species this rarely occurred.

Sporadically registered new flowers of some wood species were a notable phenomenon. In September, new flowers were found on the bilberry, rowan tree and pedunculate oak, and in late October, also on the wayfaring tree. In one case, second flowering of the black locust was observed. The horse chestnut also newly came into leaf and blossomed to a significantly larger extent than in previous years. Some flowers showed unusual deviations from the normal ones; for example, monoclinous flowers were observed on the pedunculate oak.

6. Evaluation of Snow Water Storage

6.1. Snow Water Storage in the Czech Republic

The amount of water stored in snow cover has been evaluated by the Czech Hydrometeorological Institute since the late 1960s. The need to know the amount of water in the snow cover particularly increased after the construction of water reservoirs. First, the snow reserves were only evaluated for the three most significant water reservoirs in Bohemia – Lipno, Orlík and Nechranice. The calculation was carried out on the basis of knowledge of snow depth, which often had to be professionally estimated. However, the biggest problem consisted in acquiring actual data from observers, and as such, there were frequent delays in the calculations.

Commencing in the 1970s, the snow water equivalent (content) was calculated using the elevation zone methodology. The principle of this calculation consists in extrapolating the snow water equivalent point measurement in the areas with the same elevation. The introduction of this methodology made it possible to extend the calculation also for other major catchment areas of reservoirs in the Czech Republic.

Since 2005 geographic information systems (GIS) have been used for the calculation. The calculation is based on an extension of the "orographic interpolation", which captures the real snow distribution in the most reliable way in the country. Using GIS, the calculation became faster and much more accurate. Thanks to that measure, the list of evaluated catchment areas (representing the reservoirs) could also be extended by small catchment areas where the snow water equivalent was not directly measured. At present, the snow water equivalent is evaluated for a total of 135 catchment areas, consisting mostly of catchment areas of reservoirs. The calculated data represent the values of measurement performed on Mondays and are published on the Czech Hydrometeorological Institute's website (http://www.chmi.cz/files/portal/docs/poboc/CB/snih/aktual.htm) no later than Tuesday, 01:00 p.m.

To asses the calculated amount of water in the snow cover, a snow water equivalent database was created for each of the evaluated catchment areas for the 1970–2015 period. Using this database, it is possible to quickly compare the current snow water equivalent data for the given catchment areas throughout the 1970–2015 period and to also identify the years with the maximum and minimum values for a given calculation week.

The following graphs (Figs 6.1.–6.6.) show the evolution of snow storage in the individual winters since 1970 for selected areas of the Orlík, Nechranice, Kružberk, Vír, Morávka and Lipno Reservoirs. From the individual graphs, it is obvious that in all the selected catchment areas, the water storages accumulated in the snow cover were the largest in the winter of 2005–2006, and the calculated maximum values were at least five times as great as the average values for the entire period of 1970–2015. By contrast, for the entire winter period, there was the least water in the snow storagess in the winter of 2013–2014. During that winter, the maximum snow storages occurred as early as late 2013 and then a rapid loss of snow was recorded in most of the monitored catchment areas. In some catchment areas (especially those in Moravia), snow no longer occurred as early as late February. The winter of 2014–2015 can also be generally evaluated as a below-average period in comparison with the period of 1970–2015. However, as compared with the previous winter of 2013–2014, the recorded snow water equivalent data were twice as high on the individual dates.

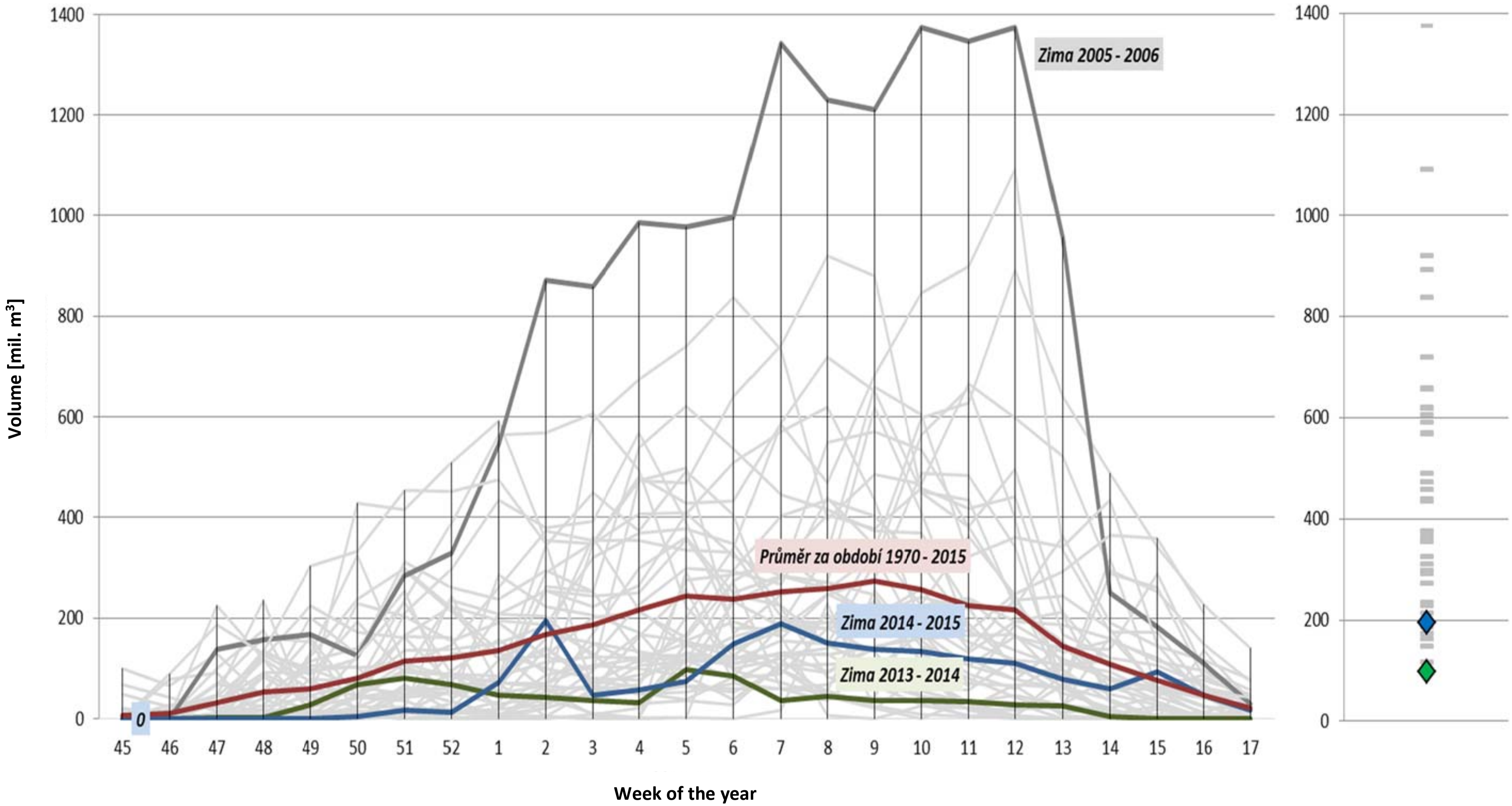


Figure 6.1. Evolution of snow storages and comparison of their maxima in the catchment area of the Orlík Reservoir in individual winters since 1970 (average value for 1970–2015 in red).

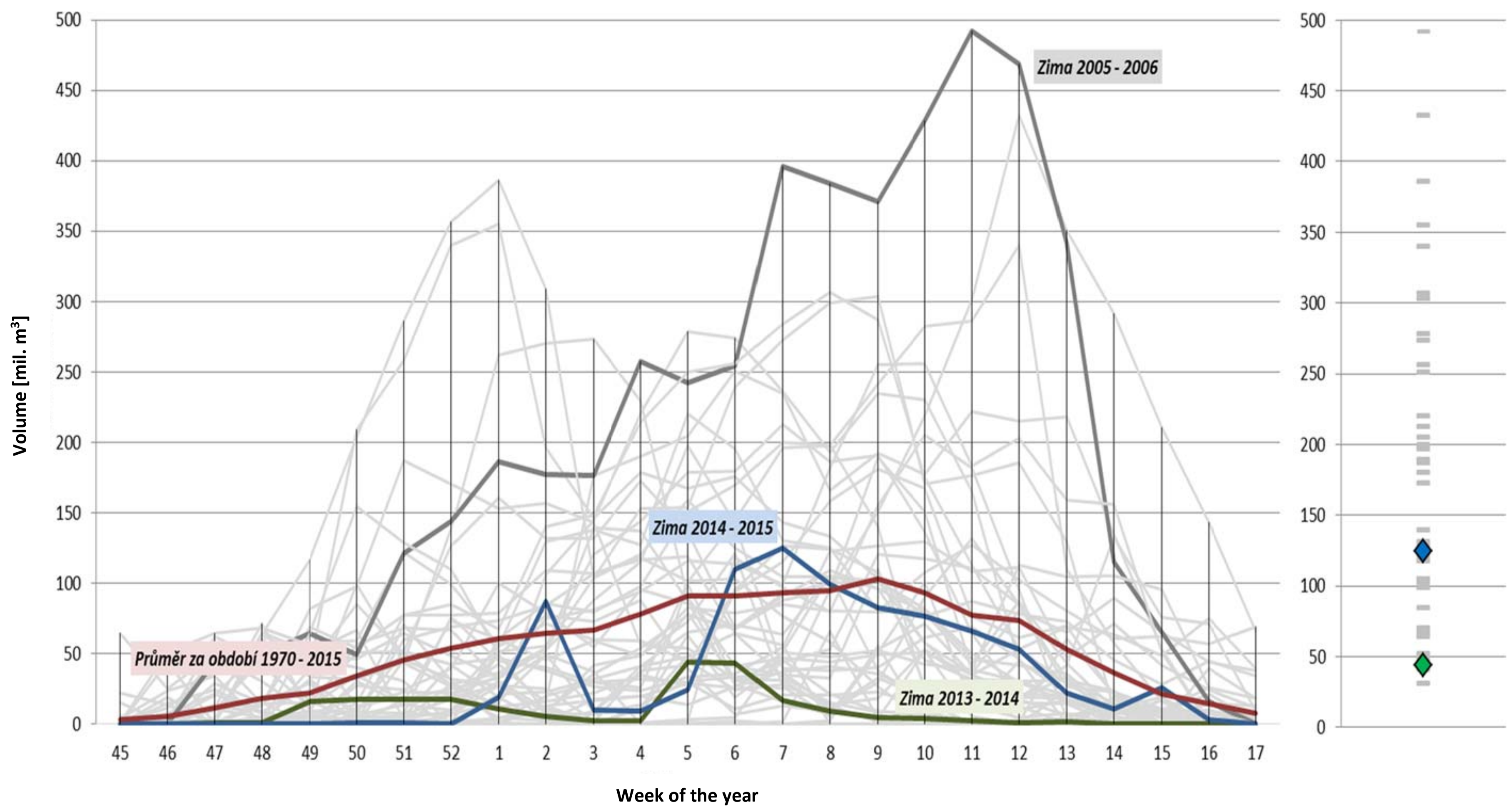


Figure 6.2. Evolution of snow storages and comparison of their maxima in the catchment area of the Nechranice Reservoir in individual winters since 1970 (average value for 1970–2015 in red).

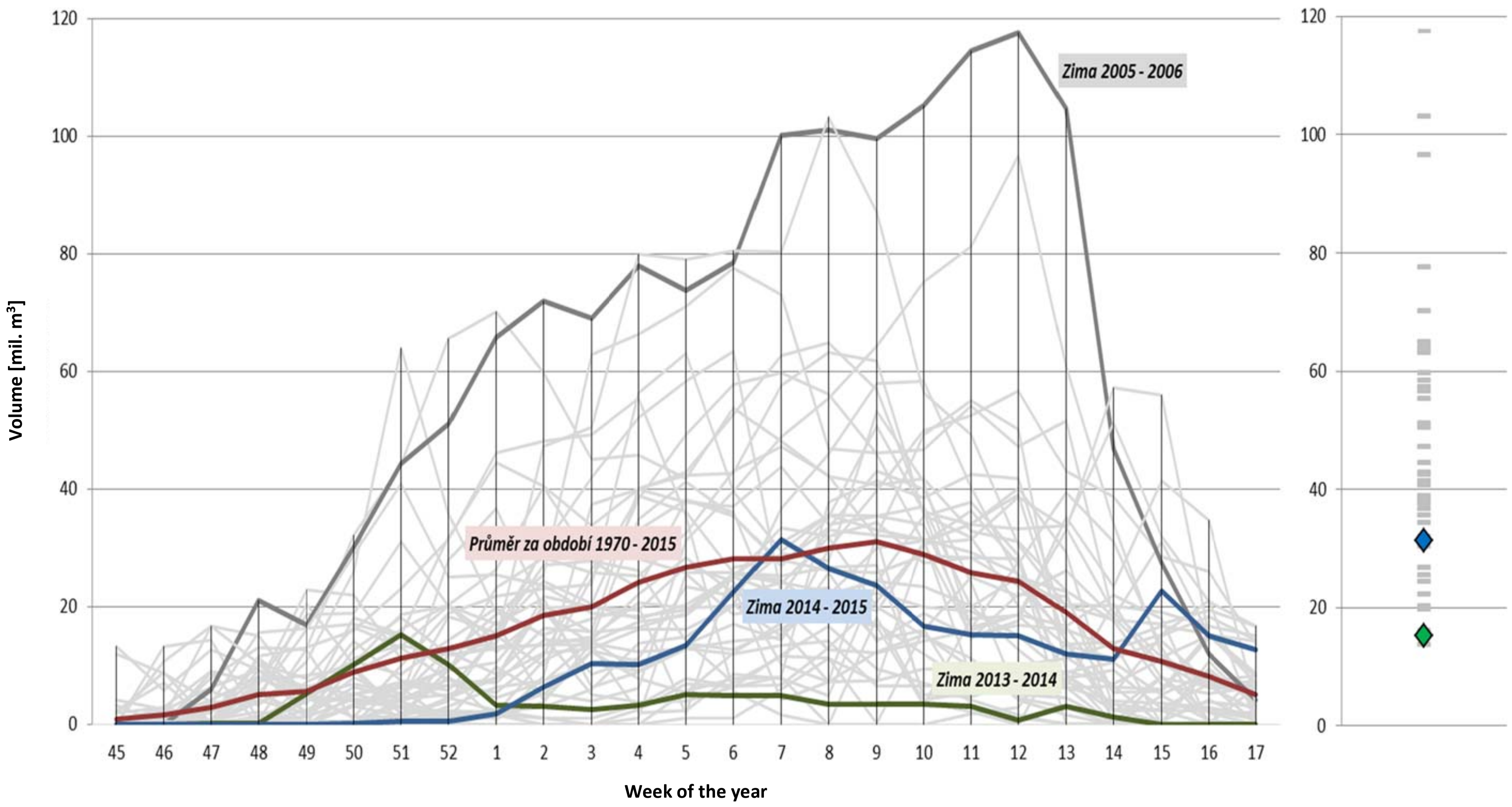


Figure 6.3. Evolution of snow storages and comparison of their maxima in the catchment area of the Kružberk Reservoir in individual winters since 1970 (average value for 1970–2015 in red).

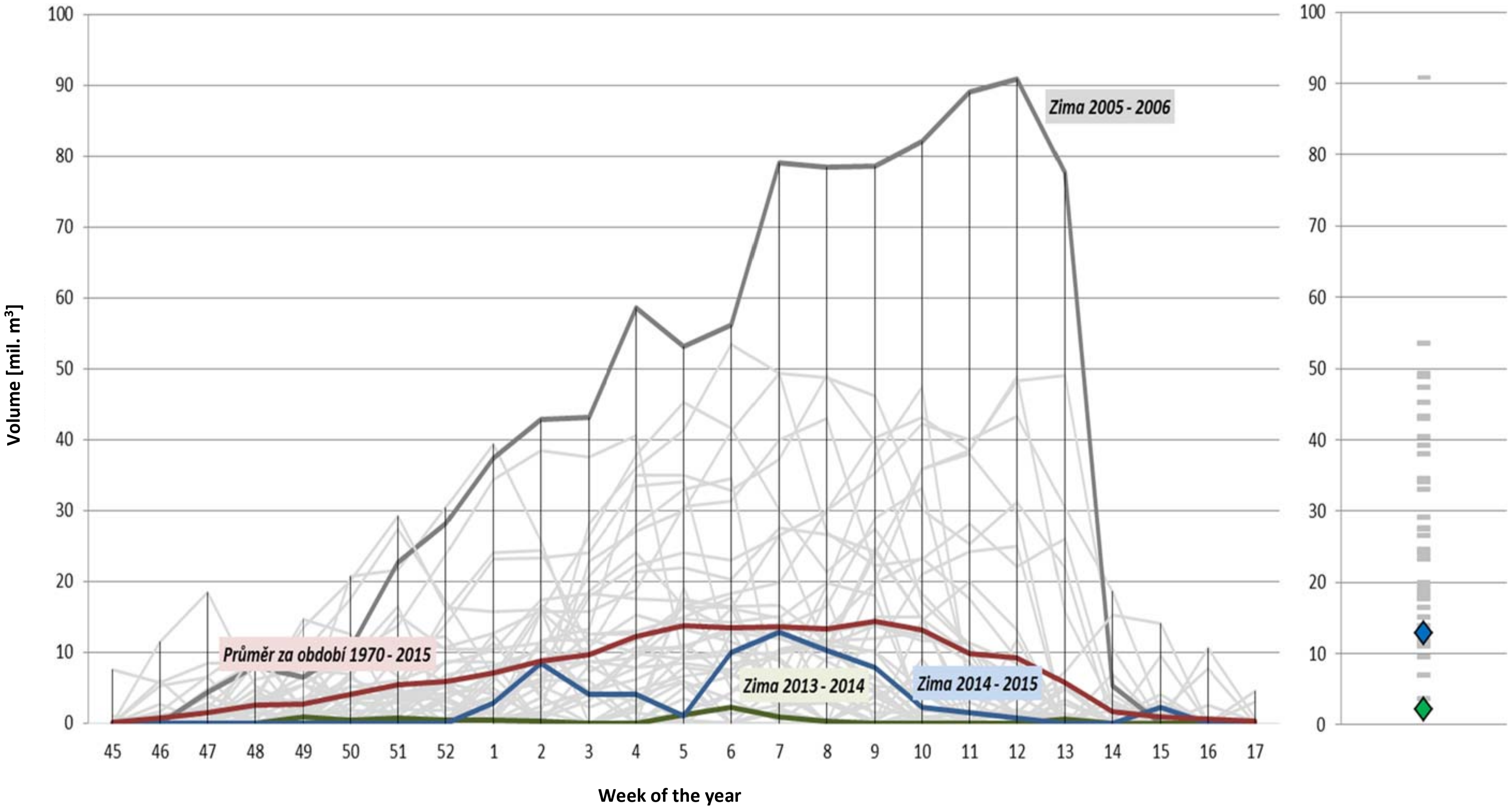


Figure 6.4. Evolution of snow storages and comparison of their maxima in the catchment area of the Vír Reservoir in individual winters since 1970 (average value for 1970–2015 in red).

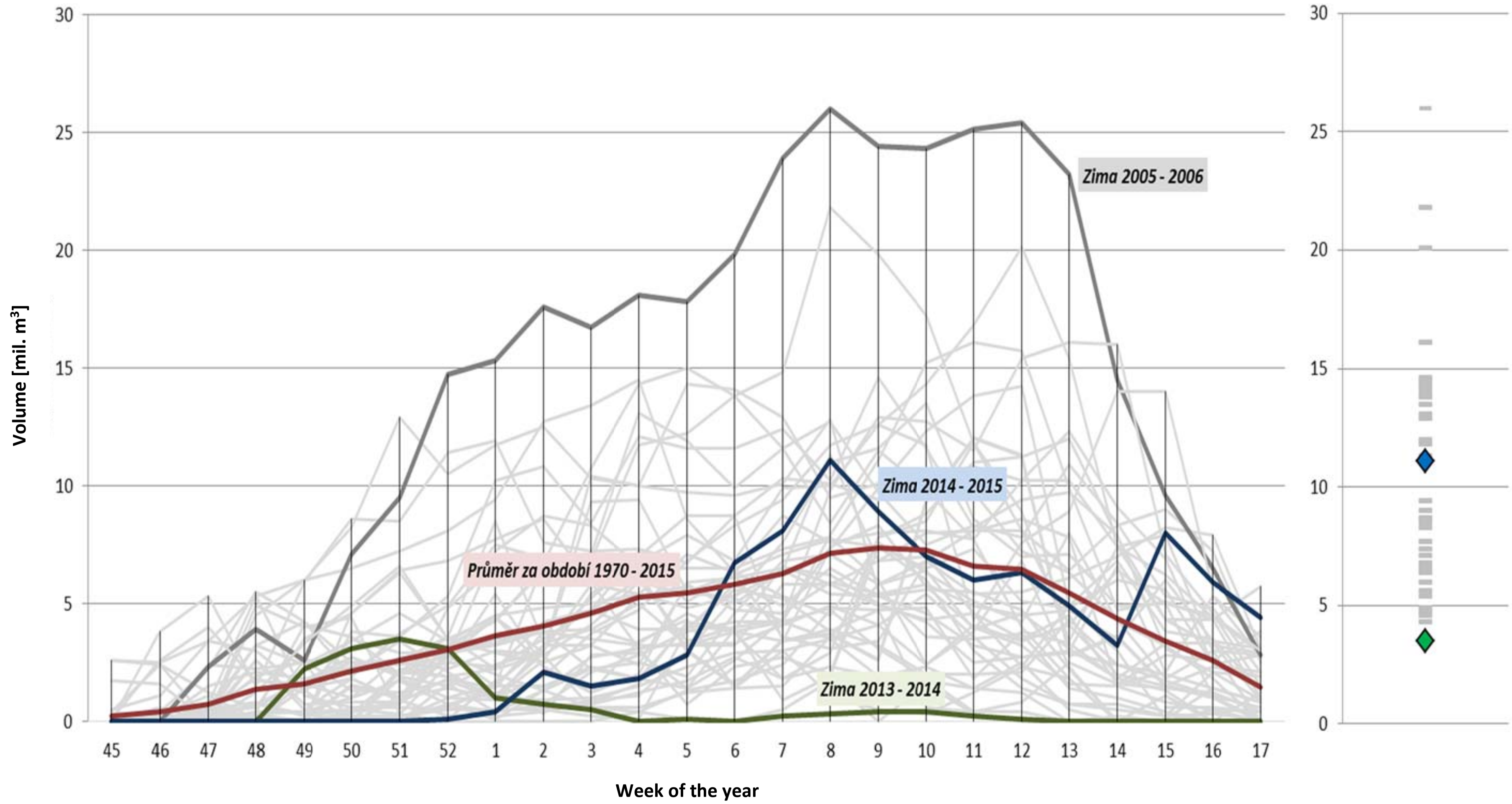


Figure 6.5. Evolution of snow storages and comparison of their maxima in the catchment area of the Morávka Reservoir in individual winters since 1970 (average value for 1970–2015 in red).

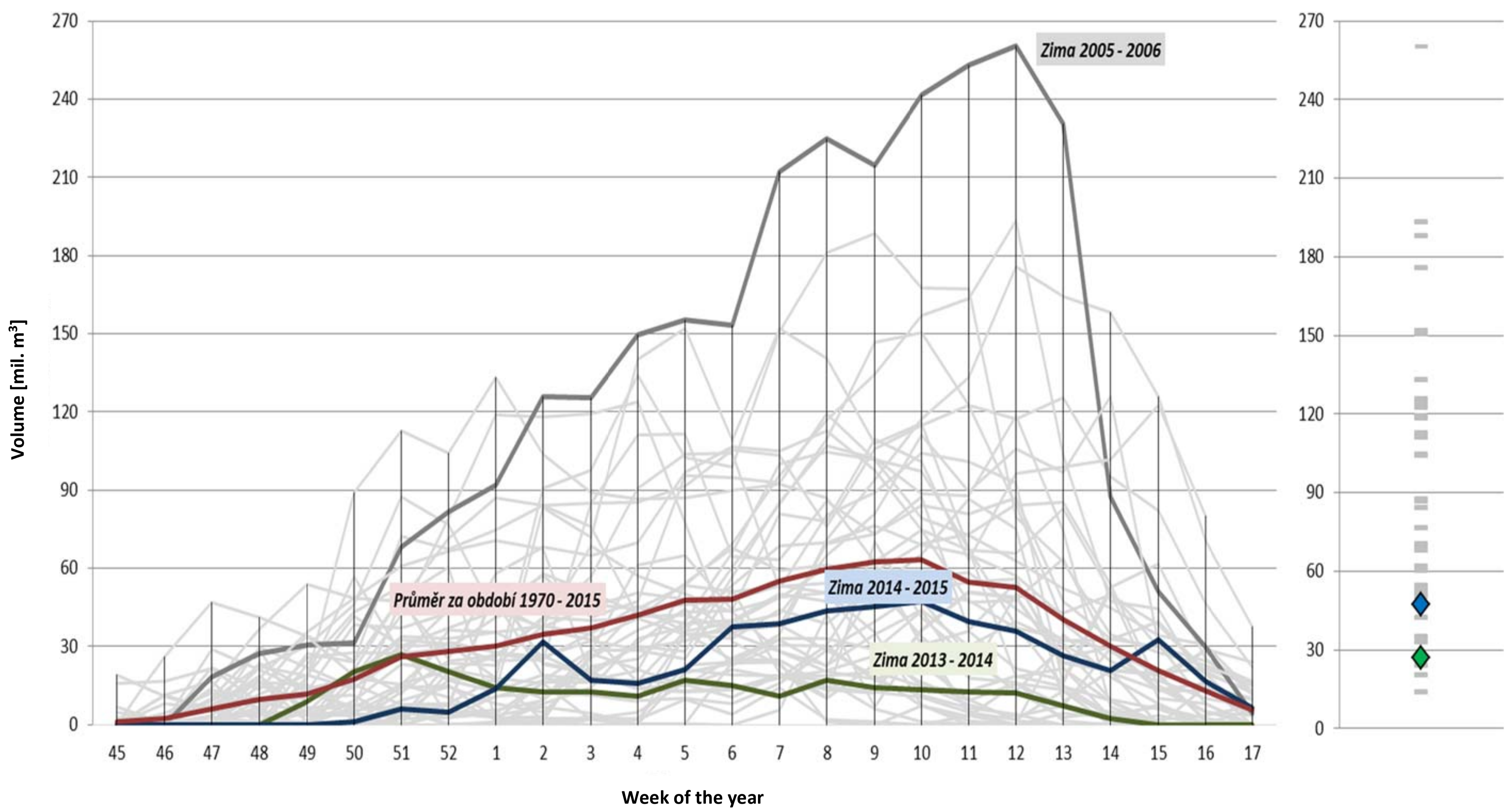


Figure 6.6 Evolution of snow storages and comparison of their maxima in the catchment area of the Lipno Reservoir in individual winters since 1970 (average value for 1970–2015 in red).

6.2. Evaluation of Years 2014 and 2015

The time series of recorded discharges in selected catchment areas and the temperature and snow parameters of previous winters at representative stations (Figs. 6.7. to 6.10.) were evaluated. In general, it is possible to summarize that for all of the tested catchment areas, it was true that in the years where there were significant below-average discharges, the snow storages were also below-normal or no higher than normal.

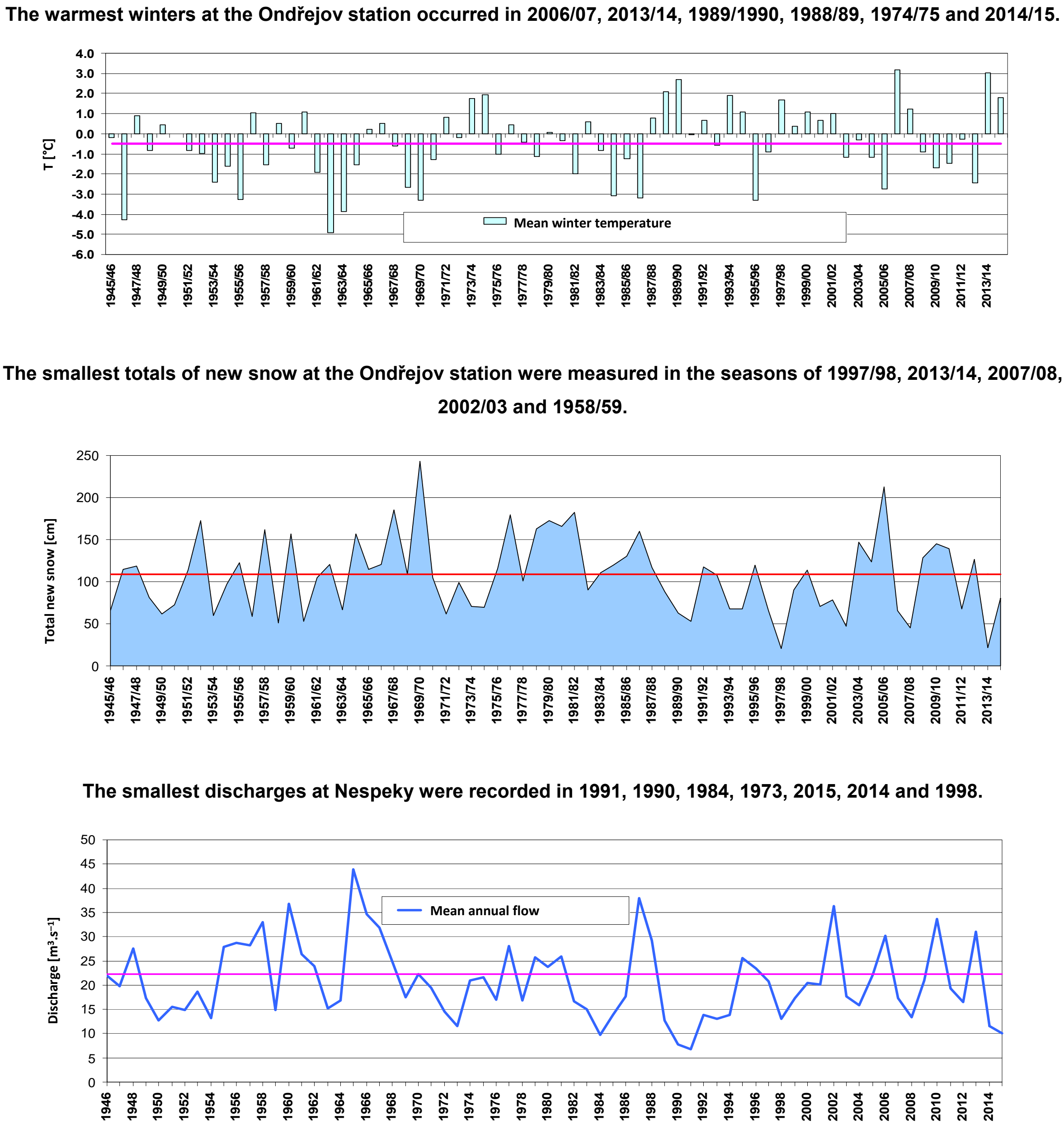
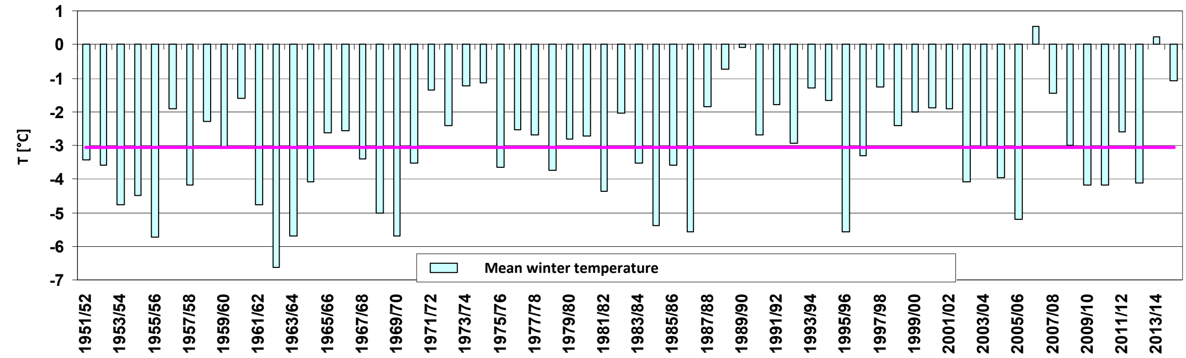
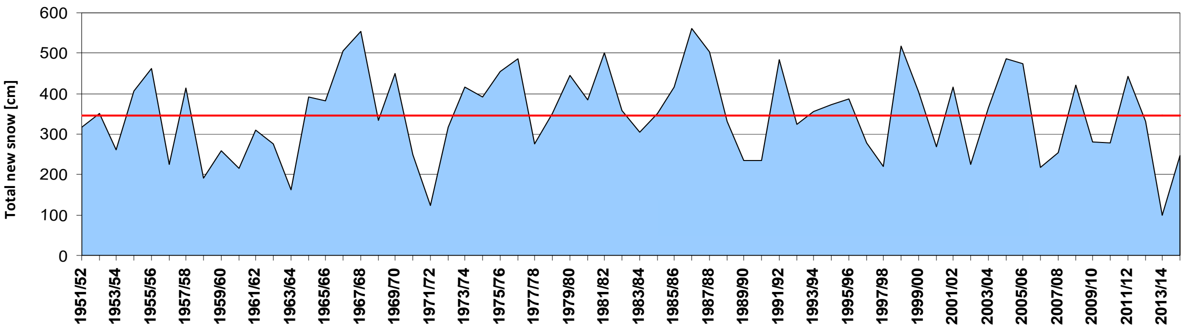


Figure 6.7. Sázava River basin.

The warmest winters at the Desná station occurred in 2006/07, 2013/14, 1989/1990, 1988/89, 1974/75 and 2014/15.



The smallest totals of new snow at the Desná station were measured in the seasons of 2013/14, 1971/72, 1963/64, 1958/59 and 1960/61.



The smallest discharges at Železný Brod were recorded in 1959, 1972, 2014, 2003, 1960, 1963 and 1991.

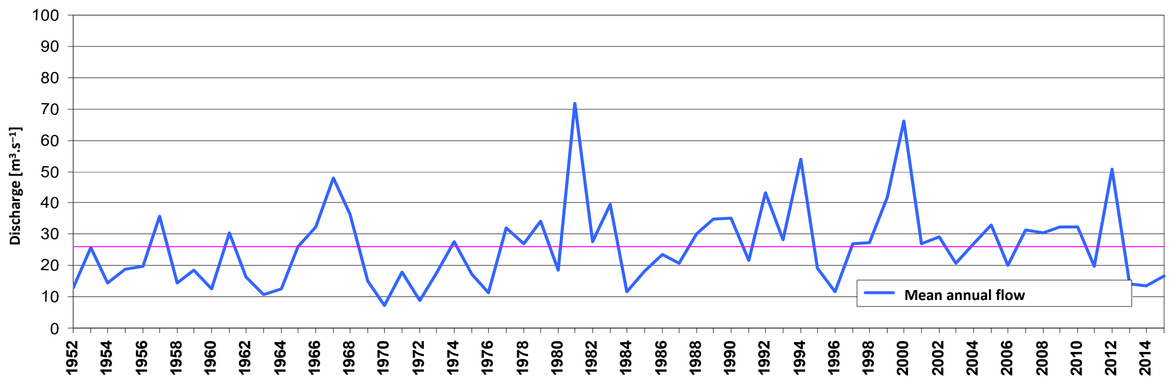
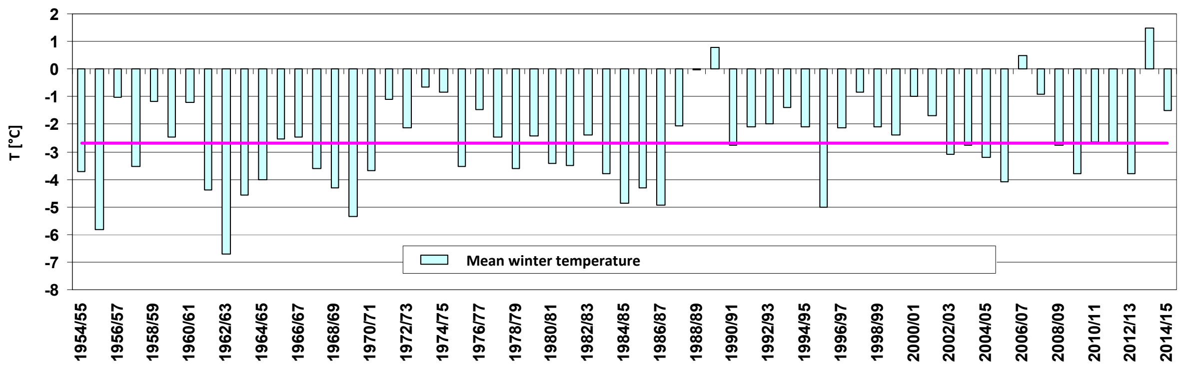
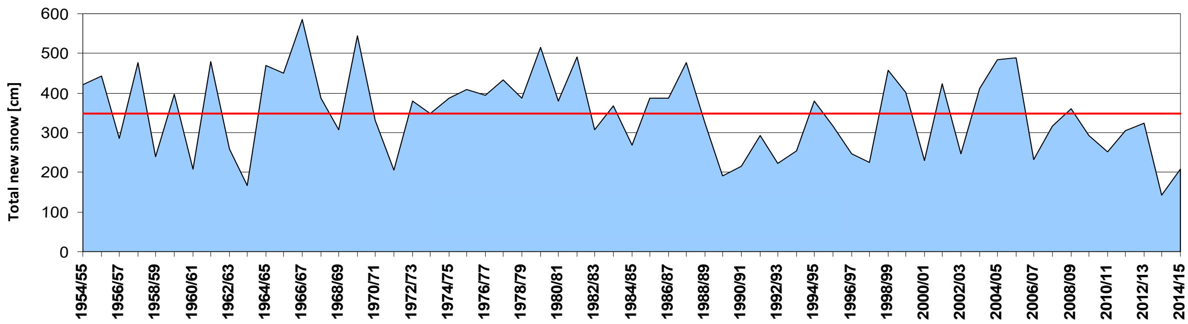


Figure 6.8. Upper Jizera River basin.

The warmest winters at the Churáňov station occurred in 2013/2014, 1989/1990 and 2006/2007.



The smallest totals of new snow at the Churáňov station were measured in the seasons of 2013/14, 1963/64, 1989/90, 1971/72, 1960/61, 2014/15 and 1990/91.



