



# Water in Switzerland – an Overview

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**Geosciences**  
Platform of the Swiss Academy of Sciences  
Swiss Hydrological Commission CHy

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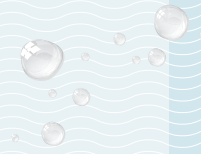
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# Foreword

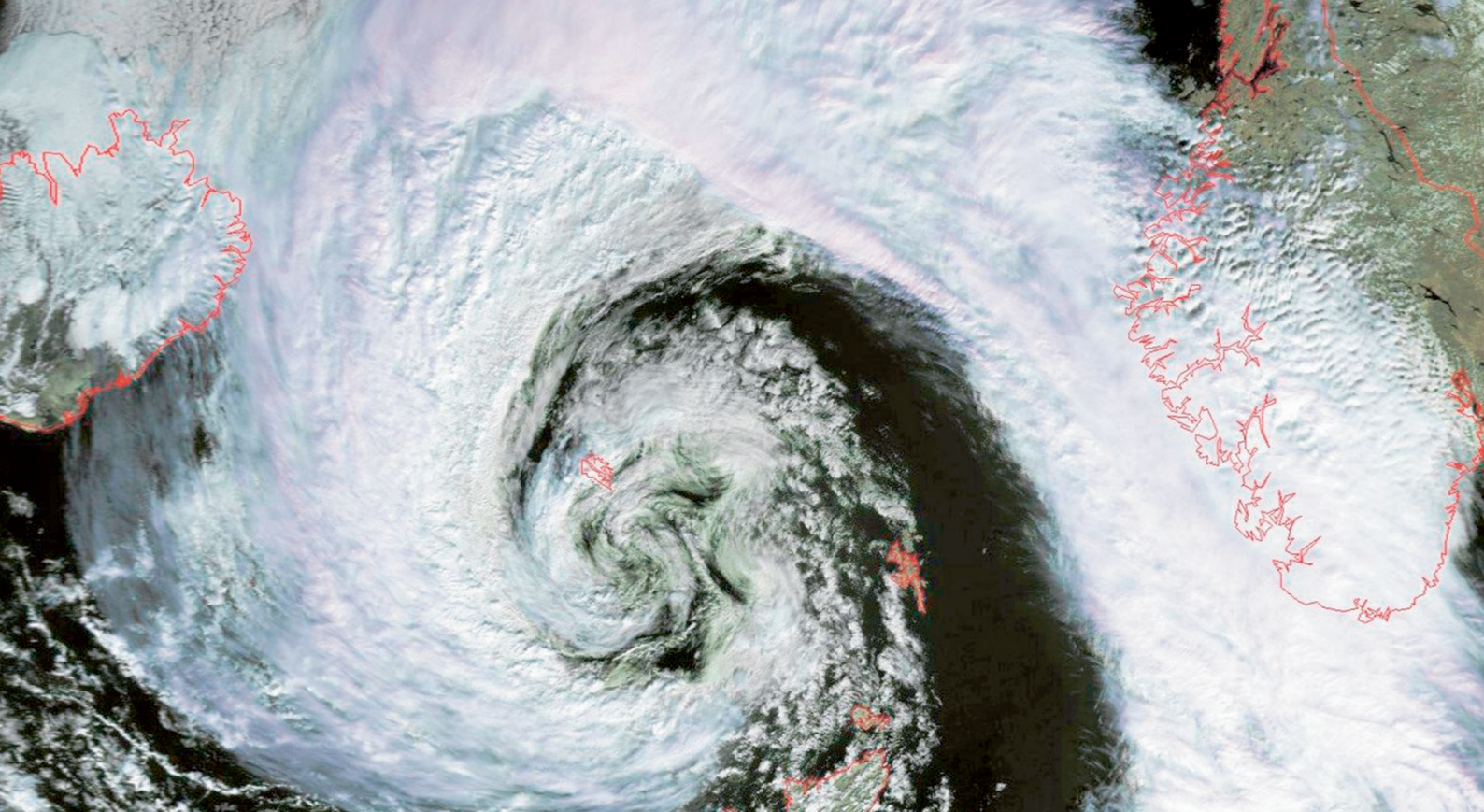


The brochure “Water in Switzerland – an overview” is a product of the Swiss Hydrological Commission CHy of the Swiss National Academy of Sciences (SCNAT). It was created as part of a working group of the “Platform Geosciences” of SCNAT, which was founded to focus on the “sustainable use of limited resources” in Switzerland. This brochure serves as a source of information for the general public and for schools. In the appendices, there is a table with all the important numbers regarding water in Switzerland, as well as explanatory illustrations of the water balance in Switzerland since 1901, the water budget, and Switzerland’s water exchange with neighboring countries. The most important technical terms used in this booklet are explained in the glossary. More information will also be made available on the Internet at <http://chy.scnatweb.ch>.

Starting with the origin of Switzerland’s abundant water resources, the high amount of precipitation in the Alps, relevant hydrological, water management, social and environmental aspects of water are considered. Since a large part of Switzerland’s precipitation falls as snow, the storage of water in snow and glaciers plays an important role in the seasonal distribution of runoff, especially in high-altitude catchments. Hydropower, fisheries and recreation depend on reliable runoff. Water therefore has environmental, cultural and economic functions that may at times conflict with one another. How this conflict is addressed will determine the future of energy in Switzerland. Presently, over half of Switzerland’s electricity needs are met with hydropower. This share is expected to increase as nuclear power is phased out of the Swiss energy mix. As a result, ecosystems will come under increasing pressure in the future. Finally, climate change will also have serious implications for the seasonal availability of water resources that will affect humans and the environment alike.

We hope that this understandable compilation will contribute to the spread of water knowledge in Switzerland. Everyone who contributed to the preparation of this factsheet is sincerely thanked for their efforts.

Prof. Dr. Rolf Weingartner  
President of the Swiss Hydrological Commission



# Water resources in Switzerland

## Where the water comes from

**Rain and snow are the main sources of the water that flows into Swiss lakes, rivers and groundwater. From which region the humidity for our precipitation originates, depends on the general weather situation and on the time of year.**

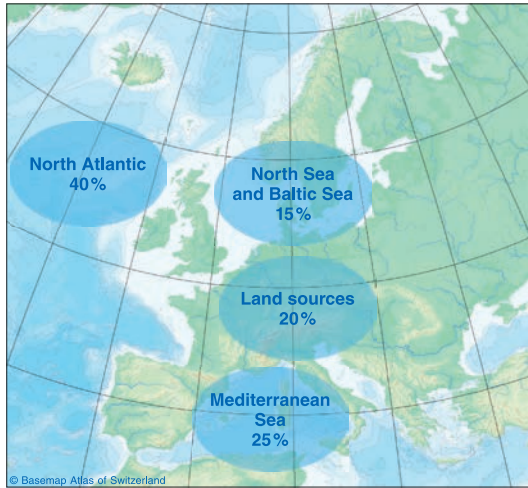
The dominant weather system at a particular point in time determines the origin, form and intensity of precipitation in Switzerland. In the summer, precipitation usually falls as rain and as a result of convective processes (thunderstorms). In winter, precipitation is more widespread (advective) and often falls as snow. Two weather patterns in particular, although rare, can lead to extreme conditions, as shown in Figure 1 b. The pattern shown in the bottom left figure leads to drought; the pattern in the bottom right figure, to flooding. In the mountainous areas of Switzerland, the elevation above sea level plays an important role in the amount and form of precipitation: the higher the elevation, the more the precipitation, and the more frequently it falls as snow.

