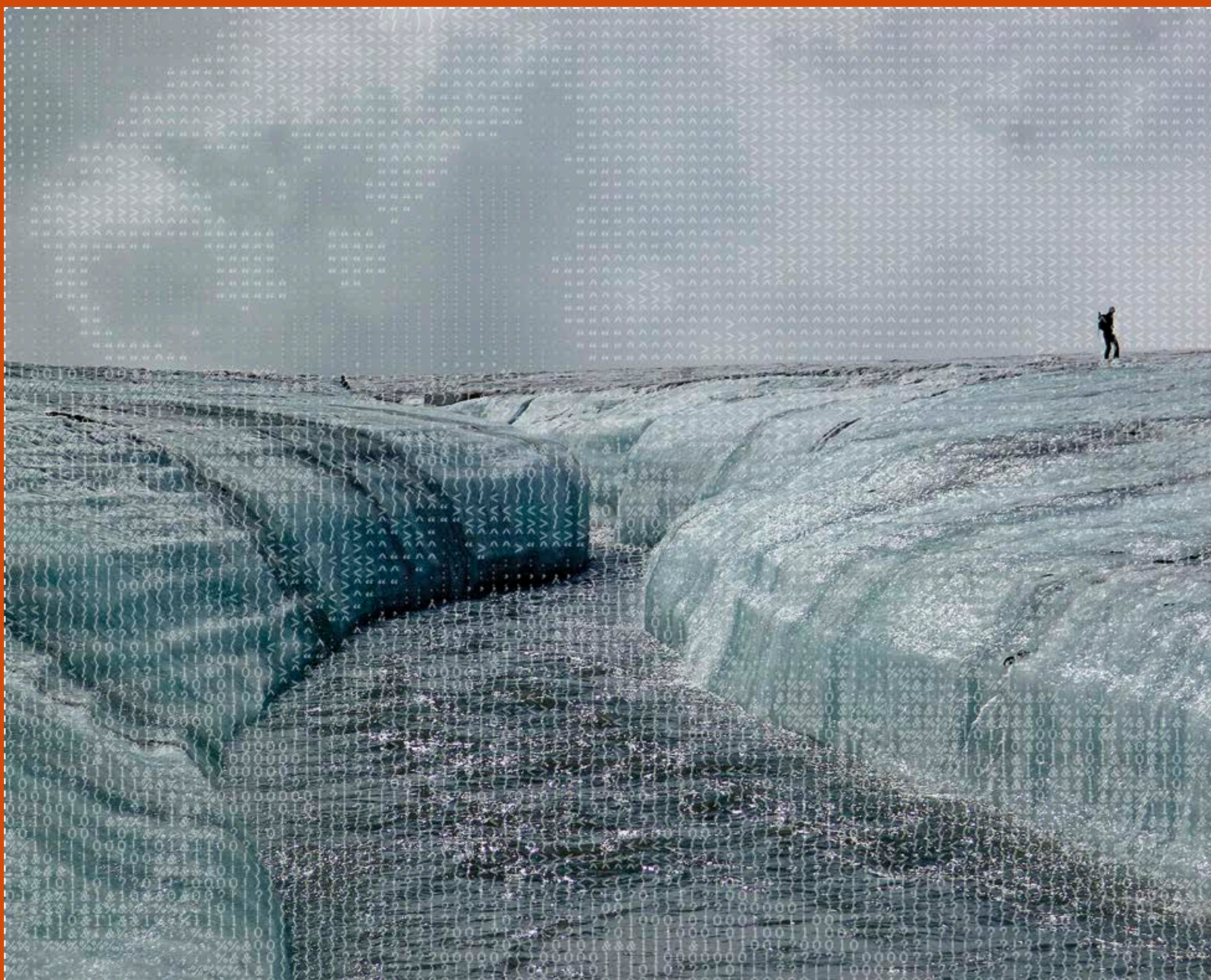
> Hydrological Yearbook of Switzerland 2015

Discharge, water level and water quality of the Swiss water bodies



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> Contents

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A torrent pouring out of the Faverges glacial lake (Glacier de la Plaine Morte)
at the beginning of August 2015.
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This publication is also available in French, German and Italian.

Further information and data at www.foen.admin.ch/water

> Foreword

The hydrological year 2015 was marked by two significant but very different hydrological events: a week of serious floods from late April to early May and then a long warm and very dry period lasting from the spring until the winter of 2015/16. Although such contrasting events can repeatedly occur naturally, recurrent extremes of weather are reinforcing the impression within society that the effects of climate change are slowly but surely being felt. The media have also taken this on board, as shown by the many inquiries made to the Federal Office for the Environment (FOEN) in summer 2015.

Together with MeteoSwiss and other federal offices, the FOEN set up a new network, the National Centre for Climate Services (NCCS), the purpose of which is to provide information on climate change and its effects to decision makers and the population at large. The FOEN Hydrology Department is the project leader for projects on the subject of "Hydrological Principles for Adaptation to Climate Change" to supply answers to questions about the economy (agriculture, water management) or the community, for example in relation to flood protection.

The text and tables in the Hydrological Yearbook are based on large amounts of data, which are collected, stored, analysed and utilised. It is beyond the scope of this Yearbook to list all the tasks required to provide high quality data. But in 2015, the collation and transferral of such data is worthy of particular mention: the Hydrology Department, together with the Federal Institute of Metrology (METAS), developed a concept to indicate how the electronic equipment at the hydrometric monitoring stations can be replaced in order to standardise the facilities at all the stations and modernise data transfer. Tests at 15 stations over a period of six months showed that the technology selected is reliable, robust and versatile.

With the publication of the 2015 edition, the Hydrological Yearbook is again appearing with regular frequency. Sincere thanks are due to everyone who contributed to this Yearbook. The Hydrological Yearbook now has a format which the FOEN is convinced will stand the test of time.

Olivier Overney
Head of the Hydrology Division
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> Abstracts

The Hydrological Yearbook of Switzerland is published by the Federal Office for the Environment (FOEN) and gives an overview of the hydrological situation in Switzerland. It shows the changes in water levels and discharge rates of lakes, rivers and groundwater and provides information on water temperatures and the physical and chemical properties of the principal rivers in Switzerland. Most of the data is derived from FOEN surveys.

Keywords:
hydrology, rivers, lakes, groundwater, water level, discharge, water temperature, water quality

Das «Hydrologische Jahrbuch der Schweiz» wird vom Bundesamt für Umwelt (BAFU) herausgegeben und liefert einen Überblick über das hydrologische Geschehen auf nationaler Ebene. Es zeigt die Entwicklung der Wasserstände und Abflussmengen von Seen, Fliessgewässern und Grundwasser auf und enthält Angaben zu Wassertemperaturen sowie zu physikalischen und chemischen Eigenschaften der wichtigsten Fliessgewässer der Schweiz. Die meisten Daten stammen aus Erhebungen des BAFU.

Stichwörter:
Hydrologie, Fliessgewässer, Seen, Grundwasser, Wasserstand, Abfluss, Wassertemperatur, Wasserqualität

Publié par l'Office fédéral de l'environnement (OFEV), l'Annuaire hydrologique de la Suisse donne une vue d'ensemble des événements hydrologiques de l'année en Suisse. Il présente l'évolution des niveaux et des débits des lacs, des cours d'eau et des eaux souterraines. Des informations sur les températures de l'eau ainsi que sur les propriétés physiques et chimiques des principaux cours d'eau suisses y figurent également. La plupart des données proviennent des relevés de l'OFEV.

Mots-clés:
hydrologie, cours d'eau, lacs, eaux souterraines, niveaux d'eau, débits, température de l'eau, qualité de l'eau

L'«Annuario idrologico della Svizzera», edito dall'Ufficio federale dell'ambiente (UFAM), fornisce una visione d'insieme degli eventi idrologici in Svizzera. Illustra l'andamento dei livelli idrometrici e delle portate dei laghi, dei corsi d'acqua e delle acque sotterranee e contiene informazioni sulle temperature e sulle proprietà fisiche e chimiche dei principali corsi d'acqua in Svizzera. I dati in esso pubblicati provengono in gran parte da rilevazioni effettuate dall'UFAM.

Parole chiave:
idrologia, corsi d'acqua, laghi, acque sotterranee, livelli delle acque, portate, temperatura dell'acqua, qualità dell'acqua

> Summary

Weather conditions

The 2015 annual temperature in most regions of Switzerland was 1.0 to 1.4 degrees above the 1981–2010 average. The annual precipitation only reached 60 to 85 % of normal in most areas north of the Alps. It was 80 to 100 % widely in the Alps, while 70 to 95 % was recorded on the south side of the Alps.

Snow and glaciers

Averaged over the winter of 2014/15 as a whole, the snow depths on the southern Alpine slopes were above average, except for the southern Graubünden valleys, and the adjacent regions to the north and west; elsewhere they were widely just on average. The glaciers in the Swiss Alps had above-average mass losses in 2015. The hot July led to extreme glacier melt though the cooler weather in August and September prevented record values.

Discharge conditions

Most of the 2015 annual average surface water discharges were below normal. The discharges in glaciated catchments were normal to above average. A flood event at the beginning of May brought very high peak discharges in western Switzerland between Lake Geneva and Basel. Precipitation was extremely low in the second half of the year. Many monitoring sites recorded below-average discharges every month from July to December. In some regions the monthly levels never rose above 80 % of the long-term average from July onwards. Widespread new record low monthly discharges were measured on the north side of the Alps.

Lake levels

New monthly record high levels occurred in May. Average water levels on Lakes Neuchâtel and Geneva were some 30 cm above the long-term monthly average. The level of Lake Neuchâtel had never been higher since the second Jura water correction. The long period of low precipitation in the second half of the year did not generate low water levels in all the lakes. Some benefited from the relatively high levels they had following the May floods. Lakes which did not benefit from this effect recorded new seasonal low levels in the autumn.

Water temperatures

Overall, the 2015 annual average values continue the unbroken trend towards higher water temperatures observed since 1960. Anormal temperature profile over time was recorded in the rivers in the spring, but a period of extreme hot weather began in July. The resultant steep rise in water temperature in some locations was repeatedly interrupted by cooling periods, as was also the case later in the summer and autumn.

Stable isotopes

In 2015 the stable isotopes in the precipitation were again characterised by low δ-values for the winter. Above-average δ-values were measured in the summer, in line with the 2015 heatwave. However, another consequence of the hot summer was that more glacier melt water – with more negative δ-values – was discharged at that time.

Groundwater

The year 2015 began with widely normal groundwater levels and spring discharges and ended at a low level due to the prolonged drought from June.

1 > Notable phenomena in 2015

Intensive precipitation led to a flood situation at the beginning of May 2015. The levels in some water bodies reached risk level 4. In contrast, the summer months of July and August 2015 will be remembered as exceptionally hot and dry. In autumn too, precipitation was well below average for the time of year. The situation was particularly extreme on the Central Plateau and in the Jura in mid-November.

1.1 Flood event of early May 2015

Exceptionally intense precipitation in early May caused levels in the waterbodies to the north of the Alps, in particular in western Switzerland to rise very sharply. The meteorological and climatological evaluation of the heavy precipitation by MeteoSwiss indicated that strong westerly to south-westerly high-altitude winds brought moist and increasingly mild air originating in the subtropics to the Alpine region. The front remained almost stationary over Switzerland for some time, causing prolonged and often copious precipitation. The measured precipitation remained high throughout the six-day precipitation period.

Precipitation total from 30 April to 6 May 2015 (mm)

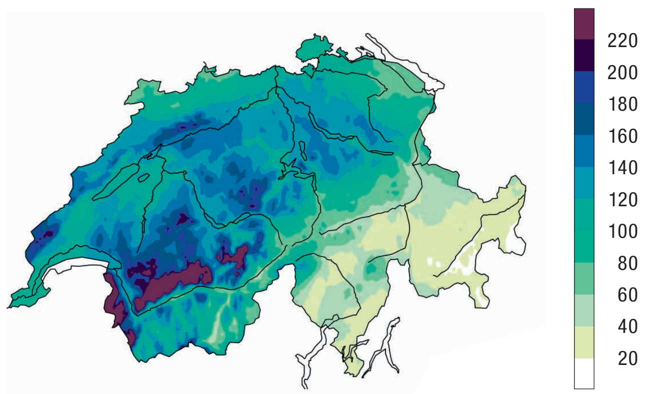


Figure 1.1 *Spatial distribution of precipitation totals from 30 April to 6 May 2015. The absolute values in millimetres are shown. Source: MeteoSwiss.*

Over a month's precipitation in six days

From 30 April to 6 May an average of some 100 mm of rain fell across Switzerland. Rainfall was highest in Lower Valais, the Vaud Alps and the adjacent Bernese Oberland. Around the Dents du Midi and from Les Diablerets to the Wildstrubel area, higher elevations received 200 mm precipitation or more (Figure 1.1). In some locations this represents up to 140 % of the usual total precipitation for the whole month of May.

Rapid rise in water levels

The intense rainfall caused the rivers and lakes in the affected regions to rise rapidly and steeply. The first peak discharges were observed on the evening of Friday 1 May. By the morning of Saturday 2 May many smaller water bodies had reached maximum levels not recorded for a long time or even at all in recent decades.

As rain continued to fall in the days that followed, larger water bodies such as the rivers Aare and Rhine, Lake Thun and the three major lakes along the edge of the Jura (Lakes Biel, Neuchâtel and Murten) also rose to high levels, reaching risk level 4 (high flood risk) in some locations. The heavy rainfall also led to distinct and immediate rises in groundwater levels on a local basis.

At times the Rhine carried so much water that it had to be closed to shipping. Due to the foresight in regulating the lakes, it was possible to avoid even higher peak discharges and flood damage in the Aare. Critical situations did occur in some locations and landslides were a consequence of the saturated ground.