The smallest discharges at Sušice were recorded in 1972, 1973, 1971, 1963, 1960 and 2003.

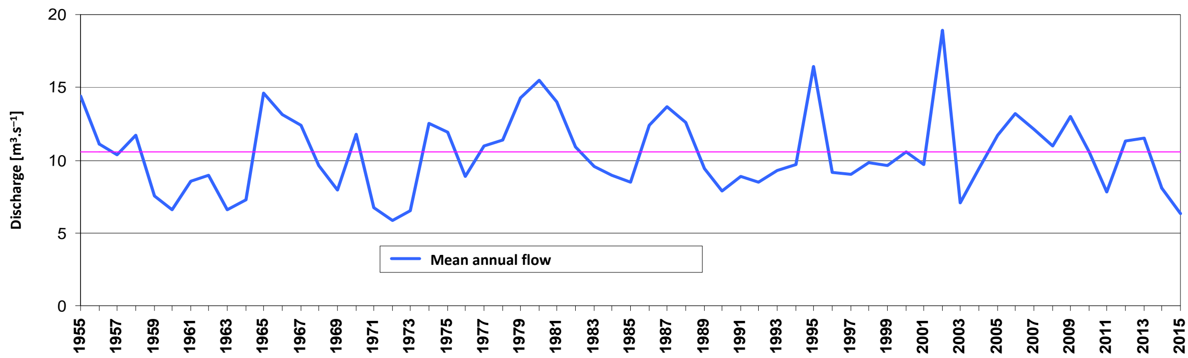
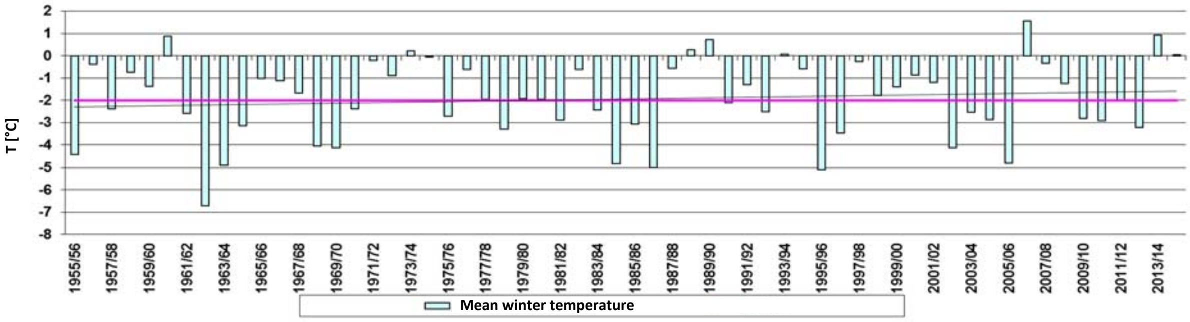
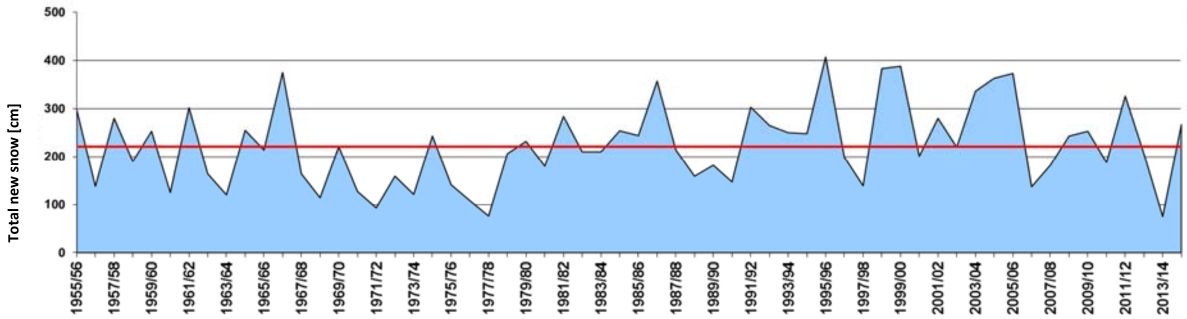


Figure 6.9. Otava River basin.

The warmest winters at the Světlá Hora station occurred in 2006/2007, 2013/2014, 1960/61, 1989/1990 and 1988/89.



The smallest totals of new snow at the Malá Morávka station were measured in the seasons of 2013/14, 1977/78, 1971/72 and 1976/77.



The smallest discharges at Krnov were recorded in 1990, 1961, 2003, 1969, 1957, and 2014.

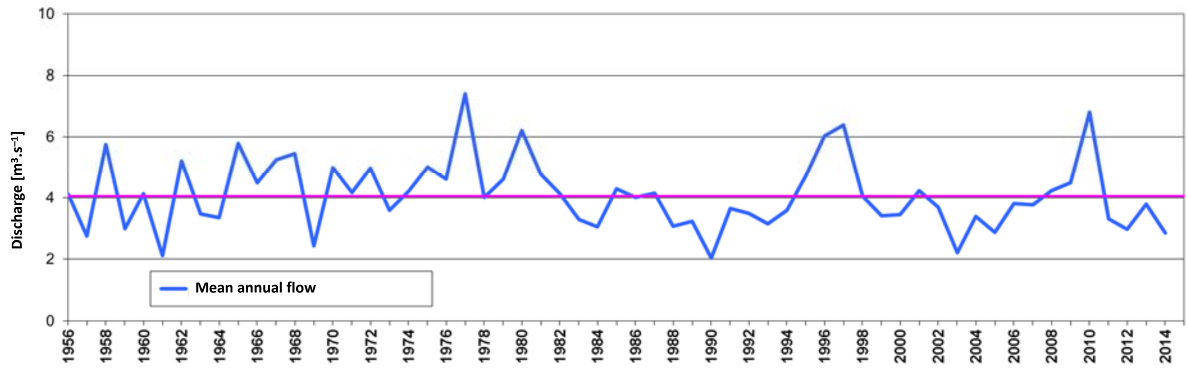


Figure 6.10. Opava River basin.

The influence of snow storages on runoff was evaluated for the spring and summer months. Emphasis was placed on the years with the lowest recorded snow storages (total new snow for the winter season) at selected stations of the climatological and precipitation gauge networks and the subsequent runoff amount in the period from March to June, and possibly also in July in such years.

In the Sázava River basin, the small annual flows and small discharges in the spring months of March to May, possibly also in June (1990, 1991, 1950), corresponded to the small snow storages in 1949/1950, 1989/1990, 1990/1991, 1997/1998 and 2013/2014.

In the Jizera River basin, the small snow storages in the winters of 2014, 1972, 1964, 2007 and 1959 did not sufficiently increase the flows in March or April, and the flows in April ranked among the lowest in many of the observations. In 1990, when there was also little snow, there were extraordinarily low discharges until the summer, and in 2015 the relatively dry months were only those in the summer.

In the Otava River basin, there were considerably below-average discharges from March to July, and there were also low annual flows in 2014, 1964 and 1990, i.e. years with strongly below-normal snow storages. In 2015, when there were also extraordinarily low snow storages, a drought did not manifest itself until May.

In the Opava River basin, small discharges in the spring months after poor snowfalls in the winter (1957, 1961 and 1964) occurred less frequently than in the case of other catchment areas.

From the monitored cases, it has generally followed that the relationship between small snow storages and minimum discharges (flows) is not provable.

For all the catchment areas, a correlational relationship between the snow cover in a given year and the respective monthly average discharges for March to June was created. The closest relationship was mostly shown in the months when the snow melts, i.e. April. This event only occurred in March in the Sázava River basin, where its elevation above sea level is the lowest. On the other hand, for the Otava River in Sušice, the highest correlation coefficient of 0.65 was found to be in May. However, the correlation coefficients were relatively low, ranging from 0.2 to 0.65. In the following months, the correlation coefficient declined, as shown by the course of correlation for the Jizera River basin in Fig. 6.11.

The results indicate that the correlational relationship between the accumulated snow storages and the occurrence of hydrological drought is relatively loose. It is caused by the fact that the runoff size in the spring months is influenced by other factors, especially by precipitation, soil saturation, air temperature, soil temperature and soil freezing.

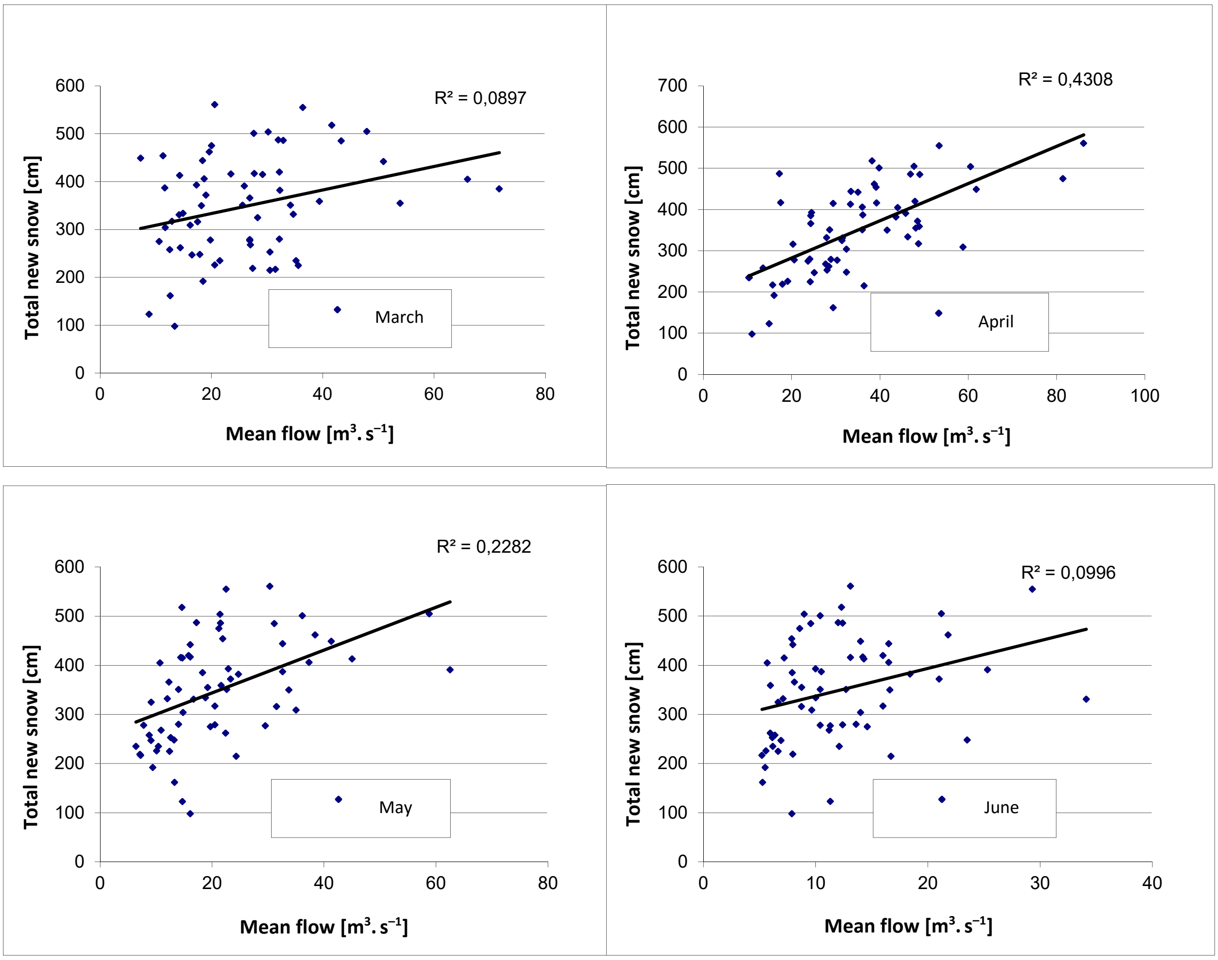


Figure 6.11. Correlational dependence of new snowfall totals and average discharges in March to June in the Upper Jizera River basin.

7. Evaluation of Minimum Flows

In the growing season, the occurrence of minimum discharges in watercourses is always associated with a significant precipitation deficit and gradually decreasing water reserves in the catchment area. In the case of streams with a natural hydrological regime, the minimum discharges (flows) are formed entirely by outflows of groundwater reserves. In the event that significant precipitation occurs, the flows grow in the short-term and usually quickly fall back to the level reached before the precipitation period.

In winter, the minimum discharges may sometimes occur in periods with negative air temperatures, when the stream partially or fully freezes over, or the minimum discharge may continue to occur as a result of the previous precipitation deficit. The water reserves in the catchment area may also be relatively significant, for example, in the form of snow cover. This period of minimum discharges always ends at the onset of the thaw period.

The decline in discharges below Q_{355d} (355-day flow) is one of the basic features indicating the beginning of the period with minimum discharges. This is the flow that is reached or exceeded for a period of 355 days in a year on the long-term average. If the discharge further decreases to the values of the 364-day flow and less, then this may already be a very significant hydrological drought.

In 2015 the period with the occurrence of minimum discharges began approximately at the end of June. It was a period of hydrological drought in the growing season, when the long-lasting lack of atmospheric precipitation was later accompanied by periods of tropical air temperatures, which reached extreme values on some days. This fact led to a further drop in the water levels due to the increased evaporation from the ground, water reservoirs and the streams themselves. In many streams, the discharges even reached levels that were relatively significantly below the 364-day flow. In the most streams, the hydrological drought was interrupted for a short time by the precipitation period in mid-August.

7.1. Minimum Discharge Measurement Documentation

During July, August and September 2015, the Czech Hydrometeorological Institute’s personnel performed more than 850 hydrometric measurements, and at some profiles, the measured discharges were even the lowest for the period of monitoring performed by the gauging stations. Should we select only the lowest measured discharges at the individual hydrometric (i.e. stream-gauging) profiles for the said months, the 355-day flow or even less would be measured in 258 cases. Of this number, in 160 cases, there was a 364-day flow or even less. In some cases, a complete dry-up of the watercourse or just slight discharges were recorded (see Table 7.2.).

Table 7.1. below shows the results of some hydrometric measurements when the measured discharge was significantly lower than the 364-day flow.

Table 7.1. Results of selected hydrometric measurements.

Watercourse	Station	Catchment Area [km^2]	Date	Water Stage [cm]	Flow Rate Q [m3.s^{-1}]	Ratio Q/Q_{364d}
Sedlický potok	Leský Mlýn	71.7	12. 8.	8.5	0.001	0.05
Cidlina	Nový Bydžov	455.9	17. 8.	4	0.007	0.08
Úterský potok	Trpísty	297.2	28. 7.	1	0.001	0.11
Úslava	Plzeň-Koterov	733.2	7. 8.	6.5	0.047	0.19
Brzina	Hrachov	133.3	7. 8.	26	0.001	0.20
Doubrava	Pařížov	201.2	12. 8.	2	0.030	0.23
Lomnice	Dolní Ostrovec	391.4	13. 8.	27	0.004	0.23
Rokytenka	Žamberk	59.7	20. 7.	9.5	0.033	0.25
Smědá	Višňová	187.5	3. 9.	15	0.165	0.26
Úhlavka	Stříbro	296.6	14. 8.	11	0.017	0.28
Sázava	Zruč nad Sázavou	1420.7	6. 8.	43	0.396	0.31
Lužnice	Pilař-Majdalena	935.2	11. 8.	99.5	0.060	0.33
Osoblaha	Osoblaha	201.0	21. 8.	76	0.013	0.34
Smědá	Frýdlant v Čechách	132.5	26. 8.	2.5	0.193	0.35

Photo 1. Discharge measurement using the flow tracker instrument at the Hrachov gauging station on the Brzina creek (7 August 2015, Lucie Petrová).

Table 7.2. Overview of profiles where stream dry-up was detected

Watercourse	**Station**	**Catchment Area [km^2]**	**Date**	**Discharge Q [m^3.s^{-1}]**
Rokytenka	Žamberk	59.7	13. 8.	0
Žejbro	Vrbatův Kostelec	49.1	14. 8.	0
Klejnárka	Chedrbí	63.7	11. 8.	0
Brzina	Hrachov	133.3	10. 8.	0
Úterský potok	Trpísty	297.2	14. 8.	0
Lomnický potok	Pila	60.2	13. 8.	0
Vrbovec	Bystrc	15.1	31. 7.	0,0001
Sloupský p.	Sloup (*)	50.0	7. 7.	0
Bílá voda	Holštejn (*)	57.7	21. 7.	0,0002

(*) – Profiles located in the Moravian Karst dry up more often, but usually in a later period of the year.

The map in Fig. 7.1. symbolically shows the results of hydrometric measurements performed in July, August, September (and October) 2015, when the lowest discharge measured in the said period equaled or was less than the 355-day flow. The measurement date is also specified for each symbol. It must be added that the map is based on the data that were stored in the Czech Hydrometeorological Institute database as of the map preparation date.

This map is one of the supporting documents showing that the hydrological drought hit practically the entire Czech Republic, and the large number of profiles with a discharge (flow) less than or equal to the 364-day flow shows that it was very significant. The fewest measurements with a discharge less than Q_{355d} were recorded in the northwest of Bohemia, where the precipitation deficit was less distinct than the normal value, as well as in some areas of South Moravia.

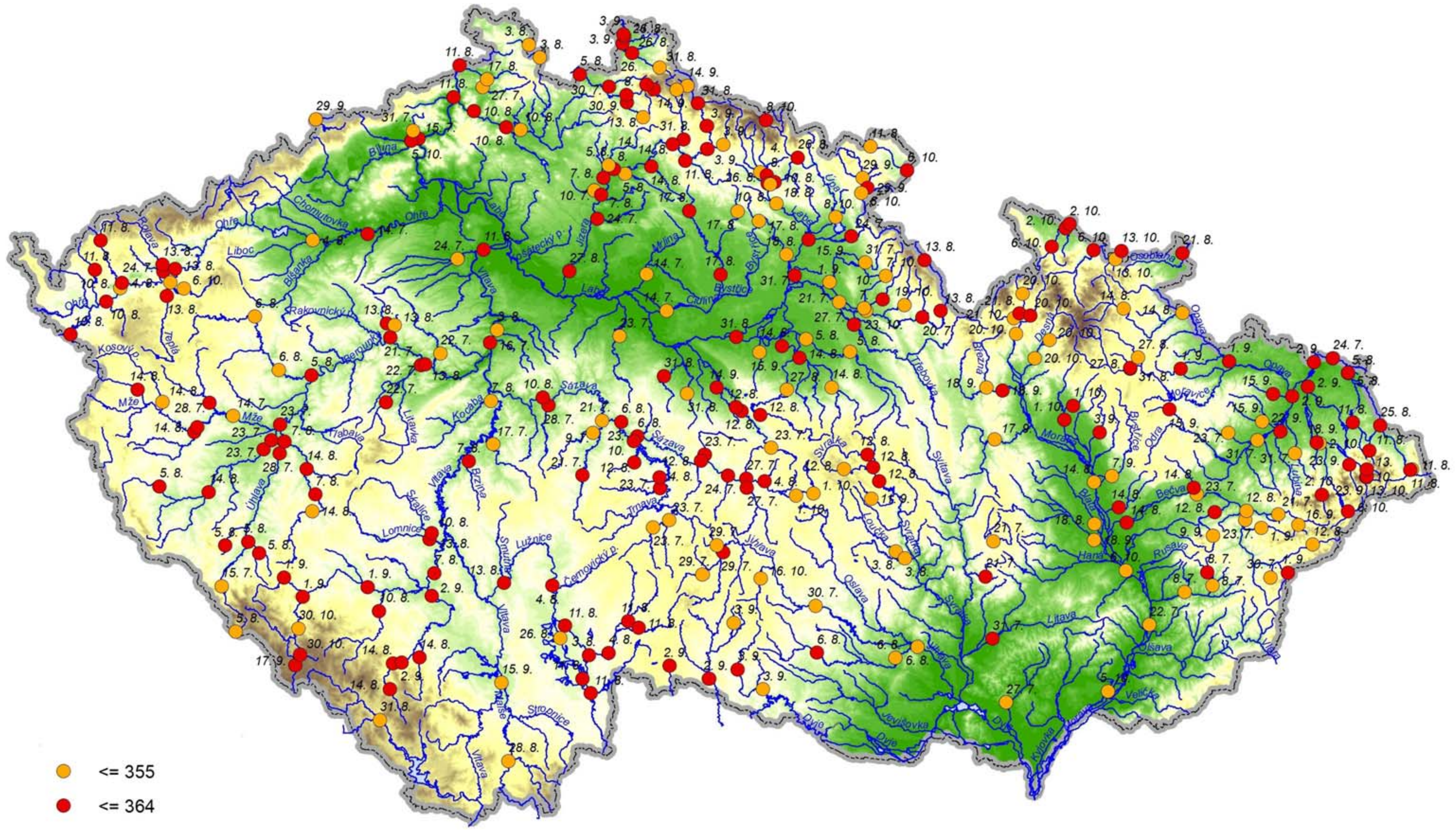


Figure 7.1. Overview of stream-gauging profiles where a 355-day flow and less was measured.

7.2. Evaluation of Water-Bearing Capacity Development for Selected Streams

Figs. 7.2.–7.7. present the hydrographs of average daily discharges from 1 April 2015 to 30 September 2015 at selected gauging stations, indicating the lines of long-term average discharges (Q_a), 355-day flow (Q_{355d}), and 364-day flow (Q_{364d}). It should be noted that this is preliminarily evaluated data, which may still be updated within the overall evaluation of discharges at all gauging stations. These hydrological characteristics correspond to the reference period of 1981–2010.

The changes in water-bearing capacity during the year were mainly affected by the precipitation deficit, which already manifested itself during the winter when the snow reserves were below-normal as compared with the period 1970–2014 (see Chapter 6), in particular, at lower and medium elevations. In addition, most snow reserves accumulated by the beginning of January 2015 were reduced in the second week of January due to the marked warming and abundant rainfall, which also occurred in mountain areas. Streams in the Vltava River basin, especially in the southwest of Bohemia, reached flood stage. The thaw at the end of March and at the beginning of April did not any longer cause such a significant increase in the discharge, because in late March snow only lay in mountain areas and thawed gradually. In addition, the snow melting was slowed down by a significant, but short, cooling period in the first week of April.

As early as the beginning of May, stream levels had mostly declined, which was occasionally interrupted by insignificant precipitation. For example, the Orlice river's level at Týniště nad Orlicí (Fig. 7.2.) dropped below the long-term average discharge as early as the second half of April, which also occurred on the Odra river at Svinov (Fig. 7.6.), but during May, the river level still fluctuated. An example of a small submontane stream (Blanice river at Blanický Mlýn, Fig. 7.5.) clearly shows a greater flow fluctuation due to intermittent rainfalls during June and a stream level drop below the level of its 355-day flow only in early August.

The end of June and the beginning of July, when temperatures were significantly rising and gradually reaching tropical values, can be described as the beginning of an extremely dry and extraordinarily warm period that lasted until mid-August. At many profiles, the stream level dropped significantly below the level of its 355-day flow (see the map in Fig. 7.1.), and many small watercourses and some larger creeks dried up.

Table 7.3. Selected gauging stations with the number of days with values of flow less than Q_{355d} and Q_{364d} for the period from 1 April to 30 September.

Watercourse	Station	Catchment Area [km²]	Number of Days with Q_{355d} and Less [days]	Number of Days with Q_{364d} and Less [days]
Orlice	Týniště nad Orlicí	1,554.2	74	43
Jizera	Železný Brod	791.3	64	48
Lužnice	Bechyně	4,057.1	70	36
Blanice	Blanický Mlýn	85.5	48	38
Odra	Ostrava-Svinov	1,613.7	73	31
Morava	Strážnice	9,144.8	37	0

Photo 2. Lomnický creek at the Pila gauging station (13 August 2015, Karel Bohuslav).

Besides the lack of precipitation, a substantial role was also played by greater evaporation from watercourses and reservoirs, which was strikingly evident especially in the catchment areas with extensive pond systems, in particular, in the Lužnice river basin (Fig. 7.4.). This confirmed the fact that during the drought, large fish ponds worsen the streamflow regime because they retain water, and in addition, in a period of high temperatures there is high evaporation from the ponds. In contrast, the large multipurpose water reservoirs (Lipno, Orlík) which improve the minimum flow rates in times of drought significantly improve the flow conditions in the stream stretches downstream of the water reservoirs. The Vltava River cascade reservoirs significantly contributed to the mitigation of hydrological drought impacts on the lower reaches of the Vltava and Elbe Rivers (see Section 7.5.).

Hydrological drought in the streams was mitigated for a short time in mid-August, when relatively heavy precipitation occurred in most of the Czech Republic. In some places, the three-day rainfall amounted to even more than 100 mm, and sporadically, the rainfall recurrence interval reached 50 years (see Chapter 3). For example, in the Svitava river basin area as far as the Bílovice nad Svitavou (1,120 km^2) gauging station site, the rainfall amounted to 98 mm on average in the period from 16th to 19th August, of which however, only 2.6 mm ran off directly! In the left-bank tributaries of the Morava river (Moštěnka, Olšava, Velička), there was a similar situation. Precipitation only caused an insignificant increase in the level of watercourses. Practically all the rainwater soaked into the soil or evaporated. The only run off occurred on impervious surfaces. That situation thus indirectly showed the extent of soil drought in mid-August and also indirectly documented the retention capacity of the soil. The discharge wave of mid-August is clearly shown in the hydrograph for the Orlice River at Týniště nad Orlicí (Fig. 7.2.). After the precipitation episode, the water stage very quickly dropped almost to its previous level.

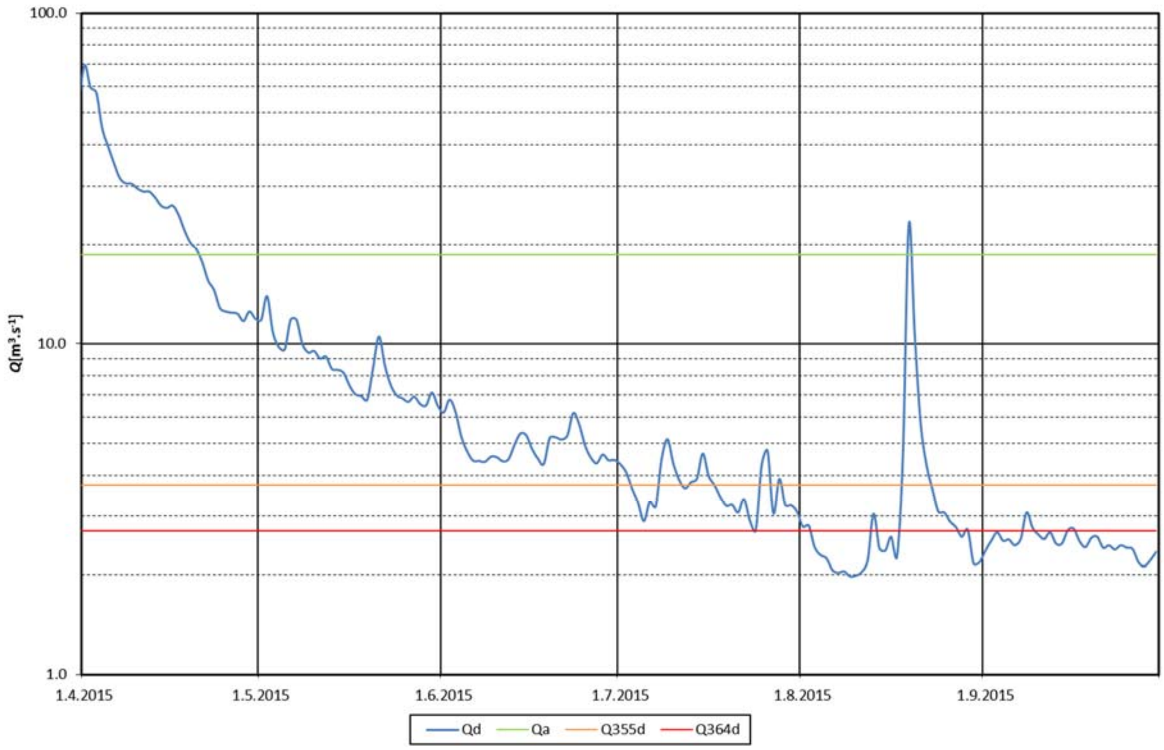


Figure 7.2. Hydrograph of average daily discharges of the Orlice river at Týniště nad Orlicí.

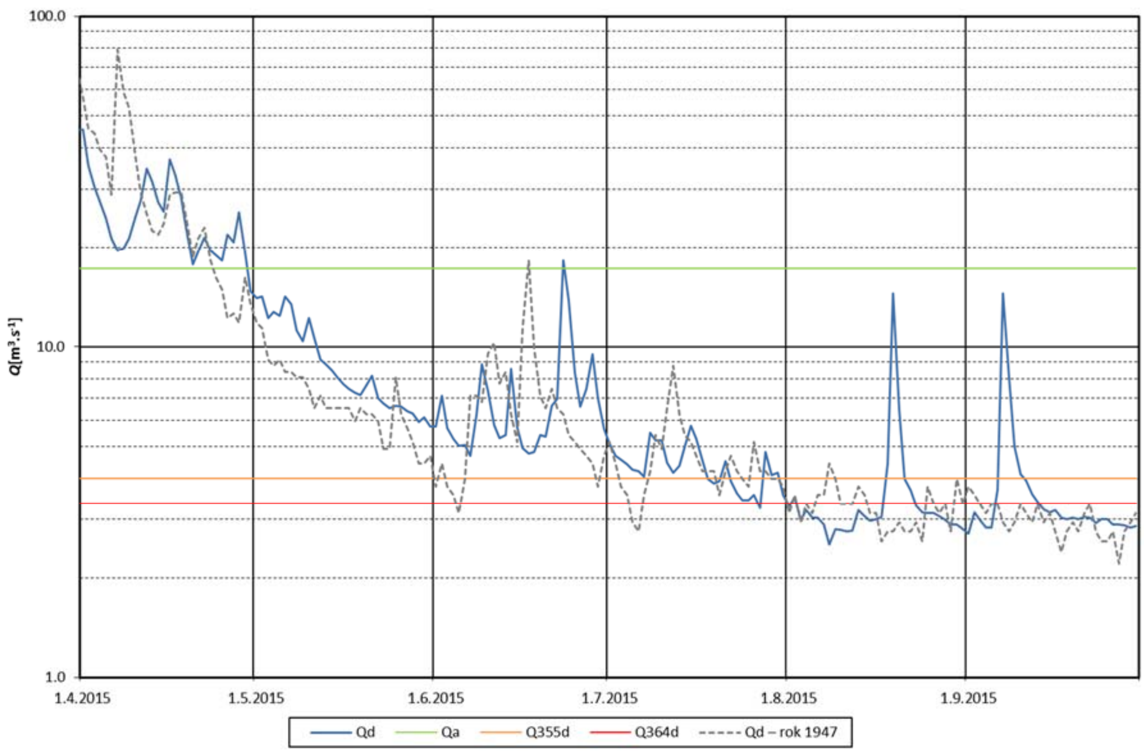


Figure 7.3. Hydrograph of average daily discharges of the Jizera river at Železný Brod.

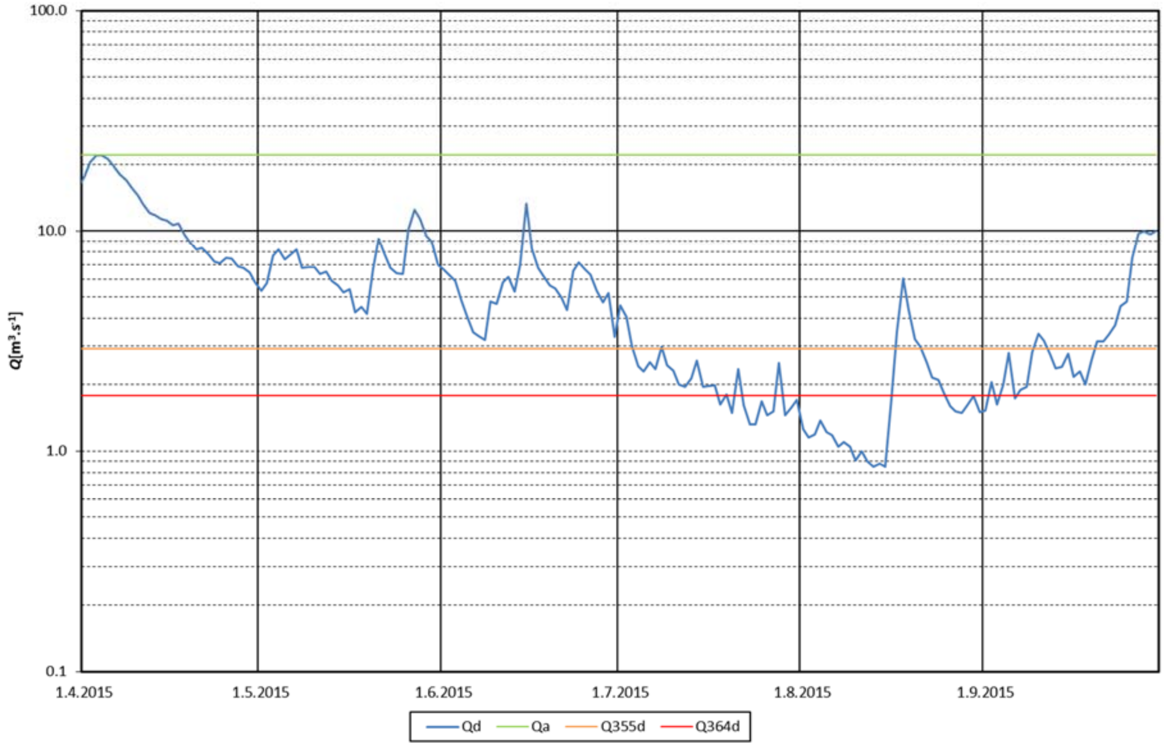


Figure 7.4. Hydrograph of average daily discharges of the Lužnice river at Bechyně.

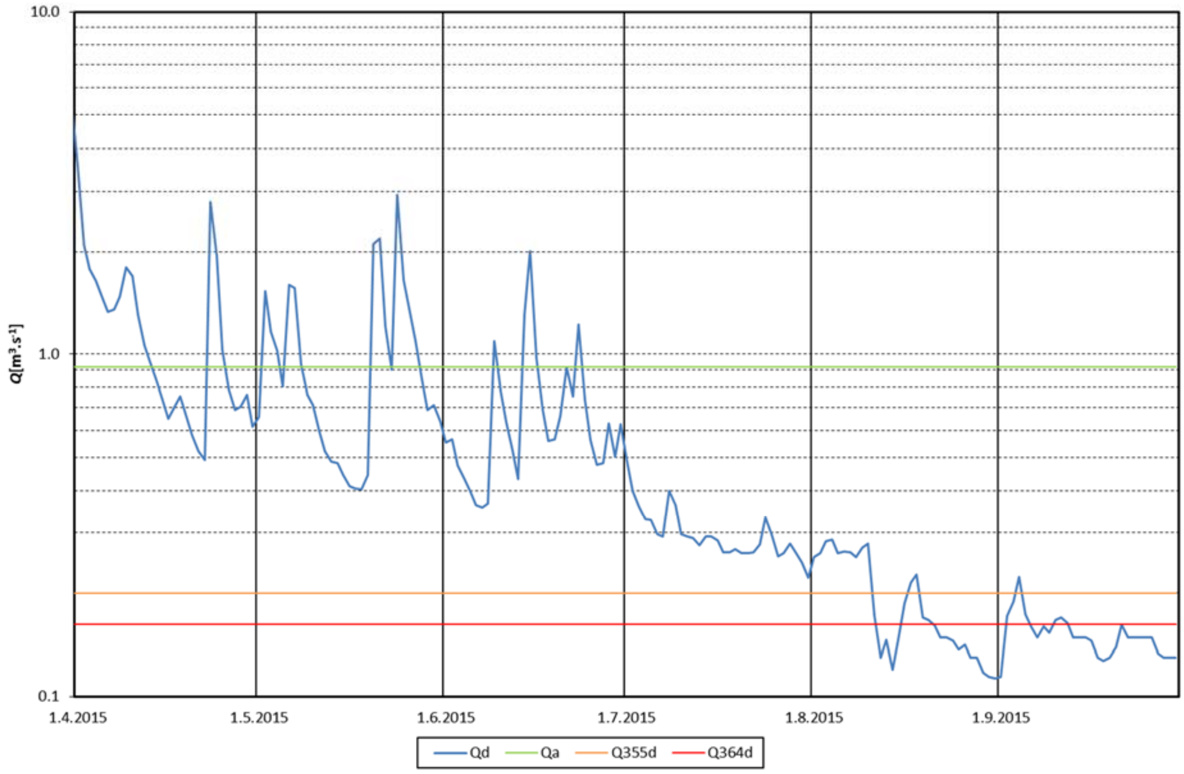


Figure 7.5. Hydrograph of average daily discharges of the Blanice river at Blanický Mlýn.

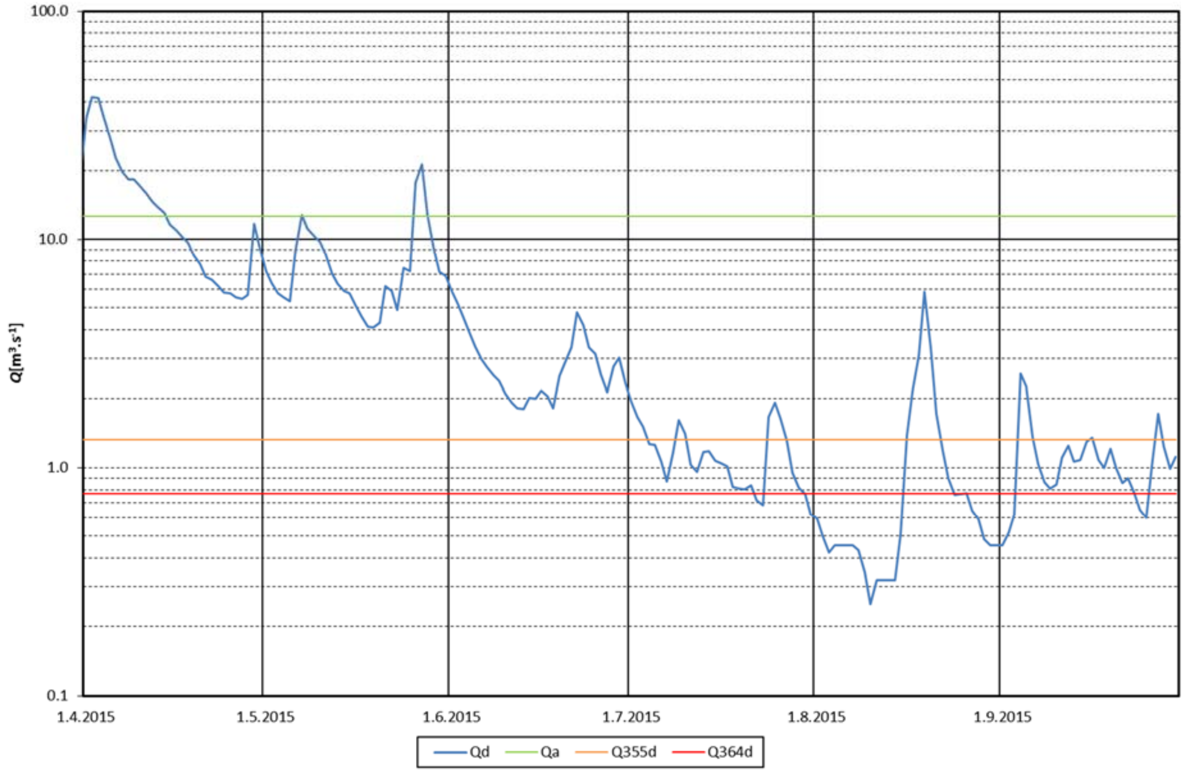


Figure 7.6. Hydrograph of average daily discharges of the Odra river at Ostrava-Svinov.

