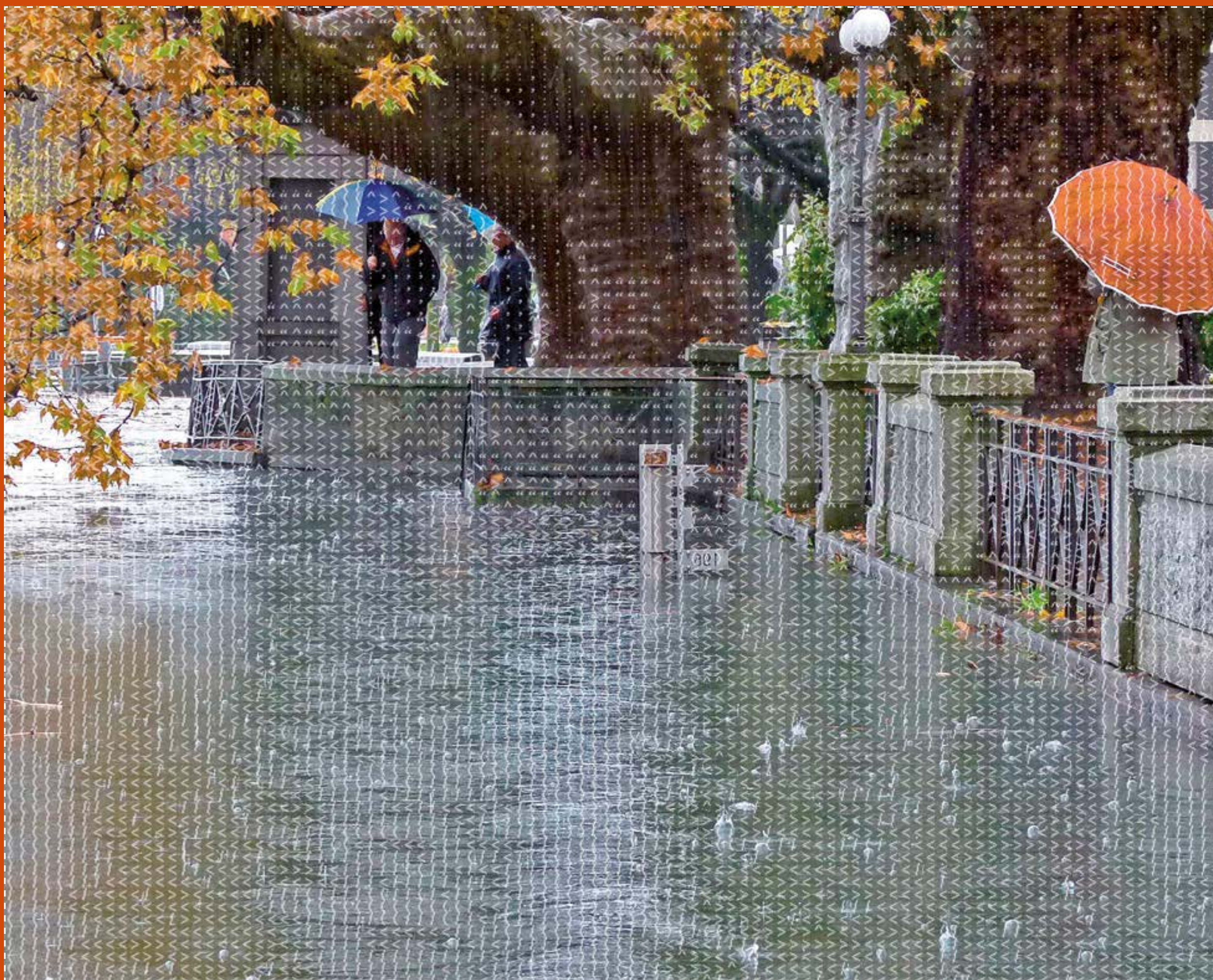
> Hydrological Yearbook of Switzerland 2014

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



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> Contents

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> Foreword

The summer of 2014 brought some very wet weeks to the northern side of the Alps. The above-average precipitation resulted in flood events, both large and small. Further heavy rainfall hit Ticino in November. Water levels in Lake Maggiore and Lake Lugano were around hazard level 5. The events are described in this Yearbook in the "Notable Phenomena" chapter and in the descriptions of the water levels and discharges in the Swiss rivers and lakes.

Despite the high rainfall and low sunshine levels in the summer, 2014 was a warm year. This is apparent from the detailed analyses by the FOEN which are shown in Chapter 1, with a comparison between the data for 2014 and for 2003, which is still remembered by many as the "heatwave summer".

The results of National Research Programme 61, "Sustainable Water Management", indicate the way in which Switzerland might respond in future to the challenges of floods or a hot summer. At a conference in November 2014, the main results from the 16 research projects were presented and discussed with a panel of representatives from politics, research, the Federal Administration and associations. Scientific bases and methods for sustainable management of Swiss water resources in the context of climate change now exist; the FOEN is building on these and they will continue to influence its hydrology remit.

In addition to these phenomena and events, there were also changes within the FOEN: the head of the Hydrology Department, Dominique Bérod, left to take up a new challenge at the *Group on Earth Observations* (GEO), and since 2015 the Hydrology Department has been headed by Olivier Overney. The FOEN thanks Dominique Bérod for his great commitment to Swiss hydrology and wishes him and his successor Olivier Overney all the best in their new positions.

Karine Siegwart
Vice Director
Federal Office for the Environment (FOEN)

> 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 from 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

Along with 2011, the year 2014 was the warmest since records began in 1864. Averaged across the whole of Switzerland, the 2014 annual temperature was 1.2 °C above the 1981–2010 average. The annual precipitation exhibited normal or slightly below normal levels in most regions. On the southern side of the Alps and in the Engadine, however, the year was much wetter than usual, with 120 to 170 % of the reference value. The Lugano and LocarnoMonti stations recorded levels of between 150 and 160 %.

Snow and glaciers

On the southern slopes of the Alps, in the Upper Engadine and some adjacent areas, snow cover averaged over the winter was twice the normal depth, while in Southern Valais it was slightly above average. In other regions snow depths were below the long-term average. The glaciers in the Swiss Alps displayed relatively low mass losses in the hydrological year 2013/14 compared with the previous decade. The glaciers in the Engadine and Southern Valais actually recorded slight gains.

Discharge conditions

On the northern side of the Alps the average annual discharges in the major river regions were below or close to the 1981–2010 average. The rivers Rhine, Aare, Reuss and Limmat were within the normal range. In the Thur, Doubs and Rhone, discharges were less than 90 % of the expected volumes. The Inn, Ticino and Maggia discharges were well above the long-term average.

On the Aare, Reuss, Limmat and Thur, the months of March to June were drier than usual, whilst July and August and in some cases November were wetter. The Rhone at Porte du Scex carried comparatively little water from May to September. The abundant and prolonged precipitation in Ticino in November resulted in widespread very high monthly averages.

Water temperatures

In the larger river basins, deviations from the average for the 1981–2010 reference period ranged between +0.5 and +1.1 °C. High annual means similar to those of the record year 2011 were reached at a few stations. In the first half of 2014 the stations widely recorded average or above-average water temperatures in every month except May. After a cool and cloudy summer water temperatures rose to well above normal from September to December.

Stable isotopes

In 2014 the stable isotopes in the precipitation were again characterised by low δ-values in the winter. The summer values remained at the long-term average. In the Jura and the Alps, below-average δ-values were measured in the summer. High amounts of precipitation in Ticino in November 2014 created lower δ-values in the water.

Groundwater

Normal groundwater levels and spring discharges were observed widely in Switzerland in 2014. However, in June some local low groundwater levels and spring discharges did occur, along with some high values in August and at year end.

Lake levels

In 2014 the annual average water levels in most of the larger lakes on the northern side of the Alps were close to the 1981–2010 long-term average. Levels considerably above average could not be prevented on Lakes Maggiore and Lugano, despite lake regulation, due to the prolonged precipitation in October and November. On Lake Maggiore the November 2014 mean was 147 cm above the November long-term average water level.

1 > Notable phenomena in 2014

"After the flood is before the flood." Rarely has this message – familiar to natural hazard experts – proved as true as in the rainswept summer of 2014: scarcely had discharges and water levels in the Swiss rivers and lakes fallen before further downpours began, causing levels to rise sharply once again. Despite the rain in the summer, the annual mean water temperatures were above average over 2014 as a whole. New monthly maximums were recorded at year end.

1.1 Flood events in July and August 2014

A flood event generally lasts for one or just a few days. It is quite rare for periods of intensive precipitation over a longer period to generate one event after another, making the individual events difficult to separate. Some key points of the events of summer 2014 and the highest discharge peaks are highlighted here.

Two to three times the normal rainfall

July 2014 will be remembered by many as very wet. It did indeed rain for several weeks – with some dry intervals. Heavy rainfall returned again and again, and was locally torrential and accompanied by thunderstorms. According to data from the Federal Office of Meteorology and Climatology MeteoSwiss, in July 2014 twice the rainfall normally recorded in July fell in widespread areas across Switzerland, in some places even three times that amount. New record totals for the month of July were recorded at many monitoring stations west of the Reuss in particular, but there were also new July maximums locally in Eastern Switzerland.

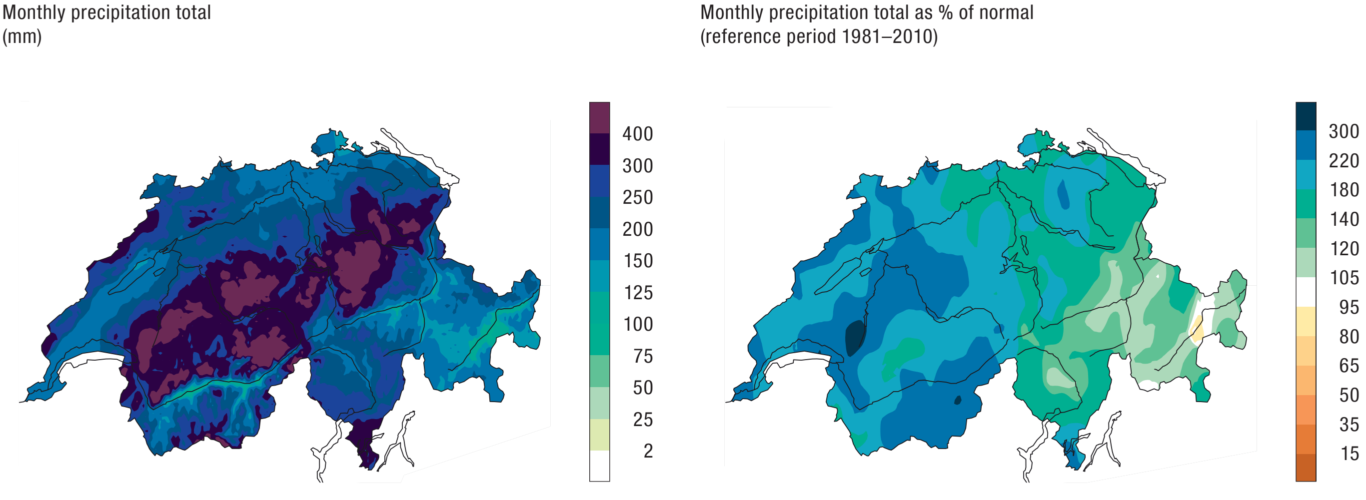

Figure 1.1 *Spatial distribution of monthly precipitation totals in July 2014: The absolute values in millimetres (left) and the relative values in % of the norm (right) are shown. Source: MeteoSwiss.*

Discharge situation: "After the flood is before the flood."

Despite the abundant rainfall, no widespread individual event of the type experienced in 2005 or 2007 occurred during the summer. Instead there were widespread repeated smaller floods on Swiss rivers such as occur statistically every two to five years, although isolated higher annuality events were recorded (see table). Lake levels were also higher in some areas. New seasonal or even absolute records were measured on some rivers, such as the Gürbe, Emme, Albula and Simme. The high discharges caused some significant damage locally.