Flood events in early May 2015 – Rivers

Station name	Period (years)	Previous record (m^3/s)	Date (month/ year)	Previous record May (m^3/s)	Date (year)	HQ_{2015} (m^3/s)	Date	Time	Return period	Max. risk level reached
Aare – Bern, Schönau	80	613	5/1999	613	1999	510	04.05.15	17:42	30–50	4
Aare – Brügg, Aegerten	80	761	5/1999	761	1999	737	07.05.15	23:40	50–100	4
Aare – Murgenthal	80	1262	8/2007	926	1985	**974**	04.05.15	08:55	10–30	3
Aare – Thun	80	564	5/1999	564	1999	480	05.05.15	10:22	50–100	4
Arve – Genève, Bout du Monde	80	840	9/1968	548	1999	**905***	02.05.15	08:02	>100	5
Broye – Payerne, Caserne d'aviation	95	415	12/1944	161	1977	**253**	02.05.15	00:15	10–30	3
Grande Eau – Aigle	80	123	11/1944	52.3	1999	**60.2**	04.05.15	08:17	10–30	3
Gürbe – Belp, Mülimatt	92	60.8	8/2014	44.6	1999	**51.4**	04.05.15	07:07	10–30	3
Murg – Murgenthal, Walliswil	34	57.3	8/2007	27.7	2013	**53.4**	01.05.15	21:35	10–30	3
Rhône – Chancy, Aux Ripes	80	1700	11/1944	1305	1999	1238	02.05.15	07:45	10–30	2
Rhône – Genève, Halle de l'Ile	80	740	11/2002	650	1978	**689**	07.05.15	06:05	30–50	–
Sarine – Broc, Château d'en bas	92	460	9/1940	269	1999	**325**	02.05.15	02:35	10–30	3
Simme – Latterbach	29	316	8/2005	225	1999	213	04.05.15	07:41	10–30	2
Simme – Oberwil	94	200	11/1944	136	1999	128	04.05.15	07:25	10–30	3
Veveyse – Vevey, Copet	31	155	7/2007	76.4	1999	**159***	02.05.15	02:25	30–50	4

Flood events in early May 2015 – Lakes

Station name	Period (years)	Previous record (m AMSL.)	Date (month/ year)	Previous record May (m AMSL.)	Date (year)	HW_{2015} (m AMSL.)	Date	Time		Max. risk level reached
Bielersee – Ligerz, Klein Twann	32	430.88	8/2007	430.19	1999	**430.51**	06.05.15	15:15		4
Brienzersee – Ringgenberg	74	566.05	8/2005	565.36	1999	564.76	06.05.15	08:35		2
Lac de Neuchâtel – Neuchâtel, Port	32	430.27	8/2007	430.05	1999	**430.44***	08.05.15	14:55		3
Lac Léman – St-Prex	72	372.88	12/1965	372.43	1986	**372.43**	07.05.15	04:35		2
Murtensee – Murten	32	430.47	4/2006	430.09	1983	**430.44**	08.05.15	18:05		3
Thunersee – Spiez, Kraftwerk BKW	74	559.25	8/2005	559.17	1999	558.39	05.05.15	03:32		4
Vierwaldstättersee – Luzern	79	435.23	8/2005	434.94	1999	434.15	06.05.15	21:55		2
Zugersee – Zug	85	414.49	5/1999	414.49	1999	414.06	07.05.15	03:45		2

* New record highs
Bold: New May record highs

New records on the Arve and Lake Neuchâtel

The Arve at Geneva had discharge volumes not seen since records began in 1935. It recorded in excess of a 100 year flood on 2 May. A new record level was also recorded on Lake Neuchâtel at Neuchâtel on 8 May: with a water level of 430.44 m AMSL, it exceeded the previous record of 430.27 m in August 2007 by 17 cm.

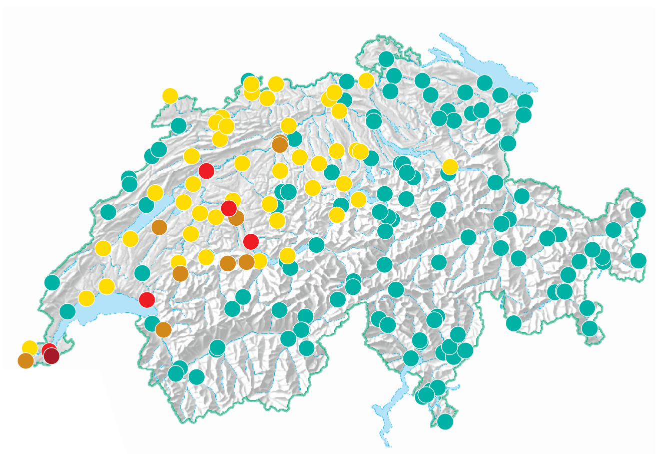
New records for the month of May were recorded in many places, including on the Broye, on the Aare at Murgenthal, the Birse at Moutier, the Gürbe at Belp, the Venoge at Ecublens and the Veveyse at Vevey (30-year flood) and on Lakes Biel, Murten and Geneva.

Detailed information on the peak data and maximum risk levels reached can be found in the table on page 7 and in Figure 1.2.

Normalisation of water levels

After the rainfall had subsided, levels and discharges fell in most of the rivers and lakes. The Bernese Oberland lakes, the three major Jura lakes and the River Aare below Lakes Thun and Biel remained high, but thanks to the subsequent good weather, the flood situation also returned to normal on these waterbodies in the second half of May.

Flood situation on the rivers
Start of May 2015



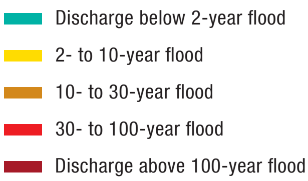


Figure 1.2 *Maximum discharges compared with flood statistics.*

1.2 Drought in summer and autumn 2015

After a first half year with generally average to slightly wet conditions, precipitation was exceptionally low in large areas of Switzerland from the end of June 2015 (Figure 1.3). The resultant drought had a perceptible impact on the levels of surface waters.

As early as mid-July, some monitoring stations on the western Plateau were recording discharges only to be expected every two to ten years on average. The low water situation intensified during the months of August and September. Small and medium-sized rivers in the Jura and on the central and eastern Plateau were increasingly also affected by exceptionally low discharges which only occur every two to ten years and in some cases even less often. From July onwards local authorities in some regions ordered restrictions and bans on water extraction from rivers.

Increasingly, the levels in numerous lakes were well below the seasonal norm. This was particularly the case for Lakes Constance and Walen and in Central Switzerland Lakes Sarnen, Lucerne and Zug. Lakes Zurich and Pfäffikon even recorded new monthly record lows in August and September. On the three major Jura lakes and Lakes Thun and Brienz, water levels remained within the normal seasonal range, however. The discharges on most of the rivers fed by the glaciers in the Alps were also normal for the time of year or were even elevated due to the exceptionally high melt.

As a result of some precipitation, the low water situation temporarily eased slightly from the end of September to the middle of October. Although discharges remained widely below average, lake levels – except in Lake Zug – gradually returned to the long-term seasonal average range.

The low water situation was then exacerbated once again by the extreme drought from the end of October. Water levels are generally rather low at that time of year, though the situation was much more pronounced in 2015. The major rivers, particularly the Aare from Lake Biel, the Limmat, the Thur and the Rhine below Lake Constance, then recorded discharges equivalent to only about half the seasonal norm and which occur statistically only every two to ten years (Figure 1.4). In mid-November many streams and smaller rivers on the north side of the Alps recorded low discharges expected even less frequently. Rivers in the Jura were particularly affected, as were increasingly those in the foothills of the Alps. A few streams and river sections such as the upper reaches of the Töss even dried out completely. Fish had to be removed from the water in some places.

Half year precipitation totals 2015 in % of normal
(reference period 1981–2010)

January–June 2015

July–December 2015

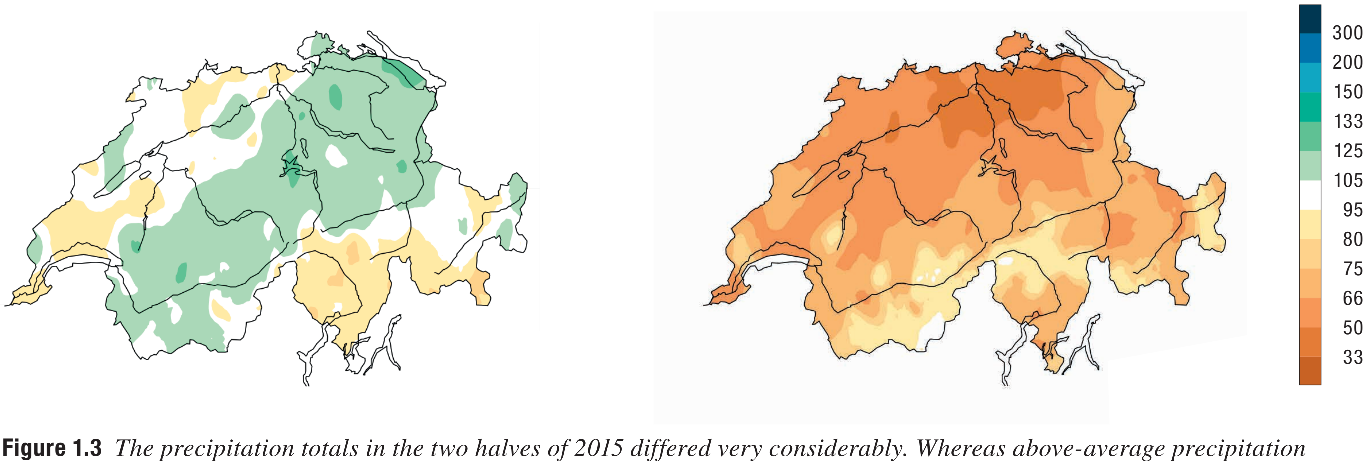


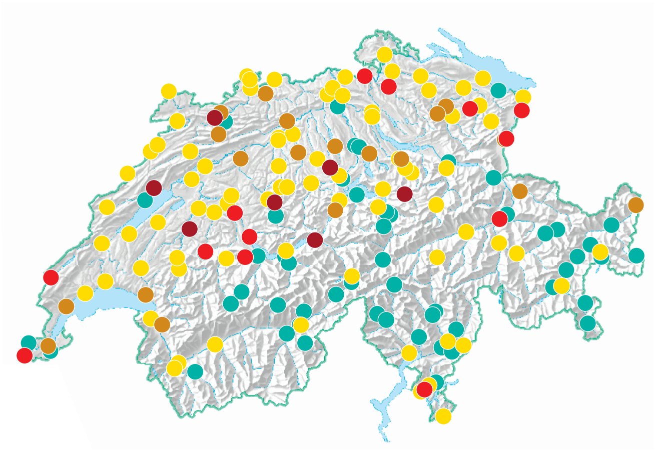
Figure 1.3 *The precipitation totals in the two halves of 2015 differed very considerably. Whereas above-average precipitation fell in large parts of Switzerland from January to June, the July to December totals were well below the 1981–2010 average throughout the country. Source: MeteoSwiss.*

Most of the lakes again had well below-average levels. Lake Brienz, the three major Jura lakes and Lake Lugano were now also affected. New November lows were reached on Lakes Sarnen and Zurich. The levels for Lakes Aegeri and Pfäffikon were the lowest ever recorded since records began in 1974 and 1987 respectively.

The precipitation beginning on 20 November on the north side of the Alps eased the situation, especially in small and medium-sized rivers, but the return of dry weather in December allowed discharges to fall again. Monitoring stations in the Alps, such as on the Rhone and in the Alpine Rhine basin, were then worst affected by exceptionally low discharges.

The extreme lack of precipitation on the south side of the Alps also resulted in low water discharges with a return period of between two and ten years in Ticino (Figure 1.4). Levels also fell to very low values in Lakes Maggiore and Lugano.

Low water situation in the rivers
2015



Discharge above 2-year low water
2- to 10-year low water
10- to 30-year low water
30- to 100-year low water
Discharge below 100-year low water

Figure 1.4 *Minimum discharges (mean over 7 days) compared with the low water statistics.*

Increasingly low groundwater levels and spring discharges

The prevailing drought from June initially had little effect on groundwater levels and spring discharges because they started from a normal to high level following the above-average precipitation in May. Therefore widespread normal groundwater levels and spring discharges were still recorded in the summer (Section 5.1). As the drought continued, however, groundwater levels and spring discharges fell continuously. Initially, low groundwater levels were limited to small river valleys in the Jura, central Plateau and Alpine foothills. Karst springs in the Jura and unconsolidated rock springs on the central Plateau fed from groundwater resources near the surface also suffered falls in discharge. Nevertheless, groundwater levels and spring discharges were generally higher in summer 2015 than in the hot summer of 2003.

As lower air temperatures arrived in the autumn, the glacier melt in the Alps and therefore also river water infiltration from the large Alpine rivers into the groundwater decreased and groundwater levels along the major rivers fell in the autumn. Due to the prolonged drought of autumn 2015, groundwater levels and spring discharges fell widely below those of 2003. In the Jura the lowest levels and discharges of 2015 occurred in mid-November, because some high rain there on the 20 and 21 of the month allowed the groundwater to recharge significantly. In the other regions, the year's lowest levels and discharges were recorded at the end of December. New record lows for December occurred locally, e. g. at the Glattfelden monitoring site (Figure 1.5).