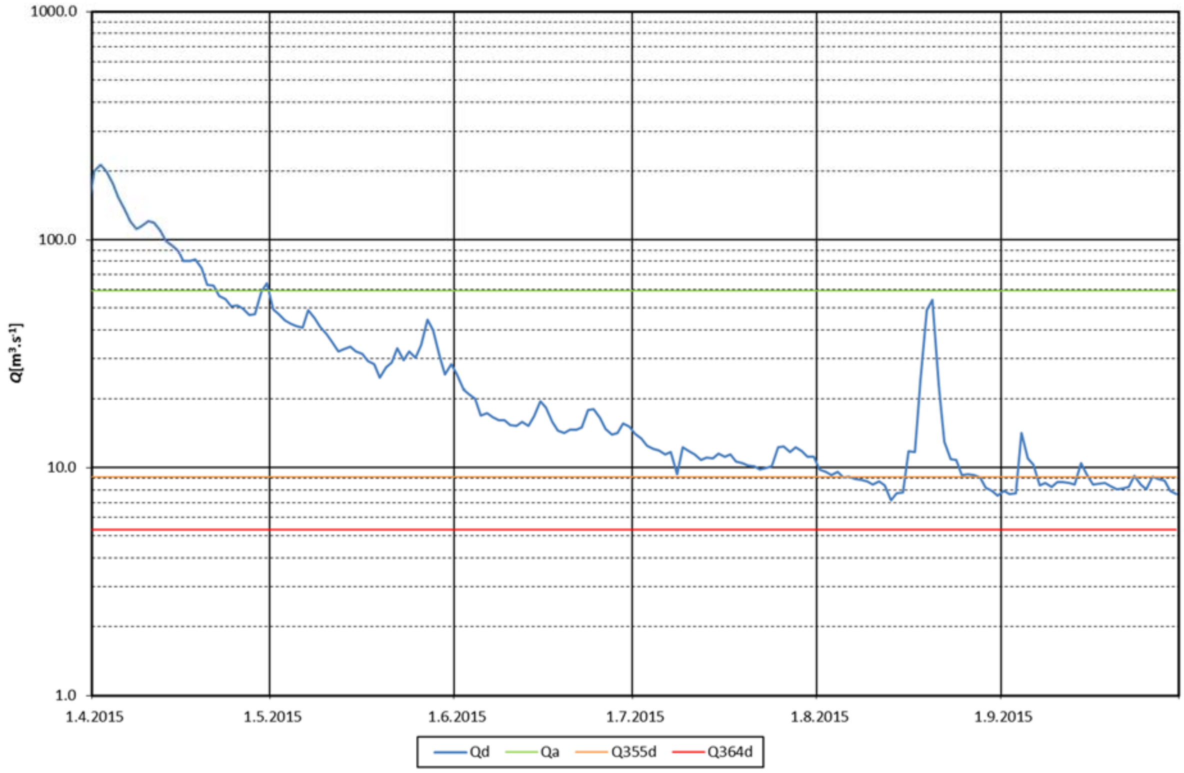


Figure 7.7. Hydrograph of average daily discharges of the Morava river at Strážnice.

After the temporary cooling at the beginning of the second half of August, temperatures again increased to tropical values in the last week of August, and in most streams the hydrological drought resumed and continued to occur to a greater or lesser extent during September. At the Bechyně gauge (Fig. 7.4.), the discharges were affected by pond draining.

At the Železný Brod gauge on the Jizera river (Fig. 7.3.), a period of very small discharges (below Q_{364d}) was interrupted twice – in the above-mentioned precipitation period of August and then also in the first 10-day period of September, when heavy rainfall occurred in the Jizera Mountains and the Giant Mountains (Krkonoše Mountains) on 6th September. If those two precipitation episodes had not occurred, the discharge course would have been very similar to that of 1947 year (see Fig. 7.3.).

From the aspect of low flows extremity, the course of discharges on the Morava river downstream appeared to be different, because at the Strážnice gauge (Fig. 7.7.) the river level did not drop below the 364-day flow. This can be explained by the fact that Southeast Moravia was hit by heavy rainfall lasting several days, not only in mid-August, but significant precipitation occurred in Central Moravia and South Moravia over a few days in July as well.

During October, there were two major precipitation episodes (6th–8th, 13th–16th October), which mitigated the hydrological drought except for Southwest Bohemia and the north and northeast of the Czech Republic.

7.3. Analysis of Minimum Flows Extremity

To describe the extent of drought in the watercourses, 30-day minimum runoff depth values were calculated for the year 2015 and compared to individual years of the period of evaluation of discharges at the selected stations. A continuous period of 30 days in each year in which the lowest runoff was reached (regardless of the calendar month) was used. The 30-day runoff depth values were calculated for the individual years starting 1 April and ending 31 March of the following year. Figs. 7.8.–7.13. present bar charts for selected gauging station profiles, where the bars represent the runoff depth and the color lines represent the 30-day runoff depth corresponding to the 355-day flow (Q_{355d}) and 364-day flow (Q_{364d}). At Děčín on the Elbe river (Fig. 7.11.), the 30-day minimum runoff depth values are shown for the period since 1901 because of graphical clarity, and at all the other gauging station profiles, for the entire period of flow evaluation. Since the minimum discharge may also occur in winter (in January or February), then in any such case, the minimum values for the period of April–March are assigned to the previous year. This, for example, concerns the minimum discharges in January and February 1954, which are assigned to the year 1953.

The Jizera river at Železný Brod (Fig. 7.8.) is a typical submontane stream where the minimum discharges may occur in both winter and summer. The hydrological regime is partially influenced by the operations of Josefův Důl and Souš reservoirs in the Jizera Mountains. The 2015 drought can be considered as the most significant hydrological drought of a "summer" type since 1947. The 1953, 1962 and 1969 minima occurred in winter.

As per the nature of the hydrological regime at the individual profiles, the Lužnice river at Bechyně (Fig. 7.9.) represents a watercourse whose discharges are influenced by the operation of an extensive pond system in the Třeboň and Jindřichův Hradec regions. The hydrological regime is significantly influenced especially during pond draining and filling, which is most pronounced in the minimum discharge periods, and this influence also strongly manifested itself in 2015. The hydrological drought at the Bechyně gauging station in 2015 can be assessed as extreme, because the 30-day runoff depth was probably the lowest for the entire discharge evaluation period. This extreme resulted from the significant precipitation deficit, long-lasting tropical air temperatures in July and August, and related high evaporation from the ponds. From the graph in Fig. 7.9., it is further obvious that major droughts occurred there in 1950, 1951, 1953, as well as in 1990 and 2003.

The Sázava river at Zruč nad Sázavou (Fig. 7.10.) is a stream with a little affected hydrological regime. From the beginning of discharge evaluation, the most striking hydrological drought was recorded there in 1947, and the 1943, 1952, 1953 and 2003 droughts were comparable to the 2015 hydrological drought.

The series of evaluated average daily discharges for the Děčín gauging station on the Elbe river (Fig. 7.11.) has been available the longest, since 1888. For better clarity, the graph shows data only since 1901. The hydrological regime is significantly influenced by operating the Vltava river cascade reservoirs (Lipno I – since 1960, Orlík – since 1963) and partially also by operating the water reservoirs located in the Ohře (Eger) river basin (Nechranice reservoir – since 1968). From the graph in Fig. 7.11., it is obvious that the 2015 hydrological drought was the most striking in the period for being influenced by water reservoir operations. Prior to the water reservoirs were constructed, there were significant droughts in 1904, 1911 and 1947. By increasing the minimum discharges, the water reservoirs on the Vltava and Ohře Rivers have significantly reduced the effects of hydrological drought on the Vltava River downstream of the Vltava river cascade and on the Elbe River downstream of its confluence with the Vltava river.

The Odra river at the Ostrava-Svinov gauging station (Fig. 7.12.) does not have any significantly affected hydrological regime. The graph shows that a drought similar to that of 2015 also occurred in 1928, 1932, 1947, 1951–1953, 1962, 1963, 1992 and 1993. It is thus obvious that most periods of significant hydrological drought were recorded more frequently at that station before 1970 than in the last 45 years.

At the Strážnice on the Morava river (Fig. 7.13.), the hydrological regime is not significantly influenced by anthropogenic activity. From the graph, it follows that the 2015 hydrological drought was not in any way extreme at that profile. Since the beginning of systematic discharge evaluation, the discharge value has even been the 15th lowest! Over the last 30 years, the 1992, 1993, 2003 and 2004 droughts were more significant than the 2015 drought.

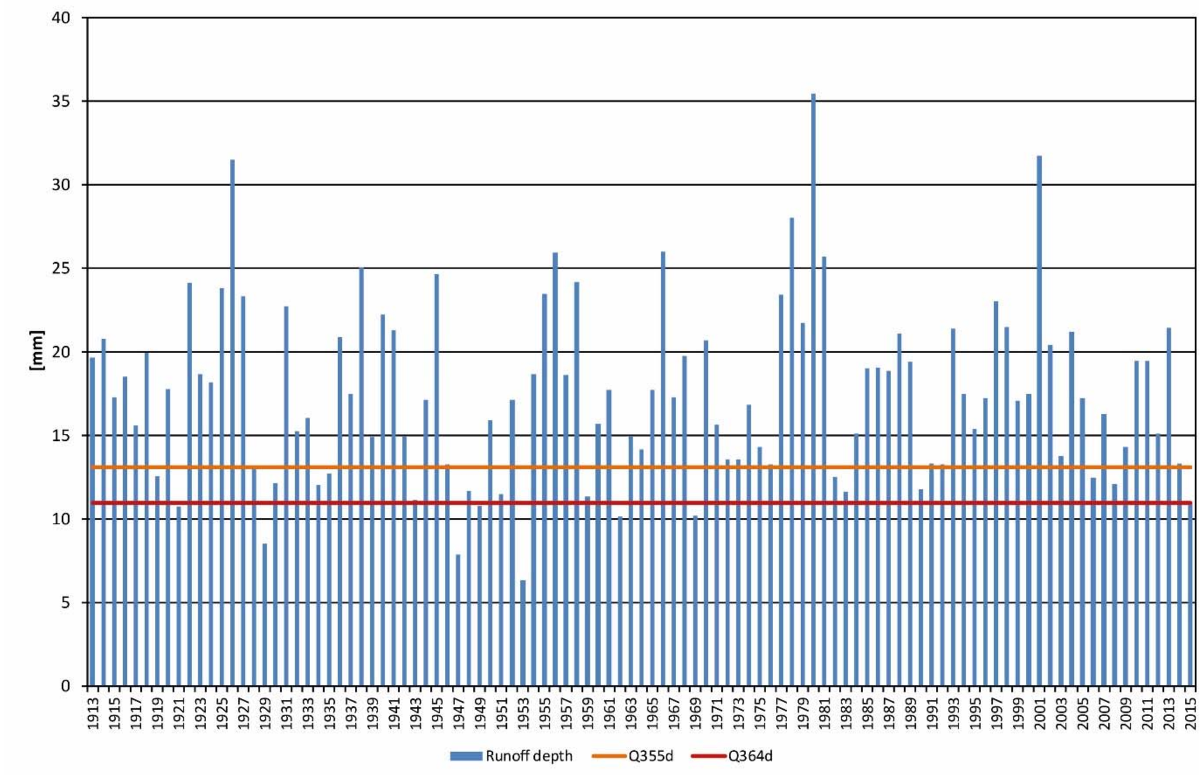


Figure 7.8. 30-Day annual minimum runoff depth in the Jizera river at Železný Brod.

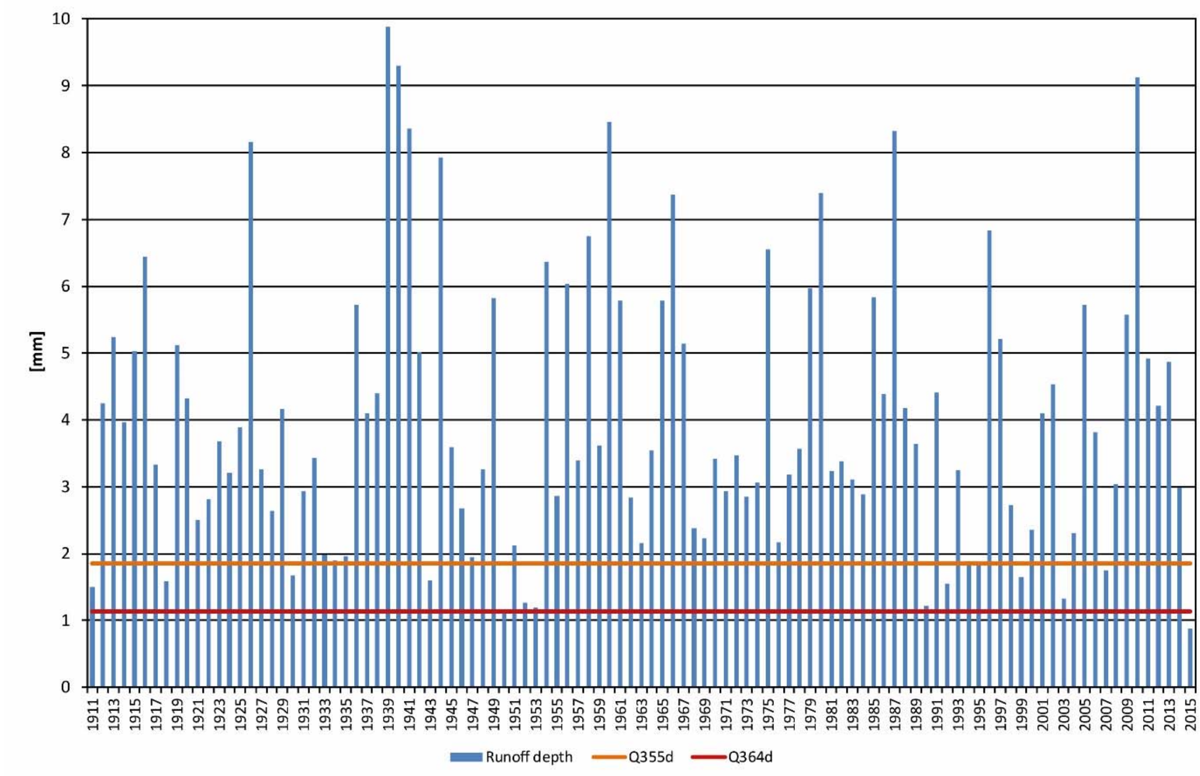


Figure 7.9. 30-Day annual minimum runoff depth in the Lužnice river at Bechyně.

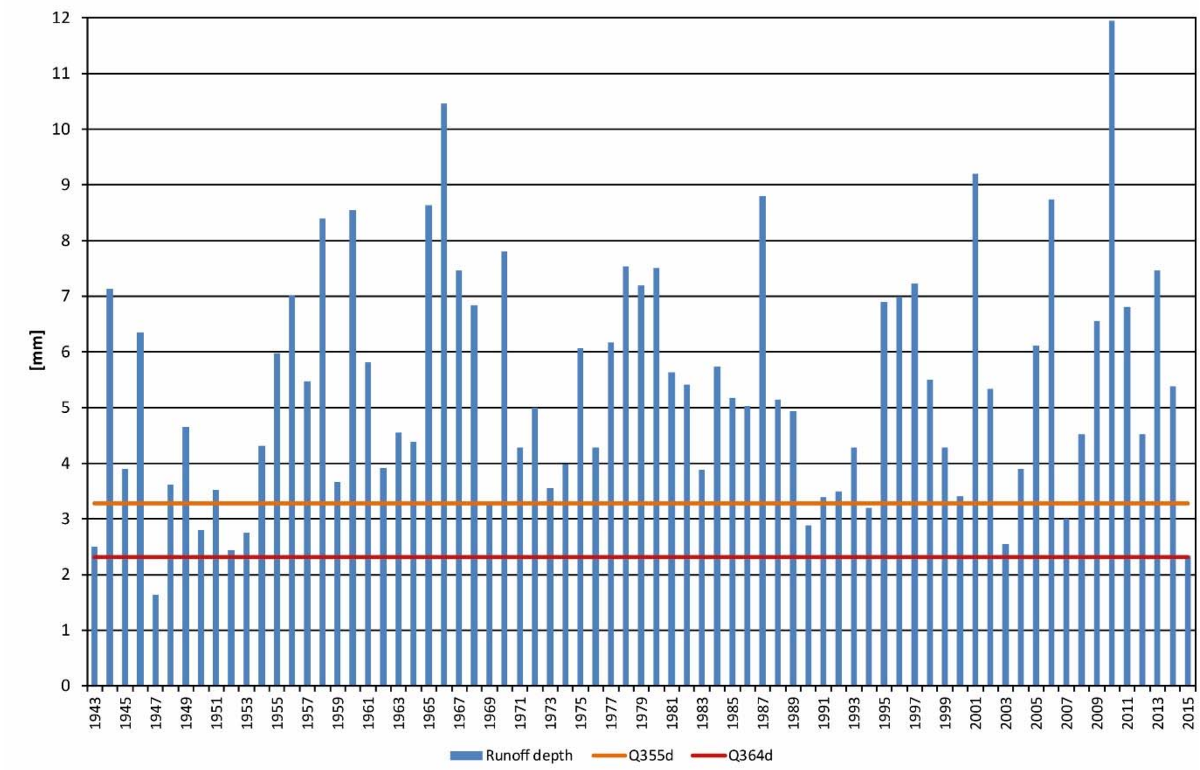


Figure 7.10. 30-Day annual minimum runoff depth in the Sázava river at Zruč nad Sázavou

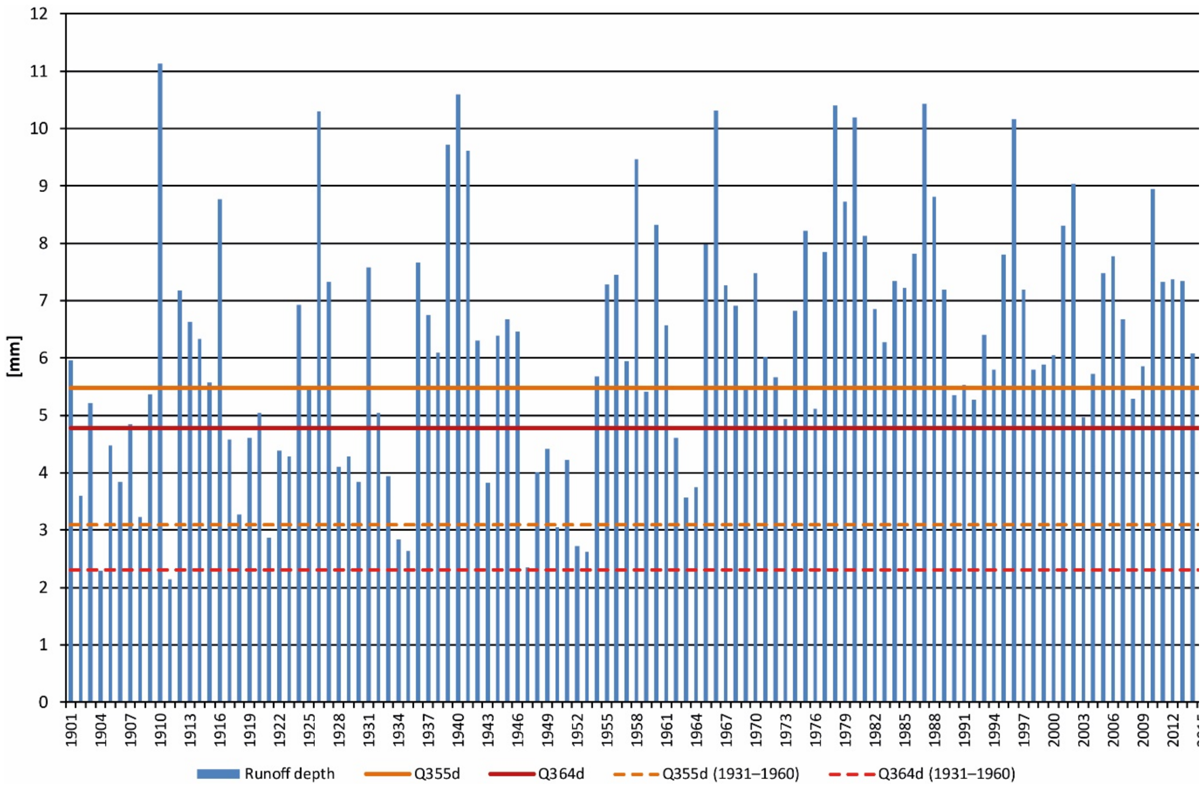


Figure 7.11. 30-Day annual minimum runoff depth in the Elbe river at Děčín.

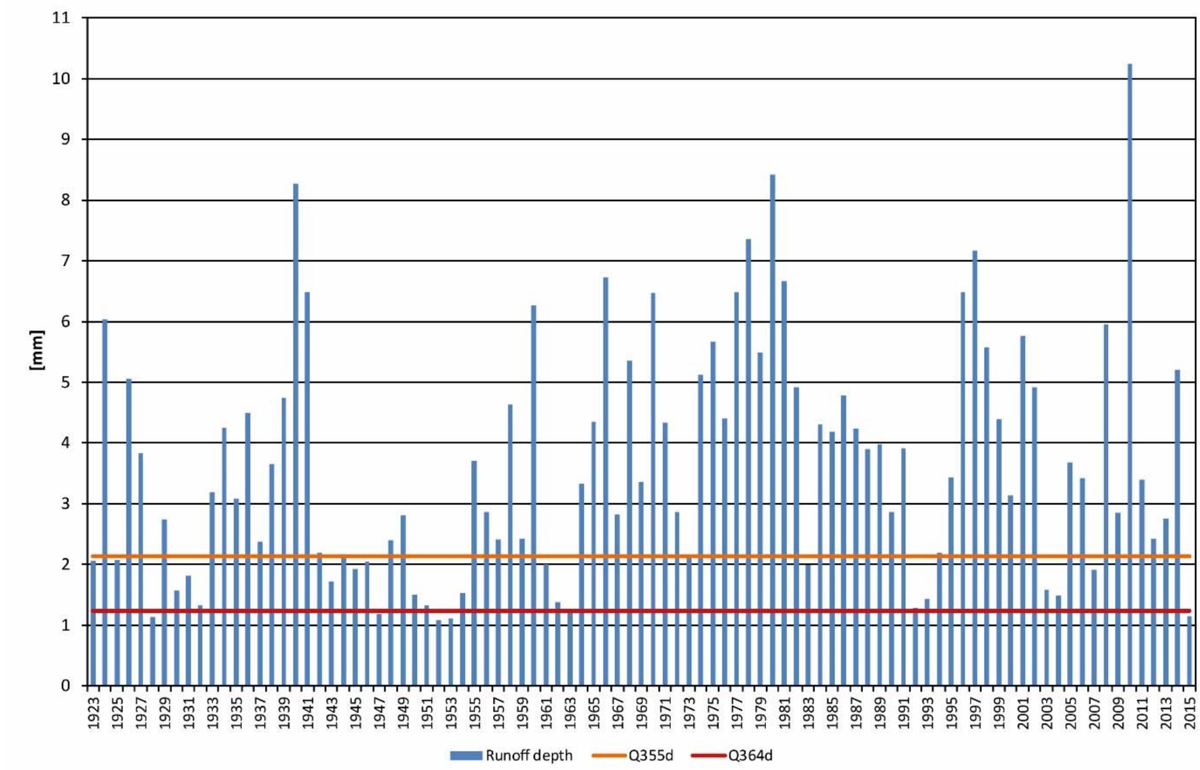


Figure 7.12. 30-Day annual minimum runoff depth in the Odra (Eger) river at Ostrava-Svinov.

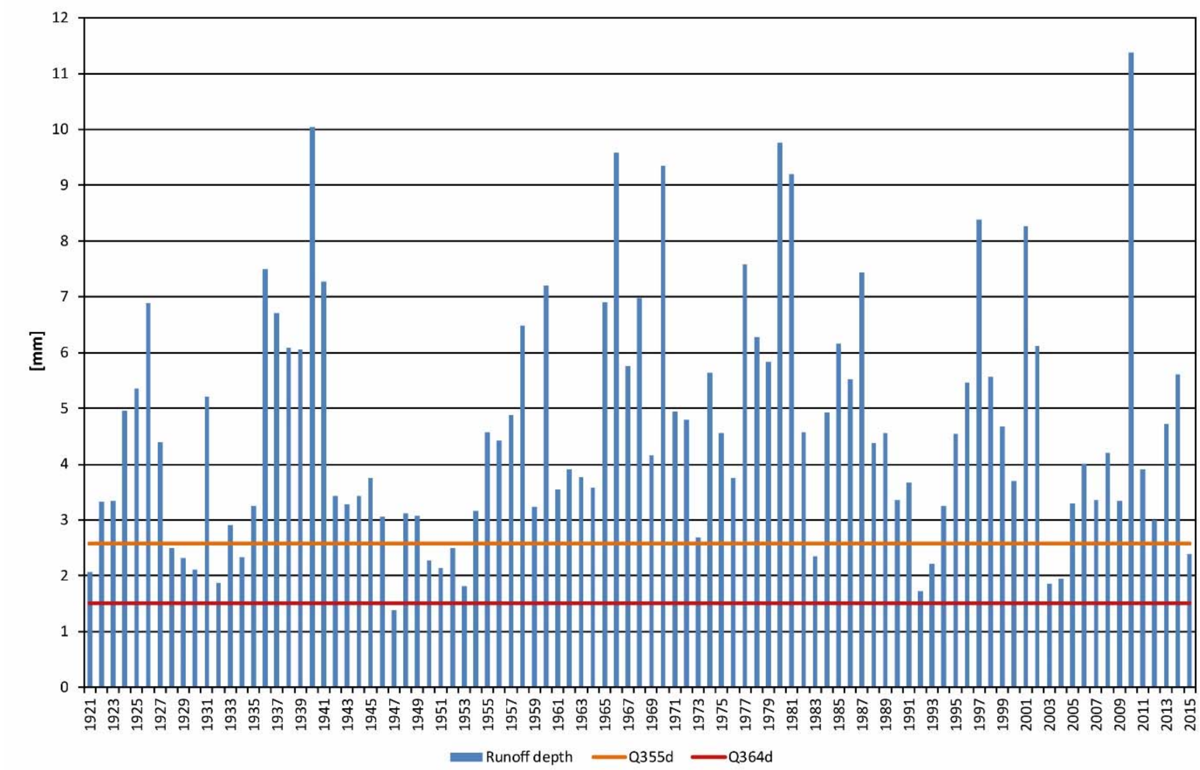


Figure 7.13. 30-Day annual minimum runoff depth in the Morava river at Strážnice.

At the above-mentioned gauging stations, the lowest 30-day runoff depth was recorded in the period from mid-July to mid-August 2015. The one exception was the Strážnice gauging station, where the lowest 30-day runoff depth was recorded in the period from mid-September to mid-October.

At eight selected gauging stations, a statistical estimate of extremity for the 7-day and 30-day annual minimum runoff depths was made (see Table 7.4.). The greatest extremity of hydrological drought was recorded on the tributaries of the Vltava river in South Bohemia, where the recurrence interval of both the runoff depth values equals 100 years, and on the Otava River at Písek equals 50 years. There was also a major drought in Central Bohemia and East Bohemia, which corresponded to the recurrence interval of 20–50 years on the Orlice river at Týniště nad Orlicí and on the Sázava river at Zruč nad Sázavou. On the Jizera river at Železný Brod, the estimated extremity of hydrological drought is influenced by the occurrence of minimum discharges in a few winter periods. By contrast, the 2015 drought in South Moravia was not too significant – for the Morava river at Strážnice, the recurrence interval of annual minima equals 5–10 years.

Table 7.4. Recurrence interval of 7-day and 30-day annual minima at selected profiles.

Watercourse	Station	Catch-ment Area [km^2]	Beginning of Time Series Q_d	Recurrence Interval [years]	
				7-Day Annual Minima	30-Day Annual Minima
Orlice	Týniště nad Orlicí	1,554.2	1911	20–50	20–50
Jizera	Železný Brod	791.3	1912	10–20	10–20
Lužnice	Bechyně	4,057.1	1911	100	100
Otava	Písek	2,913.7	1912	50	50
Sázava	Zruč nad Sázavou	1,420.7	1943	20–50	20–50
Odra	Ostrava-Svinov	1,613.7	1923	20–50	10–20
Bečva	Dluhonice	1,592.8	1920	5–10	5–10
Morava	Strážnice	9,144.8	1921	5–10	5–10

7.4. Anthropogenic Impact on Minimum Flows

In some stretches of watercourses, discharges are increased in the periods of minimum flows by operating reservoirs intended for this purpose. One of these stretches is the reach of the Vltava river downstream of the Vrané reservoir, where the effects of the Orlík and Lipno reservoirs are apparent.

To determine the actual impact of reservoirs on minimum discharges on the lower reach of the Vltavariver, a calculation (estimate) of a series of average daily discharges Q_d was made for the Praha-Chuchle gauging station without taking into account the improving impacts by selected water reservoirs located upstream in the Vltava river basin (Vltava river cascade reservoirs and Římov reservoir).

The calculation (estimate) of a series of average daily discharges without taking into account the improving impacts made by the water reservoirs is based on a procedure of adding up the series of average daily discharges at the gauging stations that are not significantly influenced. Any discharge affection caused by the water reservoirs in the Berounka and Sázava river basins was not taken into consideration. The calculation takes into account the times of travel for the individual flow series to the Praha-Chuchle profile. To simplify the calculation, the travel time was calculated with an average flow velocity of 0.5 m.s^{-1}, and the travel time was rounded to whole days. The discharge (data) series from gauging stations, as set out in 7.5. below, were included in the calculation.

Table 7.5. Gauging stations included in the calculation.

Watercourse	**Station**	**Catchment Area [km²]**
Teplá Vltava	Chlum-Volary	347.6
Studená Vltava	Černý Kříž-Volary	102.4
Polečnice	Český Krumlov	197.7
Malše	Pořešín	436.4
Stropnice	Pašinovice-Komařice	399.9
Bezdrevský potok	Lékařova Lhota	123.7
Lužnice	Bechyně	4,057.1
Otava	Písek	2,913.7
Lomnice	Dolní Ostrovec	391.4
Skalice	Varvažov	367.9
Brzina	Hrachov	133.2
Mastník	Radíč	268.6
Kocába	Štěchovice	308.6
Sázava	Nespeky	4,038.7
Berounka	Praha-Radotín	8,781.6
Radotínský potok	Radotín II	68.2
Total Catchment Area		**22,936.7**
Vltava	Praha-Chuchle	26,730.0

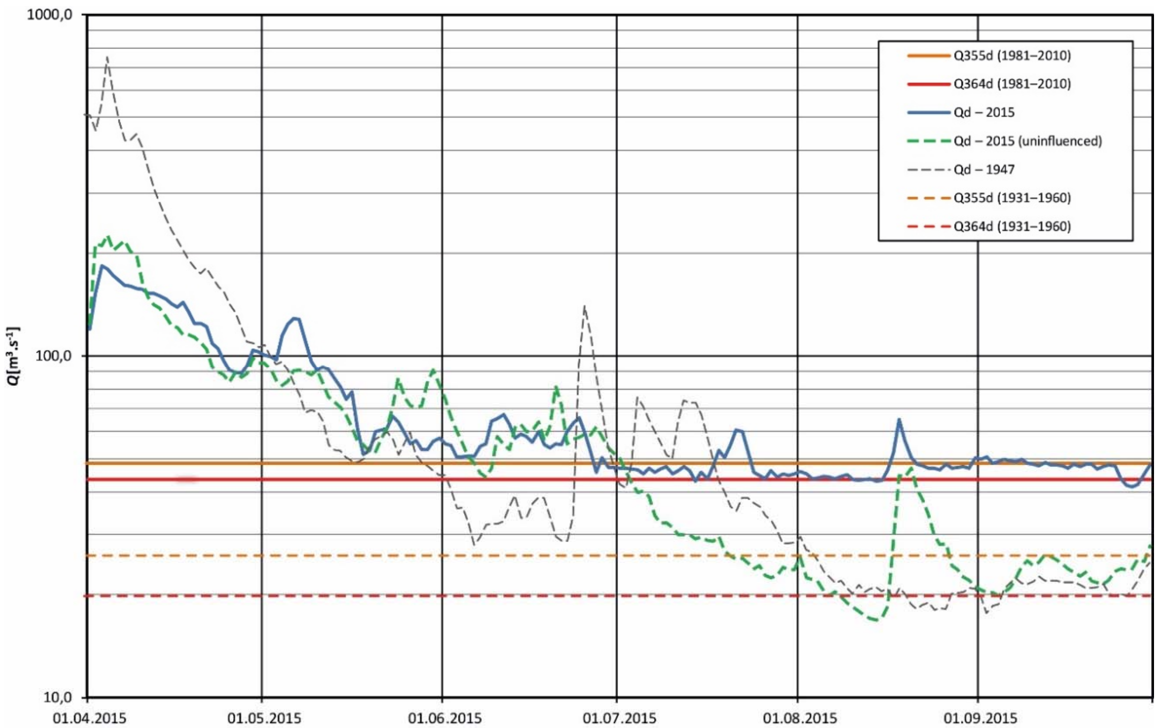


Figure 7.14. Hydrograph of monitored average daily discharges from the Vltava river at Prague in 1947 and 2015 and the hydrograph of calculated average daily discharges at the Praha-Chuchle gauge in 2015 without the impacts of the Vltava river's cascade reservoir operations. The empiric values of Q_{355d} and Q_{364d} for the reference periods of 1931–1960 and 1981–2010 are presented for comparison.

The discharges at the above-mentioned gauging stations represent runoff from 85.8% of the river basin area at the Prague-Chuchle gauging station profile. The remaining part of the runoff to the Prague-Chuchle gauging station profile was computed on the basis of the runoff calculated from the unmeasured parts of Vltava river basin from the daily runoff depth values. These values were set according to analogue stations whose runoff conditions correspond to the relevant parts of the unmeasured drainage area. The Český Krumlov station on the Polečnice creek, the Lékařova Lhota station on the Bezdrevský creek, and the Radíč station on the Mastník creek entered, as the analogues, were entered into the said calculation.

Should we compare the hydrographs of discharge values monitored and calculated (without any water reservoir impact) for the Praha-Chuchle, it is obvious that, until early July, their courses were similar. However, upon commencing the second 10-day period of July, an unambiguous decline in the discharge values is obvious for the calculated series. Meanwhile, the discharge values within the monitored series continuously stay around the value of 45 $m^3.s^{-1}$, which means that the discharge started to be significantly increased there. Therefore, the storage volume of water reservoirs was thus being drained. The lowest flows in the calculated time series occurred in the period from 8-16 August, when their values were lower than 20 $m^3.s^{-1}$. The minimum value of the calculated series was reached on 14 August and amounted to 16.8 $m^3.s^{-1}$. From the graph in Fig. 7.14., it is further obvious that the precipitation that occurred in mid-August, which partially also hit the Vltava river basin, would have caused a substantially greater increase in the discharge as compared with the increase of the monitored discharges at Praha-Chuchle, which were transformed by the water reservoir operations.

From a comparison of the series of monitored and calculated average daily discharges, it follows that the increasing in the flows by the reservoirs operation even reached approximately 25 $m^3.s^{-1}$ in the period of the lowest discharges. The period over which the discharges were significantly increased lasted from the first 10-day period of July until the end of September.

Based on a comparison of the calculated average daily discharges (without water reservoir impacts) with the 1947 discharge hydrograph at the Praha-Modřany (Fig. 7.14.), it is possible to say that the size of minimum discharges at the Praha-Chuchle profile in 2015 would have been comparable with 1947 if the discharges had not been improved by the Vltava river cascade reservoirs. However, the 1947 discharge course was different, because the significant decline in the discharge values started substantially sooner in comparison to 2015.

7.5. Summary

The 2015 hydrological drought hit practically the entire Czech Republic. Over several weeks, the level of most streams significantly dropped below the 355-day flow, as evidenced by field measurements. In some regions, a complete drying up of some streams even occurred.

The hydrological drought was caused by a lack of precipitation, as well as by abnormally high temperatures and an associated high evaporation from the ground, watercourses and water reservoirs. It was only interrupted by short-lasting rainfall episodes in mid-August and mid-October.

The water reservoirs with significant storage volumes contributed to the mitigation of the hydrological drought by increasing the minimum discharges. For example, due to the influence of water reservoirs, the discharge of the Vltava river at Prague did not drop below 43 $m^3.s^{-1}$, which was the value of an approximate 330-day flow. Without this affection, less than 40 $m^3.s^{-1}$, and for a short period of time even less than 20 $m^3.s^{-1}$, would most likely have flowed through Prague for a period longer than three months. By contrast, fish ponds, like those in South Bohemia, made the hydrological drought more pronounced by retaining water, and in addition, water largely evaporated from their surfaces.

Different degrees of anthropogenic influences, physical-geographic conditions, and climatic conditions in the Czech Republic caused the hydrological regime of minimum discharges to be regionally varied. Evaluating the extremity of the 2015 hydrological drought nationwide is therefore quite difficult. Based on the evaluations completed so far, it follows that the recurrence interval of 30-day and 7-day annual discharge minima varies in a relatively wide range from 10 to 100 years.

8. Groundwater Evaluation

The evaluation of the course of groundwater levels so far in 2015 was based on the reporting network monitoring sites representing various geographical and geological environments in the Czech Republic.