Flood events July/August 2014

Station name	Period (years)	Previous maximum (m^3/s)	Date (month/ year)	Previous maximum July/ August (m^3/s)	Date (year)	HQ_{2014} (m^3/s)	Date	Time	Return period
Aare – Thun	78	570	5/1999	557	2005	403	01.08.2014	10:02:30	10–30
Albula – Tiefencastel	87	123	8/2005	123	2005	**133***	13.08.2014	13:05:00	50–100
Emme – Eggiwil. Heidbüel	38	245	6/1997	178	2012	**312***	24.07.2014	09:27:30	>100
Emme – Emmenmatt	96	495	6/1997	472	1977	426	24.07.2014	10:12:30	10–30
Gürbe – Belp. Mülimatt	90	59	7/1938	55.8	2007	**61***	11.08.2014	03:22:30	50–100
Gürbe – Belp. Mülimatt	90	59	7/1938	59	1938	58	13.07.2014	06:27:30	30–50
Gürbe – Belp. Mülimatt	90	59	7/1938	59	1938	49	29.07.2014	08:17:30	10–30
Hinterrhein – Fürstenau	39	715	9/1981	715	1988	688	13.08.2014	13:25:00	10–30
Julia – Tiefencastel	36	101	9/1981	89.5	1988	**118***	13.08.2014	12:15:00	10–30
Kander – Hondrich	32	273	8/2005	175	2002	**225**	22.07.2014	08:22:30	50–100
Kander – Hondrich	32	273	8/2005	175	2002	199	28.07.2014	20:27:30	10–30
Luthern – Nebikon	25	76	7/2002	76	2002	60	28.07.2014	17:57:30	10–30
Lütschine – Gsteig	89	254	8/2005	175	2002	**215**	22.07.2014	06:55:00	50–100
Ova da Cluozza – Zernez	51	16	9/1999	12.8	1985	11	13.08.2014	13:50:00	10–30
Ova dal Fuorn – Zernez. Punt la Drossa	53	17.3	9/1960	12.7	1999	**13**	13.08.2014	13:30:00	10–30
Sellenbodenbach – Neuenkirch	22	38.3	8/2007	20.5	2010	**25**	11.07.2014	19:12:30	10–30
Sense – Thörishaus. Sensematt	85	495	7/1990	333	2007	300	11.08.2014	02:32:00	10–30
Simme – Oberried/Lenk	69	34.5	7/1982	33	1992	**42***	01.08.2014	16:45:00	50–100
Simme – Oberried/Lenk**	69	34.5	7/1982	33	1992	28	07.08.2014	17:55:00	10–30
Sionne – Sion	6	5.11	8/2007	5.11	2007	**7***	02.08.2014	19:45:00	10–30
Weisse Lütschine – Zweilütschinen	80	112	10/2011	89.5	1982	88	22.07.2014	05:55:00	10–30

* Absolute maximum values ** Glacial lake outburst flood on the Plaine Morte
Bold: New July or August maximum

The main events of summer 2014

Some particular examples are highlighted below:

> 22 July: Heavy precipitation up to high elevations caused discharges to reach hazard level 5 on the Kander and level 4 on the Lütschine The Kander – Hondrich monitoring station recorded a flood with a return period of more than 50 years and the Lütschine – Gsteig station a flood with a return period of over 30 years.

> 24 July: An extremely violent stationary thunderstorm at the headwaters of the Emme caused a flood with a return period of more than 100 years (hazard level 5). A new absolute maximum was recorded at the Emme – Eggiwil station. Further down the Emme at Emmenmatt and Wiler, a 10-year flood was observed. In the days that followed, the Emme rose sharply several times (Figure 1.3).

> 1 August: After a stationary storm, the Simme at Oberried/Lenk reached hazard level 5 with a discharge expected less frequently than every 100 years.

> 7 August: A glacial lake outburst flood on the Plaine Morte during fine weather led to a 10- to 30-year flood of hazard level 3 on the Simme at Oberried/Lenk. This local event produced some spectacular images. Similar glacial lake outburst floods have been known to take place in the Grindelwald and Gorner glaciers and can occur regularly in the summer months.

> 11 August: The discharge on the Gürbe reached a level that only occurs on average every 50 to 100 years (hazard level 5). 50 to 60 cm of rain fell in the catchment over a few hours and the saturated ground could not absorb the volumes of water.

> 13 August: Heavy rainfall with embedded thunder cells lasting for several hours was also sufficient to cause a hazard level 4 flood on the Albula at Tiefencastel. Such a discharge volume occurs statistically every 50 to 100 years.

Flood situation on the rivers
in July and August 2014

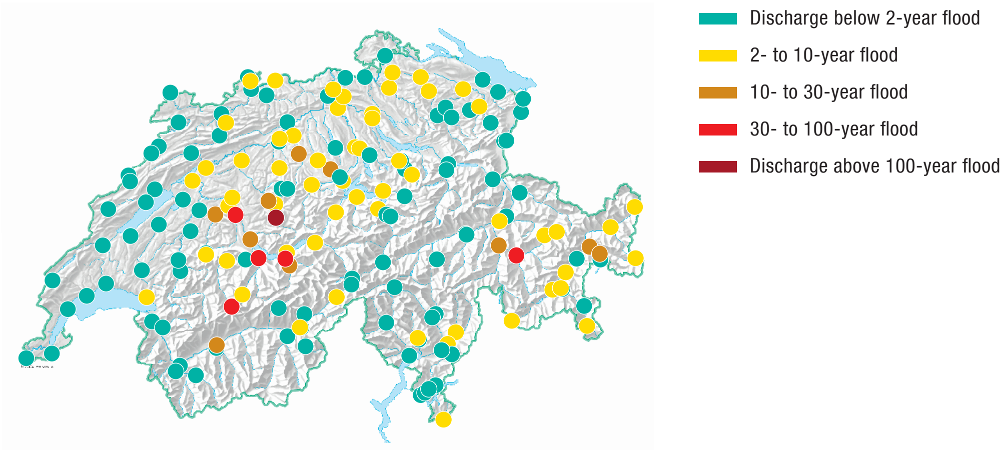

Figure 1.2 *Flood situation on the rivers in July and August 2014: Maximum discharges compared with flood statistics.*

Saturated ground and brief, violent thunderstorms

The events described above had some unusual features:

> Precipitation over several weeks caused the ground to become saturated. It was barely dry before more rain fell.
> Due to the saturated ground in the second half of July, fairly short bursts of thundery rain were enough to generate additional floods. Locally, this thundery rain led to some sharp increases in discharge in smaller rivers and to considerable damage.
> As more rain fell, it could often not seep into the ground and was discharged directly as surface runoff. This caused local flooding and damage not due simply to rivers bursting their banks.
> The main areas of damage were in the cantons of Bern, Lucerne and St. Gallen. Worst affected were the communes of Schangnau (BE), Schüpfheim (LU) and Altstätten (SG).
> Landslides occurred in some places as the ground was saturated for a long period and precipitation was high and intense. Many road and rail routes were impassable for a time (e.g. rail line at Flamatt, train accident at Tiefencastel).
> Regulation of the large Swiss lakes played an important part in preventing more widespread damage. During brief intervals without rain, water was drained away by opening the sluice gates on Lakes Biel, Thun and Zurich and to some extent on Lake Lucerne in order to accommodate the rainfall to come. Also, by controlling the lake outflow, flood waves could be prevented from overlapping and generating even higher discharges (e.g. Lake Biel outflow and Emme flood or Lake Thun outflow and Aare).

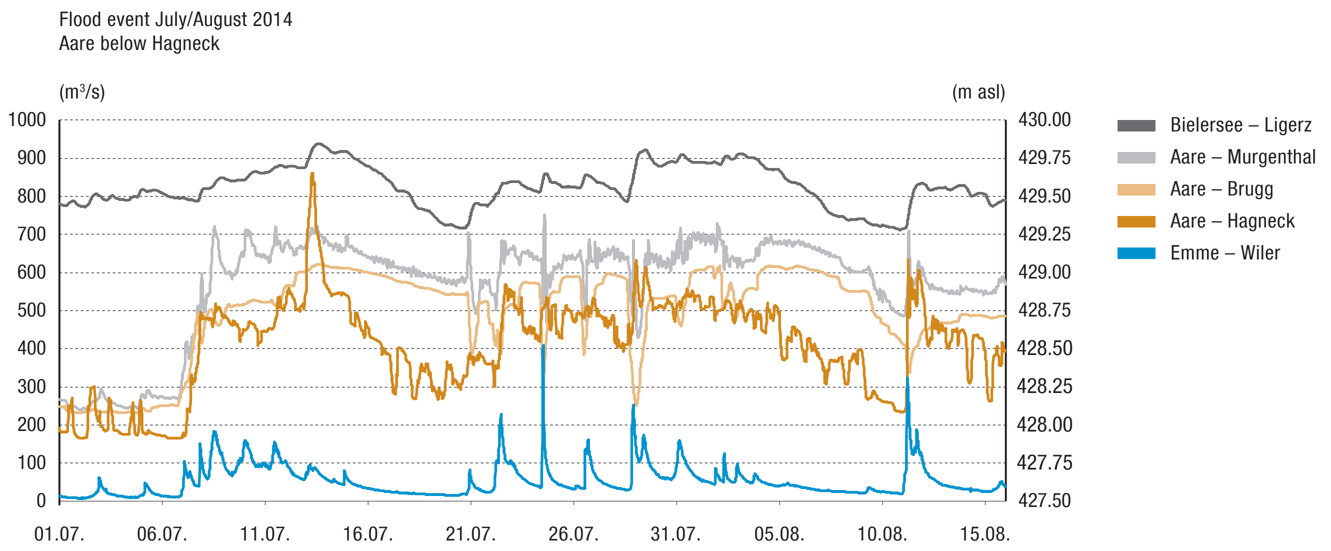

Figure 1.3 *Flood on the Aare: water level and discharge at various FOEN monitoring stations between Hagneck and Brugg from July to mid-August 2014.*

1.2 Surface water temperatures

In Switzerland the temperatures of selected rivers have been continuously recorded since 1963. During this period, measurements have indicated annual average temperature rises of up to 2.5 °C and even up to 3 °C in summer (see Section 4.3). In addition to various natural influencing factors, the water temperatures are principally determined by human influence. The increasing trend in annual mean values over the past 50 years is attributed to climate change and also to direct anthropogenic influences such as hot water discharges (e.g. from cooling systems). Non-Alpine stations with lakes in the catchment and low groundwater influence generally exhibit the greatest temperature rises. In contrast to Alpine station temperatures, temperatures at non-Alpine stations are determined by solar radiation and precipitation (drought) rather than melt water.

An uneventful year until an unusually warm autumn

Averaged over the year 2014 as a whole, temperatures in most of the rivers were unusually high. However, water temperatures throughout the year were far more moderate than during the heatwave year of 2003 (see Figure 1.4). The high 2014 annual averages were not due to a hot summer but to the above-average temperatures in the winter, spring and autumn. The months of October, November and December in particular saw temperatures well above normal and new monthly maximums were recorded at numerous stations in that period.

Despite record temperature, no widespread heat-related fish deaths

Under the Waters Protection Ordinance (WPO), water temperatures must be as near natural as possible so that indigenous species can thrive. Higher temperatures accelerate metabolic processes in the aquatic environment and alter the growth rate, lifecycle and activity of many aquatic organisms. The water solubility of oxygen is also reduced. Stress on aquatic organisms caused by lack of oxygen and/or temperature-related susceptibility to diseases – such as proliferative kidney disease (PKD) in fish – can massively increase mortality even at a water temperature of 15 °C. Temperatures over 25 °C often cause the death of cold-water fish species such as trout and grayling after just a few days and at over 30 °C the stress on the metabolism of these species becomes acute and fatal. Aquatic organisms at lake outflows are particularly at risk. Due to the warming effect of lakes, stations located

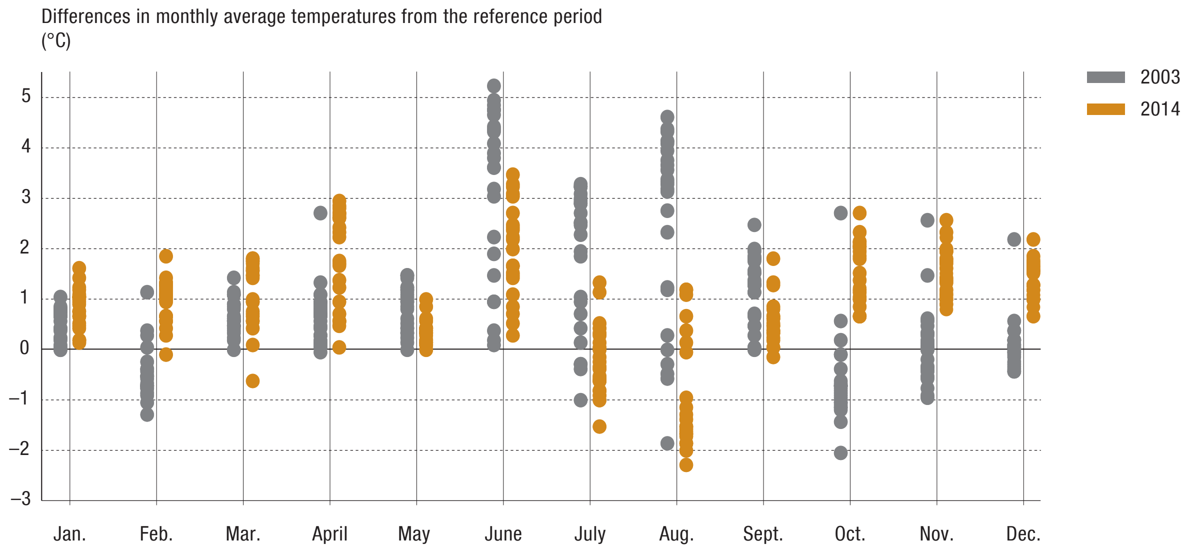

Figure 1.4 *Differences in monthly average temperatures in 2003 (grey) and 2014 (orange) from the monthly averages in the reference period 1981–2010. Each point represents a temperature monitoring station. The stations analysed represent the main rivers in the Central Plateau, Alpine foothills and Valais.*

below lakes record higher summer and winter temperatures than those at a similar elevation without a lake influence. The increases in average annual temperature over the last 50 years are also greatest at lake outflows.