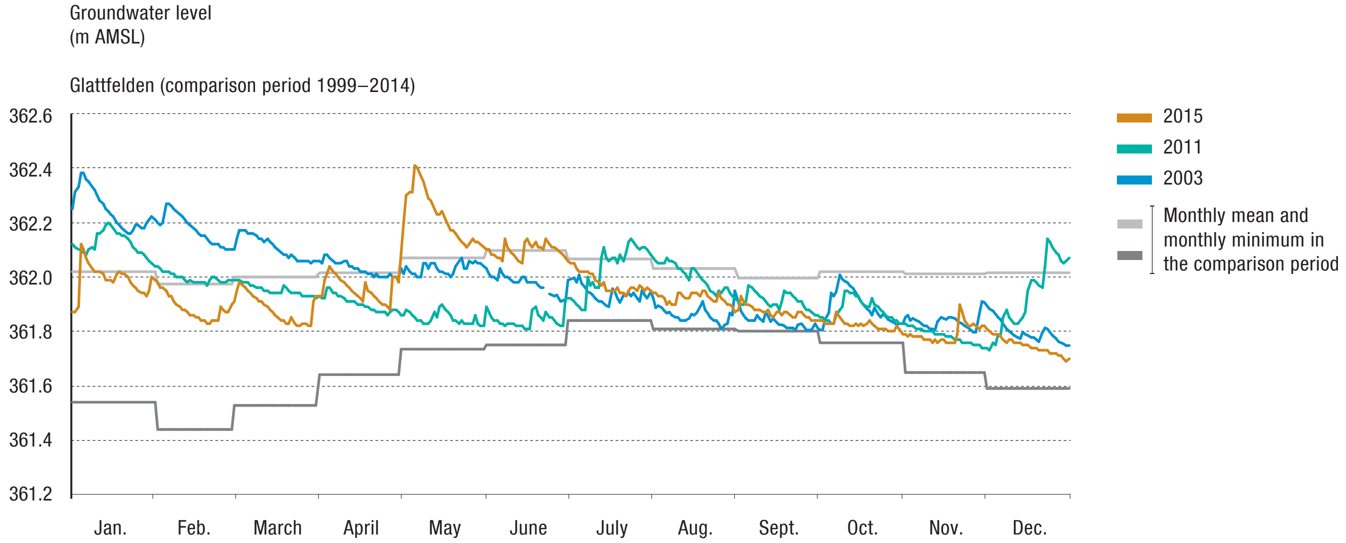


Figure 1.5 *Groundwater level at Glattfelden in 2015 and compared with the dry years of 2003 and 2011 and with the long-term statistical data for the 1999–2014 comparison period.*

High water temperatures during the hot period from July 2015

Water temperatures in the spring of 2015 were still in line with the long-term trend for the 1988–2014 period (Figure 1.6). This meant that the previous annual average record highs were only exceeded at a few stations in 2015 despite the summer heatwaves. From June and during subsequent months, unusually rapid changes of temperature and wide fluctuations in maximum temperatures followed by periods of rapid cooling were observed (see also Section 4.3). The water temperatures recorded considerably exceeded the mean daily data in the long-term monitoring sets along the Aare, Emme, Kleine Emme and Rhine and at other stations, particularly in July (Figure 1.6).

As a result of the elevated water temperatures and the lack of longer cooling periods due to poor weather, fish deaths occurred in some places. The fact that the heat coincided with the low water period served to intensify the negative effect of the heatwave. Great efforts had to be made to remove cold-loving trout, for example those in the Emmental and Fricktal, and to resettle them in cooler waters. If the temperature exceeds the tolerance range of the fish, this can have an additional impact: It means that the young fish develop faster, the competitiveness and disease resistance of the salmonids is reduced and heat-tolerant fish of the carp type and other less sensitive species can become dominant. Habitats are then lost – in the short term at least – and there is a risk of immigration and longer-term expansion of other species.

Water temperatures in the last quarter of 2015, especially in November and December, were often higher than the data in the long-term monitoring sets (Figure 1.6). The daily record highs were exceeded repeatedly at many stations (Figure 4.12). Even if the high temperatures are still within the tolerance range of the fish, indirect consequences for population development in the waterbodies can also be expected at that time of year: embryos can develop more quickly and in the spring hatching can occur even earlier.

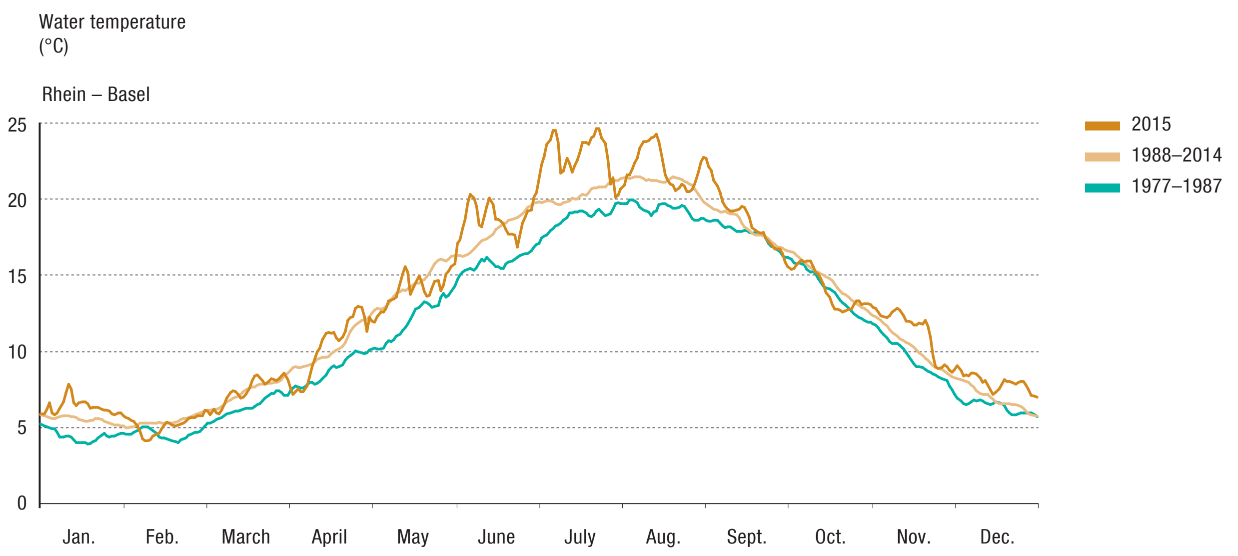


Figure 1.6 *Water temperatures in the Rhine at Basel: Shown are the averaged daily mean values over the 1977–1987 and 1988–2014 periods and the daily mean values for 2015.*

2 > Weather conditions

The annual temperature in 2015 was 1.0 to 1.4 degrees above the 1981–2010 average in most regions of Switzerland. The annual precipitation generally reached only 60 to 85 % of normal on the north side of the Alps. In the Alps precipitation was widely 80 to 100 % whilst the south side recorded 70 to 95 %.

In the first half of January the weather in Switzerland was determined mainly by mild westerly and south-westerly winds, but north-westerly and northerly winds brought winter conditions back to the country in the second half of the month. February proved wintry, with widespread below-average temperatures and snowfall down to low elevations on both sides of the Alps. Despite the cold February, the Swiss winter was very mild overall, exceeding the 1981–2010 average by 0.7 degrees.

After some dull and wet days early in the month, March brought glorious high pressure weather until around mid-month. It ended with late winter snow down to 600 m and stormy conditions on both sides of the Alps. Switzerland basked in predominantly calm, sunny and mild spring weather in April.

As April ended and May began, a period of very high precipitation set in. An average of around 100 mm of rain fell throughout Switzerland in just six days. The highest rainfall occurred in Lower Valais, the Vaud Alps and the adjacent Bernese Oberland. Higher elevations in these regions received 200 mm of precipitation or even more. With further heavy rainfall towards the middle of the month, several monitoring stations recorded their wettest May since records began, particularly in the western Alps and the Bernese Oberland.

The summer of 2015 ranked as the second warmest after 2003 in the 152-year Swiss monitoring history. July was widely the hottest month since records began on the south side of the Alps, in the Engadine, Valais and western Switzerland. From 1 to 7 July 2015 Switzerland experienced a week of extreme heatwave. At the end of that week Geneva recorded 39.7 degrees, the highest temperature ever recorded on the north side of the Alps in Switzerland. On the south side the heatwave began in mid-July.

Precipitation was widely well below average as early as the summer. This low level continued in the autumn. Above-average precipitation fell over wide areas only in September and uniquely in the west of Switzerland, the Ticino and Graubünden. Widespread below-average amounts were recorded in October and the first three weeks of November remained mainly free of precipitation throughout Switzerland.

The south side of the Alps experienced record low precipitation for the November/December period. In Lugano and Locarno-Monti precipitation was only 0.8 mm; the norm is 200 to 250 mm.

The prolonged extremely mild and almost precipitation-free high pressure weather led to a remarkable scarcity of early winter snow nationwide.

Source: Federal Office of Meteorology and Climatology (MeteoSwiss)

Annual precipitation total (% of normal)

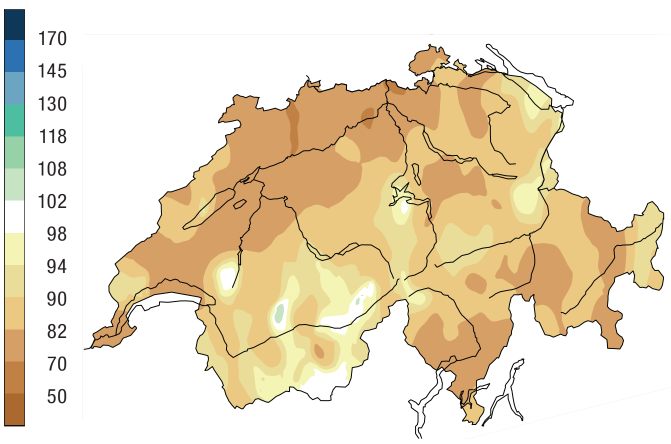


Figure 2.1 *Annual precipitation in 2015 was well below average in most Swiss regions. North of the Alps it was only 60 to 85 % of the 1981–2010 average.*

3 > Snow and glaciers

Measured over the winter of 2014/15 as a whole, snow depths on the southern slopes of the Alps were above-average, except for in the southern Graubünden valleys, and the adjacent areas to the north and west; elsewhere they were widely just on average. The glaciers in the Swiss Alps had aboveaverage mass losses in 2014/15. The hot July caused extreme glacier melt.

3.1 Snow

In the first half of October 2014 the weather was dominated by southern high pressure systems, with precipitation in the form of snow only falling in the high mountains. On 21 October a deep cold front caused a drop in temperature.

In November a thick blanket of snow with a snow line generally above 2000 m AMSL formed at high elevations in Upper Valais, on the central southern slopes of the Alps, but also in the adjacent regions to the north from the eastern Bernese Oberland to Surselva. It contributed to above-average snow depths over the whole winter.

December was exceptionally mild with little snow until a cold front at the end of the month brought snowfall, which carpeted the central Plateau in particular with large amounts.

January was characterised by high precipitation in the south and the Engadine but average elsewhere. The first half of January was mild and springlike and the snow line was well above 2000 m AMSL at times. Winter conditions returned in the second half of January and a series of cold fronts brought repeated snowfalls to the central Plateau and in the Jura. By month end there were also significant amounts of snow in the west and north.

Snowfall in February was well above average in the south and slightly below average in the north. High snowfall occurred mainly in Upper Valais, on the main central Alpine ridge and in northern Ticino, largely due to heavy falls in mid-February.

Although March was very sunny in the north, snowfall early in the month and above all a heavy fall at the end in the west and north meant that snow depths were average or slightly above.

April brought average snowfall only in the Alpine foothills. In the south there was very little precipitation, bringing a threat of forest fires at times.

The beginning of May was marked by intense precipitation in the western and northern Alps. Because the snow line was generally high, the rain caused any remaining snow to melt. Heavy snow fell again in mid-month on the southern Alpine slopes and from 18 to 22 May in the central and eastern Alps, but it soon melted.

Despite isolated cooler periods, which did not occur in the hundred-year summer of 2003, there was practically no summer snowfall below 3000 m AMSL between June and August 2015. Even before the July heatwave there was no snow below 2000 m AMSL in many parts of the country after about 20 June.

Source: WSL Institute for Snow and Avalanche Research (SLF)

Snow depth (% of normal)

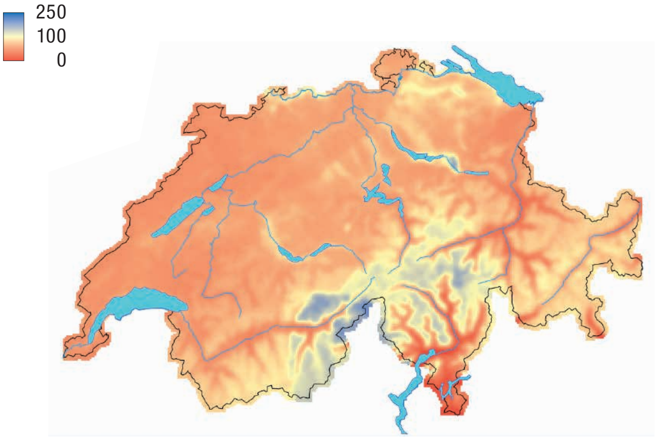


Figure 3.1 *Snow depth in winter 2014/15 compared with the 1971–2000 period. The months of November to April are included.*

3.2 Glaciers

In the hydrological year 2014/15, mass balance monitoring was carried out on 21 Swiss glaciers. Average snow depth was determined on the glaciers in mid-April 2015. The snow only started to disappear when the hot period began in July. The hot, stable summer weather that continued with few interruptions until mid-August resulted in exceptionally high glacier melt. Significant cooling and new snowfall in the second half of August and in September finally ended this phase of high mass losses.

The differences in mass balance from glacier to glacier were particularly pronounced in 2015. The least drastic melts with an average ice thickness loss of some 70 cm occurred in southern Valais (Findelen Glacier, Allalin Glacier). In contrast, the glaciers between the Bernese Oberland and Valais suffered very badly. Extreme thickness losses of over 250 cm were recorded (Glacier du Tsanfleuron, Glacier de la Plaine Morte). Most of the Swiss glaciers in both the northern and southern Alps had thickness losses of between 100 and 200 cm. Smaller, low elevation glaciers where the winter snow melted away completely during July were worst affected by the hot weather.

Transposed to all the Swiss glaciers, the estimated volume loss for the hydrological year 2014/15 was 1300 million cubic meters of ice. This represents a reduction in the total glacier volume still in existence of nearly 2.5 %. Although the glacier melts were well above average, they did not beat the records set in the hot summer of 2003. The mass balance of the Swiss glaciers for the hydrological year 2014/15 is within a range similar to the years 2006 and 2011, which were also very negative.

Source: Department of Geosciences, University of Fribourg, and Laboratory for Hydraulics, Hydrology and Glaciology (VAW)

Figure 3.2 *Snow had disappeared from the glaciers by the beginning of August 2015, except at very high elevations. Brunegg Glacier at the foot of the Bishorn in Valais.*

4 > Rivers and lakes

The majority of mean annual discharges were below normal in 2015. Glaciated regions had normal or above-average discharges. A flood event at the start of May brought very high peak discharges in western Switzerland. Precipitation was extremely low in the second half of the year. New monthly minimum discharges were recorded widely on the north side of the Alps. The heatwave in July led to record high water temperatures in the rivers.