8.1. Evaluation of Shallow Borehole Levels

The course of the average overall level in shallow boreholes within the reporting network for the Czech Republic is shown in Fig.8.1., where the y-axis indicates the standard deviation. The graph shows an increasing deficit in shallow groundwater aquifers since spring. In the period of the usual spring maxima, the levels did not even reach the normal values (black line in the graph) of the monthly exceedance probability curve. Commencing in April, they were declining with a greater than usual intensity for the given months. The declines were not uniform throughout the Czech Republic. Differences in the categorization of levels in the shallow boreholes within the monthly exceedance curve for individual regions are shown in Table 8.1.

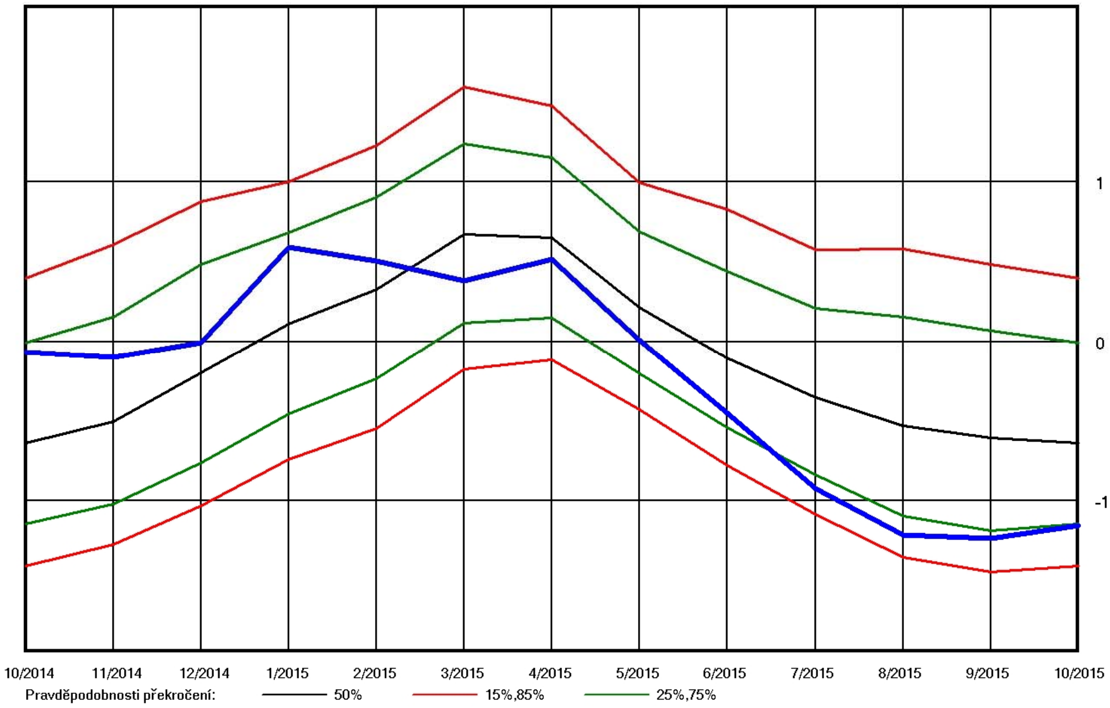


Figure 8.1. Course of evaluation of average standardized levels of shallow boreholes within the reporting network (marked in blue) for the period from October 2014 in comparison with the long-term monthly values for 1981–2010.

From the values set out in the table, it is obvious that the levels in shallow boreholes started to significantly decline in the Upper and Middle Elbe and the Lower Vltava River basins as early as March and as early as June, respectively. The areas most affected by the drought included North and South Bohemia (the Upper and Middle Elbe and the Upper Vltava River basins) and Northeast Moravia (the Odra River basin).

Table 8.1. Probability of exceedance of recorded levels in shallow boreholes in 2015 in relation to the monthly exceedance probability curve for individual river basins.

SHALLOW BOREHOLES	Classification of groundwater level values on the monthly consumption curve [%]									
Basin	jan	feb	mar	apr	may	jun	jul	aug	sep	oct
Horní a střední Labe	36	60	81	67	77	82	**88**	**88**	83	83
Horní Vltava	29	45	67	69	67	71	82	**87**	**86**	77
Dolní Vltava	19	52	80	65	73	69	77	76	74	70
Berounka	18	39	60	59	54	63	77	79	77	71
Dolní Labe	32	48	67	56	61	64	68	73	69	66
Odra	32	33	54	56	58	76	**84**	**87**	**89**	**90**
Morava	30	33	54	43	53	60	71	71	68	70
Dyje	21	26	44	48	55	67	75	74	67	67

In Table 8.1., the light color is used to highlight the low levels according to a monthly exceedance probability curve range of 75–84%, and the dark color is used to highlight the very low levels below the drought threshold – 85% of the monthly exceedance probability curve.

The groundwater level was evaluated according to the probability of exceeding the level in the borehole in the relevant calendar month. The monthly exceedance probability curve values represent the variability in the period from 1981 to 2010, where values ranging from 25 to 75% indicate a normal level. The values with an exceedance probability of 75–85% indicate a below-normal level, and values above 85% indicate a strongly below–normal level. Analogically, the exceedance probability of 15–25% indicates an above-normal level.

Table 8.2. provides an overview of the number of the historically lowest levels, expressed as a percentage of the number of monitored shallow boreholes within the reporting network. The selected years represent periods with low groundwater levels. It clearly shows a significant increase in the number of extremely low levels this year, as well as an upward trend in their number during the summer and autumn.

Table 8.2. Share of the number of shallow boreholes with the recorded historical minimum level in selected years.

	The number of historical minimum groundwater levels in shallow boreholes [%]							
	2015	2007	2003	1994	1993	1992	1990	1984
jul	21	13	5	5	13	3	3	5
aug	24	10	4	5	7	13	7	5
sep	26	2	7	3	5	14	6	4
oct	26	2	6	4	4	21	6	3

In terms of the categorization of levels in shallow boreholes according to the exceedance probability curves, the driest period so far has been the 33rd week (mid-August), when 59% of the shallow borehole levels dropped to the strongly below-normal or extraordinarily below-normal level. The boreholes with such a low level occurred throughout the Czech Republic; however, most of them were situated in Northeast and Southwest Bohemia. There was a similar situation in the 40th week (late

September), when the groundwater level worsened in the northeast (the Odra River basin). By contrast, there was a slight improvement in the southeast (the Dyje River basin). (See Figs. 8.2a. and 8.2b.)

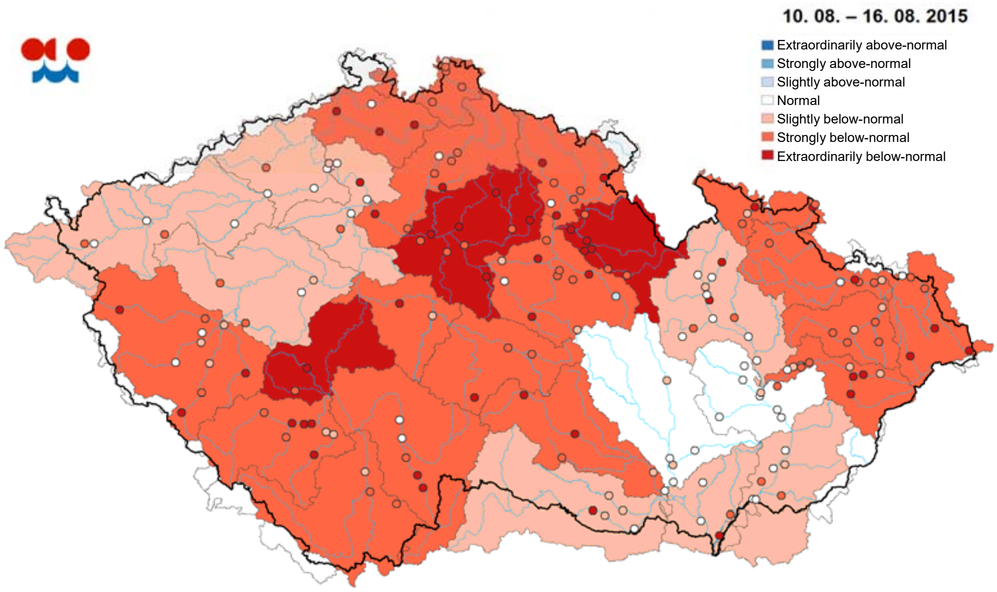


Figure 8.2a. Groundwater level in shallow boreholes – 33rd week 2015.

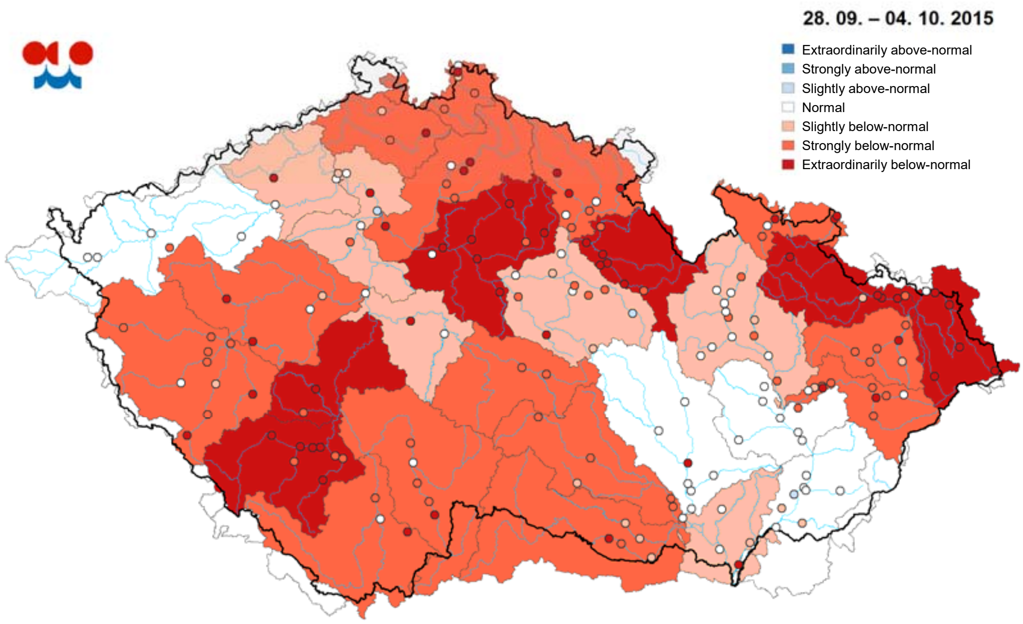


Figure 8.2b. Groundwater level in shallow boreholes – 40th week 2015.

Rainfall in mid-August contributed to mitigating the decline in borehole levels, and in places, temporary increases in the levels were even recorded. However, in the following weeks, the monitored variables were again declining, albeit more moderately than in the previous period. In September, the number of boreholes with a low water level therefore remained similar to that of August.

In October, the levels in shallow boreholes largely stagnated on average in most of the Czech Republic. In the Upper and Middle Elbe, Odra and Morava River basins, their decline continued. By contrast, in the Vltava, Berounka and Dyje River basins, slight increases in these levels were recorded. There was a slight increase in the number of boreholes with a normal level (38%), as well as in the number of boreholes with an above-average level (18%). Even though the number of below–average boreholes decreased (58%), the number of boreholes with a level below the drought threshold (85% of the monthly exceedance probability) did not change (46%). Their highest number was recorded in the Odra River basin (78%), as well as in the Upper and Middle Elbe River basins (66%).

In late October 2015, the driest areas were situated in the northeast of Bohemia (the Upper and Middle Elbe River basins – 83% of the monthly exceedance probability curve) and in the northeast of Moravia (the Odra River basin – 89% of the monthly exceedance probability curve). In those regions, the vast majority of the historically lowest monthly level values were also measured. Their number (26%) was higher than that of the same period of the similarly dry year of 1992. More favorable groundwater levels occurred in South Moravia (the Dyje River basin – 67% of the monthly exceedance probability curve) and in the western half of Bohemia (the Berounka River basin – 66% of the monthly exceedance probability curve). (See Fig. 8.2c.)

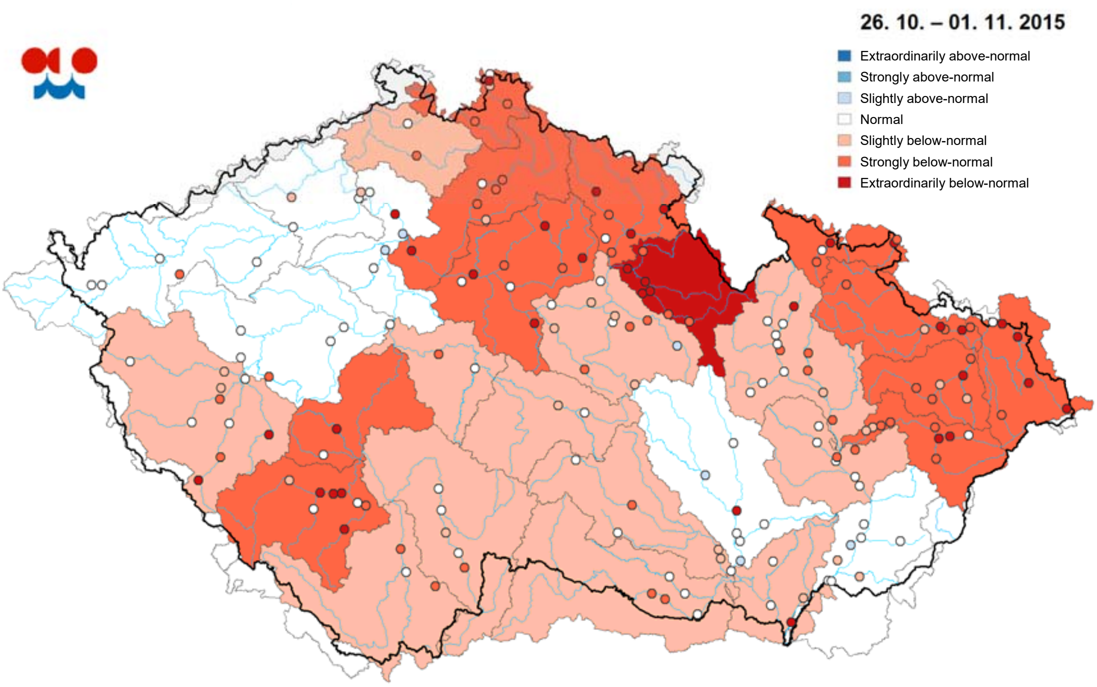


Figure 8.2c. Groundwater level in shallow boreholes – 44th week 2015.

The graph in Fig. 8.3. shows changes in the levels of shallow boreholes between the individual weeks of 2015 (brown line), as well as year-on-year differences between 2015 and 2014 for individual calendar weeks (blue line). There is a noticeable steady decline in the levels (negative values) from the 8th week, which was interrupted by short-lived increases from the 18th to the 20th weeks. Based on a year-on-year comparison, it is possible to observe an increasing difference from the 28th week, when the level values increasingly differed as they decreased from the levels recorded in the same period of 2014.

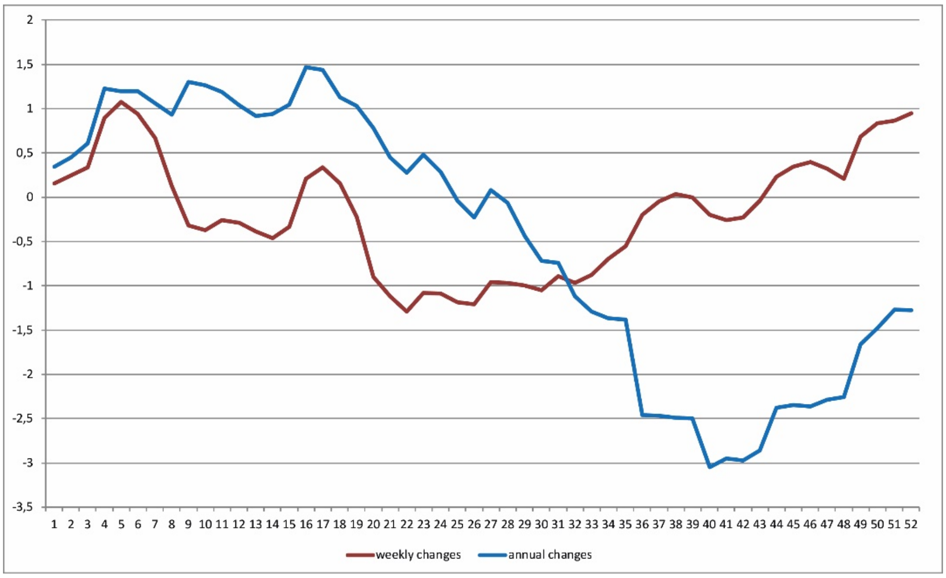


Figure 8.3. Comparison of weekly and year-on-year changes (rise +, decline -) in shallow borehole levels in the weekly evaluation of 2015. The level values have been standardized.

8.2. Spring Yield Evaluation

The course of the average total yield of springs within the reporting network for the whole country is shown in Fig. 8.4. The graph shows a clearly increasing deficit of deeper groundwater aquifers (represented by springs) already from February 2015. Even though the yield values grew up to April, when maximum spring values usually occur, the normal level (black line in the graph) on the monthly exceedance curve was not reached. After that, the spring yields diminished with greater intensity than usual for the given months. The yield decrease did not take place evenly throughout the country. Differences in the yield categorization within the monthly exceedance curve for the individual regions are shown in Table 8.3.

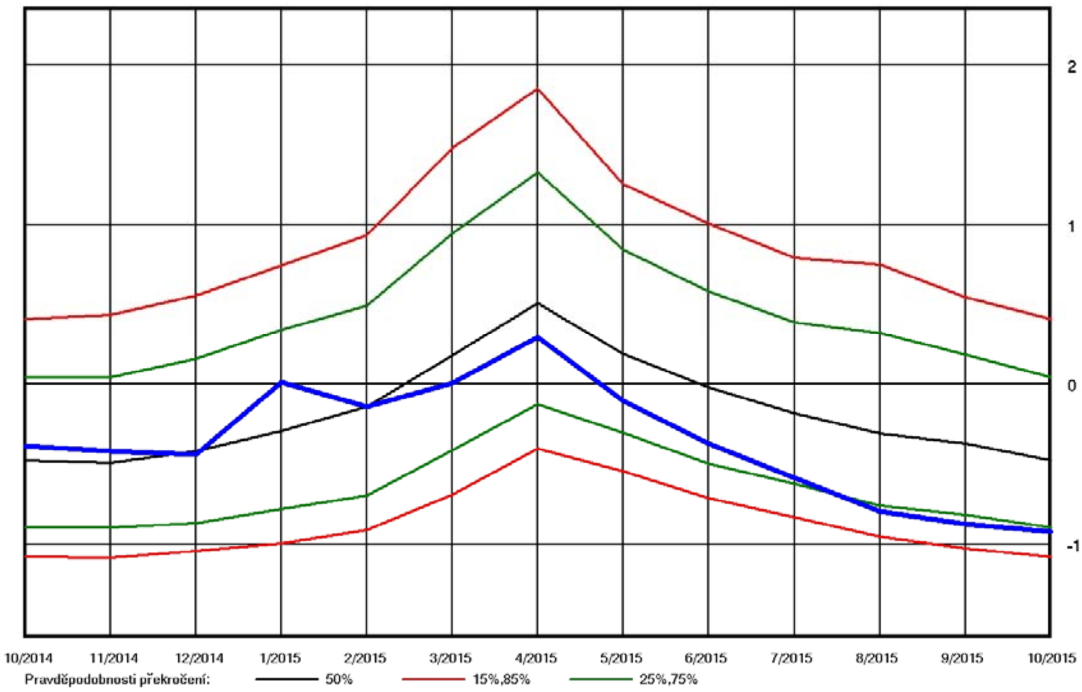


Figure 8.4. Course of evaluation of the average standardized yield of springs within the reporting network (marked in blue) for the period from October 2014 in comparison with the long-term values for 1981–2010.

Table 8.3. Probability of exceedance of the spring yields recorded in 2015 with respect to the monthly exceedance curve for individual river basins.

SPRINGS	Classification of volume values on the monthly consumption curve [%]									
Basin	jan	feb	mar	apr	may	jun	jul	aug	sep	oct
Horní a střední Labe	48	62	74	72	76	80	**84**	**87**	**88**	**87**
Horní Vltava	27	39	56	61	68	63	67	76	81	77
Dolní Vltava	44	61	73	69	75	76	78	82	82	80
Berounka	17	34	37	42	47	43	45	64	62	59
Dolní Labe	53	62	64	60	62	65	68	72	72	72
Odra	37	45	43	50	67	75	**85**	**86**	**88**	**88**
Morava	30	44	49	48	64	73	80	76	76	79
Dyje	36	42	51	58	59	64	69	70	68	66

In Table 8.3., the light color is used to highlight the low yield values in a range of 75 – 84% of monthly exceedance probability curve, and the dark color is used to highlight the very low values below the drought threshold – more than 85% of the monthly exceedance probability. From the table, it is obvious that the areas most affected by the drought included, already from July, Northeast Bohemia (the Upper and Middle Elbe and Upper Vltava River basins) and Northeast Moravia (the Odra River basin).

Table 8.4. provides an overview of the historically lowest yield values, expressed as a percentage of the number of monitored springs within the reporting network for selected years. It clearly shows a significant increase in the number of springs with extremely low yield values or dry springs, as well as an upward trend in their number during the summer and autumn.

Table 8.4. Share of the number of springs with the recorded historical minimum yield in selected years.

	The number of historical minimum values of spring volume [%]							
	2015	2007	2003	1994	1993	1992	1990	1984
jul	15	9	7	1	8	5	4	2
aug	16	7	7	2	9	6	6	3
sep	24	2	7	1	11	4	9	2
oct	27	2	6	2	8	7	7	1

Figure 8.5. Comparison of the Jičínka Stream's spring in June 2012 (1.9 $l.s^{-1}$) and October 2015 (0.09 $l.s^{-1}$).

In terms of categorization according to the monthly exceedance probability curves, the yield was lowest in September (40th week). (See Fig.8.6b.) However, small values were already reached by the monitored springs in July and August (see Fig. 8.6a.). The sporadic increases in the yield in August only lasted a short time. Therefore, the number of springs with a low yield remained at 66% in late August, of which 56% of those springs were below the drought threshold (85% of the monthly exceedance probability curve). At the end of August and at the beginning of September, the Odra River basin was the driest area, where the drought threshold was reached by 85% of the springs. In the case of springs situated on the Lower Vltava and Lower Elbe River basins, 70% of the springs were below the drought threshold. A more favorable situation occurred in the southern regions (the Upper Vltava and Dyje River basins), where a third of springs only declined to the drought limit. The overall categorization of monitored spring yields within the monthly exceedance curves became worse throughout the Czech Republic, and except for the Dyje and Berounka River basins, the spring yields were below-normal. The lowest yield values were reached in the Upper and Middle Elbe and Odra River basins, amounting to only 13% of the normal yield value with the river basin categorization within the monthly exceedance probability curve corresponding to 87% and 86%, respectively. The yield was also small on the basis of an overall year-on-year comparison, where only 23% of the evaluated springs reached or exceeded the 2014 values. It was only in the Berounka River basin where the yield of 40% of the springs reached the 2014 values, while in the Dyje and Lower Vltava River basins, no spring reached its 2014 yield.

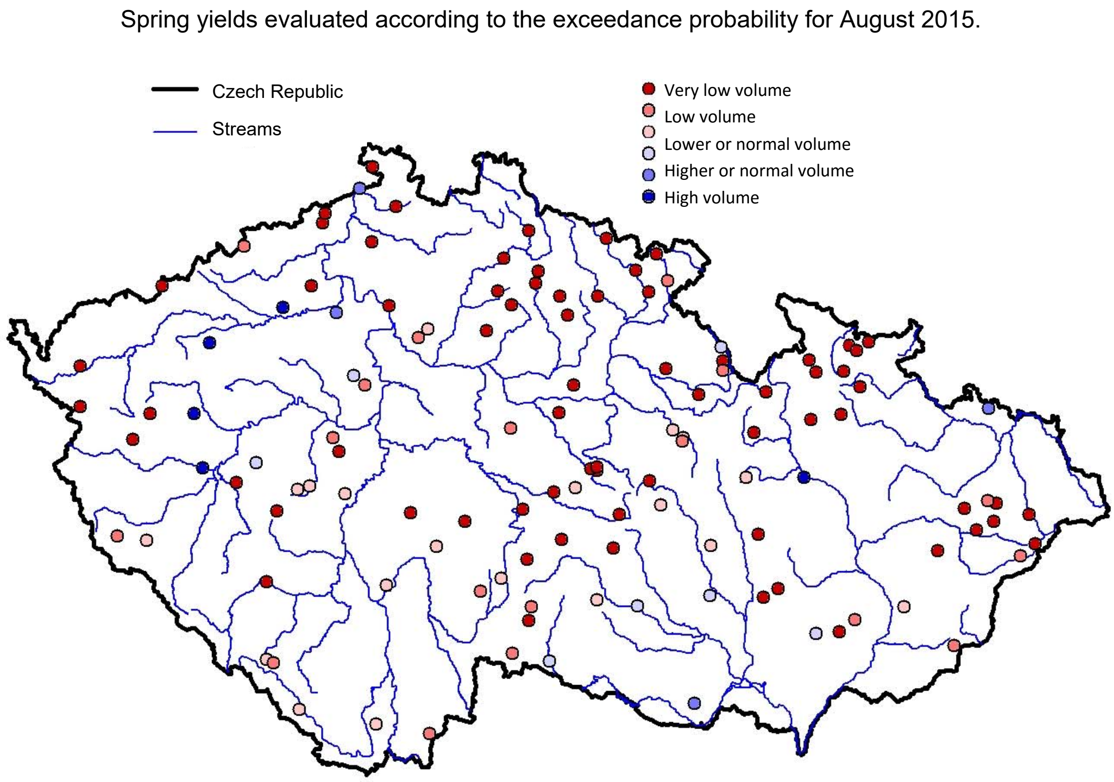


Figure 8.6a. Spring yields – 34th week 2015.

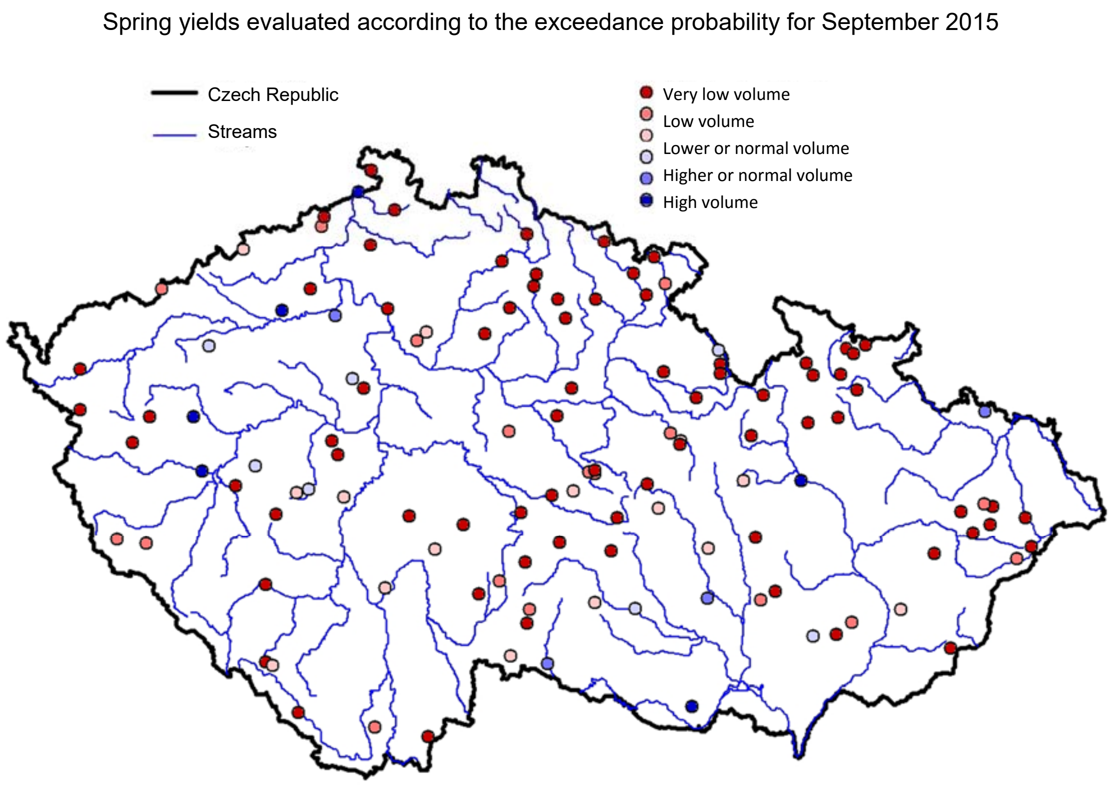


Figure 8.6b. Spring yields – 40th week 2015.

In September, the yield decrease continued from the summer, mainly in the northeast (the Odra River basin) and Central Bohemia (the Lower Vltava River basin). In the southeast of the Czech Republic (the Dyje River basin), as well as in the northwest of the Czech Republic (the Lower Elbe River basin), the yield was constant. The overall shares of springs with a normal or above-normal yield did not change too much (15%), and as such, the share of springs with low yields remained at 85%. The number of springs with a yield below the drought threshold (85% of the monthly exceedance probability curve) continued to be high, amounting to 60%. The Odra River basin continued to be the driest area, where the drought threshold was reached by 85% of the springs. In the Lower Vltava and Lower Elbe River basins, 70% of the monitored springs were below the drought threshold. Their lowest share (35%) was reached in the Dyje River basin. The overall categorization of springs according to the monthly exceedance probability curves did not significantly change in the Czech Republic (see Table 8.3.)*.* The lowest yields were reached in the Upper and Lower Elbe and Odra River basins and identically corresponded to the 88% of the monthly exceedance probability curve. Low yields were also reached according to an overall year-on-year comparison, where 89% of the monitored springs failed to reach their yield of September 2014. In the Berounka, Odra and Morava River basins, no spring reached its 2014 level.

Spring yields evaluated according to the exceedance probability for October 2015

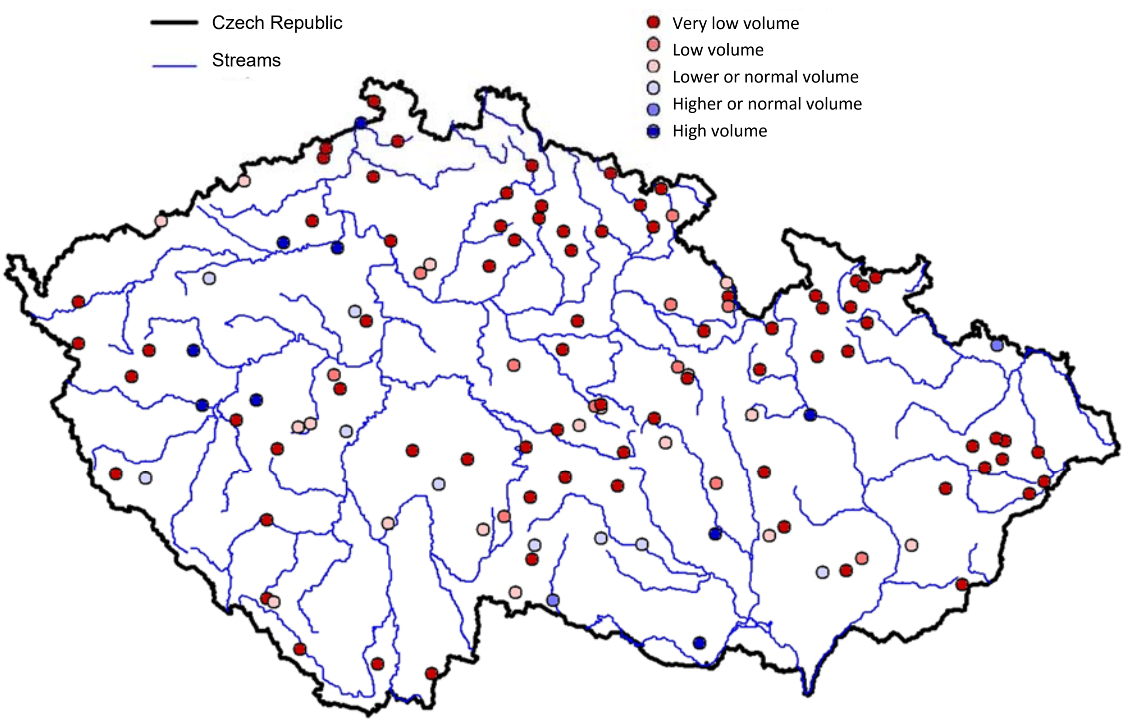


Fig. 8.6c. Spring yields – 44th week 2015.

In October the overall decline in spring yields eased off. In the south of the Czech Republic (the Upper Vltava and Dyje River basins) and in West Bohemia (the Berounka and Lower Elbe River basins), the yields were constant. In the northeast of the Czech Republic (the Upper and Middle Elbe and Odra River basins) and in Central Bohemia (the Lower Vltava River basin), slight decreases or a stagnation of the spring yield continued. The total share of springs with below-normal yields remained high (82% of springs), and the number of springs with yields below the drought threshold was also high (60%). The Odra River basin continued to be the driest area, where the drought threshold was reached by 92% of springs. As for the springs in the Lower Vltava and Lower Elbe River basins, 60–67% of springs were below the drought threshold. The lowest share of springs below the drought threshold (40%) was in the Berounka and Dyje River basins. The overall categorization of the spring yields in the individual river basins / catchment areas within the monthly exceedance probability curves did not significantly change from September. The lowest yield was reached by the springs in the Upper and Middle Elbe and Odra River basins, where no spring reached its normal yield. Categorization within the monthly exceedance probability curve corresponded to 87% and 88%, respectively. Small yields were also confirmed through an overall year-on-year comparison, where 95% of the monitored springs failed to reach their 2014 level.

8.3. Evaluation of Deep Borehole Levels

The situation regarding the deepest aquifers monitored through deep boreholes was somewhat different. Up to May, the levels in deep boreholes were constant with occasional drops and increases and were comparable with 2014. A slight decline started to manifest itself only at the onset of summer. Even though as compared with 2014, there was an obvious decline in variable intensity in most of the monitored areas, the decline data were not as extremely low as those in shallower aquifers. Only in the permo-carboniferous area of East Bohemia was there a significant decline at the level of 67% of the monitored deep boreholes (see Fig. 8.7.).

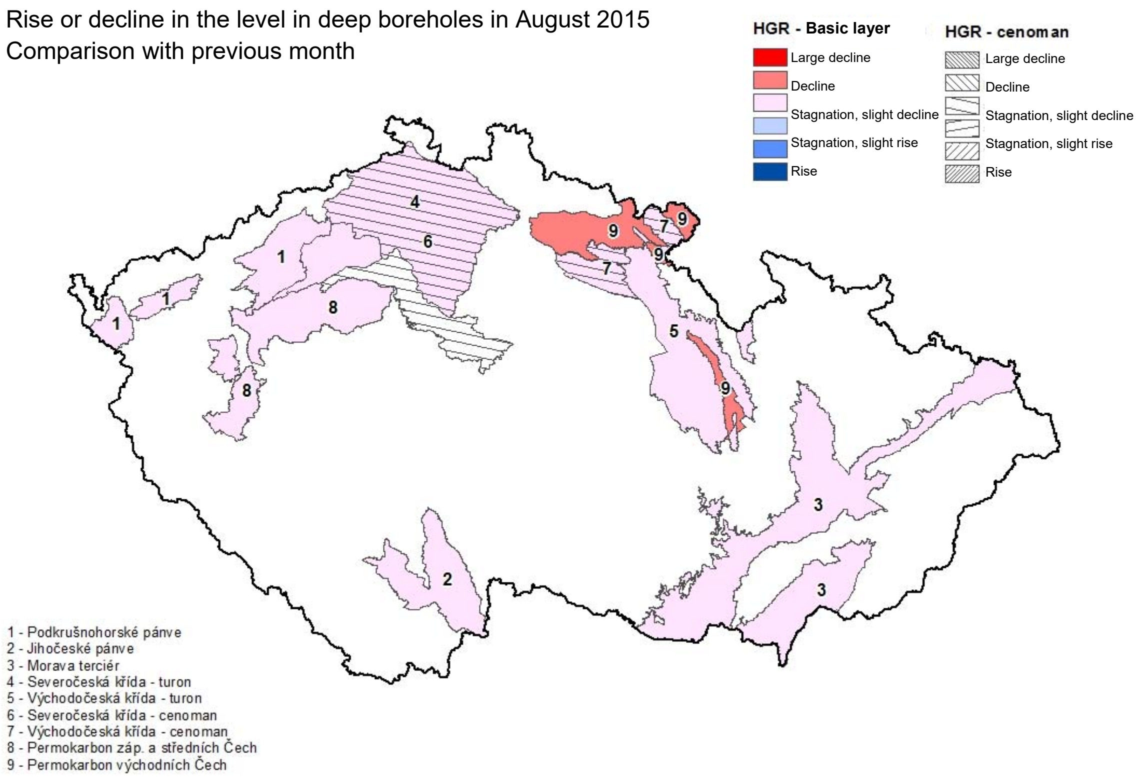


Figure 8.7. Rise or decline in the level in deep boreholes in August 2015.

