International Commission for the Hydrology of the Rhine basin (CHR)

Annual CHR Report 2019

Editors: Eric Sprokkereef — Rijkswaterstaat, VWM, Lelystad

Photo title page: ***Low water at Lobith (border Germany-Netherlands)***

CHR
KHR

Contributions:
Federal Office for the Environment, Department of Hydrology, Bern
MeteoSwiss, Zurich
WSL — Institute for Snow and Avalanche Research, Birmensdorf and Davos
Institute of Geography, University of Fribourg
Research Institute for Hydraulic Engineering, Hydrology and Glaciology (VAW)
Swiss Federal Institute of Technology Zurich (ETH), Zurich
Federal Institute of Hydrology, Koblenz
German Weather Service, Offenbach
Office of the Vorarlberg State Government, Bregenz
Central Institute for Meteorology and Geo-Dynamics, Vienna
Rijkswaterstaat, Transport and Water Management, Lelystad
Royal Dutch Meteorological Institute, De Bilt

Secretariat of the CHR
P.O. Box 2232
3500 GE Utrecht
The Netherlands
Email: info@chr-khr.org

Website: www.chr-khr.org

International Commission for the Hydrology of the Rhine Basin

The International Commission for the Hydrology of the Rhine Basin (CHR) works within the framework of the International Hydrological Programme (IHP) of UNESCO and the Hydrology and Water Resources Programme (HWRP) of the World Meteorological Organization (WMO). It is a permanent, independent, international commission and has the status of a foundation, registered in the Netherlands. Members of the commission include following scientific and operational hydrological institutions of the Rhine basin:

- Federal Ministry of Agriculture, Regions and Tourism, Section I — Water Management — Division I/3 Water Management (HZB), Vienna, Austria,
- Office of the Vorarlberg State Government, Department VIID — Water Management, Bregenz, Austria,
- Federal Office for the Environment, Bern, Switzerland,
- INRAE, Antony, France
- Université Gustave Eiffel, Nantes, France
- Federal Institute of Hydrology, Koblenz, Germany,
- Hessian State Office for Nature Conservation, Environment and Geology, Department W3 “Hydrology, Flood Protection”, Wiesbaden, Germany,
- International Centre for Water Resources and Global Change, Federal Institute of Hydrology, Koblenz, Germany
- Water Management Specialist Administration, Luxembourg,
- Deltares (an independent institute for applied research), Delft, Netherlands,
- Rijkswaterstaat — Transport and Water Management, Lelystad, Netherlands.

1. Hydrological Overview for The Rhine Catchment Area

Meteorological characteristics

Austria, Source: Central Institute for Meteorology and Geodynamics (CIMG)
As in the previous year, 2019 was also extremely warm in Austria. In terms of area average, the air temperature in the lowlands was 1.6 °C above the climatological average measured from 1981-2010, which means that 2019 was the third-warmest year in Austria in the low-lands.

The temperatures which contributed to this result were mainly those measured in June 2019. With a deviation of +4.7 °C, it was the warmest June since temperature measurement was recorded in Austria. Other major contributions to the high temperatures took place in February (dev. +2.3 °C), March (+2.3 °C), November (+2.1 °C), and December (+3.0 °C). January 2019 was the coldest in the high alpine regions since 1987, with a deviation of -3.5 °C. With an anomaly of -2.5 °C, May was the coldest May since 1991. January and May were the only months that had below-average temperatures in 2019.

In Lower Austria, Vienna, Burgenland, and southern and eastern Styria, 2019 was 1.8 to 2.3 °C warmer than the average temperatures in 1981-2010. In the Vorarlberg, in parts of Tyrol, Upper Austria, Salzburg, Carinthia, and Upper Styria, the average deviations were between +1.2 and +1.8 °C. In northern Tyrol, and south of the Inn, and in some places in East Tyrol, the temperatures were 0.9 to 1.2 °C warmer than the recorded average.

Just like 2015, 2017, and 2018, 2019 was decidedly sunny. As an area average, the sunshine duration was 6 percent longer than in an average year.

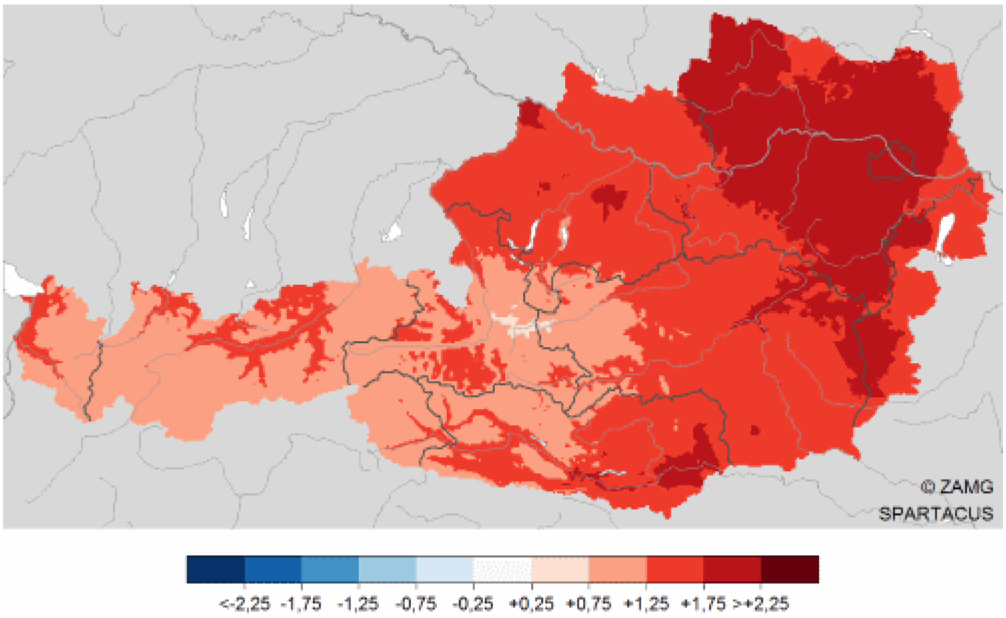

Figure 1: Temperature in Austria in 2019: Deviation of temperature from the multi-annual average/s of 1981-2010. Source: ZAMG

Averaged over the entire national territory, precipitation conditions in Austria were in balance. However, there were significant differences in the usual rainfall distribution within the national territory. From Vorarlberg to Upper Styria, as well as in East Tyrol and Carinthia, precipitation was between 5 to 25 percent more than in an average year. In some places, the precipitation readings were in line with the averages. In Upper Carinthia and in some places in Eastern and Northern Tyrol, precipitation was up by up to 40 percent.

February (apart from the south and southwest), March, April were dry months, as were all three summer months. With an Austria-wide deficit of -56 percent, June was particularly remarkable. Relatively widespread rainfall occurred in January and May, which produced an average of 83 and 57 percent more rainfall respectively. November 2019 saw enormous amounts of rain and snow along and south of the main Alpine ridge, with the result that this month's precipitation levels significantly pushed up the precipitation balance for the south of the country.

In conjunction with the abundant precipitation, large amounts of snow on the Northside of the Alps and on the main ridge of the Alps in January were recorded, setting new records at some of the weather stations. For example, the ZAMG at the Reutte weather station (T, 850 m) registered the highest maximum total snow depth of 116 centimeters, the highest since recorded measurements commenced in 1937. New records were also set for the 15-day totals for fresh daily snowfall, such as Hochfilzen (T, 962 m) with a fresh-snow totals of 451 centimetres.

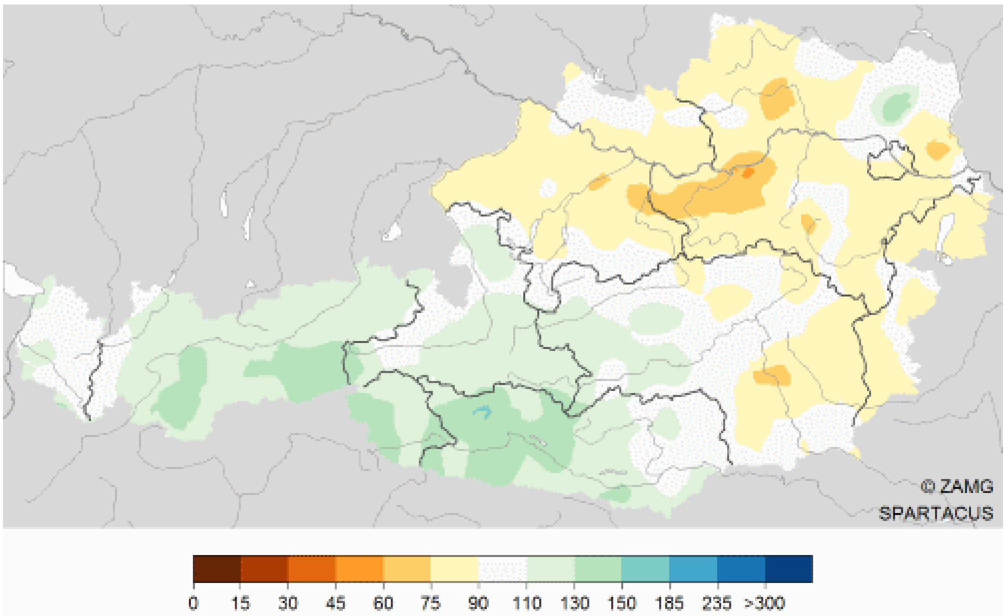

Figure 2: Precipitation in Austria in 2019: Deviation of precipitation from the multiannual average 1981-2010. Source: ZAMG

Meteorological characteristic for the Austrian Rhine region. Source: Hydrographic Service of the Vorarlberg

In 2019, the monthly precipitation levels for January, May and October were well above the average for those months. August and September recorded average rainfall, while the other months were well below average rainfall (Figure 3). The annual rainfall in the Austrian part of the Rhine catchment area amounted to 107% of the long-term average.

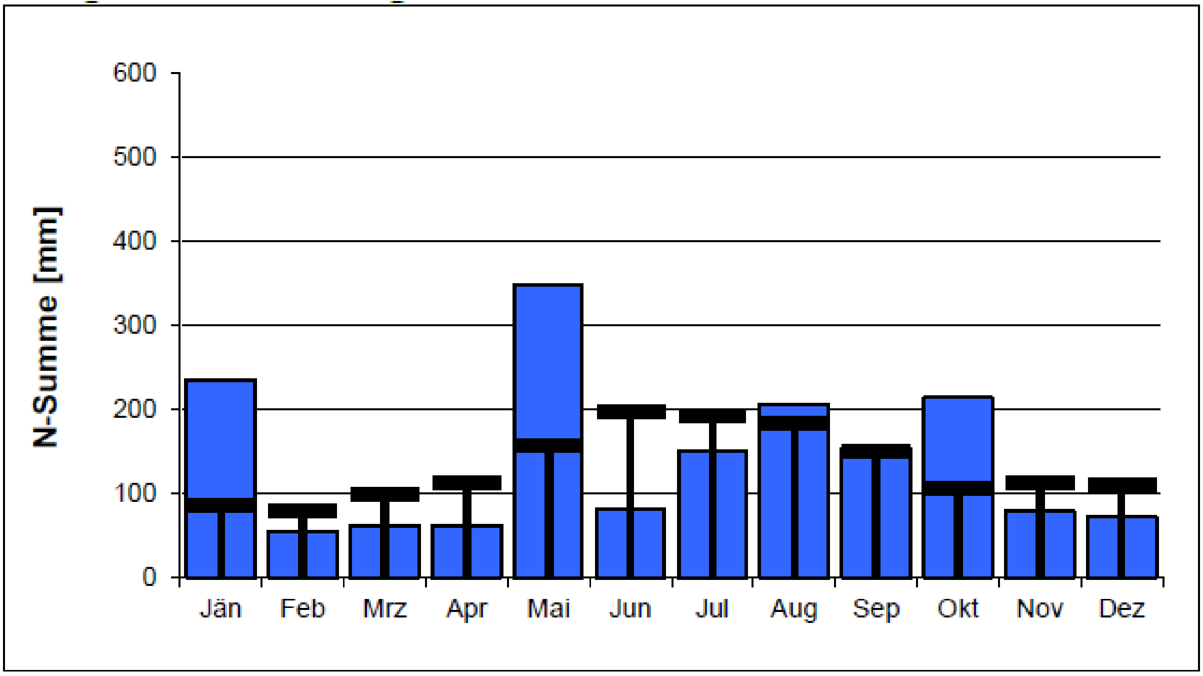

Figure 3: Monthly precipitation totals in 2019 (blue columns) compared to the long-term monthly average (1981 — 2010) at the Bregenz Altreuteweg measuring station

Switzerland, Source: Federal Office of Meteorology and Climatology (MeteoSwiss)
As a result of the frequent North Föhn (wind), the winter of 2018/19 had exceptionally low precipitation levels on the southern side of the Alps. Massive temperature fluctuations took place in the mountains. After a mild December, mountains above 1,000 m above sea level registered the coldest January in more than 30 years. Subsequently, the mountain temperatures rose from the 2nd to 5th-mildest February values since temperature measurement was first recorded. The lively west-wind activity brought widespread above-average winter precipitation, except in the southern region. The largest precipitation surpluses were recorded on the Eastern Alps.