4.1 Discharge conditions

The annual mean discharges of the major river regions in 2015 were close to the average for the 1981–2010 reference period on the Rhone down to Lake Geneva and on the Ticino, Inn and Alpine Rhine. Those on the Aare, Reuss, Limmat, Thur and Doubs were 10 to 15 % below the long-term average. Only three quarters of the normal volumes were discharged on the Birs and Maggia. The effect of snow and glacier melt can be seen in the medium-sized catchments (Figure 4.2). Regions with significant glaciation discharged average and even above-average volumes despite modest precipitation. The Saltina, the Massa and the Reuss at Andermatt exceeded the normal level by around 15 % and the Rosegbach by as much as 20 %.

Discharges in many areas of western Switzerland and the central Plateau were within 70 to 90 % of the normal range. The lowest volume was discharged on the Mentue at only 65 % of normal. The catchments with normal discharges (90 to 110 %) were in the Bernese Oberland, the central and eastern Alpine foothills, Ticino and the Engadine. But annual mean data gives little indication of the conditions during the year. In some regions average annual discharges were characteristic of a wet first half year and a dry second half. This split between the two halves of the year is illustrated very well on the Aare, Reuss and Limmat (Figure 4.3), and also

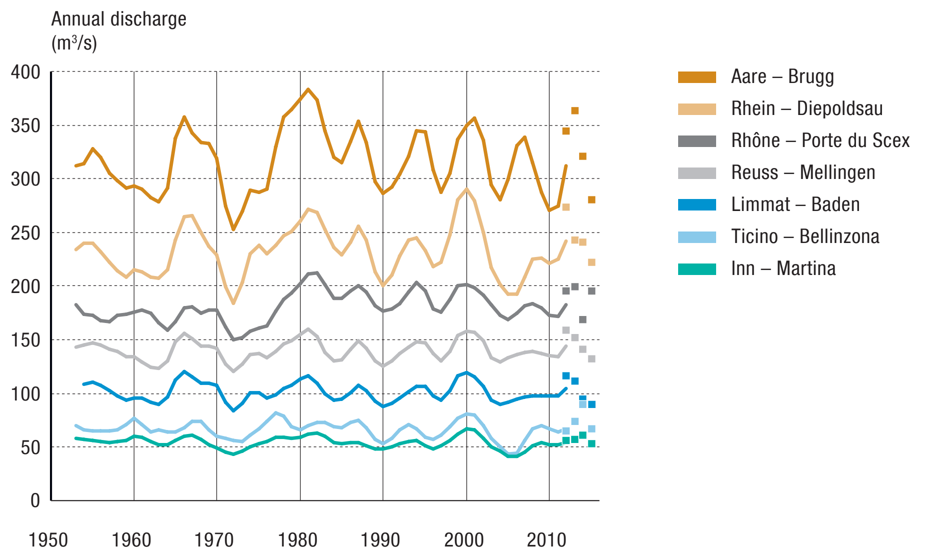


Figure 4.1 *Changes in the annual discharges for selected large catchments from 1950. Rolling averages (over 7 years) are shown as lines and the last four annual discharges are shown as points.*

on the Emme, Thur and Muota (Figure 4.4). On the Thur at Andelfingen, from January to June 20 % more water was discharged than the long-term average, but from July to December it was less than half the normal volume.

The months which stood out in the first half of the year were January and May with some discharges significantly higher than the long-term average. A deep depression which moved into the Alpine region from the north in the first few days of the year brought some very humid and very mild air to Switzerland. The precipitation combined with the snow melt led to steep increases in water levels in northern and north-eastern Switzerland. However, the most notable event in the first half of the year was the flood at the beginning of May (Chapter 1). On the Aare, Reuss, Limmat and Rhine, the May discharges represented the highest monthly values of the year. On the Lütschine at Gsteig, the May discharge was also much higher than normal. The monthly discharges in June, July and in August (just) were actually even higher than in May (Figure 4.4) because the Lütschine is a catchment with a high glacial effect. Here the highest discharges are expected in high summer during the snow and glacier melt.

The exceptionally low precipitation in the second half of the year (Figure 1.3) resulted in below-average discharges being recorded at many monitoring sites every month from July to December. In some regions the monthly values never rose above 80 % of the long-term average from July onwards. They even remained below 40 % of normal from June to year end on the Dünnern at Olten and the Töss at Neftenbach.

During such long periods of low water, discharges can be expected to be below monthly minimums in some locations and records will be broken. From July to December there were new low water records every month, mainly on the north side of the Alps. The notable month is November, when new lowest monthly minimums were recorded at many monitoring stations on the Central Plateau east of the Aare. The Glatt at Herisau recorded six new monthly record lows from July to December. However, this was not sufficient to set a new record low annual mean, because – as already mentioned – discharges in the first half of the year were comparatively high.

2015 was fairly uneventful in relation to floods. Apart from the flood in early May (Chapter 1), very few appreciable events occurred. The event at the beginning of the year on the north side of the Alps brought new monthly record highs on the Sorne, Töss, Glatt at Herisau and elsewhere. The flood in May was the worst of the year by far. More than a dozen monitoring stations between Lake Geneva and Basel recorded a new May record high.

Discharge conditions of selected medium-sized catchments

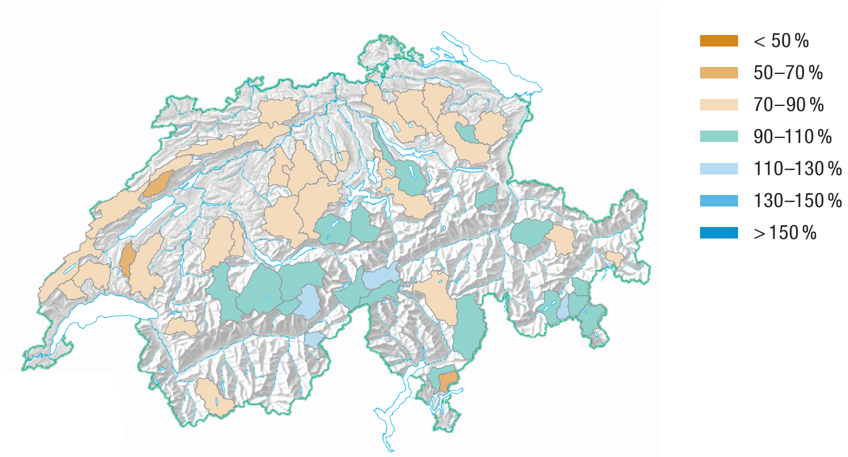


Figure 4.2 *Annual mean 2015 compared with the mean discharge for the long-term reference period 1981–2010 in selected medium-sized catchments [%].*

Monthly mean discharges of selected large catchments

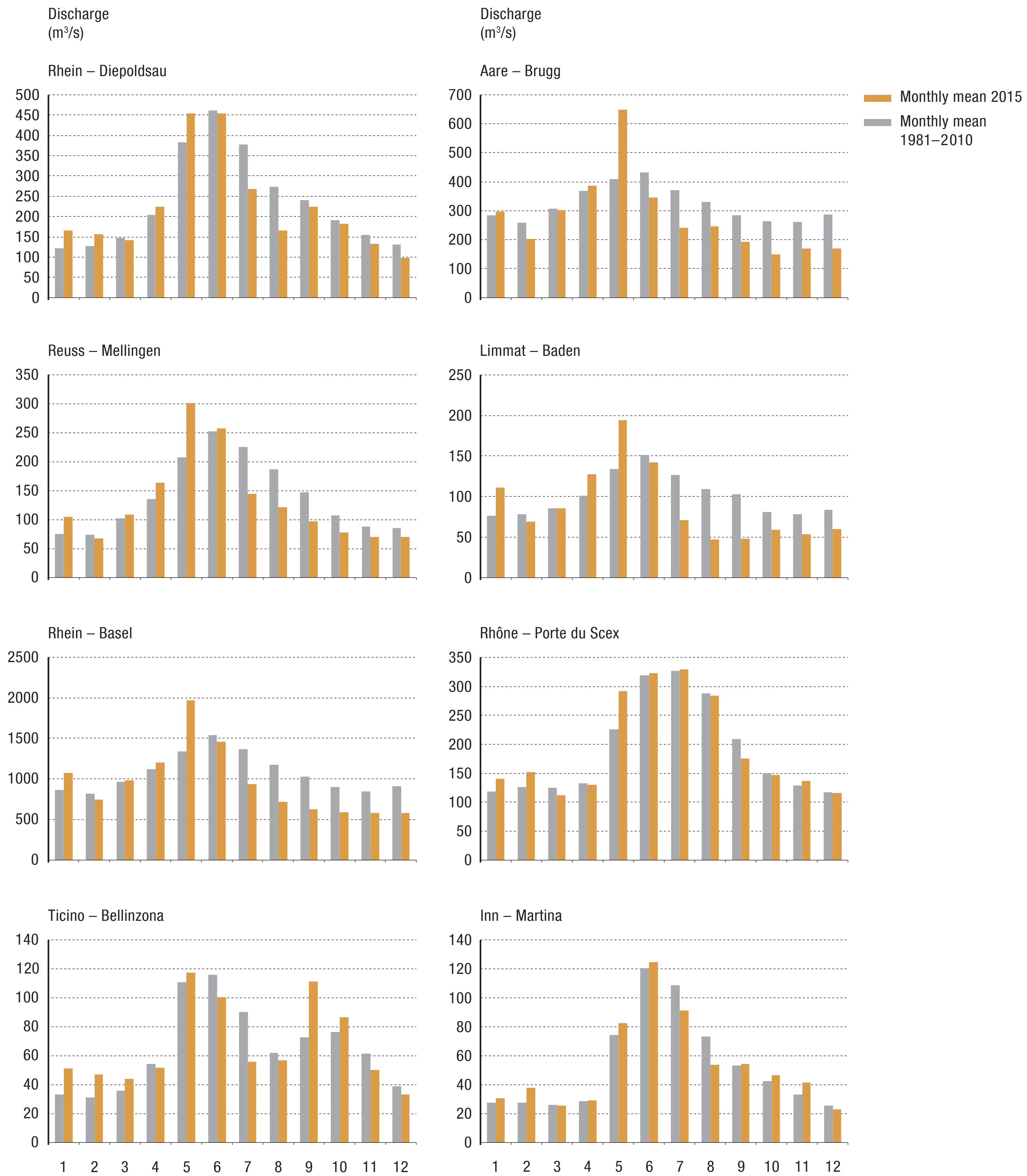


Figure 4.3 *Monthly mean discharges 2015 (orange) compared with the monthly means for the long-term reference period 1981–2010 (grey).*

Monthly mean discharges of selected medium-sized catchments

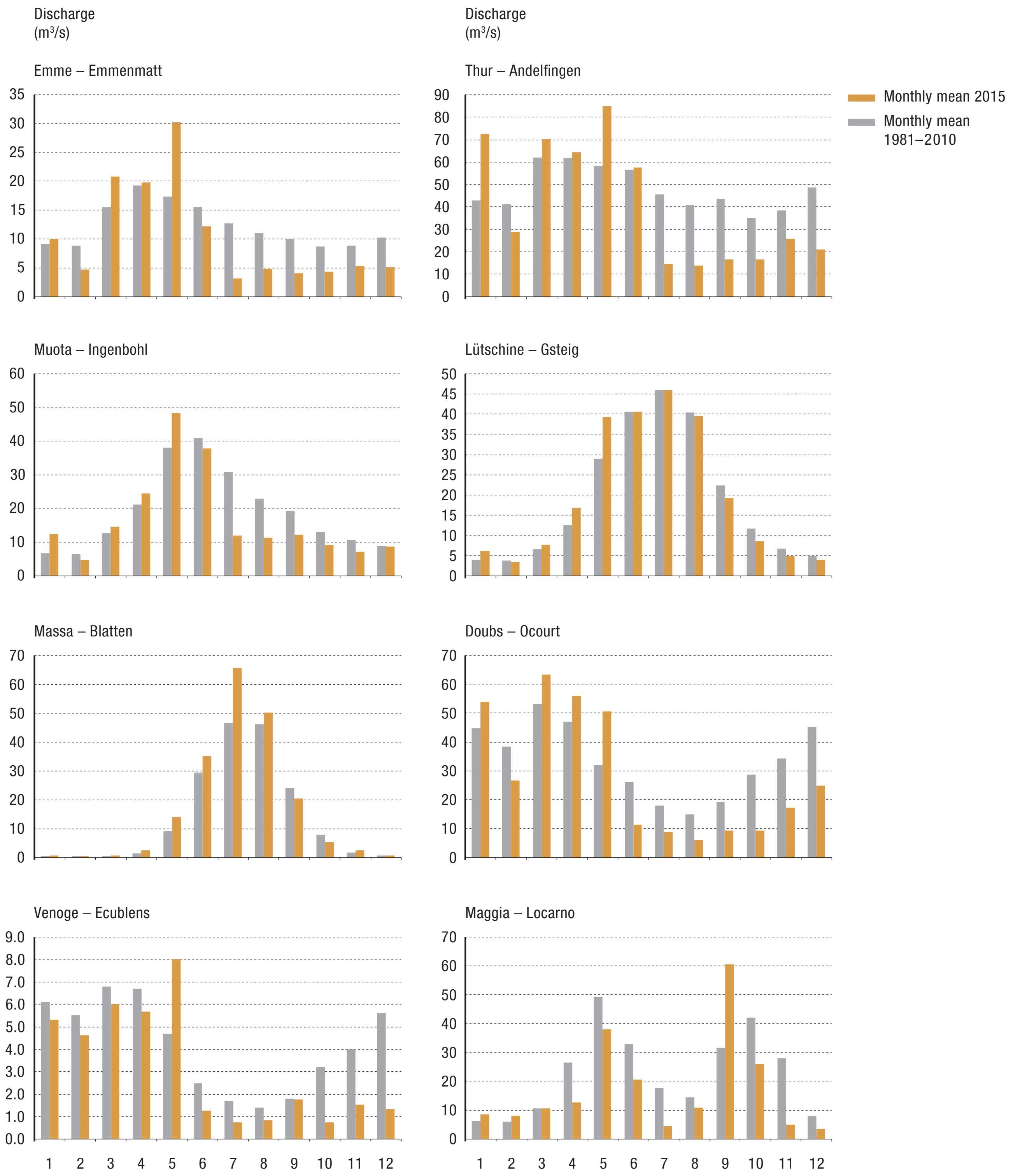


Figure 4.4 *Monthly mean discharges 2015 (orange) compared with the monthly means for the long-term reference period 1981–2010 (grey).*