### The importance of the North Atlantic

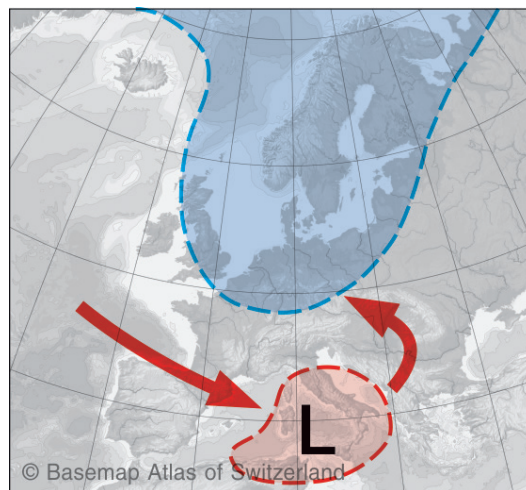
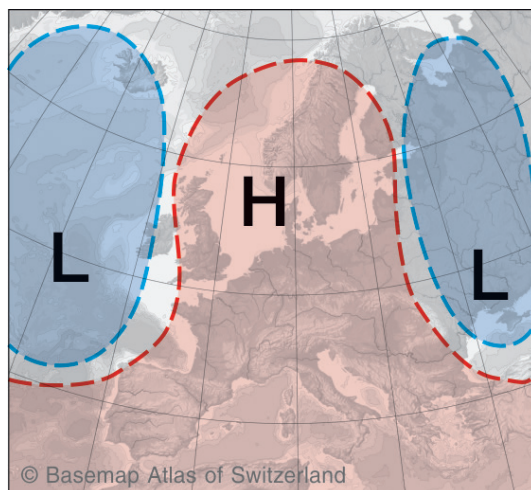
The amount and origin of the moisture that is transported to Switzerland depends on large-scale atmospheric circulation and the resulting winds. As shown in Figure 1 a, about 40% of the precipitation that falls in Switzerland is evapo-

rated from the North Atlantic. Another 25% comes from the Mediterranean, 20% from the land surface of Central Europe, and 15% from the North and Baltic Seas. However, these figures can vary significantly depending on the season. In winter, the North Atlantic contributes an even greater proportion of moisture, while in summer the Central European land area plays a more important role than is shown in the illustration. In addition, the Alps act as a weather divide, often preventing the transport of moisture from one side of the mountains to the other. Thus, southern Switzerland receives most of its moisture from the Mediterranean while northern Switzerland gets it from the northern seas. In general, the source regions for moisture change significantly throughout the year. This doesn't necessarily affect the total annual rainfall in an area, however.





**Figure 1 a:** Switzerland's moisture sources, 1995-2002 (after Sodemann et al., 2010).



**Figure 1 b:** Two typical weather patterns that can lead to extremes in Switzerland: The "Omega block" (left) has a strong and stable anticyclone (H) over Europe that leads to droughts like the one in summer 2003. The "5b weather type" (right) is a characteristic low pattern (L) that is known to result in large amounts of rain. This pattern brings very moist and mild air into Switzerland, especially in the spring and autumn, causing the snowline to rise. If the soil is already saturated with water, this can lead to major flooding.



## Discharge regimes: The seasons of the river

For each of Switzerland's rivers, there is a seasonally characteristic discharge volume, known in technical jargon as a "regime". The regime depends on the region, its elevation and whether it is glaciated or not. Comparable flow regimes can be grouped into types.

In Switzerland, whether precipitation is stored as snow or ice plays an important role in how and when discharge occurs in a catchment. Alpine rivers experience peak runoff during the spring and summer, as first the snow and then the glaciers begin to melt. In the Jura, precipitation temporarily stored as snow contributes only slightly to the peak discharge, while melting ice plays no role. In the Central Plateau, almost all precipitation flows directly into rivers year-round. This leads to various seasonal and regional distributions of runoff and runoff peaks. Experts differentiate between regimes dominated by melting ice (glacial), snowmelt (nival) or rain (pluvial). In Switzerland, there are 16 different regimes; their typical discharge curves are shown in Figures 2 and 3.

### Alpine Regime



a-glaciaire



b-glaciaire



a-glacio-nival



b-glacio-nival



nivo-glaciaire



nival alpin

### Jura and Central Plateau Regimes



nival de transition



nivo-pluvial préalpin



pluvial supérieur



pluvial inférieur



nivo-pluvial jurassien



pluvial jurassien

### Southern Alpine Regime



nival méridional



nivo-pluvial méridional



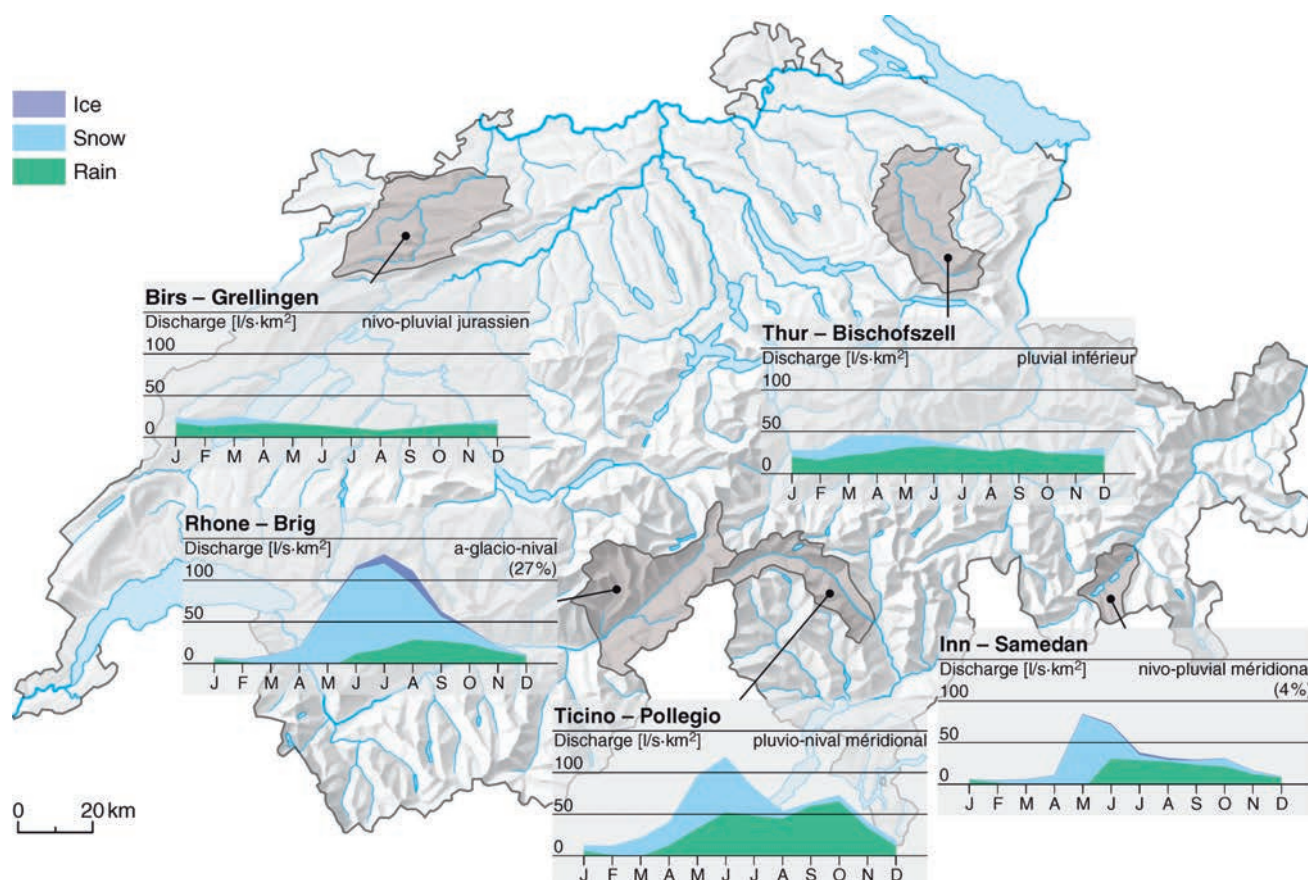
pluvio-nival méridional



pluvial méridional

**Figure 2:** The 16 discharge regime types, after Weingartner and Aschwanden (1992). The Pardé coefficients from January to December are shown. The coefficient is a normalized discharge value (ratio of the average monthly discharge to the mean annual runoff), which permits the comparison of different catchments.





**Figure 3:** Flow regimes for five representative catchments from different regions of Switzerland for the period 1984 through 2005. Where applicable, the glacier coverage in the catchment is given (in %). The runoff (liters per second and km<sup>2</sup>) from January to December is divided into snow melt, glacier melt and runoff from rain or groundwater. For example, the Inn River: low runoff during the winter months is typical for “nivale” regimes because the precipitation is stored as snow. This melts in May and June, resulting in a peak discharge during these months. Data source: Köplin et al., 2011

### Leakage from the catchment area

Of course, a river can have several different regimes over its course from the high mountains to the flatlands. The Rhone River has a very different regime near Brig than it does near its mouth in the Mediterranean, for example. The discharge of a river depends on the size of its catchment area, which may be a single valley or an entire political region. Precipitation falling on the catchment surface flows toward lower elevations under the influence of gravity, unless it is evaporated or cached as snow, glacier ice, groundwater, or in a lake. The slope of the catchment area, as well as the soil and vegetation, also influences the speed at which the water moves through the catchment. On average, one third of the precipitation flows away directly, one third is evaporated (see Appendix 4), and a third is stored as snow (and flows away later).

The catchment area consists of the area from which all the water passing a given measurement point flows. To use the Rhone example, the alpine catchment area including Brig is approximately 900 square kilometers, 27% of which are highly glaciated. The regime here is strongly influenced by the melting of snow and glacial ice, as Figure 3 shows. In contrast, the catchment area at the point where the Rhone meets the Mediterranean is 90,000 square kilometers ( $= \times 100$ ), and the discharge increases from 40 cubic meters per second to 1,600 ( $= \times 40$ ). A general rule is: the larger the catchment area, the greater the discharge.

