> Hydrological Yearbook of Switzerland 2011

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

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> Contents

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Authors
FOEN, Hydrology Department
Weather: Federal Office for Climatology and Meteorology (MeteoSwiss)
Snow: WSL Institute for Snow and Avalanche Research (SLF)
Glaciers: Department of Geosciences, University of Fribourg,
and Laboratory of Hydraulics, Hydrology and Glaciology (VAW)

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> Foreword

Switzerland will become warmer and in summer drier. More frequent and longer heatwaves and longer summer droughts can be expected in future. This is indicated by the latest scientific information from Swiss climate researchers which was published in September 2011 under the leadership of Federal Institute of Technology Zurich and by MeteoSwiss, partly in the form of scenarios for climate change in Switzerland (CH2011). This trend is also clear from analyses in the FOEN project "Climate change and hydrology in Switzerland" (CCHydro). Even if Switzerland has enough water in the future, pressure on the available water resources is likely to increase and there may be temporary conflicts of interest concerning water on a local basis.

Some Swiss agencies already faced these challenges in 2011, a year which will go down in history as the year of weather records. Hydrologically, it was also an unusual year: Long dry periods alternated with isolated significant flood events. Temporary local water shortages occurred during the long drought of spring 2011.

At federal level various projects are under way to develop solutions and measures for optimum management of the water resources and resolution of local scarcity issues. Thanks to appropriate water supply distribution plans and water supply infrastructure, large-scale water shortages are unlikely to occur in Switzerland in the long term.

The work on hydrometry within the Federal Administration was also reorganised in 2011. On 1 January the Instruments and Laboratories Section (SIL) of the FOEN Hydrology Division was transferred to the Federal Office of Metrology (METAS). Since then the FOEN specialists have been working closely with colleagues at METAS, who are now responsible for equipping hydrometric gauging stations, maintaining and operating hydrometric instruments and operating the calibration channel in Ittigen (BE) on behalf of the FOEN. This is an important basis for the collection of data, which is also published and discussed in this Hydrological Yearbook.

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

Averaged over Switzerland as a whole, the year 2011 was 1.2 degrees warmer and therefore the warmest since records began in 1864. In some regions, it was clearly too dry. In Western Switzerland precipitation was only 60 to 80 % of the 1981–2010 long-term average. In the rest of Switzerland amounts varied between 70 and 95 %, and were slightly over 100 % locally.

Snow and glaciers

The winter of 2010/11 was drier and warmer than normal and also sunnier in the north. As a result, snow depth over the winter as a whole was below average in most areas. It was average in Northern Ticino, Upper Engadine and the southern valleys of Graubünden. The 2010/2011 hydrological year was also marked by very high glacier mass losses.

Discharge conditions

The discharges in the large catchments were well below average. They reached only 70 to 80 % of the long-term annual average to the north of the Alps. Low precipitation in the spring and very low snow melt led to very low water levels in rivers and lakes, especially in the Jura and Central Plateau.

An unusual rain-on-snow event in autumn 2011 brought new maximum October discharge peaks to stations in the Bernese Oberland and Central Switzerland.

Lake levels

The average water level in 2011 was below the 1981–2010 long-term average by 10 cm in Lake Constance and by 12 cm in Lake Neuchâtel. For Lake Neuchâtel this is the lowest average of the entire gauging period. In Lakes Geneva and Maggiore there was only a slight deviation from the long-term average. Several lakes recorded the lowest seasonal values but no absolute records.

Water temperatures

The 2011 annual average water temperatures were widely above the long-term average. The previous highest average was exceeded at more than 20 stations in the temperature monitoring network. Average temperatures were exceeded by a small margin only in catchments with relatively high glaciation.

Stable isotopes

In the year 2011 the stable water isotopes in the Rhine above Lake Constance, the Rhone above Lake Geneva and in Ticino had the lowest δ values in spring during the snow melt and the highest following the precipitation in July and August.

Groundwater

In 2011 Swiss groundwater levels and spring discharges were low due to the persistent drought. In May and June 2011 they were significantly lower than in the hot summer of 2003 because the levels at the beginning of that year had been higher.

1 > Notable phenomena in 2011

The spring of 2011 will be remembered as extremely warm and dry. These weather conditions resulted in unusually low water levels and high water temperatures. In the autumn another extreme event caused concern when the rivers in the Bernese Oberland flooded after heavy snow and rainfall.

1.1 Drought in spring 2011

In the first few months of the year, wide areas of Switzerland experienced unusually low levels of precipitation (cf. Section 2). Because snowfall at the end of 2010 had also been low, there was very little snow cover in spring 2011 and as a result both snow melt and rain failed to replenish the rivers and lakes.

This led to very low water levels in rivers, lakes and groundwater, especially in the Jura and Central Plateau. Unusually, the low level occurred in spring. As a rule the basins are filled in spring, and in the Central Plateau and Jura low levels tend to occur in late summer, autumn or winter.

Lakes and rivers with new record spring lows

New lows for May and June were measured for the Swiss lakes, but no new absolute records. For example, between 25 March and 20 May 2011 the lowest levels since 1983 were recorded in Lakes Murten and Neuchâtel. During the period from 13 May to 18 June, levels in Lake Walen in 2011 were the lowest since records began in 1910. For several days in June the water levels in Lakes Zurich, Constance and Maggiore also fell to historic lows for the time of year.

The river discharges observed in spring 2011 were equivalent to levels occurring about every two to five years. For a few days record May and June figures were measured in some large rivers. The discharges in the Aare at Brugg (Figure 1.1) and the Rhine at Basel were extremely low, particularly in May. New minimums were recorded in the Limmat in Zurich on 42 days from mid-April to mid-June (records since 1938).

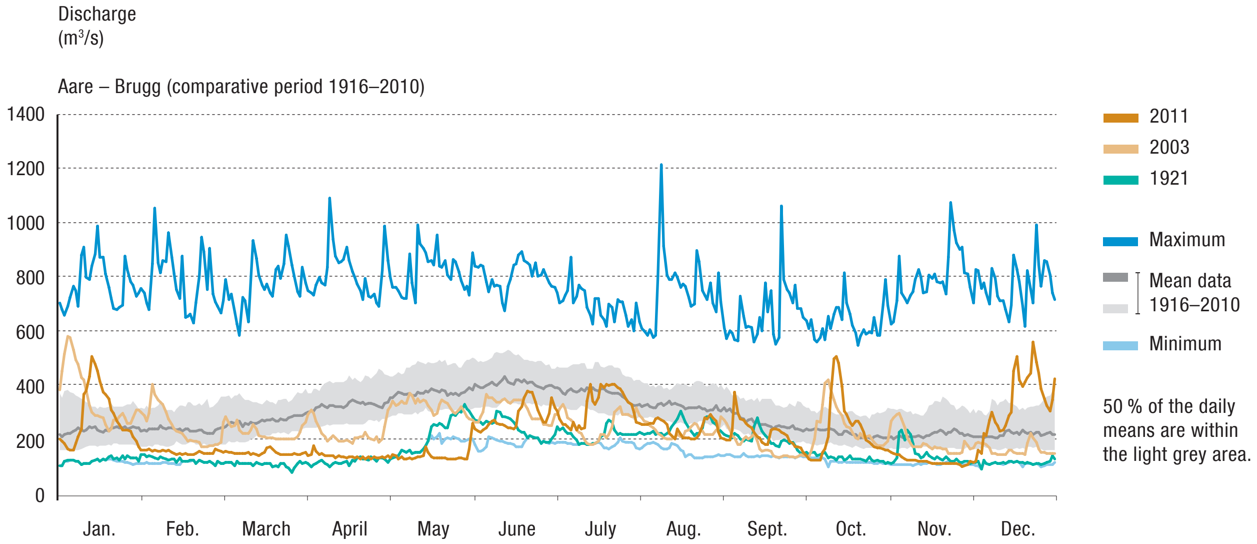


Figure 1.1 *Discharge in the Aare at Brugg in 2011 compared with the dry years 2003 and 1921 and the long-term statistical data.*

Exceptionally low groundwater levels

Groundwater levels were extremely low in the small river valleys of the Jura, Central Plateau, foothills of the Alps and Ticino, particularly in May and June. They were also low in the valleys of the large Alpine rivers due to the precipitation deficit and low snow melt.

A very significant reduction in the spring discharges was recorded in karstified springs in the Jura and unconsolidated rock springs in the Central Plateau, which are fed by groundwater sources near the surface. The springs in fissured rock were less affected by the drought in the first half of 2011.

Groundwater levels and spring discharges were much lower in May and June 2011 than in the equally dry and warm year of 2003 because, in contrast to that year, they did not benefit from a high initial level in the preceding winter (cf. Figures 1.4 and 1.5).

New maximum water temperatures for April and May

The combination of long hours of sunshine and low water levels caused exceptionally high water temperatures, particularly in April and May 2011. The seasonal maximums in the Central Plateau occurred mainly during April in the small and medium-sized rivers such as the Thur, Birs, Saane, Broye and Emme.

In the major rivers below the lakes, the highest values were largely recorded towards the end of April and in May. Some of the previous seasonal records were exceeded by over 2 °C. On 12 May a water temperature of 18.9 °C in the Rhine at Rheinfelden was 3.1 °C higher than the previous highest value measured on that date since 1974 (cf. Figure 1.2).

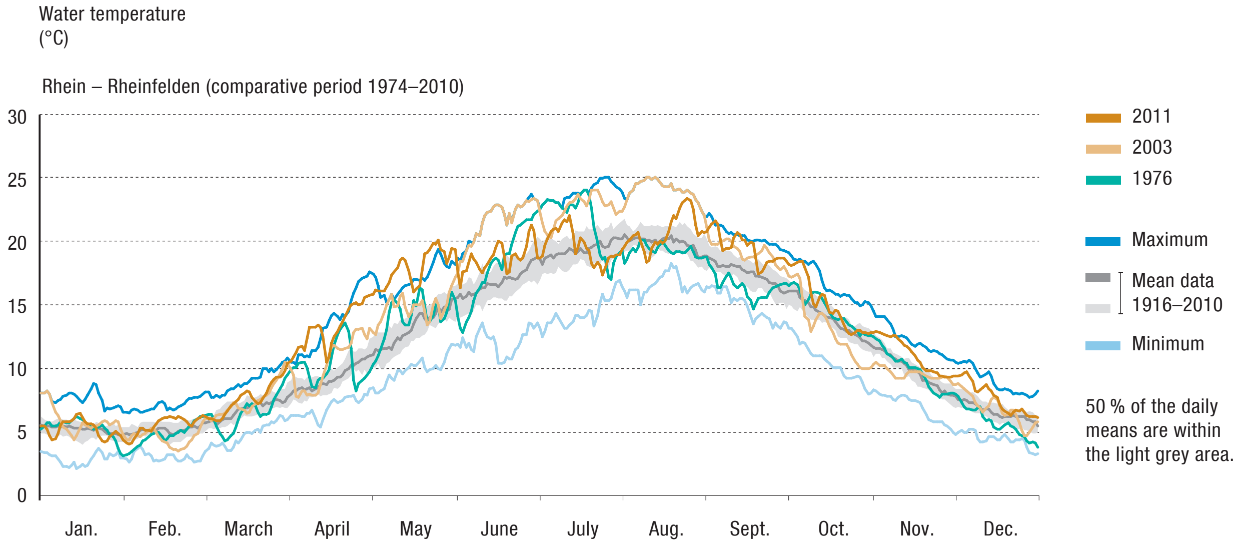


Figure 1.2 *Water temperature in the Rhine at Rheinfelden in 2011 compared with the dry years of 2003 and 1976 and long-term statistical data.*

Normalisation of the situation during July 2011

At the end of June the water levels in Lakes Zug, Zurich, Constance and Walen were still very low compared with the long-term monthly average (cf. Figure 1.3). At the same time, high levels of precipitation caused flooding on some rivers in the Bernese Oberland, Central Switzerland and the Zurich region on 30 June of a magnitude occurring statistically once every two years (two-year event). A 5- to 10-year flood was recorded on the Sihl and even a 10- to 20-year flood on the Lorze and Engelberger Aa.

Rivers with a small or medium-sized catchment are affected more quickly by rain than larger rivers, lakes and groundwater. Consequently, north of the Alps a widespread low water situation does not exclude the possibility of simultaneous local flooding.

It was only with the above-average levels of precipitation in July that larger rivers, lakes and groundwater north of the Alps rose to normal levels for the time of year. Groundwater sources located far from rivers or deeper underground took somewhat longer to revert to normal. Another very dry period followed from the end of October to early December, which was again clearly reflected in the discharge data (cf. also Section 4.1), although it was less significant than the drought in the spring.