Daily mean discharges of selected large catchments (1/2)

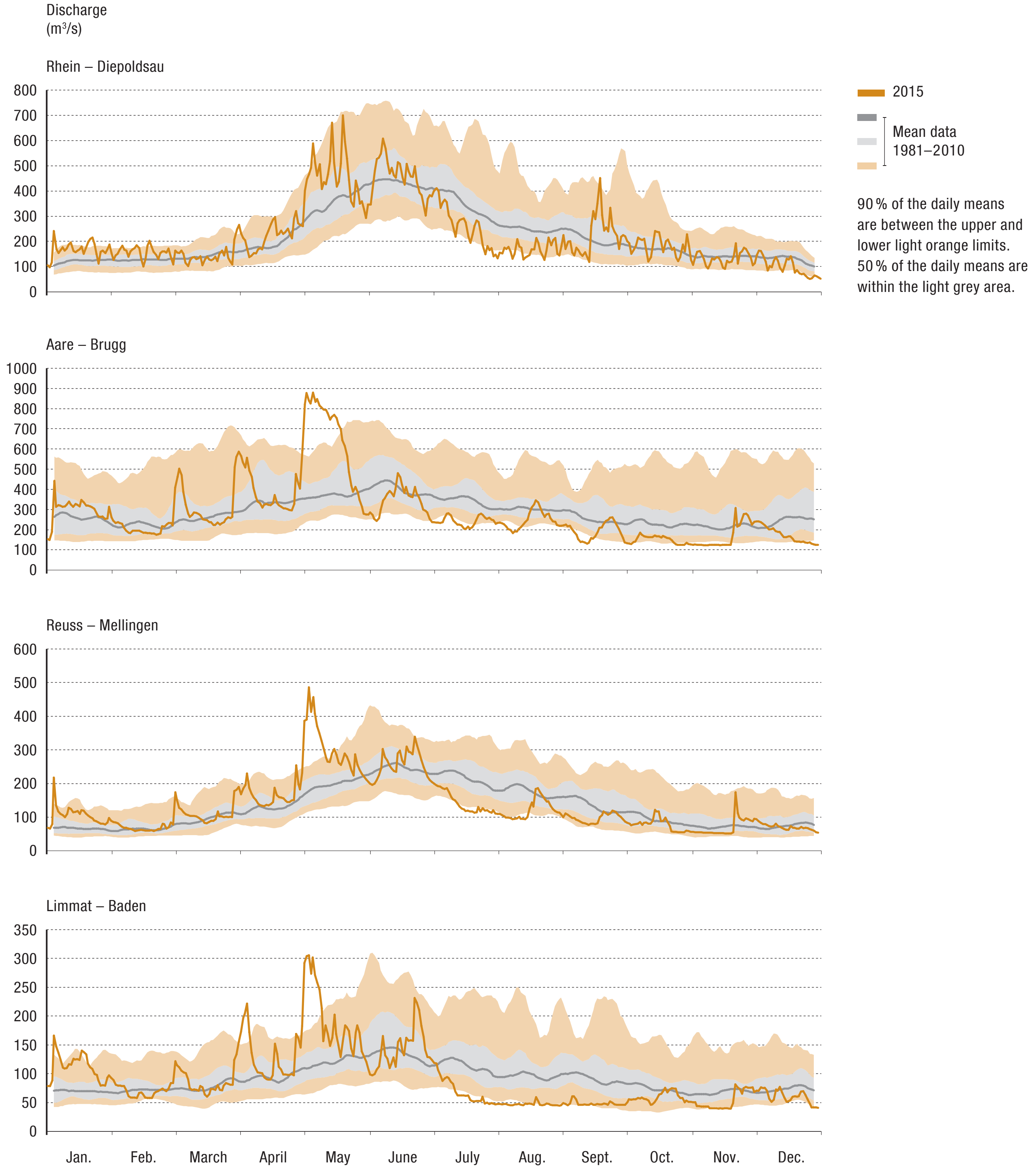


Figure 4.5 *Daily mean discharges 2015 (orange line) compared with the daily means for the long-term reference period 1981–2010.*

Daily mean discharges of selected large catchments (2/2)

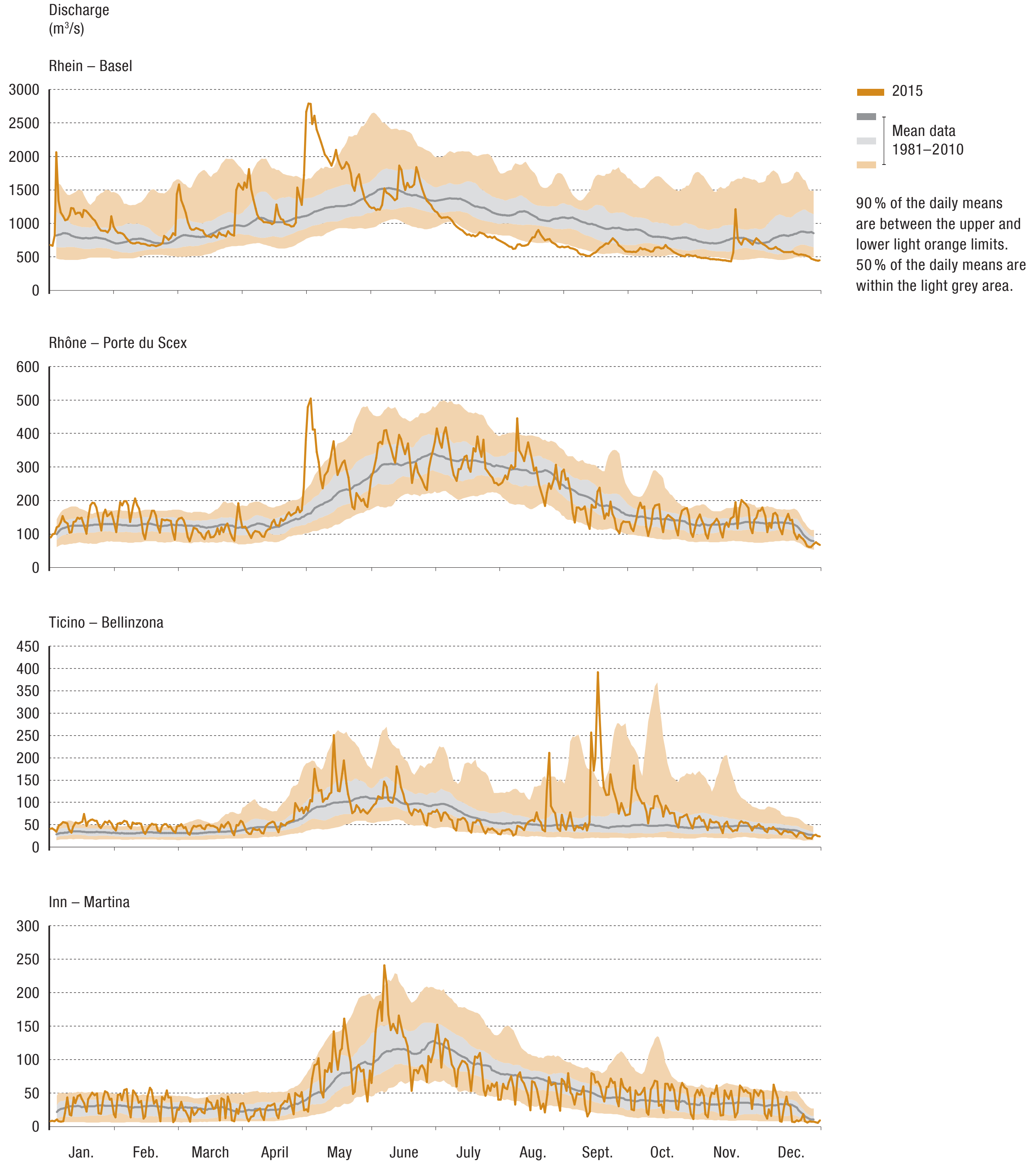


Figure 4.6 *Daily mean discharges 2015 (orange line) compared with the daily means for the long-term reference period 1981–2010.*

Daily mean discharges of selected medium-sized catchments (1/2)

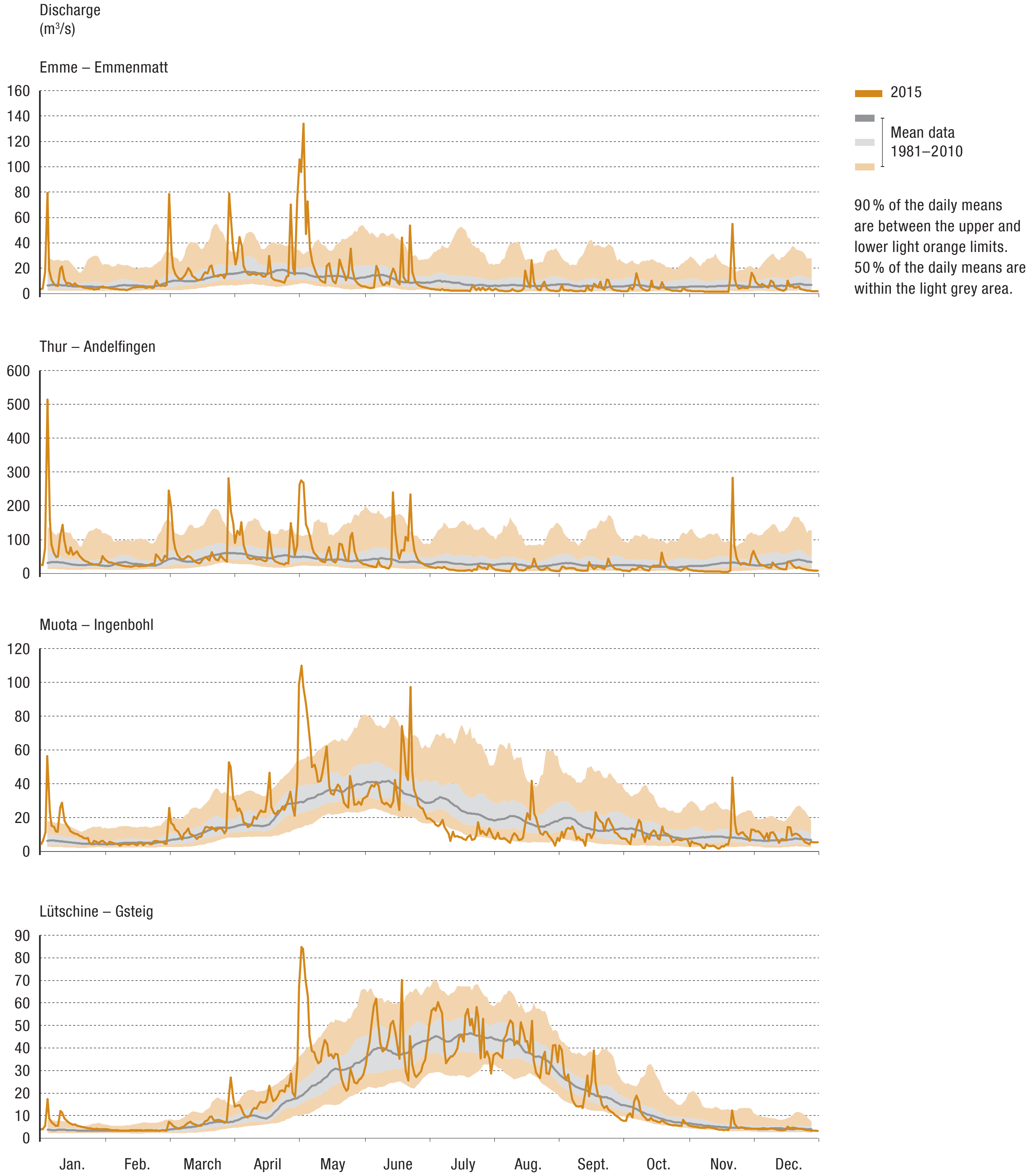


Figure 4.7 *Daily mean discharges 2015 (orange line) compared with the daily means for the long-term reference period 1981–2010.*

Daily mean discharges of selected medium-sized catchments (2/2)