# The water budget of Switzerland

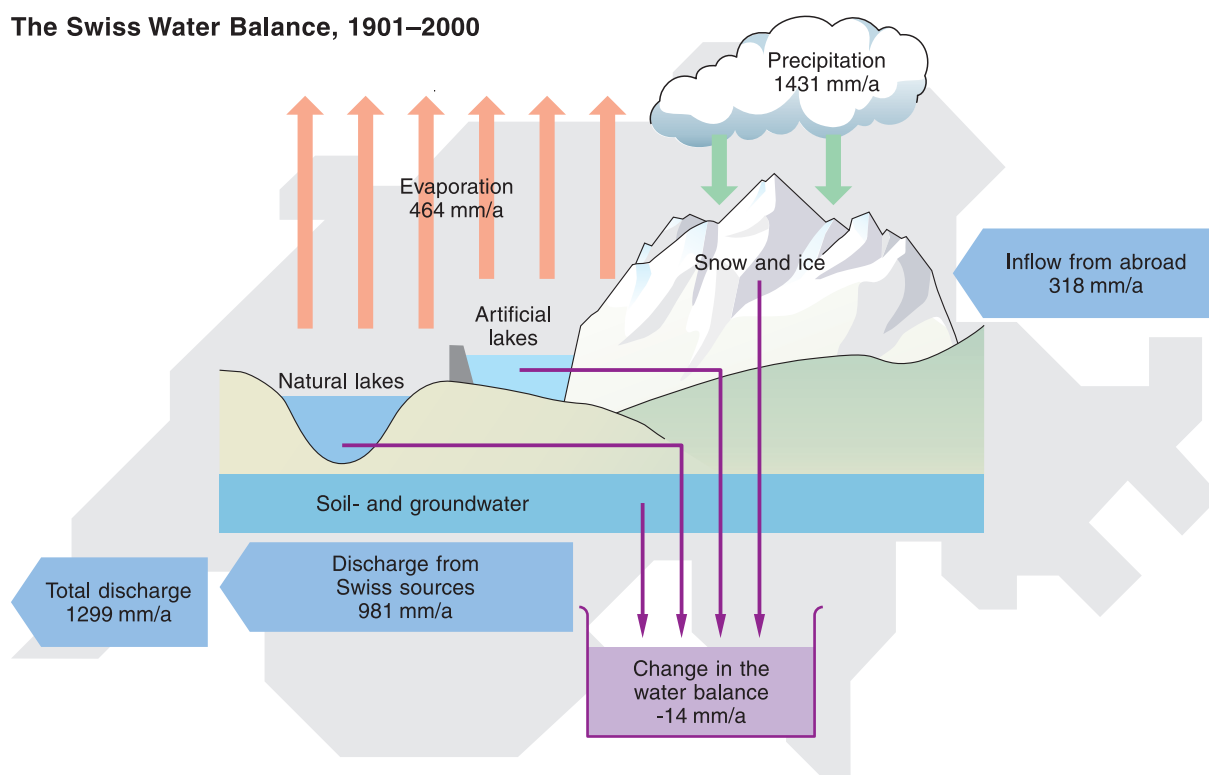
Just as one balances the household budget with income, savings and expenditures, the hydrological budget is a balance of gains and losses: precipitation minus evaporation minus changes in storage (snow, glaciers, lakes, groundwater) = discharge.

The water flowing in the rivers and streams of Switzerland is a renewable, available resource essential for human life and well being. Because so many of the rivers that flow through other European countries originate in Switzerland, Switzerland has a great responsibility as the “water tower of Europe”. Thanks to extensive measurements of precipitation and runoff, as well as of the stored snow and ice masses, the water balance of Switzerland is well documented. We know, for example, that 40% of Swiss discharge comes from snowmelt, and barely 2% from the melting of glaciers.

## Evaporation as an important factor

In contrast to runoff, evaporation of water is usually not measured directly but is derived from the water balance (evaporation = precipitation minus runoff minus reservoir changes; Spreafico & Weingartner 2005). Evaporation takes place at different locations: from water surfaces, from soil and from plant pores (transpiration). The total evaporation is called “evapotranspiration”. Evapotranspiration depends on the air temperature and the amount of water present in the soil. Higher air temperatures result in an increase in the maximum possible (potential) evaporation. This means that for an increase of actual (real) evaporation, there must first be enough water present in the soil.

## The Swiss Water Balance, 1901–2000



**Figure 4.** Switzerland’s water balance, 1901-2000 (Hubacher & Schädler 2010). If a layer of water 1 mm deep were spread evenly over the surface of Switzerland, this would require 41.3 million cubic meters of water. Given an average precipitation of 1431 mm/y, nearly 60 billion cubic meters of water per year thus fall on the surface of Switzerland! The change in the reservoir of –14 mm/year means that yearly 600 billion liters of water disappear from Switzerland as a result of glacial retreat. The change in the components of the water balance since 1901 is shown in Appendix 2 (Fig. 12); an illustrated balance sheet is located in Appendix 4 (Fig. 14).





Evapotranspiration is not the same throughout Switzerland: because evaporation through plant pores contributes significantly to the total evapotranspiration, vegetation density is important. As one moves from the agricultural fields and forests of the Central Plateau up through the meadows and forests of the pre-Alps to the talus material and glaciers of the Alps, vegetation density decreases with elevation. This is due to both decreasing temperature and decreasing land use intensity. Thus, the potential evaporation from plants also decreases with elevation.

Especially in summer, evaporation in the Alps leads to a “recycling” of precipitation. Up to two thirds of the evaporated water forms new thunderstorm clouds during its ascent, which then rains down again regionally (van der Ent et al. 2010).

### Groundwater: The great unknown

Although at least 80 % of drinking water comes from groundwater (see Water consumption and use), the renewal of this resource is not well understood. An unknown portion of the effluent from the water balance feeds the groundwater, while the same amount of groundwater feeds back into watercourses (the total water balance doesn't change). It is assumed (Sinreich et al. 2012) that only about 10% of the theoretically usable groundwater in Swiss reservoirs can be sustainably replaced (equivalent to about a third of the annual rainfall, or 18 km<sup>3</sup>). The natural replacement of the groundwater depends on the aquifer type (see Glossary). Water can linger for a long time in different aquifers. This time is determined by the underlying geology (how well can the [rain] water seep into the aquifer?), by the size of the

groundwater resources, and by the presence of watercourses. The residence time of groundwater can be between a few months (along rivers such as the Aare) to over 10 years (limestone areas like those found in parts of the Alps and Jura mountains). In the case of heavy precipitation in karst areas, the rivers react quickly, although the majority of the water flows away underground before emerging at a source. Thus, all groundwater is not well mixed. Imagine a wet sponge: if more water is introduced, some of the water already in the sponge is pressed out.



# The impacts of climate change

The total water supply in Switzerland will change only slightly over the next century. However, the seasonality of precipitation will change, with more precipitation falling during the winter and less during the summer. Additionally, the amount of water stored as snow or ice in the mountains will decrease significantly, causing water levels in rivers to change more frequently and with greater variability.

## Shrinking glaciers

The melting of Switzerland's glaciers has been observed for many years. Since the end of the Little Ice Age around 1850, the volume of glaciers in Switzerland has decreased by more than half. As temperatures increase, glaciers melt faster and precipitation falls more often as rain than as snow. When glaciers melt, the important "glacial reservoir" of the water balance changes.

At the moment, glaciers are not in equilibrium with the current climate conditions. Were the climate to remain as it is today, the glaciers would continue to shrink over the next several decades to half of their current volume. However, experts expect an increase in temperature of 3°C by the year 2085 (plus or minus one degree). This warming will have severe repercussions for Swiss glaciers: according to models, only 20 to 30% of the current glacier volume will remain by 2100. Most of the remaining glacier volume will be in the Rhone catchment area, thanks to the largest glacier in Switzerland, the Aletsch (Figure 5). Runoff regimes shaped by glacier runoff will almost completely disappear (see Figure 6).

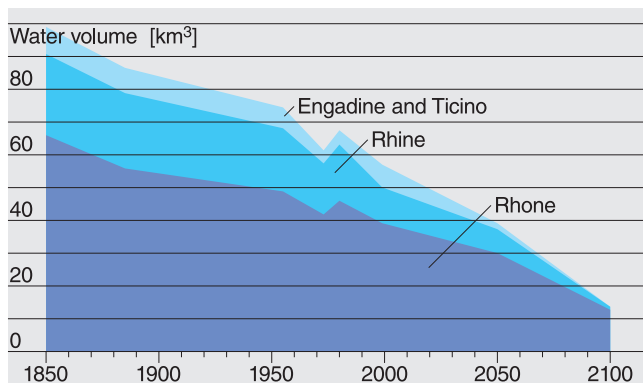
## Less snow

40% of the runoff in Switzerland today comes from melting snow. With climate change, this share will fall to about 25% by the year 2085 because rising air temperatures will cause the snowline to climb about 150 meters per degree of warming. Thus, less precipitation will be stored as snow, with the consequence that it

will immediately run off. The first effects are already measurable: the seasonal peak flows in nival-dominated catchments occur earlier in the spring and are less pronounced.