The temperature of the Rhine at Rekingen, where there is a great risk of elevated temperatures, is mainly determined by Lake Constance. To analyse the danger to the aquatic biocoenosis from elevated temperatures in 2014, the number of hours with an average in excess of 15 °C, 18 °C, 23 °C or 25 °C was recorded. Figure 1.5 shows where thresholds were exceeded in 2014 compared with the heatwave year 2003. In both years water temperatures of 15 °C or over were only reached in isolated cases by the end of May. In 2014 the hot, dry spell of several days from 7 to 13 June brought daily averages of over 18 °C. It then remained warm for a very long time but the 23 °C level was never exceeded. Temperatures did not fall to below 15 °C again until 22 October 2014. In contrast to 2014, the high temperatures in 2003 only continued until 5 October, but they rose to over 25 °C for more than a week in the first half of August. That event caused the mass death of more than 50,000 graylings in the Rhine below Lake Constance.

To summarise, temperatures in 2014 remained above 15 °C during an unusually long warm spell. The growth phase of flora and fauna in the water was greatly extended. However there was a complete absence of hot spells with temperatures over 23 °C, so that the mass fatalities seen in previous hot years were not observed.

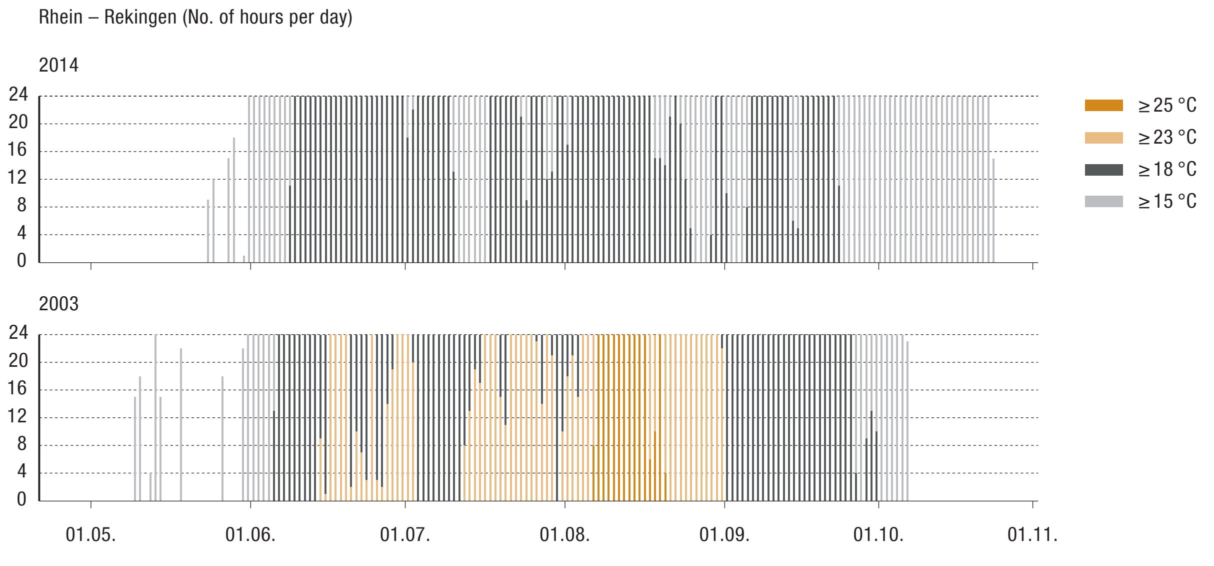

Figure 1.5 *Temperatures in the Rhine at Rekingen. Shown are the number of hours per day on which hourly averages reached 15 °C, 18 °C, 23 °C and 25 °C.*

Threat posed by heat is increasing

Despite wide annual variations, temperatures in the critical ranges between 15 and 30 °C have increasingly been recorded from 1970 to 2014 (cf. Figure 1.6). The most marked examples are the temperatures over 23 °C at the Rhine – Rekingen station, though no clear trend is apparent for those between 15 and 18 °C. Hourly averages over 25 °C were not recorded until the second half of the monitoring period, in 1994, 2003, 2006 and 2013. At lower levels we can also see an increase in the frequency at which critical limits were exceeded in rivers without a dominant lake influence, whereas warming at alpine elevations is considerably moderated in some cases by cooler melt water. Due to climate change, which causes both increasingly long warm temperature periods and increasingly higher maximum temperatures, a further increase in the water temperature of rivers and lakes can be expected in the coming decades. Sensitive aquatic organisms are likely to become less tolerant of elevated temperatures caused by human activity and so more susceptible to disease.

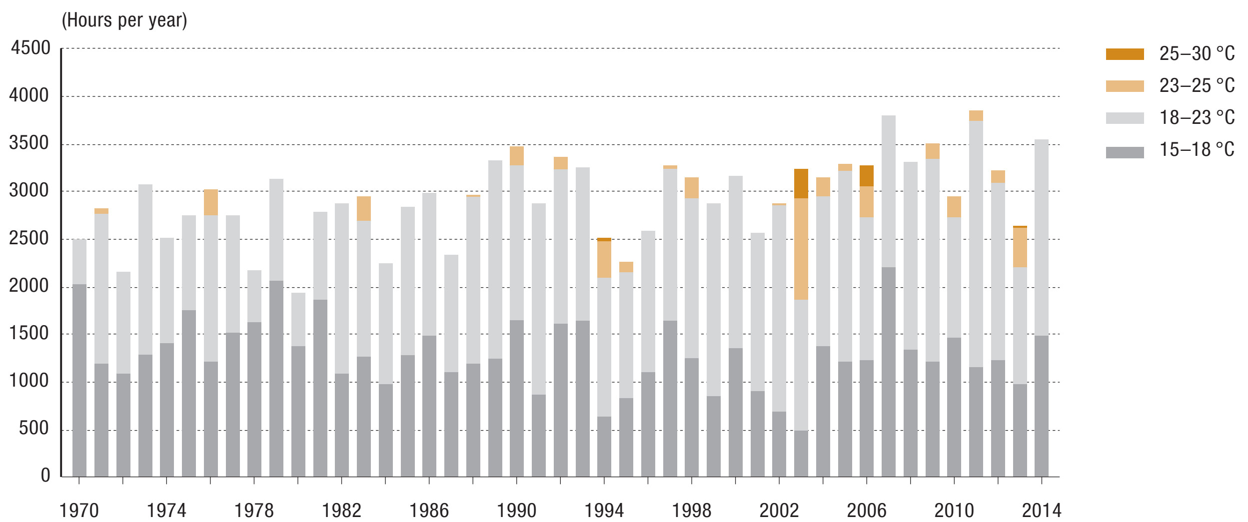

Figure 1.6 *Number of hours per year in which the Rhine at Rekingen reaches a specific temperature. The thresholds correspond to the critical ranges for selected aquatic organisms.*

2 > Weather conditions

Together with 2011, the year 2014 was the warmest since records began in 1864. Averaged across the whole of Switzerland, the 2014 annual temperature was 1.2 °C above the 1981–2010 mean. Annual precipitation reached normal or slightly below normal levels in most regions. On the southern side of the Alps and in the Engadine, however, the year was very wet, with 120 to 170 % of the reference value.

2014 began with record precipitation on the southern side of the Alps, where some regions recorded the highest levels of any winter by far since records began 151 years ago. In contrast, the lowlands of Northern Switzerland remained largely free of snow during the winter of 2013/14. A steady influx of mild air masses from subtropical regions brought the third warmest winter in Switzerland since records began in 1864. Averaged over the country as a whole, the increase over the 1981–2010 mean was 1.7 °C.

In the first half of the year, temperatures were above average in every month except May. The prolonged mild period resulted in the third warmest first half year since records began in 1864. The national average temperature was 1.5 °C above the 1981–2010 mean.

True summer weather only arrived during a heatwave lasting about a week in the first half of June. During the high summer months of July and August, the main feature of the weather was frequent heavy rain. Extreme rainfall mainly occurred in July. New records for the month were set at many monitoring stations in the western half of Switzerland and a few in the eastern half.

After the cool summer, autumn was warm. Switzerland recorded the fourth warmest October and second warmest November since records began. With September also mild, this was the second warmest autumn of the 151-year Swiss monitoring series for the country as a whole.

With the extreme mild weather came the heavy rains on the southern side of the Alps. Following an already wet October, rain totalling four or five times the monthly average fell in some parts of Ticino during November. The prolonged torrential rain caused Lakes Maggiore and Lugano to rise significantly. Over several days towards the middle of November both lakes overflowed their banks, leaving parts of Lugano and Locarno under water.

The above-average temperatures in the autumn continued into December. Snow generally lay only above 1000 to 1500 m AMSL where amounts were below average. Even after mid- December, Alpine snow cover was widely only 30 to 60 % of the normal depth for that time of year. With the arrival of cold air from the north-west and north, the weather changed from extremely mild to cold and wintry within two days from 26 December. On the northern side of the Alps snow fell as far down as the lowlands from 26th to 29th of the month.

Source: Federal Office of Meteorology and Climatology (MeteoSwiss)

Annual precipitation total (% of normal)

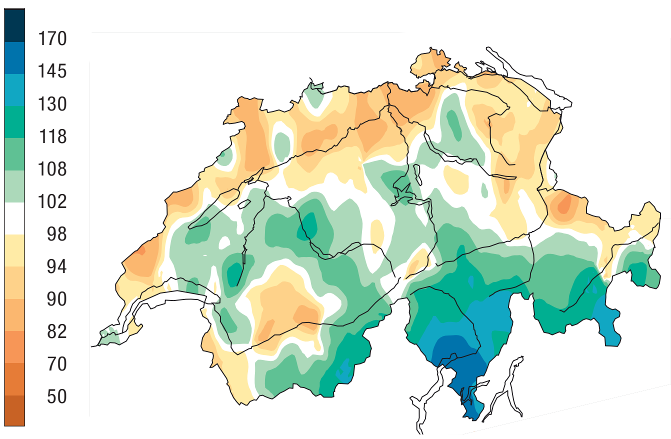

Figure 2.1 *Annual precipitation was normal or slightly below average in most regions. 2014 was very wet on the southern side of the Alps and in the Engadine.*

3 > Snow and glaciers

On the southern slopes of the Alps and the Upper Engadine and some adjacent areas, snow depth averaged over the winter was twice the normal level and slightly above average in Southern Valais. In other regions snow depth was below the long-term average. The glaciers in the Swiss Alps experienced relatively low mass losses in the 2013/14 hydrological year compared with the previous decade.

3.1 Snow

Snow fell at high elevations and on the mountain tops as early as October in four phases. At many monitoring stations in all parts of the Swiss Alps between 11 and 15 October, new maximum snow depths were measured for those dates.

Snow also fell repeatedly in all regions in November. The heaviest snowfall period lasted from 19 to 23 November and deposited 80 to 120 cm of snow from the Simplon region to Western Ticino. Snow depth was above average for the time of year in Valais and on the western and central slopes of the Northern Alps.

The first three weeks of December were marked by low precipitation, a lot of sunshine and often mild temperatures. Snow cover was correspondingly light. It snowed over the Christmas period; snowfall was heavy on the southern slopes of the Alps. The depths of new snow on 26 December were exceptional. The 120 cm measured at the San Bernardino monitoring station was the highest since records began 63 years ago.

More snow fell in January, mostly in the southern regions, where snow cover was very deep. The principal areas were in Western Lower Valais, Northern and Central Ticino, the Upper Engadine and the southern valleys of Graubünden. February also brought several periods of precipitation in rapid succession on the southern Alpine slopes with large amounts of snow. At some stations in Northern and Central Ticino, 3 to 3.5 m of snow fell in the month.

In March, snow only fell at the beginning of the month; otherwise the weather was mild and sunny. Stations in the south recorded new maximum snow depths at the beginning of the month but these were greatly reduced by melts, particularly up to medium elevations. Towards the end of the month snow depth was well below average in the Northern Alps.

Up to one metre of snow fell in three days at the end of April, principally affecting the main Alpine ridge from the Mattertal to the Goms. May saw significant amounts of snow, mainly at high elevations in Valais, the Northern Alps and Graubünden. The reduction in snow depth continued at this time but was delayed in early and mid-May as the zero degree isotherm fell to below 2500 m.