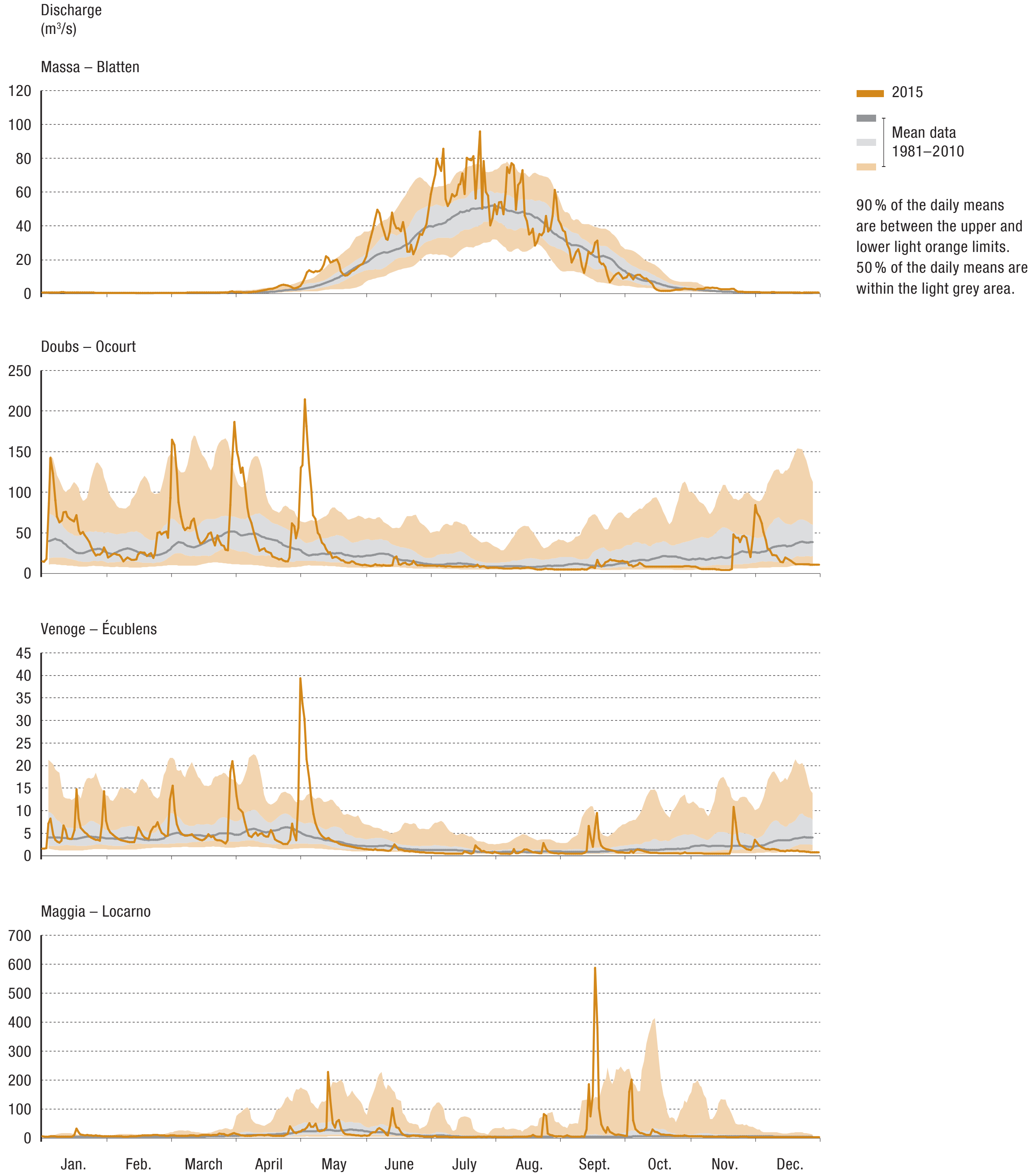


Figure 4.8 *Daily mean discharges 2015 (orange line) compared with the daily means for the long-term reference period 1981–2010.*

4.2 Lake levels

In general, the annual mean water levels on the larger Swiss lakes only vary by a few centimetres from the long-term average. Short-term fluctuations often balance out over the year as a whole. 2015 was no exception. In the main, levels were a few centimetres below average, though they were just above average in a few lakes. Noteworthy for large negative variances were Lake Lugano (–8 cm), Lake Zug (–9 cm) and Lake Walen (–13 cm). Lake Constance was the exception in 2015 with a high positive variance of 12 cm.

A common feature of the lakes shown in Figure 4.9 is that all the 2015 monthly means from January to May were above the corresponding long-term monthly means, although conditions at the beginning of the year were not the same everywhere. Lake Constance had quite a high water level at the end of 2014 and the beginning of 2015. On average it was 50 cm above the corresponding long-term average in January and still more than 30 cm above in February. In Lake Maggiore the average level in January and February was also more than 30 cm above normal. Lakes Neuchâtel and Geneva began at a normal level for the time of year. The monthly means for both lakes remained at the long-term average in the second half of the year, whereas levels well below average were recorded in Lake Constance from July to September. The water level in Lake Maggiore was 30 cm in August and more than 60 cm below the long-term monthly average in December.

In May new monthly record highs occurred. On Lakes Neuchâtel and Geneva, average water levels were around 30 cm above the long-term monthly means. On Lake Neuchâtel the highest level, recorded on 8 May, of 430.44 m AMSL was not just a record for May (previously 430.05 m AMSL in 1999), it was an all-time record for the lake (previously 430.27 m AMSL in August 2007). The level of the lake had never been higher since the second Jura water correction. The flood warning limits were exceeded on 15 days, although the two highest danger levels (430.50 and 430.75 m AMSL) were not reached. It was not only the high water level that was remarkable, it was also the speed of the changes. The lake rose more than 90 cm in seven days – from a normal level for the time of year to a new record. Similar dynamics were also observed on Lake Geneva in May, when the level rose by some 70 cm in a few days. Here the flood warning limits were exceeded on three days (level 2).

The long period of low precipitation in the second half of the year was not reflected in very low water levels in the lakes shown in Figure 4.10. The relatively high level after the May floods – particularly in Lake Constance – is responsible for this. The water level in that lake at the beginning of the summer was high for that season, meaning that it did not fall below the 5 % quantile even after a long period of steady decrease. As it is regulated, Lake Zurich (not shown in the figures) could not benefit from this effect. From mid-July its water level remained within the range of lowest seasonal values. For August, September and November 2015 there were new monthly record lows on Lake Zurich.

Monthly mean water levels of selected lakes

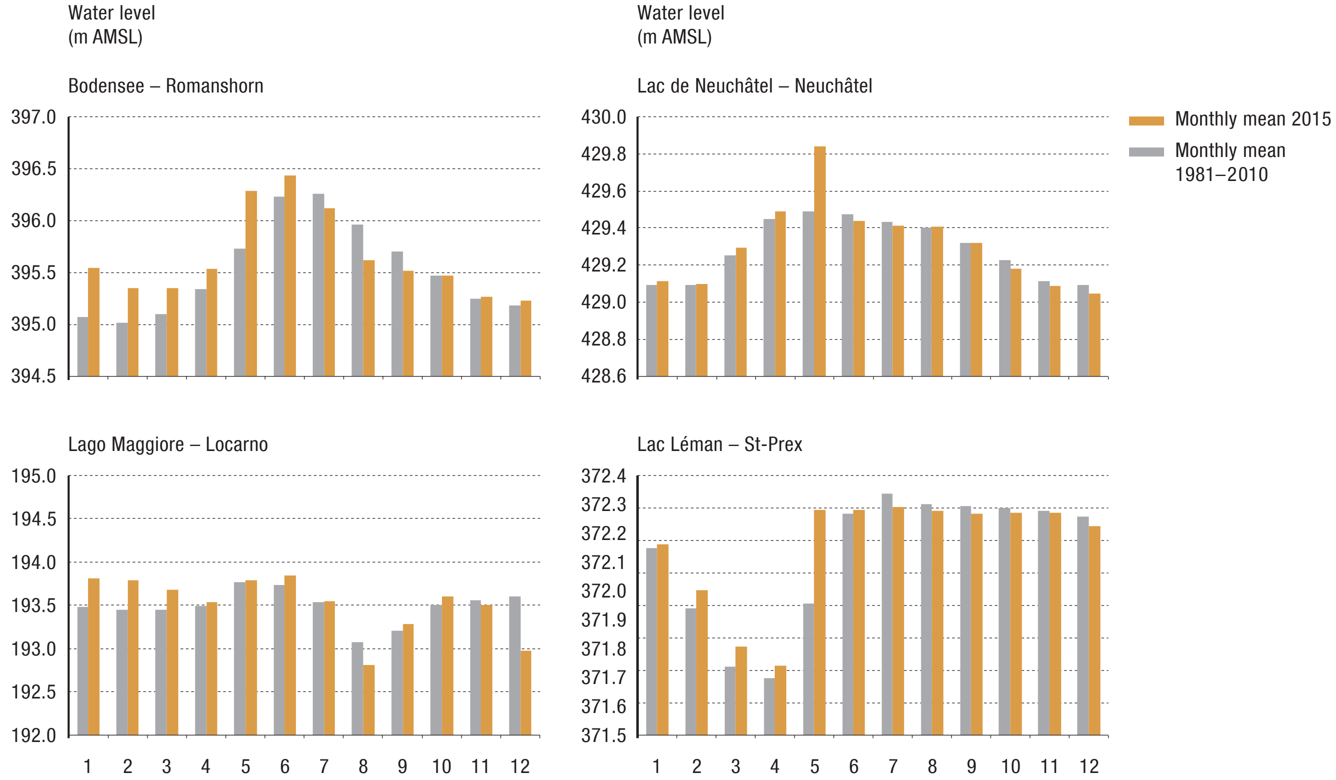


Figure 4.9 *Monthly mean water levels 2015 (orange) compared with the monthly means for the long-term reference period 1981–2010 (grey).*

Daily water levels of selected lakes

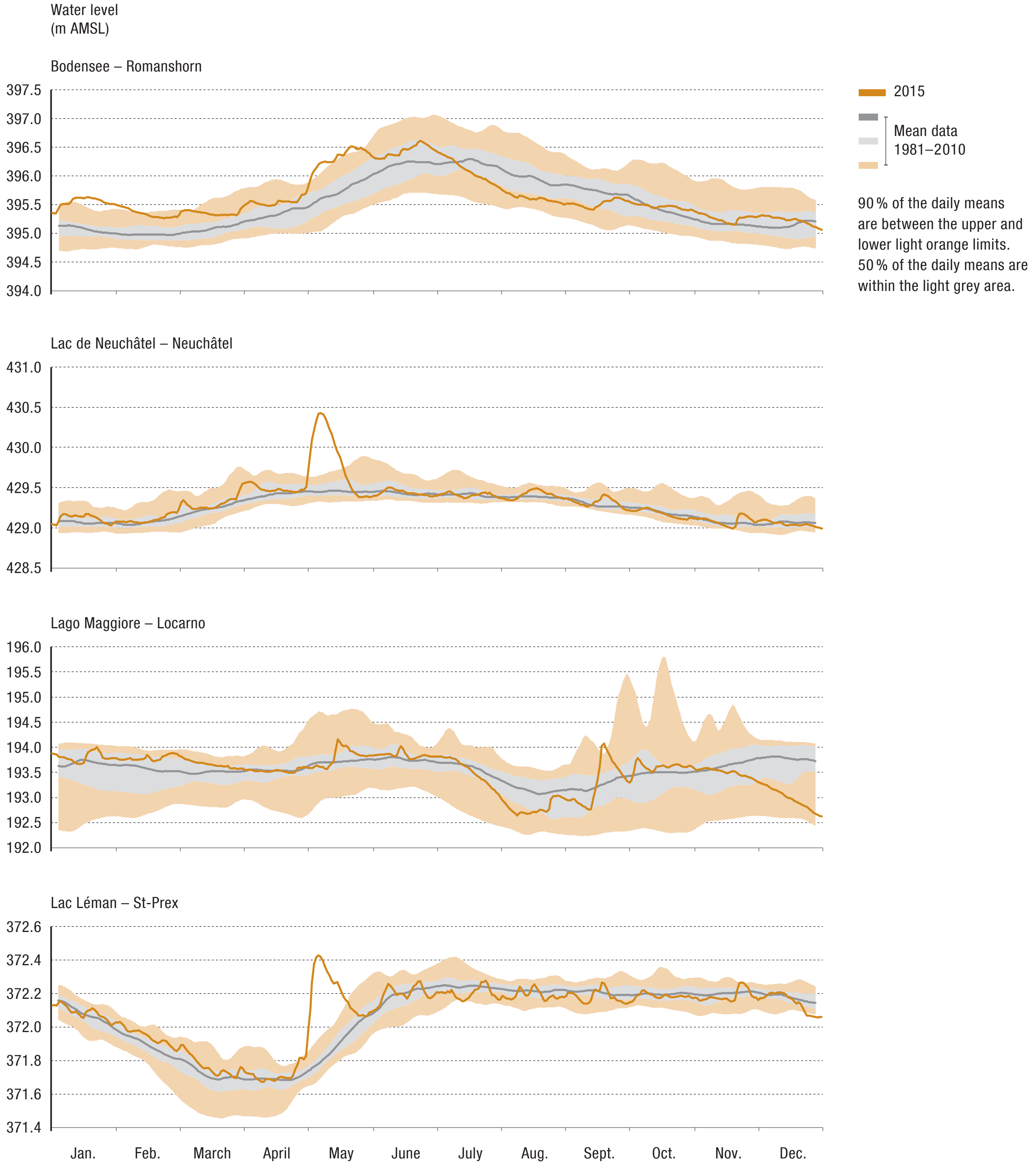


Figure 4.10 *Daily mean water levels 2015 (orange line) compared with the daily means for the long-term reference period 1981–2010.*

4.3 Water temperatures

Whereas an unusually large number of new record high annual mean water temperatures were recorded in 2011 and 2014, annual mean levels were exceeded less frequently at the stations in 2015. Although the weather was mild in the spring, it was also wet, resulting in a normal temperature profile for the rivers and lakes. No significant hot periods occurred until July. The resultant steep increase in water temperature in some cases was repeatedly interrupted by cooling periods, as also happened later in the summer and autumn. This led to distinctive cyclic temperature profiles with high maximums followed by falls to below the long-term average and even record low temperatures, as for example at the Rhône – Porte du Scex station (Figure 4.12). It was not until the prolonged period of fine weather in the autumn and winter that relatively steady hydrographs with higher water temperatures were seen.

In general, the 2015 annual means tend to continue the uninterrupted trend of elevated water temperature observed since 1960. Although the annual mean temperature, e.g. at the Rhein – Basel station, was slightly lower than in 2014, it was much higher than in 2012 or 2013 (Figure 4.11).

Cyclic temperature profile from spring to autumn

2015 was marked by an exceptional heatwave in July. As a result, new maximums were recorded in many rivers. At some monitoring stations, new July record highs or even record high temperatures in the 30- to 40-year monitoring series were recorded. Over the past 40 years it had never been as hot in July as it was along the Aare at the monitoring sites at Thun and Bern, along the Reuss at Lucerne and Mellingen, etc. New record highs were recorded on the Glatt at Rheinsfelden, on the Aare at Hagneck and Brügg, and, within a slightly cooler range, in the Engelberger Aa at Buochs. The water temperatures in the Alpine catchments affected by the snow and glacier melt remained much lower than on the Central Plateau. Isolated thunderstorms and cold fronts introduced cooler weather and a widespread and significant reduction in water temperatures. This resulted in extreme cyclic temperature profiles into the autumn, particularly in the Rhine basin.

High temperatures in autumn and winter 2015

At the end of 2015, prolonged periods of fine weather with a steady flow of warm air tended to generate a stable or only slightly fluctuating water temperature profile at many stations. In places this led to situations in which the water temperature persisted at a relatively constant level for several weeks in November, contrary to the long-term trend.