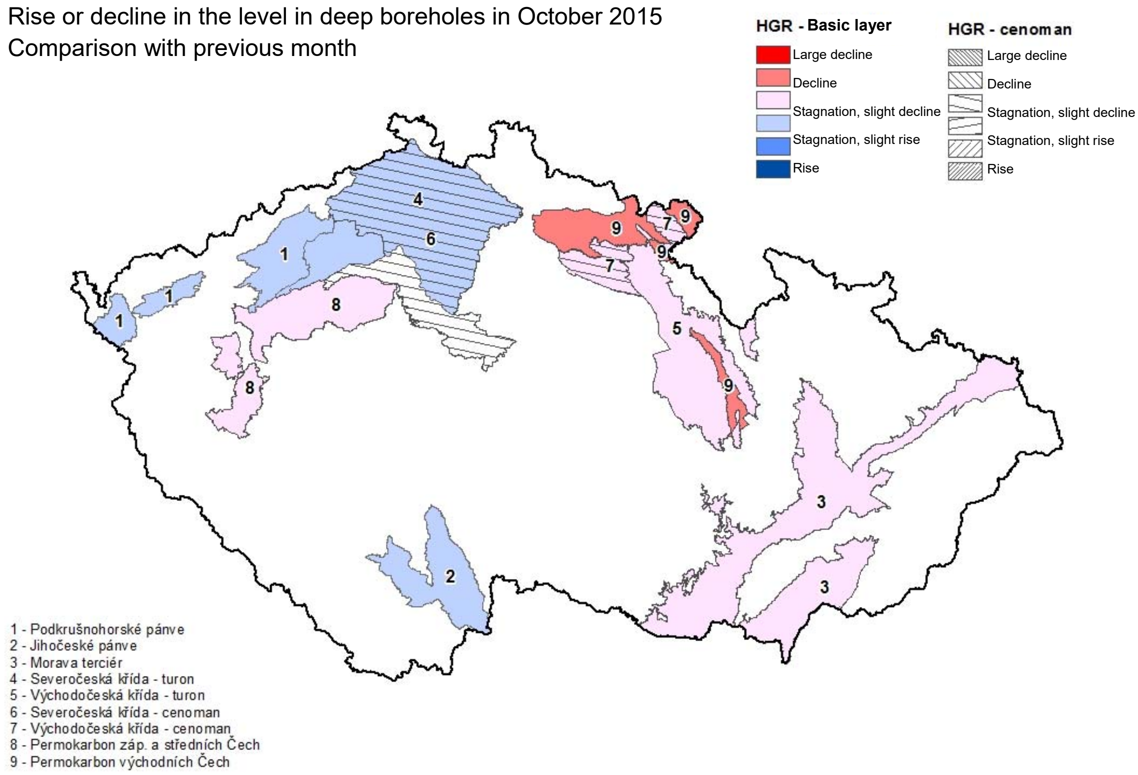


Figure 8.8. Rise or decline in the level in deep boreholes in October 2015.

In October the level of groundwater in deep aquifers in most of the monitored areas stagnated or slightly changed. A decline in the level of groundwater in boreholes was only recorded in the permo-carboniferous area of East Bohemia (50% of the monitored boreholes) and in the Giant Mountains (Krkonoše) basins (33% of the monitored boreholes). In other areas, no major decline or rise occurred. In comparison with the same month of 2014, the groundwater level declined in most of the monitored boreholes. In the area of the Tertiary sediments in Moravia, the permo-carboniferous area of East Bohemia, and the area of the Cretaceous Turonian age in North Bohemia, there was a very significant decline in the groundwater level (see Fig. 8.8.).

8.4. Conclusion

The groundwater evaluation for the period from January to October 2015 shows an obvious deficit in the shallow groundwater aquifers, which occurred as early as spring 2015, when the groundwater levels in the shallow boreholes were slightly or strongly below-normal. Very low groundwater levels in the shallow acquirers occurred as early as March, especially in the Upper and Middle Elbe and Lower Vltava River basins. In terms of the categorization of groundwater levels in the shallow boreholes within the monthly exceedance curve, the driest period was that of the 33rd week (mid-August), and in terms of the spring yield, the driest period occurred in late September.

As early as July 2015, the areas most affected by the drought in both the shallow and deep aquifers included Northeast Bohemia (the Upper and Middle Elbe River basins) and Northeast Moravia (the Odra River basin). A somewhat different situation occurred in the case of the deepest aquifers monitored using deep boreholes. Up to May, the groundwater levels in the deep boreholes were constant with occasional declines and rises and, based on a year-on-year comparison, were similar. A slight decline started to manifest itself only at the onset of summer and continued until October, where the groundwater levels started to stagnate, and in Northeast Bohemia, they started to slightly rise.

In the course of the year, the lowest borehole levels and spring yields usually occurred at the beginning of autumn (September, October). Then, with falling temperatures at the end of the growing season, the groundwater recharge improved. Forecasting the future development and recharge of groundwater is thus totally dependent on the amount and nature of precipitation in the coming months. Therefore, an overall and more accurate evaluation of the 2015 drought and comparison with previous dry years (e.g. 1974, 1992 and 2003) will be possible only after the end of the complete annual cycle.

9. Evolution of Water Storage in Reservoirs

The precipitation deficit and hydrological drought were negatively reflected in the process of filling water reservoirs, especially water reservoirs with storage effects. Those reservoirs are used for direct water offtake from the reservoirs or for an improvement of the river flow downstream the reservoirs. Ensuring such storage effects in the case of decreasing inflows into the water reservoirs inevitably led to a relatively rapid emptying of most of the reservoirs. Free water surface evaporation in the summer months with above-average temperatures, especially during the period with the unprecedented number of tropical days, significantly contributed to the loss of water from water reservoirs.

The significant water reservoirs are included, on the basis of data from the River Basin Companies, in the evaluation provided by the Czech Hydrometeorological Institute in its regular weekly reports. Most of the water reservoirs are subject to a one-year refilling scheme, where the reservoir storage volume is usually refilled in the period of increased spring inflows. At the end of April 2015, the reservoir water levels were also quite normal, corresponding to that season. The storage volumes of significant water reservoirs were filled at more than 90% of their capacity, except for the Šance Reservoir whose water level was kept lower due to ongoing work in its pool. The storage volumes of other reservoirs were mostly filled at 85% and more of capacity. The Orlík and Brněnská Reservoirs were only filled at 76% and 67% of capacity, respectively.

The precipitation deficit in the spring months and the overall lower water bearing of streams resulted in reduced inflows, and the reservoirs started emptying – some of them already from April (Želivka, Žlutice, Přísečnice, Nechranice, Seč, Opatovice) and the other ones in May and June, or as late as July (Římov, Fláje, Hracholusky). During the summer, the drops in levels of most of the reservoirs deepened and consistently continued until October. In some cases, they were interrupted by insignificant periods of temporarily increased inflows (Seč, Souš, Nýrsko, Kružberk, Vír and Opatovice).

As of the deadline for providing input data for the report, i.e. as of the end of October 2015, the water level of most of the water reservoirs was still declining. The arrested decline or rise in water levels resulting from rainfalls in October and increased inflows only manifested themselves in some water reservoirs in South and West Bohemia (Římov, Nýrsko, Hracholusky, Žlutice, Fláje) and South Moravia (Mostiště, Vranov, Dalešice, Nové Mlýny).

On 2 November 2015, the storage volumes of water reservoirs were filled as follows:

Less than 30%	Rozkoš, Šance*
30 to 50%	Pastviny, Seč, Fláje*, Orlík, Morávka, Žermanice, Vranov
50 to 70%	Souš, Lipno, Hracholusky, Žlutice, Těrlicko, Opatovice, Slušovice, Vír, Dalešice
70 to 90%	Vrchlice, Josefův Důl, Římov, Slapy, Želivka, Nýrsko, Skalka, Jesenice, Horka, Stanovice, Přísečnice, Nechranice, Kružberk, Brněnská, Mostiště, Nové Mlýny lower impoundment reservoir

* In the Šance and Fláje Reservoirs, the water level was reduced for operational reasons.

The course of filling selected reservoirs in 2015 is shown in Figs. 9.1. to 9.10. From the reservoirs operated by each of the River Basin Companies, one drinking water supply reservoir and one non-drinking water supply reservoir were selected. In some cases, where input data were available, the course of water reservoir filling is described for a two-year period in comparison with the reservoir operations over other previous dry years.

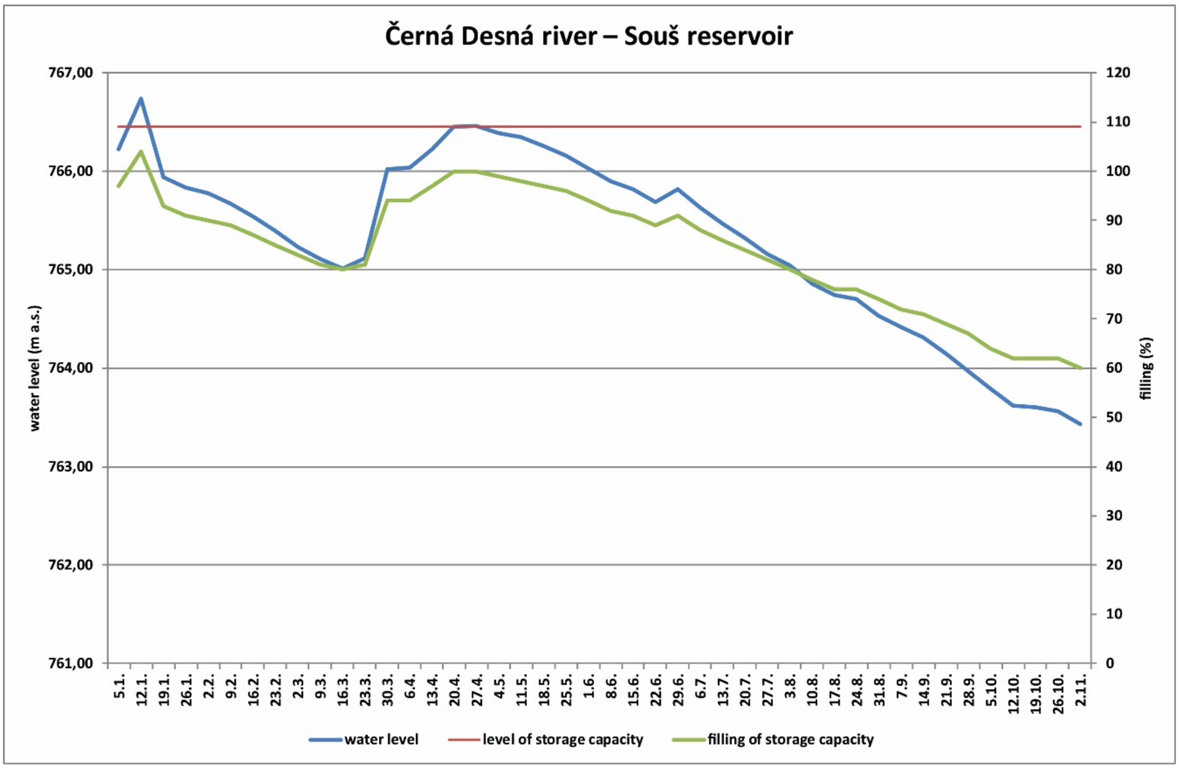


Figure 9.1. Souš Reservoir management in 2015.

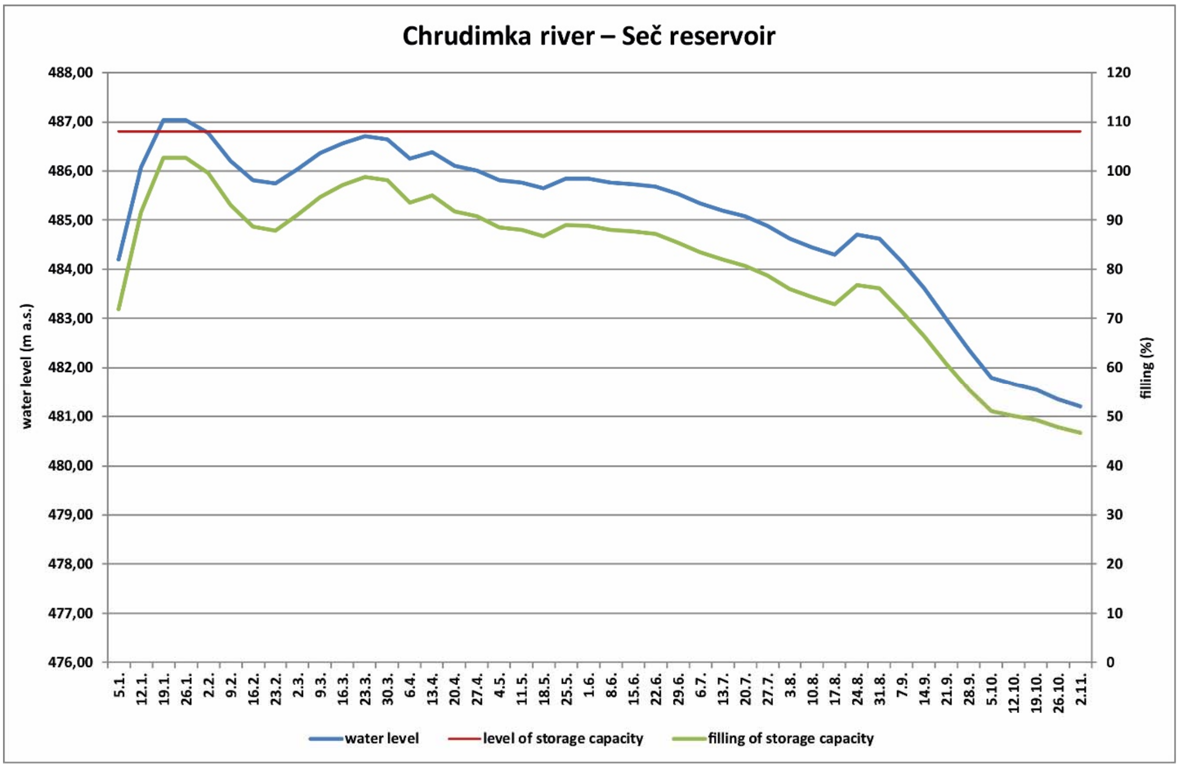


Figure 9.2. Seč Reservoir management in 2015.

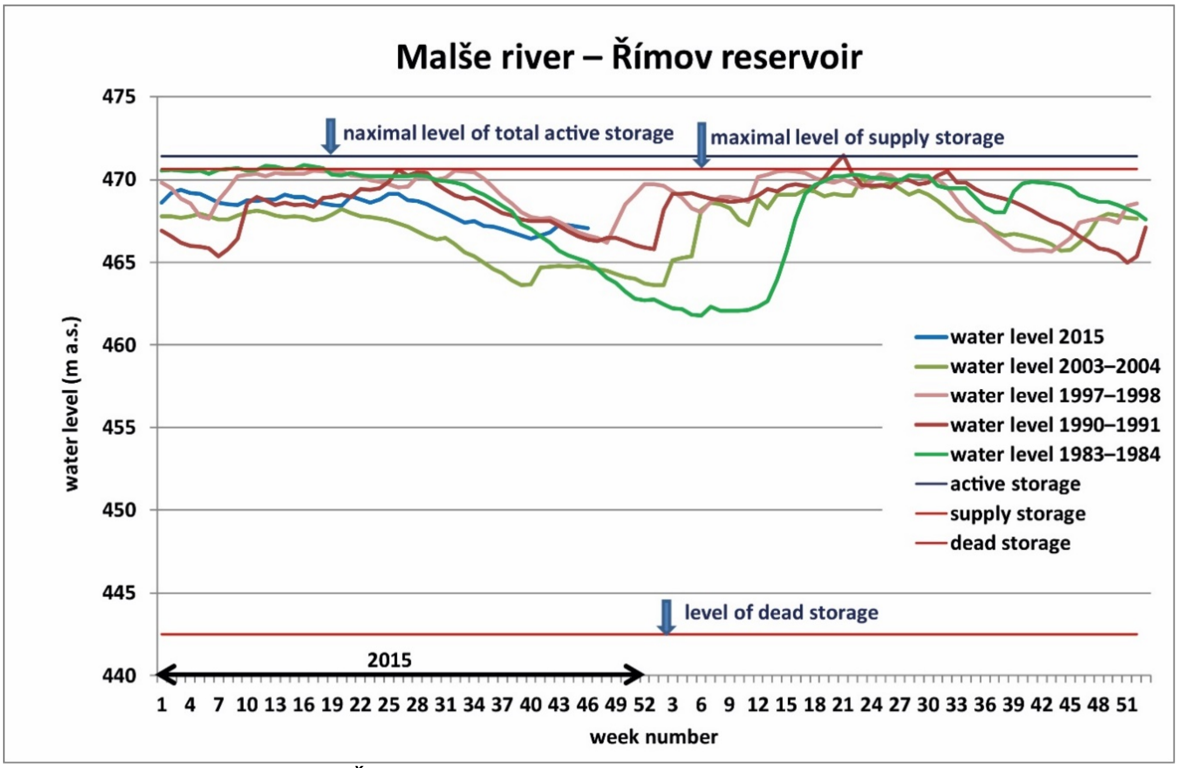


Figure 9.3. Course of the Římov Reservoir water level in 2015 in comparison with other dry years.

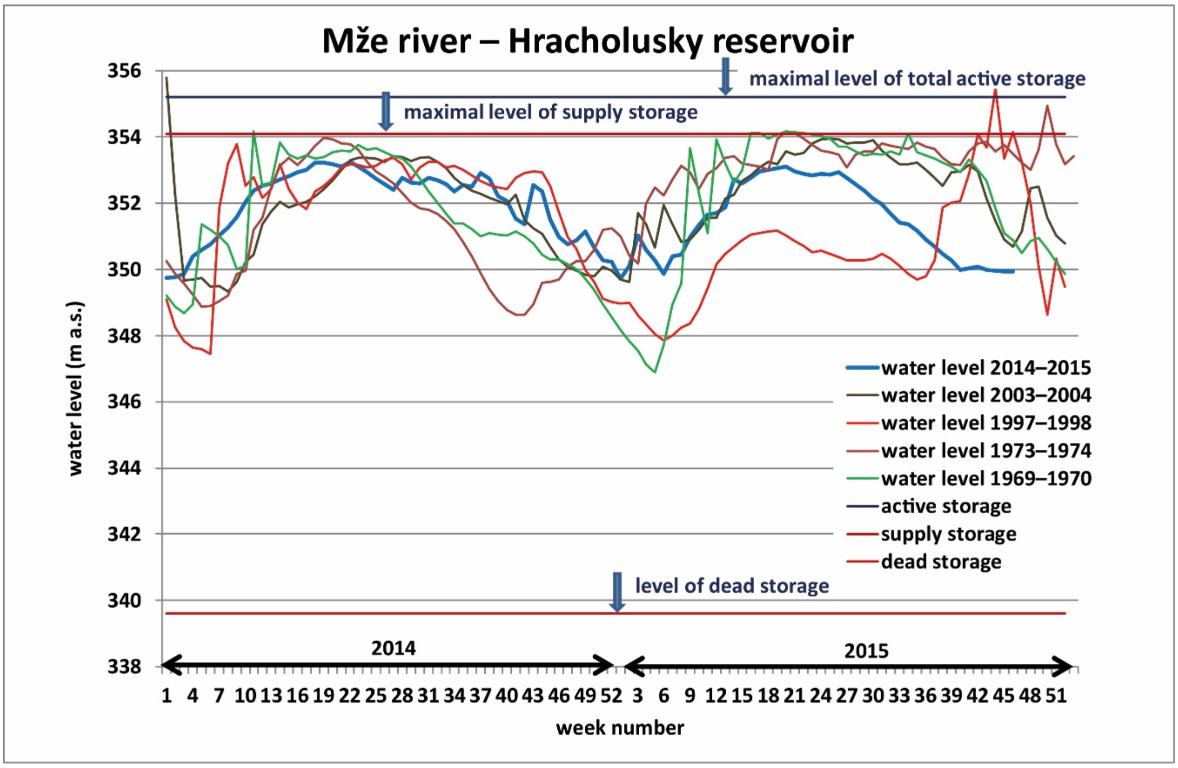


Figure 9.4. Course of the Hracholusky Reservoir water level in 2014–2015 in comparison with other dry years.

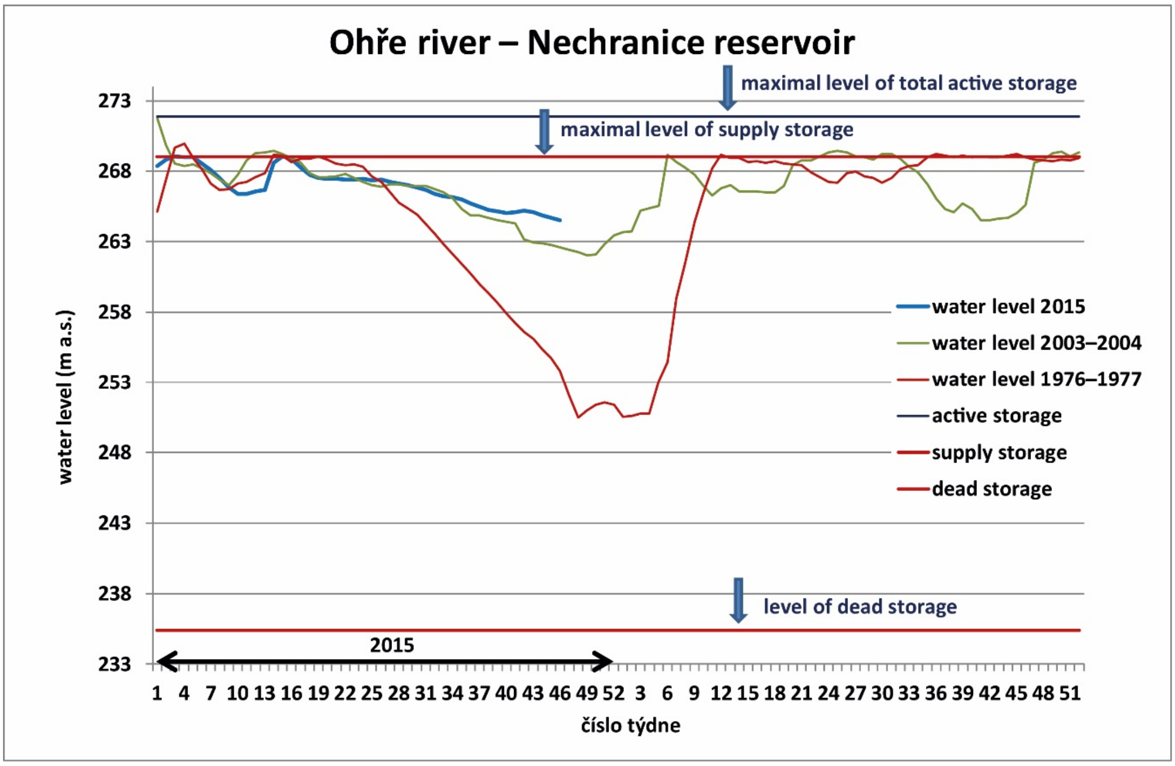


Figure 9.5. Course of the Nechranice Reservoir water level in 2015 in comparison with other dry years.

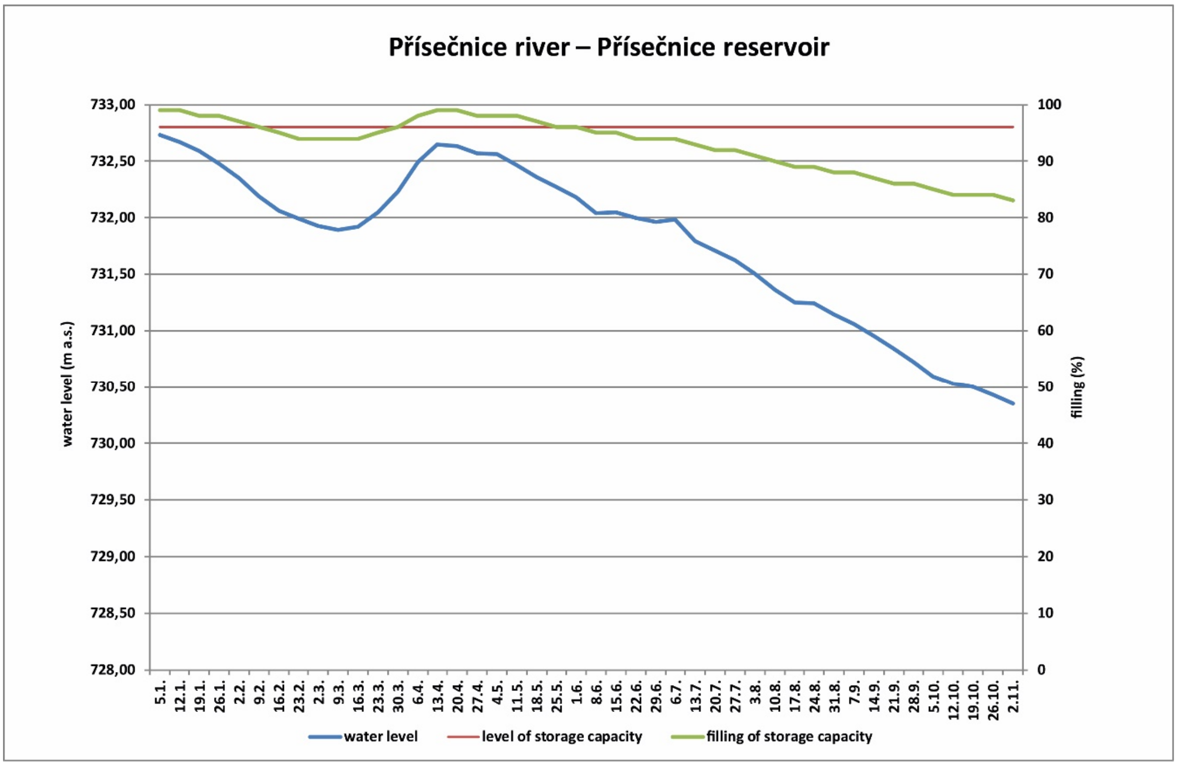


Figure 9.6. Přísečnice Reservoir management in 2015.

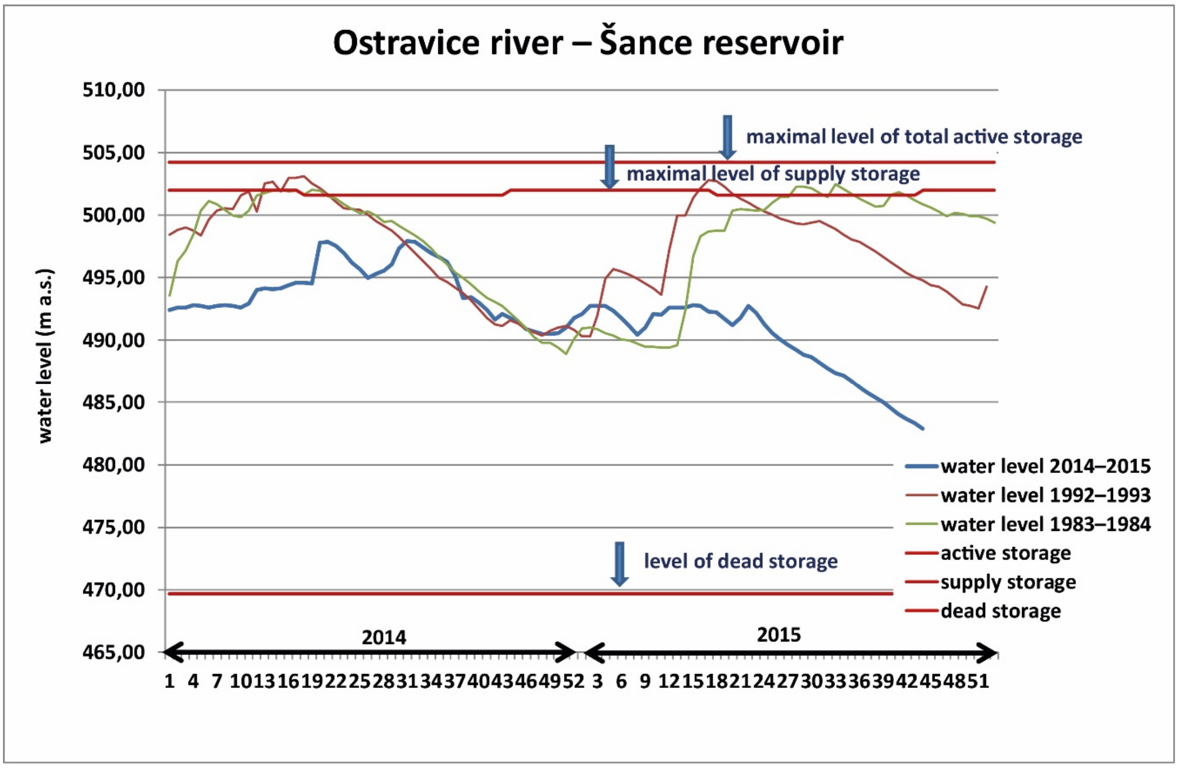


Figure 9.7. Morávka Reservoir management in 2015.

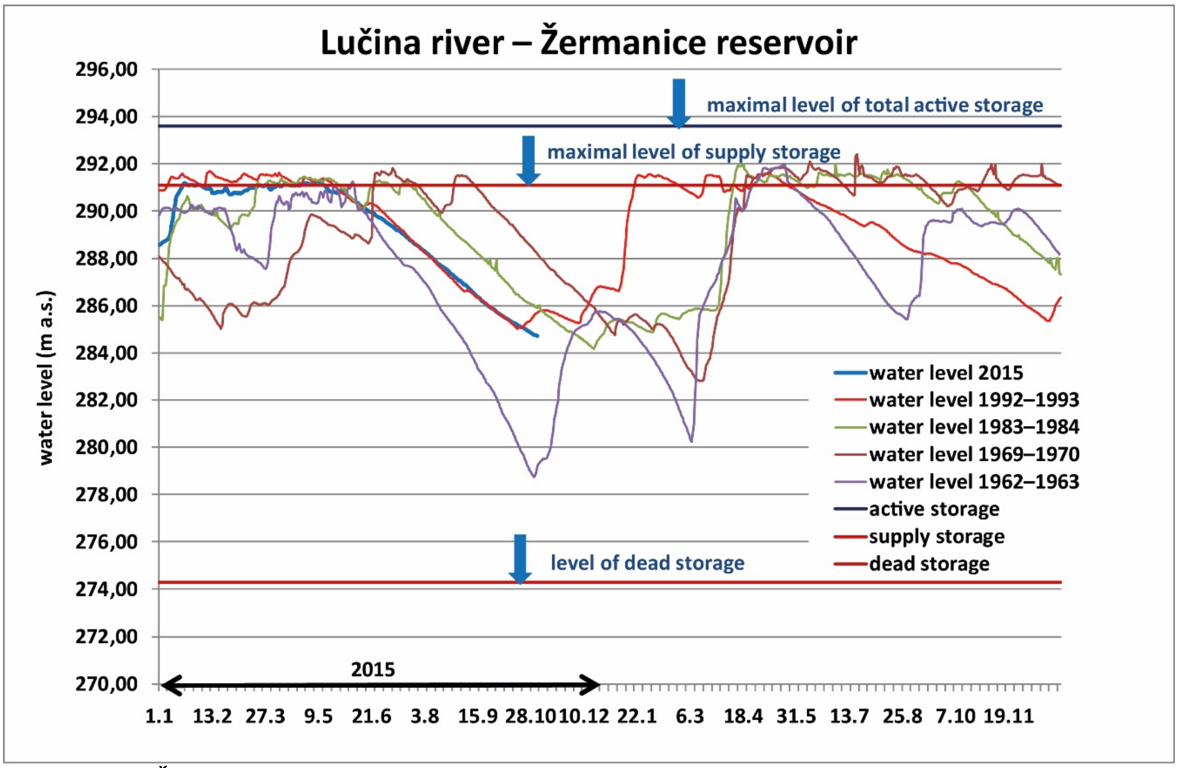


Figure 9.8. Žermanice Reservoir management in 2015.

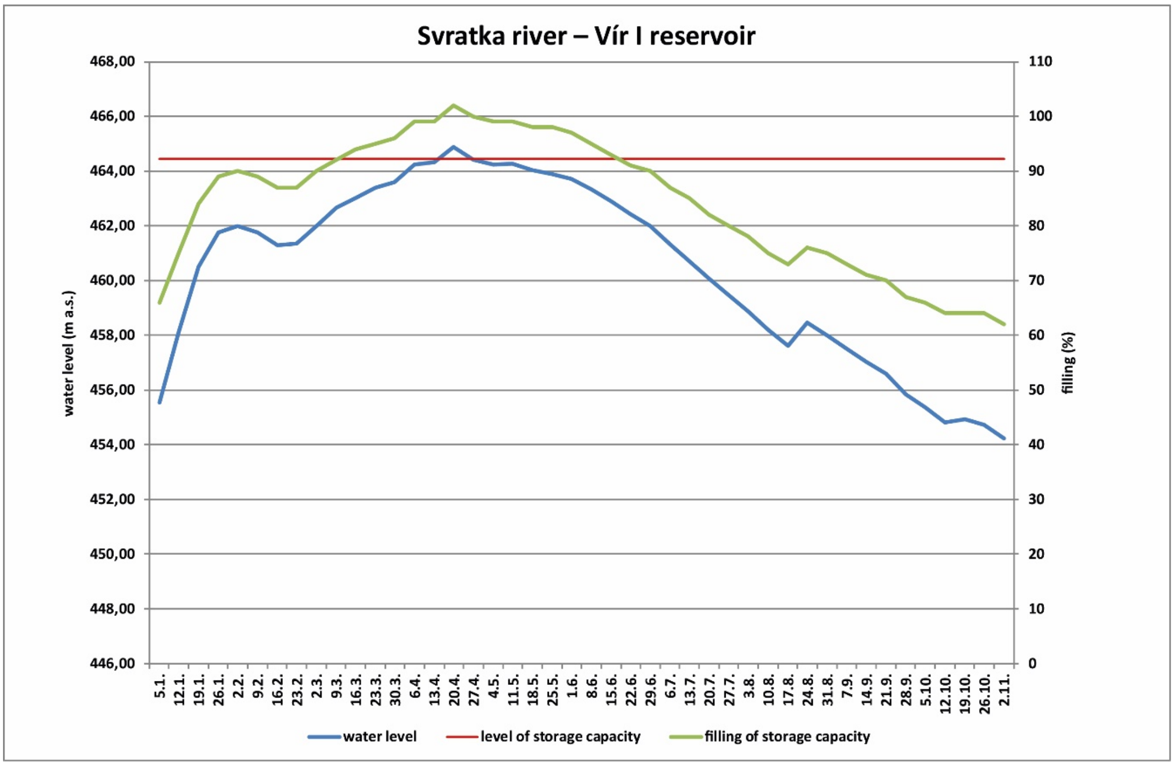


Figure 9.9. Vír I Reservoir management in 2015.

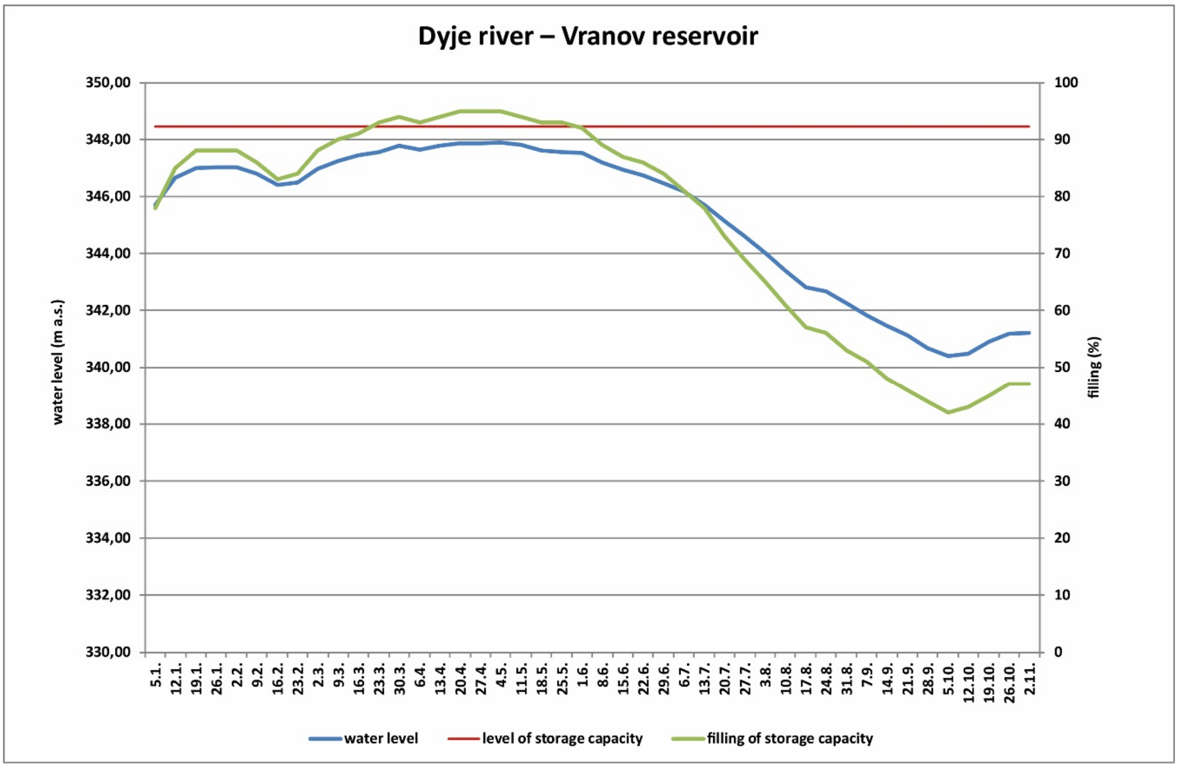


Figure 9.10. Vranov Reservoir management in 2015.

Most of the monitored reservoirs are refilled in a one-year cycle, i.e. the reservoir is emptied during the dry period of the year and it is again refilled during increased spring inflows. This was also the case in previous years with the lowered water bearing of streams. This is documented by the graphs of reservoir filling, which include a comparison of the course of filling in 2015, or possibly in the two-year period of 2014–2015, with that of other dry years. It is possible to say that at the end of hydrological year 2015, the storage volumes of the reservoirs in the Odra River basin situated in the Beskydy Mountains and in the Upper and Middle Elbe River basins were emptied the most.

In the case of the Šance Reservoir in the Odra River basin, which was only filled at 20% of capacity, the reservoir water level was artificially reduced as early as 2014 because of problems encountered at the dam. In 2015 it was further reduced, so that remedial work could be performed on the dam. Water supply from the reservoir was limited, and within the water system, it was replaced by higher water offtake from the Kružberk and Slezská Harta Reservoirs. As a result of the drought in that region, the water offtake from the Žermanice Reservoir for industrial purposes was also reduced.

In the Upper Elbe River basin, the Rozkoš Reservoir was emptied the most (filled at 26% of capacity), which is however a common situation in the case of this reservoir. In case of more extensive emptying, the reservoir can be refilled through water transfer from the Úpa River. The Pařížov Reservoir on the Doubrava River was temporary empty and the Les Království Reservoir was nearly emptied on the level of dead storage. The minimum residual outflow from those reservoirs had to be restricted, as well as the outflow from the Husinec Reservoir on the Blanice River and the Klabava Reservoir.