Spring yielded below average precipitation in large parts of Switzerland. In contrast, high levels of precipitation ocurred regionally. The Central and Eastern Alps precipitation levels ranged between 150 to 200% more when compared to the 1981 — 2010 standard. Locally, it was one of the springs with the highest levels of precipitation since precipitation measurements were recorded High levels of precipitation occurred mainly in April, on the southern side of the Alps, in Graubünden, along the Central Alps, and along the Upper Valais. Locally, record amounts of snow fell for the month of April. Regular fresh snowfalls and an unusually cool May preserved the alpine snow cover at high levels usually seen in winter. The summer heat subsequently caused the snow cover to melt quickly.

The sustained heat in June and July resulted in two extended heat waves with a daily temperature maximum of at least 30° C. In contrast to the extremely warm and extremely dry summer of the previous year, many areas of Switzerland received sufficient rainfall during this summer. The levels usually ranged from 80 to 100% compared to the norm. In Valais and Ticino, local values ranged between 120 to 140%.

After the third-warmest summer, Switzerland registered the sixth warmest autumn since the first year of recorded measurement, which was in 1864. October, in particular, contributed to the high autumn temperatures. In Switzerland, September had overall low precipitation levels, and October recorded high precipitation levels. A high level of precipitation was recorded in a short space of time on the southern side of the Alps, shortly after the middle of October. In November, the southern side of the Alps again saw high levels of precipitation. Together, all three months of autumn recorded almost 150% compared to the norm. North of the Alps, autumn precipitation was average.

With the abundance of precipitation and the declining snow line in November, considerable amounts of fresh snow fell at the higher altitudes of the southern Alps. Regionally, fresh snowfalls added to the new November records. From the middle of December, the frequently-occurring Southern Föhn on the northern slopes resulted in extremely mild thaws. At the end of the year, snow depths on the entire Alpine slope decreased between 60 to 90% compared to the long-term (multi-year) average. In southern Valais, northern Ticino, and parts of Grisons, the levels were 110 to 140% above average. With a national average of 2.5° C above the 1981 — 2010 standard, December ended as the third warmest since measurement began in 1864.

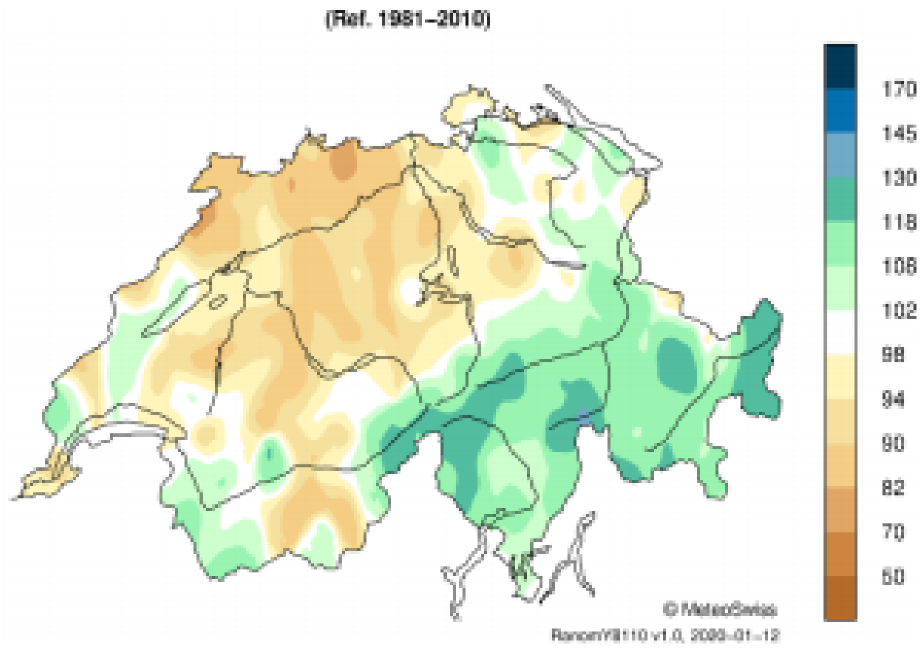

Figure 4: Annual precipitation in Switzerland in 2019, laid out as percentages of the norm (1981-2010).

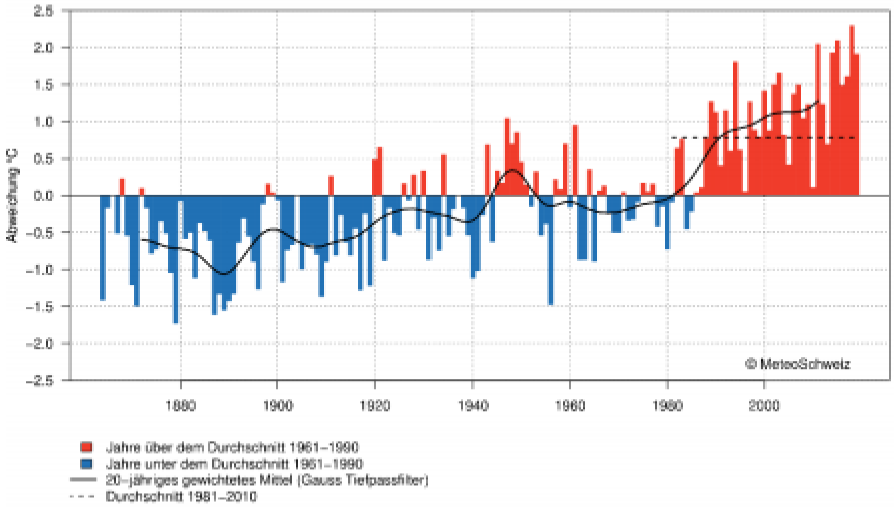

Figure 5: Deviation from the Swiss annual temperature in 2019 from the long-term average (reference period 1961-1990). The overly-warm years are coloured red, the overly-cold years are coloured blue. The black line shows the temperature progression averaged over 20 years.

In the snow records taken over 100 years, there is a slight decrease in fresh snow levels regionally, but no change in the broader areas. Fresh snowfalls show a slight increase in some areas and a slight decrease in others. Some other areas have not shown any changes. However, these analyses are based on non-homogeneous data.

The ozone status in the higher atmosphere over Switzerland has remained stable in recent years. This result is in contrast to a decrease in the total ozone of around 6% between 1970 and 1995.

Table 1: Annual values in 2019 at selected MeteoSwiss measuring stations, compared to the 1981-2010 standard norm

Station	Height	Temperature (°C)			Duration of sunshine (h)			Precipitation (mm)		
	m a.s.l	Means	Norm	Dev.	Total	Norm	%	Total	Norm	%
Bern	553	10.1	8.8	1.3	1985	1683	118	999	1059	94
Zurich	556	10.6	9.4	1.2	1878	1590	118	1041	1134	92
Geneva	420	11.8	10.6	1.2	2113	1768	120	842	1005	84
Basel	316	11.6	10.5	1.1	1934	1590	122	786	842	93
Engelberg	1036	7.7	6.4	1.3	1438	1350	106	1495	1559	96
Sion	482	11.8	10.2	1.6	2174	2093	104	608	603	101
Lugano	273	13.9	12.5	1.4	1956	2067	95	1675	1559	107
Samedan*	1709	2.8	2.0	0.8	1710	1733	99	815	713	114

Norm = Long-term/multi-year average 1981-2010
Dev. = Deviation of temperature compared to the norm
% = Percent in relation to norm (norm = 100%)

Germany, Source: German Weather Service (DWD)
In the German Rhine region, the series of low-precipitation years continued within the hydrological year 2019 (November 2018 to October 2019). This applies to both of the major sub-catchment areas outlined here

- *Upper Rhine* (Basel to Mainz including the Main region), in 2019 precipitation was 809 mm, only 83.8% and
- *Central and Lower Rhine* (Mainz to Lobith), only 741 mm was recorded, which is 81.6% of the average climatic value of between 1981 and 2010.

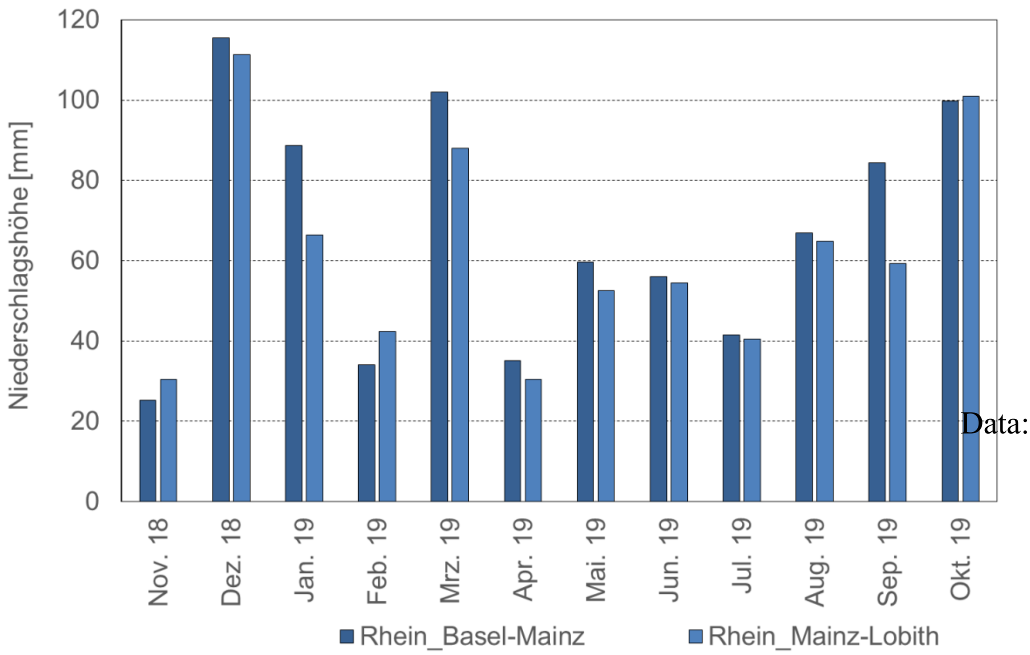

Figure 6: Area precipitation according to months for the hydrological year 2019 in the German Rhine region, for the Upper Rhine (Basel to Mainz including Mainz), as well as Central and Lower Rhine (Mainz to Lobith)

However, there was a wide range of fluctuation within the individual months, as illustrated by the figures calculated month by month over the course of the year (Figure 6 / absolute values of precipitation and Figure 7 / anomalies as a percentage of the reference value). The periods with the highest precipitation in both areas was recorded in December, March and October with up to 130% compared to the average. The months of January and September were above the climate only in the southern sub-catchment area. November 2018 and February 2019 and April to August 2019 were exceptionally low in precipitation and in uninterrupted succession, also the months of April to August 2019. Only about 50% of the climatic mean values mostly attained. The driest month was November 2018; 25.2 mm (Upper Rhine) and 30.5 mm (Central and Lower Rhine), only 32% and 38% of the climatic mean value between 1981 to 2010 were attained.