## Increasing discharge variability

Presumably, the total annual precipitation falling in Switzerland will not change significantly. However, the seasonal distribution of precipitation will change. Experts expect a strong decrease in summer precipitation of about 20% by the year 2085, and an increase in precipitation during the winter months (September to February). The combined effects of changing seasonality and reservoir size will have strong implications for river runoff. Flood situations in winter and unusually low water levels in summer are likely to occur with increasing frequency, especially in water-sensitive regions like the Valais, Ticino or the Central Plateau. The Central Plateau is even expected to experience a new regime, the "pluvial de transition" (Figure 6, bottom right). This regime is characterized by high flows in the winter and a pronounced minimum during the summer due to a lack of snowmelt in May and June. As hot, dry summers are likely to become more common, very low water levels may also occur more frequently in years with little precipitation.



**Figure 5.** Evolution of the volume of water stored in Swiss glaciers (Rhone and Rhine river basins, Engadine and Ticino). Since the end of the Little Ice Age around 1850, the glacier volume has decreased by half. More than 70 % of the remaining volume should be gone by the end of this century. FOEN, 2012.

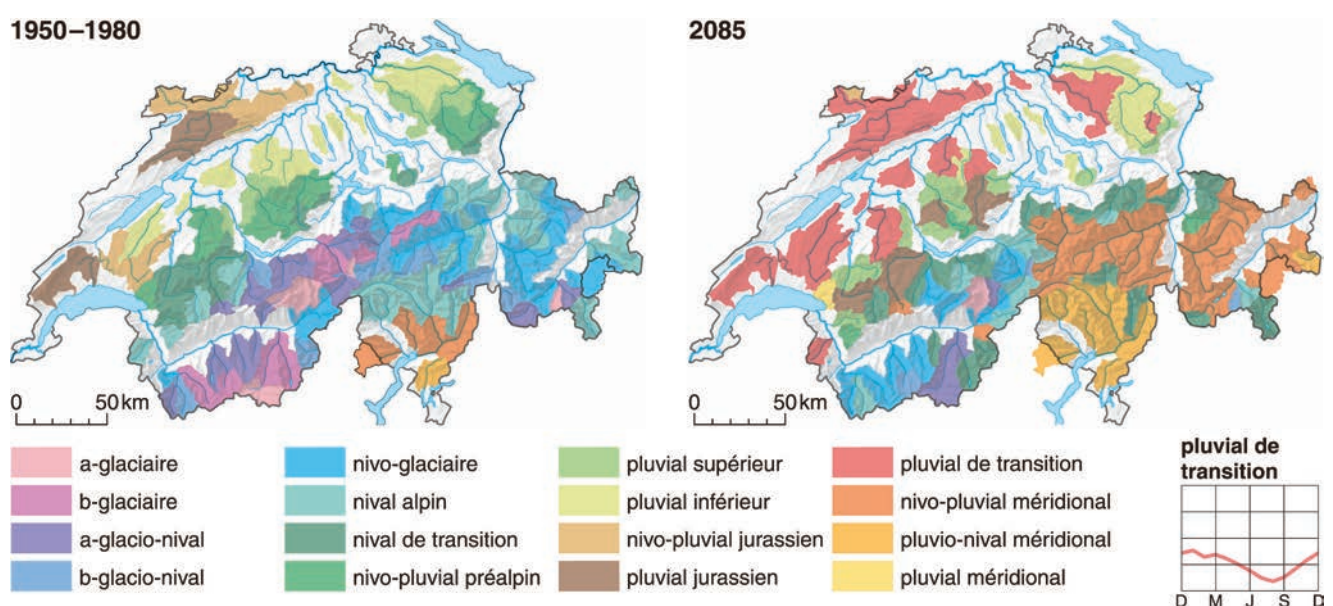




### Big impacts

The increasing irregularity of discharge and the increased number of extreme events will also create challenges for businesses dependent on rivers, such as power producers and water traffic on the Rhine. However, many other people in Europe will also feel the effects of these changes: some of the biggest rivers in

Europe begin in Switzerland (Rhine, Danube, Po and Rhone). However, compared to other areas of the world, Switzerland is likely to be spared the worst impacts of climate change. In addition, Switzerland has the scientific knowledge, political will and the financial capacity to adapt to these changes in a timely manner (FOEN 2012b).



**Figure 6:** Flow regime changes for 189 medium-sized catchments in Switzerland. Left: The classification from the Hydrological Atlas of Switzerland (HADES) for the period 1950-1980. Right: The catchment classifications simulated for the future to 2085. Bottom right: the new regime “pluvial de transition”, with a pronounced minimum in August. We refer to the text and the flow regime types of Switzerland in Figure 2. FOEN, 2012.

# Water consumption and use

Water is used in Switzerland for a variety of purposes. This precious liquid is not only used for domestic purposes like showering and washing dishes, but also in trade, industry and agriculture. In addition, more than half of Switzerland's electricity comes from hydropower. By making wise choices about the products and foods we consume and about how we manage our drinking water, we can make a contribution to the global conservation of water resources.

There are two different purposes for extracted water: consumption and use. Use refers to the water that is taken for energy or cooling and later returned, clean, to the environment. Consumption refers to water withdrawals that are consumed or contaminated, such as drinking water, irrigation water, rinse water, and water used for evaporative cooling or sewage.

## Hydropower as the primary water user

Most extracted water is used to produce energy (see Table 1 in Appendix 1). Hydroelectric plants produce 50-60% of the energy used in Switzerland, or about 36 TWh (terawatt-hours). This corresponds to roughly 50 times the energy contained in the Rhine Falls near Schaffhausen. On average, a drop of water flows ten times through a turbine before leaving Switzerland. About 30% of the total energy contained in Swiss rivers is currently used to generate electricity (BFE 2004). According to the Swiss Federal Office of Energy, it is possible to increase this share by 10% by 2050 without relaxing the existing environmental and water protection laws (BFE 2012). Due to increasing temperatures, hydropower stations in heavily glaciated catchments will benefit over the short term, and most likely not experience negative impacts over the medium term.

## Water consumption

Mr. and Mrs. Swiss need about 170 liters of drinking water a day for drinking, cooking, washing and cleaning. Thus, domestic consumption constitutes about a quarter of the total water consumption in Switzerland. Agriculture accounts for another 20%. However, about half of the water attributed to agriculture is actually pumped through the farmers' fountains and is not actually used. A good half of the total water budget is used by commerce and industry (see Figure 7). Thus, about half of all used water is extracted by public services (drinking water) and half by the private sphere (agriculture, industry). Each year, one-third of the water volume of Lake Thun is consumed in Switzerland (2.2 km<sup>3</sup>).

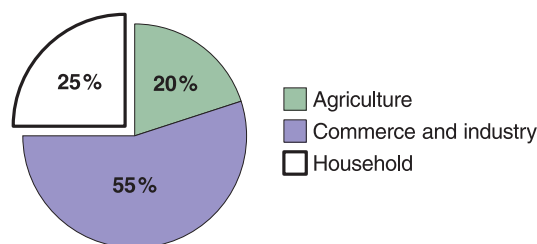


Figure 7: Water consumption in Switzerland (including private wells): Percentages according to the field of use (Data: Freiburghaus 2009).

## Drinking water

Where does the drinking water in Switzerland come from? 40% comes from spring water, 40% is pumped from groundwater, and the final 20% is taken from surface water, usually lakes. Lake water needs a two-step treatment process to reach drinking level quality. A third of the drinking water goes through a single step treatment, and half of the water doesn't need any treatment at all. Thus, the drinking water in Switzerland has a level of quality that can compete with that of mineral water. Drinking water is distributed throughout Switzerland via 53 000 kilometers of piping, a length sufficient to circle the country 28 times. These pipes must be replaced about every 50 years, which corresponds to 1000 kilometers of new pipeline every year. This is necessary because about 15% of drinking water is lost each year to leaky pipes.

As Figure 8 shows, water consumption per capita is declining. This indicates that people are aware of water issues and use water-saving devices and methods, such as water-saving showerheads. In addition, devices like dishwashers and laundry machines have become more efficient. However, a substantial portion of water savings is not actually saved, but relocated: water-intensive industries such as textile production have been transferred abroad. In addition, an increasing amount of goods and foodstuffs, which require plenty of water to produce, are imported. Thus, "virtual water" is an important element of the water budget.