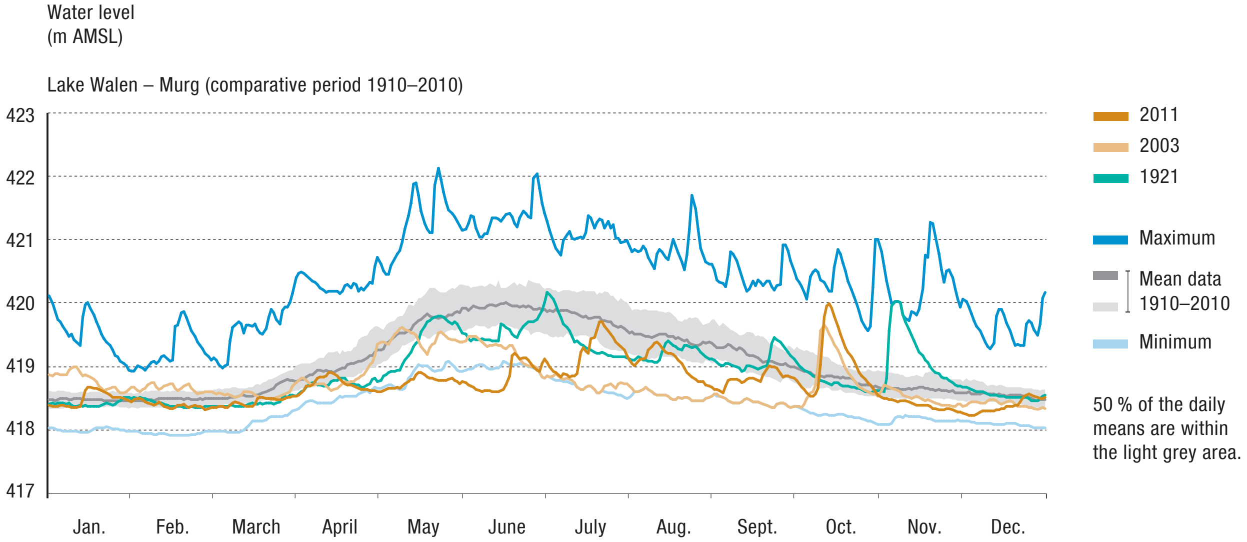


Figure 1.3 *Water level in Lake Walen at Murg in 2011 compared with the dry years of 2003 and 1921 and the long-term statistical data.*

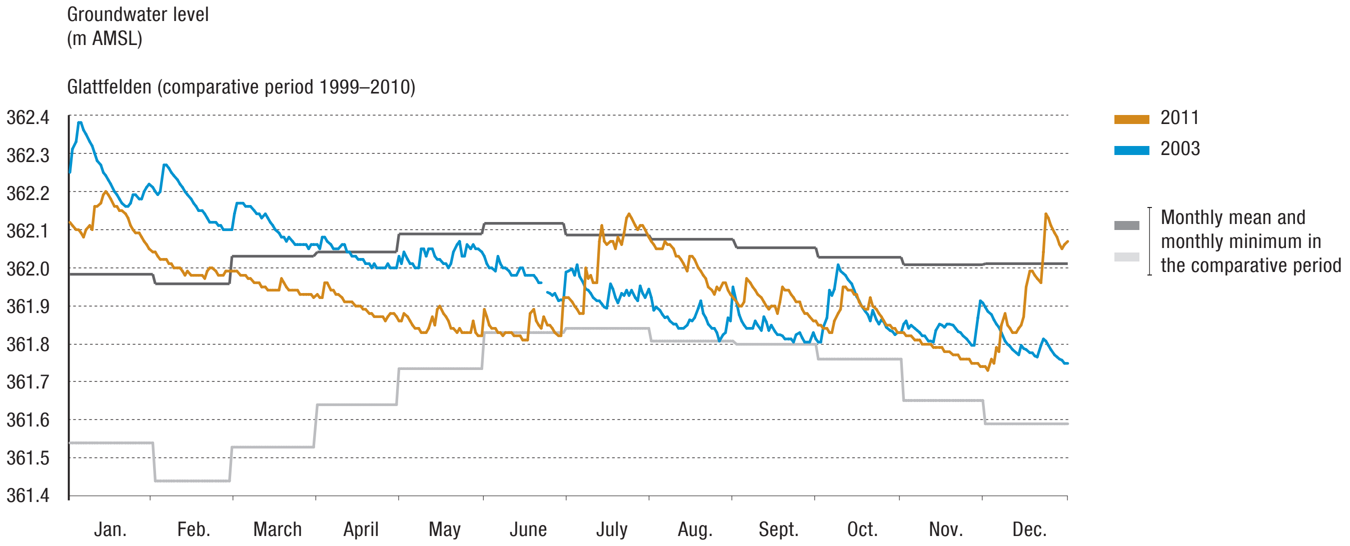


Figure 1.4 *Groundwater level at Glattfelden in 2011 compared with 2003 and the long-term statistical data.*

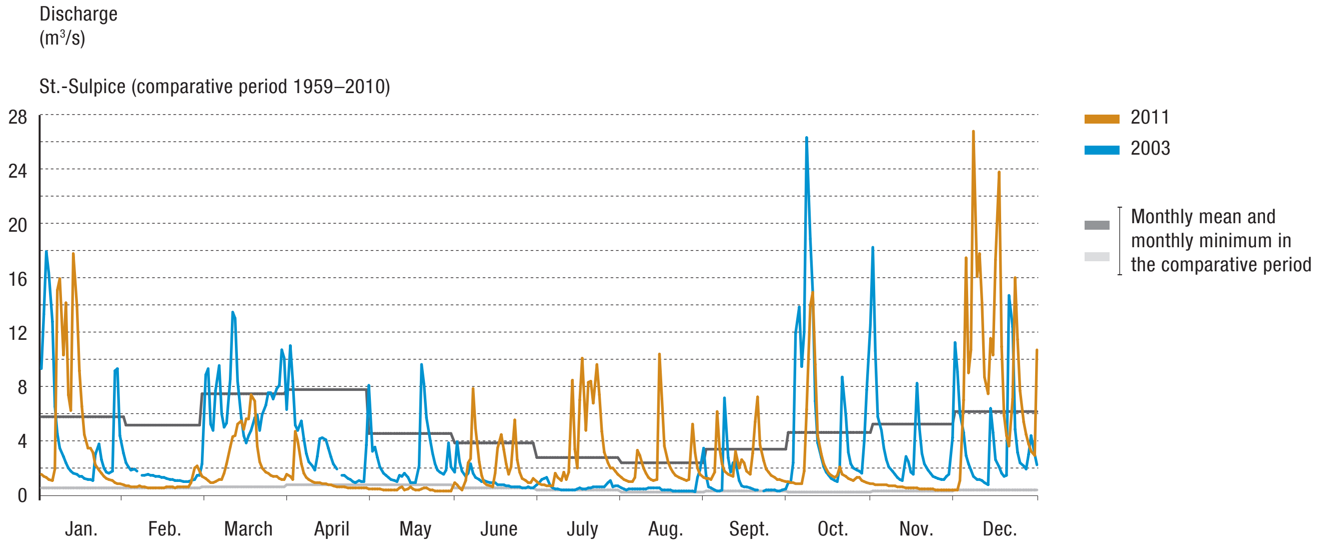


Figure 1.5 *Spring discharge at St.-Sulpice in 2011 compared with 2003 and the long-term statistical data.*

1.2 “Low water” indicator

The annual minimum discharge for 41 long-term FOEN discharge monitoring stations is determined over seven consecutive days (NM7Q). An event is defined as low water if its discharge is less than the $NM7Q_{10}$ discharge calculated for the station (NM7Q discharge below which values only occur statistically every 10 years). The “low water” indicator shows the total low water events per year. The analysis is carried out separately for Alpine and non-Alpine indicator stations, as low discharges in the two regions are caused by different processes: low water levels are associated with low temperatures at Alpine stations and with drought at non- Alpine stations. The indicator stations were selected on the basis of minimal anthropogenic influence (i.e. no power stations or supply outlets or inlets in the catchment). Figure 1.6 shows the indicator for non-Alpine stations.

As detailed in Section 2, the year 2011 was much drier than normal in many regions. This led to low discharges in the spring, especially in the Central Plateau and the Jura (cf. Section 1.1). However, the levels were not as low as in other dry years. Only one indicator station in the non-Alpine area – Gürbe at Belp – had a low water event in 2011.

An analysis of low water events between 1930 and 2011 does not indicate a clear trend for the non-Alpine discharge monitoring stations. The striking years are 1947, 1949, 1962 and 2003, with a great many low water events. In the lower lying catchments, these events are caused by long dry spells and are generally observed in summer or autumn. Dry periods of this kind will presumably become more frequent due to climate change.

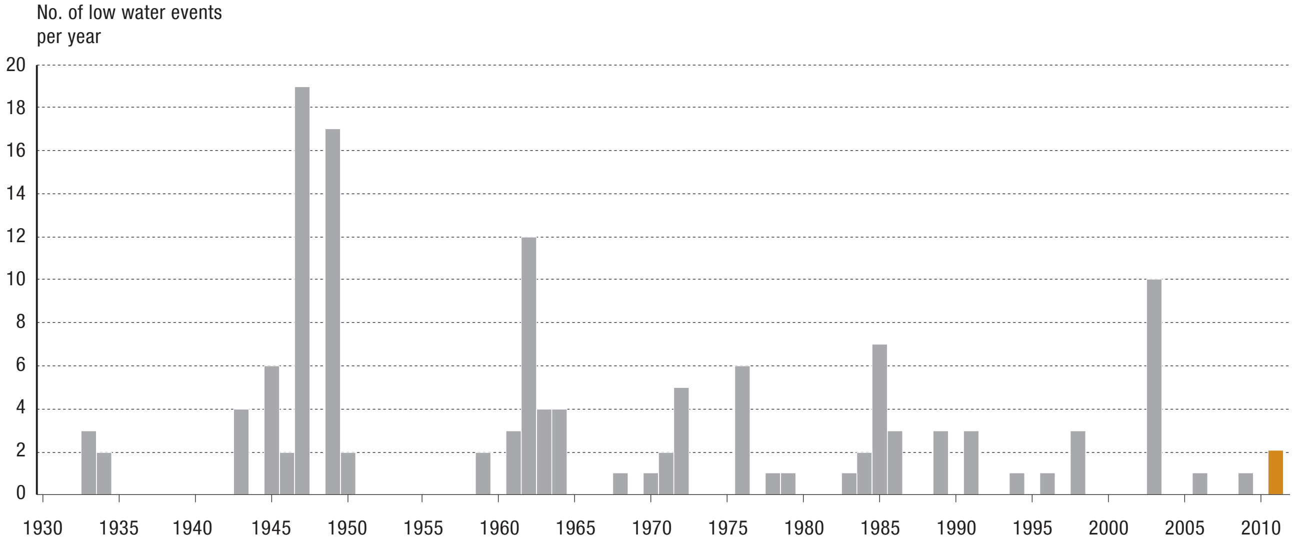


Figure 1.6 *Number of low water events per year at selected non-Alpine stations. In orange, the 2011 indicator value.*

1.3 "Low groundwater levels and spring discharges" indicator

The "Low groundwater levels and spring discharges" indicator gives a nationwide overview (by annual comparison) of the frequency of unusually low groundwater conditions. If the groundwater level and spring discharge exhibit above-average falls due to unusually long dry periods, local water supply shortages can result. In addition, low groundwater levels and spring discharges can damage the ecosystems that depend on groundwater. The quantitative scenarios on climate change in Switzerland in the CH2011 project (OCCR [Oeschger Centre for Climate Change Research], FOEN, MeteoSwiss, C2SM, Agroscope and ProClim) tend to indicate that summer droughts will occur more often and last longer in the future, and that low groundwater levels and spring discharges may therefore occur more frequently.

The "Low groundwater levels and spring discharges" indicator is calculated as a percentage of monitoring stations per year at which the frequency of low groundwater levels or spring discharges is above average compared with the long-term mean. The indicator calculation is based on the monitoring stations in the NAQUA QUANT module, which map the state and development of groundwater quantity at national level (cf. Section 5) and indicate potential effects of climate change on groundwater sources.

In dry years the "Low groundwater levels and spring discharges" indicator is generally above 50 %, i.e. most of the monitoring stations record an above-average number of days with low groundwater levels or spring discharges. The prolonged precipitation deficit in 1998, from 2003 to 2005 and in 2011 therefore caused unusually high values for this indicator (Figure 1.7).