As a result, the long-term monitoring series values were exceeded, at the Rhein-Rekingen and Aare-Bern stations for example (Figure 4.12). Cooling did not occur until the end of November. A similar situation then developed in December and continued until the year end. This was clearly seen, for instance, on the Aare at Thun, Bern, Hagneck and Brugg, on

(Continued on page 29)

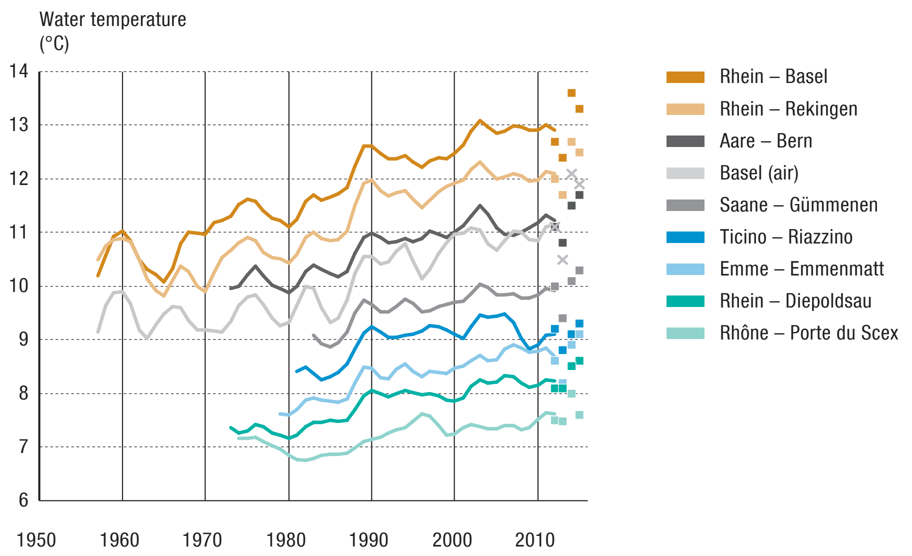


Figure 4.11 *Changes in water temperatures from 1954 to 2015 in selected Swiss rivers. Rolling averages (over 7 years) are shown as lines and the last four annual means as points or crosses (air).*

Mean daily water temperature at selected stations

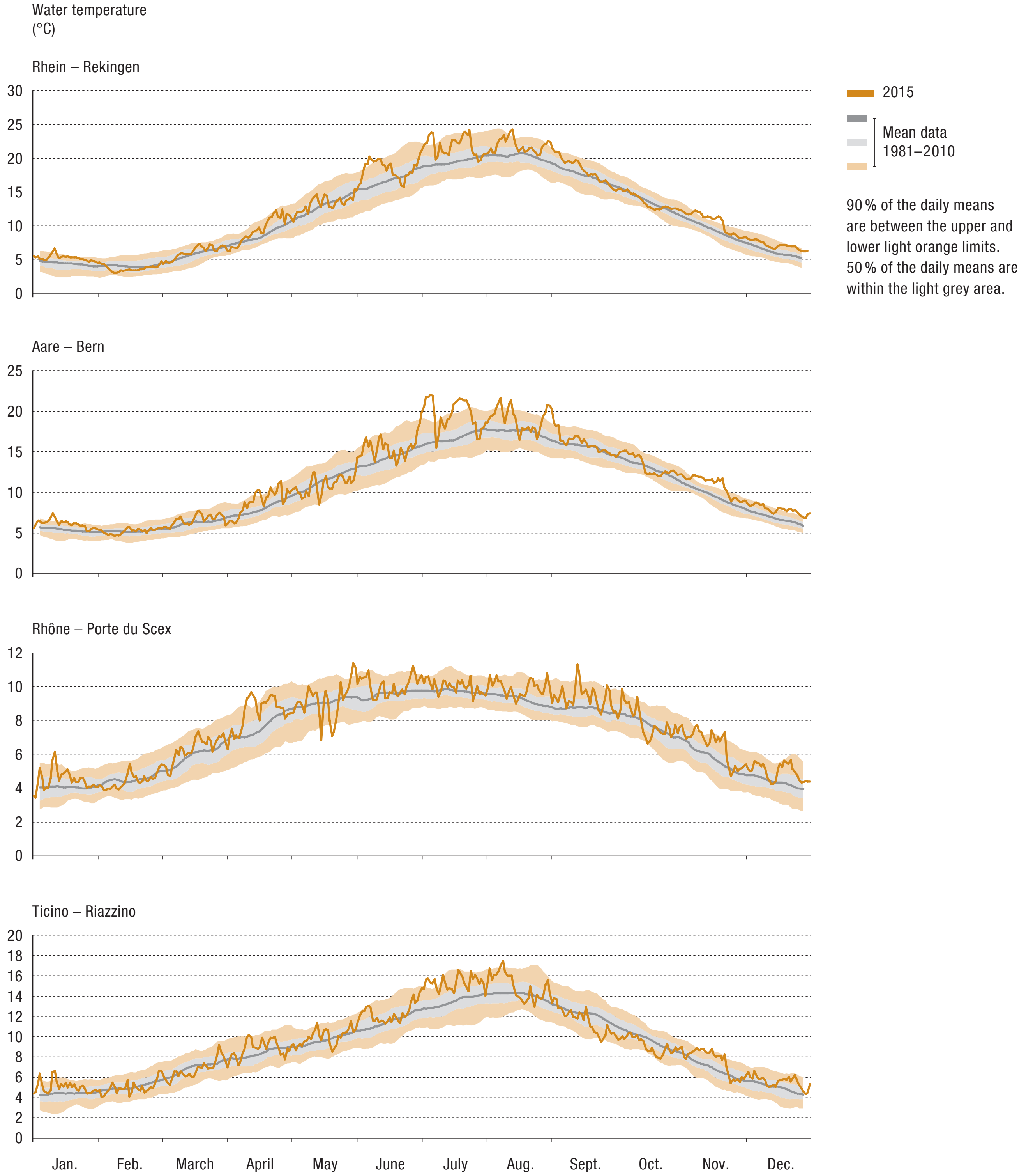


Figure 4.12 *Daily mean water temperatures 2015 (orange line) compared with the daily means for long-term reference period 1981–2010.*

(Continued from page 27)

the Linth at Weesen and also along the Rhine (Rheinfelden, Laufenburg) and a few stations along the Rhone and rivers in Ticino.

4.4 Stable isotopes

The stable water isotopes in precipitation, rivers, lakes and groundwater are natural tracers which represent important additional sources of information for regional climatic, environmental and water studies. They enable individual water components to be distinguished and the average level of a catchment to be estimated. The correlation between stable isotopes in water and temperature and relative humidity in the areas where precipitation forms has increasingly been incorporated in meteorological studies in recent years. As part of the NAQUA ISOT module, long-term regional changes in deuterium (^{2}H) and oxygen-18 (^{18}O) are recorded at 13 representative precipitation monitoring sites and nine sites on rivers (Figure 4.13) to provide reference data for these analyses.

In line with the general trend in temperature, $\delta^{2}H$ and $\delta^{18}O$ values in the precipitation increased at all the monitoring sites from about 1980 until the beginning of this century. The general picture is not consistent but is dominated by seasonal fluctuations. In the last ten years this trend seems to have been halted. There has been a clear drop in the δ-values measured in the winter season. Once again in 2015, the stable isotopes in precipitation have δ-values which are low for the winter. Reflecting the 2015 heatwave, above-average δ-values were measured in the summer.

In rivers, the seasonal trend in $\delta^{2}H$ and $\delta^{18}O$ values is also detectable but is less pronounced due to the different regional mix conditions in the discharge (e.g. in the Aare, Rhine and Rhone). Here too the trend has changed in recent years. The below-average δ-values (in the long-term comparison) since 2013 along the Aare, in the Rhine at Weil and in the Rhone above Lake Geneva continued in 2015. The hot summer of 2015 also caused more glacier melt water – with more negative δ-values – to be discharged at that time. Therefore low δ-values were recorded widely in the large rivers flowing from the Alps in July 2015.

Monitoring sites in the National Groundwater Monitoring NAQUA (ISOT module)

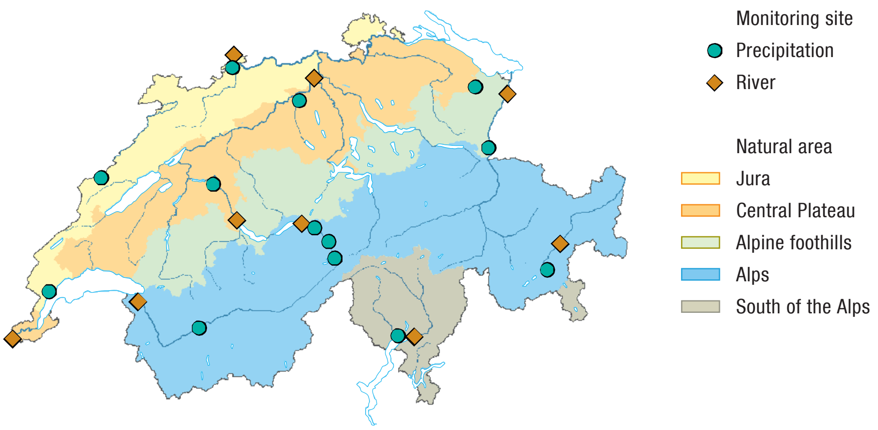


Figure 4.13 *Monitoring sites in the NAQUA ISOT module to monitor the isotopes in precipitation and in rivers in Switzerland, 2015 status.*

4.5 Water quality / physical and chemical characteristics

The status and trend of water quality in Swiss rivers is surveyed by the FOEN under the National River Monitoring and Survey programme (NADUF) at 17 monitoring sites (Figure 4.14) and jointly with the cantons under the National Surface Waters Quality Monitoring programme (NAWA) at 111 monitoring sites. In addition to monitoring changes in water constituents (e.g. nutrients and micropollutants), the surveys are intended to evaluate the effectiveness of water protection measures. The water quality analyses therefore focus on longer-term changes rather than seasonal fluctuations and for this reason they are published with thematic priorities in the Hydrological Yearbook. Further information and data can be found on the website (see p. 35).

Phosphorus content in rivers

Water pollution from nutrients has generally fallen considerably in recent decades. A significant decrease in phosphorus content is apparent at most NADUF stations; this is very clear to see since the phosphate ban in detergents in 1986. Levels were reduced still further from 1990 by the continual development of wastewater treatment plants. High concentrations only occur now for limited periods, such as during flood events. In small central Plateau rivers with a high population density and a high proportion of intensive agriculture in the catchment, reductions since 1986 have been quite erratic (e.g. Glatt, Figure 4.15). In large rivers with catchments with a variety of land uses and lakes (e.g. Rhine and Aare), the decrease is more continuous. The phosphorus content in the water has seasonal fluctuations because concentrations fall in the summer months due to phosphorus uptake by plants. These seasonal fluctuations have also declined in the rivers with upstream lakes since the phosphate ban in detergents. In contrast, the phosphorus content has only shown slight longer-term changes in Alpine rivers in catchments with a low population density and a low proportion of intensive agriculture (e.g. Rhone).

National River Monitoring and Survey (NADUF) monitoring sites

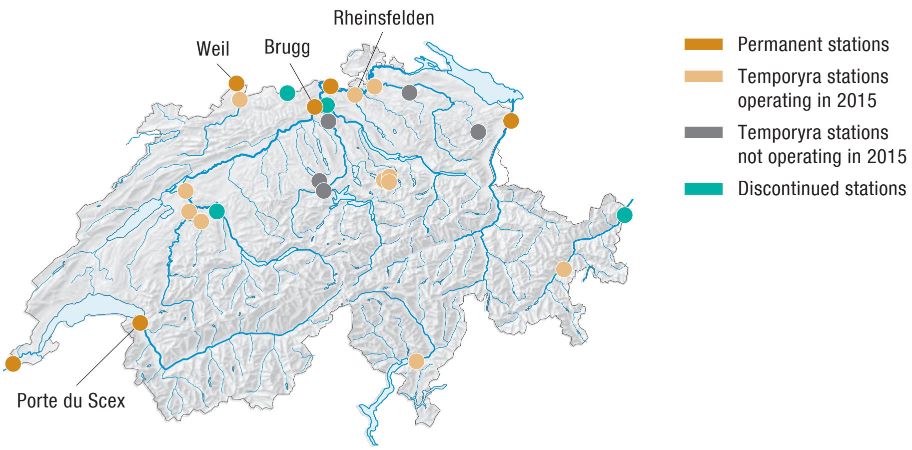


Figure 4.14 *National River Monitoring and Survey programme (NADUF) monitoring sites to monitor water quality in Switzerland, 2015 status.*