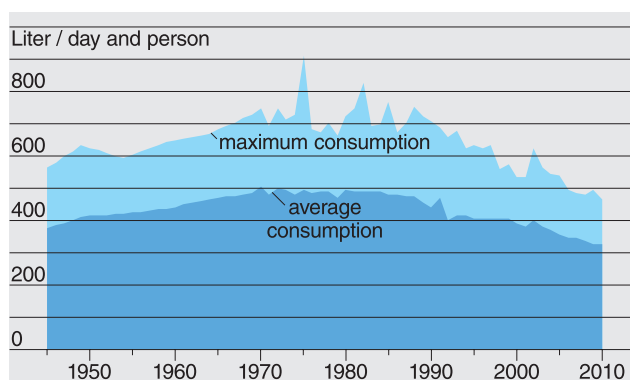


### Virtual water

“Virtual water” refers to water that is used in other countries (see Appendix 1) to produce the agricultural and industrial products consumed in Switzerland (60% and 40% of the virtual water share, respectively). If the water consumed virtually by each person is added to the Swiss water consumed by each person, the total amounts to over 4000 liters per person per day. If all the products that we consume were produced in Switzerland, we would use about a third of our renewable water resources (the water now flowing in streams and rivers).

### Water consumption for agricultural products

In Switzerland, the production of milk, beef and pork products accounts for three quarters of all agricultural water consumption. In contrast to animal products, most plant products are imported. This is reflected in the virtual water shares: most virtual water is in cocoa, followed by coffee, sugar, nuts, wheat, oilseeds and rice. Many of these plants would not survive in the Swiss climate, as many of them are grown in tropical areas where it rains a lot. The problem arises when the same products are grown in drier regions where they need to be heavily watered. Thus, water scarcity in some regions is exacerbated by the production of export products. Examples include the production of cotton (1 kilogram of cotton requires 10 000 liters of water) and rice (2500 liters for one kilogram) in China, Spain or Portugal.



**Figure 8:** Evolution of the average and maximum potable water consumption per resident and day (including commerce, industry, public uses and losses) from 1945 to 2011. The maximum daily consumption increased to 900 liters per person in 1976 on account of an exceptional drought in the first half of the summer (Statistics SVGW, [www.trinkwasser.ch](http://www.trinkwasser.ch)).

### Conclusion

It is a matter of concern that, of our daily consumption of agricultural and industrial goods, only about 25% is supplied by domestic water resources. Three quarters of our needs are supplied by other regions of the world, where water restrictions (if any) are often less stringent than in Switzerland.

Switzerland also exports products (about half of the total production of agriculture and industry is exported) whose production requires a lot of water. The balance of virtual water (imported virtual water minus exported virtual water) is positive and corresponds to the volume of Lake Thun. In other words, an amount of water equivalent to the volume of Lake Thun is used to produce foreign goods that are consumed in Switzerland.

# Water quality and ecology

In recent decades, the water quality in Switzerland has increased thanks to scientific knowledge and political action. However, it is too early to rest on our laurels: micropollutants are increasing, biodiversity is decreasing and climate change is already having an influence on the aquatic environment.

## Rising water quality

Less than 30 years ago, swimming in the Rhine was not recommended due to the presence of chemical impurities such as phosphorous and nitrate originating from urban, industrial and agricultural areas. Thanks to the expansion of wastewater treatment since 1980, the ban on phosphate in laundry detergents in 1985 and the greening of agriculture since 1990, the nutrient load is slowly but steadily decreasing (see Figure 9). As a result, the quality of Swiss waters has risen, especially in lakes that were once heavily contaminated. Depending on population, livestock density and the residence time of water in a lake, phosphorous and nitrate concentrations evolve differently. Today, phosphorous is mainly leached out of soils and washed into lakes and rivers by precipitation. It will take decades until this store of phosphorous is depleted. The presence of phosphorous and nitrate in water leads to over-fertilization of the aquatic environment, or eutrophication. This occurs because algae (phytoplankton) have the nutrients they need for practically unlimited growth. However, growth requires oxygen; as the algae grow, the oxygen content of the water decreases until fish and other aquatic life “suffocate”. A study shows that nearly

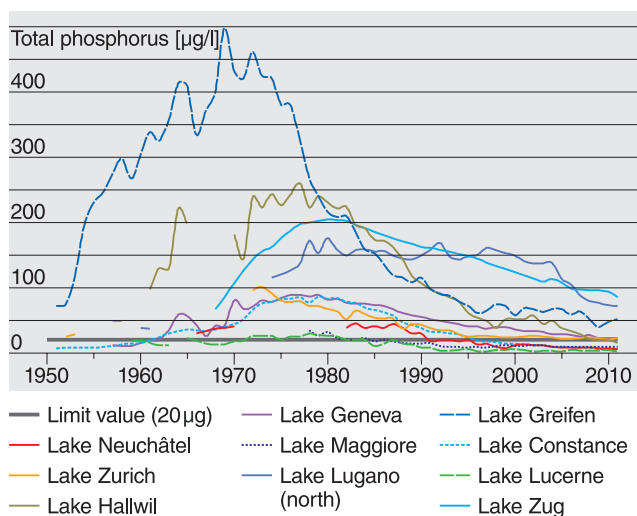
40% of the native whitefish species in Switzerland have disappeared due to the eutrophication of lakes (Vonlanthen et al. 2012). These species are now found only in deep, less affected mountain lakes such as Lake Thun, Lake Brienz and Lake Lucerne.

## New contaminants

The recent increase in micropollutants from drugs and pesticides is worrying. These include hormones and nanoparticles, the fate and behavior of which we know very little about. Also a cause for concern is the elevated nitrate levels in groundwater from the Central Plateau resulting from agricultural practices.

## Rising water temperatures and changing runoff

Climate change represents a new, dual challenge for the ecology of aquatic environments (FOEN 2012). In addition to changing flow patterns, both air and water temperatures rose by 0.1 to 1.2 degrees Celsius between 1970 and 2010, depending on the flow regime. In glaciated catchments, the increase and fluctuation range (variability) of the temperature changes are less pronounced (see Figure 10). However, experts expect an increase in air temperature of three to four degrees by the year 2085. This warming will be especially felt in the summer, when the seasonal redistribution of runoff will result in lower summer runoff in the Central Plateau, Jura and south of the Alps. Together, generally warmer water and lower water levels in the summer will cause local water bodies to warm even more, with consequences for aquatic life and water users. Current warming has already led trout populations to retreat to elevations 100 to 200 meters higher than their traditional ranges (Hari et al. 2006). Lower, warmer discharge flows also reduce the oxygen concentration in lakes and rivers and strongly influence the spread of fish diseases such as proliferative kidney disease (PKD).



**Figure 9:** Time series of the phosphorus content of selected Swiss lakes. To meet legal requirements, phosphorus should be below 20 micrograms per liter of water. Source: FOEN.

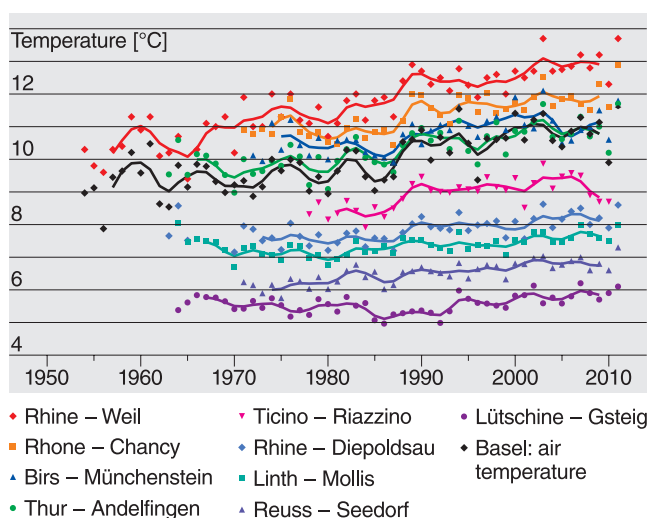




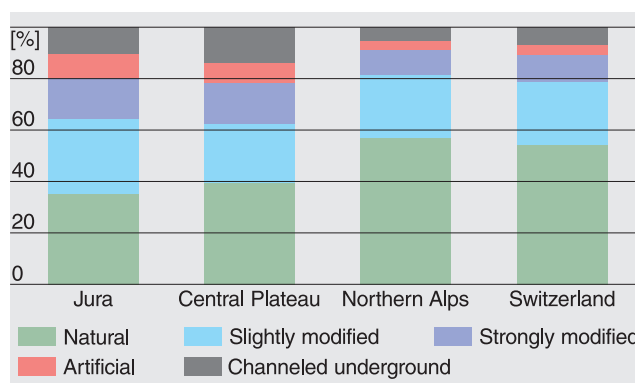
### Natural rivers for diversity and flood protection

Urban expansion and the intensification of agriculture and flood protection measures strongly increase the pressure on rivers. A quarter of Switzerland's watercourses are either channeled or diverted through culverts, as shown in Figure 11. Human intervention has reduced the ecological structural diversity of watercourses, thereby also reducing biodiversity (Ewald and Klaus, 2010). By "structural diversity", experts refer to a varied stream- or riverbed with gravel and sand bars, places of both fast and slow flowing water, zones with different water depths, fallen trees and networks of banks and floodplains. These different habitats in and around the water are important for a high level of biodiversity. Structural diversity is found especially in flat areas where rivers can meander freely and naturally.