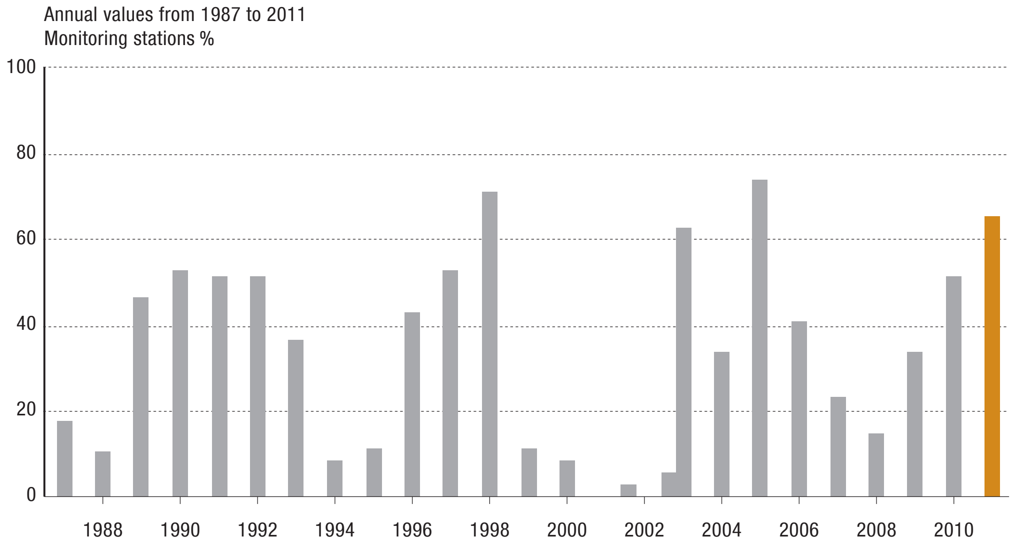


Figure 1.7 *Monitoring stations per year at which the frequency of low groundwater levels or spring discharges was above average. In orange the 2011 indicator value.*

1.4 Floods in the Bernese Oberland and Valais of 10 October 2011

The storm on 10 October 2011 caused damage totalling over CHF 85 million in Valais, the Bernese Oberland, Central Switzerland, the basin of the River Linth and Schächental. The climatic event underlying the floods can be divided into three phases: a cold front on 6/7 October, a build-up phase with heavy snowfall and finally a warm front on 9/10 October with high precipitation and a rapid ascent of the zero degree isotherm.

The combination of precipitation and rapid melting of the snow cover resulted in high discharges in a number of mountain streams and rivers.

Although the precipitation totals and snow melt rates during the event were high, when viewed separately they were in no way exceptional. But when combined they caused some critical discharge situations. Discharges were affected in variable ways, with very high and unusual peaks in the west and lower, more moderate annual levels in Central and Eastern Switzerland. This can largely be explained by regional differences in various factors and processes during the storm:

- Before the rain started, during the build-up phase much greater amounts of snow fell in the north-eastern parts of the Swiss Alps than in the west. There was approximately the same amount of precipitation during the warm phase in all regions of Switzerland. However, the proportion of precipitation falling as rain was much higher in the Bernese Oberland than in the Linth basin and Schächental.

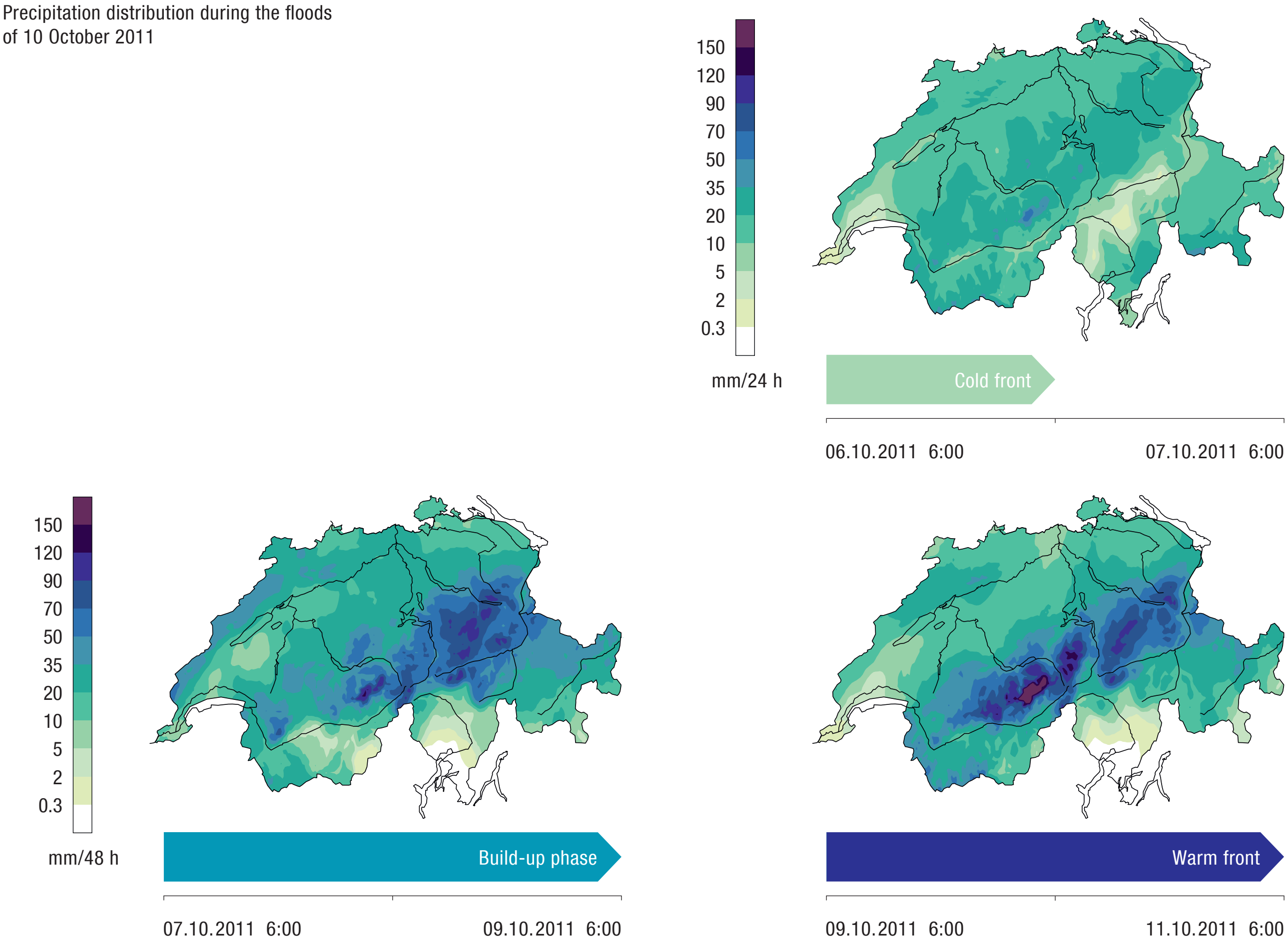

Precipitation distribution during the floods of 10 October 2011

Figure 1.8 *Large-scale precipitation distribution during the three phases of the floods around 10 October 2011. Data from automatic and manual precipitation measurements by MeteoSwiss.*

- The combination of wind, high air temperatures and humidity during the warm front phase generated substantial turbulent heat flows which supplied most of the energy for an intensive snow melt. Less snow cover and initial moisture penetration reduced the ground's capacity to absorb rain and melt water in Lötschental and Kandertal, resulting in faster discharge ability than in the east. In general, the contribution made by the melting snow can certainly be rated as important, but based on the discharge volume it played a lesser role than the precipitation.
- The simulation of the ground moisture between 6 and 13 October shows a similar picture for all the catchments (incomplete saturation of the ground) and therefore on 9 October a theoretically similar basic discharge ability. Because the discharge reacted relatively quickly to the precipitation, rapid discharge processes must have played a significant role; this is confirmed by the discharge simulations. The conditions and factors that led to the rapidly initiating discharge processes are largely unknown, however, and why the discharge ability was so high remains an open question. Unfortunately, meaningful regional measurements to verify the ground moisture simulations do not exist.

For the time being it will remain hard to forecast combined rain-on-snow events with any great accuracy and to issue timely warnings. The main reasons for this are the limited possibilities for comparison with such rare events, the accuracy limitations of model input data and the insufficiently detailed process depiction in the discharge models.

Source: Data and analyses by MeteoSwiss, WSL (Federal Institute for Forest, Snow and Landscape Research) and FOEN.

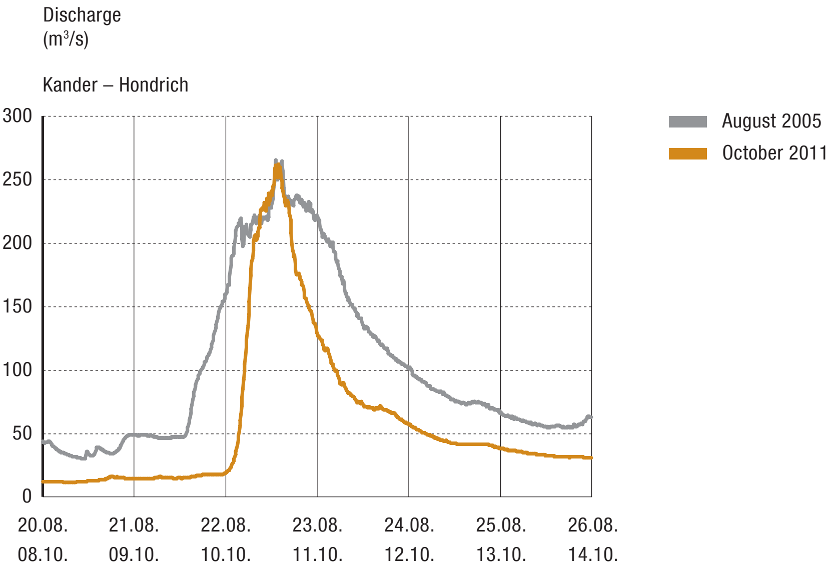


Figure 1.9 *Comparison of the discharge hydrographs for October 2011 (orange) and August 2005 (grey) at the Kander – Hondrich station.*

2 > Weather conditions

Averaged across Switzerland as a whole, the year 2011 was around 1.2 degrees warmer than the 1981–2010 reference value and therefore the warmest since records began in 1864. 2011 was far drier than average in some regions. In Western Switzerland, precipitation was only 60–80 % of the reference value. In the rest of Switzerland annual precipitation varied between 70 and 95 %.

Precipitation was already below average in December 2010 on the northern flank of the Alps and in the inner Alps. The low precipitation conditions from the beginning of the year resulted in a severe drought. The prolonged warm spell resulted in the warmest spring in Switzerland since records began in 1864.

On 1 June winter returned to higher Alpine regions. The snow line descended locally to medium elevations. The passage of a cold front on 27/28 June triggered very intensive precipitation interspersed with thunderstorms, which caused flooding, primarily in Central Switzerland. On 10 July violent thunderstorms caused massive flooding, mainly in Eastern Switzerland. During the night of 12/13 July, heavy thunderstorms deposited rain over Switzerland. These were followed on 13 July by a cold front with further heavy rain.

The first two months of summer were generally wet. The month of July was the coldest since 2000, and the wet weather continued during the first half of August. The second half of August and first half of September saw high summer conditions, until a powerful blast of polar air arrived on 17 September with intense precipitation. After this wintry interlude, mild, sunny weather moved back in.

The warm autumn weather lasted into the first few days of October, but conditions soon changed. By 9 October more than 50 cm of new snow had fallen widely at higher elevations in the Central Alps, in the eastern part of the northern flank of the Alps and in Graubünden. On 10 October mild and very moist air masses predominated, triggering high levels of precipitation on the northern flank of the Alps. At the same time the zero degree isotherm ascended rapidly to over 3000 m AMSL, causing an intensive snow melt. Critical flood situations occurred in some places (cf. Section 1.4). The floods were followed by calm autumn weather.

The Föhn wind set in at the end of October/beginning of November. A long Föhn period of continuous heavy rain set in to the south of the Alps from 3 to 6 November. While the south received unusually high levels of precipitation due to the Föhn, areas to the north of the Alps suffered prolonged drought. As the period of high pressure continued, there was a virtual absence of precipitation between 19 October and the end of November, in particular in Valais through Central Switzerland to Lake Constance.

In mid-December there were large snowfalls in many mountain regions. It turned mild before the festive period and snow disappeared from the lowlands. Snow returned to the mountains in the final days of the year, with widespread above-average cover at higher elevations by year end.

Source: Federal Office for Climatology and Meteorology (MeteoSwiss)

Annual precipitation (% of normal)

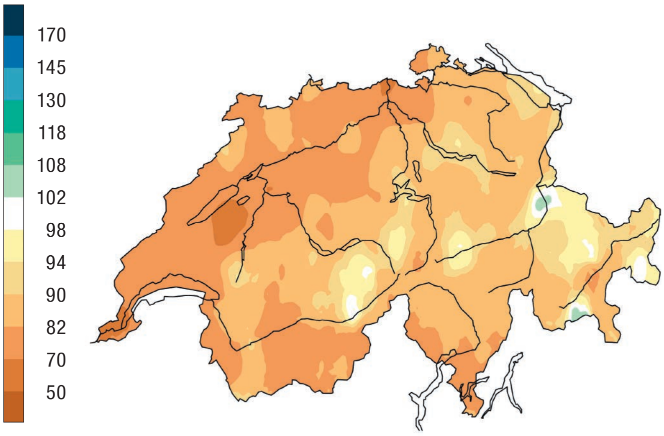


Figure 2.1 *2011 was a dry year: Annual precipitation was only 60 to 80 % of normal in Western Switzerland and 70 to 90 % in other regions.*

3 > Snow and glaciers

The winter of 2010/11 was drier and warmer than normal, and in the north it was also sunnier. As a result snow depths over the winter as a whole were below average in most areas. They were average in Northern Ticino, the Upper Engadine and the southern valleys of Graubünden. The 2010/11 hydrological year was also marked by very high glacier mass losses.