The below-average precipitation in Germany was accompanied by excessive average temperatures (Figure8); overall, 2019 was the second-warmest year since the beginning of systematic weather records began in Germany in 1881.

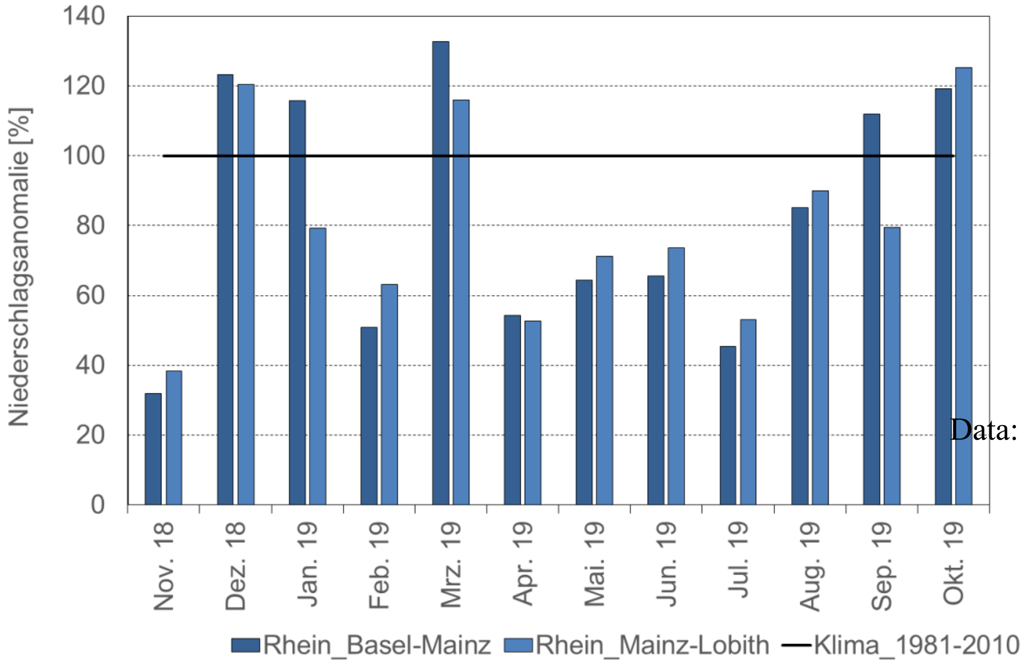

Figure 7: Monthly precipitation anomalies for the hydrological year 2019 in the German Rhine region for the Upper Rhine (Basel to Mainz including Mainz) and Central and Lower Rhine (Mainz to Lobith); reference values (climate values) are the average precipitation totals of the reference period from 1981 to 2010.

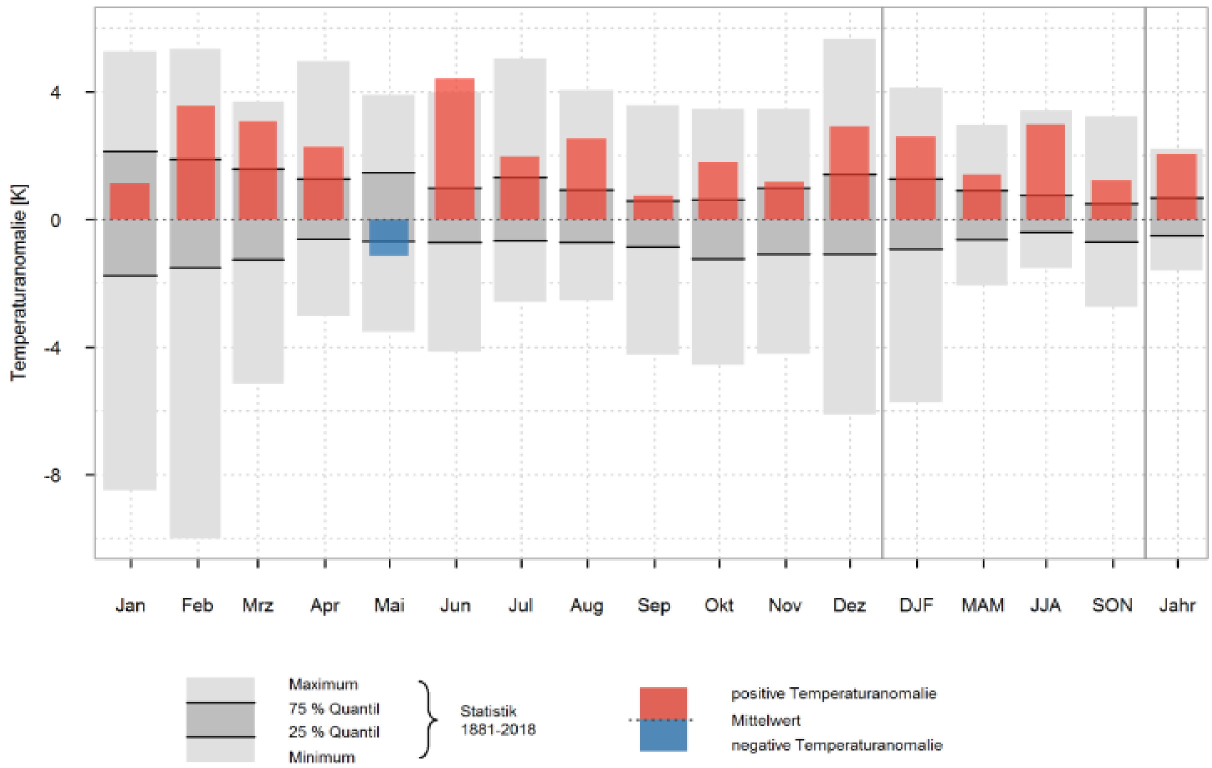

Figure 8: Monthly and seasonal absolute temperature anomalies [K] in Germany in 2019, analysed using the average values of the reference period from 1961 to 1990 (Evaluation and chart: DWD – German Weather Service, retrieved on the 4th of December (04.12.2020), 2020

https://www.dwd.de/DE/leistungen/besondereereignisse/temperatur/20200102_bericht_jahr2019.pdf?__blob=publicationFile&v=4)

June 2019 was the warmest June since 1881, and the low rainfall and hot weather led to a potential evaporation rate, which was, on average, 32% above the long-term average and caused major soil dehydration, using up groundwater reserves. (An apparent paradox was observed though: the actual (real) evaporation rate was in fact at below-average levels — simply because the groundwater levels were so exhausted, that there was too little residual moisture to have evaporated...). According to the DWD, soil moisture levels in the following month of July[1] was only 49.8 per cent on average nationwide (water-holding capacity), which is lower than any level ever measured in July when compared to the period 1991 to 2018.

The Netherlands, Source: Royal Dutch Meteorological Institute (KNMI)
2019 was the sixth consecutive extremely warm year, with a mean temperature of 11.2°C measured at the De Bilt station. The emerging picture fits in with the trend of a warming overall climate. The reading of 40.7 °C on 25 July at Gilze-Rijen station in the south of the country, was the highest temperature recorded for at least 3 centuries in the Netherlands. Only November and May, in particular, were cooler, September was normal and all other months' average temperatures were (significantly) above the long-term average (Fig. 9).

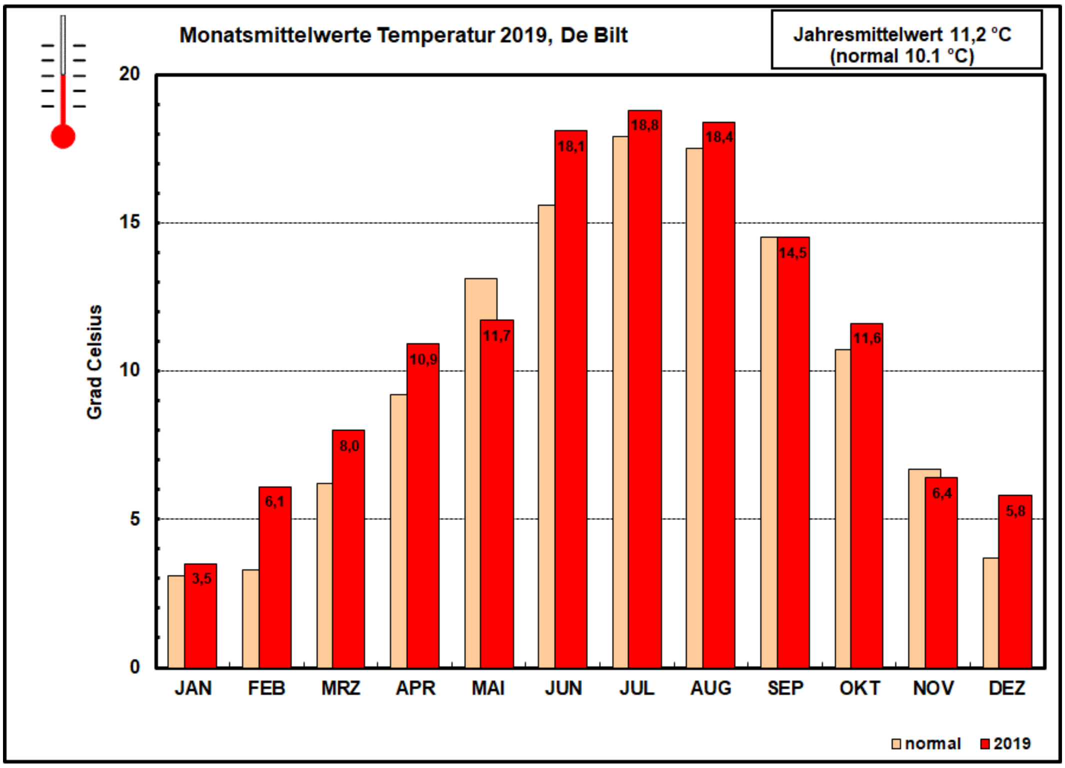

Figure 8: Monthly average temperature values at the De Bilt station in 2019, compared to the long-term (1981-2010) mean value (Source: KNMI)

January was quite mild with a mean temperature of 3.5°C. The month was dry and in the second half of the month, winter conditions prevailed. February was very mild at 6.1°C and also very sunny. Spring was generally very mild, but showed her various moods. March was mild and mostly wet with a mean temperature of 8.0°C. April was also very mild and very sunny. On 20 April, temperatures above 20°C were measured in many places, and in the south of the

[1]https://www.dwd.de/DE/presse/pressemitteilungen/DE/2019/20190926_agrarwetter_sommer2019_news.html, accessed on the 4th of December (04.12.2020), 2020

country the first summer days (temperatures above 25°C) could be enjoyed. May was too cool with an average temperature of 11.7°C yet sunny and dry.

The summer of 2019 was very warm with a mean temperature of 18.4 °C in De Bilt. Since 1901, there have only been 3 summers that were warmer. The summer was characterized by fluctuations of very warm and cooler periods. Two heat-waves were registered at the De Bilt station. Between (23?) and 27 July, the orange warning code was announced due to extreme heat. The summer of 2019 was dry once again, but less extreme than the summer of 2018. June was the warmest month of June since 1901, averaging 18.1°C. It was very sunny, but also wet thanks to a changeable period in the middle of the month.

July was very warm with a mean temperature of 18.8°C. The heat between the 24th an the 26th of July was extreme. For the first time in at least 3 centuries, a temperature of above 40 °C was measured in the Netherlands. The month of August was also warm at 18.4 °C, and also very sunny.

Autumn was quite mild, sunny and wet. The average temperature in September was normal. October was mild and wet. The end of the month was dry, sunny and cool, and the first frost of the winter half was registered. In November, temperatures were slightly below normal and it was very sunny. December was very mild and dry at 5.8°C.

With 1964 hours of sunshine, 2019 was very sunny. The longstanding average is 1639 hours, and 2019 ranks as the third-sunniest year since observations began. Almost all months of the year, except for January and October, were sunnier than usual.