The federal government has reconsidered the channeling of rivers, especially after the floods of 1999, 2005 and 2007. To avoid similar incidents in the future (the flood of 2005 was the most financially damaging incident in the last 100 years), a new strategy is needed. Thanks to restoration, rivers get more space, which helps slow floodwaters and prevent rivers from breaching their banks. At the same time, flow spaces are ecologically enhanced and become more attractive as recreational areas, as is the case for the Thur, Birs, Linth and Brenno rivers.



**Figure 10:** Water temperatures over the last decades for nine selected stations and Basel (air temperature). For stations with cold mean water temperatures (e.g., Lüttschinen-Gsteig), the temperature jump in 1987-1988 is less evident than in the Ticino, for example. In addition, there is less variation from one year to another in mountain water temperatures. Both illustrate the balancing effect of glaciers. Source: FOEN.



**Figure 11:** Eco-morphological status (5 categories) of watercourses in the Jura Mountains, the Central Plateau, the Northern Alps and for the whole of Switzerland (percentages). Source: Biodiversity Monitoring in Switzerland, as of 2010.



# Challenges for Switzerland

**In the near future, Switzerland will have to deal with two major challenges with respect to water. In order to overcome them, a balanced interplay of science, politics, population and economy is extremely important.**

## Hydropower gains prominence

Since Switzerland elected to decommission its nuclear power plants (NPP), interest in hydropower has grown. Hydropower is indeed a largely ecological energy source but, like all other power sources, it has its downsides: flows below hydropower plants are altered, and the construction and expansion of small power plants partially offsets the effectiveness of restoration efforts. Hydropower plants also break up the continuity of streams and rivers, with negative consequences for fish. Pumped storage power plants provide electricity during peak times and during the winter, but they need more electricity to pump water back into the reservoirs than they produce themselves. Used in combination with wind turbines and solar power, however, pumped storage power plants would have a big advantage. The energy produced by wind and solar technologies could be used to drive the water pumps directly, a process that would help smooth out the variability of energy captured from the wind or sun. By further developing its wind, water and solar capacities, Switzerland could distinguish itself as the energy reservoir of Europe.

Over the next several decades, licenses to renew and expand hydropower plants will come due. The discussions and decisions about renewal permissions, reservoir extensions and so on will take place amidst environmental, social and economic concerns about how to best use limited water resources. Which sections of the river are valuable as recreation and refuge areas (leisure, fisheries, biodiversity)? Which should be protected for their scenic value? Which can be used for water management? How should high and low flows created during hydropower production be managed? To answer these questions, holistic decision aids (e.g. Hemund 2012) and the involvement of the affected population will be crucial.

## Climate change alters the seasonal availability of water

Climate change will have an impact on snow and ice, which are key natural water reservoirs. In addition, a redistribution of rainfall is expected, with more precipitation in the winter and significantly less in the summer. Together, these changes will affect the seasonal distribution of runoff. Experts expect the peak discharge season to shift from the early summer to the winter months, and to last longer. Low water levels will become more frequent in late summer for most parts of the Central Plateau.

These changes in the water cycle will have economic consequences: the legal regulations for issues like water abstraction, the release of cooling water, the regulation of lakes, residual water amounts for hydroelectric power plants and many others will need to be checked. Because the risk of summer water scarcity is likely to increase, the water supply must be reconsidered. It must be determined if additional, multipurpose reservoirs will be needed to help meet future needs. River traffic on the Rhine is also likely to be affected by the increasing irregularity of discharge, particularly by low water levels.





### Finding new ways

Despite the improving quality of water in Switzerland and the high security of the water supply, it is necessary to work together on sustainable water use:

#### Water supply:

- By combining different and currently independent water supply systems, the security of the supply would increase.

#### Agriculture:

- Irrigation can be made more efficient by using better technologies, such as drip irrigation.
- The use of fertilizers and plant protection products (pesticides, herbicides, fungicides) must be reconsidered.

#### Hydropower:

- The renewal or expansion of existing power plants should focus on reducing artificial fluctuations in discharge (“hydropeaking”) below the power plants.
- Restoration measures and improved discharge consistency from hydropower plants should help preserve and increase fish stocks.

#### Industry and commerce:

- Certain substances, such as hormones and nanoparticles from drugs and cosmetic products, create problems in the water cycle because conventional wastewater treatment plants cannot remove them. Sophisticated technical measures are required to dispose of micropollutants before they accumulate in the environment. The consequences of micropollutants for human, animal and plant health is difficult to estimate. What chemicals are really necessary? Which can be replaced by other, more biodegradable substances?

#### Wastewater treatment:

- The widely applied practice of separating rainwater and wastewater significantly relieves the pressure on wastewater treatment plants.
- The consolidation of smaller wastewater treatment plants allows for more efficient cleaning.
- New methods must be developed so that the smallest amounts of micropollutants can be found and removed from wastewater.





# Glossary

**Annual precipitation:** the average amount of precipitation that falls in a particular place each year. It is usually expressed in millimeters. On the Central Plateau, total annual precipitation is about 1000 mm. This means that a one meter deep (= 1000 liters of water per m<sup>2</sup>) layer of water would cover the region if no runoff or evaporation was present.

**Aquifer:** permeable body of rock, often with very small cavities (pores), that can store groundwater.

**Blue water:** unpolluted water that runs off into streams and rivers or resides in lakes and groundwater.

**Catchment area:** closed hydrologic unit in which the **water balance** is considered. Every drop of water that falls on this surface flows away under the force of gravity, assuming it does not evaporate or get stored as snow or ice, or in groundwater or lakes. If the discharge of a river is measured at a location (e.g., the Aare River in Bern), the catchment area comprises the area from which rainfall sooner or later runs off.

**Discharge:** the volume of water that flows through a given cross section per second (in m<sup>3</sup> per second).

**Discharge regime:** describes the average flow variation of a stream or river over time. The discharge regime is closely related to seasonal changes in climate.

**Drinking water:** clean, potable water that is treated as needed and conducted through public lines to households and other users.

**Ecomorphology:** οἶκος: house or household, μορφή [morphé]: shape or form and λόγος: the doctrine. Thus, ecomorphology describes the science of the structural nature of a body of water and its shore area, as well as its interactions with plants and animals. Sections of a river are classified depending on the water depth and velocity (e.g., pool, riffle, glide and runner).

**Eutrophication:** if large amounts of nutrients (often nitrate or phosphate from fertilizer and sewage) enter into a body of water, algae can reproduce very quickly and lower the oxygen content of the water in such a way that biodiversity (especially for fish) decreases. Some of the smaller lakes in intensively used agricultural areas (e.g., Hallwilersee) must be artificially oxygenated to prevent eutrophication.

**Evapotranspiration:** in the environment, water evaporates to form water vapor (an invisible gas), for example over water bodies such as seas, lakes and rivers. The water that is present in the soil (soil moisture) can also evaporate. In addition, plants "sweat" during photosynthesis, a process known as "transpiration". This invisible water vapor can re-condensate into water droplets if the air cools sufficiently, forming fog or clouds.

**Groundwater:** water that is located underground (such as in the aquifers in the karst regions or in the Central Plateau). Most of the water (approximately 80 %) is found in karst areas (Alps, Jura Mountains) and at depths between 100 and 1000 meters. Renewable groundwater is the proportion of groundwater that can be sustainably used; that is, without affecting the quantity or quality. This proportion varies by region (on average, 10 % of the available groundwater) and depends mainly on the underlying geology and the presence of watercourses.

**Gray water:** volumes of polluted water no longer usable as **drinking water**.

**Green water:** rainwater stored in the soil that is used by plants.

**Hydropeaking:** Rapid changes in flow below hydropower plants result from peaking operations, where water is typically stored in a reservoir at night and released through turbines to satisfy increased electrical demand during the day. This artificial increase or decrease in discharge is known as "hydropeaking", and poses a problem for downstream ecosystems due to the rapidly changing volume, flow rate and temperature of the water.