3.1 Snow

At high elevations the weather was already wintry by October 2010. There were heavy snowfalls in October and November, particularly on the southern flanks of the Alps. In December it snowed widely and often, at times down to low elevations. At year end snow depths were still normal to above average. Wintry spells were quite frequent on the Central Plateau in November and December but were non-existent in late winter. As temperatures fluctuated widely, it rained in January 2011 even up to high elevations, resulting in significant wet snow avalanche activity on 13 January and springlike snow conditions at medium altitudes.

Snow began falling first in mid-February in the south and then in the north and west at the end of the month. It also snowed repeatedly in March, but less heavily. At the height of winter snow depths were widely below average at all elevations.

In April snow depths were well below average in all regions. At high elevations they were only 50 % of the long-term average and at medium levels just 25 %. Many long-term SLF observation stations (e.g. Andermatt, Arosa, Fionnay, Grimsel, Hasliberg, Ulrichen, Weissfluhjoch) recorded new minimums or had never been free of snow so early as in spring 2011. The low snow depth up to summit elevations was caused mainly by the precipitation deficit from January. The total amount of new snow from January to March was only 30 % of the long-term average, making it the lowest since records began. Throughout the winter there was no single large snowfall event with a metre or more of new snow within three days.

By May, snow had disappeared at high altitudes, especially in the north. On the southern flank of the Alps snow cover was still complete on north-facing slopes above about 2300 m AMSL. The winter of 2010/11 was the sixth lowest for snow since records began around 60 years ago, based on average snow depth from November to April. In terms of total new snow, it ranks fifth among the winters with the least snowfall.

During the June to September period there were seven distinctive spells of cold weather. As a result of the repeated snowfalls, snow cover was generally complete in the high peaks by August. Little snow fell at medium and high elevations, except on 28 August and 19 September.

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

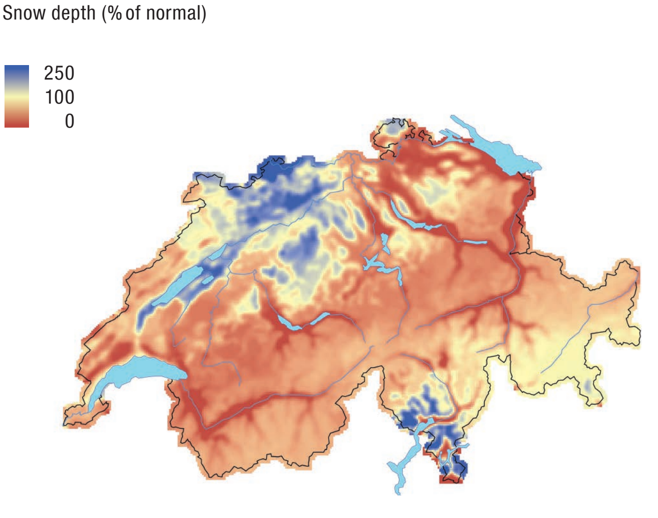


Figure 3.1 *Snow depths 2010/11 compared with the 1971–2000 period during the winter months of November to April.*

3.2 Glaciers

The glaciers recorded high mass losses in the 2010/11 hydrological year. 2010/11 is the third worst year of the last decade, after 2002/03 and 2005/06 (cf. the VAW glacier reports 1960–2011). The main reason for the high glacier melt is the below-average amounts of snow and the very early disappearance of snow cover due to the warm early summer. As a result, changes in glacier storage were in large part responsible for the discharge, which was highest in the hot month of August.

On the nine glaciers studied, mass balances were measured of between –720 mm water equivalent (on the Adler glacier) and –2460 mm water equivalent (on the Tsanfleuron glacier). A clear north-south disparity is detectable. Glaciers which are influenced by the climate south of the Alps have mass balances only slightly below the long-term average (Basodino, Adler, Findelen), but on the more northerly glaciers relatively consistent mass balances of the order of –2000 mm water equivalent were measured. This figure is well below the mean for the last decade. The north-south disparity can probably be explained by heavy snowfalls on the south side of the Alps in spring 2011.

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

Figure 3.2 *View from the Grialetsch glacier in September 2011.*

4 > Rivers and lakes

The discharges in the large catchments were far below average. In autumn 2011 they only reached 70 to 80 % of the long-term annual average on the north side of the Alps. An unusual rain-on-snow event in autumn 2011 resulted in new maximum October discharge peaks in stations in the Bernese Oberland and Central Switzerland. The previous annual mean record was broken at many stations in the temperature-monitoring network.

4.1 Discharge conditions

In the large river regions, the annual averages were well below those for the 1981–2010 reference period. The Rhine, Limmat, Reuss and Rhone only discharged about 80 % of the long-term average; the Aare reached just 70 %. The Ticino and Inn were quite close to average at approximately 90 %. Some of the medium-sized catchments in Western and North-Western Switzerland did not even reach 50 % of the usual annual average (cf. Figure 4.2), for example the Aubonne, Venoge, Mentue, Broye, Ergolz and Dünnern. At around 20 stations in the FOEN monitoring network west of the Reuss, 2011 was the year with the lowest discharge of the entire measurement period.

Normal annual means were recorded in the catchments of the Poschiavino, Lonza and Engelberger Aa. Only the Massa had discharges which were well above normal.

Looking at the monthly discharges, it is quite clear how the below-average annual levels came about. In the large catchments north of the Alps and in the Rhone down to Geneva, the monthly values from February to June were generally below normal. The discharge deficits were particularly pronounced in May. The Aare at Brugg did not even reach one third of its normal May discharge, the Limmat was only at 50 % and the Reuss was at just 53 %. Discharges in the second half of the year were also below average, but not to the same extent as in May and June.

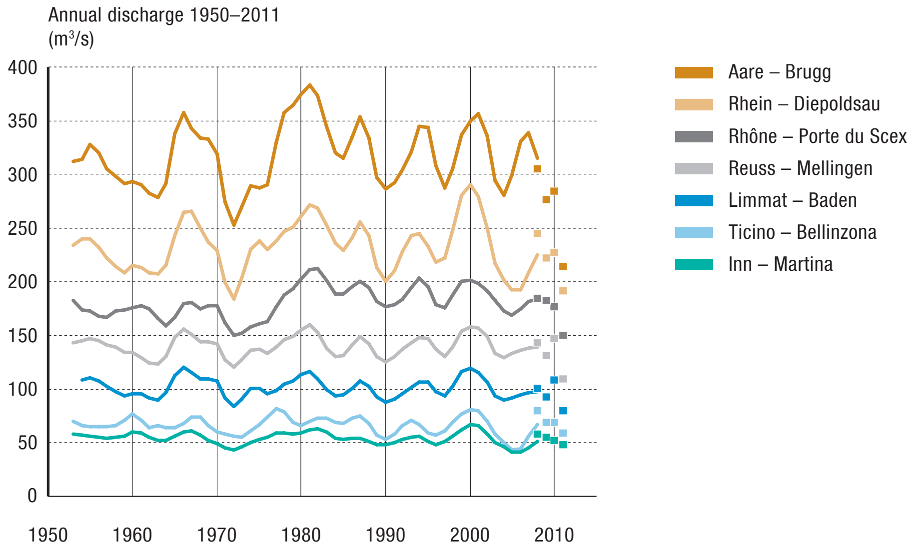


Figure 4.1 *Changes in the annual discharges for selected large catchments from 1950. Moving averages (over seven years) are shown as lines and the last four annual discharges are shown as points.*

November was a particularly dry month. The Aare at Brugg reached 44 %, the Limmat at Baden 52 % and the Reuss at Mellingen 60 % of normal in November. December was close to or above average. In the medium-sized catchments some discharge conditions were even more extreme: The well below-average May discharges were 32 % in the Emme, 30 % in the Thur and only 13 % in the Venoge. All twelve months of 2011 were below normal in the Venoge. As a result of the high air temperatures the Massa, with its highly glaciated basin, discharged above-average levels in every month except January, March and July.

The dry spells in the first half of the year and from late October to early December can be clearly seen in the daily discharge graphics. The hydrographs for the large river basins were well below the 5 % quantile for long periods. The high discharges in mid-October, which are described in detail in connection with the rain-on-snow event referred to in Section 1.4, are equally evident.

Lowest daily means for the respective months were recorded in many places north of the Alps in April and May and to a lesser degree in June. They affected both large river basins (Aare – Brugg in April and May; Limmat – Baden in May and June; Rhine – Rheinfelden in May) and medium-sized catchments (Venoge – Ecublens in April and May; Dünnern – Olten in March, April, May, June and July).

The lowest daily mean and highest discharge peak were both recorded in July. Lowest daily means occurred in just a few catchments in the Jura, whilst the highest ever July maximums were recorded in the Upper Valais and parts of the Maggia catchment. A remarkable event occurred on the Vispa at Visp: July saw both the highest July discharge peak and the lowest July daily value in the measurement series since 1965. Many stations were affected by the rain-on-snow event described in Section 1.4 – primarily in the Bernese Oberland and Central Switzerland – resulting in new maximum October discharge peaks. And the prolonged drought from mid-October to early December led to new minimum daily averages for November and December at some monitoring stations.

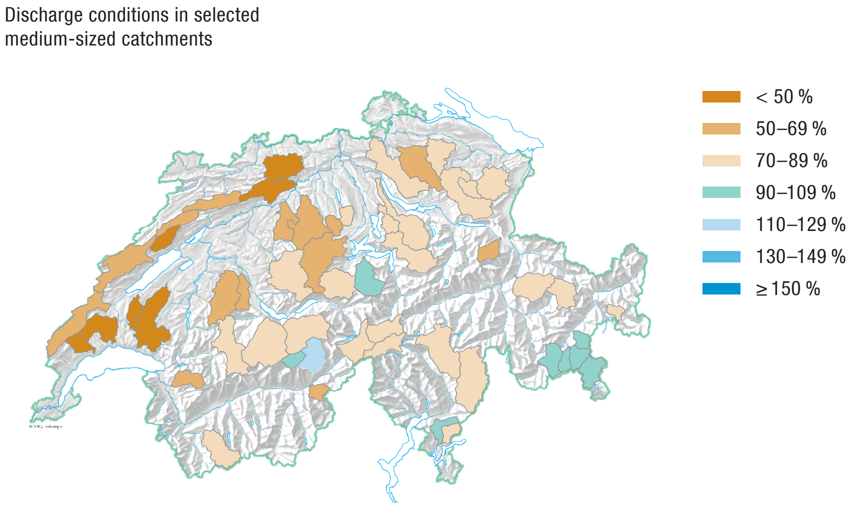


Figure 4.2 *Annual mean 2011 compared with the mean discharge for the long-term average period 1981–2010 [%] in selected medium-sized catchments.*

Monthly mean discharges in selected large catchments

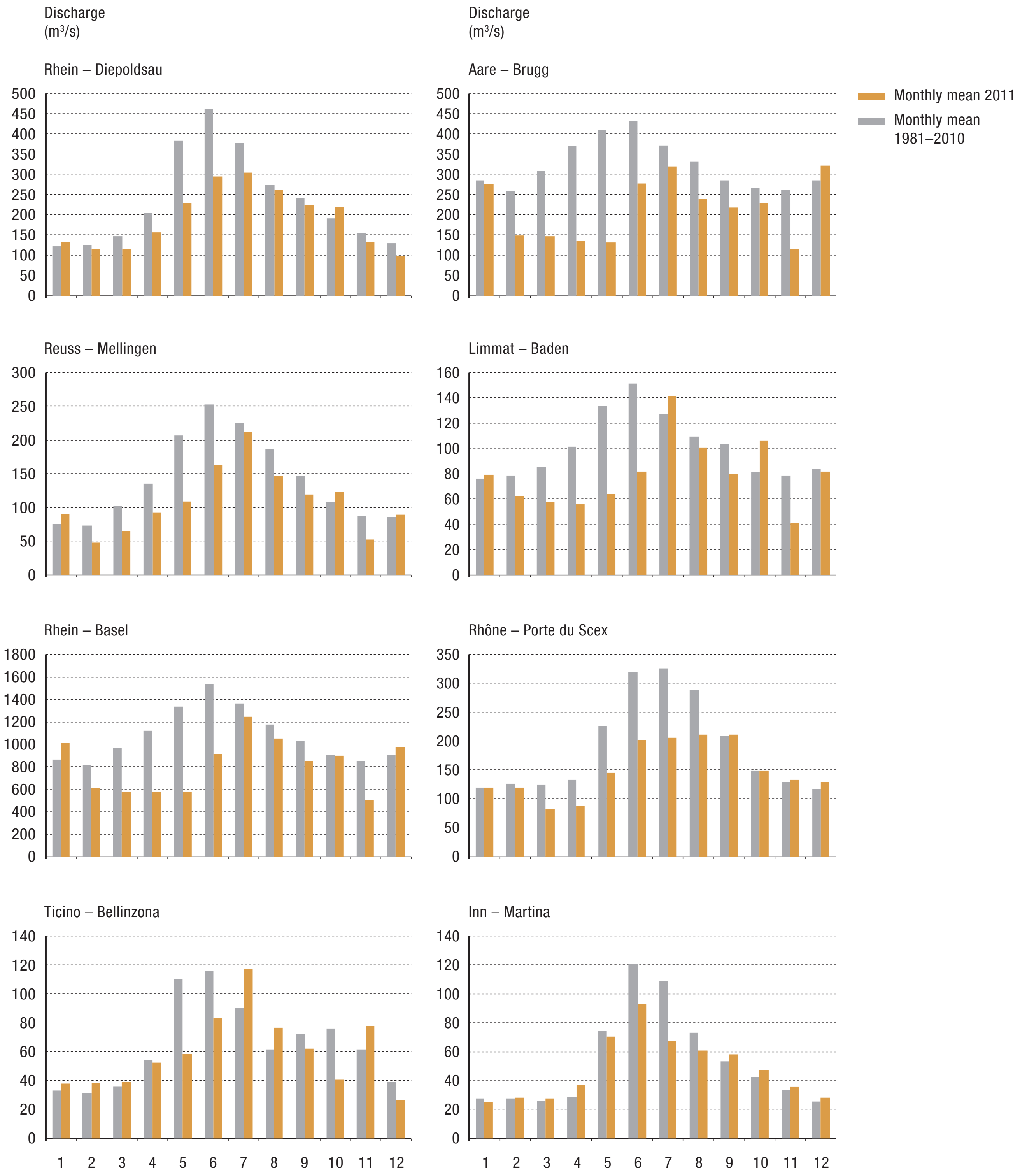


Figure 4.3 *Monthly mean discharges 2011 (orange) compared with the monthly mean for the long-term average period 1981–2010 (grey).*