With an average of 783 mm of rainfall for the entire country, 2019 was relatively dry. The multi-annual average is 847 mm. After the extremely dry year in 2018, 2019 was also too dry in the east of the country once again. In 2019 it was a wet year in the Northwest, thanks to the rainy latter half of the summer, and the autumn months (Fig. 10).

Snowfall was rare. It was only on the 22nd of January that snow fell over almost the entire country, and remained on the ground in the interior for several days.

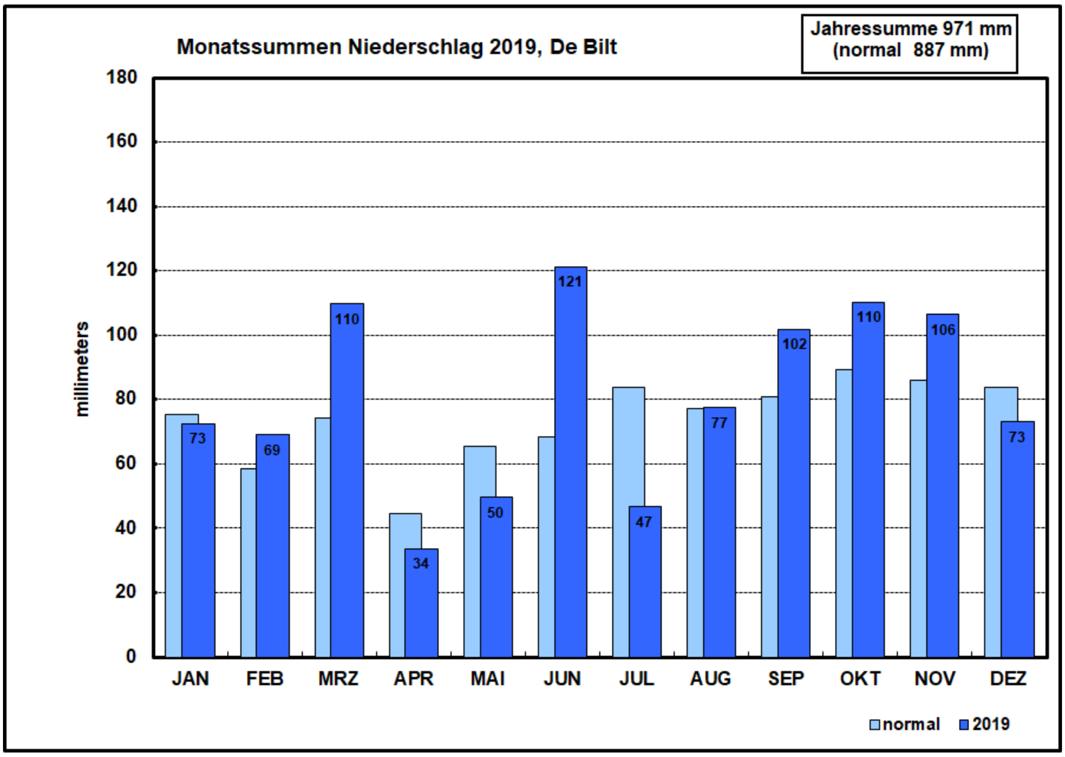

Figure 10: Monthly precipitation totals at the De Bilt station in 2019 compared to the multi-annual (1981-2010) mean value (Source: KNMI)

Snow and Glaciers

Source: Snow: WSL Institute for Snow and Avalanche Research SLF
Glacier: Geographical Institute of the University of Fribourg and Research Institute for Hydraulic Engineering, Hydrology and Glaciology (VAW)

Snow

On 27 October 2018, a southern frontal system (orographic uplift) brought significant rainfall, which also spread to the north. Until then, apart from the highest peaks, hardly any snow was present. In the following days, especially in the south, vast amounts of snow fell at altitude. After the sharp onset of winter at the end of October, the southern frontal systems repeatedly lead to precipitation in the south in November. In the north, however, conditions remained mostly dry. In December, it only snowed at high altitudes in the north. During a high-precipitation period lasting from 8 to 10 December, a large quantity of snow fell. A closed snow cover at above 2000 m above sea level was seen on the entire Swiss Alp region. Two more high-precipitation events, with a high snow line, occurred during the days leading up to Christmas, bringing a large amount of snow to the higher Alpine slopes.

In January, snowfalls were distributed in a similar way to December: a large amount of precipitation in the north, and most often dry in the south. Between 2 and 15 January, 2 to 3 metres of fresh snow fell on the central and eastern slopes of the Alps in northern Grisons. Only in the last week of January was there once again snow on the north side of the Alps, this time mostly in the western region. The northern mountain region experienced the coldest in over 30 years. Given the low temperatures, it often snowed in low altitudes, so that the snow depth there, especially in the valleys, was quite a bit above the average.

The first half of February brought some precipitation in all the Swiss Alp regions. From mid-February, high-pressures dominated, so it was very mild. As the weather warmed, the valleys that had had above-average snowfall in January thawed out again. Despite the mild temperatures, snow-melt at altitudes was rather low.

From 6 to 7 March, almost 50 cm of snow fell in the south. Otherwise, precipitation was concentrated in the north, even during March. The most snow (50 to 80 cm) fell on 15-16 March.

On 3 and 4 April, mild and humid air flowed over the Alps from the south, while the northern side of the Alps, from the west, cold air flows dominated. The humid air which glided from the south over the cold air triggered extreme snowfalls on the central Alpine slopes. Towards the end of the month, a strong Föhn wind blew simultaneously with the precipitation in the south and north. This accelerated the snow-melt in the north, due to the accompanying high temperatures.

May was exceptionally cool with little sunshine. It snowed repeatedly at medium altitudes, and at the beginning of May, even at low altitudes. The frequently cloudy and cold weather caused the snow in this snow-filled winter to melt slowly at altitude. Together with the vast amounts of fresh snow, it meant that overall snow depths increased rather than decreased in May. There was still an exceptionally large amount of snow at high altitudes at the end of May.

The second warmest June since measurement began, accelerated the snow-melt, which was very slow in May. At medium altitudes, the snow cover mostly disappeared. At the end of June, there was still a little more snow at high altitudes than is normal for this time of year. This was especially the case on the northern Alpine ridge and in northern Grisons.

Glaciers

For some time now, one year of near-record glacier loss has followed the next. The mean balance measurement for 20 Swiss glaciers shows the same result for 2019: The balance between snow gain and melt loss is again extremely negative. However, the situation is less dramatic than over the last two years. During April and May, there was 20 to 40% more snow mass on the glaciers than usual. At the beginning of June, a snow depth of six metres was measured in some places. Since the melt started relatively late, it prompted hope of lower glacier-volume losses than in previous years, until the first heatwave arrived in the summer. During the two intense, one-week hot periods at the end of June and the end of July, however, snow and ice masses on the Swiss glaciers melted so fast within just 15 days, that it was equivalent to the annual nationwide consumption of drinking water. As a result, the thick snow cover quickly disappeared, and the accelerated melting continued until early September. Over the past 12 months, it caused around 2% of Switzerland's total glacier volume to be lost. Over the past five years, the loss constitutes more than 10% — such a loss has never been previously observed in the more than 100 years of available data.

The glacial volume assessment in 2019 is characterized by regional differences. Losses, particularly in the east, and on the northern side of the Alps, have been higher than the average over the last decade. For many glaciers, a reduction of one to two meters in the average ice thickness was measured (e.g. Silvrettagletscher, Glacier de Tsanfleuron). In the Gotthard region and towards its southern regions, conditions were more favourable due to heavy snowfall at the beginning and end of winter. Some glaciers recorded relatively low losses (e.g. St. Annafirn, Ghiacciaio del Basòdino). The disintegration of small glaciers continues: more than 500, mostly nameless glaciers, have already disappeared since around 1900. The Pizol Glacier was one of the first glaciers that had a long history of recorded data, that had to be deleted from the network of measurements.

Hydrological Status of the Rhine Region in 2019

Water levels in the large lakes in the Rhine's catchment area.

Austria

At the beginning of the year and at the end of the year, the water level of Lake Constance was slightly above the long-term averages measured between 1864 to 2018, for the respective calendar day. Only during three periods (15 April — 21 May, 16 July — 13 August and 20 September — 6 October) was the water level below the average. The melting Alpine snow-caps and above-average precipitation led to a significant increase in the water level in May. The highest level for 2019 was reached on the 20th of June. (See Figure 11).

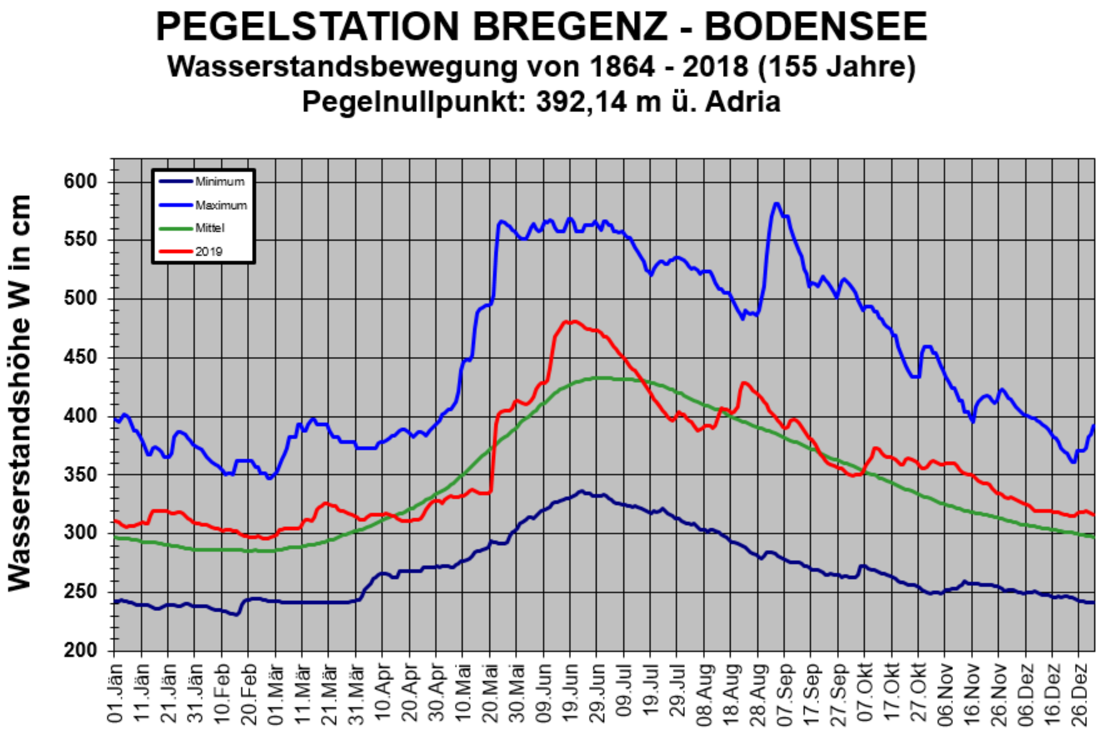

Figure 10: Water level measurement values from existing charts for Lake Constance at the gauge level in Bregenz in 2019 (red curve), compared with long-standing minimum and maximum values, as well as the averages

Switzerland

After the annual water level of most large lakes was below the long-term average in 2018, due to the persistent drought, 2019 was very well-balanced. At Lake Constance (upper lake region) the deviation from the norm was +23 cm, at Lake Walen +5 cm and at Lake Lugano — 7 cm. For the other large lakes, however, the difference was less than 5 cm. Large deviations from the norm are also not expected at regulated lakes. If these occur anyway, they indicate exceptional circumstances in which it is not possible to comply with a regulatory framework. Just like in 2018, when the required minimum quantities could not always be drained from the lakes due to the drought. In a year like 2019, no major discrepancies can be assessed from the long-term average when viewed over the entire year.