In case of a group of multiple consecutive dry years, an important function is performed by reservoirs with a multi-year refilling cycle, whose typical representative is the Švihov Reservoir on the Želivka River used for drinking water supply. Its reservoir storage volume of 246 million m^3 is greater than the volume of the average annual inflow into the reservoir. The reservoir can thus ensure the required water offtake for an extended multi-year dry period, during which it is being emptied, such that after a few years, it is again refilled. The situation on the Švihov Reservoir is shown in Fig. 9.11. Over the last years, the reservoir has been minimally emptied; only after this year's drought was its level below 90% of its storage volume. Of course, this is caused by a lower water offtake for a water treatment plant, which does not come close to reaching its designed capacity. More extensive emptying of the reservoir occurred in the period from 2003 to 2005, and in particular, during the multi-year drought in the period from 1989 to 1992, which still did not reflect any reduced drinking water consumption caused by higher water supply prices. At the current offtake, the reservoir's water management can maintain sufficient reserves even in a drought period.

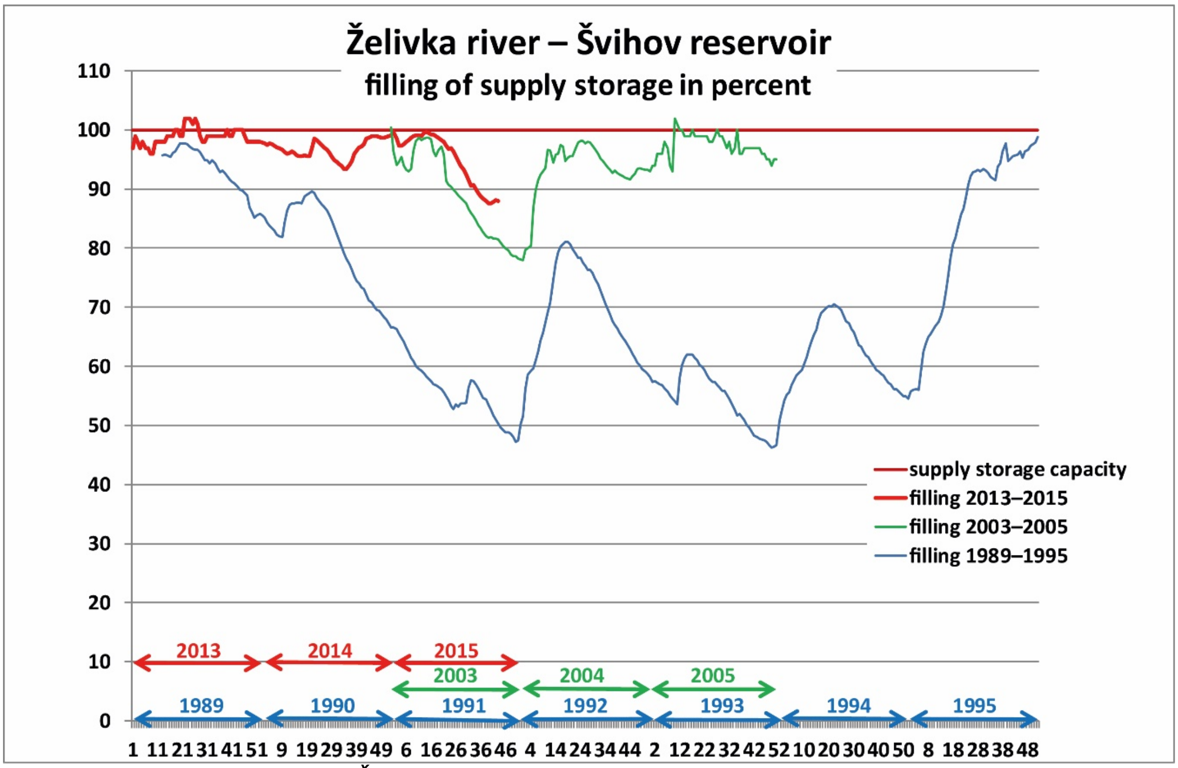


Figure 9.11. Course of the Švihov Reservoir's filling in comparison with other dry periods.

In general, water reservoirs connected to water systems managed by water control centers, which provide for the overall purpose of the system, better resist drought. An example is the water system of reservoirs in the Odra River basin, which successfully overcame the above-mentioned problems at the Šance Reservoir. Other examples include the system of the Skalka-Jesenice-Nechranice Reservoirs in the Ohře River basin and the reservoirs forming interconnected drinking water systems (Josefův Důl-Souš, Přísečnice-Fláje).

Vltava River Cascade

The system of Vltava River Cascade reservoirs is a multipurpose system, and the priority of individual purposes and the method of its control are based on the System Operating Rules. In terms of drought impacts, the primary purpose consists in ensuring the minimum flows in the Vltava River ($6 m^3.s^{-1}$ downstream of the Lipno II Reservoir and $40 m^3.s^{-1}$ downstream of the Vrané Reservoir), which was fully taken care of by the key water reservoirs of Lipno I, Orlík and Slapy even during the 2015 drought.

The course of Lipno I Reservoir's water level fluctuation in 2014 and 2015 is shown in Fig. 9.12. It is necessary to point out that the reservoir storage volume emptying may not always be caused by small inflows in a drought period, but by an intentional pre-emptying and releasing of part of the storage volume for capturing floods. The graph provides a comparison with other drought periods that occurred in the past. It is obvious that the reservoir was not refilled to its full storage volume in spring 2015 and from July it was being systematically emptied. Even though, its storage volume level in late October (68%) was quite comparable with other dry years.

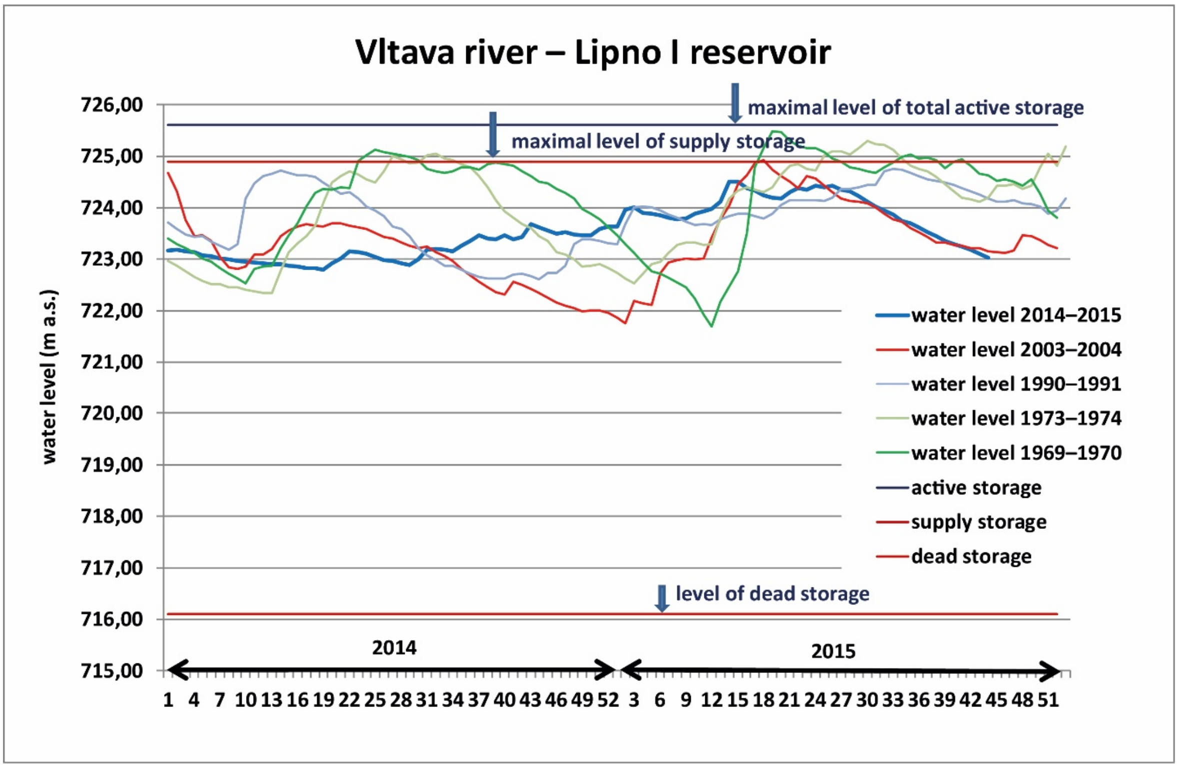


Figure 9.12. Course of Lipno I Reservoir water level in 2014–15 in comparison with other dry years.

The Orlík Reservoir was relatively more drained (Fig. 9.13.). Its storage volume was not refilled due to the dry winter in spring 2015 either, and, from July to late September, the reservoir level was continuously declining down to 34% of its storage volume. Such a reduced water level of the reservoir has occurred several times (February 1969, March 1970, March and April 1976), but never in the autumn. The 2003 course (red line) was comparable, as the Orlík Reservoir level was declining from June to the end of the year, and the storage volume was only partially refilled in spring 2004. Even though the reservoir storage function was not jeopardized in 2015, the significant drop in the reservoir water level in the summer and autumn caused the recreational purpose of the reservoir to be significantly limited (see Fig. 9.14.).

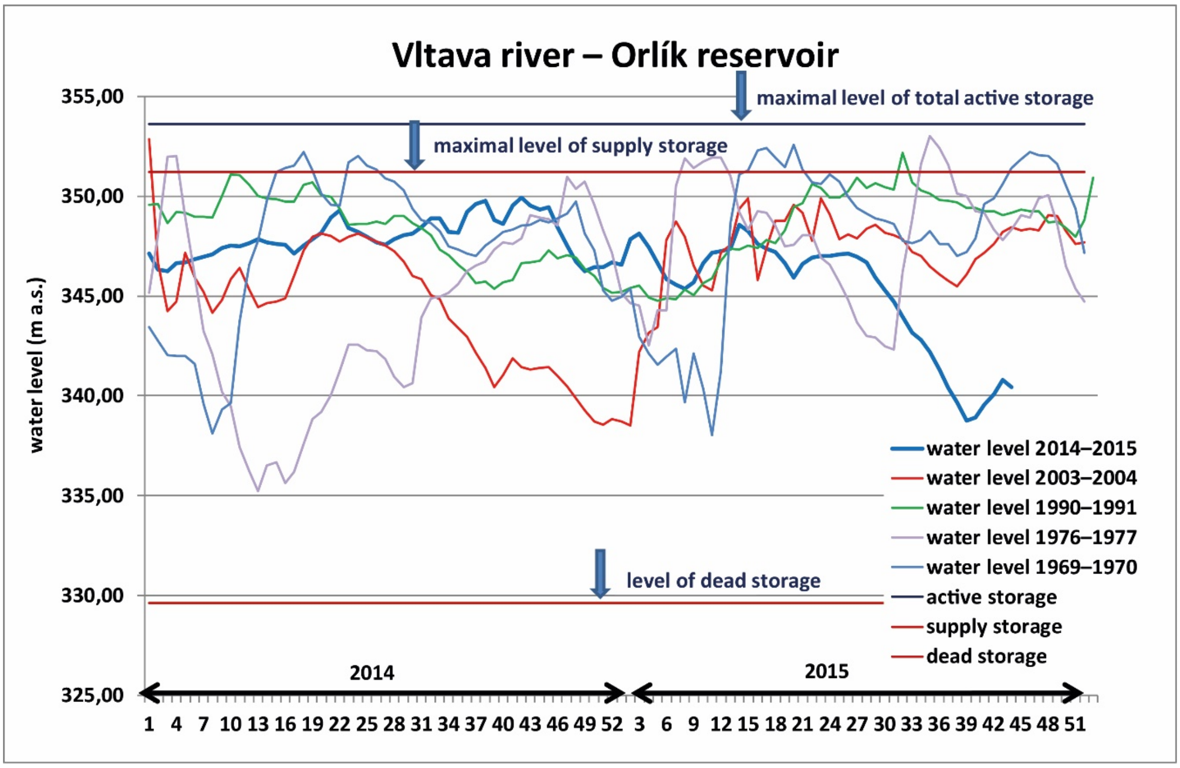


Figure 9.13. Course of the Orlík Reservoir's water level in 2014–2015 in comparison with other dry years.

Fig. 9.14. Partially emptied Orlík Reservoir in the recreational season of 2015.

The Vltava River cascade reservoir system is controlled by the Water Management Control Center of the Vltava River Basin Company, under the comprehensive System Operating Rules. The Rules include a summary control flowchart of the Orlík and Slapy Reservoirs for controlling the storage function of the system. During its implementation water amounts in the storage spaces of both the reservoirs are added up and compared with the control volumes, which are variable during individual months. The control flowchart is calculated to ensure the minimum Vltava River flow of $40m^3.s^{-1}$ downstream of the Cascade and the permitted surface water offtake on the stretch of Kořensko-Vrané. If the aggregate storage volume in the Orlík and Slapy Reservoirs is greater than the control volume as of a given date, then such a volume can also be used for other purposes, e.g. for an improvement of the flow to higher levels, or conversely, to values intended for capturing flood flows.

The total filling of the storage volumes of the Orlík and Slapy Reservoirs during 2015 in comparison with the course of control volumes is presented in the graph in Fig. 9.15. From the graph, it is obvious that there were sufficient water reserves in both the reservoirs to ensure the supply function of the system at all times. The aggregate storage volume of both the reservoirs was closest to the control line in the 39th week, i.e. in late September, amounting to approximately 28 million m^3. However, it is necessary to point out again that even a possible decline in the aggregate volume below the contol line does not indicate any disruption of the basic supply function of the system.

Over the entire drought period, the Vltava River Cascade reservoirs significantly influenced the flow regime in the Vltava River and subsequently, in the lower reach of the Elbe River, where the drop in flows would have been much greater if it had not been for such influence. The lower section of the graph in Fig. 9.15. describes the size of such reservoirs' influence on the Vltava River flow through the Orlík and Slapy Reservoirs based on changes in the water volumes of these reservoirs computed in weekly steps. It should be added that the system of the Skalka-Jesenice-Nechranice Reservoirs had a similar positive effect on the Ohře River's flow; the Rozkoš Reservoir on the Metuje and Elbe Rivers' flows, and the Vranov Reservoir on the Dyje River's flow, etc.

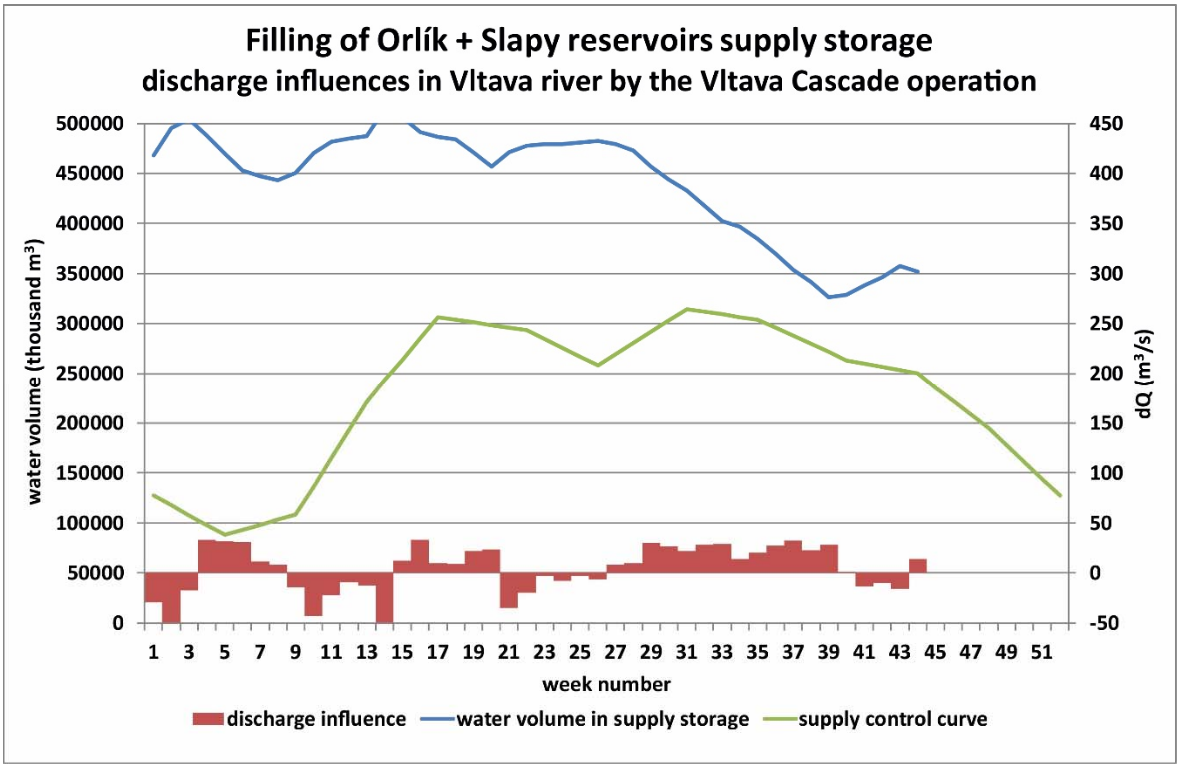


Figure 9.15. Course of the aggregate storage volume of Orlík and Slapy Reservoirs in 2015 and comparison with control volumes as per the System Operating Rules. Water reservoir operations influencing the Vltava River flow rate downstream of the Vltava River Cascade (weekly averages).

The water reservoirs with significant storage volumes contributed to the mitigation of hydrological drought by improving the minimum discharges. In October, most of the reservoirs continued to be filled above 30% of the storage volume. The main drinking water supply reservoirs operated without any drought-related failure, with exception of above mentioned Šance reservoir. The minimum runoff from most of the reservoirs was also ensured, as required by the Operating Rules. It must have been reduced only in case of several reservoirs in the Odra river basin (in Beskydy mountains) and in the Labe and Vltava river basins (Pařížov, Husinec, Klabava). In general, water reservoirs confirmed their important regulative function during both floods and droughts.

10. 2015 Drought Compared with Historical Drought Events

Evaluation of the 2015 drought in the historical context is limited by a potential data source, because for the time being, measured data are only available for a period of the last hundred years. Moreover, in many cases it will be necessary to digitize and check the historical water level data and convert them into discharge data. In particular, this applies to the early instrumental data of the 19^{th} century (water stages, snow depth, etc.), as well as to later data, for example, those of the 1930s and 1940s. Therefore, a comparison of historically dry episodes cannot be uniformly carried out in all aspects.

Comparison of Dry Periods in 1904, 1947, 1994, 2003 with 2015

The comparison of individual dry years 1904, 1947 and 2015 is a very difficult task, because it is necessary to take into account the previous long-term evolution, evolution of snow storages in the same year, precipitation deficit development, runoff during the spring thaw, course of maximum and average daily temperatures, possibly also the rate of runoff decline phase, and probably some other aspects.

Comparing the discharges in Prague and Děčín is complicated by the influence of water reservoirs, as well as by irregular riverbed adjustments for navigational purposes performed after 1890. In Děčín during three instances of the same water stages of 119 cm, highly variable discharges were measured. A discharge of 46 $m^3.s^{-1}$ was measured in 1904. Five years later, in 1911, a discharge of 55.5 $m^3.s^{-1}$ was measured. In 1917 the discharge amounted to 73 $m^3.s^{-1}$. It is interesting to note that the absolutely lowest discharge of 37.9 $m^3.s^{-1}$ was determined through hydrometric measurement on 21 August 1921 at a water stage of 95 cm.

After the Orlík Reservoir was commissioned in late 1961, improving the discharges downstream of the Vrané reservoir, discharges began reaching more than 15$m^3.s^{-1}$ in times of drought. The Vltava River cascade's influence in 1994, 2003 and 2015 is evident from Fig. 10.2. Discharges during older drought episodes (1904) could only be compared at a limited number of profiles where hydrometric measurements were being performed at that time, or it was possible to estimate such discharges using a balance. Table 10.1 presents a comparison of discharges at selected profiles in 1904, 1947 and 2015.

Undoubtedly, the most interesting figure is that of the hydrometrically determined discharge of the Vltava River at Prague, Q_{min} = 12 $m^3.s^{-1}$, which was measured on 18 August 1904 and was smaller than the 1947 discharge. On the other hand, attention must be given to the discharges on the Upper Elbe River in 1947, when the minima were not reached until September. At the outlet water gauge at Brandýs nad Labem, the discharge only dropped to 10.4 $m^3.s^{-1}$ on 23 September. On the critical day, the discharge on the stretch of the Elbe River upstream of the city of Hradec Králové (at Josefov) amounted to 2.8 $m^3.s^{-1}$. (Otherwise, it mostly amounted to 3.4 to 4.5 $m^3.s^{-1}$). On the same day, the Orlice River only showed a discharge of 2.5 $m^3.s^{-1}$ at the outlet water gauge at Týniště nad Orlicí, and the Chrudimka Stream only showed a discharge of 0.92 $m^3.s^{-1}$ at Nemošice. In Nymburk upstream of the confluence of the Elbe and Jizera Rivers, a discharge of approximately 7.8 $m^3.s^{-1}$ was recorded. The Jizera River produced a remarkable water bearing volume; on 22 September, its discharge amounted to 5.8 $m^3.s^{-1}$ at the Tuřice profile. However, these values require further verification.

The second striking data are those of the Ploučnice River discharge at the outlet water gauge at Benešov nad Ploučnicí, where the minimum of 3.5 $m^3.s^{-1}$ was already reached on 31 May. Over the period of absolute minima in August and September, a discharge of approximately 4.5 $m^3.s^{-1}$ was recorded. According to the evaluated data of 1947, the joint contribution of the Ploučnice and Jizera Rivers ranged from 10 to 11 $m^3.s^{-1}$, which roughly corresponds to the Ploučnice and Jizera Rivers' contribution estimated for August 1904. In both dry years, the contribution of both streams draining the Cretaceous basin was therefore very similar and reached almost the same magnitude as the Vltava River discharge at Prague (12 to 15 $m^3.s^{-1}$) and the runoff from the entire Elbe River basin upstream of the confluence with the Jizera River (7.5 to 10 $m^3.s^{-1}$). This shows the great significance that groundwater contributes to the Elbe River's tributaries in the Bohemian Cretaceous Basin in times of drought.

Table 10.1. Comparison of minimum discharges in 1904, 1947 and 2015.

Flow	Station	1904		1947		2015
		$Q_{minVIII}$ [$m^3.s^{-1}$]	Date	Q_{min} [$m^3.s^{-1}$]	Date	
Jizera	**Tuřice**	5,2	(18. 8.)	5,6	(21. 9.)	4,8 (P)
Labe	**Brandýs nad Labem**	15,5	(19. 8.)	10,4	(22. 9.)	-
Vltava	**České Budějovice**	2*		4,25	(21. 9.)	9,7
Lužnice	**Bechyně**	1,2		2,3	(1. 9.)	0,85
Otava	**Písek**	1,8*		3,09	(21. 9.)	3,3
Sázava	**Poříčí nad Sázavou**	2,5	(18. 8.)	1,4 !	(1. 9.)	1,69 (N)
Vltava	**Davle**	7,5		13,7	(2. 9.)	34 (Z)
Berounka	**Beroun**	4,5	(18. 8)	3,3	(3. 9.)	4,6
Vltava	**Praha**	12,0 !	(18. 8.)	17,7	(3. 9.)	43,5 (***16,8)
Labe	**Mělník**	35,0	(17. 8.)	33,4	(22. 8.)	-
Ohře	**Louny**	3,9	(19. 8.)	0,6 !	(24. 9.)	8,1
Ploučnice	**Benešov nad Ploučnicí**	3,0 až 6,0	(18. 8.)	3,5	(31. 5.)	-
Labe	**Děčín**	39**		40,1	(22. 8.)	76,8

Notes: A verified value is missing.
** A rough estimate resulting from the balance.*
*** By Novotný (1963), (N); Nespeky, (P: Předměřice n. J., Z: Zbraslav); red – most critical values, blue – strongly influenced by the reservoirs.*
**** An estimate of the discharge without any influence of the Vltava River cascade reservoirs.*

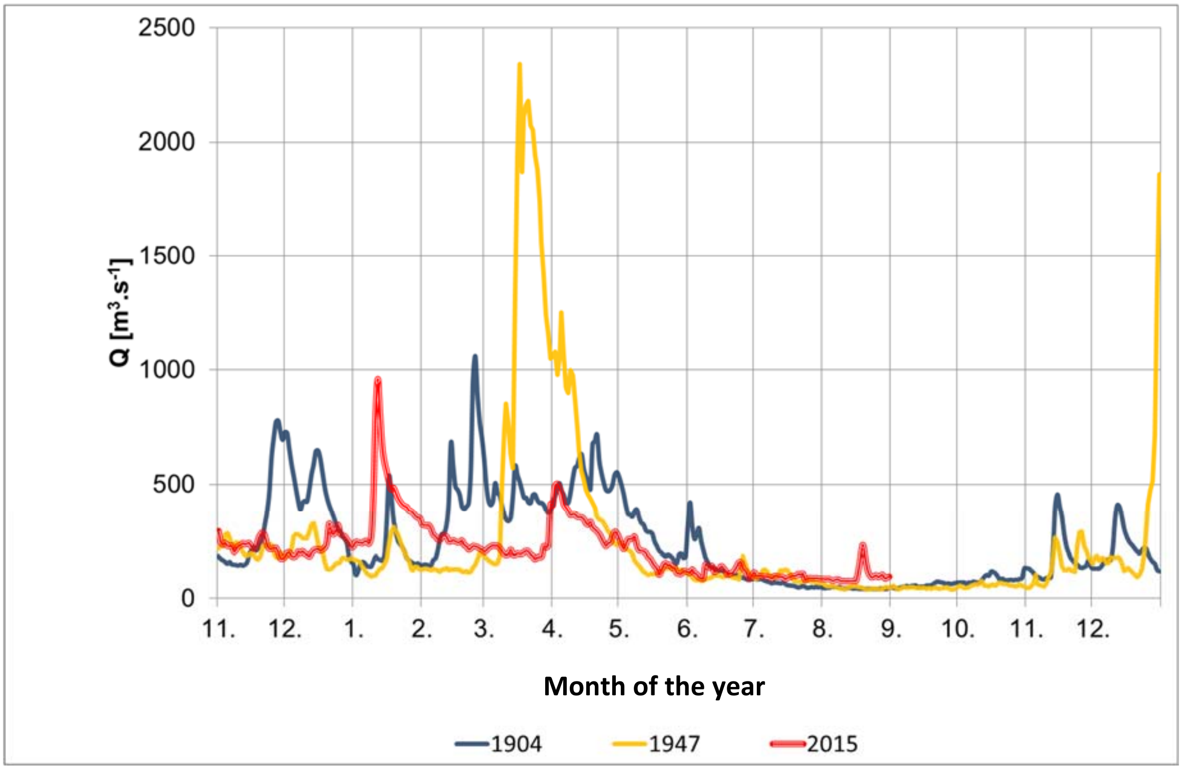


Figure 10.1. Evolution of the Elbe River discharges at Děčín in the selected dry years 1904 and 1947 in comparison with 2015.

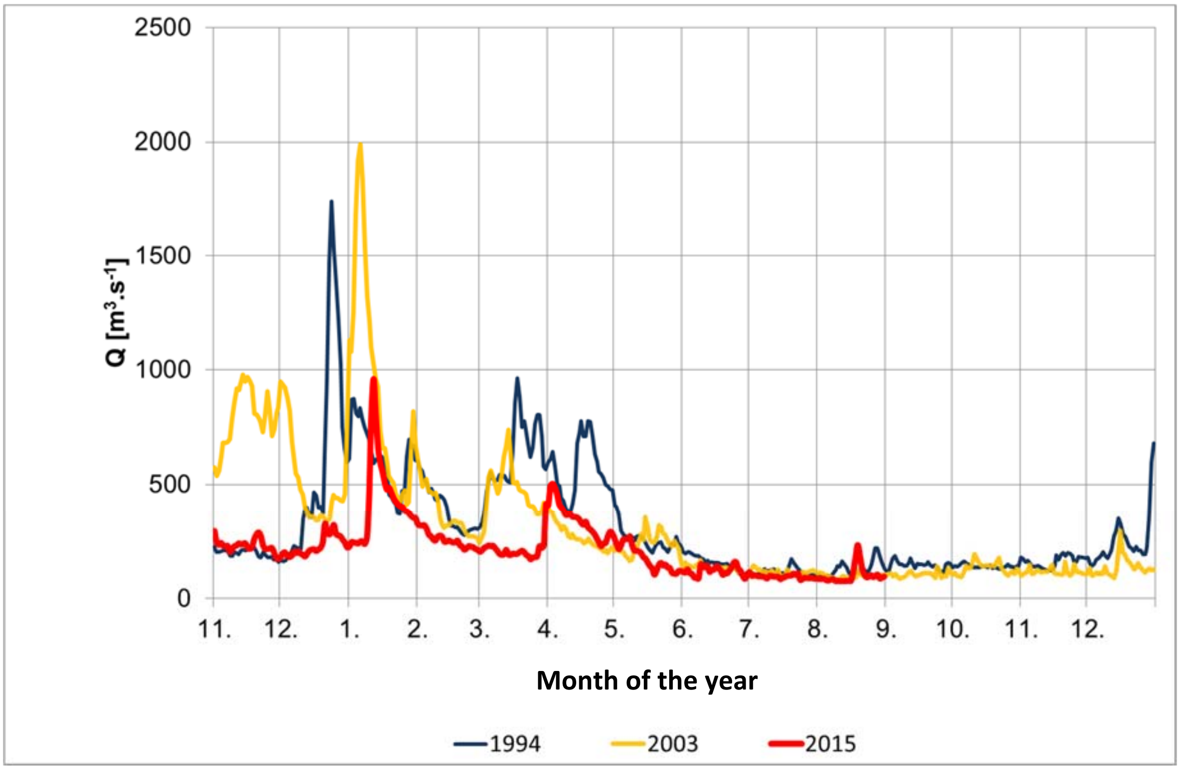


Figure 10.2. Evolution of the Elbe River discharges at Děčín in the selected dry years 1994 and 2003 in comparison with 2015.

Antecedent Conditions before Dry Periods of 1904, 1947, 2003 and 2015

The influence of the previous long-term evolution on the occurrence of a hydrological drought particularly manifested itself in the 1874 drought preceded by several dry years, at least from 1868. In the droughts in 1904 and 1947, such an evaluation is not quite unambiguous. The 2015 drought was preceded by two winters which were poor in precipitation and snow starages and regional floods in summer 2013, which hit most of Bohemia. In this respect, a certain parallel was the year 1874, which was preceded by extensive flash floods in 1872 within the same span of time.

As for the conditions of immediately preceding winters, the 1947 winter was the coldest and most snow-rich. According to contemporary reports, soil was frozen to a depth of more than 50 cm after quite severe frosts (initially without snow cover). In 1904 the conditions for snow cover formation at lower elevations were much worse than in 1947. In the mountainous areas of the Giant Mountains (Krkonoše Mountains), snow cover of 50 to 150 cm was formed. In 2015 the conditions for snow cover formation were evidently the least favorable. Significant snow cover was only formed in the mountains.

When comparing the runoff in the spring months, the runoff response that occurred in 1947 can be considered the most significant (see Figure 10.1.). Even though in 1904 the stream levels were fluctuating, the runoff situation was not comparable with that of 1947. The level fluctuation in 1904 was much longer and was followed by fluctuations in May caused by flash floods. Even though the runoff phase in 2015 was relatively the weakest of those in the years compared, there is some similarity to the situation in 2003 in terms of the time of flood events, which also occurred in January. The year 1994 somewhat resembles the years 2002 and 2015, and the most significant runoff phase began as early as late 1993.

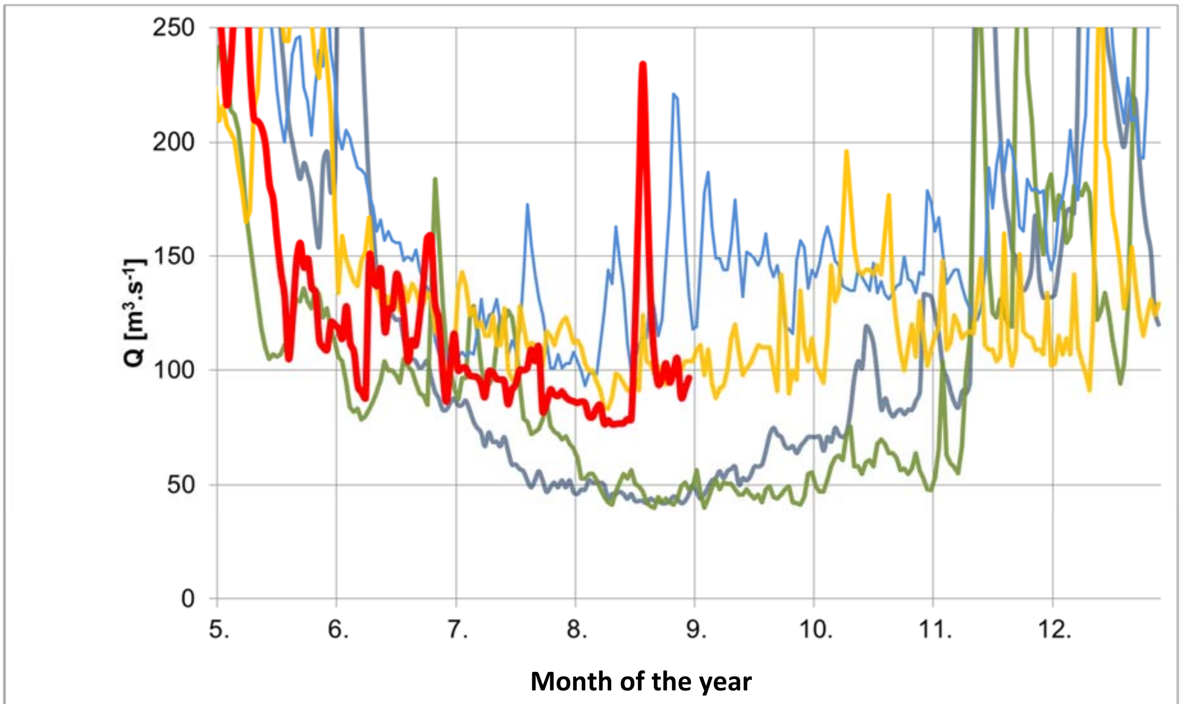


Figure 10.3. Evolution of small discharges (up to 150 $m^3.s^{-1}$) of the Elbe River at the Děčín profile in the selected dry years 1904, 1947, 1994 and 2003 in comparison with 2015.

As for the air temperature, the year 2015 was the most critical with a large number of tropical days with temperatures well above 30 °C. However, over a series of months, the year 1947 was also very warm, and the maxima of around 30 °C were recorded as early as May, several times in June, July and also in September. The summer days in 1947 came even sooner than in 2015. The 1904 summer was the “coldest” of the instances listed. The daily maximum temperatures exceeded 30 °C only exceptionally.

The fastest decline in the level at the Děčín profile was recorded in 1947, probably followed by the year 1904. In 2015 the stream levels themselves remained relatively low as early as January.

In conclusion, it is possible to say that the dry periods in 1904, 1947 and 2015 were approximately comparable in terms of the minimum discharges in the Elbe River basin. Without contributions from the reservoirs, the minimum discharges of the Vltava River in Prague in 2015 would not have exceeded the value of 20 $m^3.s^{-1}$, and on the Elbe River at Děčín, the minimum discharges would most likely have been close to 40 $m^3.s^{-1}$, thus corresponding to the minima in 1904 and 1947. A more detailed evaluation of the minimum discharges in the Lower Elbe River in 2015 has not yet been performed.

10.1. Comparison of 2015 Agro-Climatic Characteristics with 2003 and Long-Term Average for 1981–2010

A comparison between the two years was performed for the Doksany and Strážnice climatological stations. A curve of modeled agro-climatic conditions during 2015 (up to mid-October) was produced and compared with 2003, which was also characterized by significant signs of drought. The trend of variables in both the years has been compared with their long-term average for the period of 1981–2010.

For both the climatological stations, Figs. 10.4. to 10.9. present the weekly cumulative values of selected agro-climatic characteristics – potential evaporation from bare soil (PEVA_HP), potential evapotranspiration from grassland (PEVA_TP), basic moisture balance of grassland (ZVLBI_TP) (shown in the graphs on the left), and continuous accumulation of daily values from the beginning of the year to mid-October (shown in graphs on the right). The data are in millimeters.

If we mutually compare both selected stations and both analyzed years, there are apparent differences in the timeline of characteristics. In 2015 the moisture situation, expressed using the above-mentioned indicators, was worse at the Doksany station. By contrast, it was generally more favorable at the Strážnice station during 2015.

The evaporation (PEVA_HP) and evapotranspiration (PEVA_TP) characteristics for the Doksany station representing North Bohemia (see the graphs in Figs. 10.4. to 10.7.) document a worse moisture situation (higher evaporation and higher evapotranspiration) in 2015 than in 2003, especially during the growing season. By contrast, at the Strážnice station, representing Southeast Moravia, the manifestations of drought according to the above-mentioned model parameters were more intense in 2003 than in 2015. However, it must be emphasized that in most of the remaining areas of South Moravia (in the Břeclav and Znojmo regions), the moisture situation was less favorable than at the Strážnice station, and in principle, it was comparable with that of 2003 for part of the year.

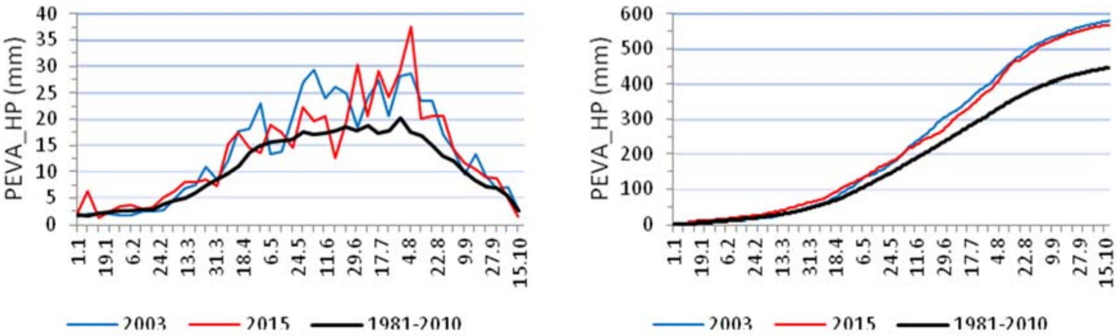


Figure 10.4. Doksany station, potential evaporation from bare soil in mm.