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

Snow depth (% of normal)

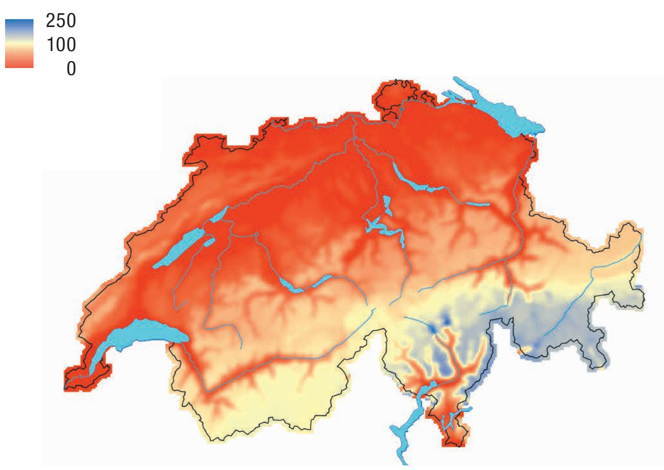

Figure 3.1 *Snow depth 2013/14 in the winter months of November to April compared with the 1971–2000 period.*

3.2 Glaciers

In the hydrological year 2013/14, mass balance measurements were made on some 20 Swiss glaciers. They included determining the volume of winter snow and the melt during the summer. By mid-April amounts of snow on the glaciers were found to be below average in the Northern Alps and generally above average in the Southern Alps. After a period of intensive snow melt in June, July and August were characterised by changeable weather. This particularly benefited high-elevation glaciers because there were repeated new snowfalls which reduced glacier melt considerably. However, the relatively warm weather in September led to further melting.

Zero or even slightly positive mass balances were measured on glaciers on the main southern Alpine ridge and in the Engadine (e.g. Findelen, Allalin, Vadret dal Murtèl), but the Ghiacciaio del Basòdino glacier in Ticino slightly lost mass. The glaciers surveyed on the main northern Alpine ridge exhibited moderate mass losses (e.g. Rhone Glacier, Glacier du Tsanfleuron). These were not overly dramatic with ice thickness reductions of 400 to 900 cm water equivalent. Glaciers in North-Eastern Switzerland (Silvretta, Pizol) experienced significant losses in thickness of over one metre.

The regional variations in glacier mass balance were very pronounced this year. The asymmetry between northern and southern Alpine regions is due to the frequent occurrence of southern blocking conditions in the winter and spring. The differences were reinforced by the elevations of the glaciers: in the generally lower level glaciers of the northern Alps, most of the precipitation fell in the summer months in the form of rain, whereas the glaciers in Southern Valais in particular benefited from repeated summer snowfall.

Extrapolated to all the Swiss glaciers, the mass loss for the hydrological year 2013/14 is estimated at 380 million m^3. This equates to a reduction in Switzerland's existing ice reserves of some 0.75 %. Despite slight mass gains in some regions, negative mass balances were the norm nationwide. Nevertheless, the 2013/14 weather conditions can be said to be relatively favourable overall for the glaciers in the Swiss Alps. Since 2002 the glaciers have only had comparatively low mass losses in 2012/13, but this cannot be called a trend reversal even though the glacier melt was less drastic than the long-term average.

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

Figure 3.2 *View of the Glacier de la Plaine Morte (BE), end of September 2014.*

4 > Rivers and lakes

On the northern side of the Alps the average annual discharges were widely below or close to the 1981–2010 average. Above-average discharges were measured on the southern side of the Alps and in the Engadine. 2014 will go down as an extremely warm year. In the major river regions the deviations from the average for the reference period were in the range +0.5 to +1.1 °C.

4.1 Discharge conditions

To the north of the Alps the annual average discharge in the major river regions was below or close to the 1981–2010 mean. The Rhine, Aare, Reuss and Limmat were within a normal range (90 to 110 %). The Thur, Doubs and Rhone discharged less than 90 % of their expected volumes. The Inn, Ticino and Maggia were well above the long-term average. The Maggia recorded the highest percentage discharge of the main rivers at 160 % of normal. The annual average discharge picture for the medium-sized catchments is more differentiated but not totally different (Figure 4.2). To the north of the Alps the values varied widely between approx. 80 and 110 %. Below this range were the Dünnern at Olten (70 %) and the Seyon at Valengin (74 %); above it was the Gürbe at 140 %. To the south of the Alps and in the Engadine, widespread above-average discharges were measured, with the highest relative values on the Moesa, Brenno, Cassarate and Vedeggio. In 2014 the Verzasca at Lavertezzo and the Magliasina at Magliaso recorded the highest annual average in the 25- or 35-year monitoring period.

The graphics of monthly average discharge volumes clearly indicate that there were both markedly positive and negative deviations from the norm. On the Aare, Reuss, Limmat and Thur, the months of March to June were drier than normal and July, August and in some cases November were wetter. The picture was similar on the Rhine at Diepoldsau, although March and April, rather than being dry, experienced near-normal discharge levels.

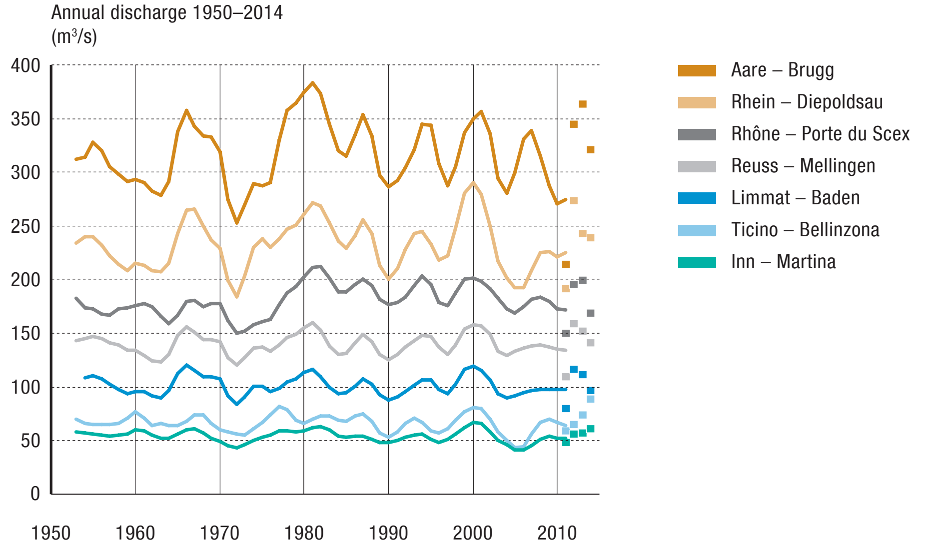

Figure 4.1 *Changes in the annual discharges for selected large catchments from 1950. Moving averages (over seven years) are shown as lines and the last four annual discharges are shown as points.*

The Rhone at Porte du Scex carried comparatively little water from May to September. On the Doubs there were massive deviations from the norm: in March (44 %), April (25 %) and December (47 %) the discharges were well below normal and in July and August well above (about 300 % of the long-term monthly average). In 2014, if the March and April discharges on the Doubs had occurred in July and August and the July and August discharges in March and April, the conditions would have been considered normal in those months. The abundant and prolonged precipitation in Ticino in November led to widespread very high monthly averages (e.g. Figure 4.3, Ticino at Bellinzona, and Figure 4.4, Maggia at Locarno). On the Maggia the November discharges were almost six times the long-term monthly average. The relative deviations were also considerable on the Maggia in February (over 200 %) and September (only about 20 %), but the absolute differences were much smaller than in November and are thus less apparent.

The daily discharge picture is similar on the Aare, Reuss and Limmat: dry conditions were generally predominant in the first half of the year, interrupted by shorter phases of normal or slightly above average discharges. Then came the two flood months of July and August, which figured large on the hydrographs on the northern side of the Alps (Section 1.1). Between the Aare and the Reuss there were new highest July discharge peaks at some 10 monitoring sites, including the Aare at Bern, the Emme at Eggiwil and the Engelberger Aa at Buochs. After quite a calm autumn, discharges surged significantly again in November without generating high peak floods.

On the southern side of the Alps, the first four months were already quite wet. A few higher discharge events occurred between May and August, but the highest were in October and November and caused the prolonged floods on Lakes Maggiore and Lugano. During this period a new October maximum of about 1500 m^3/s was observed on the Maggia at Locarno.

Throughout 2014 the Rhone at Porte du Scex recorded the discharge fluctuations very typical of this catchment, which are caused by hydropower use. From the start of the year to the end of April and from October to year end, these weekly fluctuations remained at a normal level for the time of year. From May to September discharge volumes were generally below average, but some peaks exceeded the 75 % quantile and at the end of July – with the highest discharge volume of the year – the 95 % quantile.

Discharge conditions in selected medium-sized catchments

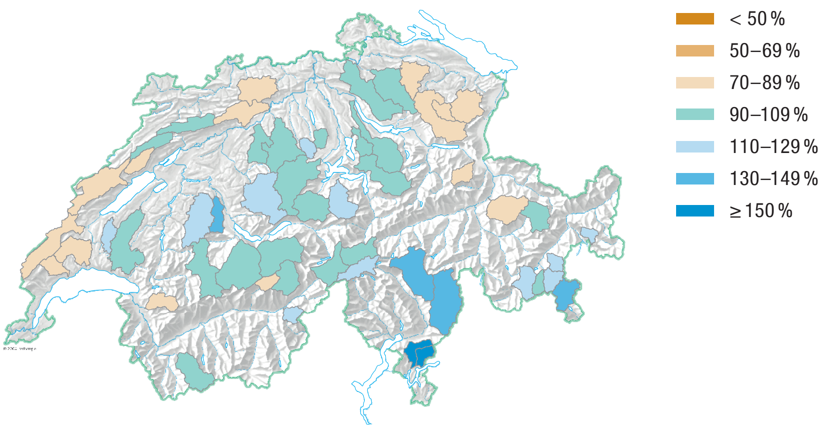

Figure 4.2 *Annual mean 2014 compared with the mean discharge for the long-term average period 1981–2010 in selected medium-sized catchments [%].*

Monthly mean discharges in selected large catchments

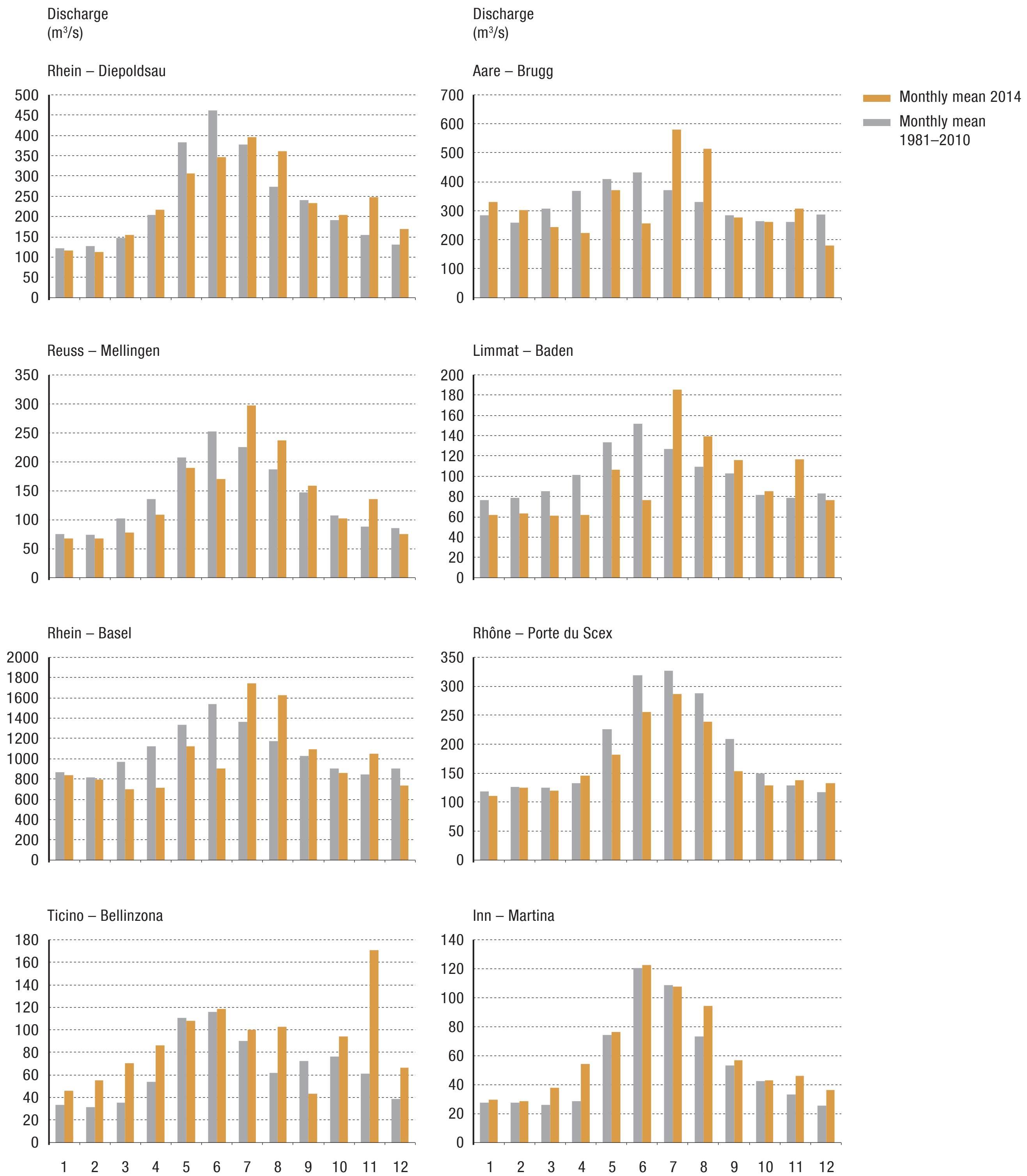

Figure 4.3 *Monthly mean discharges 2014 (orange) compared with the monthly mean for the long-term average period 1981-2010 (grey).*