**Intensity (of precipitation):** *precipitation* (rain, snow, hail, etc.) can fall with varying levels of strength, from fine drizzle to heavy rain showers or thunderstorms. The intensity of precipitation depends on the type of weather and on the elevation. A unit commonly used to measure the intensity of precipitation is the number of liters of water that falls on one square meter in 10 minutes, one hour, or one day.

**Interception:** the fraction of precipitation that does not fall directly on the ground, but is caught by vegetation (leaves, branches, trunks) and is therefore either delayed in reaching the ground or directly re-evaporated.

**Irrigation canals:** historical irrigation canals ("Suonen") in Canton Valais, the driest region of Switzerland. These canals bring water from mountain streams – in a rather adventurous way – to the dry pastures, fields, vineyards and orchards below.

**Moisture sources:** areas from which large amounts of water evaporate into the atmosphere and form clouds that later rain out over Switzerland.

**Pardé-coefficient:** this coefficient is named after a famous French hydrologist and gives a normalized discharge value (ratio of the average monthly discharge to mean annual discharge). The coefficient allows the comparison of *flow regimes* from different *catchment areas*.

**Precipitation:** see *annual precipitation* or *intensity (of precipitation)*.

**Pumped storage power plant:** in hydroelectric power plants, there is a difference between diverted flow and storage power plants. Numerous diverted flow power plants are located along our rivers because they are enabled by the river gradient. In contrast, storage power plants are situated below reservoirs (artificial lakes), and work due to the change in height between the dam and the power plant below. If water can be pumped back into the reservoir, the system is called a pumped storage power plant.

**Restoration (or renaturation):** Switzerland's watercourses have been strongly modified (straightened, channeled, culverted), which has affected the natural diversity of flora (e.g., rare plants) and fauna (e.g., fish) in and along rivers. These modifications are often done as flood protection measures. However, it is now known that these measures often increase the risk of flooding because water can travel much faster in a straight channel. Flood protection can be combined with restoration by allowing rivers more space to meander, creating a win-win situation for both humans and nature.

**Specific discharge:** This volume corresponds to the *discharge* per unit area of the *catchment*. It is typically expressed in liters per second and km<sup>2</sup>.

**Storage:** in the hydrological system, a unit of water can be "removed" from the water cycle for a short (snow cover, soil moisture, groundwater) or long (lakes, groundwater, glaciers) period of time before re-entering the water cycle.

**Surface runoff:** the fraction of precipitation that directly enters stream channels as a function of gravity.

**Surface water:** natural and artificial streams, rivers and lakes.

**Variability (of precipitation or runoff):** *annual precipitation* varies from year to year and is therefore usually calculated for a period of 30 years. The variability represents the scatter of the annual precipitation within this period (e.g., the difference between the driest year and the year with the most precipitation). This analysis can also be performed for the discharge of a watercourse.

**Virtual water:** is the amount of water necessary to produce products abroad (agricultural products, processing of raw materials, etc.) that are then consumed in Switzerland. A distinction is made between *green*, *blue* and *gray water*.

**Water balance:** *Discharge* = *Precipitation* minus *Evapotranspiration* minus the *storage change*. The water balance formula represents a highly simplified description (mean) of the hydrological system of a closed basin.

**Water consumption:** refers to the quantities of (drinking) water that are evaporated, lost or contaminated (*gray water*) during consumption.

**Watercourses:** streams, rivers.

**Water resources:** describe the quantity of water that can be used sustainably and is stored in the meantime (e.g., as rain water, snow and glacier melt, in rivers and streams, or in groundwater).

**Water supply:** Man has no influence on the amount of precipitation that falls in different regions of the world. We are the mercy of nature. A part of the precipitation evaporates and some is cached (e.g., as snow). The rest is the water supply, which flows into streams and rivers and feeds lakes and groundwater.

**Water use:** is mainly used to describe quantities of water that are used to generate hydroelectric power or for cooling before being returned (clean) to the environment.



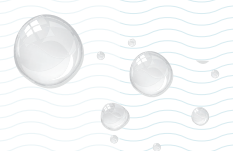






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# Links

Water Factsheet (available in G/F/I)

- More facts and figures about water in Switzerland, as well as documents for the classroom  
<http://chy.scnatweb.ch>

Hydrological foundations and data from the Federal Office for the Environment (available in G/F/I/E)

- Current and historical data for the whole of Switzerland  
[www.hydrodaten.admin.ch](http://www.hydrodaten.admin.ch)

Factsheets from the Swiss Water Management Association (available in G/F)

- Factsheets about water power  
[www.swv.ch/Downloads](http://www.swv.ch/Downloads)

Hydrological Atlas of Switzerland HADES (available in G/F/I/E)

- Worksheets on the topic of hydrology for the upper secondary level, excursion guide "Paths through the Water World", and access to digital data as a subscriber  
[www.hades.unibe.ch](http://www.hades.unibe.ch)

E-Dossier on water from PHBern (available in G with some materials in E)

- Additional factsheets, worksheets, field measurement instructions, audio and visual resources, news articles, maps/plans and scientific reports  
<http://campus.phbern.ch/bildungsmedien/themenportal/e-dossier-wasser>

Water – A Swiss Perspective (2005) (Available in G/F/E/S)

- Switzerland is a country rich in water. Discover how Switzerland uses its water resources and what dangers may be connected with the water. Seventeen different videos, as well as documents, graphics and photos, explain why Switzerland is known as the "water tower of Europe" and how this obliges Switzerland to make special efforts in water conservation.  
[www.swissworld.org/dvd\\_rom/water\\_2006](http://www.swissworld.org/dvd_rom/water_2006)

Irrigation canals in Wallis (Valais) (available in G and F)

- Well-documented site about the historic irrigation canals in Canton Wallis (Valais). The site includes an image gallery, an inventory of the canals (with a map), and additional references (such as guides for hiking excursions).  
[www.suone.ch](http://www.suone.ch)

Hydroweb (available in G and F)

- An interactive platform that allows the user to explore the aquatic environment in Switzerland by adjusting influencing parameters such as temperature, precipitation, evaporation or topography. In addition, educational materials for middle and high school students are available, including a short introduction for teachers and exercises that can be solved using Hydroweb.  
<http://lasigpc8.epfl.ch/hydroweb>

Drinking water (available in G/F/I)

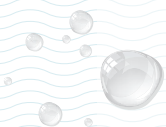
- A lot of interesting facts about the Swiss drinking water, as well as useful information sheets.  
[www.trinkwasser.ch](http://www.trinkwasser.ch)

Drinking water quality (available in G/F/I)

- Here you can find information about the water quality in your community  
[www.wasserqualitaet.ch](http://www.wasserqualitaet.ch)

Physical geography animations (hydrology focus) (available in G)

- Descriptive animations for various themes in physical geography, such as the Genoa low.  
[www.geog.fu-berlin.de/~schulte/animationen.html](http://www.geog.fu-berlin.de/~schulte/animationen.html)
- Teaching tip: To discuss the theme "water" on a global level, the book "Who owns the water?" (Lanz K. et al 2006, Lars Müller Publishers) is recommended. Supported scientifically and financially by the Swiss Federal Institute for Water Resources (Eawag), the book contains descriptive text and illustrations and is available in English and German.