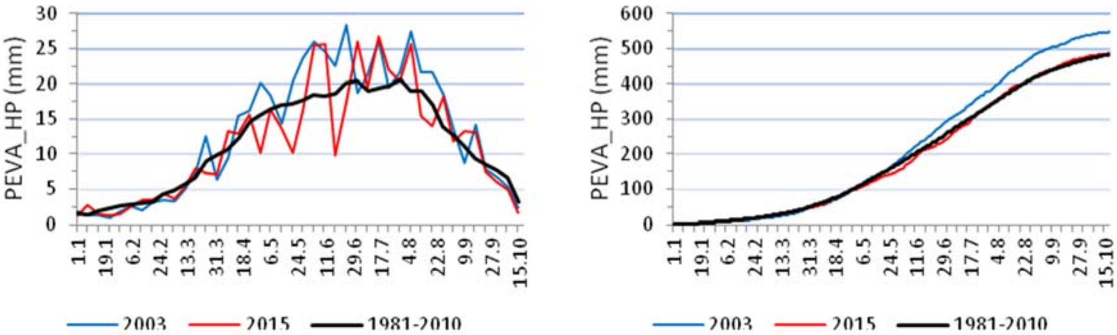


Figure 10.5. Strážnice station, potential evaporation from bare soil in mm.

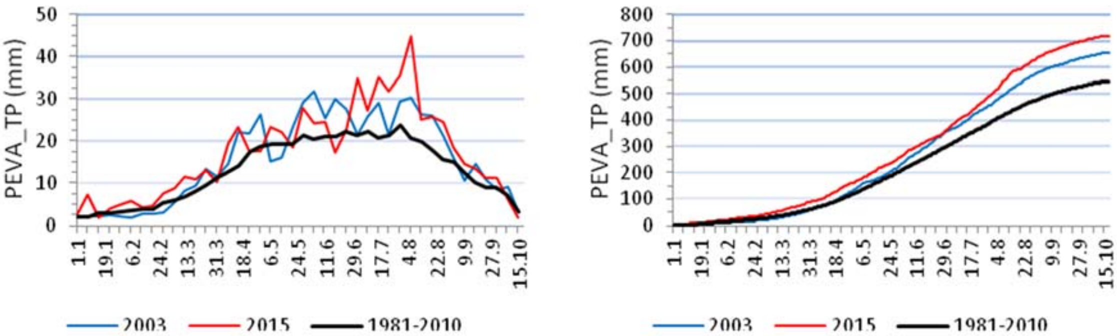


Figure 10.6. Doksany station, potential evapotranspiration from grassland in mm.

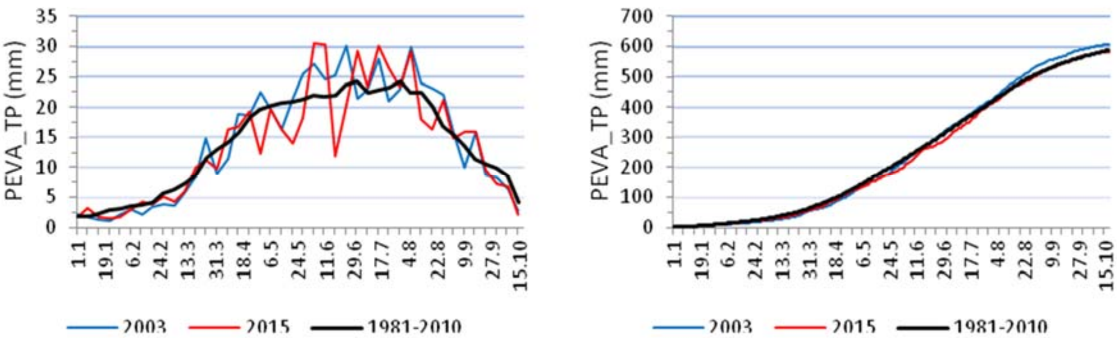


Figure 10.7. Strážnice station, potential evapotranspiration from grassland in mm.

The results of an analysis of the moisture balance (ZVLBI_TP) as the basic indicator specifying the intensity of a potential drought (graphs in Figs. 10.8. to 10.9.) are more unambiguous than in the case of evapotranspiration characteristics. In 2015 and 2003 the moisture situation at both stations was mostly worse than the long-term average for the period of 1981–2010. At both stations, the moisture situation in the period from the beginning of 2003 up to mid-October 2003 was also worse than in 2015, and the differences were larger at the Strážnice station. The differences between the 2003 and 2015 cumulative data are especially noticeable in the summer.

To understand the impacts of this year's drought on agricultural production and wild vegetation, it is important to evaluate not only the summer period of the worst drought, but especially the growing period (i.e. from April to September) as a whole. For the four selected stations, the graphs in Figs. 10.10. to 10.13. present a comparison of the average modeled soil moisture value, expressed as a percentage of available moisture capacity, at a depth of 40 cm (arable layer) under grass cover for the growing period from 1961 to 2015. The three driest years are marked in orange for each station. The graphs show that at the selected stations, the growing period of 2015 only ranked among the extreme dry periods in Opava, where it was the driest it had ever been in 55 years, and in Prague-Ruzyně, where it was the second driest. By contrast, at Strážnice it was the ninth driest, which confirms the fact that this year Southeast Moravia was not hit by the drought as much as South and Southwest Moravia. The growing period at the Doksany station appears to be the least dry, remaining only slightly below average in comparison with the other years. It is possible to say that in 2015 the area represented by the Doksany station was located at the "boundary" between the severe drought-affected area of Central Bohemia and the relatively more humid region of Northwest and North Bohemia.

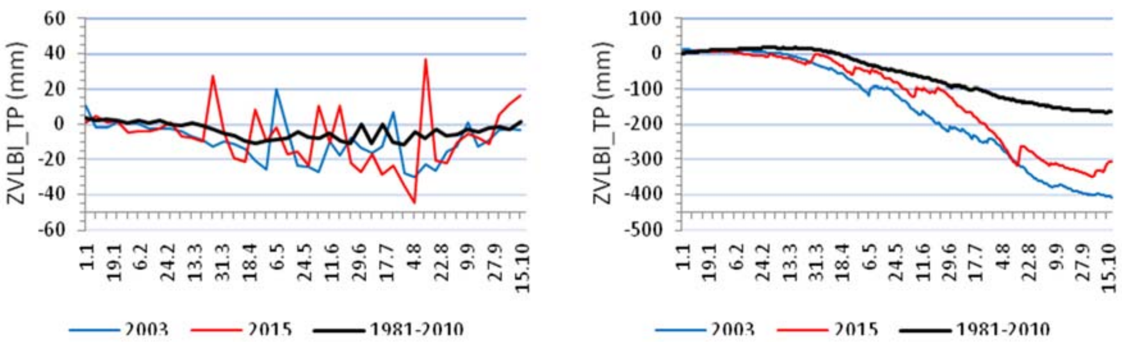


Figure 10.8. Doksany station, basic moisture balance of grassland in mm.

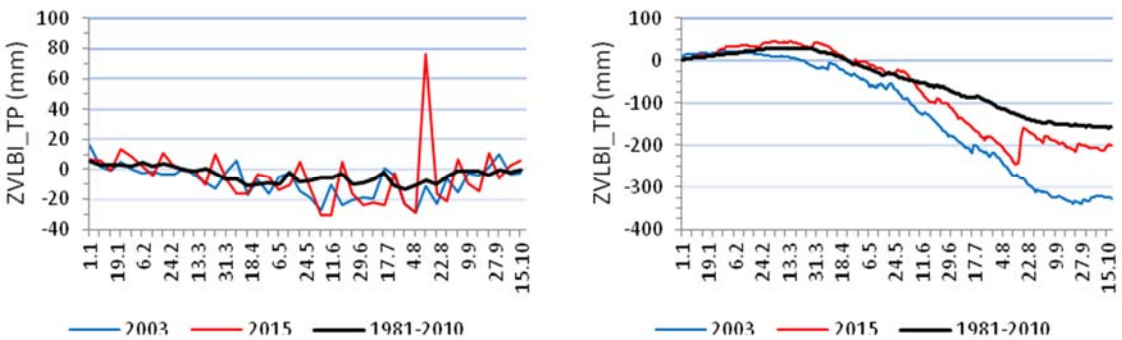


Figure 10.9. Strážnice station, basic moisture balance of grassland in mm.

From the graphs, it also follows that the unambiguously driest growing period was recorded for the arable soil layer in 2003. At three stations, this year was the driest of the 55 years evaluated. Only in Opava was it the second driest, but the average moisture was only 1% higher than the available moisture capacity in 2015.

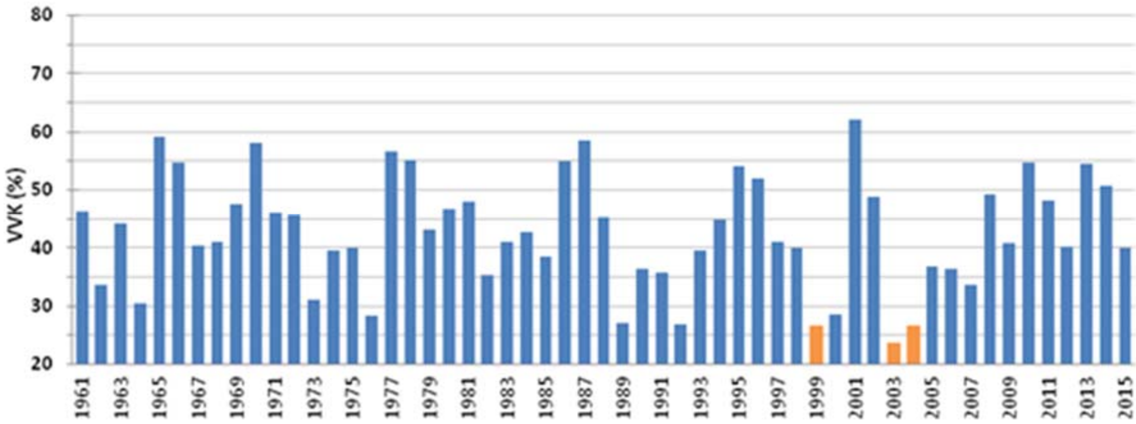


Figure 10.10. Soil moisture expressed as a percentage of available moisture capacity (VVK) at a layer of 0 to 40 cm under grass cover at the Doksany station, average for the growing period in individual years from 1961 to 2015.

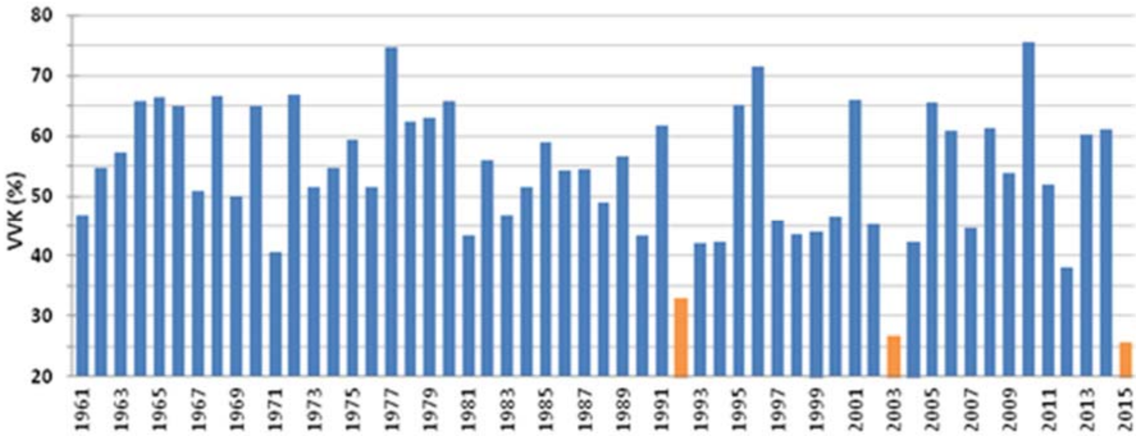


Figure 10.11. Soil moisture expressed as a percentage of available moisture capacity (VVK) at a layer of 0 to 40 cm under grass cover at the Opava station, average for the growing period in individual years from 1961 to 2015.

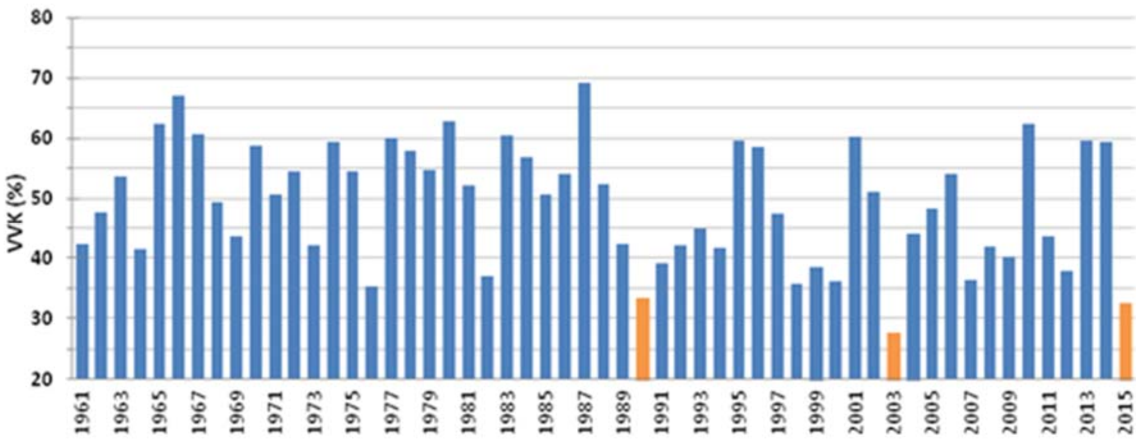


Figure 10.12. Soil moisture expressed as a percentage of available moisture capacity (VVK) at a layer of 0 to 40 cm under grass cover at the Prague-Ruzyně station, average for the growing period in individual years from 1961 to 2015.

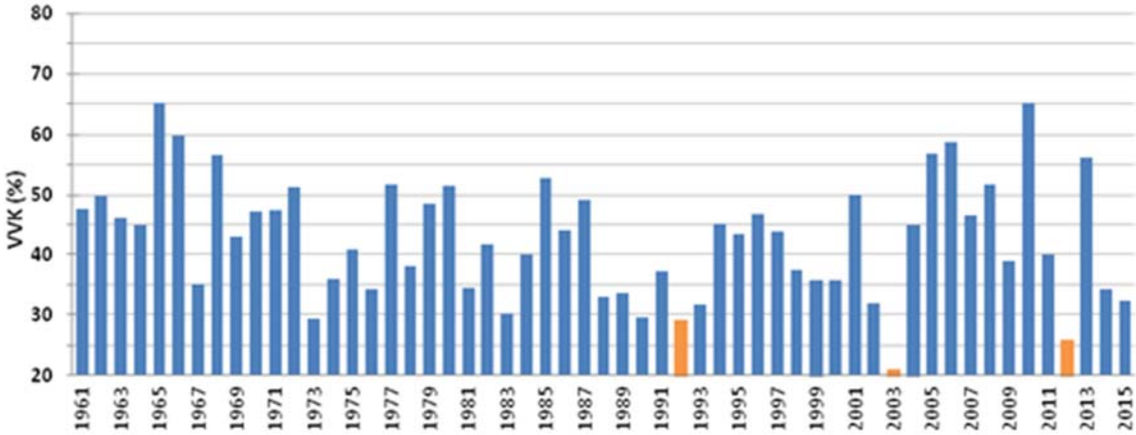


Figure 10.13. Soil moisture expressed as a percentage of available moisture capacity at a layer of 0 to 40cm under grass cover at the Strážnice station, average for the growing period in individual years from 1961 to 2015.

Figure 10.14. State of grassland on 7 May 2015, Chlumek hill (480m above sea level) at Rataje nad Sázavou (photo by Libor Elleder).

Figure 10.15. State of grassland on 6 August 2015, Chlumek hill (480m above sea level) at Rataje nad Sázavou (photo by Libor Elleder).

10.2. Evaluation of Precipitation (SPI), Runoff (SRI) and Groundwater Level (SGI) Indicators in 2015 in Comparison with Other Past Drought Events

The text below describes the results of an evaluation of frequently used indicators of the level of drought for precipitation, runoff and groundwater. This includes a standardized precipitation / runoff / groundwater index and a cumulative drought magnitude precipitation / runoff / groundwater index. The methodology of their calculation is described in the Appendix.

Precipitation

According to an evaluation using one-month precipitation totals (Standardized Precipitation Index 1 – SPI1**,** Drought Magnitude Precipitation Index 1 – DMPI1**)**, there were four dry episodes in the Czech Republic in 2015. One minor episode occurred at the beginning of the year and lasted 7 weeks, and the second episode beginning in March lasted 6 weeks. In both episodes, a moderate actual drought (SPI1) was reached. The third episode lasted 16 weeks from early May to mid-August, when it was interrupted by significant regional precipitation. In that episode, an actual severe drought was recorded in the last ten-day period of July and early August, when only 34–37% of the normal precipitation fell. In terms of overall drought magnitude (DMPI1), the end of that period (33rd week) had already been rated as an extraordinary drought. Since November 2014, the total precipitation deficit reached approximately 150 mm by that time. The last episode lasted approximately 4 weeks from mid-September to early October, when a strong drought occurred, and the deficit increased by a further 15 mm.

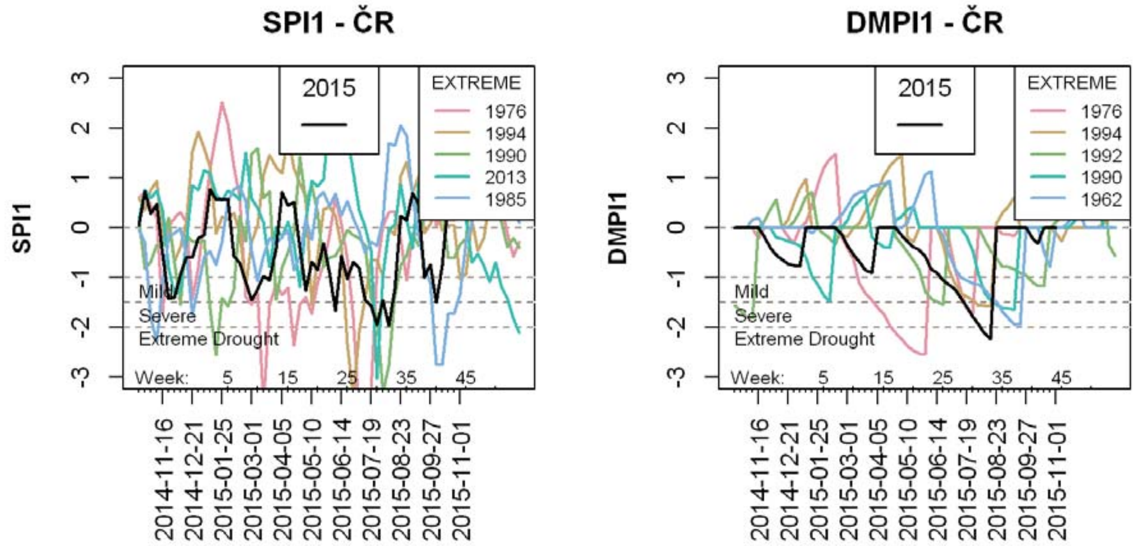


Figure 10.16. Evolution of one-month precipitation totals in the Czech Republic according to SPI1 and DMPI1.

All the above-mentioned episodes of drought and their evolution over time can be seen in Fig. 10.16. As it follows from a comparison with the course of five major periods since 1961, which culminated in the same period of the year (26th–38th week), the third episode of 2015 was the most significant. In terms of drought magnitude (DMPI1), which expresses the precipitation deficit, an extraordinary drought occurred. Other similarly significant periods also occurred in 1962, 1973, 1991 and 2003; however, they culminated later in September. Even according to the actual short-term value of SPI1, this was one of the most significant episodes of drought in the said period. Worse episodes only occurred in 1962, 1973 and 1990.

However, the extreme drop in discharges and groundwater levels in summer 2015, which is shown below, was caused not only by that extraordinary third episode, but also by the synergistic effects of that period and previous periods with below-average precipitation. These were further aggravated by the two consecutive winters of 2013/14 and 2014/15 and the extreme temperatures of summer 2015. The fourth period then had an impact on maintaining the low levels of water resources until the end of October. That combined impact on the level of water resources is more evident from the evaluation using 3-month and 6-month precipitation totals.

The evaluation using 3-month precipitation totals (SPI3, DMPI3) is shown in Fig. 10.17., where the entire year 2015 merged, as early as late April 2015, into one period of major drought, which had not even ended by October 2015 (a total of 28 weeks up to then). During that period, an extraordinary drought (DMPI3) was even recorded over 4 weeks at the end of the measured series. In terms of the actual level (SPI3), the below-normal period has lasted since early December 2014. Although at that time, it was not severe enough to be classified as a drought, but the precipitation deficit had already started to accumulate. According to SPI3, the drought culminated in the 32nd week of the year (9 August 2015) and was also classified as extraordinary for the 30th to 33rd weeks. At that time, the precipitation total for three previous months corresponded to approximately 55% of the normal. In late October, the drought had almost ended as SPI3 started to turn positive. The total deficit amounted to a precipitation of 115 mm.

From a comparison with the course of five major episodes of drought since 1961, it follows that in terms of the actual level according to SPI3, the year 2015, together with the year 1976, have been the absolute driest (3-month total as of the 32nd week).

According to DMPI3, overall drier periods occurred in 1976 and especially in 2003 when the drought continued until the beginning of the following year and lasted a total of 42 weeks. The other major episodes of drought ended in the autumn or at the end of the year.

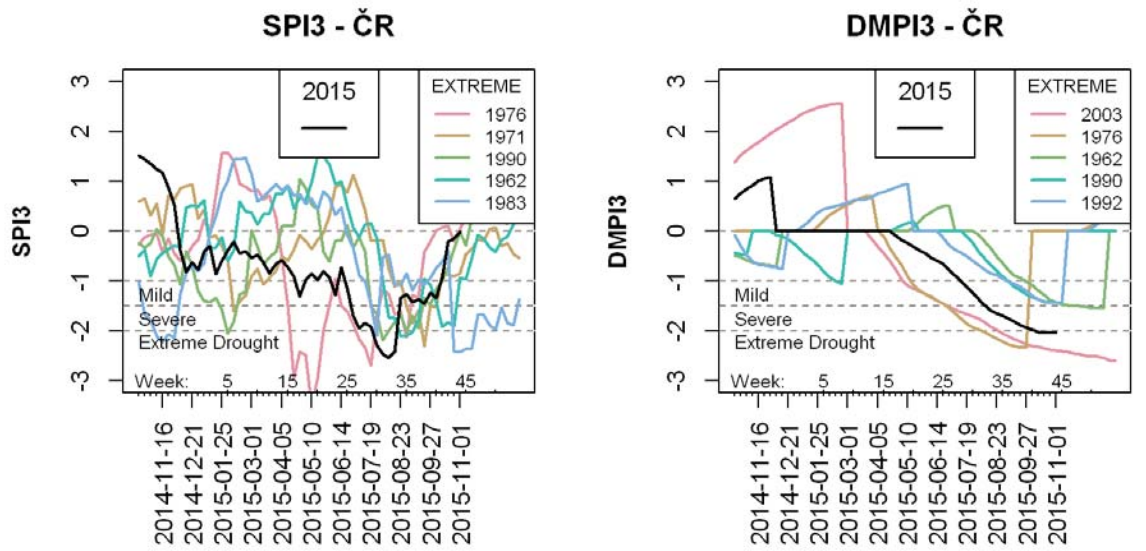


Figure 10.17. Evolution of 3-month precipitation totals in the Czech Republic according to SPI3 and DMPI3.

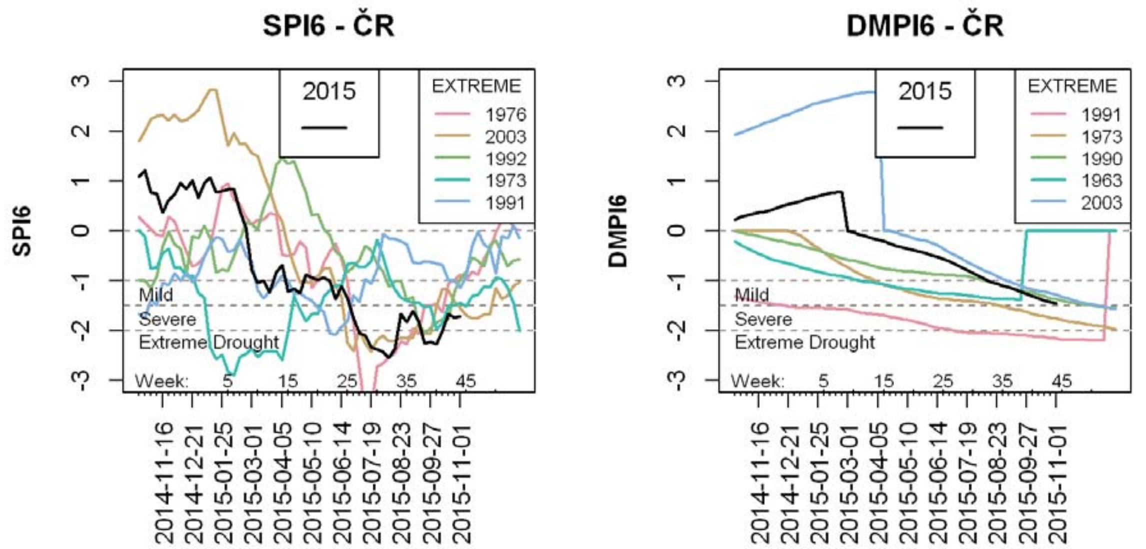


Figure 10.18. Evolution of 6-month precipitation totals in the Czech Republic according to SPI6 and DMPI6.

An evaluation using 6-month precipitation totals (SPI6, DMPI6) is shown in Fig. 10.18. The deficit started to accumulate in early March 2015, when the drought also began and continued up to late October, i.e. a total of 35 weeks with an overall deficit.

According to SPI6, the drought culminated in the 32nd week of the year as extraordinary with a precipitation total for the previous six months corresponding to 60% of the normal. In terms of actual and overall levels (S-type and DM-type indicators), similar extreme droughts also occurred, for example in 1976 and 2003. Those dry episodes ended as early as the following winter, from which it can be assumed that this could similarly occur in the case of 2015. Even though the 1991 and 1973 droughts were overall larger, their course was less intense.

Locally at the individual stations with monitoring capabilities available since 1900, the 2015 drought can be evaluated as one of the largest. In Čáslav it was the largest ever drought, and, by contrast, the drought in Brno was less pronounced and was classified as moderate to severe (Fig. 10.19.). The results are summarized in Table 10.2.

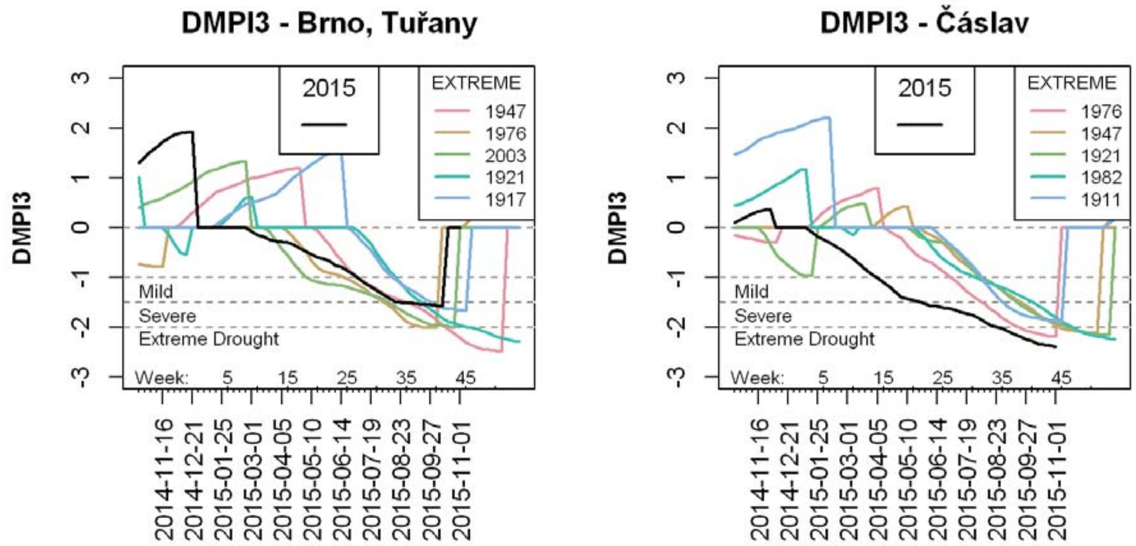


Figure 10.19. Evolution of 3-month precipitation totals according to DMPI3 in Čáslav and Brno.

As per SPI3, droughts were most frequently recorded in 1904, 1976, and moreover, in 1911, 1921 and 1947. In 1904 and 1976 in the period around the 2015 drought peak, i.e. around mid-August, the actual 3-month precipitation deficit was usually larger. From this perspective, those droughts were more severe than 2015 drought.

Tab. 10.2. Major droughts since 1900 according to SPI3 and DMPI3 in chronological order (no more than the 5 worst years). The droughts that were more severe than the 2015 drought are marked in bold. Much more severe droughts are underlined, and the other droughts are roughly comparable with the 2015 drought.

Station	SPI3	DMPI3
Klementinum	**1900**, **1904**, **1947**, **1976**, **1990**	1911, **1943**, 1976, 1990, 2003
Brno	**1904**, **1917**, **1921**, **1976**	1917, **1921**, **1947**, **1976**, **2003**
České Budějovice	**1904**, **1911**, 1923, **1947**	1904, **1911**, **1981**, 2003
Čáslav	**1904**, **1911**, **1976**, **1994**	1921, 1947, 1976, 1982
Opava	1904, 1921, 1992	1921, 1932, 2003

According to DMPI3, droughts were most frequently recorded in 1921, 1976 and 2003, and less frequently in 1911 and 1947. As of late October, the 2015 drought is fully comparable with the total precipitation deficits in those years. However, a number of drought episodes lasted until the end of the year or even continued into the following year. The 1947 drought in Brno and the 1911 drought in České Budějovice ended at the end of the year. It will be possible to close the comparison only after the 2015 drought episode has subsided at all the stations.

Discharges

When evaluating discharges, it is necessary to take into account the fact that a number of stations were influenced by water reservoir management, which significantly improved discharges in the periods of minima. Impacts of the 2015 drought on the Vltava River at Prague-Chuchle, the Ohře River at Louny, the Elbe River at Ústí and Labem, the Odra River at Bohumín and the Dyje River at Trávní Dvůr were therefore significantly weaker than those at the other evaluated stations. Due to the improvement of discharges through the reservoirs at the above-mentioned water gauging stations and in view of the lowest runoff reached, expressed as the SRI (Standardized Runoff Index), the drought can be evaluated at most as moderate (Fig. 10.20. on the right). The discharge of the Dyje River did not even reach the moderate drought level. It was only the last affected station on the Elbe River at Němčice that was hit by a severe or even extraordinary drought. According to the total deficit in discharges over the period of the drought, evaluated using the DMRI, there was a severe drought on the Vltava River and at both the monitored stations on the Elbe River. The Ohře and Dyje Rivers did not even reach any moderate drought (Fig. 10.21. on the right).

As per the lowest discharges measured at the relatively little-affected hydrometric stations, expressed as the SRI, the 2015 drought in Bohemia can be characterized as extraordinary. It was only on the Jizera River the drought was evaluated to be severe to extraordinary. The stations there recorded the lowest discharges since the beginning of their monitoring (Fig. 10.21. on the left). In Moravia, for the time being, it is possible to make an assessment based on the monitoring performed at only two stations. In North Moravia, an extraordinary drought was reached on the Odra River, where one of the lowest discharges during the observation period was measured. The minimum discharge values measured on the Morava River at the Kroměříž water gauging station can be described as a severe drought.

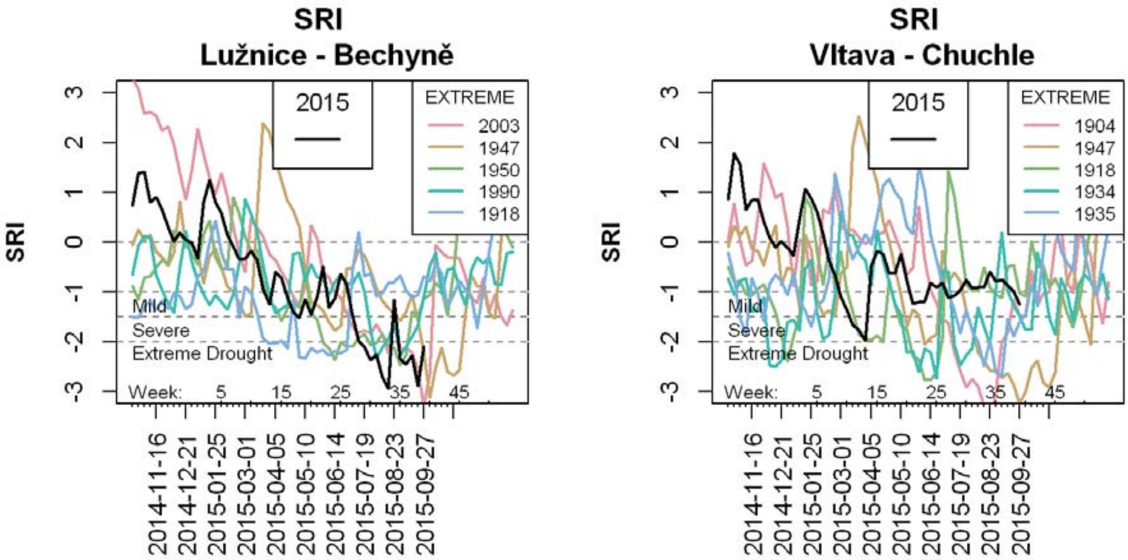


Figure 10.20. Comparison of droughts according to the total discharge deficit, evaluated using the SRI, at unaffected pristine station (on the left) and at a station with artificially increased discharge (on the right).

According to the total runoff volume deficit, evaluated using the DMRI, the Orlice, Jizera, Lužnice and Otava Rivers experienced an extraordinary drought (Fig. 10.21. on the left). The Berounka River experienced a severe or even extraordinary drought. On the Odra River, there was a severe drought. It is more difficult to perform an evaluation regarding the Sázava and Morava Rivers, because the drought was briefly interrupted by a runoff rise above normal in response to the rainfall in mid-August and was divided into two episodes. It can be concluded that, on the Sázava River, there was a severe or even extraordinary drought, and the Morava River experienced a severe drought (Fig. 10.21. on the left).

Results of the comparison of the 2015 drought with the droughts of previous years are summarized in Table 10.3. The beginning of observation is different at individual stations. Therefore, the major droughts that occurred in the first half of the 20th century, such as the 1904, 1911 and 1947 droughts, are represented in the table less frequently than would correspond to their significance or real extent, and, by contrast, it is also possible to find minor droughts that occurred later there. Taking into account this fact, it is possible to say that according to the SRI, the 1918, 1947 and 1950 droughts were recorded most frequently (5 occurrences per each year among 8 included stations), followed by the 1930 and 1952 droughts (3 occurrences per each year). The year 2003, with two occurrences, ranks among other similar years. According to the DMRI, droughts were most frequently recorded in 1947 (7 occurrences among 8 included stations), 1950 (5 occurrences), 1990 and 2003 (3 occurrences in each year).

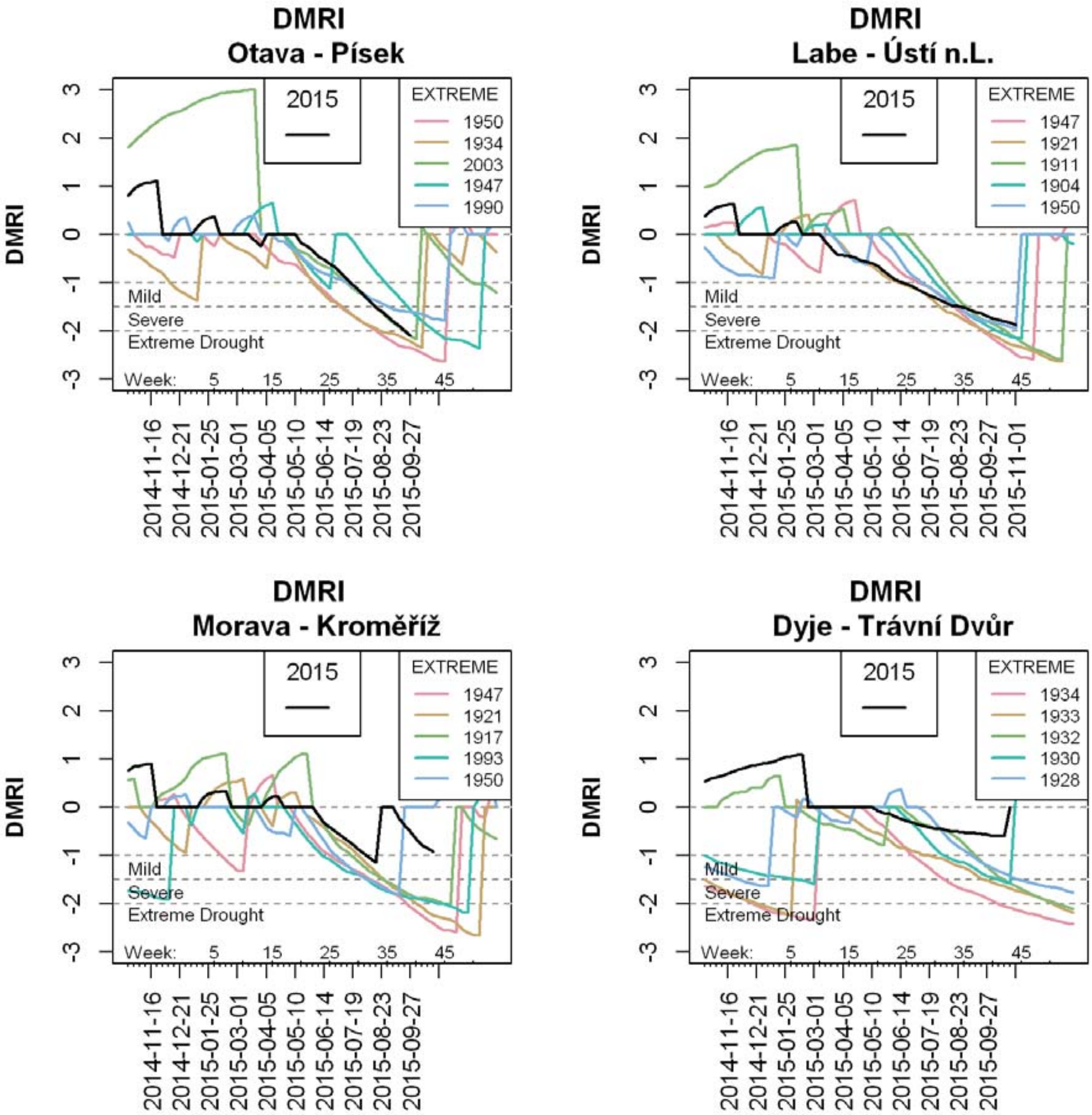


Figure 10.21. Comparison of droughts as per recorded discharges, expressed as the DRMI, at unaffected pristine station (on the left) and at a station with artificially increased discharge (on the right).