Total phosphorus content in rivers 1974–2015

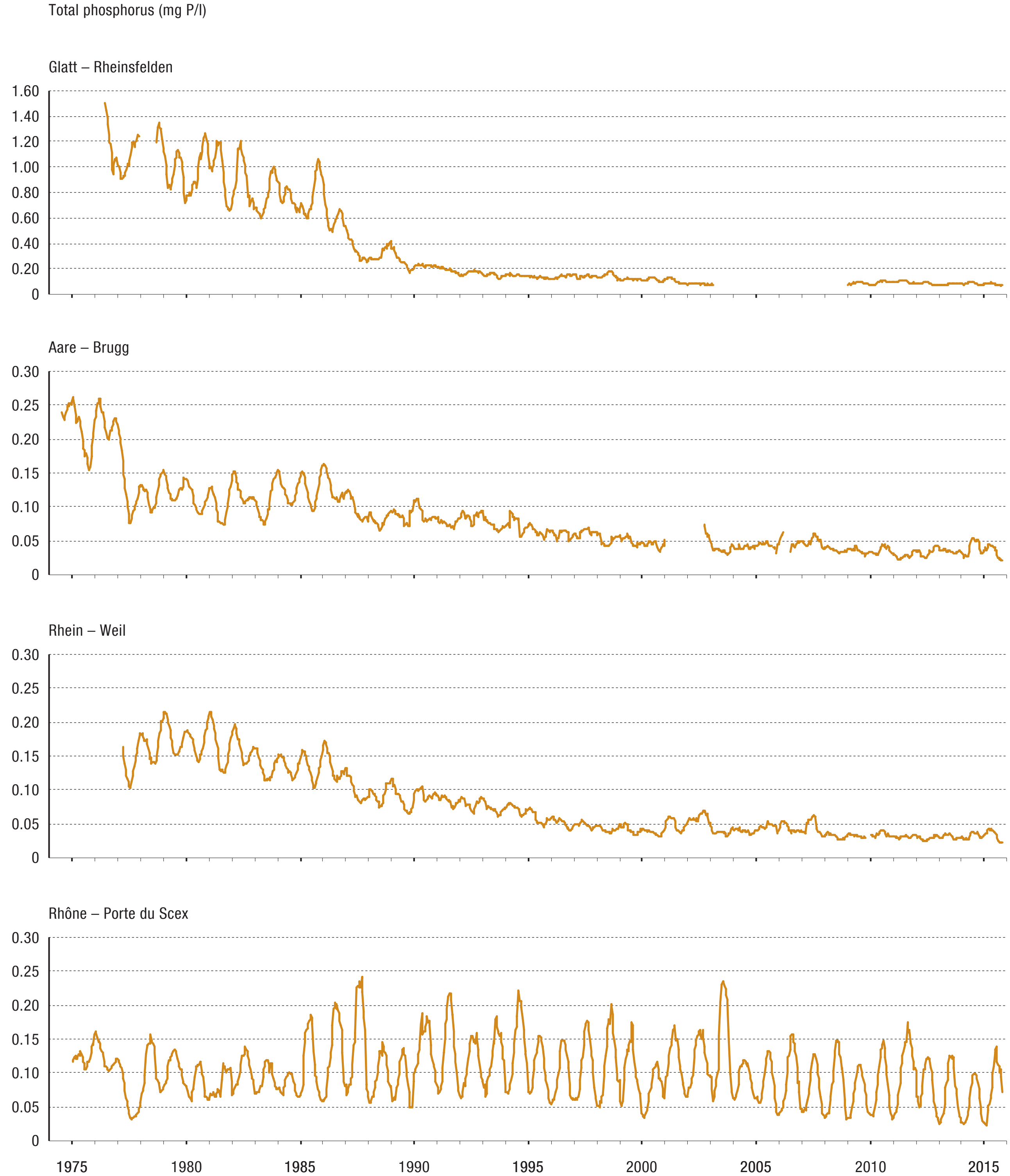


Figure 4.15 *Changes in total phosphorus content in 14-day composite samples from 1974 to 2015 at selected NADUF stations. Rolling averages over 11 composite samples are shown.*

5 > Groundwater

The year 2015 began with normal groundwater levels and spring discharges over wide areas and ended with low levels due to the prolonged drought.

5.1 Groundwater quantity

By continuously monitoring groundwater levels and spring discharges at around 100 monitoring sites under the NAQUA QUANT module, a nationally representative overview of the status and trend of groundwater quantity can be created. The potential impact of climate change on groundwater resources, for example the predicted increase in extreme events such as floods and drought, can also be identified.

The year 2015 began with normal groundwater levels and spring discharges nationwide. In January above-average precipitation for the month fell in large parts of Switzerland. In February precipitation which was well above average continued to fall on the south side of the

Alps, but the month was comparatively dry to the north of the Alps. As a result groundwater levels and spring discharges recorded in March were normal nationwide but the trend was inconsistent (Figure 5.1, Groundwater situation on 09.03.2015).

At the beginning of May exceptionally high precipitation fell in the Alps and on their northern side, which led to a rise in groundwater levels along the rivers in the wake of the floods in Lower Valais and western and eastern Switzerland (Chapter 1). That month of high precipitation overall caused

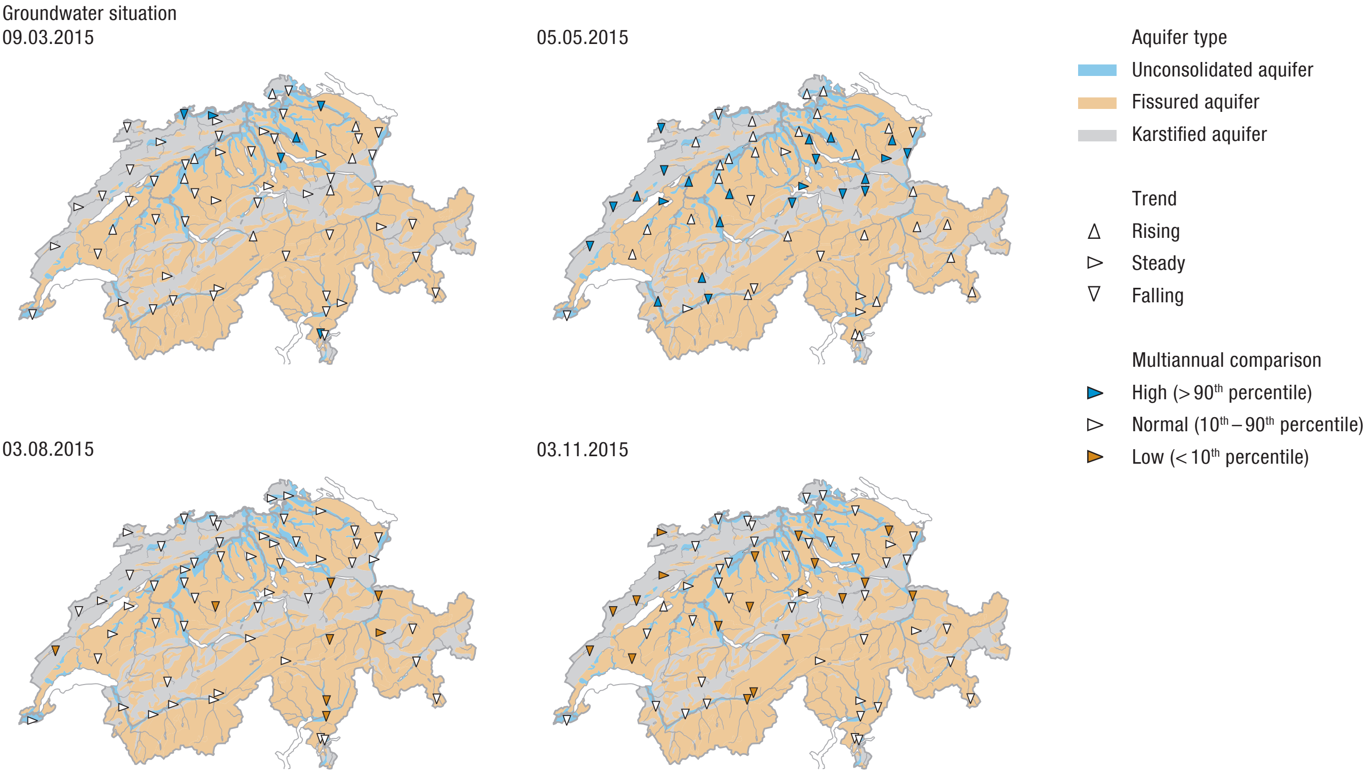


Figure 5.1 *Groundwater levels and spring discharges and their trends on four reference dates in 2015 and compared with the 2000–2014 monitoring period.*

groundwater levels to be generally high and springs also had elevated discharges. However, normal groundwater levels were recorded in Ticino in May due to below-average precipitation in the previous two months (Figure 5.1, Groundwater situation on 05.05.2015).

To begin with the prolonged drought from June onwards had little effect on Swiss groundwater resources due to the high initial levels and spring discharges when the drought set in. Unconsolidated aquifers along the major rivers from the Alps also benefited from the high river water infiltration caused by the exceptionally high glacier melt during the hot month of July. Although falling groundwater levels and spring discharges were recorded in August, they were mostly still within the normal range (Figure 5.1, Groundwater situation on 03.08.2015).

As the prolonged drought continued, groundwater levels and spring discharges fell further. By the beginning of November they were widely low on the north side of the Alps, with a falling trend. On the south side of the Alps the groundwater levels monitored were still normal, however, due to the average or above-average precipitation in September and October (Figure 5.1, Groundwater situation on 03.11.2015).

Precipitation was high in some locations at the end of November but the benefit was felt only in a few local aquifers in the Alps and in the Neuchâtel and Bernese Jura. Following the dry December, normal or low groundwater levels and spring discharges were recorded north of the Alps at the end of 2015. November and December were both exceptionally dry, particularly on the south side of the Alps, which also led to low groundwater levels there at the end of December.

5.2 Groundwater quality

The quality of groundwater in Switzerland is generally good to very good. In large urban areas and in regions with intensive agriculture, however, it can contain traces of undesirable artificial substances.

Under the NAQUA National Groundwater Monitoring programme, the status and trend of groundwater quality are recorded at 550 nationally representative monitoring sites (Figure 5.2). In addition to early detection of problematic substances and undesirable developments, checks on the effectiveness of measures to protect groundwater also play an important role, which is why groundwater quality analyses focus on statistically significant longer-term changes rather than seasonal fluctuations. These analyses are therefore not published in the Hydrological Yearbook. Further information and data can be found on the website (page 35).

Monitoring sites of the National Groundwater Monitoring NAQUA
(TREND and SPEZ modules)

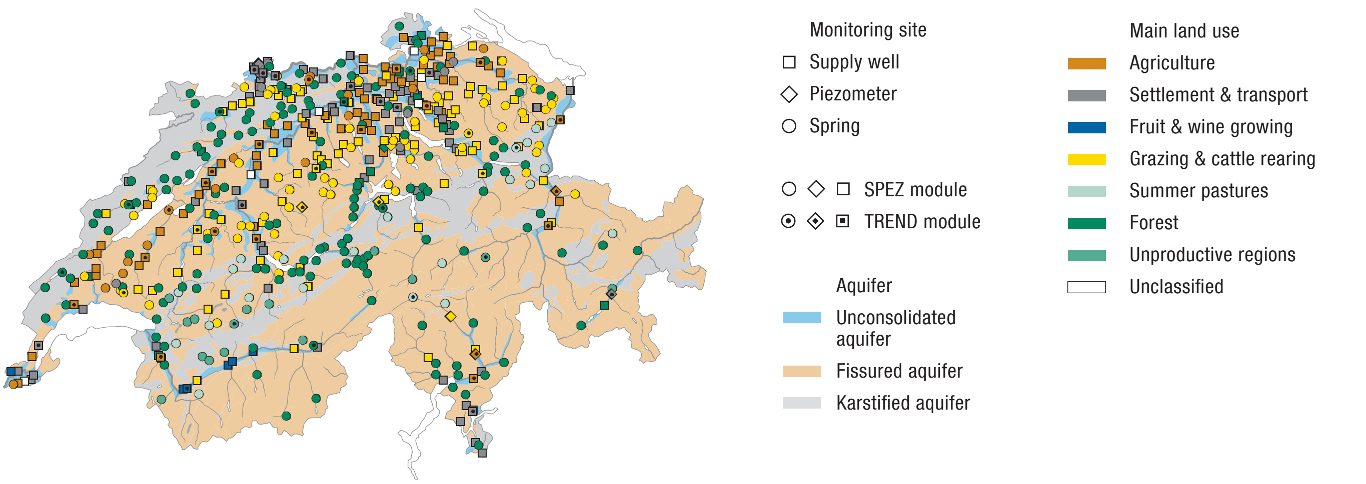


Figure 5.2 *Monitoring sites of the NAQUA TREND and SPEZ modules to monitor groundwater quality with main land use in the catchment and type of aquifer. 2015 status.*

> Annex

Glossary

National Groundwater Monitoring (NAQUA)

The NAQUA National Groundwater Monitoring programme consists of the four modules QUANT, TREND, SPEZ and ISOT. Groundwater quantity is monitored in the QUANT module and quality is monitored in the two modules TREND and SPEZ. The ISOT module observes the water isotopes in precipitation, the rivers and groundwater.

National River Monitoring and Survey programme (NADUF)

The monitoring programme follows the development of water constituents in selected Swiss rivers.

National Surface Waters Quality Monitoring (NAWA)

In collaboration with the cantons, the FOEN creates the data basis used to document and analyse the status and trend of Swiss surface waters at national level.

Quantile

A quantile is a measure of position in statistics. It defines the percentage of data in a distribution which is above or below a specific limit. For example, the 95 % quantile is the threshold showing that 95 % of a mass of data is lower and 5 % is higher. The best known quantile is the median (or 50 % quantile). It divides the data in a distribution into two equal parts.

Reference value

Average values (reference values) for different parameters from a long-term monitoring period are needed to describe the average climatological or hydrological conditions at a station. The reference period 1981-2010 is used in this Yearbook whenever possible.

Danger level

In accordance with the provisions of the Alarm Ordinance, the FOEN uses a five-step danger scale to warn of floods. The danger levels give information on the intensity of the event and its potential impact and make recommendations on how to respond. The flood limit for lakes defines the transition from the “considerable danger” to the “high danger” level. Floods can occur increasingly at this level. Buildings and infrastructure can be affected.

^{2}H, ^{18}O

Deuterium (^{2}H) is a natural stable isotope of hydrogen. Oxygen-18 (^{18}O) is a natural stable isotope of oxygen. Isotopes are atoms of an element with the same proton number but a different neutron number.

δ-values (delta values) are ratios of the corresponding isotopes $\delta(^{2}H/^{1}H)$, abbreviated to $\delta^{2}H$, and $\delta(^{18}O/^{16}O)$, abbreviated to $\delta^{18}O$.

Further information on the website

Further information on the themes of the Hydrological Yearbook and the FOEN hydrometric monitoring networks and current and historical data can be found on the website at: www.bafu.admin.ch/hydrologicalyearbook

- Current and historical data: www.hydrodaten.admin.ch/en/
- FOEN Hydrological Bulletin: http://www.hydrodaten.admin.ch/en/hydro_bulletin.html
- FOEN Groundwater Bulletin: www.hydrodaten.admin.ch/en/groundwater-bulletin.html
- Results of the NAQUA National Groundwater Monitoring Programme: www.bafu.admin.ch/naqua
- Results of the National River Monitoring and Survey Programme (NADUF) – data download: www.eawag.ch/en/department/wut/main-focus/chemistry-of-water-resources/naduf/
- National River Monitoring and Survey Programme (NADUF) – description of the monitoring network: www.bafu.admin.ch/naduf
- Water indicators and further information about water www.bafu.admin.ch/water
- National Centre for Climate Services (NCCS): www.nccs.ch