A monthly breakdown shows how the average annual values were determined. The water level on Lake Constance was not lower than the corresponding norm period in any month of the year. The highest monthly deviation from the norm occurred in June, with a disparity of almost half a meter. In the second half of the year, the deviation was never less than 19 cm. On Lake Neuchâtel, where the annual average for 2019 was only 1 cm above the long-term value, the monthly measurements for the water levels from April to September, did not deviate from the norm by more than 2 cm. Due to the low rainfall winter 2018/19 on the southern side of the Alps, the water levels on Lake Maggiore remained relatively low (— 41 cm in February and — 72 cm in March). The deficits were compensated in the summer and especially at the end of the year (+42 cm in November and +47 cm in December). The monthly deviations on Lake Geneva are, as usual, very small: in January they were 5 cm and from February to December never more than 2 cm.

2019 was an uneventful year. Lake Constance nonetheless resulted in almost 30 days of water levels at security level two and three. From 12 June to 8 July, the water level was above the threshold of levels 1 and 2, 396.65 m above sea level. The level reached danger level 3 on 14 June, and rose to 396.98 m above sea level by 17 June, then only fell below the level 3 threshold around 10 days later. The reason for this flood was a strong southerly to south-westerly high-altitude current with intense precipitation as well as an intensified snow-melt rate (see also Chapter 1). It is not uncommon for Lake Constance to rise to a level of 397 m above sea level. In recent years, he has reached several times higher water levels at the Romanshorn measuring station, including in June 2016 (397.35 m above sea level) and in June 2013 (397.04 m above sea level). The seal was quite different in June 2018. The sea level was still 395.10 m above sea level at the end of the month and declined to 394.92 m above sea level, due to the long dry period which lasted until October.

Lake Neuchâtel remained well below danger level 2 throughout the year. Only in mid-May did the water level began to approach danger level 2, yet it remained 26 cm below. No floods occurred in 2019, but low water phases were also not an issue on Lake Neuchâtel.

The progression of water levels on Lake Maggiore in 2019 showed some similarities with 2018 progression: relatively low water levels in spring and autumn, and a very rapid increase in autumn and winter. Threat level 2 was also reached here: the water level was five days at the end of October and four days at the end of November. However, the 2018 peak level (195.36 m a.s.l.) was not reached. The maximum measurement was 194.90 m above sea level in 2019, 46 cm lower than in the previous year and more than two metres below the peak since 1943 (197.57 m above sea level in October 2000). These figures show once again the vast range of water levels that can occur on Lake Maggiore (5.52 m). In contrast, the corresponding range for Lake Geneva is minor. Only 1.85 m between the minimum and maximum values measured over in the 77-year series. In 2019, the minimum and maximum water level was 71 cm.

Water levels and discharges

Austria

In 2019, the outflow of the Alpine Rhine was 20% above the long-term average. The above-average precipitation of the other Lake Constance flows from Austria also led to above-average outflows. The annual flow compared to the long-term average (1951 - 2018 Alpenrhein, Bregenzerach.i.e., 1984 -2018 Dornbirnerach) was as follows

- at Bregenzerach 108% (MQ 2019 = 50.0 m^3/s, long-term MQ = 46.5 m^3/s);
- at Dornbirnerach 109% (MQ 2019 = 7.68 m^3/s, long-term MQ = 7.03 m^3/s);
- at the Alpine Rhine 120% (MQ 2019 = 276 m^3/s, long-term MQ = 231 m^3/s).

Switzerland
The annual average discharge of major river basins in 2019 ranged from — 25% to +20% compared to the values of the norm, i.e., the norm for the period 1981-2010. Significantly below-average discharges were measured in the north and northwest of Switzerland on the Birs, on the Doubs and the Aare, near Brugg. The figures were clearly above-average in the south and south-east of the country, on the Maggia, on the Inn River and on the Rhine near Diepoldsau. Normal values, with a deviation of less than +/— 10% from the long-term reference value occurred on the Thur, the Limmat, the Reuss and the Rhone.

The relatively modest annual average for 2019 on the Aare near Brugg is nothing out of the ordinary. Since 1950, the corresponding value has been lower than in the year under review for 19 years; the last time was in 2017. At the Inn, near Martina, where the annual average was significantly higher than the average, discharges were only above the level of 2019 every 9th year.

In the medium-sized catchment areas, the annual averages ranged between 60% to 140% of the norm. Annual discharges in the catchments around the Gotthard and in southern Ticino reached over 130 % of the norm. River Julia had a new record high annual discharge at Tiefencastel, where discharges have been measured since 1977. The previous peak in 1987 was significantly exceeded.

The lowest values, with annual discharges below 70% of the corresponding reference value, can be found on rivers in the central midlands (Dünnern, Murg, Wigger and Suhre) and on the Ergolz. The annual discharge at the Murg near Murgenthal hasn't been so low in 40 years. Ergolz near Liestal was the only catchment area to remain below 60% of the reference value. However, 2019 was not an extreme year at that location. The annual average of 2003, for example, only came to around 52% of the norm, compared to only 41% in 1943.

The example of these two rivers shows that when comparing the discharge volumes of different catchments, the same measurement periods should be considered - in the yearbook, reference is therefore made to the 1981 - 2010 standard period whenever possible. Compared to this standard, the annual discharge of the Ergolz in 2019 was lower than the value for the Murg. The Murg, however, recorded a record that the Ergolz did not. The reason: while the discharge from the Ergolz at Liestal has been measured since 1934, the measuring station on the Murg at Murgenthal has only been in operation since 1981. A low-flow value reaches a new record value more quickly in a short series of measurements than over a long period. However, the shorter a measurement series is, the less informative it is about the capacity and behaviour of a catchment area. For this reason, long-term measurement networks are of great importance, especially if statements about slow changes in a catchment area are to be documented (e.g., changes of use or consequences of climate change).

The main catchment areas with low annual discharges in western and north-western Switzerland were below average from the beginning of the year to late summer, with relatively small discharges in January, April, July and September. Examples of this are the Aare at Brugg and the Doubs near Ocourt. In December, increased discharges were also measured in these catchments.

A single month may provide an above-average annual result. This is what happened at the Inn near Martina. With the exception of June, monthly discharges were at a level that can be expected from the long-term averages, but still slightly higher than the norm in the second half of the year. Together with the sharply above-average June value (almost 70 % above the long-term monthly average), this resulted in an exceptionally high annual discharge.

In the large catchment areas of central and eastern Switzerland and Ticino, besides the June discharge, increased discharges were recorded in October, November and December, and in the river area of the Aare, especially in December. The massive melting of glaciers became noticeable on the Rhone in June, July and August.

Even in a low-event year such as 2019, there are stations in an extensive measuring network to measure discharges that have not previously occurred there. In this regard, the months of June and July are worth mentioning: in June, new record June maximum temperatures were measured at more than a dozen stations. These stations are located mainly in Ticino, Grison and Upper Valais. In July, new minimum monthly values were measured at some stations, such as individual stations in French-speaking Switzerland, Ticino and north-eastern Switzerland, as well as at several stations in the Emme catchment area, as well as in Upper Gau (Oberaargau). The measurement of very low water levels and very low discharges can be challenging and are sometimes inaccurate (see Hydrological Yearbook of Switzerland 2017). It is therefore advisable to include recordings of neighbouring stations in an assessment when exceptional measurements have been taken, especially when provisional data is being evaluated, as in this case.

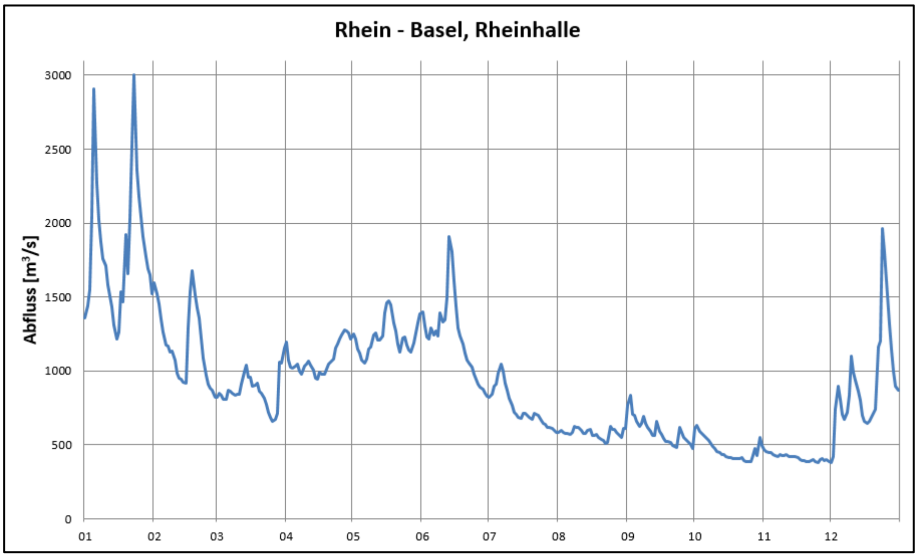

Figure 12: Discharge hydrograph at the Rhine gauge - Basel, Rheinhalle in 2019

Germany
In view of these conditions, the 2019 discharge year on the Rhine consequently developed into a low-water year. Table 2 shows this in numbers based on the representative gauges Maxau, Kaub and Duisburg-Ruhrort.

Table 2: Year-round and seasonal discharge averages for 2019 compared to the long-term reference values for the period 1961 to 2019 at the levels of Maxau /Oberrhein, Kaub/Mittelrhein and Duisburg-Ruhrort/Niederrhein (Data: WSV)

hydrologische Jahre	MQ(1961/2019) [m³/s]	MQ(2019) [m³/s]	MQ(2019) Verhältnis zum MQ(1961/2019) [%]	SoMQ(1961/2019) [m³/s]	SoMQ(2019) [m³/s]	SoMQ(2019) Verhältnis zum SoMQ(1961/2019) [%]	WiMQ(1961/2019) [m³/s]	WiMQ(2019) [m³/s]	WiMQ(2019) Verhältnis zum WiMQ(1961/2019) [%]
Maxau	1260	1130	90	1360	1300	96	1170	959	82
Kaub	1690	1410	83	1650	1500	91	1740	1330	76
Duisburg-Ruhrort	2260	1790	79	1980	1680	85	2550	1910	75

The mean discharge in 2019 did not even reach average values in any of the river sections represented by the gauging stations, with a south-north gradient emerging: Relatively speaking, higher discharges in the Upper Rhine (at least 90 % of the multi-year MQ) contrasted with lower discharges in the river sections further downstream: At the Lower Rhine gauge Duisburg-Ruhrort, the MQ(2019) of 1790 m^3/s only attained 79 % of the multi-year reference value. On a seasonal basis, the summer water flow proved to be more stable than that of the winter half of the year, which, especially in the case of the Lower Rhine, remained significantly (by 25%) below the long-term comparison of 1910 m^3/s.

Table 3: Average and extreme values of the 2019 discharge compared to the long-term reference values for the period 1961 to 2019 at the Maxa/Upper Rhine-Westphalia, Kaub/Mittelrhein and Duisburg-Ruhrort/Niederrhein gauges (Data: WSV)

hydrologische Jahre	MQ(1961/2019) [m^3/s]	MQ(2019) [m^3/s]	MNQ(1961/2019) [m^3/s]	NQ(2019) [m^3/s]	NQ(2019) Datum	NM7Q(2019) [m^3/s]	NM7Q(2019) Datum	MHQ(1961/2019) [m^3/s]	HQ(2019) [m^3/s]	HQ(2019) Datum
Maxau	1260	1130	603	434	26.11.2018	451	21.11.2018	3250	2710	22.05.2019
Kaub	1690	1410	792	546	24.11.2018	556	23.11.2018	4340	3550	18.03.2019
Duisburg-Ruhrort	2260	1790	1040	705	29.11.2018	709	23.11.2018	6640	5580	18.03.2019

The characteristics of a low-water year is also reflected in the hydrological extreme values recorded along the Rhine in 2019 (Table 3). The discharge peaks, which occurred in the more pluvial Middle and Lower Rhine sections in March with high precipitation, and in the more heavily nival-influenced Upper Rhine in the midst of the alpine snowmelt phase on 22 May, were consistently below the multi-year MHQ and thus represented insignificant events.