According to the SRI, the drought that particularly occurred on the Otava and Lužnice Rivers in 2015 ranks among the most significant drought episodes that their basins have experienced, including those in 1947 and 2003. The Orlice River discharge was even lower in 1921. The discharges of the Sázava, Berounka and Odra Rivers were lower in 1947, 1952 and 1947, respectively. However, in Bohemia and on the Odra River, the year 2015 ranks among the extreme years, and by contrast, a number of lower discharges were recorded on the Morava River.

In terms of the overall magnitude of the drought as per the DMRI, the Orlice and Jizera Rivers only experienced more severe droughts in 1921 and 1911, respectively. On the Lužnice River, the 2015 drought along with the 1950 drought were the most severe. The Otava River only experienced more severe droughts in 1950 and 1934, the Sázava River in 1947 and 1990, and the Berounka River in 1918 and 1964. The only worse year on the Odra River was 1947, and the worse years experienced by the Morava River particularly included 1921, 1947, 1917 and 1993.

Tab. 10.3. Major droughts (5 worst years at the maximum) according to SRI and DMRI in chronological order.

Stanice	SRI	DMRI
037000 – Orlice, Týniště n. O. (1911)	1918, **1921**, 1922, 1930, 1994	1918, **1921**, 1947
042000 – Labe, Němčice (1947)	**<u>1947</u>**, 1950, 1952, 1953, 1992	**<u>1947</u>**, 1950, **1953**
101800 – Jizera, Předměřice (1911)	**1911**, 1921, 1929, 1930, 1934	**<u>1911</u>**, 1947, 1929
133000 – Lužnice, Bechyně (1911)	1918, **1947**, 1950, 1990, **2003**	**1950**, 1947, 1990, 2003
151000 – Otava, Písek (1911)	1918, 1947, 1950, 2003	**1934**, 1947, **1950**, 2003
161000 – Sázava, Zruč n. S. (1944)	**1947**, 1950, 1952, 1991, 1994	**1947**, 1950,1976, **1990**
198000 – Berounka, Beroun (1951)	1918, **<u>1952</u>**, 1953, 1960, 1964	**1918**, 1960, **1964**, 1998
200100 – Vltava, Chuchle (1900)	**<u>1904</u>**, **<u>1918</u>**, **<u>1934</u>**, **<u>1935</u>**, **<u>1947</u>**	**<u>1904</u>**, **1911**, **<u>1947</u>**, **<u>1950</u>**, **<u>1964</u>**
219000 – Ohře, Louny (1922)	**<u>1934</u>**, **<u>1935</u>**, **<u>1947</u>**, **<u>1949</u>**, **<u>1964</u>**	**<u>1935</u>**, **<u>1947</u>**, **<u>1949</u>**, **<u>1964,2014</u>**
240000 – Labe, Ústí n.L. (1900)	**<u>1911</u>**, **<u>1918</u>**, **<u>1921</u>**, **<u>1934</u>**, **<u>1947</u>**	**1904**, **<u>1911</u>**, **<u>1921</u>**, **<u>1947</u>**, 1950
257000 – Odra, Svinov (1923)	1928, 1931, **1947**, 1950, 1952	1928, **<u>1947</u>**, 1950, 1951, 1992
294000 – Odra, Bohumín (1920)	1925, **<u>1928</u>**, **<u>1930</u>**, **1947**, **<u>1950</u>**	**<u>1921</u>**, 1928, **1950**, **<u>1951</u>**, **<u>1992</u>**
403000 – Morava, Kroměříž (1916)	**<u>1918</u>**, **<u>1922</u>**, **<u>1930</u>**, **<u>1947</u>**, **<u>1950</u>**	**1917**, **<u>1921</u>**, **<u>1947</u>**, 1950, **1993**
437000 – Dyje, Trávní Dvůr (1926)	**<u>1927</u>**, **<u>1928</u>**, **<u>1929</u>**, **<u>1932</u>**, **<u>1934</u>**	**<u>1928</u>**, **<u>1930</u>**, **<u>1932</u>**, **<u>1933</u>**, **<u>1934</u>**

Note: The droughts that were larger than the 2015 drought are marked in bold. The droughts that were much larger than the 2015 drought are underlined, and the other droughts are roughly comparable with the 2015 drought. The stations highlighted in gray are significantly influenced by water reservoir management. The beginning of the monitoring period is specified in brackets. In Beroun, measurements were also performed for a short period from 1912 to 1920.

In terms of the total runoff deficit, the year 2015 in Bohemia and on the Odra River therefore ranks among the worst years ever. A number of larger or similar episodes were recorded on the Morava River in the past. It is interesting that the course of the 2015 drought on the Jizera River was very similar to that of 1947, on the Otava River to that of 2003, and on Odra River to those of 1928 and 1992.

Groundwater

According to the levels of shallow boreholes within the reporting network in terms of the actual state (as per the SGI – Standardized Groundwater Index), i.e. according to the lowest recorded levels related to the seasonal normal, the year 2015 has been one of the driest years since 1961 (Fig. 10.22.). The drought began in early April and continued even in late October. It culminated in the 33rd week of the year, i.e. in mid-August, when an extraordinary level of drought was recorded. Similar low groundwater levels in the same period of the year were particularly measured in 1973, 1983, 1990, 1992 and 1993. Since that time, the groundwater levels have practically remained the same, but due to the fact that the indicator takes into account the seasonality, and the minimum groundwater level data in September are generally lower than in August, the SGI slightly rose to the level of a severe drought in September. The rise in groundwater levels following the rainfall in mid-August is also obviously discernible.

However, in terms of the overall state (expressed as the DMGI – Drought Magnitude Groundwater Index), there were drought periods in the past that were more significant than those in 2015, more specifically, in 1973, 1992 and 1993. From their continuation in winter, it is possible to deduce that the 2015 drought regarding groundwater will most likely continue into the winter. This drought can only be stopped by significantly above-normal precipitation totals during at least one or two winter months or as a result of the melting of significant snow storages. For example, the 1992 and 1993 drought covered more years, and lasted from 1991 almost continuously until the end of 1993, which was also the case of the 1973 drought, which continued into 1974. A drought similar to that of 2015 occurred in 1964. Even though the 1976 drought was smaller than the 2015 drought, its course, especially in the beginning, was very similar.

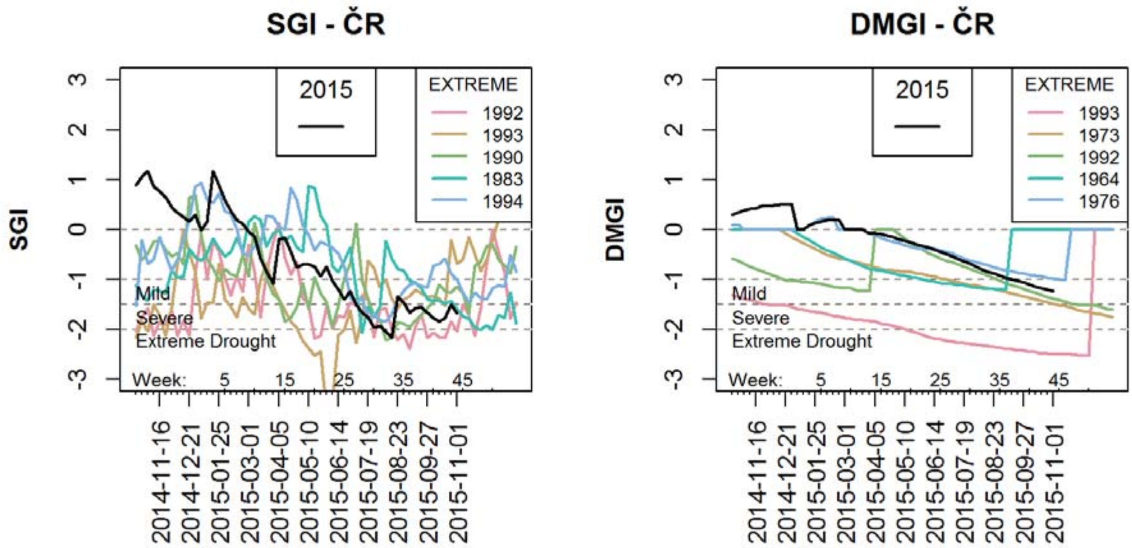


Figure 10.22. Evolution of average weekly levels in shallow boreholes in the Czech Republic according to the SGI and the DMGI.

10.3. Evaluation of Runoff Using Deficit Volumes

The minimum specific runoff data in 2015 for the hydrometric stations evaluated in Chapter 10.2. are set out in Fig. 10.23. The smallest specific runoff was measured on the Lužnice River and at Svinov on the Odra River, and the largest runoff was measured on the Jizera River.

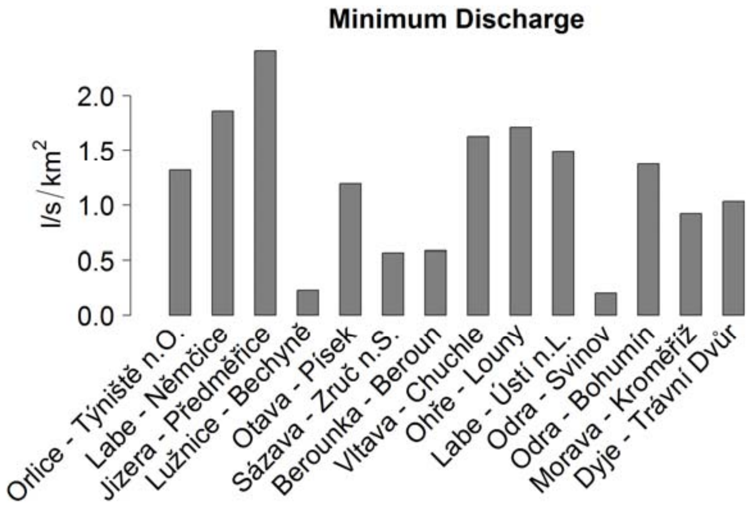


Figure 10.23. Minimum specific runoff at hydrometric stations in 2015.

These stations were also evaluated using the method of deficit volumes and were found to be below the Q_{80} annual limit (i.e. the average daily discharge with an exceedance probability of 80%). An example of the evaluation of the 2015 drought in comparison with 2003 is presented in Fig. 10.24.

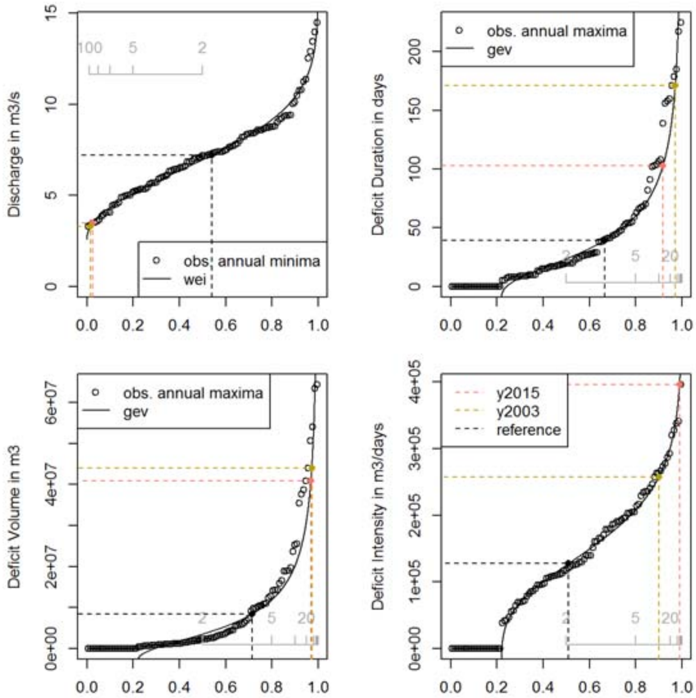


Figure 10.24. Evaluation of the 2015 drought on the Otava River at Písek in comparison with 2013. From the left: minimum discharge, duration, deficit volume magnitude and intensity.

The shortest drought was that on the Dyje River at Trávní Dvůr (43 days), and the longest droughts were those on the Orlice River, the Elbe River at Němčice and Ústí nad Labem, and the Lužnice River at Bechyně (155 to 160 days). The drought on the Vltava River at Prague-Chuchle, the Berounka River, and the Morava River at Kroměříž (130 to 145 days) also lasted a relatively long time. Droughts at the other stations were shorter.

The deficit volumes at the individual stations cannot be compared, because it depends on the specific runoff, which is usually larger in catchment areas with higher precipitation totals. The magnitude of the deficit volumes is therefore expressed through their recurrence interval (Fig. 10.25.). From this perspective, the largest droughts appear to be those on the Lužnice, Orlice and Otava Rivers with recurrence intervals of 41, 36 and 32 years, respectively. The shortest recurrence intervals for uninfluenced stations were found on the Sázava River (15 years) and the Morava River at Kroměříž (15 years). As for the stations influenced by improved runoff, the shortest recurrence intervals were determined on the Dyje River (3 years) and the Ohře River (6 years). On the Vltava River at Prague-Chuchle and the Elbe River at Ústí nad Labem, the improved runoff resulted in reduced recurrence intervals of only 10 and 12 years, respectively.

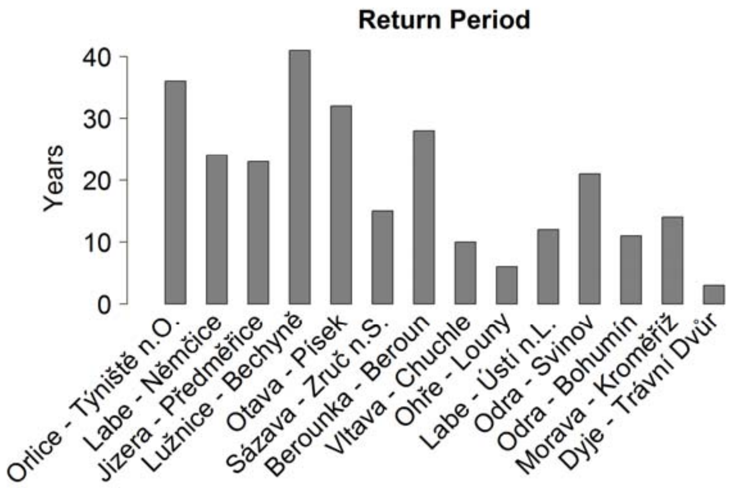


Figure 10.25. Recurrence intervals of deficit volumes at hydrometric stations in 2015.

11. Drought Impact on Water Quality

Of course, the drought as a hydrological extreme also affects the water quality and aquatic flora and fauna. The minimum discharges may adversely affect the survival of aquatic organisms due to insufficient oxygenation of water, weakened dilution of discharged polluted water, and complete drying out of some localities. On the other hand, (i) the leaching of substances from the soil and (ii) overall soil loss by water erosion in the form of suspended solids are reduced.

It will be possible to evaluate impacts on water quality only during 2016. This evaluation will be based on data from the operational monitoring of surface water quality performed by the River Basin Companies (Povodí state enterprises). This evaluation will be performed after obtaining laboratory analyses of samples of the Czech Hydrometeorological Institute's solid matrices monitoring.

The currently known manifestations of drought in surface waters thus particularly consist in the forced shutdown of automatic suspended load samplers due to declining water levels of monitored streams, which disable sampling by devices installed in the stream. Last but not least, this also includes the possible impacts on individual samples of suspended load as a result of a possible sediment re-suspension when taking samples at profiles with very low water levels, and thus also an overestimation of the concentration of suspended load in such samples taken. In the monitored period, a total of 286 samples of suspended sediments taken at 7 stations were evidently affected due to the low water stage, and probable impacts were assessed at 10 stations. It will be possible to quantify the total number of affected samples only after the hydrological data have been verified.

12. Conclusion

When this report was completed, the drought, particularly that of groundwater, was still continuing. However, the precipitation that occurred in most of the Czech Republic in October corresponded to normal values and ended the drought at surface soil layers and mostly also the drought of surface streams. The future course of the agricultural and hydrological droughts will depend on the development of precipitation, the nature of the upcoming winter, the snowmelt amount and its course. Therefore, the results presented in this report cannot be considered final. In 2016 the Czech Hydrometeorological Institute will update this report based on verified data for the entire year of 2015 after the data on groundwater produced from the 2016 spring thaw have been added.

For the 2015 hydrological year (i.e. from November 2014 to October 2015), the rainfall only amounted to 500 mm in the Czech Republic, which together with the 1973 hydrological year has been the smallest value for the last 55 years under evaluation. In addition, in Bohemia this was preceded by the 2014 hydrological year with below-average precipitation. Therefore, the precipitation deficit has now been increasing in Bohemia for two years and has reached 220 mm. The 2014 hydrological year deficit in Moravia was made up in the second half of 2014, but the precipitation deficit was increasing again during 2015. and at the end of October 2015 the precipitation deficit in Moravia was approximately only 50 mm less than that in Bohemia. The differing patterns of precipitation in Bohemia and Moravia are shown in Fig. 12.1.

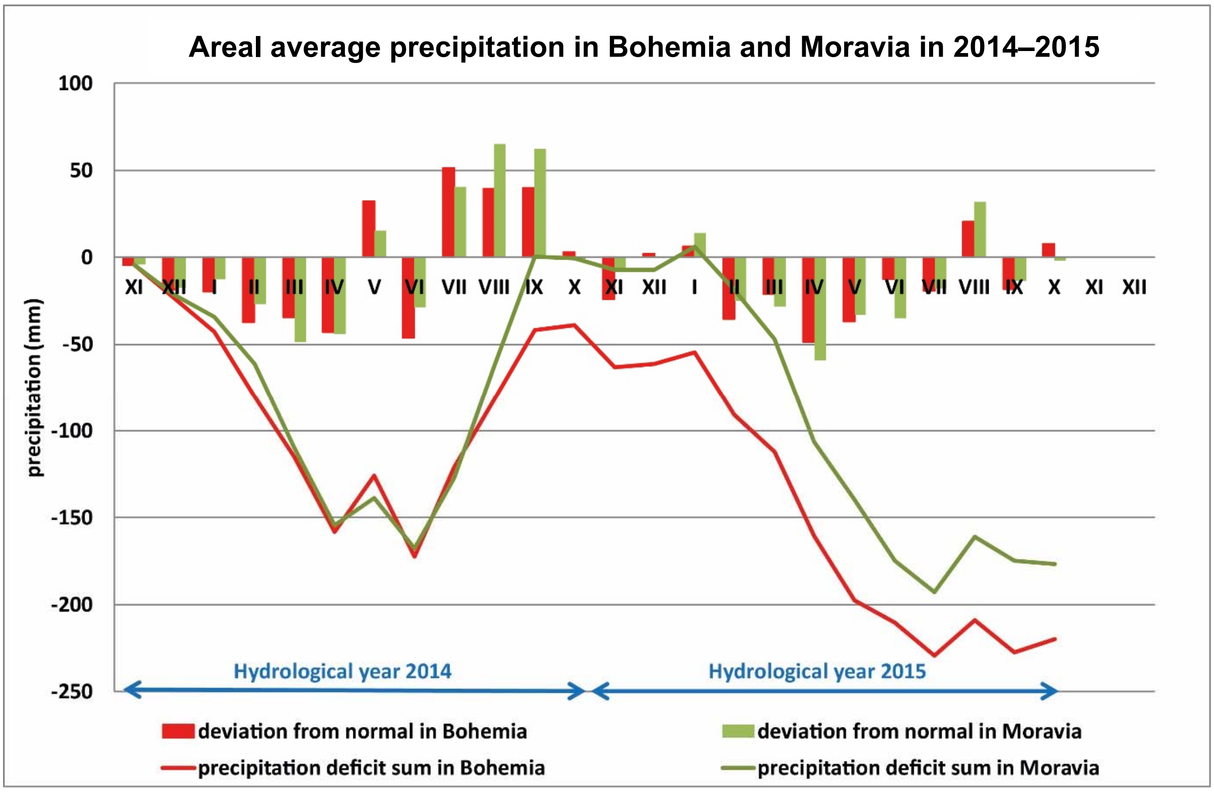


Figure 12.1. Comparison of monthly precipitation in the 2014 and 2015 hydrological years with the long-term averages for the reference period from 1961 to 2010.

It is very difficult to estimate the future course of precipitation. The seasonal prediction of precipitation using climate model outputs has recently significantly developed, but the accuracy of such outputs remains limited. The models only provide relatively more reliable predictions in areas where there are large atmospheric or oceanic circulation phenomena, such as the El Niño – Southern Oscillation (ENSO). However, Central Europe ranks among the areas with weak manifestations of such phenomena, whose links with regional climate variability are still poorly understood. Therefore, the ability of climate models to predict seasonal weather patterns in Central Europe is very limited. Moreover, the currently available outputs of models produced in foreign forecasting centers do not provide any robust signal for the precipitation amount in the Czech Republic for the period from December 2015 to February 2016.

There is a real possibility of multi-year drought development, which has already occurred several times since 1961. The most significant cases of multi-year below-normal precipitation periods occurred in Bohemia in 1961–1964, 1971–1973, 1982–1985 and in particular, from 1989 to 1992 with a total precipitation deficit of 365 mm. In Moravia this mainly includes the years 1971–1973, 1982–1984, and the longest period from 1988 to 1994 with a total deficit of 513 mm.

It is not possible to mathematically express the probability of occurrence of similar multi-year drought periods using the climate models. A statistical analysis of the time series of areal precipitation totals for 1961–2015 does not provide any results that could be used for predicting the evolution of the next year's precipitation.

More consecutive drought years may primarily be reflected in the hydrological consequences. In particular, they may result in a decline in groundwater reserves, which is usually expressed through the magnitude of basic runoff, or may be significant in terms of water reservoir operations.

Recommendations

This report only deals with the meteorological and hydrological aspects of drought. It does not have any ambitions for a comprehensive evaluation of its progress or effects on society and its economic activities or for any proposals for measures to mitigate its consequences. Nevertheless, the completed evaluation has provided the following recommendations for monitoring and evaluating the drought's causes and manifestations:

– First off, we can say that it is very difficult to evaluate the magnitude of drought, in particular, in terms of its complex manifestations. Another reason is the lack of sufficient quantitative information about historical episodes of drought that would allow performing a more detailed statistical evaluation of this extreme phenomenon.

– **It is therefore necessary to maintain the monitoring of hydrological and climatological elements at such a level that provides the longest and most homogenous time series of atmospheric precipitation, air temperature, snow water equivalents, discharges, groundwater stages and other variables necessary for a continuous evaluation of drought conditions, as well as for drought evaluation in a historical context.**

– At the same time, it is appropriate to focus on finding and evaluating relevant information from historical drought episodes that would allow understanding the various aspects and manifestations of an extreme drought.

– At some hydrometric stations, the measurement was interrupted when the water stage significantly dropped. It will be necessary to consider technical modifications on those stations so as to ensure their functionality even in the case of extreme low water stages.

– In accordance with Czech Government Resolution No. 620 of 29 July 2015, it is necessary to select appropriate identifiers that would be used for a representative assessment of the level of drought in its individual aspects.

– Due to the variety of information and data describing various aspects of drought, it is appropriate to introduce a comprehensive and user-friendly presentation of information on the progress of drought in one place (portal).

– In view of the need for further research and development, it is necessary to focus on the existing opportunities and development of seasonal predictions of climatic and hydrological elements and their rapid application to the Czech Hydrometeorological Institute's operations.

Technical Appendix

Technical Appendix to Chapter 4

Evaporation, Evapotranspiration and Moisture Balance Evaluation Methods

The agro-climatic characteristics represent modeled and not measured data. The AVISO Model and the basic meteorological data of 198 / 268 climatological stations (operational processing for the year 2015 / long-term data processing for the period from 1981 to 2010, respectively) were us ed for the evaluation.

Due to the fact that these are special elements, their characteristics are briefly described.

Evaporation from water surface is measured at 22 sites within the network of the Czech Hydrometeorological Institute's monitoring stations in the Czech Republic. The original manual measurement, using GGI-3000 devices and initiated in 1968, has been gradually replaced with automated EWM measuring instruments since 2000. Periodic measurements generally take place in frostless periods.

Potential evaporation from bare soil, or potential evapotranspiration from grassland represents the total water amount in millimeters that can evaporate from the subsoil, i.e. from bare soil (evaporation from bare soil) or from soil with grass (evapotranspiration from grassland consisting of evaporation from soil and plant transpiration) at the current optimal water saturation of the soil profile and under specific climatic conditions. In practice, this means that its values are influenced by the course and variability of basic meteorological elements (air temperature and humidity in the form of water vapor pressure, sunshine, wind velocity, and indirect precipitation), by means of which calculations are made in the day interval, and not by moisture conditions at the upper soil layers which are assumed to be optimal and stable during the evapotranspiration or transpiration processes. The daily model calculation is based on the modified algorithm in accordance with the generally accepted Penman-Monteith methodology.

Actual evaporation from bare soil, or actual evapotranspiration from grassland represents the total water amount in millimeters that evaporates in actual natural conditions from the subsoil, i.e. from bare soil (evaporation from bare soil) or from soil with grass (evapotranspiration from grassland consisting of evaporation from soil and plant transpiration). Within this meaning, the actual natural conditions are understood to be, besides the specific climatic conditions influencing the evaporation, the actual moisture conditions in the upper soil profile. However, in practice, there may be a limiting case when the climatic conditions indicate maximum evaporation, but the actual evaporation or actual evapotranspiration is lower due to the moisture deficit in the soil; in other words, in the natural environment, there is a lack of soil moisture available for any evaporation to occur.

The model calculation of actual values in the day interval results from the interaction between the actual condition of the given evaporating surface (bare soil, grassland) and the moisture balance of the soil profile to the minimum depth (bare soil) or to the depth of active rooting (grassland). The actual condition of the evaporating surface is understood to be the modelled characteristics (grass height, active rooting depth, leaf area index, etc.) based on daily data about the course of weather at a particular location. In the AVISO Model calculations, the soil profile is represented by a bilayer model of water circulation at the soil profile, and the moisture conditions at both of the layers are continuously evaluated in the day interval.

The actual soil moisture along with the actual condition of the evaporating surface (bare soil, grassland) is of crucial importance for the calculated values of actual evapotranspiration.

The moisture balance of grassland, expressed in millimeters, is an appropriate parameter to specify the possible climatic drought. This is the mutual difference between the precipitation and potential evapotranspiration from grassland (basic moisture balance of grassland) or between the precipitation and actual evapotranspiration from grassland (actual moisture balance of grassland). In the former case, this is in essence a climate balance, where the determining factors are only the measured meteorological elements without considering subsoil impacts. In the latter case, besides the meteorological measurement, it also includes the actual moisture condition of the soil horizon, which plays a significant role.

Technical Appendix to Chapter 6

Snow Measurement and Evaluation of Water Reserves in Snow Cover by the Czech Hydrometeorological Institute

Selected stations of the Czech Hydrometeorological Institute monitor three standard parameters of snow cover:

- Depth of newly-fallen snow (new snow) – SNO
- Overall depth of snow cover (old and new snow combined) – SCE (Snow Cover Extent)
- Water equivalent of overall snow cover – SWE (Snow Water Equivalent)

The depth of newly-fallen snow (SNO) is considered to be a layer of snow that fell from 07:00 a.m. of the previous day to 07:00 of the measurement day. The depth of newly-fallen snow is measured by a snow measuring plate of a size of 30×30 cm and a ruler whose zero touches the plate during measurement. The depth of newly-fallen snow is measured at a location undisturbed by wind. The plate cleaned from snow is placed on a snow cover and lightly pressed, so that its upper surface is at the same level as the snow cover. Or, if there is no continuous snow cover at the station, then the plate is placed directly on the soil. After each measurement, snow is removed from the plate.

The overall depth of snow cover (SCE) is measured using snow stakes (fixed and portable). A fixed snow stake should be installed at a location where the snow cover is not very affected by wind. The overall depth of snow cover is also measured every day from 07:00 a.m., provided that there is continuous snow cover. The depth of discontinuous snow cover is not measured. A portable snow stake is used to measure the snow cover at several locations (at least three) that are not affected by wind. The average of such measurements is the final figure. Both the depth of newly-fallen snow and the overall depth of snow cover are measured in whole centimeters, and snow cover of a depth of less than 0.5cm is referred to as a sprinkling of snow.

The snow water equivalent (SWE) means the amount of water contained in and created by a complete melting of the snow cover and is expressed in millimeters of the water column. A precipitation gauge vessel and a measuring glass or a snow gauge are used for measuring the snow water equivalent. The snow water equivalent is measured if there is continuous snow cover of a depth of no less than 4cm at 07:00 a.m. on Mondays. The snow water equivalent for discontinuous snow covers is not measured. If the snow water equivalent is measured using a precipitation gauge vessel, then the whole snow layer is taken at an undisturbed location to be subsequently melted, and the water from the melted snow is measured using a measuring glass.

When using a snow gauge for measurement, a sampling cylinder is inserted into the snow layer, and the snow cover depth is then read. The sampling cylinder is then pulled up with the entire column of snow and weighed. For a known diameter of the cylinder, the snow water equivalent is calculated. Measurements are to be performed at least at 3 different locations, and the resulting snow water equivalent value is the arithmetic average of all measurements.

Snow Gauging Station Types

The stations that measure input data (snow cover extent and snow water equivalent) for evaluating snow reserves in the Czech Hydrometeorological Institute can be divided into several main groups. The first, most important group deals with data obtained from snow cover extent and snow water equivalent measurements performed regularly at climatological and precipitation gauging stations (from a total of approximately 720 stations). This group is further divided into the first sub-group consisting of approximately 370 operational stations whose data are immediately available in the database for operational use during Monday's measurement day. Data from the other stations are recorded in the station's monthly reports, and these values are not available until the beginning of the next month.

Another set of input data includes data from profile measurements at selected climatological and precipitation gauging stations (approximately 20 sites) and from regular profile measurements performed by the Department of Applied Hydrology in the Jizerské Mountains and the western area of the Giant Mountains (Krkonoše), (40 sites). The "profile measurements" are more detailed field measurements of the snow cover extent and snow water equivalent. The measurement is performed at 10 points of each profile, of which the water value is measured at the outer and middle points, and the snow depth is only measured at 7 intermediate points. The snow depth at the profile is determined as the arithmetic average of 10 measured depths. The water value at each of the 3 points is used to calculate the water density (the quotient of water value and depth). The average density is calculated as the arithmetic average of these 3 densities. The snow water equivalent at the profile is then the product of the average depth and average density. The snow depth is specified in centimeters, the water value in millimeters, and the density is a dimensionless number (ranging from about 0.05 for powder snow to 0.6 for firn).

The third group includes expeditionary measurements of profiles, which are focused on the periods of maximum snow water equivalent values or periods of exceptional situations or periods before expected intense snow melting. Such measurements are mostly performed at locations where the Czech Hydrometeorological Institute's station network is underdeveloped (mainly in highlands and mountains).

The last group of input data consists of data from 15 automatic snow gauging stations (as of 2015). These are termed "cushions", and they are located in all major mountains and highlands of the Czech Republic. The elevation of those stations ranges from 650 to 1,060m above sea level. The stations used in the Czech Hydrometeorological Institute's network operate on the principle of a cushion filled with glycol and water, where hydrostatic pressure is sensed, and if loaded, it is increased by the snow cover weight. The cushion has the dimensions of a measuring surface of 7 to 9m^2. An ultrasound scanner is mostly used for measuring the snow depth at the stations, and, in exceptional cases, a laser scanner is used for such purposes. From the obtained snow water equivalent and snow cover extent values, it is possible to calculate the snow density, which is used for checking the data measured by the observers in a given area.

Figure P.1. Automatic snow gauging station at Javoří Pila, Šumava Mountains.

Evaluation of Water Reserves in Snow Cover

Before using the input data of snow cover extent and snow water equivalent for the calculation of water reserves, all such data are checked and possibly corrected and supplemented.

The Czech Hydrometeorological Institute regularly evaluates water reserves in the snow cover on a weekly basis from 1 November to 30 April of the following year.

The current reserves evaluation methodology processes data from the snow gauging stations in the GIS environment for the entire Czech Republic. The interpolation of measured data is performed using the Clidata DEM method, which is based on the "linear local regression" with preserved values from the gauging stations. This approach allows the snow reserves to be calculated for any (catchment) area. An important factor for the accurate areal interpolation of snow water equivalent point values is the determination of height of the zero isohione (i.e. zero snow line), which is considerably different in different regions of the Czech Republic during the winter season. It is estimated on the basis of data obtained from ground-based observations and satellite observations of Earth.

The outputs of the evaluation of water reserves in the snow cover are as follows:

- Weekly report with information on water reserves in the snow cover in the Czech Republic, including an expected evolution in the following week,
- Grid map of the Czech Republic with interpolated snow water equivalent data,
- Tables of water reserves in 135 selected catchment areas, regions and elevational ranges,
- Database of historical evaluations of water reserves in the snow cover since 1970.

Technical Appendix to Chapter 10

Drought Indicator Calculation Methodology

Indicators derived from the Standardized Precipitation Index (**SPI**) (McKee et al., 1993) were used for evaluating the drought magnitude. The SPI was originally based on the monitoring of precipitation totals (McKee et al., 1993). The indicator compares the precipitation totals with their long-term normal typical for a relevant month. The indicator represents the transformation of the oblique distribution of probability of time series of precipitation totals into the standard normal distribution with the mean value equal to zero and the standard deviation equal to one, i.e. a z-distribution. The indicator values are classified into categories that determine the period character (Fig. P.1.).

In terms of a more general use of the SPI concept, it is important that the procedure used for determining the SPI can also be used for describing other variables, such as the discharge amount in surface streams or the fluctuation of groundwater reserves. These types of indices are designated as the **SRI** (Standardized Runoff Index) and **SGI** (Standardized Groundwater Index), respectively. For example, the SRI was used by Shukla and Wood (2008) for evaluating modelled runoff series. These indices are supplemented with the **SPEI** (Standardized Precipitation Evapotranspiration Index), which represents a modification to the SPI with the correction of precipitation data for losses due to evapotranspiration. This indicator appears to be more appropriate for evaluating the actual available precipitation amount and thus also for characterizing the drought in terms of requirements (Vicente-Serrano et al., 2010). This group of indicators (**S**-type) allows expressing the extremity of the actual magnitude of a given variable in the context of the accruals and deferrals used (data time scale).

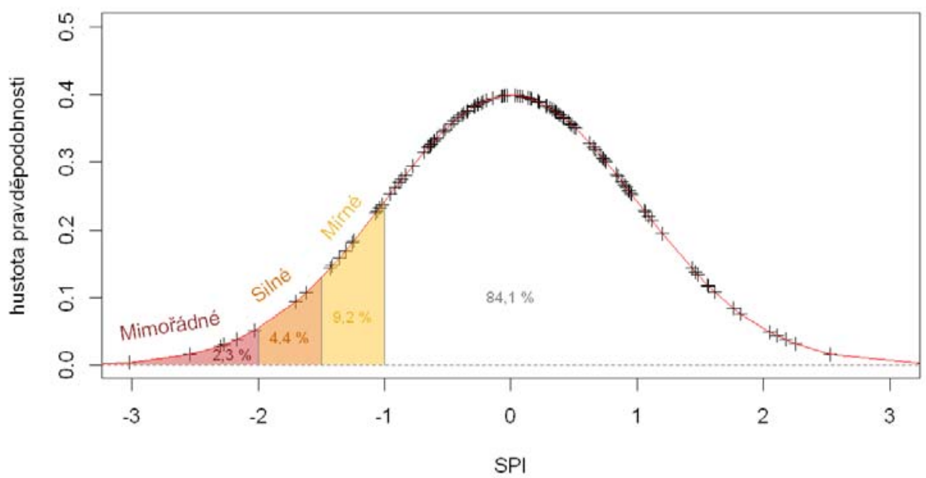


Figure P.2. Drought classification according to the SPI (moderate, severe and extraordinary drought). The probability of occurrence of a relevant drought category is expressed as a percentage.

The introduced integration of the **S**-type indicator in time and the subsequent conversion of such values into the z-distribution are an extension of the SPI concept. To some extent, this is an analogy to the determination of deficit volumes of surface water. This approach not only expresses the drought magnitude in an actual time step, but also during the entire drought episode. This group of indicators (**DM** – Drought Magnitude-type) allows expressing an overall progress in the evolution of a variable throughout the drought. The indicators are evaluated on a weekly basis. Details of their determination are specified by Vlnas et al. (2015).

Using the above-mentioned indicators, the course of the 2015 drought was evaluated in terms of precipitation, runoff and groundwater. The precipitation totals were evaluated in individual weeks as the average of totals from selected stations for the entire Czech Republic and 6 individual stations with long monitoring series since 1900 (Prague-Klementinum, Brno, České Budějovice, Čáslav and Opava) for the running 1-month (SPI1, DMPI1), 3-month (SPI3, DMPI3) and 6-month totals (SPI6, DMPI6). The time series of precipitation totals for the Czech Republic starts with the year 1961 and ends with October 2015. The series of individual stations start with the year 1900 and end with October 2015.

The course of the drought of surface water was evaluated in individual weeks for 14 selected hydrometric stations on the Elbe, Vltava, Lužnice, Otava, Sázava, Berounka, Jizera, Ohře, Odra, Morava and Dyje Rivers. The time series mostly start at the beginning of the 20th century, when the stations were built, and end in September or October 2015.

The groundwater stage was evaluated for the entire Czech Republic as the average level of all shallow boreholes within the reporting network (180 monitors). The time series of the monitors start no sooner than 1961 or later, when the boreholes were constructed, and end in October 2015.

The criterion for comparing the 2015 drought magnitude with the magnitudes of other years' droughts was the sum of values of a respective indicator for the period of 8 weeks before and 8 weeks after the peak of the drought episode. The drought episodes (5 worst years) culminating in the same 12-week period are compared, and the droughts culminating in any other period of the year are not included. The reason for such a selection consists in the compatibility with the precipitation analyses presented at the beginning and end of this report. Another reason is the fact that the indicators take into account the seasonality, and therefore, for this purpose, it does not make sense to compare a drought culminating for example in autumn with low rainfalls with a drought occurring in winter with different normal characteristics.

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