# Appendix 1

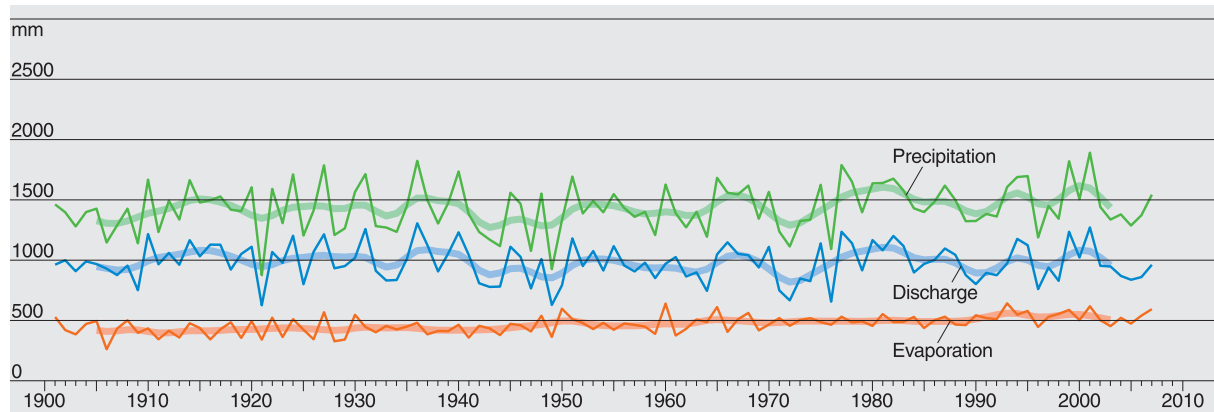
## Water quantities in Switzerland

Components	km <sup>3</sup> water	km <sup>3</sup> water / year
Precipitation <sup>a</sup>		60
Evaporation <sup>a</sup>		20
Discharge		53
from water bodies flowing into Switzerland <sup>a</sup>		13
from snow melt <sup>b</sup>		22 (fraction CH: 17)
from glacier melt <sup>a</sup>		0,6
Storage change (primarily glacier melt) <sup>b</sup>		< 1
<b>Natural reservoirs</b>		
Lakes (Swiss portion) <sup>a</sup>	130	
Glaciers in year 2012 <sup>b</sup>	55 ± 15	
Total groundwater <sup>c</sup>	150	
Fraction in karst regions	120	
Fraction that is renewable	18	
Fraction that is used		1.3
Soil water (available to plants) <sup>a</sup>	7	
Maximum snow reserves (ca. April) <sup>b</sup>	7	
<b>Water consumption</b> (including private wells) <sup>d</sup>		
Fraction of drinking water		1
Fraction which is treated by wastewater		1.5
Commerce and industry		1.1
Fraction for artificial snow production		0.02
Domestic uses		0.5
Agriculture		0.4
Fraction for irrigation		0.1 – 0.2
Fraction for potable water for farm animals		0,05
Losses		0.1
Public purposes (fountains, administration, ...)		0.1
<b>Virtual water</b> <sup>e</sup>		
Water used in the production of products		
Agricultural products (production and consumption in CH, including water consumption)		1.4
Agricultural products (Imported)		7.4
Industrial products (Imported)		5.0
Exports		5.1
<b>Energy industry</b>		
Hydropower <sup>f</sup>		550
Reservoirs <sup>a</sup>	4	
Continuous flow cooling (nuclear power plants) <sup>d</sup>		1.6
Cooling towers <sup>g</sup>		0.04

**Table 1:** Current values of the water balance components, water consumption and water use for Switzerland (a: Hubacher & Schädler, 2010, b: FOEN 2012, c: Sinreich et al 2012, d: Freiburg House, 2009, e: SDC & WWF 2012, f: calculated from BFE 2012b, g: data from nuclear power plant operators). 1 km<sup>3</sup> = 1 billion m<sup>3</sup>. 41 km<sup>3</sup> corresponds to a layer of water about 1 m deep over the surface of Switzerland (41.285 km<sup>2</sup>). To illustrate the magnitude of the reservoir: The water content of Swiss lakes (130 km<sup>3</sup>, considering only the Swiss portion) corresponds to a 3 m deep layer of water spread over the entire area of Switzerland, or more than 2 years' worth of precipitation. The overall water balance of Switzerland (Fig. 14) is clearly illustrated in Appendix 4.

## Appendix 2

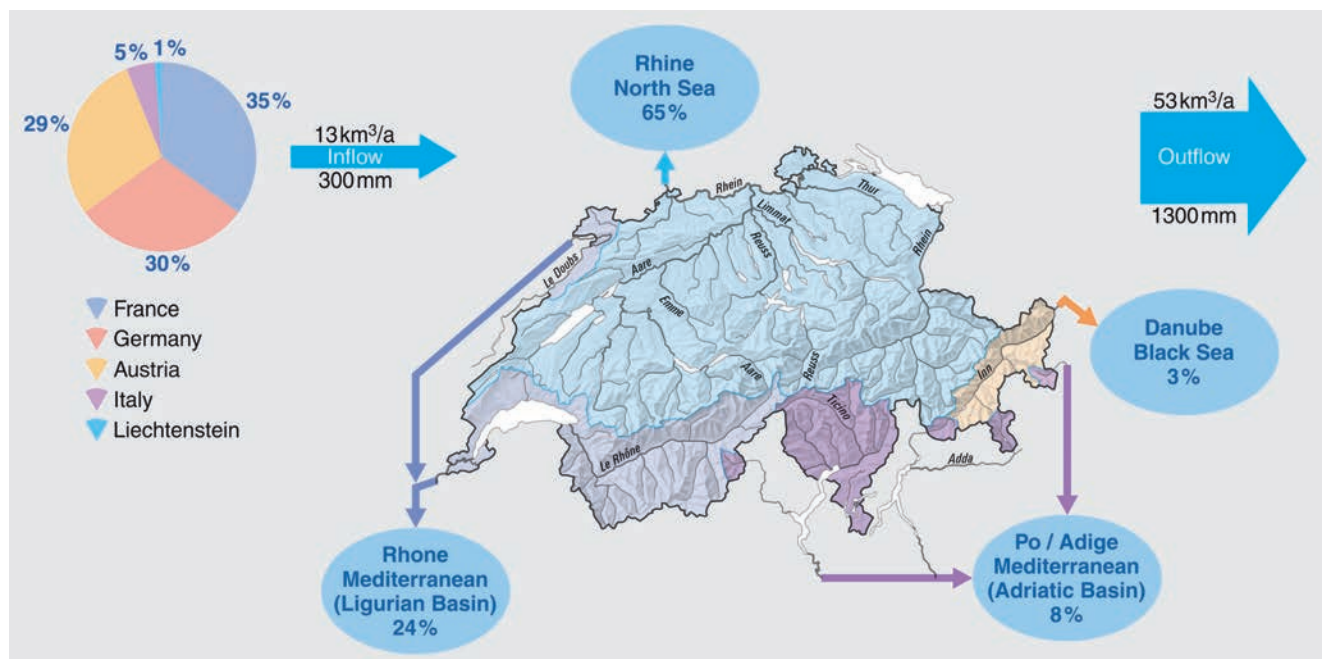
### Time series of precipitation, discharge and evaporation



**Figure 12:** The water balance of Switzerland since 1901. Both precipitation and evapotranspiration have increased slightly, while the discharge – apart from the year-to-year variability – has remained constant. From: Hubacher R., Schädler B. 2010.

## Appendix 3

### Where flows the water from Switzerland

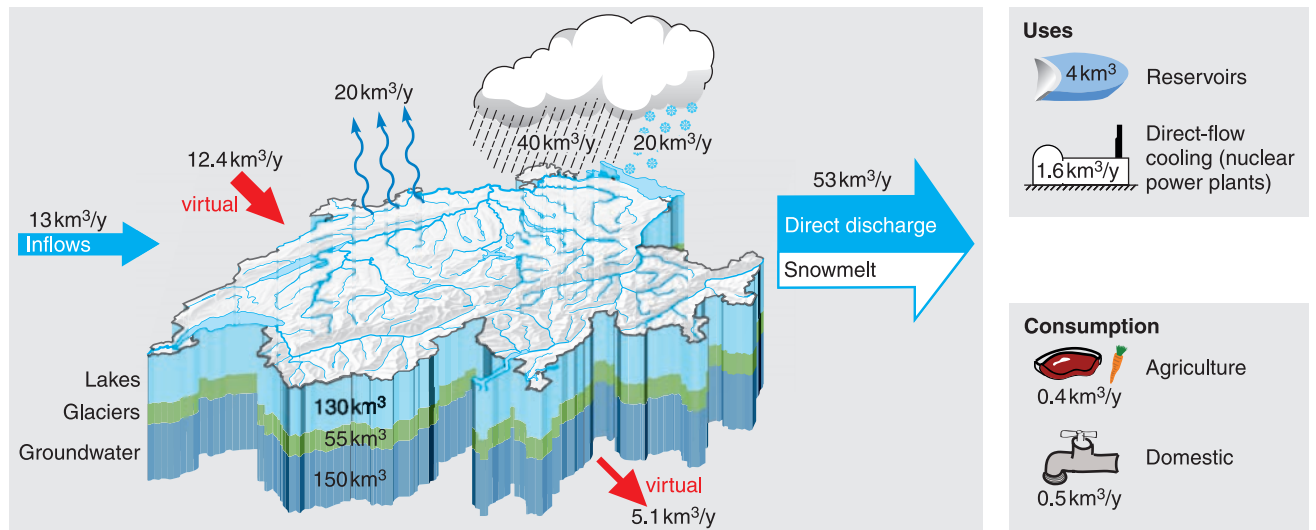


**Figure 13:** Geography of inflows (shares listed by country) and outflows (Swiss portion of the total) of Switzerland.



# Appendix 4

## Water balance of Switzerland



**Figure 14.** Water balance of Switzerland. The reservoirs, inputs (precipitation, inflows from other countries, virtual water from imports) and outputs (evaporation, discharge to other countries, virtual water from exports) are illustrated. Important areas of water use and consumption are also shown.  $10 \text{ km}^3$  corresponds to a layer of water 25 cm deep distributed across the whole of Switzerland.