Monthly mean discharges in selected medium-sized catchments

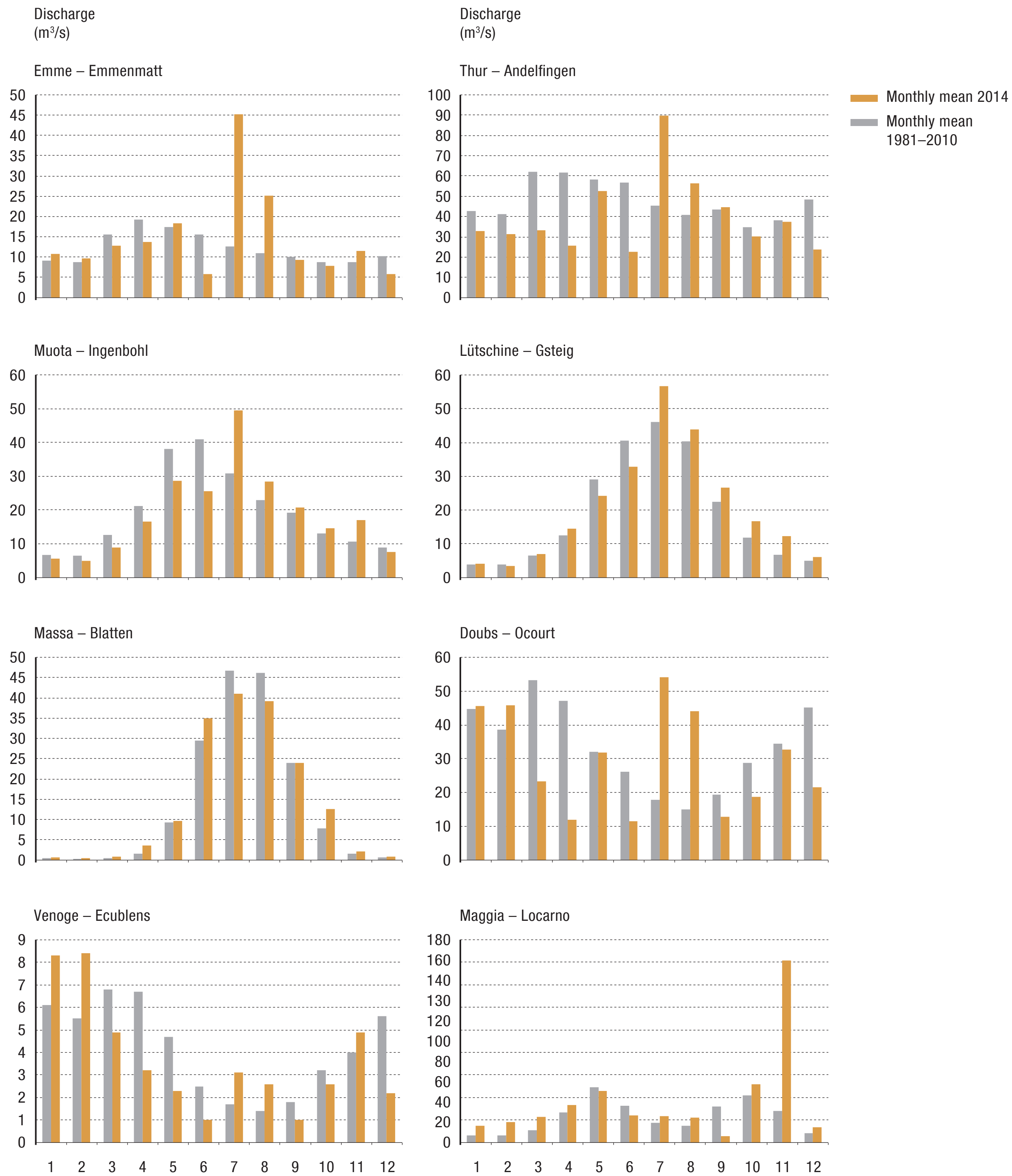

Figure 4.4 *Monthly mean discharges 2014 (orange) compared with the monthly mean for the long-term average period 1981–2010 (grey).*

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

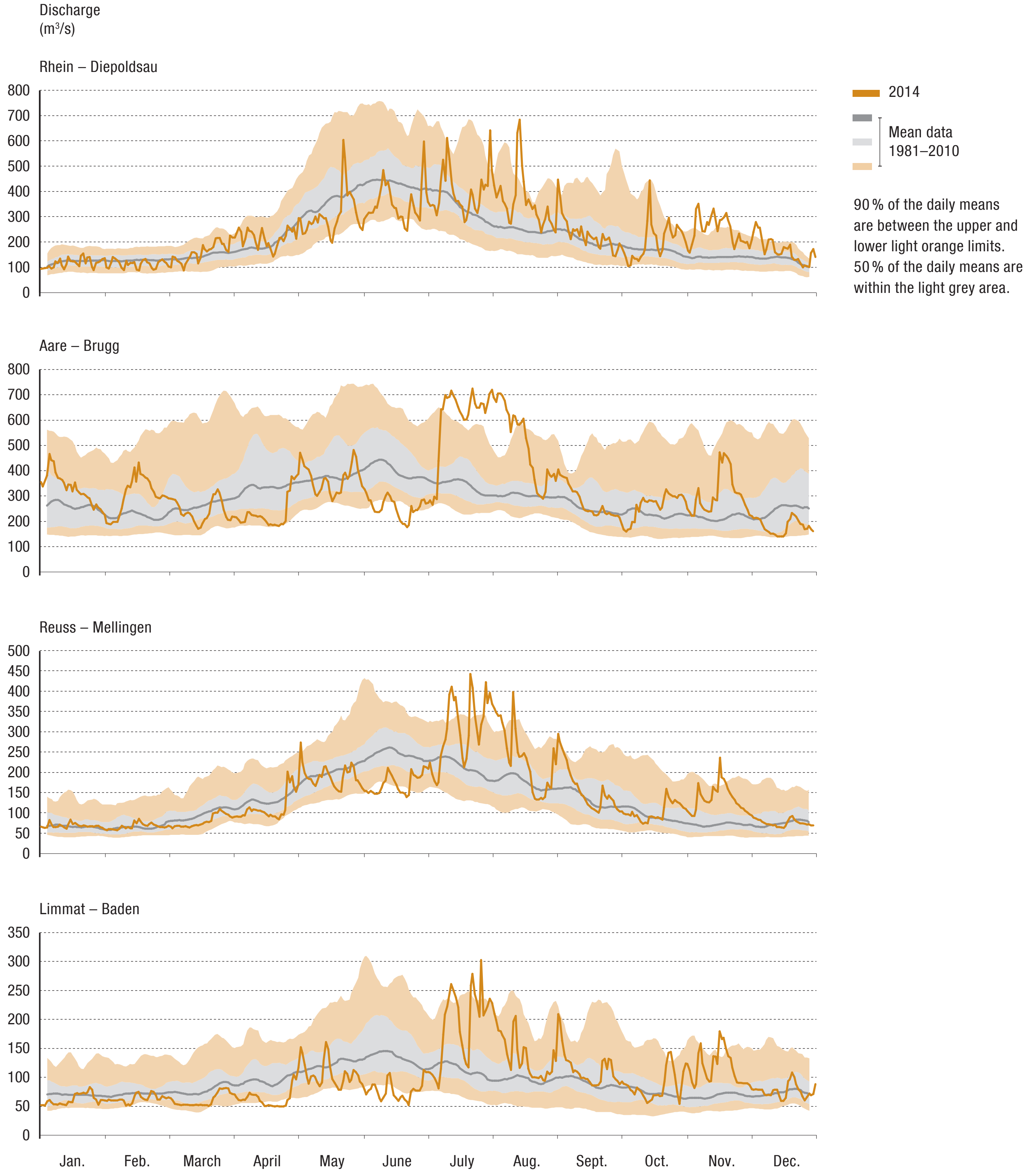

Figure 4.5 *Daily mean discharges 2014 (orange) compared with the daily mean for the long-term average period 1981-2010 (grey).*

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

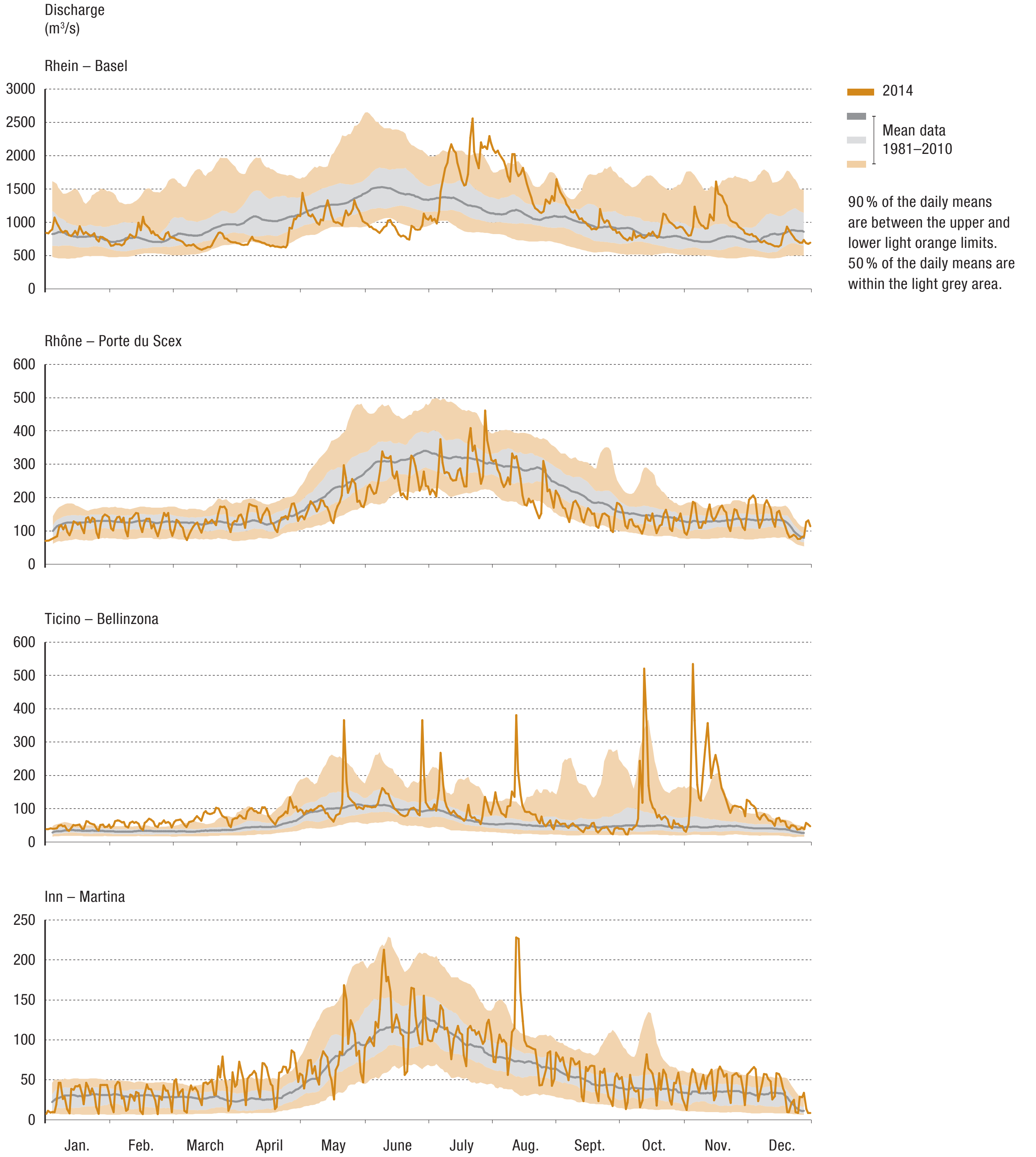

Figure 4.6 *Daily mean discharges 2014 (orange) compared with the daily mean for the long-term average period 1981–2010 (grey).*