Monthly mean discharges in selected medium-sized catchments

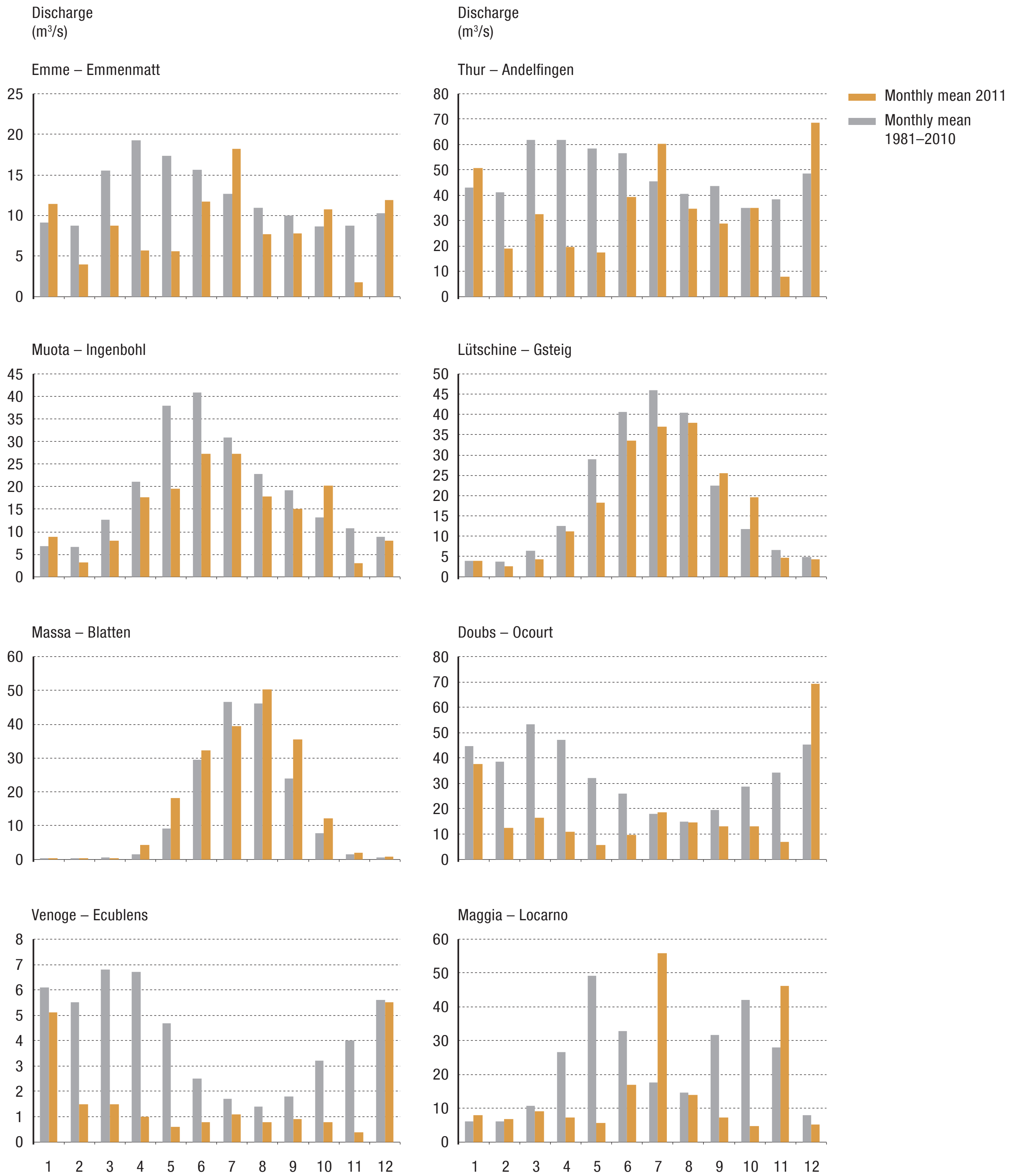
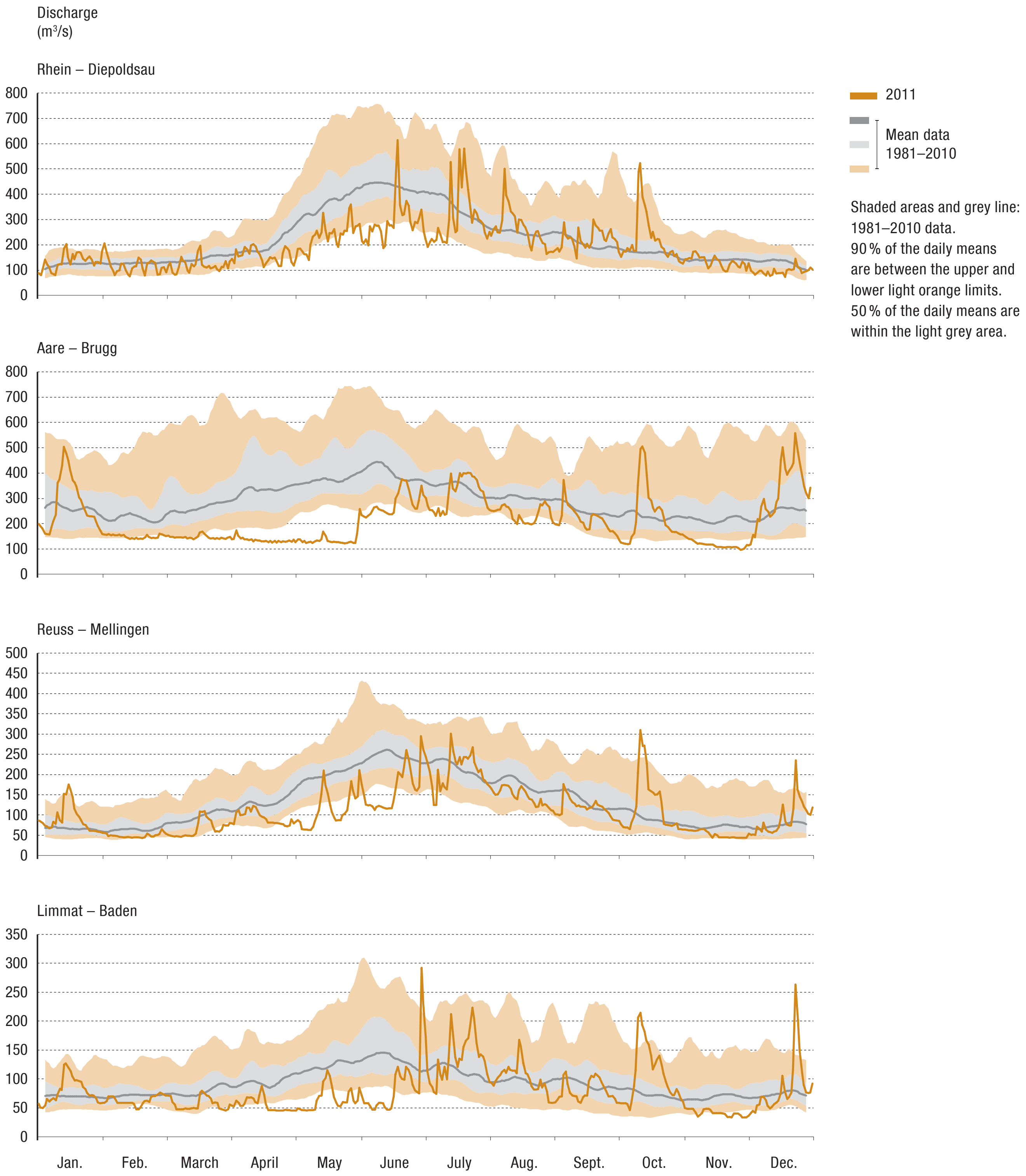


Figure 4.4 *Monthly mean discharges 2011 (orange) compared with the monthly mean for the long-term average period 1981–2010 (grey).*

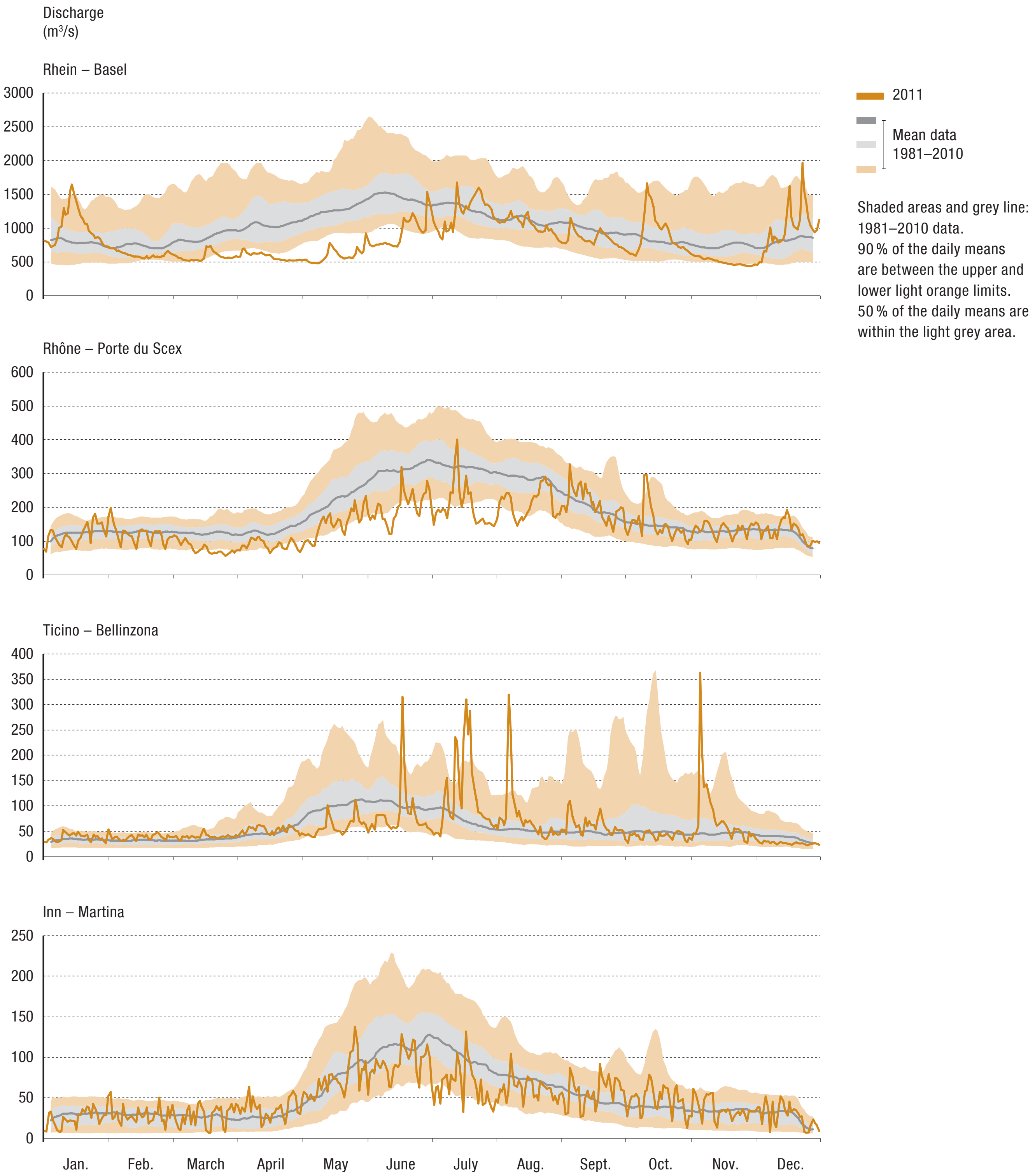
Daily mean discharges in selected large catchments (1/2)



Shaded areas and grey line: 1981–2010 data. 90 % of the daily means are between the upper and lower light orange limits. 50 % of the daily means are within the light grey area.