The lowest water supply was recorded uniformly in all current sections during the last week of November. The NQ always fell below the multi-year mean MNQ for the period 1961 to 2019, most markedly at the Duisburg Ruhrort gauge (the NQ of 705 m^3/s reached on 29.11. was around 32 % below the MNQ). Nevertheless, the NQ (2019) on the Rhine cannot be classified as especially extreme. According to preliminary calculations, the associated re-intervals are uniform in the range of approx. 2 years.

Figures 13, 14 and 15 show the discharge pattern for 2019 on a daily basis against the backdrop of many years of historical comparison values.

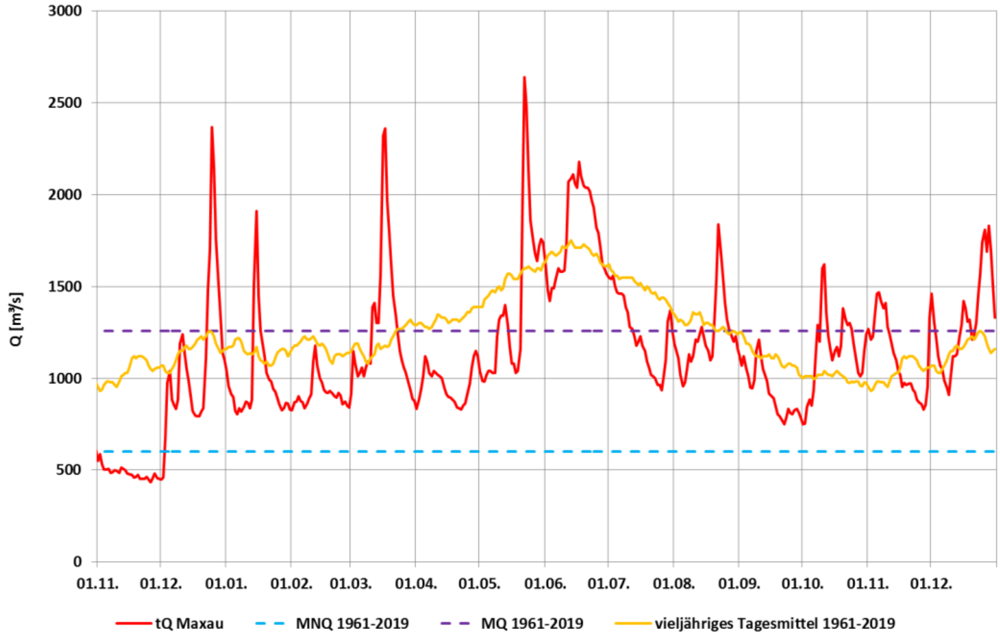

Figure 13: Daily discharges (tQ) at the Upper Rhine gauge Maxau in 2019 (extended hydrological year from November 1, 2018, to December 31, 2019) against the background of long-term daily averages as well as the MNQ and MQ values for the reference period 1961 to 2019

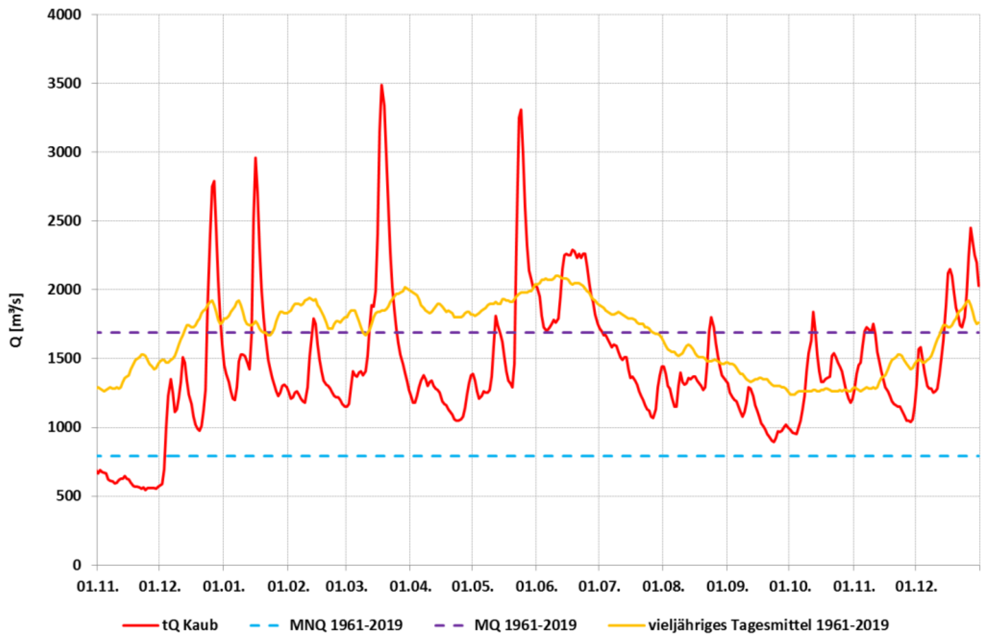

Figure 14: Daily discharges (tQ) at the Kaub Middle Rhine gauge in 2019 (extended hydrological year from November 1, 2018, to December 31, 2019) against the background of long-term daily averages as well as the MNQ and MQ values for the reference period 1961 to 2019

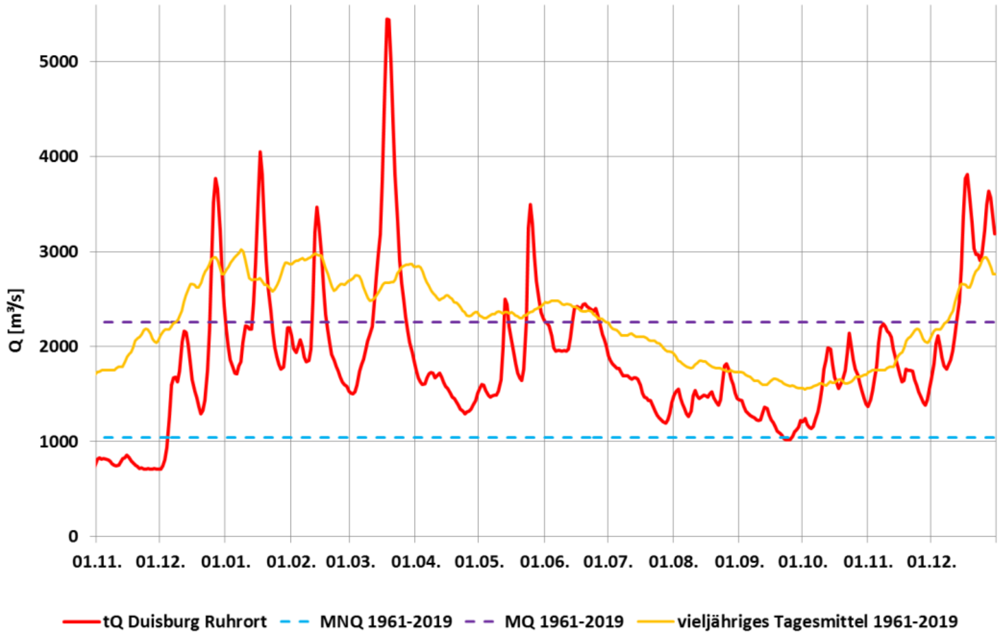

Figure 15: Daily discharges (tQ) at the Lower Rhine gauging station Duisburg-Ruhrort in 2019 (extended hydrological year from 1.11.2018 to 31.12.2019) against the background of the multi-year daily means as well as the MNQ and MQ values of the reference period 1961 to 2019.

The Netherlands

For the Netherlands, 2019 was characterised by the absence of extreme discharges and water levels. As a result, 2019 is significantly different from 2018. Figure 16 (red line) shows that only a single discharge peak was measured, with the floodplains being inundated. This peak value of just over 5000 m3/s and a water level of 12.87 m a.s.l. at the Lobith gauge is not unusual, however, and has a return interval of 1 to 2 times per year.

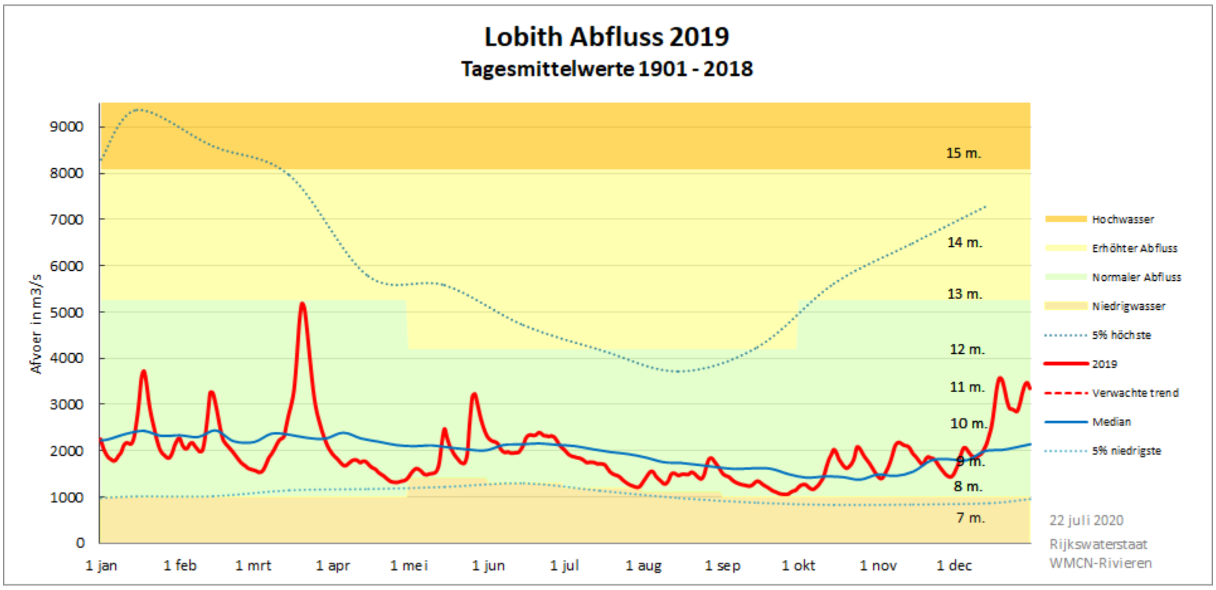

Figure 16: Hydrograph of the daily mean discharges at the Lobith gauging station in 2019 (red curve) in comparison with long-term minimums, maximums and mean values, from 1901-2018

In the summer months, there were also no unusual developments. Rhine discharges were significantly higher than in the dry year 2018. No flood reports were issued by the Dutch Water Management Centre in 2019.

Water Temperatures

Austria

At 12.8 °C, the annual average of the water temperature of Lake Constance was 0.8 °C above the long-term average of 12.0 °C. With a few exceptions, which were due to snow melting in the high mountains and cold weather phases, the daily average was above the daily average of the long-term measurements between 1976-2018. (see Figure 17).