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

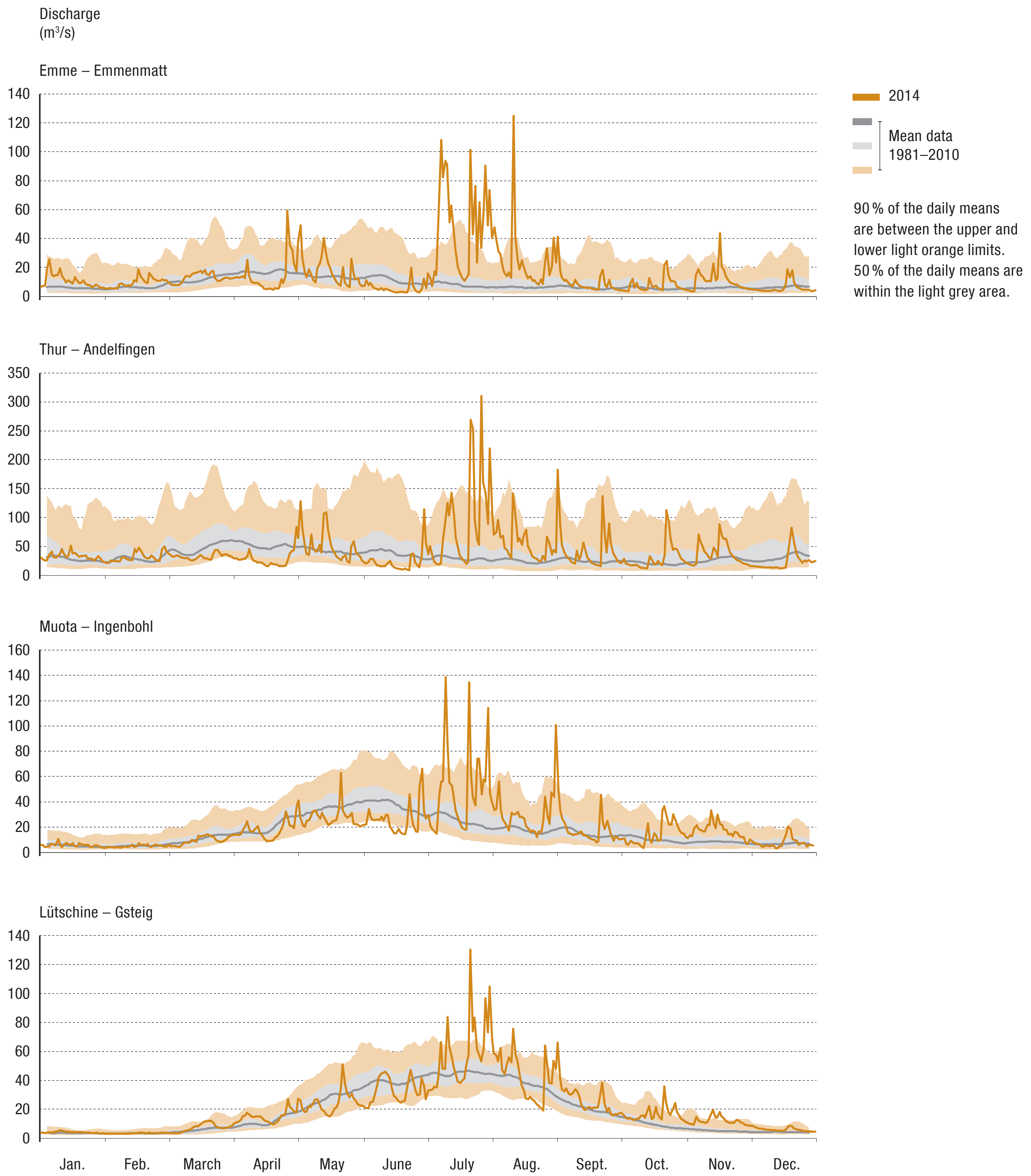

Figure 4.7 *Daily mean discharges 2014 (orange) compared with the daily mean for the long-term average period 1981–2010 (grey).*

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

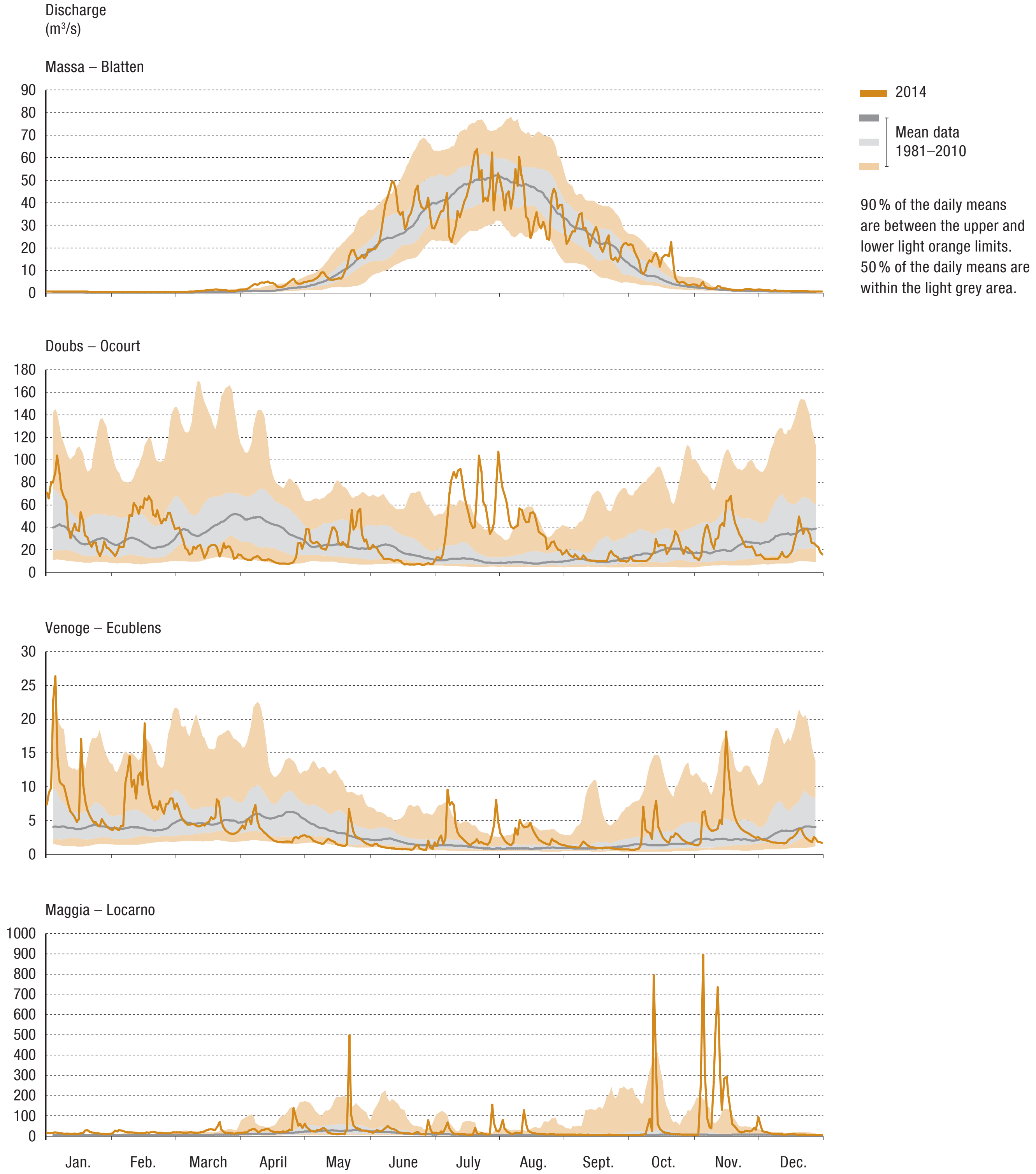

Figure 4.8 *Daily mean discharges 2014 (orange) compared with the daily mean for the long-term average period 1981–2010 (grey).*

4.2 Lake levels

The 2014 average water levels in most of the larger lakes on the northern side of the Alps were close to the mean for the 1981–2010 reference period. Large positive deviations in Lakes Maggiore and Lugano were evident at 34 and 16 cm above normal respectively. Prolonged precipitation in October and November meant that levels far above average could not be prevented, despite lake regulation. Lake Walen also exhibited significant deviations, but these were negative. The annual average, at 13 cm, was well below normal. However, neither the positive deviations for Lake Maggiore nor the negative deviations for Lake Walen were extreme. Some 5 % of the annual means in Lake Maggiore since 1943 have been higher than in 2014 and some 12 % of the annual means in Lake Walen since 1930 have been lower than in 2014.

When data for individual months is considered, differences are naturally greater than when comparing annual averages. For Lake Maggiore, the November 2014 mean was 147 cm above the November long-term average water level but still 156 cm below the maximum measured in any November since 1943. Figure 4.9 shows that above-average water levels were measured in most months on both the northern and southern sides of the Alps. Although the outlook on Lake Constance in June was still for low water, from July onwards levels were above the long-term average without exception, the greatest deviation of about half a metre occurring in August and September. Evidence of the wet summer is clear to see in the hydrographs for Lake Neuchâtel: July and August 2014 were 17 and 11 cm above normal.

A more detailed time resolution shows that the water levels on Lakes Constance and Geneva rarely extended beyond the 5 % and 95 % quantiles. On Lake Constance the upper limit was just reached in July, August and November; on Lake Geneva there were very short periods early and late in the year when the 95 % limit was reached. The situation was different on Lakes Neuchâtel and Maggiore: the prolonged precipitation in July and August left their mark north of the Alps. The two flood phases pushed the hydrological system on the lakes adjacent to the Jura to the limit. As already mentioned, the high water levels in Ticino were not extreme in the context of the entire monitoring period, but the floods they caused made them very significant for many people affected in the densely populated area. The flood limits triggering warnings were exceeded on more than 20 days with the highest hazard level on several. Level 5 is reached on Lake Maggiore if the water level exceeds 195.75 m AMSL.

Monthly mean water levels in selected lakes

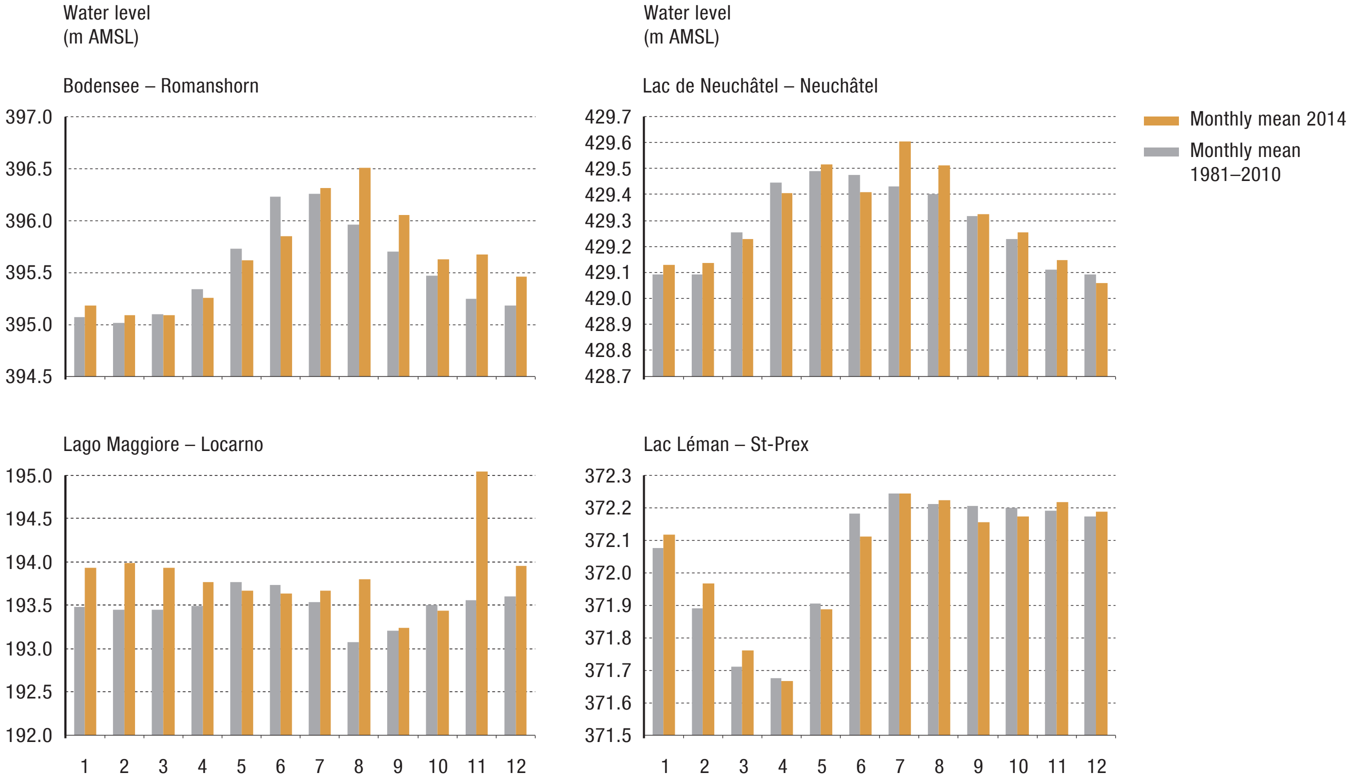

Figure 4.9 *Monthly mean water levels 2014 (orange) compared with the monthly mean for the long-term average period 1981–2010 (grey).*