Figure 4.5 *Daily mean discharges 2011 (orange line) compared with the daily mean for the long-term average period 1981–2010.*

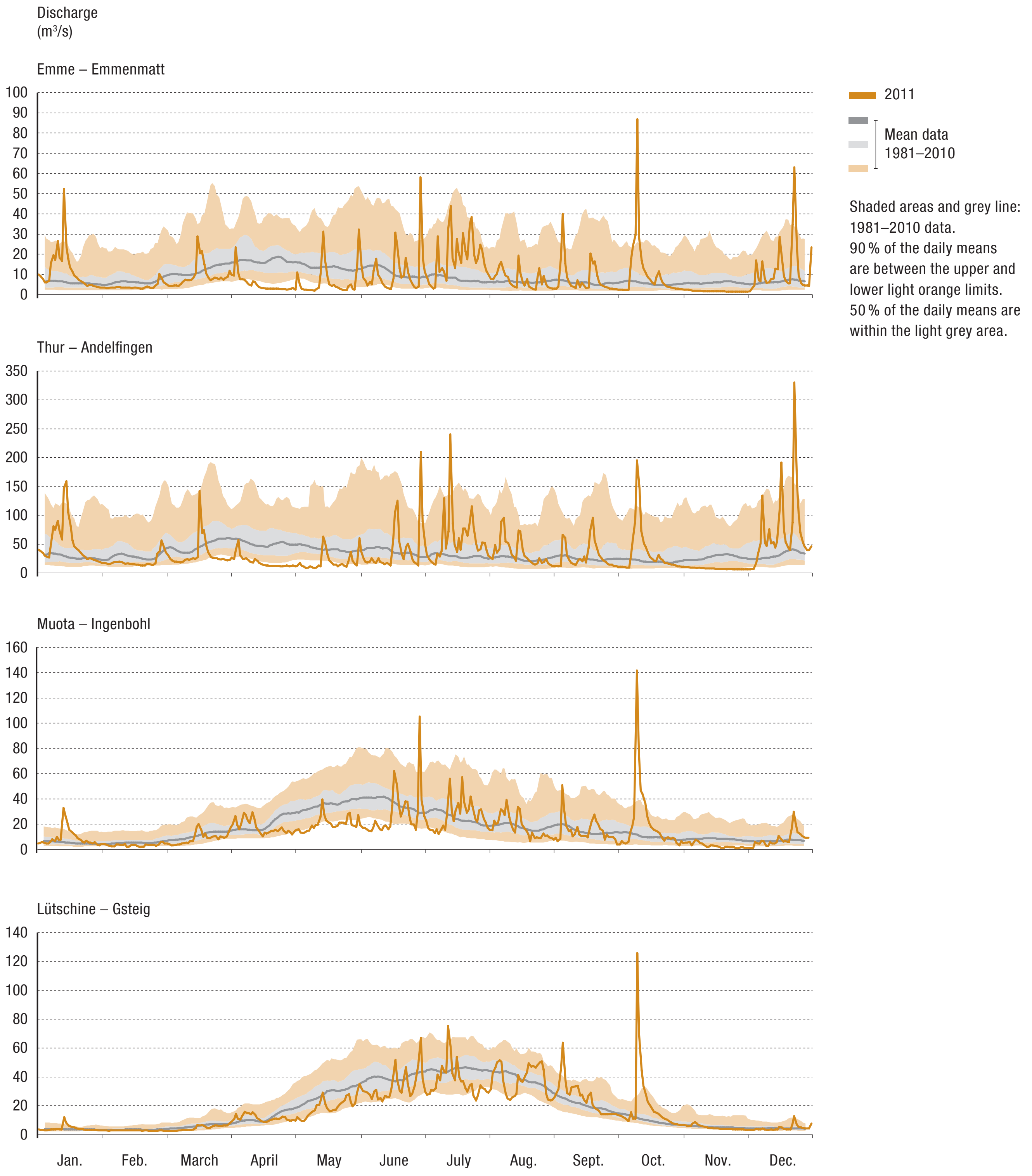
Daily mean discharges in selected large catchments (2/2)



Shaded areas and grey line: 1981–2010 data. 90 % of the daily means are between the upper and lower light orange limits. 50 % of the daily means are within the light grey area.

Figure 4.6 *Daily mean discharges 2011 (orange line) compared with the daily mean for the long-term average period 1981–2010.*

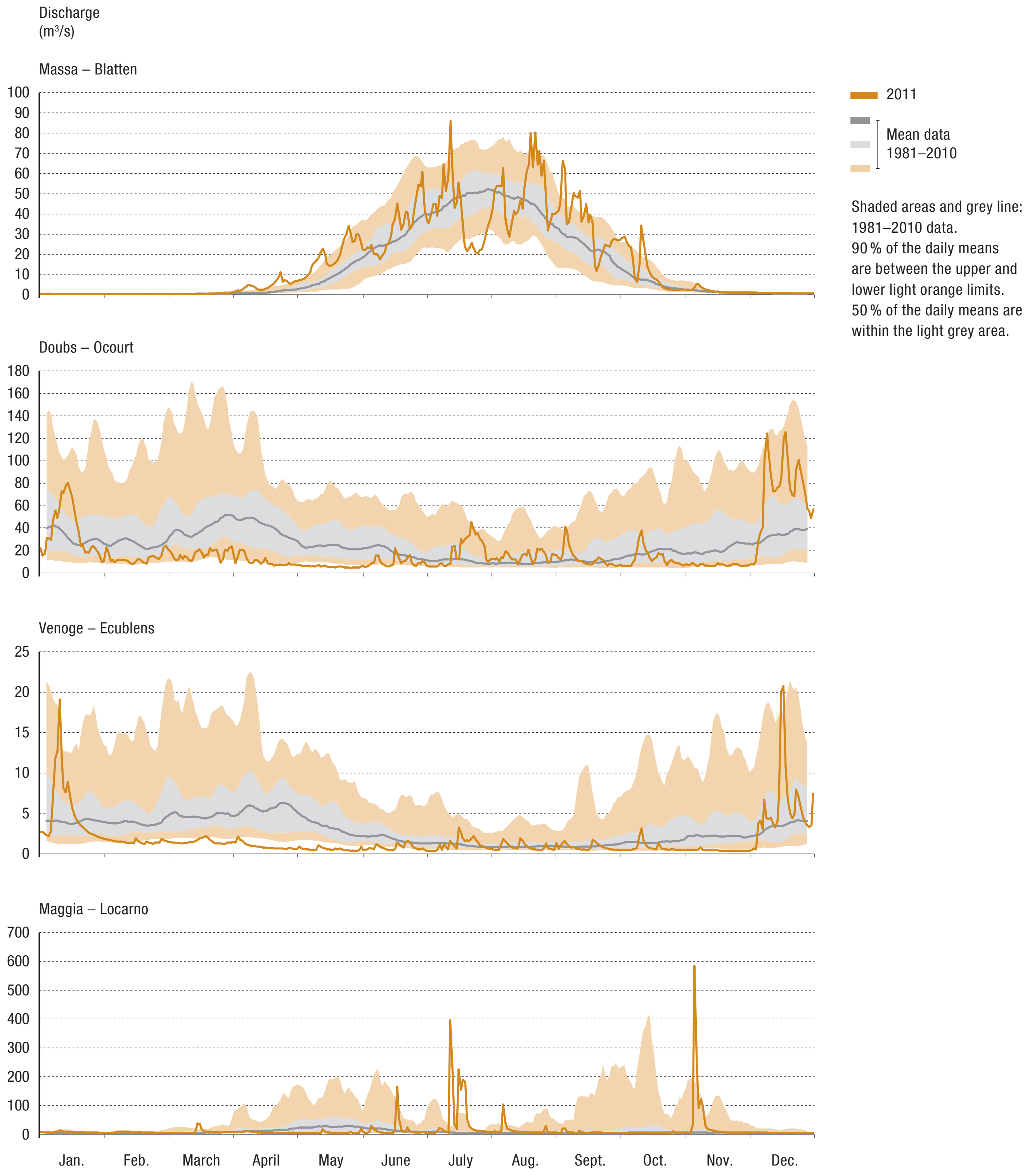
Daily mean discharges in selected medium-sized catchments (1/2)



Shaded areas and grey line: 1981–2010 data. 90 % of the daily means are between the upper and lower light orange limits. 50 % of the daily means are within the light grey area.

Figure 4.7 *Daily mean discharges 2011 (orange line) compared with the daily mean for the long-term average period 1981–2010.*

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



Shaded areas and grey line: 1981–2010 data.
90 % of the daily means are between the upper and lower light orange limits.
50 % of the daily means are within the light grey area.

Figure 4.8 *Daily mean discharges 2011 (orange line) compared with the daily mean for the long-term average period 1981–2010.*

4.2 Lake levels

The 2011 mean water level on Lake Constance was 10 cm below the mean for the long-term average period 1981–2010; on Lake Neuchâtel the figure was 12 cm, the lowest annual mean for that lake of the entire monitoring period (since 1983). 2011 was not an extreme year for Lake Constance; the 2011 annual mean was still 33 cm above the lowest figure for the entire monitoring period. Since 1930 a quarter of the annual means have been lower and three quarters have been higher than in 2011. For Lakes Geneva and Maggiore the deviations from the long-term average were small.

At the beginning of the year the water level in Lake Constance was significantly above the long-term average. The January mean was 34 cm higher than normal. Levels were then below average from April to July, with the greatest monthly difference in June (–64 cm). In the autumn the level remained very close to the seasonal mean.

In Lake Neuchâtel all the monthly mean water levels were lower than the corresponding values for the reference period. The greatest monthly deviations, between 25 and 32 cm, were recorded from March to May.

The water level in Lake Geneva was close to the long-term average in every month except May (–9 cm). Lake Maggiore had very wide deviations from the norm, both upwards and downwards: at the beginning of the year water levels were well above average, but were just as far below in May and June; in July and particularly August they were again considerably above average. The greatest deviation from normal of –95 cm was recorded in October.

The graphics showing daily water level (cf. Figure 4.10) give striking evidence of the situation regarding these monthly averages. In the second half of January the water level in Lake Constance was above the 95 % quantile. A continuous fall and stabilisation at a winter level was then observed until the beginning of May. Although this level is normal for the winter, it is below average for the summer. By the end of July water levels had returned to normal. The continuous fall in the lake level until the end of the year was interrupted in mid-October during a flood event (cf. Section 1.4).

The distinctive low water phases in Lake Neuchâtel are very clearly evident. The persistent low winter level led to new minimum daily values in April and May. New daily minimums also occurred in November.