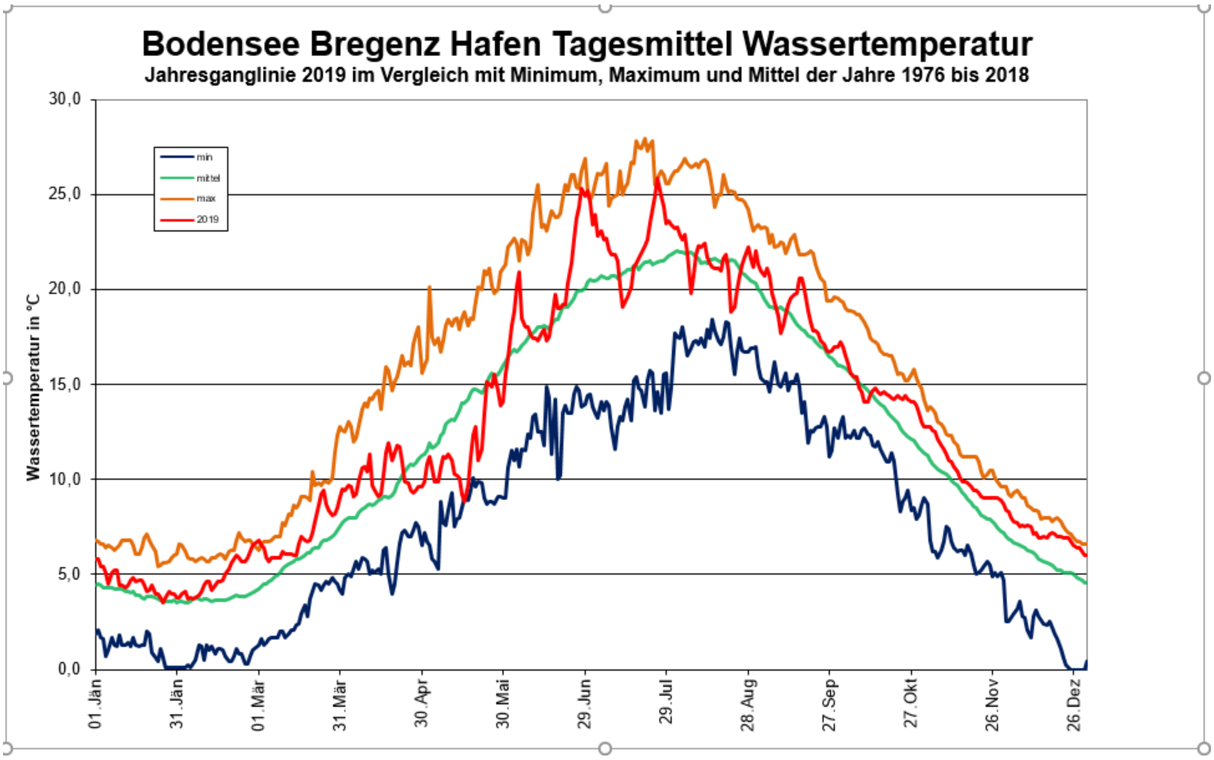

Figure 19: Measurement values of the water temperature of Lake Constance at the Bregenz gauge in 2019 (red curve), compared with the longstanding minimum, maximum and average levels for the years 1976-2017

Switzerland

Although 2019 was again a very warm year in terms of air temperature, the average annual values of the water temperature did not attain any new record highs. The annual maximum was not exceeded in 2019, but the annual minimums were not undershot either. On the other hand, the monthly water temperature minimums and maximums painted a slightly different picture: in the mountains, winter was characterized by massive temperature fluctuations. In the Alpine region, this led to the water temperature measuring stations occasionally exceeding or falling below the previous monthly extreme values. Only in the south, where milder temperatures prevailed but very little precipitation occurred due to the northerly Föhn, did both new maximum temperatures and new monthly minimum values occur at a few stations. Temperature drops below the previous minimums can be observed, for example, in waters that are strongly affected by glaciers.

It was only with the long-lasting thermal periods in June and July that, after a balanced spring throughout Switzerland, more and more new monthly maximums were observed once again at individual locations. The number of exceedances was more or less equally distributed in both months and only varied spatially in their occurrence. Compared to the extreme years of 2011, 2014, 2015 or even 2018, however, only a few highs were recorded. These maximums occurred in June and July, earlier in the summer than, for example, in the hot summer of 2018, when water only rose to very high temperatures in July and August.

In November, the water temperature finally reached regular monthly extreme values at individual stations in the western part of Switzerland. Likewise, a southern Föhn situation in November and the above-the-norm air temperature during this month, led to temperatures exceeding the monthly maximums, especially on the Swiss plateau and occasionally also in the south. Interestingly, during this time, monthly minimums again occurred in glacier-affected stations.

The Netherlands
At the Lobith gauge, the average water temperature at 14.0 °C was approximately 0.9 °C above the annual long-term average (1961-2019) (see Fig. 18). In the overall ranking of highest mean water temperatures, 2019 came in 11th (measurement range 1908-2019).

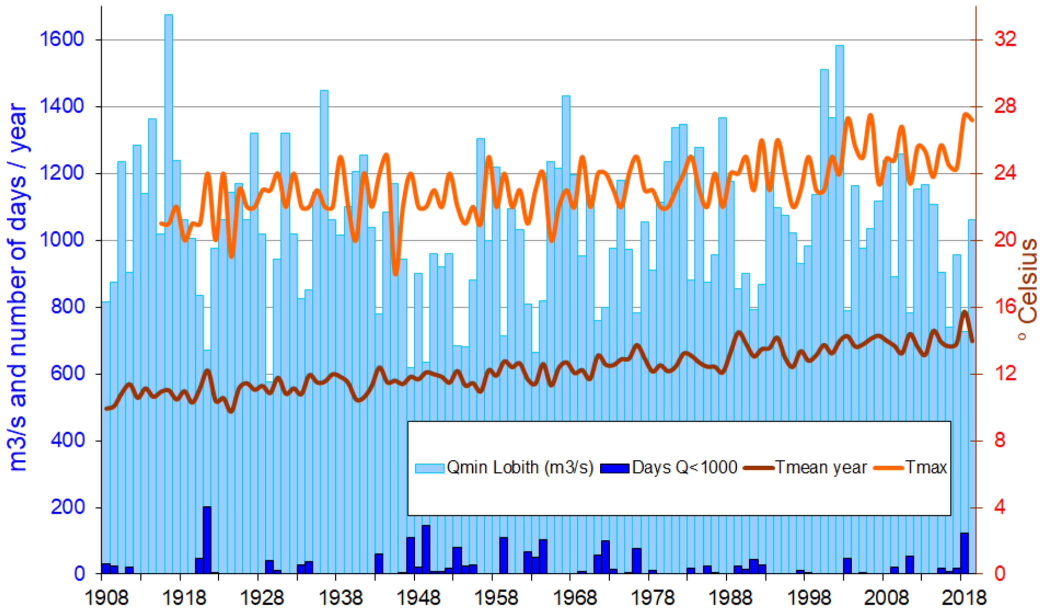

Figure 18: Average and maximum water temperatures 1908-2019 at the Lobith/Rhine gauge

Groundwater

Austria
The dry year of 2018 brought below-average groundwater levels at the beginning of 2019. The snow-melt and the high-precipitation months of January and May caused groundwater levels to rise above the long-standing seasonal average.

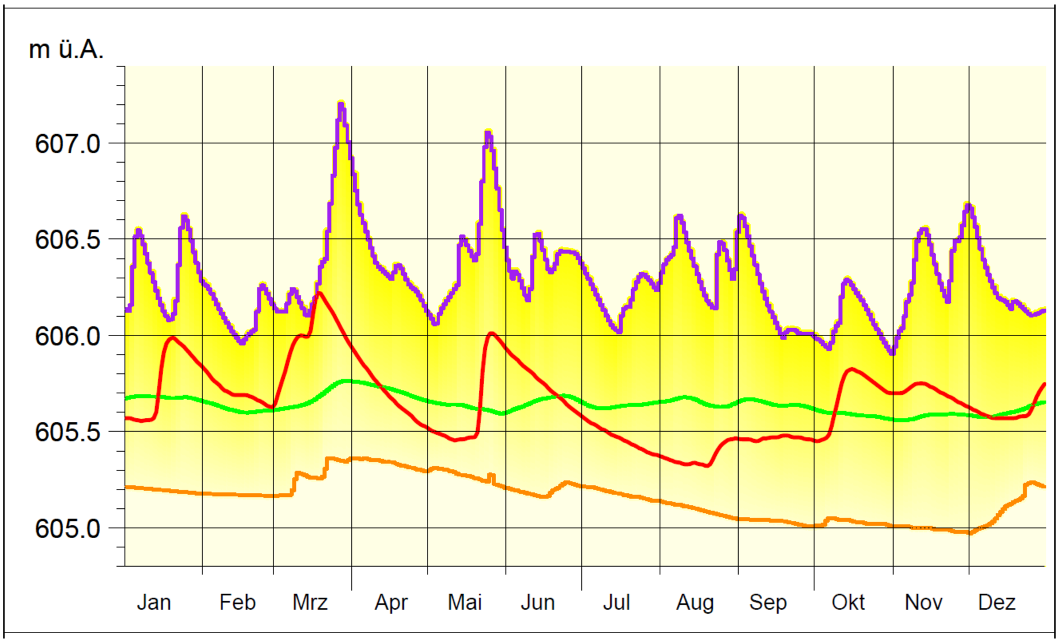

Figure 19: Groundwater level gauges in 2019 compared with long-term minimums, maximums and averages (1985 — 2018) Andelsbuch Bl 30.1.03 (Bregenz Forest)

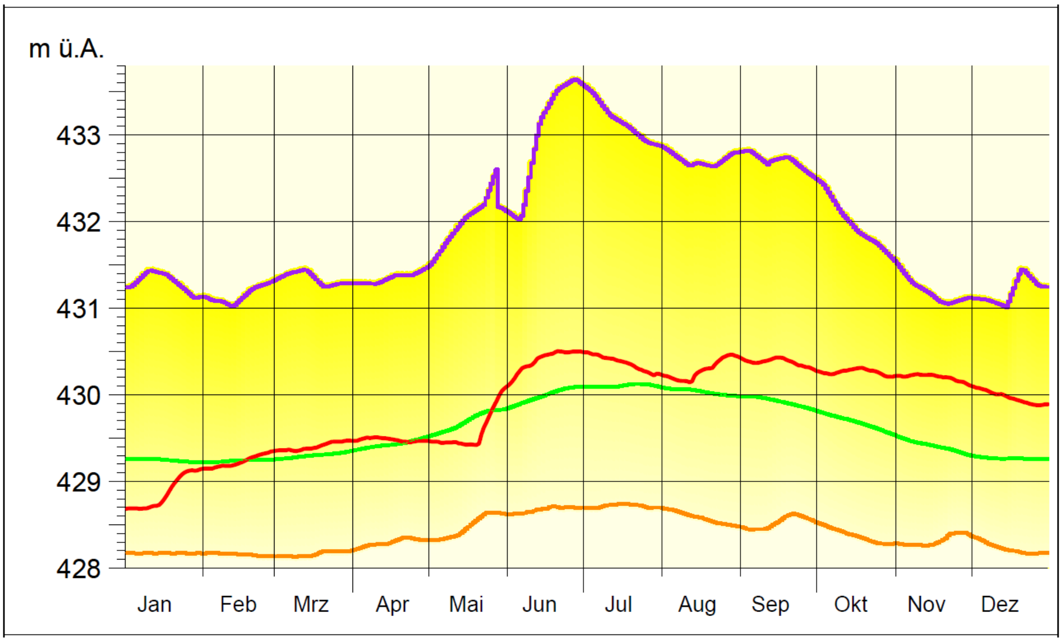

Figure 20: Hydrographs of groundwater levels in 2019 compared with long-term minimum, maximum and averages (1954 - 2018) Feldkirch-Altenstadt gauging station, Bl 01.32.01 A.

Switzerland

The continuous observation of groundwater level, or source outflow, at around 100 measuring points within the framework of the NAQUA National Groundwater Observation makes it possible to map the current state and the development of the groundwater volume at the country level compared to long-term data. This can also be used to demonstrate possible long-term influences on groundwater resources as a result of climate change, such as the projected increase in extreme events such as floods and drought.

In accordance with the long-term weather patterns (temperature and precipitation), longer periods with rather low or high groundwater levels and spring outflows can often be identified in Switzerland's groundwater. In this regard, 2019 falls within a period that has lasted since 2015, which provides a multi-year comparison of low groundwater levels and source outflows.

In January 2019, groundwater levels and source outflows were still low at every third measurement point due to the 2018 drought. The above-average precipitation in eastern Switzerland in January 2019 mainly affected surface groundwater deposits. In Central and Western Switzerland, as well as in Ticino, low groundwater levels and source outflows continued due to the below-average precipitation in January and February.

In April and May 2019, groundwater levels and source outflows on the North side of the Alps steadily declined as a result of the widespread below-average precipitation. In Grison and Ticino, on the other hand, abundant precipitation in April caused groundwater levels and source outflows to rise in the short-term. At the beginning of May, normal to deep groundwater levels and source outflows were observed on the southern side of the Alps.