Daily water levels in selected lakes

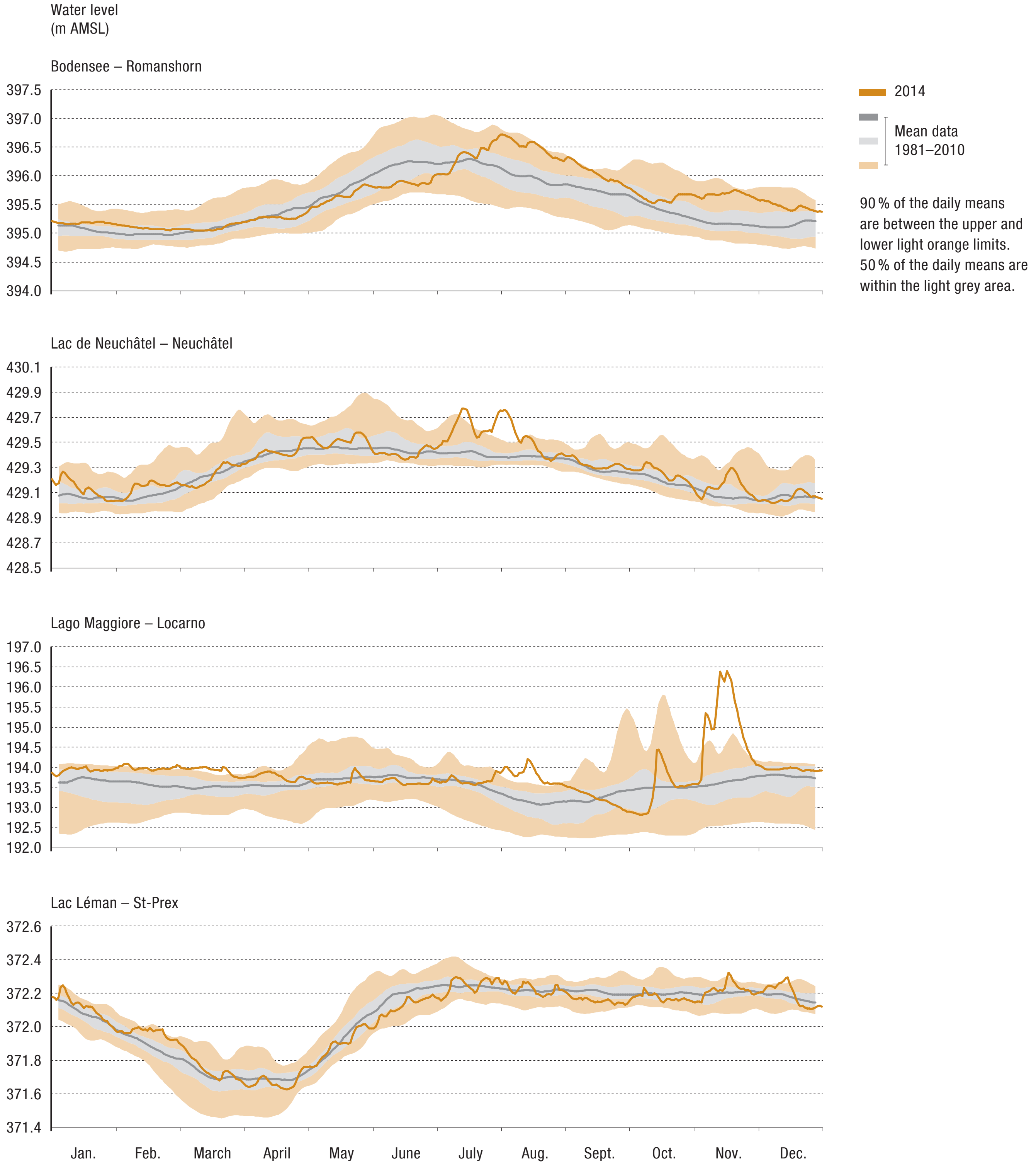

Figure 4.10 *Daily mean water levels 2014 (orange) compared with the daily mean for the long-term average period 1981–2010 (grey).*

4.3 Water temperatures

2014 will go down in the records as an extremely warm year. The high air temperatures were reflected in the annual mean surface water temperatures. In the larger catchments the deviations from the mean for the 1981–2010 reference period were in the range +0.5 to +1.1 °C (Figure 4.11). Some stations recorded a high annual average similar to the record year 2011.

In the first half of 2014, many stations recorded average to above average water temperatures in every month except May, with new monthly maximums. After a cool and cloudy summer, water temperatures rose from September to December to values well above normal. Along with October, December proved unusually warm with new monthly maximums at many stations.

The temperature on the Rhine peaked early

The Rhine at Rekingen normally reaches its highest temperature of the year in August. However, 2014 was characterised by an extreme temperature rise due to an exceptional hot spell early in June, so that the annual maximum temperature was reached on 14 June (Figure 4.12). The week-long heatwave in the first half of June led to water temperatures in June with a monthly mean of 3.1 °C above normal for the 1981–2010 period. Temperatures dropped back to below normal in the subsequent summer months. Exceptions were Alpine rivers such as the Rhone at Porte du Scex, where the extremely low sunshine levels in summer 2014 led to a reduced inflow of cold melt water and to comparatively high temperatures.

Prolonged elevated temperatures in the autumn

After the mainly cool summer, water temperatures rose from September to October to unusually high levels. The seemingly record-breaking warm spell from the end of September was brought to a temporary end on the evening of 21 October by a north-westerly flow with an active cold front followed by a cold polar air flow. This abrupt temperature drop is easily seen on all the annual water temperature graphs. After this distinct fall, temperatures at most stations returned to elevated levels relative to the norm, where they remained until year end.

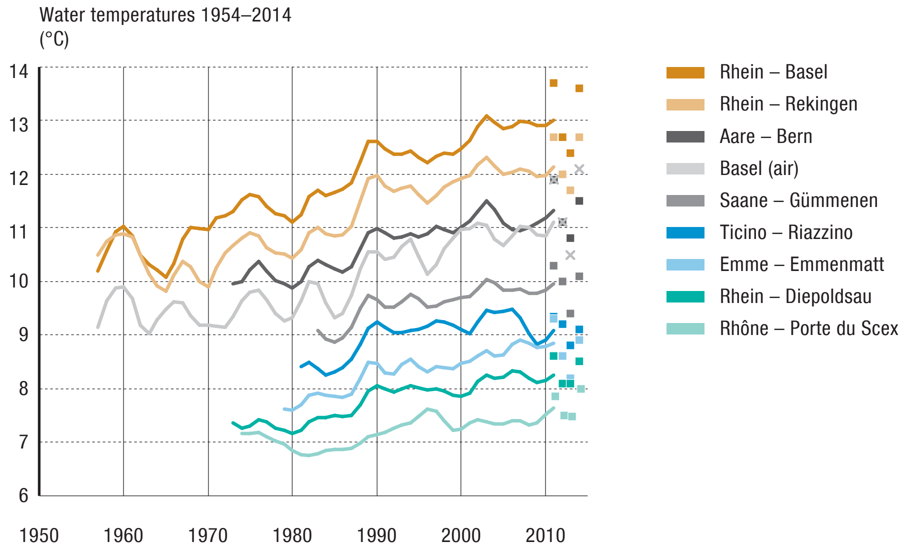

Figure 4.11 *Changes in water temperature from 1954 to 2014 in selected Swiss rivers. Moving averages (over seven years) are shown as lines and the last four annual means are shown as points or crosses (air).*

Mean daily water temperature at selected stations

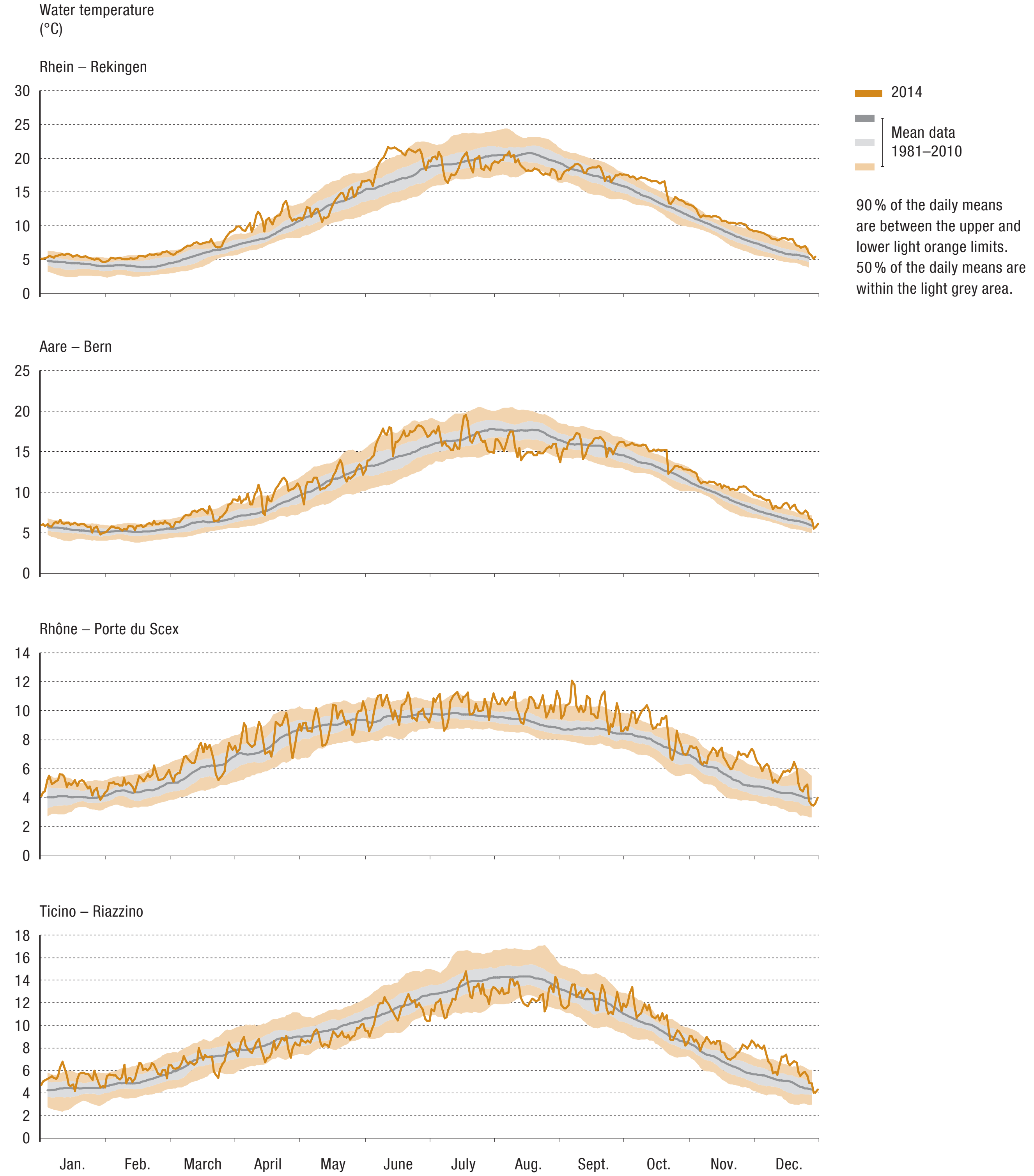

Figure 4.12 *Daily mean water temperature 2014 (orange) compared with the daily mean for the long-term average period 1981–2010 (grey).*

4.4 Stable isotopes

Stable water isotopes are suitable for determining the origin of water components in regional climatic, environmental and water body studies. As part of the NAQUA ISOT module, long-term regional changes in deuterium (^2H) and oxygen-18 (^{18}O) are recorded at 13 representative precipitation monitoring sites and nine sites on rivers (Figure 4.14), to provide reference data for these analyses.

In relation to precipitation, an increase in δ^2H and $\delta^{18}O$ values between 1980 and 2005 can be observed at all the monitoring sites. The general picture is not consistent but is dominated by seasonal fluctuations. Since 2005 this trend seems to have been halted. The δ-values recorded in the winter seasons are now much more negative. Again in 2014, the stable isotopes in the precipitation have low δ-values in the winter. The summer levels remain at the long-term average. Below-average δ-values were measured in the Jura and the Alps in the summer. In the Ticino (LocarnoMonti station) the δ-values in the precipitation were lower in November 2014 due to the heavy rainfall. Therefore the annual mean $\delta^{18}O$ weighted by the precipitation was 0.6 ‰ more negative than the previous year.