Monthly mean water levels in selected lakes

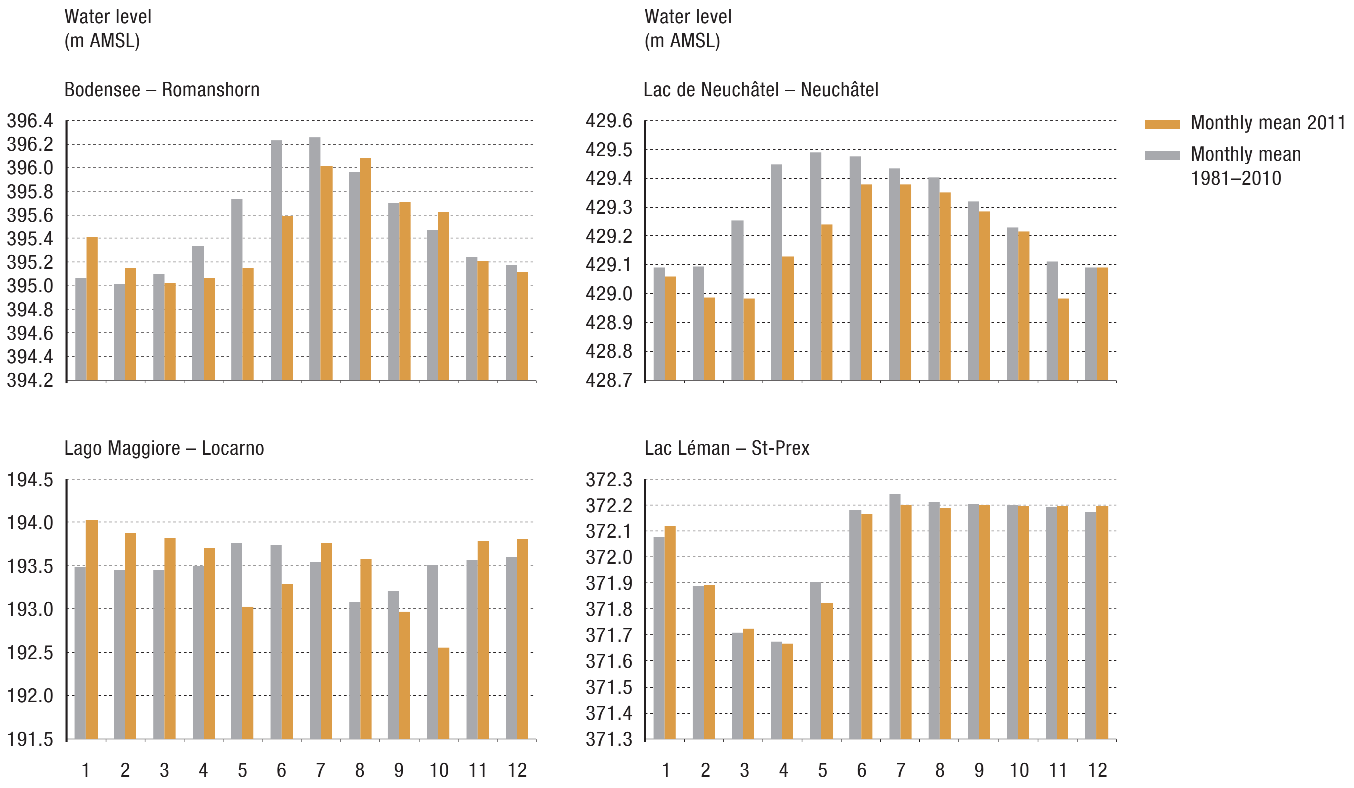
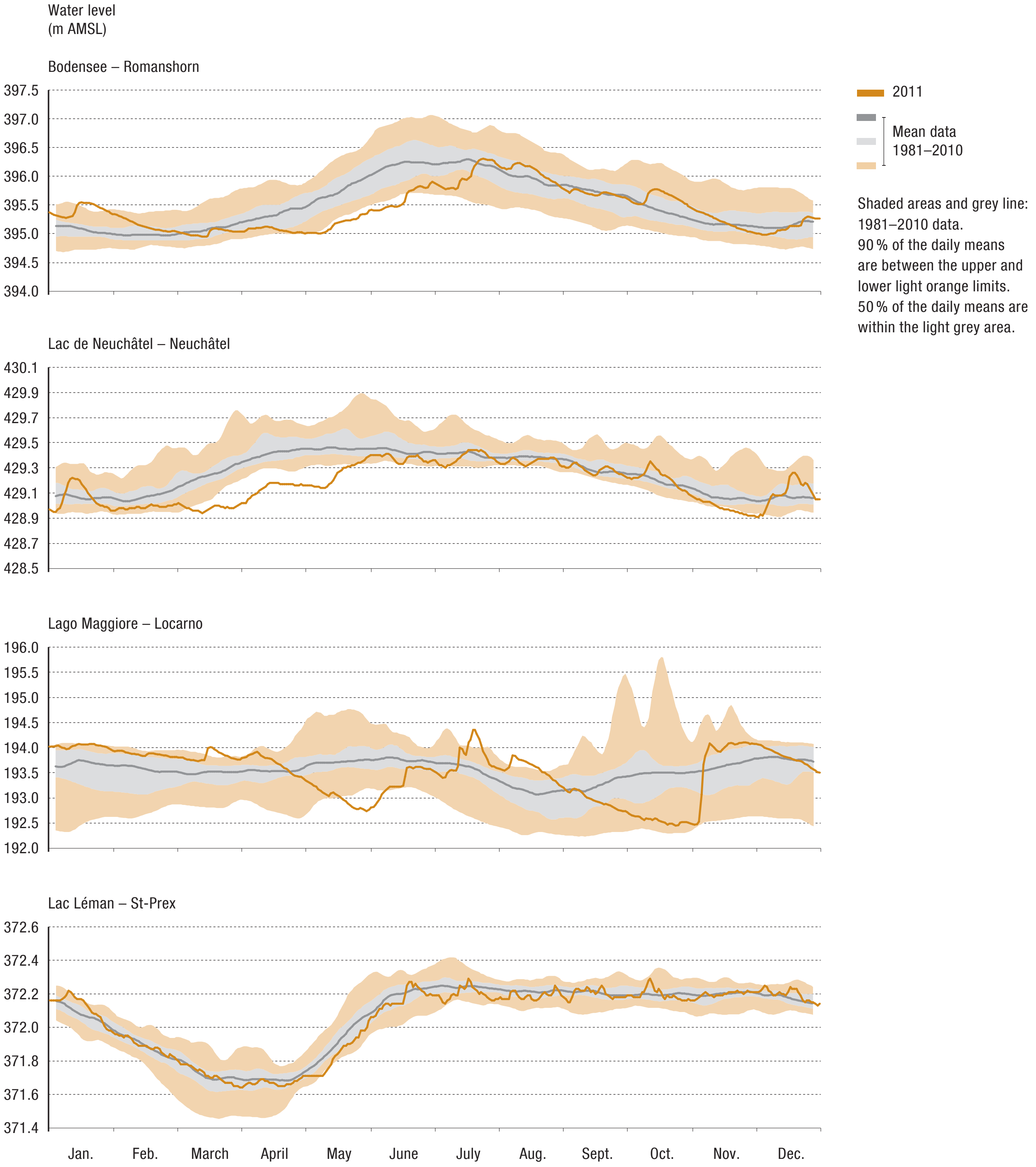


Figure 4.9 *Monthly mean water levels 2011 (orange) compared with the monthly mean for the long-term average period 1981–2010 (grey).*

Daily water levels in selected lakes



Shaded areas and grey line: 1981–2010 data. 90 % of the daily means are between the upper and lower light orange limits. 50 % of the daily means are within the light grey area.

Figure 4.10 *Daily mean water levels 2011 (orange line) compared with the daily means for the long-term average period 1981–2010.*

4.3 Water temperatures

The 2011 annual mean water temperatures were significantly above the long-term average (cf. Figure 4.11). The previous record annual mean was exceeded at more than 20 stations in the temperature-monitoring network.

Normal temperatures were exceeded by a small margin in catchments with a relatively high glaciation percentage, for example the Rhone at Sion (+0.2 °C with 18 % glaciation) and the Inn at S-Chanf (+0.3 °C with 10 % glaciation). High air temperatures cause snow and glaciers to melt rapidly, releasing large amounts of cold water into lakes and rivers. The highest above-normal temperatures of about 1.5 °C occurred in the lower sections of the Aare and Rhine. Low discharge and high air temperatures also result in high water temperatures in medium-sized catchments. The Broye at Payerne recorded just 50 % of its normal discharge in 2011 and had a mean annual temperature which was 1.5 °C above normal.

Figure 4.12 shows that there were long periods with water temperatures well above average in 2011. The Rhine and the Aare exhibit a similar pattern. In April and May the 95 % quantile limit was significantly exceeded for prolonged periods. This phase of about two months was briefly interrupted two or three times when the water temperatures dropped to their mean level. The only periods with below-average temperatures occurred at the beginning of the year and from mid-July to mid-August.

The temperature of the Rhone at Porte du Scex rose continuously from mid-March to mid-July to significantly above the long-term average. Some below-average levels were recorded in October. The range within which the temperatures varied is however much smaller in the Rhone than in the Rhine. The difference between the highest (July 9.8 °C) and the lowest (January 4.1 °C) monthly means (averages for the whole monitoring period) is less than 6 °C for the Rhone, but 16 °C for the Rhine at Rekingen (August 20.1 °C; February 4.1 °C).

In the Ticino at Riazzino, temperatures throughout most of the year varied within a narrow range between the 5 % and the 95 % quantile. Only over two periods of several days in May were the temperatures above the 95 % quantile limit.

In many catchments the year 2011 brought new monthly maximum water temperatures. New maximums were recorded at 20 stations in May; September and October both had around 10 stations with new maximums.

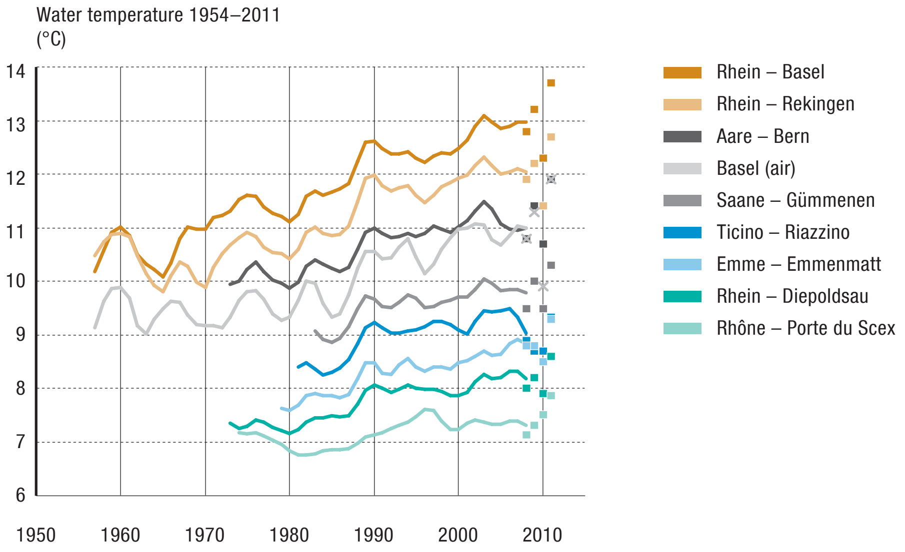
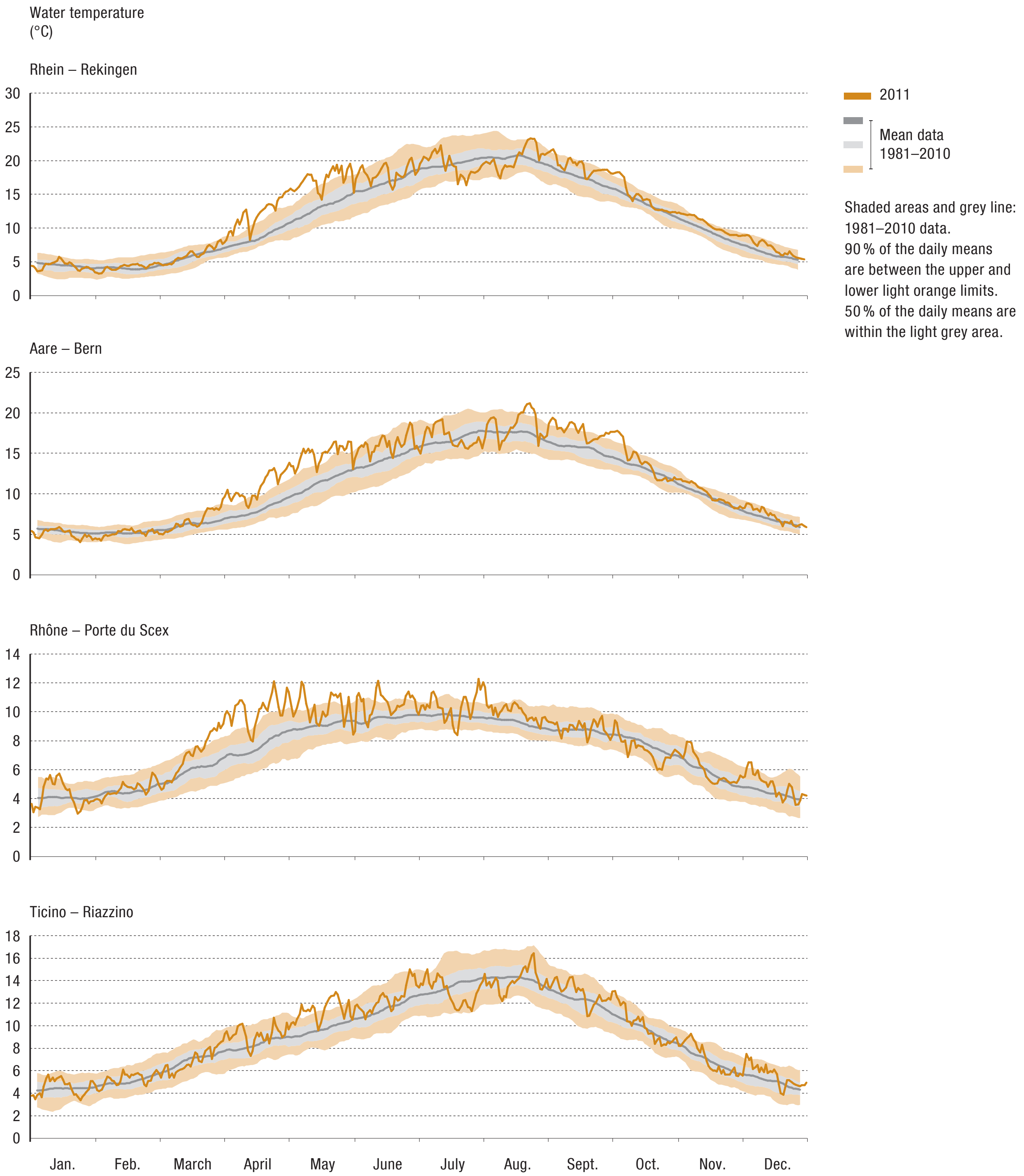


Figure 4.11 *Changes in water temperature from 1954 to 2011 in selected Swiss rivers. Moving averages (over seven years) are shown as lines and the last four annual means are shown as points or crosses (air).*

Mean daily water temperature at selected stations



Shaded areas and grey line: 1981–2010 data. 90 % of the daily means are between the upper and lower light orange limits. 50 % of the daily means are within the light grey area.