The abundant precipitation in Central and Eastern Switzerland in May increased groundwater levels in these areas in small deposits, also in those connected to rivers. In the wake of the high temperatures of early June, increased snow-melts and glacier-melting took place at medium and high altitudes. As a result, the groundwater levels in the river-valley plains of the Alps remained within the normal range due to increased river water filtration at normal levels. In other areas, these declined accordingly, as a result of the overall below-average precipitation.

In the course of the country-wide intensive precipitation in October and November, groundwater levels and spring outflows rose widely. Thus, from October to December, normal to high groundwater levels and spring discharges for this time of year were observed increasingly.

Suspended Solids

Austria
At 4.3 million tonnes, the annual suspended solids load at the Alpine Rhine at the Lustenau monitoring station in 2019, was more than twice as high as the average for the annual range in 2009 - 2018 (approx. 2.0 million tonnes). The highest monthly volume was recorded in June, with a volume of approx. 2.379 million tonnes. This represents 55% of the total annual volume.

The lowest daily volume was recorded on 10 February, measuring around 60 tonnes, and the largest daily volume was recorded on 12 June, at 487 880 tonnes (11.3% of annual volume).

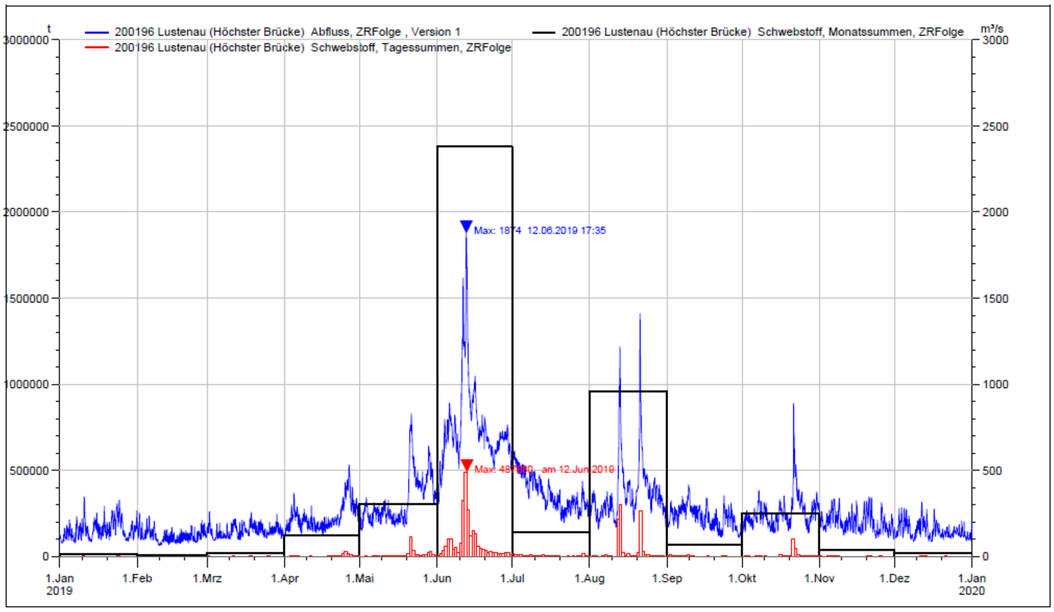

Figure 21: Monthly suspended solid loads at the Alpine Rhine at the Lustenau gauge station in 2019, with daily volume (red curve) and outflow line (blue curve).

2. International Commission for the Hydrology of the Rhine basin (CHR) Activities in 2019

The CHR met twice in 2019, these meetings took place on 28 and 29 March in Nuremberg (Germany) and on 17 and 18 October in Dornbirn (Austria).

Personnel Changes Within the CHR
In the spring session, Mr. Harald Köthe was welcomed as the new Head of the ICWRGC and as the the Federal Republic of Germany's CHR representative.
At this meeting, a special tribute and a minute's commemorative silence for the fatally injured Swiss representative Olivier Overney, were observed. The autumn meeting reported that Mr Carlo Scappozza took over the Hydrology Division of the FOEN in Switzerland on 1 October 2019. Mr Scappozza is expected to be present at the first meeting of 2020.
At the autumn meeting, Mr Sprokkereef announced that he will resign as Secretary of the CHR at the beginning of 2020 after some 17 years. His successor is Mr. Roel Burgers. He will be onboarde at Rijkswaterstaat from November 2019 and will be attend the next meeting.
Mr Ruijgh said his goodbyes at the autumn meeting. Mrs Judith ter Maat takes over as representative of Deltares.

Current and Future Activities Within the Framework of CHR Projects
ASG-Rhein: Contribution of Snow and Glacier-melt to the Rhine Outflows
The second phase of the ASG project started in 2018. Work on the first phase of the ASG project was limited to the period 1901 to 2006. For phase 2, the following 6 work programmes have been formulated:
1. Extension of modelling until 2016
2. Improvements to process modelling
3. Future climate scenarios
4. Stress-test scenarios
5. Improvement of water management measures
6. Routing the outflows

With regard to the climate scenarios to be calculated, there is a compromise between the countries involved (CH/D and NL) and, among others, the DWD.
For the Netherlands, the low-water outflows, and the proportion of glacier-water contained therein, are very important.

Preliminary results were presented at a meeting of the ASG Project Steering Group in June 2019.

The second interim report was published in November 2019.

Socio-economic influences on the low-water regime of the Rhine
In the spring session, the preliminary study "Integrated Overview of the Effects of Socio-Economic Scenarios on the Discharge of the Rhine" was discussed. The modelled water consumption ("water abstraction") was found to be of the correct order of magnitude and corresponds to a EUROSTAT table of water abstractions for various applications.
There were some discussions regarding the filling of the open-cast mines.

The project will continue as a kind of Umbrella project, whereby the CHR will gather knowledge from the various Rhine-bordering countries and publish this information. The CHR is of the opinion that it is very important to pool respurces and knowledge. The aim should be to collate, publish and present a commonly-held (agreed) expert opinion for the Rhine River basin, so as not to confuse the issue with the numerous different results.

A project outline was discussed at the autumn session. The idea is to create an overview at a high level of abstraction. The CHR has commissioned Deltares to continue the project. In particular, the (water) consumption for agriculture, industry (cooling water) and the changes caused by reservoir/dam management, will be further investigated. The quantification will take place by means of workshops, to be organized.

The project work will be accompanied by a CHR Steering Group. A first vote/discussion will take place via Skype in early 2020. The preliminary study is expected to be completed before the summer of 2020.

Hydrological Memory of the Rhine
During the autumn 2018 session, the CHR expressed its interest in a project in which historical data is collected and made available. It was decided to carry out a preliminary study first. A concept specification was presented at the spring session 2019. The BfG will award a contract to the University of Bonn for a 2-year project, including a post-doctoral study.

The contract with the short name HISTG-Rhine (Historical Rhine) is a preliminary study "Quantification of Historical High and Low-Water Levels of the Rhine" and a concept study "Hydrological Memory of the Rhine Area".

In the autumn meeting of 2019, a 4-level concept was presented, which was developed in collaboration with the BfG and the University of Cologne. All institutes and organisations are to be involved in the project, including the Federal WSV. Currently, the conceptual preparations and internal coordination taks are underway at the BfG. National and international networking will also be discussed. The work has not yet been distributed.

Sediment
At the spring meeting it was noted that the topic of morphology is still of interest to the CHR. At the request of Mr Frings of RWTH Aachen, the CHR decided to finance the publication and release of an English-language summary of the sediment report "From Source to Mouth" in an internet journal.

The CHR has been informed that the working group "Rhine in the German/Dutch Border Area" met for the first time in Nijmegen in December 2018. This working group conducts geometric and hydromorphological studies for shipping, with forecast calculations and recommendations for the development and/or maintenance on the border area along the Netherlands and Germany. RWS, Deltares, WSV, BAW and BfG are involved in this project.

The negative river bed changes (so-called "river-bed degradation") play an important role in the Rhine and the Danube river systems. The CHR should try to engage with these scientific issues and/or participate in workshops on these topics. It deals with questions regarding the stability of the sole, but also with issues on general sediment management.

On behalf of Rijkswaterstaat, the Dutch engineering firm Blueland has carried out an overview of completed and ongoing projects in the domain of sediment transport. From a Dutch perspective, an inventory was made of the gaps in knowledge in the field of morphology. This overview was available at the autumn session. The CHR has decided to entrust BOKU (Mr

Habersack) and Blueland the task of expanding on the Dutch overview for the entire Rhine region. Payment for this desktop study is made from CHR funds.

Climate Change
The CHR has found that it is important to address the effects of climate change on the hydrology of the Rhine and the continuation of Rheinblick 2050 with regard to dealing with extremes. There is a direct connection to the current ASG2 and SES projects. The concrete steps which need to be taken will be further discussed during the course of next year. The CHR could carry out or commission the scientific analysis. It is important for the ICPR to pose questions to the CHR in this regard.

Community of Practice Young River Professionals
The initiative for the so-called "Rheingold Project" was taken by a Rijkswaterstaat employee. The CHR Secretariat has established contacts with the Dutch IHP/HWRP Secretariat and will continue to follow developments. The Dutch IHP/HWRP Secretariat (has organised) a so-called "Game-A-Thon" in May 2020, inviting young scientists to develop a "serious game" on cross-border collaboration in the domain of groundwater issues in the Rhine region.

CHR's Strategic Orientation
The results of the interviews with CHR members have been summarized by the secretariat. The main results of the interview round were discussed in the spring session of 2019.
The following conclusions were drawn:
1) The CHR is the only commission/group in the Rhine river basin that deals with hydrology scientifically.
2) The visibility of the CHR can be improved through targeted discussions and communication.
3) Collaboration with the other Rhine Commissions can be improved through targeted profiling.
4) The CHR could strengthen the EU's understanding of the Rhine and the CHR could have a positive impact on the EU's decision-making.
5) The link to UNESCO/WMO could be strengthened.
A revised version of the strategy document was discussed in the autumn 2019 session. It was agreed to divide the document into a strategic paper, and a work programme.

With regard to linking the CHR with WMO and UNESCO, a so-called Letter of Intent (LoI) will be prepared. The aim is to renew collaboration with WMO and UNESCO. In addition to the Memoranda of Understanding with WMO and UNESCO, agreements with the Rhine Commissions ICPR and CHR are also being prepared, in order to strengthen collaboration. A preliminary meeting will take place on 25 November in the run-up to the CCNR's Low-Water Symposium.

CHR Anniversary 2050
CHR 2020 wants to celebrate its 50th anniversary with a symposium. A jubilee publication will also be printed.
The scheduled date for the event is/was 23-25 September 2020 in the Netherlands.
In the meantime, the event has been postponed to March *2012. (*Mistake? Shouldn't it be 2021?)

A concept programme of the event was discussed in the autumn session of 2019.

The first day of the event should be oriented more along political lines, and take a more festive form. The new CHR strategy will be presented on this day and collaboration between the states and between the CHR and external organisations will be reaffirmed.
The current CHR projects will continue to be presented on the first day. Presentations for the Rheinblick and SES Rhine projects should be scheduled.
On the second day, the future of the CHR will be discussed.

Collaboration with Other Organizations
On 21 June 2019, the German CHR representative Mr Köthe took part in the CCR event "Shipping and other Uses of the Rhine within the Framework of the Challenges of Climate Change" and represented the CHR in the panel discussion in Strasbourg. An experience report was exchanged with the CHR colleagues.

The Chairman of the CHR was invited to the General Assembly of the ICPR in Malbun, Liechtenstein (July 4-5, 2019). There, he delivered a lecture outlining the CHR projects and the desired collaboration with the ICPR.

On 25 November 2019, the secretariats and presidents of the three Rhine Commissions met in Bonn to discuss the strengthening of their collaboration.

A meeting was held at the Danube Commission in Kiev at the end of October 2019. The topic was how hydrological knowledge should be used. Mr Habersack and Mr Köthe took part in the Kiev meeting.

CHR Publications
The CHR published the Rhine region's Hydrological Annual Report for 2018 in two languages.