In rivers, the general trend in δ^2H and $\delta^{18}O$ values is also detectable but to a much lesser extent (e.g. Aare, Rhine, Rhone). Here too the trend has changed in recent years. In the long-term comparison, the δ-values were below average in 2013 along the Aare and in the Rhine at Weil and this trend continued in 2014 despite the higher air temperatures. The Rhone above Lake Geneva also recorded below-average δ-values in 2014. In June 2014 unusually low δ-values were recorded widely in the Swiss rivers due to a spell of hot weather with significant snow and glacier melt. In the Ticino at Riazzino, the δ-values in November 2014 hardly varied from the previous year's levels despite the high precipitation. The likely reason is that this became mixed with precipitation which had already infiltrated soil and groundwater in the preceding months.

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

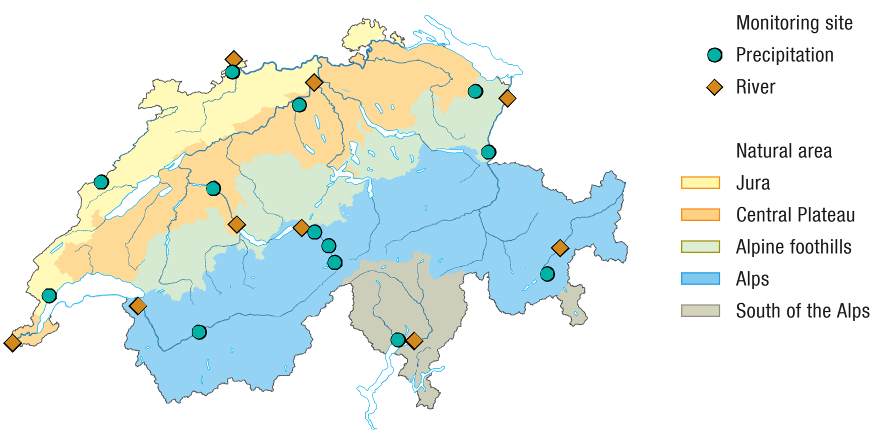

Figure 4.13 *Monitoring sites in the NAQUA ISOT module to monitor the isotopes in precipitation and in rivers in Switzerland, 2014 status.*

4.5 Water quality/physical and chemical characteristics

The quality of water in Swiss rivers is generally good. Nutrient levels have fallen significantly over recent decades. However, the input of micropollutants continues to pose a challenge. Peak levels of pollution from plant protection products and biocides have also been detected in smaller watercourses during rainfall.

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 18 monitoring sites 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, 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 not routinely published in the Hydrological Yearbook. Further information and data can be found on the website (c.f. p. 34).

National River Monitoring and Survey (NADUF) monitoring sites

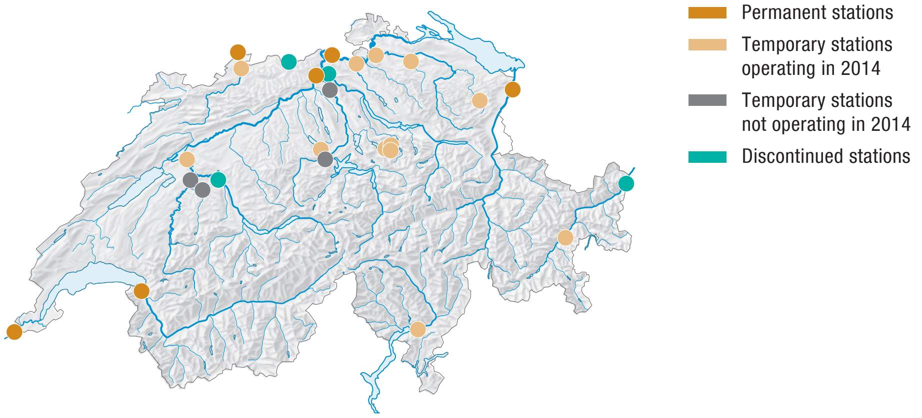

Figure 4.14 *National River Monitoring and Survey programme (NADUF) monitoring sites to monitor water quality in Switzerland, 2014 status.*

5 > Groundwater

In 2014 groundwater levels and spring discharges were mainly normal.

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.

By observing groundwater levels and spring discharges over the longer term, significant fluctuations with a specific periodicity can be identified. For example, Swiss groundwater levels alternate regularly between periods of high and low levels lasting for a number of years. These situations are generally linked by a transition range during which groundwater levels and spring discharges are average for a period of time.

The high groundwater levels and spring discharges on the northern side of the Alps at the beginning of 2014 normalised in most places because of the below-average precipitation levels in February and March, but continued to be high on the southern side of the Alps as a result of high precipitation (Figure 5.1, Groundwater situation on 12.03.2014).

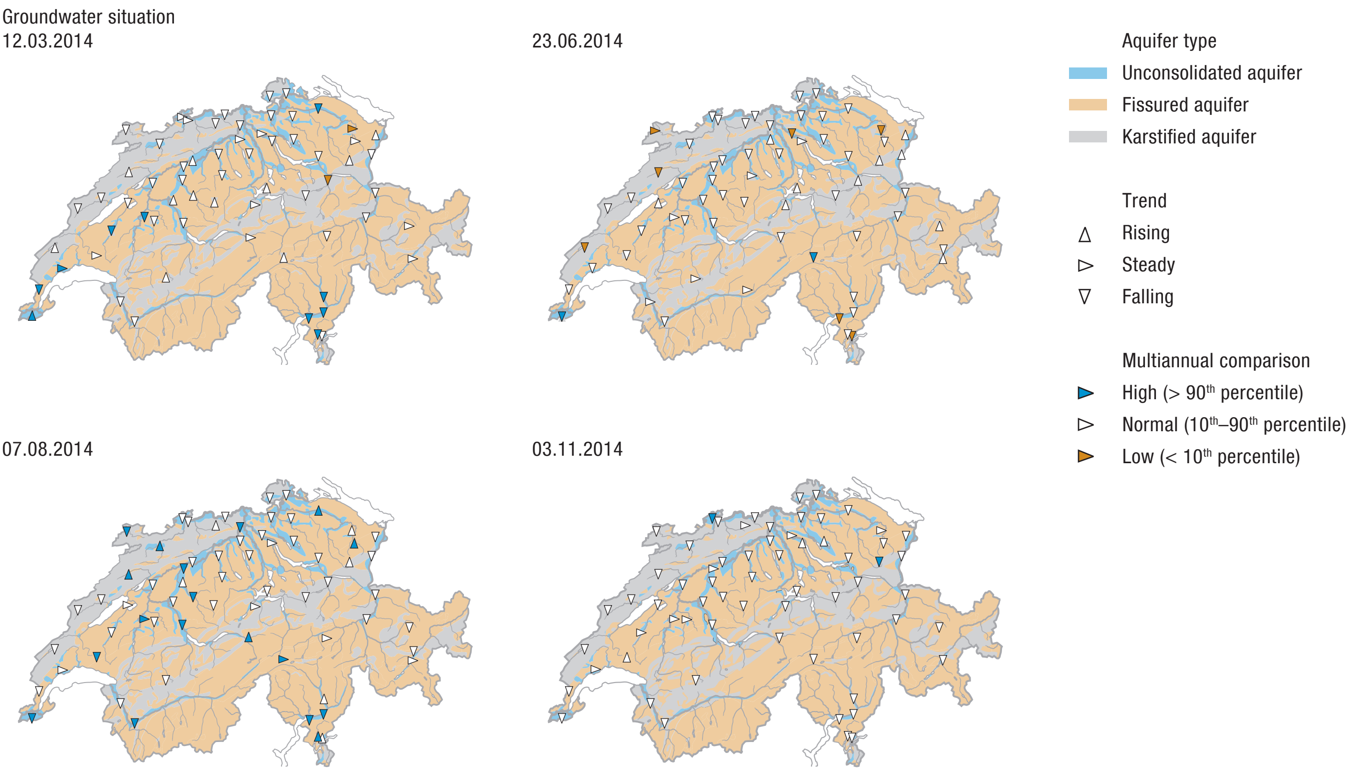

Figure 5.1 *Groundwater levels and spring discharges and their trends on four reference dates in 2014 and compared with the 1994–2013 monitoring period.*

As a result of the below-average precipitation in the three spring months, groundwater levels and spring discharges fell nationwide. In June groundwater levels at the valley gravel on the Central Plateau were still within the normal range but were locally low. Some spring discharges were low in karstified aquifers in the Jura due to the below-average precipitation in the previous months. Normal to low groundwater levels were observed in Ticino in June (Figure 5.1, Groundwater situation on 23.06.2014).

Prolonged heavy rainfall in July led to widespread high groundwater levels and spring discharges. The heavy rain caused river levels in the catchment of the Aare to rise, resulting in increased river water infiltration. Groundwater levels rose rapidly along the Aare and Emme. The low spring discharges at the end of June normalised quickly due to the above-average precipitation (Figure 5.1, Groundwater situation on 07.08.2014).

The high groundwater levels and spring discharges in early August normalised due to the variable precipitation amounts in September and October. By the beginning of November groundwater levels were within the normal range throughout Switzerland (Figure 5.1, Groundwater situation on 03.11.2014).

The high November precipitation in Ticino caused groundwater levels and spring discharges to rise unusually sharply, resulting in new maximum groundwater levels for the month of November at the QUANT monitoring sites in Ticino. The Lamone site even recorded a new absolute maximum level of 307.71 m AMSL on 17.11.2014 (reference period 1981–2014).

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. 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 FOEN website (p. 34).

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

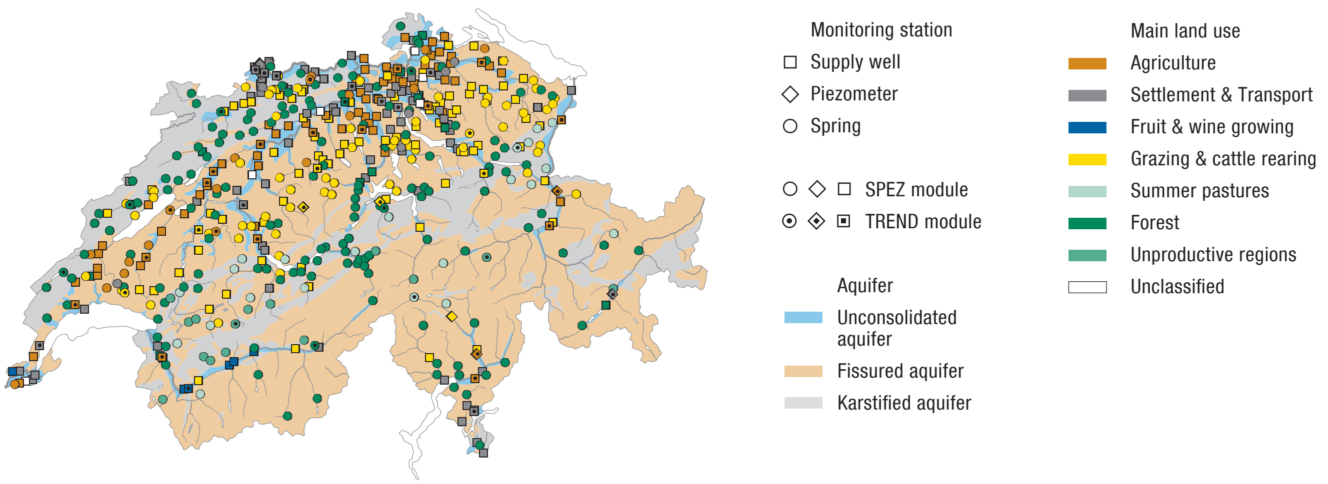

Figure 5.2 *Monitoring sites of the NAQUA TREND and SPEZ modules to monitor groundwater quality with main land use in the catchment and type of aquifer, 2014 status.*

> Annex

Glossary

National River Monitoring and Survey Programme (NADUF)

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

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 water and, river water.

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. A quantile 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.

Risk level

In accordance with the provisions of the Alarm Ordinance, the FOEN uses a five-step risk scale to warn of floods. The risk 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 “significant risk” to the “high risk” level. Floods can occur increasingly at this water level. Buildings and infrastructure can be affected.

^{2}H, ^{18}O

Deuterium (^{2}H) is a natural stabile 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

Detailed information on the FOEN hydrometric monitoring networks and current and historical data can be found on the website at:
www.bafu.admin.ch/hydrologischesjahrbuch

> Current and historical data:
www.hydrodaten.admin.ch/en
> FOEN Hydrological Bulletin:
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:
www.bafu.admin.ch/naqua
> Results of the National River Monitoring and Survey
> Programme (NADUF):
www.bafu.admin.ch/naduf
> Water indicators:
www.bafu.admin.ch/indikatoren_gewaesser