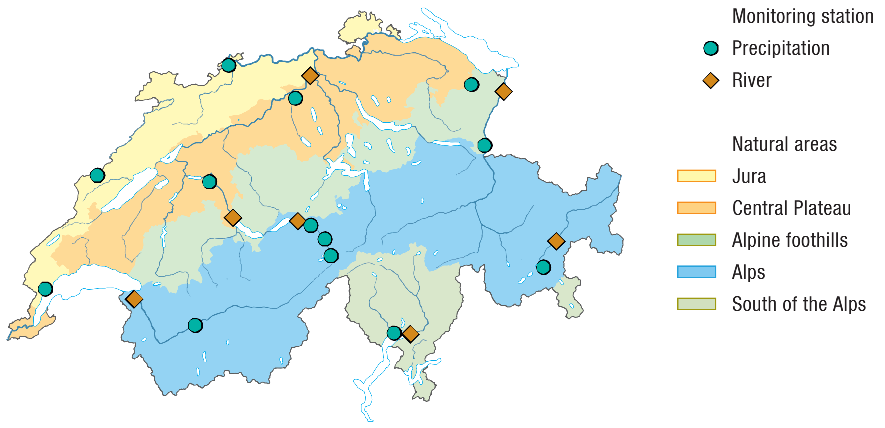
Figure 4.12 *Daily mean water temperature 2011 (orange line) compared with the daily mean for the long-term average period 1981–2010.*

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 (^{2}H) and oxygen-18 (^{18}O) are recorded at 13 representative precipitation monitoring stations and seven stations on rivers (Figure 4.13), to provide reference data for these analyses.

In relation to precipitation, an increase in δ^{2}H- and δ^{18}O values between 1980 and 2005 can be observed at all the monitoring stations, but no such trend has been apparent for the δ-values since 2005. The nationwide picture for stable isotopes in the precipitation in 2011 was marked by an unusually long period from spring to autumn with above-average δ-values. This reflects the above-average temperatures at that time.

From 1994 to 2008 a general increase can be seen in the δ^{2}H and δ^{18}O-values in the rivers (e.g. Aare, Rhine, Rhone), but here again the trend is not seen after 2008. In the year 2011 the stable isotopes in the Rhine above Lake Constance, the Rhone above Lake Geneva and the Ticino recorded their lowest δ-values in spring during the snow melt and their highest δ-values following the precipitation in July and August.



Monitoring stations of the National Groundwater Monitoring NAQUA (ISOT module)

Figure 4.13 *Monitoring stations in the NAQUA ISOT module to monitor the isotopes in precipitation and in rivers in Switzerland, 2011 status.*

4.5 Water quality/Physical and chemical characteristics

The quality of the 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 17 monitoring stations and jointly with the cantons under the National Surface Waters Quality Monitoring programme (NAWA) at 111 monitoring stations. 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 (cf. p. 35).

National River Monitoring and Survey (NADUF)
monitoring stations

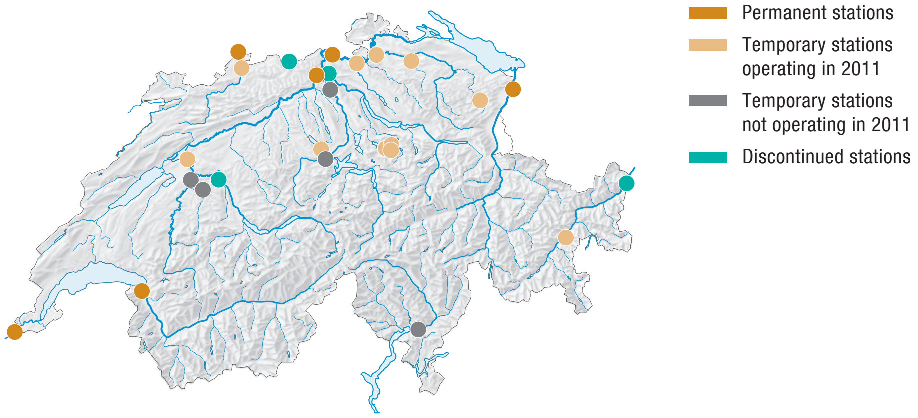


Figure 4.14 *National River Monitoring and Survey Programme (NADUF) monitoring stations to monitor water quality in Switzerland, 2011 status.*

5 > Groundwater

Groundwater levels and spring discharges were low in Switzerland in 2011 due to the prolonged drought.

5.1 Groundwater quantity

By continuously monitoring groundwater levels and spring discharges at around 100 monitoring stations 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 long 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.

In 2011 the groundwater levels and spring discharges recorded in Switzerland were low as a result of the prolonged drought. The changes over 2011 were as follows:

Groundwater levels were normal at the beginning of 2011 (Figure 5.1, Groundwater situation on 10.01.2011), but fell sharply afterwards as a result of the precipitation deficit. Groundwater levels and spring discharges were significantly lower in May and June 2011 than in the hot summer of 2003

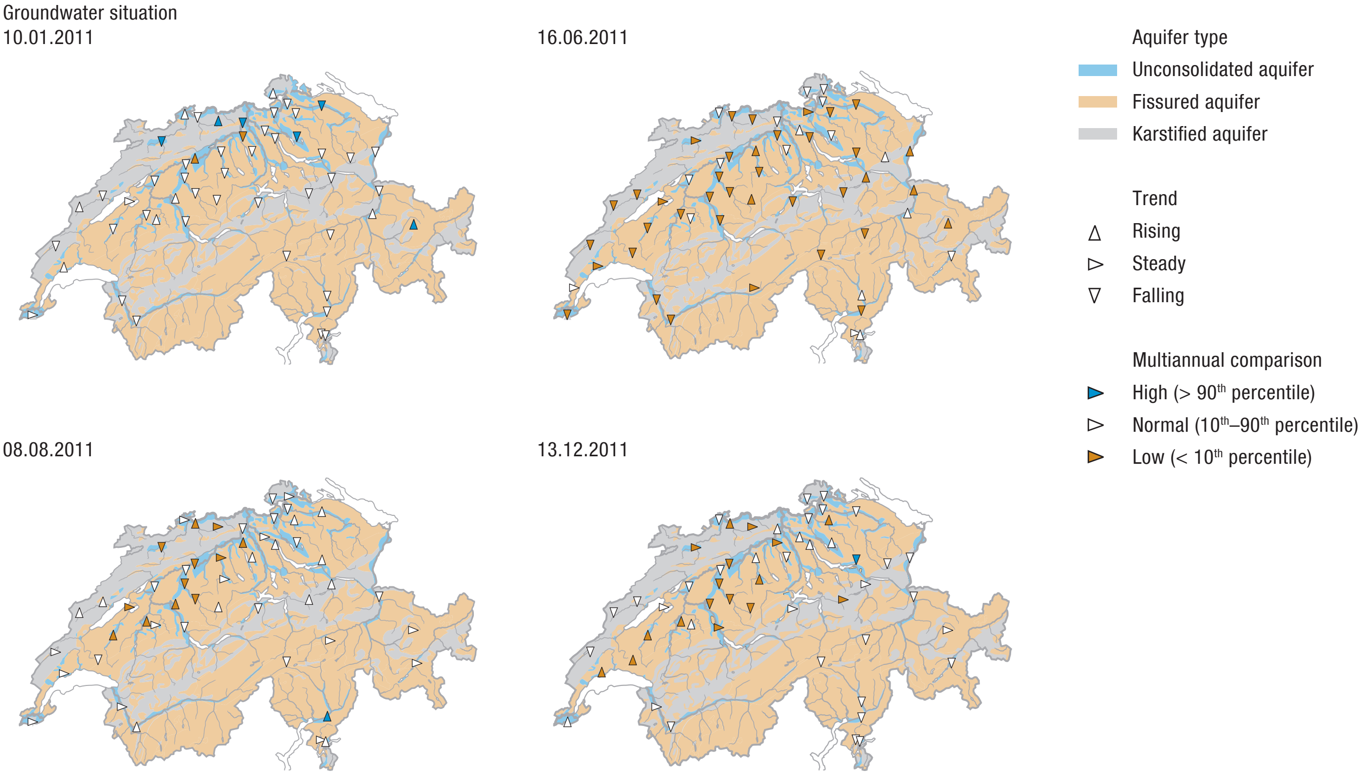


Figure 5.1 *Groundwater levels and spring discharges and their trends on four reference dates in 2011 and compared with the 1991–2010 monitoring period.*

having started from a higher initial level at the beginning of 2003. In the small river valleys of the Jura, the Central Plateau and the Alpine foothills including Ticino, groundwater levels in May and June 2011 were exceptionally low compared with the long-term levels for those two months (Figure 5.1, Groundwater situation on 16.06.2011). The levels in the valleys of the large Alpine rivers (Aare, Reuss, Rhine) were also low because of the precipitation deficit and low snow melt (cf. also the "Low groundwater levels and spring discharges" indicator, Section 1.3). A very sharp fall in discharge was recorded in karstified aquifers in the Jura and unconsolidated aquifers on the Central Plateau, which are fed by groundwater sources near the surface. The fissured aquifers generally reacted less to the drought in the first half of the year.

Groundwater levels and spring discharges returned to normal in Eastern and Central Switzerland as precipitation increased in July and August 2011, but they remained low in North-West Switzerland and the Broye valley (Figure 5.1, groundwater situation on 08.08.2011). The persistent drought in autumn 2011 caused widespread low groundwater levels and spring discharges in Switzerland until late December 2011 (Figure 5.1, Groundwater situation on 13.12.2011).

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 Quality 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.

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

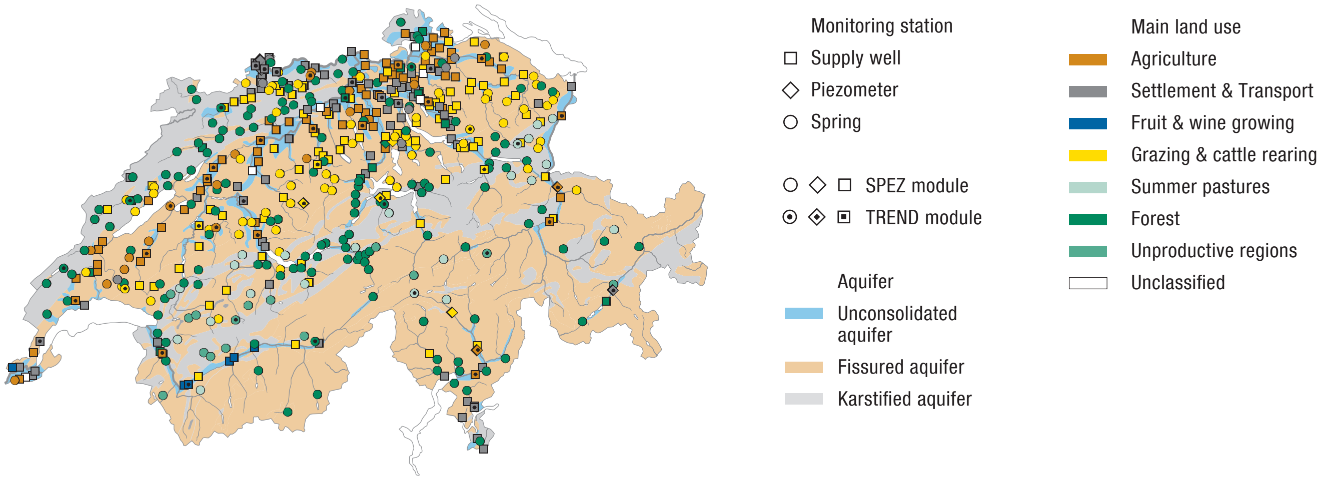


Figure 5.2 *Monitoring sites of the NAQUA TREND and SPEZ modules to monitor groundwater quality with main land use in the catchment and type of aquifer 2011 status.*

> 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, river water 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 water bodies at the 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.

^{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

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
- FOEN Hydrological Bulletin:
  www.hydrodaten.admin.ch/warnungen-vorhersagen
  > Hydrologisches Bulletin
- FOEN Groundwater Bulletin:
  www.bafu.admin.ch/grundwasserbulletin
- 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
- Swiss climate change scenarios (CH2011):
  www.ch2011.ch
- Climate change and hydrology in Switzerland (CCHydro):
  www.bafu.admin.ch/projekt-cchydro